

CONTROLS OF DEPOSITIONAL ENVIRONMENTS ON RESERVOIR QUALITY IN TERMS OF POROSITY AND PERMEABILITY GABO FIELD NIGER DELTA.

Nduaguibe, T. W and Ideozu, R. U.

Department of Geology, University of Port Harcourt, Rivers State, Nigeria.

Corresponding author email: richmond.ideozu@uniport.edu.ng

Abstract

The controls of depositional environments on reservoir quality have been evaluated in terms of porosity and permeability of the Gabo Field, Niger Delta, Nigeria. Data used in this research include Well logs, Core data and photos, and grain size analysis for Wells 51 and 52 in the study area. Standard methods as applicable in petrophysical and sedimentological analysis has been adopted. Thirteen reservoir units have been identified in wells 51 and 52 which had 5 reservoirs cored each. The lithofacies units of the identified reservoirs across the study area, comprise pebbly sands, coarse -, medium -, fine- and very fine-grained sands, sandy mud, silty sands and heteroliths. The heteroliths – very fine-grained silty muds are highly bioturbated. *Ophiomorpha* and skolithos are the major trace fossils with sedimentary structures (ripple lamination, wavy lenticular and planar beds, cross bedded sands, coarsening and fining upward). The facies associations interpreted for the study area are Channel and Coastal barrier systems and the environment of deposition as distributary channel, upper and lower shoreface. The sedimentary processes that deposited facies ranged from high energy regimes, reworking by waves to low energy with periodic influx of silts and muds. The average porosity and permeability for reservoirs in Well 51 is 16.7% and 1317 Md, reservoirs in Well 52 is 28.2% and 2330Md whereas porosity range for the study area is 2% - 32% and permeability is 1.2 – 10600 Md. The reservoir quality reservoir of the sand units in Well 51 (7, 9 and 13) and Well 52 (5, 7, 9, 11 and 13) is excellent - good, this is because of the dynamics environments of deposition (upper shoreface and distributary channel) as well as the mechanisms that play out during deposition such as bioturbation, sorting, sedimentary structures formed. Whereas the poor quality across the reservoirs especially the lower shoreface and prodelta facies is as result of lack bioturbation, connectivity, multiplicity of burrows that may have been plugged by clay and intercalation of shale and sand (heteroliths). This research has shown that environments of deposition have direct influence the reservoir quality in terms of porosity and permeability.

Key words: Porosity, permeability, skolithos, *Ophiomorpha*, lithofacies, reservoir, bioturbation, channel and coastal barrier systems.

Introduction

The Gabo Field is one of the oil fields in the Niger Delta Basin. Most Wells drilled in the Tertiary Niger Delta have penetrated several sandstone units in the Benin and Agbada Formations, separated by clay/shale brakes (Reyment, 1965). The sandstone units' thickness apparently increases upward while the shale thickness appears to be increasing downward and probably overlies a Basement Complex, (Short and Stauble, 1967). Niger Delta covers an area of 75,000 square kilometers, opens to the South Atlantic Ocean and out builds into the Gulf of Guinea which is probably an extension of the Benue Trough. It merges westward across Okitipupa and Dahomey Embayment, (Reyment, 1967). The quality of a reservoir sand unit in a depositional system can be related to its: porosity, permeability, type of depositional environment, thickness and its lateral continuity, these in turn are influenced by the textural features such as sorting, grain size, roundness, sphericity, cement, clay content, the presence of trace fossils, sedimentary process and structures and energy of deposition of medium. This research seeks to evaluate the influence of depositional environment and its mechanisms on reservoir quality of Gabo Field in relation to porosity and permeability and how it can contribute to the optimization of resource exploration and exploitation within the Gabo Field. The study area is located within the south-western part of the coastal swamp Depobelt region of Niger Delta (Figure 1-2). The geology of the Niger Delta has been well established in addition to the stratigraphy, structural framework and petroleum geology (Doust and Omatsola, 1989, 1990; Reijers, 1996; Kulke, 1995; Ekweozor and Daukoru, 1994; Evamy *et al*, 1978). See Figure 3-4.

