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SEQUENCE STRATIGRAPHIC APPRAISAL: COASTAL SWAMP DEPOBELT IN THE NIGER DELTA BASIN NIGERIA

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ABSTRACT

Mid-Lower Miocene Agbada sedimentary intercalations of "AB" Field in the coastal swamp depobelt, Western Niger-Delta, were evaluated to determine their sequence stratigraphic character. The analysis was based on a combination of data sets including logs of six wells to describe lithic variations of the Agbada Formation within the 'AB' Field. These well logs were integrated with biostratigraphic data to develop a sequence stratigraphic framework. The results revealed two maximum flooding surfaces dated 10.4Ma and 9.5Ma. A sequence boundary dated at 10.35Mya was also identified across the field. The strata in the study area were divided into lowstand system tracts (basin floor fan, slope fan and prograding wedge), transgressive and highstand systems tracts. Biostratigraphic data suggested that these sediments were deposited in coastal deltaic to bathyal marine environments. Basal deposits directly overlying sequence boundaries where formed by the migration of large distributary channels. Upward coarsening sets of inclined beds, hundreds of feet thick, record progradation of deltas into slope. Blocky and upward fining well-log patterns are interpreted to reflect deposition in shoreline, paralic, and fluvial environments. The thick sequences of highly microfossiliferous are the probable petroleum source rocks. The massive sand formation of the basin floor fan, the sand-rich prograding wedge and the highstand sands as well as the transgressive sands constitute good reservoirs. The distal shale toes of the prograding wedge and transgressive shales as well as highstand shales form seals for the stratigraphic traps formed in the study area.

KEYWORDS:- Sequence stratigraphic tool, system tract deposits.

INTRODUCTION

The Tertiary Niger Delta Basin is a prolific oil province within the West African subcontinent (Fig. 1). The basin covers an area of some 70,000km^2 area within the Gulf of Guinea in Western Africa. Its origin is associated with the failed arm of a rift triple junction associated with the opening of the South Atlantic during the late Jurassic that persisted into the Middle Cretaceous (Lehner and De Ruiter, 1977).

Three formations are defined (Short and Stauble, 1967) within the 4km (13,000 ft) thick Niger delta clastic wedge based on sand/shale ratios estimated from subsurface logs: (1) Basal offshore-marine and prodelta shale of the Akata Formation, (2) Interbedded sandstone and shale of the dominantly deltaic Agbada Formation and (3) The fluvial continental sands of the Benin Formation.

Sequence stratigraphy offers a model in which a series of system tracts within a depositional sequence is deposited in response to a cycle of relative fall and rise of sea level. The analysis of these cycles can be used to explain how the mechanisms of sediment accumulation, erosion and inter-related processes produced the current configuration of these rocks, and the time involved in their deposition, as each layer is bounded by surfaces that transgress time (Wheeler, 1958; Middleton, 1973; Vail et al 1977; Galloway, 1989; Catuneanu, et al, 1988; Catuneanu, 2002; Embry, 2002; Mitchum, 1977; Fischer & McGowan 1967; Van Wagoner et al; 1990; Van Wagoner et al; 1988; Kerans & Tinker, 1997; and Mitchum & Van Wagoner, 1991).

Sequence stratigraphy was applied to sedimentary analysis of 'AB' Field of the Niger Delta Basin using well logs integrated with high resolution biostratigraphic data of six wells to develop a sequence stratigraphic framework for the field. This was done by ascertaining the major bounding surfaces, their age relationships as well as depositional environments.

The study area described as 'AB' Field is on the onshore part of the Western Niger Delta Basin. The delta is composed of mega units coastal swamp depobelts (Fig.3). It is described as a shelf-contained entities with respect to stratigraphy, structure-building, and hydrocarbons distribution. The field covers an area of 450km square. The six exploration wells studied are all deviated (Fig. 4). The major producing Agbada Formation has an average depth of 5,700ft in 'AB' Field. The aim of this appraisal is to subdivide the stratigraphic column of the "AB" Field into sequences and systems tracts based on the integration of available well logs and high resolution biostratigraphic data. This will help to delineate potential reservoirs, source rocks and stratigraphic traps, by identifying facies and their associations as a tool for the development of a sequence stratigraphic framework of the field. This is done through the identification of parasequence and establish parasequence set stacking pattern major bounding surfaces, system tracts and predict field wide sequence stratigraphical relationships.

