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SEISMIC FACIES AND DEPOSITIONAL ENVIRONMENT OF CLASTIC DEPOSIT OFFSHORE NIGER DELTA

Abraham Opatola
Department of Geology
University of Port Harcourt, Port Harcourt, Nigeria
E-mail: a.opatola@yahoo.com

ABSTRACT

The integration of three-dimensional seismic reflection data with well and paleobathymetry data in the eastern offshore Niger Delta reveal four seismic facies packages in the area study. The environments of deposition of the area consist of the shelf, slope and deepwater settings characterized by deposition within the inner neritic, middle neritic, outer neritic and upper bathyal paleowater depth. The interpreted environment are dominated by the submarine canyons and channel-levee systems which consist predominantly of turbidite, distributary channel complexes, hemipelagic and debris flow deposits which appears on seismic section as layered and chaotic facies. The depositional model of the area generated by integration of seismic, paleobathmetry, paleogeographic and well data shows that the deposition transect down the axis of fluvial depositional systems transporting sediment through submarine canyons into the base of slope and basin plain as fans. The complex fault pattern as well as the discontinous nature of sand bodies favours the formation of combined structural and stratigraphic traps in the area.

INTRODUCTION

The stratigraphic and sedimentologic framework of the onshore Niger delta is well defined because of the data available from many oil and gas exploration tests. However, the offshore portion (shelf edge and slope) and at greater water depth, wells data are sparse, and the geologic framework is not well known. The deep water part of the eastern offshore Niger delta has been surveyed by the petroleum industry and as a part of regional study of the Pleistocene series; we utilized these data to interprete Pleistocene sedimentology. Seismic facies - zones of different seismic character - were delineated on seismic profiles and interpreted geologically on the basis of facies geometry, waveform pattern, and borehole data.The area of study lies in the offshore portion of the eastern Niger delta (Figure 1). The purpose of this work is to interprete the depositional environment from seismic reflection configuration pattern and establishes an analog model for the understanding of the depositional environment, reservoir distribution and trapping mechanism in the offshore eastern Niger Delta.

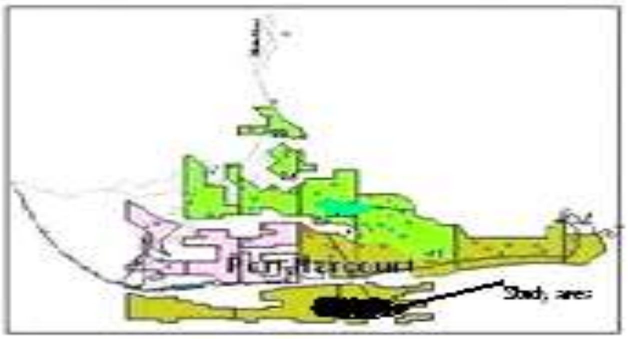


Figure 1: Location map of the study area.

REGIONAL GEOLOGY OF THE NIGER DELTA

The Niger Delta complex is one of the most prolific hydrocarbon provinces in the world. It is situated in the Gulf of Guinea (Figure 2) and extends throughout the Niger Delta Province (Klett *et al,* 1997). The Delta is an arcuate, wave- and tide- influenced progradational deltaic system which started from the Eocene to present. From the Eocene to the present, the delta has prograded southwestward, forming depobelts that represent the most active portion of the delta at each stage of its development (Doust and Omatsola, 1990). The Niger Delta is constructive in its centre and destructive on either flank. The modern delta covers 75,000 km^2 and extends over 300 km from apex to the mouth. Deposits of the Niger Delta system are a progradational clastic wedge that reaches a maximum thickness of about 12 km. Current production is put at over 2.0 million barrels of oil and 165,000 barrels of condensate per day. Estimated recoverable reserves are about 43.5 billion barrels of oil and 1240 trillion cubic feet (tcf) of gas. The Niger Delta clastic wedge formed along a failed arm of a triple junction system (aulacogen) that originally developed during break up of the South American and African plates in the late Jurassic (Burke et al., 1972; Whiteman, 1982). The Benue-Abakaliki trough represents a failed arm of a rift triple junction with the rift basin trending in the NE-SW direction into the Gulf of Guinea. The Niger Delta complex is cut by numerous approximately East-West trending synsedimentary faults and folds. It is deformed by well-developed growth faults and large mud diapirs.

