A PALYNOSTRATIGRAPHIC STUDY OF THE ENVIRONMENTS AND THERMAL MATURATION OF ONSHORE OREDO FIELD, NIGER DELTA

BY

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NIGERIA

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CERTIFICATION

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DEDICATION

I dedicate this work to God Almighty, my ‘Divine Enabler’, who inspired and enabled me to successfully carry out this research despite all odds. To Him be Glory, Honour and Praise.

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ABSTRACT

The Niger Delta is a mature basin in Nigeria with petroleum reserve of about 40 billion barrels. The onshore Niger Delta Paleogene-Neogene, where exploration commenced and was concentrated before activities shifted to the offshore and deep-offshore Neogene-Quaternary, has not been fully explored. The shift of exploration focus led to a neglect of work on onshore Paleogene palynostratigraphy. This study was aimed at investigating the palynostratigraphy, paleoclimate and hydrocarbon potential of the periods.

Five hundred and eighty-five ditch cutting samples in Oredo Field, OML 111: Oredo-2 (244); Oredo-4 (195); and Oredo-8 (146) were provided by the Nigeria Petroleum Development Company, Benin. Sub-samples (25 grams each) were subjected to conventional palynological maceration procedures for the retrieval and concentration of palynomorphs and palynomacerals, while standard laboratory procedures were applied for micropaleontological sample preparation and lithologic descriptions. Retrieved palynomorphs and palynomacerals were mounted on microscope slides and observed using a high-power research photomicrographic microscope. The microfauna and lithology were studied using a stereomicroscope. Characteristic palynological assemblages associated with the recognised systems tracts within the sequence stratigraphic framework were defined. Biostratigraphic data were processed using conventional biostratigraphic software with stratigraphic ages cross plotted against depth generated in chronostratigraphic charts. Data were analysed using descriptive statistics.

The palynomorph assemblages contained abundant and diverse palynomorphs with pollen, fungal spores, dinoflagellate cysts and pteridophyte spores constituting, respectively, 63.0%, 18.8%, 8.1% and 7.4% of the totality of assemblages in the three wells. Twelve new palynological zones were established from the stratigraphic distribution of marker species based on their appearance and extinction datums and local assemblage ranges. Four palynocycles (1, 2, 3 and 4) of alternating wet and dry climatic regimes were identified based on ecological indicator plant species. The percentage distribution of the palynomacerals revealed the dominance of amorphous organic matter with phytoclasts and palynomorphs, which aided the subdivision of the wells into three palynofacies associations: PF-I, PF-II and PF-III. Two distinct organic facies represented by orange to orange-brown (TAI 3) and yellow to orange (TAI 2) indicating early mature and immature hydrocarbon potentials, respectively, were recognised. Recovery of microforaminifera, consisting of 87.0% benthics and 13.0% planktics was generally low. Two lithostratigraphic units, Agbada and Benin Formations, were delineated. Integration of palynostratigraphic and foraminiferal data suggested a Middle Eocene (Paleogene) to Early Miocene (Neogene) age for the analysed intervals. A combination of the palynofacies associations with other biostratigraphic data indicated palaeoenvironments shoaling from marine to terrestrial/continental. Two systems tracts – Transgressive Systems Tract (TST) and highstand systems tract – were recognised. Marine lithofacies with their associated TST in the Eocene are mature and lie within the oil and gas “windows”. Mapping of 41.0, 39.4, and 38.0 Ma maximum flooding surfaces with associated 40.1 and 38.7 Ma sequence boundaries were revealed.

A new and more detailed palynostratigraphic zonation comprising twelve zones for the Niger Delta Paleogene/Neogene was established. Four palynocycles of alternating wet and dry climatic cycles were revealed. The Eocene shale within the Agbada Formation were matured regarding hydrocarbon potentials.

Keywords: Paleogene - Neogene, Palynocycles, Palynomorphs, Systems tracts, Hydrocarbon potentials

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LIST OF ABBREVIATIONS

AAPG	American Association of Petroleum Geologists
AOM	Amorphous Organic Matter
BBW	Black and Brown Wood
C	Carbon
CI	Colour Intensity
CH	Charcoal
CH_4	Methane
CO_2	Carbondioxide
CPC	Charred Poaceae Cuticle
CYL 1	Palynocycle 1
CYL 2	Palynocycle 2
CYL 3	Palynocycle 3
CYL 4	Palynocycle 4
Dbh	Diameter at Breast Height
DOM	Dissolved Organic Matter
EC	Epidermal Cuticle; European Community
ESR	Electron Spin Resonance
FAD	First Appearance Datum
FE	Fungal Element
FDO	First Downhole Occurrence
GIGO	Garbage in Garbage Out
GM	Gelified Matter
H/C	Hydrogen/Carbon Ratio
HCl	Hydrochloric acid
HF	Hydrofluoric acid
H	Hydrogen
H_2O	Water
HST	Highstand Systems Tract
H_2S	Hydrogen Sulfide
ITCZ	Intertropical Convergence Zone
ITD	Intertropical Discontinuity

JDZ	Joint Development Zone
LAD	Last Appearance Datum
LDO	Last Downhole Occurrence
LST	Lowstand Systems Tracts
MFS	Maximum Flooding Surface
MFSC	Maximum Flooding Surface Condensed Section
MWL	Microforaminifera Wall Lining
NAPE	Nigeria Association of Petroleum Explorationists
NAOC	Nigerian Agip Oil Company
NPDC	Nigerian Petroleum Development Company Limited
NCT	Non-Cuticular Tissue
NH_3	Anhydrous Ammonia
NO_3	Nitrate
O	Oxygen
O/C	Oxygen/Carbon Ratio
PETM	Palaeocene-Eocene Thermal Maximum
PC	Principal Components
PCA	Principal Components Analysis
PF-I	Palynofacies I
PF-II	Palynofacies II
PF-III	Palynofacies III
POM	Particulate Organic Matter
PVA	Polyvinyl alcohol
SB	Sequence Boundary
SCI	Spore Colouration Index
SPDC	Shell Petroleum Development Company
SPH	Sporomorph
SO_4	Sulphate ion
SOM	Sedimentary/Organic Matter
STOM	Structural Organic Matter
TAI	Thermal Alteration Index
TAS	Thermal Alteration Scale
TD	Terminal Depth

TST	Transgressive Systems Tracts
USTOM	Unstructured (Structureless) Organic Matter
VR	Vitrinite Reflectance (R_o)
$ZnBr_2$	Zinc Bromide

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Revenue generated from petroleum exploitation has remained the main-stay of the Nigerian economy since the 1970s. This is in spite of the glut in the international petroleum market and the clamour for diversification into other sectors of the economy in recent years (Adegoke, 2002; Vanguard News, 2019). While performing the flag off ceremony of the Spud-In of Kolmani River II Well Drilling on February 2, 2019, President Buhari affirmed that the commodity was still essential to the country's economic survival (Vanguard News, 2019; Guardian Newspaper, 2019).

Petroleum exploration in Nigeria, traced back to the establishment of the Mineral Survey Corporation in 1903 by the then colonial administration, gave rise to the formation of the German Nigerian Bitumen Corporation in 1907. The corporation oversaw the drilling of 15 barren shallow wells in the old Abeokuta Province between 1937 and 1939. The corporation subsequently discovered crude oil in Araromi in Ilaje area of Okitipupa Province about 100 kilometres to the east of Lagos in 1908 but had its activities cut short by the First World War (Nationlineng.net, 2014). However, oil was struck in commercial quantity in 1956 at Oloibiri (Oloibiri – 1) in present Bayelsa State and was drilled with production commencing in 1958 by the Royal Dutch Shell group (Avuru, 2005; NNPC, 2009; Siollun, 2009; Tamuno, 2011; Nationlineng.net, 2014). Thus, oil was first discovered at Araromi, a fishing coastal community, western Ondo State, at its boundary with Ogun State. Though, the 'significant pioneer achievement' was aborted by the outbreak of the war in 1914, it set the stage for subsequent exploration activities leading to the commercial drilling at Oloibiri (Nationlineng.net, 2014).

Currently, petroleum is derived from nine of Nigeria's thirty-six states: Akwa Ibom, Bayelsa, Cross River, Delta, Edo, Rivers, Abia, Imo and Ondo. Three of these states: Bayelsa, Delta and Rivers supply approximately 75% of the country's output (Siollun, 2009). Nigeria is ranked the 14th world's oil producing nation with income from petroleum resources making up 80% of the country's income (NDRMP, 2005; NNPC, 2009; Aniefiok *et al*., 2013). Egbogah (2017) projected that the petroleum industry will remain the highest source of revenue to the Nigerian economy in the foreseeable future.

The Niger Delta basin, one of the seven identified sedimentary basins in Nigeria, accounts for the bulk of this hydrocarbon generation (Doust, 1990; Bellingham *et al*., 2014). The delta is a huge sedimentary basin at the rift triple junction on West African coast, which resulted from the continental separation of Africa and South America at the Gondwana breakup during the Mesozoic Era (Burke *et al*., 1972; Salard-Cheboldaeff, 1990).

Over 2000 oil wells have been explored in the Niger Delta basin with the basin currently producing petroleum from over 150 fields, the sediments of which extend in age from the Eocene to the Pliocene (Ozumba, 2011). Although the delta is a mature basin that has been extensively explored and exploited over the years, some schools of thought still believe it still has a lot to offer in terms of hydrocarbon resources. According to Omatsola (2017, pers. comm.), the Niger Delta basin still has reserve of about 40 billion barrels of petroleum. Avuru (2017, pers. comm.) posited that the second phase of exploration and development of the basin requires tremendous work and financial capabilities with attendant risks, stressing the need to carry out lots of sequence stratigraphic studies. In his own contribution at the monthly technical session of the Nigerian Association of Petroleum Explorationists (NAPE) in October, 2017, Ndefo (pers. comm.), a former Exploration Manager of ELF Nigeria PLC, pointed out that the onshore Niger Delta had not been fully exploited.

The slump in the product price of petroleum has been having negative impact on the economy of producing countries such as Nigeria, which are solely or largely dependent on petroleum for their revenue generation. Consequently, petroleum producing companies round the world necessarily have to reduce their business costs by adopting various means such as downsizing of workforce and downward review of operation costs. According to Schneidermann (1996), such steps at cost reduction are often aimed at turning focus on exploration models which combine high quality data with effective use of tools by experts. In petroleum exploration, stratigraphic methods of analysis and interpretation, essential in most geological studies such as basin evaluation and dynamics, offer such advantages.

Whittaker *et al*. (1991: 813) described stratigraphy as "the interpretation and fuller understanding of rock successions as sequences of events in the geological history". The authors also asserted that established "stratigraphical procedures and principles promote systematic and rigorous study of the composition, geometry, sequence, history and genesis of rocks".

Biostratigraphy has gone beyond the earlier classical and occasional "chronostratigraphic tool in regional exploration which is unreliable in establishing valid fine-resolution correlation frames at a reservoir scale" (Rull, 2002: 284). With the advent of quantitative high-resolution methods, biostratigraphy has attained its rightful status in exploration and production activities (Rull, 2002; Twiddle, 2012). In addition to the conventional approach of using biostratigraphy solely as a dating medium, other approaches, involving sequence modelling, employing chronostratigraphic correlation in the absence of age restricted microfossils, are being developed (Morley, 1995a, b). Morley (1995a, b) posited that inputs from such models into seismic data can bring about precise sequence evaluation unattainable by seismic information alone.

Sedimentary organic matter (SOM), recorded during palynological analyses are essential in the identification and deduction of depositional environments ranging from onshore through coastal to sea bottom settings (Hart, 1986; Love, 1987). Palynological derivatives (including palynomacerals) in sedimentary basin are controlled by the dynamics of the water currents in the same way like clastic sediments. This attribute confers the potential to be used in identifying depositional settings on palynomacerals. These organic debris are sorted based on their buoyancy characteristics (Love, 1987; Parry *et al*.,1981; Campbell, 1999).

Hydrocarbons are obtained from organic matter in source rocks by thermal maturation with the quantity of hydrocarbon generated being a direct measure of the source potential (Katz,1983; Tissot and Welte, 1984; Peter, 1986; Oyede, 1988). The more macerals become heated, the more their chemical and physical features change. Out of the two changes the more obvious are the chemical changes and are more difficult to monitor and measure. The physical change, resulting from the chemical changes, are easily measured with standard microscopy for visual determination of colour, reflectance, florescence, translucency, and absorption (Hart, 1986). This is possible due to thermally induced chemical changes on the particulate organic matter which are reflected by sequential alteration of physical features such as colour, light transmission, reflectivity, index of refraction and spectral fluorescence among others (Bostick, 1971; Staplin, 1977). Batten (1996) also opined that the response of palynological matter to rising temperature reflected its chemical composition.

Climate change through time in the tropical equatorial region has been marked by alternating climatic phases. The effect of these changes is reflected in variations in vegetation – rain forest wet phases and savanna in dry phases. The dynamic nature of vegetations generally makes them respond in complex ways to climate change and other environmental changes (EC, 2016). According to Harrington *et al*. (2004), regional environmental changes, resulting from climate change, play a significant role in the floral association within a regional vegetation type. The vegetation and plant species distribution of a region are generally controlled by climate. However, other local environmental factors such as micrometeorology, soil nutrients status, pH, water-holding capacity and topography have also been found to influence the vegetation in an area. Thus, extreme climate change resulting from greenhouse gas emissions influences the vegetation patterns of a region (Sykes, 2009).

Palynology offers a significant dimension for determining vegetation changes through the integration of pollen records over wide areas and across vegetation boundaries (Pietsch and Gautam, 2013). The Guineo-Congolian tropical rain forests, spanning from Senegal to western Kenya and northern Angola, is populated with an estimated 8000 plant species in Africa (Van Gemerden, 2003**)**. This African rainforest region is known to have witnessed alternating phases of decrease in forest zone during drier conditions with expansion during wetter periods due to change in climate particularly in the Quaternary (Van Gemerden, 2003).

1.2 Statement of the Problem

Before shifting to the offshore and deep-offshore (younger sediments) and the delta flanks (older sections), exploration activities started and were concentrated in sediments of Eocene to Pliocene ages of the onshore Niger Delta (Ozumba, 1999; Ozumba and Amajor, 1999a, b). This facilitated an appreciable understanding of the geology, tectonics, and evolution of the Eocene – Pliocene sequence of the delta (Ozumba, 1997). Be that as it may, there exists low published information on the biostratigraphy/ palynology of Palaeocene-Oligocene sediments from Nigeria (Adeonipekun and Oyelami, 2015; Orijemie, 2016). This may be due to what Ozumba and Amajor (1999a) described as the relatively thin Paleogene sediments encountered in the basin and the current concentration of exploration and drilling activities on the thick sediments of early Miocene to Pliocene sections.

The Paleogene and Neogene Periods constitute the Cenozoic Era succeeding the Mesozoic and preseeding the pre-Quaternary interval in the geologic time scale spanning between 66.0Ma and 2.59 Ma (Gradstein *et al*., 2012). The Paleogene is a geologic period that began 66.0 Ma and ended 23.0 Ma ago. It consists of the Palaeocene (66.0-56.0 Ma), Eocene (56.0-33.9 Ma) and Oligocene Epochs (33.9-23.0 Ma). The Neogene is a geologic period that spans 20.41 Ma from the end of the Paleogene Period (ca 23.0 Ma) till the beginning of the Quaternary about 2.59 Ma ago. The Neogene is divided into Miocene (23.0-5.33 Ma) and Pliocene (5.33-2.59 Ma) Epochs (Gradstein *et al*., 2012).

Attempts at improving the existing palynological zonations schemes of the Niger Delta Neogene have been made in contemporary time (Morley and Richards, 1993; Adeonipekun *et al*., 2016). However, there has not been any holistic effort geared towards this direction for the Paleogene section of the basin since the earlier efforts of authors such as Germeraad *et al*. (1968), Boom (1977), Evamy *et al*. (1978) and Legoux (1978). The Biostratigraphic Subcommittee of the Stratigraphic Commission of the Niger Delta expected to provide standardized Paleogene to Recent biostratigraphic zonal schemes with uniform and accepted zonal boundaries and index foraminiferal and palynomorph species (NDSC, 1996) is yet to publish it palynological reports. The micropalaeontology and nannofossil volumes of the report have since been published.

1.3 Aim and Objectives of Study

This work is aimed at closing existing gaps in the palynostratigraphy of the Late Paleogene to Early Neogene and shed light on its paleoclimate as well as sediment maturity for hydrocarbon potential estimation of the area. This is to be done through the application of palynological, foraminiferal, sedimentological and sequence stratigraphic approaches for the refinement of the biostratigraphy, improvement of knowledge on its sequence stratigraphy and emerging trends in petroleum exploration plays and concepts.

Towards achieving the aim of this project, the main objectives are:

a. Age determination of the strata penetrated by the three wells from detailed analysis of the occurrence pattern of the palynomorphs and foraminifera encountered.
b. The construction of refined and improved palynostratigraphic zonation scheme for the Early to Middle Tertiary of the delta.
c. Deduction of the prevailing palaeoenvironmental and palaeoclimatic settings during sediment deposition of the well sections.
d. The characterization of palynomorphs in systems tracts within a sequence stratigraphic framework.
e. An estimation of the thermal maturity of sediments.
f. The correlation of recognized events across the three well sections studied.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview

This review is on work done in the Niger Delta over the last 55 years covering mostly the Palaeogene and Neogene periods. Until the first decade of this century, published reports in palynology, nay biostratigraphic studies, on the Niger Delta basin were limited in number relative to other parts of the world. This dearth of publications has been attributed to the propriety policies of the various operating petroleum companies which restricted the results of the research activities of their personnel to in-house use only (Ogbe, 1982; Oboh, 1992; and Oyelami, 2016).

Two perspectives of literature review, the Conceptual and Empherical, were used for this report. Under the Conceptual Review, the importance of palynology and palaeoecology in biostratigraphy are considered. The concept behind palynofacies and thermal alterations of organic matter are also reviewed. The general concept of sequence stratigraphy and the geology of the Niger Delta basin are also reviewed.

The significant aspects of the study such as palynostratigraphy, palynofacies and thermal maturity studies, and foraminiferal biostratigraphy in the Niger Delta are reviewed. Other aspects such as applications of biostratigraphy in sequence stratigraphy and climate change vegetational change studies are also subjected to review.

2.2 Conceptual Review

2.2.1 Biostratigraphy, Palaeoecology, and the Importance of Palynology

Biostratigraphy, which can be described as the systematic ordering of rock layers into defined units on the basis of type and pattern of occurrence of embedded biological fossils (cf. Hedberg, 1976; Hankock, 1977; Adegoke, 2002), is a key aspect of stratigraphy. High resolution biostratigraphy has traditionally been employed for time-stratigraphic control of Niger Delta sediments (Stacher *et al.*, 1993). This has made possible the correlation of depositional sequences providing detailed environmental analyses and geological modelling for characterization of seal potentials within reservoirs (Stacher *et al*., 1993; Feam, *et al*., 1996).

It is now common practice to deploy fossil groups such as planktonic foraminifera, pollen, spores and dinoflagellates, among others, for the refinement of stratigraphic framework and improvement of biozone correlation to absolute time-scale (Stacher *et al*.,1993). Feam *et al*. (1996) highlighted that chronostratigraphic model is the foundation of regional stratigraphic correlations and forms the basis for geological modelling for timing hydrocarbon. According to Feam *et al*. (1996), local biostratigraphic zonation schemes enable correlation within the regional framework.

Thus, biostratigraphy has become indispensable in the field of geosciences and much more in petroleum exploration and exploitation (Poumot, 1989; Ehinola *et al*., 2009). The three main fossil groups under focus in biostratigraphy - palynomorphs, foraminifera and nannofossils - are important and complementary to one another. Pollen, pteridophyte spores and associated planktic forms, dinoflagellate cysts are some of the major widely used groups in high resolution biostratigraphy (Adegoke, 2002). Others, closely associated with these include microforaminiferal wall linings, acritarchs, chitinozoans, scolecodents, colonial algae, fungal spores, among others. These groups are collectively referred to as palynomorphs and are studied in palynology.

"Palynology is the study of extant and fossil pollen, spores, and similar organic-walled, microscopic-sized forms whose outer walls are resistant to maceration by strong acids and to degradation in acidic and non-oxidative sediments or deposits, their dispersal, and the applications thereof" (Sowunmi, pers. comm., 2018). Palynology has made significant contributions to the advancement of stratigraphic knowledge and it is an essential field in sediment dating and characterization (Poumot, 1989).

Palynology was first applied as a biostratigraphic tool in petroleum exploration in 1936 when it was successfully used in Mexico when age determination and correlation of economically significant strata were not possible by marine micropaleontology and lithological methods (Hopping, 1967; Sarjent, 2002). However, it must be pointed out that palynology has been in use as a stratigraphic tool by peat stratigraphers and in coal exploration as far back as the late nineteenth century in Scandiniavia (Edtman, 2007; Traverse, 2008).

Since the early 1950s, Shell has engaged palynology successfully in Venezuela in non-marine sections where marine paleontology could not be used (Kuyl *et al*., 1955). Consequently, palynology has contributed greatly to stratigraphic knowledge worldwide (Salard-Cheboldaeff, 1990; Traverse, 2008). Palynostratigraphy has been successfully deployed for correlation of strata from the Cretaceous to the Tertiary (Hopping, 1967; Jansonius and McGregor, 1996; Traverse, 2008). Palynology remains an essential tool in the stratigraphic control of wells while drilling, complementing seismic and structural interpretations as well as reservoir correlations in regions with continental, non-marine sequences such as the Sudan Rift valley basin (Kaska,1989; Stead and Awad, 2005; Eisawi and Schrank, 2008) and the northern South American basin such as the Cuervos Formation Basin of Colombia (Jaramillo, *et al*., 2005).

According to Christopher and Goodman (1996; 436), "reliable biostratigraphic correlation is dependent on the ability to define, differentiate, and recognize biostratigraphic units". Palynostratigraphy has made possible the construction of reliable zonation schemes for the Niger Delta basin. Most of these zonation schemes were established on the evolution of species (appearance or/and disappearance), their quantitative abundance, peaks or acme (Germeraad *et al.,* 1968; Evamy *et al.,* 1978; Legoux, 1978; Salard-Cheboldaeff, 1990; Morley and Richards, 1993; Adeonipekun *et al.,* 2016).
Due to their abundance in open marine environments and their short stratigraphic ranges which make them significant and reliable for biostratigraphic studies, planktonic foraminifera have been widely used as biochronological standard fossils for the Early Cretaceous to the Recent (Postuma, 1971; Whittaker *et al*., 1991; Christopher and Goodman, 1996). These short stratigraphic ranges of planktonic foraminifera are used for biostratigraphic zonations.

However, palynological zonation, though very important for correlations across diverse environments, from non-marine to marine, is subject to facies control. This makes it to be more applicable for local or regional settings with limited adoption into global chronology. In addition, the preponderance of pollen and spores in deposits as well as the long stratigraphic ranges of some index or marker species, necessitates the use of other bioevents in addition to the evolutionary (base occurrence) and extinction (top occurrence) points often in use for planktonic foraminifera zonation.

Palynology and its significance in biostratigraphic and paleoecologic interpretations is well entrenched in its applications in hydrocarbon exploration and depositional history. This significance in stratigraphy has been attributed to several characteristic features of palynomorphs (Sowunmi, 1986; Holloway and Bryant, 1986; Traverse, 2008).

Pollen and spores, especially the anemophilous types, are mostly produced in high abundances making them abundant relative to other microfossils (Traverse, 2008). For example, Forsac *et al*., (1987) established that *Bombax buonopezense* (Kapok), *Ceiba pentandra* (silk cotton) and *Ricinnus communis* produce 5.3 million, 2.6 million and 1.7 million pollen grains per flower, respectively. This production, coupled with their microscopic sizes in the range between 5 µm and 200 µm, has made most palynomorphs ubiquitous in sedimentary rocks of all ages (Traverse, 2008).

The external wall of palynomorphs, the exine, is composed of a mixture of cellulose and a more resistant compound called ‘sporopollenin’. The sporopollenin is made up of copolymers of carotenoid and carotenoid esters, the presence of which confers great resistance on the walls of palynomorphs making them resistant to decay and enables them to be preserved for millions of years (Diego-Taboada *et al*., 2014). The oldest known palynomorph is assigned the latest Devonian (ca. 362.5Ma) and that of embryophyte spore is the lower Silurian (ca. 430.0Ma) (Traverse, 2008). In addition to this are the diagnostic features of the pollen and spores through which their parent plants can be identified. These are distinguishing features by which the pollen of one genus or species can be differentiated from those produced by other plant taxa.

The significance of palynological application in stratigraphy is further accentuated by the fact that palynomorphs are encountered in diverse environments from terrestrial through non-marine to deep marine settings. This makes correlation across terrestrial and marine deposits possible (Woodson, 1997). Besides, the rate of production of pollen and spores, which is often highest amongst wind-pollinated plants, and their level of preservability, which is largely dependent on the quantity of sporopollenin deposited in the exine, the nature of the sedimentary deposit also constitute a significant factor in their preservation. Preservation is better ensured in non-alkaline, anoxic, and lower energy depositional settings (Traverse, 2008).

Studies on the production, preservation, dispersal and sedimentation processes of pollen, spores and most other palynomorphs have been carried out and reported by different authors such as Muller (1959), Havinga (1964, 1966), Germerrad *et al*. (1968), Batten (1981), Campbell (1991; 1999), Campbell and Campbell, (1994), Chmura *et al*. (1999) and Traverse (2008) among others.

Nonetheless, spores and pollen preservation entail complex factors according to Cushing 1966 cited in Traverse (2008). The silt-sized or very fine sand-sized nature of pollen and spores makes them to be subjected to air current for dispersal away from the parent plants before settling on soil surface (Traverse, 2008). However, the bulk of produced spores and pollen are washed into rivers for onward transport to depositional basins (Muller, 1959; Germerrad *et al*., 1968).

Palynological deductions have been used for palaeoenvironmental reconstruction for more than a century. Its application in palaeoecology continues to make tremendous contributions to the knowledge of vegetational and environmental history (Rachele, 1976). The main objective of palaeoecological investigation of palynofloral assemblage is to relate the fossil pollen with its vegetational provenance. Conclusions can then be drawn about ancient climate and environmental changes by studying the extanct components of a vegetation (Traverse, 2008).

Palynologists have endeavoured to gain palaeoecological information on Tertiary palynomorphs from the study of their assemblages (Frederiksen, 1985). Tipsword *et al*. (1968) also observed that palaeocology has taken up important role in basin evaluation during petroleum exploration. Tipsword *et al*. (1968: 111) averred that: “oil and gas reservoirs were deposited in specific environments with a definite relationship between petroleum occurrence and depositional history”.

2.2.2 Palynofacies and Thermal Alteration of Organic Matter

The concept of organic facies and its applications constitute a significant tool to characterization of palaeoenvironments, basin analysis and hydrocarbon exploration. Organic matter embedded in sedimentary deposits experience changes in their chemical composition with time. These changes reflect variations in temperature and burial history/records (Mendonça Filho *et al*., 2012). The study of this dispersed organic matter, occurring with palynomorphs, commonly referred to as organic debris, palynoclasts or palynomacerals, is now classified as palynofacies. According to Batten (1996:1018), facies is "a body of sediments of a specified character that represents a particular environment of deposition". Since facies cover wide features, prefixes are often attached for classification of its essence in a particular study, hence we have palynofacies, lithofacies etc.

Combaz (1964) coined the term "palynofacies" to describe the "total assemblage of microscopic organic constituents presents in a rock that remain after maceration in hydrochloric acid (HCl) for carbonates and by hydrofluoric acid (HF) for silicates, concentration and mounting using normal palynological preparation procedures" (Mendonça Filho *et al*., 2012: 129).

Palynofacies evaluation, therefore, entails the complete study of all aspects of the assemblage of palynological organic matter including the recognition of the component organic matter, particle sizes, abundance as well as their preservation. It has been applied in various fields such as palaeontology (palynology), stratigraphy, sedimentology, palaeoenvironmental studies, petroleum exploration, environmental studies among others (Tyson, 1995; Mendonça Filho *et al*., 2012).

Palynofacies is valuable in suggesting the potentiality of a sediment as a source rock indicating the effects of thermal maturation (Hart, 1986; Love, 1987; Batten, 1996). Since the introduction of the term palynofacies, different other terms have also been proposed by other authors. These include "palynological facies" by Hughes and Moody-Stuart (1967), "organopalynology and organopalynofacies" Quadros (1975), "palynoclast" Powell *et al*. (1990), and "biofacies" Traverse (2008) among others.

Organic matter could either be kerogen and bitumen factions. Kerogen is the solid organic matter in source rocks insoluble in low-boiling organic solvents **(**Mendonça Filho *et al*., 2012; Leythauser, 2005). It is derived from the aggregation of resistant macromolecular biological materials such as cellular lipids, algal cell walls, membranous cuticles, spores, and pollen among others (Leythauser, 2005). Bitumen, on the other hand, is the organic matter soluble in organic solvents **(**Mendonça Filho *et al*., 2012).