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Fig.1: Global position of the Niger Delta

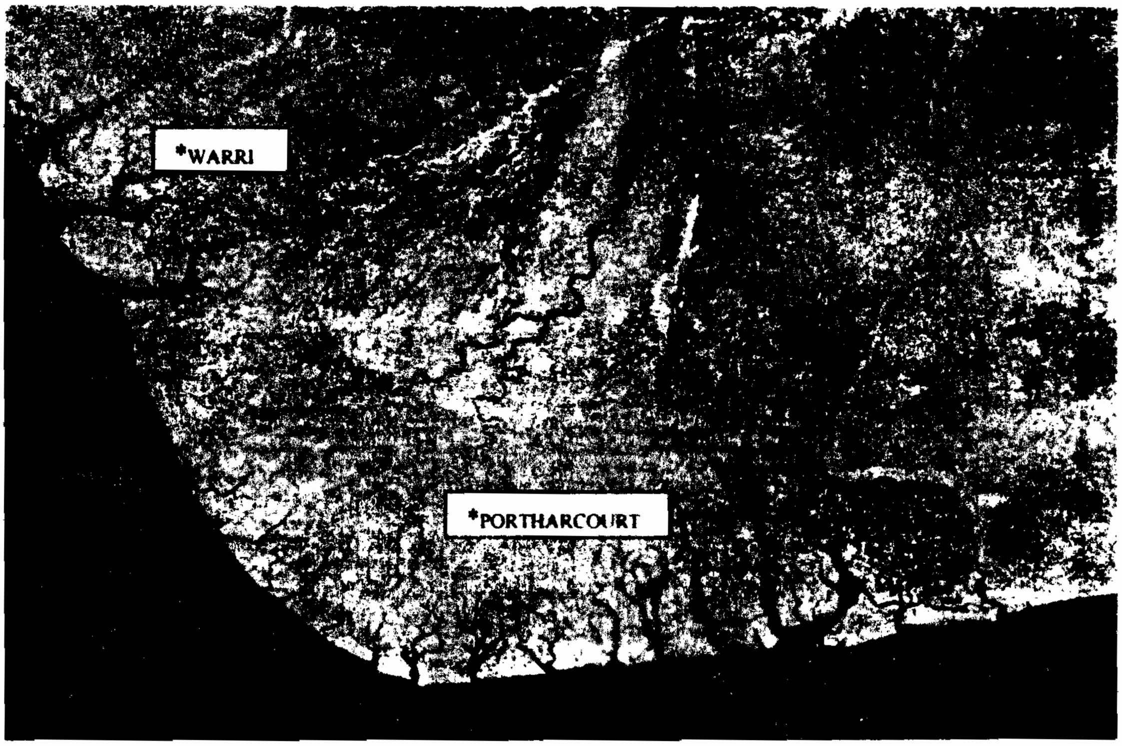

Fig.2: Satellite image of the Niger Delta Basin

Fig. 3: Stratigraphy and Depobelts of the Niger Delta Basin.

