# LITHOFACIES DISTRIBUTION AND DEPOSITIONAL ENVIRONMENT OF THE SEDIMENTARY SUCCESSION IN VIBRE-001WELL, NIGER DELTA

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Abstract

The results of detailed geological core description and characterization of depositional environment of the sedimentary succession in VIBRE-001 Well is supplied in this paper. An interpretation for these sedimentary units was carried out by using integration of lithofacies characterization and sedimentologic log data. Thirteen lithofacies were identified in this study: silty shale, black shale, grey shale, bioturbated sand-dominated heterolithic, bioturbated mud-dominated heterolithic, laminated sandstone, bioturbated sandstone, wavy bedded heterolithic, coal, underclay, cross-bedded sandstone and planar laminated fine-very fine grained sandstone. Combinations of closely related lithofacies were grouped into coastal barriers-shelf, fluvial dominated upper delta plain, lower delta plain, trangressive sands and offshore shelf facies associations. The primary depositional environments are deltaic-fluvial, barrier islands and tidal flat that suggests deposition in environments fluctuating within marginal marine setting under a terrestrial influence.

Keywords: Core description; Lithofacies; Facies association; Environments; sedimentary succession; characterization

## Introduction

Core analysis is defined as the laboratory measurement of the physical and chemical properties of samples of recovered core, for purposes of multiple disciplines. The result of core description is the subdivision of cores into lithofacies, based on lithology, grain size, sedimentary structures (physical and biogenic), and stratification produced by different processes during deposition. The processes of transport and deposition can be determined by looking at individual layers of sediment. The size, shape and distribution of particles all provide clues to the way in which the material was carried and deposited (Nichols, 2009).

There are uncertainties militating against determining the environment of deposition due to distinctive characteristics of sediments that made them. Previous work indicates that analytical results such as gamma ray GR and spontaneous SP log basic shapes of facies (Shell, 1982), can be integrated facies delineation which helped in the interpretation of the depositional environments and their characteristics. This study focuses on utilizing detailed core to understand the distribution of lithofacies and environments of deposition of VIBRE-001 Well, Niger Delta Basin. It is important to note that the availability of core slabs of the wellbore became a propelling force and strong motivation to carry out this research thereby reducing uncertainties. Overall, sedimentary structures, hydrocarbon intervals, depositional environments and genetically related units are direct evidences and advantages of using core slabs detailed sedimentological descriptions.

### *Location*

"VIBRE-001Well" lies within the onshore portion of the Niger Delta Province (Figure 1) delineated by the geology of southern Nigeria and south western Cameroon (Michele *et al*., 1999). 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 (Short and Stäuble 1967).

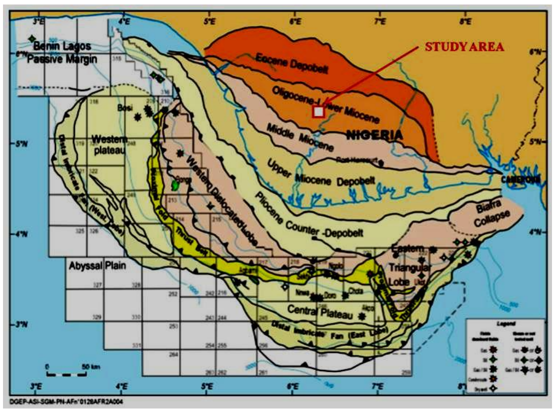


**Figure 1: Geological map of Niger Delta Province (Source from SPDC, 2006)**

## Materials and Methods

The materials that were available for this work are conventional cores provided from intervals of 6963 ft – 7336 ft (359 ft) depths with a total of 22 core slabbed samples. These cores were well preserved and labelled for a successful core study. Macroscopic description carried out with Digital Camera, Lens, measuring tape and writing materials involving observation and description of geologic features such as lithology, thickness, colour, grain size, sedimentary structures, beddings, trace fossils, associated minerals, hydrocarbon show, nature of overlying/underlying contacts and post – depositional features (cementation and compaction). Vertical sequences of aforementioned sedimentologic features according to Visher (1965) are among the most exact technique for delineating depositional environments.