The growth faults are closely associated to development of the diapers which is as a result of shale mobility induced by internal deformation and occurred in response to two processes (Kulke, 1995). First was the overburden on the poorly compacted, over-pressured, prodelta and delta-slope clays and secondly because of the slope instability. Some of the growth faults can be traced for tens of kilometers laterally and trend almost parallel to the positions of early delta fronts. This indicates an intimate relationship between the sedimentation and syn-depositional deformation. The structure and stratigraphy of the delta are primarily controlled by the interplay between rates of sediment supply and local accommodation patterns that are strongly influenced by the growth faults. Most of the faults are listric normal faults, although other types include; crestal faults, flank faults, counter-regional faults and antithetic faults (Figure 3). There are three diachronous formations that constitute the predominantly regressive Cenozoic subsurface of the Niger Delta. These formations have been reported by several workers including Short and Stauble, 1965; Weber and Daukoru, 1975; Knox and

Omatsola, 1989; Tuttle et al., 1999). The formations are the Akata (marine shales), Agbada (paralic sands and silts) and Benin (non marine sands) formations (Figure 4). These formations were deposited in marine, transitional and continental environments respectively. Together they decrease in age basinward forming a thick, overall progradational passive margin wedge with about 12km of thick sedimentary section in the central part of the delta overlying the igneous and metamorphic basement rocks of the Precambrian age. Almost all the petroleum in the Niger Delta is found in paralic sands of the Agbada Formation. Several directional trends form an "oil-rich belt" having the largest field and lowest gas:oil ratio (Ejedawe, 1981; Doust and Omatsola, 1990). This belt extends offshore from northwest to southeast and roughly corresponds to the transition between continental and oceanic crust. The hydrocarbons are trapped in rollover anticlines or against growth faults, especially along footwall (Figure 4). Minor stratigraphic traps also occur in some fields due to lateral facies changes or in association with clay- filled channels (Orife and Avbovbo, 1981).). The Niger Delta is comprised of five offlapping siliciclastic sedimentation cycles. These cycles or depobelts as they are more typically called, grade 250 kilometers southwestward over oceanic crust that underlies the Gulf of Guinea (Stacher, 1995). The depobelts are defined by synsedimentary fault trends that formed in response to different rates of subsidence and sediment supply (Doust and Omatsola, 1990). The source rock for the hydrocarbon in the Niger Delta has been a source of controversy among various authors. While some favour the belief that the source rocks for petroleum is the shales of the Agbada Formation which contain organic carbon contents (Short and Stauble, 1965). Others believe the main source of petroleum to be the marine Akata Formation (Weber and Daukoru 1975; Ekweozor and Daukoru, 1984). Basically the reservoir rock in the Niger Delta is the Agbada Formation sandstones and unconsolidated sands. They range from Eocene to Recent in age. The main features of the reservoirs of the Agbada Formation is controlled by the depositional environment in which they are found and their depth of burial. Edwards and Santogrossi (1990) describe the primary Niger Delta reservoirs as Miocene paralic sandstones with 40% porosity, 2 Darcy's permeability, and a thickness of 100 meters. Reservoir units vary in grain

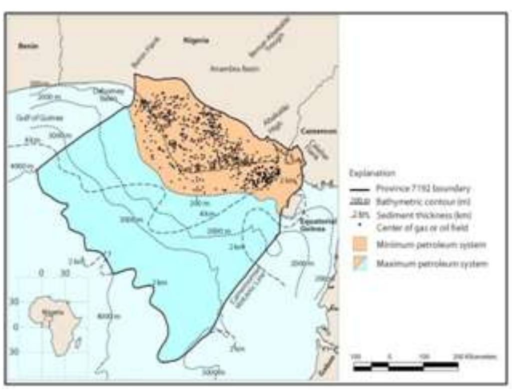


Fig 2: Map of Niger Delta showing Province outline (maximum petroleum system); and key structural features. Minimum petroleum system as defined by oil and gas field center points; 200, 2,000, 3,000, and 4,000m bathymetric contours shown by dotted contours; and 2 and 4 km sediment isopach shown by dashed lines (From Tuttle et al., 1999).