The molecular weight of kerogene is higher relative to that of bitumen with the latter derived from kerogen during petroleum generation. Elemental analysis is a particularly useful means of determining kerogen composition using the elementary ratios of the atomic composition of major elements of carbon (C), hydrogen (H) and oxygen (O) leading to the recognition of three categories: Types I, II and III (Hunt, 1979; Tissot and Welte, 1984; Mendonça Filho *et al.*, 2012).

Kerogen Type I is made up of a high initial H/C atomic ratio and low initial O/C ratio. Its lipid materials, especially aliphatic chains are high /rich while its polyaromatic nuclei and heteroatomic bonds are low. Kerogene Type I is either obtained from alga lipids (freshwater algae) or from organic matter saturated in lipids by microbial activity such as amorphous organic matter (AOM). It has high hydrocarbon generation potential and is rare in worldwide occurrence.

Kerogen Type II is common in most petroleum source rocks with relatively high H/C and low O/C ratios. It is made up of aliphatic chains of moderate length and naphthenic rings. Its content of polyaromatic nuclei and heteroatomic ketone and carboxylic acid groups are more significant than those in Type I, though less than in Type III. The higher H/C ratio associated with Kerogen Type II, made up of mixture of saturated hydrocarbon ring networks (naphtenes) and aliphatic chains with some poly-condensed aromatic ring structures, is derived from pollen grains, spores, cuticles and marine organic matter deposited in a reducing environment, with medium to high sulphur content. It is abundant in the most prolific petroleum source rocks. Both Kerogen Types I and II are formed under anaerobic conditions (Leythaeuser, 2005; Mendonça Filho *et al.*, 2012).

Kerogene Type III is associated with low H/C ratio with a comparatively higher O/C than in the other two kerogen types. It is dominated by condensed polyaromatic and oxygenated functional groups with aliphatic chains. This results from the high contributions from higher land plants rich in cellulose and lignin-derived components. They may also be due to deposition of organic matter obtained from marine organisms in dysaerobic to oxic conditions. Kerogen Type III source rocks yield minimal quantities of oil but could be high in gas content; upon heating they convert in part to liquid and gaseous hydrocarbon (Leythaeuser, 2005; Mendonça Filho *et al.*, 2012).

A secondary type of kerogen of indeterminate composition may also occur as Kerogene Type IV. This kerogene type is made up of only aromatic components. The organic matter is carbonized because of combustion or natural pyrolysis or/and oxidation. It has no potential for hydrocarbon generation (Mendonça Filho *et al*., 2012).

Kerogen's presence in source rocks can be detected by microscopic particles traceable to their biological or diagenetic affinity such as algae, epidermal cuticles, herbaceous tissues, and spores (Taylor *et al*., 1998, cited in Leythaeuser, 2005). These particles which can be macerated from the embedding matrix by laboratory acid preparation are referred to as macerals. The macerals that are replete with hydrogen are called liptinites. These are made of remains of waxy and fatty plant tissues such as sporonites: the external walls of pollen and spores; cutinite: remains of cuticles and cuticular layers; resinite: resins and oil secretions on resin bodies and alginate: remains of resistant oil-rich algae (Stach *et al*., 1975; Massoud and Kinghorn,1985).

Vitrinites are coalified humic materials originating from lignin and cellulose of plant cell walls which constitute the major components of humic coals. They are from woody plant tissue with either minima or maximum gelification during diagenesis. Organic particles that have been extremely oxidized either chemically or through bacterial activities are called inertinite. These are plant tissues that have be subjected to natural carbonization processing of charring, oxidation, mouldering and fungal destruction prior to sediment deposition. They are made up of charcoal-like substances high in carbon and low in oxygen and hydrogen contents. They are graphite-like in structure (polycyclic aromatic) and are usually classified as "dead carbon" since they are not hydrocarbon productive (Stach *et al*., 1975; Massoud and Kinghorn, 1985; Leythaeuser, 2005).

Studies have shown that thermal alteration differs among the assorted particulate organic matter in deposits. Dormans *et al.* (1957) observed that the alteration track in exinite, that is, spores, pollen and cuticle, revealed a wider range than vitrinite (woody cells), macrinite and fusinite largely due to the higher hydrogen content and exine chemical composition in the exinated organic matter. In the same vein, Teichmuller 1952 (cited in Staplin, 1977) averred that the level of coal carbonization can be estimated on the basis of colour and reflection changes of exinite. Observations such as these resulted in the development of techniques applied in hydrocarbon exploration to measure thermal alteration by means of colour and light transmission of exinite.

Staplin (1977:11) asserted that “the use of colour and light transmission scales and the study of debris by palynologists in petroleum geology is aimed at obtaining a rough measure of the state of the sediment organic matter with regard to petroleum generation”.

Increase in subsurface temperature over geologic time results in the generation of hydrocarbon from source materials in a process called maturation. Maturation can either be catagenesis or metagenesis (Tissot and Welte, 1984). The principal driving force in petroleum maturation and generation is high temperature from burial heat generated in the subsurface because of increasing depth. Thermal alteration/degradation of kerogen resulting in the cracking or breaking down of carbon-carbon bonds yields oil and gas (Mckenzie and Quigley, 1988 cited in Leythaeuser, 2005). The maximum temperature at which kerogen transforms into petroleum is called the ‘liquid window’ or oil window’ and it reaches beyond 80-150°C temperature mark (Leythaeuser, 2005).

Depending on the level of advancement of hydrocarbon generation, the source rock organic matter can be described as immature, when the hydrocarbon generation is still at the formative stage; mature, when hydrocarbon generation is at peak or/and overmature, when hydrocarbon generation capability has been exhausted (Evans and Staplin,1971; Leythaeuser, 2005). There exist different techniques for recognizing and measuring thermal alteration. The commonly used of these, according to Burgess (1977) are: Palynomorph Colouration, Spore Translucency, Vitrinite Reflectance, Florescence Microscopy, Electron Spin Resonance (ESR), Liquid Inclusions in Minerals, Conodont Colour Alteration, and Infrared Spectra Analysis. Burgess (1977) made a comparison of these methods based on relative cost, speed of analysis, measurement quality, application and limitation (Table 2.1).

The two optical methods of vitrinite reflectance and palynomorph colour are well known for thermal maturity determination (Oyede, 1988; Batten, 1996). Vitrinite Reflectance (R_o): Vitrinite reflectance increases exponentially with a linear increase in temperature (Ting, 1975). Conventional reflectance microscopy is being used to measure the

Table 2.1: A Comparison of Thermal Alteration Methods (After Burgess, 1977)

METHOD	RELATIVE COST	SPEED OF ANALYSIS	MEASUREMENT QUALITY	APPLICATION	LIMITATIONS
PALYNOMORPH COLOUR	INEXPENSIVE	FAST	SUBJECTIVE	REGIONAL TRENDS	INTERPRETATIVE
SPORE TRANSLUCENCY	”	SLOW	QUANTITATIVE	”	NOT APPLICABLE IN UNFOSSILIFEROUS ROCKS
VITRINITE REFLECTANCE	”	FAST	”	REGIONAL TRENDS PALEOTEMP.	POST-SILURIAN ROCKS
FLUORESCENCE MICROSCOPY	MEDIUM COST	”	”	PALEO-TEMPERATURE	PROCESSING AFFECTS METHOD
ESR-KEROGEN METHOD	EXPENSIVE	SLOW	”	PALEO-TEMPERATURE	BULK MIXTURE ANALYSIS
LIQUID INCLUSIONS IN MINERALS	INEXPENSIVE	”	”	”	SPECIAL SAMPLING NECESSARY
CONODONT COLOURATION	”	FAST	SUBJECTIVE	REGIONAL TRENDS	LIMITED TO PALEOZOIC & LATE MESOZOIC
INFRA-RED SPECTRA	MEDIUM COST	SLOW	SUBJECTIVE	PALEO-TEMPERATURE	INTERPRETATIVE

reflectance of organic particles. This method was developed by coal petrologists before it was applied to disperse organic particles in sediments. An international standard which ensures an accurate scale comparing thermal maturation and reflectance of vitrinite makes vitrinite reflectance a useful statistical estimator in data analysis (Hart, 1986).

However, this method, according to Oyede (1988), requires the usage of expensive equipment with high level of care and precision in controlled environments. Also, its reliability can be equivocal due to error from cutting samples, caving, and recycling. Another problem that may affect the accurate estimate of reflectance is what Hart (1986) described as difficulty of finding sufficient vitrinite in a sample.

Following the initial efforts of quantifying the relative opacity of organic matter under the microscope using the thermal alteration index (TAI) by Staplin in 1969, spores and pollen in sediments are now known to be subjected to gradual changes in both their chemical and physical properties with increasing burial depth, temperature and pressure. This application of colour changes in palynological matter in estimating thermal maturation is referred to as the thermal alteration index (TAI) or spore coloration index (SCI) (Staplin, 1969).

These changes are reflected in the physical properties of the embedded palynomorphs such as their colour, reflectance, and fluorescence. Results of measurement of these properties are calibrated relative to the standard Thermal Alteration Index (TAI) scale with the aim of assessing the level of hydrocarbon maceration and potential (Ujiie, 2000). TAI is a visual estimate, usually measured on miospores (particularly spores), which allows for the establishment of a wide range of thermal maturation scale. Though the application of spore colour changes in thermal maturation is inexpensive, it could be subjective in quality measurement since colour changes are estimated and not measured.

As Batten (1996) put it, achieving consistency in the determination of maturation levels using visual assessment of palynomorphs colour is not easy to accomplish due to differences in exine thickness and composition, level of oxidation and degradation, and occurrence of reworked elements. Batten (1996) reported difficulties in using palynomorphs in transmitted light at the threshold between the late mature and over-mature end of the thermal scale because of challenges in recognising differences between dark brown and black.

Many numerical scales relying on palynomorph colours in sediments which are related with organic maturation stages and hydrocarbon production have been published. These include Staplin (1969), Correia (1971), Jones and Edison (1978), Fisher *et al.* (1980), Batten (1980; 1981) and Rovina (1981). Some of these scales have been compared and correlated with other thermal maturation indices in sedimentary rocks. Table 2.2 gives values of the spore colouration index (SCI) with associated spore colours in relation to thermal alteration index (TAI) with corresponding hydrocarbon potential.

Table 2.2: Correlation of thermal maturation indicators in sediment (Sowunmi, 2019, pers. comm.)

Spore coloration index (SCI)	Thermal alteration index (TAI)	Generalized hydrocarbon zone
4.0 (Golden yellow-deep yellow)	2.0	Immature
5.0 (Yellow orange -light orange)	2.3	Immature
6.0 (mid orange-dark orange)	2.6	Oil
7.4 (orange, brown-light brown)	2.8	Oil
8.1}	3.0	Oil
8.3} (mid-dark brown)	3.2	Oil & wet gas
8.5}	3.4	Wet gas
8.7}	3.5	Wet gas
9.2 (very dark brown – brown, black)	3.8	Methane
10 (black)	4.0	Methane
10+ (black)	5.0	Overmature

2.2.3 Sequence Stratigraphy

Sequence stratigraphy, a subdiscipline of stratigraphy, has been succinctly defined as "the study of rock relationship within a chronostratigraphic framework of repetitive, genetically related strata bounded by surfaces of erosion or non-deposition, or their correlative conformities" (Van Wagoner *et al*., 1988:39). Mitchum (1997) also defined a sequence as a succession of genetically related strata bounded by unconformities with their correlative conformities.

This modern stratigraphic approach is applied for the provision of chronostratigraphic framework for correlating and mapping sedimentary basins and for stratigraphic predictions (Emery, 1998). This is aimed at enhancing exploration and exploitation with a view to recognizing, discovering and evaluating new hydrocarbon reservoirs and reducing attendant risks in management decision making (Wornardt, 1993).

The sequence is the fundamental unit of sequence stratigraphy and can be subdivided into systems tracts. The systems tracts are defined by their position within the sequence and by the stacking patterns of parasequences and parasequence sets, the fundamental building block, delineated by marine-flooding surfaces (Van Wagoner *et al*., 1988). The delineation of sedimentary rock sections into sequences, parasequences and systems tracts offers a very powerful tool for chronostratigraphic analysis of sedimentary strata. Sedimentary rocks are subdivided into genetically related units bounded by surfaces of chronostratigraphic importance with sequence and sequence boundaries. Systems tracts interpretation enables the prediction of facies relationships within the sequence (Van Wagoner *et al*., 1988).

Sequence stratigraphy makes possible the subdivision of geological history into time scales of the third order of 0.5 MY (Mannot and Wannier, 1992; Wornardt, 1993). According to Mannot and Wannier (1992), these strata units define the basis for mapping lithofacies distributions, such as source rocks, reservoirs, and seals at the basin level. While the 3-dimensional mapping of parasequences may provide detailed models of the geometry and inter connectivity of reservoirs, of primary porosity distribution and of the availability and extent of barriers (seals) on a wider scale.

Different geological disciplines such as biostratigraphy, seismic stratigraphy, chronostratigraphy and sedimentology are applied in sequence stratigraphy (Emery, 1998). Both high resolution biostratigraphy and palaeobathymetry data are key in sequence stratigraphic analysis as they aid in the recognition of maximum flooding surfaces and condensed sections. Integrating inferences from these data enables accurate identification of maximum flooding surfaces ties to those from well-logs and seismic profiles thereby providing a means to age dating the surfaces and tying them to the global cycle chart. The systems tracts or surfaces are independently picked on well logs and seismic profile but are tied to those picked on biostratigraphic data.

Also, with the aid of palaeobathymetry, the water depth at which the reservoir sands were deposited from which the different systems tracts can be selected can be accurately identified. This integration with high resolution biostratigraphy and palaeobathymetry constitutes a significant contribution to seismic sequence stratigraphy (Wornardt, 1993). With bioevents abundance and diversity histogram trends of recorded microfossils, high resolution biostratigraphy, integrated with logs signatures, has been providing important time framework for delineation of sequences and systems tracts (Wornardt *et al.*, 1992).

Conventional sequence stratigraphic approach entails the recognition of sequence boundaries, maximum flooding surfaces and systems tract boundaries in a sequence with a view to identifying systems tracts associated with source rocks and seals with potential hydrocarbon reservoir (Wornardt, 1993). From the abundance and diversity curves of total planktonic foraminifera and/or nannofossils, the maximum flooding surface condensed section (MFSCs) and sequence boundaries are identified in a stratigraphic sequence. Condensed sections are hemipelagic sediments deposited under low sedimentation rates which are characterized by abundant and diverse fossils. Condensed sections are well developed at periods of regional transgression of the shoreline. The highest abundance and diversity value may represent the MFS condensed sections (Van Wagoner *et al*., 1988).

According to Van Wagoner *et al*. (1988), a marine-flooding surface separates younger and older stratum across an abrupt increase in water depth. Electronic log features of high gamma ray, high SP, low resistivity, high conductivity, and low sonic log which are characteristics of the shale portion in a well section indicate maximum flooding surfaces within the condensed sections. This represents point of log signatures shift from upward-fining in the transgressive systems tract to upward-coarsening in the highstand systems tract (Wornardt *et al*., 1992).

Located between the maximum flooding surfaces are the sequence boundaries, characterized by low fauna abundance and diversity signatures (Wornardt *et al*., 1992), which are often overlain by systems tracts such as lowstand basin floor fan complex, slope fan complex, prograding complex, transgressive systems tract and highstand systems tract (Figures 2.1 and 2.2) (Vail and Wornardt, 1991). According to Sturrock (1998: 97), "a sequence boundary is a chronostratigraphically significant surface produced as a consequence of a fall in relative sea-level".

Sequences and systems tracts are recognized from log signatures by annotating time-significant bioevents on the well-log with juxtaposition of palaeobathymetric indices (Wornardt *et al*., 1992). Figure 2.3 shows the associated well-log signatures identified with depositional sequences and system tracts in different water depths in the Gulf of Mexico. Systems tract is is made of the lowstand systems tract (LST), transgressive systems tract (TST) and highstand systems tract (HST).

The LST is recognized by a significant drop in relative sea-level leading to an abrupt basin-ward shift in facies leading to the superimposition of shallower or non-marine deposits over deeper marine ones (Sturrock, 1998). The LST is typified in the proximal fossil record by an underlying hiatus, a sudden shallowing up of biofacies or the superposition of non-marine assemblages on marine. While in the deep basin, it is recognized by increase in the siliciclastic sediment supply rates as well as sediments containing reworked fossils with low abundance of autochthonous fossils (Armentrout *et al*., 1991; Sturrock, 1998).

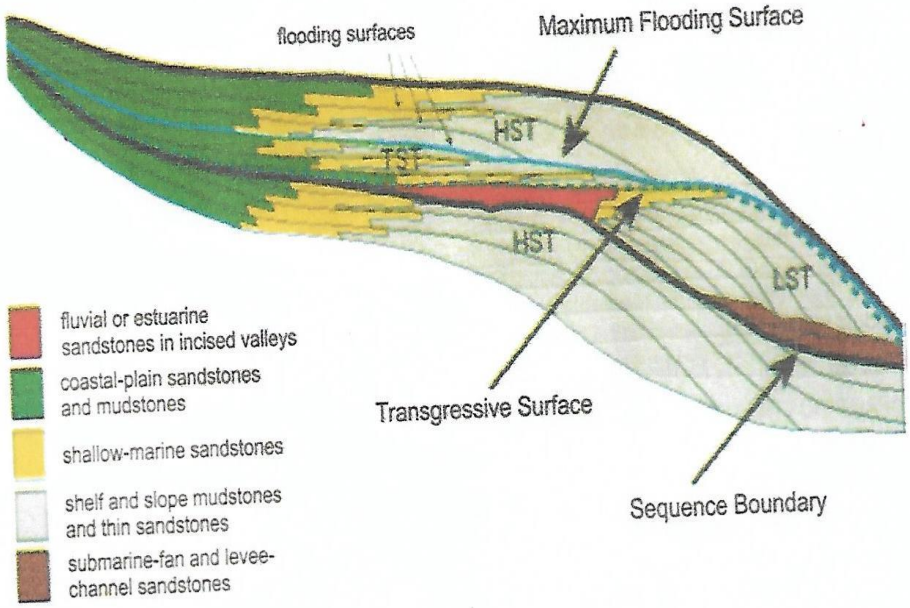


Figure 2.1: Classic Sequence Stratigraphic model showing key surfaces and systems tracts (Culled from Rull, 2002)

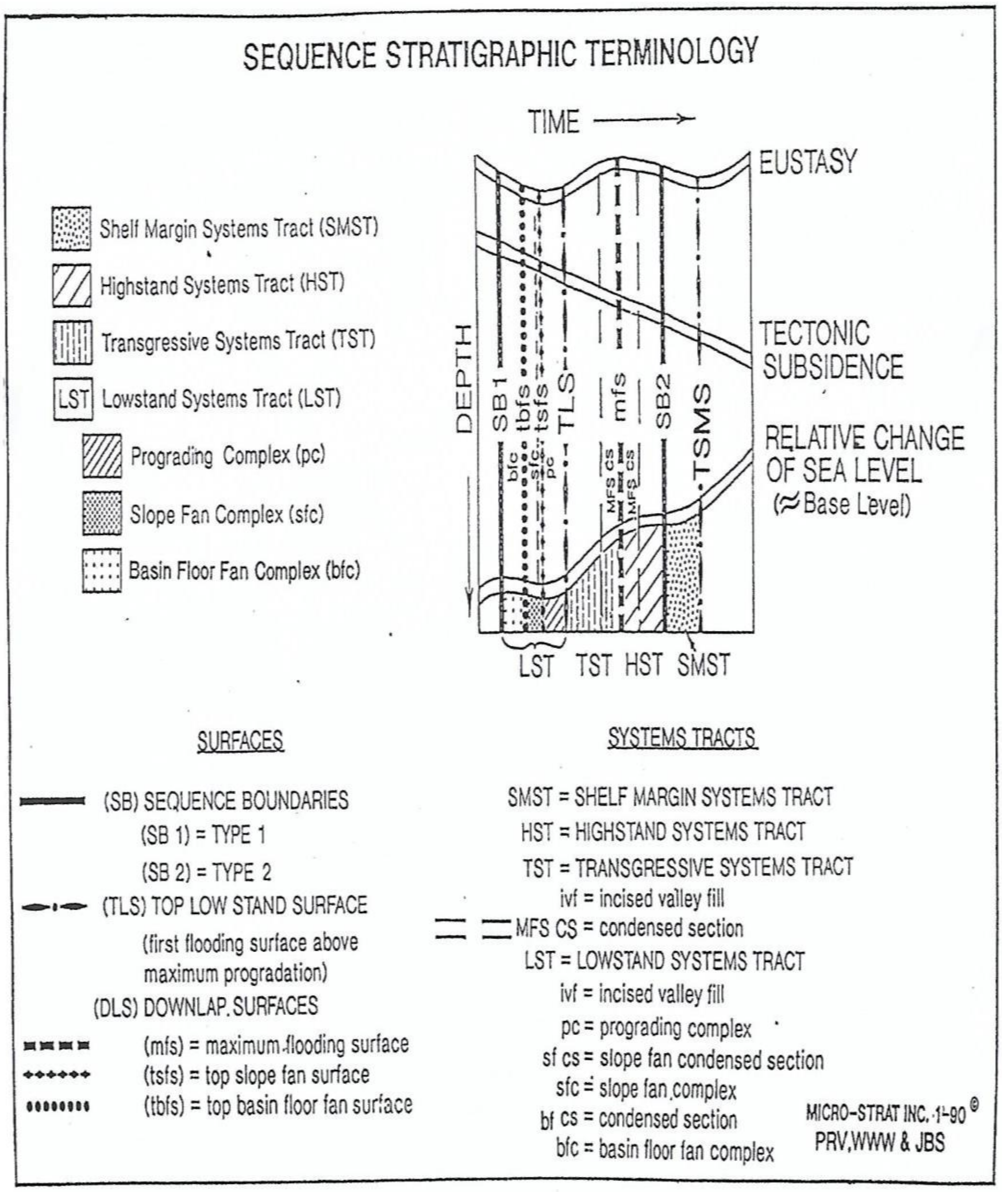


Figure 2.2: Sequence Stratigraphic terminology (After Wornardt *et al*.,1992)

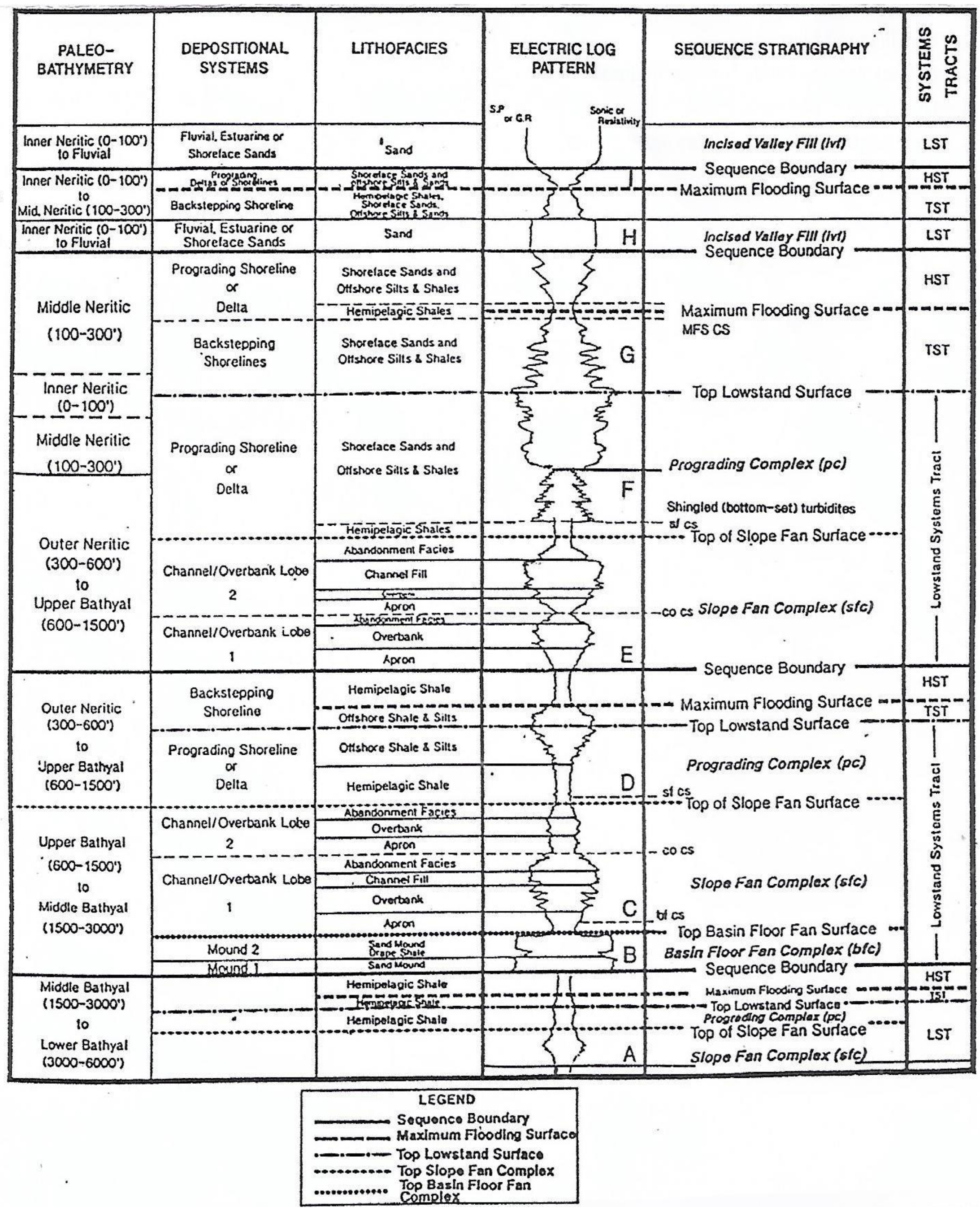


Figure 2.3: Typical Log Patterns Associated with Gulf of Mexico Depositional Sequences and System Tracts (Culled from Wornardt *et al.,* 1992).

The TST is the middle systems tract of a sequence and it is characterized by one or more retrogradational parasequence sets. Its base is the transgressive surface above the lowstand or shelf-margin systems tracts separating the two systems tracts (Van Wagoner *et al*., 1988; Sturrock, 1998). The transgressive surface is diachronous since it represents a retrogradational biofacies boundary between terrestrial and marine environments. Its presence may be inferred by the sudden superposition of marine assemblages over marginal or non-marine ones (Sturrock, 1998).

On top of the TST is a marine-flooding surface (downlap surface) onto which the toes of the prograding clinoforms with the overlying HST downlap. The marine-flooding surface marks the change from a retrogradational to an aggradational parasequence set and is the maximum flooding surface (MFS). The condensed section is mostly situated between the transgressive and distal highstand systems tracts (Van Wagoner *et al*., 1988). The maximum flooding surface seperates the transgressive and highstand systems tracts representing the maximum landward extent of marine.

A widespread condensed section may develop on the drowned shelf and in deep basin during the MFS due to sediment starvation. The condensed sections, on the gamma-ray logs, are usually made up of high sonic travel-time shales, associated with high levels of uranium in organic-rich low-density (Sturrock, 1998).

The maximum flooding surface (MFS) depicts the most inland distribution of diverse, open marine, cosmopolitan, abundant, plankton and deep water benthics (Sturrock, 1998). According to Sturrock (1998), the MFS condensed section represents a biostratigraphically significant event associated with abundant planktonic fossils with optimum potential for dating and correlating sediments across basins. It is a more correlatable event than the sequence boundary (SB) which is sometimes difficult to date or recognized with biostratigraphic data.

The uppermost systems tract in a typical sequence is the HST and is widespread on the shelf, usually characterized by one or more aggradational parasequence sets that are succeeded by one or more progradational parasequence sets with prograding clinoform geometries. The HST parasequences onlap onto the sequence boundary landwards and downlap onto the top of the transgressive or lowstand systems tract basinwards. It is bounded at the top by a sequence boundary and the bottom by the downlap surface (Van Wagoner *et al*.,1988).

2.2.4 The Niger Delta Geologic setting

The knowledge of the geology of the Niger Delta basin is *sine qua non* in a biostratigraphic study such as this since an understanding of taphonomic processes in drainage systems is essential for the recognition of microfloral assemblages in depositional environments (Chmura *et al*., 1999; Cambell, 1991; 1999). The basin's geology has been intensively and extensively researched and published over the last 50 years, mostly by staff of petroleum exploration companies working in the area (Asseez, 1976; Orife and Avbovbo, 1982; Knox and Omatsola, 1989; Reijers *et al*., 1996; Michele *et al*., 1999; Reijers, 2011).

