

Review

Sequence stratigraphic approach to hydrocarbon exploration in Bobsaa field, onshore Niger Delta

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This study combined seismic, well logs (from BK-1 and BK-2 wells), paleobathymetric and biostratigraphic tools in the evaluation of Bobsaa field in the shelf setting of the Niger Delta, Nigeria. This was done to determine the lithostratigraphy, chronostratigraphy, possible reservoir sands, age and depositional environment of the study area for opportunities that will support exploration program. Different Formations, lithologies, lithofacies, sediment types, depositional sequences and their environments of deposition were identified from log signatures of the two wells. High resolution biostratigraphic data consisting of microfauna abundance and diversity chart aided in the delineation of the Maximum Flooding surfaces (MFSs), paleobathymetric interpretation and in age determination. The locally recognized cycles were correlated with the globally recognized eustatic cycle chart. Depositional sequences, system tracts, system boundaries and candidate MFSs were identified based on their diagnostic characteristic log patterns in the studied wells and age-dated with marker species. Sequence Boundaries (SBs) were recognized from logs, age-dated where possible, and constrained by age control sensu. Interpretation showed that the lithology is dominated by alternating sand and shale, occurring approximately in a ratio 70:30 within the logged intervals. From the log successions, prograding delta deposits and channel deposits were interpreted. Four MFSs and four SBs were recognized from BK-1 well while two MFSs and three SBs were recognized from BK-2 well. All the MFSs and SBs fall between Late Miocene to Middle Miocene interval. Biostratigraphic analysis showed four foraminifera Zones: *Globorotalia merotumida/plesiotumida/Ammobaculites agglutinans* Zone; *Globorotalia acostaensis/Uvigerina subperegrina* Zone; *Globorotalia mayeri/Spirosigmoina oligocaenica* Zone and *Globigerinoides subquadratus/Uvigerina sparsicostata* Zone. The results suggest sediment deposition within the Coastal Deltaic and Shallow marine environments for the two wells. The integrated interpretation of different datasets in the study area has enabled the sub-division of the stratigraphic column of the wells into sequences, systems tracts and sedimentary cycles. These sequences may have potential to serve as excellent source rock and seals while the systems tracts may depict excellent seals and stratigraphic traps.

Keywords: Sequence stratigraphy, biostratigraphy, Lithofacies, depositional sequences.

INTRODUCTION

The search for hydrocarbon is becoming increasingly more difficult and expensive. Because most of the identified structural closures on the shelf and upper slope have been drilled, the search for hydrocarbons requires more creativity in optimizing and integrating existing data. Sequence stratigraphic analysis and carefully calibrated seismic facies mapping are valuable guides to estimating

the risk of drilling these plays. This we believe will give companies a competitive advantage and substantially reduce their risk in bidding on offshore blocks by allowing them to properly evaluate new and previously-leased blocks (Vail and Wornardt, 1990).

Sequence stratigraphy provides a logical and useful aid in exploration ranging from frontier areas with limited well control to exploration in mature areas with many wells, and production application (Sangree, Vail and Mitchum, 1990).

Frontier area exploration uses include identification of

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lithologies of the Akata formation (Paleocene to Recent) are dark gray shales and silts, with rare streaks of sand of probable turbidite flow origin (Doust and Omatsola, 1989). Marine planktonic foraminifera in this Formation make up to 50% of the microfauna assemblage and suggest shallow marine shelf deposition (Doust and Omatsola, 1989). The lithologies of Agbada Formation consist of alternating sands, silts and shales arranged within ten to hundred feet successions defined by progressive upward changes in grain size and bed thickness. The strata are generally interpreted to have formed in fluvial-deltaic environments. The formation ranges in age from Eocene to Pleistocene. The top of the formation is the recent subaerially-exposed delta top surface and its base extends to a depth of 4600 feet. The base is defined by the youngest marine shale. Shallow parts of the formation are composed entirely of non-marine sand deposited in alluvial or upper coastal plain environments during progradation of the delta (Doust and Omatsola, 1989). Although lack of preserved fauna inhibits accurate age dating, the age of the formation is estimated to range from Oligocene to Recent (Short and Stauble, 1967). The formation thins basinward and ends near the shelf edge.

