International Journal of
Science Inventions Today
www.ijsit.com
ISSN 2319-5436
Research Article

PETROLEUM RSERVOIR STUDIES OF X-FIELD, ONSHORE, NIGER DELTA

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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.

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:

- 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 properties
- To accurately evaluate the total volume of recoverable hydrocarbon reserves in place.

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. Figure 1

Figure 1: Location Map of the Study Area

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.

GEOLOGICAL OVERVIEW

The Niger Delta is situated in the Gulf of Guinea (Figure 2) 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).

Structural Province:

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 kilometers to the south

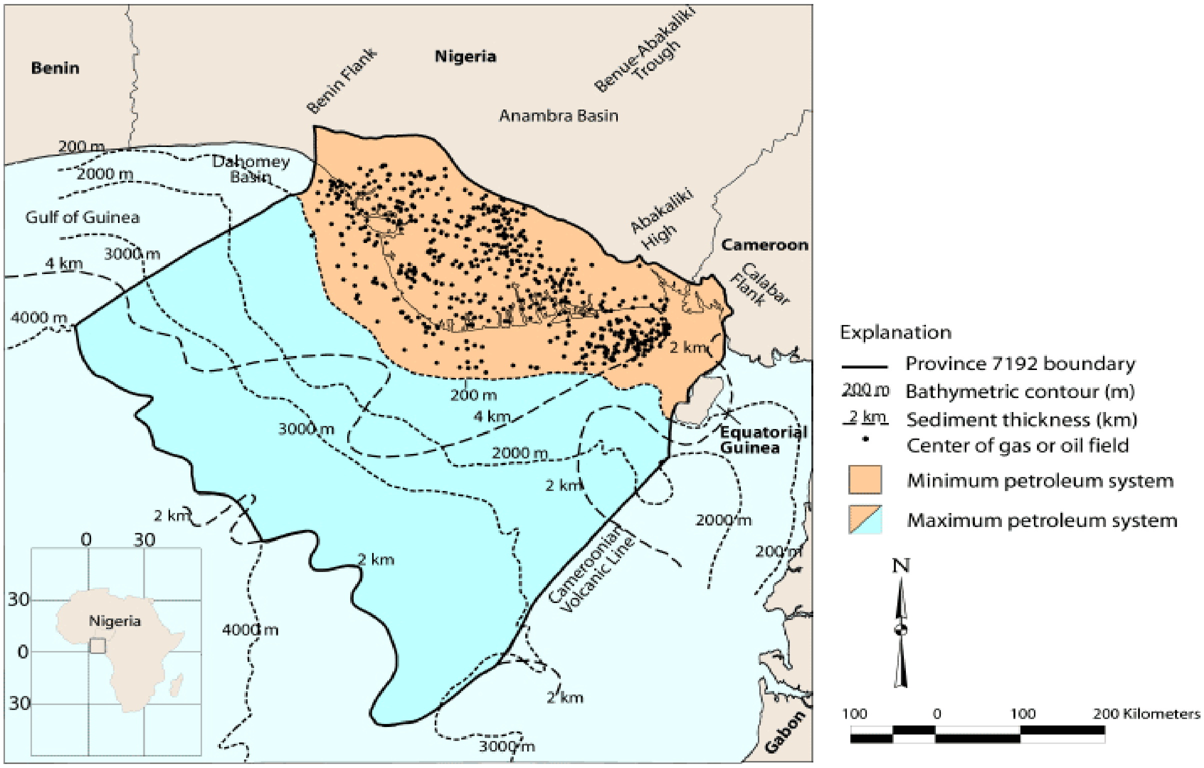

Figure 2: Index map of the Niger Delta showing province outline

and southwest. The province covers 300,000Km^2 and includes the geologic extent of the Tertiary Niger Delta (Akata-Agbada) Petroleum System.

Tectonics and Structure:

The tectonic framework of the continental margin along the West Coast of equatorial Africa is controlled by Cretaceous fracture zones expressed as trenches and ridges in the deep Atlantic. The fracture zone ridges subdivide the margin into individual basins, and, in Nigeria, form the boundary faults of the Cretaceous Benue-Abakaliki Trough, which cuts far into the West African shield. The trough represents a failed arm of a rift triple junction associated with the opening of the South Atlantic. In this region, rifting started in the Late Jurassic and persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977). In the region of the Niger Delta, rifting diminished altogether in the Late Cretaceous. Figure 3 shows the gross paleogeography of the region as well as the relative position of the African and South American plates since rifting began.