The basin is an integral part of the southern Nigeria sedimentary basin (Figure 2.4) (Murat, 1972). Situated on the margin of the West African continent in the Atlantic Ocean, the basin is located at the junction of the continental separation in the Cretaceous (Whiteman, 1982; Michele *et al*., 1999; Obaje, 2009) between latitudes 3° and 6°N and longitudes 5°and 8°E. According to Merki (1970), the contemporary Niger Delta is flanked in the north-western rim by the subsurface extension of the West African Shield, the Benin Flank, and at the eastern fringe by the subsurface continuation of the Oban Massif, the Calabar Flank. On its northern fringe lies the Senonian Abakaliki Uplift and the Anambra Basin. To the south, the basin appears open ended into the Atlantic (Figure 2.5). Reijers *et al*. (1996), however posited that the basin of the delta extends beyond the geographical boundary of the modern delta into the continental margins of Cameroun and Equatorial Guinea as well as the Gulf of Guinea.

By virtue of its substantial hydrocarbon accumulation, the basin is ranked as one of the most prolific in the world, accounting for about five percent of the world's oil and gas reserves (Reijers *et al*., 1996, Michele *et al*., 1999). The Niger, Benue and Cross rivers tributaries culminating in the deposition of about 1,200,000 km^2 of continental deposits resulted in the formation of the delta area of 75,000 km^2 with a clastic fill of about 12,000 m depth (Reijers,1996).

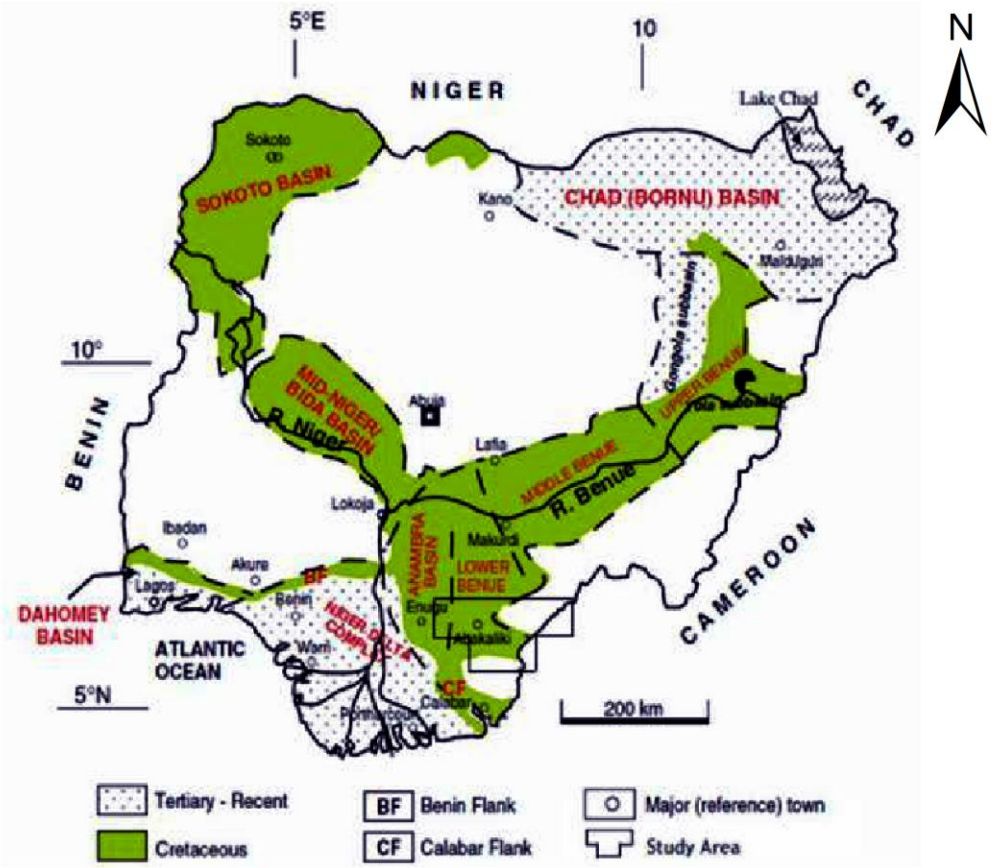


Figure 2.4: Map of Sedimentary Basins of Nigeria (After Obaje, 2009)

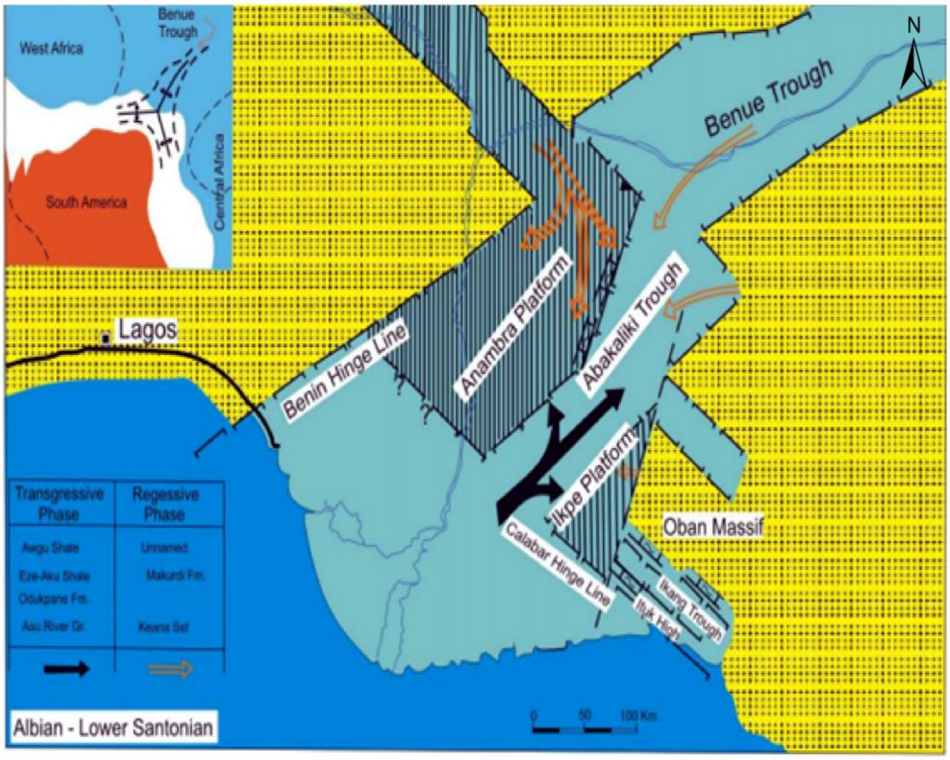


Figure 2.5: Niger Delta frame (After Merki, 1970)

The coastal sedimentary southern basin of Nigeria has experienced three major depositional cycles since it originated in the Early Cretaceous. The first of these cycles, according to Short and Stauble (1967), probably occurred between the middle Cretaceous and the Santonian. The second cycle involved the growth of a proto-Niger Delta during the Late Cretaceous leading to its submergence in a major sea transgression in the Palaeocene. The third phase, which is characterized by the transgression of the entire southern Nigeria, culminated in the formation of the recent Niger Delta from Eocene to the present. The present-day Niger Delta expereinced series of alternating transgressions and regressions reaching its maximum extent well into the Atlantic in the Plio/Pleistocene (Short and Stauble, 1967) (Figure 2.6).

According to Short and Stauble (1967), factors such as sediments transportation and deposition as well as the shape and growth of the delta influence the physiography of the recent delta. Its climate is determined by the movements of the intertropical convergence zone marking the boundary between the humid, rain laden south-westerly monsoon winds and the dry harmattan in the north. The Niger Delta vicinity enjoys a very uniform temperature of about 20°C at night to above 30°C in daytime. The precipitation of the delta region is highest around July when the southwest trade monsoon wind manifests its influence, recording 400 inches in a year in the east to 150-170 inches with the least precipitation of about 75 inches in the north of the delta (Short and Stauble, 1967).

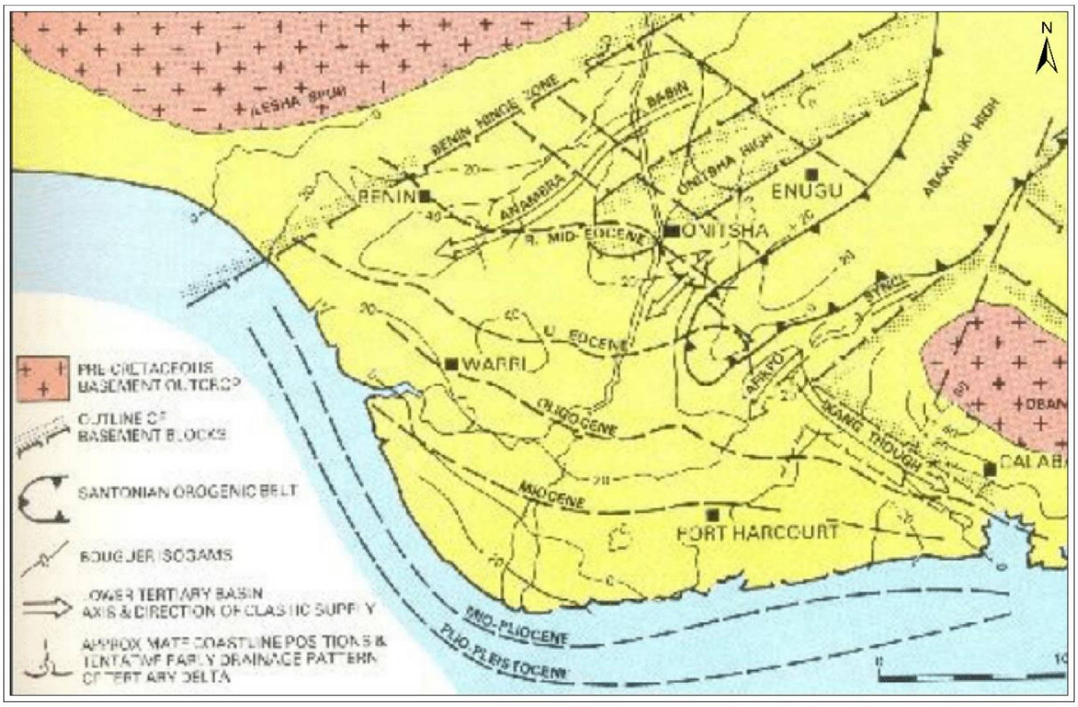


Figure 2.6: Growth Map of Niger Delta (After Short and Stauble, 1967)

The three main depositional environments typical of most deltaic environments, the continental, transitional and marine environments, are present in the recent Niger Delta (Short and Stauble, 1967). These have been categorized into the continental delta top facies, the paralic delta front facies, and the pro-delta facies belts (Reijers *et al*., 1996). The continental environment is made up of the alluvial environments, braided stream, and meander belt systems of the upper deltaic plain. The sediments of this environment are mainly sandy with feldspar grains common and sand grains commonly limonite-coated (Short and Stauble, 1967). Sedimentation in the lower flood plain of the delta-top environment is controlled by fluvial processes.

The brackish-water lower deltaic plain, that is, mangrove swamps, flood-plain basin, marsh and coastal area of beaches, barrier bars and lagoons constitute the transitional environment. Grains making up the sediments in this environment are finer than those in the continental environment. Strong currents sweeping the river mouth bars and delta front dominate the mangrove swamps to the coast. The marine environment is made up of the submarine part of the delta, the delta fringe with its fine sand, silt and clay and the associated marine faunas. The marine environment merges into the holomarine beyond the reach of deltaic influence (Short and Stauble, 1967). A combination of large waves generating strong longshore drift emanating from the southwest controls beach ridge and shore-face complexes on the delta coast (Reijers *et al*., 1996).

Short and Stauble (1967) proposed three subsurface stratigraphic units for the delta; viz.: Benin, Agbada and Akata Formations (Figure 2.7).

Benin Formation

The Benin Formation is found across the entire Niger Delta from the Benin-Onitsha axis uptil the present coastline. The formation is made of more than 90% sandy with few shale intercalations progressively increasing toward the base. The sand and sandstone are coarse grained, gravelly, poorly sorted, sub-angular to well-rounded and bear lignite streaks and wood fragments. The sand and sandstone are white or yellowish brown.

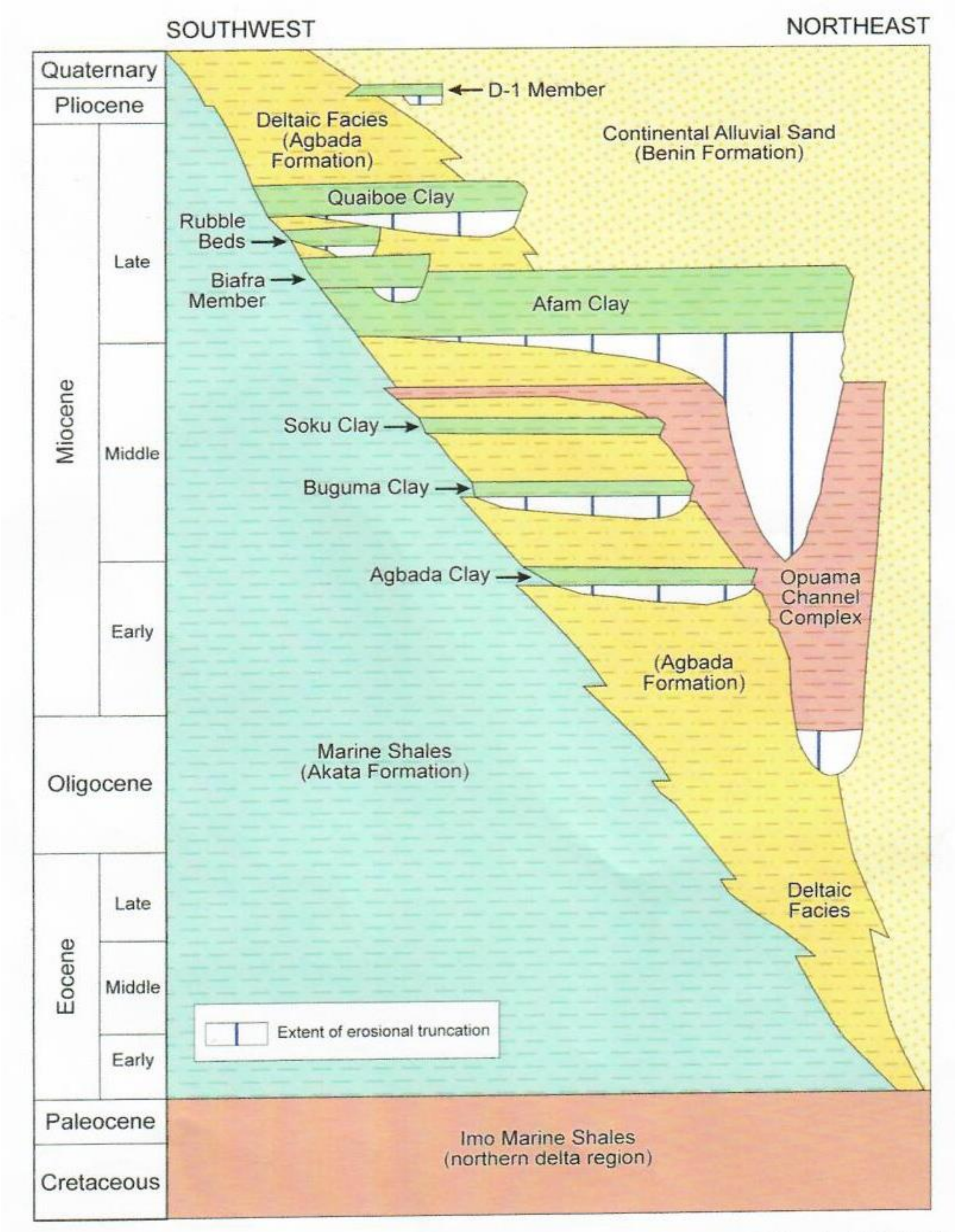


Figure 2.7: Niger Delta lithostratigraphic summary (Culled from Adeonipekun *et al*., 2016)

Hematites grains and feldspars are common features of this formation. The shales, containing some plant remains and dispersed lignite, is greyish brown, sandy to silty. The formation is a continental deposit of probable upper deltaic depositional environment with estimated from Oligocene to Recent. The formation thickness varies but often exceeds 6000 ft with very few hydrocarbon deposits (Short and Stauble, 1967).

Afam Clay Member, an ancient valley fill Miocene sediment, has been recognized as distinct member of the Benin Formation in the eastern flank of the delta basin by Short and Stauble (1967). The member is made of laminated, brownish grey to dark grey clay, intercalated with few sandstone bodies commonly silty and finely sand-bearing siltstone string and lenses.

Agbada Formation

Lying beneath the Benin Formation is the Agbada Formation, a sandstones and shales sequence. This formation, made up of a largely upper sandy unit with minor shale intercalations and a lower shale unit thicker than the overlying sandy unit, occurs in the subsurface of the entire delta area. Subsidence, changes in sediment supply and delta depositional axes causing local sea rises and falls have been adduced to the different sand, sandstone, and shale composition of this formation.

The formation is richer in microfauna at the shale beds basal portion than the above layer which becomes progressively sandy and silty upward where the fauna become sparse or absent. The Agbada Formation, over 10,000 ft thick, ranges from Eocene upsection to Pliocene/Pleistocene downsouth and Recent in the delta surface. Much of the petroleum exploited in the Niger Delta basin comes from this formation (Short and Stauble, 1967).

Akata Formation

This is the lowermost stratigraphic unit of the delta and constitutes a uniform shaly sequence made up of dark grey sandy, silty shale with plant contents on top. There is evidence of thin sandstone lenses towards the top especially at the interphase with the overlying Agbada Formation. The formation is a marine sequence laid in front of the advancing delta with planktonic foraminifera accounting for over 50% of the rich microfauna and the benthonic assemblage. The formation which is over 4000 ft thick and is believed to range from Palaeocene to Recent in age. (Short and Stauble, 1967).

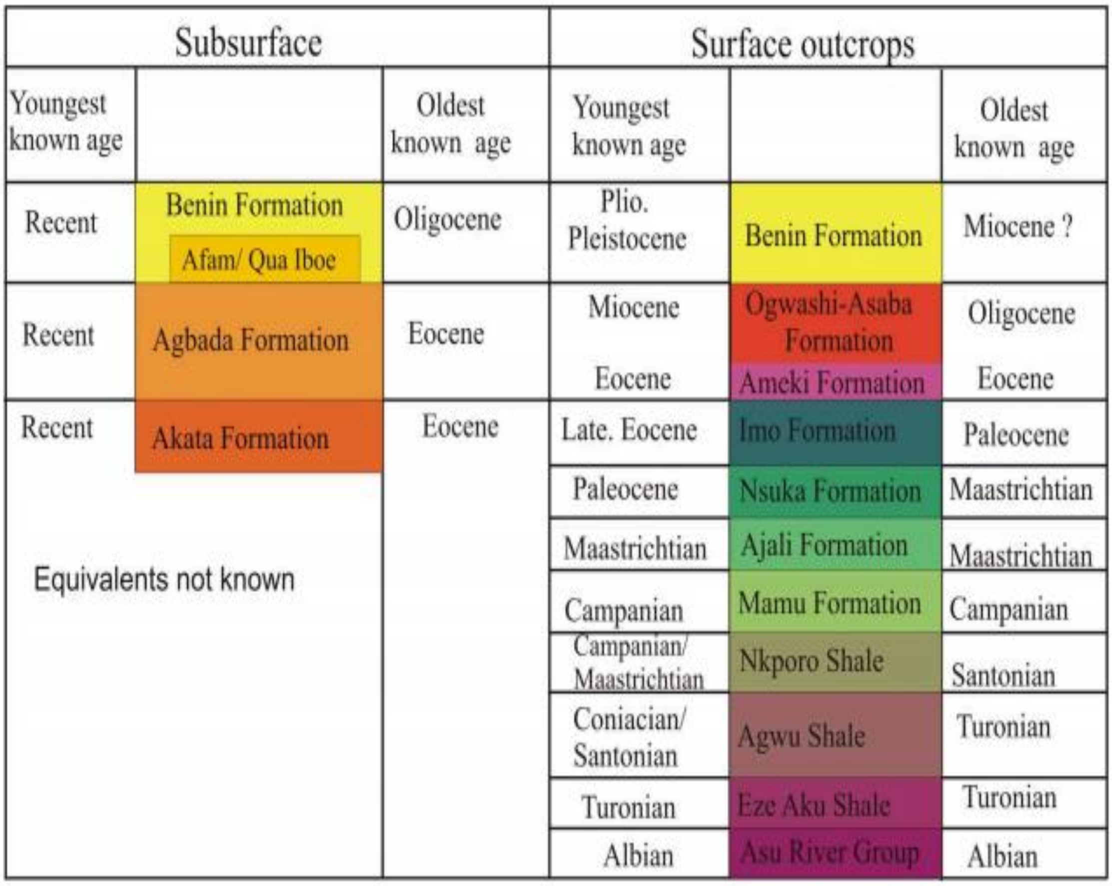
These three formations have been associated with the surface outcrop lithofacies of the Anambra basin as Imo Shale (Akata), Ameki (Agbada), Ogwashi-Asaba (Upper Agbada facies) and Benin (Benin) formations (Reijers *et al*., 1996) (Table 2.3). The Niger Delta sedimentary wedge reveals at least five distinct depobelts or depocenters (Figure 2.8). These are: Northern Depobelt, Greater Ughelli, Central Swamp, Coastal Swamp and Offshore, each depocenter is 30 – 60 km wide with the oldest lying way up in the inland and the youngest deposited offshore.

Each depobelt is bounded by fault at both the proximal and distal ends. Sediment supply and accommodation space due to basement subsidence and growth faults have been suggested for sedimentation in the depobelts. This, in combination with oscillating sea level, resulted in the repeated vertical stacking marine deposits succeeded by diverse shoreface sands and coastal plain deposits (Reijers *et al*., 1996). Knox and Omatsola (1989) refers to the sedimentation processes in the depobelts as ‘Escalator Regression Model’.

These depobelts are the progradations of the delta basin southwestward from Eocene to the present. The depobelts represent the most proactive parts of the delta at every developmental stage resulting in one of the largest regressive deltas in the world with sediment thickness above 10 km at the depocenter. The Northern Depobelt is the northernmost of the depobelts coinciding with the shoreline during the Early Eocene to Oligocene (Idiagbor *et al*., 2017).

The Niger Delta climate ranges from the hot equatorial forest within the southern lowlands through the humid tropical of the northern highlands to the cool montane type in the plateau area around Obudu (NDRMP, 2005). The climate is controlled by the varying position of the intertropical convergence zone marking the threshold between the, moisture-laden south westerly monsoon winds and the north east trade winds (Figure 2.9). The area of the Niger Delta enjoys generally high but constant temperatures round the year with the average monthly maximum and minimum temperatures ranging between 28°C and 33°C and from 21° C to 23°C respectively.

Table 2.3: Niger Delta Formations compared with Surface Outcrops (Adapted from Short and Stauble, 1967)



Subsurface			Surface outcrops		
Youngest known age		Oldest known age	Youngest known age		Oldest known age
Recent	Benin Formation Afam/ Qua Iboe	Oligocene	Plio. Pleistocene	Benin Formation	Miocene ?
Recent	Agbada Formation	Eocene	Miocene	Ogwashi-Asaba Formation	Oligocene
			Eocene	Ameki Formation	Eocene
Recent	Akata Formation	Eocene	Late. Eocene	Imo Formation	Paleocene
Equivalents not known			Paleocene	Nsuka Formation	Maastrichtian
			Maastrichtian	Ajali Formation	Maastrichtian
			Campanian	Mamu Formation	Campanian
			Campanian/ Maastrichtian	Nkporo Shale	Santonian
			Coniacian/ Santonian	Agwu Shale	Turonian
			Turonian	Eze Aku Shale	Turonian
			Albian	Asu River Group	Albian

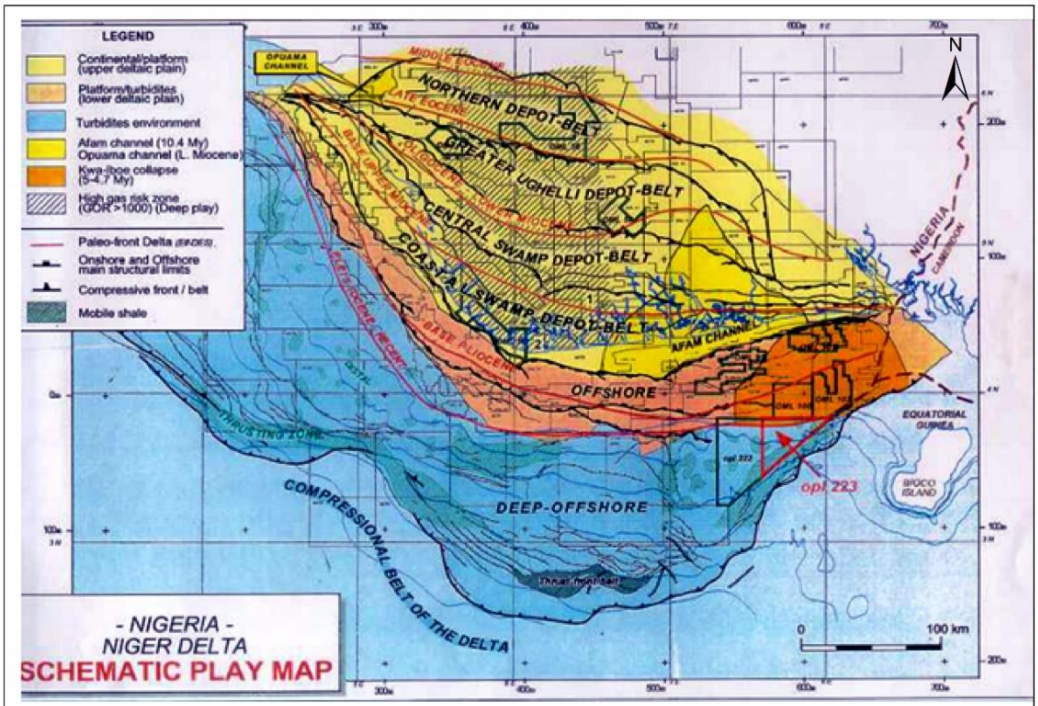


Figure 2.8: Niger Delta Depobelts (After Knox and Omatsola, 1989)

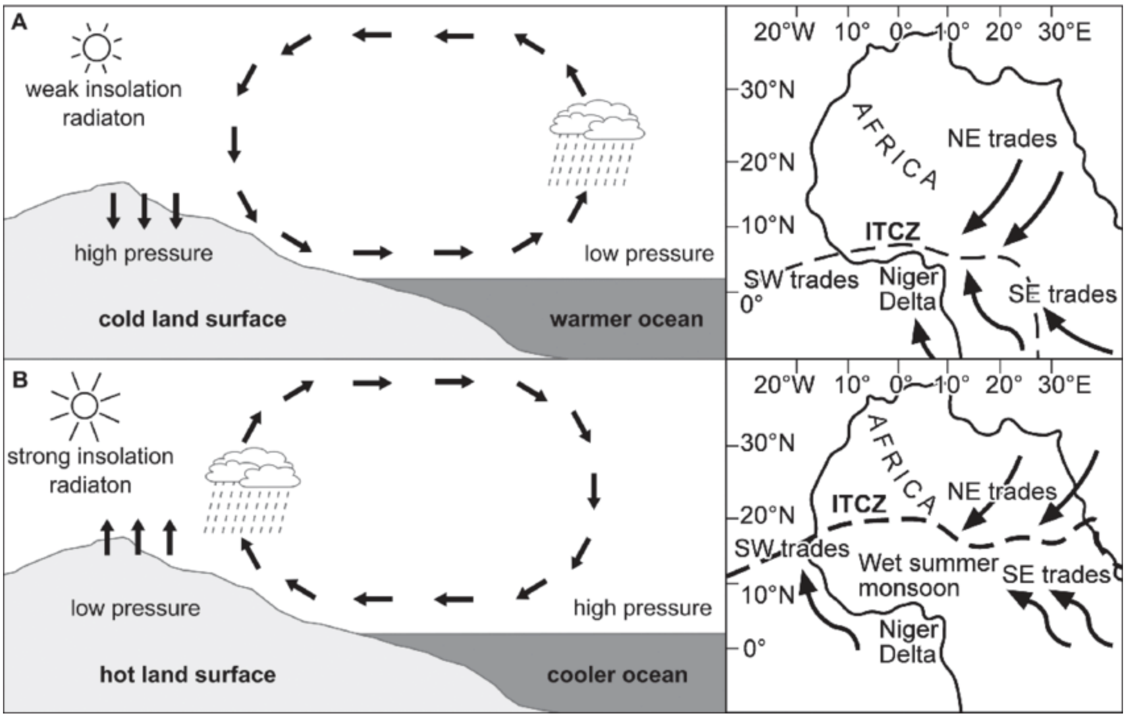


Figure 2.9: Seasonal positions of the Intertropical Convergence Zone (Culled from Adojoh *et al*., 2017)

The precipitation is highest at about July when the southwest trade monsoon wind reaches its southernmost extent. The mean annual rainfall ranges from 4000 mm in the coastal belts, decreasing inland to 3000 mm in the mid-delta to between 2000 mm and 1500 mm towards the northern parts of the delta (NDRMP, 2005). Rainfall is heavy in the coastal part of the delta due to its proximity to the equator (Wikipedia, 2011).

