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Prediction of Good Quality Reservoir Sands through Integrated Depositional Systems and Sequence Stratigraphic Framework Interpretations: Example from Late Miocene to Early Pliocene Deposits of Okan Field, Niger Delta, Nigeria

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Abstract
The sequence stratigraphic framework and depositional systems of Okan Field were investigated by interpreting and integrating biozones, biofacies, and wireline logs (gamma ray and resistivity) with the aim of predicting the most favourable reservoirs within the analysed sections. Three depositional sequences bounded by their unconformities were delineated. Three sequence boundaries (SBs) named 1, 2 and 3 were delineated from the base of the studied sections to the top. The sequence boundaries 3 and 2 were dated 10.5Ma and 12.5Ma respectively. Three maximum flooding surfaces (MFSs) dated 9.2Ma, 11.6Ma and 13.4Ma were interpreted. The 9.2Ma MFS was marked by Last Downhole Occurrence (LDO) of *Globigerinoides extremus* and *Sphaeroidinellopsis seminulina*, the 11.6Ma MFS was marked by First Downhole Occurrences (FDOs) of *Globorotalia continuosa*, *Globorotalia obese, Globorotalia mayeri* and *Cassigerinella chipolensis* with some glauconite occurrence. The 13.4Ma MFS was marked by high gamma ray value and peak benthic and planktic foraminifera occurrence. The depositional systems interpreted were found to be associated with particular system tracts within the sequences. The late highstand system tracts (HSTs) are dominated by point bars while the early HSTs are dominated by shoreface sands. Lowstand system tracts (LSTs) are dominated by shoreface sands exhibiting a multistorey geometry. The early transgressive system tracts (TSTs) are dominated by point and barrier bars. The most favourable reservoirs were found to be asoociated with the LST shoreface deposits, possessing good reservoir - seal pairs. The shoreface reservoirs were capped by relatively thick TST deposit consisting of thick shales which serves as a seal.

INTRODUCTION

The sequence stratigraphic concepts was developed on the passive continental margin (Vail *et al*., 1977) but little progress has been made in understanding the depositional systems as they relate to systems tract architectures in a basin especially in Niger Delta. Dong *et al*. (2011) showed that depositional systems are associated with particular system tracts within the lacustrine basins.

The Niger Delta is a working petroleum system. Exploration for hydrocarbons requires that good quality sands are predicted and their lateral continuity established amongst one of the least requirements for hydrocarbon accumulation in basins. The quality of these reservoirs can be assessed by examining the depositional systems in relation to the associated third order system tracts. The purpose of study is to reconstruct the sequence stratigraphic framework and predict the most favourable reservoirs within the study area.

The study area is within Okan Field (Fig. 1) located in western offshore Niger Delta. Okan oil field is the first commercial field to be discovered on the continental shelf of Nigeria. On December 19, 1961 immediately after having been granted offshore OPLs “C” and “D”, Nigerian Gulf Oil Company (now Chevron Nigeria Limited) carried out a reflection seismic programme. Interpretation revealed a number of structural areas of interest, including the anticline on which Nigeria Gulf sited their first exploratory test in Nigeria. The first well, Okan-1 was spudded on December 8, 1963 and completed as a new field discovery on January 1, 1964 (Frankl and Cordry, 1967, Whiteman, 1982).

Regional Geology of the Niger Delta

The evolution of Niger Delta is related to the evolution of Benue Trough, which began in the Cretaceous during the opening of the South Atlantic, leading to the separation of Africa and South America. Its development appears to have been centered on two major subsiding basements, the Anambra embayment, in which some 600 to 700 metres of sediments accumulated and a younger more southerly region where subsidence was extensive and some 1,200 metres of sediments were deposited (Reyment, 1965).

In Palaeocene and Eocene times (early Tertiary), marine shales were deposited over most of Niger Delta area and paralic and marine/paralic sediments appear to have been restricted to the area where the present Cross River flows between the Abakaliki Fold Belt and the Oban Massif.

A Niger Delta Complex first appears in microfloral stratigraphic plots (Fig. 2a) during the time interval P330 to P430 and lay west of the present course of the Niger River. Isopach and facies distribution patterns form the basis of these conclusions (Evamy *et al*., 1978). The Niger Delta Complex continued to grow during Eocene time as a result of epeirogenic movements on the Benin and Calabar Flanks of the delta basin (Murat, 1972). In P480, the Late Eocene time, the rate at which the Niger Delta Complex prograded increased as a major regressive phase got underway which has lasted with minor transgressions until the present day. During Oligocene and earliest Miocene times (P520-P630) successive overlapping depocentres developed in the Niger Delta Complex. A thick sequence of paralic sediments accumulated and Evamy *et al*. (1978) relate this to pronounced subsidence and a relatively slow advance of the delta front. In Late Miocene to Pliocene time i.e P830-P900 (Fig. 2b) the delta complex continued to prograde. A large depocentre developed in the eastern offshore and the youngest depocentre (P900) is now located in the western offshore. This is situated landward of the Pliocene centres due to a combination of subsidence, sediment supply and eustatic Pleistocene fluctuation of sea-level (Whiteman 1982).

Well sections through the Niger Delta generally display three vertical lithofacies subdivisions, namely the Benin, the Agbada and the Akata Formations corresponding to delta top, delta front and prodelta respectively. Recent work by Reijers (2011) proposed that these formations be elevated to Group level to enable subdivision of other units to formations. The lithological characterizations of these lithostratigraphic units have been described by Short and Stauble, 1967, Weber and Daukoru, 1975 and Whiteman, 1982. The Benin Formation consists of massive continental sands and gravels accounting for about 90% of all the lithofacies within the formation with few shale intercalations, which becomes more abundant toward the base. The Agbada Formation consists mostly of shoreface and channel sands with minor shales in the upper part, and alternation of sands and shale in equal proportion in the lower part. Oil and gas reverses in the Niger Delta Basin mainly occurs in sandstone reservoirs throughout the Agbada Formation. The Akata Formation composed mainly of marine shales, sandy and silty beds, which are thought to have been laid down as turbidites and continental slope channel fills.

