*Scientia Africana, Vol. 14 (No.2), December 2015. Pp 99-114*
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# LITHOFACIES AND DEPOSITIONAL ENVIRONMENTS STUDY OF THE "B3" RESERVOIR SAND (3899-3950) m, WELL-05, BIWA FIELD, NIGER DELTA, NIGERIA.

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*Received: 09-09-15*
*Accepted: 20-10-15*

## ABSTRACT

*The "B3" reservoir sandbodies, in Biwa field, Niger Delta, were investigated for lithofacies and depositional sequence. Textural analysis, sedimentary structure and bioturbation intensity were used to study the core data for the various lithofacies types and were integrated with the gamma ray log in the cored interval for the determination of lithofacies association and depositional sequence. The study revealed five 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 interpreted from the cored intervals include: Braided Channel-Point Bar, and a well developed shoreface succession comprising the three main domains of Upper Shoreface, Middle Shoreface, and Lower Shoreface and capped by a Shelf Mudstone subfacies. The braided channel facies association shows a fining upward sequence, capped by an overbank deposit of mudstone lithofacies, while the Upper, Middle and lower shoreface subfacies consist of coarsening upward sequence of sandstone succession of medium to coarse and fine to medium sand facies associations respectively. The facies association of the sand bodies in the study interval can be interpreted as a deposit of braided channel, capped by a prograding shoreface deposits. This observation implies a fluvial dominated process as observed in the cored interval of "B3" reservoir sandbodies, Biwa Field.*

## INTRODUCTION

The study area, "Biwa Field" is located within the Niger Delta basin. It lies between longitudes 5.05°E and 7.35°E and latitudes 4.15°N and 6.01°N (Fig. 1) on the onshore part of the Niger Delta. The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and the South Atlantic Ocean where a triple junction developed during the separation of South America and Africa in the Late Jurassic (Whiteman, 1982).

