CHAPTER 1

1.0 INTRODUCTION

1.1 Background

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 well in Nigeria. The first well, Okan-1 was spudded on December 8, 1963 and completed as a new field discovery on January 1, 1964. Appraisal/development drilling began immediately and as of July 1, 1966, 26 wells had been drilled of which 2 were dry and abandoned (Frankl and Cordry, 1967). Cumulative production from the field was 22, 274, 270 bbls as of August 1966 (Whiteman, 1980). However, more wells have been drilled since then but today most of the wells are no longer producing. Therefore, there is need for proper re-appraisal of the wells to determine the means of improving on the field's production.

For the purpose of this study, three wells, Okan-65, 75RD and 78 were selected for high resolution biostratigraphic interpretation in a sequence stratigraphic context. The studied intervals range from 6, 560 – 11, 200ft in Okan-65, 5, 980 – 13, 600ft in Okan-75RD and 5, 990 – 11, 855ft in Okan-78.

1.2 Statement of problems

Sequence stratigraphic concepts help in exploration and production of hydrocarbon by defining play boundaries and prospect. The challenge, however, is how to use these concepts to find more petroleum either through exploration or field development. Sands in siliciclastic environment such as Niger Delta mainly serve as reservoirs for hydrocarbon. The problem, however, is that these sands are not always continuous because they pinches out laterally. Therefore, proper predictions of their distribution laterally and vertically will help define the play boundaries and prospects, which will reduce exploration risk. There have been proven successes in using the sequence stratigraphic concepts in locating lowstand system tracts (LSTs) and early transgressive system tracts (TSTs) reservoirs (Bowen *et al*., 1996). In carrying out this research I want to know if I can solve the following problems:

1. Define the distribution of sands which could be the possible hydrocarbon reservoirs in the area of interest.
2. The possibility of using species names in place of codes used by different oil companies in Nigeria in biozonation and dating of Niger Delta sediments (Can there be a uniform Niger Delta zonation shemes at the public domain?).

1.3 Objectives

The objectives of the project are as stated below:

- Subdivision of the geological sections into their chronostratigraphic zones and subzones.
- Finding the specific (fossil species) names that can serve as the uniform biozonal names instead of different alphanumeric names used by oil companies in Nigeria
- Determination of the ages and environments of deposition of all sequences penetrated by the wells.
- Establishment of sequence stratigraphic framework of the analyzed sections.
- Correlation of the key surfaces (Sequence Boundaries and Maximum Flooding Surfaces) in each of the wells.

1.4 Scope of the work

This work cuts across the following geological disciplines:

(i) Sedimentology: Samples from the three wells were subjected to textural (grain size, sorting, colour and roundness) and accessory mineral analyses.

(ii) Log interpretation: Gamma ray logs of the three wells were interpreted in the context of the ratios of different lithofacies namely: sand, shale, silt and combination of two or three of the lithofacies.

(iii) Biostratigraphy: Palynology, micropaleontology (foraminifera) and calcareous nannofossil were carried out to establish chronostratigraphic biozones/subzones and their palaeobathymetry.

(iv) Sequence stratigraphy: Integrated results from sedimentology and biostratigraphy enabled the interpretation of sequence architectures of the studied sections. The chronostratigraphic surfaces were correlated across the three wells which clearly showed the reservoir intervals.

1.5 Data set

The data set were supplied by Chevron Nigeria Limited and consist of the following:

1. **Ditch-cutting samples:**

The samples were weighed and divided among the following biostratigraphic and sedimentological disciplines: micropalaeontology, palynology, nannopalaeontology and sedimentology. The samples were supplied at 30ft intervals and a total of one hundred and fifty-six (156) samples were available for Okan-65 well, two hundred and fifty-six (256) for Okan-75RD while two hundred (200) were for Okan-78 well. Samples for foraminifera and palynology were composited at 60ft intervals while samples for nannofossil and sedimentology were processed as they were supplied (i.e. at 30ft intervals).

2. **Wireline logs (gamma ray and resistivity):**

These were used for lithogic and stacking patterns interpretations. The combination of the logs with accessory minerals and other materials help in interpretation of depositional environments.

3. **Base map:**

The base map (Fig. 1.1) shows the positions of the wells, which served as a guide during correlation.

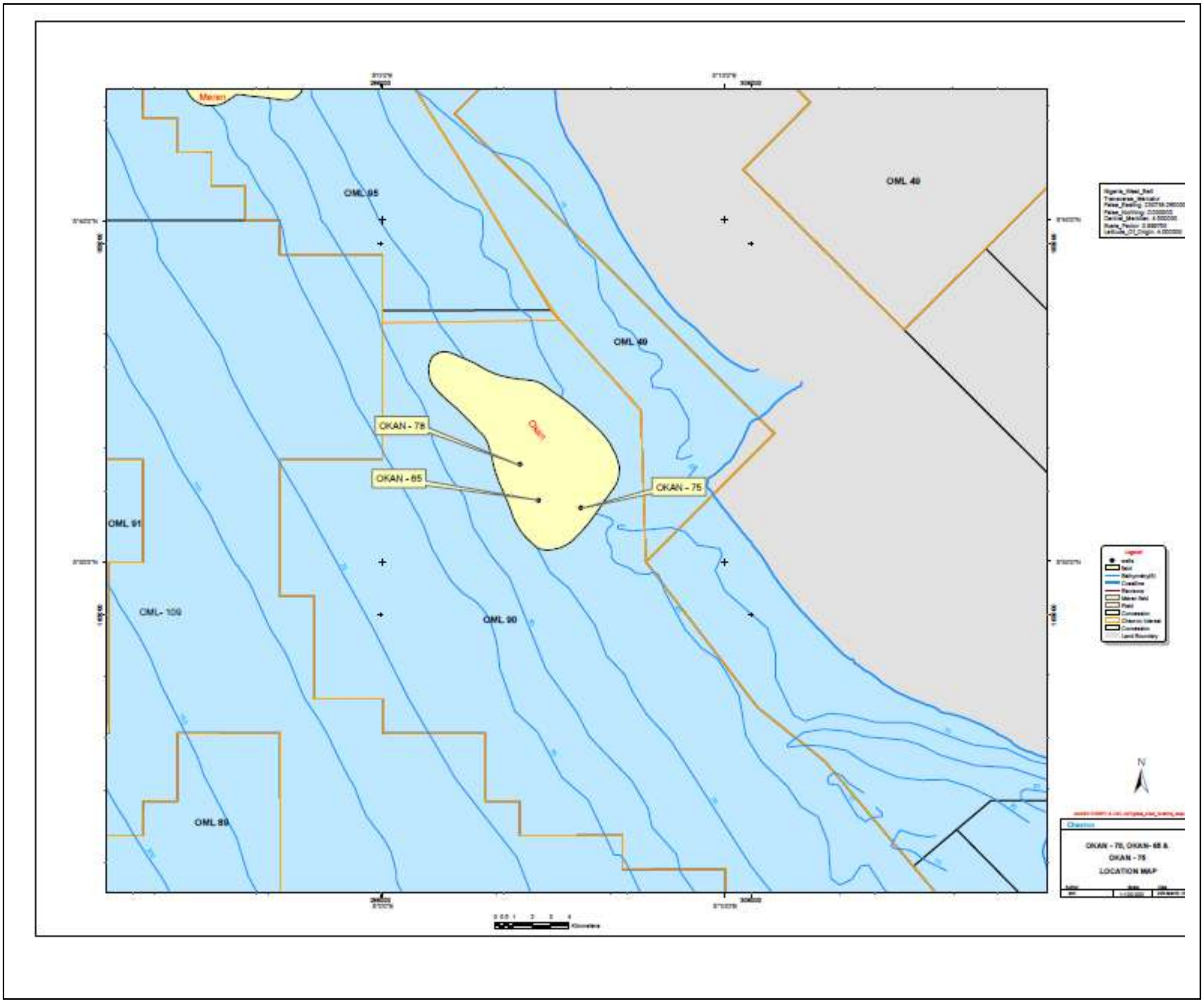


Fig. 1.1: Base map of the field showing the locations of Okan-65, 75 and 78 wells

Chapter 2

2.0 LITERATURE REVIEW

2.1 Review of the Niger Delta geology

The Niger Delta Basin is situated on the continental margin of the Gulf of Guinea in equatorial West Africa, between latitudes 3^0 and 6^0N and longitudes 5^0 and 8^0 E. It ranks amongst the world's most prolific petroleum producing Tertiary deltas that together account for about 5% of the world's oil and gas reserves and for about 2-5% of the present-day basin areas on earth. The Niger Delta present day drainage area of 1,200,000km^2 has produced a delta area of about 75,000km^2 with a clastic fill of about 12,000m (Reijers *et al.*, 1996). 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).

By Late Cretaceous and Early Cenozoic time, subsidence of the continental margin was well underway as oceanic crust cooled; by Early Palaeocene time the sea had flooded onto the area's old shoulders and flanks underlain by continental crust such as the Anambra Basin (Whiteman, 1982). This transgression terminated the development of the Anambra Basin, Delta Complex and by this time the sea had flooded into the Afikpo syncline; the Cameroon Basin and into the Dahomey Basin. At that time, the Abakaliki and Benue Fold Belt however, were topographically and structurally high and the sea did not extend to them.

The Niger Delta Complex began to evolve in Palaeocene and Eocene times within this framework which has dominated the depositional and structural scene at the eastern end of the Gulf of Guinea.

According to Whiteman (1982), four major depocentres can be identified as having operated during Mid Eocene times:

1. The Anambra Depocentre fed by proto-Benue-Niger system with the former providing most of the sediment;
2. Onitsha depocentre fed by sediments derived from the Abakaliki Fold Belt and Onitsha High
3. The Afikpo depocentre fed by the Cross River System and
4. Ikang depocentre on the Calabar Flank.

In Palaeocene and Eocene times, 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. 2.1a) 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. 2.1b) 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).

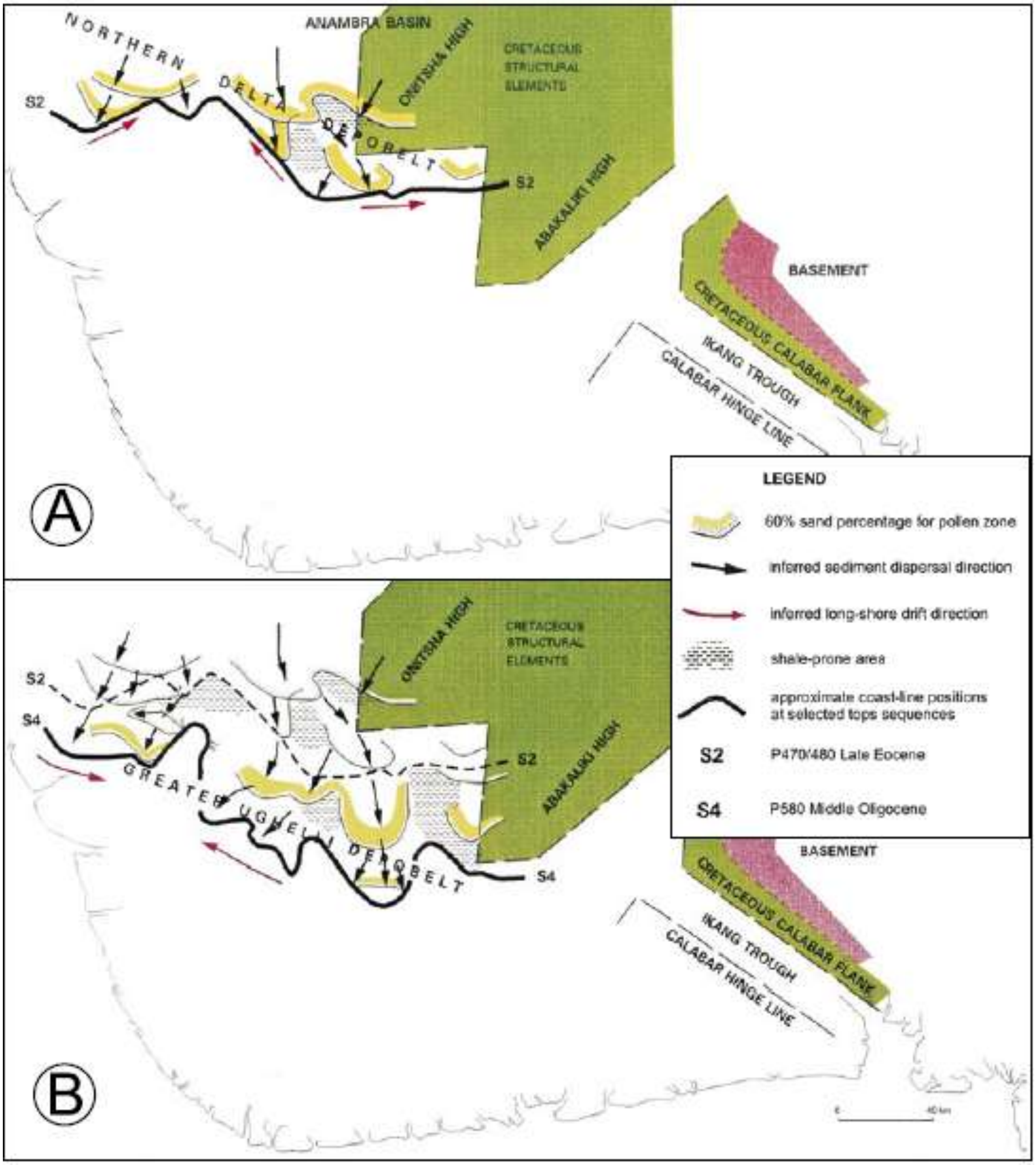


Fig. 2.1a: Palaeo-drainage trend and stratigraphic evolution of Northern Delta (A) and Greater Ughelli Depobelts based on microfloral units (after Evamy *et al.,* 1978, modified by Reijers, 2011)

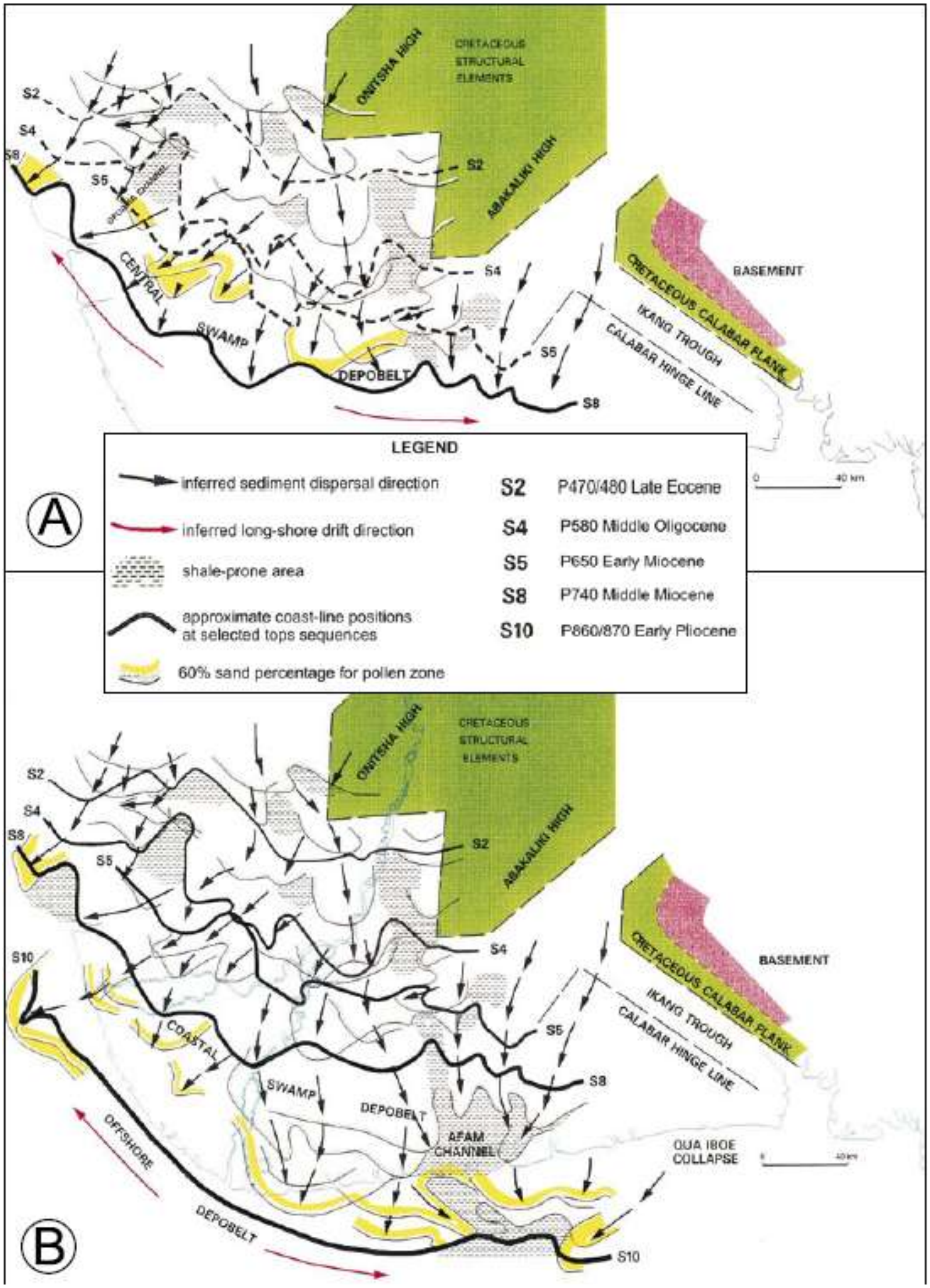


Fig.2. 1b: Palaeo-drainage trend and stratigraphic evolution of Central Swamp (A) and Coastal Swamp and Offshore Depobelts based on microfloral units (after Evamy *et al.,* 1978, modified by Reijers, 2011)

The Niger Delta Basin is marked on the northwest by a subsurface continuation of the West African shield, the Benin Flank. The eastern edge of the basin ends with the Calabar Flank, which is a continuation of southeast-northwest trending Oban Masif that breaks off to form the Anambra Basin and the Abakaliki Uplift (Murat, 1972) Fig. 2.2.

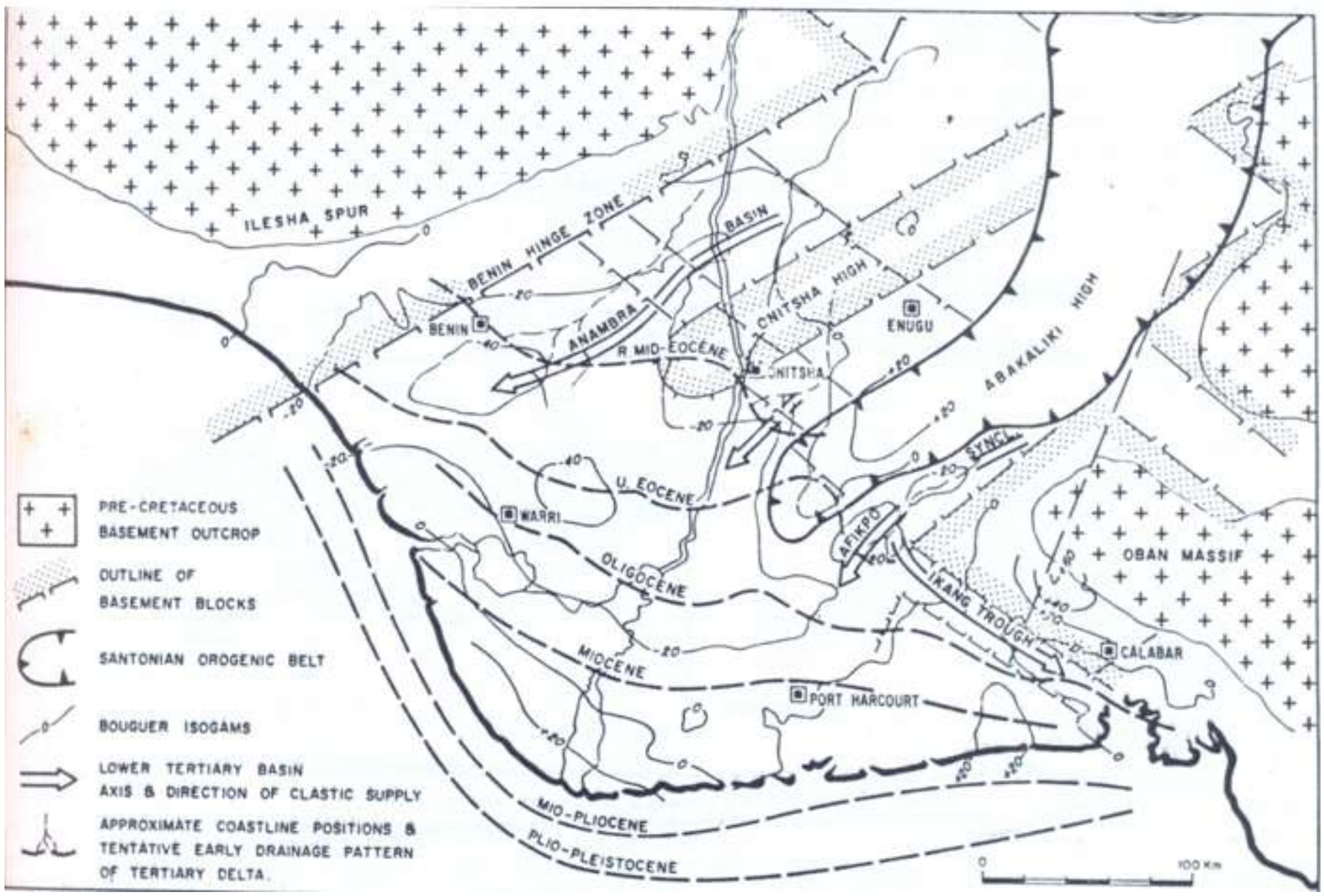


Fig. 2.2: Niger Delta megatectonic framework (modified after Short and Stauble, 1967)

It has been shown that the Niger Delta sedimentary wedge consists of series of discrete depocentres or depobelts, each characterized by an individual proximal - distal facies trend within the Agbada Formation. During major progradational pulses, the delta top deposits advance over the Agbada deposits. Under the influence of sediment loading, new depobelt-bounding fault develop and sedimentation of Agbada deposits moves towards this realm, which previously was distal; thus, creating a new, younger deposits of the Benin Formation. Major regional faults thus determine the location of each depobelt (Reijers *et al.*, 1996).

Knox and Omatsola (1989) recognized five (5) major depobelts, each 30-60km wide with the oldest depobelt lying furthest inland and the youngest located offshore. The depobelts are:

a. Northern Delta
b. Greater Ughelli
c. Central swamp
d. Coastal Swamp
e. Offshore Depobelts.

2.2. Lithostratigraphy of the Niger Delta

Well sections through the Niger Delta generally display three vertical subdivisions. These are an upper delta top lithofacies, delta front lithofacies and pro-delta lithofacies. These correspond respectively to the Benin Formation, Agbada Formation and Akata Formation of Short and Stauble (1967). Recent work by Reijers (2011) proposed that these formations be elevated to Group level to enable subdivision of other units to formations.

2.2.1. Benin Formation (Oligocene – Recent)

This is an upper delta – top lithofacies (Reijers *et al*, 1996). The formation is about 280m (1000ft) thick, but may be up to 2,100m in the region of maximum subsidence (Whiteman, 1982). This consists of massive continental sands and gravels. The type section as described by Short and Stauble (1967) is Elele-1 well, 24 miles NNW of Port Harcourt. The lithology penetrated by Elele-1 is predominantly (more than 90%) sandy with a few shale intercalations, which become more abundant towards the base. The sand and sandstone are coarse to fine – grained, commonly granular in texture and are generally unconsolidated. The sands are white or yellowish brown in colour and may be cross-bedded. In general, they appear to be very poorly sorted. Few shaly intercalations have been described. The shales are normally greyish brown, sandy to silty and contain plant remains and dispersed lignite. The recognition of the formation is based on its high sand percentage, few minor shale intercalations and the absence of brackish water and marine faunas (Adeniran, 1995). Composition, structure and grain size of the sequence indicate deposition in a continental, probably upper deltaic environment. The sand and sandstone may represent point- bar deposit, channel fills or natural levees, where as the shales may be interpreted as backswamp deposits and oxbow fills (Short and Stauble, 1967). In the eastern part of the delta, Benin Formation is separated into two main parts by a thick clay sequence known as Afam Clay Member.

2.2.2 <u>Agbada Formation</u> (Eocene – Recent)

This 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. The alternation of sand, sandstone and shale are the result of differential subsidence, variation in sediment supply and shifts of the delta depositional axes, which causes local transgressions and regressions (Short and Stauble, 1967). The thickness is given as between 2,700 and 4,200metres (9,600 – 15,000ft) across the delta (Short and Stauble, 1967; Weber and Daukoru, 1975). The maximum thickness occurs towards the center of the basin (Whiteman, 1982). In practice, the top is defined (from wireline logs) as the base of the first major sand of the Benin Formation, and the base by the first significant shale body considered being the top of the Akata Shales (Adeniran, 1995).

Oil and gas reverses in the Niger Delta Basin mainly occur in sandstone reservoirs throughout the Agbada Formation. The shales are seals to reservoirs and as such are very important (Short and Stauble, 1967, Weber and Daukoru, 1975).

2.2.2.1 Cyclic sedimentation associated with Agbada Formation

In the west, the formation shows series of overlapping sequences, which may represent successive vertical facies changes due to rapid deepening of the basin in this area. While in the east, four distinct units are described (Orife and Avbobvo, 1981), and these include:

a. Biafra Bed – which is the oldest unit, overlies the Akata Formation and consists of alternating shale/ coarse sand sequences. The Biafra sands are very fine to coarse grained, light to brown, poorly to well sorted and moderately consolidated. Sand percentages range from 75% in the upper part to 50% or less in the lower part. The marine shales are dark grey, hard and fissile with occasional shell fragments (Opara, 1981). The Biafra sands serve as the major reservoir with unconformably overlying Qua Iboe shales providing a caprock.

b. Rubble Bed – this overlies the Biafra Bed and it is made up of shale, unconsolidated sands and silts with an unconformity towards the top of the unit. This Rubble Bed and the underlying Biafra Bed are said to be the hydrocarbon members of the formation. The most significant contrast between Rubble Bed and Biafra is seen in the wireline response on the dipmeter log. Rubble Beds show a very chaotic "bag of nails" pattern of dips similar to the Qua Iboe shale. This erratic dip pattern is in sharp contrast with the relatively constant dip and azimuth of the underlying Biafra.

c. Qua-Iboe Bed – this is predominantly shale with occasionally alternating sandy layers. The contact of the Qua Iboe shale with underlying Biafra strata or Rubble Beds is identified on wireline logs partly by the first major sand break. It overlies the Rubble Bed with the base being erosive. The erosional surface truncated both the Rubble Bed and the Biafra Beds up-dip in the north where the sediments are much older. The erosional surface is filled with the Miocene clay deposit. It also contains oil and gas.

d. D-1 Bed – which is the topmost, consists predominantly sands with occasional shale intercalations, which are of marine and brackish origin.

Weber (1971) outlines a complete cycle of sedimentation in paralic sequence like Niger Delta to show the following:

- a thin fossiliferous transgressive marine sand followed by
- an offlap sequence which commences with a marine shale and continues with laminated fluviomarine sediments
- Barrier-bar / or fluviatile sediments may follow before another transgression terminates the cycle.

Petrophysical logs from Uzere West field showed that those cycles can be easily recognized in the logs especially when the properties of various types of deposits are related to the log response (Weber, 1971). The above environments as described by Weber (1971) are presented below:

1. <u>Onlap Sands (Transgressive marine sand)</u>

Most cycles begin with the erosion of the underlying sand unit and the deposition of thin fossiliferous transgressive marine sand. The resistivity logs of these sands show very high values because their pores are partly filled with carbonate cement. And often the gamma radiation emitted by the transgressive sands is also high due to a high percentage of the potassium-rich glauconite. The transgressive sands are mainly derived from reworking and winnowing of the eroded beds. In addition, the gravelly sands contain an abundance of debris such as shell fragments, foraminifera, bryozoa and fish otoliths. Weber (1971) noted that this type of transgressive sand is probably associated with a regional transgression which pushed the shoreline back over a considerable distance. The presence of abundant glauconite is indicative of slow marine deposition.

There is also another less common type of onlap deposit which is generally thicker than the type above. Weber (1971) distinguished between this second type of transgressive sand as having up to 10metres thick while the first type is up to about 3metres. In this type of onlap sand, the contact between the onlap and underlying offlap sediment is less erosive. The onlap seems to have taken place more gradually and the onlap sands have the character of fluviomarine sediments. However, Instead of the normal upward coarsening of the fluvionarine deposits, these onlap sands become finer upwards and finally grade into marine clay.

Offlap Sediments

2. Marine clay

The marine clay overlying the onlap sands is usually quite silty and sandy. A gradual decrease of faunal remains and a diminishing diversity in species indicates an upwardly increasing sedimentation rate. Streaks and lenses of very fine sand to silt occur throughout, clay and plant remains can be abundant. The faunal interpretation, combined with occasional abundant of plant remains indicate that the clays were deposited in the inner to middle neritic zones**.**

3. Fluviomarine (Deltaic Fringe) and Barrier-Foot Deposits

The marine clay gradually becomes sandier and changes to laminated clay/silt/fine sand towards the top. As a result of rapid sedimentation, the layers are little disturbed by burrowing. This is of interest because this part of the offlap cycles is deposited on a very flat slope. Thus after folding in a rollover structure, these intervals can be used for deriving accurate structural dips from the dipmeter logs (Weber, 1971).

Gradually the fluviomarine character becomes more pronounced because the sand laminae thicken and the average grain size increases. Secondly, the plant remains are very common and occasionally accumulate in thin lignitic streaks. This type of deposit is termed “barrier foot” and it is often form the proximal fluviomarine (frontal part of coastal barriers).The gamma radiation associated with barrier foot deposit is usually high, often higher than that of the marine clay.

4. <u>Barrier Bar</u>

The barrier foot is often overlain by the higher energy barrier beach and washover sands. The cleaner and coarser sands deposited in the zone where wave action takes place are termed “barrier bar’’ deposits (Weber 1971). The sands are fine with an average grain size of 250-60 microns while the sorting of the sand varies considerably.

The main part of the barrier bars is usually parallel bedded with occasional small-scale cross-bedding in the lower part and a limited number of burrows. Silty clay breaks and lignite beds are common. The upward coarsening is often fairly gradual and is reflected by gradual changes in sp log and gamma- ray log response. This coarsening is almost always accompanied by an upwardly increasing permeability. Thus, in oil-bearing reservoirs of this type the resistivity generally increases in an upwards direction.

Clay breaks in the barrier bar, unlike clay breaks in fluviatile sediments, can often be correlated over large distances. These continuous clay breaks reduce the vertical permeability of many barrier-bar reservoirs.

5. <u>Tidal Channels</u>

Tidal Channels - fills often consist of series of thin cross-bedded fining upwards sequences with a clay pebble or gravelly lag deposit at the base, and separated by thin clay beds. The grain-size distributions are similar to those of fluviatile deposits in the lower deltaic plain. Clay breaks between these sequences give the channel-fills a serrated character on sp and gamma ray logs. The clay breaks are generally difficult to correlate in contrasts to the very continuous clay breaks in barrier bar.

6. <u>Fluviatile Deposits</u>

- Point-bar
- Distribuary channel fills

6.1. <u>Point-Bar deposits characteristics</u>

- They have fairly constant low gamma radiation and the SP response is also quite constant.
- The fluviatile sediments have a characteristic upward fining grain-size distribution, however, the log response shows an upward coarsening sequence
- The logs character shows a sharp base which is an indication of erosive character of the fluviatile sand bodies.
- Backswamp deposits consisting of silty clay, thin sands and peat are commonly preserved between and beside point-bar sands.

6.2 <u>Distributary Channel fills characteristics</u>

- Similar in grain-size distribution and internal structure to point-bar sands but frequently form composite sand units.
- The upward fining grain-size distribution is often pronounced in the upper part of the fills which are commonly composed of laminated wavy-bedded clay and silty sand. Plant remains and clay pebbles are common.
- Around the distributary-channel fills, natural lavee deposits of clayey fine sand and crevasse sands are found interbedded with backswamp lagoonal sediments.

On the landward side, the exposures are mainly the lateral equivalents of the (Oligocene – Miocene) Ogwashi – Asaba Formation and the (Eocene) Ameki Formation (Weber and Daukoru, 1975). The two- folds division of the Agbada Formation into an upper sand and sandy- shale unit and a lower shaly unit (Short and Stauble, 1967) correspond roughly to these two surface lateral equivalents (Adeniran, 1995).

2.2.3 Akata Formation (Palaeocene – Recent)

This is a pro-delta lithofacies. The Akata Formation occurs at the foot of the basin and constitutes the oldest formation and the major time – transgressive lithological unit of the delta. It is composed mainly of marine shales, sandy and silty beds, which are thought to have been layed down as turbidites and continental slope channel fills. The thickness of the formation ranges between 560 and 5,560metres (Short and Stauble, 1967; Weber and Daukoru, 1975). The formation is tectonically controlled; as such the thickness varies across the delta, with the maximum thickness at the center of the basin (Whiteman, 1982).

The mature Eocene to Miocene shales of the Akata and the Agbada Formations constitute the major source rocks of the Niger Delta Basin (Reijers *et al*, 1996). The formation probably underlies the whole of the Niger Delta Complex, south of the Imo Shale outcrop which itself was probably deposited under similar conditions of deposition and may be considered as an up-dip equivalent of the Akata Facies.

2.3 Structural styles in Niger Delta

2.3.1. Synsedimentary Structures, Growth Faults and Mud Diapirs

The most striking structural features of the Cenozoic Niger Delta Complex are the large synsedimentary fault (growth fault), rollover anticlines and diapirs which deform the delta complex, largely beneath the Benin Sand facies.

Four basic types of growth faults and rollover anticlines are recognizable in Nigerian scene based on the study of 150 oil fields by Whiteman (1982). These growth faults and rollover anticlines are classified as:

1. One fault rollover anticlines (Type A)
2. Rollovers associated with multiple growth fault (Type B)
3. Simple anticlines associated with the growth faults and anticlines faults (Type C) and

4. Collapsed anticline structures which are complexly faulted by closely spaced growth and antithetic faults and which are associated with diapiric shale structures (Type D). This type is common in coastal region (see Fig. 2.3).

