Application of basin modeling to prospect maturation: A case study of "P" Field offshore Niger Delta

Dr. Abimbola Durogbitan[1], Simon Eyogwe[2], Fadekemi Ogunleye[3], Collins Ibekwe[4],

[1,2]*Amni International Petroleum Development Company Ltd,* [3,4] *Energy and Mineral Resources Ltd,*

ABSTRACT

Basin and petroleum systems modeling is used to gain insight into a petroleum system. It has proven to be an effective tool for discovering hydrocarbon in green basins. This is done by representing all the necessary parameters and geological processes that must be simultaneously present and persist till present day to support hydrocarbon generation, accumulation and preservation. When a structure that is likely to hold hydrocarbon is identified through seismic interpretation, and its seismic attributes show reservoir presence, it is termed a "prospect". This prospect can then be matured through petroleum systems analysis. This analysis involves a comprehensive understanding of the origin of present-day subsurface structures that support hydrocarbon accumulation and the likelihood that a basin is expected to contain hydrocarbon. The weakness in this approach is that the petroleum systems elements are analyzed independent of the geodynamics accompanying the generation and accumulation of hydrocarbon. Basin modeling is a technique that goes a step further to simulate these processes to provide a better understanding and interpretation of the geologic elements and processes that control and favor hydrocarbon accumulation in geologic space and time. This reduces E&P risks associated with maturing an identified prospect. This paper shows how 1D and 3D basin modeling techniques were used to predict the presence of charge in identified prospects within an asset in Niger Delta and predict the hydrocarbon type (oil or gas) present. An integrated approach utilizing data analytical inputs from different disciplines was adopted. Inputs to the model included basement maps, basement lithology, stratigraphic profiles from well and seismic data, global sea level curve data and results from compaction trend analysis. The resulting model was calibrated using temperature data while the hydrocarbon type in the prospect was calibrated using known reservoirs. Several sensitivities were run to capture different scenarios. The results of the thermal model showed that the optimal hydrocarbon accumulation window (60°C -120°C) ranged from 7000 ft to 16,000 ft for the field – the identified prospect was within this depth range. The Eocene to Recent source rock maturity ranged from 1.3 -2 % Ro in the southern portion of the study area to 0.7 – 1.3 % Ro in the northern portion. Hydrocarbon charge commenced at 8 Ma to present day (0 Ma). Traps were in place before hydrocarbon generation and migration occurred for the prospects. However, the seal integrity of the northern prospects was compromised as hydrocarbons were observed to have re-migrated up dip and outside the field. From the model, deeper prospects to the south appeared to be the most prospective and the hydrocarbon type was identified as oil.

Keywords: Maturation, Modeling, Prospect, Attributes, Sensitivities, Reservoir, Charge, Structures

INTRODUCTION

Basin modeling tracks the evolution of a basin through geologic time as it fills with sediments that may eventually generate or contain hydrocarbons. Over the years, it has proven to be an effective tool for hydrocarbon exploration particularly to gain insight into a petroleum system.

In hydrocarbon exploration, discovering a trap from seismic interpretation and using attributes to confirm reservoir presence defines a prospect. This prospect can then be matured using an approach like petroleum systems analysis. This approach assumes that fluids will be encountered when a well is drilled into the prospect, provided a comprehensive study of the elements of the petroleum system is carried out. The weakness in this approach is that the elements are analyzed independently, with no consideration for the geodynamics accompanying processes like generation, migration and accumulation of hydrocarbon in the present day.

Petroleum generation, migration and accumulation are critical processes in prospect evaluation. The existence of these can be resolved using basin modeling. Basin modeling is a technique that provides a better understanding of these processes and the elements that control hydrocarbon accumulation in geologic space and time. This can serve as a technique in prospect maturation. By carrying out 1D & 3D basin modeling, the prospects are further matured beyond what petroleum systems analysis can realize. It reduces further the risks associated with the geodynamics of hydrocarbon accumulation.

Prospects were identified in the P field, off shore Niger delta using seismic depth volume which was interpreted to define traps. Using the depth volume, attributes were also generated to help infer reservoir presence. Risks associated with charge, accumulation and fluid fill type were identified. To reduce these risks and predict charge and fluid fill, 1D and 3D basin modeling techniques were used in the prospect maturation process.