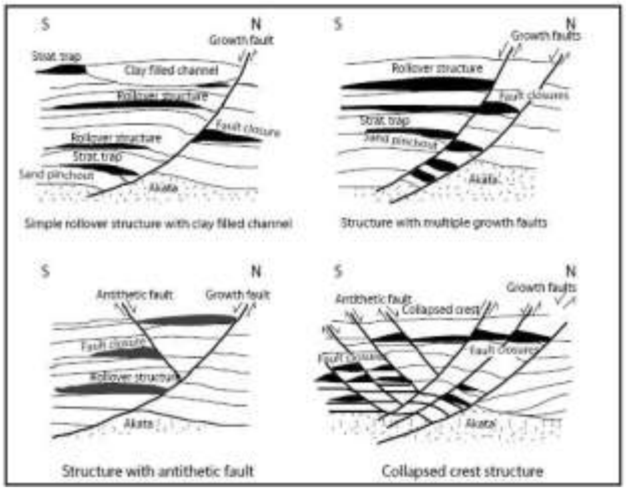


Fig 3: Examples of Niger Delta oil field structures and associated trap types. Modified from Doust and Omatsola (1990) and Stacher (1995).

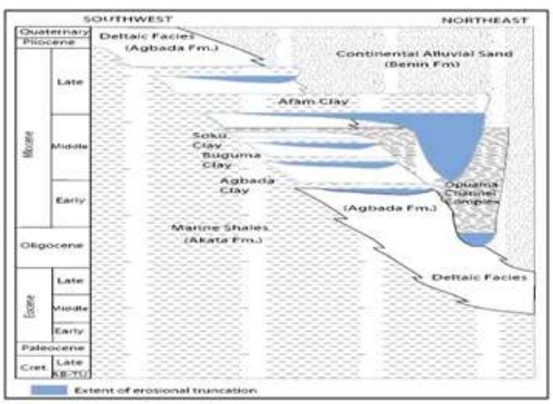


Figure 4: Stratigraphic column showing the three formations of the Niger Delta (Tuttle et al.1999). Modified from Doust and Omatsola (1990)

size; fluvial sandstones tend to be coarser than the delta front sandstones. Point bar deposits fine upward; barrier bar sandstones tend to have the best grain sorting. Kulke (1995) reported that most sandstones are unconsolidated with only minor argillaceous and siliceous cement. Potential reservoirs in the outer portion of the delta complex include deep channel sands, lowstand sand bodies and proximal turbidite sandstones (Beka and Oti, 1995). The main trapping patterns in the Niger Delta are structural which were formed during synsedimentary deformation of the Agbada Formation. Different structural elements such as those associated with simple rollover structures, clay filled channels, structures with multiple growth faults, structures with antithetic faults, and collapsed crest structures. (Doust and Omatsola, 1990). However, Beka and Oti, 1995 showed that stratigraphic traps are most likely in the flanks on the Delta. The primary seal rock in the Niger Delta is the interbedded shale within the Agbada Formation. They provide seals for the reservoir rocks in three (3) ways namely as clay smears along faults, as interbedded sealing units against which reservoir sands are juxtaposed due to faulting, and as vertical seals produced by laterally continuous shale-rich strata (Doust and Omatsola, 1990).

INTERPRETATION METHODS AND CONTROL

The methods of study involved identification and mapping of Late Miocene-Pleistocene stratigraphic unit in the offshore Niger delta, sedimentologic interpretation of these intervals and interpretation of Pleistocene geologic history. Log and Paleontologic data from offshore Niger delta provided geologic control for identifying pleistocene datum. Methods of unit correlation and interpretation using seismic profiles as discussed by Vail et al., 1977, Armentrout (1990); Heinon and Davies (2006) are followed. Seismic sequences are defined by widespread correlatable reflections (maximum flooding surface) or reflection termination groups, instead of unconformities because of the structural complexity of the Eastern offshore Niger Delta and the scarcity of widespread unconformities. By assuming that seismic reflections are isochronous surfaces or unconformities, it is possible to establish the relative order or sequence of stratigraphic units (Brown and Fisher, 1977). The chronologic sequence of depositional and structural events can thus be accurately determined. Reflection on seismic profiles were followed until they were truncated by a fault or a diapir correlations across the disrupting feature were made by comparing profile segments on each side of a diapir or a fault, and then by aligning reflections. Seismic facies were delineated by mapping units defined reflection continuity, reflection amplitude, geometric relations between reflectors and general reflection form (flat, folded, faulted) Stuart and Caughey, (1977).
The seismic data used in this study was part of a merged 3-D seismic volume acquired by Elf Producing Nigeria Limited in the eastern part of offshore Niger delta recoded to 4,500 milliseconds, Ten wireline logs including gamma ray, resisitivity, neutron, density and sonic logs with biofacies and paleobathymetric data for two wells were made available.

