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Geostastistical Prediction of Turbidite Reservoir Heterogeneity and Quality of "AFUN" Field Deep Offshore Niger Delta, Nigeria

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ABSTRACT

Hydrocarbon assessment in deepwater settings is very challenging and expensive. Reservoir modelling through geostatistical analysis can be used for better prediction of deepwater facies as well as reducing uncertainties associated with field development. Geostatistical analysis of seismic and well log data was employed to predict reservoir heterogeneity and quality in deepwater turbidite systems of "AFUN" field. Biostratigraphic data and gamma ray log signature were interpreted for chronostratigraphic correlation across the wells. The static properties of the reservoir such as Porosity (ϕ), Volume of shale (Vsh), Water Saturation (Sw), Net-to-Gross (NTG) and fluid type were generated. The subsurface structures and stratigraphy were interpreted with the extraction of seismic attributes from the generated time structure maps. The reservoir modelling involved the population of the reservoir architecture (structure and stratigraphy) with rock properties using stochastic algorithms. Four main petrophysical parameters with lithofacies were modelled in order to determine how these properties are spatially distributed within the subsurface. From the models, it can be deduced that synthetic and antithetic faults constitute the structural framework of the reservoirs in the study area. The faulting system therefore contributing to reservoir complexity. Also, the lithofacies model built for the reservoirs revealed three facies with the sandy turbidite ranging from 15- 45 %, shaly turbidite ranges from 9-24 % while shale ranges from 35-74 %. The model also showed that there are vertical and lateral changes in reservoir properties created by reservoir heterogeneity. The reservoir heterogeneity and quality in deep water turbidite systems could thus be accurately predicted using geostatistical analysis.

Introduction

Deep offshore fields are often associated with development challenges arising from geologic uncertainties such as facies distribution and heterogeneity, sand continuity and connectivity, and reservoir quality (Eaton, 2006). The geologic heterogeneities can however influence the reservoir architecture and fluid flow patterns of such deposits which in turn have implications on the reservoir characteristics (Darling, 2005). Typical turbidite reservoirs exhibit complex structural geometry and subtle stratigraphic features (Marchand et al., 2002). Hence the conventional reservoir characterization method could not be accurately delineating structurally complex and stratigraphic heterogeneous submarine environments. This is due to high variation in the rock types and stacking patterns of the deposits over short lateral extent (Tyler and Finley, 1991). Lateral continuity or connectivity of flood plain deposits depend on sediment supply as well as the stage lowstand.

In order to understand the complex structure and stratigraphy of the field, for prediction of reservoir heterogeneity and quality of the deposits, geostatistical techniques were employed using the following objectives: (i) evaluation of the reservoir depositional facies and environment of deposition; (ii) investigation of how parameters of reservoir quality varies laterally across the turbidite deposits; (iii) delineation of the architectural elements the control the quality of deepwater turbidite reservoir and; (iv) building models for predicting reservoir heterogeneity and quality.

Geostatistics provides the most efficient framework to build accurate and reliable static models of reservoirs. It is valuable for facies distribution in various geological environments as well as petrophysical properties distribution and structural uncertainty quantification.

Geology of the Study Area

The "AFUN" Field, lies within the deep offshore Niger Delta of water depth of about 990-1117 m (Figure 1). The study area is entrenched within the Gulf of Guinea at the Western Inner Fold Thrust Belt of the delta toe divided into lobes by the Charcot fracture zone. The lobes are characterised by numerous fracture zones (Corredor et al., 2005). "AFUN" Field covers an area extent of approximately 812 km2 and has six oil wells drilled. The sediments have been deposited during Early to Late Miocene (Reijers et al., 1997).

The depositional environments in the Niger Delta extend from the delta plain in the continental setting, transitional delta front environment, to the prodelta and submarine fan

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environment (Nwachukwu and Chukwura, 1986). Over the last decade, advances in drilling technology have opened the deep-water Niger Delta to exploration. The deep offshore of Niger Delta occurs at water depth ranging from 500m to 2000m (Slatt, 2006) and consist s of marine sediments that transported and deposited by gravity flow processes (Weimer and Slatt, 2004) in a classical shale tectonic province (Wu and Bally,2000). The main reservoirs consist of Miocene turbidite systems.

The three stratigraphic sequences of Niger Delta starting from the marine shale of Akata Formation, middle Paralic Agbada Formation and the topmost Benin Sands (Short and Stauble, 1967). In the deepwater fold and thrust belts, Akata Formation is about 500m (16400ft) thick and composed of thick shales, at the base of the delta sequence which served as source rocks. This sequence contains few streaks of sand which were suggested to be turbiditic origin that possibly acts as potential reservoirs in deepwater environment. The overlying sequence (Agbada Formation) is about 2500m (11500 ft) thick consist of an alternation of sand, silts and clay. The primary reservoirs in the offshore Niger Delta are the channel and basin floor fan deposits in the Agbada Formation (Bilotti et al., 2005; Avbovbo,1978).