### *Sedimentological Analysis*

Adequate analysis of sedimentary environment and their lithofacies context strongly requires standard sedimentological procedures. Three hundred and ten (310) core samples examined under AmScope SM-2T Trinocular Stereo Microscope in Sedimentological Laboratory. 10% HCl was used to check for presence of carbonate. Comparator chart was employed for estimating sediments texture (Maju-Oyovwikowhe and Lucas, 2019). Additionally, sediment composition (clast type, mineraology and fossil content) was guided by Suthren, (2013) grain size estimation (Figure 2) which made interpretation of succession easier.

**Results**

Sandstone and mudrock are the major lithologic constituents encountered in the study area. Minor lithologic constituents of the cores include coal and underclay/paleosol. However, the study of sedimentology in which sedimentary facies refers to the sum of the characteristics of a sedimentary unit (Nichols, 2009) define lithofacies. Thirteen lithofacies have been recognized in the study area. They are discussed below with representative photographs to explicate their lithological characteristics and sedimentary structures.


**Figure 2: Microscopic grain size analysis (by Suthren, 2013)**

***Black shale lithofacies***

The lithofacies is laminated fissile very well-sorted mudrock that typically contains organic carbon. They were identified as black shale and pyritic black shale of clay, silt and plant materials. Associated minerals are quartz and mica. Thickness ranges from 4-5 ft. Sedimentary structures include fissiles thin laminae to very thin beds. Trace fossils of thin-walled *Planolites*, *Chondrites* belonging to *Cruziana* assemblage are moderate to intense bioturbation Pyrite, as nodules are common (Figure 3). Overlying facies are grey shale and sand-dominated heterolithic while underlying facies are sand/mud-dominated heterolithic having are either sharp or gradational contacts. The environment of deposition is interpreted to be in a low-energy, open marine shelf in a transgressive marine setting.

***Wavy bedded heterolithic lithofacies***

This lithofacies consists of clay, silt and very fine to fine to medium sand. They include cross stratification, hummoky cross stratification, streaky, lenticular, wavy, and flaser bedding but absence of recognizable burrows probably due to tidal effects. It was observed at two intervals with thickness of 3 ft and 9 ft. (Figure 3). This lithofacies is overlain by mud-dominanted heterolithic facies and underlain by sand-dominated heterolithic facies. The wavy bedded heterolithic lithofacies is interpreted as subtidal coastline settings (Flint *et al.*, 1988).

***Grey shale lithofacies***

This lithofacies consists of fissile very well-sorted mudrock of clay, silt and plant materials occurring as dark grey to light grey, sometimes micaceous. Thickness ranges from 2-10 ft. Sedimentary structures include fissiles thin laminae to lenticular siltstone laminae and common siderite, in the form of nodules, cement, or bands were observed. Horizontal to vertical small *Planolites* burrows were observed. The gray shale facies exhibit coarsen upward, with upper contacts being gradational with overlying mud-dominanted heterolithic facies while lower contacts are mainly sharp with underlying black shale and medium-fine (Figure 4). However, the facies is interpreted as being deposited by suspended sediment fallout and periodic low-energy currents in a slightly restricted basin or an offshore, moderate-depth setting (Nwajide, 2005).

***Planar laminated sandstone lithofacies***

This lithofacies consist of brownish fine to very fine grained sediments 16 ft thick in study area. Sedimentary structures are essentially parallel well developed ripple laminations bounding to the surfaces of the bed and thin laminae of grey shale outline ripple lenses of sand. The lithofacies grades into overlying laminated dark grey shale and exhibits sharp contact with underlying cross bedded sandstone (Figure 4). These lithofacies were deposited during low flow regime of quiet environment change from storms to floods (Baker Hughes, 1999).