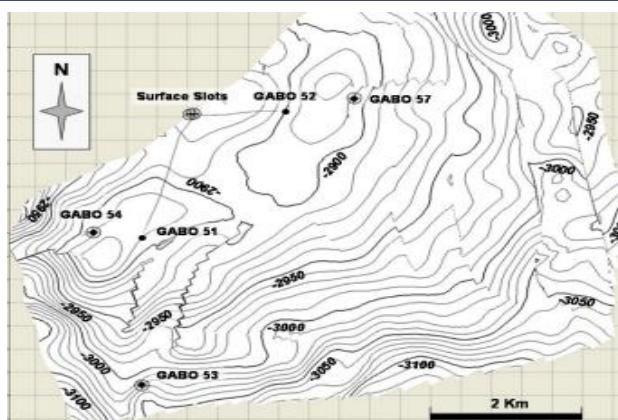


Figure 1 Base map of Gabo Filed

Source Total E and P 2014

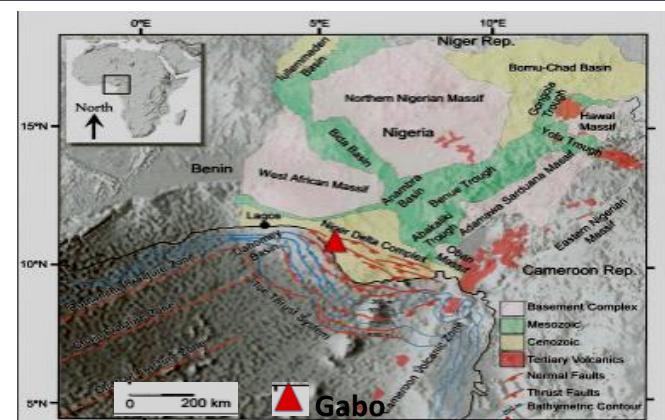
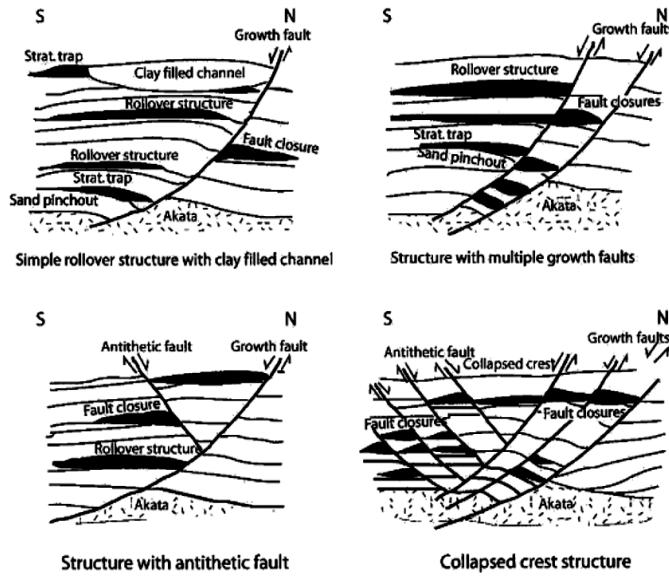
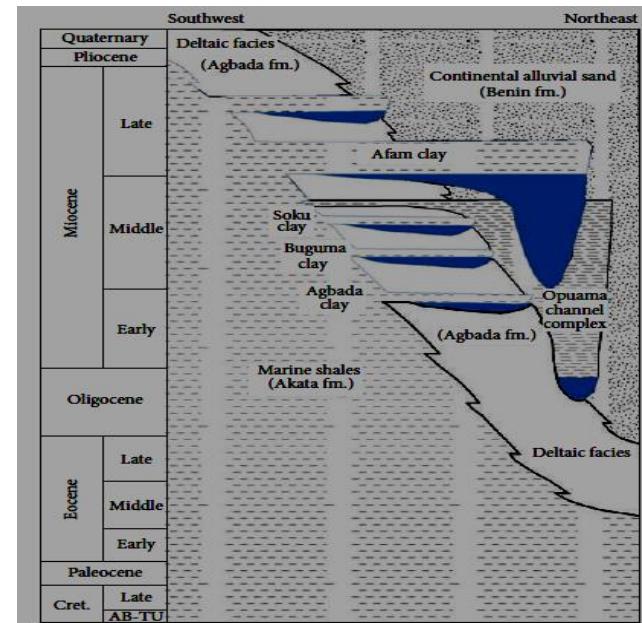


Figure 2 Location of Gabo Filed

(modified from Mitchum, 2006)

Figure 3 Niger trapping systems
(Modified from Doust and Omatsola (1990))

and Stacher (1995).

Figure 4 Stratigraphic structure of the Niger Delta
(After Shanon and Naylor 1989; Doust and Omatsola (1990))

Materials and Methods

Materials.

The materials of this research have been provided by an International Oil Company in Nigeria (for propriety reasons, the name of the company and field is omitted) through the Department of Petroleum Resources (DPR). The data set provided include the following:

1. Well logs and mud logs
2. Core photos and core data
3. Lithofacies description
4. Location map

Methods

The work flow diagram illustrates the methodology applied in this research (Figure 5). Quantitative petrophysical analysis and evaluation was carried out on the two wells to determine their Porosity (ϕ) and Permeability (K) from

the well logs compared with core data. See Figure 3. The formula upon which the software computes the petrophysical parameters are shown below.