Source rocks in the Niger Delta might include marine interbedded shale in the Agbada Formation, marine Akata Formation shales and underlying Cretaceous shales (Evamy et al., 1978; Ekweozor et al., 1979; Ekweozor and Okoye, 1980; Bustin, 1988; Doust and Omatsola, 1990). Reservoir intervals in the Agbada Formation have been interpreted to be deposits of highstand and transgressive systems tracts in proximal shallow ramp settings (Evamy et al., 1978). Structural traps formed during synsedimentary deformation of the Agbada Formation (Evamy et al., 1978; Stacher, 1995), and stratigraphic traps formed preferentially along the delta flanks (Beka and Oti, 1995), define the most common reservoir locations within the Niger Delta complex. The primary seal rocks are interbedded shales within the Agbada Formation.

METHODOLOGY

Well logs comprising SP, GR and resistivity logs of two wells, seismic data, check shot data, high resolution biostratigraphic data and a base map showing relative positions of the wells on the field were utilized for this study.

Well Log Description

The gamma ray log, which responds to natural radioactivity of the Formation, has a shale reference line of 75 API. The higher the API value, which range between (0-150 API), the finer the sediments. High API values represent shale and low API value represents

sands. Deflections to the right and left of the baseline were interpreted as shaly and sandy Formation respectively. The log signature also aided in determining the environment of deposition. Maximum Flooding Surfaces (MFSs) were identified as the shaliest part of the section with a high gamma ray value while the sequence boundaries are identified within the coarsening upward pattern between the Maximum flooding surfaces. The Gamma ray log provides a measure of sediment type, with curve deflection to the right indicating increase in clay content. MFS's can be interpreted from Gamma Ray log as "spikes" associated with Uranium concentrations in condensed sections.

The SP log which records the voltage produced in the formation arising from the differences in salinities between the resistivities of mud filtrate (Rmf) and the formation water (Rw). Shale base line on the SP log is defined by a straight line on the log. Permeable formation such as sandstone is characterized by deflection on the curve. If $R_w > R_{mf}$, the deflection is to the left and vice versa. Resistivity log measures the resistance of rock unit to flow of electric current. Porous and permeable sands containing hydrocarbon will give high resistivity response while brine bearing sands and shales give low resistivity response. Log shapes were interpreted to predict lithology, lithofacies, depositional environment and the depositional sequence.

Seismic Data

Sequence Boundaries (SBs), Maximum Flooding Surface (MFSs) and Systems tracts were identified on the seismic profiles. The systems tracts identified on both well logs and seismic data were subsequently tied together by the use of 2-way time check shot data (Figure 4d). Faults were also picked on the seismic sections along the Dip sections (Inline). The faults are represented on the seismic lines as discontinuous lines along a preferred orientation of reflectors. The faults were correlated by assigning names and these are transferred from Dip section to the strike sections of the seismic section.

High Resolution Biostratigraphic Data

High resolution biostratigraphic data consisting of microfaunal abundance and diversity chart aided in the delineation of the MFSs, paleobathymetric interpretation and in age determination. The locally recognized cycles were correlated with the globally recognized eustatic cycle chart (Haq et al., 1988).