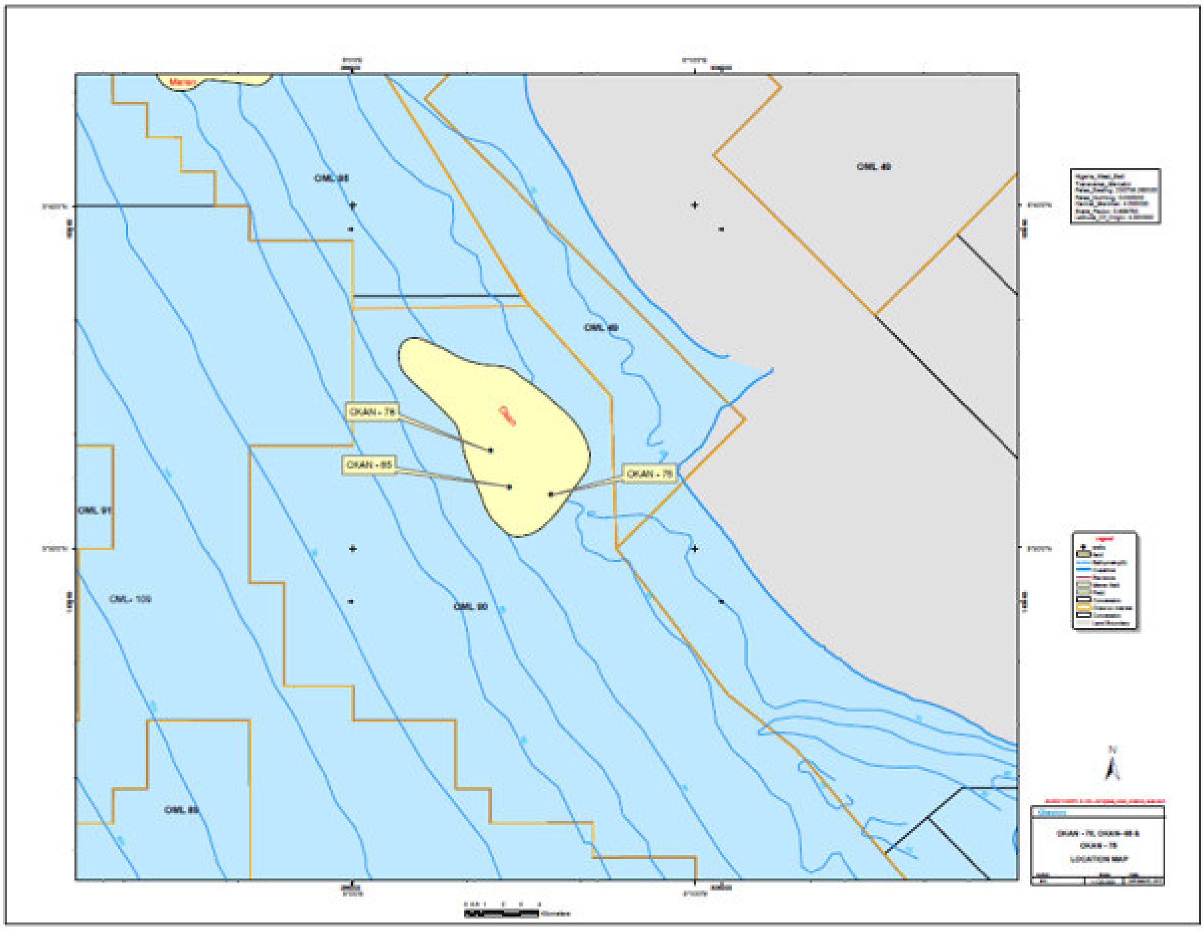


Fig. 1: Location map of the three selected Okan Wells

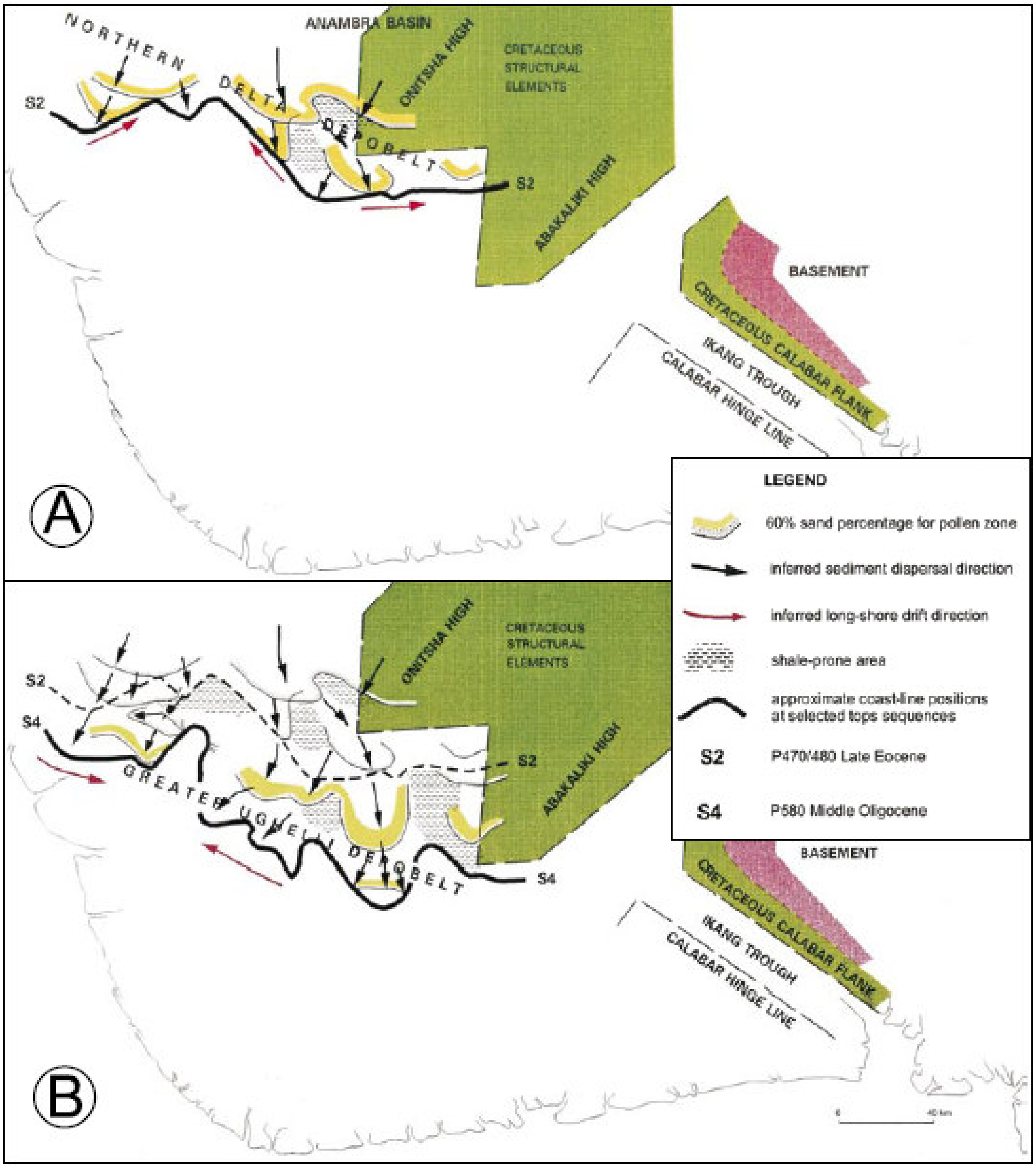


Fig. 2a: Palaeo-drainage trend and stratigraphic evolution of Northern Delta (A) and Greater Ughelli Depobelts based on microfloral units (after Evamy *et al.,* 1978, modified by Reijers, 2011)

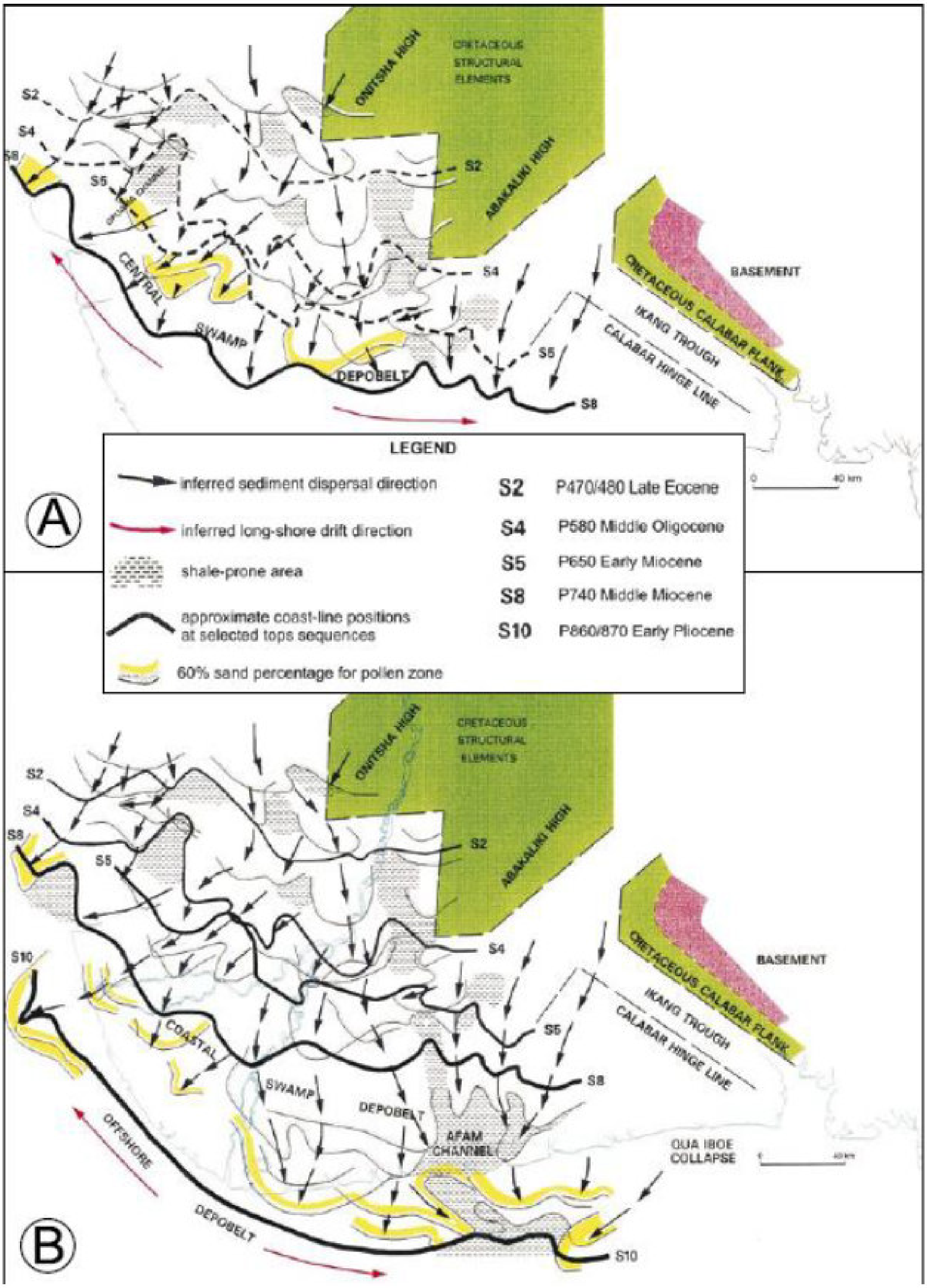


Fig.2b: Palaeo-drainage trend and stratigraphic evolution of Central Swamp (A) and Coastal Swamp and Offshore Depobelts based on microfloral units (after Evamy *et al.,* 1978, modified by Reijers, 2011)

DATA SET AND METHOD

The data set consist of ditch-cutting samples from three wells (65, 75RD and 78), core photographs of 6 inches each ranging from 11, 946 – 12, 104ft of Okan 76 ST, wireline logs which include gamma-ray and resistivity and base map. StrataBug software was used for plotting fossils and accessory minerals distribution charts.

A clean 5ml spoon was used to scoop one spoonful (or two to three spoonfuls if sample is rich in drilling mud) into the corresponding labeled aluminium dish/cup. The samples were then covered with soapy water and allow to stay for 30 minutes. Samples were thereafter washed through 63µm screen until free of mud and dried at low temperature of about $50^{0\backslash}C$ for I hour. The sample was allowed to cool and then store in well-labelled phial or small pharmaceutical nylon bags. The sedimentological analysis was carried out using stereomicroscope (incidence light techniques) and the main parameters determined are: Lithologies e.g. percentages compositions of sand, shale and silt; textures such as color, grain-size, sorting and roundness; and accessory/index mineral contents and other materials.

The main lithologies were determined by virtual inspection using microscope while sand/shale ratios were estimated from the gamma-ray logs of the wells. Textures were determined using grain-size comparator while the accessory minerals such as mica flakes, pyrite, glauconite, and other materials such as ferrigenous materials, carbonaceous detritus, shell fragments and rootlets were counted on each sample. The technique used for accessory mineral/other materials counting was based on abundances of each index mineral/materials. For example: 1 – 4 count is regarded as rare and denoted as 1 , 5 – 9 counts is few and denoted as 2, 10 – 14 counts is common and denoted as 3 while 15 and above count is regarded as abundant and denoted as 4.

Lithofacies deduction was based on integration of gamma-ray log motifs (electrofacies), accessory minerals and other accessory materials, textural and lithological characteristic of the analysed sections in the three wells.

Interpretation of sequence stratigraphy begins with the identification and dating of condensed sections from biostratigraphic study within which maximum flooding surfaces (MFSs) were identified when integrated with gamma-ray log interpreted results. The integrated results from paleobathymetry, condensed sections and stacking patterns of parasequence sets enabled the delineation of sequences into system tracts. The interpreted system tracts were compared with the interpreted depositional systems to establish the trend of distribution of good quality sands.