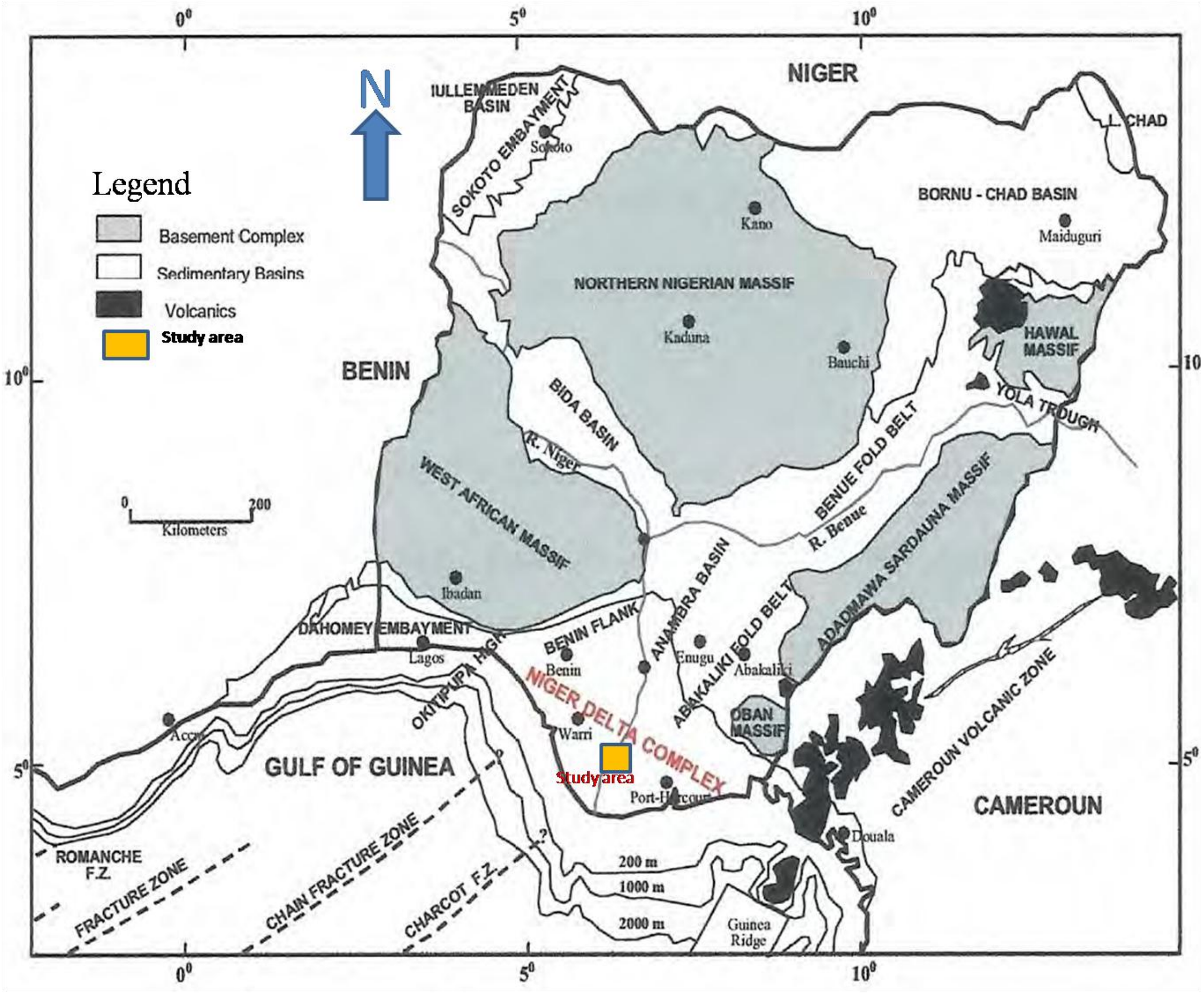


**Fig. 1:** Map of Nigeria, showing Niger delta basin (modified after Whiteman, 1982) and the location of Study area.

The Niger Delta basin is a matured sedimentary basin with several works been undertaken and documented on the geology of the Tertiary Niger Delta basin. Short and Stauble (1967) was one of the pioneer workers on the geology of the Niger Delta. They provided the initial information on the sediments and subsurface distribution of the stratigraphic units in the Niger delta. Some works have also been done by Whitaker (1985); he identified the following depositional environments in the Niger Delta as mangrove swamp, channel deposits, shoreface and marine. This study is designed to take a critical look at the stratigraphy, and lithological characterization, in order to determine the various lithofacies types and interprete the depositional environments and facies relationships responsible for the deposition of the reservoir sandbodies in the cored depth "B3" (3899-3950) m, in Well-05, Biwa Field, based on sedimentological studies using core and log data, and to create a conceptual depositional model for the Biwa reservoir sandbodies.

**Stratigraphic and Geologic Setting**

The origin and formation of the Niger Delta have been related to the separation of Africa and South America and the subsequent opening of the South Atlantic in Aptian-

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Albian times (Etu-Efeotor, 1997). According to Short and Stauble, (1967), the coastal sedimentary basin of Nigeria has been the scene of three depositional cycles. The first began with a marine incursion in the middle Cretaceous and was terminated by a mild folding phase in the Santonian time. The second included the growth of a proto-Niger Delta during the late Createaceous and ended in a major Paleocene marine transgression. The third cycle, from Eocene to Recent, marked the continuous growth of the main Niger Delta. Studies in the Niger Delta revealed three vertical lithostratigraphic subdivisions or Formations: the Benin Formation, which is an upper delta top lithofacies; the Agbada Formation, which contains the hydrocarbon reservoirs, and the lower Akata Formation, which is the over pressured shales and the source of hydrocarbon generation. Table 1 shows the type section as described by Short and Stauble (1967).

**Table 1:** Stratigraphy of the Niger Delta and the Surface Equivalent (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/ SANTONIAN** | AWGU SHALE | TURONIAN |
| | | | **TURANIAN** | EZE AKU SHALE | TURONIAN |
| | | | ALBIAN | ASU RIVER GROUP | ALBIAN |

The sediments of the Niger Delta can be divided into three diachronous units of Paleocene to Recent age that form a major regressive cycle, all of which are present in both onshore and offshore depobelts (figure 2). The uppermost unit, the Benin Formation, comprises continental / fluviatile and backswamp deposits up to 2500m thick. These are underlain by the Agbada Formation of paralic, brackish to marine, coastal and fluvio-marine deposits, organized into coarsening upwards 'offlap' cycles. The underlying Akata Formation comprises up to 6500m of marine pro-delta clays. Shales of the Akata Formation are overpressured and have deformed in response to delta progradation. Shales of the Akata Formation constitute a world-class source rock.

