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Lithofacies Analysis and Depositional Environments of the Waz Fields, Niger Delta, Nigeria.

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ABSTRACT
Lithofacies analysisservesas a viable means of reconstructing the depositional environments of sedimentary bodies. Through core descriptions of the reservoir sand bodies, nine lithofacies types have been identified, namely: Fineto Medium GrainedSandstone Facies (FMS), Cross-bedded Fine to Medium Grained Sandstone Facies (CFMS), Sandy Heterolithic SandstoneFacies(SHS), Muddy Heterolithic SandstoneFacies(MHS), Mudstone Facies (MF), Medium to Coarse Grained Sandstone Facies (MCS), Bioturbated Fine to Medium Grained Sandstone (BFMS) and Coarse to Pebbly Grained Sandstone (CPS). Four types of facies associations (shoreface, channel deposits, braided bars and shelfalmuds) were inferred. The ichnofossils present were a preponderance of Ophiomorpha and Skolithos; occurring sparingly were the Planolites and Paleophycus.
Keywords:*Facies, Ichnofacies, Heterolithic, Lithofacies,*

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I. INTRODUCTION

Facies analysis is often the first criterion in the investigation of depositional environments of sedimentary rocks. In lithofacies identification; facies analysis is unavoidable, because it comprises of the most easily accessible characteristics of sedimentary rocks. However, depositional environments of ancient sediments are reconstructed using several sedimentaryfacies approaches (lithofacies, ichnofacies,biofacies etc.) which open up the possibilities as to how sediments were deposited and the processes which brought about them.
In this study, core photo images were used to study, in order to generate the various lithofacies, and facies architecture and subsequently infer the depositional environments of the Waz Fields, Niger Delta.

Location of Study Area

The study area "Waz Field" is located onshore of the Niger Delta within 3^oN and 6^oN andLongitude 5^oE and 8^oE (fig. 1).

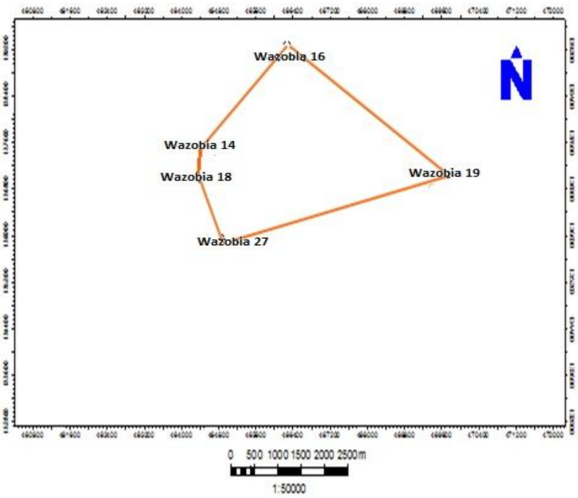

Figure 1: Base map of Study Area showing wells

Aim and Objectives of Study

The aim of this study is to determine the depositional environment of the Waz Field.

The objective include:-

- To determine the various lithofacies,
- Construct a depositional sequence for reservoir lithology,
- Determine the facies association and therefore infer the depositional environment of Waz Field.

Geologic Setting

The Waz Field is one of the onshore fields in the Niger Delta. The Niger Delta originates from the Geology of the Southern Nigeria and the South Western Cameroon which characterizes the Niger Delta. The Northern boundary is characterized by the Benin flank whichis an east-north-east hinge line flanked to the south by the West African Basement Massif. The outcrops of theCretaceous on the Abakiliki High, and much further to the east-south-east the Calabarflank, both define the north eastern boundary.

The South Nigeria basin originated during the Early Cretaceous from an X-shaped depression in the basement complex of the African shield, oriented north-south-west and north-south-east (Short and Stauble, 1967). The thickest sedimentation occurred along the northeast-southwest Benue rift valley and its eastern parallel equivalent, the Abakiliki trough. The southern Nigeria, sedimentary basin is made up of subsurface formations of Niger Delta, (Akata, Agbada and Benin Formations) and their outcrop equivalents where applicable (ShortandStauble, 1967). In order of theoldesttothe youngest formation, the Asu River Group is Albian in age and consists of dark micaceous sandy shale and fine-grained sandstone and is restricted to the southeastern part of Nigeria. During the Turonian, a marine transgression led to the development of the EzeAku Shale and is in turn overlain by the Awgu Shale ranging from Coniacian to early Santonian.