Growth faults and associated anticlines are predominant structures of the Niger Delta (Corredor et al., 2005). Damuth (1994) recognized three structural zones in the offshore Niger Delta which include: an extensional zone, an intermediate translational zone and a compressional zone. After Connors et al., (1998), five main structural domains were identified which include: an extensional province, a mud-diapir belt, the inner fold and thrust belt, a transition zone and the outer fold and thrust belt. At the deepwater toe of the delta, a series of large fold and thrust belts (Figure 1) is composed of thrust faults and fault-related folds. Recent discoveries in this fold and thrust belt include the Agbami, Bonga, Chota, Ngolo, and Nnwa fields, all of which have structural traps formed by contractional folds (Hooper et al., 2002). The contractional part of the deep-water Niger Delta is divided into three major zones: the inner fold and thrust belt, the outer fold and thrust belt, and the detachment- fold province (Figure 2). The inner fold and thrust belt is a highly shortened and imbricate fold and thrust belt, whereas the outer fold and thrust belt is a more classic toe-thrust zone with thrust-cored anticlines that are typically separated from one another by several kilo meter (Suppe et al., 2004). The detachment fold belt is a transitional zone between the inner and outer fold and thrust belts that is characterized by regions of little or no deformation interspersed with broad detachment anticlines that accommodate relatively small amounts of shortening (Shaw et al., 2004).

The deformation in the contractional toe of the Niger Delta is driven by updip, gravitational collapse of shelf sediments. Basinward motion of these shelf sediments is accommodated by normal faults that sole to detachments within the prodelta marine strata that lie above the basement (Figure 3). Slip on the detachments is transmitted to the deep water, where it is diverted onto thrust ramps and consumed by contractional folds in deep-water fold and thrust belts (Figure 3). This style of gravitationally driven, linked extensional and contractional fault systems is common in passive-margin deltas (Rowan et al., 2004), including the Gulf of Mexico basin (e.g., Peel et al., 1995). The Niger Delta fold and thrust belts occupy the outboard toe of the delta in water depths ranging from 1 to 4 km (0.6 to 2.5 mi) below sea level and create a very gentle, regional seafloor slope away from the coast.

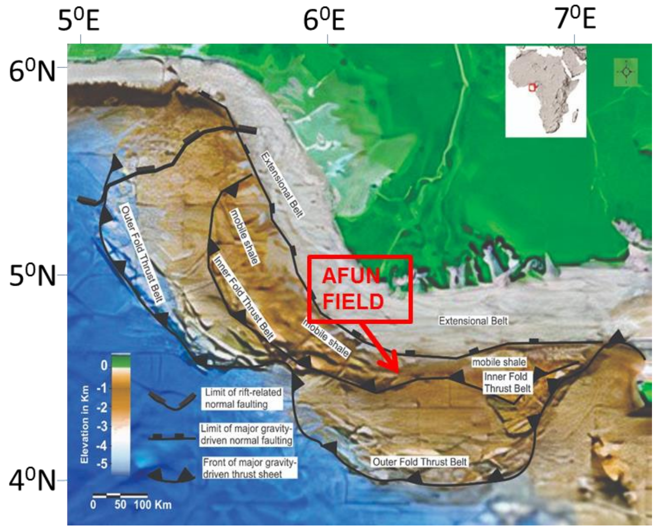


Figure 1. Map showing the Location of the Study Area (Corredor et al, 2005).

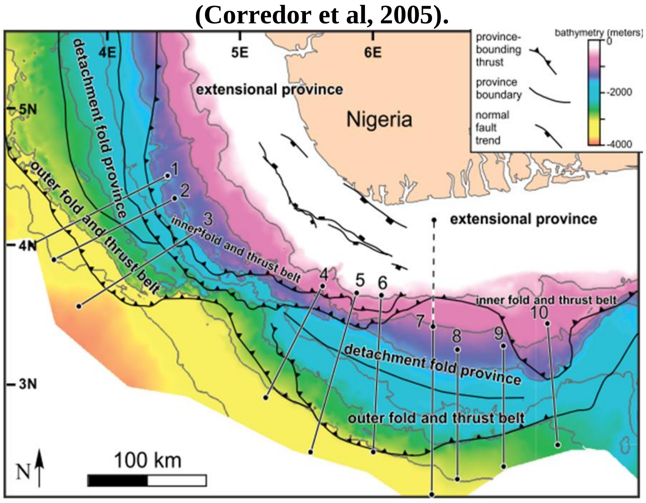


Figure 2. Map of the offshore Niger Delta showing the structural provinces (modified from Connors et al., 1998).

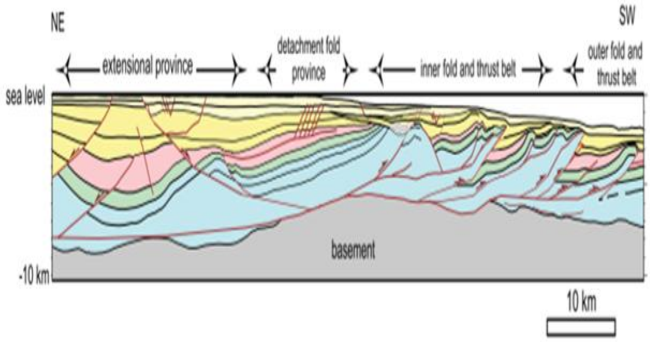


Figure 3. Regional geologic cross section through the central Niger Delta modified from Shaw et al. (2004).

Methodology

The data sets used for this study include post stacked time migrated 3-D Seismic data and Well data comprising five wireline logs: Gamma ray, Resistivity, Neutron, Density and Sonic logs; and Biostratigraphic data from wells drilled within “AFUN” Field, Niger Delta. Seismic and well log data were quality checked, imported and analysed using Petrel Software.

Time significant surfaces were identified using gamma ray log and biostratigraphic data. These datasets were then used to carry out chronostratigraphic correlation across all wells in the study area. The stacking trends were delineated from the chronostratigraphic correlation and then used to identify systems tracts, and define stratigraphic sequences. The depositional environments of the study area were predicted from the identified stacking patterns and biostratigraphic information. Lithostratigraphic correlation within the delineated stratigraphic sequences was carried out. Hydrocarbon bearing sands were identified within the established systems tracts using a combination of gamma ray and resistivity logs.