Sequence Stratigraphic Analysis

Depositional sequences, system tracts, system

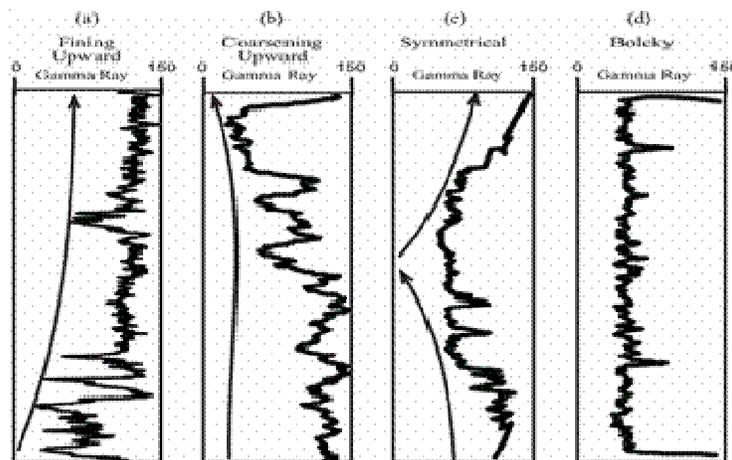


Figure 2. Representative gamma ray patterns observed in Bobsaa field (a) Fining upward (b) Coarsening upward (c) Symmetrical and (d) Blocky log patterns

Table 1. Chronostratigraphic horizons (MFS's and SB's) recognised in BK 1 well

DEPTH (FEET)	MAXIMUM FLOODING SURFACES (MA)	SEQUENCE BOUNDARIES (MA)	EPOCH
7890		7.26	
7900	7.65		LATE MIOCENE/
8935		9.22	MIDDLE MIOCENE
9104	10.5		
10255		11.8	
10492	12.28		
11260		12.72	
11405	13.1		

boundaries and candidate MFS's were identified based on their diagnostic characteristic log patterns in the studied wells and age-dated with marker species. SB's were recognized from logs, age-dated where possible, and constrained by age control sensu.

INTERPRETATION

Lithostratigraphy

Interpretation of gamma ray logs of the wells studied showed that the lithology is dominated by alternating sand and shale, occurring approximately in a 70:30 ratio within the logged intervals. Based on the varying proportion of sand and shale with few occurrences of silt, two major lithostratigraphic units were identified: the Benin and Upper Agbada Formation. Following standard interpretations of the Agbada Formation, log successions that gradually decrease in gamma-ray value and then rapidly increase (gradually coarsen and then abruptly fine) are interpreted to be prograding delta deposits. Those that abruptly decrease in gamma

ray value and have "blocky" or gradually increasing trends (abruptly coarsen and remain sandy or gradually fine) are interpreted to be channel deposits (Figure 2)

Chronostratigraphy

From the chronostratigraphic studies of the two wells, four maximum flooding surfaces and four sequence boundaries were recognized from BK-1 (Table 1) well while two maximum flooding surfaces and three sequence boundaries were recognized from BK-2 well (Table 2). From these results, all the MFS's and SB's falls between Late Miocene to Middle Miocene interval which allow the accurate correlation of the wells (Tables 3 and 4) and for the calibration of the seismic section.

Biostratigraphy

The high resolution biostratigraphic, sequence stratigraphic and paleoenvironmental analysis of the BK 1 and BK 2 well showed four (4) foraminiferal "Zones":

Table 2. Chronostratigraphic horizons (MFS's and SB's) recognized in BK 2 well

DEPTH (FEET)	MAXIMUM FLOODING SURFACES (MA)	SEQUENCE BOUNDARIES (MA)	EPOCH
8950		9.22	
9105	10.5		LATE MIOCENE/
10505		11.8	MIDDLE MIOCENE
10560	12.28		
11485		12.72	

