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LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS STUDY OF THE "A1" RESERVOIR SAND, WELL-5, BOGA FIELD, NIGER DELTA, NIGERI

Okengwu, K. O.* and Amajor, L.C.
Department of Geology, University of Port Harcourt, Port Harcourt, Nigeria
kingsley.okengwu@uniport.edu.ng

ABSTRACT

The "A1" reservoir sand, in Boga field, Niger Delta, were investigated for it lithofacies and depositional environments. The study revealed seven lithofacies types. Integration of the lithofacies with well log data from base to top of reservoir sandbodies helped to group the sandbodies into facies association that occur together and are considered to be genetically or environmentally related. Two facies associations comprising of the, Fluvial Channel-Point Bars, and a well developed shoreface succession comprising the three main domains of Upper Shoreface, Middle Shoreface, Lower Shoreface and Shelf Mudstone subfacies. The Upper and Middle shoreface subfacies consist of coarsening upward sequence, sandstone succession of medium to coarse and fine to medium sand facies associations respectively. The integration of wireline log and core data reveal that the environment of deposition of "A1" reservoir sands lies within the marginal marine environments. The study interval, also, exhibited abundant fluvial processes, as well as muddy laminations, corresponding to a weak winnowing by the wave action, and very few swaley cross-stratifications indicating high reworking by wave action. The facies association of the sand bodies in the study interval can be interpreted as a deposit of a prograding wave - dominated shoreface setting with fluvial dominance. This observation implied a fluvial dominated process as seen in cored interval of "A1" reservoir sandbody, Boga Field, Niger Delta.

Keywords: Lithofacies, Depositional environment, Shoreface, Fluvial, Prograding, Wave-dominated.\.

INTRODUCTION

The reconstruction of depositional environments in clastic sequences provides the optimum framework for describing and predicting reservoir development and reservoir distribution on both regional (exploration) and field (production) scales (Johnson and Stewart, 1985). Sedimentological models are developed from the recognition of depositional environments, from which an understanding of reservoir character can be gained. This study is designed to take a critical look at the stratigraphy, and lithological characterization, and to determine the various depositional environments in the reservoir depth and creating a conceptual depositional model for the "A1" reservoir sand in Boga Well based on sedimentological studies using core and log data.

LOCATION OF STUDY AREA

The study area, "A1" Reservoir Sand, Boga Field, Niger Delta is located within the Greater Ughelli Depobelt of the Niger Delta region. It lies between longitude 5.05°E and 7.35°E and latitude 4.15°N and 6.01°N (figures 1) on the onshore part of the Niger Delta. The Niger Delta basin ranks among the world's most prolific petroleum producing Deltas (Selley, 1997).

The "A1" Reservoir Sand is between 3888m-3718.6m depth of about 30.6m thick.

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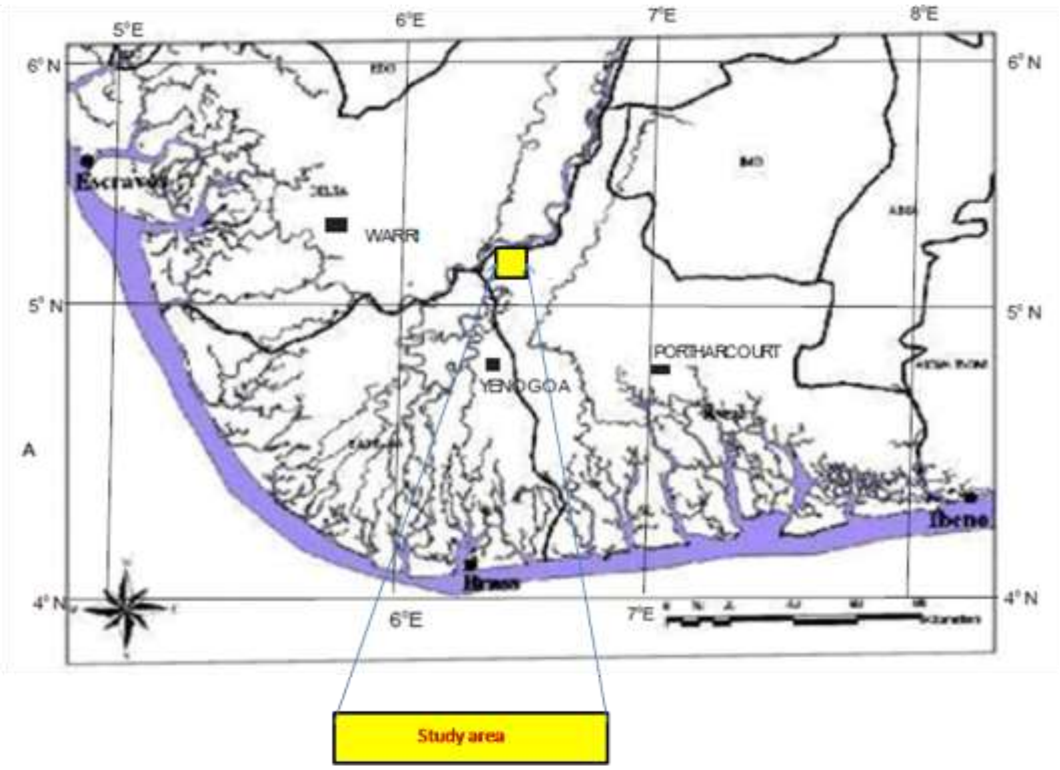