A subsidence initiated a renewed marine transgression, leading to the deposition of the Campano-MaastrichianNkporo shale which in turn is overlain by the Maastrichian to Paleocene Mamu, Ajali and Nsukka formations. Amarine influence in the lower part of the Mamu formation which led to a period of regression and the deposition of Paleocene Imo Shale in the east which is the outcrop equivalent of the subsurface Akata Formation also occurred. Overlying the Imo Shale is the Ameki Formation, overlain by the Oligocene to Miocene OgwashiAsaba Formation. Collectively,the Ameki and OgwashiAsaba Formations are known as the outcrop equivalents of the subsurface Agbada Formation. Capping the entire sequence is the Benin Formation (Reijers*et al.,* 1997).

II. METHODOLOGY

Two main methods of study were employed in this research work. They are core description and the use of wireline logs interpretation:-

Core photo Interpretation

The core images revealing various lithologies were studied in order to determine the intricate sedimentological characteristics. This entailed comparing the observed characteristics being described from cores with a core description chart. Typical characteristics to look out for were texture, composition, and nature of contacts, composition, digenetic features, biogenic and structural features. Core images were studied at designated calibrations (every one meter apart).

Facies Analysis

This technique studies for the recognizably different but adjacent sediments deposited in different depositional environments. Depending on the aspect of the rock being studied, a host of characteristics could be brought forward. However, for the sake of the scope of this work, the facies analyses were restricted to observable physical traits (lithofacies) and recognizable trace fossils present.

Afterwards, the identified facies were named making use of the recognized parameters. For example a cored interval with fine to medium grains and with cross bedding sedimentary structures was designated the facies name:*Crossbedded Fine to Medium Grained Sandstone*. The facies names were also assigned codes, and the Crossbedded Fine to Medium Grained sandstone would be allotted a code such as CFMS. The code-system and naming is in compliance with Mial, 1996.

III. RESULTS, INTERPRETATIONS AND DISCUSSION

Ninelithofaciestypes were recognized in the “Waz Field” Reservoir Sand, based on lithology andsedimentary structures (Plate 1-9). For each lithofacies identified, facies description and interpretationfor the facies is immediately followed. Some of the lithofacies in the study interval occur separately indifferent positions in the section and may even be repeated (Fig. 2)

Medium to Coarse Grained Sandstone Facies (MCS)

The medium to coarse grained sandstone lithofacies group (Plate 1)are clastic sediments consisting of mostly light brown colour grains. It reveals a moderate sorting of grains and angular shapes. Sparse content of clay are present. Few iron nodules are encountered. Thebeds are generally massive.

Plate 1 Medium to Coarse grained sandstone facies.

Interpretation

The light brown colour grains purport aerobic environments and the sorting is characteristic of a depositional energy regimethat was high for most of the deposition, fluctuating seasonally. The angular grains are alsosuggestive of proximal provenance since the grains had little reworking. The environment inferred from this would pass for a fluvialchanneldeposit.

Crossbedded Fine to Medium Grained Sandstone Facies (CFMS)

This facies consists of fine to medium sand grains and reveal very striking stratifications and crossbeds (Plate 2) across several intervals. The crossbeds have planar bounded surfaces. The sorting of the grains is fairly moderate. Most of the grain contacts are rounded and the sedimentation was almost clean (little or no observable clay cementation except where they occurred as thin mud drapes).

Plate 2: Crossbedded Fine to Medium Grained Sandstone.

Interpretation

The crossbeds bounded by planar surfaces indicate that the sediments were deposited as ripples or dunes which advanced due towater current. All theherringbone structures, cross stratifications,clay drapes, flasers, and occasional mud laminations permit an interpretation of tidal influence. The mud drapes ensued due to slack periods (Plink-Bjorklund, 2005).

Trough crossbeds are typically associated with sand dune migration, strong upper flow energy prevalence in channel environments which could very much be influenced by waves. A tide dominated environment (tidal channel) is inferred.

Fine to Medium Grained Sandstone Facies (FMS)

It comprises of fine to medium grained sandstone (Plate 3) that are properly sorted with massive intervals. The grains are relatively clean, void of silt, clay and smaller grain proportions. The grain shapes and contents are fairly rounded.