RESULTS AND DISCUSSION

SEDIMENTOLOGY

Accessory minerals

The accessory minerals and other accessory materials were interpreted from the dish-cutting samples and integrated with electrofacies interpreted from the gamma-ray log in order to typify the lithofacies and their environments of deposition. This becomes necessary since none of the wells studied has any core data. Three accessory minerals namely: glauconite/glaucony, pyrite and mica and three other accessory materials namely: carbonaceous detritus, shell fragments and ferruginous materials were identified using incident light stereomicroscope. The bases for the use of these accessories are stated below.

The Glaucony and Glauconite

Glaucony minerals are authigenic, that is, they crystallize within the sedimentary environment, which is in contrast to almost all other silicate minerals found within sediments that are detrital. Odin and Matter (2003) noted that the process of formation of glaucony appears to require a particular microenvironment at the interface between oxidizing seawater and slightly reducing interstitial waters. This typically occurs at water depths of between about 50 and 500m, and on the outer parts of continental shelves and upper parts of continental slopes.
Glaucony identified helped us in sedimentological and sequence stratigraphic interpretations based on the following reasons:

1. It is a reliable indicator of deposition in a shallow marine environment, although it can be reworked into deeper water and occasionally into shallower environments by currents.
2. It is most abundant within shelf sediments under conditions where sedimentation of other material such as terrigenous clastic or carbonate is slow. It therefore commonly occurs in condensed sections; that is, strata which have been deposited at anomalously low sedimentation rates. The recognition of periods of low sedimentation rate on the shelf is important when assessing evidence of changes in sea level because outer shelf sedimentation tends to be slowest during periods of sea level rise.

The presence of glaucony in some thin sands enabled us to define deposits known as transgressive marine sands (Weber, 1971) which mark the onset of transgressive deposits. These sands were delineated in the studied wells in the following intervals:

Okan-65: 6720- 6710ft and 7090-7060ft;
Okan-75RD: 6420-6410ft, 8300-8285ft and 11950-11930ft
Okan-78: 6490-6460ft and 8270-8260ft

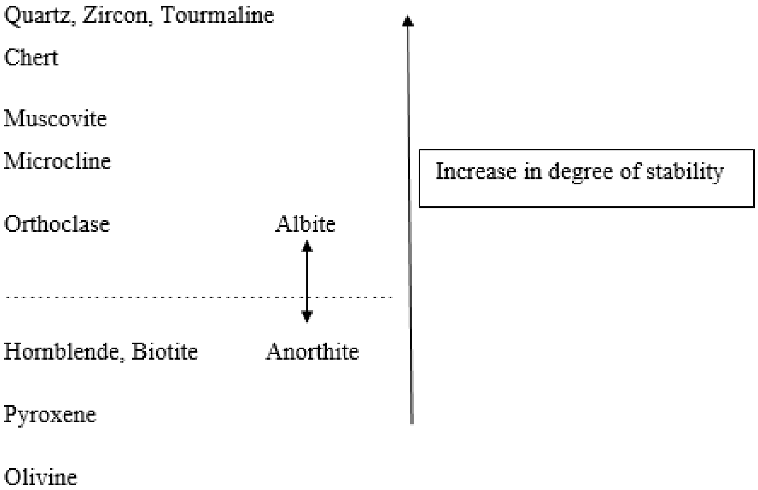
Pyrite

Pyrite (FeS) is a common iron sulphide mineral in sediments that occurs as finely disseminated particles that appear black, and may give a dark coloration to sediments. Pyrite is common as early-diagenetic crystals in the reduced environment of organic-rich muds, particularly in fluvial or coastal (deltaic, lagoonal) swamps (Miall, 2000). Pyrite is also associated with unoxidized, disseminated, organic particles in the black muds of anoxic lake and ocean basins. Therefore, common occurrence of pyrites in shale confirms the reducing conditions under which the sediments were deposited. Results from the interpretation of depositional environments showed that most of the shales were deposited in slightly to deeply axonic conditions as typified by common to abundant pyrites in the sediments. See sedimentological chart on Fig. 2.

Mica Flakes

Abundance of micaceous minerals (muscovite and biotite) in sediments depends mostly on the degree of chemical stability of the minerals. The order of stability is approximately the reverse of Bowen's reaction series (Folk, 1980). It is expected that the Albite group in which muscovite belongs should be more stable than the Anorthite group where biotite belongs (Table 1).

Table 1: Stability Series for Terrigenous Minerals (after Folk, 1980)



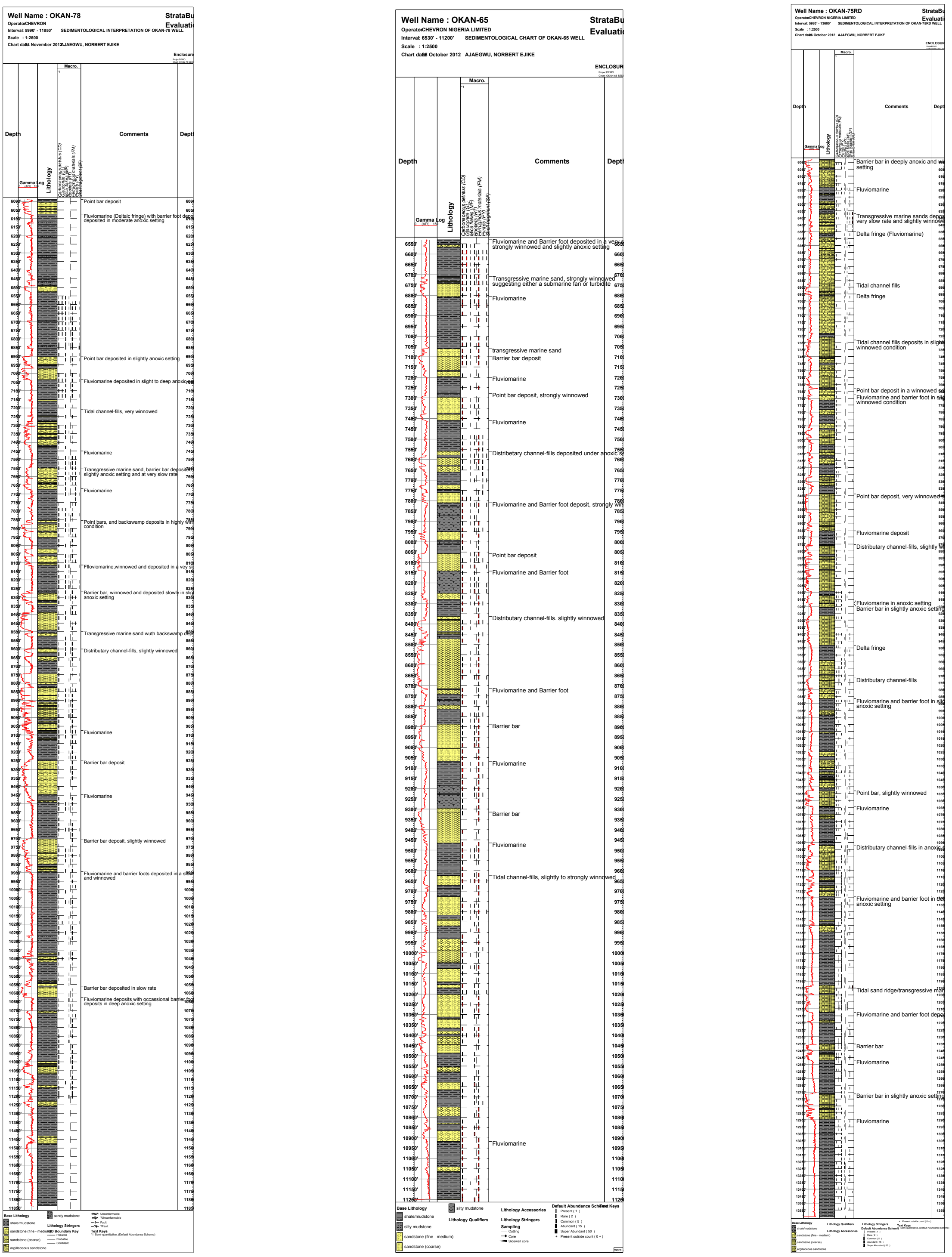


Fig. 2: Depositional systems interpreted in Okan-78, -65 and -75RD wells

Muscovite is more stable than biotite and is expected to be more abundant. It is the most micaceous mineral identified in the sediments. In situations where muscovite and biotite occur together, it showed that the sediments were deposited in shallower environments such as coastal and inner neritic or are not long transported for biotite not to be weathered. In samples where both muscovite and biotite occur abundantly but the paleobathymetry from foraminiferal interpretation indicates relatively deeper environment such as middle and outer neritic, the interpretations were done with caution. The anomalous abundance of muscovite and biotite within such intervals could be as a result of lost circulation materials introduced during drilling. At depth range of 10350ft to 10850ft in Okan-78 well and 10900ft to 11200ft in Okan-65 well, the abundance micaceous minerals could be as a result of introduced lost circulation materials during drilling. Therefore, micas were not used in those intervals for interpretation. The results of sedimentological interpretations were displayed in Fig. 2.

Accessory materials

Carbonaceous Detritus

Selley (1980) reported that microscopic particles of lignite and coal are a common minor component of many sands. The presence of carbonaceous detritus was traditionally taken as a criterion of a non-marine or deltaic environment. However, this is invariably untrue as it is unlikely that many of the coals found in carbonate sequences are terrestrial in origin but may probably be due to marine algae (Selley, 1980).

The presence or absence of carbonaceous detritus is not therefore an indicator of non-marine or marine environments. It is a winnowing index which reflects the degrees of turbulence and agitation to which sediment has been subjected. Therefore, the presence of carbonaceous detritus in sediments was interpreted to be slightly or strongly winnowed depending on the abundance of the mineral.

Shell Fragments

Most shell-bearing marine animals live at relatively low densities on the sea-floor (Brenchley and Harper (1998). During intervals of normal sedimentation, particularly in environments below fair-weather wave base, shells are generally buried at low densities and are dispersed throughout the sediment, except where life clusters are preserved. However, the geological record contains abundant examples of shells that occur at high densities; these deposits are termed shell concentrations (Branchley and Harper, 1998).