After rifting ceased, gravity tectonism became the primary deformational process. Shale mobility induced internal deformation and occurred in response to two processes (Kulke, 1995). First, shale diapirs formed from loading of poorly compacted, over-pressured, and prodelta and delta-slope clays (Akata

Formation) by the higher density delta-front sands (Agbada Formation). Second, slope instability occurred due to a lack of lateral, basin ward, support for the under-compacted delta-slope clays (Akata Formation). For any given depobelts, gravity tectonics were completed before deposition of the Benin Formation and are expressed in complex structures, including shale diapirs, roll-over anticlines, collapsed growth fault crests, back-to-back features, and steeply dipping, closely spaced flank faults (Evamy et al., 1978). These faults mostly offset different parts of the Agbada Formation and flatten into detachment planes near the top of the Akata Formation.

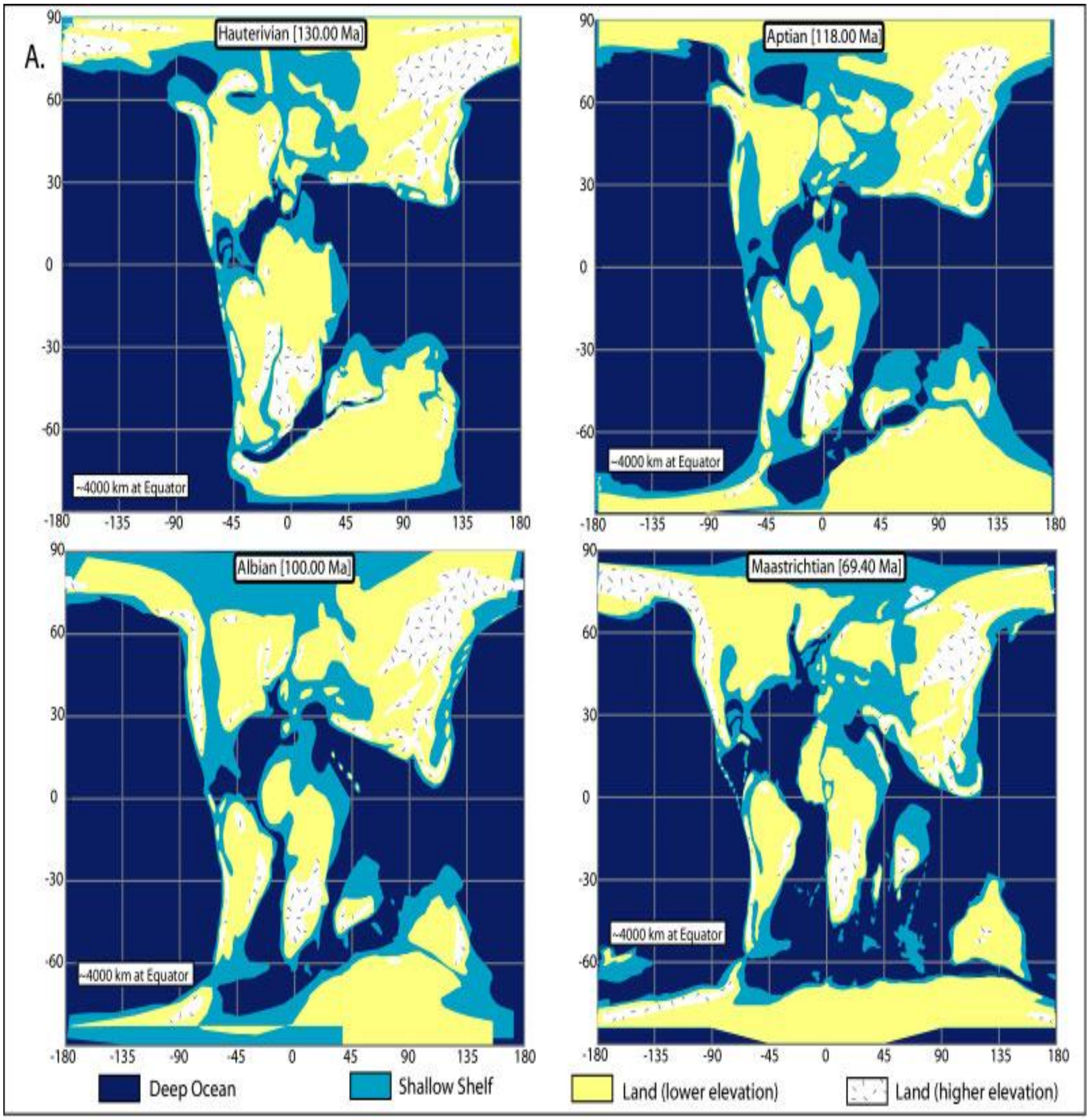

Figure 3: Paleogeography showing the opening of the south Atlantic, and development of the region around Niger Delta