DISTRIBUTION OF ENVIRONMENT

Pliocene seismic facies in eastern offshore Niger Delta are characterized by layered strong reflector units, weak intervals, and irregular chaotic intervals. The whole seismic section was divided into four seismic facies packages. They included facies units D,A,M,Y. Units D, A and M were identified on layered seismic facies, while unit Y occurred on chaotic seismic facies.

Facies Unit D

Between 306/4036 and 1250/4144 shot points, in 0- 1500 time window, unit D displayed parallel to sub parallel reflection configuration. A hummocky (wavy) reflection pattern was also observed between 906/4102 and 2042/4393 shot points. Reflection continuity was generally continuous. Reflector strength (amplitude) was moderate basinward of the section and high landward of the section. Frequency was uniform and relatively high throughout the seismic facies package. The facies display sheet-like blanket-geometry which was slightly divergent to the south. It forms a concordant relation at the top of the facies package and downlap at the base. The seismic facies analysis in combination with paleobathymetry data revealed hemipelagic deposits, channel deposits, turbidite fans, distributing channels and levee complexes as the depositional facies which occur within delta-marine to basin plain environmental setting.

Facies Unit A
This unit terminates against a fault F2 mapped at 1706/4283 shot points, and extends north of the section within 600 to 1000ms time window. It is characterized by low-to-high amplitude, continuous reflection, moderate frequency, subparallel configuration. Unlike unit D, this facies package is characterized by prograding clinoform which is concordant at the top but downlaps at the base. The facies is interpreted to be associated with hemipelagic deposits, channel fill, turbidite and slope fan, within the prograding shelf and slope environmental setting.

Facies Unit M
Between 306/4063 and 1906/4324 shot points. The seismic facies was characterized by parallel to subparallel, hummocky and moderately chaotic internal configuration. From a fault, F_6 mapped at 1606/4242; the facies display parallel to subparallel reflection configuration. Generally, it is characterized by moderately continuous reflection continuity, high amplitude, and relatively uniform frequency of moderate scale.
Unlike D and A unit, M is associated with discordant relation at the bottom and down lap at the top. The characteristic depositional facies are interpreted as hemipelagic deposit, channel deposit, slump, mass transport deposit, and failed sediment masses. The associated environments of deposition are interpreted as submarine canyon, lower slope and deep-water setting.

Facies Unit Y
This unit extends downward from 1800ms at the 306/4063 shot point. It is characterized by an acoustically transparent and chaotic reflection configuration. The frequency of reflections is low and reflection continuity is highly discontinuous. The amplitude is variable from low-to-high. It is characterized by mounded geometry with a discordant top geometry. Interpreted facies include debris flow deposits, slumps, mass transport complexes and failed sediment masses which were probably deposited in submarine canyon, lower slope and deep water setting. Chaotic reflection patterns with low amplitude are interpreted as failed sediment masses (diapiric shale). Chaotic reflection packages with high amplitude represent mass transport complexes such as conglomeratic turbidite.