Effective Porosity

$$\Phi_{\text{eff}} = \Phi_D - (V_{\text{sh}} \times \Phi_{D\text{sh}}) \quad (1.0)$$

Where:

Φ_{eff} = Effective porosity

Φ_D = Total porosity

V_{sh} = Shale volume

$\Phi_{D\text{sh}}$ = Shale porosity from density log

$$GR_i = (GR_{\text{log}} - GR_{\text{min}}) / (GR_{\text{max}} - GR_{\text{min}}) \quad (2.0)$$

$$V_{\text{sh}} = 0.083 \times (2^{(3.7 \times GR_i)} - 1)$$

Where: GR_i = Gamma ray index,

GR_{log} = Gamma ray log reading,

GR_{min} = Minimum Gamma ray log reading, which signifies clean sand and GR_{max} = Maximum Gamma ray log reading, which signifies 100% shale. Both equations calculate the volume of shale.

Permeability

$$K = (250 \times \Phi_{\text{eff}}^3 / S_{\text{wirr}})^2 \quad [\text{Tixer equation}] \quad (3.0)$$

Where:

K = Permeability

Φ_{eff} = Effective porosity

S_{wirr} = Irreducible Water Saturation

Results and Discussion

The results of this research are presented in Figures 6 - 8 and Tables 1 – 15. In Well 51, the total cored intervals are 3687 – 3719m (32 m), 3764 – 3794 (30m) and 34078 – 4129 (51m). Three reservoir units have been delineated 7 (a and b), 9 (a and b) and 13 (a and b). See Tables 1 - 5. In Well 52, the total cored intervals are 3687 – 3719m (32 m), 3764 – 3794 (30m) and 34078 – 4129 (51m). Three reservoir units have been delineated 7 (a and b), 9 (a and b) and 13 (a and b). See Tables 6 - 10.

Discussion

Environment of Deposition (EoD)

Environments of deposition (EoD) play a key role in reservoir characterization as well as in reservoir quality and performance predictions across a field (Toba and Ideozu, 2017, 2018). Reservoir sand bodies deposited in different depositional environments are characterized by different sand shape and geometry, size and heterogeneity. The depositional environment of the reservoirs have been interpreted based on well logs motifs using standard shape of GR-log (Figures 6 -7) and interpretation from core photos. Clastic sedimentary facies display characteristic vertical profiles based on which grain size, fining upward sequence or coarsening upward sequences. Determination of such these vertical variations in grain size from GR-log is valuable in the interpretation of depositional environments. See Figures 6 -7. In Well 51 the environments of deposition comprise fluvial channels, distributary channels, upper shoreface, lower shoreface and prodelta (See Tables 2 -5) whereas in Well 52 the environments of deposition comprise flood plain, fluvial channels, distributary channels, upper shoreface, lower shoreface and prodelta. See Tables 6 – 10.