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 will proceed with three major frameworks:

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

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 ontothis Cartesian box.
- On the Cartesian box, the facies geometry will be firstly simulated. Some of the mostcommon techniques for populating the facies information are: geostatistical indicatorsimulation (Deutsch and Journel, 1992; Goovaerts, 1997), Boolean techniques(Haldorsen and Damsleth, 1990) and more recently geostatistical simulation usingmultiple-pointgeostatistics (Strebelle, 2002).
- At the fifth stage petrophysical properties such as water saturation, porosity and permeabilitywill be populatedwithin each facies. This will be performed using standard geostatistical algorithmssuch as the sequential Gaussian simulation technique (Deutsch and Journel,1992), which is appropriate for modeling “homogeneously heterogeneous” permeability and porosity within a layer or within each facies type.

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.

Introduction to the X-Field:

X-Field is located in the onshore ,Northern delta depo-belt of the Niger Delta Basin. The X-Field has a faulted structure separating four (4) major segments of the reservoir. Two Appraisal wells (XCPG2 and XCPG3) 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 horizon. The field is an irregular relief zone with low relief at the centre and high relief at the flanks.

Geological Description of F1 Sand:

The combination of gamma ray and resistivity logs revealed that the upper section of the F1 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 0.25 in XCPG2 well and 0.20 in XCPG3 well. The permeability values vary from 1000mD to 1900mD.

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). The shale separating this reservoir from the F1 reservoir thickens.

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 X-Field. Formulas used in volume estimation are presented in table 1

$Shale_{Indicator} = \frac{GR_{log} - GR_{min}}{GR_{max} - GR_{min}}$	Eqn 1.0
$Vsh = 0.083 * 2^{(3.7*Shale_{indicator})} - 1.0$ (Larionov Equation)	Eqn 2.0
$\emptyset_D = \frac{\rho_{ma} - \rho_b}{\rho_{ma} - \rho_{fl}}$	Eqn 3.0
$Por_{eff} = (1 - Vsh) * PoroT$ (Bob Harrison, London Russian Style)	Eqn 4.0
$Sw = \frac{0.082}{\emptyset\_Den}$ (Udegbunam, et al. 1988)	Eqn 5.0
$F = \frac{0.62}{\emptyset_D{}^{2.15}}$	Eqn 6.0
$Swirr = \sqrt{\frac{F}{2000}}$	Eqn 7.0
$K = 307 + 26552\emptyset^2 - 3450(\emptyset s_{wirr})^2$ (Owolabi et al, 1994)	Eqn 8.0