The southwest monsoon wind, the harbinger of cool humid ocean air, believed to be in operation since the Palaeocene (Burke, 1972) with its counterpart, the northeast trade wind which come with the dry continental harmattan winds, continues to influence the climate of the basin. The extent, duration, and relative positions of the zone of convergence of the two winds systems; the Intertropical Convergence Zone (ITCZ) with its highest northward extent in July and maximum southward reach in January every year wrought climate changes in the West Africa sub-region where the delta basin is situated (Figure 1.9) (Short and Stauble, 1967; Sowunmi, 1981a, 1986, 1991). Tropical climate, made up of a rainy season between April and October and a dry season from November to March, prevails on the Nigerian Coastal zone which includes the delta over an area of about 75,000 km² (Awosika and Folorunsho, 2008).

2.3 Empherical Review

2.3.1 Palynostratigraphic Studies in the Niger Delta

The earliest palynological publications on this shore were authored by expatriates working for the multinationals. These include: Clarke (1966), Van Hoeken-Klinkenberg (1966), Clarke and Frederiksen (1968), Germeraad *et al*. (1968), Knaap (1971), Boom (1977), Evamy *et al*. (1978) and Legoux (1978). Others were: Biffi and Grignani (1983), Poumot (1989), Salard-Chelboldaeff (1990) and Morley and Richards (1993). The pioneering and significant contributions of Nigerian authors such as Sowunmi (1973; 1981a & b), Ogbe (1982), Oboh and Salami (1989), Oboh (1992) and Oboh *et al*. (1992) during this period should not go unmentioned.

By the end of the first decade of this century, there had been a tremendous increase in the number of published papers on palynological studies of the Niger Delta. This proliferation is best explained by increased activities in Nigerian universities, in collaboration with the petroleum industry. The collaboration facilitated internship arrangements for many of the students in the laboratories of some petroleum and petroleum servicing companies around the country.

Notable among the more recent publications are: Adeonipekun and Ige (2007), Adojoh and Osterloff (2010), Durugbo *et al*. (2010a; b), Durugbo (2013), Adebayo *et al*. (2012, 2016), Adebayo (2013, 2014, 2015), Adebayo and Ojo (2014), Ajaegwu *et al*. (2012), Bankole *et al*. (2014, 2016), Ola and Bamisile (2014a), Oloto (2014), Oloto *et al*. (2012; 2014), Soronnadi-Ononiwu *et al*. (2014), Adelabu and Opaleye (2015), Adeonipekun *et al*. (2016), Adojoh *et al*. (2015), Aturamu *et al.* (2015), Osokpor *et al*. (2015), Essien *et al*. (2016), Inyang *et al*. (2016), Oyelami (2016), Olayiwola and Bamford (2016), Asadu and Ofuyah (2017), Durugbo and Olayiwola (2017), Lucas and Fregene (2017) and Afolayan *et al*. (2018), Adeonipekun and Sowunmi (2019). Others include: Ikegwuonu *et al*. (2020), Igbinigie and Ogbamikhumi (2021), Efemena *at al*. (2021), Ononeme *et al*. (2021) and Chukwuma-Orji (2022).

The first three published palynological reports on the Niger Delta were largely descriptions of fossil palynomorphs of the Palaeogene and their inferred modern affinities (Van Hoeken-Klinkenberg, 1966; Clarke, 1966; Clarke and Frederiksen, 1968). Clarke (1966) and Clarke and Frederiksen (1968) described for the first time, several fossil pollen such as *Peregrinipollis nigericus* (*Brachystegia* sp.), *Marginipollis concinnus* (cf. *Barringtonia racemosa*) and *Areolipollis* (*Justicia*) from the Late Tertiary of Nigeria, which were identical with some of those in the modern families of Acanthaceae and Lecythidaceae.

In continuation of his earlier study on the Nigerian Maastrichtian palynomorphs from two borehole samples from both the Lower and Upper Coal Measures in Enugu and Inyi respectively of eastern Nigeria (Van Hoeken-Klinkenberg, 1964), Van Hoeken-Klinkenberg (1966) studied three borehole samples from the Niger Delta, Nigeria: Egoli-1, Gbekebo-1 and Owan-1 and compared the Nigerian Maastrichtian, Paleocene and Eocene palynoflora with those of South American of the same age.

Van Hoeken-Klinkenberg (1966) revealed that all the Maastrichtian palynomorphs described earlier by Van Hoeken-Klinkenberg (1964) were also present along with many new ones of the Maastrichtian, Paleocene, and Eocene. For example, *Proxapertites* *operculatus* (Van der Hammen,1956), was reported to have its first appearance just above the Maastrichtian-Paleocene boundary as was the case in South America, while *Mauritiidites crassibaculatus* (van Hoeken-Klinkenberg,1964) has its first occurrence just below the Maastrichtian-Paleocene boundary. Van Hoeken-Klinkenberg (1966) revealed an Eocene floral assemblage with diverse pollen grains represented by numerous small-sized triporate and brevicolpate grains. *Verrucatosporites usmensis* (Van der Hammen, 1956) was recorded for the first time in the Eocene of the Niger Delta as was reported in South America.

Though these initial publications were largely descriptive they are still very relevant in the Niger Delta biostratigraphic studies because the species described and illustrated are those of several index species, thus aiding their recognition when encountered. In what remains the most comprehensive and relevant study of pollen and spores of the Tertiary of some parts of tropical regions of the world including the Niger Delta basin, Germeraad *et al*. (1968) documented almost 20 years of palynological investigations. The study, Germeraad *et al*. (1968), was aimed at enhancing a better interpretation of Tertiary sediment stratigraphy where other means of correlation have failed, by erecting a time-stratigraphic zonation which can be adapted to the level of the geological problem being investigated. The study was based on a very large number of samples mostly collected at surface level as well as cores and sidewall of drilled wells.

Germeraad *et al*. (1968) highlighted various factors identified as affecting the pollen spectra of sediments analysed. These factors were differentiated into primary and secondary factors. Primary factors determine the parent plant of the pollen and spores, and include changes due to biological evolution and migration, or increases and decreases in response to climate change or topography. The secondary factors influence dispersal of these palynomorphs before fossilization. Germeraad *et al*. (1968) opined that evolutionary change will provide the most reliable basis for the erection of chronostratigaphic zonation for a region. The examples of Poaceae and Asteraceae whose first appearance datums (FAD) and consequent development have worldwide time-stratigraphic importance were cited. Sudden appearances in stratigraphical records without traces of phylogeny were identified to be common as a result of developments linked with climatological factor resulting in changes in the environment causing abundance and extension in the geographical range of the involved parent plants.

Botanical identification of extinct pollen and spores and link to their corresponding extant forms with known climatological tolerances have been identified as a direct way of recognizing the impact of climate changes in the stratigraphic distribution trends of many species. This is based on the principle of actualism, formerly known as principle of uniformitarianism, which stipulates that ‘present-day processes provide a sufficient explanation for past geomorphological phenomenon’ (Encyclopedia.com, 2019). Though, this principle which is fundamental to the science of geology and is believed to be sufficient in accounting for all geologic phenomena, may be affected by possible changes in earth’s processes over geologic time such as temperature variations and erosional surfaces (Britannica.com, 2015).

Though most extanct plant families appear to be in existence about 45 Ma before present, (Raven, 1983), many pollen and spore taxa pre-Oligocene have poor or unknown botanical affinities (Frederiksen, 1985), thus limiting possible climatological inference from such extinct fossils. Germeraad *et al*. (1968) also opined that change in climate may also result in immigration of some plant species leading to the extension of their geographical range somewhere else, though the development of new pathways of migration, which has been linked to mountain building, was also identified as another factor.

Local facies control is also recognized as another significant factor influencing the distribution of floral species by Germeraad *et al*. (1968). The complicated stratigraphic distribution patterns of fossil forms encountered in sediments do not suggest a homogenous pollen rain fall in the sedimentary environments. Most samples investigated by Germeraad *et al*. (1968) were deltaic-marine silts, clays and shales, sediments which resulted from transportation, mixing, size sorting and possible re-deposition of the pollen and spores. Muller (1959) had suggested that water transport was of greater importance than wind transport in a humid environment.

After dispersal, every plant pollen or spore undergoes an initial stage of air transport which may be a short period particularly with autocthonous plant within restricted location and with conditions that aid preservation. However, pollen and spores from montane vegetation in the tropics and wind-pollinated such as *Alnus* and *Pinus* are subjected to distance transportation in large quantities by air currents. All these finally settle on the earth surface and are either transported down by water flow or become oxidized and destroyed. The part of the pollen rain found in rivers or ocean are either deposited in alluvial and coastal sediments of the delta or offloaded into the sea with sediments.

Another factor highlighted by Germeraad *et al*. (1968) is reworking of older sediments into younger ones. This is best recognized/identified by adequate knowledge of the floral composition in the study area making it possible to distinguish foreign palynomorphs from local ones. Palynomorphs colour is another way to decipher reworked fossils from *in situ* species; the former ones appear abraded in texture and darker in colour. According to Germeraad *et al*. (1968), the combined factors of climate and topography as well as environmental conditions, the tolerance levels of the different species and their dispersal dynamisms, result in the complex stratigraphical distribution patterns which may hamper chronostratigraphical correlation lines.

Germeraad *et al*. (1968) classified the recognized zones in their study as biostratigraphical units and not time-stratigraphic units since some of the zonal boundaries cannot be extended over long distances. However, the zones have identical successions regionally and are grouped into Pantropical, Transatlantic and Intracontinental zones based on their lateral extent. The proposed zones were correlated with mostly planktonic foraminiferal ages, though zones in areas without foraminiferal ages were not tied to fauna ages. Thus, the recognized zones may not be diachronous in their areas of validity, they are not isochronous over long distances.

Nevertheless, the recognized zones (Germeraad *et al*., 1968) are rather too extensive and wide for meaningful chronostratigraphic delineation. For example, in the Pantropical zones, the upper *Proxapertites operculatus* Zone lies within the lower Eocene, *Monoporites annulatus* Zone virtually corresponds to the middle Eocene while the *Verrucatosporites usmensis* Zone corresponds to the upper Eocene. The basal *Magnastriatites howardi* Zone is assigned the entire Oligocene with the upper part of the zone designated lower Miocene.

Boom (1977), an unpublished version of the often cited Evamy *et al*. (1978), is undoubtedly the most comprehensive and, by far, the most referenced literature on the palynological zonation of the Niger Delta. Based on undisclosed computer-calculated statistics for processing palynological data of every species encountered in core and sidewall samples from about 315 wells spread across the delta, a review of definitions and characteristics of the microfloral zones and subzones in the Nigerian Tertiary was carried out. These zones and subzones were coded for the purpose of the internal use of SPDC staff. While some new markers were introduced, the significance of most of the zonal and subzonal microfloral markers was ascertained by the review. A total number of eight microfloral zones (P200 – P900), spanning Paleocene to Pliocene and/or younger, were reviewed.

Legoux (1978) also studied and descriped the morphology of many pollen groups aimed at refining the palynostratigraphic zonation of the Neogene, and by extension, the Paleogene (Eocene-Oligocene) of the Niger Delta. Two new genera, *Retibrevitricolporites* and *Belskipollis* were identified with 14 new species assigned to the genera *Praedapollis*, *Striamonocolpites*, *Arecipites*, *Spirosyncolpites* and *Racemonocolpites*. From the stratigraphic distribution of pollen species, two superzones, TII and TIII and sixteen (16) zones were defined by the author from the middle Eocene to the Pleistocene.

These earlier microfloral zonation schemes in Nigeria are still beset with the serious challenge of wide zones/subzones defining very extensive time span. This, no doubt, impaired on the palynostratigraphic resolution of the region. For example, the Danian and Selandrian Stages of the Paleocene Epoch have been assigned to P200 Zone spanning a duration of 8.5 Ma. The same applies to most subzones refined by Boom (1977), particularly in the Paleogene. The zonation scheme of Legoux (1978) also has the problem of wide and extensive zonal boundaries.

While attempts at reviewing and further subdividing most of the subzones in the Neogene have been made by subsequent workers such as Morley and Richards (1993) and Adeonipekun *et al*. (2016), no such attempt has been made for the Paleogene. This study is therefore aimed at finer subdivisions of existing subzones within the Paleogene of the delta basin.

Ogbe (1982) studied several wells using micropaleontological and palynological data of sedimentary sequence of the Niger Delta basin. The encountered microfossil assemblages revealed three main transgressions: a prodelta transgression of Late Cretaceous, the main transgression (Early Miocene) and the ‘worldwide’ Pleistocene transgression. Age determination based on both palynological and palaeontological parameters (with emphasis on planktonic foraminifera) suggests a late Cretaceous (Maastrichtian) to Recent age for the sequence studied.

Oligocene sediments from southern Nigeria which, thitherto were either barren or eroded, probably due to regression during the period, were first recognized in Nigeria in the delta by Ogbe (1982). Paleoecological deductions largely derived from the abundance and specific composition of planktic and agglutinated benthics suggest the youngest sections in all the wells to be barren of marine faunas. These sections have been assigned to the non-marine Benin Formation cosisting of massive, very porous sands, gravels (fluviatile) and thin shale of Eocene to Recent age. The marine section is made up of marginal marine: inner neritic (0-100 metres) ascribed to either Agbada or Akata Formations; middle neritic (around 100 metres) and rare outer neritic deposits (100-200 metres) of Akata and Imo Formations.

From palynological analyses carried out on 15 subsurface Tertiary boreholes, an abundant and diverse assemblage of Oligocene peridinoid dinoflagellate cysts was recovered by Biffi and Grignani (1983). Seven new species of *Lejeuncysta*, two new species of *Selenophemphix* were proposed and described. *Lejeuncysta fallax* was emended while four new species, tentatively assigned to *Lejeuncysta* were described. Though, the contribution of Biffi and Grignani (1983) borders on descriptive palynology, it no doubt added to an improved understanding of dinoflagellates in the Oligocene of the Niger delta basin. However, non-identification of four species of *Lejeuncysta* is a slight shortfall of the study.

Salard-Chelboldaeff (1990) reviewed and synthesized palynological literature published since 1963 using Cretaceous-Tertiary sediments from West Africa (including the Nigerian sedimentary basins) with a view to describing the paleofloral successions based on the occurrence, abundance and extinction of pollen and spore corresponding to standard chronostratigraphic zonation. Salard-Chelboldaeff (1990) was cognizant of the fact that pollen and spores are isolated plants elements with no evidence of the botanical identity of the parent plants. This limits palynology to the relative age determination resulting from assemblage characteristic of the vegetation of the period in consideration.

However, Salard-Chelboldaeff (1990) asserted that the results of her palynological investigation clarified some stratigraphic and paleoenvironmetal problems thitherto unresolved through foraminiferal studies. These assertions include, among others: the extinction of Chlamydosperms and records of palm-trees in the families Liliaceae and Proteaceae in the Maastrichtian and the advancement of palm-trees. Also included are: reduction of Gymnosperms population in Palaeocene and the increase diversification of dicotyledon species from Eocene to Recent, displaying the luxuriant vegetation of these periods. The palynological assemblages recovered from middle Eocene to early Miocene in the study agree with reported diversification and luxuriant vegetation. From the established palynostratigraphic scheme applied to the Cretaceous and Tertiary basins, Salard-Chelboldaeff (1990) was able to reconstruct the intertropical African vegetational history from Neocomian to Pliocene with index pollen and spore marker species.

From a suite of well preserved and diverse pollen and spore taxa, Adebayo *et al*. (2012) assigned a late Oligocene – middle Miocene age to the mainly shaly section of Bog-1 Well from the Niger Delta. The palynofloral assemblage suggested deposition in marginal marine environment as indicated by very rare occurrence of dinoflagellate cysts and reasonable proportions of cuticular material.

Biostratigraphic and lithologic studies of core samples from three offshore wells in the in southwestern Niger Delta were carried out by Oloto and Promise (2014). The stratigraphic occurrences of index planktic and benthic foraminifera were used to establish early-middle Miocene age for three of the studied wells, Bongo ST-1, Ngolo-1 and Opukushi-25 and early Miocene for Bongo-4 well. Occurences of floral species such as *Magnastriatites howardi*, *Verrutricolporites rotundiporus*, *Praedapollis africanus*, *Crassoretitriletes vanraadshooveni*, *Racemonocolpites hians*, *Echiperiporites estelae*, *Pachydermites diederixi*, *Grimsdalea magnacavata* and *Echitricolporites spinosus* corroborated the assigned ages. From records of depth sensitive benthics and foraminiferal test linings, and floral assemblage including *Pediastrum* sp., fungal spores as well as accessory minerals, a marginal marine to shallow marine (littoral-middle neritic) depositional environment was established.

Osokpor *et al*. (2015) characterized the lithofacies, and age-dated the studied sediments from a depth interval between 318-2073 m of well PML-1 in the northern depo-belt of the Niger Delta, based on recovered palynofloral assemblages. The sediments were zoned into correlated age units that fit into formational units on the basis of first and last appearances, occurrences and co-occurrences and/or absence of pollen and spore. Based on these parameters, the well section analysed was delineated into two palyzones: *Ephedra clavicristata* and *Auriculopollenites echinatus* Range Zones in the Oligocene and three palyzones: *Verrutricolporites laevigatus*/V*errutricolporites scabratus* Range Zone, and *Verrutricolporites rotundiporus* and *Marcocolporites* sp. Abundance Zones in Early-Late Miocene. The gross sedimentological analysis of the well lithology showed a cyclic association of twelve lithofacies groups typifying the Ameki Formation in the lower section, overlain by Agbada and Benin Formations. However, the use of *Ephedra clavicristata* and *Auriculopollenites echinatus* for the definition of Oligocene palyzones by Osokpor *et al*. (2015) is objectionable as the two genera are more associated with older ages than suggested. Salard-Chelboldaeff (1990) assigned *Ephedripites montanaensis* and *E. elsikii* to Turonian and *A. echinatus* to an age not younger than the Eocene. This is suspected to be a case of wrong identification of the marker species or misappropriation of nomenclature.

Essien *et al*. (2016) attempted an elucidation of the stratigraphy at the late Oligocene (Chattian) to early Miocene (Aquitanian/Burdigalian) transition using assemblages and index marker events reflecting their paleoecologic changes based on paleoclimatic fluctuation across the transitional period. The study was based on palynological information derived from ten onshore and offshore wells from the Niger Delta of Nigeria. Essien *et al*. (2016) observed that pollen records offered higher stratigraphic resolution relative to dinoflagellate cyst records in the Upper Oligocene strata. Essien *et al*. (2016) defined the Oligocene/Miocene boundary using the top occurrence of *Cicatricosisporites dorogensis* and the base occurrence of *Verrutricolporites laevigatus* in the well sections analysed.

Inyang *et al*. (2016) in their palynological investigation of a well designated T-Well, southwestern Niger Delta, recorded moderately rich palynofloral assemblages made up of stratigraphic markers such as *Crassoretitriletes vanraadshooveni*, *Verrutricolporites* *rotundiporus*, *Psilatricolporites crassus*, *Retitricolporites irregularis*, *Monoporites annulatus*, *Zonocostites annulatus*, *Verrucatosporites* sp., *Pachydermites diederixi*, *Magnastriatites howardi* and *Striatricolpites catatumbus*. Based on this recovery, the penetrated sequence of the well was delineated into two Pantropical Zones of *Magnastriatites howardi* and *Crassoretitriletes vanraashooveni*, dated early to middle Miocene age. A humid, warm and very wet tropical coastal climate was inferred from the dominant mangrove swamp, rainforest and freshwater palynomorphs recorded. Also, continental influence over the coastal area which fluctuated from fluvio-deltaic to shallow marine environment was indicated by the preponderance of land-derived palynomorphs above marine indicators.

Adegbie and Ochigbo (2017) conducted palynological and micropaleontological studies on 62 samples from Ochigbo-1 Well, offshore Niger Delta. From the rich, moderately good, diverse and well preserved palynomorphs assemblages, four (4) palynological zones, namely: (i) *Crassoretitriletes vanraadshooveni*/P700 Zone (Middle Miocene); (ii) *Magnastriatites howardi*/P600 Zone (Early Miocene – Late Oligocene); (iii) *Retibrevitricolporites obodoensis*/*protrudens* /P500 Zone (Early – Late Oligocene; and (iv) *Racemonocolpites hians*/P400 Zone were defined.

The foraminiferal assemblages suggested that the well ranged from late Campanian- late Miocene. Wet climate environmental conditions ranging between brackish and deep-marine environments alternating in transgressive and regressive settings were inferred from the foraminiferal assemblages.

Asadu and Ofuyah (2017) carried out palynological study on 110 samples from a well offshore Niger Delta, with the aim of determining the age of the well sequence. Lithostratigraphic studies on the samples revealed intercalations of fossiliferous grey sandy shale with medium-coarse grained, sub-rounded to rounded sandstones characteristic of the paralic Agbada Formation. Nine miospore biozones were erected from the first and last downhole occurrences of diagnostic markers from well preserved and diverse palynological assemblages. A comparison of the zones with standard palynological zones in the Niger Delta region suggests the Oligocene (Chattian)/Lower Miocene age for the well segment.

A critical review of Asadu and Ofuyah's (2017) contribution to palynological research studies in the Niger Delta reveals some wrong inferences from the results. The most striking is the age assignment of Oligocene to *Doualaidites laevigatus*. Asadu and Ofuyah (2017:18) explicitly stated that "this pollen has not been recorded in sediments older than Oligocene". This is completely out of place as *D.* l*aevigatus*, in the Niger Delta, has its extinction point at the end of the Eocene as confirmed by most of the literature quoted by authors such as Salard-Chelbodaeff (1990) and Jan du Chene *et al*. (1978) as well as this author's quarter of a century residual knowledge of palynology of the Niger Delta. The presence of *Doualidites laevigatus*, as reported by Asadu and Ofuyah (2017), should rather suggest at least late Eocene age rather than Oligocene or a possible misidentification of this marker species. This suggestion of possible misidentification is supported by the fact that the photomicrograph of the supposed *D. laevigatus* in Figure 17, Plate 1 is not clear enough.

Furthermore, the assertion of Asadu and Ofuyah (2017) that "the occurrence of *Zonocostites ramonae* at the base of the well indicates an age not older than Oligocene" and that "there has not been any record of this marker pollen in Nigeria in pre-Oligocene time" is arguable. As much as it is generally believed that *Z. ramonae* has its evolutionary entry point in the Oligocene in the west coast of Africa, other evidence has emerged to point to a possible older date for this event. Kogbe and Sowunmi (1975) reported *Z. ramonae* pollen from the Eocene in the Gwandu Formation, north-western Nigeria. In the comparison of their biozones with other zonation schemes the results of Asadu and Ofuyah (2017) are at variance with those of several authors, particularly that of Evamy *et al*. (1978). In Figure 5 of Asadu and Ofuyah (2017), the depicted P620, P630-P670 and P780 subzones should all lie within the early – middle Miocene contrary to the Oligocene/Lower Miocene age assigned.

Lucas and Fregene (2017) used 190 ditch cutting samples from depths 20-1820ft (6.09-3603.7m) from Greater Ughelli Depobelt, Niger Delta basin, to erect palynological zones. Records of diagnostic palynomorphs such as *Praedapollis africanus*, *Peregrinipollis africanus* and *Retibrevitricolporites obodoensis* revealed an Oligocene to early Miocene age with P-zones P560, P580-P620 was established. The P580 and P620 subzones are combined due to the non-recognition of the boundary markers, Top/FDO of *C. dorogensis* and/or *Gemmatriporites* sp.

Ikegwuonu *et al*. (2020) carried out palynostratigraphic study on 27 outcrop samples on Paleogene sequences from Bende-Umuahia sector of the Niger Delta. The study aimed at establishing the palynofloral assemblage zones and the sediment age. The lithostratigraphic study revealed sandstone, carbonaceous shale, mudstone, limestone and lignite lithofacies assigned to the Imo, Ameki and Ogwuashi Formations.

The palynostratigraphic analysis yielded 65 pollen and spores and 51 dinoflagellate cysts. On the basis of the first and the last occurrences of two or more species, six informal palynomorph assemblage zones, Zones A-F were established. These are: Zone A – *Scabratriporites simpliformis-Bombacidites annae* Zone; (middle Paleocene), Zone B – *Foveotricolpolrites crassiexinus-Mauritidiites crassiexinus* (late Paleocene); Zone C – *Striatopollis catatumbus-Momipites africanus* Zone (early Eocene); Zone D – *Margocolporites umuahiaensis-Gemmastephanocolporites brevicolpites* Zone (middle Eocene); Zone E – *Cicatricosisporites dorogensis-Perfotricolpites nigericus* Zone (late Eocene) and Zone F – *Verrucatosporites usmensis-Magnastriatites howardii* Zone (Oligocene-early Miocene). The erected zones wee correlated to the other zonations in the subsurface Niger Delta basin.

Ikegwuonu *et al*. (2020) suggested integration of palynological study with foraminiferal and nannofossil biostratigraphy towards strengthening the biozonation of the study area. They also opined that additional information of the outcrop strata to results obtained from the subsurface Niger Delta will ensure basin-wide regional correlations.

A palynological study carried out on core samples of paralic sand and shale sequence of Agbada Formation of Vidal-1 well, central Niger Delta, Nigeria between interval 6963 and 9860 ft by Efemena *et al*. (2021). The study was aimed at age determination and reconstruction of depositional environment. The stratigraphic distribution of diagnostic markers facilitated four palynological zones. These are: the *Crassoretitriletes vanraadshooveni*/P700 Zone, the *Magnastriatites howardii*/P600 Zone and P500 Zone and the *Verrucatosporites usmensis*/P400 Zone of both Gemmeraad *et al*. (1968). The Zones were further sub-divided into P720, P680-P650, P540 and P470 subzones of Evamy *et al*. (1978). The delineated zones range between late Eocene and middle Miocene. The floral assemblage suggests deposition fluctuating between marine and nearshore environments.

Using ditch cutting samples, Igbinigie and Ogbamikhumi (2021) carried out sedimentological and palynological analyses between depths 640-3500 ft of Deb-1 well. The well lithofacies is made up of successions of shales, shaly sand, sandy shale and sand. The palynological assemblage and stratigraphic distribution of index markers include: *Racemonocolpites hians*, *Peregrinipollis nigericus*, *Ctenolophonidites costatus*, *Verrucatosporites usmensis*, *Cinctiperiporites mulleri*, *Spinizonocolpites microbaculatus*, *S. echinatus* and *S. baculatus*. The assemblage revealed delineation of the P570, P480 and P470 palynological Zones of Evamy *et al*. (1978). From the suites of the recovered palynomorphs, a predominantly coastal deltaic depositional environment with evidence of fresh within a wet climate water inflow was inferred.

The results of the palynological analysis of fifty ditch cutting samples obtained in F-Field of the Greater Ughelli depobelt of the Niger Delta were reported by Ononeme *et al*. (2021). These were used in the reconstruction of the depositional environment of the sediments penetrated by the well sequence. Two distinct paleoenvironments; viz, Continental-Transitional and Paralic (Inner Neritic) Environments were inferred. The Continental-Transitional Environment was characterized by abundance of pollen and spores such as *Zonocostites ramonae*, *Monoporites annulatus* and *Verrucatosporites usmensis*. The paralic (Inner Neritic) Environment was suggested based on the recovery of dinocysts such as *Spiniferites* sp., *Sumatradinium hispidicum* and *Lingulodinium machaerophorum*.

Although, Ononeme *et al*. (2021) alluded to the sediments analysed as Tertiary in age (a terminology which use is obsolete), the study failed to identify the index marker species for the age determination. This is more so when a range chart of the recovered palynomorphs is shown in Table 1 of the report. However, the records of the top occurrence of *Cicatricosisporites dorogensis*, *Gemmatriporites* sp., *Praedapollis africanus* as well as rich occurrence of *Racemonocolpites hians* and *Striamonocolpites rectostriatus* suggest Oligocene-early Miocene for the well section studied.

Sixty-nine ditch cutting samples between interval 1373 and 1812 m from Awaizomne-1 well, Northern Depo-belt, eastern Niger Delta were subjected to lithologic and palynological studies by Chukwuma-Orji (2022). Four interval range zones were erected using the first and last occurrences of diagnostic species from the assemblage of rich palynomorphs (pollen, spores and dinocysts) recorded. These are: *Psilatriporites* sp.-*Racemonocolpites hians* Zone (early Oligocene); *Praedapollis africanus-Doualaidites laeviagtus* Zone (late Eocene); *Doualaidites laevigatus-Praedapollis flexibilis* Zone (middle Eocene) and *Verrucatosporites usmensis-Retitricolpites ituensis* Zone (early Eocene).

The lower Agbada Formation was suggested from the lithologic description of the well section. Brackish water setting and inner neritic – upper bathyal environments were inferred from recovered dinocyst taxa such as *Lingulodinium machaerophorum*, *Polysphaeridium zoharyi* and *Homotryblium* spp.