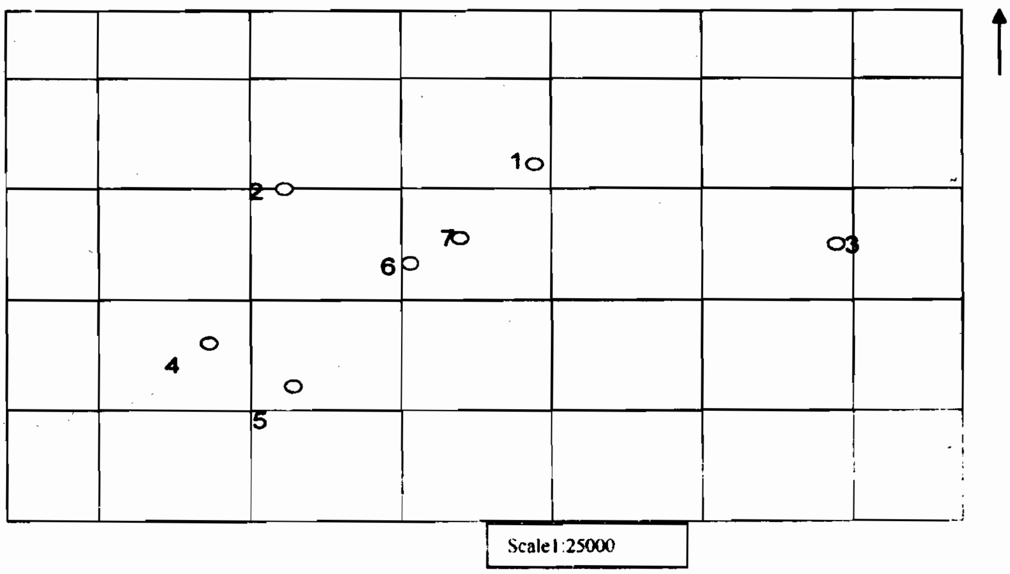

Fig. 4: Well locations within AB Field

METHODOLOGY

The study focuses on the interpretation of depositional processes within the Niger Delta clastic wedge in 'AB' Field. Stratigraphic surfaces observed were correlated between wells mapped across a 400 square km area. Sequence stratigraphy is best determined when well logs are tied to biostratigraphic markers. Using these two combination, it is possible to identify, match and tie sequence stratigraphic surfaces as well as interpret the stacking patterns of the vertical sedimentary sequences. The character of electric logs of wells that penetrate the clastics often reflect changes in grains size and so was easily applicable to use in this process.

- Interpret lithology from log character, confirm with cores and ditch cuttings where possible.
- Interpret depositional environments from micropaleontology, palynology or from paleoecology and then from well log character.
- Interpret condensed sections from faunal abundance and diversity to recognise:

(a) Major condensed sections associated with maximum flooding surfaces.
(b) Secondary condensed sections not associated with maximum flooding surfaces.

(c) Base of lowstand prograding wedges.
(d) Base of lowstand slope fans.
(e) Minor condensed sections between attached lobes in slope fans.

- Age date with high resolution biostratigraphy and correlate with global/company sequence cycle chart.
- Interpret sequence and system tract boundaries, from log character.
- Identify and correlate parasequence and marker beds.
- Construct well log sequence stratigraphic cross-sections.
- Prepare a chronostratigraphic chart from key cross sections to summarize stratigraphic framework.
- Predict the source rock, reservoir rock and seal for any potential petroleum accumulation.

The data base made available for this study were supplied by Shell Petroleum Development Company and they include; Base map of six well locations, Structural map, well log data: Gamma ray, Spontaneous potential, Resistivity, Neutron (CNL), and Density (FDC), Biofacies data, Pollen/faunal zonations and Global/company sequence cycle chart.

RESULTS AND DISCUSSION

Lithostratigraphy

The lithological profile of AB-1 derived from gamma ray log signature of the subcrop has the following key lithological units within the Tertiary Agbada Formation of AB Field.

Retrogradational facies (11,670 – 9,850 ft AHD): This lithologic unit is dominantly composed of marine shale, 70% and sandstone 30%. The marine shale units are fine-grained with a dark to medium grey or dark brown colouration in which siderite cements may be common. The sandstones are transgressive marine sands. Biostratigraphic analysis indicates that these facies were deposited in an inner to middle neritic zones.

Progradational facies (9,850 – 7,720 ft AHD): This lithologic unit is dominated by sand, which accounts for about 60% and 40% shales. Biostratigraphic analysis indicates that they were deposited in inner neritic to bathyal zones.

Progradational facies (7,720 – 6,900 ft AHD): This lithologic unit is dominantly composed of sand, which accounts for about 70% while shales make up 30%. Biostratigraphic analysis indicates that these facies were deposited in middle neritic to bathyal zones.

Retrogradational facies (6,900 – 6,500 ft AHD): This lithologic unit is dominated by marine shale, which accounts for about 70% and 30% sandstone. The marine shale units are fine-grained deposits comprising of shales and silty shales in which siderite cements may be common with a dark to medium grey or dark brown colouration. The sandstones are transgressive marine sands. Biostratigraphic analysis suggests that these facies were deposited in middle neritic to bathyal zones.

Progradational facies (6,500 – 5,110 ft AHD): This unit is dominated by sand 60% and 40% shales.
Biostratigraphic analysis indicates that these facies were deposited in proximal fluvial marine to bathyal zones.

Biostratigraphy

High-resolution biostratigraphic data were analysed for faunal abundance and diversity, condensed sections where identified by stacks of biofacies populations. Maximum flooding surfaces were identified by peaks in micro faunal abundance and diversity. Faunal diversity minima were used to pick sequence boundaries. Micro-flora/fauna zonations were used to establish age relationship. The biofacies signatures revealed condensed sections at 5110-5261ft AHD, 6200-6681ft AHD and 8780-9652ft AHD in AB-1.