Table 1: Formulae Algorithms Used for Petrophysical Evaluation of X-Field

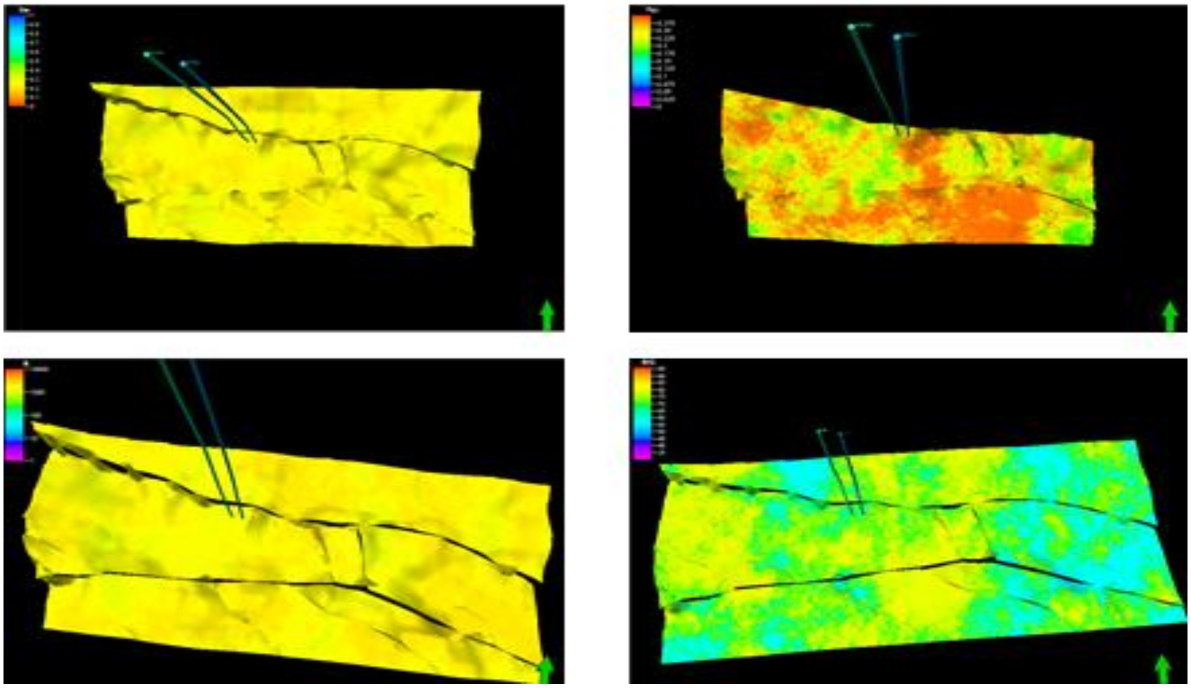

Figure 4: Petrophysical Properties Distribution for X-Field Reservoir

RESULTS AND INTERPRETATION

Geological Characterization:

Three-dimensional geologic models were constructed for E2, and F1 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.

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 formulaas shown in table 2 above.Fluid contacts in the E1, E2, and F1 reservoirs across the two wells are as presented in table 5.Permeability values were derived on the basis of porosity relationship, table 2.