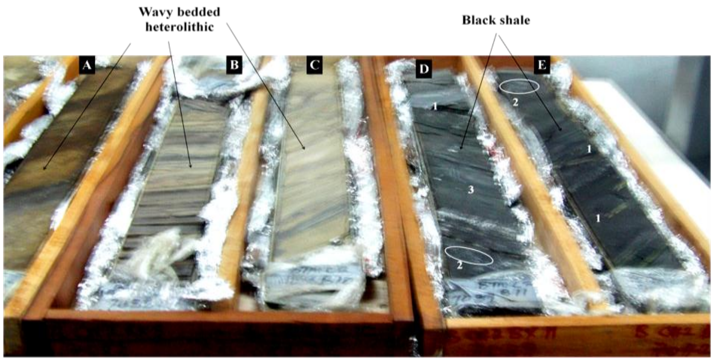


**Figure 3: (A-C) Wavy bedded heterolithic liithofacies, (D and E) Black shale lithofacies displaying bands (1), *Planolites* burrows (2) and pyrite nodules (3).**

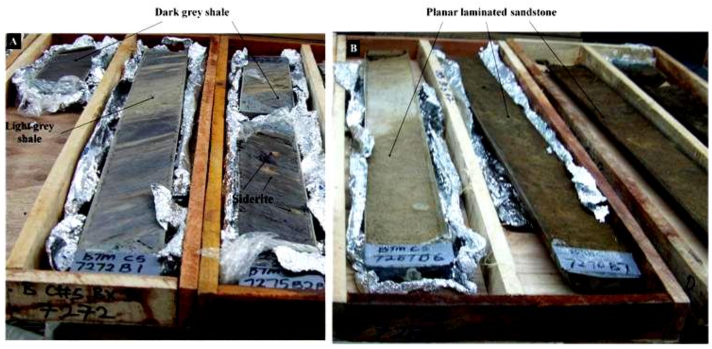


**Figure 4: (A) Grey shale lithofacies with siderite cementation (B) Planar laminated sandstone lithofacies.**

***Silty shale lithofacies***

Silts matrix in shale components characterized this facies. This lithofacies comprises of shale with light grey colour, medium sandy silty to silty clay which occurred only 6987-6984 ft (3 ft) (Figure 5). Small burrows belonging to *Cruziana* ichnofacies distinguish this interval as highly bioturbated subfacies. Upper and lower contacts are gradational with overlying mud-dominanted heterolithic and sand-dominated heterolithic respectively. The environment of deposition is interpreted to be in a low-energy, open marine shelf in a transgressive marine setting.

***Coal lithofacies***

The lithofacies comprises of organic material that is rich in carbon with structureless to thinly laminated, and can sometimes be inclined >15°. In core, thickness ranges from 1-2 ft, black with vitreous luster on cleat surfaces Post-depositional features include nodular pyritization and mineralization. Upper contacts were observed to sharp with overlying sand-dominated heterolithic, mud-dominanted heterolithic and black shale facies in the three depths coal occured. Lower contacts are gradational with the underlying underclay facies. The depositions are attributed to a continental or marginal marine environment (Figure 5).

***Underclay lithofacies***

This is very fine-grained sediments, ashlike, sand, silt, and clay containing plant fragments. Thickness ranges from 1-2 ft. In Figure 5, upper contacts are seen as sharp and gradational into coal while lower contacts are gradational light grey medium to fine grained. The deposition is interpreted as non-oxidized environment.

***Bioturbated Sandstone lithofacies***

The bioturbated sandstone lithofacies is composed of very micaceous and organic-rich, brown to dark grey, coarse to fine grained moderate to well-sorted sandstone. Thickness ranges from 3-16 ft. This facies is characterized by a low bioturbation, bedding boundaries sharp mud-lined and pelleted burrows interpreted as Ophiomorpha. The bioturbated sandstone facies is overlain by dark grey shale and underlain by black shale (Figure 5). The lithofacies is considered a storm deposit forming after high-energy current deposition due to marine flooding or storm currents that was subsequently bioturbated.

***Bioturbated sand-dominated heterolithic lithofacies***

This lithofacies consist of clay, silt and fine to very fine sand. Thickness ranges from 1- 20ft. Sedimentary structures are streaky, lenticular, wavy, and flaser bedding, may contain siderite concretions or syneresis cracks. Recognizable burrows are *Ophiomopha* generally infilled with fine sand but *Thalassinoides Palaeophycus and Planolites* are confined to muddy zones (Figure 6). The setting is characterized by low to moderate energy deposition where offshore processes are prevalent (Reinson, 1984).