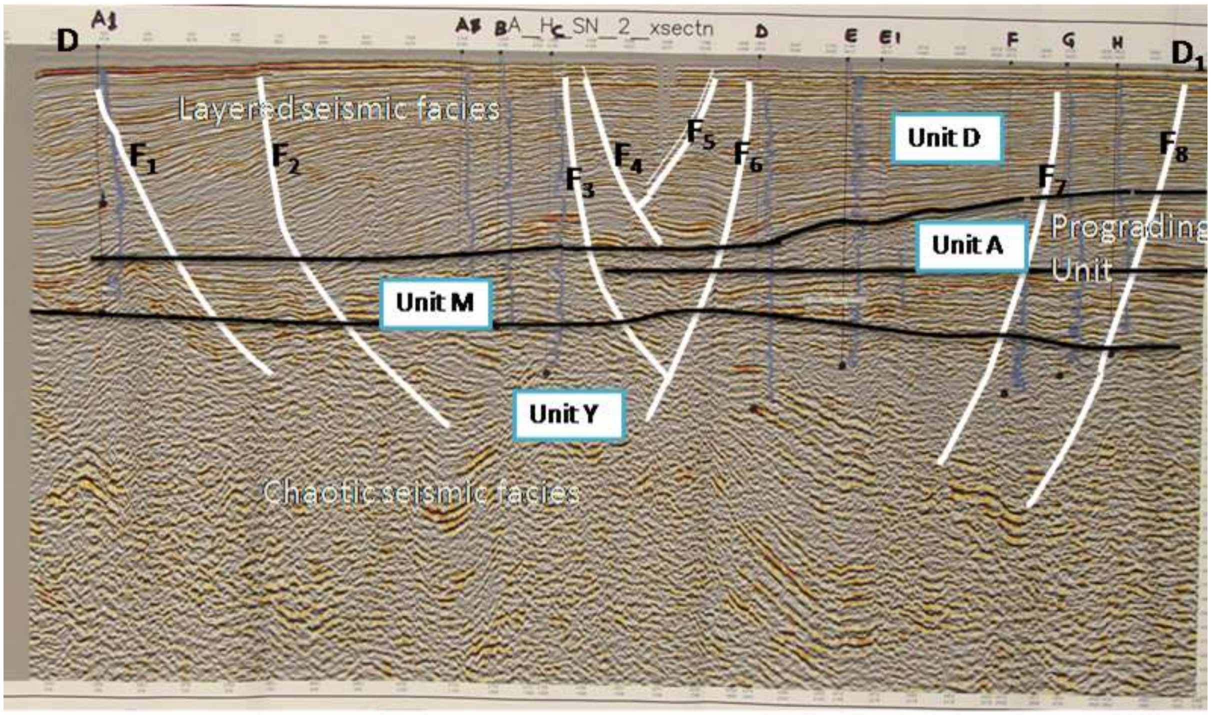


Figure 5: Seismic Line DD1 showing faults pattern and seismic facies packages.

Table 1: Seismic Characteristics and Depositional Facies Interpretation for Line DD[1]

Seismic Facies	Reflection Configuration	Reflection Geometry	Reflection Continuity	Amplitude	Frequency	Depositional Facies	Depositional Environment
Unit D	Hummocky Perallel and Sub-parellel	Sheet like-blanket, Slightly divergent gerometry Concordant at the Top, onlap at the base.	General continuous	Moderate to High	Relatively Uniform and high	Hemipelagic deposit (condensed section), channel and overbank deposit, turbidite fans, distributary's channel and levee complexes.	Shelf, delta front, basinal plain
Unit A	Sub-parallel, Transparent and Hummocky	Prograding sigmoid clinoform. Concordant at the Top, downlap the base.	Relatively continuous	Generally low to high	Relatively uniform and moderate	Hemipelagic deposit (condensed section), channel fill. Turbidite and slope fan.	Prograding shelf and slope
Unit M	Parallel to subparallel, hummocky and chaotic.	Variable lens-shaped to mound. Downlap at the Top, discordant at the bottom.	Generally, moderately continuous	Generally low to high	Relatively uniform and moderate	Hemipelagic deposit, channel deposits and mass transport complexes.	Submarine canyon, lower slope and deep-water
Unit Y	Transparent-reflection and chaotic	Mounded and discordant at the top.	Highly discontinuous	Variable, low-to-high, with frequent display of high amplitude	Generally low	Debris flow deposit, slump,mass transport and failed sediment masses.	Submarine canyon, lower slope and deep-water

The seismic facies represent sediments that were deposited at different paleowater depth in response to different period of sea level changes. The layered seismic facies (Parallel, subparallel, divergent and chinoform) reflect the distribution of environment within the shelf, slope and basinal settings which characterized the Benin formation, Agbada formation and top of Akata formation. The seismic fiacies become chaotic in the deeper section which are the characteristics of Akata formation and represent the basinal areas which are dominated by shale diapirism, hemipelagic sedimentation and gravity flow deposit. The depositional model of the area (Figure 7) which was generated by integration of seismic paleobathymetry, paleogeographic and well data shows that the deposition systems transporting sediment through submarine canyons into the base of slope and basin plain as fans. The environment of deposition ranges from the shelf, prograding shelf/slope and submarine canyon lower