The project aimed at using a basin model to further mature prospects identified in the P field. The approach was to simulate burial and thermal history models and carry out generation and migration studies. The prediction of hydrocarbon fluid fill was calibrated using proven reservoirs within the field. The study, in the end, took the operator closer to a drill decision.

Regional Geology

The “P” field lies within 10 m water depth in the Coastal Swamp depobelt of the Tertiary Niger Delta. The Niger Delta basin (Figure 1) is situated in the Gulf of Guinea and extends throughout the Niger Delta Province of Nigeria as defined by Klett (1997). The onshore portion is delineated by the geology of southern Nigeria and southwestern Cameroon. The northern boundary is the Benin flank–an E-NE trending hinge line south of the West Africa basement massif. The northeastern boundary is defined by outcrops of the Cretaceous Abakaliki high and further E-SE by the Calabar flank–a hinge line bordering the adjacent Precambrian rocks. The offshore portion of the province is defined by the Cameroon volcanic line to the east and the eastern boundary of the Dahomey basin to the west. The delta prograded southwestward from Eocene to Recent, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust, 1990). These depobelts form one of the largest regressive deltas in the world with an area of about 300,000 sqkm (Kulke, 1995). Three lithostratigraphy units have been identified in the Niger Delta: The pro delta Akata shales, the delta front Agbada sand and shale intercalations and the continental Benin sands. Structures within the province are generally syn depositional in nature. They include growth faults, rollover anticlines and shale diapers. The Niger Delta Province consists of one identified petroleum system (Ekweozor, 1994) which is the Tertiary Niger Delta (Akata – Agbada) Petroleum System.

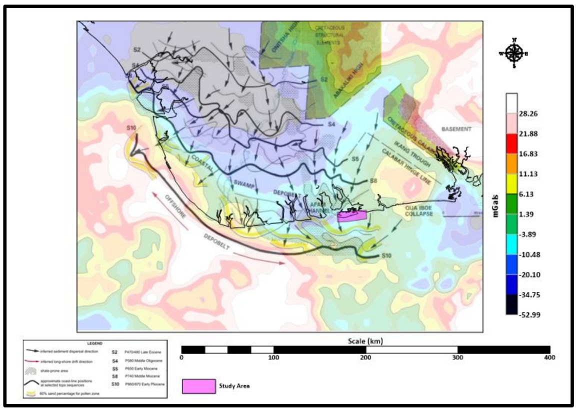

Figure 1: Map showing study area, Paleo-shorelines of the Niger delta and its bounding structural elements shown by magnetic map underlay.

MATERIALS AND METHOD

An integrated approach was used to build the basin model following an understanding of the petroleum system within the field. Data from various disciplines were used. The model integrated information from seismic data, well logs and biostratigraphy. It also incorporated the Niger delta chronostratigraphic chart and used regional information to fill data gaps. Calibration data (BHT, pressure and porosity) were gotten from well sources and used in the absence of geochemical data (vitrinite reflectance). Basement morphology, depth to basement maps and basement lithology were gotten from litho-constrained inversion of potential field data.

Input to the model

The age assignment table (Figure 2) summarizes the input ages, the formations they represent and the roles they play in the petroleum system. It also shows the onset of rifting and depositional sequence. Age information for the layers was gotten from biostratigraphy data, which was then mapped on depth seismic cube. The basin model captured the "P" field from basement to sea bed. Compaction trends were analyzed to capture erosion, but due to the nature of the Niger delta, i.e., rapid deposition, records of erosion are not properly preserved. Resulting layers from the construction of the basin model is shown below (Figure 3). Layers were assigned petroleum system elements, based on the petroleum systems analysis done for the field.