Table 1: Microfaunal Zonation Of AB-1

					OML XXX
TOP	*BOTTOM*	*F.ZONE*	*RELIABILITY*	*REMARKS*	*DATE*
DEPTH	*DEPTH*		*GRADIENT*		*REVISED*
0	4200			No Data	02/03/2006
4256	4483			Barren	
4509	6233	F9600/F9700			
6320	12980	F9600	1	Top Nonion 4	
13040	13760			Undiagnostic	
	MICROFAUNAL MARKER				
	6440	F9650	3	No Uvigerina 8 Ass. Fauna only	

Table 2: Palynological Zonation of AB-1

			AB-01		
P ZONE	TOP	BOTTOM	RELIABILITY	REMARKS	DATE
	DEPTH	DEPTH	GRADIENT		REVISED
					12/04/2002
	0	4250		No data	
P830	4256	5628	4	q.b. 45	
P820	5660	6720	2	q.b. 292	
P788	6800	6980		Negative	
P784	7046	11210	3	t. reg. 250	
P770	13610	13700	2	t. 440	

Sequence Stratigraphy

The lithology of the AB-Field was dominated by alternating intercalations of sand and shale. The parasequences identified from well log characters were of the coarsening upward cycles, consisting of shale at the base and sand at the top. From the parasequences, parasequence sets stacking patterns were built. The parasequence stacking patterns identified were aggrading, prograding and retrograding. Parasequence set cycle order was on the average of 5,000 years for the deposition of each cycle deposit. The first major bounding surface identified down hole was the maximum flooding surface (MFS) occurring at 9,850 ft along hole depth (AHD) which formed when the last fine-grained widespread transgressive sediment was deposited. The MFS is within a condensed section composed of sediments rich in the tests of micro-fossils that were not buried by sediment deposition because sedimentation rates were slow in comparison to the area of sea floor available for sedimentation. The MFS was age dated with biostratigraphy at 10.4Ma. Beneath the MFS, is the transgressive system tracts (TST) formed during a rise in sea level, above the shelf margin as eustasy began to rise rapidly. The TST is associated with a ravinement erosion surface formed when the transgressing sea reworks either the prior sequence boundary or the sediments that may have collected during the regression that followed the formation of the sequence boundary. The system tracts above the MFS was observed from log signatures to be the high stand system tracts (HST) which was interpreted to have been deposited at a time of still stand of base level. Parasequence sets identified include progradational and aggradational sets. The HST was associated with a slow rise of relative sea level followed by a slow fall when the slower rate eustatic change balances that of tectonic motion resulting in sedimentation outpacing accommodation space. The prograding highstand clinoforms developed in the process capped by aggrading parasequences that thin upward. The SB at the base of the LST occurs at 7,720 ft AHD and was age dated at 10.35Ma biostratigraphically. The lowstand system tract (LST) occurred with a fall in sea level induced by eustasy falling rapidly, causing fluvial incision up dip with formation of a sequence boundary focusing sediment input at the shoreline. Basin floor fans (BFF) resulting from slope instability were deposited as sediments transported from the fluvial systems are rejuvenated by the forced regression. The top of the (BFF) was identified at 7,340 ft AHD. The slope fans (SF) formed when sedimentation rates slowed as reduction in slope instability prevented sediments from being displaced far down slope. The top of the SF was identified at 7,110 ft AHD. With slow relative sea level rise induced by a rise in eustasy there was an increase in accommodation space relative to sedimentation resulting in lowstand prograding wedge (LPW) characterised by parasequences that aggraded. The top of the LPW was identified at 6,900 ft AHD. A final TST with a condensed section developed above the LST terminating in an MFS at 6,500 ft AHD age dated with biostratigraphy at 9.5Ma. The top of the final HST was not covered by petrophysical well log data.