Petrophysical parameters were computed and used to characterize identified reservoirs across the wells. The wireline logs for all the wells were used to obtain both the static properties of the reservoir such as Porosity (ϕ), Volume of shale (Vsh), Water Saturation (Sw), Net – to – Gross (NTG), and fluid type. A cut-off of porosity (12%), Sw (60%), Vcl (50%) was used. The fluid types in the identified reservoirs were discriminated using a combination of available neutron log, density log and pressure data. The result of this interpretation would serve as a viable determinant to obtaining an adequate volumetric estimation and reservoir modeling.

Thereafter, structural interpretation was carried out to identify and map geologic structures from 3-D Seismic data. A velocity model was computed using available checkshot data to generate the synthetic seismogram in order to establish well to seismic tie. With the well tied to seismic data, horizons were identified, picked and interpreted based on tops of the identified reservoir sands. Time structure maps of the mapped horizons were generated and depth converted using the computed velocity model.

Attributes extraction was carried out on the generated time maps to image depositional environment and extract the attribute of turbidite deposits and their general morphology.

In order to capture the diverse geological complexities that may be associated with the mapped reservoirs in "AFUN" field, the reservoir modeling was carried out using geostatistical methodologies in order to capture the reservoir heterogeneity. Geostatistical analysis was done by populating the reservoir architecture (Structure and Stratigraphy) with rock properties. Sequential Indicator Simulation (SIS) and Sequential Gaussian Simulation algorithms of geostatistical methods were carried out to simulate discrete variables and continuous variables respectively. A geological facies model was developed to incorporate the reservoir heterogeneities and characterize reservoir quality to best simulate reservoir production. The result of this analysis should be reliable for "AFUN" field development, as geostatistical tools are particularly effective when dealing with data sets with vastly different degrees of spatial density and diverse vertical and horizontal resolution. The six (6) wells in the study area are closely spaced. Due to the closeness of the wells, it is believed that there would be a strong dependency and the model output has a tendency to be better representative of the distribution of the subsurface facies. The result of this analysis is expected to provide a more realistic estimate of hydrocarbon volumes; and as well, optimize targeting of infill opportunities that exist within the field.

Whole well lithofacies log was developed for each of the six wells. The lithofacies log is a subdivision of the lithology, which includes sand, shaly sand and shales. The Sequential Indicator Simulation (SIS) algorithm was used to distribute the discrete properties for each of the wells. The facies modelling is based on the sequence stratigraphic and attributes extraction results. Stratigraphic modelling was carried out, using log correlation to delineate the reservoir architecture and continuity. A field and reservoir wide (for the modelled levels) correlation exercise was carried out as a means of validating the reservoir tops and bases, to ensure consistency of the reservoir picks, and to correlate the reservoir. This was done within the established sequence stratigraphic framework.

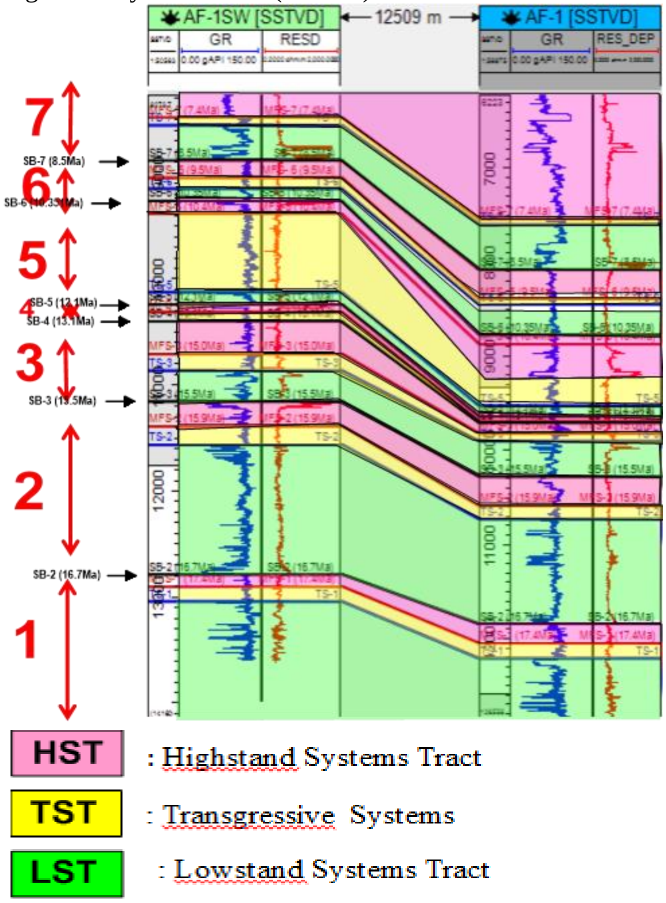
"AFUN" field is bounded to the north by an east-west trending synthetic growth fault. The mapped faults were converted from time to depth with the aid of the generated velocity model. The faults were then converted to model faults. The pillar gridding was done with a I and J increment of 100 (100 x 100). These faults were modelled, defining their lateral shape and geometries. The modelled faults and the horizon structure formed the basis of the 3D structural framework. The faults were built using key pillars while joints of the key pillars formed the fault plane. These faults defined breaks in the 3D grid. Having modelled the faults, 3D grid was then generated from the fault model.