	Age [Ma]	Horizon	-	Depth Map	Erosion Map	Layer	-	Event Type	Facies Map	No. of Sublayers	Max. Time Step [Ma]
1	0.00	Bathymetry_01		Bathymetry_01		Bathymetry_01		Deposition	Map_Layer_207_Facies	1	10.00
2	5.50	SB 5.5 Ma (SB 5		SB 5.5 Ma (SB 5		SB 5.5 Ma (SB 5		Deposition	Map_Layer_208_Facies	1	10.00
3	5.80	MFS 5.8 Ma (MFS 5		MFS 5.8 Ma (MFS 5		MFS 5.8 Ma (MFS 5		Deposition	Map_Layer_209_Facies	1	10.00
4	6.30	SB 6.3 Ma (SB 6		SB 6.3 Ma (SB 6		SB 6.3 Ma (SB 6		Deposition	Map_Layer_210_Facies	1	10.00
5	7.00	MFS 7.0 Ma (MFS 7		MFS 7.0 Ma (MFS 7		MFS 7.0 Ma (MFS 7		Deposition	Map_Layer_211_Facies	1	10.00
6	8.20	SB 8.2 Ma (SB 8		SB 8.2 Ma (SB 8		SB 8.2 Ma (SB 8		Deposition	Map_Layer_212_Facies	1	10.00
7	9.20	MFS 9.2 Ma (MFS 9		MFS 9.2 Ma (MFS 9		MFS 9.2 Ma (MFS 9		Deposition	Map_Layer_213_Facies	1	10.00
8	10.60	SB 10.6 Ma (SB 10		SB 10.6 Ma (SB 10		SB 10.6 Ma (SB 10		Deposition	Map_Layer_214_Facies	1	10.00
9	11.60	MFS 11.6 Ma (MFS 11		MFS 11.6 Ma (MFS 11		MFS 11.6 Ma (MFS 11		Deposition	Map_Layer_215_Facies	1	10.00
10	23.00	Akata Depth Grid		Akata Depth Grid		Akata Depth Grid		Deposition	Map_Layer_216_Facies	1	10.00
11	125.00	Basement		Basement							

Figure 2: Age assignment table used in the model.

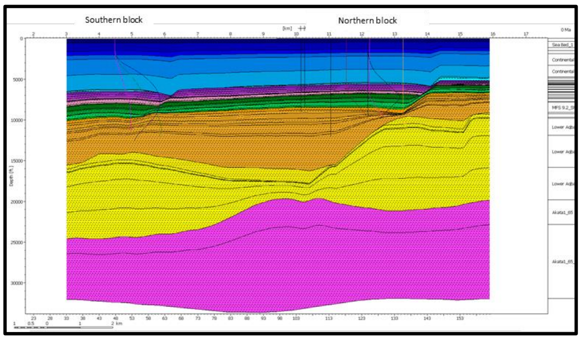

Figure 3: 2D slice in the Y-direction showing layers in the model.

A dynamic model approach was used to capture the basin's evolution, hydrocarbon generation and expulsion. The model considered several geological processes that are crucial to the generation and accumulation of hydrocarbon within the basin. Some of the most important processes captured in the model include rifting, tectonic and thermal subsidence, deposition, compaction, hydrocarbon generation, expulsion, and migration. The principles applied were in line with the analytical and mathematical simulations for geological processes as described by Kauerauf (2009).

To achieve the objectives of this project, 1D burial history and thermal modeling and 3D petroleum generation, expulsion, migration and accumulation studies were carried out using the workflow shown below (Figure 4).

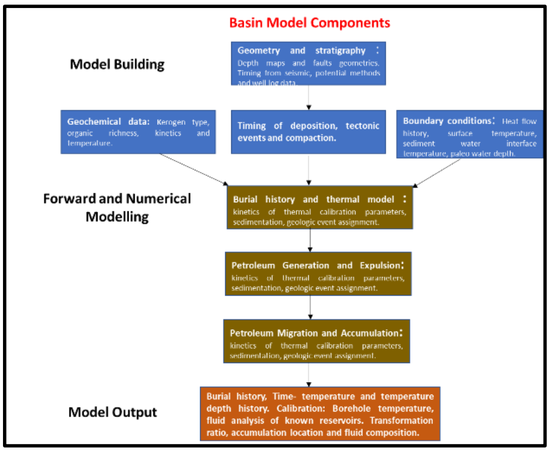

Figure 4:Workflow used in the basin and petroleum system modeling of the P field.

RESULTS AND DISCUSSIONS

The simulation of the basin model provided insight to several processes that the P field has undergone that may affect petroleum accumulation within the prospects.

Results from the 1D model include the burial history model, temperature model, the generation model and the limits of the optimal hydrocarbon accumulation window.