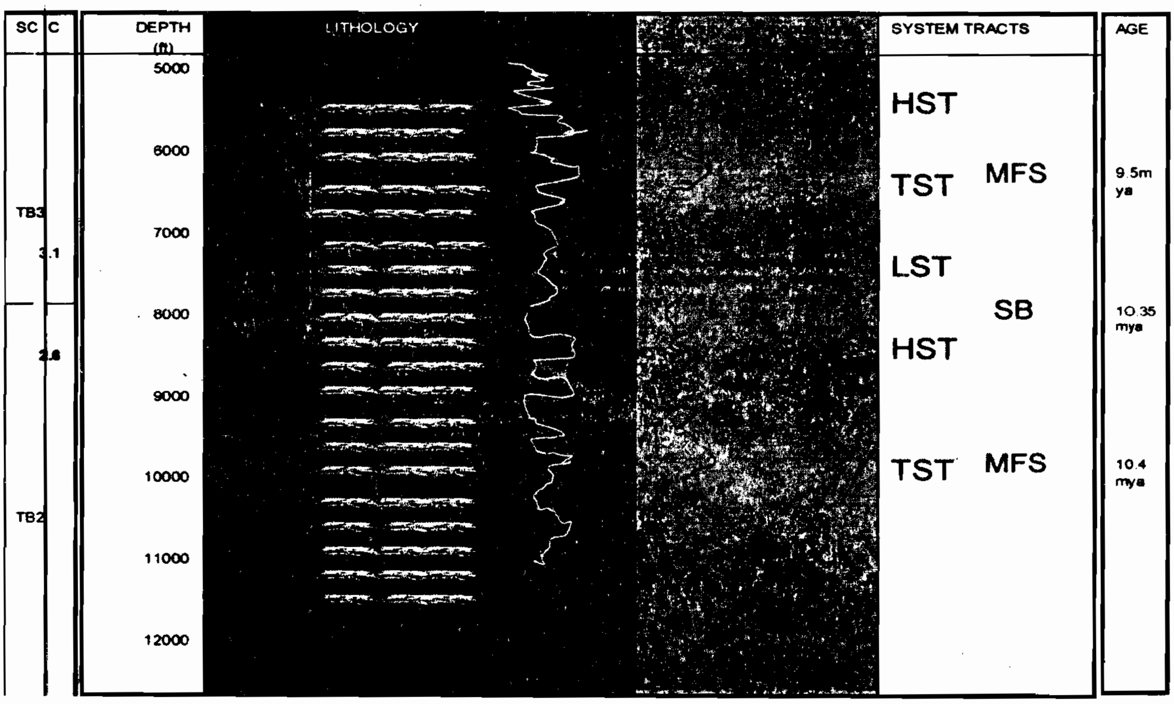

Fig. 5: Stratigraphic summary model of AB-1

KEY: HST: Highstand system tracts MFS: Maximum flooding surface
TST: Transgressive system tracts
LST: Lowstand system tracts SB: Sequence boundary

DISCUSSION

The AB stratigraphic intervals fall within the parelic sequence of alternating sand and shale bodies of variable thicknesses. The sand/shale ratios generally decrease with depth suggestive of a fining downward motif. The entire sequence constitutes an overall prograding delta with some periods of transgression.

Integrated results of well log and biofacies interpretations revealed that the paleoenvironment of deposition of the sediment, in 'AB' Field ranged from inner neritic to deep marine; Three stacking patterns – progradational, aggradational and retrogradational patterns were identified, Two maximum flooding surfaces and a 3RD order sequence boundary were delineated. The basin floor fan, the sand-rich prograding wedge, the transgressive sands and the highstand sands constitute good (potential) reservoirs. The distal shale toes of the prograding wedge as well as highstand shales and transgressive shales form seals for stratigraphic traps formed in the study area. Possible migration pathways include carrier beds and faults. The reservoir units include; Channel Sandstone, Channel Heterolith, Upper Shoreface Sandstone, Lower Shoreface Heterolithic, and coastal Plain Sandstone. Stratigraphic traps identified include submarine fan and lowstand wedge.

Sequence stratigraphic correlation of AB Field was achieved through the identification and correlation of flooding surfaces (chronostratigraphic lines) across the wells. The intervening stratigraphic units were thereafter correlated within the time lines defined by flooding surfaces, thus revealing two maximum flooding surfaces (MFS) and a third order sequence boundary (SB) across the field. The log character is of upward-coarsening sandstone successions that generally correlate across AB Field to mostly blocky and upward-fining successions that are less continuous between adjacent well. Progression from prograding delta deposits to delta top and fluvial facies was recognised.