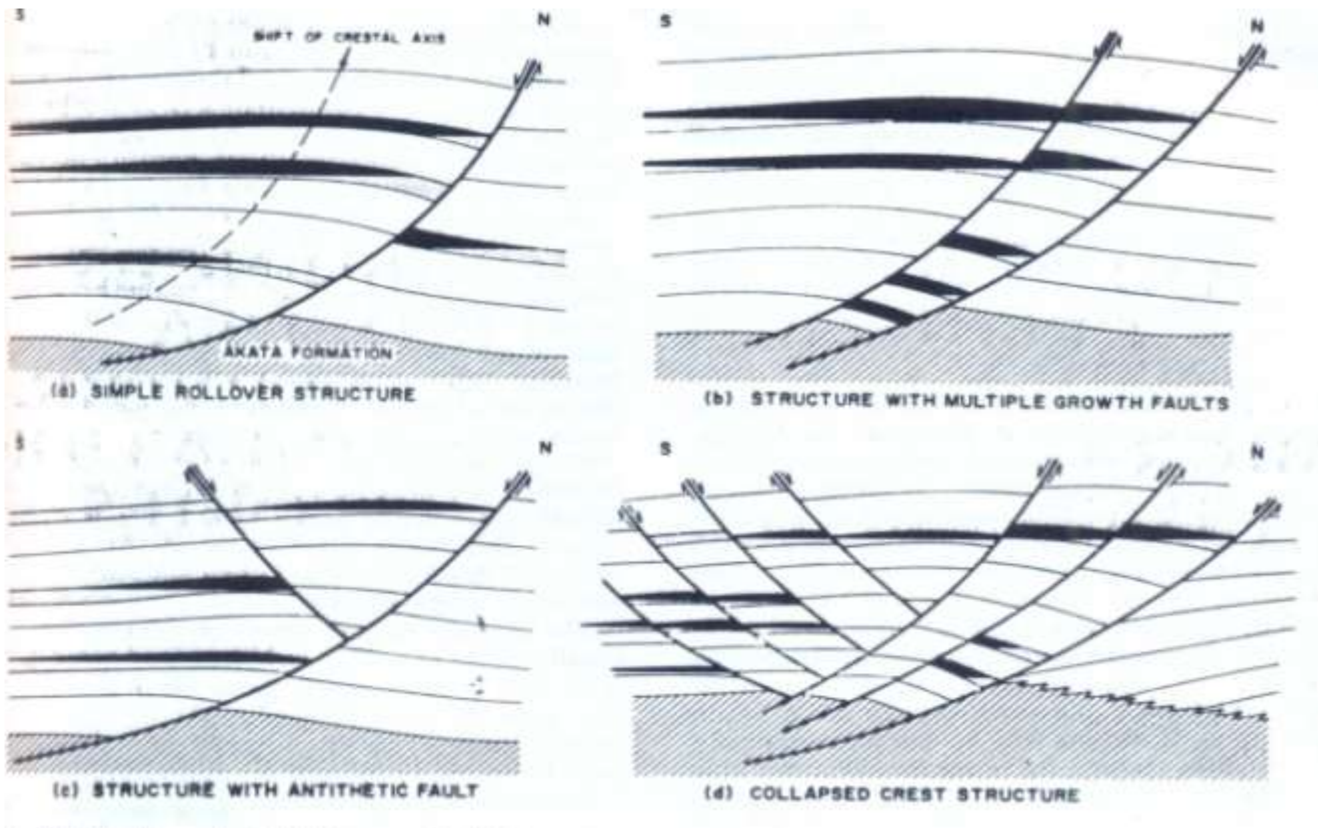


Fig. 2.3: Rollover anticlines associated with simple and complex growth faults (after Evamy *et al*., 1978)

Nigerian growth faults in plan are frequently crescent shaped with the concave side facing the down thrown block i.e. usually towards the sea. Traces tend to be linear in the eastern delta complex and crescent shaped in the western and southern parts. Growth faults die out upwards either in or below the base of the relatively “massive” Benin Sands facies. They affect mainly the Agbada and Akata facies, a fact which points to the important mud compaction element in their evolution. Growth faults act as migratory paths for hydrocarbons generated in the Akata shales and muds so enabling them to migrate and accumulate in the Agbada reservoir sands. They act also as seals to migration. Sands juxtaposed across a fault are often connected but if the fault throw exceeds sand thickness the faults zone can become a seal, dependents on the amount of shale smeared into its fault plane.

2.3.2. Origin of Niger Delta Growth Faults and Rollovers

Growth faults and rollovers anticlines in Nigeria are polygenetic in origin and a variety of hypotheses have been advanced to explain them (Whiteman, 1982).

1. The simple "land slip" type of growth faults and
2. The complex growth faults which are clearly related to Akata mud diapirism.

Short and Stauble (1967) thought that growth faults were formed by mass movements of sediments under the influence of gravity and that the existence of high energy conditions producing marked facies differentiations at the delta front and the presence of deep oceanic water provided an idea "landslip" set up. They assumed that much of the fault movement was contemporaneous and this produced an abrupt thickening of units across the fault on the down thrown side. Frankl and Cordry (1967) followed the explanation and postulation of Short and Stauble (1967) that the growth faults (and associated rollover anticlines) were:

1. Initiated by gravitational sliding of large packages of sediments along the edge of the delta' and
2. That growth continued subsequently for a time due to shale flowage deep in the Akata Formation which is known in several wells to be under compacted and quite mobile.

Frankl and Cordry (1967) pointed out that some of the rollover anticlines associated with growth faults were "severely" faulted internally, that the intensity of folding diminished upward and that the Benin Formation is either usually unfolded or faulted or only slightly modified structurally.

The concept of shale diapirism was added as one of the origin of growth faults. Essentially unstable depositional masses were thought to have slipped along glide planes (growth faults) which were curved and the rollover anticlines were thought to be "wrinkles" or "buckles" produced at the foot of the slides (Whiteman, 1982). Merki (1972) differentiated and illustrated three main types of growth faults based on concept of shale diapirs.

1. **Type-1:** simple growth fault and structures as exemplified by the Ughelli and Afiesere structures. Figures strongly as a controlling force in development.

2. **Type-2:** complex growth faults and rollovers involving marked clay diapirism and "antithetic" secondary expansion faulting as exemplified by EA-2 structure. Progressive uplift due to clay diapirism features strongly in the formation of this type of structure. Up- thrusting is a major force in the formation of this type of structure.
3. **Type-3:** "Back to back" clay ridge structures which are a feature of the outer shelf. These consist of two growth faults showing opposing hade and bounding a very strongly diapiric structure.

Weber and Daukoru (1975) recognized three kinds of diapiric structures "shale upheaval ridge" in Nigeria:

1. Mud diapirs which occur on the landwards side of major growth faults and which because of their positive nature restrict sedimentation on the up thrown side of the growth fault and enhance sedimentation on the downthrown side.
2. Mud diapirs ("shale bulges") located on the seaward side of growth faults which act as positive elements producing collapsed crest structures unconformities etc. and so produce zones of thicker and thinner sediments.
3. Mud diapirs or "shale bulges" which were extruded in a seaward direction on the upper continental slope as a consequence of differential loading of plastic almost uncompacted marine shale. As sedimentation continued these offshore mud diapirs or bulges were buried and their diapiric growth continued producing shale dome like structures.

Again, Evamy *et al*. (1978) classified synsedimentary faults structures into"

A. Synsedimentary Faults:

1. **Structure Building Faults:** these faults define the up dip limits of major rollover structures (Fig.2.3). They are essentially concave in a horizontal plane in a down dip direction. The degree of curvature varies from sub-linear in the east to crescent shaped in the western and southern parts of the delta complex.
2. **Crestal Faults:** crestal faults parallel the axis of rollover structures and differ from structure building faults in that they: show less curvature in the horizontal plane; are generally steeper in the vertical plane; display less growth and tend to be less continuous.

Synthetic and antithetic forms occur but antithetic forms do not show growth. Vertical displacements are sometimes large and at depth they may throw a sandy section against older marine shales.

3. **Flank Faults:** flank faults are located on the southern limbs of major rollover structures and may themselves be deformed by rollover at shallow levels. Southerly dips developed on either side of the faults typify these structures at depth.
4. **Other Faults:** these includes: a) antithetic counter regional faults which do not show growth because they are extensional phenomena and; b) K-type flank faults characterized by their extremely close spacing and complexity.

Examples of these fault types are shown in 2.4 below.

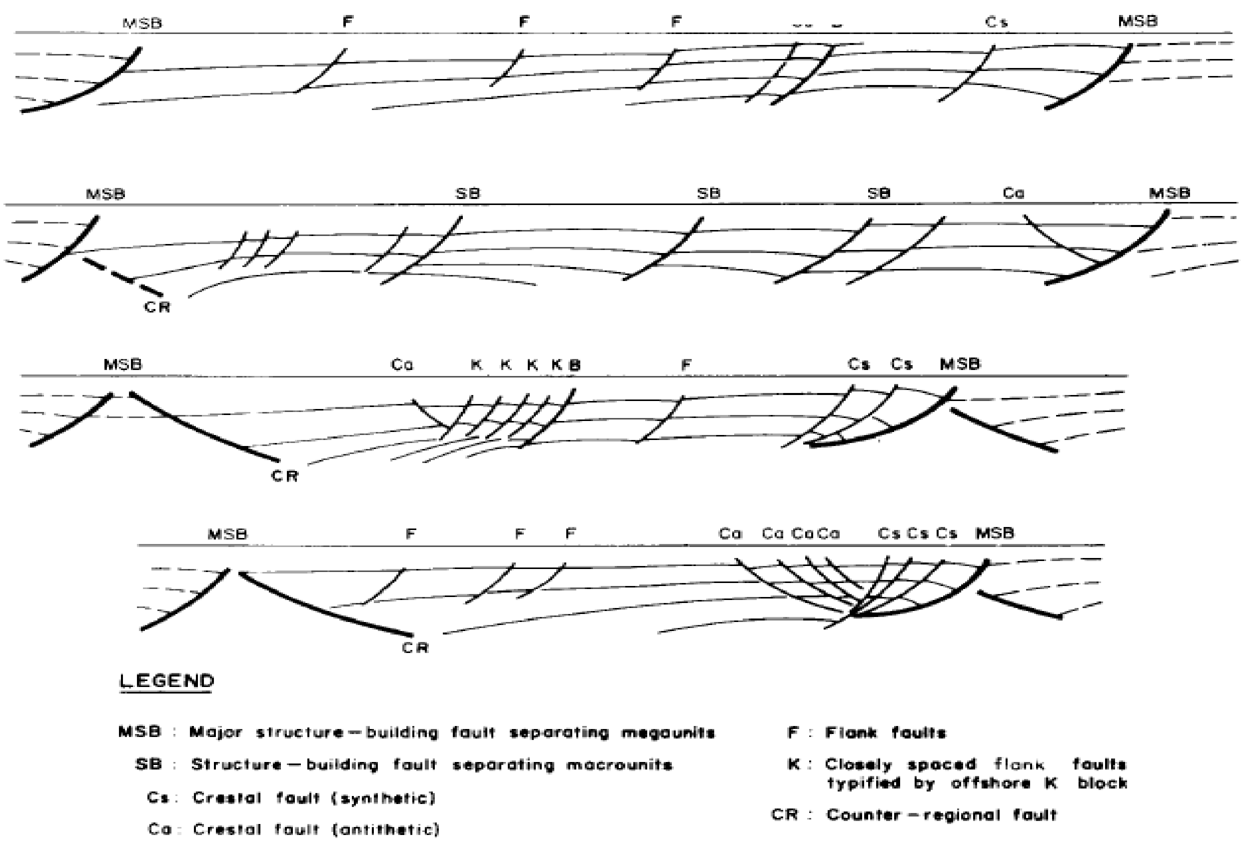


Fig. 2.4: Synsedimentary fault types and megaunits (after Evamy et al., 1978)

2.4 Biostratigraphy

Biostratigraphy is the study of rocks layers based on their fossil contents. It uses the chronostratigraphic range of fossil species to correlate stratigraphic sections and their palaeoenvironmental preference to provide information on depositional setting (Sturrock, 1996). Three microfossils groups are normally studied for high resolution biostratigraphy. These groups are: palynology, micropaleontology and nannopaleontology.

Palynology is the study of organic-walled microfossils. Palynomorphs recoverable under this discipline include: pollen, spores, dinoflagellate cyst, acritarch, fungal spores, freshwater algae and foraminiferal wall linings.

Micropaleontology involes the study of mineral (calcerous, phosphatic and siliceous) walled microfossils. Those with calcerous skeleton include: foraminifera, ostracodes and calpionellids. Those with silica as the main wall composition include: diatoms and radiolarian. Conodont is one example of phosphatic microfossil.

Nannopalaeontology covers the study of nannofossils, which are the smallest of the microfossil groups routinely examined. This group includes: coccoliths, nannoliths, discoasters and calpionellids.

2.5 Sequence stratigraphy

Sequence stratigraphy is defined as delineation of time bounded stratigraphic sequences, commonly carried out at the seismic scale (Homewood *et al*., 2002). It is defined by Embry (2009) as 1) the recognition and correlation of stratigraphic surfaces which represent changes in depositional trends in the rock record and 2) the description and interpretation of resulting, genetic stratigraphic units bound by those surfaces. There are two conceptual frameworks used for sequence stratigraphic analysis namely: 1) one developed by Exxon researchers which uses unconformities as the boundaries of sequences (Vail *et al*., 1977; Van Wagoner *et al*., 1988) and 2) the one that uses maximum flooding surfaces as genetic sequence boundaries (Galloway, 1989). Both types of sequences include the deposition of one complete relative sea-level cycle.
Sequence stratigraphy provides unifying framework in which observations of intrinsic properties such as lithology, fossil content, chemistry, and age can be compared, correlated, and perhaps re-

evaluated. Its main function, therefore, is to provide support data to exploration and production teams for possible re-mapping of the field.

A sequence is defined by Vail *et al*., (1977) as a stratigraphic unit composed of relatively conformable succession of genetically related strata bounded at its top and base by unconformities or their correlative conformities. The framework adopted in this work is based on Vail *et al*., (1977) model.

2.5.1 Key Terminology Used in Sequence Stratigraphy

Sea level:

1. **Bathymetry**: water depth measurement; the sea-level measured from surface of the sediment.
2. **Eustasy**: worldwide changes in 'absolute' sea level, measured using a reference system (the moon or the centre of the Earth) independent of the depositional system.
3. **Relative sea level**: sea level measured from a reference point in the bedrock; does not take into account sediment thickness but does include subsidence added to the eustatic level. Therefore, it is an apparent rise and fall of sea level with respect to the land surface (See Fig. 2.5).

Sediment Accumulation:

1. **Accommodation**: total space (volume) available for sediment accumulation; in shallow marine domain, this corresponds approximately to the volume delineated by sea level and the substratum at the beginning of surface and the sea level.
2. **Available space**: space remaining between the sediment surface and the sea level. See Fig, 2.6.
3. **Base level**: in stratigraphic terms, it is the equilibrium surface below which sediment settles and above which erosion occurs. It is an irregular surface whose intersection with the earth's surface determines the areas under erosion, sedimentation or transit (Fig. 2.7). According to geomorphological usage: base level equals sea level.

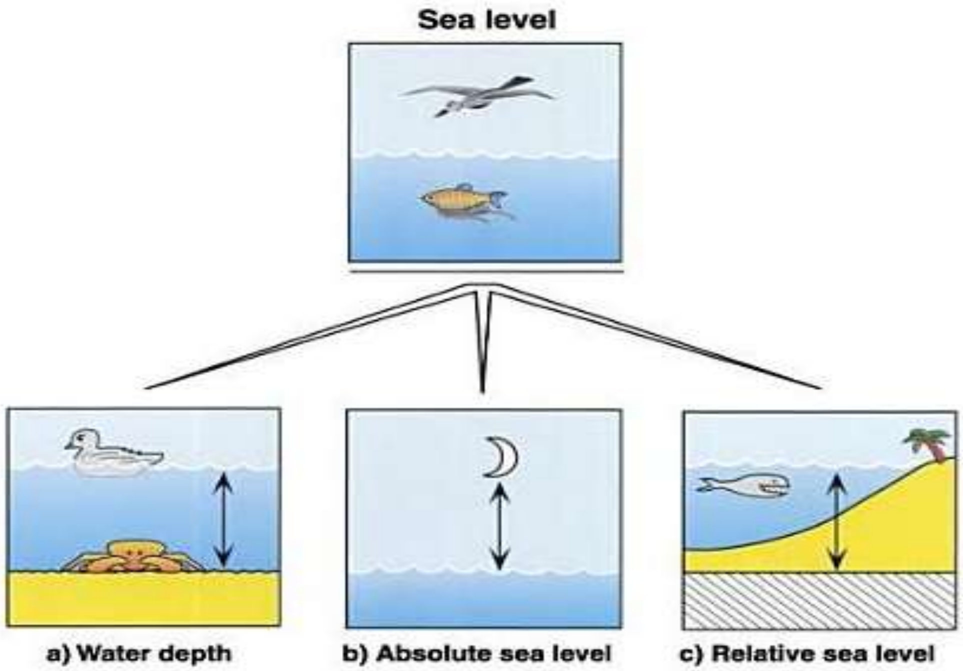


Fig. 2.5: Different sea levels showing the differences in Bathymetry, Eustasy and Relative Sea level (After Homewood *et al*., 2002)

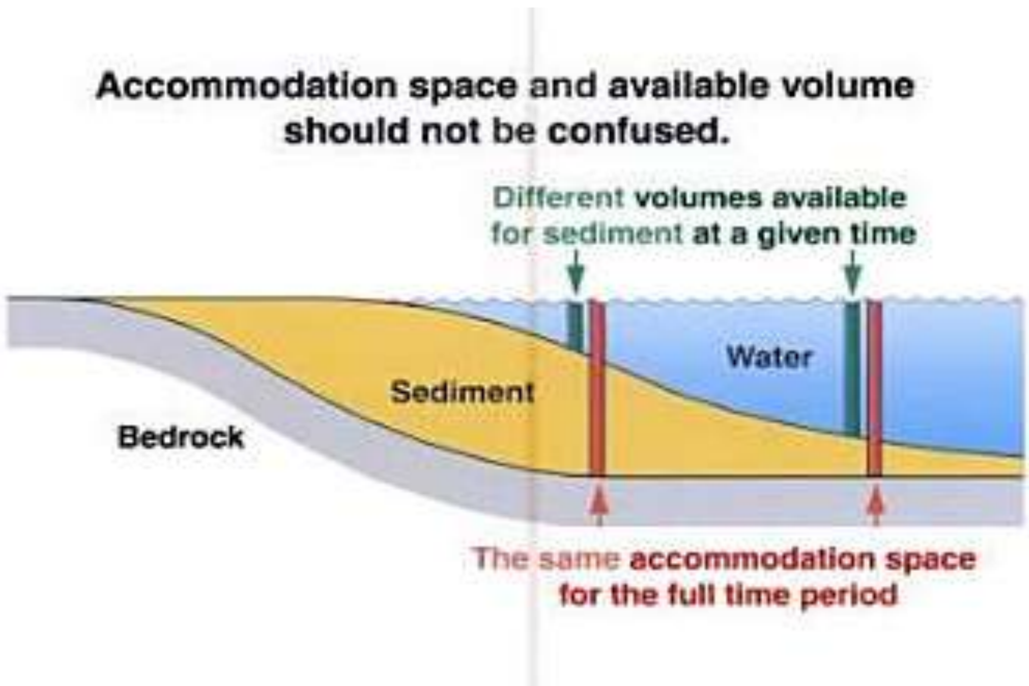


Fig. 2.6: Illustration of difference between accommodation and available space for sediment accumulation (After Homewood *et al*., 2002)

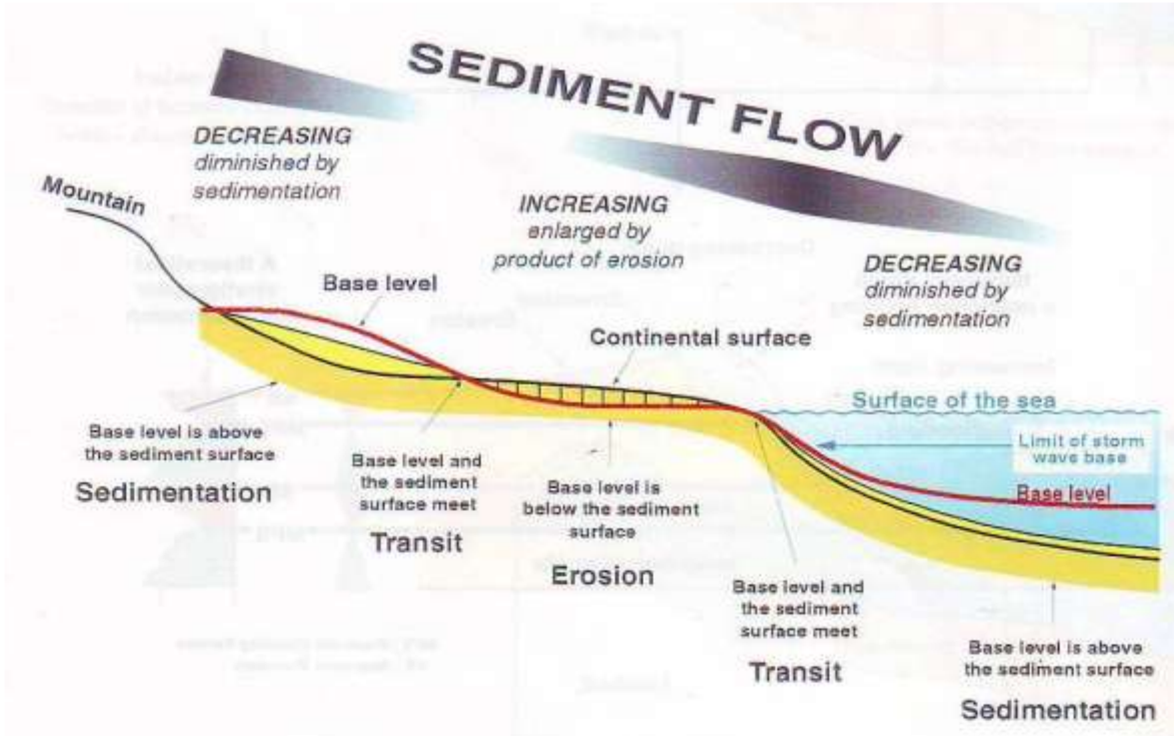


Fig. 2.7: Base level (in stratigraphic sense) showing areas under erosion, sedimentation and transit (After Homewood *et al*., 2002)

Stratigraphic Surfaces:

1. **Sequence boundary**: unconformity (in continental or proximal position) and its correlative conformity (in distal position) corresponding to the most regressive configuration of stratigraphic architecture.
2. **Maximum flooding surface**: the surface which corresponds to the most transgressive stratigraphic architecture and marks the limit between genetic units. It is a useful correlation marker. In the continental domain, there will be no marine facies despite the term ‘flooding’.
3. **Transgressive ravinement surface**: the erosional surface cut by wave action during transgression.

Stratigraphic Architectures:

For us to understand the concept of stratigraphic architecture, the term parasequence and parasequence set will be defined because it is the stacking patterns of the paraseqences within the parasequence set that determine the architecture.

A parasequence is defined as a relatively conformable, genetically related succession of beds or bedsets bounded above and below by marine flooding surfaces and their correlative surfaces.

A parasequence set is a succession of genetically related parasequences forming distinctive stacking pattern bounded by major marine flooding surfaces and their correlative surfaces.

There are three stacking patterns of parasequence sets (Fig. 2.8) based on the rate of sediment supply to that of accommodation:

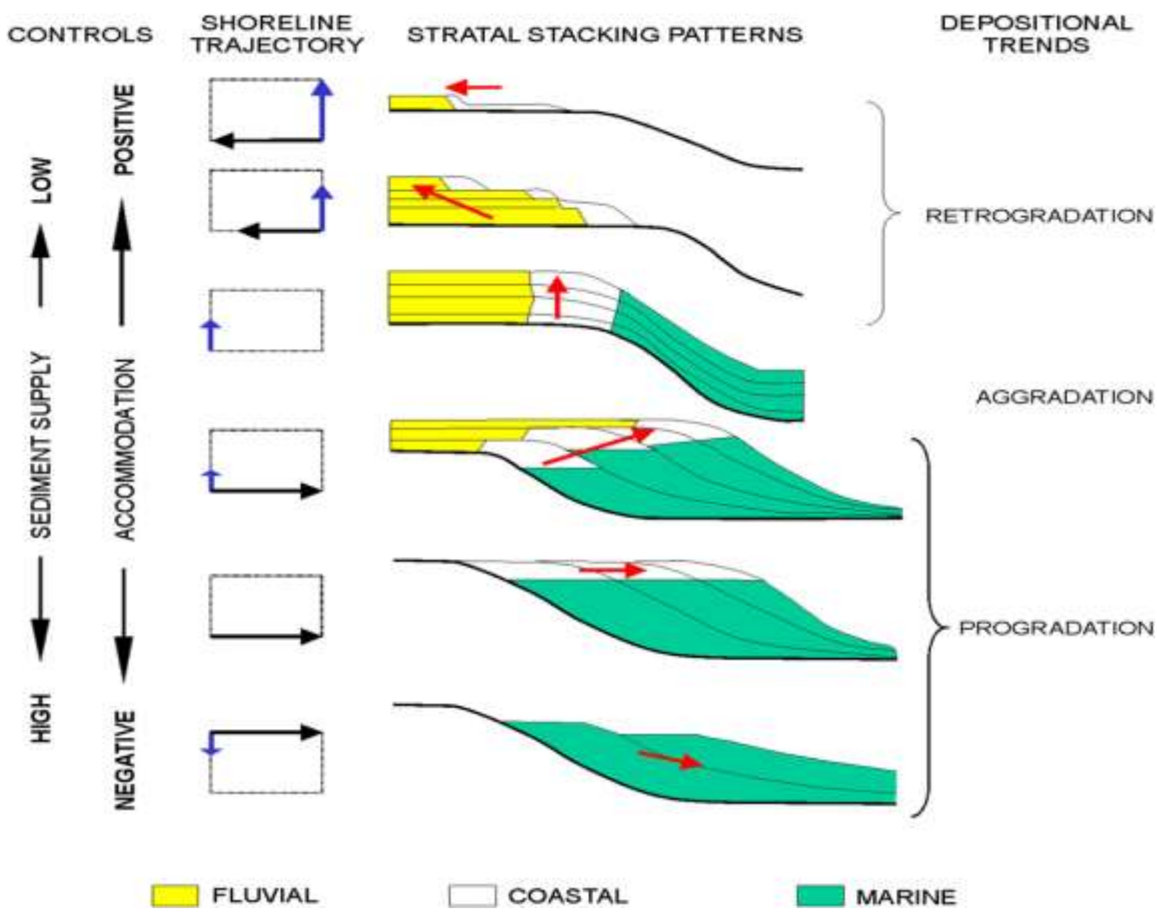


Fig. 2.8: Stratigraphic architectures showing the effects of rates of change in accommodation and sediment supply (after Martins-Neto and Catuneanu, 2009)

1. **Progradational (basinward stepping)**: in a progradational parasequence set, successively younger parasequences are deposited farther basinward; overeall, the rate of deposition is greater than the rate of accommodation.
2. **Retrogradational (landward stepping)**: in a retrogadational parasequence set, successively younger parasequences are deposited farther landward, in a back stepping pattern; overall, the rate of deposition is less than the rate of accommodation.
3. **Aggradational (vertical stepping)**: in an aggradational parasequence set, successively younger parasequences are deposited above one another with no significant lateral shifts; overall, the rate of accommodation approximates the rate of deposition.

CHAPTER 3

3.0 METHODOLOGY

3.1 Work flow

The work flow below (Fig.3.1) illustrates the steps taken in carrying out this project. The number of samples processed for each discipline is tabulated in Table 3.1 below. Sample processing techniques and analysis are explained in this chapter. Others are treated in the later chapters.

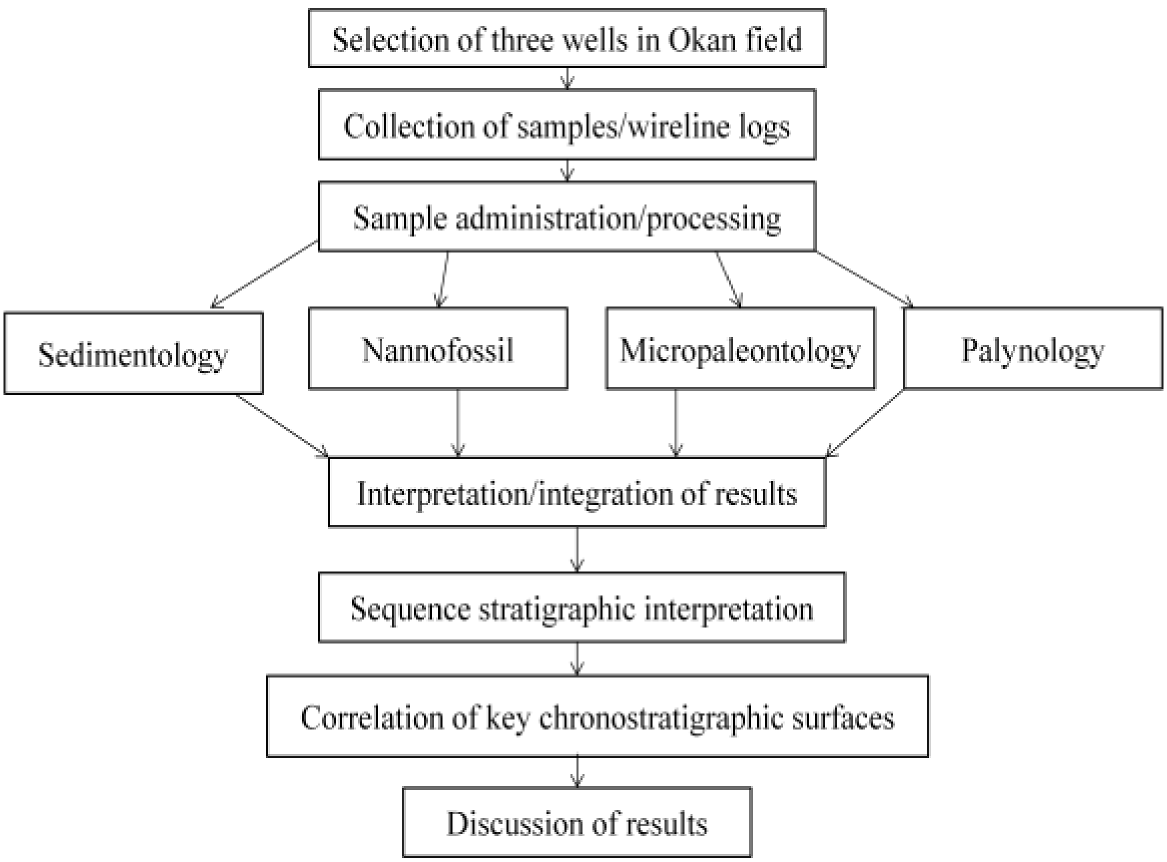


Fig 3.1: Work flow showing the steps taken in carrying out the project

Table 3.1: Sample Processing Summary Table for Okan-65, 75RD and 78 Wells

DISCIPLINE / WELLS	FORAMINIFERA	PALYNOLOGY	NANNOFOSSIL	SEDIMENTOLOGY	DEPTH RANGE (ft)
Okan-65	78	78	156	156	6, 560 -11, 200
Okan-75RD	128	128	256	256	5, 980 -13, 600
Okan-78	100	100	200	200	5, 990 -11, 855
Total number of samples/well	**306**	**306**	**612**	**612**	

3.2 Sample preparation procedures

Standard sample preparation procedures were used for each of the four disciplines; sedimentology, palynology, micropaleontology and nannofossil.

3.2.1 Sedimentological/Lithological Sample Preparation Procedures

1. Sample log was prepared to detect sample gaps/missing samples.

2. Samples were laid down on a flat surface in a sequential depth order (in batches).

3. Clean aluminium dishes/cups were labeled with sample depths (using stickers or masking tape and ink) starting with the shallowest sample to the deepest sample

4. Samples were then treated in batches of not more than twenty samples per batch to prevent contamination.

5. 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.

6. Samples containing hydrocarbon or oily substance were placed in fumed chamber and covered with chlorothene/chloroform and allowed to soak for 15 minutes after which the chlorothene/chloroform was decanted.

7. Samples without hydrocarbon or any oily substance were covered with soapy water and allow staying for 30 minutes.

8. Samples were then washed through the 63µm screen until free of mud and clean

9. Residue was collected in the sample dish/cup after being well rinsed with water from the wash bottle and the clear supernatant water decanted

10. The residue was dried at low temperature (at about 50^{o}C) for 1 hour

11. The sample was allowed to cool and then store in well-labelled phial or small pharmaceutical nylon bags.

3.2.2 Palynological Sample Processing

The steps are as follows:

(i) **<u>Pre-sample Preparation Operations</u>**

The samples were crushed to small fractions (between 0.25mm to 2.5mm) with a porcelain mortar and pestle and composited at 60ft intervals. The composited samples were placed on enamel tray and mounted on a top load digital balance. 25 grams of the samples were measured and ready for processing.

(ii) **<u>Dissolution of Carbonates</u>**

10% dilute Hydrochloric acid (HCl) was added to samples in enamel plate and stirred with rod to remove any calcareous matter. The addition of dilute HCl continued until the samples no longer produce effervescent.

(iii) **<u>Dissolution of Silicates (Digestion of samples)</u>**

The dried samples were transferred from enamel plate into polypropylene beakers. This was followed by addition of conc. Hydrofluoric acid (HF) to the samples to dissolve the silicates. The samples were stirred at regular intervals (every one hour) with plastic rod and then left overnight in the fumed cupboard. Samples were thoroughly washed and decanted three times with distilled water.

The action of HF causes digestive disaggregation of the sample with resultant release of organic matters. This removes any component silica, silicates, or metal oxides (Phipps and Playford, 1984). In HF, silica and silicates are converted to silicon tetrafluorides (SiF_4) and fluosilicic acid (H_2SiF_6) respectively. Metal oxides are converted to fluorides.