Table 3. The Chronostratigraphic data of BK 1 well

DEPTH (Feet)	AGE
7470 – 10255	Late Miocene
10255 - 11800	Middle Miocene

Table 4. The Chronostratigraphic data of BK 2 well

DEPTH (FEET)	AGE
7460 -- 10505	Late Miocene
10505 -- 11600	Middle Miocene

Table 5. Biostratigraphic zonation within BK-1 Well

EPOCH	AGE	FORMATIONS	FORAMINIFERA BIOZONES	NANNOFOSSIL BIOZONES	TIME (Ma)		
			GRADSTEIN, 2004, BLOW, 1969, 1979, BERBBREN et al., 1995	GRADSTEIN, 2004 & MARTINI, 1971			
MIOCENE	UNDIAGNOSTIC	BENIN	INDETERMINATE	BARREN	INDETERMINATE	INDETERMINATE	
	LATE		TORTOIAN	N16 - N18	GLOBOROTALIA ACOSTAENSIS / UVIGERINA SUBPEREGRINA / GLOBOROTALIA MAYERI / SPIROSIGMOILINA OLIGOCAENICA / GLOBIGERINOIDES SUBQUADRATUS / UVIGERINA SPARSICOSTATA	NN6 - NN10 / NN8 - NN7	BASE DISCOASTER QUINQUERAMUS / HQ DISCOASTER HAMATUS / BASE CATINASTER POLIHIUS / HQ CYCLICAROLITHUS FLORIDANUS / HQ CALCIDISCUS PREMACINTYREI / HQ SPHENOLITHUS HETEREMORPHUS
	MIDDLE	AGBADA	N11 - N14				
			N10				

Globorotalia merotumida/plesiotumida/Ammobaculites agglutinans Zone; *Globorotalia acostaensis/UVigerina subperegrina* Zone; *Globorotalia mayeri/Spirosigmoilina oligocaenica* Zone and *Globigerinoides subquadratus/UVigerina sparsicostata* Zone. Nannofossil zones NN6 to NN11 were related to the N10 to N16 of Foraminiferal and Calcareous Nannofossil biostratigraphic data provides

broad constraints on the age and depositional environments of the wells.

Sequence Stratigraphic Division

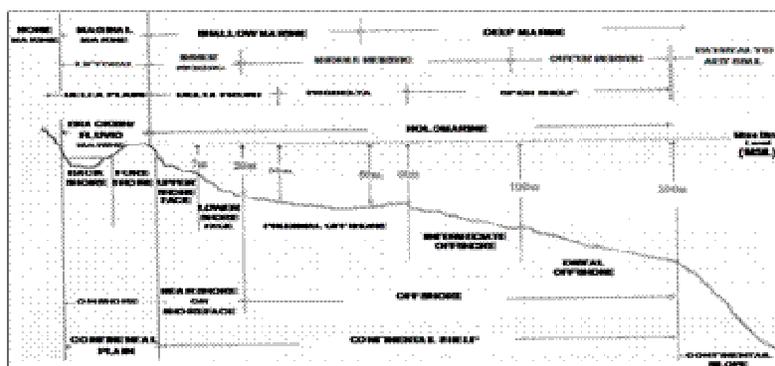
Four 3rd order sequences were defined within the Agbada Formation of Bobsaa field using the well logs,

Table 6. The sequence stratigraphic interpretation of BK 1 well using the well logs, paleobathymetry, biostratigraphic and lithologic data

DEPTH (Feet)	Sequence Stratigraphic Interpretation
4010 – 7890	PGC
7890 – 7900	HST
7900 – 8105	TST
8105 – 8935	PGC
8935 – 9104	HST
9104 – 9130	TST
9130 – 10255	PGC
10255– 10492	HST
10492– 10545	TST
10545– 10900	PGC
10900– 11300	HST
11300– 11900 TD	TST

Table 7. The Sequence Stratigraphic Interpretation of BK 2 well using the well Logs. Paleobathymetry, Biostratigraphic and Lithologic Data

Depth (Feet)	Sequence Stratigraphic Interpretation
3920 – 8950	PGC
8950 – 9105	HST
9105 – 9135	TST
9135 – 10505	PGC
10505 – 10560	HST
10560 – 10690	TST
10690 – 11485	PGC
11485 – 11600 TD	HST