Figure 1-- Map of Niger Delta basin, showing location of study area

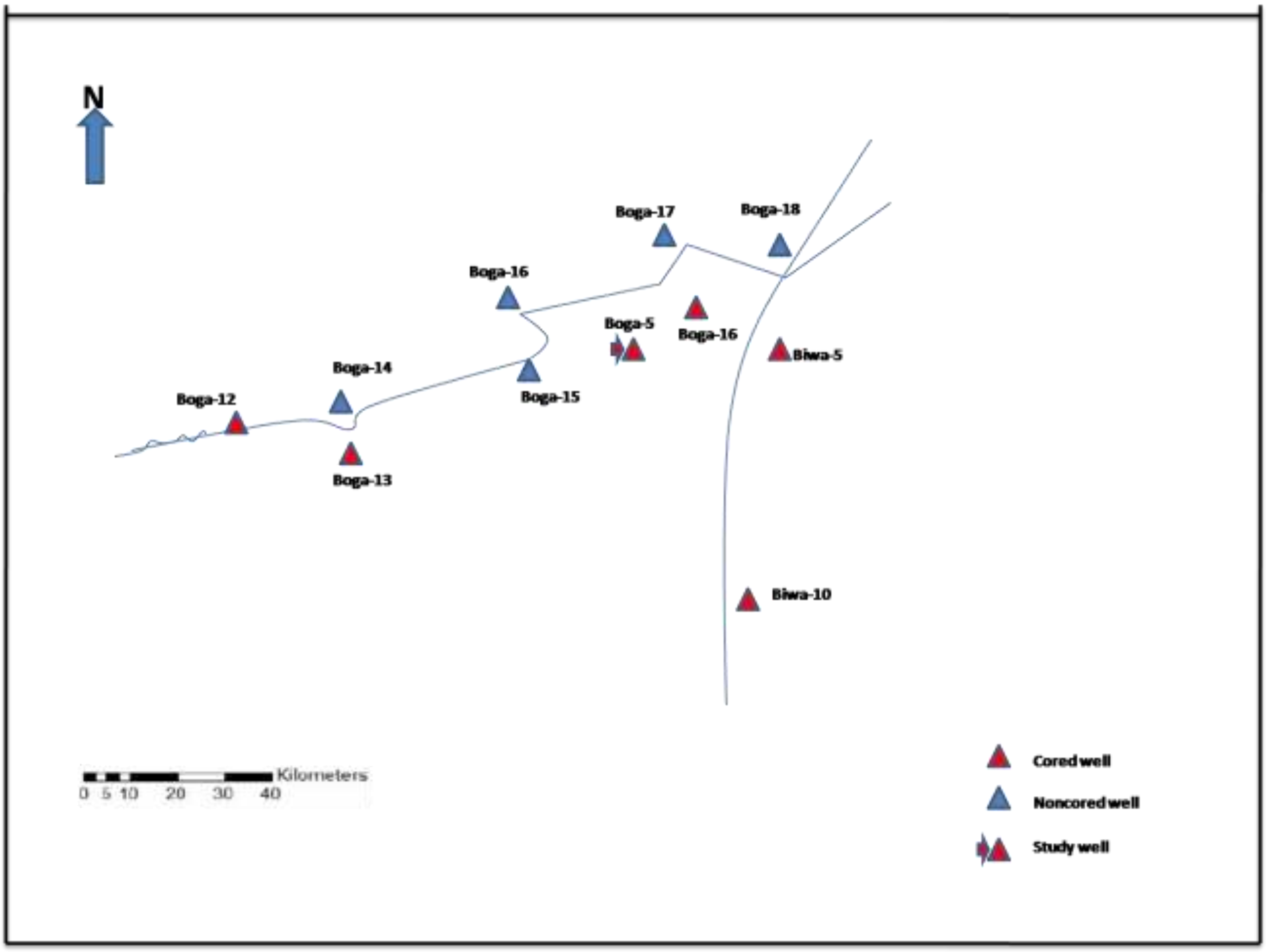


Figure 2: Map of Study Area (basemap) showing cored and noncored wells.

OBJECTIVES

The objectives of this study include:-

1. To dertermine the lithofacies from core and well log.
2. Interpret the depositional environments and facies relationships.
3. Create a conceptual depositional model for the Boga reservoir sand bodies based on sedimentological studies.

A. Stratigraphic and geologic setting

The formation of the Niger Delta has been related to the separation of Africa and South America and the subsequent opening of the South Atlantic in Aptian-Albian times (Etu-Efeotor, 1997). It has also been documented that a triple function developed at the position of what is now the outer Niger Delta (Etu-Efeotor, 1997).

The Tertiary section of the Niger Delta is divided into three formations, representing prograding depositional facies that are distinguished mostly on the basis of sand-shale ratios. The type sections of these formations are summarized in a variety of papers (Avbobvo, 1978; Doust and Omatola, 1990; Kulke, 1995). It was described in Short and Stauble (1967); it subdivided the recent Niger delta into three lithostratigraphic units, ranging in age from Paleocene to Recent. They are the Akata, Agbada, and Benin Formations, from bottom to top. This sequence exhibits a very strong diachronous relationship (table 1). The type sections are described in detail in Short and Stauble (1967).

Akata Formation

The Akata Formation is located at the base of the Niger delta sequence and consists of prodelta, hemipelagic, and pelagic shales deposited in marine environments. It is composed of thick shale sequences (potential source rock), turbidite sand (potential reservoirs in deep water), and minor amounts of clay and silt. Beginning in the Paleocene and through the Recent, the Akata Formation formed during lowstands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and oxygen deficiency (Stacher, 1995).

Table 1: Regional stratigraphy of the Niger delta area (modified after Short and Stauble, 1967).

SUBSURFACE			SURFACE OUTCROPS		
YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE	YOUNGEST KNOWN AGE	FORMATION	OLDEST KNOWN AGE
RECENT	BENIN	OLIGOCENE	PLIO/ PLEISTOCENE	BENIN	MIOCENE
RECENT	AGBADA	EOCENE	MIOCENE	OGWASHI-ASABA	OLIGOCENE
			EOCENE	AMEKI	EOCENE
RECENT	AKATA	EOCENE	L. EOCENE	IMO SHALE	PALEOCENE
			PALEOCENE	NSUKKA	MAESTRICHTIAN
			MAESTRICHTIAN	AJALI	MAESTRICHTIAN
			CAMPANIAN	MAMU	CAMPANIAN
			CAMP/MAESTR	NKPORO SHALE	SANTONIAN
			CONIACIAN/TUR	AWGU SHALE	TURONIAN
			SANTONIAN	EZE AKU SHALE	TURONIAN
			ALBIAN	ASU RIVER GROUP	ALBIAN

Agbada Formation

Deposition of the overlying Agbada Formation, the major petroleum-bearing unit, began in the Eocene and continues into the Recent. The formation consists of paralic siliciclastics over 3700 meters thick and represents the actual deltaic portion of the sequence. The clastics accumulated in delta-front, delta-topset, and fluvio-deltaic environments. In the lower Agbada Formation, shale and sandstone beds were deposited in equal proportions, however, the upper portion is mostly sand with only minor shale interbeds.

Benin Formation

The Benin formation which is the upper deltaic-top like lithofacies has been described as "coastal plain sands". The formation outcrops in Benin, Onitsha and Owerri provinces and elsewhere in the delta area (Reyment, 1965).

It consists mainly of massive, highly porous, fresh water sandstone with minor shale. The Benin formation extends from the west across the Niger Delta area and southwards beyond the present coastline. The sands and sandstone are coarse to fine and the sediment consist of alluvial and upper coastal plain sands that are up to 2000 m thick (Avbovbo, 1978)

The Niger Delta basin consists of a series of depocenters or belts (Stacher, 1995). Major structure building growth fault determine the location of each depobelt. The entire sedimentary wedge was laid down sequentially in five major depobelt each 30-60km wide, with the oldest lying further inland and the youngest located off shore (figure 3) (Reijers 1996).