***Bioturbated mud-dominated heterolithic lithofacies***

This lithofacies is dominantly mudrock that consists of clay and silt and sandstone coarse to fine sand Thickness ranges from 1-13ft. Sedimentary structures are streaky, lenticular, wavy, and flaser bedding, may contain siderite concretions, completely churned by a variety of organisms. Trace fossils of, Chondrites, *Palaeophycus, Planolites*, *Teichichnus* and *Thalassinoides* are abundant (Figure 6). These features are indicative of offshore transition zone which extends from mean fair-weather wave base to mean storm wave base. It has been noted to be characterized by alternating low to periodically high energy deposition (Reinson, 1984).

***Laminated Sandstone lithofacies***

This lithofacies is depicted by laminations in well-sorted fine grained sandstone that consist of silt, fine to medium sand and minor shale. Thickness ranges from 3-11 ft. Sedimentary structures are parallel laminae, wavy laminae, swaley cross stratification and lesser hummoky cross stratification. Cosets are 0.1 - 0.5 ft thick. Very low to moderate bioturbation constituting the assemblages of *Skolithos*, *Palaeophycus*, *Siphonichnus*, *Ophiomorpha* and escape trace were observed. According to Reinson (1984) The lithofacies id deposited within high energy zone in slightly deeper water below the limit of the surfzone.

***Cross bedded Sandstone lithofacies***

This lithofacies consists of medium to very coarse grained sandstone. They are moderately to very well-sorted. Thickness ranges from 3-20ft. Sedimentary structures are trough cross-beddings, typically in 15 – 30cm thick sets with dip angle 10º-40º, interbedded with low angle bidirectional planar cross-bedded sets. These foresets are the product of ripple migration whose bounding surfaces are curved with very thin intermittent shale seams. They are overain by heterolithic sandstone and underlain by facies such as mud-sand heterolithic or sharp, erosive basal contacts with shale. The intensity of bioturbation is moderate vertical Ophiomorpha burrows may suggest a stressful environment. This is the high energy conditions environmental settings.

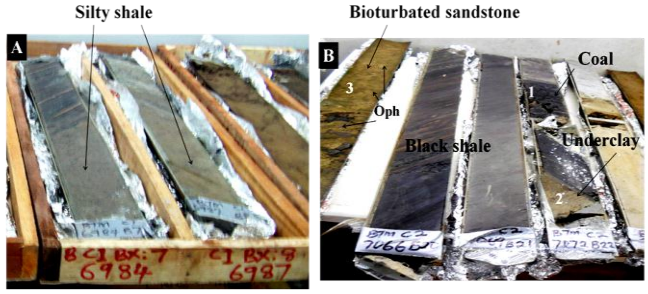


**Figure 5: (A) Silty shale lithofacies, (B) Clay lithofacies(1), Underclay lithofacies (2) and Bioturbated sandstone displaying *Ophiomorpha* burrows (3).**

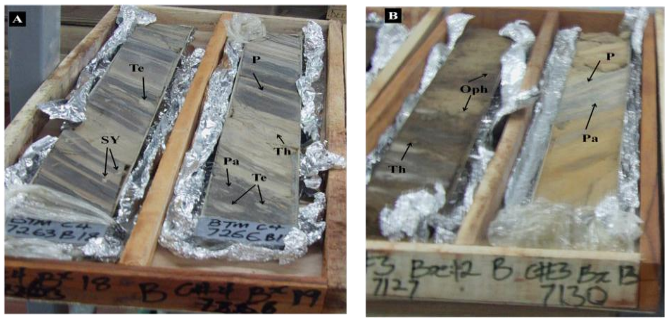


**Figure 6: (A) Bioturbated mud-dominated heterolithic lithofacies burrowed by *Planolites* (P), *Palaeophycus* (Pa), *Thalassinoides* (Th) and *Teichichnus* (Te). (B) Bioturbated sand-dominated heterolithic lithofacies burrowed by *Ophiomopha* (Oph), *Planolites* (P), Palaeophycus (Pa) and *Thalassinoides* (Th).**

***Heterolithic Sandstone lithofacies***

The heterolithic sandstone lithofacies is composed of moderate to well-sorted, medium to very fine grained sandstone. It is 6 ft thick between 7320 – 7314 ft. Sedimentary structures are wavy laminae unidirectional current ripple beds with mud drape that inclined up to 15° Upper contacts is gradational with overlying cross bedded sandstone while and lower contact is gradational with sand dominant heterolithic lithofacies. The heterolithic sandstone facies is interpreted as forming from coastline settings.