(iv) **Removal of Fluoride gels**

Fluoride, which is observable in the residue as either a thick gel or a fine crystalline precipitate must be removed to ensure release of organic materials. Conc. HCl (ca. 1/3 of volume of material + water left) was added to the beaker containing the samples and boiled on hot metal plate for about 40minutes to remove fluoride gel. The samples were then thoroughly washed and decanted repeatedly for three times.

(v) **Filtration**

The cooled samples were mixed with water and liquid detergent (morning fresh) and transferred into the filtration tube. Addition of this liquid detergent was to wash off oil from those samples suspected to contain oil. The filtration was done using 10um polypropylene Estal Mono sieve. The process of filtration was over when the water coming out became clear of dirt. The cleared sample was poured into petri-dish and allowed to settle. Then, it was decanted and poured into the test tube.

(vi) **Oxidation of organic matter**

The aim of oxidation is to transform at least partially decomposed organic debris into alkali-soluble "humic acid", thereby removing unwanted organic matter and producing ultimately a palynomorphs-rich residue. This was performed for the residues that are too dark. To the residue in the test tube, drops of Nitric acid (HNO_3) was added and allowed to stand for 3 minutes. The time allowed for the proper oxidation depends on the experience of the technician because some samples require more oxidation time for proper bleaching.

(vii) **<u>Neutralization of acids</u>**

The essence of neutralization is to stop the process of bleaching. Two methods are involved: either by addition of water and centrifuging for up to 3 times or by addition of 10% Potassium hydroxide (KOH). The former was the one chosen for this project. If KOH is chosen, it should be allow standing for 5 minutes for proper neutralization before centrifuging 3 times with distilled water.

(viii) **<u>Cleaning of residues</u>**

Ethanol was added to the residues in test tubes, centrifuged and decanted three times for proper cleaning of the remaining dirt. The residue is now ready for mounting on slides.

(ix) **<u>Preparation of microscopic slides</u>**

With one or two drops of residue on the cover slip and gently smeared to cover the cover slip, the residue was allowed to get dried. Optical norland adhesive was drop on the glass slide and the cover slip face with the dried residue mounted on the glass slide. The mounted slide was then dried by curing over ultraviolet light.

(ix) **<u>Preservation of the residues</u>**

The residues were preserved by adding drops of alcohol and stored in a well labeled vials.

(x) **<u>Study of Slides/ Photography</u>**

The prepared slides were studied under Leica transmitted binocular microscope. Identification and analysis were attempted for as many forms as possible with the help of publications from different authors. Marker species were selected for microphotography and the microscope used was Olympus attached with photo tube with digital diplay on computer screen.

(xi) **<u>Data Capture</u>**

The data generated from the analysis was captured in the database in StrataBug format and saved in readable format as coma separated version (CSV), which is accessible to other numerical software.

(xii) **<u>Data Presentation</u>**

The results of the palynological analysis were presented on distribution charts showing: age, biozones, lithology, abundance, diversity and phytoecological groupings. The distribution charts were produced on a scale of 1: 5000.

(xiii) **<u>Data Interpretation and Integration</u>**

The results were integrated with micropalaeontological and sedimentological results to determine the age of sediments penetrated by the wells, biozones, palaeoenvironments and sequence stratigraphic framework of studied sections.

3.2.3 Micropalaeontological (Foraminifera) Sample Processing

The following steps were followed in preparing samples for foraminifera analysis.

Step I: Pre-sample Preparation Treatment

(i) Samples were first composited at 60ft intervals

(ii) 25g of samples were weighed in a pan using weighing balance

(iii) The samples were crushed with pestle in a porcelain mortar to smaller fragments

Step II: **Weighing and Soaking**

(i) Weighed samples were washed in kerosene for about 12-18 hours to disintegrate shale and drilling mud.

(ii) Kerosene was decanted and samples were then soaked in mild detergent to remove kerosene and further disaggregate the shale

Step III: Sieve Washing

(i) The samples were washed under running tap water through a 63micron sieve until samples become clean of drilling mud.

(ii) Residues were then poured into a pan and water was decanted from the clean residue

(iii) Residues were dried in an oven at about 70 – 80^{o}C.

Step IV: Packaging of Dried Residues

(i) Dried residues were sieved into coarse, medium and fine-grained fractions using a column of 1mm, 50micron and 75micron

(ii) The fractions were packed into a labeled vials or envelops

Step V: Microscopic Picking

(i) Small quantity of residue was spread in a tray and the fossil contents (foraminifera and other microfauna such as ostracods and gastropods) were picked from each fraction and stored in a labeled slide using stereoscopic binocular microscope (Wild microscope)

(ii) The slide was then covered with cover slip and properly labeled to indicate well name, sample type and depth.

3.2.3.1 Micropalaeontogical Analysis

The foraminifera and other micofauna accessories were subjected to detailed qualitative and quantitative analysis. Standard monographs, text books and index foraminifera type collections aided in the identification of fossils to generic and species levels.

3.2.3.2 Data Capture

The data generated from the analysis were captured in the database in StratBug and Excel formats and saved in a readable format as CSV, which is accessible to other numerical software.

3.2.3.3 Data Presentation

The results were presented on distribution charts showing age, biozones, lithology, abundance, diversity and environments of deposition (palaeobathymetry). The distribution charts were produced on a scale of 1:5000.

3.2.3.4 Data Interpretation and Integration

The results were interpreted and integrated with other biostratigraphic results to optimize biostratigraphic control of the wells with respect to age of sediments, condensed sections, biozones, paleobathymetry and sequence stratigraphic framework of the studied sections.

3.2.4 Calcareous Nannofossil Sample Preparation

The choice of the preparation method to be adopted depends on the type of samples available for analysis. To optimize recovery, centrifuge method was adopted.

1. Samples are logged at 30ft intervals and the washed with 63µm sieve to remove drilling mud if present on the samples.

2. Samples are dried at 80^{o}C on a hotplate.

3. 2g of washed and dried samples (at every 30ft intervals) were soaked overnight using 0.25gm of sodium hexametaphosphate in 500ml of distilled water in a 50ml tube to help disperse the clays and ensure even distribution of particles in the final mount.

4. Samples that are hard were subjected in an ultrasonic bath for five minutes.

5. The centrifuge was decelerated and the suspension decanted and set aside

6. Processes (4) and (5) above were repeated if necessary until the suspension is nearly clear.

7. Two glass cover slips (32mmx22mm) were placed on a hotplate at 80^{o}C and two or three drops of suspension were pipette on it to dry, making sure it fills the surface area of the cover slips for each depth.

8. Place a drop or two of Optical Norland adhesive (mounting medium) on labeled (depth and well name) glass slide (76mmx26mm) and immediately invert the dried glass cover slip on it.

9. The slides were exposed to UV light to cure (harden)

10. The microscopic analysis was carried out using Olympus BH 2 rotating stage polarizing microscope at a magnification of X1000. The microscope allows images to be viewed in both in phase and crossed polar.

3.2.4.1 Calcareous Nannofossil Analysis and Data Capture

1. The slides were mounted on the transmitted light microscope with polarizing techniques and 100 fields of view were observed per traverse at an average of six traverses per slide.

2. Detailed analysis involving both quantitative and qualitative analyses of the calcareous nannofossil was done using relevant published text books, monographs and albums.

3. Species identified in each slide were recorded on separate calcareous nannofossil logging sheets

4. Calcareous nannofossils distribution, abundance and diversity were plotted and saved in StrataBug format.

3.2.4.2 Data Interpretation

The generated data were interpreted specifically with the aim of optimizing biostratigraphic control of the wells. The bases for interpretation are clearly stated as follows;

1. Age: calcareous nannofossil age was based on index species using internationally published nannofossil zonation scheme of Martini (1971) and Okada and Bukry (1980).

2. Biozonation: calcareous nannofossil biozonation is based on the distribution of species recovered with the criteria for zonal subdivision clearly stated.

3.3 Sedimentological and lithological analyses of Okan- 65, 75RD and 78 wells

The sedimentological analysis was carried out using stereomicroscope (incidence light techniques) and the main parameters determined are:

1. Lithologies e.g. percentages compositions of sand, shale and silt;

2. Textures such as color, grain-size, sorting and roundness; and

3. 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 distribution of sand and shale in each sample. 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.

CHAPTER 4

4.0 RESULTS AND DISCUSSION

4.1 Accessory minerals and other accessory materials used in depositional systems intrepretation

Accessory minerals

4.1.1 The Glaucony and Glauconite

The term glauconite is commonly used by geologi1sts to refer to a dark green mineral that is found quite commonly in marine sediments (Nichols, 2009). However, not all the green grains minerals are composed of glauconite but of various other components (Odin and Matter, 2003). In correct usage the use of the term should be restricted to potassium rich mica, which has the mineral name glauconite, because this is in fact only one member of a group of potassium and iron rich phyllosilicate minerals that are closely related.

Generally, materials made up any of these distinctive end members (potassium and iron-rich phyllosilicate); medium to dark green minerals is referred to as glaucony. 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.

Glauconitization, (i.e. the process of forming the mineral) occurs at the sea floor on substrates such as the hard parts of foraminifers, other carbonate fragments, faecal pellets and lithic fragments. 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 (Odin and Matter, 2003).

Glaucony is important in sedimentology and stratigraphy for a number of 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.

3. Because the mineral is authigenic and also rich in potassium, it can be dated by radiometric methods and the age obtained corresponds to the time of deposition. Direct radiometric dating of sedimentary materials is rarely possible, but glaucony/glauconite is the exception and consequently is very important in relating strata to the geological time scale.

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

4.1.2 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). Plant remains, impressions, and replaced (petrified) wood are commonly associated with these forms of iron (Weber, 1971). 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. 4.1.

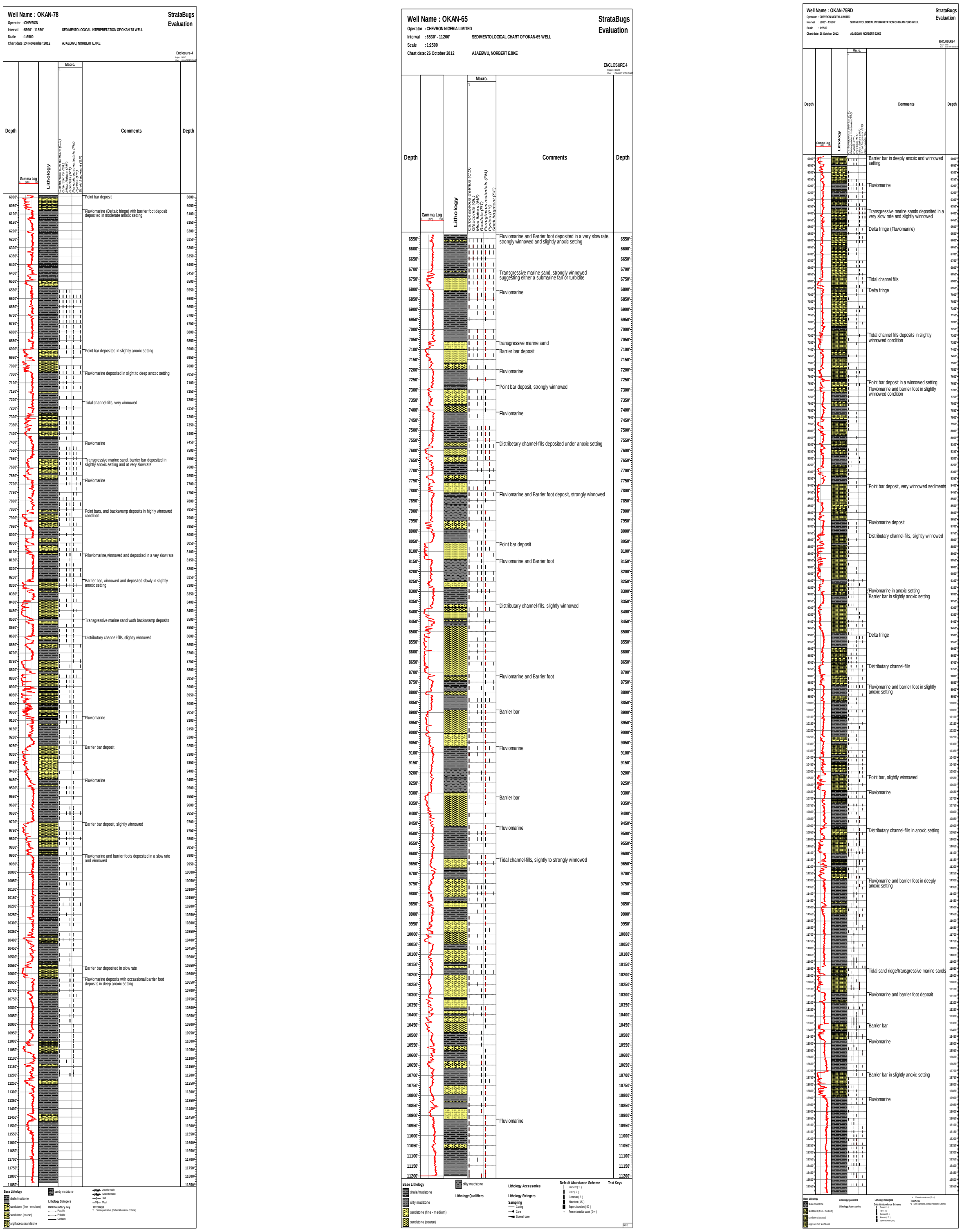


Fig. 4.1: Depositional systems interpreted in Okan-78, -65 and -75RD wells

4.1.3 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 to is more stable than the Anorthite group where biotite belongs (Table 4 .1).

Table 4.1: Stability Series for Terrigenous Minerals (after Folk, 1980)

Quartz, Zircon, Tourmaline

Chert

Muscovite

Microcline

Increase in degree of stability

Orthoclase Albite

……………………………………………

Hornblende, Biotite Anorthite

Pyroxene

Olivine

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 these environments 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. 4.1.

Accessory materials

4.1.4 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.

4.1.5 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.

4.1.6 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).

4.2 Integrated Lithofacies and Depositinal Systems

Lithofacies interpretation was based on integration of gamma-ray motifs, accessory minerals, 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. Closer looks at the log motif and the associated accessory minerals and other materials reveal four lithofacies named A, B, C and D with their depositional systems.

4.2.1 Lithofacie A: Hemipelagic shale

This lithofacie 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) or barrier foot when it occurs with common rootlet and at the proximal part of the thick shale which often showed high gamma-ray value (Weber, 1971) (Fig. 4.2).

4.2.2 Lithofacie 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 was interpreted as transgressive marine sand deposited at a very slow rate (Fig. 4.2).

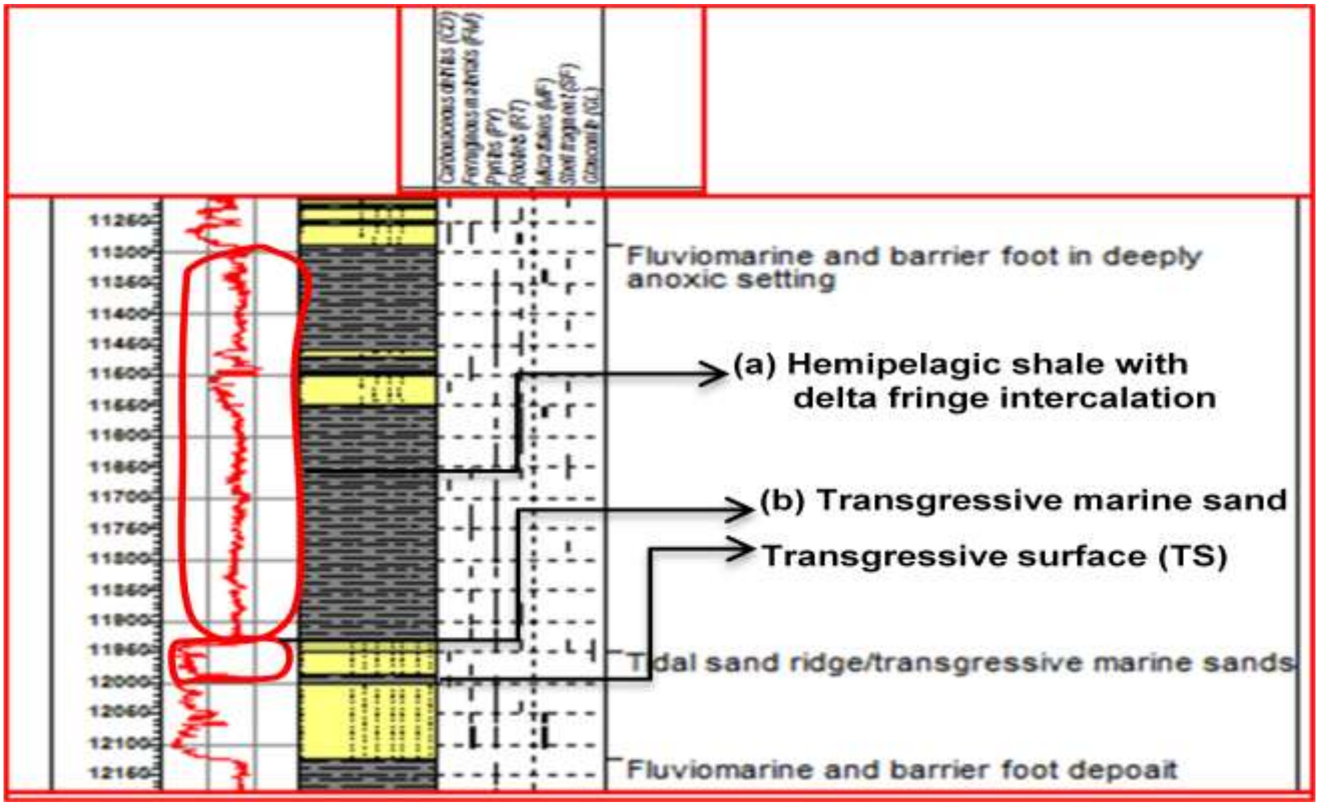


Fig. 4.2: Lithofacie A: Hemipelagic shale and Lithofacie D: Glauconitic sand (Transgressive marine sand)

4.2.3 Lithofacie B: Regressive sawtooth multistorey sands.

They have 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. It contains shell fragments and carbonaceous detritus and sometimes ferruginous materials. It is bounded below by outer to middle neritic (marine) deposit and at the top by coastal (non-marine) deposit. It is slightly winnowed, having few carbonaceous detritus. It is interpreted as shoreface sands (Figs. 4.3).

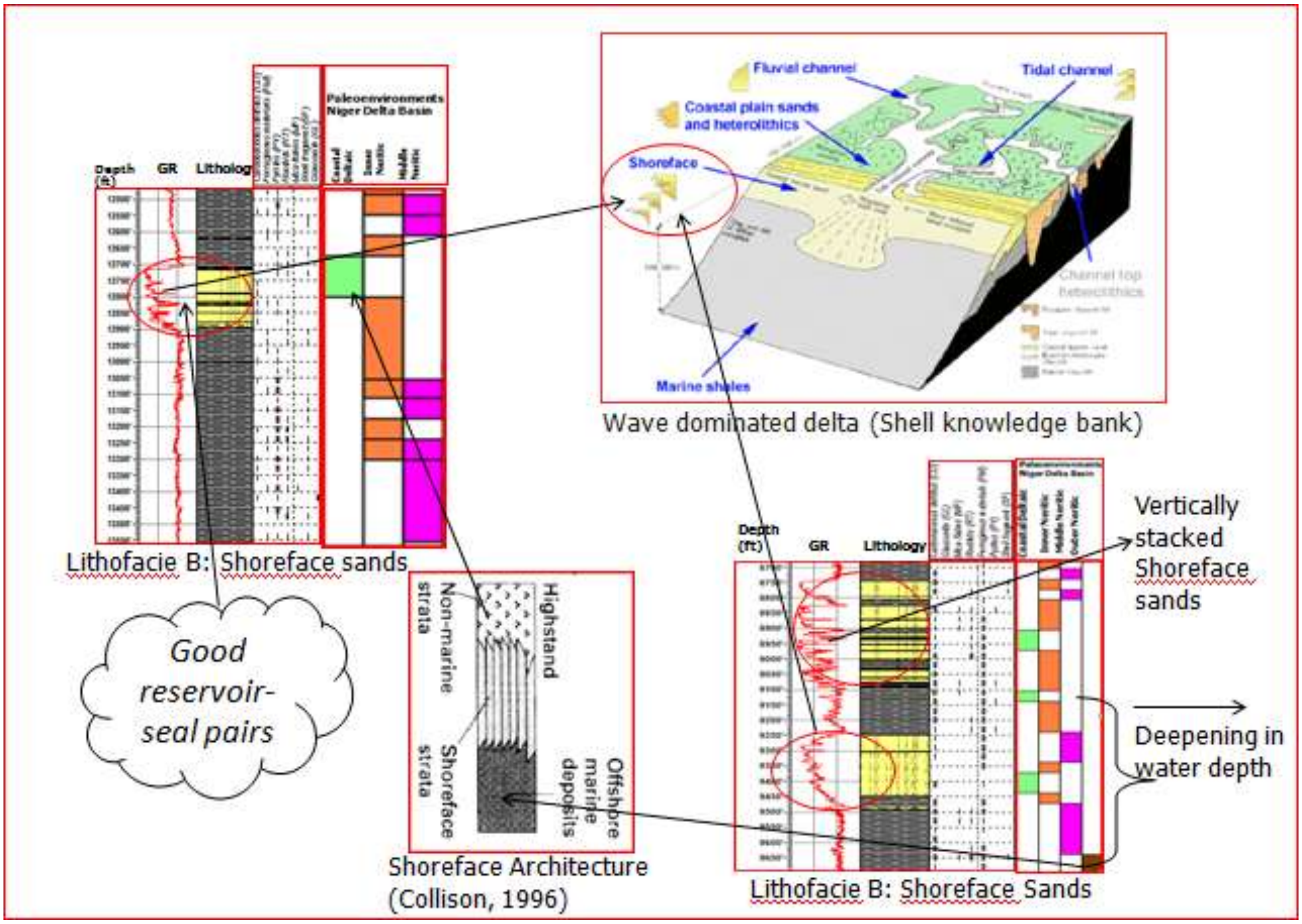


Fig. 4.3: Lithofacie B: Regressive sawtooth multistorey channel fill sands

4.2.4 **Lithofacie C: Blocky channel fills sands**.

These represent 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. 4.4). Where deposit of this nature are stacked vertically one on top of the other, the depositional system is interpreted to be a distributary channel fill.

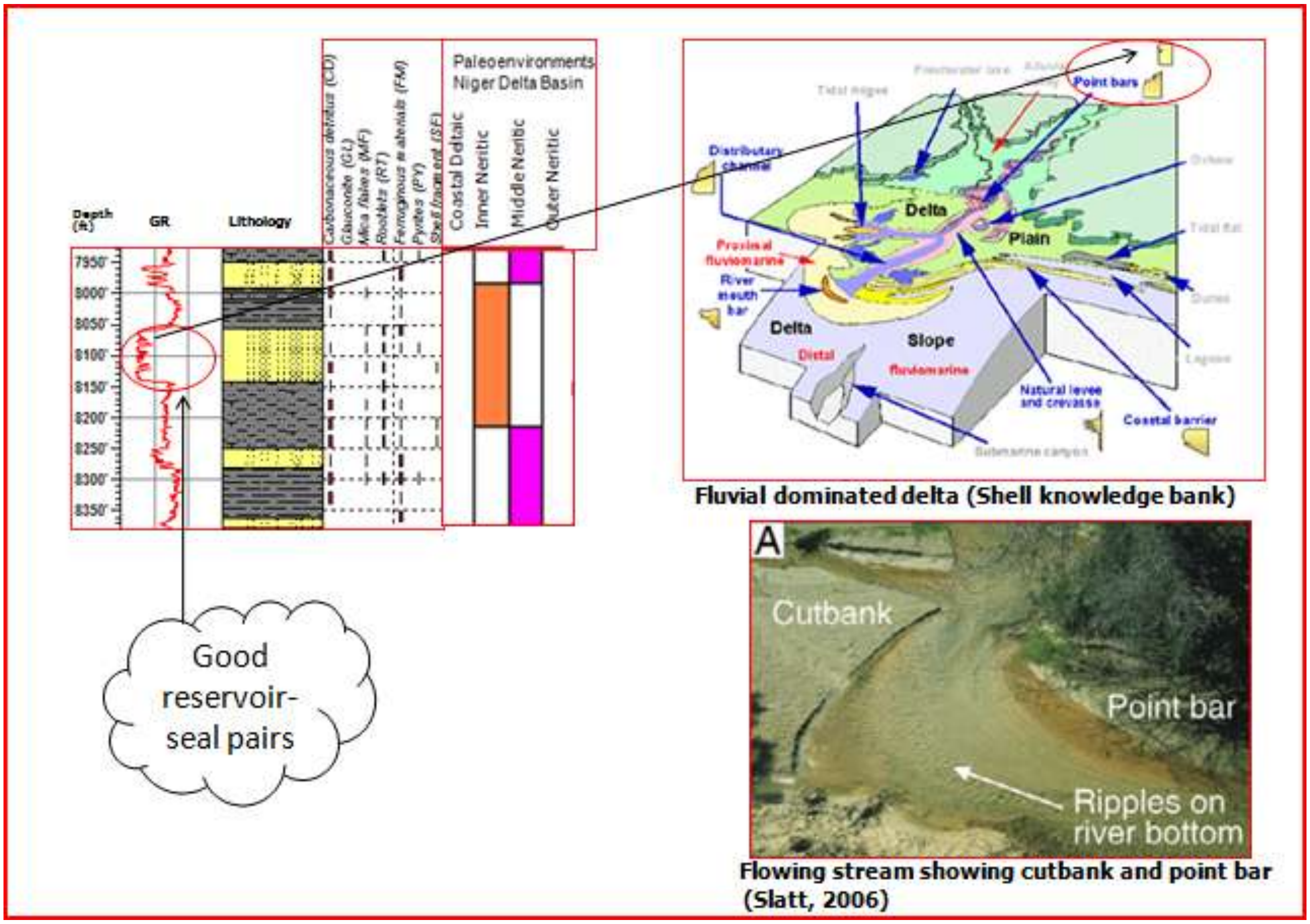


Fig. 4.4: Lithofacie C: Blocky channel fills sands

4.3 Biostratigraphy

Three fossil groups were studied. These groups with their recovered fossils were: palynomorphs (pollen, spores, dinoflagellate cyst, acritarch, fungal spores, freshwater algae and foram wall linings), microfossils (foraminifera) and nannofossil (coccoliths and discoasters). The calcareous nannofossil recovery was rather poor and was not integrated with other fossil groups for interpretation.

4.3.1 Palynological biostratigraphy

4.3.1.1 Systematics

DIVISION I Sporites H. POTONIE, 1893

Class A Aletes

Genus *Corrusporis*

Type species *Corrusporis* sp. (Bryophyte spores)

Pl 1, Fig 5

Description: This group comprises medium to large sized alete spores with rounded amb; laesurae indistinct; wall generally thick in relation to spore size; sculptural elements varying from pilos through conate to spinose with solid base. Combinations of these sculptural elements are often found present within one specimen.

Occurrence: Has rare occurrence through out the analysed intervals

Botanical affinity: Belongs to genus Hypolepsis sparsisora or Thelipteris falciloba or Catascopium (Bryophytes). The genus belongs to family Polypodiaceae (Salard- Cheboldaeff, 1972)

CLASS B Monoletes IBRAHIM, 1933

Genus *Verrucatosporites* THOMSON AND PFLUG, 1953

Type species *Verrucatosporites usmensis* VAN DER HAMMEN, 1956 & GERMERAAD, HOPPING & MULLER, 1968)

Pl.1, Fig. 10

Description: Monolete spore, laesura on the distal part, bilaterally symmetrical, heteropolar, exine thick and tectate, margin echinate, gemmate to verrucate, spore plano-convex in shape.

Remark/ Occurrence: The ornamentation varies from verrucate to gemmate. It occurs throughout the interval investigated.

Botanical affinity: Identical to Indo-Malesian climbing fern *Stenochlaena palustris* (Germeraad *et al*, 1968; Salard-Cheboldaeff, 1972).

Verrucatosporites spp.

Pl. 1, Fig.11, 12 & 13

Description: Spore ellipsoidal in polar view, laesura monolete, longitudinally arranged in the center of the spore, short and wider at the center, bilaterally symmetrical, heteropolar, exine coarsely reticulates.

Remark: Different from *V. usmensis* by absence of gemmate and spines

Botanical affinity: Resembles recent spore of *Pyrrhosia schimperiana* (Polypodiaceae) (Salard-Cheboldaeff, 1972)

Genus *Laevigatosporites* IBRAHIM, 1933

Laevigatosporites spp.

Pl.1, Fig. 1 and 2

Description: Spore ellipsoidal to plano-convex in shape, laesura monolete, laesura short and at the center of the spore, exine thin and psilate.

Remark: The shape varies from ellipsoidal to plano-convex. It occurs throughout the intervals

Botanical affinity: Polypodiaceae (Salard-Cheboldaeff, 1972)

Class C Triletes (REINSCH, 1881) POTONIE & KREMP, 1954

Genus *Leoitriletes* NAUUMOVA, 1939 ex ISHCHENKO, 1952

emend. R. POTONIE AND KREMP, 1954

Type species *Leoitriletes adriennis* (POT. Et. GELL, 1933) KRUTZSCH, 1959

Pl. 1, Fig. 8 and 9

Literature: *Leoitriletes adriensis* (POT. et. GELL, 1933) KRUTZSCH, 1959, p. 57, pl. 1 & 2

Occurrence: It has a common occurrence through out the intervals analysed in the three wells

Botanical affinity: Belongs to family Polypodiaceae particularly genus Lygodium

Genus *Polypodiaceoisporites* POTONIE, 1956

Type species *Polypodiaceoisporites* spp.

Pl.1, Fig. 3 and 4

Description: Trilete spore, laesura long and wider at the contact area, convex-triagular in shape, radial axes rounded, proximal face granulate to perforate, exine tectate, equatorial region cingulate.

Remark/Occurrence: Has a common occurrence and the exine varies from psilate to granulate

Botanical affinity: Sallard Cheboldaeff, 1972 indentify this specie to belong to genus Pteris? under the family of Polypodiaceae

Genus Stereisporites THOMSON AND PFLUG, 1953

Type species Stereisporites sp.

DIVISION II Pollenites R. POTONIE, 1931

Class A Monoporitae IVERSEN et TROELS-SMITH, 1950

Genus *Cyperaceaepollis* KRUTZSCH, 1970

Type species *Cyperaceaepollis* sp.

Pl. 3, Fig. 6, 7, 8 and 9

Description: Pear to conical-shaped, inaperturate, exine tectate, tectum perforate; perforations approximately circular, irregularly distributed, lateral lacunae distinct, ovate-oblong, edges entire or slightly undulating. Columellae distinct, of uniform length, regularly distributed; sculpture absent (psilate).

Occurrence: From 8630 to 7230ft in the three wells and an important marker in Late Miocene

Remarks: Shape varies from conical to pear-shaped

Botanical affinity: Belongs to family Cyperaceae (Ghazali, 1993).

Genus *Monoporites* (COOKSON, 1947) ex VAN DER HAMMEN, 1954

Monoporites annulatus VAN DER HAMMEN, 1954

Pl. 2, Fig. 3 and 4

Description: Single grain, spheroidal in shape, slightly protruding, exine thin, atetate, psilate, exine with small circular pore surrounded by annulus

Remark: Very abundant and diverse throughout the studied intervals. Started occurring in Nigeria from the base of Middle Eocene but more abundant in Neogene than in Paleocene (Germeraad *et al*, 1968)

Botanical affinity: Closely resembles Poaceae (Gramineae) pollen (Germeraad *et al*, 1968)

Age: Upper Paleocene to Recent (Van Der Hammen, 1954; Germeraad *et al*., 1968)

Genus *Pandanites* Elsik, 1968

Pandanites sp.

Pl. 5, Fig. 6 and 7

Description: Small sized, spherical, monoporate, spinose pollen grain. Grain is bilaterally symmetrical, pore almost isodiametrical and nearly annulate. Exine is fairly thin and bears sparse and irregular distributed spinulose ornament.

Occurrence: Has a rare occurrence

Botanical affinity: this form is close to pollen of species Pandanus candelabrum Beauv of Pandanaceae family (Sowunmi, 1973a).

Class B Triporatae IVERSEN & TROELS –SMITH, 1950

Genus *Psilatriporites*

Psilatriporites spp.

Pl.2, Fig. 24 & 25

Description: Single grain, convex-triagular in polar view, triporate, pores at the three radial zones, radial axes rounded, exine psilate, slightly perforate.

Remark: It occurs throughout the studied intervals.

Botanical affinity: Unknown

Genus *Corsinipollis* Nakoman, 1965

Corsinipollis jussiensis Nakoman, 1965

Pl. 4, Fig. 8

Description: Medium sized pollen grain, isopolar, radially symmetrical, triporate. Grains occur singly or more commonly in tetrad. The grain is oblate in equatorial view; pores are longitudinally elongated with thick granular annulus and thic exine. The pores and annuli bulge out conspicuously.

Remark: It has a very rare occurrence in the studied intervals

Botanical affinity: It compares with grain of tropical rainforest palm known as Arecinae, particularly the genus *Sclerosperma manni* (Sowunmi, 1972)

Class C Stephanoporatae IVERSEN & TROELS-SMITH, 1950

Genus *Pachydermites* GERMERAAD, HOPPING & MULLER, 1968

Pachydermites diederixi GERMERAAD, HOPPING & MULLER, 1968

Pl.4, Fig. 1

Description: Medium to large in size, circular in polar view, isopolar, stephanoporate, three to six pores, pores marginal, exine thick, psilate, tectate with cingulum.

Remark: Has a common occurrence. Number of pores varies from 3 to 6.

Botanical affinity: Identical with the pollen of Symphonia globulifera (Guttiferae) (Germeraad, *et al*, 1968)

Class D Periporitae IVERSEN & TROELS-SMITH, 1950

Genus *Echiperiporites* VAN DER HAMMEN & WYMSTRA, 1964

Echiperiporites estelae GERMERAAD, HOPPING & MULLER, 1968

Pl.2, Fig. 9

Description: Pollen grain isopolar, spheroidal, periporate, pores are visible, echinate at the amb, spines long, thick, conical.

Remark: There is variation in sizes and exine is folded in some.

