The Concept of Reservoir Characterization: A Case Study of Niger Delta, Nigeria

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Abstract The 3-D geologic model of the X-Field presented in this study demonstrates application of a detailed reservoir characterization and modeling workflow for a field. The static modeling 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 modeling. The cell geometries have been kept orthogonal to avoid any anticipated simulation problems. In this research work, 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 for the X-Field that has been effective at the well scale.

Keywords Reservoir, X-Field, 3-D geologic model

Introduction

Reservoir characterization is a detailed description of a reservoir using all available data. It involves integration of data to build a spatial representative earth model. This spatial model is then used in flow simulators, which can predict reservoir performance [1]. The purpose of this study will not only be to build a model that is consistent with currently available data, but also to build one that gives a good prediction of its future behaviour. An accurate and reliable reservoir characterization study is crucial and indispensable to production optimization. However, a major challenge in today's reservoir characterization is the integration of different kinds of data to obtain an accurate and robust reservoir model.

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 [2]. 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 employs the use of static modeling 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.

Aim and Objectives

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

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.

Stratigraphy of the Study Area

The Niger Delta Basin covers an area of about $75,000 Km^2$ and is composed of an overall regressive clastic sequence that reaches a maximum thickness of 9,000 to 12,000m (29,500 to 39,400ft). The Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios [3-4].

The Akata Formation at the base of the delta is of marine origin and is composed of thick shale sequence (potential source rock), turbidities sand (potential reservoirs in deep water), and minor amounts of clay and silt. Beginning in the Paleocene and through the Recent, the Akata Formation formed during low stands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency. The formation underlies the entire delta, and is typically over pressured. The approximate range of the thickness is about 6,000m [5-6].

Deposition of the overlying Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent [7-8]. The formation consists of paralic siliciclastics over 3,700meters thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. The Agbada Formation is overlain by the third formation, the Benin Formation, a continental latest Eocene to Recent deposit of alluvial and Upper coastal plain sands that are up to 2,000m thick [9].

Methodology

(A) 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 [10]. This study aims to present the current practice for building a static reservoir model.. The workflow proceeds 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 [11]. 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.

(B) Geological Description

Exploration and development of sandstone reservoirs require a reasonable prediction of sandstone occurrence and morphology [12]. 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.

(i) 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 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 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.

(ii) Geological Description of E2 Sand

E2 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).

Results and Interpretation
Geological Characterization

Three-dimensional geologic models were constructed for E1, E2, 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.

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 [13-14]. 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 [15].

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 [16]. 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 [5, 17].Total porosity was calculated from density log,water saturation was computed.

Correlation and Stratigraphy

The reservoir horizons were qualitatively identified using the surfaces from seismic as benchmark [18]. 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

Hydrocarbons-In-Place Volume

The original hydrocarbon-in-place volume of the X-Field reservoir was evaluated on the basis of the generated volumetric model using the following parameters [19-20]:

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

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

The volume estimation of the X-Field reservoir showed that E1 contains a STOIIP of 53MMSTB with GIIP of 20835BSCF; E2 contains STOIIP of 37MMSTB with a GIIP of 43319BSCF, while F1 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.
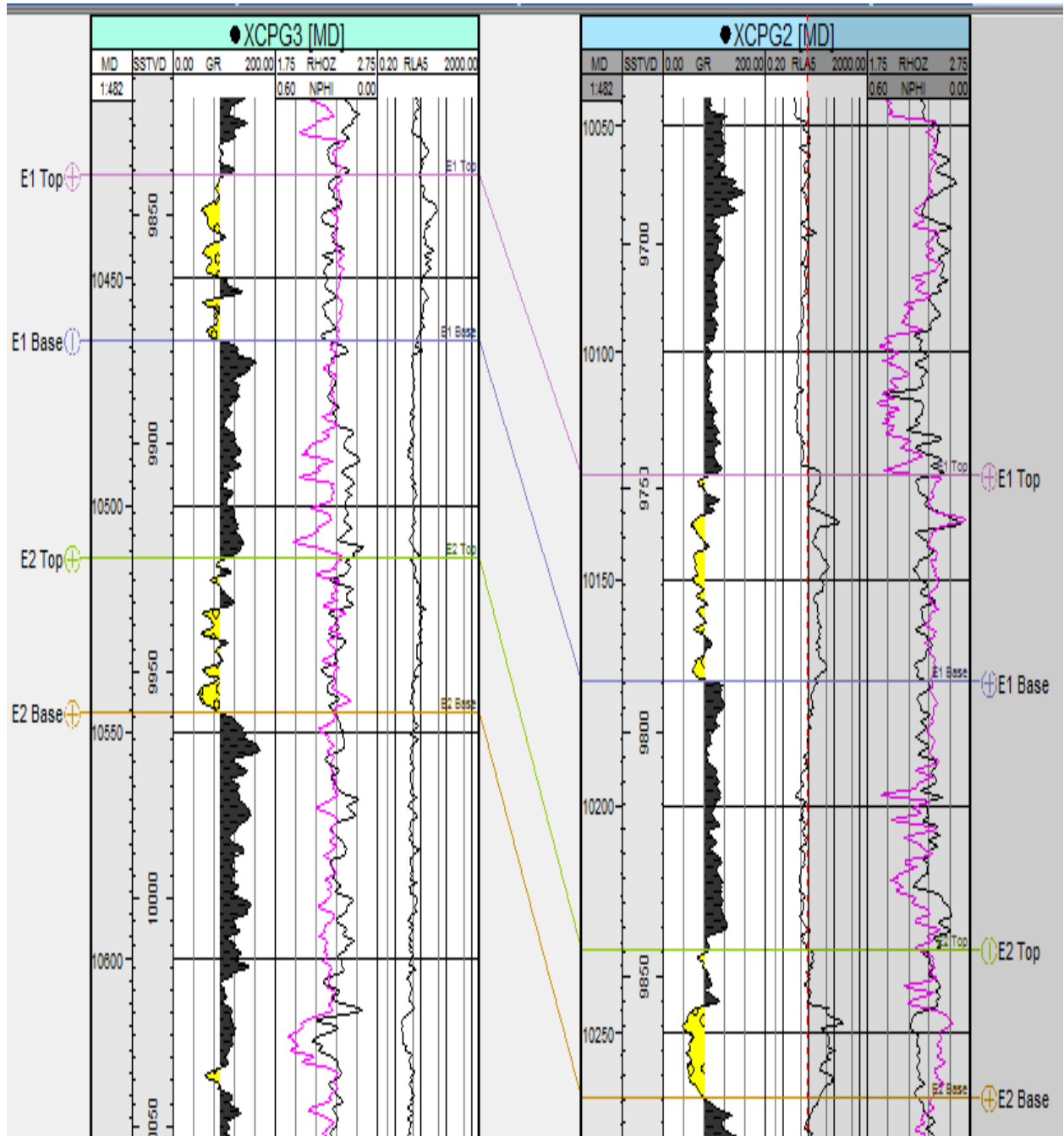