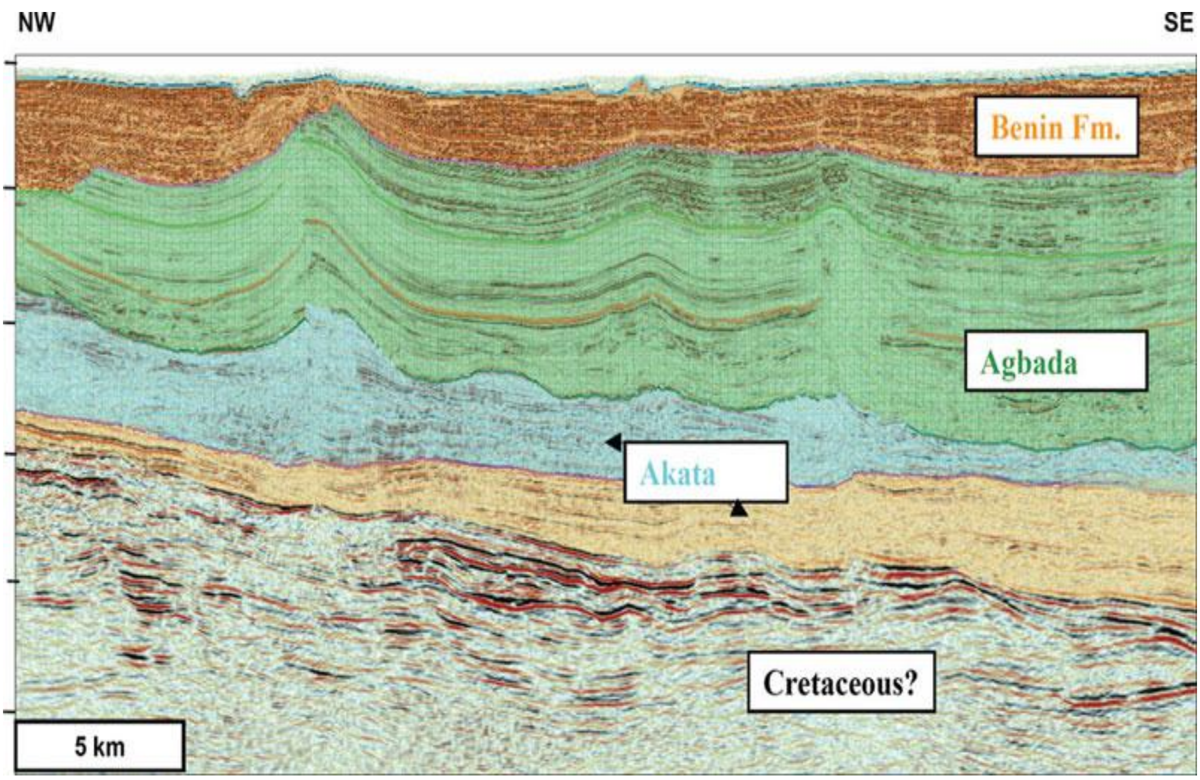


**Fig. 2:** Schematic diagram showing the various Formations in the Niger Delta, (Ajakaiye, and Bally, 2002).

**MATERIALS AND METHODS**

Several methods were adopted for this study.

The data set used includes, base map showing the structural element and location of wells, suite of wireline log, and set of core photographs.

The core photographs provided by Total (E&P) was studied and described from bottom upwards.

The procedure for the description is as follows:

a. The detail of the cores photos was done on the core sedimentological description chart,

b. Texture, litho unit boundaries, nature of contacts, composition, digenetic features, biogenic and physical sedimentary structures were described and recorded,

c. Their lateral and vertical changes in lithology was noted and studied,

d. Study of sedimentary structures such as cross bedding, lamination e.t.c. The degrees of bioturbation were also indicated.

e. 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), and

f. Interpretation of various lithofacies within the core were intergrated with the wireline log pattern to arrive at lithofacies association and distinct reservoir genetic units.

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

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

**WIRELINE LOG SHAPES**

Figure 3 shows facies indication from Gamma Ray, for idealized examples of both Log shapes and sedimentological facies (Schlumberger,1989). The sedimentological implication of this relationship leads to a direct correlation between facies and log shape. 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, and is interpreted to be a shoreface or delta front. A bell shaped log with gamma ray value increasing upwards to a lower value indicates increasing clay content (Figure 3) nand is interpreted to be a fluvial point bar or a tidal channel deposit.