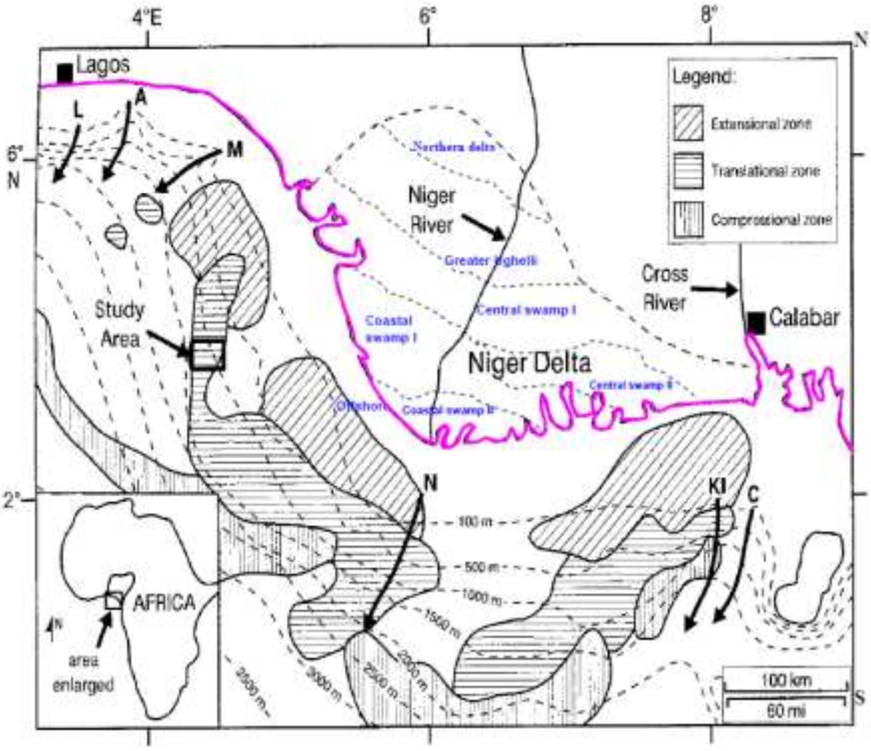


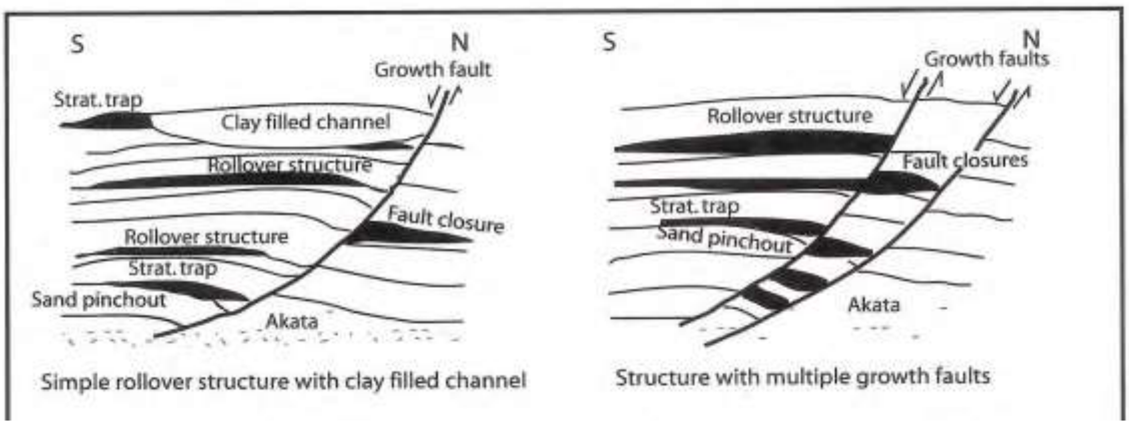
Figure 3: Map of Niger Delta showing the different depobelt (modified after Knox and Omotsola, 1989)

Structural Setting

Weber and Daukoru, (1975), recognized four main types of oil field structure (figure 4), they are:-

1. Simple rollover structure
2. Structure with multiple growth fault
3. Structure with antithetic fault
4. Collapsed crest structure

These structures are generated by rapid sedimentation and gravitational instability during the accumulation of the Agbada deposits and continental Benin sands over the mobile undercompacted Akata prodelta shale.



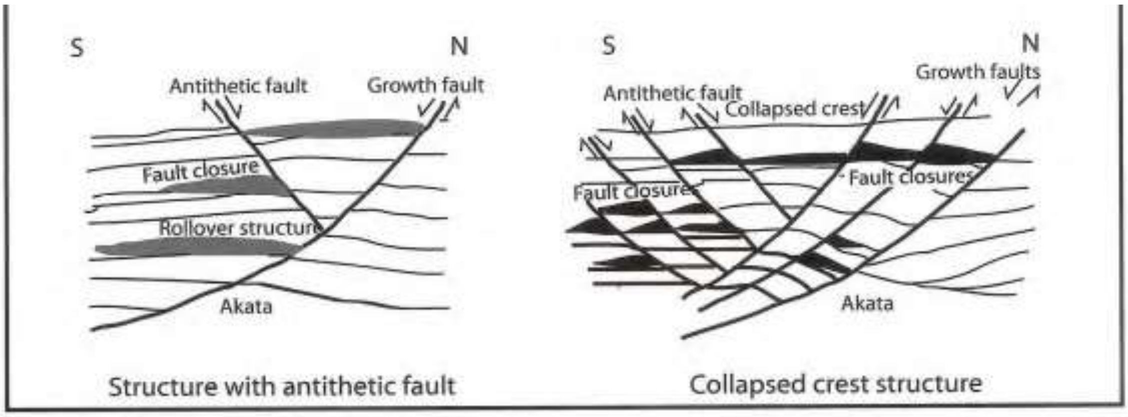


Figure 4: Examples of Niger delta oil field structures and associated trap types
(Burke, 1972; Reijers, *et al.*, 1997; Tuttle, *et al.*, 1999).

MATERIALS AND METHODS OF STUDY

Several methods were adopted for this study and the Data used for this research work was made available by Total Nigeria (TPNG), Port Harcourt.

Data Available

The data set used includes the following:-

- Base map showing the structural element and location of wells, figure 2.
- Suite of wireline log.
- Set of core photographs.

Methods

The core photographs provided were studied and described from bottom upwards.
The procedure for the description is as follows:

1. The detail description of the cores photos were done on the core sedimentological description chart
2. Texture, litho unit boundaries, nature of contacts, composition, diagenetic features, biogenic and physical sedimentary structures were described and recorded
3. Their lateral and vertical variation of lithology were noted and studied.
4. Study of sedimentary structures was carried out noting features like cross bedding, lamination e.t.c. The degrees of bioturbation were also indicated.
5. Based on the descriptions, lithology and grain size, dominant sedimentary structures, the lithofacies types were determined and interpreted using the lithofacies classification scheme (table 2)
6. Interpretation of various lithofacies within the core was intergrated with the wireline log pattern to arrive at lithofacies association and distinct reservoir genetic units.