**Figure 3.** Depositional Environments and Bathymetric ranges used in Paleoenvironmental interpretations. (Modified after Allen, 1965) [Not to scale]

paleobathymetry, biostratigraphic and lithologic data from well-1 (Table 6) and well-2 (Table 7)

Depositional environment

The Paleoenvironmental studies of the two wells studied for this project was based on the qualitative

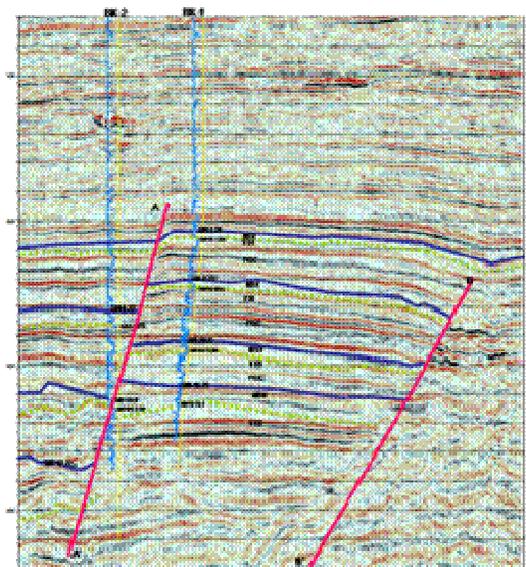
evaluation of the Paleo environmental ranges of selected environmentally significant benthic foraminifera (Adegoke et al 1976 and Murray 1991). The results suggest sediment deposition within the Coastal Deltaic and Shallow marine (Shallow Inner Neritic, Inner Neritic and Middle Neritic (Figure 3) environments for the two wells (Tables 8 and 9).

Table 8. The environment of deposition interpreted using the well log signatures of bk-1 well.

DEPTH (Feet)	DEPOSITIONAL ENVIRONMENT
4010 – 7890	Upper shore face, Massive channel sands with thin shale / mudstone breaks.
7890 – 9520	Alternating channel tidal sands and marginal marine shales/mudstone.
9520 – 10525	Marine shale/mudstone overlain by Delta front sandstones.
10525 – 11260	Inter-distributary channel tidal sands and marine shales/mudstone
11260 – 11900	Marine shales/mudstones inter bedded with regressive sandstones

Table 9.The environment of deposition interpreted using the well log signatures of bk-2 well

DEPTH (Feet)	DEPOSITIONAL ENVIRONMENT
3920 – 7930	Massive channel sands with shale/mudstones break
7930 – 9540	Alternating channel, tidal sands and marginal marine shales/mudstone
7930 – 9540	Alternating channel, tidal sands and marginal marine shales/mudstone
9540 – 10690	Marine shales/mudstone overlain by Delta front sandstones
10690 – 11600	Alternating channel, sands and marine shales/mudstones

**Figure 4.** Seismic interpretation of Bobsaa field showing the depositional sequences and systems tracts

Chronostratigraphic correlation

The chronostratigraphic significant datums defined from the results of the high resolution biostratigraphic and sequence stratigraphic analyses of the project wells include the 7.65Ma, 10.5Ma, 12.28Ma, 13.1Ma MFS's as well as the 7.26Ma, 9.22Ma, 11.8Ma, and 12.72Ma SB'S as shown in (Tables 1 and 2) These time significant surfaces were used in the regional correlation of the studied wells along this trend; BK- 1 and 2 Trend, The correlation panel is shown in Enclosure 4.