Horizon making involved building of vertical layering in the grid (model) generated during pillar gridding. Zone making process was then employed in zoning the reservoir model into flow units. After zoning, gas-oil-contacts and oil-water-contacts were specified in the model. The horizons were made and zoned into separate hydraulic units using the interbedded shales within the reservoirs. Proportional layering was chosen in other to depict the less stratigraphic complexity associated with the reservoir. The contacts were made for each structural compartment.

Property modelling was done using Sequential Gaussian Simulation (SGS) algorithm. All the property logs prepared in Techlog (validated with core data) were imported into Petrel. These logs were then scaled up. Scale up of well logs involved sampling property values from well logs into the 3D grid in such a way that each grid cell would have a single value for each property. Having assigned property values (both facies and petrophysical) to each grid cell at well locations, the next thing was to distribute properties in the inter-well grid cells in order to realistically preserve the heterogeneity of the studied reservoir. This was achieved by first performing data analysis and then modelling the properties. Data analysis was done in order to identify trends in the data, remove the identified trends, apply transformations on the residual property data, and eventually define variogram model that describes the data and serves as input into property modelling process. Variogram model for each property was generated to identify anisotropy and infer the direction of maximum data continuity before generating each property's sample variogram and variogram model. It is these variogram models that were used in populating properties in 3D grid using various algorithms during modelling of properties. The products of the property distribution within the 3D grid are the property models: facies, porosity, water saturation and net-to-gross models.

Results and Discussion

The results of chronostratigraphic correlation of the wells in the study area yielded seven (7) depositional sequences based on dated surfaces – Sequence Boundaries and Maximum Flooding Surfaces. Sequence stratigraphic analysis showed that three systems tracts namely Lowstand Systems Tracts, Transgressive Systems Tracts and Highstand Systems Tracts. The six (6) Lowstand Systems Tracts (LST) that were delineated are of both Lowstand Slope Fan (LSF) and Lowstand Prograding Wedge (LPW) varieties. Consistently, LSF are characterised by six cycles of retrograding events while LPW are characterised by six cycles of prograding events (Figure 4). Sequence stratigraphy and analogs were used to predict the depositional environments (Table 1). Both LSF and LPW are predicted to be submarine fan deposits which are vertically smeared by pro-deltaic mud. The results of the stratigraphic analysis showed that seventeen reservoirs exist within the field of study. Eleven reservoirs belong to the Lowstand System Tracts and six reservoirs belong to the Highstand System Tracts (Table 1).



SB: Sequence Boundary
MFS: Maximum Flooding Surface
1 – 7: Depositional Sequences

Figure 4. Chronostratigraphic correlation of the study area showing the sequences and identified systems tract.

The three (3) reservoirs (C4, F1 and G1) studied based on the systems tract they belong to, the net pay of the hydrocarbon bearing sand and the sand quality, have their thicknesses ranging from 14 ft to 175 ft, effective porosity range from 7% to 26%, water saturation range from 46% to 90% and net to gross ranging from 10% to 70%. The average porosity values of the reservoirs that were analysed are 21%, 28% and 27%. This indicates that the reservoirs have good storage capacity (Tables 2 to 4).

The analyses of structural interpretation provided information on the subsurface structures and stratigraphy that enhanced the understanding of reservoir heterogeneities and prediction of sand availability in the study area. Thirty (30) mapped faults include growth faults, reverse faults, collapsed crest structure and as well as faults that are synthetic and antithetic to the growth faults. The growth faults are believed to act as pathways for the updip movement of hydrocarbon from the Akata Formation to the Agbada Formation. The structural interpretation showed that the area has been subjected to compressional forces which resulted in reverse faulting system in toe thrust zone influenced by shale diapirs (Figure 5). The synthetic seismogram generated established a fair to good well-to-seismic tie. The structure maps revealed some contour closures that are anticlinal structure forming traps for the reservoirs. The structures are faulted North-South trending rollover anticlines (Figure 5). Generally, it was observed that the discoveries are at the central part and towards the southern part of the field. The eastern part of the "AFUN" field below the shale diapir are bounded by stacked viable prospects while the south-western part of the field is bounded by promising leads.

Amplitude analysis revealed that the mapped sands (which are overlain by the TST) have their amplitude randomly distributed and suggestive of lithology effect, for example a decrease in sand impedance due to porosity increase (Bacon et al, 2003). This amplitude response could be due to the different depositional environments of the overlying shales which are characterised by their unique acoustic impedances, mineralogy and hence seismic responses (Figure 6). From the Root Mean Square (RMS) amplitude analysis, it was observed that amplitude wraps around the hanging wall closure at the eastern part and also bright amplitudes were observed at the crest of the structures.

Table 1. Relationship between the systems tracts, reservoirs and their respective predicted depositional environment.

SEQUENCE	SYSTEM TRACTS	RESERVOIRS	INFEERED DEPOSITIONAL ENVERANMENT PER SEQUENCE	FORMATION
7	HST-7	G4		AGBADA
	TST-7			
	LST-7	G1,G2 and G3	Submarine Fan	
6	HST-6			
	TST-6			
	LST-6	F1	Submarine Fan	
5	HST-5	E2		
	TST-5			
	LST-5	E1	Submarine Fan	
4	HST-4	D2		
	TST-4			
	LST-4	D1	Submarine Fan	
3	HST-3	C5 & C6		
	TST-3			
	LST-3	C1,C2,C3 &C4	Submarine Fan	
2	HST-2	B2		
	TST-2			
	LST-2	B1	Submarine Fan	
1	HST-1			
	TST-1			
	LST-1		Submarine Fan	

Table 2. Summary of the Computed Petrophysical Parameters obtained for C4 Reservoir.