Plate 3: Fine to Medium Grained Sandstone.

Interpretation

The rounded grains indicate a farness from provenance suggesting that the sediments were allowed substantial reworking. The nearabsence of bioturbation suggests an aerobic depositional setting. The characteristics best describes the lower shoreface.

Bioturbated Fine to Medium Grained Sandstone Facies (BFMS)

This lithofacies consists of grains which are predominantly fine with grains of the medium-size occurring in a lesserproportion (Plate 4). A predominance of rounded grains over angular ones is observed. The most noticeable feature of the lithofacies is the intense bioturbation (*Ophiomorpha* and *Skolithos*).

Plate 4: BioturbatedFine to Medium Grained sandstone.

Interpretation

The *Ophiomorpha* and *Skolithos* relics are typical of near shore environments. Below wave base. The dominance of larger burrows may also characterize the influence of tidal estuarine environment. The sorting of the sandstone is probably by tides or wave action.

Mudstone Facies (MF)

This lithofacies series reveal intervals of black to greycoloure mudstone (Plate 5). Both massive and parallel-laminated regions occur. Bioturbationis scarce but where noticeable, there are *Planolites* and *Ophiomorpha* existent. It shows virtually astructureless structure as a result of the intensity of bioturbation.

Plate 5: Mudstone Facies.

Interpretation
Mudstones are typically deposits of low energy regimes and where it occur occasional with silts; itsuggests a minimal increase in energy level. In the study area, the appearance of occasional thin parallel laminae are indicative of fluctuating turbidity currents and because the bioturbations of *Paleophycus*are partly noticeable; it suggests that sedimentation had occurred before bioturbation, hence a preservation of the laminae.
According to Walker and Plint (1992) and Reineck and Singh (1980) mudstones typically represent lower shoreface to offshore depositional environments.

Coarse to pebbly Grained Sandstone facies (CPS)
The grains consist of coarse to pebbly grained sediments that reveal poor sorting and angular to subrounded grains (Plate 6). Sparse opportunistic *Ophiomorphanodosa* burrows which are shown as inclined ovals are present. There is an obvious unidirectional current pattern observed from the pebbles.

Plate 6: Coarse to Pebbly Grained Sandstone

Interpretation
The coarse to pebbly grained sandstone could be interpreted as tidal deposits, deposited during high energy currents. The fining upward sequence of the grains is also suggestive of relative decrease in energy level and is indicative of fluvial processes. Angular to subrounded grain shapes are indicative of texturalsubmaturity.
The unidirectional current pattern observed from the pebbles would also allow for fluvial factors to be operational (Ojo and Akande, 2003; Rust and Jones, 1987.)

Bioturbated Medium to Coarse grained Sandstone (BMCS)
The grain sizes range from medium to coarse grained sandstone sediments and are light to darkish brown in colour (Plate 7). The sorting is moderate to well sorted with grains that range from angular to rounded morphology. There is a high degree of bioturbation wherein the burrows are expressed as both vertical and horizontal mottling of (*Ophiomorpha* and *Skolithos*). Thin mud flasers occur sparsely.

Plate 7: Bioturbated Fine to Medium Grained‘

Interpretation
The *Ophiomorphanodosa* and *Planolites* with fragments of shells and skeletons part support regions with highanaerobic conditions. Thecoarseness suggests a lag deposit, deposited by strong ephemeral current asin storms and major flood (Dalrymple,2001). The near to absence of internal bedding structures indicate rapid rate of sedimentation.

SandyHeterolithsic Sandstone Facies

This consists of interbedded layers of alternating sand and mud intervals with a predominance of sand intervals (Plate 8). The grains are well sorted andfine grained. There existsthe presence of crossbeds, planar-laminated beds, herringbones, flasers, all in no small measure. There is a pervasive cementation. Bioturbation intensity is moderate to sparse with restricted burrows of *Planolites*and *Skolithos*. Wave and current ripple-marks arealso mildly evident.

Plate 8: Sandy Heterolithic SandstoneFacies (SH)

Interpretation

The alternations of fine grained sand to silty-sand and mud isreflective of rising and ebbing sedimentationand suspension depositional processes. Tidal actions also come into consideration dueto thecrossbeds and flaser deposits. The sparseness of bioturbation activities indicate stressed environments. The faciescould be interpreted to be a lower shoreface environment with a dominant sedimentation process from bedload transport.