Table 2: Tabulated Lithofacies Scheme (After S.P.D.C, Nigeria)

DOMINANT GRAIN SIZE		DOMINANT SEDIMENTARY STRUCTURE	SECONDARY SEDIMENTARY STRUCTURE
S (sandstone)	c - coarse	M (massive)	C (cement-general)
	m - medium	X (cross-bedded)	S (siderite)
	f - fine	P (planar, parallel bedded)	/d (soft sediment deformed - slumped, slide, micro-faulted)
>90% sand		H (hummocky - swaley cross-bedded)	
	s (sandstone dominant)	W (wave rippled)	
H (heterolithic)	>50% sand / >50% mud	C (current rippled)	
		B (bioturbated)	
	m (mudstone dominant)	R (rooted)	
>90% mud		F (fossiliferous)	
M (mudstone)		O (organic-carbonaceous)	
C (coal)			

Wireline Log Shapes

The Gamma ray log is an indicator of shale content in a formation, it shows greater detail and are related to the sediment character and depositional environment.. It is a log of the natural radioactivity of the formation along the borehole, measured in API, particularly useful for distinguishing between sands and shales in a siliclastic environment. A bell shaped log with gamma ray value increasing upwards to a lower value indicates increasing clay content (Figure 5). A funnel shape with the values decreasing regularly upwards shows a decrease in clay content. The decrease in clay content is correlated to an increase in sand content and grain size. Shapes on the Gamma ray log can be interpreted as grain size trends and by sedimentological association as cycles. A decrease in gamma ray value will indicate and increase in grain size. Fine grain size will correspond to higher gamma ray values. The sedimentological implication of this relationship leads to a direct correlation between facies and log shape.

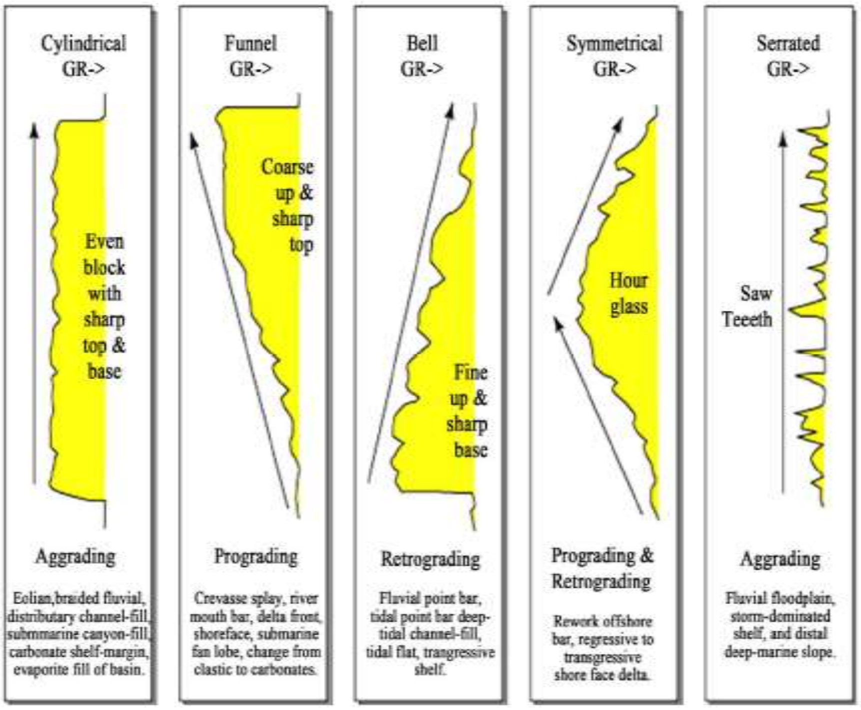


Figure 5: Facies indication from Gamma Ray, the idealized examples of both Log shapes and sedimentological facies (Schlumberger, 1989).

RESULT AND INTERPRETATION

Facies Analysis

Seven lithofacies were recognized in the "A1" Reservoir Sand, Boga Field, based on lithology and sedimentary structures. For each lithofacies identified, facies description and interpretation for the facies is immediately followed. Some of the lithofacies in the study interval occur separately in different positions in the section and may even be repeated.

Lithofacies 1: Bioturbated very-coarse to medium grained sandstone facies occur between (3688-3691m) depths. It consists of very coarse to medium grained, massive and poorly sorted, with occasional granule grains (figure 6). Bioturbation is moderate with burrows of large *Ophiomorpha Irregularia* and *Skolithos.* Physical sedimentary structure is not pronounced, but biogenic structure ranges from low to moderate bioturbation.

Interpretation: The coarse to pebbly nature of this lithofacies suggests a lag deposit generated by strong ephemeral current as in storm and major flood (Dalrymple *et al.,* 1992). Lack of predefined internal bedding structure indicates rapid sedimentation (Allen, 1983). Intensively bioturbation correspond to a zone where nutrient is abundant. This lithofacies is suggestive of a lag deposits.

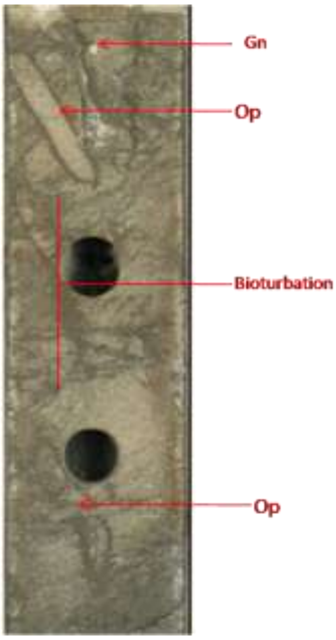


Figure 6: Boga Well-5 (Depth 3689-3689.5) Reservoir "A1"; Gn: granule; Op: Ophiomorpha

Lithofacies 2: Coarse to pebbly sandstone facies occur between (3691-3695m) depth, with sharply defined scoured base (Figure 7). The sandstone is poorly sorted with no visible sedimentary structure. The clast size ranges from pebbles to granules. The grain size generally increases upward. Bioturbation is rare except for sparing occurrence of single and robust *Ophiomorpha* burrow in places.

Interpretation: The coarse to pebbly grained nature of this lithofacies indicates a channel or a lag deposit, generated by repetitive strong ephemeral current as in storms and major flood (Moslow and Heron, 1978). Lack of predefined internal bedding structure indicates rapid sedimentation. Occurrence of monospecific ichnofaunal is indicative of a restricted and stressed environment. This section on the Gamma ray log shows serrated funnel shape indicating middle to upper shoreface.