Well Identifier	Top (MD, ft)	Base (MD, ft)	Gross Thickness (ft)	Net Sand (ft)	N/G (Sand)	Vshale	ØT	Øeff	Sw
AF-1	9910.84	9931.02	20.18	6.58	0.326	0.415	0.198	0.132	0.624
AF-1SW	10879.90	10915.45	35.55	1.42	0.040	0.668	0.223	0.076	0.568
AF-3ST1	8972.19	8999.58	27.39	1.6	0.65	0.581	0.237	0.109	0.41
AF-4ST1	10171.42	10500.79	329.27	0	0	0.871	0.161	0.008	0.996
AF-5	8918.64	8958.51	39.87	25.59	0.642	0.352	0.247	0.205	1

Table 3. Summary of the Computed Petrophysical Parameters obtained for F1 Reservoir.

Well Identifier	Top (MD, ft)	Base (MD, ft)	Gross Thickness (ft)	Net Sand (ft)	N/G (Sand)	Vshale	ØT	Øeff	Sw
AF-1	8449.46	8607.15	157.69	126.78	0.804	0.316	0.250	0.214	0.999
AF-1SW	9146.68	9202.63	55.95	0	0	0.759	0.249	0.042	1
AF-3ST1	7708.20	7767.16	58.96	6.07	0.103	0.423	0.275	0.190	0.998
AF-4	8258.26	8429.86	171.60	122.35	0.653	0.247	0.280	0.227	0.250
AF-4ST1	8256.19	8429.51	173.32	93.94	0.542	0.307	0.273	0.206	0.638
AF-5	7443.20	7467.86	24.66	18.37	0.745	0.311	0.322	0.241	1

Table 4. Summary of the Computed Petrophysical Parameters obtained for G1 Reservoir

Well Identifier	Top (MD, ft)	Base (MD, ft)	Gross Thickness (ft)	Net Sand (ft)	N/G (Sand)	Vshale	ØT	Øeff	Sw
AF-1	8000.08	8080.13	80.05	75.09	0.938	0.227	0.236	0.220	0.14
AF-1SW	8825.07	8879.04	53.97	30.33	0.562	0.346	0.281	0.188	0.469
AF-3ST1	7406.05	7469.43	63.38	12.93	0.204	0.496	0.277	0.146	0.995
AF-4	7923.38	7985.67	62.29	18.13	0.291	0.395	0.239	0.183	0.998
AF-4ST1	7917.32	7984.65	67.33	0	0	0.674	0.243	0.055	0.996
AF-5	7060.52	7114.67	54.15	51.17	0.945	0.198	0.315	0.258	0.991

The six (6) wells are relatively closely spaced which make them suitable for statistical analysis. Due to the closeness of the wells, it is believed that there would be a strong geological and physical dependencies and the model output has a tendency to be better representative of the distribution of the subsurface facies. The result of this analysis is expected to capture the reservoir heterogeneity and provide a more realistic estimate of hydrocarbon volumes; and as well, optimize targeting of infill opportunities that exist within the field.

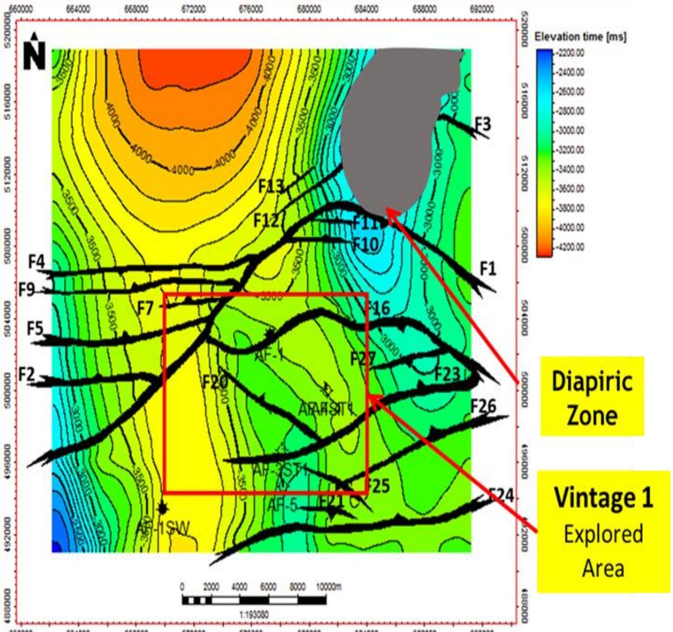


Figure 5. Representative time structure map showing the diapiric zone, explored area and mapped faults.

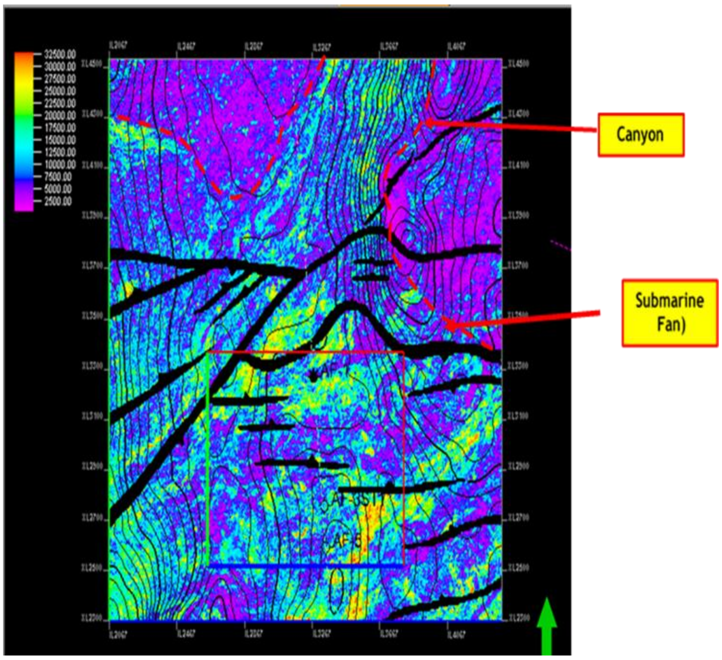


Figure 6. Representative attribute map showing Submarine Fan Model for "AFUN" Field.