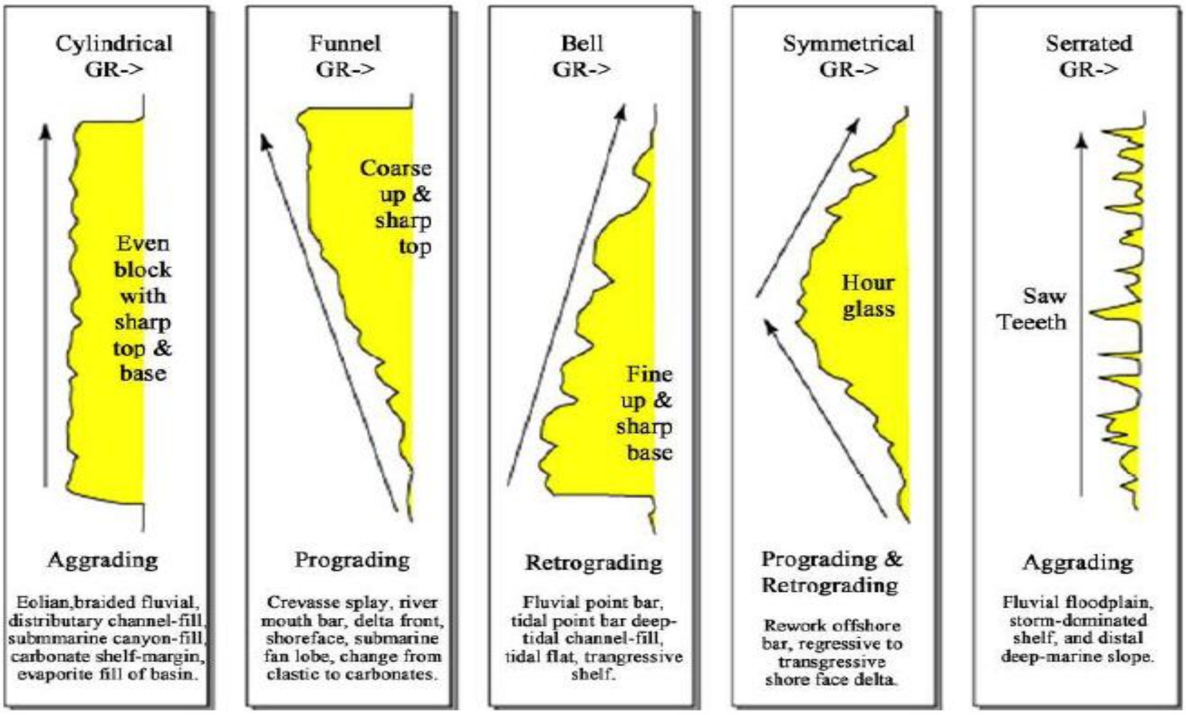


**Fig. 5:** Facies indication from Gamma Ray, the idealized examples of both Log shapes and sedimentological facies (Schlumberger, 1989).

## RESULT AND DISCUSSION

### Lithofacies Types

Five lithofacies types were identified based on core description and log shape of the "B3" Reservoir Sand (3950-3899) m, well-05, Biwa field. For each lithofacies identified, facies description and interpretation for the facies immediately followed. Some of the lithofacies in the study interval occur separately in different positions in the section and may be repeated. The lithofacies types are presented here from the bottom to the top of Reservoir "B3" as seen in the depositional sequence for reservoir "B3" (Fig. 4).

### Bioturbated Pebbly Sandstone Facies (BPS)

The lithofacies (BPS) in the cored interval of the study well; it occur as a very coarse to pebbly sandstone, poorly sorted and moderately bioturbated (Plate 1). The clast size ranges from granule to pebble size. The primary sedimentary structure of this lithofacies is not well defined as structure is slightly obliterated by the bioturbation in some intervals (3882.5-3874.5) m, with mud drapes in places. Ichnofacies in this sandstone is dominated by large *Ophiomorpha Irregularia* and *nodosa* burrows. The facies grades upward into the pebbly sandstone facies in the cored interval.

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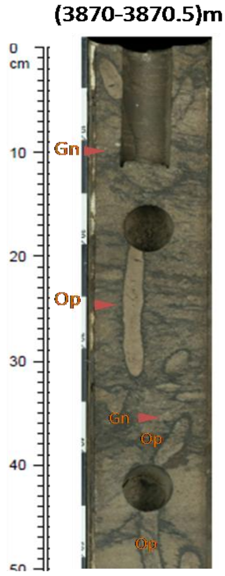


**Plate 1: Bioturbated Pebbly Sandstone (BPS) Facies.**
**(Op: *Ophiomorpha* burrow, Gn: Pebble grain)**

**Pebbly Sandstone Facies (PS)**

The lithofacies PS occurs as a thick bed of very coarse to pebbly sandstone with sharply defined scoured base (Plate 2). The sandstone is poorly sorted with no visible sedimentary structure. The clast size ranges from granules to pebbles. The grain size generally reduces upward. Bioturbation is rare, but mud drapes are found in few places. This lithofacies occurs in the cored interval of (3860.9-3863) m. The facies overlies the bioturbated pebbly sandstone facies in the cored interval.

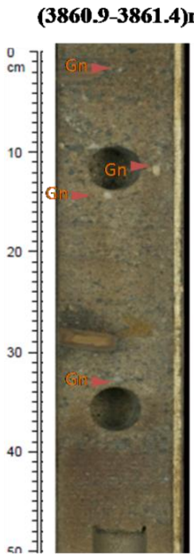


**Plate 2: Pebbly Sandstone (PS) Facies**
**(Gn: Granule grain size).**

**Medium to Coarse Grained Sandstone Facies (MCS)**

This lithofacies (MCS) consists of medium to coarse grained sandstone (Plate 3). The facies is poorly sorted and consists of bimodal grain size sorting. The granules are rounded to sub angular in shape, with size ranging in size from 0.1-2cm and are predominantly of extra-formational lithology (typically quartz). Mud flasers are found in few places. Bioturbation intensity is rare to absent in this facies. Physical sedimentary structures in this lithofacies are not pronounced except for the massive bedded nature of the facies. The lithofacies (MCS) in the cored interval occurred twice at (3882-3884.5; and 3858-3860.5).