2.3.2 Palynofacies and Thermal Maturity Studies in the Niger Delta

Most of these recently published works dwelt on palynological investigations with emphasis on both age determination and paleoenvironmental reconstruction of the depositional environments of penetrated sediments. However, a very low number of published materials were on palynofacies of the basin. The few palynofacies studies are the pioneering efforts of Oyede (1992), Oboh *et al*. (1992), Oboh (1995) and the later contributions of Chukwuma-Orji *et al*. (2019), Fadiya *et al*. (2020) and Fajemila *et al*. (2022). It needs be pointed out, however, that most of these studies were conducted on the Miocene sediments of the basin for obvious reason of oil prospecting. In the area of thermal maturity determination using the colour of palynomorphs, the publications of Oyede (1988), Oboh (1995), Odedede *et al*. (2012) and Lucas and Omodolor (2018) remain the available materials from the region; others being on the Anambra Basin (Chiaghanam *et al*. 2014; Edegbai and Emoferieta, 2015; Durugbo, 2016 and Lucas and Ebahili, 2017) and the Northern Benue Trough (Onoduku and Okosun, 2016).

The perceived lack of interest in palynofacies studies in Nigeria may be due to several reasons. The first amongst these may include practitioners' unbelief or lack of trust in palynofacies for the reconstruction of depositional environments and determination of source rock potentials. For example, Edet (pers. comm., 2014) expressed his apathy to its applications in a keynote address he delivered to members of the Palynological Association of Nigeria in 2014. He believed efforts and time are being expended on the study of macerated plants debris that do not necessarily yield meaningful results.

However, detailed study of contributions of authorities in this aspect of palynology over the years suggest otherwise (Batten, 1996; Oboh, 1992). In addition, the application of palynofacies in routine biostratigraphic studies for many oil and gas companies for over 25 years in the basin attests to its significance.

Secondly, lack of technical knowhow in palynofacies analysis could be another significant reason for its poor practice since it is completely different from routine analysis for palynomorphs. Few Nigerians are knowledgeable about its analytical procedure. Thirdly, the different nomenclatural approaches to palynodebris classification could be another limiting factor. Fourthly and lastly, the perception that application of palynofacies studies may amount to duplication of efforts in palynostratigraphic studies may also be another important reason. This may assume that the conventional palynological studies, without palynofacies studies, can be used in drawing paleoenvironmental inferences.

Palynofacies study, which has been aptly defined as a study of body of sediments with distinctive palynological organic matter assemblage reflecting environments and related to a characteristic range of hydrocarbon-generating potential (Mendonça Filho *et al.*, 2012), was pioneered in Nigeria by late Ade Oyede as a Shell Nigeria Staff in 1988. Oyede (1988) introduced some simple techniques for typifying source rocks based on the recognition of the microscopic organic contents of 92 sidewall core samples from eleven wells within the Niger Delta basin. Oyede (1988) coined the term palyno-geochemistry for this technique of examining palynological slides with a combination of transmitted white light and incident ultraviolet ray, which is fast and relatively cheap.

A simple and independent technique such as pyrolysis test-tube analysis was used for a rapid, low-cost assessment, though subjective, of source rock potential. The level of maturity was estimated by using the colour of sporomorphs present in a sample and the fluorescence intensities of liptinite macerals. The sporomorph colour intensity (CI) and the vitrinite reflectance (VR) data showed good correlation. Most of the wells analysed were dominated by terrestrial organic matter which support the waxy nature of most crude oil from the delta region. The immature to near-mature states of the samples suggested that fully matured generative sequences were yet to be tested in most of the wells

In a subsequent publication, Oyede (1992) showcased the significant contributions of palynofacies to environmental reconstruction and basin evaluation by integrating palynofacies analysis with sedimentological techniques. Oyede (1992) illustrated the palynomaceral contents of samples from diverse depositional settings by carrying out palynofacies studies on cores from the Niger Delta. An up to date palynofacies scheme was attempted. Four palaeoenvironments were recognizable from the studies on the core samples. These are the Mangrove Swamp, Channel Deposit, Shoreface and Marine.

Oyede (1992) concluded by making a case for the Amsterdam Organic Matter Classification Scheme, being useful, not subjective and a veritable means of communication among practitioners across the world, as well as allowing better definition of depositional environments. However, improved, objective and standardized organic matter classifications have been introduced by different authors as alluded to in Chapter One.

Oboh *et al*. (1992) interpreted the depositional environments of Miocene sediments penetrated in the Igbomotoru-1 well between interval 1123 and 3583 metres using palynological and lithological data. The frequency of occurrence and abundance of *Zonocostites ramonae* (*Rhizophora* spp.) in most of the samples was suggestive of mangrove vegetation at sediment deposition, while its paucity indicated deposition in a freshwater setting which lacked *Rhizophora* spp. The recorded organic matter consisted of mostly phytoclasts of different sizes, indicating proximity to source. The inferred environment for the studied well sequence is mostly transitional with some marine influence towards the base.

Oboh (1995) carried out sedimentological, petrological, palynodebris, palynomorphs and spore colouration studies on 50 m long cores from two boreholes. Seven deltaic depositional sub-environments were recognized, while ten lithofacies were delineated from grain size, textures, sedimentary structures, and trace fossil. The lithofacies represent five sandstone (S1-S5), three heterolithic (SM1-SM3) and two mudstone (M1, M2) facies.

Oboh (1995) recognized 14 categories of palynodebris within the studied section in an assemblage she described as “predominantly terrestrially derived”. These are: pollen and spores, fungal spores, cuticle, parenchyma, well preserved wood, brown wood, black debris, degraded bundles, resins, black specks, AOM, degraded debris, algal remains and MWL. Ninety-three taxa, dominated by angiosperm pollen, were identified in the study with palynomorphs more found in finer-grained lithofacies SM2, M1 and M2 containing richer organic matter. Abundant species recorded include the tricolporate grains like *Zonocostites ramonae*, *Verrutricolporites rotundiporus* with Graminidites (Poaceae pollen).

The environmentally controlled palynofacies associations were identified from the visual and statistical analyses. These are: Palynofacies Association A/C which is rich in light-textured components e.g. palynomorphs, cuticles and lath-shaped wood fragments and Palynofacies Association B/D rich in black debris, mostly angular, equidimensional wood fragments with higher amounts of parenchyma and resins. The concomitant occurrence of abundance grass pollen with the mangrove species suggested a drier climate wet enough to encourage mangrove vegetation. From the visual and quantitative spore colouration, the sediments of the E2.0 Reservoir were immature to marginally mature.

Sedimentological and palynofacies analysis were undertaken on one hundred and ninety ditch cutting samples (20-11820 ft; 6.09-3603 m) of X2 well from the Greater Ughelli Depo-belt, Niger Delta by Lucas *et al*. (2018). The aim of the study was to determine the organic thermal maturation and source rock potential of the sediments. Seven lithofacies and forty-nine lithozones were recognized from the sedimentological analytical results obtained from the mineralogical composition, textural properties and fossil contents. The lithofacies of the well sequence revealed sandstone, shale sand, sandy shale, clay, sandy clay, clayey sand and shale.

The palynofacies assemblage made up of pollen and spores, woody plant components, amorphous organic matter were used in the identification of the hydrocarbon potential of the well sequence. The dark brown to black woody elements suggests the well sequence is gas prone with the spore colour light brown to brown colour index suggesting a mature petroleum hydrocarbon phase with Spore Colour Index 4-6. The palynofacies analysis suggests 70% oil and 30% gas generation of kerogen type II.

Chukwuma-Orji *at al*. (2019) carried out a palynofacies analysis on a suite of fifty ditch cuttings between depths 2179 and 3528 m. The study was aimed at establishing the palyno-stratigraphic, zones, age and inferring the depositional environments of the well sequence. A low to abundant pollen and spores with small to large sized palynomacerals 1 and 2 alongside few occurrences of palynomacerals 3 and 4 with no record of structureless organic matter resulted from the well palynofacies analysis. The well lithofaciesis made of alterations of shale and sandstone of the Agbada Formation.

The age diagnostic palynomorphs recorded such as *Multiareolites formosus, Verrutricolporites rotundiporus, Crassoretitriletes vanraadshooveni* and *Racemonocolpites hians* aided the establishment of three zones. These zones are: the *Multiareolites formusus-Zonocostites ramonae, Verrutricolporites rotundiporus-Crassoretitriletes vanraadshooveni* and *Alnipollenites* zones. The proposed zones were related and correlated to the P770, P780 and P820 subzones of Evamy et al. (1978) in the middle to late Miocene. On the basis of of the palynofacies assemblages encountered in the Ida-4 well sequence, a low delta plain to delta front and pro-delta setting in a coastal-deltaic environment of deposition was inferred.

Manuemelula *et al*. (2019) analysed twenty ditch cutting samples between depth 3660 and 11400 ft of Well-001 in the Meren Field, western Niger Delta. The result of their palynofacies analysis resulted in the recognition of five palynofacies assemblages. These are: Palynofacies I which depicts fluvio-deltaic and moderately distal oxic environments; Palynofacies II suggesting a nearshore dysoxic-anoxic environment. The other three assemblages are: Palynofacies III, a marginal marine within a proximal dyoxic-suboxic environment; Palynofacies IV: fluvio-deltaic/nearshore, oxic environment and Palynofacies V, a fluvio-deltaic/nearshore (proximal shelf) under oxic condition.

The dominance of terrestrial organic matter suggests sediments deposition in a nearshore environment. From the diagnostic palynomorphs which include *Monoporites annulatus*, *Pachydermites diederixi*, *Striatricolpites* sp., and *Zonocostites ramonae* recorded, the well sequence was assigned to the early to late Miocene.

In a study aimed at establishing the age and reconstructing the palaeoenvironments of sequences penetrated by two shallow offshore Niger Delta wells. Fadiya *et al*. (2020) assigned a late Miocene age within the P800 palynological zone to the wells. The recovery of particulate organic matter, dominated by Amorphous Organic Matter (AOM), Phytoclasts and Palynomorphs aided the delineation of three palynofacies assemblages (PF-A, PF-B and PF-C) which indicated depositional environments ranging from distal shelf, marginal and shoaling to proximal within conditions varying from oxic, suboxic to anoxic. A correlation of the two wells on the basis of the recognized bioevents and subzones reveals a perfect correlation between the wells.

A palynofacies study on late Miocene-early Pliocene sediments offshore Eastern Niger Delta, Nigeria, carried out by Fajemila *et al*. (2022), indicated relative abundance of land -derived palynomorphs, small to medium sized palynomaceral types I and II (opaque phytoclast), low frequencies of small to medium sized palynomacerals III and IV with structureless organic matter as well as rare marine palynomorphs. The palynofacies assemblage indicates deposition in a coastal-deltaic (dysoxic-anoxic condition) environment belonging to kerogen type III with gas prone sediments at greater depth.

Furthermore, the palynofacies results suggested two depositional sequences made up of a sequence boundary (SB), a maximum flooding surface (mfs) and three parasequencies. Fajemila *et al*. (2022) averred that the result of their study will facilitate the refinement of sequence stratigraphic frameworks and the reconstruction of the Niger Delta basin depositional environments.

2.3.3 Studies of Foraminifera in the Niger Delta

Some other publications such as those of Ogbe (1982), Oloto and Promise (2014), Ukpabi *et al*. (2014), Adeigbe and Ochigbo (2017), combined palynological studies with foraminiferal analysis for achieving high resolution biostratigraphic results. The earlier publications of Petters (1981, 1982 and 1984) marked the very first set of published materials on foraminiferal studies from the region. Subsequent publications include those of Ozumba (1995, 1997), Adeniran (1997), Okosun and Liebau (1999) and Ozumba and Amajor (1999a). The turn of the century also ushered in an increased wave of publications in the reporting of foraminiferal research in Nigeria. Some of these include: Bassey and Alalade (2005), Adegbie *et al*. (2011), Chukwu *et al*. (2012), Okosun *et al*. (2012), Omoboriowo *et al*. (2011), Ozumba (2011), Fajemila (2012), Obaje and Okosun (2013a and b), Obiosio (2013), Ajayi and Okosun (2014), Fadiya *et al*. (2014), Adeigbe and Adeleye (2016) and Ola and Bamisile (2014b).

Adegoke *et al*. (1971) studied the planktonic foraminiferal composition of 36 offshore bottom samples explored by the R/V Pillsbury Deep-Sea Biological Expedition from the Gulf of Guinea. The study was aimed at discussing details of the recorded planktonic species and comment on their distribution pattern. Twenty-two planktonic species and two subspecies were recorded with the assemblage mostly tropical with inclusion of some cold-water tolerant species. Dominant among these are: *Globigerinoides ruber*, *G. trilobus*, *Globoquadrina dutertrei* and *Globorotalia menardii menardii*. Four-broad bathymetric biofacies were recognized based on planktonic species distribution and abundance.

From the abundant and diverse foraminiferal assemblages recovered from ditch cuttings between 306 and 3076 m in the Parabe-1 well, offshore western Niger Delta, an Oligocene-Pliocene age was assigned by Petters (1979). The study recognized two distinct biostratigraphic horizons: the *Globorotalia tumida* level, assigned to the Pliocene age and the *Globorotalia opima nana* and *G. opima opima* level, suggesting late Oligocene. The assertion that West African Neogene benthonic foraminiferal assemblages exhibit endemism was confirmed by the study from the recovery of new benthonic species.

Petters (1981) reported that three marginal basins in the Gulf of Guinea, viz; the Benue Trough, the Dahomey Embayment and the Niger Delta. These basins exhibit peak foraminiferal assemblage development at major marine transgressions in the Oligocene and younger transgressions particularly in the Niger Delta paralic sequence. The Late Cretaceous to Tertiary sea level upsurges mark major transgressions in the Gulf of Guinea. The progressive increase in faunal diversity between the Albian and the Eocene as depicted by the transgressive shallow shelf benthonic faunal assemblages was established in the Gulf of Guinea.

Ozumba (1997) assigned upper Cretaceous (Maastrichtian) to late Oligocene age to three western flank wells of the Niger Delta, i.e., Benin West-1, Beniwei-1 and Gilli Gilli-1. The age assignment was based on results of foraminiferal biostratigraphic and sequence stratigraphic analyses. Biostratigraphic evidence suggested that some foram zones are either thin sequences or completely absent. Slow rates of deposition and complete absence of deposition were adduced for the thinness and the observed hiatus by the author. Ozumba (1997) reported highest extinction of foraminiferal species at the Cretaceous/Tertiary and Paleocene/Eocene boundaries. The author also noted foraminiferal abundance in the latest Paleocene and mid-Eocene with high diversity in the latest Paleocene. Ozumba's (1997) observation supports the recorded latest Paleocene transgression in the delta. The three wells analysed penetrated eleven biozones in the Cretaceous-Early Oligocene. These are: *Afrobolivina afra* Taxon Range Zone; *Planorotaloides compressa* Taxon Range Zone; *Planorotaloides pseudomenardii* Taxon Range Zone; *Morozovella acuta – Morozovella velascoensis* Taxon Range Zone; *Globorotalia rex* Taxon Range Zone; *Bolivina owerri* Partial Range Zone; *Cassigerinelloita amekiensis* Taxon Range Zone; *Truncorotalloides rohri* Assemblage Zone; *Chiloguembelina martini* Partial Range Zone; *Nonion* 8 Partial Range Zone; *Pseudohastigerina micra* Partial Range Zone. Deep basinal conditions predominated the Upper Cretaceous (Maastrichtian) to the latest Eocene.

Stratigraphically significant species, occurring in at least two wells, were used to erect a quantitative planktonic foraminiferal biostratigraphy from Benin River-1, Okan-73 and Meji-20 in the western Niger Delta by Adeniran (1997). The biochronologic framework was correlated with standard radiometric planktic foraminiferal events in the tropics and subtropics of the Atlantic, Mediterranean and Pacific Oceans. The Oligocene/Miocene boundary was identified only in Benin River-1 well and was placed at the last appearance of *Globigerina* cf. *ciperoensis* and *Cassigerinella chipolensis,* closely related with the LAD of *Globorotalia opima nana* and the bloom of *Globigerinoides* in the well. The lower/middle Miocene boundary was recognized in Okan-73 well and was defined by the *Orbulina biohorizon* occurring above the peak occurrence of *Praeorbulina glomerosa*. The Miocene/Pliocene boundary identified in Okan-73 and Meji-20 wells was defined by the last appearance of *Globigerinoides ruber seigliei*.

Five wells in the eastern Niger Delta were subjected to quantitative foraminiferal biostratigraphy by Okosun and Liebau (1999). Benthonic foraminiferal biozones were proposed in the study. This is largely due to the fact that most of the wells (except Akata-1) studied contain sparse or were devoid of planktic foraminifera and were dated Late Oligocene-Middle Miocene based on benthic forams. The Akata-1 well with good representation of planktonic and benthic foraminifera penetrated Oligocene-Miocene. Increased occurrence and diversification of *Globigerinoides* marked the late Oligocene/Miocene boundary. Also, the recognized lower-middle Miocene boundary, identified only in Akata-1, was marked by the *Orbulina* datum.

Hitherto, planktonic foraminifera were thought to have little usefulness for age zonation in the Niger Delta since the sediments were deposited mostly in shallow marine to shelfal setting; benthic foraminifera had been relied upon for age dating in the region. However, the abundant occurrence of planktonic foraminifera, including diagnostic forms, previously neglected, from many areas of the delta has initiated a study aimed at determining their potentials for the erection of planktonic foraminiferal zones for the Niger Delta basin by Ozumba (2011). Ozumba (2011) proposed 23 zones which he envisaged, when successfully tested and affirmed, will enhance the integration of the Niger Delta scheme to the International Geological Time Scale. The wells studied ranged in age from lower Paleocene to Pleistocene. Ozumba (2011) opined that, though the Niger Delta had its beginning in the Early Eocene, its Anambra precursor - exhibits a continuity with the overlying deposits making the wells drilled to penetrate older sediments into the Paleocene.

Obiosio (2013) recorded 18 species from a rich *Bolivina* assemblage from Tonjor-1 well, onshore Niger Delta. One taxon zone, *Bolivina attenuata* Cushman, an interval range zone, *Bolivina ottaensis* Reyment and two concurrent subzones: *Bolivina foliacea* and *Bolivina jacksonensis* were established using the *Bolivina* species recovered. The index planktonic foraminifera associated with the bolivinids indicated a late early Eocene age for the zones. The diverse bolivinids permitted the recognition of late Early Eocene marine transgression. Deposition in an oxygenated slope to bathyal environment was indicated by the strong costae and larger tests.

Lithologic and foraminiferal analyses conducted on a well designated AM-2 were used to determine the age and reconstruct the palaeoenvironment of the well which tested Agbada and Akata Formations by Fadiya *et al*. (2014). The age diagnostic planktic foraminifera recorded such as *Globigerina eocena*, *Pseudohastigerina micra*, *Hastigerina* cf. *bolivariana*, *T. cerroazulensis cerruazulensis*, *T. pseudomayeri* and *T. cerruazulensis pomeroli* as well as the occurrence of benthic foraminiferal species: *Hyskinsina hourqi*, and *Nonion oyae* aided the assignment of middle-late Eocene age. The following four informal benthonic foraminiferal assemblages were established: (i) *Altistoma tenuis* Zone (P12); (ii) *Eponides africana* Zone (P13/P14), (iii) *Uvigerina peregrina*/*Lenticulina grandis* Zone (P15) and (iv) *Bolivina ihuoensis*/*Hopkinsina hourqi* Zone (P16). The zones were related to four identifiable Condensed Sections dated 35.9Ma, 36.8 Ma, 38.0 Ma and 39.4 Ma. From the association of recovered benthic foraminiferal, Inner to Middle Neritic environments were inferred.

Ola and Bamisile (2014b) recovered significant calcareous and arenaceous species from the foraminiferal analysis of 69 composited ditch cutting samples of Meren 31 ST-2 well, offshore Niger Delta and utilized them in age determination and environmental reconstruction of the wells. From the benthonic foram recorded, two informal benthonic zones were defined from Early to Middle Miocene age from the well section studied, though results from the palynological studies of Ola and Bamisile (2014a) on the same samples suggest a middle to late Miocene age. Sediment deposition fluctuated between inner to middle neritic and coastal deltaic environments.

Ukpong *et al*. (2017) carried out lithologic and foraminiferal analysis on ditch cutting samples within interval 2590 and 3300 metres of Well K-27, Greater Ughelli depo-belt, Niger Delta. The study was aimed at age dating and biozonation of the well sediments. Lithologic results indicated lithofacies within the paralic Agbada Formation. The rich assemblage of benthic foraminifera such as *Hopkinsina bononiensis*, *Spiroplectammina wrightii*, *Uvigerinella sparsicostata*, *Lenticulina grandis* and *Bolivina imperatrix* aided the recognition of P18-P19, P20/N1, P21/N2 and P22/N3 foraminiferal zones. The recognised zones were assigned early - late Oligocene and younger.

Four plantic foraminiferal zones: *Globigerina selli*/*Pseudohastigerina barbadoensis* zone (P18-P19), *Globigerina ampliapertura* zone (P20/N1), *Globorotalia opima opima* zone (P21/N2) and *Globigerina ciperoensis ciperoensis* zone (P22/N3) were also defined. These zones could be useful for worldwide correlation of similar sequences.

Ukpong and Anyawu (2018a) carried out foraminiferal, lithologic and paleoenvironmental analyses on U-12 Well from the northern depo-belt of the Niger Delta basin. A suite of ditch cutting samples and well logs from interval 2008 – 3396 metres of the well were used. The study resulted in the assignment of late Eocene to early Oligocene age for the paralic Agbada Formation sediments encountered in the well sequence. The P16/17 – P18/19 planktonic foraminifera zones were recognized from the study. The distribution of foraminifera within the well sediments suggested deposition in cool, well oxygenated saline marine environments ranging from non-marine, shallow inner neritic through middle neritic to outer neritic settings. Results from this study is expected to facilitate ag dating, stratigraphic characterization and correlation across Paleogene fields in the Niger Delta.

Ukpong and Anyawu (2018b) researched into the biostratigraphy and paleoenvironment penetrated by the Beta-24 Well sequence using ditch cuttings and well logs between interval 2008 and 3396 metres. Lithologic description revealed penetration of the paralic Agbadaa Formation lithofacies. Typical Paleogene foraminifera assemblage of *Bolivina tenuicostata*, *B. imperatrix*, *B. ihuoensis* and *Globigerina ampliapertura* were recorded. This assemblage aided the erection of the P16/17 and P16/17 – P18/19 foraminiferal biozones and the late Eocene – early Oligocene age for the well sequence. From the foraminiferal assemblage, deposition environments ranging from non-marine through shallow inner neritic to outer neritic were inferred.

Using ditch cutting samples from wells C (2410 - 2770 m) and F (2000 – 3320 m), Ukpong *et al*. (2018) carried out foraminiferal biostratigraphic study in the Niger Delta. A rich and diverse assemblage of foraminifera species, mostly dominated by benthic foraminifera, was recovered from the transitional lithofacies of the Agbada Formation. Two foraminiferal zones: P17/18 (*Globorotalia cerroazulensis*/*Pseudohastigerina micra* zone) and P18 (*Pseudohastigerina micra* zone) were recognized in well C. Well F was made up of four foraminiferal zone: P16-17/P18-19 (*Globorotalia cerroazulensis*/*Pseudohastigerina micra* – *Globigerina ampliapertura* zone).

The sequences penetrated by the two wells presented continuous and complete records of foraminiferal assemblages that suggested the Priabonian to the Repulian ages between late Eocene (P16/17) and early Oligocene (P18/19) epochs.

2.3.4 Applications of Biostratigraphy in Sequence Stratigraphy

The significance of the application of biostratigraphy in the new frontiers of sequence stratigraphy and climate change studies has been well documented in numerous publications that have emerged since the initial work of Poumot (1989). While some of these publications have highlighted the usefulness of biostratigraphy in the emerging trends in exploitation and exploration activities (Adegoke 2002; Giwa *et al*., 2006 and Fadiya, 2014), many others have actually shown its practical applications in sequence stratigraphy (Anyiam and Mode, 2008; Ozumba and Amajor (1999b); Nton and Ogungbemi, 2011; Adegoke, 2012; Odedede *et al*., 2012; Onyekuru *et al*., 2012; Oyedele *et al*., 2012; Obaje, 2013; Ojo and Gbadamosi, 2013; Soronnadi-Ononiwu *et al*., 2013; Ajaegwu *et al*., 2014; Akpan *et al*., 2014; Bassey *et al*., 2014; Agraka *et al*., 2015; Momta and Odigi, 2015; Okengwu and Amajor, 2015; Essien and Beka, 2016; Kelechi *et al*., 2016; Nwokocha and Oti, 2016; Olaleye, 2016, Adeonipekun and Sowunmi, 2019 and Adeonipekun et al., 2023).

In general, most of the authors referred to above conducted their research on the Neogene period of the Niger Delta basin. Only very few authors worked on the Paleogene of the basin, largely for reasons alluded to earlier. Some of these citations which are relevant to the current study in terms of their ages and research contents will now be reviewed.

Powell (1992) and Gregory and Hart (1992) were some of the first set of researchers to apply palynological records in sequence stratigraphic concepts. Powell (1992) used dinocysts for age determination, locating condensed sections and biofacies for environmental interpretation using example from the North Sea. Gregory and Hart (1992) recorded dominance of pollen and spores from hygrophytic to xerophitic plants with minor representation of marine elements in LST. The TST feature an increase in marine elements together with pollen of meso-xerophilous plants while there was a reduction in the marine with rise in the pollen content of hydrophilic and hygrophilic within the HST in the study.

Blondel *et al*. (1993) characterized palynofacies and flooding surfaces, in the coastal environments of the Miocene in central Tunisia, by adopting the concepts of Gregory and Hart (1992). They asserted that palynological constituents are useful in identifying flooding surfaces and delimiting systems tracts, especially in their studied area where maximum flooding surfaces were not easily identified due to facies type.

Holz and Dias (1998) applied the concept of sequence stratigraphy in relation to palynological events in an Early Permian rock succession in the southern part of Brazil where there were diverse regressions and transgressions. This was with a view to testing whether the changes in sea-level impacted the pollen/spore history as predicted in earlier studies of Gregory and Hart (1992) and Blondel *et al*. (1993). Gregory and Hart (1992) and Blondel *et al*. (1993) had earlier revealed transgressive surfaces and MFS showing characteristic palynological signatures; lowlands depict high spore content with a gradual decreasing spore record associated with transgressive systems tract.

Holz and Dias (1998) corroborated the earlier proposed models which averred that palynological and sequence stratigraphic records have direct relationship with significant chronostratigraphic flooding surfaces and sequence boundaries. Specifically, Holz and Dias's (1998) study confirmed the applicability of the model in different geological settings. Their study detailed a noticeable reduction in the proportion of pollen/spores characterizing the identified maximum flooding surfaces. Higher percentages of spores were also associated with the lowstand and initial transgressive deposits while the late transgressive deposits were rich in pollen. However, the contrast in the composition of pollen/spore record of their sequence II highstand deposits from the model of Gregory and Hart (1992) was adduced to the influence of the coastline paleogeographical configuration.

In her integration of palynological and sedimentological data, Oboh (1996) established important regional sequence stratigraphic interpretations of Upper Cretaceous (Campanian) sedimentary rocks in the Book Cliffs, east-central Utah. In the study, Oboh (1996) used detrital organic matter (palynodebris) and sedimentological criteria to infer palynofacies and identify the depositional framework. By correlating two identified major palynofacies assemblages with sequence stratigraphic interpretations, Oboh

(1996) concurred with earlier workers on the significant application of palynology to sequence stratigraphy.

Morley (1995b) averred that systems tract could be delineated based on palynomorph assemblages which may suggest changes in the coastal geomorphological character at various sea levels. Thus, Morley (1995b) opined that sequence stratigraphic interpretations derived from inputs of land-derived miospores should be integrated with those based on marine microfossils.

Based on the representation of terrestrially derived palynomorphs, Morley (1995b) proposed a generalized model for the characterization of stratigraphic sequences and differentiation of system tracts. This model suggests that at sea level fall, lower coastal plain facies with their associated floral communities are at minima level, while increasing sea level results in a distinct development in the representation of brackish water plant species such as mangroves largely due to the drowning of coastal areas. Highstand phases are marked by the progradation and expansion of upper coastal plain facies together with the associated freshwater swamp plant assemblages. This model is based on the establishment of the fact that land-derived palynomorphs deposited in marine sediments are mostly water-transported as silt-sized sedimentary particles.

Morley (1995b) asserted that sporomorphs (pollen and spores) deposition within distal depositional settings are expected to be lower during lowstand. Maximum flooding surfaces are expected to reflect the lowest miospore (pollen and spores) deposition rates as the provenance of terrestrial vegetation is farther from the depositional site at this time. Morley (1995b) concluded that the application of biostratigraphy is key in understanding depositional sequences in petroleum exploration rather than play secondary role in stratigraphy. He posited that data from the different biostratigraphic disciplines (micropal eotology and palynology) be fully integrated together with lithological data. This, he believed, will facilitate a more precise subsurface correlation and facies interpretation.