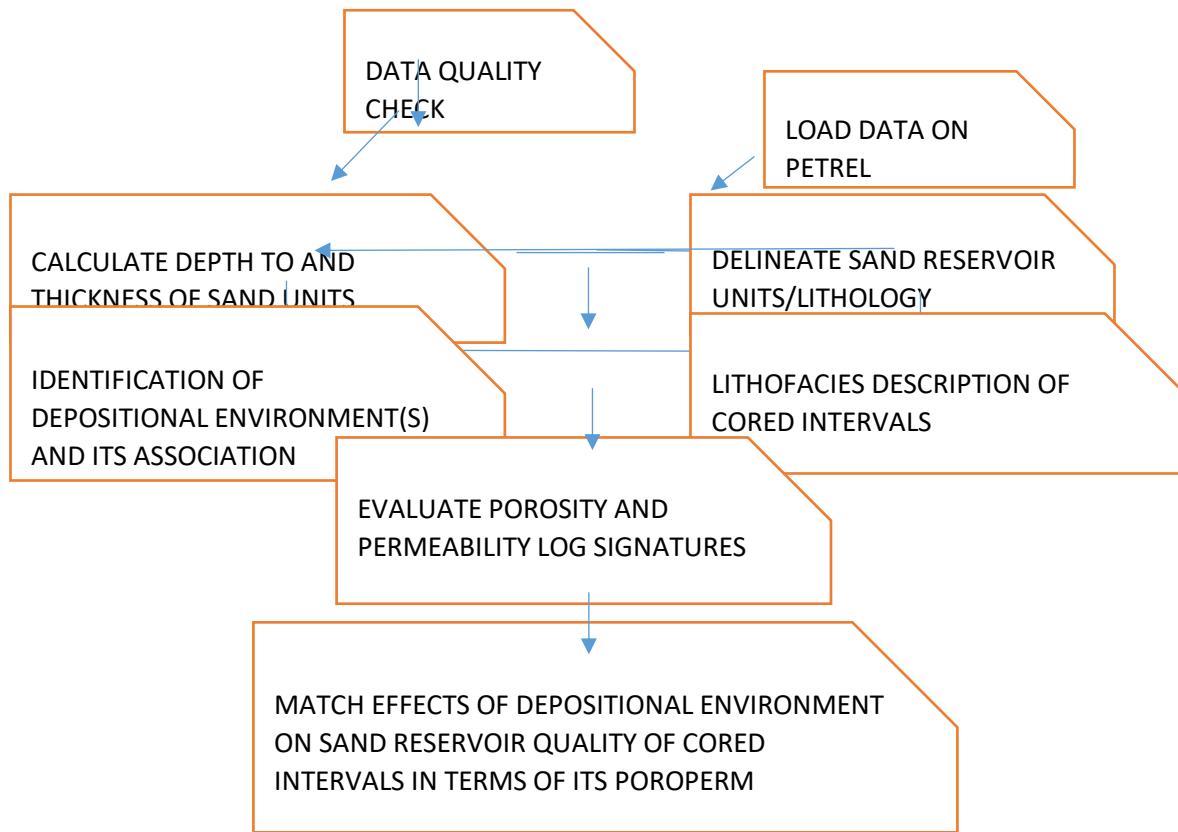


Figure 5 Work-flow chart

Table 1 Reservoir thickness in well 51.

Reservoir	Lithology	Top (m)	Bottom (m)	Thickness (m)	Number of cores	Cored length m
7	Sand	3686	3699	13	1	30
9	Sand	3773	3791.5	18.5	1	30
11	Sand	4087	4109.40	22.4	2	46.3
13	Sand	4097.3	4098	0.7	Un cored	—

Table 6 Reservoir thickness in well 52.

Reservoir	Lithology	Top (m)	Bottom (m)	Thickness (m)	Number of cores	Cored length m
5	Sand	3324	3336	12	1	17
7	Sand	3445	3468	23	1	30
9	Sand	3542	3556	14	1	18
11	Sand	3690.5	3698	7.5	1	18
13	Sand	3797	3810	13	1	17

Reservoir Quality

The quality of a reservoir rock can be evaluated in terms of porosity and permeability. Hydrocarbon reservoir sands that are thick enough, highly porous and permeable give better prospects, higher volume and profit and as such, major Oil Companies indicate keen interest in such reservoir sands. The reservoir quality of the sand units studied (Well 51: sands 7, 9 and 13; Well 52: sands 5, 7, 9, 11 and 13) have higher quality because of their environments of deposition as well as the mechanisms that play out in them such as bioturbation, textures and sedimentary structures interpreted as distributary channels, fluvial channels and upper shoreface (See Tables 2 -3 and 6 – 7). The least quality reservoirs occur probably due to lack of bioturbation, connectivity and type of lithology interpreted as flood plain, lower shoreface (heteroliths) and prodelta shales. See Tables 4 – 5 and 8 – 9.

Table 2 Core Description, Deposition Environment, Porosity and Permeability for reservoir units in Well 51

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity Mean and Range (%)	Permeability Mean and range (md)
7	a	3687 – 3697	10	Medium to coarse grained, cross bedded sandstone, poorly sorted, low angle crossbedding, bioturbated- <i>ophiomorpha</i> . High energy flow regime	Fluvial channel	21.5 16 - 28	1047 600 – 1600
	b	3710 – 3718	8	Coarsening upward very fine to fine- grained cross ripple laminated sandstone, low angle crossbedding to current ripple bedding. High energy regime reworked by waves	Upper shoreface	25.25 16 - 29	1037.5 500 – 1400
9	a	3773 – 3783	10	Pebbly-coarse medium grained cross bedded fining upward sandstone, planar cross bedded to low angle crossbedding, poorly sorted with bioturbation. Trace fossil present include <i>ophiomorpha</i> and <i>skolithos</i> . High energy flow regime.	Fluvial Channel	21.89 8 - 29	1210.07 500 – 1800
	b	3783 – 3790	7	Fine to very fine-grained well sorted sandstone, wave rippled to current bedding and planar bedding. High energy regime reworked by waves	Upper shoreface	22.2 4 – 29	780 6 - 1800
13	a	4088- 4101	12	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiomorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	21.89 8 – 29 (Estimated)	1215 510 – 1800 (Estimated)
	b	4101 – 4106	5	Fine to very fine-grained sandstone, well sorted, wave ripple lamination, current ripple and planar current bedding. High energy regime reworked by waves	Upper shoreface	25.25 16 – 29 (Estimated)	1039 520 – 1400 (Estimated)

Summary

Wells 51 and 52, sands 7, 9 and 13 are probably the same sand units since they have similar log signatures while sands units 5 and 11 both in well 52 are different since they have serrated log signatures and sand unit 11 has a funnel signature in addition. There are no Porosity and Permeability plots for sand 13, Well 51 and sands 9, 11 and 13 in Well 52 to calculate average values because of lack of lack of data. From their lithofacies and core photo description, sedimentary process and structure, textures, environment of deposition, gamma ray and resistivity logs these reservoir sands units have high quality.