The first output is the burial history curve (Figure 5). This provides information on the Sediment Accumulation Rates (SARs). This also provides information on basin evolution with regards to change in accommodation space. The burial history curve also called geo-history plot, confirmed the geological evolution of the study area. It was deduced from the burial history curve that there are two major depositional episodes; one with low SAR from the Cretaceous to the Early Paleocene and a period of high SAR from the Paleocene to Recent. A change was observed in accommodation space caused by basin opening (stretching). The effect is seen in water depth values reaching, a maximum in the post-rift - thermal sag phase. Also, the plot showed a rapid reduction in water depths from approximately 3000 ft in the Eocene to much shallower depths in the present day. This is consistent with a reduction in accommodation space and high sediment influx associated with the Niger Delta. The model is seen to be consistent with the geology and progradational pattern of the Niger Delta.

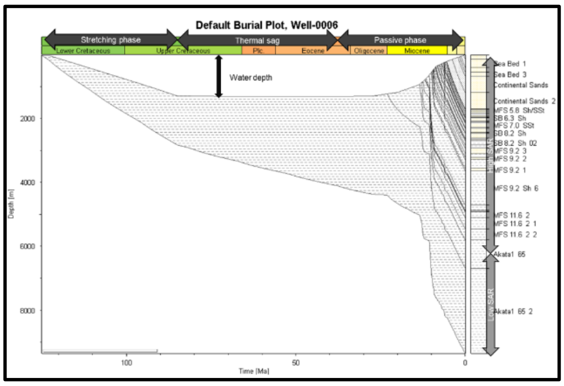

Figure 5:1D burial history model of well-06 in the P field.

The temperature model showed a good match between modelled temperatures and recorded temperatures at well locations (Figure 6). This served as a calibration between modelled and observed data using well-06 as reference.

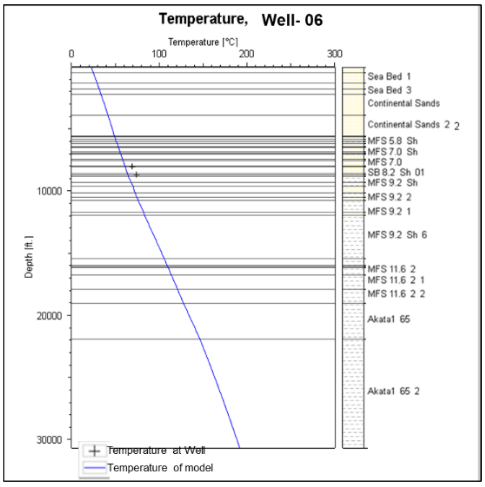

Figure 6:Temperature plot of well -06 in the P field.

Generation plot (Figure 7) shows the generation potential of the designated source rocks and the time generation started within the study area (8 Ma). The plot does not reach a peak mass, which means generation is still ongoing. This information infers that before hydrocarbon generation began, the prospect was already existing and trapping configuration was in place.

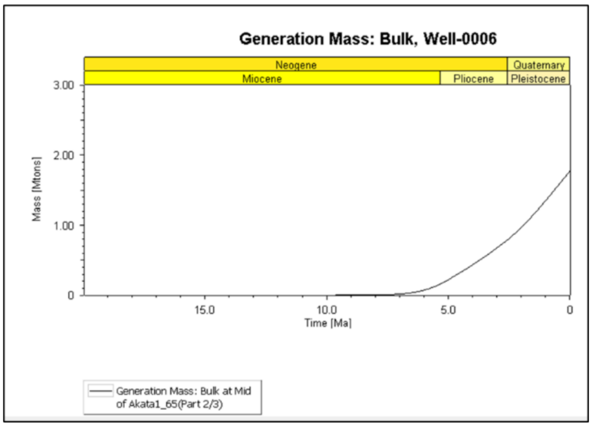

Figure 7: Generation plot for the P field showing the age generation started within the field.

The optimal hydrocarbon accumulation zone is depicted by overlaying the 60°C - 120°C isotherms on the depth plot. This gives an indication of the depth range to explore for hydrocarbons within the area. From the plot, the optimal hydrocarbon accumulation zone ranges from 7,000 ft to 16,000 ft (Figure 8). The identified prospects are within this depth range.