Sequence boundaries within the Agbada Formation, in the area of AB Field, are defined by channel-form deposits observed to directly overly the sequence boundaries and these are deposits of the "Lowstand Rivers". Vertical logtrends within these sequences are similar to those predicted by the standard models for prograding deltaic shorelines. Deposits directly above sequence boundaries are coarse grained, and generally fine upward. Log trends generally change from thicker, sandier, blocky and upward-fining successions to thinner upward-coarsening successions, suggesting a progression from channel deposits to dominantly offshore prograding lobes. This reflects deepening upward from the sequence boundary to maximum flooding surface characterised by (retrogradational parasequence set) depositional shoaling. The Agbada Formation is generally interpreted to contain fluvial-deltaic deposits (Weber and Daukoru, 1975). Well logs through the sequences clearly show an up-section progression from blocky upward fining successions (channel deposits) to upward-coarsening successions (prograding lobes) which reflects a progression from fluvial depositional settings to pro-delta and deltaic shorelines. Eustatic Sea level variations during the Middle to Late Miocene correlates with sequences in AB Field. Lowstand shelf exposure occurred when incised fluvial valleys carried sediments directly to the slope edge depositing facies directly above sequence boundaries. As accommodation filled, the locus of sediment deposition and loading would also have shifted seaward. The evolution of channel meanders appear to be similar to fluvial meandering channels in terms of direction and geometry of channel migration channel fills are coarse-grained. Well log correlations indicate that most reservoir sandstones are associated with the sequence boundary.