Van der Zwan and Brugman (1999) developed a new approach to determine reservoir connectivity across growth faults in a high subsidence region in the EA Field of the Niger Delta where conventional biostratigraphy proved non-effective. This innovative high-resolution correlation tool referred to as ‘Biosignals’ was premised on the ‘pollen-parent plant-ecology' relationship. Pollen and spores, based on such relationship, were grouped into vegetational zones from which components of vegetation zones were identified in ascending order from dominant spore, through swamp, rain forest, savanna to montane.

Van der Zwan and Brugman (1999) averred that a fourth-order sequence stratigraphy was reflected by the vegetational stacking patterns with biosignal evidence ascribing the tidal channels in one of the wells studied, EA-13, to lowstand sequences. The authors also inferred dry climate and low water level to the sandy middle portion in EA-1 well and correlated the two regional MFSs with humid climate and high sea level.

This approach facilitated correlation of reservoirs across growth faults. Thus, by comparing sequence stratigraphy with palynological records as it relates to palynomorphs preservation and taphonomy, Holz and Dias (1998: 218) averred that 'sequence stratigraphy should always be the natural handmaiden of stratigraphic palynology'.

Adegoke (2002) highlighted the positive impact high resolution biostratigraphy and sequence stratigraphy have made on Exploration and Production activities with the provision of chronostratigraphic and facies framework, particularly in the Cenozoic. The author also pointed out cooperation of biostratigraphers with other asset management team such as the geophysicists, regional geologists, and production scientists as well as engineers. Adegoke (2002) opined that the Nigerian oil industry had a lot to learn from the Gulf Coast experience by re-interpreting old wells data to come up with a chronostratigraphic scheme for the entire Niger Delta.

Adegoke (2002) projected that the new millennium will experience improvements in the application of System Tracts (3rd Order) and Parasequences (4th Order) as platform for detailed correlation, defined by improved biostratigraphic time scales. He opined that the data generated (biostratigraphic, seismic and petrophysical) will become progressively integrated into 3-D geological and structural models. These models will closely resemble subsurface reservoir conditions, enhancing and enabling the correct timing of hydrocarbon generation and expulsion, trap formation in frontier basins and discovery of by-passed oil or mature basins.

Giwa *et al*. (2006) observed that the complexities and uncertainties of the world's matured hydrocarbon basins have necessitated a change in biostratigraphic applications in petroleum industry from its hitherto routine age dating of rock units. This resulted into "production biostratigraphy" where biostratigraphy can be applied in reservoir characterization, correlation and wellsite operations using specific bioevents. Some of the recent biostratigraphic advances Giwa *et al*. (2006) highlighted include seismic/sequence stratigraphy, high resolution biostratigraphy, ecostratigraphy, quantitative stratigraphy and biostratigraphic workstations, high impact biostratigraphy and wellsite biostratigraphy.

Adojoh and Osterloff (2010) evaluated the relative changes in pollen and spore distributions within the Niger Delta Eocene to Pliocene sediments to refine the existing depositional models of the basin, hitherto associated with productivity trends in foraminifera and calcareous nannoplankton. Changes in phyto-ecological assemblages associated with prevailing conditions influencing local ecosystems were mapped to stratigraphic sequence related to the deposition of the Niger Delta complex through time.

In what appears to be the very first application of palynology in surfaces and systems tracts mapping after the model of Morley (1995a and b), Odedede *et al*. (2012) established the sequence stratigraphy and determined depositional paleoenvironments from results of palynological analyses of an offshore depo-belt well code-named, E-12. The analysed paralic sequence yielded rich and well preserved palynomorph assemblage indicating a middle Eocene age, equivalent to the P400 Zone. From recovered assemblage of palynomorphs, shallow marine to brackish environments were inferred. Spore colouration indices of maturity study conducted revealed pale-yellow to brownish colour, inferring matured organic source rocks.

Odedede *et al*. (2012) applied the integration of palynofacies assemblages and lithofacies to delineate two maximum flooding surfaces, which are potential source rocks seals in the well, dated 41.6 Ma and 42.0 Ma. The progradational phases of LST age dated 46.7 Ma to 47.1 Ma were recorded between depth 2511.6 m and 2529.8 m in the well. Two TST, which may be potential source rocks, were marked between intervals 1871.5 m to 1962.9 m and 2218.9 m to 2511.6 m and are dated 42 Ma and 46.7 Ma respectively based on lithofacies and palynofacies parameters. Highstand systems tracts were delineated in the well sequence and dated 47.1 Ma to 48.7 Ma and 41.6 Ma to 38.9

Ma, which may serve as good quality reservoir as well as poorer quality mudstones providing a reservoir “seal” to prevent the leakage of potential recoverable hydrocarbon. The characterization of maximum flooding surfaces with maximum diversity and abundance of palynomorphs with minima dinoflagellate cysts by Odedede *et al*. (2012) runs contrary to the model of Morley (1995a and b) and other authors.

Bassey *et al*. (2014) used biostratigraphic parameters such as foraminiferal diversity and population, microfaunal and microfloral zonations and paleobathymetry together with gamma ray and resistivity logs of three wells from the Uniabr Field from the northern depobelt of the Niger Delta to decipher the sequence stratigraphic achitectures of the wells. Five MFS(s) and five sequence boundaries (SBs) resulted in the identification/delineation of five 3rd order sequences. The sequences serve as excellent source rocks and provide stratigraphic traps. Palynological zonation of one of the wells, Uniabr-1 well, suggests average age range (Late Eocene to Early Miocene) in the field.

Adojoh *et al.* (2015) adopted the model of Poumot (1989) in the application of pollen /vegetation indices for sequence stratigraphy using ecological indicators by identifying the botanical affinities of different pollen and spores species of the Miocene of the Okan-1 well, Niger Delta. The evolution and extinct points of identied pollen, spores and dinoflagellate cysts were used for defining zones BZ6, BZ4, BZ2 and BZ1 respectively. Adojoh *et al*. (2015) used the change in vegetation at intervals for the identification of nine wet-dry cycles as proxy for identifying four palynocycles.

Okengwu and Amajor (2015) integrated biostratigraphic data of Biwa-1 and Biwa-2 with log signatures for the recognition of three sequences in the Biwa Field in the Greater Ughelli depobelt of the Niger Delta. The log readings in conjunction with the biostratigraphic data were used to identify the SB(s) dated 23.7 Ma, 29.3 Ma and 32.4 Ma with identified MFS(s) at 23.3 Ma and 31.3 Ma dated Oligocene to early Miocene.

Essien and Beka (2016) explored the stratigraphic patterns of depositional systems in relations to the controls of eustacy and sediments supply of different scales and phases by adopting the palynocycle model of Poumot (1989) on five wells obtained across the Eastern Thrust/Fold Belt and the Western Thrust Belt offshore the Niger Delta basin. Seventeen palynocycles (PCY 1 to PCY 17), age-dated 17.7Ma to 0.8Ma, were penetrated by the wells and correlated across the studied sections. Identified missing intervals or sections and compressed cycles which correspond to depositional cycles are believed to be periods of erosion, forced regression or unfilled incised valleys or stratigraphic condensation phases. These are possible reservoir beds or seals for hydrocarbon accumulations. Essien and Beka (2016) believe their novel approach will advance appreciable understanding of depositional systems, promote new stratigraphic plays to identify subtle traps and improve the recognition of reservoir prospects in the basin.

In the latest contribution of palynology to sequence stratigraphy, Adeonipekun et al. (2023) collated and evaluated the stratigraphic distribution of non-pollen palynomorphs (NPPs) from three offshore wells in the Niger Delta. The trends in the distribution of the accessory palynomorphs such as *Botryococcus*, *Pediastrum*, marine indicators, dinoflagellate cysts and microforaminiferal wall lining and charred Poaceae cuticle were characterized in relation to the system tracts and mapped out surfaces such maximum flooding surfaces and sequence boundaries. From the study, sequence stratigraphic significance was ascribed to the alternating trends of the recorded palynomorphs from subsurface sediments of the studied wells. Dominant *Pediastrum* with corresponding reduction in marine elements characterizes the Lowstand Systems Tract (LST) within the three wells. High values of *Bortyococcus* were more associated with the Transgressive Systems Tract (TST) as well as the Highstand Systems Tract (HST). The study has further aided in sequence stratigraphic interpretation of sandy sequences associated with poor fauna and dinocysts recoveries of the delta basin.

2.3.5 Climate Change and Vegetation

Van der Hammen (1956), based on cyclic trends in the floral records in northern South America in relation to climatic cycle, first proposed the concept of palynological cycle. This concept consequently resulted in the introduction of climatic cycles termed, ‘palynocycle’, based on detailed palaeoecological study with the attendant effect of eustasy on coastal vegetation by Poumot (1989). According to Poumot (1989), palynocycles are succession of palynobotanical associations in time. These associations are based on the quantitative assessment and botanical affinity of Tertiary pollen grains reconstructed by analogy with present-day vegetation.

Thus, in the words of Rull (2002: 281), palynocycle is "the sequential record of fossil pollen assemblages turned into a practical tool for the study of sea level oscillations and their phases, which are linked to depositional systems tracts". Poumot (1989) suggested that variations in the littoral flora (mangrove, spores, Gramineae-Casuarina, and Palmae-Pandanus) and hinterland flora such as rain forest and savanna are indicative of eustatic and climatic changes respectively.

The succession of palynocycles based on the average percentages of the different palynobotanical group results in a super-zonation referred to as "megapalynocycles". These are of lower frequency than palynocycles and may be of the 3rd order cycles of Vail's chronostratigraphic hierarchy (Poumot, 1989). Poumot (1989) opined that this quantitative palynostratigraphic approach is aimed at achieving high resolution sequence stratigraphy.

Many research studies have been published on the effect of climate change on the vegetation of the West African rainforest region. These include works of authors such as Talbot (1981), Richards (1986), Hamilton and Taylor (1991), Lezine and Vergnand-Grazzini (1993), Frédoux (1994), Maley (1996), Reynaud-Farrera (1997), Ning and Dupont (1997), Jahns *et al*. (1998), Maley and Brenac (1998), Vincens *et al*. (2000), Sowunmi (2002; 2004), Ngomanda *et al*. (2005), Tossou *et al*. (2008), Bonnefille (2011), Marley *et al*. (2017), and Boboye and Akinmosin (2018) among others.

According to Adojoh *et al.* (2017), though the Niger Delta basin is situated in environments sensitive to climate change, thereby conferring on it the potential of providing a peep into the changes in environments during the Late Quaternary of West Africa, the delta remains sparsely studied in terms of its climate and vegetation changes. Adojoh *et al*. (2017) averred that much research has not been conducted on the climate and vegetations of the Niger Delta due to the few numbers of palynological studies from the delta coasts and restrictions on oil company data. Thus, more works need to be done on climate and vegetational changes of the delta since knowledge of the region will aid in projecting the development of tropical vegetation with time and in deciphering climate change factors that engender vegetational changes. Towards achieving this goal, Adojoh *et al*. (2017: 108) proffered the need for "a high-resolution temporal framework linked to vegetation and ecological systems development".

Significant among the publications on the studies conducted on climate and vegetation changes of the basin are the works of Sowunmi (1981a, b; 1986), Dupont and Weinelt (1996), Adojoh and Osterloff (2010), Essien *et al*. (2016), Adojoh *et al*. (2017) and Adeonipekun and Sowunmi (2019). In general, results from these studies suggested that the increase and the dominance of savanna and montane plant species are indicative of dry and cooler climate while an expansion in the occurrence of fresh water swamp and mangrove swamp forests along with marine elements suggests wet climate (Sowunmi, 1981a, b; 1986, Dupont and Weinelt 1996, Essien *et al*., 2016 and Adojoh *et al*., 2017). Most of the studies also affirmed an intertwined relationship between the prevailing climate change and vegetation of the basin in conformity with previous reports from Equitorial part of West Africa (Sowunmi, 1981a, b; 1986, Dupont and Weinelt, 1996; Adojoh *et al*. (2017).

For instance, Adojoh *et al*. (2017) reported that fluctuations in the trend of Afromontane Forest (Podocarpaceae), Freshwater Swamp (Cyperaceae), Savanna (Poaceae) and Lowland Rainforest (Polypodiaceae) dominate the late glacial (MIS2) and deglaciation (MIS1) periods. This was succeeded by the establishment of coastal fringing mangroves (Rhizophoraceae) from early to mid-Holocene suggesting dry conditions during the MIS2 and MIS1 periods with warmer conditions prevailing in the interglacial periods. Also, Sowunmi (1981a and b), from direct botanical evidence of pollen analysis on Niger Delta core samples observed a series of changes in the late Quaternary vegetation in Nigeria and Cameroon. Changes in the pollen records of *Rhizophora* sp. were taken to suggest sea level changes while changes in climatic conditions determine variations in the pollen records of rain and open forests, fern spores and northern Guinea and Sudan savanna zones.

Van der Zwan and Brugman (1999) opined that these alternations of wet and dry climate phases result in correlatable cyclicity within a region. The maximum savanna-montane and maximum mangrove-marine events have been found to be mostly associated with sequence boundaries and maximum flooding surfaces respectively by various authors (Morley, 1995a; b and Essien *et al*., 2016). Transgressive-regressive cycles in geological record have engendered quite a lot of concepts and models in stratigraphy. These have been made by works such as the publications of Poumot (1989), Rull and Poumot (1997), Rull (2000), Adojoh and Osterloff (2010) and Essien *et al*. (2016). Most of these publications have brought the cyclicity of climate, with its worldwide significance, to the fore. As Whittaker *et al*. (1991: 819) put it: “important stratigraphical boundaries, particularly those between the systems, have been explicitly based on major transgressive-regressive cycles, initially founded on local observations but later extended to infer transgressive-regressive events at a global scale”.

Transgressive-regressive cycles, thought to be as a result of repetition of plate tectonic separation and reassembly on the longer time-scales and associated with glacio-eustasy on shorter time-scales, is believed to exert a major controlling influence on stratigraphy world-wide. These changes in climate have been linked with the Milankovitch variations in temperature, glaciation and precipitation as the earth orbits around the sun (Van der Zwan and Brugman, 1999).

The late Paleocene to early Eocene have been identified to be very warm with tropical and high temperature flora with maximum tropical condition recorded between the early and middle Eocene. The early Eocene marked the period of greatest expansion of paleotropical flora in the Northern Hemisphere resulting in it being referred to as the paleotropical maximum (Traverse, 2008). These warm events, at the boundary between the Paleocene and Eocene, commonly known as the Paleocene-Eocene Thermal Maximum (PETM) (55 Ma), was probably warmer than present (Jensen *et al*., 2007). Jensen *et al*. (2007) opined that this warming, which is a classic case of substantial carbon emission, was most likely better expressed in the northern latitudes than the lower latitudes.

Harrington *et al*. (2004) also concurred that most information on Paleocene-Eocene floral records were derived from studies on high latitudes. In agreement with Harrington *et al*. (2004) and Jensen *et al*. (2007), Maley (1996) averred that in comparison, the wet tropical flora is better established in South America and South East Asia than in Africa as shown by the diverse genera and species of wet habitat and forest undergrowth. Maley (1996) adduced this impoverishment of African wet tropical flora to climatic factors causing arid conditions which is believed to be more pronounced than in the other continents at the breakup of Africa and South America during the Cretaceous. Nonetheless, Adeonipekun and Oyelami (2015) while recognizing the PETM within the

Paleocene/Eocene outcrop sediments from the Shagamu Quarry, SW Nigeria, recorded decrease in the proportion of flora from the late Paleocene to the earliest Eocene.

However, Maley (1996) gave a historical account of the African rainforest since it developed at the end of the Cretaceous. The region around the Gulf of Guinea, starting from Ivory Coast to Nigeria, Cameroon, Gabon, and Congo seemed to have been dominated by wet tropical forest vegetations, mostly angiosperms. During the Tertiary, the wet tropical forests extended as far as North Africa reaching the Tethys Sea because of the location of the equator farther north than it is now and the Antarctic ice cap. This explains the identical taxa and vegetation recognizable between the Gulf of Guinea and the Tethys Sea within this age. At the end of the Tertiary with the relocation of the equator to its present position, the forest vegetation became concentrated around the equatorial axis of the Gulf of Guinea and the Congo-Zaire basin. The noticeable glacial events in the middle and high latitudes, with a cyclic season of about 100, 000 years, resulted in lower temperatures in equatorial zones and arid conditions during peak glacial phases from about 800,000 years onwards (Marley, 1996).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

Ditch cutting samples totalling 585 drilled in the Oredo Field by Nigeria Petroleum Development Company Limited (NPDC) was provided for study. These samples were from three oil wells, namely, Oredo-2: 244 samples: 300 – 4000 m, coordinates Lat. 2° 28´ N & Long. 3° 46´E; Oredo-4: 195 samples: 70 – 3770 m, coordinates Lat. 2° 28´ N & Long. 3° 53´ E and Oredo-8: 146 samples: 320 – 3680 m, coordinates Lat. 2° 28´ N & Long. 3° 51´ E in the Oredo Field in OML 111 from the Northern Depobelt of the Niger Delta, Nigeria (Figure 3.1). The distance between Oredo-2 and Oredo-8 is 1.192 km while Oredo-4 is 2.0 km from Oredo-8.

The samples in all the wells were supplied at varied intervals of 10, 30 and 40 and 60 meters. However, there were some gaps resulting from either non-provision of samples or loss of samples. These are more conspicuous in Oredo-8 well where two major gaps exist between 2680 and 2780 m and between 3280 and 3400 m.

The gamma ray and resistivity logs were made available intervals 1855 – 3450 m of Oredo-2 well, 1880 – 3800 m of Oredo-4 well and 1885 – 3680 m of Oredo-8 well.

3.2 Preparations Techniques and Analytical Methods

Standard laboratory biostratigraphic and sedimentological preparation procedures were adopted in ensuring maximum extraction of microfossils, organic matter and accessory mineral contents embedded in all the samples.

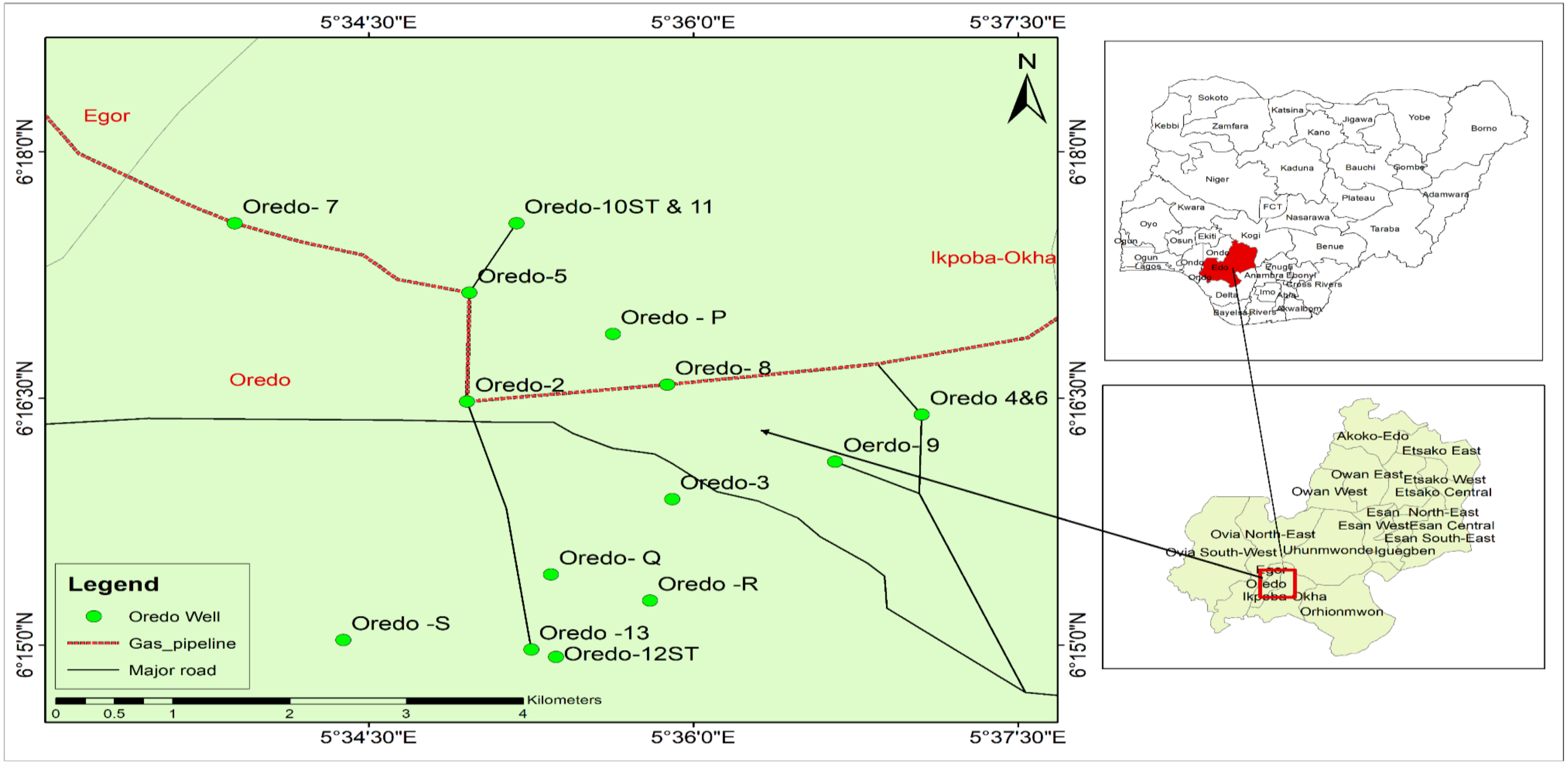


Figure 3.1: Location Map of Oredo Field, Northern depobelt, Niger Delta (GIS map with field data coordinates)

3.2.1 Palynological Preparation

a. Sample Arrangement and Sorting

Samples were arranged in sequential order on a table. Thereafter, they were composited either at 60 m intervals for the sandy upper samples or at 20 m intervals for the basal, shale portions of the wells. Fifteen grams per composited samples were placed in 250-500 ml polypropylene beakers placed in a fume chamber.

b. Removal of Carbonates

Concentrated 36% Hydrochloric acid (HCl) sufficient to cover the samples was slowly added resulting in violent effervescence which was subdued by adding distilled water. The spent HCl was decanted and the beaker filled to the top with distilled water, allowed to settle and then decanted. The process was repeated thrice to remove any remaining calcium ions which could produce a precipitate when Hydrofluoric acid (HF) is added.

c. Elimination of Silicates

Forty per cent HF enough to cover the samples was added and left overnight in the fume chamber. After 24 hours, the samples were covered with distilled water, after settling, centrifuged and decanted. The process was repeated three times to ensure complete removal of HF.

d. Removal of Silico-fluoride Gel

The residue was transferred into 150/100ml Pyrex glass beaker after the removal of HF in the previous step. Fifty per cent HCl (40ml) was added to the residue and boiled down to 20ml, allowed to cool down, filled up with distilled water, allowed to settle and decanted. This process was repeated three times until supernatant liquid was clear or neutral.

e. Heavy Liquid Separation

Separation of organic from inorganic matter was done by using Zinc bromide solution. The residue was transferred into a 15ml test tube and topped up with 10% HCl. It was centrifuged at 2000 rpm for ten minutes and then decanted. A little Zinc bromide ($ZnBr_2$) solution (s. g. 2.2) was added, stirred and then topped up with approximately 25ml $ZnBr_2$ up to ¾ full. The residue was centrifuged at 2000 rpm for ten minutes and decanted. The dark organic portion was pipetted into another test tube. This step was repeated thrice to increase recovery.

f. Filtration and Sieving

The final residue from the above process was transferred into a plastic beaker to which water was added and mixed thoroughly. The mixture was washed through a 10 µm mesh polypropylene nylon sieve with the aid of a pumping machine to facilitate complete removal of silt and clay particles. The nylon sieves were used repeatedly before disposal but washed thoroughly after each use to avoid contamination of the samples. Each sample was divided into two equal portions, each of which was pipetted into a 5 ml plastic vial; one vial was set aside for palynofacies analysis and the other was oxidized.

g. Unoxidized Kerogen Residue

The 5ml residue set aside for palynofacies or kerogen analysis was excluded from oxidation processes using nitric acid to preserve the colour of the organic components in their natural state for palynofacies and thermal alteration index studies.

h. Oxidation

The residue for palynomorphs analysis was subjected to oxidation treatment to ensure improved recovery and concentration of palynomorphs. Concentrated Nitric acid (HNO_3) was added to the residue in glass beaker in a fume chamber and left for about ten minutes. It was then covered up with water, mixed thoroughly, and centrifuged at 2000 rpm for two minutes, decanted. The process was repeated thrice with the resulting residue washed with distilled water until it was neutral. About two drops of 10% of Potassium hydroxide solution was added to the residue and thoroughly mixed to remove the oxidized humic compounds. The sample with Potassium hydroxide solution was then washed with distilled water and centrifuged at 1500RPM for 5minutes. The procedure was repeated thrice.

i. Dispersal of Organic Suspension

The final residue from the above procedure was thoroughly mixed with Polyvinyl alcohol (PVA) in a labeled phial to disperse the clumped organic residue. Preparation of the PVA entails dissolving about one gm of PVA granules in boiling water and stir. The solution boiled for a couple of minutes until the granules completely dissolved and allowed to cool before use. Few drops of formaldehyde were added for preservation. Two to three drops of PVA were required for dispersing the organic particles. The volume of the final residue in the calibrated centrifuge tube was noted.

j. Spotting and Mounting

A known volume of 100% glycerine was added to the residue which was then thoroughly mixed and transferred into a labelled vial. About 20µl of the mixture was transferred using a disposable, graduated pipette onto a cover slip (32 mm x 22 mm) and placed on a slide warmer (low temperature hot plate) to dry. Two drops of NORLAND adhesive were added. The cover slip was turned over, placed on a glass slide (76 mm x 26 mm) and permanently sealed. Two labelled slides, one each for palynomorph and palynofacies studies, were prepared for each sample.

3.2.2 Analytical Procedures

The prepared slides were painstakingly analyzed quantitatively and qualitatively by counting as well as recording the palynomorphs and particulate organic matter encountered using an Olympus Biological Microscope (Model CH). The slides were scanned with a x 20 objective, while a x 100 oil immersion objective was used for detailed observation and description.

Identification of the palynomorphs was aided by reference to published and unpublished photomicrographs and descriptions. The pollen reference slide collection of more than 3000 species in the Palynology Laboratory in the Department of Archaeology and Anthropology, University of Ibadan, Ibadan, with the in-house collection at the Palynological Unit, GEC Energy Solutions Ltd., Lagos, Nigeria were also consulted.

The recovered palynomorphs were identified as far as possible to specific, generic, and family levels. Both botanical and morphological nomenclatures were adopted. Photomicrographs of significant identified palynomorphs were taken with the aid of a Sargent-Welch 30601194 microscope with DCM 130 (1.3mpixels) Digital Camera attachment in Petrology Laboratory, Department of Geology, University of Ibadan.

3.2.3 Palynozonation

The stratigraphic occurrences of significant pollen and spores and floral assemblages recorded in the wells constitute the basis for the palynological zonations erected in this study. Inferred palynological superzones, zones and sub-zone were guided by the existing schemes of Germeraad *et al.* (1968), Evamy *et al.* (1978), Legoux (1978) and Salard-Cheboldaeff (1978).

Some of the terms in use for the establishment of the stratigraphic level of palynofloral marker species and their definitions, according to (Boom, 1977), are as follows. Some of these terms were adopted for the palynological zonation in this study.

a. Top Occurrence (First Downhole Occurrence): highest stratigraphic level at which a species is found.
b. Top Regular Occurrence: the highest stratigraphic level of a regular occurrence of a species.
c. Quantitative Top Occurrence: Stratigraphic level at which a species shows a clear quantitative top.
d. Top Rich Occurrence: Highest stratigraphic level a species occurs in rich proportion.
e. Increase: Stratigraphic level a species shows a sharp increase in percentage relative to the nearest higher sample.
f. Base Occurrence (Last Downhole Occurrence): Lowest stratigraphic level at which a species occurs.
g. Base Continuous Occurrence: lowest stratigraphic level of a continuous occurrence of a species.
h. Quantitative Base Occurrence: Stratigraphic level at which a species shows a clear quantitative base.
i. Base Rich Occurrence: Lowest stratigraphic level at which a species shows rich proportion.

3.2.4 Phyto-ecological Assemblages

The identified pollen and spores with other recovered palynomorphs were classified into phyto-ecological assemblages or groups based on the natural, ecological distribution of the extant, analogous plants entities.

The following are the phyto-ecological groups: Mangrove, Freshwater Swamp Forest, Lowland Rainforest, and Savanna. Other classified palynomorphs include: Spores (Pteridophyte Spores), Algae, Dinoflagellates, Microforaminifera Wall Lining (MWL), Fungal Spores and Acritarch.