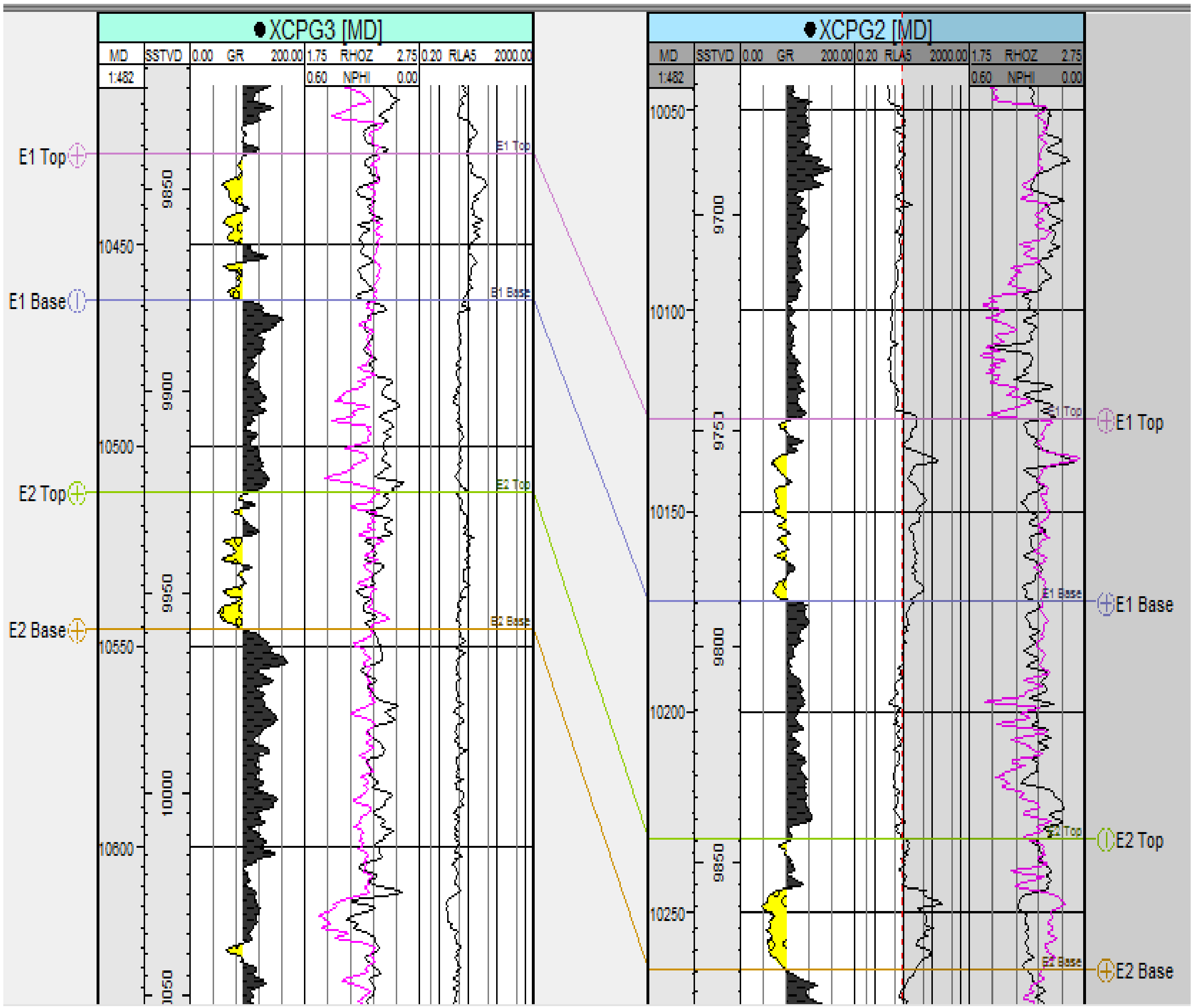

Figure 5: Correlation Panel of the interpreted F1 Hydrocarbon Sand

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: XCPG2 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: XCPG3 Petrophysical Result Summary

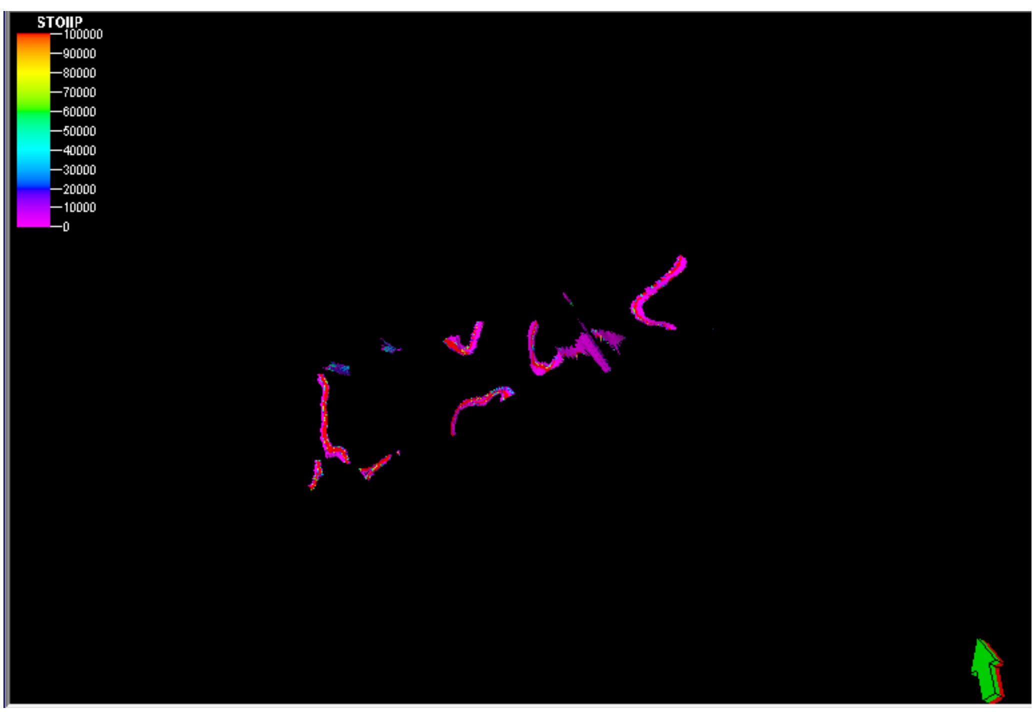

Figure 6: Volumetric Model of E1 Reservoir

CONCLUSION

Three types of 3D models have been applied in this study. The models are:

1. Structural Modeling: the structural model consists of a skeleton of the study area, including fault modeling, pillar gridding, and vertical layering.
2. Facies Modeling: The facies model is a means of distributing described facies throughout the model grid in the area of interest.
3. Petrophysical Modeling: it consists of the areal distribution of the permeability, porosity, and saturation as a function of variograms parameters, like major range and minor range.
4. Volumetric Modeling: 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 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. Quality Check of the structural and stratigraphic modeling 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. Facies logs were brought into the model using "Most of method" whereas "Arithmetic method" was used for porosity and permeability logs. 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 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 modeling similar reservoir systems worldwide.

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