The state of preservation of shells varies according to the turbulence of the environment and rates of sedimentation. The degree of fragmentation, sorting, abrasion and proportion of articulated shells generally decreases with decreasing turbulence in an offshore direction. Long-term rates of sedimentation are closely related to subsidence rate, so that low subsidence rates result in low sediment accumulation rates which in turn tend to be associated with a high degree of fragmentation.

Hiatal surfaces, at which there has been minimal sedimentation, commonly have fossils highly fragmented by bio-erosion even though they may form in relatively low energy, offshore environments. Hiatal horizons reflect long period of slow accumulation and are important in sequence stratigraphy because they help to identify two key horizons, the flooding surface and the maximum flooding surface (Branchley and Harper, 1998).

Ferruginous Materials

Abundant red iron staining materials indicates oxygenated environments, typically either the preservation of oxidized states in detrital particles or the production of oxidized colours during early diagenesis. Red beds are, therefore, mostly indicative of non-marine or high intertidal environments (Miall, 2000).

LITHOFACIES AND DEPOSITINAL SYSTEMS

Lithofacies deduction was based on integration of gamma-ray log motifs (electrofacies), accessory minerals and other accessory materials, textural and lithological characteristic of the analysed sections in the three wells. The studied sections belong to paralic Agbada Formation (Short and Stauble, 1968). The sand and shale distribution is almost equal throughout the studied sections. The interpretation of lithofacies from the integrated assessment reveals four lithofacies named A, B, C and D with their depositional systems.

Lithofacies A: Hemipelagic shale

This lithofacies is described as hemipelagic shale with average sand/shale ratio of 28/72%. It contains pyrite and sometimes foraminifera. It is deposited in slightlty to deeply anoxic setting. It is sometimes deposited with minor sands interpreted as deltaic fringe (fluviomarine) and barrier foot as the sand thickened upward (Fig. 3).

Lithofacies B: Regressive sawtooth multistorey sands.

They have relatively high density (relatively high net: gross) channel fills with appreciable backswamp shales at intervals. The average sand/shale ratio is about 68/32%. The log motif is funnel shaped with serrated edges, giving then sawtooth shape. They contain shell fragments and carbonaceous detritus and sometimes ferruginous materials. They clean up-dip and slightly winnowed. They are interpreted as shoreface sands (Figs. 4).

Lithofacies C: Blocky channel fills sands.

These represent high density (high net: gross) channel fill with little to no backswamp shale. The average sand/shale ratio is 85/15%. They contain shell fragments, rootlets and rare carbonaceous detritus and have sharp truncations at top and base of the sand and slightly winnowed. These deposits are interpreted as point bars (Fig. 5).

Lithofacies D: Glauconitic sand (Transgressive marine sand)

This unit is of thin sand with average thickness of 30ft and contains glaucony mineral. It terminates up-dip with thick hemipelagic shale. The gamma-ray character has a bell shaped motif. The sand sometimes contains pyrite. It is interpreted as transgressive marine sand deposited at a very slow rate. This type of sand usually marks the transgressive surface and initiates the transgressive system tract (Fig. 3).

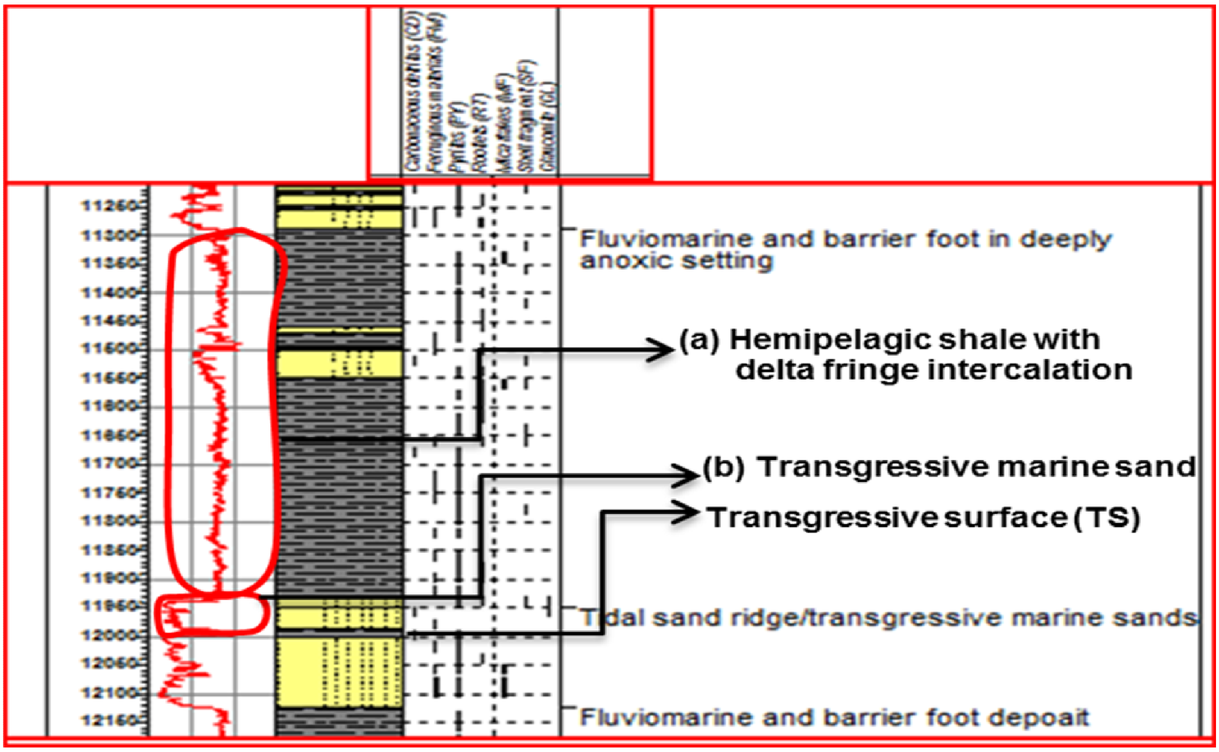


Fig. 3: Lithofacies A: Hemipelagic shale and Lithofacie D: Glauconitic sand (Transgressive marine sand)

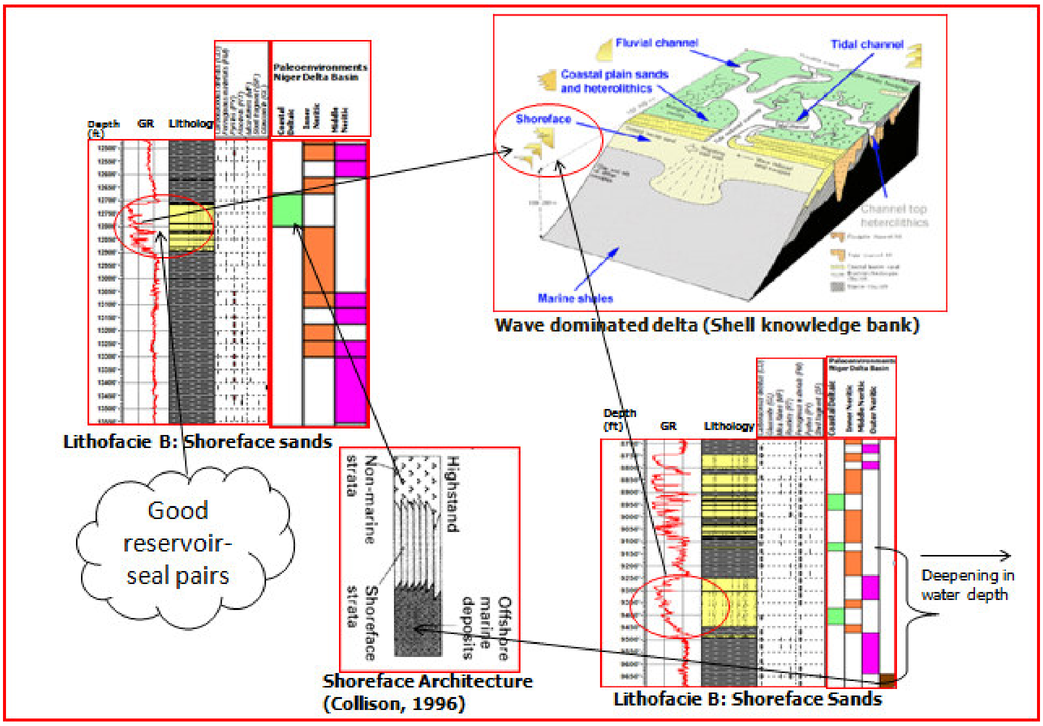


Fig. 4: Lithofacies B: Regressive sawtooth multistorey sands interpreted as shoreface sands