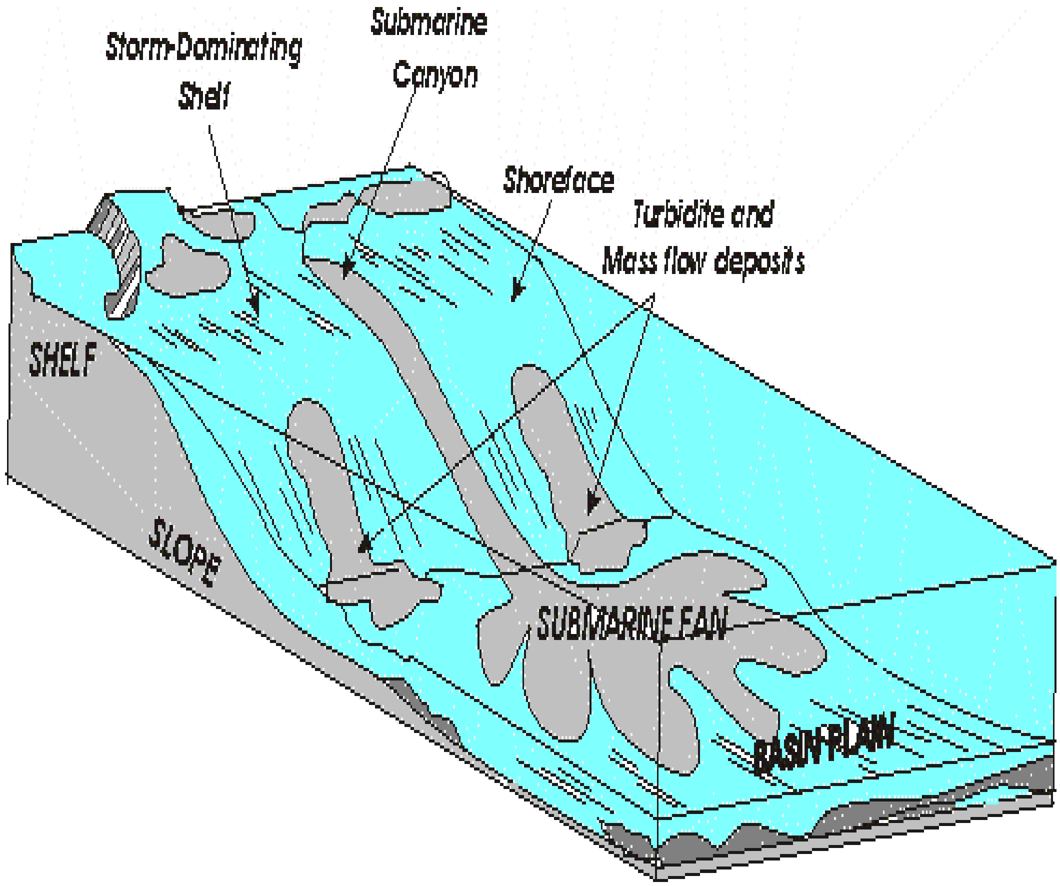
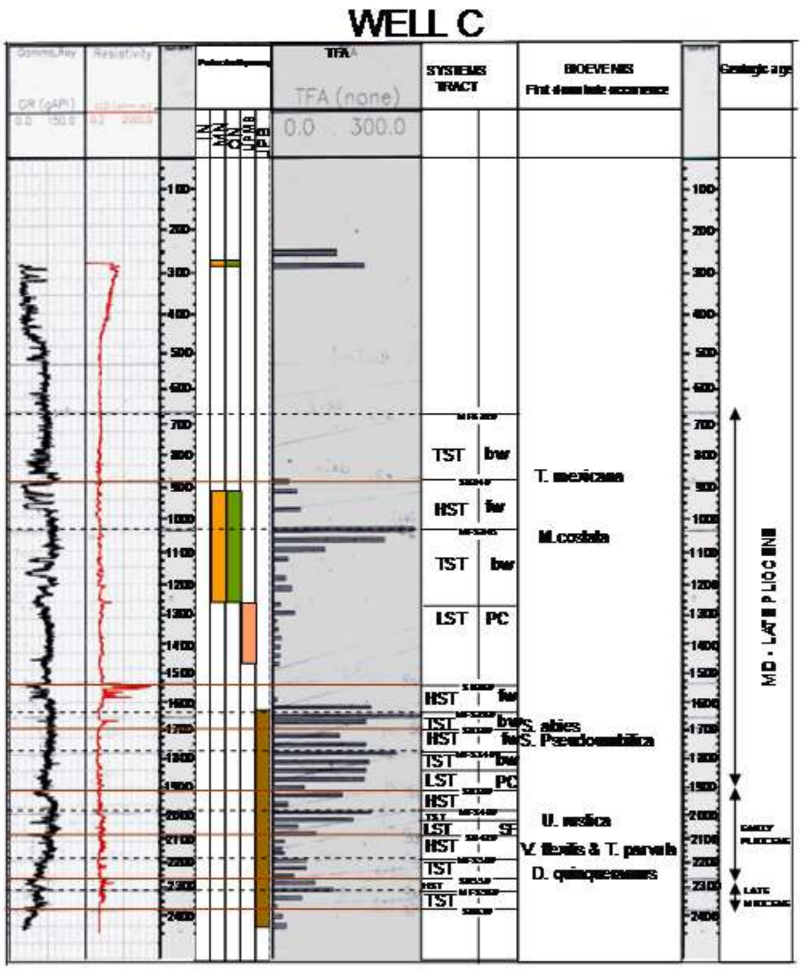


Figure 6: Conceptual depositional model of clastic deposits in the eastern offshore , Niger delta.