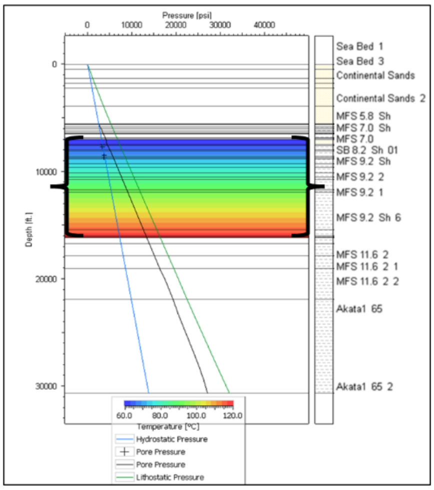

Figure 8: Pressure profile with temperature overlay showing Optimal hydrocarbon accumulation zone within the field.

The 3D model was simulated, having gained insight and confidence in modeled parameters from the 1D model. Hydrocarbon generation, expulsion and accumulation were the primary target of the 3D model using proven reservoirs as the calibration. Another insight derived from the 3D model is the vitrinite reflectance of the source rock which indicates the maturity and the transformation ratio of the source rock. This indicates the percentage of kerogen that has been converted to hydrocarbon.

The first output was the hydrocarbon charge and fluid fill. Using a known reservoir as calibration, there was a match between modeled hydrocarbon type and actual hydrocarbon type (Figure 9). Actual hydrocarbon type was based on the petrophysical interpretation of well–06 log data. The modeled fluid fill for the prospects was oil and gas for the northern prospect and oil for the southern prospect. The presence of charge in the basin model confirms the source rock's ability to generate hydrocarbon. This would have not been ascertained if a basin model wasn't carried out. Panning through geologic time in the model, at 2 Ma the northern prospect was filled to spill, but as we approach Recent (0 Ma), the reservoir is observed to lose its accumulated hydrocarbon. This loss in accumulated hydrocarbon, over time in the northern prospect suggests re-migration to up dip traps outside the "P" field and indicates a seal failure.

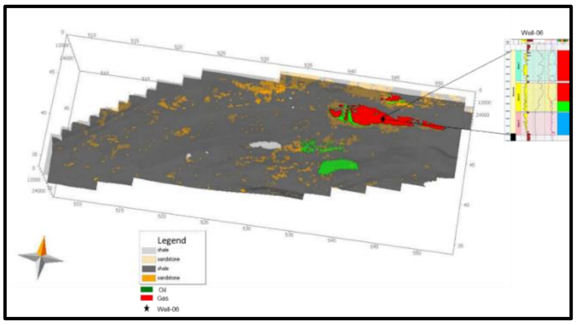

Figure 9: 3D view of modelled known reservoir and its hydrocarbon accumulations as seen from well -06 and hydrocarbon fill in identified prospects (North and South) at 0 Ma.

The source rock layer (Akata shales) was studied to understand its maturity and transformation ratio. The maturity model used was the Sweeney and Burnham (1990) Easy Ro model, for vitrinite reflectance. The vitrinite reflectance (Figure 10) values in the northern portion of the field ranged from 1.3–2% Ro which indicates that the source rock in this portion is within the main to late oil window. The values in the southern portion on the other hand ranged from 0.7–1.3% Ro showing that the source rock in this portion is already in the gas window. This variation is ascribed to the varying depths to basement of the source rock, caused by local horsts and grabens in basement topography.

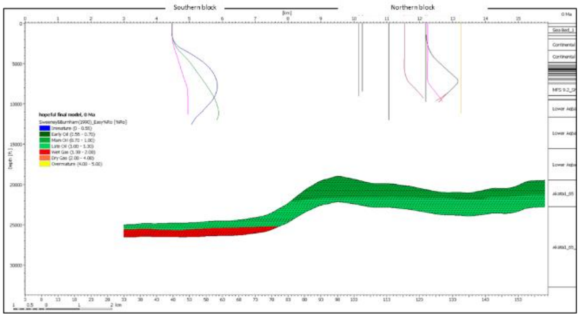

Figure 10: Cross section showing vitrinite reflectance of the source rock within the P field.