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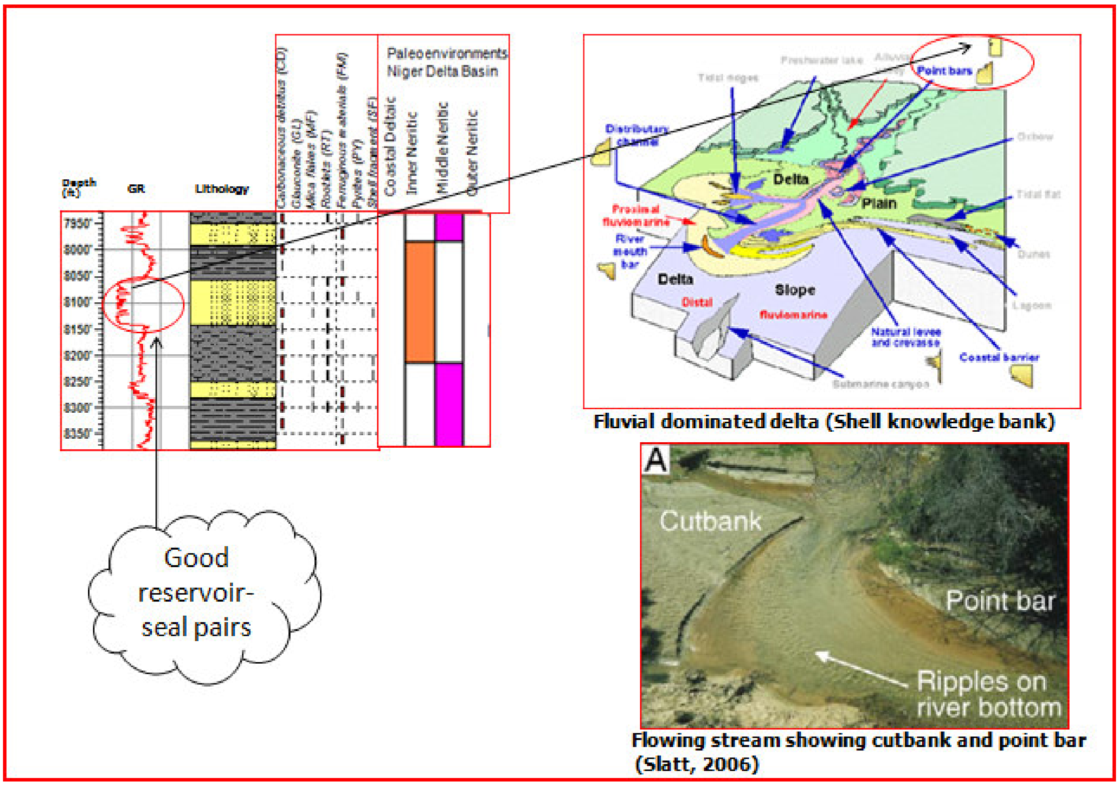

Fig. 5: Lithofacies C: Blocky channel fills sands

SEQUENCE STRATIGRAPHY

Three depositional sequences were identified based on Vail *et al*., (1977) model which uses sequence boundary as the top and base boundaries for one complete cycle. These sequences are named 1, 2 and 3. The reference scheme used for the ages of the sequence boundaries (SB) and maximum flooding surfaces (MFS) was that of Haq *et al*., (1987).

Condensed Sections

The plot of total foraminifera population (F. POLN), foraminifera diversity (F. DIVER), total planktic foraminifera (P. POLN) and planktic diversity (P. DIVER) against depth clearly showed the condensed sections intervals. These condensed sections are sediment deposited at anomalously slow rate. They were dated by planktic foraminifera marker species. Two condensed sections marked by 9.2Ma *Globigerinoides extremus* Shale and 11.6Ma *Globorotalia continuosa* Shale (Figs. 6a and 6b) were interpreted in Okan- 78, -65 and 75RD. However, Okan-75RD showed the development of a third condensed section which was dated 13.5Ma (Fig. 6c) as the older condensed section below 11.6Ma based on the scheme of Haq *et al*., (1987).

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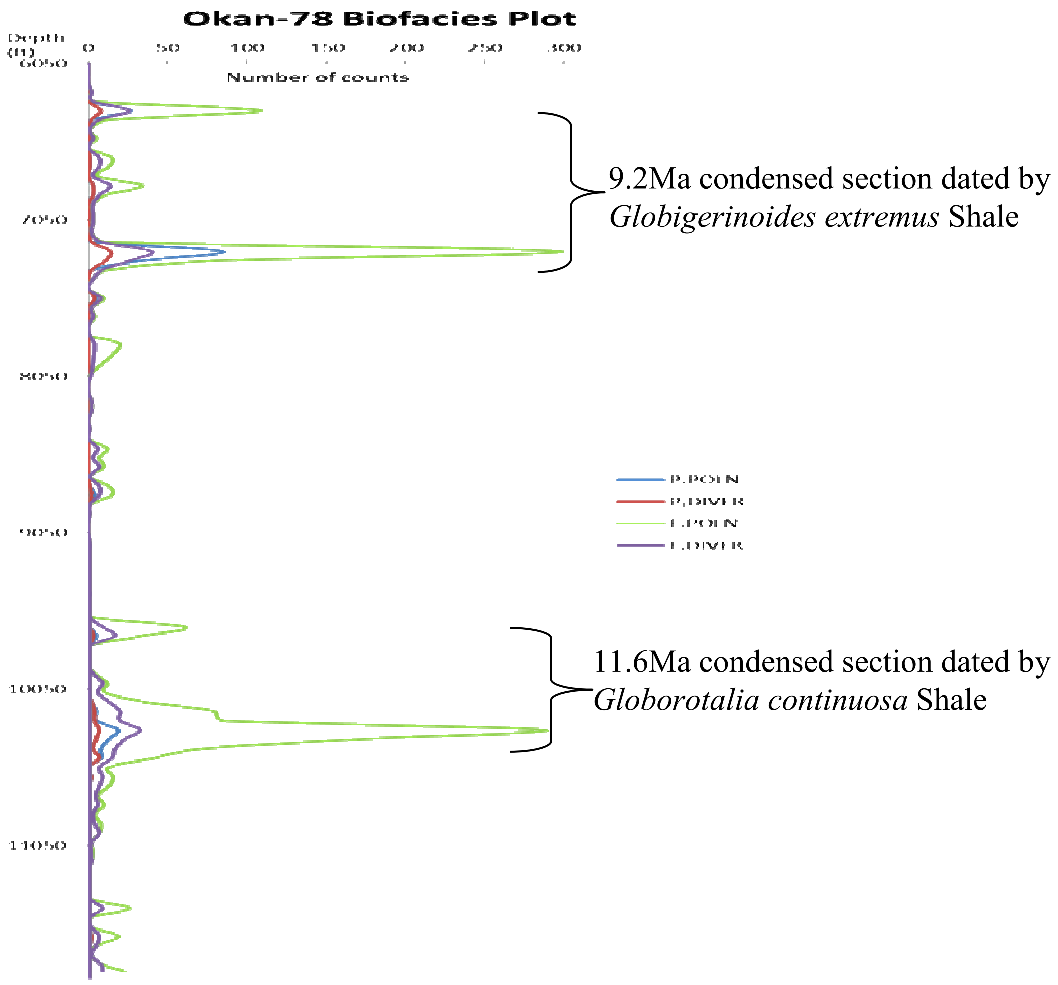

Fig. 6a: Biofacies plot of Okan-78

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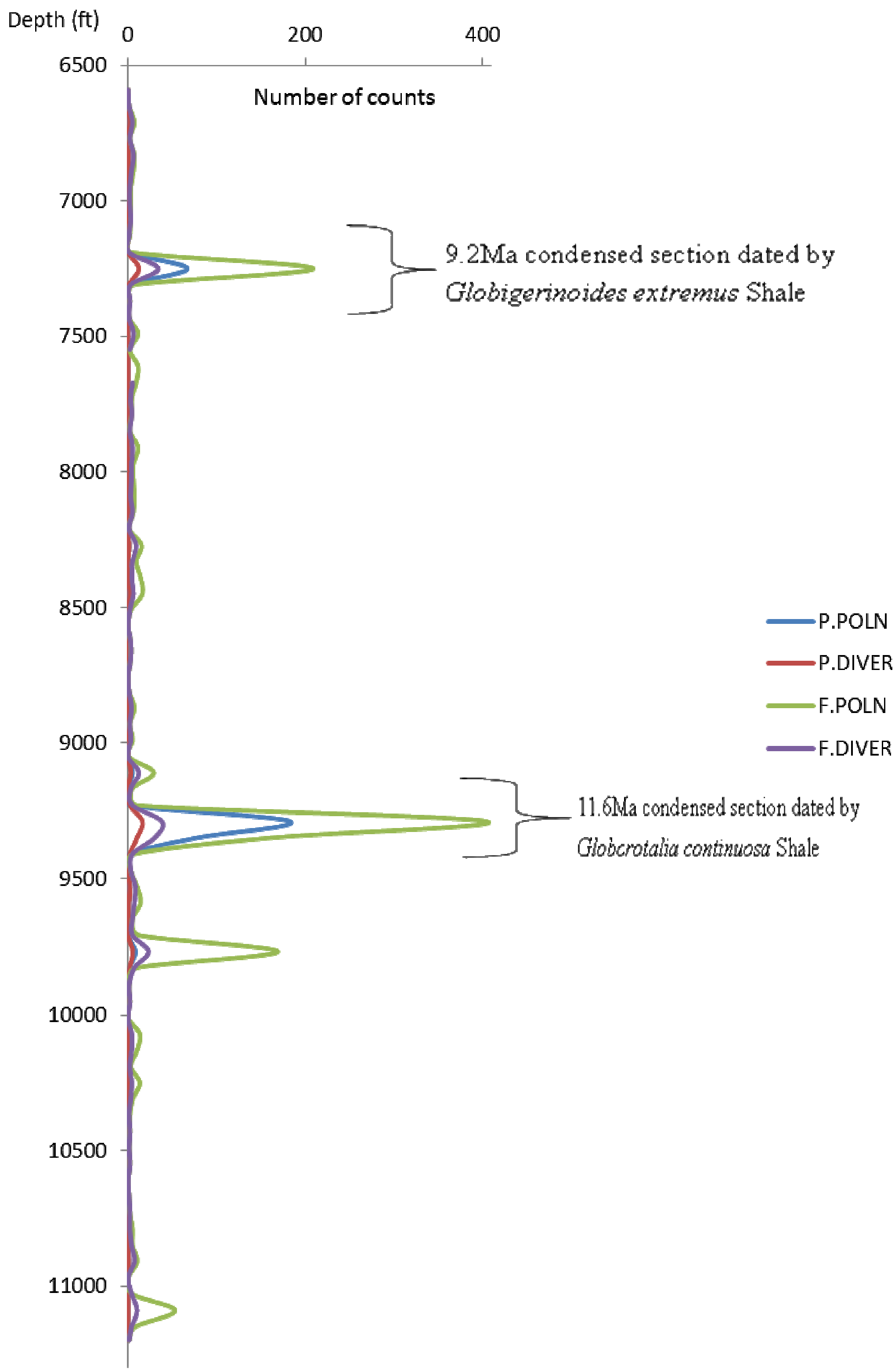