Framework Modelling

The structural framework of the reservoirs has total grid cell of 234,824. This implies that the geological heterogeneities were captured within grid resolution for the construction of a fit for purpose geological model. All the faults (synthetic and antithetic faults) that were modelled for the three reservoirs trend generally in the east–west direction. Four major intra-reservoir faults (F16, F20, F21 and F27) were identified as faults likely to compartmentalize hydrocarbon accumulations during production especially in the reservoir C4 (Figure 7).

Lithofacies Modelling

The facies model predicts lateral discontinuity of sand across the reservoirs. From the geometry of facies simulated for the three reservoirs, it was observed that lithofacies maps depict the lateral and vertical discontinuity of the reservoirs across the entire field. The results indicate that the value of sandy turbidite ranges from 15- 45%, shaly turbidite ranges from 9 – 24% while that of shale ranges from 35 – 74% (Figure 8).

Property Modelling

From the petrophysical parameters evaluated for the reservoirs, it was observed that much hydrocarbon can be economically exploited from the reservoirs of some of the wells due to their high porosity and low water saturation. The effective porosity model shows that the reservoirs have a minimum porosity of 0.05 and maximum porosity of 0.35. The model shows that the reservoirs have an average effective porosity of 0.25. From the colour legend areas with very low porosity are indicated by the purple colour while areas with high porosity are indicated with yellow colour. The effective porosity models built were in agreement with the facies model; these models point to the fact that, the effective porosity in wells AF-4ST1, AF-3ST1 and AF-5 are not as good as the other wells as a result of the shaliness of the reservoir in this well as distributed in all the three reservoirs of the facies model.

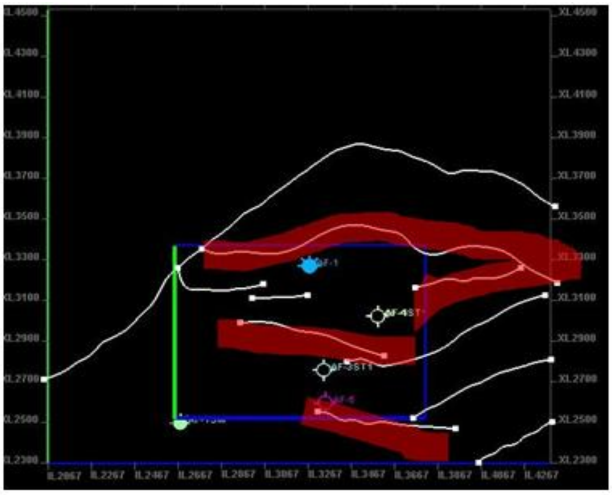


Figure 7. Four Major Synthetic and Antithetic Intra-reservoir Faults trend E-W that likely Compartmentalize the Reservoir.

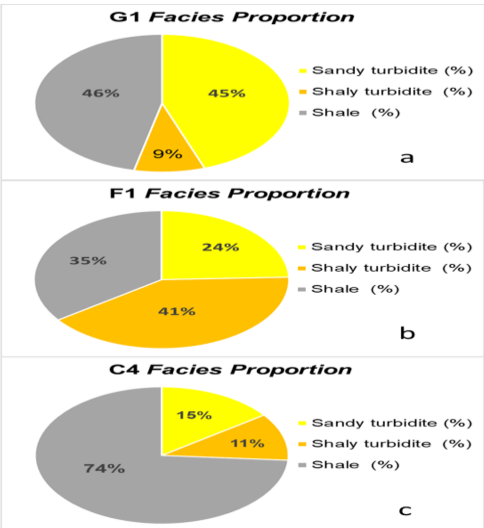


Figure 8. Pie Chart showing the Facies Proportion of Reservoirs (a) G-1 (b) F-1 (c) C-4.

The water saturation model shows that the reservoirs have a minimum water saturation of 0.08 and maximum water saturation of 0.30. These indicate that the reservoirs are 0.70 saturated with hydrocarbon. Areas with blue colour indicate part that is completely saturated with water. This model showed that, wells AF-4ST1, AF-3ST1 and AF-5 have high water saturation which makes them poor candidates for completions and development; while wells AF-1 andAF-1SW have lower water saturation and high oil saturation which make them the best candidates for completions and development.

Areas with very low volume of shale are indicated by the purple colour while areas with high volume of shale are indicated with yellow colour. The volume of shale models built were in agreement with the facies model; these models point to the fact that, the areas with high volume of shale such as in wells AF-4ST1, AF-3ST1 and AF-5 show that the zones will be poor for well development. From the colour legend areas with very low net to gross are indicated by the purple colour while areas with high net-to-gross are indicated with yellow colour. The net-to-gross defined productive zones in the reservoir for hydrocarbon exploitation. This model showed that, wells AF-1 andAF-1SW have high net-to-gross which make the two productive; while wells AF-4ST1, AF-3ST1 and AF-5 have lower net-to-gross. The net-to-gross estimated for all the reservoirs analysed showed high percentage of shale relative to sandstone (Figures 9 to 11).