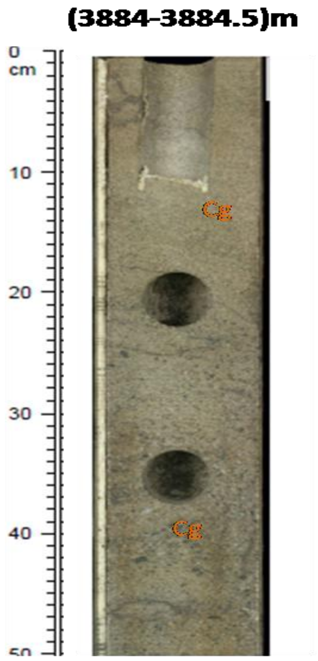


**Plate 3: Medium to Coarse Grained Sandstone (MCS) Facies (Cg: Coarse grain)**.

**Bioturbated Fine to Medium Grained Sandstone Facies (BfmSF)**

The lithofacies (BfmS) encountered in the cored section consists of fine to medium-grained sandstone, with little or no clay content, moderately sorted, with bioturbation ranging from slightly to moderately bioturbated (Plate 4). The grain-size indicates a reworking of sediment where the primary sedimentary structures have been obliterated. The common burrows include that of sub-horizontal *Planolites* and burrows of *Ophimorpha nodosa*.

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**(3855-3855.5)m**

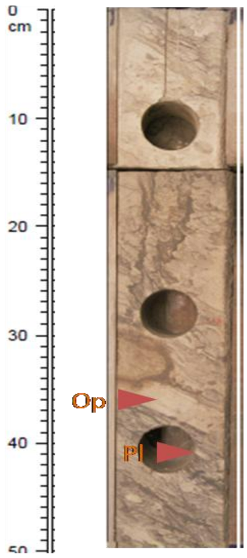


**Plate 4: Bioturbated Fine to Medium grained Sandstone (BfmS) Facies (Op: *Ophiomorpha* and Pl: *Planolite* burrow),**

**Mudstone Facies (M)**

Mudstone lithofacies (M) encountered in the cored interval consists of laminated dark-greenish-gray to greenish-black mudstone and it occurs in interval of (3854.5-3855). This facies is characterized by nodular concretions of digenetic siderite (Plate 5). Bioturbation in this facies is slight to rare, with burrowing of *Paleophycus* parallel to laminae.