Fig. 6b: Biofacies plot of Okan-65

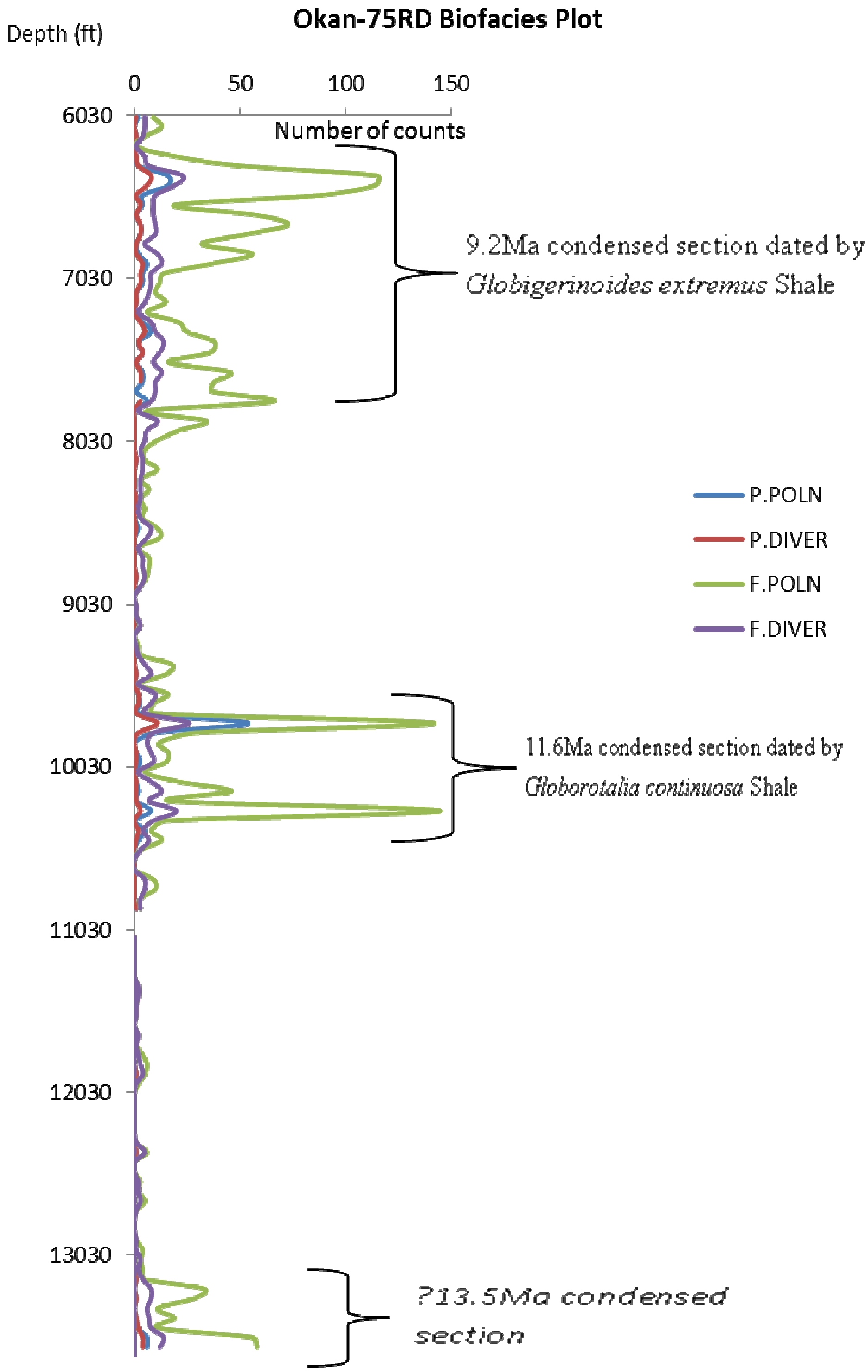

Fig. 6c: Biofacies Plot of Okan-75RD

Key Stratigraphic Surfaces

Sequence stratigraphic surfaces mark changes in stratal stacking pattern and serve as well as systems tract boundaries (Catuneanu *et al*., 2011). The Sequence Boundaries (SBs) and Maximum Flooding Surfaces (MFSs) are the key sequence stratigraphic surfaces interpreted.

The maximum flooding surfaces (MFSs) were interpreted using the following associations: sudden change from retrograding parasequence pattern to prograding pattern, abundance and diversity peak of total and planktic foraminifera associated with condensed sections and deepening in water depth (paleobathymetry), a transgressive surface (TS) which is a thin shale unit usually overlain by a thin glauconitic sand unit known as a trangressive sand. The maximum flooding surfaces were interpreted at the interval of high gamma-ray value corresponding to peak foraminifera abundance and diversity (within the condensed section).

The recognition of sequence boundaries (SBs) was based on the associations of the following events: the base of the thickest sand within a prograding parasequence stacking pattern before the onset of retrograding or aggrading stack and rare to few occurrences of forams associating with shallowing in water depth (Fig.).

System Tracts

Three system tracts were interpreted in the study. There are: Highstand System Tract (HST), Lowstand System Tract (LST) and Transgressive System Tract (TST). The gamma-ray log stacking patterns (Fig. 7a, 7b and 7c) was the bases for definition of individual system tracts while the dated MFS determined from the condensed sections and paleobathymetry determined from biostratigraphy provided the control.

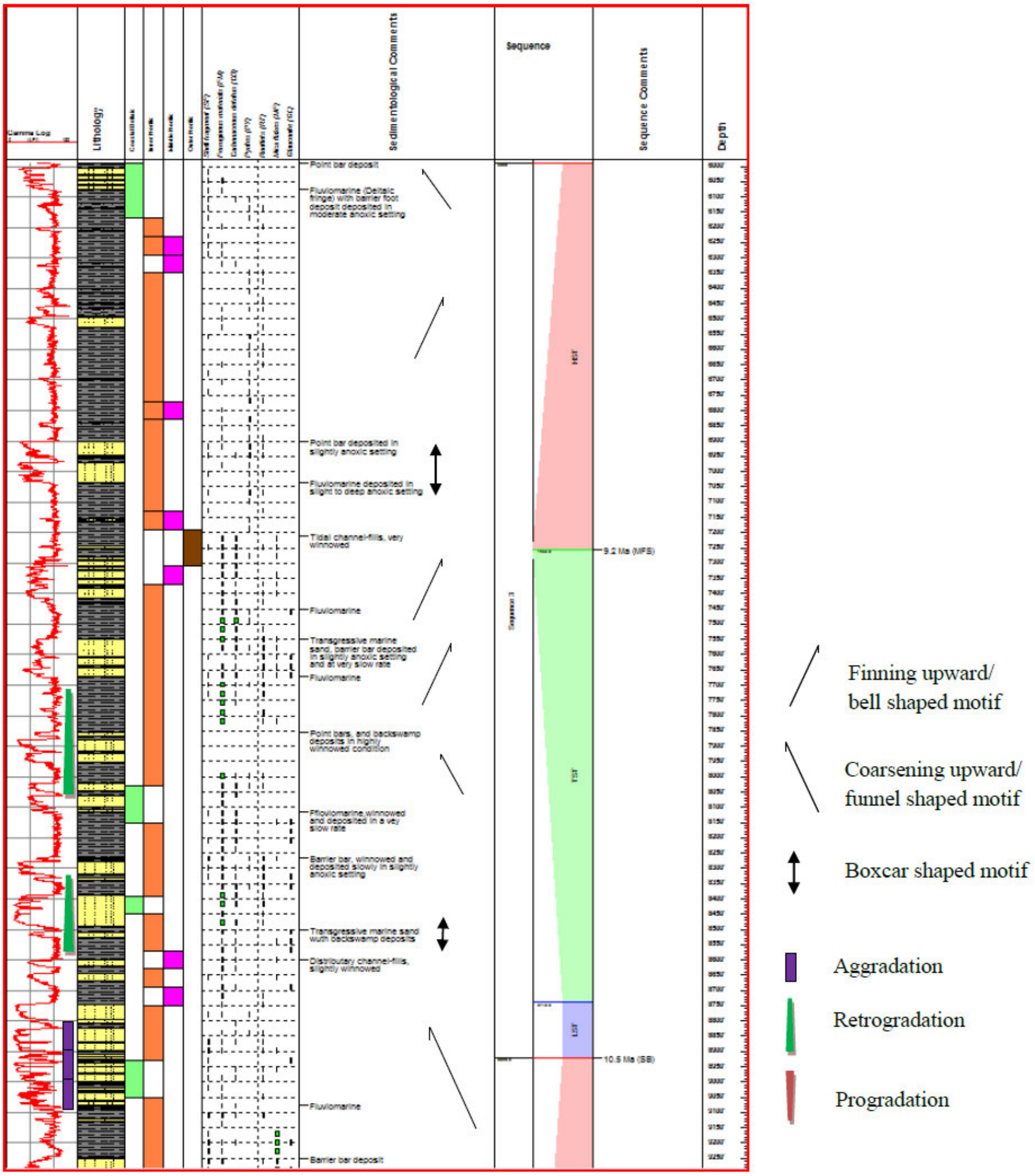

Fig. 7a: Stacking patterns interpreted in Okan-78 well.