Muddy Heterolith Sandstone Facies

The sediments of this lithofacies consist of very fine to fine grained deposits of sparse sand, silty-clay and dominating intervals of mud (Plate 9). The sediments are poorly sorted. Traces of wave beddings are observed although hugely obliterated by bioturbation activities (assemblages of *Paleophycus*, *Ophiomorpha* and *Skolithos*). Sideritenodules also abound.

Plate 9: Muddy Heterolith Sandstone Facies (MSH).

Interpretation

The availability of heterolithic sand and mud suggests that the sediments were deposited through suspension and bedload means, although the suspension load might have lingered longer owing to the preponderance of mud. The presence of siderites suggests shallow marine conditions while the trace fossils of *Paleophycus, Ophiomorpha* and *Skolithos* are indicative of low energy lower shorefaceenvironment.

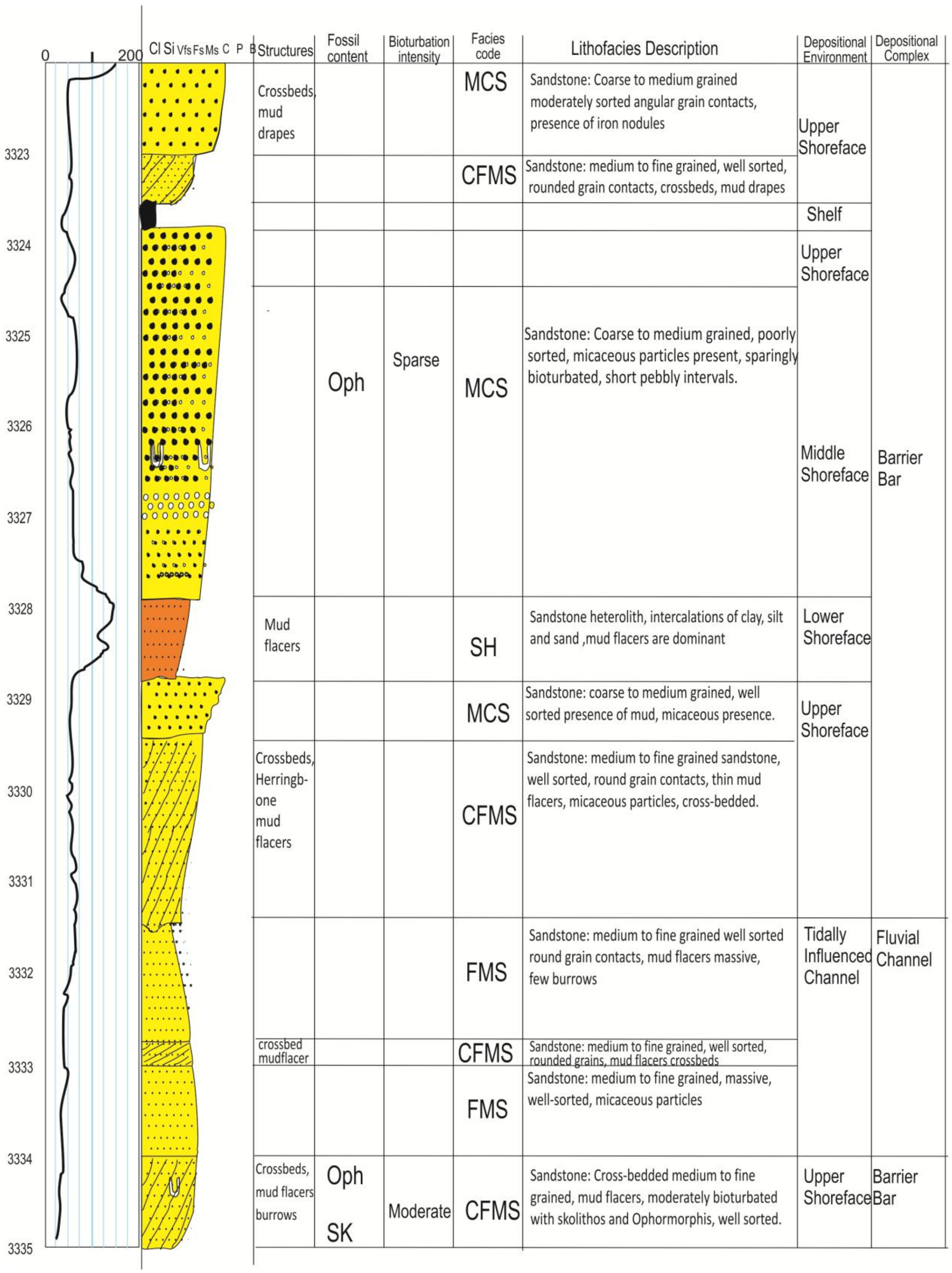

Figure 2: Depositional Sequence for Reservoir "Waz field" (3322-3335m) showing the various depositional environments**.**

Facies Association and Interpretation

Facies association according to Reading, (1979) is defined as groups of facies that occur together and are considered to be genetically or environmentally related. Faciesassociation reflects the combination of processes which occur in the depositional environment. These processes include a range of energy level within an environment of deposition.The lithofacies units described above (Plate 1-9) were grouped into facies associations which have genetic and environmental significance and can be identified as separate units in cores and on wireline logs (Figure 2). These associations of facies form the primary basis of inferring the depositional setting under which the sediments were deposited and preserved. Two facies association were identified in the Waz Field.

Facies Association 1: Barrier Bars