Botanical affinity: Probably related to pollen of Thespesia populnea (Malvaceae) (Germeraad *et al*, 1968)

Class E Monocolpatae IVERSEN et TROEL-SMITH, 1950

Genus *Psilamonocolpites* VAN DER HAMMEN & GARCIA DE MUTIS, 1965

Psilamonocolpites sp.

Pl.2, Fig. 10

Description: Single grain, bilaterally symmetrical, heteropolar, ellipsoidal in shape, exine thick, psilate, monocolpate, colpus as long as pollen itself.

Remark: It has a rare occurrence.

Botanical affinity: Probably pollen of palmae (Thanikaimoni, 1971)

Genus *Racemonocolpites* GONZALEZ GUZMAN, 1967

Racemonocolpites hians LEGOUX, 1978

Pl. 3, Fig. 3, 4 and 5

Description: A single grain, bilaterally symmetrical, monocolpate, anisopolar and convex shaped when viewed laterally. The aperture is elongated and penetrates through the ektexine and the endexine. Structurally, it is semi-tectate with gemmate sculptures.

Remarks: The grains of this species vary in size, sculptures and colpus length. It is stratigraphically important as a marker in the Miocene of Nigeria (Legoux, 1978).

Botanical affinity: Uncertain but shows close resemblance to pollen of Palmae.

Class F Dicolporatae GERMERAAD, HOPPING & MULLER, 1968

Genus *Multiareolites* GERMERAAD, HOPPING & MULLER, 1968

Multiareolites formosus GERMERAAD, HOPPING & MULLER, 1968

Pl. 4, Fig. 6 and 7

Description: Pollen grain isopolar, prolate in proximal view, dicolporatae, colpi meridional, long, distinct, pores cicular and big, exine psilate, tectate.

Remark: Has only one occurrence in Okan 75RD well at 8140-8200ft.

Botanical affinity: Belongs to the family of pollen Acanthaceae (Germeraad *et al.*, 1968)

Class G Tricolpatae IVERSEN et TROELS-SMITH, 1950

Genus *Canthiumidites* KHAN, 1976

Canthiumidites reticulates KHAN, 1976

Pl. 3, Fig. 14

Description: Medium sized trcolpate pollen grian, oval to rounded, triangular in outline. The side view is convex or spheroidal with distinct apertures. Pores are oval to circular, fairly large with granulate annulus. Wall is thick and covered with baculate sculpture.

Occurrence: Rare to common

Botanical affinity: It resembles the pollen grain of family Rubiaceae especially Canthium subcordatum (Sowunmi, 1973a)

Class H Tricolporatae IVERSEN et TROELS-SMITH, 1950

Genus *Brevicolporites* ANDERSON, 1960

Brevitricolporites guinetii SALARD-CHEBOLDAEFF, 1978

Pl. 4, Fig. 9

Description: Pollen grain isopolar, circular in polar view, triporate, pores surrounded with annulus, slightly protruding at points of pores, exine psilate with scars.

Remark: Pores are always with annulus and slightly protruding.

Botanical affinity: Resembles genus *Pentaclethra* of the family Mimosaceae (Salard-Cheboldaeff, 1978).

Genus *Peregrinipollis* Clarke, 1966

Peregrinipollis nigericus Clarke, 1966

Pl. 4, Fig. 10 and 11

Description: A single grain, radially symmetrical, sub-prolate to spheroidal. It is tricolpate, ektexinous colpi not distinctly visible. The exin bears intragranulate sculpture that ranges between reticulate and foveolate with fine perforations at the poles.

Occurrence: It has a common occurrence in the three wells

Botanical affinity: Shows strong affinity with Brachystegia of Caesalpinaceae family (Clarke and Frederiksen, 1968; Sowunmi, 1973a)

Genus *Psilatricolporites* VAN DER HAMMEN, 1956 & PIERCE, 1961

Psilatricolporites crassus VAN DER HAMMEN et WYMSTRA, 1964

Pl. 4, Fig. 2, 3 and 4

Description: Pollen grain isopolar, radially symmetrical, spheroidal, tricolporate, colpi long and curved, exine tectate, psilate to finely perforate, columellae indistinct.

Remark: Has a common occurrence throughout the studied intervals.

Botanical affinity: Probably pollen grain of Pelliciera rhizophorae (Theaceae) (Wymstra, 1968).

Genus *Retibrevitricolporites* LEGOUX, 1978

Retibrevitricolporites obodoensis LEGOUX, 1978

Pl. 5, Fig. 3

Description: Pollen grain isopolar, radially symmetrical, ovate to convex-triagular in polar view, tricolporate, slightly protruding at point of pores, pores with annulus, tectate sexine thin, nexine with scars, reticulate.

Remark: Has a rare to common occurrence.

Botanical affinity: Unknown

Retibrevitricolporites protrudens LEGOUX, 1978

Pl. 5, Fig. 4, and 5

Description: Pollen grain isopolar, radially symmetrical, oblate to spheroidal, tricolporate, pores surrounded by annulus, protruding at the point of one of the pores, two other pores reside on the nexine, tectate, columellae indistinct, reticulate.

Remark: Occurs alongside *R. obodoensis*. Distinguished from *R. obodoensis* by its strong protrusion.

Botanical affinity: Unknown

Genus *Retitricolporites* VAN DER HAMMEN, 1956 ex VAN DER HAMMEN & WYMSTRA, 1964

Retitricolporites irregularis VAN DER HAMMEN & WYMSTRA, 1964

Pl.3, Fig. 1 and 2

Description: Pollen grain isopolar, radially symmetrical, spheroidal in polar view, tricolporate, exine tectate, reticulate, reticulation very coarse, sexine without tectum, baculate at the amb.

Remark: There are considerable variations in the coarseness of the reticulation.

Botanical Affinity: Has a close resemblance with *Amanoa Oblongifolia* (Euphorbiaceae) (Germeraad *et al*, 1968).

Genus *Verrutricolporites* VAN DER HAMMEN & WIJMSTRA, 1964

Verrutricolporites rotundiporus VAN DER HAMMEN & WIJMSTRA, 1964

Pl. 4, Fig. 12

Description: Pollen grain isopolar, radially symmetrical, subprolate to ellipsoidal, tricolporate, one major colpus passing through the center as long as the pollen itself, two pores present. The exine is thick, tectate, slightly protruding at the equatorial axes, verrucate.

Occurrence: Has a common occurrence in the studied interval.

Botanical Affinity: Resembles the pollen of Crenea maritima (Germeraad et al, 1968).

Genus *Zonocostites* GERMERAAD, HOPPING & MULLER, 1968

Zonocostites ramonae GERMERAAD, HOPPING & MULLER, 1968

Pl.3, Fig. 16 - 22

Description: Pollen grain isopolar, radially symmetrical, convex-triagular in polar view, tricolporate, colpi short, ectexinous, exine thick, psilate and tectate.

Remark: Very abundant and diversified throughout the interval. They varied considerably in shape from convex-triagular to prolate.

Botanical Affinity: This has a wide resemblance to a number of species of genus Rhizophora such as *Bruguinera, Ceriops,* and *Carallia* (Rhizophoraceae) (Germeraad et al, 1968).

Class Syncolpatae INVERSEN et TROELS-SMITH, 1950

Genus *Marginipollis* CLARKE AND FREDERIKSEN, 1968

Marginipollis concinus CLARKE AND FREDERIKSEN, 1968

Pl. 3, Fig. 15

Description: A single grain, spheroidal to prolate, with finely granular exine and irregular pits generally becoming thicker and enlarged towards the poles. It has three colpi with thick margins cupped towards the colpi.

Occurrence: rare

Remarks: The diagnostic features of this genus are possession of syncolpate apertures and thickening of the colpi margins which extended to the poles. It has stratigraphic significance in the upper Tertiary of Nigeria (Clarke and Fredericksen, 1968)

Botanical affinity: Has close similarity with Lecythidaceae

Class Stephanocolporatae IVERSEN et TROELS-SMITH, 1950

Genus *Psilastephanocolporites* LEIDELMEYER, 1966

Psilastephacolporites laevigatus (Sapataceae) SALARD-CHEBOLDAEFF, 1978

Pl. 2, Fig. 6

Description: Pollen grain isopolar, ovate to ellipsoidal, stephanocolporate, 4 colpi, colpi meridional, long. Exine psilate to slightly perforate.

Remark: Has a common occurrence.

Botanical Affinity: Resembles pollen of the family Meliaceae (Salard-Cheboldaeff, 1978)

MISCELLANEOUS PALYNOMORPHS

Fungi

Genus *Psilodiporites* SALARD–CHEBOLDAEFF & LOCQUIN, 1980

Psilodiporites ellipsoideus SALARD–CHEBOLDAEFF & LOCQUIN, 1980

Pl.5, Fig. 11

Description: Fungal spore ellipsoidal, diporate, pores at both proximal and distal poles, psilate, scars on the exine.

Remark: Has pores at both poles.

Tasmanite

Genus *Tasmanite* sp.

Pl.5, Fig. 10

Occurrence: Has a single occurrence in Okan-65 at 7850-7910ft

Explanatory Note

Plate 1 (Magnification =X1000)

1&2: *Leavigatosporites* spp.; Okan-65 (7010-7070ft, EFR Q39/4) & (6920-6950ft, EFR J39)

3&4: *Polypodiaceisporites* spp.; Okan-65 (7010-7070ft, EFR E48/2) & Okan-78, (6950- 7010), EFR J30/2)

5: *Corrusporis* sp.; Okan-78, 6710-6770ft, EFR U46

6&7: *Stereisporites* sp.; Okan-65 (6590-6650ft, EFR W22/2) & Okan-75RD (9340-9400ft, U38/1)

8&9: *Leoitriletes adrennis*; Okan-65, (6680-6710ft, EFR W33/2) & (8810-8870, EFR E49/4)

10: *Verrucatosporites usmensis*: Okan-65, 7310-7370ft, EFR W22/2

11, 12 &13: *Verrucatosporites* spp.: Okan-65, (7010-7070ft, EFR P40), (7310-7370ft, V37/2) & (6920-6950ft, EFR J39)

Plate 1

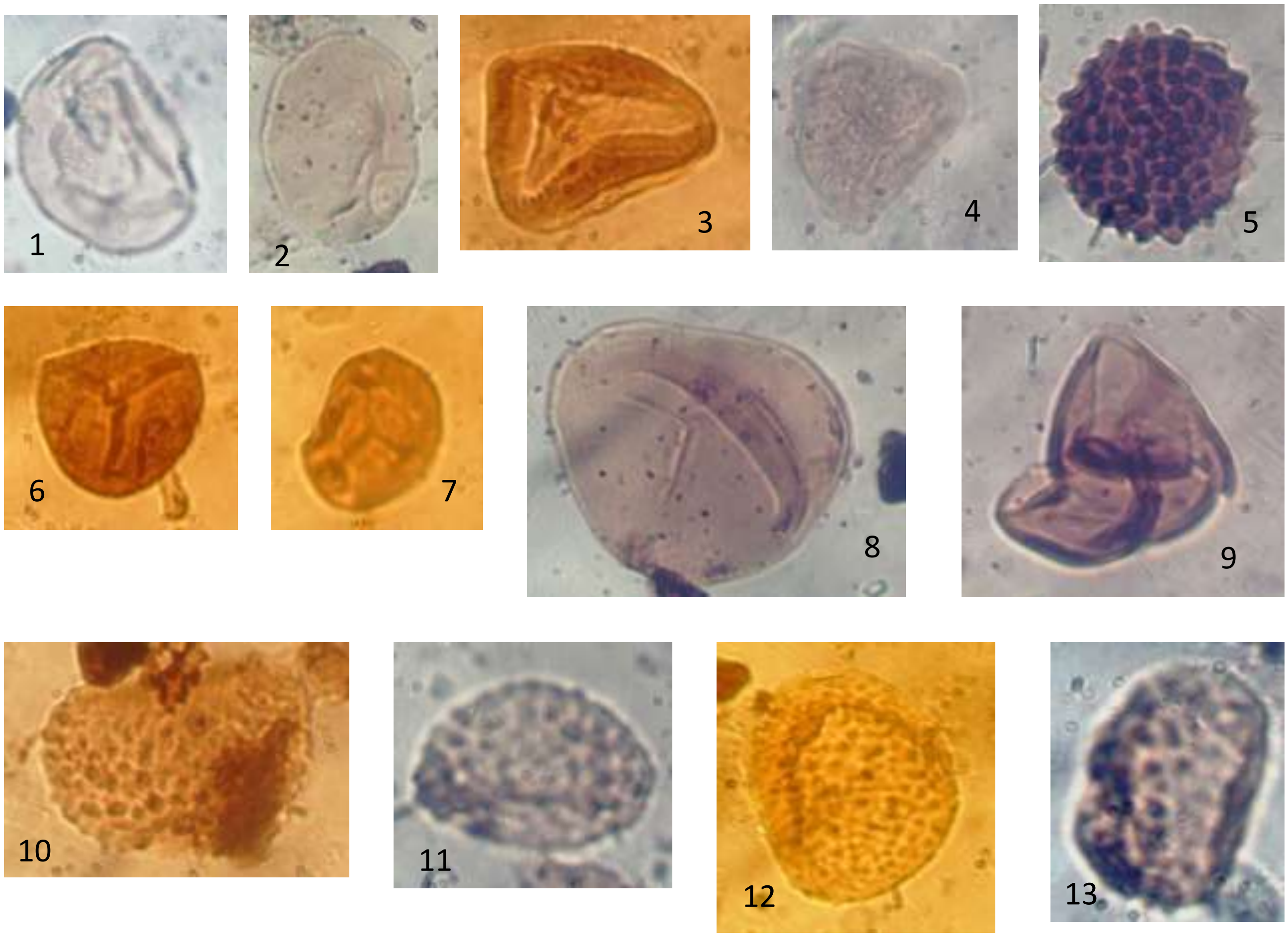


Plate 2 (Magnification =X1000)

1, 2 &5: *Belskispollis elegans*; Okan-65, 833 0-8390ft, England Finder Reference (EFR) S25/2 Okan-65, 8270-8330ft, EFR E36

3&4: *Monoporites annulatus* (low and high focus respectively); Okan-65, 7010-7070, EFR V34/3

6: Sapotaceae; Okan-78, Polar View, 6830-6850ft, EFR M38/4

7 & 8: Sapotaceae; Okan-65, equatorial views, (6920-6950ft, EFR S25/1) & (7550-7610ft, EFR J29) respectively

9: *Echiperiporites estelae*; Okan-78, 7370-7430ft, EFR H48/3

10: *Psilamonocolpites* sp.; Okan-78, 6770-6830ft, EFR K24/3

11 &12: *Echiperiporites icacinoides*: Okan-65, (high and low focus respectively) 7310-7370ft, EFR K30/1

13: *Striamonocolpites rectostriatus*; Okan-65 (8510-8570, EFR G29)

Plate 2

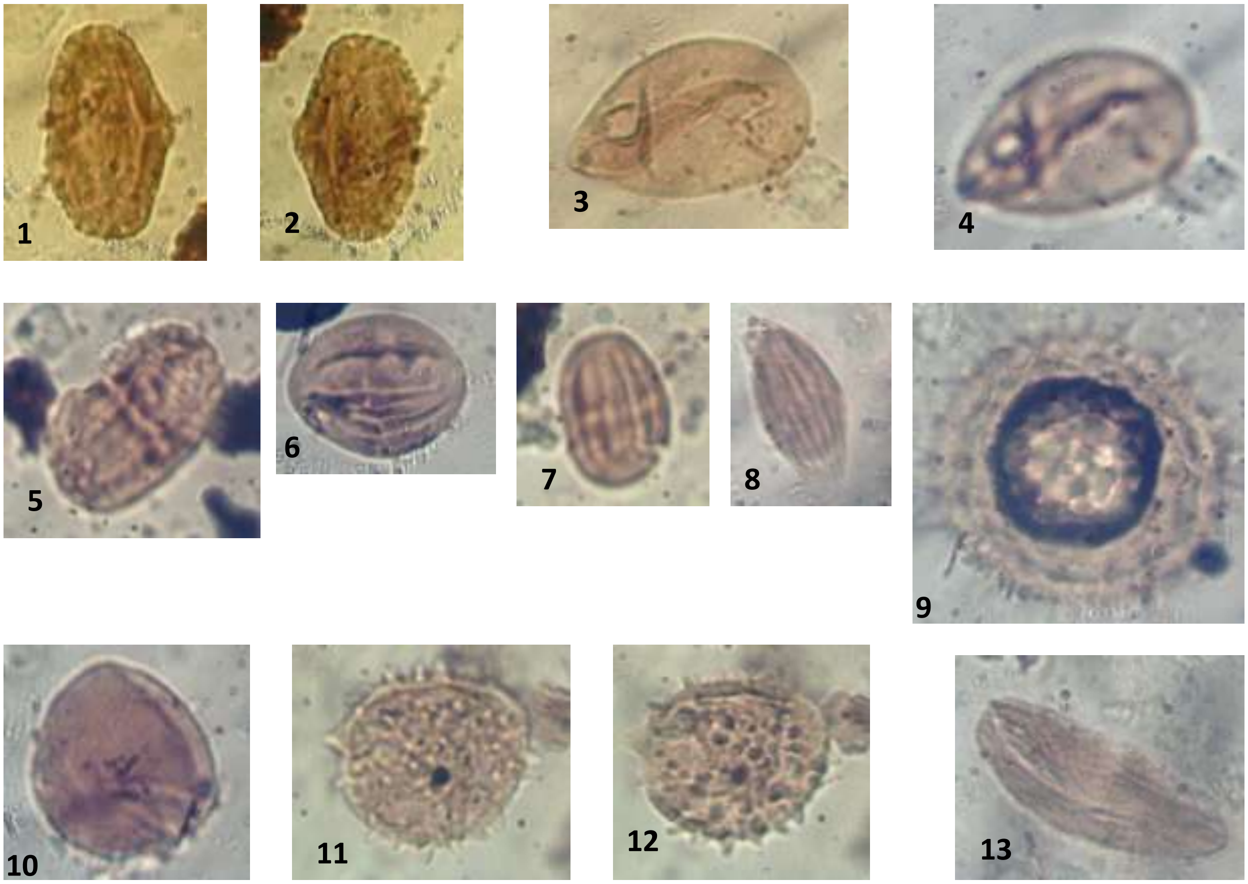


Plate 3 (Magnification =X1000)

1 & 2: *Retitricolporites irregularis*; Okan-65, (6680-6710ft, EFR F32/2) & (7730-7790ft, V37/3)

3, 4 & 5: *Racemonocolpites hians*; Okan-65 (10,310-10,370ft, EFR S26), (8630-8690ft, EFR P39/2) & (8870-8930ft, EFR P28)

6, 7, 8, & 9: *Cyperaceapollis* sp.; Okan-65, (7730-7790ft, EFR V44/3), (8570-8630ft, EFR X43), Okan-78 (7250-7310ft, EFR P29), & Okan-75RD (8260-8320ft, EFR S27)

10: *Monoporites annulatus*, Okan-65 (7730-7790ft, EFR V44/3)

11, 12 & 13: *Alnipollenites verus*, Okan-65 (8510-8570ft, EFR U41/2), (7310-7370ft, EFR W49) & (8870-8930ft, EFR U47/1)

14: *Canthumidites reticulates,* Okan-65 (7310-7370ft, EFR V43/4)

15: *Marginipollis concincus* Okan-65 (7730-7790ft, EFR K44/2)

16 – 22: *Zonocostites ramonae*

Plate 3

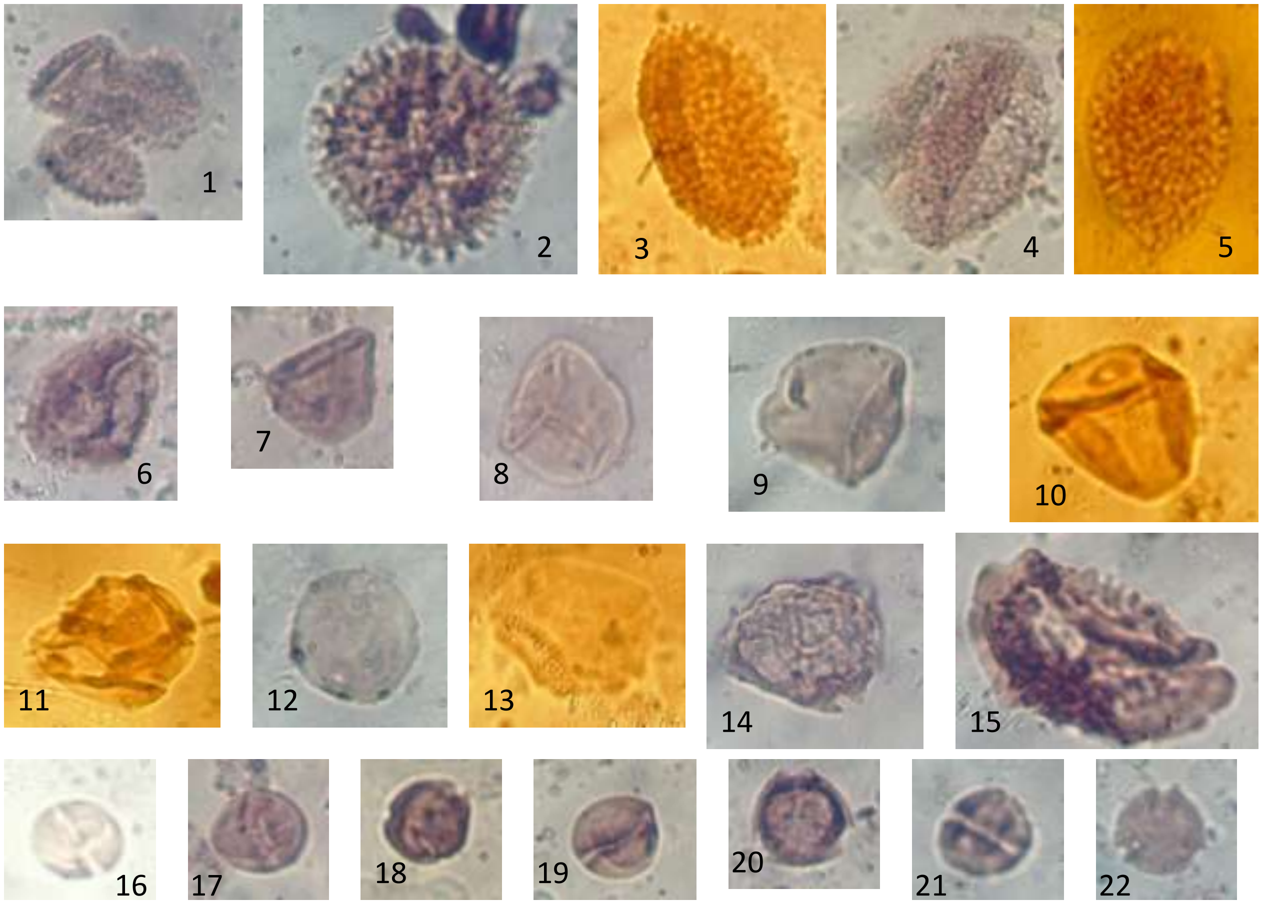


Plate 4 (Magnification =X1000)

1: *Pachydermides diederixi*; Okan-65, 8690-8750ft, EFR M34/4

2, 3 & 4: *Psilatricolporites crassus*; Okan-65, (8630-8690ft, EFR Y45/4), (7310-7370ft, EFR H44) & (7730-7790ft, EFR Y35/1)

5: *Operculodinium cetrocarpum*; Okan-65 (7970-8030ft, EFR H24)

6 & 7: *Multiareolites formosus*; Okan-75RD (8140-8200ft, EFR C25/4, high & low focus respectively)

8: *Corsinipollis jussiensis*; Okan-75RD (6530-6590ft EFR E51/4)

9: *Brevitricolporites guinetti*; Okan-65 (8690-8750ft EFR F37/1)

10 & 11: *Peregrinipollis nigericus*; Okan-65 (EFR W30, low and high focus)

12: *Verrutricolporites rotundiporus*; Okan-65, (8570-8630ft EFR S36/1)

13 & 14: *Verrutricolporites rotundiporus*; Okan-65 (8690-8750ft, EFR M44, low & high focus respectively)

Plate 4

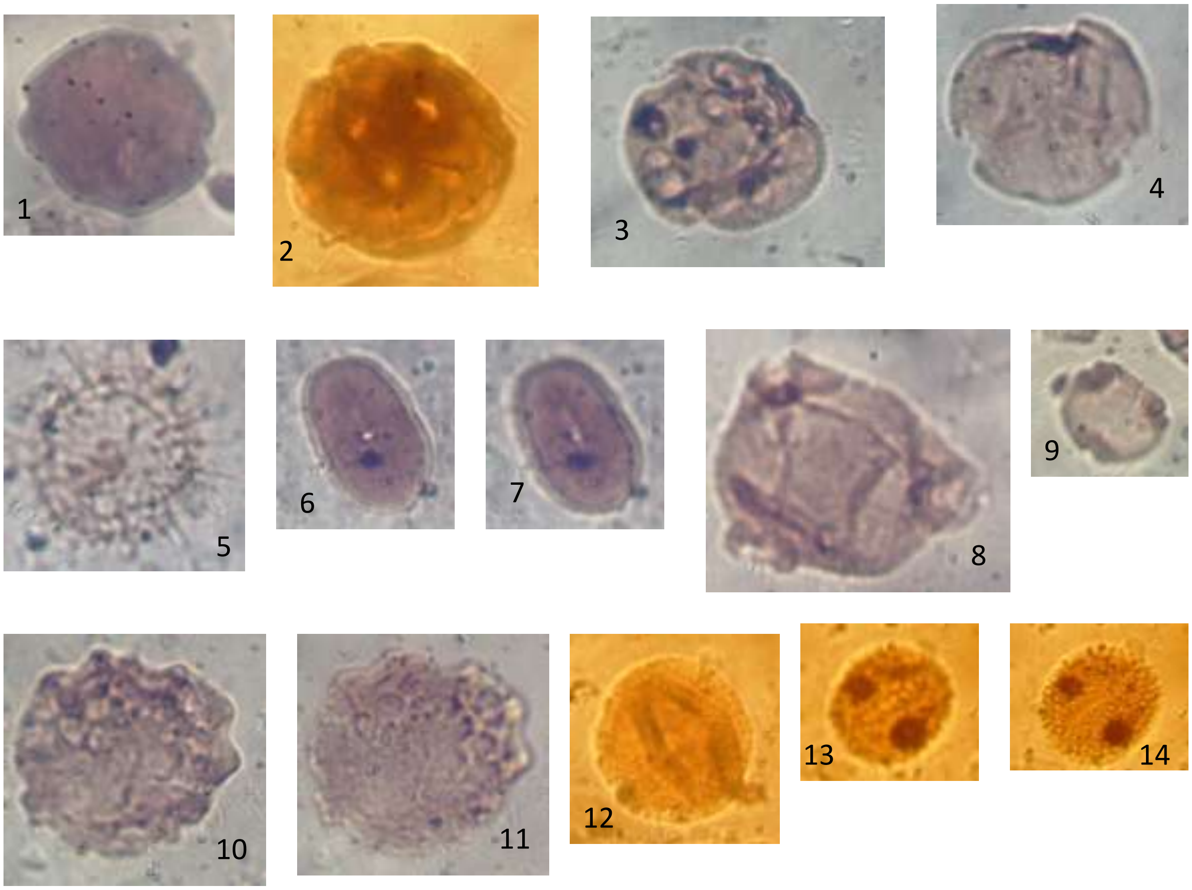


Plate 5 (Magnification = X1000)

1 & 2: *Coryllupollis avenella*; Okan-65, (6590-6650ft, EFR L34/3)

3: *Retibrevitricolporites obodoensis*; Okan-65 (8630-8690ft, EFR N22/3)

4 &5: *Retibrevitricolporites protrudens*; Okan-65 (9380-9410ft, EFR T46/3)

6 & 7: *Pandamites* sp.; Okan-65 (8570-8630ft EFR G45, low and high focus respectively)

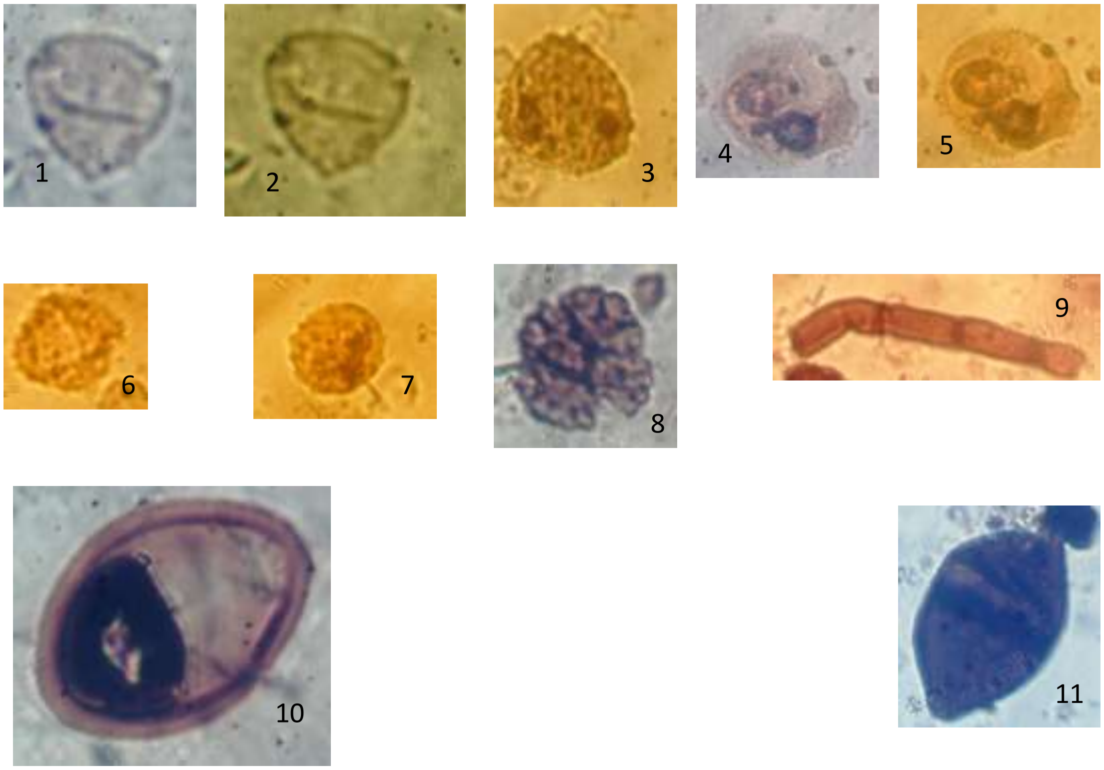
8: *Desmidiospora* type

9: *Diporicellaesporites* sp.

10: *Tasmanites* sp., Okan-65 (7850-7910ft, EFR N55)

11: *Psilodiporites ellipsoideus* (Fungal spore)

Plate 5



4.3.2. Description of Selected Palynomorphs Species

Seven (7) spores and twenty-six (26) pollen grains, one (1) dinocyst, one Tasmanite (1) and four (4) fungal spores were selected for description among others. Those selected are the ones whose morphological forms appearred very well as well as some stratigraphical important ones. For the purpose of description, the species are classified according to certain criteria discussed below.

4.3.2.1 Classification Criteria

The classification adopted for the pollen and spores is based on their morphological forms. Hence, they are classified according to their morphogroups. The morphological characters considered important are:

(i) Type and number of apertures and;

(ii) Type of sculpture or ornamentation.

<u>The Aperture:</u> The primary criterion used in the morphological classification is based on the characteristics of the aperture. The six basic types are outlined below:

a. monoletes – with a single germinal scar;

b. triletes – with a triradial mark;

c. aletes (spore) / inaperturate(pollen) – without an apertures;

d. colpates – those with slits as apertures;

e. porates – those whose apertures consist of pores;

f. colporates – those having both slits and pores.

However, for the classification of spores, only monoletes, triletes and aletes are used.

The secondary criterion is based on the number of those characters listed in the primary criterion. Thus, we determine the number of colpi, pores, and colpi with pores in the colpates, porates and colporates respectively.

<u>The Ornamentation:</u> Ten basic types of ornamentation are used in this study. They are:

a. psilate or laevigate – smooth exine

b. granulate – exine covered with small grains or granules

c. foveolate – pitted surface

d. reticulate – with mesh-like sculpture

e. straite – with fine grooves

f. verrucates – warty or covered by verrucae

g. baculate – rod-like projections

h. echinates – with pointed projections

i. clavate – with club-like projections

j. scabrate- with knobs or points

Discussion: The classification adopted in this work is the form taxa concept. The advantage of this kind of classification is that fossil spores and pollen grains are referred to morphological groups without necessarily creating complications about botanical affinities, especially where such affinities are in doubt. Though, it has been realized that fossil pollen and spores belonging to two or more families may come under the same morphological group (Table 4.2), therefore, effort has been made to relate fossil spores and pollen grains to their botanical families. About 70% of these palynomorphs are traceable to their modern representatives. In addition, those palynomorphs with probable botanical affinities help as well to decipher the environment of plants that produced them.

Table 4.2: Taxon list of selected palynomorphs identified in Okan- 65, 75RD and 78 wells

Taxon Botanical Family	**Biological name**	**Palynological name**
Pteridophytes:		
Parkeriaceae	Ceratopteris cornuta	*Magnastriatites howardii*
Schizaeceae	Lygodium microphyllum	*Crassoretitriletes vanraadshovenii*
Polypodiaceae (Senso lato)	Hypolepsis sparsisora or Thelipteris falciloba or Catascopium (Bryophytes)	*Corrusporis* sp.
	Pteris?	*Polypodiaceoisporites* sp.