Well log porosity and permeability result for all sand units in both wells have higher values than the results obtained from analyzing the core plugs, (Tables 11-15). This could be because of poor handling of the cores, technical, procedural error or probably due to the absence of bioturbation and increased or diagenesis within the sand unit. The quality of a reservoir (contained reservoir fluid) is related to the textural features and depositional environment in turn control the porosity and permeability of the reservoir.

Conclusion

From the results, the reservoirs sands have been deposited in a Channel system - in the following EoD distributary channel, flood plain and fluvial channel. Only the distributary channel and fluvial depositional environments have higher reservoir quality in terms of porosity and permeability. Whereas the other reservoirs, have been deposited in a Coastal barrier systems. With the following EoD upper shoreface, lower shoreface and pro-deltaic, only the

upper shoreface has high quality in terms of porosity and permeability. The grain size ranges of all the reservoir sands is medium to coarse (0.5 – 1.75 Φ), high energy of deposition and with some reservoir sands reworked by wave action. Reservoir sand units in the studied field are bioturbated except sand units 5 of Well 52 which also has a lower quality in terms of porosity and permeability. The non-reservoir units have moderate to good reservoir quality and are interpreted as flood plain, lower shoreface and prodelta shales.

Table 3 Core Description and Reservoir quality for reservoir units in Well 51

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity (%)	Permeability (md)
7	a	3687 – 3697	10	Medium to coarse grained, cross bedded sandstone, poorly sorted, low angle crossbedding, bioturbated- <i>ophiromorpha</i> . High energy flow regime	Fluvial channel	Good to very good	Very good to excellent
	b	3710 – 3718	8	Coarsening upward very fine to fine-grained cross ripple laminated sandstone, low angle crossbedding to current ripple bedding. High energy regime reworked by waves	Upper shoreface	Good to very good	Very good to excellent
9	a	3773 – 3783	10	Pebbly coarse–medium grained cross bedded fining upward sandstone, planar cross bedded to low angle crossbedding, poorly sorted with bioturbation. Trace fossil present include <i>ophiromorpha</i> and <i>skolithos</i> . High energy flow regime.	Fluvial Channel	Poor to very good	Very good to excellent
	b	3783 – 3790	7	Fine to very fine-grained well sorted sandstone, wave rippled to current bedding and planar bedding. High energy regime reworked by waves	Upper shoreface	Negligible to very good	Moderate to excellent
13	a	4088-4101	12	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiromorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	Poor to very good (Estimated)	Very good to excellent (Estimated)
	b	4101 – 4106	5	Fine to very fine-grained sandstone, well sorted, wave ripple lamination, current ripple and planar current bedding. High energy regime reworked by waves	Upper shoreface	Negligible to very good (Estimated)	Moderate to excellent (Estimated)

Table 4 Core Description, Depositional Environment, Porosity and Permeability of Non-Reservoir units in Well 51

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity (%)	Permeability (md)
7	a	3697 – 3704	7	Heteroliths, planar laminated slightly mudstone trace fossils present include ophiomorpha and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	17 8 - 28	288.21 0.1 -1000
	b	3704 – 3710	6	Dark grey silty shales. Low energy.	Prodelta	13.67 12 - 16	83.42 0.1 -500
9	a	3764 – 3773	9	Wavy bedded heterolithic and bioturbated, trace fossils present include ophiomorpha, planolites and skolithos. Low energy regime with periodic influx of silt.	Lower shoreface	16.7 9 – 25	241.1 0.1 - 1000
	b	3791 – 3794	3	Very fine-grained ripple laminated, interlaminated clay, intensely bioturbated. Trace fossil present include skolithos and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	18.5 12 – 25	278.5 7 - 600
13	a	4078-4088	10	Siltstone, light brownish grey, wave ripple laminated, inter laminated with mudstone. Heterolithic wavy bedding. Trace fossil present is planolites. Low energy regime with periodic influx of silt.	Lower shoreface	16.7 9 – 25 (Estimated)	241.1 0.1 – 1000 (Estimated)
	b	4121 – 4129	8	Dark grey silty shales. Low energy.	Prodelta	13.67 12 – 16 (Estimated)	83.42 0.1 -500 (Estimated)

Table 5 Core Description, Depositional Environment and Reservoir Quality of the Non-Reservoir units in Well 51