Figure 1: Correlation Panel of the interpreted E1 & E2 Hydrocarbon Sands

Table 1: XCPG2 Petrophysical Result Summary

Sand	Top (ft.)	Base (ft.)	H (ft.)	Net Sand	NTG	Φ(ave)	K(ave)	Sw(ave)
E1	10126.83	10172.24	45.41	36.5	0.80	0.22	1320.94	0.27
E2	10231.12	10264.17	33.05	30.5	0.92	0.21	1357.63	0.30
F1	10594.33	10625.16	30.84	29	0.93	0.25	1861.26	0.25

Table 2: 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 3: Fluid Contact in E1, E2, and F1 Reservoirs in Well XCPG2

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

Table 4: Fluid Contact in E1, E2, and F1 Reservoirs in Well XCPG3

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

Table 5: Hydrocarbon Volumes of E1, E2, and F1 Reservoirs

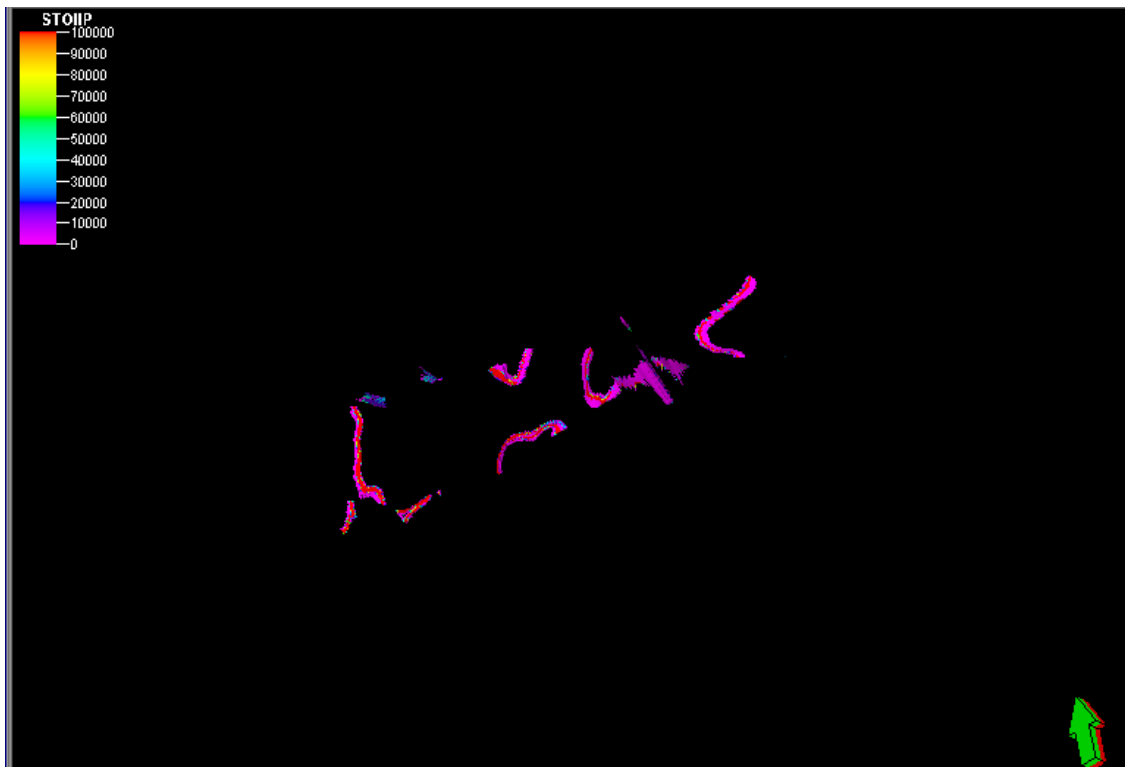| **Fault Model E1**		
Zones	STOIIP (MMSTB)	GIIP (BSCF)
1	18.23	
2	4.13	
3	30.63	
TOTAL	53	20835
Fault Model E2		
Zones	STOIIP (MMSTB)	GIIP(BSCF)
1	5.61	
2	3.60	
3	27.79	
TOTAL	37	43319
Fault Model F1		
Zones	STOIIP (MMSTB)	GIIP(BSCF)
1	3.03	
2	0.73	
3	14.24	
TOTAL	18	40279

Figure 2: Volumetric Model of E1 Reservoir

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