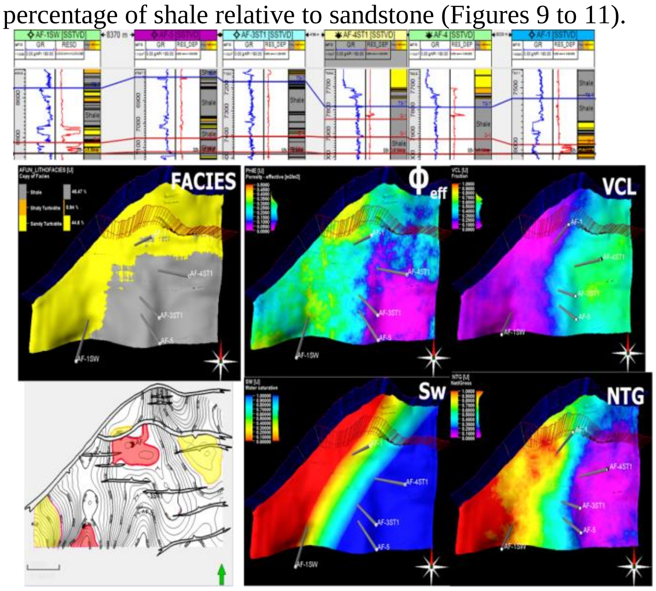


Figure 9. Reservoir Properties of G1

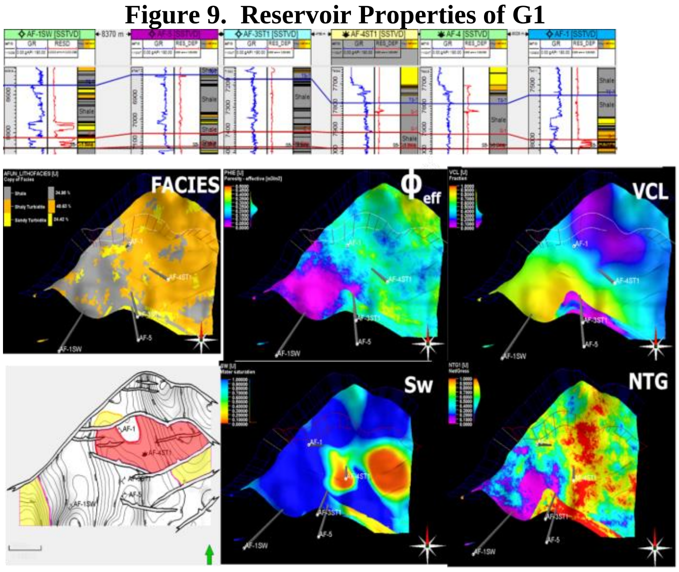


Figure 10. Reservoir Properties of F1.

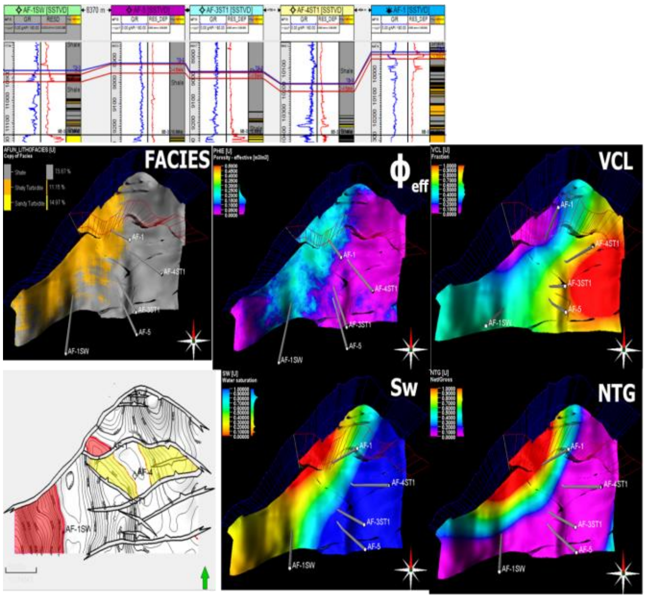


Figure 11. Reservoir Properties of C4.

Conclusions

The "AFUN" field is a deep offshore field located off the western coast of the Niger Delta in the Gulf of Guinea. The combination of seismic and well data were useful in building a reservoir model in that helps to understand the characteristics of reservoirs in the field. Reservoir quality was interpreted based on depositional features which control the reservoir characteristics in different facies of the reservoirs. Structural style and facies architecture are the two fundamental elements that defined the reservoir heterogeneity of "AFUN" Field.