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity (%)	Permeability (md)
7	a	3697 – 3704	7	Heteroliths, planar laminated slightly mudstone trace fossils present include ophiomorpha and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	Poor to very good	Very good to Excellent
	b	3704 – 3710	6	Dark grey silty shales. Low energy.	Prodelta	Good	Good to very good
9	a	3764 – 3773	9	Wavy bedded heterolithic and bioturbated, trace fossils present include ophiomorpha, planolites and skolithos. Low energy regime with periodic influx of silt.	Lower shoreface	Poor to very good	Good to very good
	b	3791 – 3794	3	Very fine-grained ripple laminated, interlaminated clay, intensely bioturbated. Trace fossil present include skolithos and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	Good to very good	Poor to very good
13	a	4078-4088	10	Siltstone, light brownish grey, wave ripple laminated, inter laminated with mudstone. Heterolithic wavy bedding. Trace fossil present is planolites. Low energy regime with periodic influx of silt.	Lower shoreface	Poor to very good	Poor to very good
	b	4121 – 4129	8	Dark grey silty shales. Low energy.	Prodelta	Poor to good	Poor to very good

Table 6 Core Description, Deposition Environment, Porosity and Permeability for reservoir units in Well 52

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity Mean and Range (%)	Permeability Mean and range (md)
5	a	3324–3328	4	Medium to coarse grained, cross bedded sandstone, moderate to poorly sorted and laminated. High energy flow regime	Fluvial channel	18.44 8 - 32	747.67 8 – 4000
	b	3328 – 3335	7	Coarsening upward fine to very fine-grained well sorted sandstone. High energy regime reworked by waves	Upper shoreface	22.71 6 - 30	6198.53 12 – 80000
7	a	3324–3328	4	Medium to coarse grained, moderate to poorly sorted, and laminated. High energy flow regime	Fluvial Channel	18.82 8 - 32	902.2 0.6 – 600
	b	3328 – 3334	6	Coarsening upward fine to very fine-grained cross rippled, laminated, trough bedded, well sorted sandstone. High energy regime reworked by waves	Upper shoreface	22.76 10 – 30	915.32 11 – 10500
9	a	3444-3468	24	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiomorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	21.89 4 – 28	9025.04 0.7 – 19000
	b	3472 – 3480	8	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiomorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	25.25 16 – 29 (Estimated)	1039 520 – 1400 (Estimated)
13	a	3790 – 3793	3	Coarsening upward fine to very fine-grained cross rippled, laminated, trough bedded, well sorted sandstone. High energy regime reworked by waves	Upper shoreface	22.76 10 – 30 (Estimated)	915.32 11 – 10500 (Estimated)
	b			Pebbly-coarse medium grained cross bedded fining upward sandstone, planar cross bedded to low angle crossbedding, poorly sorted with bioturbation. Trace fossil present include <i>ophiomorpha</i> and <i>skolithos</i> . High energy flow regime.	Fluvial channel	18.44 8 – 32 (Estimated)	747.67 8 – 4000 (Estimated)

Table 7 Core Description and Reservoir quality for reservoir units in Well 52

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity (%)	Permeability (md)
5	a	3324–3328	4	Medium to coarse grained, cross bedded sandstone, moderate to poorly sorted and laminated. High energy flow regime	Fluvial channel	Poor to Excellent	Poor to Excellent
	b	3328 – 3335	7	Coarsening upward fine to very fine-grained well sorted sandstone. High energy regime reworked by waves	Upper shoreface	Poor to very good	Moderate to Excellent
7	a	3324–3328	4	Medium to coarse grained, moderate to poorly sorted, and laminated. High energy flow regime	Fluvial Channel	Poor to Excellent	Poor to Excellent
	b	3328 – 3334	6	Coarsening upward fine to very fine-grained cross rippled, laminated, trough bedded, well sorted sandstone. High energy regime reworked by waves	Upper shoreface	Poor to very good	Moderate to Excellent
9	a	3444-3468	24	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiomorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	Negligible to very good	Poor to Excellent
	b	3472 – 3480	8	Medium to coarse-grained cross bedded blocky sandstone, low angle crossbedding moderate to poorly sorted, bioturbated, present is <i>ophiomorpha</i> and <i>planolites</i> . High energy flow regime.	Distributary Channel	Good to very good (Estimated)	Very good to Excellent (Estimated)
13	a	3790 – 3793	3	Coarsening upward fine to very fine-grained cross rippled, laminated, trough bedded, well sorted sandstone. High energy regime reworked by waves	Upper shoreface	Moderate to very good (Estimated)	Moderate to Excellent (Estimated)
	b			Pebbly-coarse medium grained cross bedded fining upward sandstone, planar cross bedded to low angle crossbedding, poorly sorted with bioturbation. Trace fossil present include <i>ophiomorpha</i> and <i>skolithos</i> . High energy flow regime.	Fluvial channel	Poor to Excellent (Estimated)	Poor to Excellent (Estimated)

Table 8 Core Description, Deposition Environment, Porosity and Permeability for Non-reservoir units in Well 52