**(3854.5-3855)m**

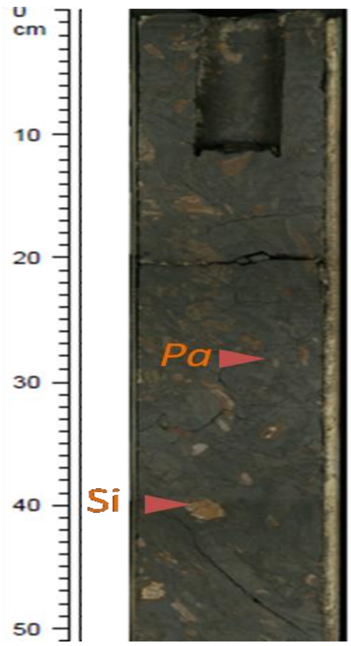


**Plate 5: Mudstone (M) Facies, (Pa: *Paleophycus* burrow, Si: Siderite nodules).**

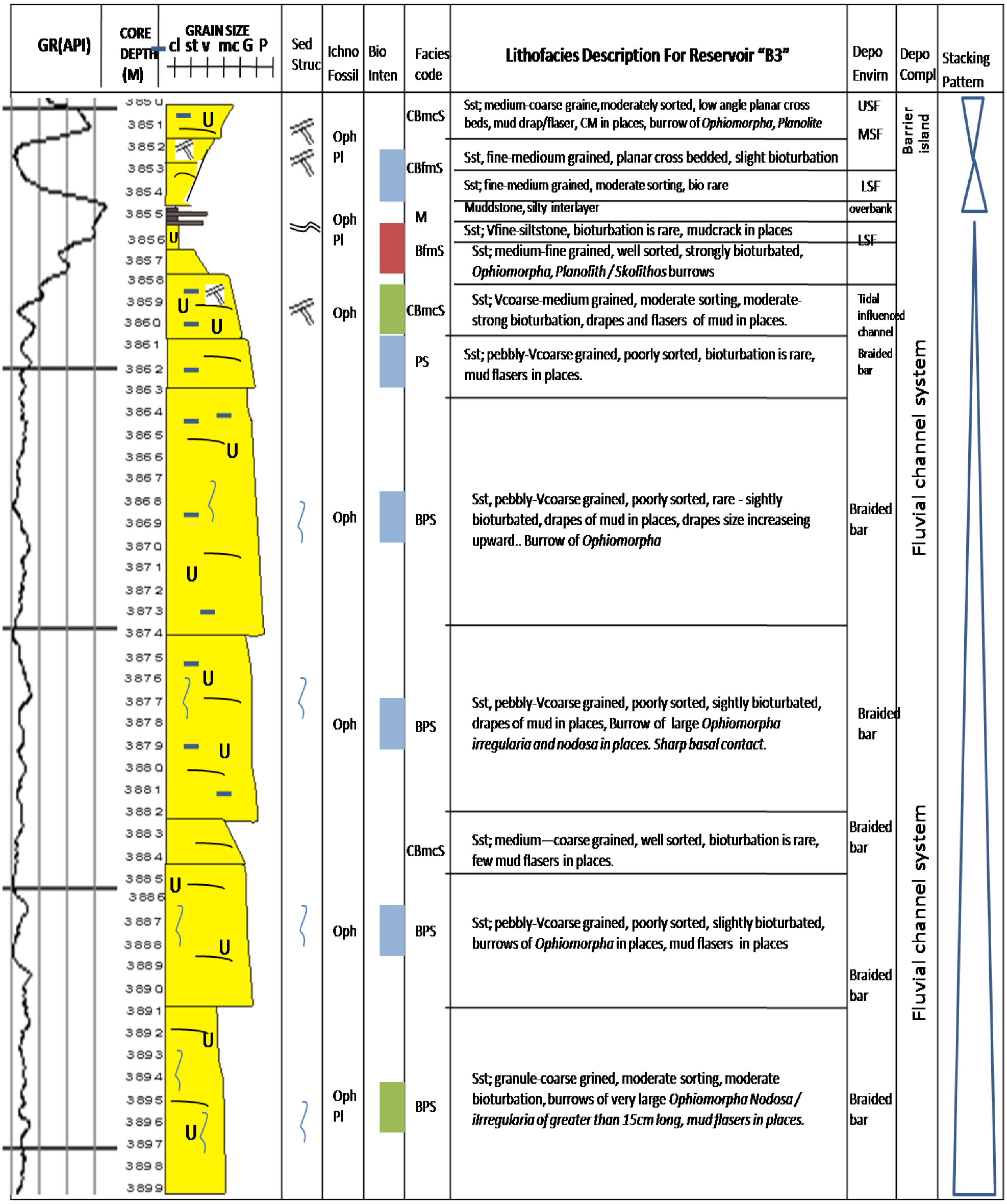


**Fig 4:** Depositional Sequence for Reservoir "B3" (3850-3899)m

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**DISCUSSION**

The pebbly nature of the lithofacies (BPS) and lithofacies (PS) are indicative of a channel or a lag deposit, generated by a strong ephemeral current as in storms and major flood (Dalrymple *et al.*, 1992, Miall, 1996). The lack of predefined internal bedding structure indicates rapid sedimentation (Allen, 1983). The bioturbation nature of lithofacie (BPS) may indicate drowning and quintessence nature of the setting before deposition of another cycle (MacEachern and Pemberton, 1994). This lithofacies (BPS) could be interpreted as a lag deposit, while the Occurrence of monospecific ichnofaunal in (PS) is indicative of a restricted and stressed environment and thus interpreted to be of tidal channel deposit.

The massive bedded sands nature of lithofacies (MCS) indicate deposits of subaqueous dunes that were formed under strong upper flow regime. The coarse grained characters of the sediment are indicative of fluvial sourcing. The bimodal sorting indicates cyclic, short term fluctuations in current strength and is interpreted to reflect tidal current modulation of the fluvial currents which supplied the coarse sediment (Miall, 1996). This lithofacies could be interpreted as deposits of fluvial channel.

The Intense bioturbation nature of lithofacies (BfmS) is indicative of a zone where oxygen content is high, with abundant nutrient and low energy condition, below wave base. Dominance of large burrows of *Ophiomorpha nodosa*, and *Planolites* with rare fossil shells, may characterize the influence of tidal or stressed estuarine environment. The intense bioturbation is an indication of lower shoreface.

The sediment of the mudstone facies (M) was deposited under quite and low energy conditions, allowing for shale lamination. 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.

**Facies Association and Interpretation**

Five (5) lithofacies types identified and described above (Plate 1-5) were grouped according to Readings, (1979) into facies associations which have genetic and environmental significance and were identified as separate units in cores and on wireline logs (Figure 4). These associations of facies formed the primary basis of inferring the depositional setting under which the sediments were deposited and preserved. Two lithfacies association have been identified in the cored interval.

**Lithofacies Association 1 (Braided Channel)**

The braided channel facies association shows a fining upward sequence. It consist from base pebbly sandstone (PS) and medium to coarse grain sandstone (McS) that fines upward (Figure 5). The unit is made up of over 70% pebbly sand of the total lithology. The poor sorting nature of the grain size indicates a fluvial dominated character in which sand deposit is by high energy fluvial current (Allen and Collinson, 1974). The mudstone sequence that capped the sequence as observed in the cored section (3854.5-3855) are the overbanks deposit which reflect waning current velocities as the channel is gradually filled. Despite the dominance of fluvial processes marginal marine depositional settings is often recorded by a restricted marine fossil assemblage, which is dominated by large robust opportunistic *Ophiomorpha nodosa* and *Ophipmorpha irregularia*. Fig. 5, is the representative vertical facies model for braided channel in the study well ("B3" 3856-3891 cored depth).

This facies association has a blocky gamma ray log signature with a sharp base.