The lithofacies associations 1consists from base to top of mudstone lithofacies (M), cross bedded fine to medium grain sandstone facies (CBFMS), and then medium to coarse sandstone (MCS).They are interpreted as that of shelfmud, middle shoreface and upper shoreface respectively. The stacking pattern displays a vertical coarsening upward sequence and a gradual transition from one lithofacies to another in a progradingshoreface. Figure 3; shows the vertical facies model for barrier bar profile in the study well. This lithofacies association occurs three (3) times in the studied well with different combinations of lithofacies at various interval of the cored section.

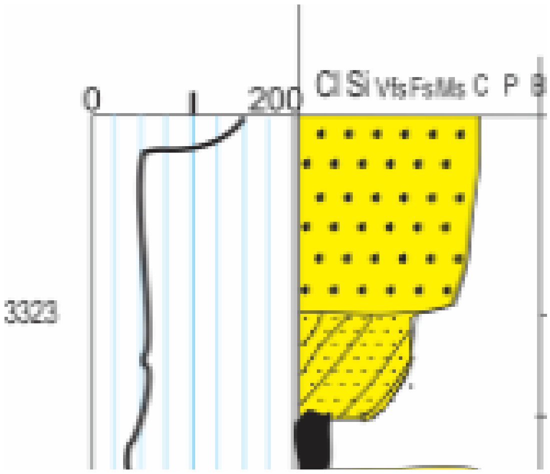

Figure 3: Shoreface Model in the Study Area

Facies Association 2 (Fluvial Channels-Point Bar)

This facies association is characterized by a fining upward sequence, consisting of fining upward coarse to medium sandstone (CMS), followed by cross bedded fine to medium sandstone that are poorly sorted and is capped by fine to medium sandstone (FMS) 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.

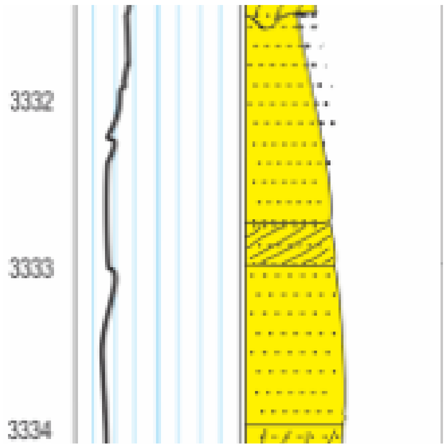

Figure 4: Fluvial Channels-Point Bar Model in the Study Area

IV. CONCLUSION

The lithofaciesidentification, Facie association and depositional environments were reconstructed for thestudy area.The result shows nine lithofacies types and two faciesassociations were also identified: whichconstituted the key for depositional environment identification. The Shorefacemodel in the study area was characterized by shelfmud, middle and upper shorefacesubfacies. The Fluvial Channel – Point Bar models in well pronounced in the study area.

Ichnofossilspresent in the study area were predominantly*Ophiomorpha, Skolithos, andPlanolites*. TheseIchnofossilsassemblages were interpreted to be of shallow marine depositional settings.

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