The plots of the percentage distribution of the phyto-ecological groups were used in the reconstruction of the palaeoenvironments of deposition, palynological characterization of the systems tracts, as well as in the delineation of palynological climate cycles.

The composition of the phyto-ecological groups and pteridophyte spores are outlined below:

Mangrove Species:

Rhizophora spp. (*Zonocostites ramonae*)
Pelliceria rhizophorae (*Psilatricolporites crassus*)
Crenea maritama (*Verrutricolporites rotundiporus*)
Nypa fruticans (*Spinizonocolpites baculatus*/*echinatus*)
Acrostichum aureum

Freshwater Swamp Forest Species:

Symphonia globulifera (*Pachydermites diederixi*)
Amanoa oblongifolia (*Retitricolporites irregularis*)
Alchornea cordifolia. (*Psilatricolporites operculatus*)
Ctenolophon englerianum (*Ctenolophonidites costatus*)
Ludwigia stenorraphe (*Corsinipollenites jussiaeensis*)
Mauritia vinifera (*Mauritiidites crassiexinus*)
Pentadesma butyraceae (*Psilastephanocolporites boureaui*)
Cyperus rotundus (Cyperus Type)

Lowland Rainforest Species:

Canthium sp. (Rubiaceae)
Combretodendron macrocarpa (*Marginipollis concinnus*)
Afzelia bellaveri (*Spirosyncolpites bruni*)
Pentacletra macrophylla (*Brevicolporites guinetii*)
Ctenolophon parvifolius (*Retistephanocolpites williamsi*)
Psilastephanocolporites sapotaceae
Napoleonaca imperialis (*Praedapollis africanus*)
Alstonia booeni (*Retibrevitricolporites ibadaneensis*)
Malancantha alnifolia (Psilastephanocolporites malacanthoides)

Savanna Species:

Justicia insularis (*Multiareolites formosus*)
Anthonotha gilletii (*Striatricolpites catatumbus*)
Brachystegia nigerica (*Peregrinipollis nigericus*)

Pteridophyte Spores:

Anemia sp. (*Cicatricosisporites dorogensis*)
Ceratopteris cornuta (Magnastriatites howardi)
Lycopodium cernuum (Lycopodiumsporites fastiginoides)
Lygodium microphyllum (Crassoretitriletes vanraadshooveni)
Polypodium vulgare (Verrucatosporites terellis)
Pteris mohasiensis (Polypodiaciesporites retirugatus)
Stenochlaena palustris (Verrucatosporites usmensis)

3.2.5 Assessment of Thermal Maturity

Changes in the colour of palynomorphs, particularly the pteridophytic spores, encountered in the un-oxidized slides as viewed under a transmitted light microscope were noted for the determination of the thermal maturity of the sedimentary organic matter.

Comparison was made with the modified Batten (1981,1982) and Gaupp and Batten (1985) correlation of thermal maturation indicators in sedimentary rocks by Batten (1996) (Table 3.1) for the estimation of the Thermal Alteration Index (TAI), Vitrinite Reflectance (R◦) and Organic Maturity.

3.2.6 Palynofacies Study

Palynofacies (kerogen) analyses of all the un-oxidised samples were conducted. The palynofacies classification scheme of Oboh (1992) was adopted and used with 300 organic particles counted per slide. Table 3.2 shows the outline of the classification scheme used in this study (Oboh, 1992).

Palynofacies data were analysed using multivariate statistical techniques such as the principal component, descriptive and cluster analyses.

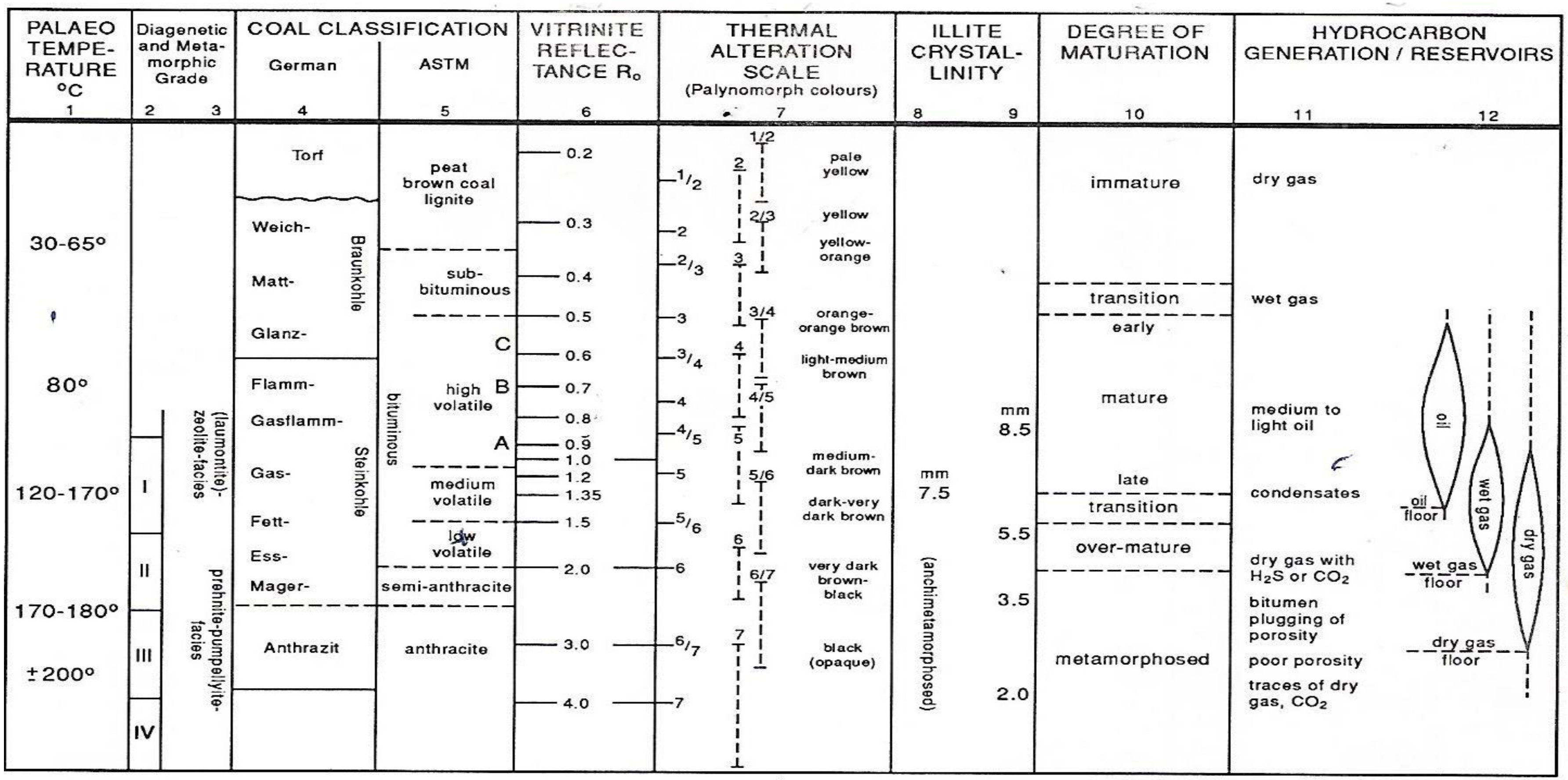
3.2.7 Statistical Analysis

3.2.7.1 Principal Component Analysis

Principal Component Analysis (PCA) is a variable reduction technique used in finding linear combinations of original variables useful in summarizing data recording loss of little information as far as possible. The technique transforms the original set of variables into a smaller set of linear combinations so that most of the variations in the original data set are explained by those linear combinations (Principal Components (PC)).

The PC's are extracted in such a way that the first PC explains the largest of the total variation in the data set. The first PC is a linear combination of the observed variables with values of first eigenvector as weights. The second PC is the weighted linear combination of the original variable. The second PC is uncorrelated with the first PC and it accounts for the maximum amount of the remaining total variation unexplained by the first PC etcetera.

Table 3.1: Correlation of thermal maturation indicators in sediments (After Gaupp and Batten, 1985; Batten, 1996)



PALAEO TEMPE-RATURE °C 1	Diagenetic and Meta-morphic Grade 2	3	COAL CLASSIFICATION German 4	COAL CLASSIFICATION ASTM 5	VITRINITE REFLEC-TANCE R_o 6	THERMAL ALTERATION SCALE (Palynomorph colours) 7			ILLITE CRYSTAL-LINITY 8	9	DEGREE OF MATURATION 10	HYDROCARBON GENERATION / RESERVOIRS 11	12
			Torf	peat brown coal lignite	0.2		1/2	pale yellow			immature	dry gas	
						1/2	2						
			Weich- (Braunkohle)		0.3	2	2/3	yellow					
30-65°						2/3	3	yellow-orange					
			Matt- (Braunkohle)	sub-bituminous	0.4								
											transition	wet gas	
			Glanz- (Braunkohle)		0.5	3	3/4	orange-orange brown			early		
				C (high volatile, bituminous)	0.6	3/4	4	light-medium brown					
80°			Flamm- (Steinkohle)	high volatile B (bituminous)	0.7		4/5				mature		oil
		(laumontite)-zeolite-facies	Gasflamm- (Steinkohle)		0.8	4				mm 8.5		medium to light oil	wet gas
				A (high volatile, bituminous)	0.9	4/5	5						
					1.0			medium-dark brown					
120-170°	I		Gas- (Steinkohle)	medium volatile (bituminous)	1.2 1.35	5	5/6		mm 7.5		late	condensates	oil floor
			Fett- (Steinkohle)		1.5	5/6		dark-very dark brown			transition		dry gas
			Ess- (Steinkohle)	low volatile (bituminous)			6			5.5	over-mature		
	II	prehnite-pumpellyite-facies			2.0	6	6/7	very dark brown-black	(anchimetamorphosed)			dry gas with H_2S or CO_2	wet gas floor
			Mager- (Steinkohle)	semi-anthracite									
170-180°										3.5		bitumen plugging of porosity	
	III		Anthrazit	anthracite	3.0	6/7	7	black (opaque)			metamorphosed	poor porosity	dry gas floor
±200°													
					4.0	7				2.0		traces of dry gas, CO_2	
	IV												

Table 3.2: Classification of Identified Particulate Organic Matter found in the Study Oboh (1992)

Palynomorph (Pal)	**Phytoclasts (Phy)**	**Structureless Organic Matter (SOM)**	**Others (OT)**
Sporomorphs (Pollen & Spores) (SPH)	Black & Brown Wood (BBW)	Amorphous Organic Matter (AOM).	Diatoms (DT)
Fungal Elements (FE)	Charcoal (Black Debris). (CH)	Gelified Matter (GM)	Miscellaneous (Undifferentiated Components) (MSS)
Dinoflagellate Cysts (DC)	Epidermal Cuticle (EC)		
Algal Elements (AE)	Filaments, Hairs and Tubes (FHT)		
Microforaminiferal Wall Linings (MWL)	Non-Cuticular Tissues (Herbaceous Materials) (NCT)		
	Tracheid Elements (TE)		
	Resin Matter (RM)		

The goal of PCA is to select as few PCs as possible so that the selected components account for most of the total variation in the original data set.

3.2.7.2 Descriptive Analysis

Descriptive analysis of data obtained from the palynofacies analysis of samples in the three wells available for study was carried out. Descriptive analysis are brief descriptive coefficients summarizing specific data set that can either be a representation of the entire or subset of sample population. It can either be broken down into measures of central tendency or measures of variability.

3.2.7.3 Cluster Analysis

For further test of abundance and significance of the particulate organic matter, their relative abundance and composition were subjected to cluster analysis in all the three wells studied. This was in order to establish their patterns of distribution, recognize the relationship within them and find out if their abundances are environmentally significant since some lower components could be significant in terms of distribution.

For this analysis, the basic variables of interest are the particulate organic matters that constitute the groups since the depths only confirms the distribution from one depth to another. As a result of this, each of these organic matters was considered across depth. This will help us to discover which particulate group is most abundant across the cluster categories.

3.2.7.4 Ternary Plot

The Amorphous Organic Matter (AOM) – Phytoclasts – Palynomorphs ternary plot of Tyson (1995), Figure 3.2, was adopted to infer depositional environments and sources of terrestrial organic matter recovered in the wells studied. Description and characterization of the nine palynofacies fields as defined by Tyson (1995) from the ternary plot is shown in Table 3.3.

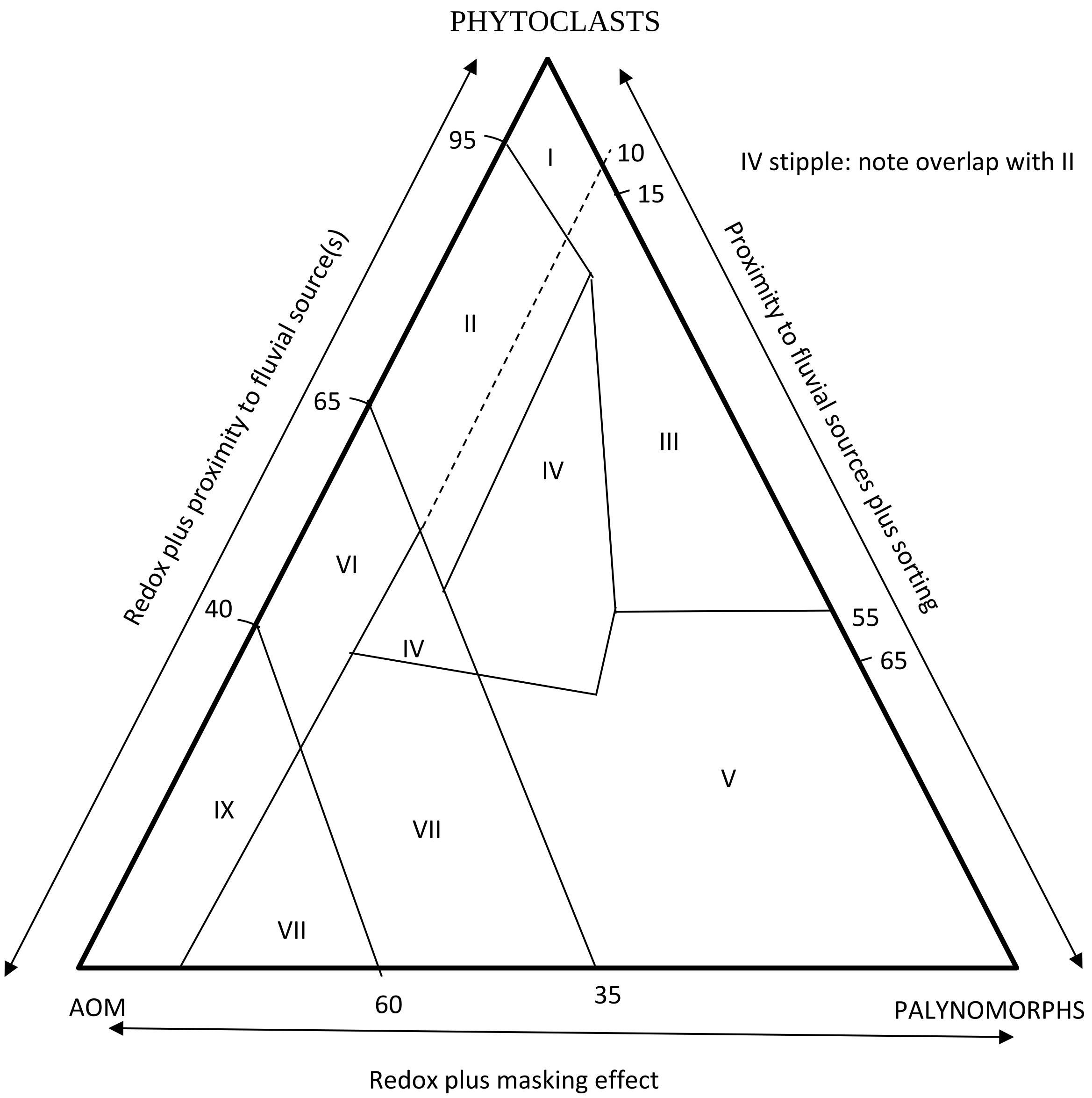


Figure 3.2: Ternary Kerogen Diagram (After Tyson, 1995)

Field I = highly proximal shelf or basin; Field II = marginal dysoxic-anoxic basin; Field III = heterolithic oxic shelf (proximal shelf); Field IV = shelf to basin transition; Field V = mud-dominated oxic shelf (distal shelf); Field VI = proximal suboxic-anoxic shelf; Field VII = distal dysoxic-anoxic shelf; Field VIII = distal dysoxic-oxic shelf; Field IX = distal suboxic-anoxic basin.

Table 3.3: Palynofacies Fields defined in the Ternary Kerogen Diagram (After Tyson, 1995)

Palynofacies Field and Environment	**Comment**	**Spores: Bissacate**	**Microplankton**	**Kerogene Type**
I Highly proximal (gas prone) dysoxic-anoxic basin	High phytoclasts supply dilutes all other components	Usually high	Very low	III
II Marginal dysoxic - (gas prone) anoxic basin	AOM diluted by high phytoclasts input, but AOM preservation moderates to good. Amount of marine TOC dependent on basin redox state. Generally low AOM preservation.	High	Very low	III
III Heterolithic oxic or IV (gas Shelf ('proximal prone) shelf')	Absolute phytoclasts abundance dependent on actual proximity to fluvio-deltaic sources. Oxidation and reworking common.	High	Common to abundant dinocysts dominant	III
IV Shelf to basin OR II Transition (mainly prone)	Passage from shelf to basin in time (i.e. increased/water depth) space (e.g. basin slope). Absolute phytoclast abundance depends on proximity to source and degree of redeposition, Amount of marine TOC depends on basin redox state. IVa dysoxic-suboxic; IVb suboxic-anoxic.	Moderate-high	Very low low	III gas
V Mud-dominated > IV	Low to moderate AOM (usually degraded).			III

oxic (distal) shelf (gas prone)	Palynomorphs abundant. Light-coloured bioturbated, Calcareous mudstone typical.	Usually low	Common to abundant dinocysts dominant	
VI Proximal (oil prone) suboxic-anoxic Shelf	High AOM preservation due to reducing basin conditions. Absolute phytoclast content may moderate to high due to turbiditic input and/or general proximity to source.	Variable low to moderate	Low to common dinocysts dominant	II
VII Distal dysoxic- anoxic (oil prone) ‘shelf’	Moderate to good AOM preservation, low to moderate palynomorphs. Dark-coloured slightly bioturbated mudstones are typical	Low	Moderate to common dinocysts dominant	II
VIII Distal dysoxic >> I (oil anoxic shelf prone)	AOM-dominant assemblage, excellent AOM preservation. Low to moderate palynomorphs (partly due to masking). Typical of organic rich shales deposited under stratified shelf sea conditions.	Low	Moderate to moderate dinocysts dominant, % prasinophytes increasing	II
IX Distal suboxic- anoxic basin (highly oil prone)	AOM-dominant assemblages. Low abundances of palynomorph partly due to masking. Frequently alginate-rich. Deep basin or stratified shelf sea deposits, especially sediments starved basins.	Low	Generally low, prasinophytes often dominant	II > I

3.2.8 Micropaleontological Sample Preparation and Analysis

Samples were orderly arranged and were composited either at 60 m or 20 m. Forty grams of each of the composited samples were measured into clean sample plates prepared and labelled. The sample plates were heated on a hot plate regulated to a temperature of about 80°C. After about 2-3 hours, the hot plate was switched off, the sample plates were removed and allowed to cool. The dried samples were weighed and soaked in kerosene overnight to disaggregate. The kerosene was then drained off and the samples soaked in water overnight. The samples were washed in water through three sieve meshes, 250, 150 and 65 µm and dried. Each of the samples was transferred into a different plastic bag in fractions of coarse, medium and fine respectively. The three bags were put in one plastic bag and labelled. The packaged samples were ready for picking and analysis.

Each of the packaged sample residue was subjected to picking of the inherent microforaminifera and the other associated fauna fossils. Fossils from all the fractions (coarse, medium, and fine) were put into a cardboard microslide and covered by 22 x 22 mm coverslip for microscopic analysis. Analysis of the picked fossils was conducted using WILD Heerbrugg stereomicroscope. Identification of the picked fauna was aided by the publications of Bolli (1969), Bolli and Saunders (1985), Petters (1982) and Postuma (1971).

3.2.9 Foraminiferal Zonation

The planktic foraminiferal zones recognized in this study are based on the revised Cenozoic Geochronologic and Chronostratigraphic Schemes of Berggren *et al*. (1995) and Blow (1969, 1979).

The significant bioevents for zonal delineation of the studied interval are:

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

3.2.10 Lithologic Sample Preparation and Description

The provided samples were logged to detect sample gaps by laying them on a flat surface in a sequential depth order. About 5 g of ditch cutting samples per depth was soaked in soapy water for 30 minutes and washed through a 63 µm sieve until the sample was free of mud. The residue was well rinsed in a stream of flowing water with the supernatant water decanted and the residue placed back in the aluminium dishes. The clean residue was dried at low temperature of about 50°C for an hour. The sample was allowed to cool and then stored in well-labelled phials.

The processed samples were described using a WILD Heerbrugg stereomicroscope following the procedures in the American Association of Petroleum Geologists (AAPG) Sample Description Manual. From the lithological descriptions conducted on the samples, their textural, index minerals and accessories constituents were noted and recorded on analysis sheets. Detailed description of each sample was also carried out.

3.2.11 Interpretation of Wireline Logs and Sequence Stratigraphic Approach

The stacking pattern sequence of the wireline logs and lithology were interpreted using the gamma ray and resistivity logs available for the three wells. From these, systems tracts, sequences, sequence boundaries and maximum flooding surfaces were identified based on the criteria of Mitchum *et al*. (1990). By plotting the well log at higher and uniform scales, the log trends were enhanced resulting in precise definition of the different systems tracts, sequence boundaries and maximum flooding surfaces. The lithofacies and depositional environments of the sequences in the wells were determined using the gamma ray log values and fining and coarsening upward signatures in conjunction with biostratigraphic information (palynomorphs and foraminifera).

The standard sequence stratigraphic interpretation procedures of Mitchum *et al*. (1990) for integrating high resolution biostratigraphic data obtained from foraminifera and palynomorphs with lithostratigraphic and well log data (Vail and Wornardt, 1991) was adopted in this study. Foraminiferal and dinoflagellate cysts abundance and diversity minima and maxima were used for identifying candidates for sequence boundary and condensed section, respectively. Condensed sections are clay-rich horizons with characteristic backstepping log motifs defined by an abrupt rise in faunal abundance and diversity accompanied by sudden increases in palaeowater depth.

Maximum Flooding Surfaces (MFSs) were selected within the identified Condensed Sections and confirmed on the gamma logs. MFSs are points of maximum shale development indicated by high gamma log and low resistivity values as well as point of highest microfossil abundance and diversity. Sequence Boundaries are recognized on the gamma log by carefully searching for points of decreasing accommodation above each Maximum Flooding Surface up to a point where there was increase in shelfal accommodation upward. In some cases, they coincide with faunal and floral minima, change in biofacies assemblages and reduction in palaeowater depth.

The intervals above the SBs to the next overlying MFSs present a variety of stratigraphic packages referred to as systems tracts; the TST, HST and LST depending on the balance between sediments supply, accommodation and subsidence.

Furthermore, palynomorphs assemblage classified into phytoecological groups, representing different palaeoenvironments, were applied for the characterization of identified system tracts following the approaches of Morley (1995a, b) and Holz and Dias (1998). Changes in the composition of palynomorph assemblages were incorporated in conventional sequence stratigraphic model to establish a sequence stratigraphic framework.

3.2.12 Data Generation

Data on the identified palynomorphs, palynofacies and foraminifera components were fed into the geological software, STRATABUG (version 2.2). Abundance of recorded species was computed as absolute numbers while the phyto-ecological groups were captured as percentage composition.

CHAPTER FOUR

RESULTS

4.1 Biostratigraphy of Oredo-2 well

4.1.1 Palynostratigraphy

Well-preserved pollen and spores constituted the abundant and diverse palynofloral assemblages encountered in the well (Enclosure 1). The dominant palynomorphs encountered include: *Retitricolporites irregularis, Psilatricolporites crassus, Monoporites annulatus, Psilamonocolpites marginatus, Retibrevitricolporites ibadaneensis, Psilatricolporites* sp., pteridophyte spores such as *Acrostichum aureum*, *Verrucatosporites terellis* and *Laevigatosporites discordatus*.

Also, a rich proportion of diverse fungal spores was recorded. Dominant among these were: *Exesisporites* sp., *Pleuricellaesporites* sp., *Basidiosporites* sp., *Diacellaesporites* sp., *Dyadosporites* sp., *Involutisporites* sp., *Diporisporites* sp., and *Phragmothyrites* sp., among others.

Recovery of dinoflagellate cysts was limited to rare and few occurrences of *Lingulodinium machaerophorum*, *Eocladopyxis paniculata*, *Lejeuncysta* sp., *Paleocystodinium golzowense*, *Oligospaeridium complex, Selenophemphix nephroides, Polysphaeridium zoharyi*, and species of *Homotryblium* and *Spiniferites*. The acritach, *Leiosphaeridium* sp. was recorded in high proportion while microforaminiferal wall lining was scanty. The brackish water alga, *Botryococcus braunii*, constituted the dominant alga recorded with few freshwater species *Pediastrum* sp. and *Concentricyst*. Charred Poaceae Cuticle recovered were rare.

The age diagnostic/significant pollen and spores encountered include: *Elaies guineensis, Verrutricolporites laevigatus, V. scabratus, Magnastriatites howardi, Cicatricosisporites dorogensis, Arecipites exilimuratus, Spirosyncolpites bruni, Verrustephanocolporites complanatus, Inaperturopollenites gemmatus, Spinizonocolpites echinatus, Spinizonocolpites baculatus, Retimonocolpites obaensis, Praedapollis africanus, Proxapertites cursus, Proxapertites operculatus,* *Striamonocolpites rectostriatus, Retitricolpites bendeensis, Psilamonocolpites marginatus, Grimsdalea polygonalis, Psilatricolporites onitshaeensis, Peregrinipollis nigericus, Cinctiporipollis mulleri, Verrucatosporites usmensis, R. ibadaneensis, Mauritiidites crassiexinus, Periretipollis spinosus, Doualaidites laevigatus, Auriculopollenites reticulatus, A. echinatus* and *A. simplex.*

4.1.2 Zonation

Zonation of the well was based on the recovered assemblages and stratigraphic distribution of the diagnostic species mentioned above with reference to previous studies such as those of Germeraad *et al*. (1968), Legoux (1978), Evamy *et al*. (1978) and Salard-Cheboldaeff (1990). Three superzones are proposed for the analysed section of the well viz: *Periretipollis spinosus, Cicatricosisporites dorogensis* and *Verrutricolporites laevigatus* Superzones. A superzone is made up of two or more zones which characterize evolutionary trends in the development and succession of the source plants.