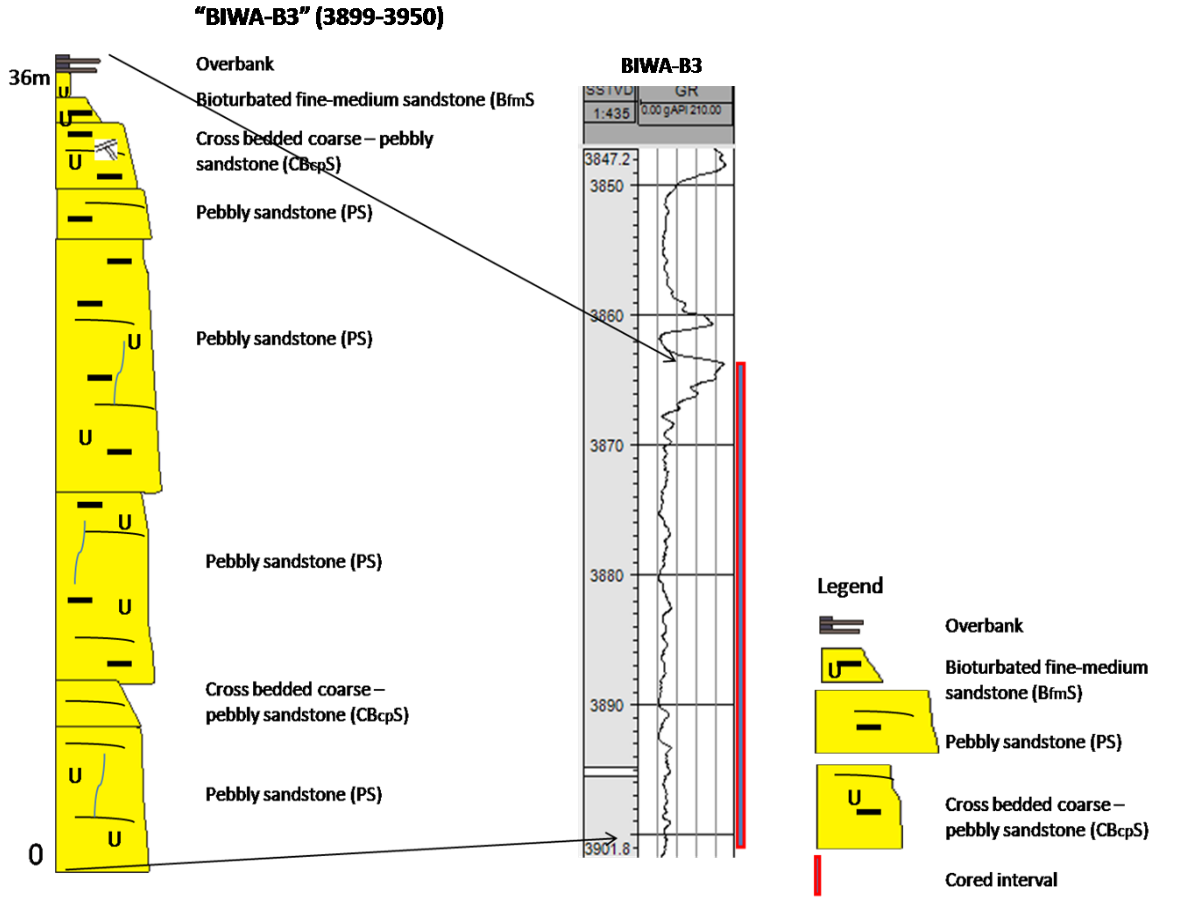


**Fig. 5**: Braided Bar Lithofacies association 1 and Log Signature for Reservoir "B3"

**Lithofacies Association 2 (Barrier bars)**

The lithofacies association 2 consists from base to top of Mudstone lithofacies (M), Bioturbated Fine to Medium lithofacies (BfmS), and Cross bedded fine to medium grained Sandstone facies (CBfmS) and Cross bedded medium to coarse grained Sandstone facies (CBmcS).They are interpreted as that of marine mudstone, lower shoreface, middle shoreface and upper shoreface respectively. The stacking pattern displays a vertical coarsening upward sequence (CUS) and a gradual transition from one lithofacies to another in a prograding shoreface. Fig. 6 shows the vertical facies model for barrier bar profile in the study area. This lithofacies association in the studied well of "B3" occur at (3850-3855m) depth.

**Shelf Mudstone Subfacies**

This subfacies association is made up of laminated dark-greenish-gray to greenish-black mudstone. It is characterized by nodular concretions of digenetic siderite. The unit is characterized by low levels of

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bioturbation 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.