The reservoir model showed that the heterogeneity and quality of the deep marine reservoir systems in the Field could be assessed by lateral and vertical variations in the stacking patterns of the submarine fans which affects the shape and scale of the reservoirs and their trapping geometry. It has also been shown that the distribution and type of architectural elements i.e. fractures within the fan system have major impact upon the reservoir distribution, continuity and connectivity of sand/shale bodies. Vertical and horizontal arrangement of reservoir or non-reservoir facies define flow units which control fluid flow and production performance of the field. The result of the modelling indicated that the geometry of facies simulated allowed reproduction of large scale heterogeneities as generated by facies boundaries. The smaller scale variability within facies was captured by the spatial distribution of petrophysical variables simulated within each facies. From the models, it can be deduced that synthetic and antithetic faults made the structural framework of the reservoirs in the study area. Also, the lithofacies model built for the reservoirs revealed three (3) facies with the sandy turbidite ranging from 15- 45 %, shaly turbidite ranges from 9 – 24 % while that of shale ranges from 35 – 74 %. The model also showed that there are vertical and lateral changes in reservoir properties such as porosity, water saturation and volume of shale created by reservoir heterogeneity. Geostatistical studies have been used successfully in this research work for reservoir description that captures the variability of the reservoir sequences and prediction of quality and heterogeneity of the reservoir which can be used for reservoir simulation. It is recommended that core data of the reservoirs of interest interval should be acquired for the wells that penetrated the reservoir at hydrocarbon interval in order to model the permeability spatially across the entire field.

References

Avbovbo, A. A. (1978). Tertiary Lithostratigraphy of Niger Delta. American Association of Petroleum Geologists. Bulletin, 62, p.295-306.

Bilotti, F. D., Shaw, J. H. Cupich, R. M. and Lakings, R. M. (2005). Detachment fold, Niger Delta, in J. H. Shaw, C. Connors, and J. Suppe, eds., Seismic interpretation of contractional fault-related folds: AAPG Studies in Geology 53, p. 103–104.

Connors, C. D., Denson, D. B., Kristiansen, G. and Angstadt, D. M. (1998). Compressive anticlines of the mid-outer slope, central Niger Delta (abs.): AAPG Bulletin, 82, p. 1903.

Corredor F., Shaw J., Suppe, J. (2005) Shear fault-bend folding, deep water Niger Delta, In: J. Shaw, C. Connors, and J. Suppe, eds., Seismic Interpretation of Contractional fault-related folds: AAPG Studies in Geology 53: 87– 92

Damuth, J. E., 1994: Neogene gravity tectonics and depositional processes on the deep Niger Delta continental margin: Marine and Petroleum Geology, v. 11, no. 3, p. 320–346.

Darling T (2005) Well Logging and Formation Evaluation. Oxford, UK: Elsevier. p5

Eaton, T.T. (2006). On the importance of geological heterogeneity for flow simulation. Sedimentary Geology 184(3):187-201

Hooper, R.J., Fitzsimmons, R.J., Grant, N. and Vendeville, B.C. (2002). The role of deformation in controlling depositional patterns in the South central Niger dElta, West Africa. Journal of structural geology 24; 847-859.

Marchand, A., Apps, G. and Li, W. (2015). Depositional processes and impact on reservoir quality in deepwater Paleogene reservoirs, US Gulf of Mexico AAPG Bulletin 99 (9): 1635-1648.

Nwachukwu, J. I. and Chukwura, P. I. (1986). Organic matter of Agbada Formation, Niger Delta, Nigeria. American Association of Petroleum Geologists, Bulletin, 70, p.48-55.

Peel, F. J., Travis, C. J. and Hossack, J. R. (1995). Genetic structural provinces and salt tectonics of the Cenozoic offshore US Gulf of Mexico.: A preliminary analysis. In Jackson M.P.A., Roberts D.G, Snelson S, (Eds). Salt tectonics: A Global perspective AAPG Memoir Vol. 65, pp. 153-175.

Reijers, T. J. A., Petters, S. W. and Nwajide, C. S. (1997). The Niger Delta Basin, in Selley, R.C, (ed.) African Basin-sedimentary Basin of the World 3: Amsterdam, Elsevier Science, p. 151 – 172.

Rowan, M. G., Peel, F. J. and Vendeville B. C. (2004). Gravity driven fold belts on passive margins, In K.R. McClay, ed., Thrust tectonics and hydrocarbon systems. AAPG Memoir 82, p. 157 – 182.

Shaw, J.H., Novoa, E. and Connors, C. D. (2004). Structural controls on growth stratigraphy in contractional fault related folds, In K.R. McClay, ed., Thrust tectonics and hydrocarbon systems. AAPG Memoir 82, p. 400 – 412.

Short, K. C. and Stauble, A. J. (1965). Outline of geology of Niger Delta: AAPG Bulletin, 51, p. 761–779.

Slatt, R.M. (2006). Stratigraphic Reservoir Characterization for Petroluem Geologists, Geophysicists and Engineers, Handbook of Petroluem Exploration and Production 6, P 379 -420.

Suppe, J., Connors, C. D. and Zhang, Y. (2004). Shear fault bend folding, In K.R. McClay, ed., Thrust tectonics and hydrocarbon systems. AAPG Memoir 82, p. 303– 323.

Tyler, N. and Finley, R. J. (1991). Architectural controls on the recobery of hydrocarbons from sandstone reservoirs. In A. D. Miall and N. Tyler, (eds.). the three dimensional architecture of terrigenousclastic sediments and its implication for hydrocarbon discovery and recovery: SEPM concepts in sedimentary and paleontology, 3:1-5.

Weimer, P. and Slatt, R.M. (2004). Petroleum Systems of Deepwater Settings, SEG/EAGE Distinguished Instructor Short Course, (Distinguished Instructor Series; no. 7) .

Wu S, Bally AW (2000) Slope tectonics - Comparisons and contrasts of structural styles of salt and shale tectonics of the northern Gulf of Mexico with shale tectonics of offshore Nigeria in Gulf of Guinea. In: W. Mohriak and M. Talwani, eds., Atlantic Rifts and Continental Margins: Washington, D.C., American Geophysical Union, 151–172