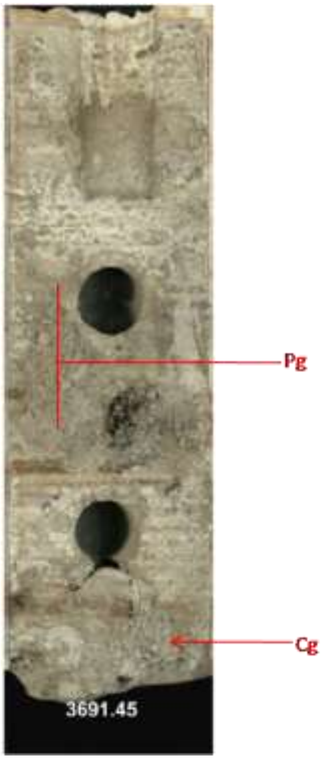


Figure 7: Boga Well-5 (Depth 3691--3691.45) Reservoir "A1"; Pg: pebble; Cg: coarse grain

Lithofacies 3: Cross Bedded Medium to Coarse grained Sandstone Facies occur the depth interval of (3695-3698m). It consists of medium to coarse grained sandstone (Figure 8). The facies is poorly sorted and is characterizes by bimodal grain size sorting appearing as alternation of coarser and finer grain strata. Bioturbation intensity is rare to absent in this facies. Physical sedimentary structure in this lithofacies include cross bedding and occasional mud drapes and flasers along crossbed.

Intrepretation: Occasional mud flasers, cross beds and the bimodal sorting is indicative of tidal current modulation of fluvial current which supply the current. This section on the Gamma ray log shows serrated funnel shape, coarsening upward grainsize indicating middle to upper shore sands. This lithofacies is interpreted as a shoreface deposits.

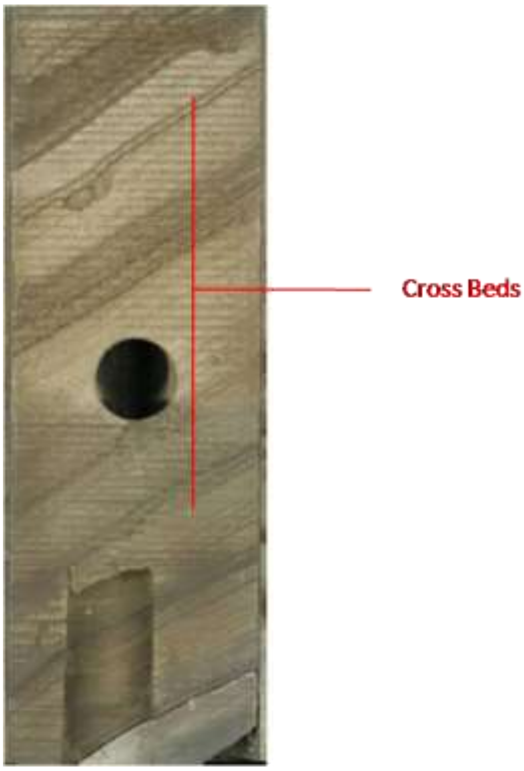


Figure 8: Boga Well-5 (Depth 3697.3--3698) Reservoir "A1".

Lithofacies 4: Bioturbated Sandstone Heterolith Facies occur between the depth intervals of (3697-3699m). It consists of fine-grained silty sand and muddy sandstone. Sorting in this facies is moderate, with the heterolithic mixture of fine sand, silt and clay. Bioturbation ranges from moderate to intense and the bioturbation structures predominate over physical structures and it obliterate the bedding structure (Figure 9). The burrows of (*Skolithos* and *Planolites)* are both horizontal and vertical, all of which cut or disrupts the original bedding or lamination. Some of the original clay lamination or ripple lamination are preserved. Physical structures on the lithofacies include, parallel to wavy bedded. The bioturbated sandstone heterolith overlies the bioturbated mudstone heterolith facies in the study interval.

Interpretation: The lithofacies records the alternation of bedload and suspension depositional processes. The bedload sedimentation are deposited during migration of wave ripples under low flow regime oscillatory wave current while the clay and silt deposits are as a result of suspension fallout, periodically interrupted by sand deposition. The localized trace fossil assemblages are indicative of a stressed environment as a result of wave current action. The intense burrow activities are indicative of deposition in a low energy environment of shallow marine or of lower shoreface. This section on the Gamma ray log shows serrated funnel shape indicating lower shoreface.

Figure 9: Boga Well-5 (Depth 3698.3—3698.8) Reservoir "A1": Op: Ophiomorpha; Sk: Skolithos

Lithofacies 5: Bioturbated Mudstone Hetrolith Facies consists of light gray, moderate to intensively bioturbated mudstone, siltstone and relics of very fine sand (Figure 10), between the core intervals of (3699-3704m). Physical sedimentary structures have not been properly preserved as a result of the bioturbation, and the only evidence of primary fabric is the presence of relics of wavy lamination. The interbedded very fine grained sandstone and siltstone are heavily bioturbated while the mud intervals are slightly bioturbated. Bioturbation in the facies is dominated by *Ophiomorpha and Paleophycus* burrows; this leads to partial to complete obliteration of the sedimentary structures in some part. The bioturbated muddy heterolith overlies the mudstone facies in the study interval.

Interpretation: The lithofacies analysis reveals the interplay of high energy event and fair-weather sedimentation. The high energy depositional phase is recorded by the wavy rippled, finer grained sandstone; the fair-weather depositional phase is characterized by the presence of interbedded, very fine grained silty sandstones, siltones and mud, which may record the latest stage of sediment fallout after the high energy sedimentation. The heterolithic nature of this facies indicates sedimentation in a setting characterized by alternating suspension fallout and bed-load, while its trace suite indicates deposition in a predominantly low energy setting below wave base. Thus this deposit is interpretaed to have been deposited in the lower shoreface environment.

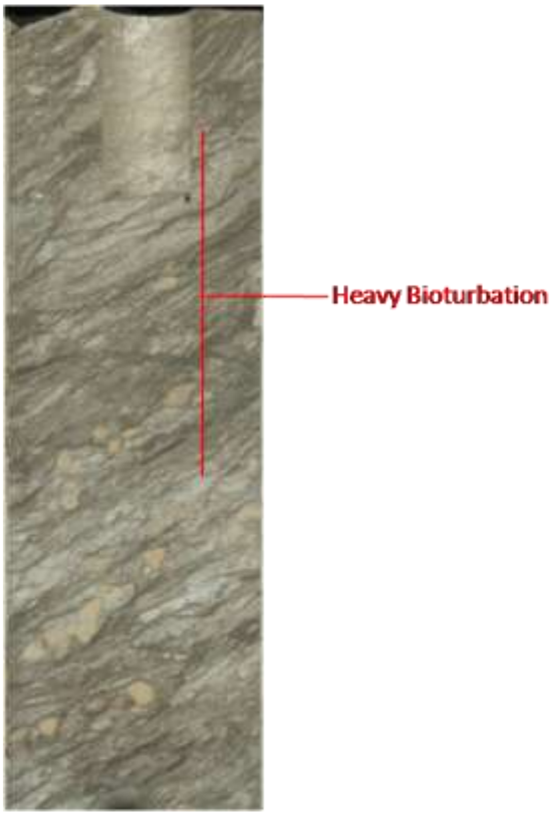


Figure 10: Boga Well-5 (Depth 3702—3702.5) Reservoir "A1".