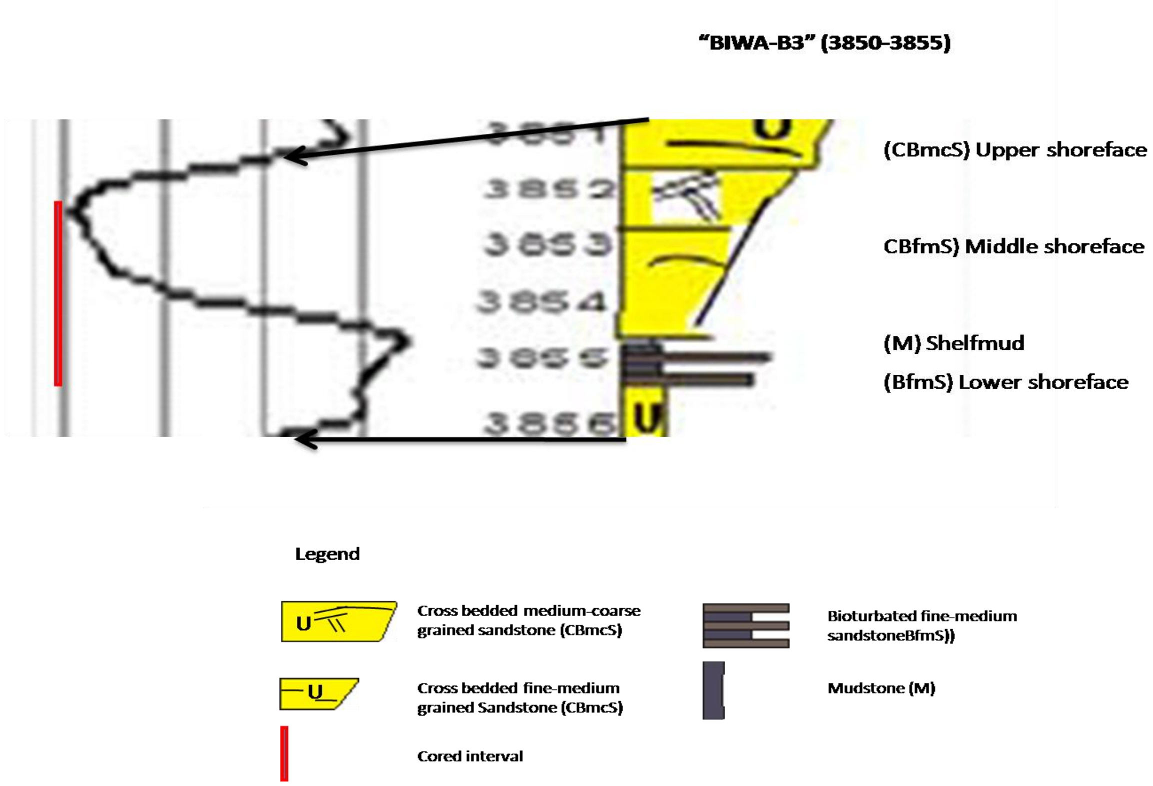


**Fig. 6:** Barrier Bar Lithofacies association 2 and Log Signatures for Reservoir "B3"

**Lower Shoreface Subfacies**

This subfacies unit 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 flaser bedding, very thin laminations. The facies is characterized by slight to moderate bioturbation and burrowing of *Ophiomorpha 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.

**Middle Shoreface Subfacies**

This subfacies unit overlie 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 include planar cross stratification and mud drapes, though, planar cross stratification may be locally developed.

**Upper Shoreface Subfacies**

This subfacies unit is characterized by coarsening-upward, shale-free sandstone with thickness up to 0.8m in the cored section. They are clean and well sorted medium to coarse-grained sandstones. This subfacies unit with little or no mud content 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. Burrows of high energy environment such as *Ophiomorpha* and *Planolite* (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.

**Depositional Model for the "B3" Reservoir Sandbodies**

The facies association of the cored intervals in the "B3" reservoir sandbodies can be interpreted as a deposit of braided channel deposit, capped by a shoreface deposit (Fig. 4). This observation is implied from the lithofacies association as seen from the cored section in the study well (Fig. 4). Indeed, this facies model is characterized by 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 (Mial, 1996).

The model established for braided bar deposit in the study well is similar to the Scott type model of Miall, 1978 erected for proximal braided stream deposits, including those occurring on alluvial fans, where gravel is the predominant facies. The deposit between interval (3899-3950m) in BIWA Field can be considered as facies model representative for braided bar deposit. It displays fining upward trend and is predominantly pebbly sandstone as those of Scott type braided bar.

The shoreface succession in the study section 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. Walker and Plint (1992), defined shoreface deposits as the interval between the mean sea-level and the mean fair-weather wave base. The shoreface model established for study well is similar to the shoreface model erected for "A1" reservoir sandbody, Well-5, Boga Field, Niger Delta (Okengwu and Amajor, 2014)

Ichnofacies serve as water depth indicators and are valuable aid to the interpretation of sedimentary environments (Pemberton et al., 1992). Hence, from the study of ichnofacies in the cored section of "B3" reservoir sandbodies, distinct trace fossil assemblages such as *Ophiomorpha* and *Planolite* ichno fossils were observed, in the "B3" reservoir sand sandbodies. The vertical movement of the *Ophiomorpha* trace fossils may have been as a result of the changing water level of the foreshore environment. Low or lack of biotubation activity seen in the mudstone at the bottom of the Shoreface deposit may be attributed to the unfavorable conditions for organisms to thrive; such condition includes absence of light, food and oxygen in the environment of deposition.

The facies association of the sand bodies in the study well can be interpreted as a deposit of braided channel deposit capped by a prograding shoreface setting. This observation indicate a fluvial dominated processes as seen in cored section of "B3" Reservoir sandbodies.

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