	Microsorium aff. Diversifolium	*Verrucatosporites* spp.
	Stenochlaena	*Verrucatosporites usmensis*
	Adiantium? or Lygodium	*Leiotriletes adriennis*
Sphagnaceae	Adiantium poiretii	*Stereisporites* sp.
	Pallaea? or Trichomanes? Or Riccia (Bryophytes)	*Laevigatosporites* spp.
	Pyrrhosia schimperiana	*Verrucatosporites tenellis*
Cyperaceae	Cyperus laevigatus	*Cyperaceae*
Angiosperms:		
Monocotyledons		
Palmae	Areca?	*Arecipites* spp.
Graminae		*Monoporites annulatus*
Dicotyledons		
Bombacaceae	Bombax buonopozense	*Bombacacidites annae*
Combretaceae	Combretum? or terminala?	*Heterocolpites laevigatus*
Convolvulaceae	Merremia sp.	*Perfotricolpites digitatus*
Ctenolophonaceae	Ctenolophon englerianum	*Ctenolophonidites costatus*
Euphorbiaceae	Amanoa	*Retitricolporites irregularis*
	?	*Psilatricolporites crassus*
	Alchornea	*Psilatricolporites operculatus*
Guttiferae	Symphonia globulifera	*Pachydermites diederixi*
Icacinaceae	Iodes Africana	*Echiperiporites icacinoides*
Lecythidaceae	Petersianthus macrocarpus	*Marginipollis concinnus*
Lythraceae	Crenea or Rotalia	*Verrutricolporites*

		rotundiporis
Leguminosae		
Cesalpiniaceae	Brachystegia	*Peregrinipollis nigericus*
	Peltophorum?	*Praedapollis africanus*
Malvaceae	Hibiscus tiliaceus	*Echiperiporites estalae*
Melastomataceae	Dissotis?	*Heterocolpites pseudostriatus*
Meliaceae	?Melia	*Psilastephanocolporites laevigatus*
Olacaceae	Anacolosia or Ptychopetalum	*Anacolosidites luteoides*
Proteaceae	Protea or Faurea	*Proteacidites cooksoni*
Sapotaceae	Butyrospermum or Manilkara	*Psilastephanocolporites perforatus*
	Mimusops	*Psilastephanocolporites* spp.
Ulmaceae	Holoptelea, Ampelocera, Hemiptelea, Phyllostylon, Ulmus Planera or Zelkova	*Ulmipollenites undulosus*
Corylaceae	Corylus sp.	?
Rubiaceae	Canthium	*Thomsonipollis magnificus*?
Rhizophoraceae	Bruguiera or Ceriops or Carallia or Rhizophora	*Zonocostites ramonae*

4.3.2 Phytoecological groups

For the purpose of displaying the recovered palynomorphs in the chart format, the recovered forms were placed under their phytoecological groups. Seven (7) phytoecological groups were recognized. Below is the list of the group with some of the palynomorphs within them.

1. Palmae/Pandanus: *Psilamonocolpites* spp., *Arecipites* spp., *Racemonocolpites hians*, *Elaeis guineensis*, *Pandanites* spp., etc.

2. Euphobiaceae/Rubiaceae: *Retibrevitricolporites obodoensis*/*protrudens*, *Retitricolporites irregularis, Canthiumidites reticularis, Anthostema aubryanum*, *Psilatricolpites operculatus*, etc.

3. Mangrove swamp: *Psilatricolporites crassus*, *Zonocostites ramonae, Verrutricolporites microporus*/*rotundiporus*, *Hetercolpites laevigatus*, etc.

4. Gramineae/Savanna: *Monoporites annulatus*, *Cyperaceapollis* spp., *Proteacidites cocksonii*, *Alnipollenites verus*, etc.

5. Freshwater swamp: *Pachydermites diederixi*, *Botryococcus braunii*, *Pediastrum* spp., etc.

6. Herb: *Echiperiporites estalae*/*icacinoides, Brevitricolporites guinetti*, etc.

7. Rainforest: *Sapotaceoidaepollenites* spp., *Peregrinipollis nigericus*, *Praedapollis flexibilis*, *Striatricolpites catatumbus*, *Belskipollis elegans*, etc.

4.3.3 Palynostratigraphic biozonation of Okan-78, 65 AND 75RD wells

The reference schemes used for the biozonation and age-dating were based on published works of Evamy *et al*. (1978), Legoux (1978) and Morley (1999). However, the alphanumeric codes of these authors were given a formal name using the names of species that marked the zonal boundaries in the studied wells. Zonation and age determination of the three well sections were based on the occurrences, abundance distribution of index species as well as palynomorph assemblage. On the basis of these parameters, the studied section of the wells has been assigned to two (2) major palynological zones namely: P800 and P700 of Evamy *et al.* (1978). The P800 zone recognized in the three wells was further assigned to *Multiareolites formosus* (P820) subzone, while the P700 zone was further subdivided into *Racemonocolpites hians* (P780) and *Verrutricolporites rotundiporus* (P770) subzones in Okan-78 and Okan-65 but in Okan-75RD, the zone was subdivided into the *Racemonocolpites hians* (P780) and combined *Verrutricolporites rotundiporus* (P770) –?*Belskipollis elegans* (?P750) subzones. The zones/subzones also correlate with H and G zones of Legoux (1978) as well as ML8, ML9 and

MM1 zones of Morley (1999) in age and floral content respectively in Okan-78 and 65 wells. However, in Okan 75RD well, the zones/subzones correlate with H and G zones of Legoux (1978) as well as ML8, ML9 and MM1-?MM2 zones of Morley (1999) in age and floral content.

The descriptions of the recognized subdivisions are given below starting from Okan-78 in the west through 65 to 75RD in the east.

4.3.3.1 Description of Recognised Stratigraphic Subdivisions in Okan-78 Well

Ninety-six (96) ditch cutting samples composited at 60ft from interval 5990–11855ft of Okan-78 well were processed and logged for their palynological contents.

Moderately abundant, well preserved and fairly diverse palynomorph assemblages dominated by *Zonocostites ramonae, Verrutricolporites rotundiporus*; species of *Sapotaceaeoidapollenites* and *Laevigatosporites* were recorded within intervals 5990-7430ft of the well section. Interval 7430-11855ft however, recorded a low abundance and low diverse miospores.

Very few specimens of sphaeromorph acritarch, *Leoisphaeridia* and freshwater algae (*Botryococcus brauni*/*Pediastrium* sp.) with total absence of marine dinoflagellate cysts were also recorded within the studied interval. The stratigraphic subdivisions are discussed below.

Stratigraphic Interval	**:**	5990-7250ft
Palynological Subzone	**:**	*Multiareolites formosus* (P820)
Age	:	Late Miocene
Subzonal Top	**:**	Tentatively placed at 5990ft, top of the analyzed section.
Subzonal Base	**:**	Subzonal base is marked by quantitative top occurrence of *Racemonocolpites hians* at 7250ft.

Characteristics:

- High abundance and high diversity of miospores were observed within this interval.
- Rich abundance of microfloral dominated by *Zonocostites ramonae*, species of *Sapotaceaeoidapollenites* and *Laevigatosporites* are diagnostic features of this interval.
- Rare to common occurrences of *Verrutricolporites rotundiporus*, *Psilatricolporites crassus* and *Racemonocolpites hians* are other significant features of the interval.

Stratigraphic Interval **:** 7250–8750ft

Palynological Subzone **:** *Racemonocolpites hians* (P780)

Age : Late Miocene

Subzonal Top **:** Quantitative top occurrence of *Racemonocolpites hians* at 7250ft marks the subzonal top.

Subzonal Base **:** Defined by the Quantitative top occurrence of *Verrutricolporites rotundiporus* at 8750ft.

Characteristics:

- Low abundance and low diversity of palynomorph characterize this interval.
- Drastic reduction in miospores especially *Zonocostites ramonae*, *Monoporites annulatus*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* are observable features of the interval.
- Sparse to rare recoveries of *Racemonocolpites hians*, *Retibrevitricolporites obodoensis* and *Verrutricolporites rotundiporus* are other diagnostic features of the interval.

Stratigraphic Interval **:** 8750-11855ft

Palynological Subzone	**:**	*Verrutricolporites rotundiporus* (P770)
Age	**:**	Middle Miocene
Subzonal Top	:	Defined by the top rich occurrence of *Verrutricolporites rotundiporus* at 8750ft.
Subzonal Base	**:**	Tentatively placed at the last depth studied (11855ft).

Characteristics:

- Slight improvement but still low abundance and low diversity in the recoveries of miospore especially *Zonocostites ramonae, species of Sapotaceaeoidapollenites, Laevigatosporites* and *Verrucatosporites* are important features recorded within the interval.
- Sparse to rare occurrences of *Verrutricolporites rotundiporus, Belskipollis elegans, Psilatricolporites crassus, Racemonocolpites hians*, *Pachydermites diederixi* and *Crassoretitriletes vanraadshoveni* are other diagnostic features recorded.

The summary table is presented below as Table 4.3a.

Table 4.3a: Palynostratigraphic Biozonation of Okan-78 Well

DEPTH (FT.)	AGE	GERMERAAD ET AL. (1968) ZONE	LEGOUX (1978)	EVAMY ET AL. (1978) ZONE	EVAMY ET AL. (1978) SUBZONE	MORLEY (1999)	BIOEVENTS
5990	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P800	*Multiareolites formosus* (P820)	ML8	
7250	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P700	***Racemonocolpites hians*** (P780)	ML9	Quantitative top occurrence of *Racemonocolpites hians*
7455							
8750	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700	***Verrutricolporites rotundiporus* (P770)**	MM1	Quantitative top occurrence of *Verrutricolporites rotundiporus*
8920							
10385							
11855							TD

4.3.3.2 Discription of Recognised Stratigraphic Subdivisions in Okan-65 Well

Seventy-eight (78) composite ditch cutting samples from interval 6560–11200ft of Okan-65 well were processed and logged for their palynological contents.

The samples yielded a moderate abundant and fairly diverse palynomorph assemblage dominated by *Zonocostites ramonae, Monoporites* annulatus, *Leoitriletes adriensis*, species of *Sapotaceaeoidapollenites*, *Verrucatosporites* and *Laevigatosporites* especially within the upper part (6560-9110ft) of the well section. The lower interval (9110-11200ft) however, recorded a low abundance and low diverse miospores.

Sparse recoveries of sphaeromorph acritarch, *Leoisphaeridia* and freshwater algae (*Botryococcus brauni*/*Pediastrium* sp.) with total absence of marine dinoflagellate cysts also constitute observable features of the studied interval.

Stratigraphic Interval	**:**	6560-7190ft
Palynological Subzone	**:**	*Multiareolites formosus* (P820)
Age	:	Late Miocene
Subzonal Top	**:**	Tentatively placed at 6560ft, top of the analyzed section.
Subzonal Base	**:**	Subzonal base is marked by quantitative top occurrence of *Racemonocolpites hians* at 7190ft.

Characteristics:

- Abundantly rich and fairly diverse miospores dominated by *Zonocostites ramonae*, *Monoporites* annulatus, *Leoitriletes adriensis*, species of *Sapotaceaeoidapollenites*, *Verrucatosporites* and *Laevigatosporites* characterize this interval.
- Rare to sparse occurrences of *Verrutricolporites rotundiporus* and species of *Stereisporites* are other significant features of the interval.

Stratigraphic Interval : 7190–8570ft

Palynological Subzone : *Racemonocolpites hians* (P780)

Age : late Miocene

Subzonal Top : Quantitative top occurrence of *Racemonocolpites hians* at 7190ft marks the subzonal top.

Subzonal Base : Defined by the Quantitayive top occurrence of *Verrutricolporites rotundiporus* at 8570ft.

Characteristics:

- Slight reduction in miospores recoveries especially *Zonocostites ramonae*, *Monoporites annulatus*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* were recorded within the interval.
- Increase in Monoporites annulatus coupled with low occurrences of *Racemonocolpites hians* and *Verrutricolporites rotundiporus* are other diagnostic features of the interval.

Stratigraphic Interval : 8570-11200ft

Palynological Subzone : *Verrutricolporites rotundiporus* (P770)

Age : Middle Miocene

Subzonal Top : Defined by the top rich occurrence of *Verrutricolporites rotundiporus* at 8570ft.

Subzonal Base : Tentatively placed at the last depth studied (11200ft).

Characteristics:

- Low abundance and low diversity in the recoveries of miospore characterize the interval.
- Moderate abundance of *Zonocostites ramonae* and *Monoporites annulatus* together with sparse to common recoveries of *Leoitriletes adriensis*, *species of Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* are important features recorded within the interval.
- Sparse to rare occurrences of *Verrutricolporites rotundiporus, Belskipollis elegans Psilatricolporites crassus* and *Racemonocolpites hians* are other salient features of the interval.

The summary table is presented as Table 4.3b.

Table 4.3b: Palynostratigraphic Biozonation of Okan-65 Well

DEPTH (FT.)	AGE	GERMERAAD ET AL. (1968) ZONE	LEGOUX (1978)	EVAMY ET AL. (1978) ZONE	EVAMY ET AL. (1978) SUBZONE	MORLEY (1999)	BIOEVENTS
6560	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P800	*Multiareolites formosus* (P820)	ML8	
7190	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P700	***Racemonocolpites hians*** (P780)	ML9	Quantitative top occurrence of *Racemonocolpites hians*
7720	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P700	***Racemonocolpites hians*** (P780)	ML9	
8570	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700	***Verrutricolporites rotundiporus* (P770)**	MM1	Quantitative top occurrence of *Verrutricolporites rotundiporus*
8880	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700	***Verrutricolporites rotundiporus* (P770)**	MM1	
10040	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700	***Verrutricolporites rotundiporus* (P770)**	MM1	
11200							TD

4.3.3.3 Description of Recognised Stratigraphic Subdivisions in Okan-75RD Well

One hundred and twenty-seven (127) ditch cutting samples composited at 60ft from interval 5980–13600ft of Okan-75RD well were processed and logged for their palynological contents.

Moderately abundant, well preserved and fairly diverse palynomorph assemblage dominated by *Zonocostites ramonae,* species of *Sapotaceaeoidapollenites* and *Laevigatosporites* were recorded within interval 5980-11800ft of the well section. Interval 11800-13600ft however, recorded a very low abundance and low diverse miospores.

Very few specimens of sphaeromorph acritarch, *Leoisphaeridia* and freshwater algae, *Pediastrium* sp. were only marine indicator present within the studied interval.

Stratigraphic Interval	**:**	5980-6880ft
Palynological Subzone	**:**	*Multiareolites formosus* (P820)
Age	:	Late Miocene
Subzonal Top	**:**	Tentatively placed at 5980ft, top of the analyzed section.
Subzonal Base	**:**	Subzonal base is marked by quantitative top occurrence of *Racemonocolpites hians* at 6880ft.

Characteristics:

- High abundance and high diversity of miospores were observed within this interval.
- *Zonocostites ramonae*, species of *Sapotaceaeoidapollenites* and *Laevigatosporites* dominate the microfloral assemblage of this interval.
- Rare to sparse occurrences of *Racemonocolpites hians*, *Verrutricolporites rotundiporus*, *Psilatricolporites crassus* and are other significant features of the interval.

Stratigraphic Interval	**:**	6880–8920ft
Palynological Subzone	**:**	*Racemonocolpites hians* (P780)
Age	:	Late Miocene
Subzonal Top	**:**	Quantitative top occurrence of *Racemonocolpites hians* at 6880ft marks the subzonal top.
Subzonal Base	**:**	Defined by the Quantitayive top occurrence of *Verrutricolporites rotundiporus* at 8920ft.

Characteristics:

- Low abundances and low diversities of palynomorph were recorded within this interval.
- Slight improvement in recoveries of miospores especially *Zonocostites ramonae*, *Monoporites annulatus*, *Verrutricolporites rotundiporus*, species of *Sapotaceaeoidapollenites* and *Laevigatosporites* are observable features of the interval.
- Sparse to rare recoveries of *Racemonocolpites hians* and *Retibrevitricolporites obodoensis* are other diagnostic features of the interval.

Stratigraphic Interval	**:**	8920-13600ft
Palynological Subzone	**:**	*Verrutricolporites rotundiporus* (P770)
Age	**:**	Middle Miocene
Subzonal Top	:	Defined by the top rich occurrence of *Verrutricolporites rotundiporus* at 8920ft.
Subzonal Base	**:**	Tentatively placed at the last depth studied (13600ft).

Characteristics:

- Appreciable miospore recoveries were recorded within the upper part (8920-11800ft) while very low abundance and low diversity of miospores were recorded within the lower part (11800-13600ft).
- *Zonocostites ramonae*, *Verrutricolporites rotundiporus,* species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* dominate the microflora assemblage of this interval.

Remarks: Poor recovery of Belskipollis elegans within the analyzed interval necessitated the combination of the two subzones, P770 - ?P750.

The summary table is presented as Table 4.3c.

Table 4.3c: Palynostratigraphic Biozonation of Okan-75RD Well

DEPTH (FT.)	AGE	GERMERAAD ET AL. (1968) ZONE	LEGOUX (1978)	EVAMY ET AL. (1978) ZONE	EVAMY ET AL. (1978) SUBZONE	MORLEY (1999)	BIOEVENTS
5980	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P800	*Multiareolites formosus* (P820)	ML8	
6880	LATE MIOCENE	ECHITRICOLPORITES SPINOSUS	H	P700	***Racemonocolpites hians*** (P780)	ML9	Quantitative top occurrence of *Racemonocolpites hians*
8920	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700	***?Belskipollis elegans*** (?P750) **--*Verrutricolporites rotundiporus* (P770)**	MM1 — ?MM2	Quantitative top occurrence of *Verrutricolporites rotundiporus*
9790	MIDDLE MIOCENE	ECHITRICOLPORITES SPINOSUS	G	P700			
13600							TD

4.3.4 Micropalaeontological biostratigraphy

4.3.4.1 Planktic Foraminiferal Biozonation of Okan-78, 65 And 75RD Wells

The following bioevents are significant in the zonal delineations of the studied interval:

- First and Last Downhole Occurrences (FDO and LDO) of chronostratigraphically important planktic and benthic foraminiferal species.
- Foraminiferal abundance and diversity peaks when datable with foraminiferal marker species whose stratigraphic ranges are well established in the Niger Delta and worldwide.

The planktic foraminiferal zones recognized in this study are based on the revised Cenozoic geochronologic and chronostratigraphic schemes of Bolli and Saunders (1988) and Blow (1969, 1979).

4.3.4.1.1 Foraminiferal Biozonation and Discription of Recognised Stratigraphic Subdivisions in Okan-78 Well

Ninety-six (96) composited ditch cutting samples of Okan-78 well were processed and analyzed at 60ft for their foraminifera and accessory microfauna contents.

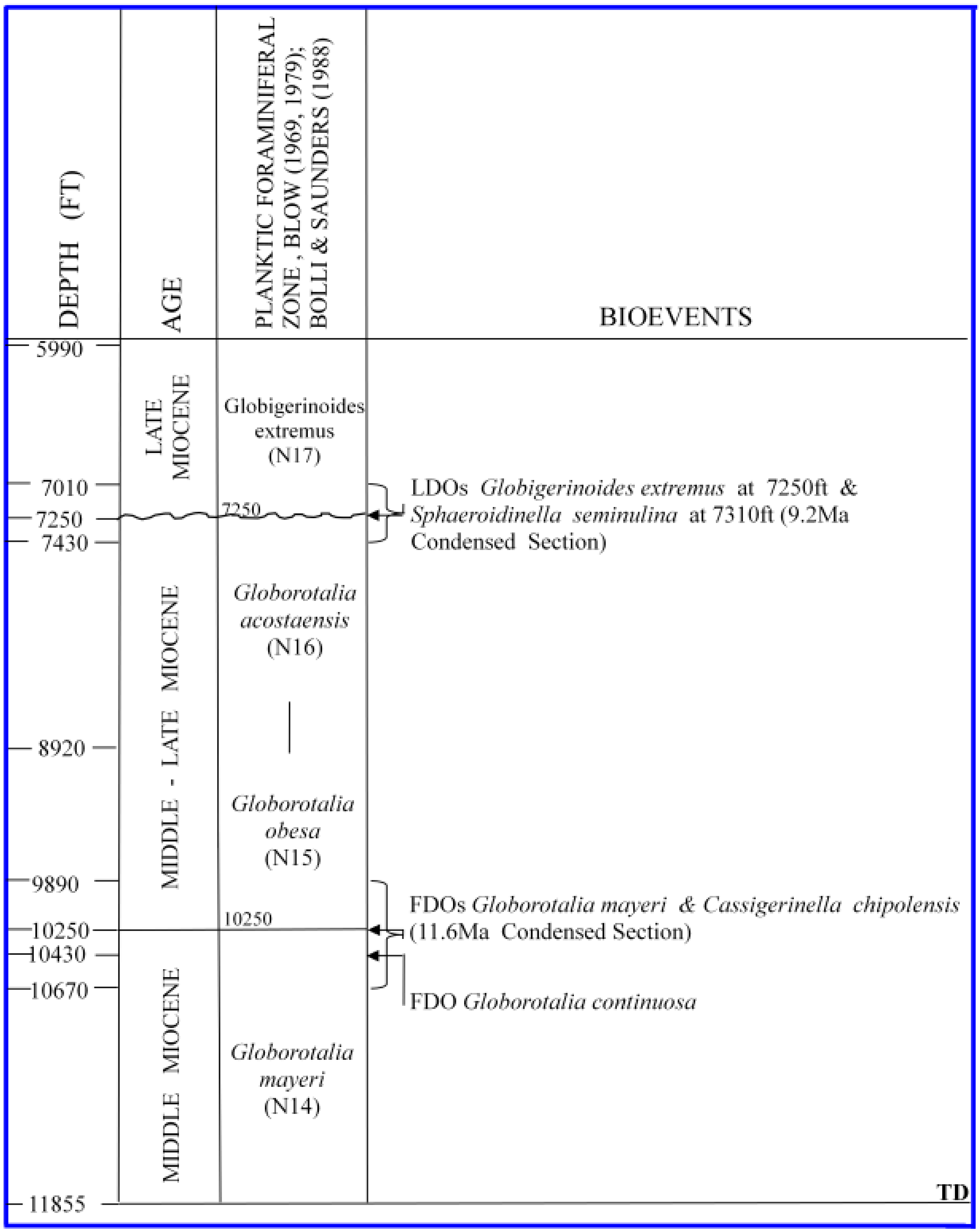
The foraminifera recoveries were generally low except within intervals 7250-7310ft and 10130-10430ft which yielded moderate to abundant and fairly diverse foraminfera. Seventy-nine (79) foraminiferal species were recovered. Twenty-two (28%) of these are planktics, forty-eight (61%) are calcareous benthics while the remaining nine (11%) species are arenaceous benthic species. Echinoid remains, shell fragments, gastropods and pelecypods are accessory microfauna recorded.

Part microfaunal distributions are contained in summary charts of the three wells as Enclosure 1 while foraminiferal abundance and diversity data are shown as Appendix 1.

Planktic foraminiferal zones

The zones recognized in this study are summarized in Table 4.4a and briefly described below.

Table 4.4a: Foraminiferal Biozonation of Okan-78 Well



Stratigraphic Interval	**:**	5990–7310ft
Plantic Zone	**:**	*Globigerinoides extremus* (N17)
Age	:	Late Miocene
Zonal Top	**:**	Tentatively placed at 5990ft, top of the analyzed section.
Zonal Base	**:**	Defined by the Last Downhole Occurrence (LDO) of *Sphaeroidinellopsis seminulina* at 7310ft.

Characteristics:

- The upper part of the interval (5990-6170ft) is barren of foraminifera. Interval 6170-7250ft yielded low abundance and low diverse planktics while moderate abundance and low diverse planktics were recorded within the basal section (7250-7310ft).
- Last Downhole Occurrence (LDO) of *Globigerinoides extremus* at 7250ft is an important N17 zone bioevent recorded.
- Few other planktics recorded include *Globorotalia acostaensis acostaensis*, *Globigerinoides trilobus trilobus*, *Globigerina quinqueloba*, species of *Globigerinoides* and *Globigerina*. A sudden influx of foraminifera was recorded at 7250ft. This may either be as a result of a fault or a facies change from a sandy top (7190ft) to shaly section (7250ft). However, this is subject to confirmation from seismic section.
- The moderate to high abundances and diversities of foraminifera recorded within interval 7190-7210ft are thought to represent the relics of 9.2Ma Condensed Section.

Remarks:

The base of *Globigerinoides extremus* (N17) Zone is normally defined by the Last Downhole Occurrence (LDO) of *Globigerinoides extremus* recorded here at 7250ft but was placed at 7310ft, the Last Downhole Occurrence (LDO) of *Sphaeroidinellopsis seminulina* at 7310ft because the base of *Sphaeroidinellopsis seminulina* is in *Globigerinoides extremus* zone. This implies that *Globigerinoides extremus* zone still gets to 7310ft.

Stratigraphic Interval **:** 7310-10250ft

Planktic Zone **:** *Globorotalia obesa* / *Globorotalia acostaensis* (N15)/ (N16)

Age : Middle-Late Miocene

Zonal Top **:** Marked by Last Downhole occurrence (LDO) of *Sphaeroidinellopsis seminulina* at 7310ft.

Zonal Base **:** Defined by the First Downhole Occurrence (FDO) of *Globorotalia mayeri* at 10250ft.

Characteristics:

- The interval is characterized mostly by very rare planktics except within interval 10090-10250ft with few planktics.
- Planktics recorded are mostly long ranging and non-age diagnostic which include *Globorotalia bolli, Globigerina quinqueloba, Globigerinoides praebulloides,* species of *Globigerinoides* and *Globigerina*.

Remarks:
Zones *Globorotalia obesa* / *Globorotalia acostaensis* (N15/N16) are combined due to poor stratigraphic record of *Globorotalia acostaensis acostaensis*, the N15/N16 boundary marker species.

Stratigraphic Interval **:** 10250-11855ft

Plantic Zone **:** *Globorotalia mayeri* (N14)

Age : Middle Miocene

Zonal Top **:** Marked by First Downhole Occurrence (FDO) of *Globorotalia mayeri* at 10250ft.

Zonal Base **:** Tentatively placed at 11855ft, last sample studied.

Characteristics:

- Rare to moderate abundance and low diverse planktics characterize the interval.
- Few planktics recorded include *Globorotalia obesa*, *Globigerinoides praebulloides*, *Globigerinoides immaturus*, *Globigerinoides bolli*, species of *Globigerinoides* and *Globigerina*.
- First Downhole Occurrence (FDO) of *Cassigerinella chipolensis* (10250ft) and *Globorotalia continuosa* (10430ft) are important *Globorotalia mayeri* zonal bioevents recorded.
- Condensed section recorded whithin interval 9890-10610ft is thought to represent 11.6Ma condensed section.

4.3.4.1.2 Foraminiferal Biozonation and Description of Recognised Stratigraphic Subdivisions in Okan-65 Well

Seventy-eight (78) ditch cutting samples of Okan-65 well were processed and analyzed at 60ft within interval 6560-11200ft for their foraminifera and accessory microfauna contents.
The samples yielded low abundant and low diverse foraminifera species except within intervals 7190-7200ft and 9239-9350ft with highly abundant and moderately diverse foraminiferal species. Seventy-three (73) foraminiferal species were recovered. Twenty (27%) of these are planktics, thirty-eight (52%) are calcareous benthics while the remaining fifteen (21%) species are arenaceous benthic species. Sponges, gastropods, echinoid remains, shell fragments, pelecypods and ostracods are accessory microfauna recorded.

Parts of the microfaunal distribution, the foraminiferal abundance and diversity plots and paleobathymetric data are presented as Enclosure 1while foraminiferal abundance and diversity data are shown as Appendix 1.

Planktic foraminiferal zones

The zones recognized in the studied section are summarized in Table 4.2b and briefly described below.

Table 4.4b: Foraminiferal Biozonation of Okan-65 Well

DEPTH (FT)	AGE	PLANKTIC FORAMINIFERAL ZONE, BLOW (1969, 1979); BOLLI & SAUNDERS (1988)	BIOEVENTS
6560	LATE MIOCENE	Globigerinoides extremus (N17)	
7250			Peak faunal abundance (relics of 9.2Ma Condensed Section) used due to non-recovery of *Globigerinoides extremus*, the N16/N17 boundary marker species
7720	MIDDLE - LATE MIOCENE	*Globorotalia acostaensis* (N16)	
		|	
8880		*Globorotalia obesa* (N15)	
9050			
9170			FDO *Globorotalia continuosa*, at 9170ft, FDOs *Globorotalia mayeri* & *Cassigerinella chipolensis* at 9230ft (11.6Ma Condensed Section)
9820	MIDDLE MIOCENE		
10040		*Globorotalia mayeri* (N14)	
11200			TD

Stratigraphic Interval : 6560–7250ft

Planktic Zone : *Globigerinoides extremus (*N17)

Age : Late Miocene

Zonal Top : Tentatively placed at 6560ft, top of the analyzed section.

Zonal Base : Tentatively placed at the peak faunal abundance at 7250ft.

Characteristics:

- Rare planktics were recovered within this zone except within interval 7190-7250ft, where planktics were abundant.
- Planktics recovered are mostly long-ranging and non-age diagnostic. They include *Orbulina universa, Globigerinoides immaturus*, *Globigerianta obliquus, Globigerina quiqueloba*, species of *Globigerina* and *Globigerinoides*.
- Sudden influx of foraminiferal species was observed at 7250ft. This may be as a result of a fault which cut off part of 9.2Ma condensed section.
- Abundant and diverse planktics recovered within interval 7190-7250ft is thought to represent the relics of 9.2Ma condensed section.

Remarks:

Peak faunal abundance was used to mark the N16/N17 boundary due to non-recovery of *Globigerinoides extremus* whose base is normally used to mark the N16/N17 boundary.

Stratigraphic Interval : 7250-9170ft

Plantic Zone : *Globorotalia obesa* / *Globorotalia acostaensis* (N15-N16)

Age : Middle-late Miocene

Zonal Top : Tentatively placed at the peak faunal abundance at 7250ft.

Zonal Base : Defined by the First Downhole Occurrence (FDO) of *Globorotalia continuosa* at 9170ft.

Characteristics:

- Paucity of planktics characterizes this interval. *Orbulina universa*, *Globigerinoides immaturus*, *Globigerinoides* spp and planktic indeterminate species were the only planktics recorded.

Remarks:

N15/N16 zones were combined due to non-recovery of *Globorotalia acostaensis acostaensis* whose base is used to mark the N15/N16 boundary.

Stratigraphic Interval : 9170-11200ft

Plantic Zone : *Globorotalia mayeri* (N14)

Age : Middle Miocene

Zonal Top : Defined by First Downhole Occurrence (FDO) of *Globorotalia continuosa* at 9170ft.

Zonal Base : Tentatively placed at 11200ft, last sample studied.

Characteristics:

- Rare to abundant planktics characterize this zone.
- Planktics recorded include *Globorotalia obesa*, *Globigerinoides trilobus trilobus*, *Globigerinoides praebulloides and Orbulina universa*.
- First Downhole Occurrence (FDO) of *Globorotalia mayeri* and *Cassigerinella chipolensis* at 9230ft are important N14 bioevents recorded.

- Condensed section recorded within interval 9050-9830ft is thought to represent 11.6Ma condensed section.

Remarks:

First Downhole Occurrence (FDO) of *Globorotalia mayeri* is normally used to define the top of N14 zone. However, because the top of *Globorotalia continuosa*, which is in *Globorotalia mayeri* zone, was recorded shallower than where the top of *Globorotalia mayeri* is, hence top of *Globorotalia continuosa* was used to mark top of *Globorotalia mayeri* zone.

4.3.4.1.3 Foraminiferal Biozonation and Description of Recognised Stratigraphic Subdivisions in Okan-75RD Well

One hundred and twenty-seven (127) ditch cutting samples of Okan-75RD well were processed and analyzed at 60ft within interval 6560-11200ft for their foraminifera and accessory microfauna contents.

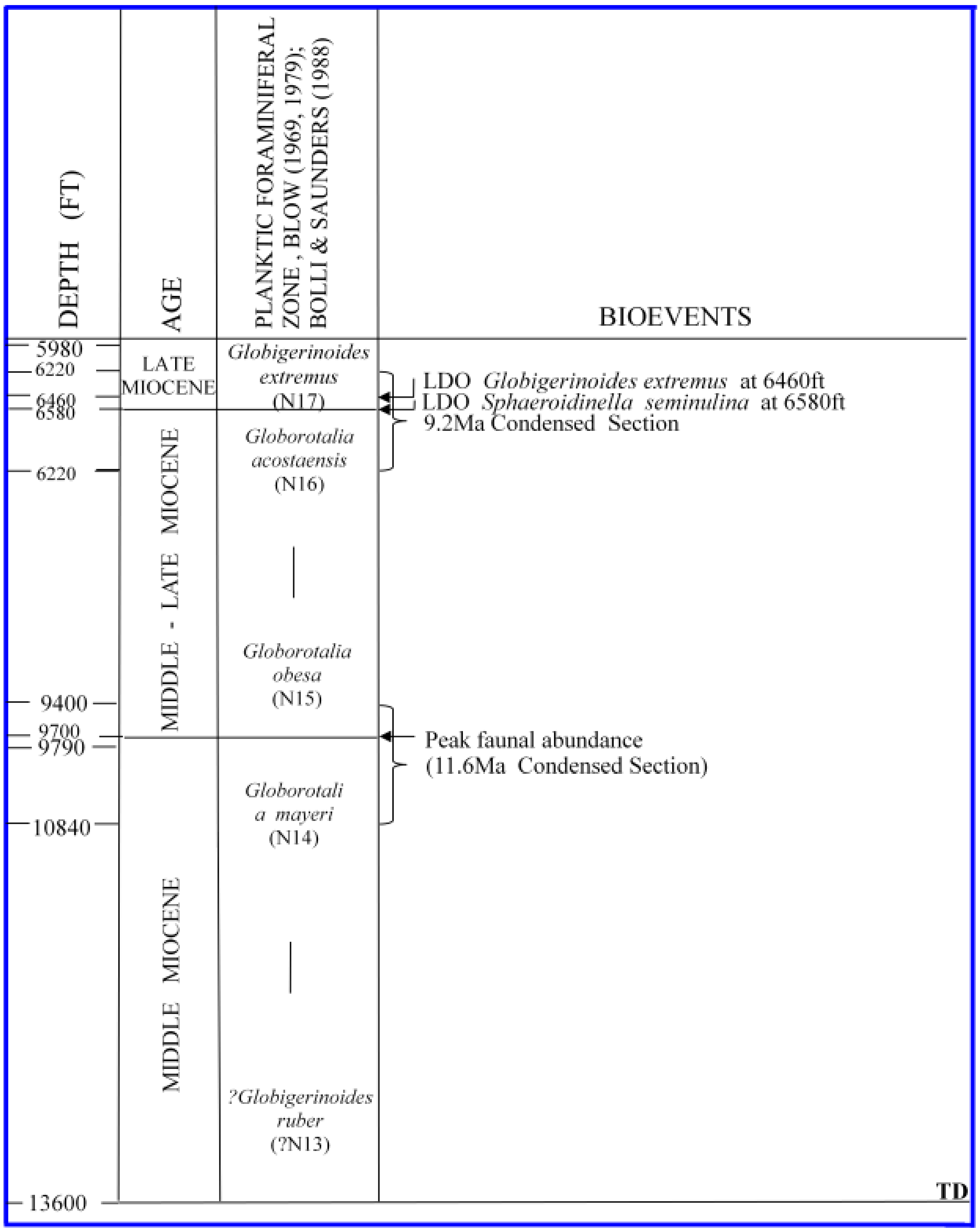
The samples yielded low abundant and low diverse foraminifera species except within interval 6340-6520ft with abundant and diverse foraminifera. Sixty-eight (68) foraminiferal species were recovered. Eighteen (26%) of these are planktics, thirty-four (50%) are calcareous benthics while the remaining sixteen (24%) species are arenaceous benthic species. Sponges, gastropods, echinoid remains, shell fragments, pelecypods, scaphopods and ostracods are accessory microfauna recorded.