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity Mean and Range (%)	Permeability Mean and range (md)
5	a	3322–3324	2	Sandy mudstone, grey and intensely bioturbated, trace fossil present is skolithos. Low energy	Flood plain	12.11 3 - 23	33.00 10 – 120
	b	3335 – 3339	4	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Lower shoreface	6 8 - 28	288.21 0.1 – 1000
	c	3339 – 3341	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120
7	a	3334 – 3342	8	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Flood plain	12.11 3 - 23	33.00 10 – 120
9	a	3468 - 3472	8	Dark grey silty shales. Low energy.	Prodelta	21.89 4 – 28	9025.04 0.7 – 19000
	b	3555 – 3559	4	Wavy bedded heterolithic and bioturbated, trace fossils present include ophiomorpha, planolites and skolithos. Low energy regime with periodic influx of silt.	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	c	3698 – 3708	10	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	d	3708 – 3710	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120
13	a	3793 – 3796	3	Heteroliths, planar laminated slightly mudstone trace fossils present include ophiomorpha and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	b	3798 – 3810	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120

Table 9 Core Description, Deposition Environment and Reservoir Quality of the Non-reservoir units in Well 52

Reservoir	Reservoir unit	Depth range (m)	Thickness (m)	Lithologic description / sedimentary processes	Environment of Deposition	Porosity Mean and Range (%)	Permeability Mean and range (md)
5	a	3322–3324	2	Sandy mudstone, grey and intensely bioturbated, trace fossil present is skolithos. Low energy	Flood plain	12.11 3 - 23	33.00 10 – 120
	b	3335 – 3339	4	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Lower shoreface	6 8 - 28	288.21 0.1 -1000
	c	3339 – 3341	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120
7	a	3334 – 3342	8	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Lower shoreface	12.11 3 - 23	33.00 10 – 120
9	a	3468 - 3472	8	Dark grey silty shales. Low energy.	Prodelta	21.89 4 – 28	9025.04 0.7 –19000
	b	3555 – 3559	4	Wavy bedded heterolithic and bioturbated, trace fossils present include ophiomorpha, planolites and skolithos. Low energy regime with periodic influx of silt.	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	c	3698 – 3708	10	Heteroliths, alternation of sandy and muddy heteroliths, planar laminated mudstones, moderately bioturbated. Trace fossils present include ophiomorpha and skolithos. Low energy regime with periodic influx of silt	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	d	3708 – 3710	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120
13	a	3793 – 3796	3	Heteroliths, planar laminated slightly mudstone trace fossils present include ophiomorpha and planolites. Low energy regime with periodic influx of silt.	Lower shoreface	12.11 3 - 23	33.00 10 – 120
	b	3798 – 3810	2	Dark grey silty shales. Low energy.	Prodelta	12.11 3 - 23	33.00 10 – 120

Table 10 Sedimentology and depositional environment of Sand Units in Well 51 Gabro Field.

WELL 51						
Reservoir	Thickness (m)	Sorting	Grain size (Φ)	Log shape	Depositional Environment	Porosity-permeability
7	13	Poorly sorted	1.75 – -.25	Cylindrical	Fluvial channel	Good
9	18.5	Well sorted	-2 - 4	Funnel shaped	Upper shoreface	Good
13	13	Poorly sorted	-.25 – 1.75	Blocky	Distributary channel	Excellent
	9.4	Well sorted	2 – 4	Funnel shaped	Upper shoreface	Excellent

Table 12 Sedimentology and depositional environment in Well 52, Gabro Field.

WELL 52						
Reservoir	Thickness (m)	Sorting	Grain size (Φ)	Log shape	Depositional Environment	Porosity-permeability
5	12	Well sorted	1.75 to -.25	Funnel shaped	Upper shoreface	Good
7	23	Moderately sorted	1.75 to -.25	Blocky	Distributary channel	Excellent
9	14	Moderately sorted	1.75 to -.25	Blocky	Distributary channel	Excellent
11	7.5	Well sorted	1.75 to 4	Funnel shaped	Upper shoreface	Good
13	13	Poorly sorted	-2 to -1	Blocky	Fluvial channel	Very Good

Table 13 Reservoir quality of Well 51, Gabro Field (Core plug values) – (Rider, 1986; Etu – Efeotor, (2007)

Sand	Permeability (md)		Porosity (%)	
	Quantitative	Qualitative	Quantitative	Qualitative
7	980.0	Good	23.5	Very good
9	950.0	Good	16.0	Good
13	–	–	–	–
Range	950.0 – 980.0	–	16.0 – 23.5	Good - Very good
average	965.0	–	19.75	Good

Table 14 Reservoir quality of Well 51, Gabro Field (based on Well log) - (Rider, 1986; Etu – Efeotor, (2007)