Lithofacies 6: Mudstone lithofacies encountered in the study interval occurs between the depths of (3704-3708m). It consists of laminated dark-greenish-gray to greenish-black mudstone (Figure 11), with parallel silt laminae of >2 mm thick. This facies is characterized by thin elongate, diagenetic siderite nodules, and nodular concretions of diagenetic siderite. Physical sedimentary structures present in this facies include wavy ripple-laminated siltstone, planar lamination and oblique planar lamination. Bioturbation in this facies is slight to rare, with burrowing parallel to laminae.

Interpretation: The sediment of the mudstone facies was probably deposited under quite and low energy conditions, allowing for shale lamination. The sections with silty laminae are indicative of the intrusion of a more energetic event. Preservation of thin laminations, absence of bioturbation, and dark colours are suggestive of anoxic and reducing bottom-water conditions. Walker and Plint (1992) and Reineck and Singh (1980) described mudstones as offshore or shelf deposits. The mudstone unit with silty laminae is interpreted to have been deposited in an overbank of a channel while the black/dark laminated mudstone is interpreted to have been deposited in a shelf environment.

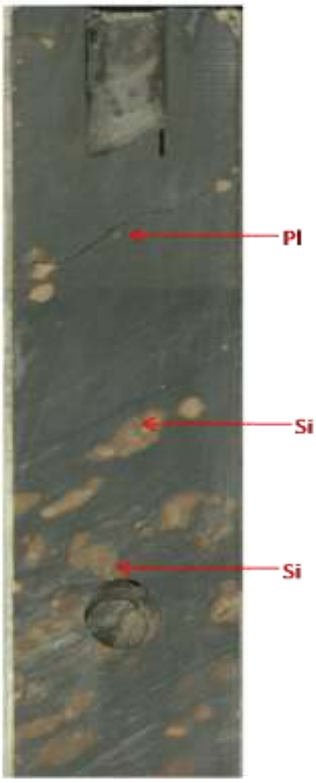


Figure 11: Boga Well-5 (Depth 3706—3706.5) Reservoir "A1"; Pl: Planolith; Si: digenetic siderite.

Lithofacies 7: Cross bedded fine to medium grained sandstone facies occurs at depth of (3708-3711.82m). It consists of moderate to well sorted, fine to medium grained sandstones (Figure 12). It consists of planar cross bedded very clean sand with little clay content. Cross-beds typically contain single and/or paired mudstone drapes along forsets of topsets. The level of bioturbation in this facies ranges from low to mederate bioturbation. Biogenic structure includes *Skolithos* and *Ophiomorpha* burrows.

Interpretation: Grain-size, sorting and cross-bedding are typical of proximal deposits under unidirectional current. They are formed under strong upper flow regime condition such as in channels and wave dominated environment (Walker, 1984). The well-sorted character of the sediments is typical of marine sourced sands reworked by tidal and wave process. Presence of clay drapes, mud chips and the bimodal sorting is indicative of tidal current modulation of fluvial current which supply the current. This section on the Gamma ray log shows bell shape, the litofacies are interpreted to be deposit of tide-dominated estuarine channels and tidal inlet channels.

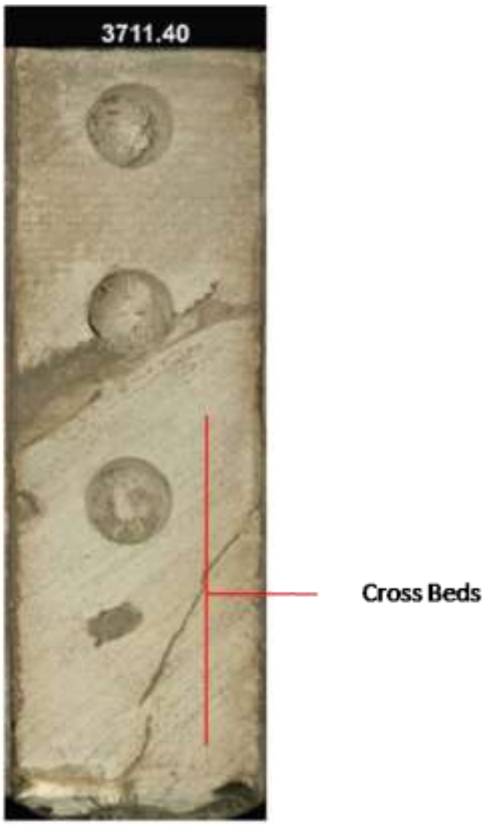


Figure 12: Boga Well-5 (Depth 3711.4—3711.9) Reservoir “A1”.

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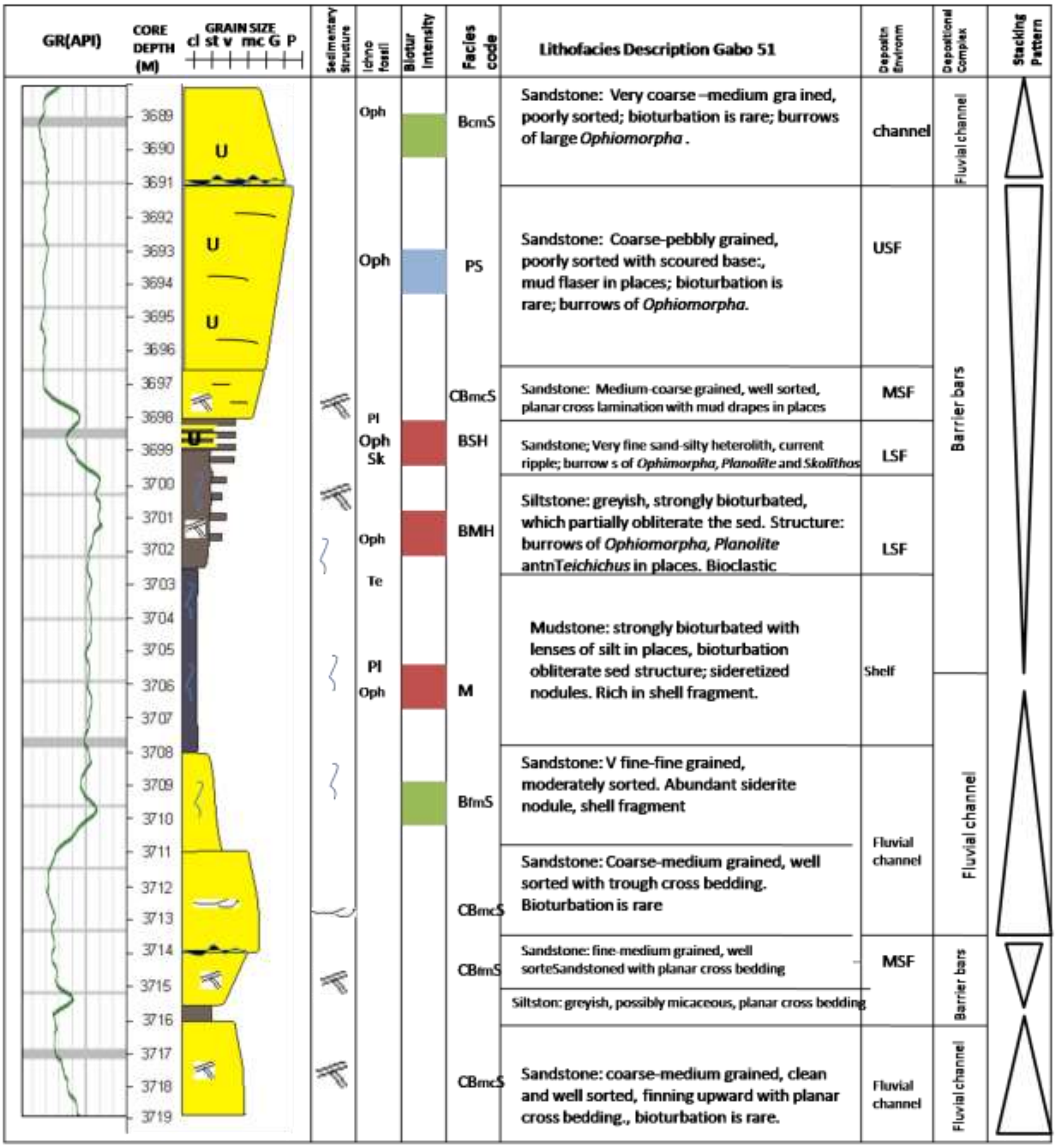