Parts of microfaunal distribution, the foraminiferal abundance and diversity plots and paleobathymetric data are presented as Enclosure 1 while foraminiferal abundance and diversity data are shown as Appendix 1.

Planktic foraminiferal zones

These zones recognized in the studied section of this well are summarized in Table 4.2c and briefly described below.

Table 4.4c: Foraminiferal Biozonation of Okan-75RD Well



Stratigraphic Interval **:** 5980–6580ft

Planktic Zone **:** N17

Age : Late Miocene

Zonal Top **:** Tentatively placed at 5980ft, top of the analyzed section.

Zonal Base **:** Defined by Last Downhole Occurrence (LDO) of *Sphaeroidinollopsis seminulina* at 6580ft.

Characteristics:

- Low abundance and low diverse planktics were recorded within this zone. Few planktics recorded include *Globigerina praebuloides*, *Globigerinoides trilobus trilobus*, *Globigerinoides obliquus* and *Globigerinoides* spp. except within interval 7190-7250ft, with moderately abundant planktics.
- Last Downhole Occurrence (LDO) of *Globigerinoides extremus* at 6460ft is an important N17 zone bioevent recorded.

Remarks:

Last Downhole Occurrence (LDO) of *Sphaeroidinollopsis seminulina* (N17 bioevent) at 6580ft was used to approximate the N16/N17 boundary because it does not get to N16 zone. Its occurrence below the usual N16/N17 marker event, the Last Downhole Occurrence (LDO) of *Globigerinoides extremus* shows that N17 still gets to 6580ft.

Stratigraphic Interval **:** 6580-9700ft

Planktic Zone **:** N15-N16

Age : Middle-late Miocene

Zonal Top **:** Approximated at the Last Downhole Occurrence (LDO) of *Sphaeroidinollopsis seminulina* at 65850ft.

Zonal Base : Approximated at 9700ft, the peak abundance of 11.6Ma condensed section.

Characteristics:

- Rare to moderate abundance and diversity of long ranging, non-age diagnostic planktics characterize this zone.
- Planktics recorded include *Orbulina universa*, *Globigerinoides trilobus trilobus*, *Globigerinoides immaturus*, *Globigerinoides obliquus*, species of *Globigerinoides* and *Globigerina*.
- Condensed section within interval 6220-7120ft is thought to represent the 9.2Ma condensed section.

Remarks:

N15/N16 zones were combined due to non-recovery of *Globorotalia acostaensis acostaensis*, the N15/N16 boundary marker species.

Stratigraphic Interval : 9170-11200ft

Plantic Zone : ?N13-N14

Age : Middle Miocene

Zonal Top : Approximated at 9700ft, peak abundance of 11.6Ma condensed section.

Zonal Base : Tentatively placed at 13600ft, last sample studied.

Characteristics:

- The interval consists of rare to few long ranging, non-age diagnostic planktics which include *Orbulina universa*, *Globigerinoides praebulloides* and *Globigerinoides quinqueloba*.

- The condensed section within interval 9400-10540ft is thought to represent the 11.6Ma condensed section based on its stratigraphic position below a positively dated 9.2Ma condensed section.

Remarks:

Zones? N13/N14 are combined due to non-recovery of *Globigerina nepenthes*, the N13/N14 boundary marker species.

4.4 Palaeoenvironmental Interpretation

Lithofacies variations provide the basis for interpreting paleoenvironmental changes, although inferences using lithofacies alone are notoriously non-unique (Katz *et al*., 2003). The reliability of palaeoenvironmental interpretations would obviously be improved by integrating biofacies, lithofacies, and gamma-ray (GR) log motifs.

Pyrite and glauconite are authigenic minerals (i.e. minerals that grow as crystals in depositional environments) and when combined with other accessory materials such as shell fragments, carbonaceous detritus, mica flakes, rootlets, gamma ray log motif and biofacies give good interpretation of depositional environments.

An association of organisms representing a particular depositional environment is referred to as a biofacies (Sturrock, 1996). Interpretations of biofacies using calcareous and agglutinating benthic foraminifera provide changes in palaeobathymetry (palaeowater depth variations).

4.4.1 Paleoenvironmental Analysis of Okan-78 Well

The marine unit (11855-9490FT)

This unit consists of shale sequence which contains about 28% sands. The shales are dark grey in colour, platy to blocky and angular in shape. Index minerals and other materials recorded in rare to common quantities within this unit include shell fragments, glauconite, mica flakes, pyrite, rootlets and ferruginous materials. The abundance of shale (78%) and persistent moderate to abundant occurrences of glauconite, pyrite and shell fragments over the sequence suggests slow sedimentation in a predominantly low energy marine and anoxic setting. The few sands present within the unit represent occasional high energy sedimentation.

Intervals 11855-10670ft and 9890-9770ft are characterized by low abundance and low diverse foraminiferal species. However, moderate to abundant and diverse foraminifera species were recovered within intervals 10670-9890ft and 9770-9590ft. Calcareous benthics recorded include *Cancris auriculus*, *Uvigerina peregrina*, *Lenticulina inornata*, *Epistominella vitrea*, *Heterolepa pseudoungeriana*, *Uvigerina subperegrina*, *Globocassidulina subglobosa*, *Bolivina scalprata miocenica*, species of *Valvulineria* and *Nodosaria*. Few arenaceous benthics recorded include *Saccammina complanata*, *Ammobaculites* spp, *Dorothia scabra*, *Haplophragmoides compressa* and *Textuleria* spp. The sediments of this interval were deposited in environments which alternate dominantly between middle and inner neritic with minor deepening to outer neritic within interval 10250-10370ft.

Low abundance and low diverse microfloral species characterize this interval. Dominance of land–derived palynomorphs such as *Zonocostites ramonae*, species of *Sapotaceaeoidapollenites* and *Laevigatosporites* were recorded within the unit. The predominance of smooth-walled and small sized miospores suggests sediment deposition within a relatively deep marine setting.

The trasitional/paralic unit (9490-5990FT)

This unit consists of sand and shale intercalations with sand/shale ratio of approximately 65/35%. The sand/shale alternations of this unit suggest frequent alternation of high and low energy sedimentary regimes probably resulting from differential subsidence and/or shifting of depositional axis common within Niger Delta. The sands are mostly fine to coarse- grained, moderately to poorly sorted and subrounded to occassionally angular. The shales are grey, platy to blocky and poorly to moderately indurated. The co-occurrence of glauconite pellets, carbonaceous materials, rootlets, shell fragments and ferruginous material within this sequence indicate shallow marine sedimentation and winnowing influence.

This interval is characterized by low abundance and low diverse foraminiferal species with some barren intervals except within interval 6350-6290ft with recovery of abundant and diverse foraminiferal species. However, interval 6170-5990ft was barren of foraminifera. Shallow water benthics present include *Lenticulina inornata*, *Heterolepa pseudoungeriana*, *Amphicoryna scalaris caudata*, *Bolivina scalprata miocenica*, *Epistominella vitrea* and *Florilus* et gr. *costiferum*. Few associated deep water calcareous benthics recorded were *Bulimina inflata*, *Praeglobobulimina ovata*, *Trifarina reussi*, *Gyroidina soldanii* and *Uvigerina peregrina*. *Alveolophragnium crassum*, *Saccammina complanata*, species of *Haplophragnium*, *Eggerella*, *Ammobaculites* and *Textularia* were the few associated arenacoeus benthics recovered. Sediments of this interval were deposited mostly in environments which alternate between inner neritic and coastal deltaic with minor deepenings to middle and outer neritic. These sediments shoal to coastal deltaic upsection.

This unit presents a low abundance and low diverse palynomorph over the lower part (9590-7590ft) of the unit while a high abundance and moderate diverse microfloral species characterize the upper part (7590-5990ft). Small sized mangrove swamp pollen, *Zonocostites ramonae* and *Verrutricolporites rotundiporus* together with smooth walled pteridophyte spores, *Laevigatosporites* spp dominate the miospore assemblage of the interval. The above palynomorph association is indicative of sediment deposited within littoral (nearshore) and shallow marine environments.

4.4.2. Paleoenvironmental Analysis of Okan-65 Well

The marine unit (11200-9050FT)

This unit consists of shale sequence which contains about 35% sands. The shales are dark grey in colour, platy to blocky and angular in shape. Index minerals recorded in rare to common quantities within this unit include shell fragments, glauconite, mica flakes, pyrite, rootlets and rare ferruginous materials. The abundance of shale (65%) and persistent moderate to abundant occurrences of glauconite, pyrite and shell fragments over the sequence suggests slow sedimentation in a predominantly low energy marine and anoxic setting. The few sands present within the unit represent occasional high energy sedimentation.

The interval is characterized by low abundance and low diverse foraminiferal species except within intervals 9770 - 9710ft and 9350 -9230ft with abundant and diverse foraminiferal species. Calcareous benthic recovered include *Lenticulina inornata*, *Bolivina scalprata miocenica*, *Florilus* ex gr. *costiferum*, *Heterolepa pseudoungeriana*, *Cibicorbis inflata*, *Globocassidulina subglobosa*, *Uvigerina peregrina*, *Trifarina reussi*, species of *Valvulineria* and *Nonion*. *Saccammina complanata*, species of *Textuleria*, *Eggerella*, *Haplophragmoides* and *Ammobaculites* were among the few arenaceous benthics recovered. The above foraminiferal association is indicative of sediment deposition in environments which alternate dominantly between inner and middle neritic with minor outer neritic influence (9350-9239ft).

The unit is characterized by low abundance and low diversity of palynomorph. *Zonocostites ramonae*, *Monoporites annulatus*, *Leoitriletes adriensis*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* were miospores which dominate the microfloral assemblage of the interval. Few marine indicators such as *Botryococcus brauni*, species of *Peadiastrium* and *Leoisphaeridia* were also recorded within the unit. Sediments of this interval are deposited within a relatively deep marine environment.

The transitional/paralic unit (9050-6560FT)

This unit consists of sand and shale intercalations with sand/shale ratio of approximately 60/40%. The sand/shale alternations of this unit suggest frequent alternation of high and low energy sedimentary regimes probably resulting from differential subsidence and/or shifting of depositional axis common within Niger Delta. The sands are mostly fine to coarse- grained, moderately to poorly sorted and subrounded to occassionally angular. The shales are grey, platy to blocky and poorly to moderately indurated. The co-occurrence of glauconite pellets, carbonaceous materials, rootlets, shell fragments and ferruginous material within this sequence indicate shallow marine sedimentation and winnoing effect.

The interval is characterized by low abundance and low diverse foraminiferal species except within interval 7250-7190ft with abundant and moderately diverse foraminiferal species. Few calcareous benthics recorded include *Lenticulina inornata*, *Bolivina scalprata miocenica*, *Heterolepa pseudoungeriana*, *Uvigerina peregrina*, *Praeglobobulimina ovata*, species of *Bolivina* and *Nonion*. Associated arenaceous benthics present include *Alveolophragnium crassum*, *Eggerella scabra*, *Saccammina complanata*, species of *Haplophragmoides*, *Textuleria* and *Eggerella.* The sediments of this interval are deposited in environments that alternate between inner and middle neritic which shoal upsection to coastal deltaic environment.

An improvement in microfloral recovery dominated by *Zonocostites ramonae*, *Verrutricolporites rotundiporus*, *Monoporites annulatus*, *Leoitriletes adriensis*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* characterize the interval. Sparse recoveries of freshwater swamp, *Botryococcus brauni* and *Pediastrium* spp as well as sphaeromorph acritarch, *Leoisphaeridia* were also recorded over the unit. The above microfloral assemblage is indicative of sediment deposited within a dominantly nearshore-shallow marine environment.

4.4.3 Paleoenvironmental Analysis of Okan-75RD Well

The marine unit (13600-9500FT)

This unit consists of shale sequence which contains about 30% sands. The shales are dark grey in colour, platy to blocky and angular in shape. Index minerals recorded in rare to common quantities within this unit include shell fragments, glauconite, mica flakes, pyrite, rootlets and rare ferruginous materials. The abundance of shale (70%) and persistent moderate to abundant occurrences of glauconite, pyrite and shell fragments over the sequence suggests slow sedimentation in a predominantly low energy marine and anoxic setting. The few sands present within the unit represent occasional high energy sedimentation.

The lower part of this interval (13600-13120ft) is characterized by moderate abundance and diversity of foraminiferal species. This is overlain by middle interval (13120-10360ft) with low abundance and low diverse foraminiferal species and some barren intervals. However, the upper part of the interval (10360-9400ft) is characterized by low to moderate abundance and diversity of foraminiferal species. *Lenticulina inornata*, *Heterolepa pseudoungerina*, *Bolivina scalprata miocenica*, *Epistominella vitrea*, *Uvigerina peregrina*, species of *Valvulineria* and *Bolivina* were among the calcareous benthics present. Few associated arenaceous benthics recorded include *Saccammina complanata*, *Haplophragoides compressa*, species of *Haplophragmoides*, *Ammobaculites* and *Textularia*. The above foraminiferal association is indicative of sediments deposited in coastal deltaic to middle neritic environments.

The interval is characterized by low abundance and low diverse microfloral species. *Zonocostites ramonae*, *Verrutricolporites rotundiporus*, species of *Sapotaceaeoidapollenites*, *Laevigatosporites* and *Verrucatosporites* dominate the miospore assemblage of the interval. Few specimens of *Leoisphaeridia* sp were only marine indices recorded. Sediment of this interval was deposited in relatively deep marine setting.

Transitional/paralic unit (9500-5980FT)

This unit consists of sand and shale intercalations with sand/shale ratio of approximately 75/25%. The sand/shale alternations of this unit suggest frequent alternation of high and low energy sedimentary regimes probably resulting from differential subsidence and/or shifting of depositional axis common within Niger Delta. The sands are mostly fine to coarse- grained, moderately to poorly sorted and subrounded to occassionally angular. The shales are grey, platy to blocky and poorly to moderately indurated. The co-occurrence of glauconite pellets, carbonaceous materials, rootlets, shell fragments and ferruginous material within this sequence indicate shallow marine sedimentation and winnowing effect.

The interval is characterized by few to moderate abundance and diversity of foraminiferal species. Calcareous benthics recorded include *Amphicoryna scalaris caudata*, *Lenticulina inornata*, *Heterolepa pseudoungeriana*, *Quinqueloculina lamarckiana*, species of *Quinqueloculina*, *Marginulina*, *Uvigerina* and *Lenticulina*. Few associated arenacoeus benthics present include *Eggerella scabra*, *Alveolophragmium crassum*, *Haplophragmoides compressa*, species of *Eggerella*, *Ammobaculites* and *Textularia*. Sediments of this interval are deposited in environments which alternate between inner and middle neritic.

The interval presents an improvement in abundance and diversity of palynomorph with land derived miospores such as *Zonocostites ramonae*, *Verrutricolporites rotundiporus*, species of *Sapotaceaeoidapollenites* and *Laevigatosporites* still dominating the microfloral assemblage of the interval. Few species of *Leoisphaeridia* and *Pediastrium* were present. The above microfloral association suggests sediment deposition within nearshore/shallow marine environments.

4.5. 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).

4.5.1 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. 4.5a and 4.5b) 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. 4.5c) as the older condensed section below 11.6Ma based on the scheme of Haq *et al*., (1987).

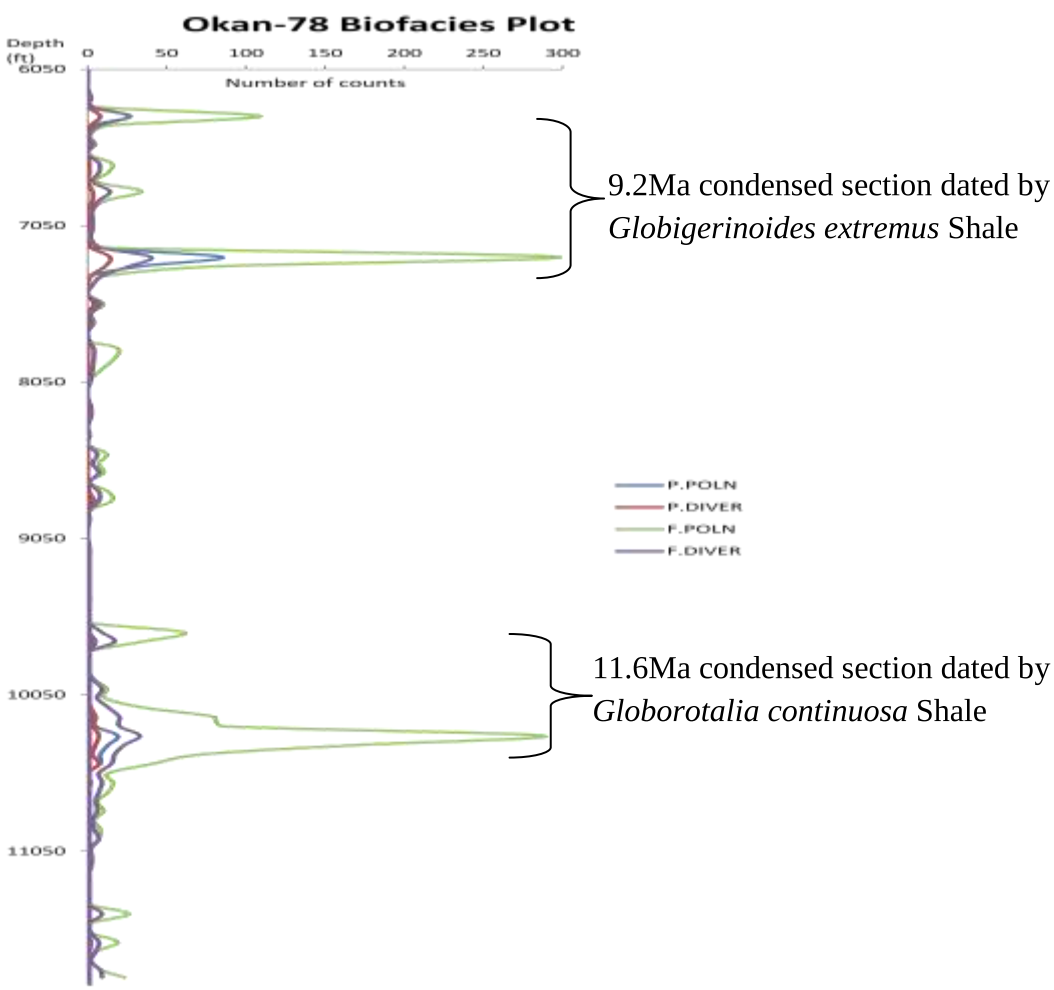


Fig. 4.5a: Biofacies plot of Okan-78

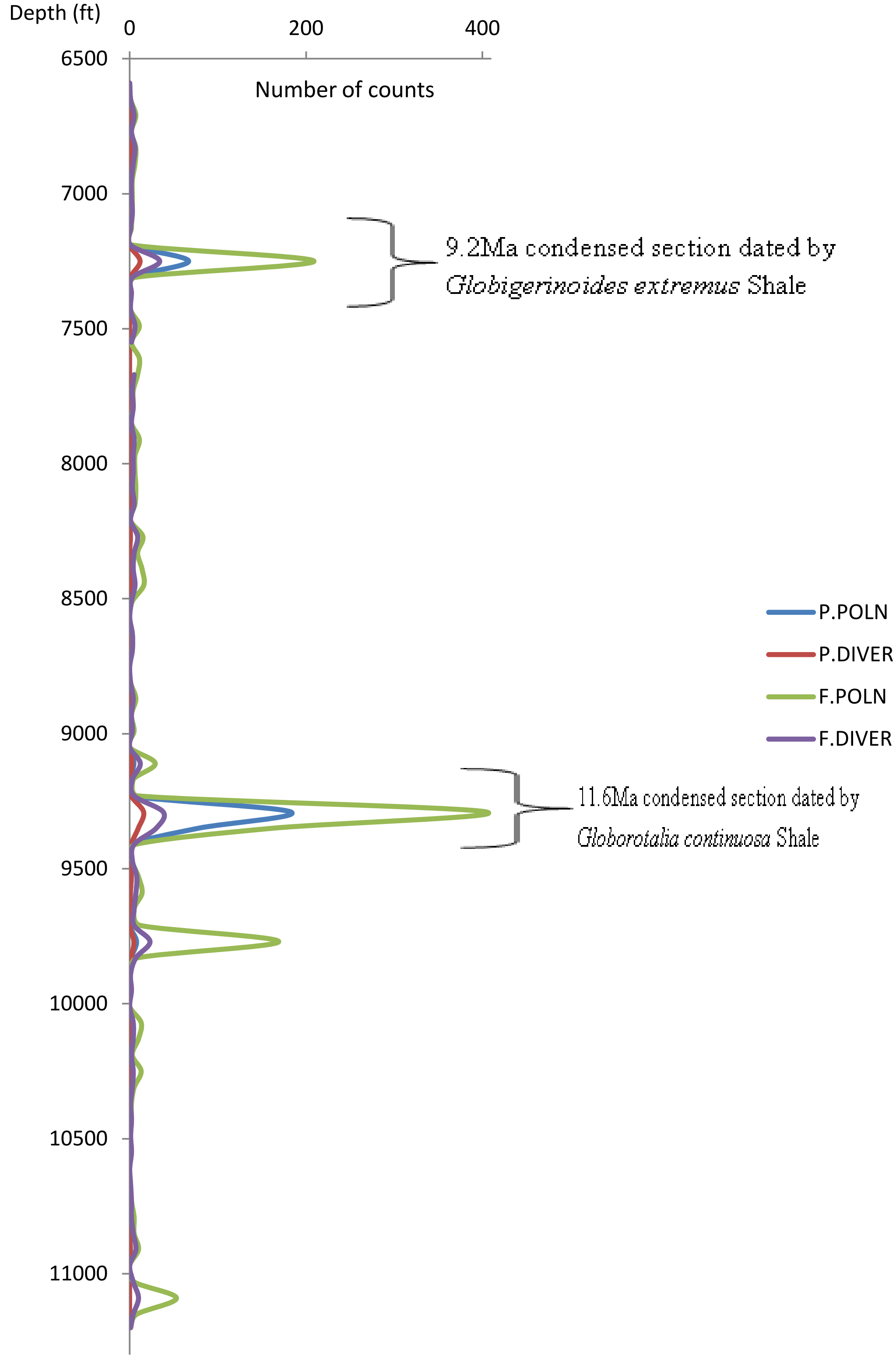


Fig. 4.5b: Biofacies plot of Okan-65

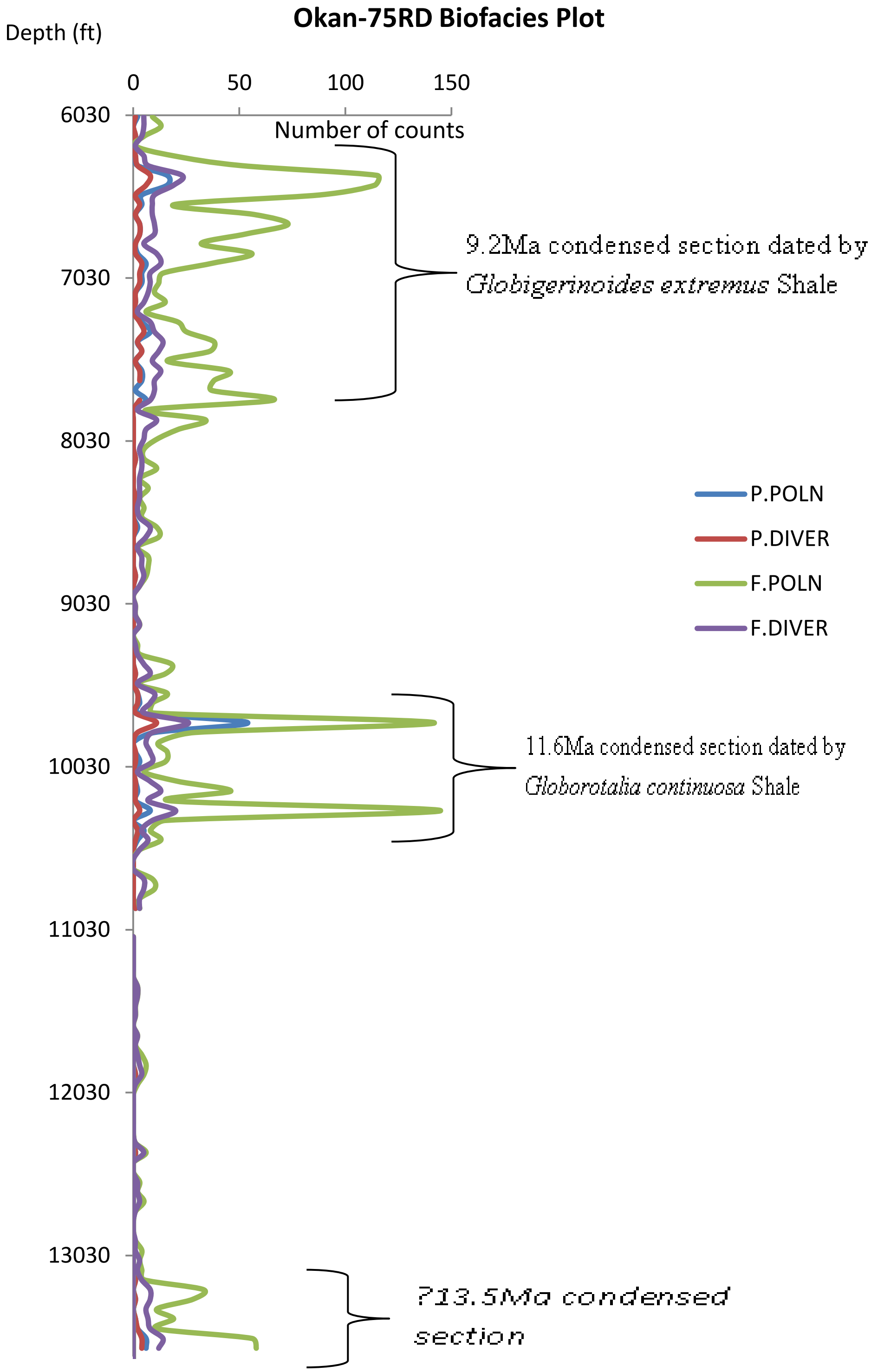


Fig. 4.5c: Biofacies Plot of Okan-75RD

4.5.2 Key Stratigraphic Surfaces

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 criteria:

- 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)

The recognition of sequence boundaries (SBs) was based on:

- The base of the thickest sand within a prograding parasequence stacking pattern before the onset of retrograding or aggrading stack
- Rare to few occurrence of forams

4.5.3 Depositional Sequences

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*.

4.5.4 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 (see Fig. 4a, 4b and 4c) 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.

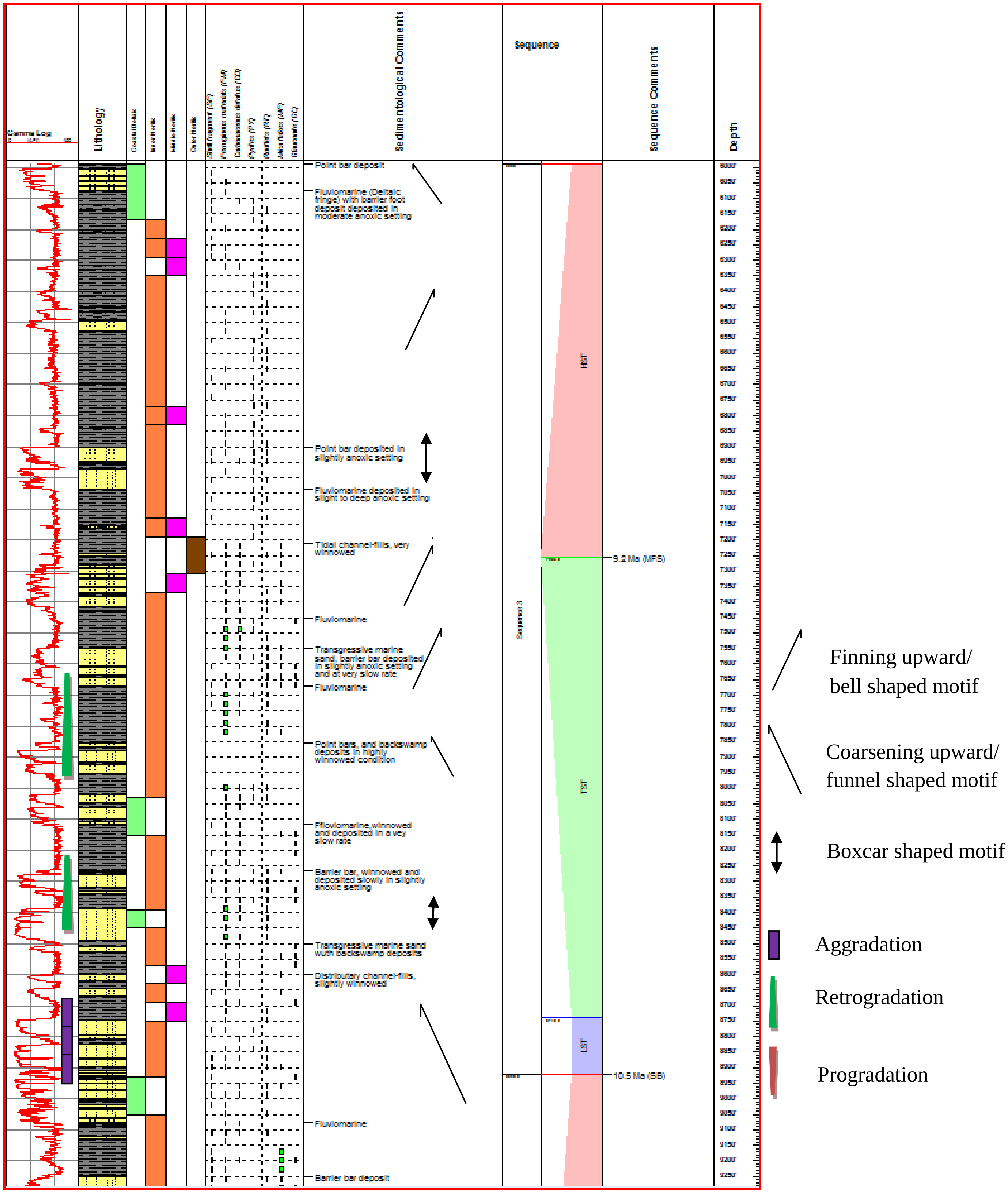


Fig. 4.6a: Stacking patterns interpreted in Okan-78 well

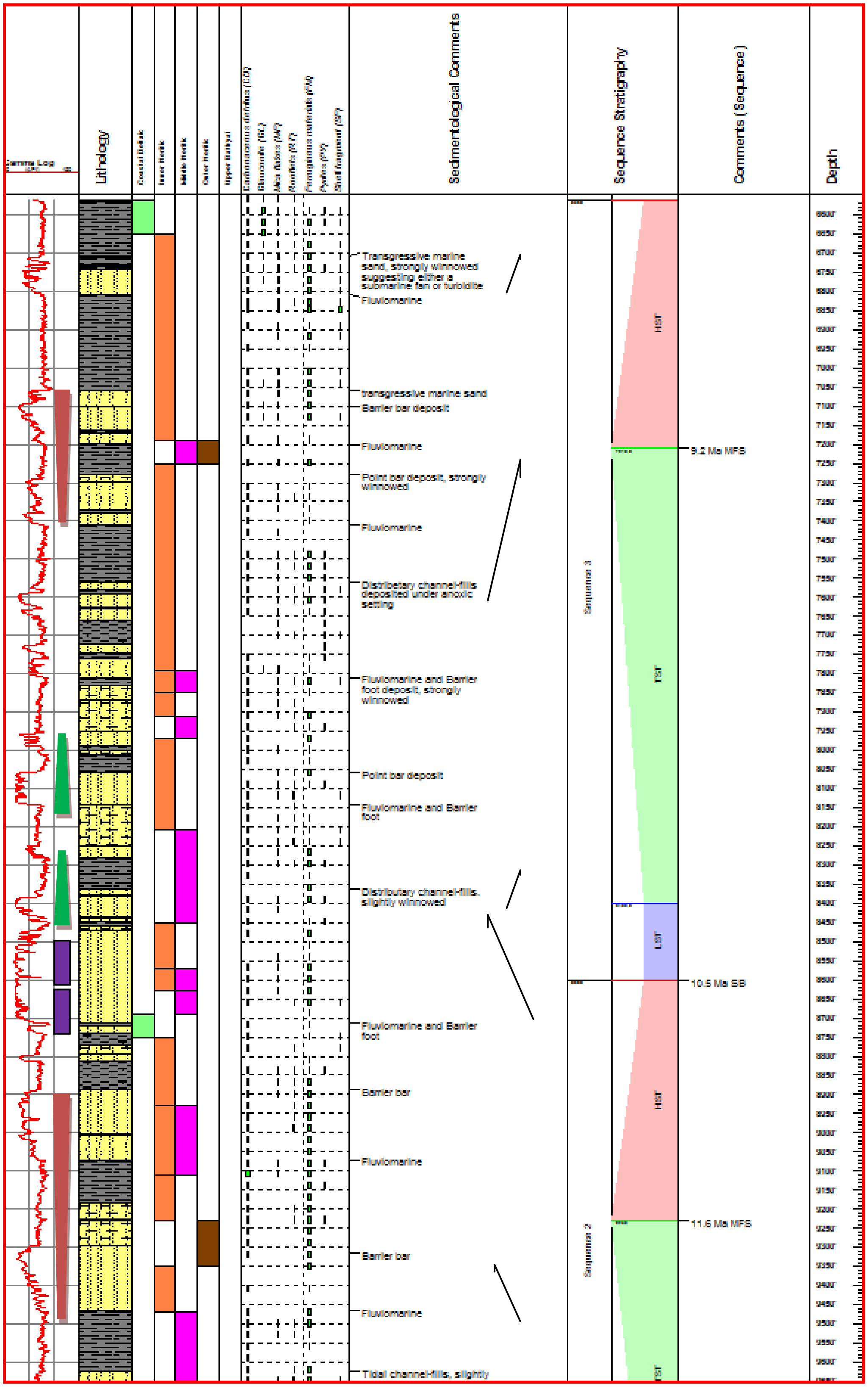


Fig. 4.6b: Depositional systems within system tracts in Okan-65

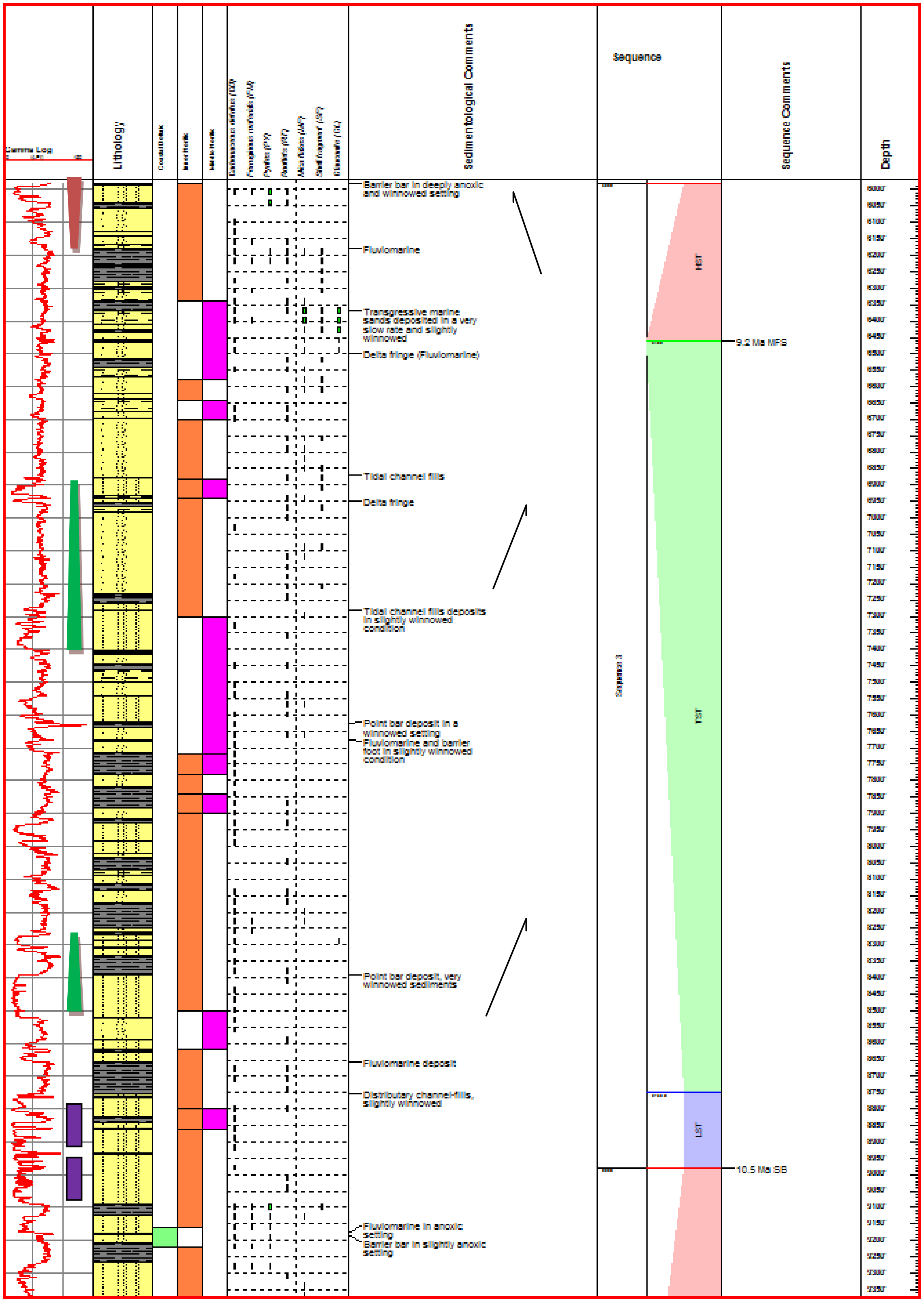


Fig. 4.6c: Depositional systems within system tracts in Okan-75RD

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.