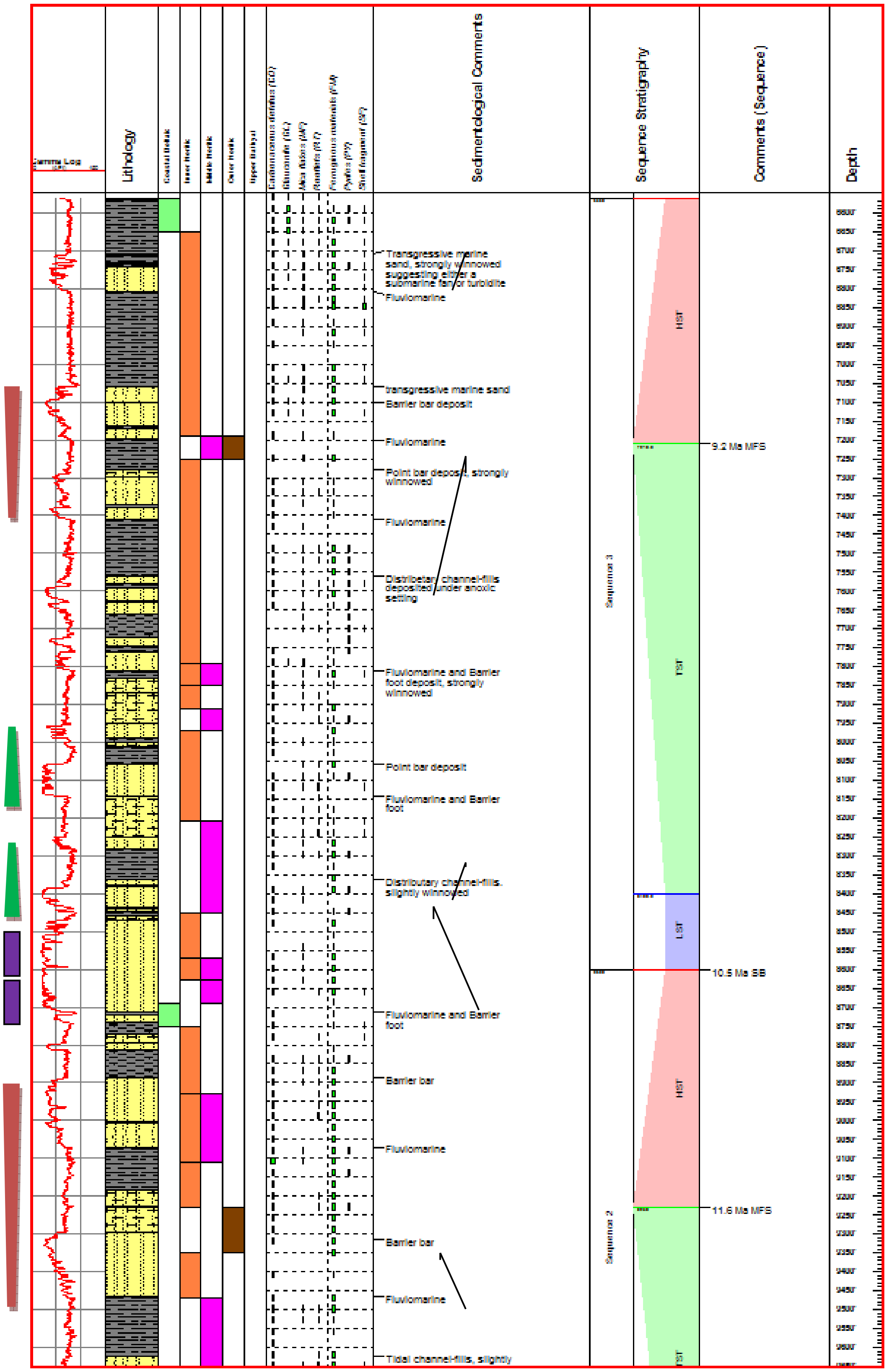

Fig. 7b: Depositional systems within system tracts in Okan-65

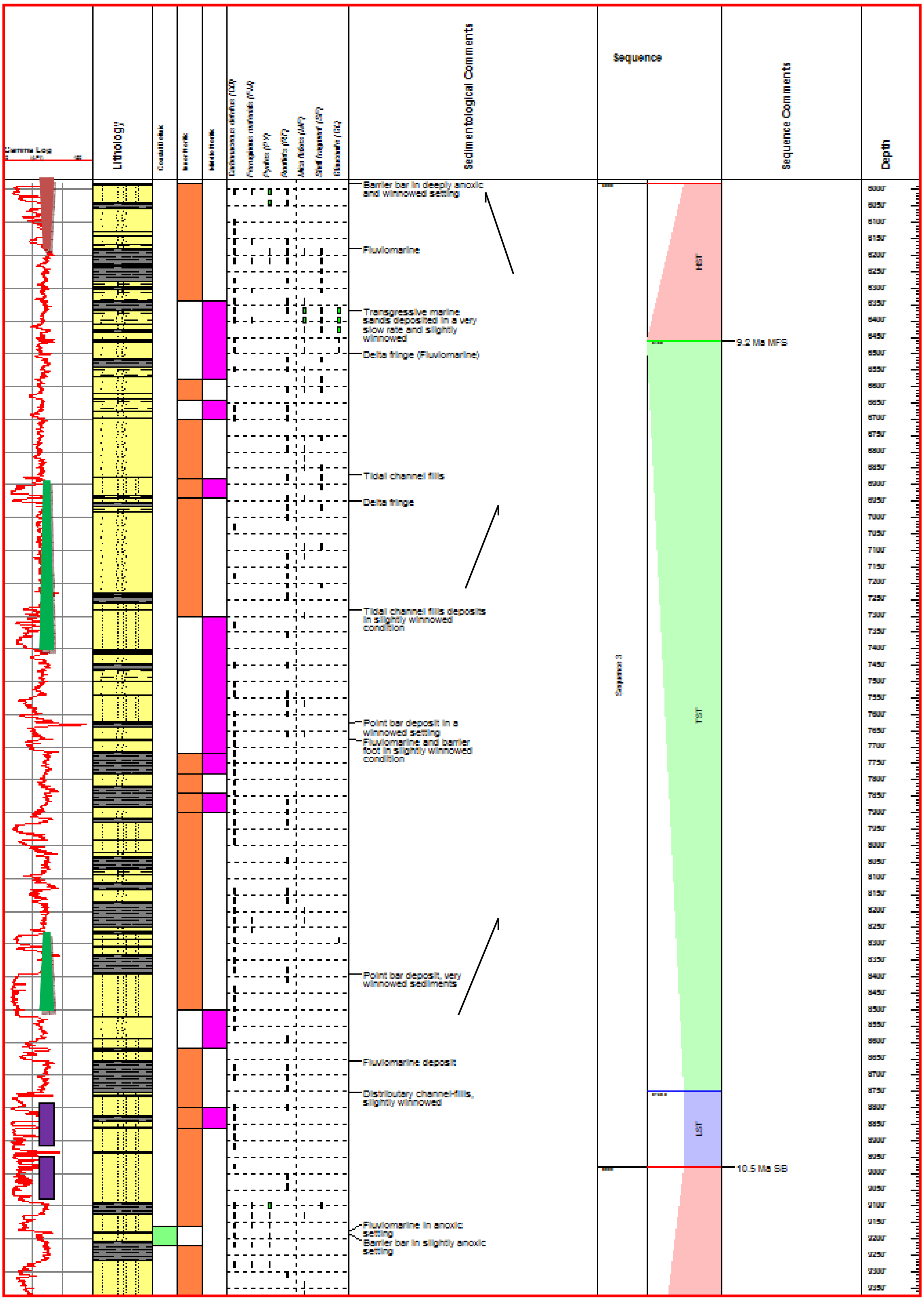

Fig. 7c: Depositional systems within system tracts in Okan-75RD

Highstand system tract (HST):

The HSTs were defined by progradational stacking patterns where individual sands thicken upward. The base of the thickest sand just before retrogradation start defined the sequence boundary. The late HSTs are associated with point bars while the early HSTs are associated with barrier bars. The high percentage of sands in HST is as a result of fall in sea-level with the shoreline moving basinward exposing the deposited sediments.

Lowstand system tract (LST):
The LSTs were defined by aggradational stacking patterns where individual sands show no obvious thickening or thinning. This shows that the sea-level is neither rising nor falling and sediment has to fill the valley before the sea start rising. The base of this system tract showed erosional truncation and defined the sequence boundary. This system tract is associated with distributary channel fills showing a multi-storey geometry. The trend of the log is usually boxcar while the paleobathymetry ranges from inner to middle neritic.
Transgressive system tract (TST):
The TSTs were defined by retrogradational stacking patterns where individual sands thin upward and individual shales thicken upward. The paleobathymetry ranges from inner to outer neritic with the MFS marked at the outer neritic interval which showed the deepest bathymetry. At the point of MFS the log signatory changes from retrogradational to progradational. The early TSTs are associated with point and barrier bars while the late TSTs are sometimes associated with thin transgressive marine sand.
Depositional Sequences
Van Wagoner et al., 1988, 1990; Vail et al., 1991; Hunt and Tucker, 1992 defined depositional sequence as relatively conformable succession of genetically related strata bounded by subaerial unconformities and their marine correlative conformities. Three depositional sequences were interpreted namely sequence 1, 2 and 3 from the base to the top of the analysed section.
Sequence 1
This sequence is recognised from the base of the studied sections. The systems tracts identified in this sequence are Transgressive and Highstand Systems Tracts. Highstand Systems Tracts (HST) were identified in Okan-65, 75RD and 78 wells, which terminates up-dip at 12.5Ma sequence boundaries (SB) at 10, 030ft, 11, 040ft and 11, 235ft respectively. Okan-75RD well appears to have penetrated deeper section than other two wells, having Transgressive System Tract (TST) that terminate with a questionable (?) 13.5Ma maximum flooding surface (?MFS) at 13, 280ft. The TST was identified based on shaly lithology (with high gamma-ray values) and peak benthic and plankthic foraminifera occurrence indicating condensed section. However, it is proper to question the MFS at that section since the base of that shale is not seen and other activities below it cannot be determined.
Sequence 2
The sequence 2 comprises TST and HST as systems tracts. In Okan-65 well, the TST was identified from 10, 030ft to 9, 230ft while in Okan-75RD and Okan-78, the same TST was identified from 11, 040ft to 9, 900ft and from 11, 235ft to 10, 280ft respectively. These TSTs terminate with 11.6Ma MFSs. The 11.6Ma MFS was marked by peak faunal abundance and diversity, generally characterised by first downhole occurrence (FDO) of *Globorotalia continuosa*, *G. obese*, *G. mayeri* and *Cassigerinella chipolensis* with presence of glauconite.
The HST was identified from 9, 230ft to 8, 600ft, 9, 900ft to 8, 950ft and 10, 280ft to 8, 920ft in Okan-65, 75RD and 78 wells respectively. This HST terminates with 10.5Ma SB.
Sequence 3
The sequence architecture of sequence 3 started with Lowstand System Tract (LST) interpreted to be an incised valley fill (IVF). It started from 8, 600ft to 8400ft, 8, 950ft to 8, 750ft and 8, 920ft to 8, 740ft in Okan-65, 75RD and 78 respectively. The LST is followed by TST which started from 8, 400ft to 7, 210ft, 8, 750ft to 6, 460ft and 8, 740ft to 7, 255ft in well 65, 75RD and 78 respectively. The TST terminates with 9.2Ma MFS which was followed by HST that formed the last systems tract in the studied sections of the three wells. The 9.2Ma MFS is marked by Last Downhole Occurrence (LDO) of *Globigerinoides extremus* and *Sphaeroidinellopsis seminulina*.
Discussion
The 13.4Ma MFS in Okan-75RD was interpreted based on the change from retrograding GR-log to prograding signatures and higher gamma value at 13, 280ft. This prograding deposit is a HST that terminates up-dip at 12.5Ma SB. In Okan- 65 and 78 wells, this SB appears to be a tidal ravinement surface (TRS) where subaerial unconformity was replaced by a younger transgressive surface of erosion at the contact between normal regressive highstand and overlying transgressive deposit (Catuneanu, 2006). The TST that followed the 12.5Ma SB could be interpreted to be deposited in a tidal-dominated estuary where the channels and point- bar sands were deposited as a result of combined effect of strong ebb tide and river acting together, while the shales were deposited when strong flood tide completely counteract the river flow, resulting in standing water which allows deposition from suspension (Catuneanu, 2006). The HST that followed this TST terminates up-dip with 10.5Ma SB.