SB - Sequence Boundary
MFS - Maximum Flooding Surface
HST – Highstand Systems Tract
TST – Transgressive Systems Tract
LST – Lowstand Systems Tract
PC – Prograding Complex
SF- Slope Fan
TFA – Total Faunal Abundance

IN - INNER NERITIC
MN – Middle Neritic
ON – Outer Neritic
UPMB- Uppermost Bathyal
UPB – Upper Bathyal
fw – forestepping wedge
bw – backstepping wedge

Figure7: Sequence stratigraphic framework of well C

WELL F

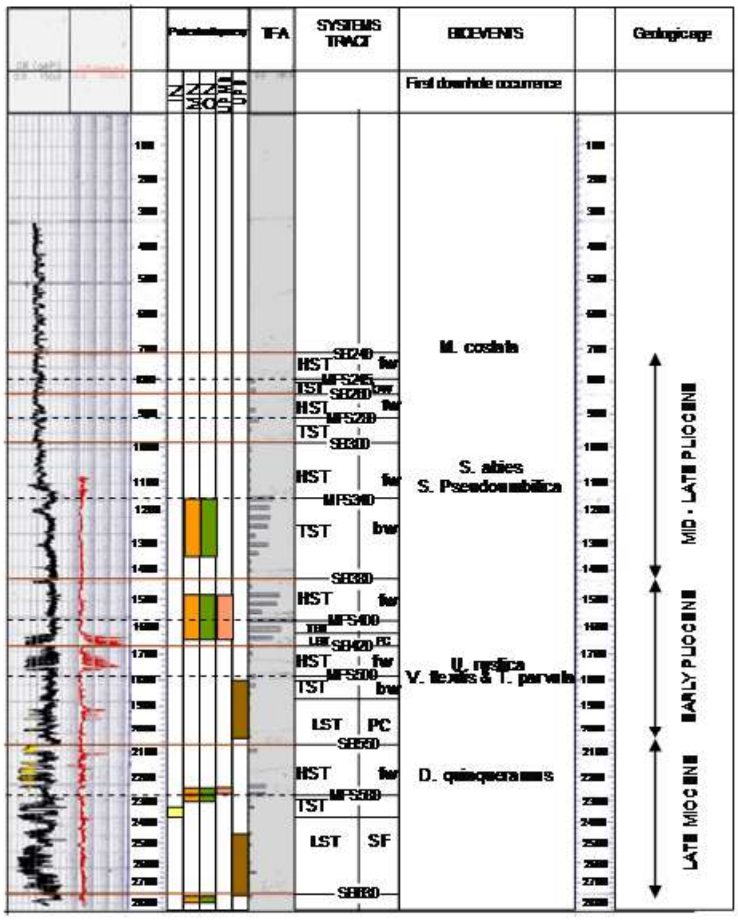


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Figure 8: Sequence stratigraphic framework of well F

Table 2: Gamma Ray Facies Association, Sequence Stratigraphic Framework, Seismic Facies and depositional Systems

Well-log Signature	Gamma-ray facies and Depositional Systems	Seismic Facies packages	Seismic Facies and depositional systems	Sequence-stratigraphic Framework
Blocky and (Bell shape) fining upward	Tidal channel, transgressive shelf, Slope channel & Mid-fan channel Environment	Layered seismic facies with clinoform, par allel to subparallel reflection	Levee channel & distributaries channel deposit Hemipelagic drape	Transgressio n
Funnel shape	Crevasse splay, Prograding delta Front, shoreface and suprafan deposit	Layered seismic facies with parallel to subparallel reflection	Distributaries channel deposit & Hemipelagic deposit	Progradation/ Transgressio n
Blocky (cylind rical and coarsening upward)	Distributaries channel, fluvial Channel & submarine canyon	Broken chaotic, hummocky, transparent seismic reflection	Conglomeratic turbidite, slope and hemipelagic deposit	Progradation
Erratic/Irregu lar	Hemipelagic deposit	Layered seismic facies with parallel to subparallel reflection	Condensed section	Transgression

CONCLUSION

The study reveals different styles of depositional pattern in the offshore eastern Niger Delta which is as a result of variation in channel behavior along the shelf, slope and submarine channel systems. The environments of deposition in offshore eastern Niger Delta consist of the shelf, slope and deep- water basin settings characterized by deposition within the inner neritic to bathyal paleowater depth which were dominated by levee channels, and fan complexes. Clastic deposits of the offshore eastern Niger delta occurred on seismic as layered and chaotic seismic configuration packages, the area lies within the extensional and diapiric zone. The complex fault pattern as well as the discontinous nature of sand bodies favours the formation of combined structural and stratigraphic traps in the area.