4.6 Discussion

The 13.4Ma MFS in Okan-75RD was picked 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 correlation panel (Fig. 4.6) showed 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).

Biostratigraphic Correlation across Okan-78, Okan-65 & Okan-75RD

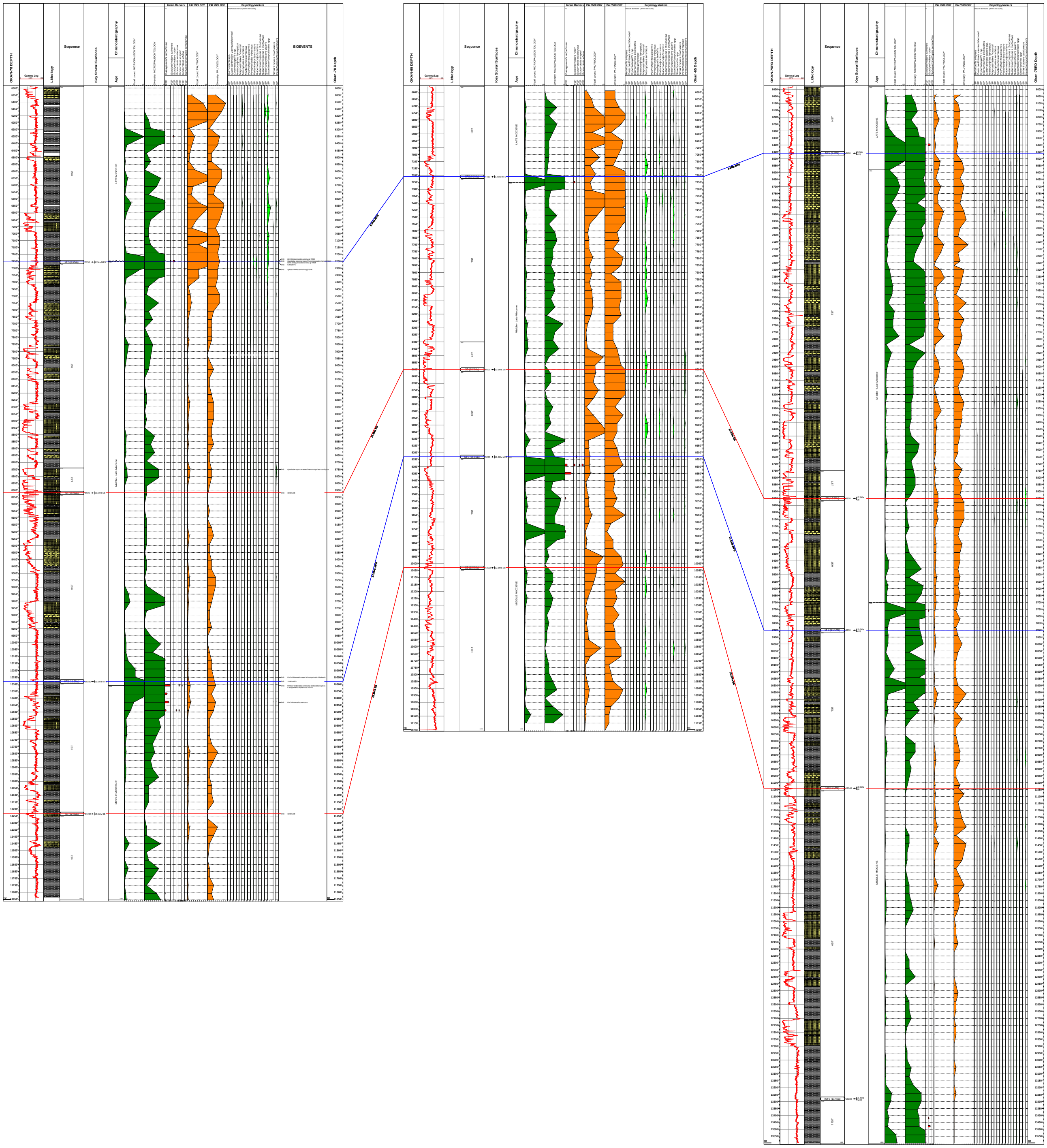


Fig. 4.7: Sequence stratigraphic correlation across Okan-78, – 65, and -75RD well

Table 4.5: 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	

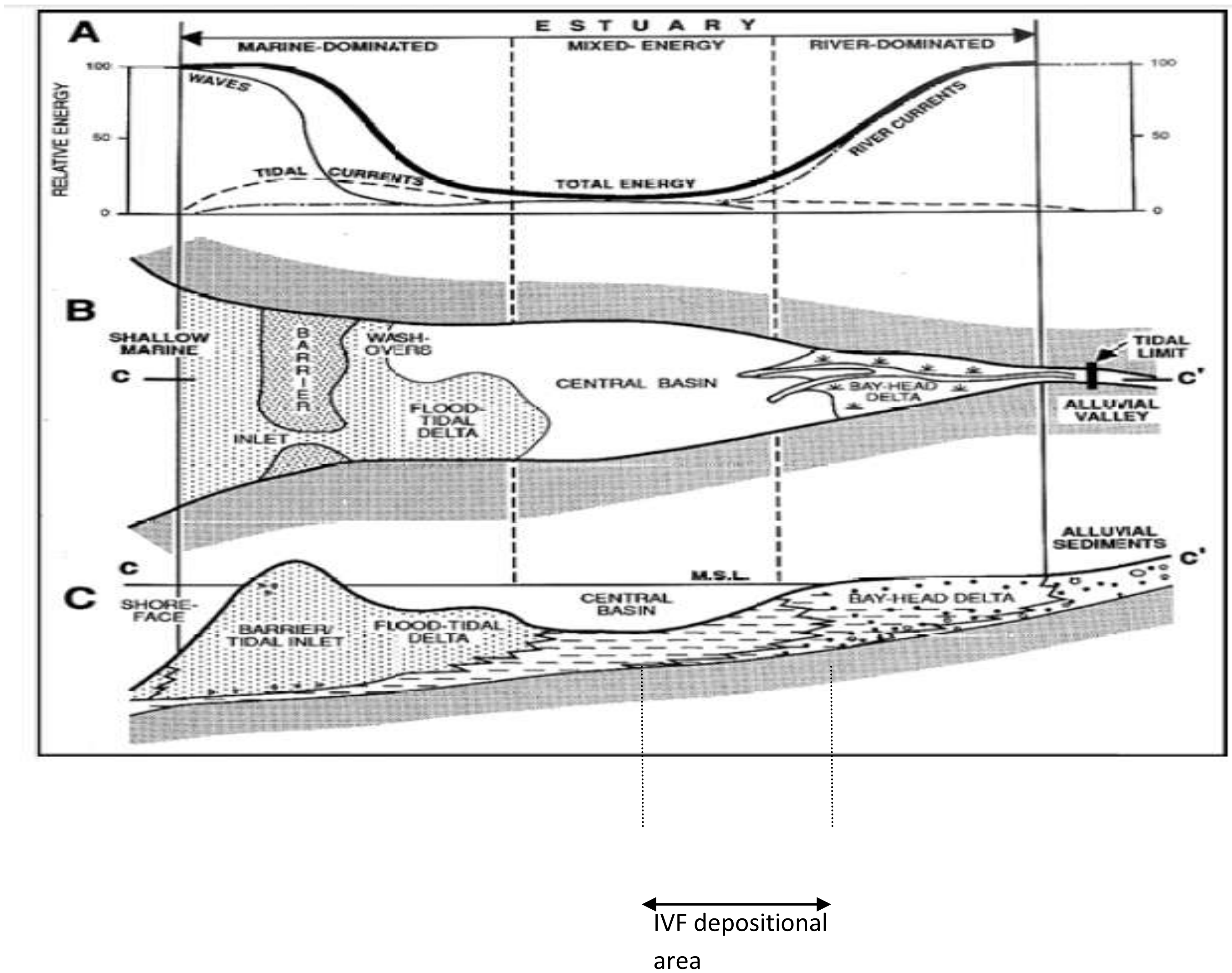


Fig.4.8: An idealized estuarine environment showing the position of incised valley fills within the studied section (after Dalrymple *et al*., 1992)

CHAPTER 5

5.0 SUMMARY AND CONCLUSION

High resolution biostratigraphic interpretation of Okan-65, 75RD and 78 wells were carried in a sequence stratigraphic context. The study intervals range from 6, 560 – 11, 200ft in Okan-65, 5, 980 – 13, 600ft in Okan-75RD and 5, 990 – 11, 855ft in Okan-78. The study was carried out for the purposes of subdividing the geological sections into chronostratigraphically zones/subzone and determining the ages and environments of deposition of all sequences penetrated by the wells. The biozones, biofacies, lithological descriptions and environments of deposition identified were used in establishing the sequence stratigraphic framework. The key sequence stratigraphic surfaces (sequence boundaries and maximum flooding surfaces) and system tracts were correlated across the wells.

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, micropalaeontological and nannopalaeontological 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.

Three palynological zones: *Verrutricolporites rotundiporus, Racemonocolpites hians* and *Multiareolites formosus* were identified from base to top of the sections. One of the achievements in this work is that the alphanumeric codes used by oil companies have been pinned down to specific fossil names. The P770 zone which marks the Late Middle Miocene was change to *Verrutricolporites rotundiporus* zone. The top of this zone is defined by top rich occurrence of *Verrutricolporites rotundiporus*, which remains fairly robust through out the zone. The P780 zone which succeeds the P770 zone in ascending order and marked the Early Late Miocene was changed to *Racemonocolpites hians* zone. The top of this zone is defined by quantitative top occurrence of *Racemonocolpites hians*. The P820 zone is the shallowest of the three zones is replaced in this work with *Multiareolites formosus* zone. The *Multiareolites formosus* did not get to *R. hians* zone and the base of it mark this zone. It it dated Early Late Miocene.

Micropalaeontological interpretations indicated three zones: *Globorotalia mayeri* (N14), *Globorotalia obesa* / *Globorotalia acostaensis* (N15)/ (N16) and *Globigerinoides extremus* (N17). The top of *Globorotalia mayeri* (N14) zone is defined by first downhole occurrence (FDO) of *Globorotalia continuasa.* This zone is dated Middle to Late Miocene. The top of *Globorotalia obesa* / *Globorotalia acostaensis* (N15)/ (N16) zone is defined by last downhole occurrence (LDO) of *Sphaeroidinellopsis seminulina* and equally dated Middle to Late Miocene. The *Globigerinoides extremus* (N17) zone is dated Late Miocence and the base is defined by last downhole occurrence (LDO) of *Sphaeroidinellopsis seminulina.*

The three well sections were dated Late Middle Miocene to Early Late Miocene based on integrated results mainly from palynology and micropalaeontology while result from nannopalaeontology was not used because of poor recovery of its markers.

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:

1. 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.

2. 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.
3. The early TSTs are associated with point and barrier bars
4. Thin transgressive marine sands mark the transgressive surfaces (TSs) ; 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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APPENDIX 1

Foraminiferal total abundance & diversity data of Okan-78 well

S/No.	Depth (ft)	Planktic Abundance	Planktic diversity	Calcareous benthic abundance	Calcareous benthic diversity	Arenaceous benthic abundance	Arenaceous benthic diversity	Total foraminiferal abundance	Total foraminiferal diversity
1	5990-6050	0	0	0	0	0	0	0	0
2	6050-6110	0	0	0	0	0	0	0	0
3	6110-6170	0	0	0	0	0	0	0	0
4	6170-6230	0	0	1	1	1	1	2	2
5	6230-6290	0	0	0	0	4	3	4	3
6	6290-6350	27	8	77	14	5	4	109	26
7	6350-6410	2	2	10	4	1	1	13	7
8	6410-6470	1	1	0	0	0	0	1	1
9	6470-6530	1	1	4	2	0	0	5	3
10	6530-6590	0	0	0	0	0	0	0	0
11	6590-6650	1	1	10	4	4	2	15	7
12	6650-6710	1	1	11	5	1	1	13	7

13	6710-6770	0	0	4	2	2	1	6	3
14	6770-6830	3	3	24	7	7	4	34	14
15	6830-6890	3	3	8	4	0	0	11	7
16	6890-6950	0	0	2	2	1	1	3	3
17	6950-7010	1	1	2	2	0	0	3	3
18	7010-7070	0	0	2	2	1	1	3	3
19	7070-7130	1	1	0	0	1	1	2	2
20	7130-7190	2	2	5	4	4	2	11	8
21	7190-7250	85	14	209	24	4	2	298	40
22	7250-7310	33	11	43	12	5	3	81	26
23	7310-7370	2	2	10	7	0	0	12	9
24	7370-7430	0	0	3	3	0	0	3	3
25	7430-7490	0	0	0	0	0	0	0	0
26	7490-7550	5	4	5	4	0	0	10	8
27	7550-7610	0	0	1	1	1	1	2	2
28	7610-7670	0	0	2	2	2	1	4	3
29	7670-7730	0	0	0	0	0	0	0	0
30	7730-7790	0	0	0	0	1	1	1	1
31	7790-7850	0	0	0	0	20	4	20	4

32	7970-8030	0	0	1	1	1	1	2	2
33	8030-8090	0	0	0	0	0	0	0	0
34	8090-8150	0	0	0	0	0	0	0	0
35	8150-8210	0	0	0	0	2	2	2	2
36	8210-8270	0	0	1	1	1	1	2	2
37	8270-8330	0	0	0	0	0	0	0	0
38	8330-8390	0	0	0	0	1	1	1	1
39	8390-8450	0	0	0	0	0	0	0	0
40	8450-8510	0	0	6	3	6	3	12	6
41	8510-8570	0	0	4	2	3	1	7	3
42	8570-8630	0	0	7	5	3	2	10	7
43	8630-8690	0	0	0	0	1	1	1	1
44	8690-8750	1	1	3	3	9	3	13	7
45	8750-8810	4	2	9	4	2	1	15	7
46	8810-8870	1	1	0	0	0	0	1	1
47	8870-8930	0	0	0	0	1	1	1	1
48	8930-8990	0	0	0	0	0	0	0	0
49	8990-9050	0	0	0	0	0	0	0	0
50	9050-9110	0	0	0	0	1	1	1	1

51	9110-9170	0	0	0	0	1	1	1	1
52	9170-9230	0	0	0	0	1	1	1	1
53	9230-92900	0	0	0	0	1	1	1	1
54	9290-9350	0	0	0	0	0	0	0	0
55	9350-9410	0	0	0	0	1	1	1	1
56	9410-9470	0	0	1	1	0	0	1	1
57	9470-9530	0	0	1	1	0	0	1	1
58	9530-9590	0	0	0	0	2	1	2	1
59	9590-9650	1	1	57	6	3	2	61	9
60	9650-9710	5	3	28	13	1	1	34	17
61	9710-9770	1	1	0	0	0	0	1	1
62	9770-9830	0	0	0	0	0	0	0	0
63	9830-9890	0	0	0	0	0	0	0	0
64	9890-9950	0	0	1	1	3	2	4	3
65	9950-10010	0	0	10	7	2	2	12	9
66	10010-10070	0	0	9	5	2	1	11	6
67	10070-10130	2	2	30	9	2	2	35	13
68	10130-10190	5	4	69	13	6	3	80	20
69	10190-10250	5	4	77	13	4	3	86	20

70	10250-10310	19	7	260	23	9	3	288	33
71	10310-10370	13	5	151	16	6	2	170	23
72	10370-10430	8	3	63	13	1	1	72	17
73	10430-10490	8	7	28	7	5	1	41	15
74	10490-10550	0	0	11	5	2	2	13	7
75	10550-10610	2	2	13	6	1	1	16	9
76	10610-10670	0	0	11	5	2	2	13	7
77	10670-10730	0	0	5	4	1	1	6	5
78	10730-10790	0	0	6	4	4	2	10	6
79	10790-10850	0	0	1	1	3	2	4	3
80	10850-10910	0	0	5	3	3	1	8	4
81	10910-10970	1	1	3	3	3	3	7	7
82	10970-11030	0	0	2	2	0	0	2	2
83	11030-11090	0	0	1	1	2	1	3	2
84	11090-11150	0	0	1	1	1	1	2	2
85	11150-11210	0	0	0	0	0	0	0	0
86	11210-11270	0	0	0	0	0	0	0	0
87	11270-11330	0	0	0	0	1	1	1	1
88	11330-11390	0	0	0	0	1	1	1	1

89	11390-11450	0	0	24	7	2	2	26	9
90	11450-11510	0	0	1	1	0	0	1	1
91	11510-11570	0	0	1	1	1	1	2	2
92	11570-11630	2	2	3	2	14	3	19	7
93	11630-11690	1	1	1	1	3	3	5	5
94	11690-11750	0	0	2	2	0	0	2	2
95	11750-11810	1	1	7	6	1	1	9	8
96	11810-11855	1	1	18	5	4	3	23	9

Foraminiferal total abundance & diversity data of Okan-65 well

S/No.	Depth (ft)	Planktic Abundance	Planktic diversity	Calcareous benthic abundance	Calcareous benthic diversity	Arenaceous benthic abundance	Arenaceous benthic diversity	Total foraminiferal abundance	Total foraminiferal diversity
1	6530-6590	0	0	0	0	0	0	0	0
2	6590-6650	0	0	1	1	0	0	1	1
3	6650-6710	2	2	5	3	0	0	7	5
4	6710-6770	0	0	1	1	1	1	2	2
5	6770-6830	1	1	1	1	5	4	7	6
6	6830-6890	1	1	2	1	3	2	6	4
7	6890-6950	1	1	0	0	2	1	3	2
8	6950-7010	0	0	0	0	3	2	3	2
9	7010-7070	0	0	0	0	3	3	3	3
10	7070-7130	0	0	0	0	2	1	2	1
11	7130-7190	0	0	0	0	3	1	3	1
12	7190-7250	67	12	141	21	1	1	209	34
13	7250-7310	1	1	1	1	4	1	6	3

14	7310-7370	0	0	0	0	2	2	2	2
15	7370-7430	0	0	1	1	0	0	1	1
16	77430-7490	0	0	3	1	8	5	11	6
17	7490-7550	0	0	1	1	1	1	2	2
18	7550-7610	0	0	4	1	7	3	11	4
19	7610-7670	0	0	6	3	3	2	9	5
20	7670-7730	0	0	2	1	2	2	4	3
21	7730-7790	0	0	1	1	3	3	4	4
22	7790-7850	0	0	0	0	2	2	2	2
23	7850-7910	0	0	1	1	10	4	11	5
24	7910-7970	0	0	0	0	6	4	6	4
25	7970-8030	1	1	0	0	5	3	6	4
26	8030-8090	0	0	0	0	7	3	7	3
27	8090-8150	1	1	2	2	3	2	6	5
28	8150-8210	0	0	1	1	0	0	1	1
29	8210-8270	1	1	5	3	9	5	15	9
30	8270-8330	0	0	2	1	7	4	9	5
31	8330-8390	0	0	2	1	12	3	14	4
32	8390-8450	2	2	0	0	14	5	16	6

33	8450-8510	0	0	0	0	3	2	3	2
34	8510-8570	0	0	0	0	0	0	0	0
35	8570-8630	0	0	2	2	1	1	3	3
36	8630-8690	0	0	0	0	3	3	3	3
37	8690-8750	0	0	0	0	0	0	0	0
38	8750-8810	0	0	0	0	1	1	1	1
39	8810-8870	0	0	3	1	4	3	7	4
40	8870-8930	0	0	1	1	1	1	2	2
41	8930-8990	0	0	0	0	5	3	5	3
42	8990-9050	0	0	0	0	0	0	0	0
43	9050-9110	5	3	23	8	1	1	29	12
44	9110-9170	0	0	1	1	3	2	4	3
45	9170-9230	2	2	6	2	1	1	9	5
46	9230-9290	183	16	217	20	5	2	405	38
47	9290-9350	78	10	81	19	3	1	162	30
48	9350-9410	2	2	4	3	0	0	6	5
49	9410-9470	0	0	1	1	2	2	3	3
50	9470-9530	2	2	2	2	6	4	10	8
51	9530-9590	1	1	6	1	7	5	14	7

52	9590-9650	1	1	1	1	3	3	5	5
53	9650-9710	0	0	3	1	9	4	12	5
54	9710-9770	8	5	141	12	28	6	169	23
55	9770-9830	2	2	3	2	4	3	9	7
56	9830-9890	0	0	1	1	0	0	1	1
57	9890-9950	0	0	1	1	1	1	2	2
58	9950-10010	0	0	0	0	0	0	0	0
59	10010-10070	0	0	1	1	12	3	13	4
60	10070-10130	0	0	1	1	9	3	10	4
61	10130-10190	0	0	0	0	3	2	3	2
62	10190-10250	0	0	2	1	11	3	13	4
63	10250-10310	0	0	1	1	4	2	5	3
64	10310-10370	0	0	0	0	2	1	2	1
65	10370-10430	0	0	0	0	2	2	2	2
66	10430-10490	0	0	0	0	1	1	1	1
67	10490-10550	0	0	0	0	2	2	2	2
68	10550-10610	0	0	0	0	0	0	0	0
69	10610-10670	0	0	0	0	1	1	1	1
70	10670-10730	0	0	0	0	2	2	2	2

71	10730-10790	0	0	0	0	5	2	5	2
72	10790-10850	0	0	1	1	4	3	5	4
73	10850-10910	1	1	2	2	7	4	10	7
74	10910-10970	0	0	0	0	0	0	0	0
75	10970-11030	0	0	5	4	0	0	5	4
76	11030-11090	0	0	37	6	16	4	53	10
77	11090-11150	0	0	2	1	6	3	8	4
78	11150-11200	0	0	0	0	1	1	1	1

Foraminiferal total abundance & diversity data of Okan-75RD well

S/No.	Depth (ft)	Planktic Abundance	Planktic diversity	Calcareous benthic abundance	Calcareous benthic diversity	Arenaceous benthic abundance	Arenaceous benthic diversity	Total foraminiferal abundance	Total foraminiferal diversity
1	5980-6040	2	1	6	3	1	1	9	5
2	6040-6100	0	0	9	3	4	2	13	5
3	6100-6160	1	1	2	1	2	2	5	4
4	6160-6220	0	0	1	1	0	0	1	1
5	6220-6280	1	1	10	3	8	1	19	5
6	6280-6340	2	2	9	3	40	2	51	7
7	6340-6400	16	8	72	10	27	5	115	23
8	6400-6460	16	6	94	11	4	2	114	19
9	6460-6520	4	1	80	6	4	3	88	10
10	6520-6580	4	3	12	4	3	2	19	9
11	6580-6640	1	1	27	5	29	3	57	9
12	6640-6700	3	3	24	3	46	4	73	10
13	6700-6760	3	3	23	3	27	4	53	10

14	6760-6820	1	1	25	2	6	2	32	5
15	6820-6880	2	1	44	5	10	5	56	11
16	6880-6940	6	4	23	6	8	3	37	13
17	6940-7000	4	3	6	3	4	2	14	8
18	7000-7060	4	3	7	4	1	1	12	8
19	7060-7120	1	1	5	4	4	2	10	7
20	7120-7180	1	1	12	2	2	2	15	5
21	7180-7240	0	0	6	2	0	0	6	2
22	7240-7300	4	3	15	3	2	2	21	8
23	7300-7360	8	5	15	3	2	2	25	10
24	7360-7420	2	2	32	9	4	3	38	14
25	7420-7480	4	4	26	5	6	3	36	12
26	7480-7540	1	1	5	3	10	5	16	9
27	7540-7600	4	3	22	5	19	5	45	13
28	7600-7660	4	3	22	2	12	5	38	10
29	7660-7720	1		28	7	8	2	37	10
30	7720-7780	6	3	49	2	11	3	66	8
31	7780-7840	0	0	5	1	1	1	6	2
32	7840-7900	0	0	19	3	15	8	34	11

33	7900-7960	0	0	14	3	7	3	21	6
34	7960-8020	0	0	4	2	7	3	11	5
35	8020-8080	0	0	3	1	2	2	5	3
36	8080-8140	1	1	1	1	3	2	5	4
37	8140-8200	0	0	1	1	10	3	11	4
38	8200-8260	0	0	0	0	3	3	3	3
39	8260-8320	0	0	5	1	2	2	7	3
40	8320-8380	1	1	1	1	1	1	3	3
41	8380-8440	0	0	2	2	3	1	5	2
42	8440-8500	0	0	1	1	3	2	4	3
43	8500-8560	2	1	2	2	7	5	11	8
44	8560-8620	0	0	5	2	7	4	12	6
45	8620-8680	0	0	1	1	1	1	2	2
46	8680-8740	0	0	3	1	4	3	7	4
47	8740-8800	0	0	4	1	3	3	7	4
48	8800-8860	1	1	0	0	5	4	6	5
49	8860-8920	0	0	1	1	2	2	3	3
50	8920-8980	0	0	0	0	0	0	0	0
51	8980-9040	0	0	1	1	0	0	1	1

52	9040-9100	0	0	0	0	1	1	1	1
53	9100-9160	0	0	2	2	1	1	3	3
54	9160-9220	0	0	0	0	0	0	0	0
55	9220-9280	0	0	0	0	2	1	2	1
56	9280-9340	0	0	3	2	0	0	3	2
57	9340-9400	0	0	7	1	11	4	18	5
58	9400-9460	1	1	3	2	11	5	15	8
59	9460-9520	0	0	1	1	1	1	2	2
60	9520-9580	2	2	4	2	10	6	16	10
61	9580-9640	3	2	3	3	3	3	9	8
62	9640-9700	2	1	4	2	3	2	9	5
63	9700-9760	54	11	86	13	2	2	142	26
64	9760-9820	10	2	17	6	2	1	29	9
65	9820-9880	0	0	8	3	4	3	12	6
66	9880-9940	1	1	10	4	5	3	16	8
67	9940-10000	3	1	5	3	7	5	15	9
68	10000-10060	0	0	5	2	0	0	5	2
69	10060-10120	1	1	18	5	2	2	21	8
70	10120-10180	2	1	29	7	15	5	46	13

71	10180-10240	1	1	5	3	13	3	18	7
72	10240-10300	8	3	122	14	15	3	145	20
73	10300-10360	0	0	9	5	6	4	15	9
74	10360-10420	5	2	1	1	2	1	8	4
75	10420-10480	2	1	9	3	4	3	13	7
76	10480-10540	0	0	2	2	1	1	3	3
77	10540-10600	0	0	0	0	0	0	0	0
78	10600-10660	0	0	0	0	0	0	0	0
79	10660-10720	0	0	1	1	8	4	9	5
80	10720-10780	0	0	4	2	6	3	10	5
81	10780-10840	0	0	1	1	2	2	3	3
82	10840-10900	1	1	0	0	2	2	3	3
83	10900-10960								
84	10960-11020	0	0	0	0	0	0	0	0
85	11020-11080	0	0	0	0	0	0	0	0
86	11080-11140	0	0	0	0	0	0	0	0
87	11140-11200	0	0	0	0	0	0	0	0
88	11200-11260	0	0	0	0	0	0	0	0
89	11260-11320	0	0	0	0	0	0	0	0

90	11320-11380	0	0	0	0	2	2	2	2
91	11380-11440	1	1	0	0	1	1	2	2
92	11440-11500	0	0	0	0	1	1	1	1
93	11500-11560	0	0	0	0	1	1	1	1
94	11560-11620	0	0	0	0	0	0	0	0
95	11620-11680	0	0	1	1	1	1	2	2
96	11680-11740	0	0	0	0	1	1	1	1
97	11740-11800	0	0	0	0	4	2	4	2
98	11800-11860	0	0	3	1	3	2	6	3
99	11860-11920	1	1	3	2	1	1	5	4
100	11920-11980	0	0	2	1	0	0	2	1
101	11980-12040	0	0	0	0	0	0	0	0
102	12040-12100	0	0	0	0	0	0	0	0
103	12100-12160	0	0	0	0	0	0	0	0
104	12160-12220	0	0	0	0	0	0	0	0
105	12220-12280	0	0	0	0	0	0	0	0
106	12280-12340	0	0	1	1	0	0	1	1
107	12340-12400	1	1	3	2	2	2	6	5
108	12400-12460	0	0	0	0	0	0	0	0

109	12460-12520	0	0	0	0	0	0	0	0
110	12520-12580	0	0	0	0	3	2	3	2
111	12580-12640	0	0	1	1	1	1	2	2
112	12640-12700	0	0	0	0	5	3	5	3
113	12700-12760	0	0	0	0	1	1	1	1
114	12760-12820	0	0	0	0	0	0	0	0
115	12820-12880	0	0	0	0	0	0	0	0
116	12880-12940	0	0	0	0	1	1	1	1
117	12940-13000	0	0	0	0	4	1	4	1
118	13000-13060	0	0	0	0	3	3	3	3
119	13060-13120	0	0	0	0	4	2	4	2
120	13120-13180	1	1	0	0	4	3	5	4
121	13180-13240	0	0	1	1	32	7	33	8
122	13240-13300	1	1	15	2	12	5	28	8
123	13300-13360	0	0	2	2	9	4	11	6
124	13360-13420	1	1	2	2	16	4	19	7
125	13420-13480	2	2	3	3	6	3	11	8
126	13480-13540	6	4	4	4	46	6	56	14
127	13540-13600	6	4	2	2	50	6	58	12

APPENDIX 2

Okan –78 GR depositional sytems interpretation

Depth (ft)	Sand/Shale %	Lithology	Motif (Sand)	Index Mineral	Depositional systems
6000 – 6005	35/65	Shale			
6005 – 6028	75/25	Sand	Boxcar	Rare shell fragments and ferruginous materials	BARRIER BAR
6028 – 6030	45/55	Shale			BACK SAWMP
6030 – 6044	72/28	Sand	Boxcar	Same as above	BARRIER BAR
6044 – 6048	45/55	Shale		Same as above	BACK SAWMP
6048 – 6058	70/30	Sand	Funnel	Same as above	BARRIER BAR
6058 – 6062	35/65	Shale		Same as above +foram	BACK SAWMP
6062 – 6075	65/35	Sand	Funnel	Same as above + Root	BARRIER BAR
6075 – 6120	30/70	Shale			MARINE CLAY
6120 – 6135	55/45	Sandy shale		Rare shell fragments and ferruginous	BARRIER FOOT
6135 – 6200	30/70	Shale			MARINE CLAY
6200 – 6210	55/45	Sandy shale		Rare ferruginous materials and Rootlet	BARRIER FOOT
6210 – 6315	30/70	Shale			
6315 – 6327	55/45	Sandy shale			