The scour surface that marked the 10.5Ma SB is followed by Lowstand System Tract (LST) interpreted as incised valley fills (IVF). The IVF was formed during the falling stage as a result of base level shift and down-cutting caused by river incision of highstand normal regression deposits creating a valley. This valley was filled during the rising stage when the sea level is transgressing. The average thickness of this IVF is about 200ft in all the wells and appears to be deposited in tidal dominated channels. From the sedimentological interpretations, the IVF is formed within the section interpreted as multi-storey channel fill and are associated with abundant shell fragments, rare to common glauconite, rare ferruginous materials and carbonaceous detritus.

These channels are actually exploration targets because they formed good reservoirs for oil and gas accumulations.

The TST that followed the LST (IVF) terminates up-dip with 9.2Ma MFS. The early TSTs have some point-bar and channel deposits while the late TSTs have thick accumulation of shales which finally terminate with MFS. The whole system tracts ended up-dip with HST at the sequence 3 with no visible sequence boundary (SB).

The development and distribution of sequences and systems tracts reflect paleogeographic changes that were strongly influenced by tectonics, sediment supply and climate changes (Dong *et al*., 2011). The correlation panel (Fig. 8) shows the presence of back - back faults that control deposition across the three wells. The Okan-65 well is at the up-thrown block of the faults while Okan- 78 and 75RD are at the down-thrown blocks. This arrangement ensured that the sequences thinned at the centre (Okan-65) and thickened at the flanks (Okan-78 and 75RD). The summary table is presented as Table 2.

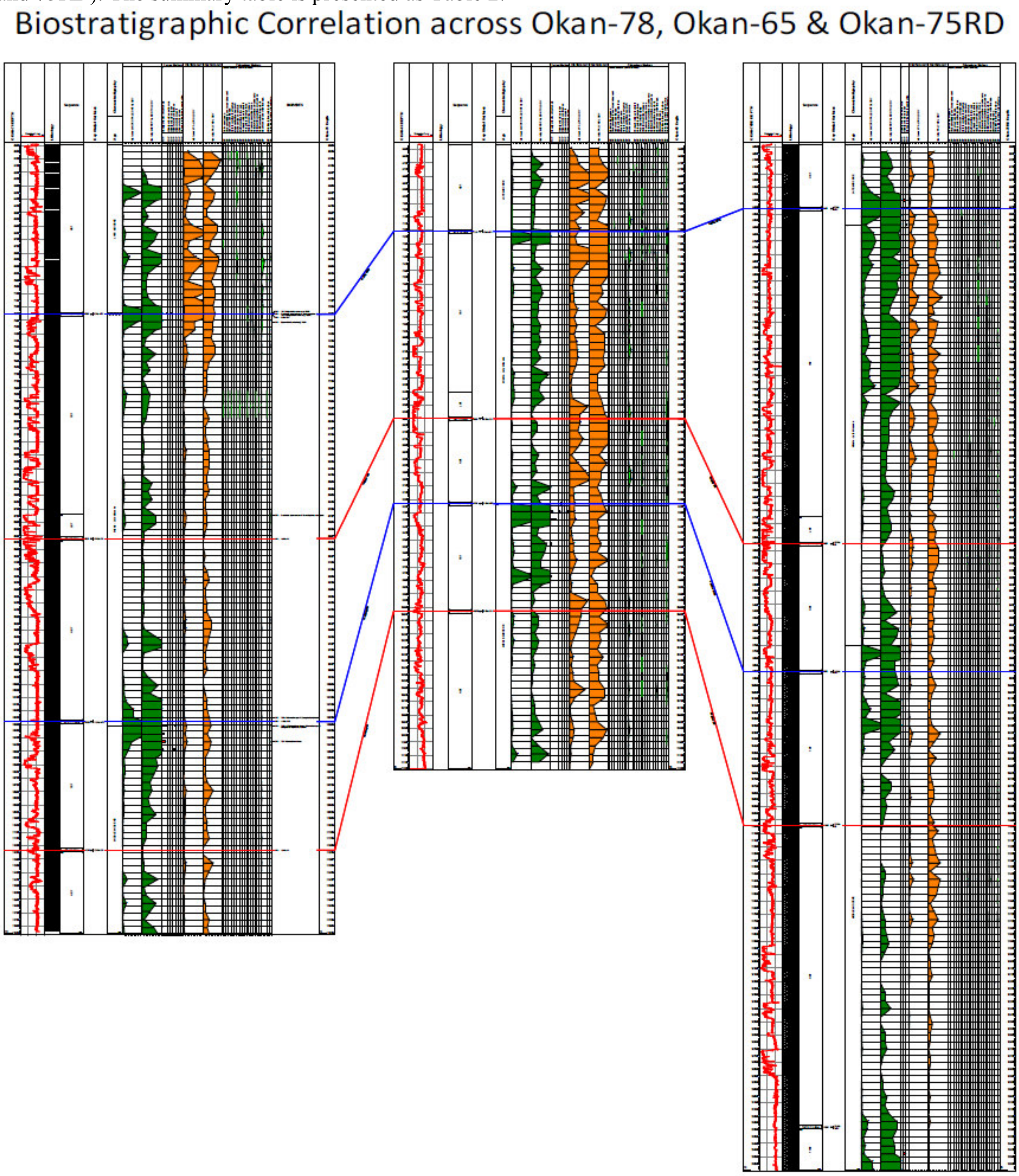

Fig. 7: Sequence stratigraphic correlation across Okan-78, – 65, and -75RD well

Table 2: Sequence Stratigraphic Comparison Table

Sequence	Stratal Surfaces	Age (Ma)	Okan-65	Okan-75RD	Okan-78	Condensed Section Event Markers	Systems Tracts	Okan-65	Okan-75RD	Okan-78
			Depth (ft)	Depth (ft)	Depth (ft)			Interval (ft)	Interval (ft)	Interval (ft)
SEQ. 3	MFS	9.2	7210	6460	7255	**LDO: Globigerinoides extremus & Sphaeroidinellopsis seminulina**	HST	7210 - 6560	6460 - 5980	7255 - 5990
	SB	10.5	8600	8950	8920		TST	8400 - 7210	8750 - 6460	8740 - 7255
							LST	8600 - 8400	8950 - 8750	8920 - 8740
SEQ. 2	MFS	11.6	9230	9900	10280	**FDO: Globorotalia continuosa, G. obese, G. mayeri and Cassigerinella chipolensis with presence of glauconite**				
	SB	12.5	10030	11040	11235		HST	9230 - 8600	9900 - 8950	10280- 8920
							TST	10030 - 9230	11040 - 9900	11235- 10280
SEQ. 1	?MFS	13.4		13280		**High GR value and peak benthic/ planktic foraminifera occurrence**	HST	11200 - 10030	13280 - 11040	11855- 11235
							?TST		13600 - 13280	

CONCLUSION

Ditch-cutting samples, wireline logs (gamma ray and resistivity), and base map were available for the study. Ditch-cutting samples from the three wells were subdivided for sedimentological, palynological and micropalaeontological analyses. The studied sections which fell within the Agbada Formation were sedimentogically characterized by integration of textural, accessory minerals/materials and lithological descriptions of the sediments. Sedimentological results indicated a cyclic pattern of sedimentation which changes from regressive to transgressive phases. The regressive phase ranges from channel fill deposits (point bars) through barrier bars/foot to transgressive marine sands while the transgressive phase ranges from fluviomarine to fully marine shales.

Two complete and one incomplete depositional sequence defined by their sequence boundaries were identified in the three wells. The sequence 1 is incomplete and only highstand system tract (HST) was identified in Okan-65 and Okan-78 while in Okan-75RD, two systems tracts namely: transgressive system tract (TST) and HST were identified. The sequence 2 comprises the TST and the HST while sequence 3 comprises lowstand system tract (LST), TST and HST. The LST in sequence 3 is interpreted as incised valley fills (IVF) deposited in tidal-dominated estuarine environment.

Integration of depositional systems and sytems tract showed that the late HSTs are associated with point bars while the early HSTs are associated with shoreface sands. The high percentage of sands in HST is as a result of fall in sea-level with the shoreline moving basinward exposing the deposited sediments. Secondly, that the LSTs are associated with shoreface sands showing a multi-storey geometry. The trend of the log is usually boxcar while the paleobathymetry ranges from inner to middle neritic. Thirdly, that the early TSTs are associated with point and barrier bars. And finally the thin transgressive marine sands mark the transgressive surfaces (TSs), which sometimes are associated with late TSTs. Therefore, most of the good quality reservoirs are within the LSTs, late HSTs and early TSTs.

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