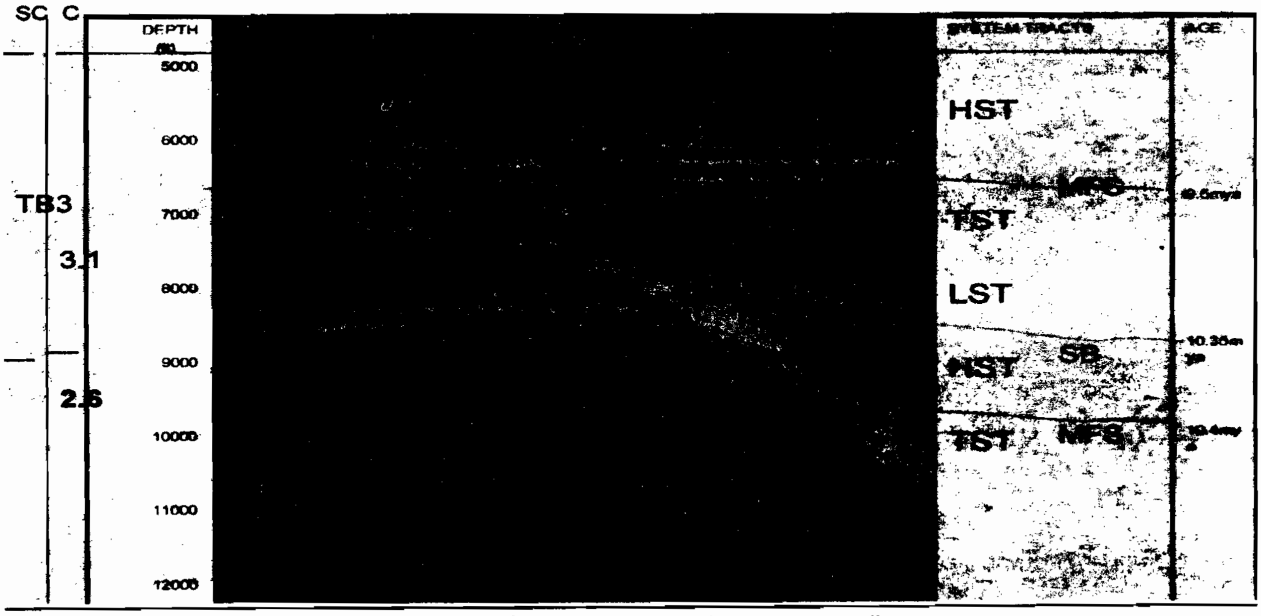

Fig. 6: Stratigraphic correlation along strike

Fig. 7: Stratigraphic correlation along dip

CONCLUSION

The depositional model of 'AB' Field based on the identified system tracts conforms to the Type 1 sequence of Vail (1987). Integrated results of well log and biofacies interpretations revealed that these strata were deposited by interaction of subsidence, eustatic changes in sea level and varying sediment supply during the late Miocene to middle Miocene. The dominant multiplicity of biofacies suggests the heterogenic depositional environment of 'AB' Field which ranges from coastal deltaic to deep marine. The chronostratigraphic framework consists of two depositional sequences related to depositional cycles 2.6 and 3.1, which were identified and delineated in the well. Two maximum flooding surfaces and a 3RD order sequence boundary were delineated across the field. Five system tracts were identified. Three parasequence stacking patterns; progradational, aggradational and retrogradational patterns were identified. Lateral/vertical continuity of facies depended on parasequence associations. Most reservoir units occur between the 10.4Ma MFS and the 10.35Ma SB. The morphology and importance of reservoirs and seals vary between systems tracts. The reservoir units include; Channel Sandstone, Channel Heterolith, Upper Shoreface Sandstone, Lower Shoreface Heterolith, and coastal Plain Sandstone. Seals include coastal plain shale and marine shales Stratigraphic traps include submarine fan and lowstand wedge. There is an observed overall shallowing -upward log trend in 'AB' Field. The basin floor fan, the sand-rich prograding wedge, the transgressive sands and the highstand sands constitute good (potential) reservoirs. The distal shale toes of the prograding wedge as well as highstand shales and transgressive shales form seals for the (potential) stratigraphic traps formed in the study area. Possible migration pathways include carrier beds and faults.

The fundamental advantage of this study is that it provides a series of tools with which sedimentary architecture can be analysed and predicted in areas far away from well control. This study developed a sequence stratigraphic model for the Agbada Formation in the Niger Delta Basin based on integrated well log and biostratigraphic data from AB Field. The following conclusions are reached;

i. One sequence boundary (major erosion surface) divides the AB Field into two sequences, each formed during relative levels of eustacy.
ii. Sequence boundary appeared to have formed by lowstand fluvial incision (as commonly interpreted in other major deltaic successions).
iii. System tracts developed in response to sedimentation accommodation and eustacy.
iv. Complex deltaic sequences can be confined to time bound systems tracts within which the constituent sediment packages can be correlated in detail on well to well basis at the fourth order parasequence level.
v. Identifying and mapping of deeper water facies that would otherwise be overlooked in routine seismic mapping are revealed by sequence stratigraphy.
vi. The forecasting and identification of prospective plays in downdip portions of the Niger-Delta basin.

Table 3: Depth and age of major surfaces in AB Field

	MFS	TLPW	TSFS	TBFFS	SB	MFS
AB	DEPTH(FT)	DEPTH(FT)	DEPTH(FT)	DEPTH(FT)	DEPTH(FT)	DEPTH(FT)
1	6,500	6,900	7,110	7,340	7,720	9,850
2	6,080	6,980	7,230	7,500	7,950	9,960
3	6,640	6,920	7,130	7,330	7,690	9,770
5	6,530	7,290	7,860	8,240	8,500	9,720
6	6,400	7,100	7,670	8,000	8,500	9,720
7	6,350	7,140	7,300	7,500	7,960	9,860
AGE	9.5MYA				10.35MYA	10.4MYA

Table 4: Parasequence type and hydrocarbon distribution

P/SEQUENCE type	H/C	WELL 5	WELL 6	WELL 7	WELL 1	WELL 2	WELL 3
AGGRADING (LST)	DEPTH (ft)	8,960 - 9030	9.00 - 9100	7,490 – 7,580	8,200 – 8,280	6270 – 6320	8340 – 8360
AGGRADING (HST)	DEPTH (ft)	9 090 -9,120	9,310 - 9330	7,750 – 7,770	8,450 – 8,470	7350 - 7370	9030 – 9065
PROGRADIN G(HST)	DEPTH (ft)	9,150 – 9,165	9,370 – 9,440	7,780 – 7,820	9,210 – 9,230	7480 – 7490	9980 - 10500
RETROGRAD ING(TST)	DEPTH (ft)	9,300 – 9,415	9,590 – 9,650	8,260 – 8,290	9,260 – 9,280	8250 – 8300	
PROGRADIN G (LST)	DEPTH (ft)	9,970 – 9,990	10,100 – 10,140	9,350 – 9390	9,380 – 9,410	8610 - 8620	
	DEPTH (ft)	10,180 – 10,240	10,750 – 10,780	9,560 – 9,570	9,650 – 9,730		
	DEPTH (ft)		10,800 – 10,880	9,580 – 9,650	10,240 – 10,280		
	DEPTH (ft)				11,170 – 11,220		
	DEPTH (ft)				11,390 – 11,420		

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