Figure 13: Graphic core description for Reservoir "A1" Boga well-5 (3688-3719m) showing the various depositional environments.

Facies Association and Interpretation

Reading, (1979) defined facies associations as groups of facies that occur together and are considered to be genetically or environmentally related. Facies association reflects the combination of processes which occur in the depositional environment. The process includes a range of energy level within an environment of deposition. The lithofacies units described above have been grouped into facies associations which have genetic and environmental significance and can be identified as separate units in cores and on wireline logs. These associations of facies form the primary basis of inferring the depositional setting under which the sediments were deposited and preserved. Two lithfacies association have been identified in the study well. The integrated interpretations of the facies association are hereby presented according to their vertical arrangement in the well starting from the base of the reservoir to the top.

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Facies Association 1: Barrier Bars

The lithofacies association 1consists from base to top of mudstone lithofacies (M), bioturbated mudstone heterolith lithofacies (BMH), bioturbated sandstone heterolith lithofacies (BSH) and cross bedded fine to medium grain sandstone facies (CBfmS).They are interpreted as that of marine mudstone, lower shoreface, middle shoreface and upper shoreface subfacies, respectively. The stacking pattern display a vertical coarsening upward sequence and a gradual transition from one lithofacies to another in a prograding shoreface (Figure 14) shows the vertical facies model for barrier bar profile in the study well. This lithofacies association occurs in twice in the studied well.

Shelf Mudstone Subfacies

This subfacies association is made up of successions of the thickly laminated mudstones (figure 14). The unit is characterized by low levels of bioturbation, except for burrows of *Paleophycus* in places, and is marked by high GR and low resistivity log response. The mudstone deposits are suspension fall-out deposit which represent low-energy environment such as an open marine self, below storm wave base. This subunit occurs twice in the study well.

Lower Shoreface Subfaies

This subfacies units consists of fine grained to medium grained sandstone interspersed with thin layers of siltstone and mud, with an upward increase in sand:shale ratio. The sedimentary structures in this facies include; cross lamination and flaser bedding.The facies is characterized by moderate to intense bioturbation and burrowing of *Ophiomorpaha nodosa* and *Planolites*. The association is characterized by gradual coarsening-upward in grain *size and is reflected by a funnel-shape of GR log curve repeated serration, indicating alternations of sand and shale as well as upward coarsening and thickening sequence of lower shoreface. This subunit occurs twice in the study well.*

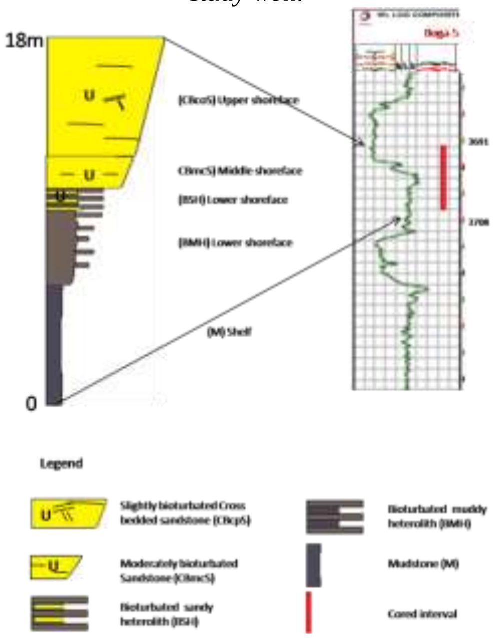

Figure 14: Vertical facies model for barrier bar profile in the study well

Middle Shoreface Subfacies

This subfacies unit overly the lower shoreface described above. It is characterized by coarser sand of fine to medium grained sandstone than the lower shoreface deposit described above. Bioturbation in this subfacies is rare and less pronounced than the lower shoreface but more pronounced than the overlying upper shoreface subfacies. Due to strong wave interaction, the sands are well sorted with low shale interlamination than the underlying subfacies. Physical sedimentary structure includes cross stratification and mud drapes, though, planar cross stratification may be locally developed. This subunit occurs twice in the study well.

Upper Shoreface Subfacies

This subfacies units is characterizes by a coarsening-upward, shale-free sandstone with thickness up to 6m in the study wells. They are clean and well sorted medium to coarse-grained sandstones. This subfacies contain little or no mud which reflects constant agitation of waves and currents that do not allow mud to settle out from suspension. Physical sedimentary structure include planar and cross bedding with both unidirectional and bidirectional cross-beds. Burrows of high energy environment such as *Ophiomorpha* and *Skolithos* (McEachern and Pemberton, 2003) characterized this unit. This facies association has a funnel shape GR log signature, which reflects the coarsening-upward sequence of the upper shoreface deposit. This subunit occur tonce in the study well.

Facies Association 2 (Fluvial Channels-Point Bar)

Allen, 1990, defined point bar deposits as a meandering river deposits with sequence consisting of in-channel deposits (Lateral accretion) followed by over bank (vertical accretion). The facies association is characterized by a fining upward sequence, consisting of fining upward coarse to medium sand (CBcmS), medium to very fine sand (CBfmS) that are poorly sorted and is capped by mudstone (M) lithofacies. The basal contact is usually sharp and may be lagged by coarser sand, gravels and pebbles. The dominant physical sedimentary structures are the planar cross bedding. Bioturbation is rare to slight and are dominated by *Ophiomorpha* burrows. The poorly sorted nature and coarse grain size of the sandstone reflect a fluvial dominated character as migrated by high energy fluvial currents. The facies association is characterized by a fining upward bell-shaped GR log signature. It occurs in the three times in the study well. (Figure 15) is the vertical facies model for fluvial channel point bar profile in the study well.