***Facies Association***

Combination of closely related lithofacies was group together into three facies associations. Coastal barrier/shelf facies association (FA 1) consist shoreface sands, subtidal channel sand, and offshore that was delineated within 7336 – 7314 ft, 7269 – 7124 ft and 7070 – 6963 ft depths intervals. Fluvial dominated deltaic facies association (FA 2) consists of fluvial channel, fluvial point bar, levee and floodplain that was delineated within 7314 – 7269 ft and 7124 – 7070 ft depths intervals.

***Interpretation***

Explications of the depositional environment fundamentally hang on standard grain size classification of grain size and sorting as well as sedimentary structures without which interpretation is not complete.

***Sedimentological estimation***

Sandstone and mudrock are the major lithologic constituents of each core. Units containing mixed sandstone and mudrock are interbbeded or bioturbated. Minor lithologic constituents of the cores include coal and underclay. Sandstone grain sizes vary from very fine to very coarse grained, at some interval locally granular or pebbly. They are brownish grey, well to moderately sorted and are 3-20 ft thick. The coarse grained character of the sediments indicates a fluvial source while medium to fine grained is characterized by high wave energy. Mudrock grain sizes are clay and silt, light to blackish grey, very well sorted and are 2-10 ft thick which suggests deposition in a low-energy, marine setting. Coal and underclay are organic materials dark brownish black and ashlike respectively with 1-2 ft thickness indicative of floodplain setting.

***Sedimentary structures***

Trough and planar beds were interpreted as dunes migrating from high-energy unidirectional traction currents in fluvial channel bars having erosive basal contacts with deeper water lithofacies. Climbing ripple lamination was interpreted in the alternating sandstone and mudstone as flaser, wavy and lenticular bedding. They are formed under varying energy unidirectional traction and suspension

sedimentation exhibiting flaser bedding consists of cross laminated sandstone with mud streaks on bounding surfaces (Reineck and Singh, 1980). Lenticular bedding associated with planar laminations was interpreted in the mudrock where clay is the major sediments that suggest suggest that deposition has occurred in a relatively quiet environment. Wavy bedding was formed as sedimentation of sand increases in prodelta and delta front settings. Swaley and hummocky cross-stratification were interpreted to have formed above fair-weather wave base by storm-generated waves in the sandstone (Leckie and Walker, 1982). Bioturbation is the major post-depositional disturbance of sediments by ichnofossils. The degree of intensity and diversity of biogenic structures are more on marine shelf deposits while simple burrows are more common in terrestrial ie fresh and brackish water sediments (Ezeh *et al*., 2016; Okoro and Igwe, 2018).