6327 – 6400	35/65	Shale			
6400 – 6412	55/45	Sandy sand			
6412 – 6450	40/60	Shale			
6450 – 6468	10/90	Shale			
6468 – 6490	55/45	Sandy sand			
6490 – 6493	15/85	Shale			
6493 – 6526	70/80	Sand	Funnel	Rare ferruginous materials and rootlets	BARRIER BAR
6526 – 6694	30/70	Shale			MARINE CLAY
6694 – 6700	52/48	Sandy sand			DELTA FRINGE
6700 – 6840	30/70	Shale			MARINE CLAY
6840 – 6855	52/48	Sandy sand			DELTA FRINGE
6855 – 6903	30/70	Shale			
6903 – 6948	70/30	Sand	Boxcar	Rare shell fragments, Pyrite, rootlet	BARRIER BAR
6948 – 6952	35/65	Shale			
6952 – 6954	65/35	Sand			
6954 – 6970	30/70	Shale			
6970 – 7035	75/25	Sand	Boxcar (Serrated)		
7035 – 7153	30/70	Shale			
7153 – 7161	45/55	Sandy sand	Funnel		
7161 – 7245	30/70	Shale			
7245 – 7250	52/48	Sandy sand	Funnel	Rare pyrite, carbonaceous detritus, mica flakes, rootlets & ferruginous	

				materials	
7250 – 7280	30/70	Shale			
7280 – 7290	52/48	Sandy sand			
7290 – 7293	25/75	Shale			
7293 – 7308	60/40	Sand	Boxcar	Rare carbonaceous detritus, ferruginous & rootlets	
7308 – 7311	15/85	Shale			
7311 – 7322	70/30	Sand	Funnel		
7322 – 7326	42/58	Shale			
7326 – 7350	70/30	Sand			
7350 – 7355	32/68	Shale			
7355 – 7370	65/35	Sand	Boxcar		
7370 – 7373	42/58	Shale			
7373 – 7375	60/40	Sand			
7375 – 7384	45/55	Shale			
7384 – 7415	70/30	Sand	Boxcar	Rare carbonaceous detritus and ferruginous materials	
7415 – 7425	40/60	Shale			
7425 – 7430	52/48	Sandy sand	Funnel	Rare pyrite and, glauconite	
7432 – 7550	30/70	Shale			
7550 – 7608	60/40	Sand	Funnel	Rare mica flakes and pyrite, few rootlets	Marine clay
7608 – 7610	25/75	Shale			
7610 – 7635	60/40	Sand	Boxcar	Carb, Shell fragments, mica flakes, ferruginous materials, glauconite and rootlets	Transgressive marine sands
7635 – 7645	38/62	Shale			
7645 – 7673	70/30	Sand	Funnel		

7673 – 7853	30/70	Shale			
7853 – 7865	60/40	Sand	Boxcar	Carbonaceous detritus, Pyrite, Ferruginous materials and rootlets	
7865 – 7877	25/75	Shale			
7877 – 7915	80/20	Sand	Funnel		Barrier bar
7915 – 7922	22/78	Shale			
7922 – 7953	72/28	Sand	Boxcar		Channel Fill
7953 – 8020	30/70	Shale			MARINE CLAY
8020 – 8045	65/35	Sand	Funnel	Few to common Carb, ferruginous materials, rare pyrite, rootlet and foram	BARRIER BAR
8045 – 8062	25/75	Shale			
8062 – 8098	65/35	Sand	Funnel		BARRIER BAR
8098 – 8105	40/60	Sandy shale			
8105 – 8113	65/35	Sand	Funnel	Rare carbonaceous detritus, shell fragments, foram	Barrier Foot
8113 – 8265	30/70	Shale			MARINE CLAY
8265 – 8270	55/45	Sandy sand		Few shell fragments, mica, pyrite, rootlets and foram	Delta fringe
8270 – 8278	25/75	Shale			BACK SAWMP
8278 – 8320	80/20	Sand	Boxcar	Rare glauconite, shell fragments mica, pyrite and foram	BARRIER BAR
8320 – 8332	25/75	Shale			
8332 – 8340	60/40	Sand			BARRIER

					FOOT
8340 – 8388	20/80	Shale			MARINE CLAY
8388 – 8491	85/15	Sand	Funnel (serrated)		BARRIER BAR
8491 – 8510	28/72	Shale			BACK SAWMP
8510 – 8528	65/35	Sand	Funnel		BARRIER FOOT
8528 – 8598	30/70	Shale			MARINE CLAY
8598 – 8600	52/48	Sandy sand			
8603 – 8622	70/30	Sand	Funnel		BARRIER FOOT
8622 – 8645	30/70	Shale			MARINE CLAY
8645 – 8670	70/30	Sand	Funnel	Rare glauconite, carbonaceous detritus and foram	Transgressive marine sand
8670 – 8745	30/70	Shale			MARINE CLAY
8745 – 8793	85/15	Sand	Funnel	Rare ferruginous materials, rootlets and	BARRIER BAR
8793 – 8795	45/55	Shale			BACK SAWMP
8790 – 8805	65/35	Sand	Boxcar		BARRIER FOOT
8805 – 8825	35/65	Shale			
8825 – 8869	90/10	Sand	Boxcar	Rare Shell fragments, rootlets, foram, mica flakes	POINT BAR

8869 – 8873	35/65	Shale			BACK SAWMP
8873 – 8898	85/15	Sand	Boxcar		POINT BAR
8898 – 8910	20/80	Shale			
8910 – 8915	72/28	Sand		Rare to few shell fragments, glauconite	Transgressive marine sand
8915 – 8917	45/55	Sandy shale			
8917 – 8927	80/20	Sand	Funnel		
8927 – 8930	35/65	Shale			
8930 – 8931	60/40	Sand			
8931 – 8936	20/80	Shale			
8936 – 8949	85/15	Sand	Boxcar		
8949 – 8951	35/65	Shale			
8951 – 8972	85/15	Sand			
8972 – 8974	38/62	Shale			
8974 – 9000	80/20	Sand	Boxcar		
9000 – 9003	40/60	Shale			
9003 – 9007	65/35	Sand			
9007 – 9020	40/60	Shale			
9020 – 9025	70/30	Sand	Funnel		
9025 – 9029	30/70	Shale			
9029 – 9033	68/32	Sand			
9033 – 9037	35/65	Shale			
9037 – 9060	80/20	Sand	Funnel (serrated)		
9060 – 9063	45/55	Sandy shale			
9063 – 9075	60/40	Sand			
9075 – 9077	40/60	Shale			
9077 – 9080	62/38	Sand			

9080 – 9087	25/75	Shale			
9087 – 9090	60/40	Sand	Bell		
9090 – 9120	30/70	Shale			
9120 – 9128	60/40	Sand			
9128 – 9245	35/65	Shale			MARINE CLAY
9245 – 9250	48/52	Sandy shale		Rare shell fragments, glauconite, pyrite, mica flakes and foran	Transgressive marine sand
9250 – 9300	78/22	Sand	Bell	Same as above	Point Bar
9300 – 9303	45/55	Shale	Funnel		BACK SAWMP
9303 – 9440	70/30	Sand		Rare carbonaceous detritus, shell fragments and rootlets	BARRIER BAR
9440 – 9480	30/70	Shale			MARINE CLAY
9480 – 9490	55/45	Sandy sand			
9490 – 9705	30/60	Shale			MARINE CLAY
9705 – 9785	75/25	Sand	Funnel		BARRIER BAR
9785 – 9790	40/60	Shale			BACK SAWMP
9790 – 9815	65/35	Sand	Boxcar		BARRIER BAR
9815 – 9817	38/62	Shale			BACK SAWMP
9817 – 9850	55/45	Sandy sand	Funnel		BARRIER BAR
9850 – 9865	30/70	Shale			MARINE

					CLAY
9865 – 9870	65/35	Sand	Bell	Rare carbonaceous detritus, mica flakes, shell fragments, rootlets	Cahnnel fill
9870 – 9882	55/45	Sand	Funnel		
9882 – 9885	36/64	Shale			CHANNEL FILL
9885 – 9895	60/40	Sand	Bell		
9895 – 10267	30/70	Shale			MARINE CLAY
10267 – 10280	55/45	Sandy shale	Bell	Rare carbonaceous detritus, shell fragments, ferruginous materials and rootlets	BARRIER BAR
10280 – 10368	70/30	Shale			MARINE CLAY
10368 – 10375	54/46	Sand	Boxcar		
10375 –10387	25/75	Shale			
10387 – 10405	75/25	Sand	Bell		BARRIER BAR
10405 – 10408	25/75	Shale			
10408 – 10420	55/45	Sandy sand	Funnel		BARRIER FOOT
10420 – 10530	30/70	Shale			MARINE CLAY
10530 – 10535	60/40	Sand			POINT BAR
10535 –	40/60	Shale			

10545					
10545 – 10560	68/32	Sand	Funnel		POINT BAR
10560 – 10564	35/65	Shale			
10564 – 10570	82/18	Sand	Funnel	Rare to few glauconite, shell fragments, mica flakes & rootlets	Transgressive marine sand
10570 – 10600	82/18	Sand	Boxcar	Carbonaceous detritus, Shell fragments and pyrite - rare	BARRIER BAR
10600 – 10625	75/25	Sand	Funnel	Rare Mica, Carbon. detritus, shell fragments, Pyrite and fossil	Barrier foot
19625 – 10705	25/75	Shale			MARINE CLAY
10705 – 10717	55/45	Sand	Boxcar	Same as above	
10717 - 10998	30/70	Shale			
10998 – 11007	65/35	Sand			
11007 – 11010	45/55	Shale			
11010 – 11015	62/38	Sand			
11015 – 11020	55/45	Sandy sand			
11020 – 11027	30/70	Shale			
11027 –	80/20	Sand		Rare shell fragments, mica	Barrier Bar

11063				flakes and foram	
11063 – 11068	55/45	Sandy sand			BARRIER FOOT
11068 – 11135	20/80	Shale			MARINE CLAY
11135 – 11150	60/30	Sand	Funnel	Rare carbonaceous detritus mica flakes, shell fragments and foran	Barrier Bar
11150 – 11230	35/65	Shale			MARINE CLAY
11230 – 11255	70/30	Sand		Rare carbonaceous detritus, mica flakes, shell fragments and ferruginous materials	Barrier Bar
11255 – 11248	40/60	Shale			
11248 – 11462	60/40	Sand		Same as above	Barrier Foot
11462 – 11428	30/70	Shale			
11428 – 11438	55/45	Sand		Rare glauconite, carbonaceous detritus, shell fragments and ferruginous materials	Transgressive Marine sand
11438 – 11475	25/75	Shale			MARINE CLAY
11475 – 11528	60/40	Sand		Rare carbonaceous detritus, shell fragments, mica flakes and foram	Barrier Bar
11528 –	30/70	Shale			MARINE

11835					CLAY
11430 – 11438	56/44	Sandy sand			
11438 – 11475	60/40	Sand	Boxcar		
11475 - 11835	30/70	Shale			

Okan –65 Depositional Systems Interpretations

Depth (ft)	Sand/Shale %	Lithology	Motif (Sand)	Index Mineral	Depositional Systems
6530 – 6550	45/55	Shale		Rare glauconite., rootlets, Carbonaceous detritus	Marine clay
6550 – 6556	53/47	Shale		Same as above	Marine clay
6556 - 6565	60/40	Sand		Same as above	
6565 – 6710	48/52	Shale		Rare - few glauconite, rare rootlets, few carbonaceous detritus and shell fragments	Marine clay
6710 – 6714	70/30	Sand	Bell	Same as above	Transgressive marine sand
6714 – 6732	40/60	Shale		Same as above	Barrier foot
6732 – 6735	70/30	Sand	Bell	Same as above	Barrier bar
6735 – 6743	45/55	Shale			Barrier foot
6743 – 6808	70/30	Sand	Funnel	Same as above	Barrier bar
6808 – 7060	45/55	Shale		Rare carbonaceous materials, shell fragments and rootlets	Marine clay
7060 – 7100	65/35	Sand	Bell	Rare carbonaceous materials and glauconite, few to common ferruginous materials	Transgressive Marine sand
7100 – 7165	75/25	Sand	Funnel	Rare carbonaceous materials and pyrite, common ferruginous materials and foram.	Barrier bar
7165 - 7171	47/53	Shale		Same as above	Barrier bar
7171 – 7196	60/40	Sand			Barrier foot

7196 – 7278	45/55	Shale			Marine clay
7278 – 7297	55/45	Sand	Bell	Rare carbonaceous detritus, shell fragements, mica flakes, glauconite. Calcite present	Transgressive marine sand
7297 – 7373	63/37	Sand	Funnel	Rare carbonaceous detritus, mica flakes, rootlets and foram	Barrier bar
7373 – 7380	48/52	Shale		Same as above	Barrier foot (BARRIER FOOT)
7380 – 7410	70/30	Sand	Funnel	Rare carbonaceous detritus and shell fragments	Barrier bar
7410 – 7560	45/55	Shale			Marine clay
7560 – 7578	72/25	Sand	Bell		
7578 - 7592	48/52	Shale			
7592 – 7626	80/20	Sand	Bell	Few pyrite, rare carbonaceous detritus, mica flakes, ferruginous materials and foram.	Transgressive marine sand
7626 – 7632	50/50	Sandy shale			
7632 – 7660	75/25	Sand	Funnel	Rare mica flakes and foram, and few pyrite	Barrier bar
7660 – 7722	50/50	Shale			Marine clay
7722 – 7745	70/30	Sand	Funnel		
7745 – 7760	40/60	Shale			
7760 – 7810	65/35	Sand	Boxcar		Point Bar (POINT BAR)
7810 – 7830	40/60	Shale			

7830 – 7870	52/48	Shale			
7870 – 7950	55/45	Sandy sand			
7950 – 7990	72/28	Sand	Boxcar		Point Bar
7990 – 8000	50/50	Shale	(serrated)		Marine clay
8000 – 8010	55/45	Sand			Barrier bar
8010 – 8058	40/60	Shale			Barrier Foot
8058 – 8142	82/18	Sand	Boxcar		Point Bar
8142 – 8250	55/45	Sandy shale		Abundant ferruginous materials, rare carbonaceous detritus and mica flakes	
8250 – 8280	70/30	Sand	Funnel	Ferruginous materials-common, Carbonaceous detritus -few, Pyrite & Rootlets—Rare	B Bar
8280 – 8363	40/60	Shale			Marine clay
8363 – 8378	60/40	Sand			
8378 – 8382	50/50	Shale			
8382 – 8400	84/16	Sand	Bell	Carbonaceous materials - few, Mica flakes and Foram – Rare	
8400 – 8435	80/20	Sand	Funnel	Carb, Pyrite, Ferruuginous materials-Rare	Barrier bar
8435 – 8441	45/55	Shale			
8441 – 8448	65/35	Sand			
8448 – 8460	40/60	Shale			
8460 – 8472	53/47	Sand shale			
8472 - 8715	85/15	Sand	Serrated channel fill	Carb. detritus -common, feruuginous materials, Rootlet & foram Rare	Point Bar

8715 – 8720	40/60	Shale			
8720 – 8742	70/30	Sand	Funnel		Channel fill (POINT BAR)
8742 – 8772	80/50	Shale			Marine clay
8772 – 8795	56/44	Sandy sand			
8795 – 8813	78/22	Sand	Boxcar		Channel Fill
8813 – 8888	50/50	Shale			Marine clay
8888 – 9004	65/25	Sand			Point Bar
9002 – 9006	80/20	Sand	Bell		Marine sand
9006 – 9070	65/35	Sand	Funnel		
9070 – 9185	45/55	Shale			Marine clay
9185 – 9225	55/45	Sandy sand			
9225 – 9230	45/55	Shale			
9230 – 9297	55/45	Sandy sand			
9297 – 9315	80/20	Sand	Bell	Rare-Carbonaceous detritus, Ferruginous materilas, & foram	Transgressive Marine sand
9315 – 9465	75/25	Sand	Funnel	Common Carb. detritus, Few ferruginous materials	Barrier bar
9465 – 9624	45/55	Shale		Common Rootlet, Rare-few foram, Few Carbonaceous detritus & ferruginous materials	Marine clay
9624 – 9671	60/40	Sand	Funnel		Barrier Foot
9671 – 9684	35/65	Shale			
9684 – 9686	55/45	Sandy sand			
9686 – 9726	42/58	Shale			
9726 – 9815	65/35	Sand	Bell	Rare Rootlet, Carb; Shell fragments, mica flakes foram, Few ferruginous	Barrier Foot

				materials	
9815 – 9837	45/55	Shale		Rare carbonaceous detritus, Ferruginous material, foram	Marine clay
9837 – 9843	70/30	Sand	Bell	Few forams, Rare Ferruginous materials & Carbonaceous detritus	Transgressive marine sand
9843 – 9868	65/35	Sand	Funnel		Barrier bar
9868 – 9932	45/55	Shale			
9932 – 9990	65/35	Sand	Bell		
9990 – 9998	48/52	Shale			
9998 – 10040	80/20	Sand	Bell	Rare-carbonaceous detritus, Ferruginous materials, Rootlets, Forams, mica flakes	
10040 – 10048	70/30	Sand	Funnel	Rare carbonaceous materials, ferruginous materials, Rootlets, Forams, mica flakes	Barrier Foot
10048 – 10075	45/55	Shale			Marine clay
10075 – 10140	60/40	Sand			
10140 – 10155	50/50	Shale			
10155 – 10170	60/40	Sand			
10170 – 10202	50/50	Shale			
10202 – 10312	65/35	Sand			
10312 – 10320	48/52	Shale			
10320 – 10325	75/25	Sand	Bell	Carbonaceous detritus - few, ferruginous materials -common, mica flakes & foram-Rare	

10325 – 10366	70/30	Sand	Funnel		Barrier bar
10366 – 10380	50/50	Shale			Marine clay
10380 – 10395	65/35	Sand			
10395 – 10405	50/50	Shale			
10405 – 10415	75/25	Sand	Bell	Glauconite and Rootlets- Rare, Ferruginous materials—few	Trangressive marine sand
10415 – 10438	70/30	Sand	Funnel		Barrier bar
10438 – 10445	80/30	Sand	Bell		Trangressive marine sand
10445 – 10488	75/25	Sand	Funnel	Carbonaceous detritus, Rootlets, Foram-Rare	Barrier bar
10488 – 10555	50/50	Shale		Rare-few, ferruginous material, Rootlet sand, foram	Marine clay
10555 – 10578	70/30	Sand		Few Rootlets, Rare carbonaceous detritus, ferruginous materials	
10578 – 10630	50/50	Shale			
10630 – 10665	70/30	Sand	Funnel		Barrier bar
10665 – 10750	50/50	Shale		Few Rootlets, Rare carbonaceous materials, ferruginous materials	
10750 – 10794	60/40	Sand			
10794 – 10828	40/60	Shale		Few—common ferruginous materials, forams and carbonaceous detritus calcite and silica are cementing materials	
10828 – 10833	58/42	Sand			

10833 – 10865	30/70	Shale			
10865 – 10918	70/30	Sand			
10918 – 11041	45/55	Shale		Few—common ferruginous materials, forams and carbonaceous detritus calcite and silica are cementing materials	Marine clay
11041 – 11064	60/40	Sand		Few-common ferruginous materials, forams and carbonaceous detritus calcite and silica are cementing materials	
11064 – 11198	40/60	Shale		Few—common ferruginous materials, forams and carbonaceous detritus calcite and silica are cementing materials	Marine clay
11198 – 11200	70/30	Sand			

Okan –75RD Depositional Systems Interpretations

Depth (ft)	Sand/Shale %	Lithology	Motif (Sand)	Index Mineral	Depositional systems
5980 – 5984	50/50	Shale			
5984 – 6040	85/15	Sand	Funnel	Common Pyrite, rare rootlets, ferruginous materials and foram	Barrier bar
6040 – 6055	46/54	Shale		Common Pyrite and foram	Marine clay
6055 – 6128	65/35	Sand	Funnel	Rare Carb, Common foram	Barrier bar
6128 – 6142	46/54	Shale			
6142 – 6165	60/40	Sand	Bell	Rare Carb, Root ferru material	Channel fill
6165 – 6180	55/45	Sandy sand			
6180 – 6228	45/55	Shale			Marine clay
6228 – 6235	60/40	Sand	Boxcar	Few carbonaceous detritus, rare shell fragments, pyrites and rootlets	Channel fill
6235 – 6280	50/50	Shale			Marine clay
6280 – 6298	55/45	Sandy sand		Rare carbonaceous detritus, Shell fragments and ferruginous materials	Delta fringe
6298 – 6306	50/50	Shale			
6306 – 6340	55/45	Sandy sand			Delta fringe
6340 – 6370	50/50	Shale			Marine clay
6370 – 6410	58/42	Sandy sand		Common mica, glauconite, Rare Rootlet, shell fragments	Transgressive marine sand

6410 – 6428	70/30	Sand		Frag. Carb. Few foram	
6428 – 6435	50/50	Shale			
6435 – 6455	60/40	Sand		Rare glauconite	Channel fill
6455 – 6458	42/58	Shale			Back Swamp shale
6458 – 6462	60/40	Sand			
6462 – 6465	42/58	Shale			Back Swamp
6465 – 6515	60/40	Sand	boxcar	Rare shell frag & Rootlet	Channel fill
6515 – 6540	50/50	Shale			
6540 – 6570	55/45	Sandy sand			
6570 – 6622	60/40	Sand		Rare foram	
6622 – 6638	70/40	Shale		Rare foram	
6638 – 6675	55/45	Sandy sand		Rare roots, carbonaceous detritus & foram	Distributary Channel fill
6675 – 6696	68/32	Sand			Same as above
6696 – 6875	60/40	Sand	Serrated		Same as above
6875 – 6930	80/20	Sand	Boxcar (fining upward)	Rare shell, rootlets, foram	
6930 – 6940	55/45	Sandy sand			
6940 – 6942	45/55	Shale			Back swamp
6942 – 6955	90/10	Sand	Boxcar		Distributary channel fill
6955 – 6965	45/55	Shale			
6965 – 6984	55/45	Sandy sand			
6984 – 7230	60/40	Sand	Boxcar	Rare Root, Carb.det	Point Bar
7230 – 7240	38/62	Shale		Rare Rootlets and forams	Marine foot
7240 – 7260	50/50	Sand		Rare Rootlets and forams	Marine clay
7260 – 7280	75/25	Sand		Rare mica & foram	Transgressive

					Marine sand
7280 – 7402	85/15	Sand	Bell		Barrier bar
7402 – 7405	48/52	Shale			Back Swamp
7405 – 7412	62/38	Sand	Funnel		
7412 – 7415	48/52	Shale			Back Swamp
7415 – 7446	65/35	Sand	Bell		
7446 – 7460	50/50	Shale			Marine clay
7460 – 7500	55/45	Sandy sand			Delta fringe
7500 – 7540	65/35	Sand		Rootlets, Carb. Detritus	Pont Bar
7540 – 7620	75/25	Sand	Multi storey funnel	Rootlets, Carb. Detritus	Barrier bar
7620 – 7622	45/55	Shale			Back swamp
7622 – 7627	62/38	Sand			
7627 – 7638	10/90	Shale			Barrier foot
7638 – 7676	65/35	Sand	Boxcar		Channel fill
7676 – 7680	45/55	Shale			Back Swamp
7680 – 7713	70/30	Sand	Boxcar		Channel fill
7713 – 7782	50/50	Shale		Rare Carb. Detritus	Marine clay
7782 – 7818	60/40	Sand			Delta Fringe
7818 – 7882	45/55	Shale			Marine clay
7882 – 7915	65/35	Sand	Bell	Rare Root Rare-few carbon	
7915 – 7930	50/50	Shale			
7930 – 7987	85/15	Sand	Funnel	Rare – few Carb. Det.	Barrier bar
7984 – 7984	45/55	Shale			Back Swamp
7984 – 8022	75/25	Sand	Funnel	Rare carb.	Barrier bar
8022 – 8026	38/62	Shale			
8026 – 8034	62/38	Sand			

8034 – 8072	50/50	Shale			Marine clay
8072 – 8090	55/45	Sandy sand			Delta Fringe
8090 – 8115	70/30	Sand	Funnel		Barrier bar
8115 – 8135	40/60	Shale			
8135 – 8174	70/30	Sand	Boxcar (serrated)		Channel fill
8174 – 8250	50/50	Shale			Marine clay
8250 – 8262	68/32	Sand		Mica flakes carb.	Barrier foot
8262 – 8270	48/52	Shale			
8270 – 8285	85/15	Sand	Bell	Rare glauconite and carb. det	Transgressive Marine sand
8285 – 8306	85/15	Sand	Funnel	Rare Carb.det	Barrier bar
8306 – 8310	50/50	Shale			Back Swamp
8310 – 8330	75/25	Sand	Funnel	Rare carb detritus	Barrier bar
8330 – 8338	38/62	Shale		Rare carb detritus	Barrier foot
8338 – 8385	50/50	Shale		Rare Carbonaceous detritus and Rootlets	Marine clay
8385 – 8390	60/40	Sand			Delta fringe
8390 – 8522	90/10	Sand	Boxcar	Common carbonaceous detritus	Point Bar
8522 – 8587	60/40	Sand			Delta fringe
8587 – 8618	75/25	Sand	Boxcar		Point Bar
8618 – 8625	47/53	Shale			Back Swamp
8625 – 8656	75/25	Sand			Point Bar
8656 – 8754	50/50	Shale			Marine clay
8754 – 8760	80/20	Sand			Barrier foot
8760 – 8765	45/55	Shale		Common carb det.	Back Swamp
8765 – 8825	85/15	Sand			Barrier bar
8825 – 8840	50/50	Shale		Common carb det.	

8840 – 8858	90/10	Sand	Boxcar	Rare carb detri	Point Bar
8858 – 8862	45/55	Shale			Back Swamp
8862 – 8933	86/14	Sand			Point Bar
8933 – 8940	30/70	Shale			Back Swamp
8940 - 9090	85/15	Sand	Boxcar		Point Bar
9090 – 9122	52/48	Shale		Rare to few pyrite,	Marine clay
9122 – 9176	80/20	Sand	Boxcar	Rare ferrg. Foram, Carb	Point Bar
9176 – 9182	42/58	Shale		Rare ferrg. Foram, Carb	Barrier foot
9182 – 9208	62/38	Sand		Rare carb, ferrug & pyrite	
9208 – 9268	50/50	Shale		Rare shell, frrg, carb, Py foram	Marine clay
9268 – 9482	75/25	Sand		Rare shell, frrg, carb, Py foram	
9482 – 9590	50/50	Shale			Marine clay
9590 – 9629	62/38	Sand			
9629 – 9665	55/45	Sandy sand		Rare pyrite, rootlet & foram	Delta fringe
9665 – 9690	60/40	Sand			
9690 – 9695	48/52	Shale			
9695 – 9715	58/42	Sandy sand			
9715 – 9735	80/20	Sand	Bell	Rare shell frg, Root, foram, few ferrg material	Trangressive Marine sand
9735 – 9788	78/22	Sand	Funnel	Rare carb. Rootlet	Barrier bar
9788 – 9794	40/60	Shale			Back Swamp
9794 – 9828	63/35	Sand	Boxcar (serrated)	Rare Carb.	Channel fill
9828 – 9830	42/58	Shale			Back Swamp
9830 – 9865	70/30	Sand	Boxcar		Channel fill
9865 – 9947	50/50	Shale			Marine clay

9947 – 9982	62/38	Sandy sand			Delta fringe
9982 – 10105	50/50	Shale			Marine clay
10105 – 10113	62/38	Sand		Rare carbonaceous detritus, shell fragments, ferruginous materials and foram	
10113 – 10248	50/50	Shale			Marine clay
10248 – 10280	70/30	Sand	Funnel	Rare carbonaceous detritus & Rootlet	Barrier bar
10280 – 10305	50/50	Shale			Back Swamp
10305 – 10360	55/45	Sandy sand		Common Carb. Rare shell ferrg, foram	Delta fringe
10360 – 10375	65/35	Sand		Common Carb. Rare shell fragments, foram and Pyrite	Barrier Foot
10375 – 10394	50/50	Shale			
10394 – 10413	75/25	Sand	Boxcar	Common Carb. Rare shell fragments, foram and Pyrite	Channel fill
10413 – 10433	50/50	Shale		Few Carb. Rare shell	
10433 - 10440	60/40	Sand	Bell		
10440 – 10443	45/55	Shale			
10443 – 10447	58/42	Sand			
10447 – 10452	33/67	Shale			
10452 – 10468	62/38	Sand	Funnel		
10468 – 10471	46/54	Shale		Rare carbonaceous detritus, Shell fragments	
10471 – 10508	64/36	Sand	Funnel		
10508 – 10529	35/65	Shale			
10529 – 10575	85/15	Sand	Boxcar	Rare shell fragments,	Channel fill

			(funnel)	mica & foram	
10575 – 10580	38/62	Shale			Back Swamp
10580 – 10640	80/20	Sand		Rare carbonaceous detritus, mica flakes and shell fragments	Channel fill
10640 – 10642		Shale			
10642 – 10645	58/42	Sand			
10645 – 10700	40/60	Shale			Marine clay
10700 – 10710	55/45	Sandy sand		Pyrite	Delta fringe
10710 – 10715	35/65	Shale			
10715 – 10733	55/45	Sandy sand			DELTA FRINGE
10733 – 10880	40/60	Shale		Abundant mica, Rare Carb., Rootlets and Pyrite	MARINE CLAY
10880 – 10900	30/70	Shale			MARINE CLAY
10900 – 10920	35/65	Shale			MARINE CLAY
10920 – 10925	70/30	Sand		Rare pyrite	
10925 – 10972	72/28	Sand		Rare shell fragments and root, abundant mica	BARRIER BAR
10972 – 11000		Shale		Rare pyrite	
11000 – 11040	75/25	Sand		Boxcar	CHANNEL FILL
11040 – 11042		Shale			BACK SAWMP
11042 – 11100	80/20	Sand		Boxcar	CHANNEL FILL
11100 – 11148	35/65	Shale			MARINE CLAY
11148 – 11155	62/38	Sand			
11155 – 11165	35/65	Shale			
11165 – 11175	80/20	Sand	Funnel	Rare mica, Pyrite, Root	
11175 – 11180	50/50	Shale			
11180 – 11183	68/32	Sand			

11183 – 11212	30/70	Shale			
11212 - 11220	62/38	Sand			
11220 – 11228	50/50	Shale		Rare Carb., Ferrg mat, pyrite	CHANNEL FILL
11228 – 11245	70/30	Sand	Boxcar		
11245 – 11254	45/55	Shale		Shell, Pyrite & Root—Rare	BARRIER FOOT
11254 – 11290	75/35	Sand	Funnel	Shell, Pyrite & Root—Rare	MARINE CLAY
11290 – 11460	40/60	Shale			BARRIER FOOT
11460 – 11470	60/40	Sand			
11470 – 11492	35/65	Shale			
11492 – 11497	60/40	Sand			
11497 – 11500	30/70	Shale			BACK SAWMP
11500 – 11546	60/40	Sand		Rare Carb, Shell Frag mt.	DELTA FRINGE
11546 – 11930	40/60	Shale		Rare pyrite foram	MARINE CLAY
11930 – 11950	85/15	Sand	Bell	Rare Carb pyrite	
11950 – 11988	85/15	Sand	Boxcar	Rare Carb., pyrite	Point bar
11988 – 12000	35/65	Shale			
12000 – 12125	85/15	Sand		Rare Pyrite & foram	CHANNEL FILL
12125 – 12183	40/60	Shale			MARINE CLAY
12183 – 12200	75/25	Sand		Rare shell & Rootlets	BARRIER FOOT
12200 – 12353	45/55	Shale			MARINE CLAY
12353 – 12356	15/85	Shale		Rare ferrug & foram –few pyrite	BARRIER FOOT
12356 – 12400	82/18	Sand	Boxcar		CHANNEL FILL
12400 – 12417	45/55	Shale			
12417 – 12420	78/22	Sand			
12420 – 12424	45/55	Shale			

12424 – 12430	78/22	Sand			
12430 – 12432	47/53	Shale			
12432 – 12470	80/20	Sand	Funnel	Rare Pyrite, Ferrg. & forams	BARRIER BAR
12470 – 12620	40/60	Shale		Rare Pyrite, Ferrg. & forams	MARINE CLAY
12620 – 12707	28/72	Shale		Rare pyrite & rootlets	MARINE CLAY
12707 – 12713	45/55	Shale		Rare pyrite & rootlets	MARINE CLAY
12713 – 12718	90/10	Sand		Rare—shell, Pyrite, Rootlets & Foram	CHANNEL FILL
12718 – 12790	85/15	Sand		Rare Carbonaceous detritus	CHANNEL FILL
12790 – 12793	37/63	Shale			BACK SAWMP
12793 – 12813	80/20	Sand	Funnel	Rare Carbon. detritus, pyrite, & ferrug. materials	CHANNEL FILL
12813 – 12815	42/58	Shale		Rare Carbonaceous detritus, pyrite, & ferrug. materials	BACK SAWMP
12815 – 12820	70/30	Sand	Bell		
12820 – 12828	30/70	Shale		Rare-Carb., Pyrite, Roots & foram	BACK SAWMP
12828 – 12848	82/18	Sand	Boxcar	Rare-Carb., Pyrite, Roots & foram	CHANNEL FILL
12848 – 12850	45/55	Shale		Rare- carbonaceous detritus, pyrite, rootlets & foram	BACK SAWMP
12850 – 12880	80/20	Sand	Boxcar (serrated)	Rare carbonaceous materials and rootlets	CHANNEL FILL
12880 – 12895	50/50	Sandy sand	Serrated	Rare—shell ferruginous materials & Rootlets	DELTA FRINGE

12895 – 13000	28/72	Shale		Few Pyrite, Rare Carbonaceous detritus & Ferrug. material	MARINE CLAY