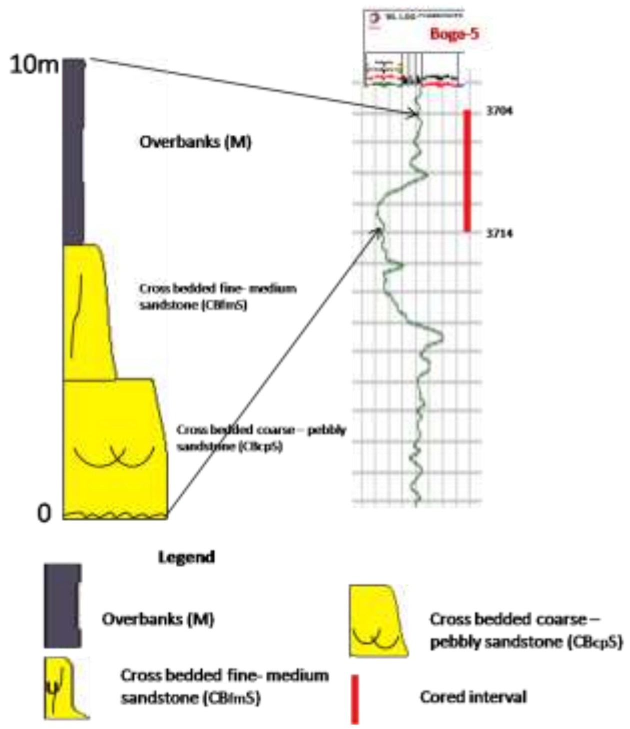

Figure 15: Vertical facies model for fluvial channel point bar profile in the study well

Depositional Model for the "A1" Reservoir Sandbodies

The facies association of the cored intervals in the "A1" reservoir sandbodies can be interpreted as a deposit of a prograding wave-dominated shoreface setting with fluvial dominance (figure 13). This observation implied fluvial dominated processes as seen in cored section of study interval. From the lithofacies association (figure 13), the shoreface is well developed; it encompasses the three main domains. The upper shoreface is located landward, above the limit of tide influence; followed by the middle shoreface; the lower shoreface is submitted to seasonal tide action and water table infringing, it is a wetter environment.

The zone submitted to tide influence is wide. It can concern both transport axis with sandy bodies like tidal bars, or mouth and more protected areas with muddier environments like offshore bay. Wave processes are not dominant compared to fluvial processes as seen in the cored section (figure 13). This interpretation is supported by the low abundance, both in thickness and frequency of shoreface deposits encountered on cored intervals and by the facies of the shoreface themselves. Indeed, facies model exhibit abundant fluvial processes, as well as muddy laminations, corresponding to a weak winnowing by the wave action, and very few swaley cross-stratifications indicate high reworking by wave action.

DISCUSSION

A detail sedimentological study of "A1" reservoir sand body, containing 31m cored samples was integrated with analysis of wire line logs to determine the various lithofacies, in order to understand the depositional environments responsible for the deposition of the reservoir sands in the Boga Well-5 field. Seven lithofacies were identified and base on the facies association, two depositional environments were identified. The depositional environment includes the shoreface deposits of the barrier bars and fluvial channel point bar deposit.

The shoreface deposit which include the three sub environments of lower, middle and upper Shoreface. Walker and Plint (1992), defined shoreface deposits as the interval between the mean sea-level and the mean fair-weather wave base. In a regressive sequence, deeper-water sediments are successfully overlain by sediments deposited in progressively shallower water. In the Niger Delta, the basal member of the regressive marine sequence consists generally of sandy clays deposits. The topmost part of the regressive sequence is composed of predominantly cross bedded sands that showed an upward increase in grain size. The unit described as lower, middle and Upper shoreface deposit within the core interval of (3691-3702.5m) (figure 14) in this study well is similar to the regressive sediment described above, showing the normal sequence of prograding clastic shoreline which grades from lower shoreface to upper shoreface made up of barrier bars and beaches. The shoreface interval of (3714-3716m) was interrupted. The interruption is represented by an erosive fluvial channel deposit overlying the middle shoreface deposit at (3705-3714m). It shows that a barrier bar was eroded by the fluvial channel influences described below.

The characteristics of the lower shoreface are also in line with the facies documented by Davies et al., (1988). However, lower shoreface was divided into proximal lower shoreface and distal lower shoreface based on their grainsize, log response and bioturbation intensity. Proximal lower shoreface was identified with sandstone dominated heterolithic facies (BSH), while distal lower shoreface was identified with mud dominated heterolithic facies (BMH) figure 14.The lithofacies association of these sub-environments is also similar to the facies of shallow marine siliciclastic deposit described by Reading (1981) and Weber (1971). Reading (1981) described shoreline siliciclastic deposit as made up of sand facies, sand dominated heterolithic facies, and mud dominated heterolithic facies and mud facies. This corresponds to a gradation from foreshore to offshore facies, while Weber (1971), stated that there is a gradual change of sedimentary characteristics from bioturbated clays with occasional silt and sand lenses (transition zone), which passes upwards into interbedded mud, silts and sand (lower/distal middle shoreface). The middle shoreface facies can be taken as proximal fluviomarine or barrier foot and lower shoreface as distal fluviomarine of Weber (1971).

Allen (1990), described the point bar deposits as a sequence that consists of in-channel deposits (Lateral accretion) followed by over bank fines (vertical accretion). The lag deposits cover a
near horizontal erosional surface and are capped by trough cross bedding (sands) which is overlain by small scale trough cross-laminations (silts). The point bar sequence encountered in this studied cored interval of (3705.5-3714m) depth and was identified in the wire line log is characterized by a fining upward sequence of cross bedded coarse to pebbly sand facies (CBcpS), followed by cross bedded fine to medium grained facies (CBfmS) and is capped by an overbank sediment of mudstone facies (M). The sequence identified in the study well is similar to the sequence identified by Adedokun (1981), who identified point bar deposit in an oil well located at North Eastern Sector Niger Delta field. The log profile of point bar in this study is similar to that proposed by Galloway and Hobday (1996). It is characterized by a bell shape, which reflects a general fining upward sequence. These features correspond to decrease in grain size and increase in interstitial clay upward.

CONCLUSION

The shoreface succession in the study area is well developed; It encompasses three main domains. The upper shoreface is located landward, above the limit of tide influence; followed by the middle shoreface; the lower shoreface. The study interval, indeed, exhibit abundant fluvial processes, as well as muddy laminations, corresponding to a weak winnowing by the wave action, and very few swaley cross-stratifications indicate high reworking by wave action. The facies association of the sand bodies in the study area can be interpreted as a deposit of a prograding wave -dominated shoreface setting with fluvial dominance. This observation implied fluvial dominated processes as seen in cored interval of "A1" reservoir sandbody, Boga Field, Niger Delta (figure 13).

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