The BK 2 well correlates with the BK 1 well which is the

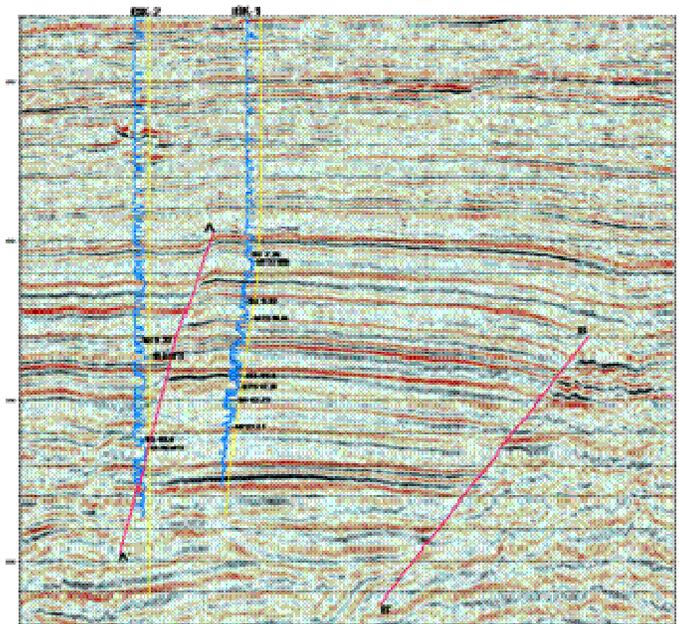
youngest at the top with top most age of 7.26Ma SB and the oldest age of 13.1Ma. The stratigraphic range of the field is between Late Miocene and Middle Miocene.

Seismic to well calibration

The high resolution chronostratigraphic framework used in the seismic interpretation is mostly MFS's and SB's all provided with the absolute ages. Nine boundaries were defined as presented in Figure 4 and in Table 8. The relationship of the wells with the structural patterns is

Table 10. Surface Boundaries (MFS'S and SB's)

MFS (Ma)	SB	No Of Wells	Seismic onset
7.65	7.26	1	Trough
	9.22	1	peak
10.5		2	trough
	11.8	2	peak
12.28		2	trough
	12.72	2	peak
13.1		2	trough
		1	peak

**Figure 5.** Seismic interpretation of Bobsaa field showing the SB's, MFS's and the faults AA' and BB'.

super-imposed on the seismic data to identify the possible MFS's and the SB's on the seismic section. BK1 well fall at the Up thrown section with respect to Fault (A) while the BK 2 well is located on the down thrown side of the same Fault A.

These wells are co relateable as a result of the relationship in the MFS's and the SB's. Some of the horizons of BK 2 well have been faulted out towards the TD of the well. One of the most interesting possibly reservoir sand identified in BK 1 well between 11153 - 11260 feet was also found in BK 2 well at 11410 – 11485 feet. This reservoir sand was dated 12.72 Ma SB (Table 10).

CONCLUSION

Interpretation of gamma ray logs of the wells studied showed that the lithology is dominated by alternating sand and shale, occurring approximately in a 70:30 ratio

within the logged intervals.

Four major 3rd order sequence boundaries and intervening maximum flooding surfaces, all between Miocene to Middle Miocene interval, were mapped. The sequences developed above a succession of basin ward-dipping normal faults, where hanging walls were displaced basin ward during deposition. Upsection the deposits broadly coarsen, but depositional environments appear to have been consistently fluvial to shallow marine (Shallow Inner Neritic, Inner Neritic and Middle Neritic).The Foraminiferal and Calcareous Nannofossil biostratigraphic data provides broad constraints on the age and depositional environments of the wells.

Possibly reservoir sand identified in BK 1 well between 11153 - 11260 feet was also found in BK 2 well at 11410 – 11485 feet was dated 12.72 Ma SB.

This study proves conclusively that with a fully integrated biostratigraphy/well log/seismic study, high resolution sequence stratigraphy can be efficiently applied to the Niger Delta.