Sand	Permeability (mD)		Porosity (%)	
	Quantitative	Qualitative	Quantitative	Qualitative
7	1,978.7	Excellent	24.8	Very Good
9	1238.3	Excellent	21.8	Very Good
13	1565.2	Excellent	22.4	Very Good
Range	1238.3 – 1978.7	Excellent	21.8 - 24.8	Very good
Average	1594.1	Excellent	22.73	Very good

Table 15 Reservoir quality of Well 52 Gabro Field (based on Well log) - (Rider, 1986; Etu – Efeotor, (2007)

Sand	Permeability (mD)		Porosity (%)	
	Quantitative	Qualitative	Quantitative	Qualitative
5	1009.7	Very Good	14.8	Good
7	1156.3	Excellent	17.9	Good
9	1068.0	Excellent	18.5	Good
11	1317.4	Excellent	16.7	Good
13	2330.0	Excellent	28.2	Very Good
Range	1009.7 -2330.0	Good - excellent	14.8 -28.2	Good – very good
Average	1376.24	Excellent	19.22	good

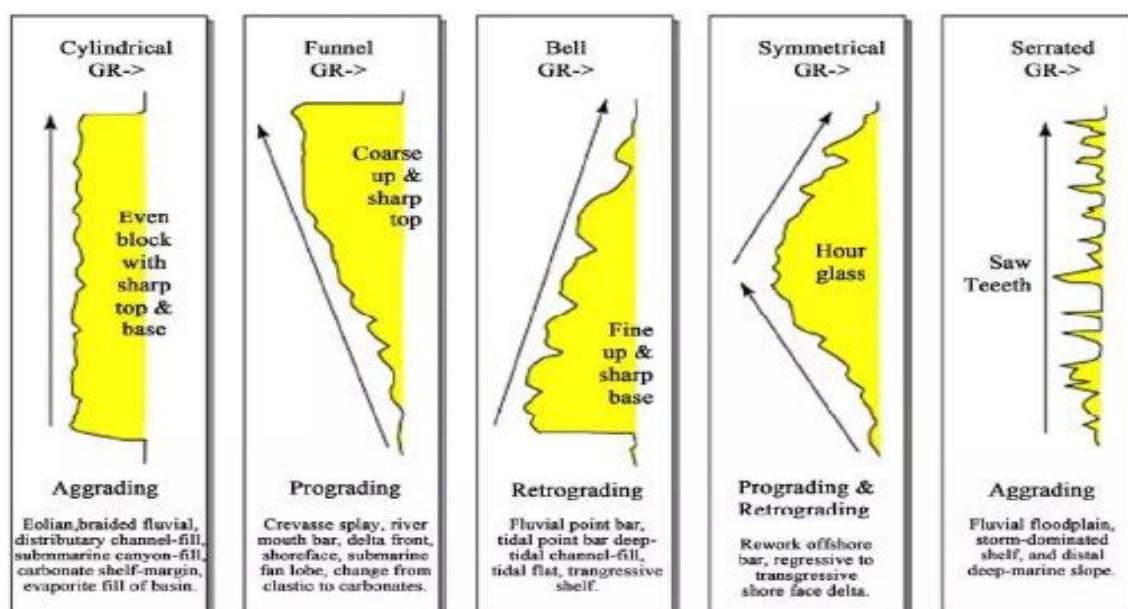


Figure 6 GR Log response for different environments - shows how vertical grain size profile of sandstone used to interpret facies (Rider, 1986;)

Well log signatures		Log patterns/ motifs	Lithofacies Descriptions	Lithofacies Interpretations
		0 API 150		
A	Low serrated gamma	 I 20m	Stacked up of bell shape (coastal barrier bar) and funnel shape (fluvial/tidally influence channel sand	Undifferentiated Continental deposits (Benin Formation)
B	Blocky and cleaning upwards	 I 20m	Funnel shape morphology with average thickness of about 50m bounded at the basal part by candidate sequence boundary or transgressive surface	Coastal barrier bar
C1	Blocky and dirtying upwards	 I 20m	Bow/ bell shape morphology, shows some high gamma values anomalies, the top units marked the transgressive surfaces while the basal marked the sequence boundaries.	Tidal/Fluvial channel fills
C2-5	Blocky sharp base	 I 20m	Blocky and sharp base shape morphology, shows some high gamma anomalies within the clean sand. The top and the basal contacts correspond to transgressive surfaces and sequence boundary respectively	Slope channel/Channel sand
D	Gradual cleaning upwards	 I 20m	Funnel shape morphology and less blocky than coastal barrier bar. The upper contact is defined by the transgressive/flooding surfaces while the basal part is defined by shallow marine deepening.	Upper shoreface sand
E & F	High serrated gamma	 I 20m	High serrated gamma ray value with aggrading stacking patterns. this can differentiated from each other by their neutron and density log characters	Offshore mudstone/ Lower shoreface deposit

Figure 7 Gamma ray facies association from well log pattern used in defining depositional environments within the study area.

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