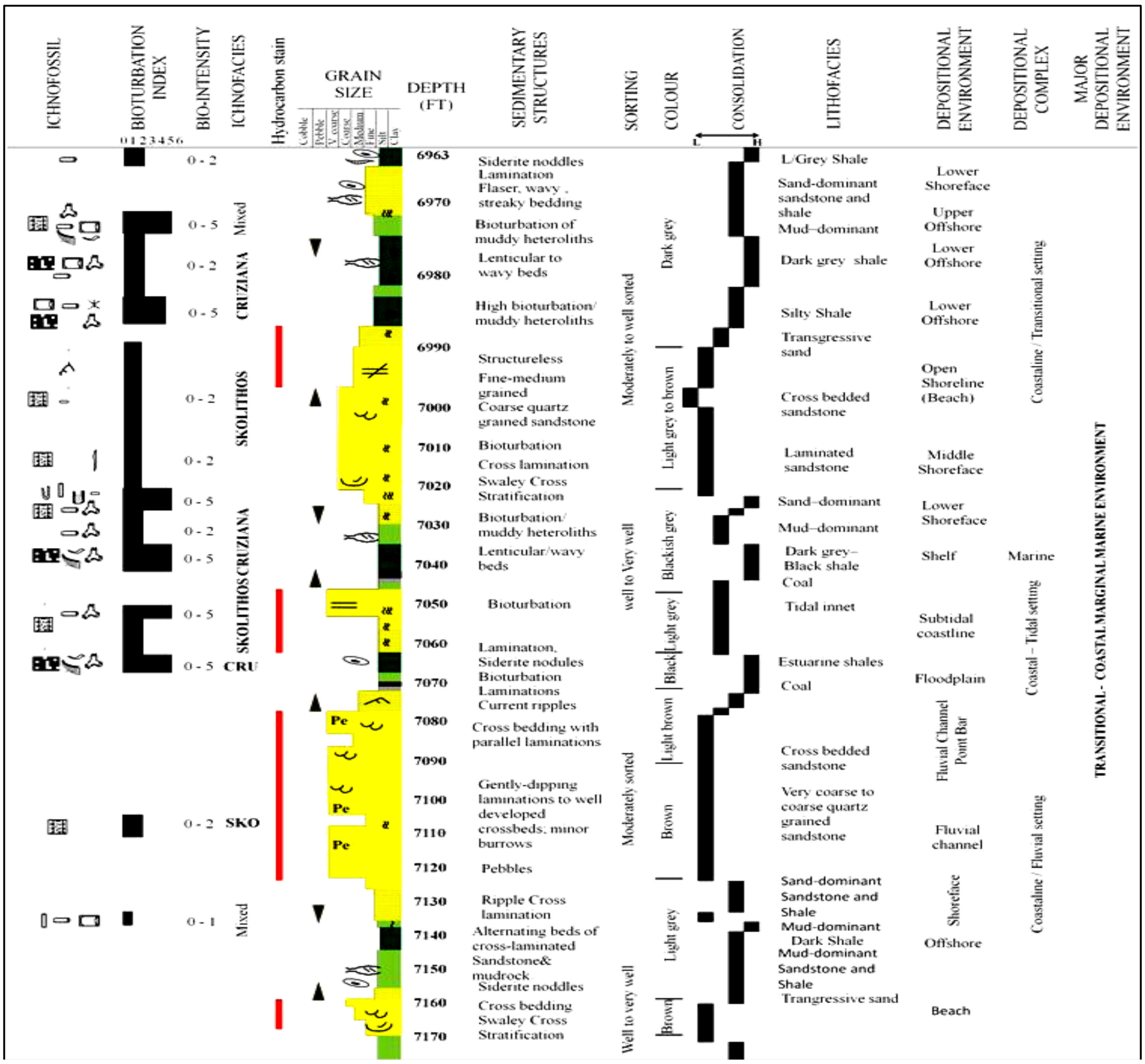


**Figure 7: Lithostratigraphic log model of VIBRE-001Well**

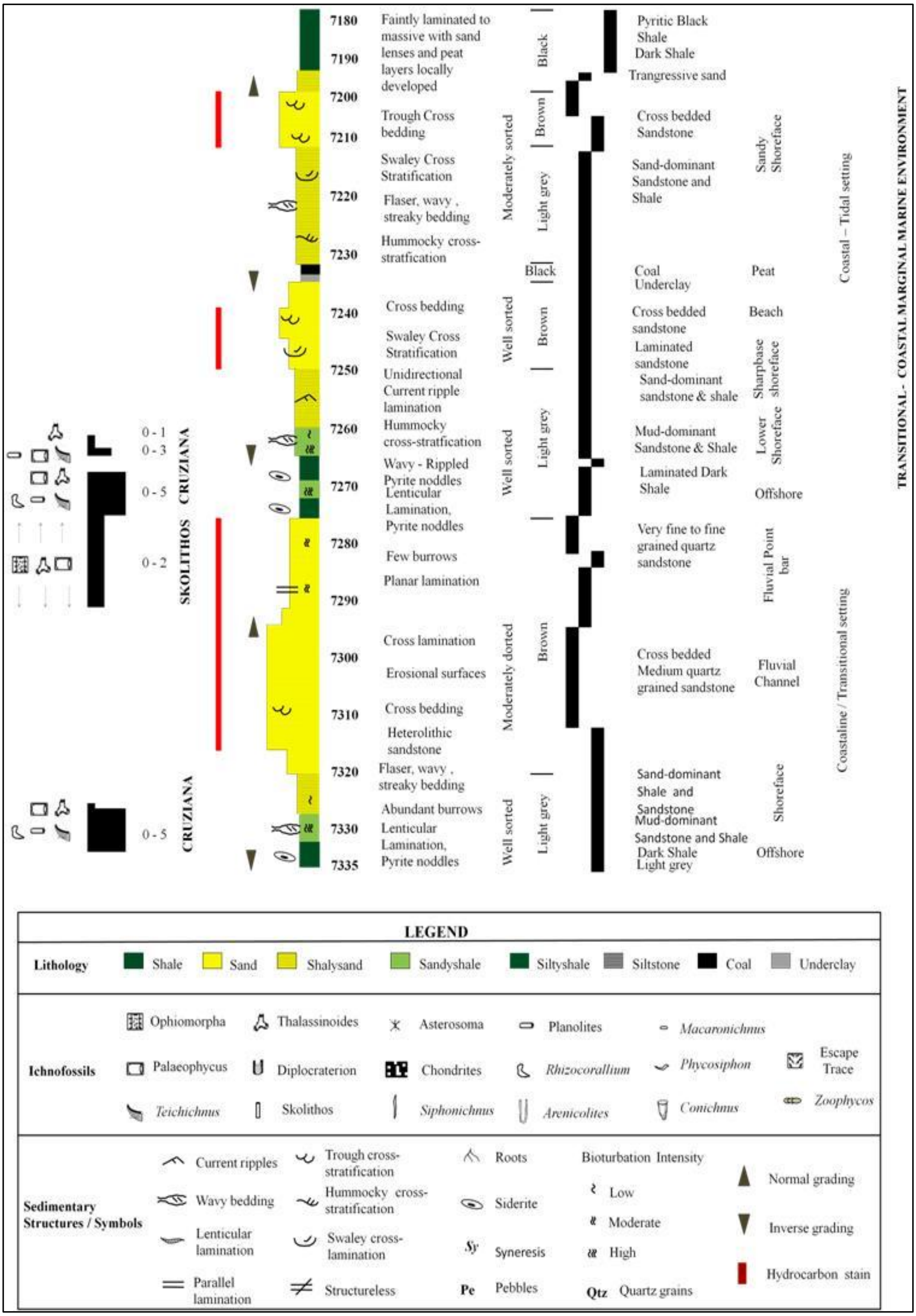


**Figure 7: Lithostratigraphic log model of VIBRE-001Well cont'd**

**Discussion**

These lithofacies types enumerated above with their peculiar sedimentary structures are deposited in different depositional environment. Estimation of depositional processes further aid the interpretation of depositional environment. Deltaic-Fluvial environment is interpreted to have continental origin from fresh water streams emptied into a standing body of water thereby making the fluvial dominating deltas. The fluvial channel and fluvial point bar were recognized at 7314 – 7276 ft and 7124 – 7078 ft depth intervals by the absence of marine fossils, unidirectional-flow cross-stratification, paleosols and scoured channels. The intervals commonly consist of well sorted sands and thus obvious potential reservoirs for hydrocarbon (Figure 7). Barrier islands environment is interpreted as the long, narrow sand bodies that occurred within deltas at 7267 – 7124 ft and 7036 – 6963 ft depths intervals by wave processes and high tides. They are characterised by trough and planar cross-bedding, swaley and hummocky cross-stratification, an upward coarsening sedimentation of increasing grain size upward, very clean coarse to medium that serve as reservoir potential beds. Tidal flat is interpreted as being developed along the coastal margins by tidal current at 7078 – 7036 ft depths intervals. The environment is delineated by the recognition of sandy, grading upward and landward into clay but becomes coarser in tidal channels with flaser bedding, cross laminations and high bioturbation (Mode and Odumodu, 2014).

## Conclusions

An increase in flow power gives rise to coarsening upward sequence with increasing grain size. On the other hand, decreasing grain size as an accompaniment to fining upward sequences formed a migrating point bar in a river. Understandingly, these two sequences peculiar to clastic environment gave assisstace to reduce the risk in of interpreting depositional environments in the study area. Lithofacies characterization has shown that thirteen lithofacies which belong to three facies associations were described and cut across three depositional systems. Deposition was controlled by process of wave, river and tides during formation. Deltaic-Fluvial, Barrier islands and Tidal flat environments were interpreted. These are environments of deposits that are generally marine environment towards the source of fluvial sediments and conclusively termed fluvio-marine environment.

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