The transformation ratio within the "P" field (Figure 11) varied from 60% in the southern portion of the field to 40% in the northern part of the field. Transformation ratio indicates the percentage of kerogen being converted to hydrocarbons. The fact that the percentages are less than 100% explains why the generation plot has not peaked.

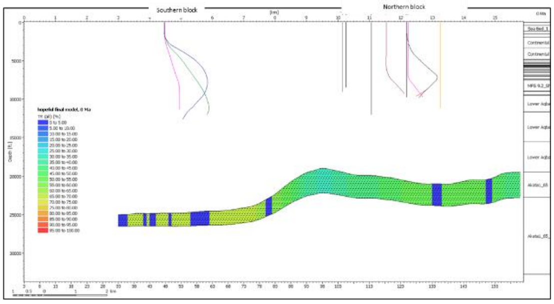

Figure 11: Cross-section of transformation ratio within the P field.

A petroleum system's event chart (Figure 12) was generated to give a total representation of the timing of petroleum system elements and processes at play within the "P" field.

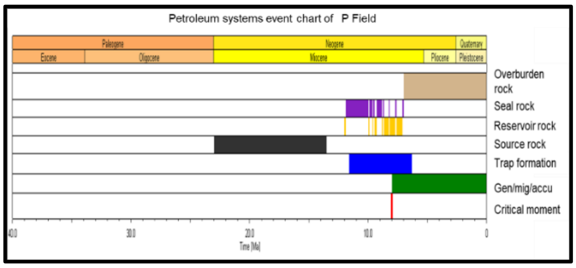

Figure 12: Petroleum system's event chart of the P field showing critical time.

The petroleum system's event chart showed the time relationship between the petroleum system elements and processes in the P field. From the chart, we see the critical moment for the P field at 8 Ma. This indicates the time when all the petroleum system elements were in place and when the generation and migration of hydrocarbon into the reservoirs commenced.

CONCLUSIONS

- This basin model was carried out as a part of prospectivity study of the P field.
- It enabled a greater insight in space and time of hydrocarbon generation, accumulation and migration processes, as opposed to just a conventional petroleum systems analysis.
- This approach integrated data input from various sources to model the field from the time of rifting to present day.
- It was deduced from the study that the prospects were within the optimal hydrocarbon accumulation zone.
- The source rock maturity varied from oil window in the North to gas window in the South of the field.
- The transformation ratio which indicates the percentage of kerogen being converted to hydrocarbons was deduced and shows that the generation that feeds the prospects has not even peaked.
- Traps and reservoirs were found to be in place before the commencement of generation of

hydrocarbons and migration to the prospects.

- By using a known reservoir for calibration, both prospects (north and south), were determined to be charged. The northern prospect with both oil and gas and the southern prospect with oil.
- The Northern prospects were evaluated to have their seal integrity compromised as re-migration to up dip reservoirs were observed through time. The southern prospect is however seen not to suffer this seal integrity problem and is therefore adjudged to be more matured.
- The integration of data from varied sources including potential field data sources enabled a look at deeper potentials, in the end taking the operator closer to a drill decision.

REFERENCES

Doust, H. (1990). Niger Delta, in, Edwards, J. D., andSantogrossi, P.A., eds., Divergent/passive Margin Basins,. *AAPG Memoir 48: American Association of Petroleum Geologists*, p.239-248.

Ekweozor, C. M. (1994). Northern delta depobelt portion of the Akata-Agbada(!) petroleum system, Niger Delta, Nigeria, in, Magoon, L.B., and Dow, W.G., eds., The Petroleum System--From Source to Trap,. *AAPG Memoir 60: Tulsa, American Association of Petroleum Geologists*, p. 599-614.

Kauerauf, T. H. (2009). *Fundamentals of Basin and Petroleum Systems Modelling.* London : Springer.

Klett, T. A. (1997). *Ranking of the world's oil and gas provinces by known petroleuum volumes.* U.S.: U.SG.S Open file Report-97-463.

Kulke, H. ,. (1995). Regional Petroleum Geology of the World. Part II: Africa, America, Australia and Antarctica. *Berlin, Gebrüder Borntraeger,*, p. 143-172.

Sweeney., A. K. (1989). A chemical kinetic model of vitrinite maturation. *Geochim. Cosmochim.*, Acta, 53:2649–2657.