REFERENCES

- Adegoke OS, Omatsola ME, Salami MB (1976). Benthonic Foraminiferal Biofacies of the Niger Delta. 1st Intern. Aymp. On Benthonic foraminiferal. Maritime Sediments, Spect. Publ. 1:272-292.
- Allen JRL (1965). Late Quaternary Niger Delta, and adjacent areas—sedimentary environments and lithofacies: AAPG Bulletin, 49:547-600.
- Beka FT, Oti MN (1995). The distal offshore Niger delta: frontier prospects of a mature petroleum province, *in* Oti, M.N., and G. Postma, eds., *Geology of deltas: Rotterdam*, A. A. Balkema, pp. 237-241.
- Bustin R.M. (1988). Sedimentology and characteristics of dispersed organic matter in Tertiary Niger delta: Origin of source rocks in a deltaic environment: AAPG Bulletin, 72:277-298.
- Doust H, Omatsola E (1989). Niger Delta: American Association of Petroleum Geologists Memoir 48:201-238.
- Doust H, Omatsola E (1990). Niger Delta, *in* J.D. Edwards and P.A. Santogrossi, eds., *Divergent/passive margin basins: American Association of Petroleum Geologists Memoir 48*: 239-248.
- Ejedawe J.E (1981). Patterns of incidence of oil reserves in Niger delta basin AAPG Bulletin, 65: 1574-1585.
- Ekweozor CM, Okoye NV (1980). Petroleum source-bed evaluation of Tertiary Niger Delta: AAPG Bulletin, 64: 125 1-1259.
- Ekweozor CM., Okogun JI, Ekong DEU, Maxwell JR (1979). Preliminary organic geochemical studies of samples from the Niger delta, Nigeria: part 1, analysis of crude oils for triterpanes: *Chemical Geology*, 27:1 1-28.
- Evamy BD, Haremboure J, Kammerling R, Knaap WA, Molloy FA, Rowlands PH (1978). Hydrocarbon habitat of tertiary Niger Delta: AAPG Bulletin, 62:1-39.
- Haq BU, Hardenbol J, Vail PR (1988). Mesozoic and Cenozoic chronostratigraphy and cycles of sea-level change. *In*: Wilgus C.K. et al.(eds.) *Sea-level changes: An integrated approach. Spec. Publs. Am. Ass. Petrol. Geol.* 42:71-108 (pp. 89-92 and figs. 12 and 13 describe typical mixed facies in early Cretaceous and late Permian-early Triassic sections from France and the Salt Range, respectively).
- Lawrence SR, Munday S, Bray R (2002). Regional geology and geophysics of the eastern Gulf of Guinea (Niger Delta to Rio Muni): *The Leading Edge*, 21:1112– 1117.
- Loutit, TS, Bradsaw, WB and Kingsley, KO (1988). Condensed sections: Key to age determination of continental margin sequences. *In*: Wilgus C.K. et al. (eds.) *Sea-level changes: An integrated approach. Spec. Publs. Am. Ass. Petrol. Geol.* 42:183-213 (importance of the condensed section to sequence biostratigraphy).
- Murray JW (1991). *Ecology and Palaeoecology of Benthonic Foraminifera.* John Wiley and Sons Inc., New York. Pp.397
- Sangree JB, Vail PR, Mitchum RM (1990). A summary of exploration applications of sequence stratigraphy: Gulf Coast Section- Society of Economic Paleontologists and Mineralogists Foundation Eleventh Annual Research Conference Program and Extended Abstracts, pp. 321-327.
- Sloss LL (1963). Sequences in the cratonic interior of North America: *GSA Bulletin*, 74:93-114.
- Sloss LL, Speed RC (1974). Relationships of cratonic and continental margin tectonic episodes: *in* Dickson, W.R, (ed.), *Tectonics and sedimentation, society of Economic Paleontologist and Mineralogists special publication 22*: 98-119.
- Stacher P (1995). Present understanding of the Niger Delta hydrocarbon habitat, *in* M.N. Oti, and G. Postma, eds., *Geology of Deltas: Rotterdam, A.A. Balkema*, p. 257-267.
- Vail PR, Wornardt WW (1990). Well log seismic sequence stratigraphy: An exploration tool for the 90's. Eleventh Annual Research Conference, Gulf Coast Section, SEPM, Program and Abstracts, December 2-5, 1990