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REFERENCES

Armentrout, J. M., Echols, R. J., and T.D Lee. 1990. Pattern of Foraminiferal abundance and diversity: implications for sequence stratigraphic analysis. In: sequence stratigraphy as an exploration tool: concepts and practices in the Gulf coast. Gulf Coast section SEPM Foundation Eleventh Annual Research Conference program and Abstracts, p53-58.

Beka, F. T., and M. N. Oti. 1995. The distal offshore Niger delta: prospects of a mature petroleum province, in Oti, M. N., and postma. G., eds, Geology of Delta; Rotterdam. A. A. Bulkema. P. 237-241.

Brown, L. F., and W.L. Fisher 1977. Seismic – stratigraphic interpretation of depositional systems: examples form Brazil rift and pull – apart basins. In payton, C. E., eds, seismic stratigraphy applications to hydrocarbon exploration. American Association of Petroleum Geologists memoir 26, p213-248.

Burke, K. 1972. Longshore drift, submarine canyons, and submarine fans in development of Niger delta AAPG, v.56, p. 1975-1983.

Ejedawe, J.E. 1981. Patterns of incidence of oil reserves in Niger Delta Basin: American association of Petroluem Geologists, vol. 65, pp 1574-1585.

Ekweozor, C.M., and E.M. Daukoru. 1994. Northern delta depobelt portion of the akata-Agbada petroleum system, Niger Delta, Nigerian, in Magoon L.B., and Dow, W.G., eds., The petroleum system from source to trap American Assiocation of petroleum Geologist Memoir 60, pp 599-614.

Doust, H., and E.M. Omatsola. 1990. Niger delta, in J. D. Edwards in A. Colella and D. B. Prior, eds., Coarse-grained deltas: International association of sedimentologists special publication, 10,pp.29-73.

Heinoi, P., and R.J. Davies. 1990. Degradation of compressive fold belts, deep water Niger Delta. AAPG Bulletin, vol.90, No. 5, pp. 753-770.

Knox, G.J., and E.M. Omatsola. 1989. Development of the Cenozoic Niger Delta in terms of the "escalator regression" model and impact on hydrocarbon distribution, in W.J.M.

Van der Linden et al., eds, 1987, proceedings, KNGMG Symposium on Coastal Lowlands, Geology and Geotechnology: Dordrecht, klumer Academic Publishers, pp. 181-202.

Kulke, H. 1995. Regional petroleum geology of the world part HL: Africa, Australia and Antarctica: Berlin, Geburder Borntraeger., pp. 143-172.

Orife, J.M., and A.A. Avbovbo. 1982. Stratigraphic and unconformity traps in the Nigeria delta: American association of petroleum Geologist Bulletin, vol.66 (2) pp.251-262.
Short, K. C., and A.J.Stauble. 1965. Outline of Niger delta: American Association of Petroleum Geologist Bulletin, vol. 51, pp. 761-779.

Stacher, P. 1995. Present understanding of the Niger Delta hydrocarbon habitat. In: Oti M.N., and postma, G., eds, Geology of Delta: Rotterdam, A.A. Balkema, pp 257-267.

Tuttle, M.L.W., R.R. Charpentier and M.E. Brownfield. 1999. The Niger Delta petroleum system: Niger Delta Province Cameroon, and Equitorial Guinea, Africa: http//greenwood.cr.usgs.gov/energy/world/of 99-5oh/chapter A. html.

Vail, P., R. Todd, and J. Sangree. 1977. Seismic Stratigraphy and Global Changes in Sea Level: part 5. Chronostratigraphic significance of seismic reflection, in C. Payton, ed, Seismic stratigraphy- application to hydrocarbon exploration: AAPG Memoir 26, pp.99-116.

Weber, K. J., and E.M. Daukoru. 1975. Petroleum geology of the Niger Delta: 9th world petroleum congress proceedinfs, v.2, pp.209-221.

Whiteman, A. 1982. Nigeria: Its Petroleum Geology, Resources and Potential. Vol. 1and 2 London graham and Trotman Ltd., 176p