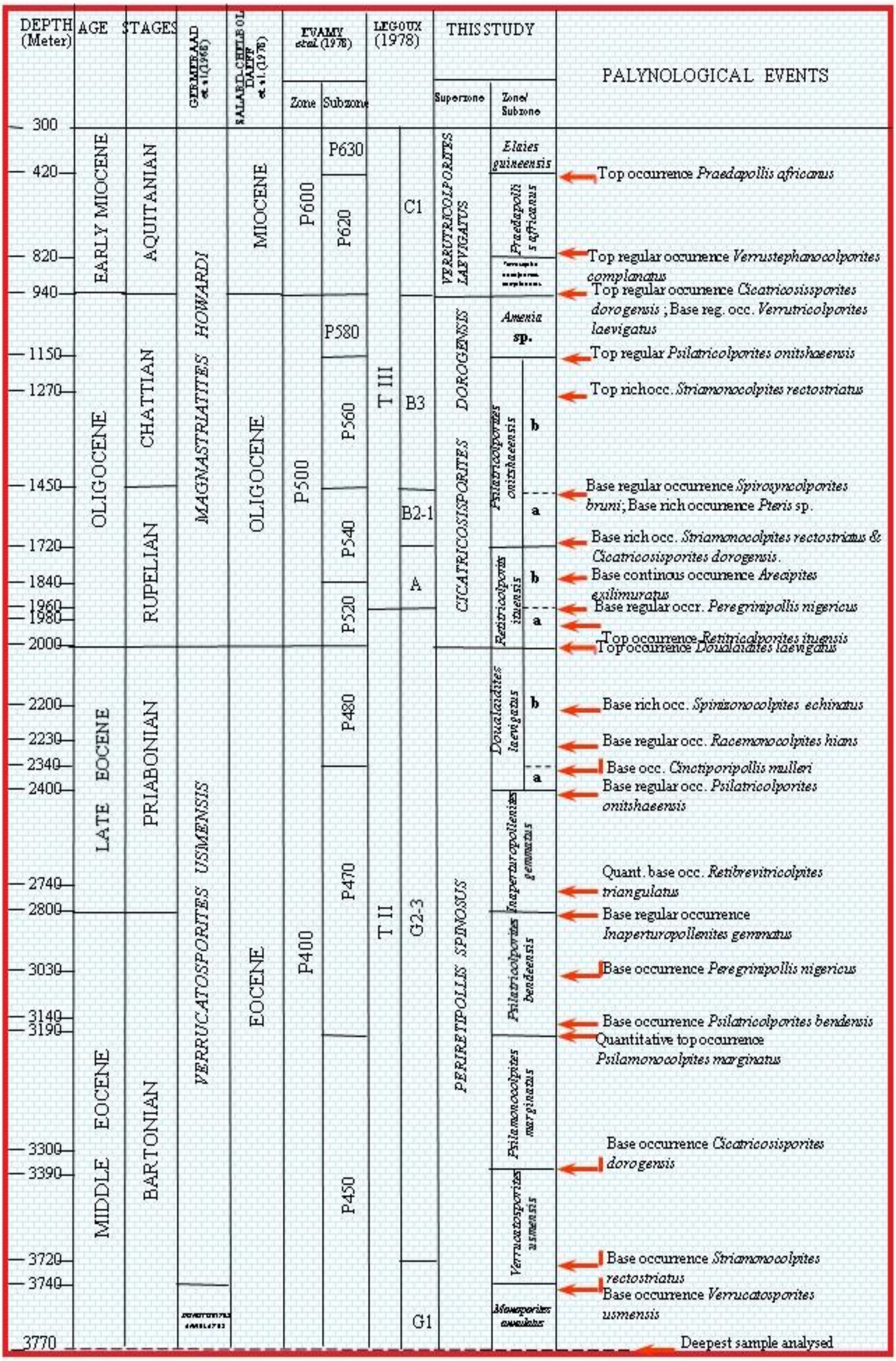
The twelve recognized zones are: *Monoporites annulatus*, *Verrucatosporites usmensis*, *Psilamonocolpites marginatus*, *Retitricolpites bendeensis*, *Inaperturopollenites gemmatus*, *Dualaidites laevigatus*, *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis*, *Anemia* sp., *Verrustephanocolporites complanatus*, *Praedapollis africanus* and *Elaies guineensis* Zones (Table 4.1). Details of the different ages encountered, as indicated by diagnostic palynomorphs, are outlined below:

Superzone:	*Periretipollis spinosus*
Interval:	4000 - 2000 m
Age:	middle-late Eocene

Definition:

Base:	Shallower than 4000 m which is the base of the last sample analysed.
Top:	Top occurrence of *Doualaidites laevigatus* at 2000 m.

Table 4.1: Palynostratigraphic zonation of Oredo-2 well



Correlation: *Verrucatosporites usmensis* Zone of Germeraad *et al*. (1968); Zone P400 of Evamy *et al*. (1978) and TII of Legoux (1978).

Description

The *Periretipollis spinosus* Superzone comprises the *Monoporites annulatus, Verrucatosporites usmensis, Psilamonocolpites marginatus, Retitricolpites bendeensis, Inaperturopollenites gemmatus* and *Doualaidites laevigatus* Zones.

Characteristic Features: The Superzone is characterised by the top occurrences (last appearance datums) of *Doualaidites laevigatus, Mauritiidites crassiexinus* and *Periretipollis spinosus.* The three pollen are also restricted to the superzone.

Cicatricosisporites dorogensis, Verrucatosporites usmensis, Monoporites annulatus, Peregrinipollis nigericus, Praedapollis africanus, Cinctiporipollis mulleri, Retitricolpites bendeensis and *Praedapollis flexibilis* have their base occurrences (first appearance datums) within the Superzone.

Zones of Superzone *Periretipollis spinosus*

Zone: *Monoporites annulatus*

Interval: 4000 - 3740 m

Assigned Age: middle Eocene

Definition:

The Zonal Base: Deeper than 4000 m, the deepest sample analysed.
The Zonal Top: Marked at 3740 m, by the base occurrence of V*errucatosporites usmensis*.

Correlation: Zone P450 of Evamy *et al*. (1978) and G1 of Legoux (1978).

Characteristics:

- *Doualaidites laevigatus, Mauritiidites crassiexinus* and *Auriculopollenites reticulatus* show their presence within the zone.
- *Psilatriporites rotundus* shows regular occurrence.

- *Verrucatosporites usmensis* is absent but has its base occurrence at the top of this zone.
- The dominant palynomorphs recorded in the zone are *Psilatricolporites crassus, Monoporites annulatus* and *Psilamonocolpites marginatus.*

Remarks: The *Monoporites annulatus* used in defining the zone is strongly believed to have its true base deeper than 4000 m depth which is the base of the last sample analysed. Germeraad *et al*. (1968) had earlier used its base to mark the basal boundary of the *Monoporites annulatus* Zone.

Zone: *Verrucatosporites usmensis*

Interval: 3740 – 3390 m

Assigned Age: middle Eocene

Correlation: Zone P450 of Evamy *et al*. (1978) and G1 - G2-3 of Legoux (1978).

Definition:

Zonal Base: Base occurrence of *Verrucatosporites usmensis* at 3740 m

Zonal Top: Base occurrence of *Cicatricosisporites dorogensis* at 3390 m.

Characteristics:

- *Striamonocolpites rectostriatus* has its base occurrence within the zone at 3720 m.
- Presence of *Doualaidites laevigatus*.
- Presence of *Verrucatosporites usmensis*.
- *Psilatricolporites crassus, Monoporites annulatus, Psilamonocolpites marginatus* remain the dominant palynomorphs in the palynofloral assemblage within the zone.

Zone: *Psilamonocolpites marginatus*

Interval: 3390 - 3190 m

Assigned Age: middle Eocene

Definition:

Zonal Base: The base occurrence of *Cicatricosisporites dorogensis* at 3390 m.

Zonal Top: Quantitative top occurrence of *Psilamonocolpites marginatus* at 3190 m.

Correlation: Zone P450 of Evamy *et al*. (1978) and G2 -3 of Legoux (1978).

Characteristics:

- *Mauritiidites crassiexinus* is regularly present within the zone.
- Presence of *Grimsdalea polygonalis.*
- *Cicatricosisporites dorogensis* has its base occurrence (FAD) at the zonal base.
- *Psilamonocolpites marginatus* abundance.

The dominant palynomorphs within the zone still remain *Psilatricolporites crassus*, *Monoporites annulatus* and *Psilamonocolpites marginatus*

Zone: *Retitricolpites bendeensis*

Interval: 3190 - 2800 m

Assigned Age: middle Eocene

Definition:

Zonal Base: Defined by the quantitative top occurrence of *Psilamonocolpites marginatus* at 3190 m.

Zoanl Top: Marked at 2800 m, the base regular occurrence of *Inaperturopollenites gemmatus*.

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Praedapollis africanus* has its base occurrence within the zone at 3030 m.
- *Retitricolpites bendeensis* has its base occurrence within the zone or close to its basal boundary at 3140 m.
- The palynofloral assemblage is dominated by *Psilatricolporites crassus* and *Monoporites annulatus*.

Zone: *Inaperturopollenites gemmatus*

Interval: 2800 – 2400 m

Assigned Age: late Eocene

Definition:

Zonal Base: Regular occurrence of *Inaperturopollenites gemmatus* at 2800 m.

Zonal Top: Base regular occurrence of *Psilatricolporites onitshaeensis* at 2400 m.

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Retibrevitricolpites triangulatus* has its quantitative base occurrence in the zone at 2740 m.
- *Psilatricolporites crassus* and *Monoporites annulatus* still constitute the dominant palynomorphs of the zone.

Zone: *Doualaidites laevigatus*

Interval: 2400 – 2000 m

Assigned Age: late Eocene

Definition:

Zonal Base: Base regular occurrence of *Psilatricolporites onitshaensis* at 2400 m

Zonal Top: Top occurrence of *Doualaidites laevigatus a*t 2000 m.

Correlation: Zones P470 - P480 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Racemonocolpites hians* has its base regular occurrence in the zone at 2230 m.
- *Cinctiporipollis mulleri* has its base occurrence at 2340 m.
- *Spinizonocolpites echinatus* has its base rich occurrence at 2200 m.
- *Retimonocolpites obaensis* and *Grimsdalea polygonalis* both exhibit regular occurrences.

Psilatricolporites crassus, Retibrevitricolporites ibadaneensis, Psilatricolporites spp. and Pteridophyte spores such as trilete spore (*Acrostichum aureum*), *Verrucatosporites terellis* and *Laevigatosporites discordatus* dominate the palynofloral assemblage of this zone.

Remark:

The *Doulaidites laevigatus* Zone was further sub-divided into sub-zones a and b by the base occurrence of *Cinctiporipollis mulleri* at 2340 m.

The Eocene – Oligocene boundary was defined by the top occurrence of *Doualaidites dorogensis* at depth 2000 m.

Superzone: *Cicatricosisporites dorogensis*

Interval: 2000 – 940 m

Age: Oligocene

Definition:

Base of the Superzone: Top occurrence of *Doualaidites laevigatus* at 2000 m.

Top of the Superzone: Top regular occurrence of *Cicatricosisporites dorogensis* at 940 m.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P400 of Evamy *et al*. (1978) and TII - TIII of Legoux (1978).

Description:

The *Cicatricosisporites dorogensis* Superzone is made up of the *Retitricolporites ituensis, Psilatricolporites onitshaensis* and *Anemia* sp. Zones.

Characteristic Features:

The superzone is characterised by the top occurrences (Last Appearance Datums) of *Cicatricosisporites dorogensis, Verrustephanocolporites complanatus, Inaperturopollenites gemmatus, Spinizonocolpites echinatus, Retimonocolpites obaensis* and *Praedapollis africanus.*

Magnastriatites howardi has its base occurrence in the superzone.

Types with top rich occurrences in the superzone are: *Proxapertites cursus*, *P.*

operculatus, Striamonocolpites rectostriatus, Retitricolpites bendeensis and *Retimonocolpites obaensis*.
Arecipites exilimuratus, Psilatricolporites okeizei, Verrustephanocolporites complanatus and *Grimsdalea polygonalis* have top regular occurrences.

Zones of Superzone *Cicatricosisporites dorogensis*

Zone:	*Retitricolporites ituensis*
Interval:	2000 – 1720 m
Assigned Age:	Oligocene
Definition:	
Zonal Base:	Top occurrence of *Doualaidites laevigatus* at 2000 m.
Zonal Top:	Base rich occurrence of *Striamonocolpites rectostriatus* at 1720 m.
Correlation:	Zone P520 and P540 of Evamy *et al*. (1978) and G2-3 – A of Legoux (1978).

Characteristics:

- *Retitricolporites ituensis* has its top occurrence at 1980 m.
- *Retimonocolpites obaensis, Spinizonocolpites echinatus, Verrustephanocolporites complanatus and Inaperturopollenites gemmatus* show top rich occurrences.
- *Grimsdalea polygonalis and Proxapertites cursus* exhibit top regular occurrences.
- *Peregrinipollis nigericus* has a base regular occurrence.
- *Psilatricolporites onitshaeensis* shows regular occurrence.

Retibrevitricolporites ibadaneensis, Trilete spore *(Acrostichum aureum), Verrucatosporites terellis, Laevigatosporites discordatus, Retibrevitricolporites crassus, Inaperturopollenites gemmatus, Spinizonocolpites echinatus, Retimonocolpites obaensis* and *Retitricolporites irregularis* dominate the microfloral assemblage.

Remark:

The *Retitricolporites ituensis* Zone was further sub-divided into sub-zones a and b by the base regular occurrence of *Peregrinipollis nigericus* at 1960 m.

Zone:	*Psilatricolporites onitshaeensis*
Interval:	1720 – 1120 m
Assigned Age:	Oligocene

Definition:

Zonal Base:	The base rich occurrence of *Striamonocolpites rectostriatus* at 1720m.
Zonal Top:	Defined at 1120 m, the top regular occurrence of *Psilatricolporites onitshaeensis*.
Correlation:	Zones P520, P540 and P560 of Evamy *et al*. (1978) and B2-1 – B3 of Legoux (1978).

Characteristics:

- *Cicatricosisporites dorogensis* exhibits abundant occurences.
- *Arecipites exilimuratus* and *Psilatricolpites okeizei* both exhibit top regular occurrences.
- *Striamonocolpites rectostriatus* has its top rich occurrence at 1270 m.
- *Retitricolpites bendeensis* shows regular presence.

Retibrevitricolporites ibadaneensis, *Retibrevitricolporites crassus*, Trilete spore (*Acrostichum aureum*), *Verrucatosporites terellis*, *Laevigatosporites discordatus* and *Retitricolporites irregularis* still dominate the assemblage within the zone.

Remark:

The *Psilatricolporites onitshaeensis* Zone was sub-divided into sub-zones a and b by the base regular occurrence of *Spirosyncolporites hians* at 1450 m.

Zone:	*Anemia* sp.
Interval:	1120 – 940 m
Assigned Age:	Oligocene

Definition:

Zonal Top:	Top regular occurrence of *Psilatricolporites onitshaeensis* at 1120 m.
Zonal Base:	Top regular occurrence of *Cicatricosisporites dorogensis* at

940 m.

Correlation: Zone P580 of Evamy *et al*. (1978) and B3 of Legoux (1978).

Characteristics:

- *Retitricolpites bendeensis* exhibits its top rich occurrence at 940 m.

The palynofloral assemblage is dominated by *Racemonocolpites hians*, *Retitricolporites irregularis,* Trilete spore (*Acrostichum aureum*), *Verrucatosporites terellis* and *Laevigatosporites discordatus.*

Remark:

The Oligocene – Miocene boundary was defined by the top occurrence of *Cicatricosisporites dorogensis* at depth 940 m.

Superzone: *Verrutricolporites laevigatus*

Interval: 940 – 300 m

Age: early Miocene

Definition:

Superzone Base: Top regular occurrence of *Cicatricosisporites dorogensis* at 940 m.

Superzone Top: Tentatively marked at the top regular occurrence of *Verrucatosporites* sp. being the topmost level of the well, at 300 m.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P600 of Evamy *et al*. (1978) and TIII of Legoux (1978).

Description:

The *Verrutricolporites laevigatus* Superzone comprises the *Verrustephanocolporites complanatus, Praedapollis africanus* and *Elaeis guineensis* Zones.

Characteristics Features:

- The superzone is characterised by the top occurrence of *Praedapollis africanus.*
- *Elaeis guineensis* has its base occurrence within the superzone.

- *Verrutricolporites laevigatus* shows base regular or rich occurrence within the superzone.

Zones of Superzone *Verrutricoolporites laevigatus*

Zone: *Verrustephanocolporites complanatus*

Interval: 940 – 820 m

Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Cicatricosisporites dorogensis* at 940 m

Zonal Top: Top regular occurrence of *Verrustephanocolporites complanatus* at 820 m.

Correlation: Zone P620 of Evamy *et al*. (1978) and C1 of Legoux (1978).

Characteristics:

- *Verrustephanocolporites complanatus* shows its regular occurrence.
- *Verrutricolporites laevigatus* has its base regular or rich occurrence at 940 m.

Zonocostites ramonae, *Monoporites annulatus*, *Retitricolporites irregularis* and Pteridophyte spores such as Trilete spore (*Acrostichum aureum*), *Verrucatosporites terellis* and *Laevigatosporites discordatus* constitute the dominant microflora of the zone.

Zone: *Praedapollis africanus*

Interval: 820 – 420 m

Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Verrustephanocolporites complanatus* at 820 m.

Zonal Top: Top occurrence of *Praedapollis africanus* at 420 m.

Correlation: Zone P620 of Evamy *et al*. (1978) and C1 of Legoux (1978).

Characteristics:

- *Psilastephanocolporites malacanthoides* has its top regular occurrence.
- *Zonocostites ramonae, Monoporites annulatus* and *Retitricolporites irregularis* dominate the zonal assemblage.

Zone: *Elaeis guineensis*

Interval: 420 – 300 m

Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Praedapollis africanus* at 420 m.

Zonal Top: Suspected to be above the topmost sample analyzed at 300 m.

Correlation: Zone P630 of Evamy *et al*. (1978) and C1 of Legoux (1978).

Characteristic:

- *Elaeis guineensis* has its base occurrence within the zone at 360 m.

Zonocostites ramonae and *Monoporites annulatus* constitute the dominant microflora within the zone.

Remark:

The lowest recovery of palynomorphs in the entire segment of the well section studied was recorded in this zone.

Age Designation of Oredo-2 well:

From the associations of palynomorphs recovered from the sediments of the Oredo-2 well studied, a middle Eocene to early Miocene age is indicated.

4.2 Foraminiferal Biostratigraphy of Oredo-2 well

4.2.1 Introduction

One hundred and twenty-four composited samples spread over the interval 4000 m to 300 m of the Oredo-2 well were processed and analysed for their foraminiferal and accessory microfaunal contents.

Foraminiferal recovery within the studied section is generally low. Samples within interval 300 – 2450 m were barren of foraminifera. Intervals 2450 - 3510 m and 3560 - 4000 m yielded low abundance and diversity while interval 3510 - 3560 m yielded highly abundant but moderately diverse foraminifera.

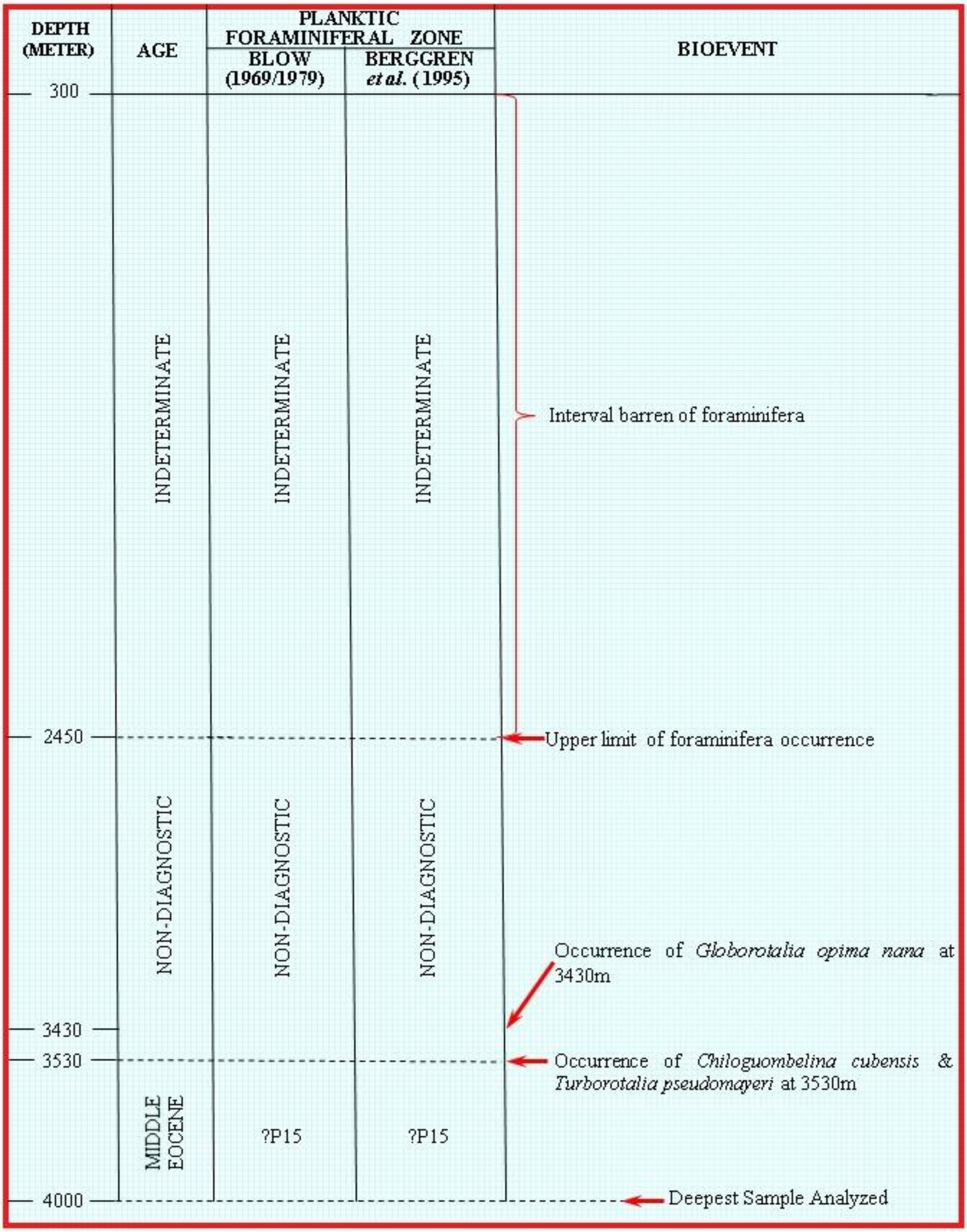
Twenty-four foraminiferal species were recovered. Four (17%) were planktics, 15 (62%) were calcareous benthics with the remaining five (21%) species arenaceous benthic species. Ostracods, scaphopods, sponges, shell fragments, gastropods and pelecypods were the accessory microfauna recorded.

The microfaunal distribution, foraminiferal abundance and diversity plots and paleobathymetric data are presented in Enclosure 2.

4.2.2 Planktic Foraminiferal Zones

Paucity of planktic foraminifera species affected the delineation of the planktic foraminiferal zones. The planktic foraminiferal zones recognized in this study are based on the revised Cenozoic Geochronologic and Chronostratigraphic Schemes of Berggren *et al*. (1995) and Blow (1969, 1979). These zones are summarized in Table 4.2 and briefly described as follows.

Table 4.2: Foraminiferal biozonation of Oredo-2 well



DEPTH (METER)	AGE	PLANKTIC FORAMINIFERAL ZONE		BIOEVENT
		BLOW (1969/1979)	BERGGREN *et al.* (1995)	
300	INDETERMINATE	INDETERMINATE	INDETERMINATE	Interval barren of foraminifera
2450	NON-DIAGNOSTIC	NON-DIAGNOSTIC	NON-DIAGNOSTIC	Upper limit of foraminifera occurrence
3430				Occurrence of *Globorotalia opima nana* at 3430m
3530	MIDDLE EOCENE	?P15	?P15	Occurrence of *Chiloguombelina cubensis* & *Turborotalia pseudomayeri* at 3530m
4000				Deepest Sample Analyzed

Stratigraphic Interval: 4000 - 3530 m

Planktic Foraminiferal Zone: ? P15

Age: middle Eocene

Diagnosis:

- The zonal base is tentatively placed at the terminal depth (TD) (4000 m) while the zonal top is approximated at 3530 m, being the depth at which *Chiloguembelina cubensis* and *Turborotalia pseudomayeri* were recovered.
- Paucity of planktics characterizes this zone. Species of *Globigerina* was the only other planktic recovered.
- Arenaceous benthics recovered include *Saccamina complanata*, *Ammobaculites strathearnensis* and species of *Ammobaculites*.
- Associated calcareous benthics recorded were *Florilus* ex. gr. *costiferum*, *Quinqueloculina seminulum*, *Valvulineria* sp., species of *Cibicides*, *Nonion* and *Lenticulina* sp.
- The accessory microfaunal recorded include gastropods, shell fragments and sponges.

Remarks: The definition of the zonal top by the sole occurrence of *Chiloguombelina cubensis*, necessitates the assignment of a probable N15 zone.

Stratigraphic Interval: 3530 - 2450 m

Planktic Foraminiferal Zone: Non-diagnostic

Age: Non-diagnostic

Diagnosis:

- The zonal base is approximated at 3530 m, being the depth at which *Chiloguembelina cubensis* and *Turborotalia pseudomayeri* were recovered. The zonal top is placed at 2450 m, being the upper limit of foraminifera recovery.

- Paucity of planktics species still characterizes this interval. *Globorotalia opima nana*, *Turborotalia pseudomayeri* and *Chiloguembelina cubensis* were the only planktics recovered.

- The occurrence of *Turborotalia pseudomayeri* at 3530 m confirmed that the well section id not younger than middle Eocene at that depth.
- Recorded arenaceous benthic assemblage includes *Ammobaculites strathearnensis* and species of *Ammobaculites and Textularia*.
- Others are calcareous benthic species such as *Quinqueloculina seminulum, Q. lamarckiana* and species of *Valvulineria*, *Nonion* and *Cibicides.*
- Scaphopod spp., shell fragments and sponges constitute the recorded accessory microfauna recorded.

Stratigraphic Interval:	2450 - 300 m
Planktic Foraminiferal Zone:	Barren
Age:	Barren

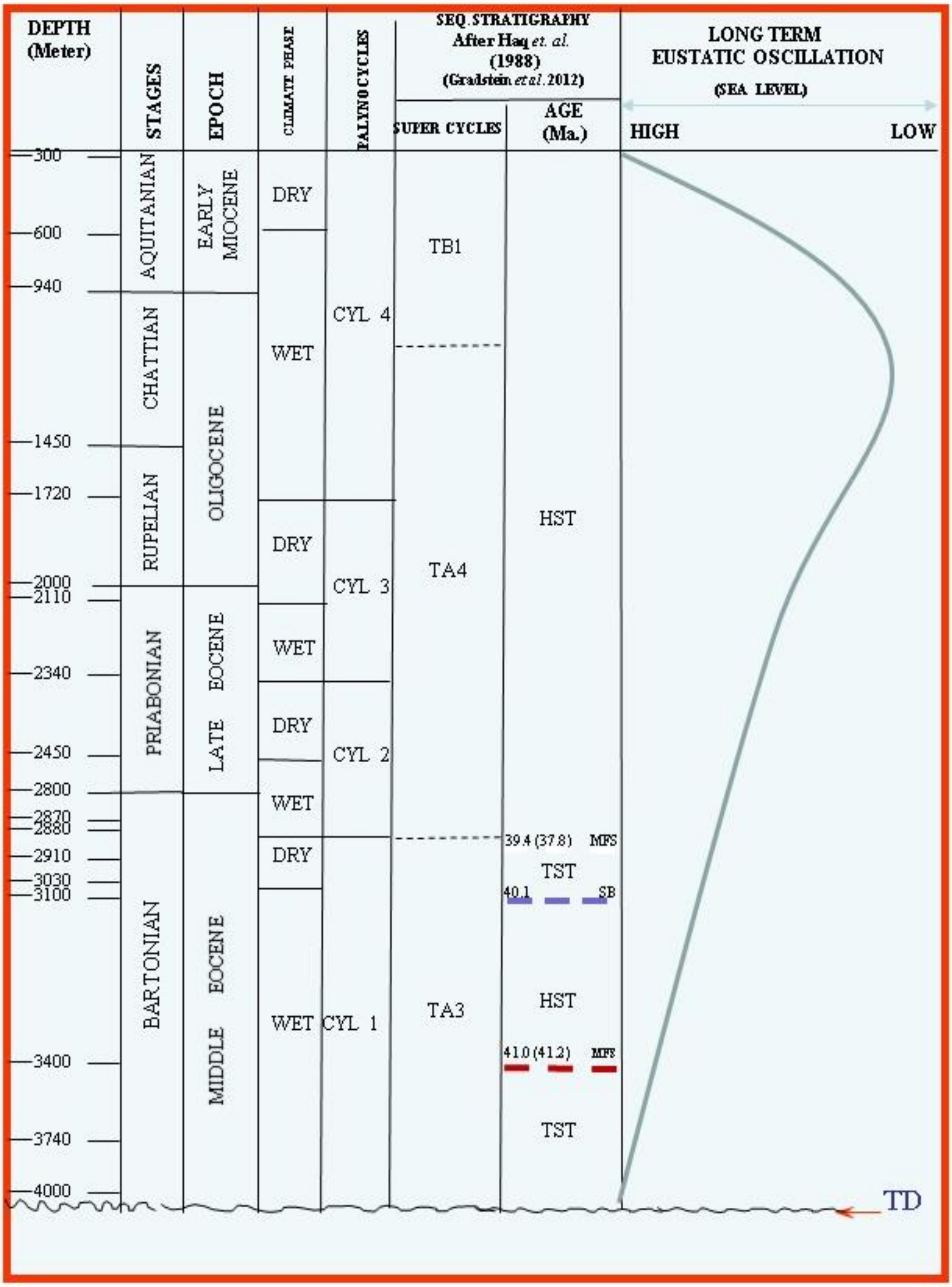
Diagnosis:

- The zonal base is placed at at 2450 m, the depth of the last recovery of foraminifera. The zonal top is expediently placed at 300 m, being top of the first sample analyzed.
- The interval is barren of foraminifera.

4.3 Palynological Climate Cycle in Oredo-2

Deductions concerning the sea level, climate change and the depositional sequences at the time of deposition of the well section were qualitatively and quantitatively made using the palynomorphs recovered. Based on the various assemblage components of environmentally significant palynomorphs recovered, four palynocycles were delineated (Table 4.3 and Enclosures 1 & 4). These cycles are described as follows:

Table 4.3: Palaeoclimate Cycle in Oredo-2 well



LEGEND

HST - HIGHSTAND SYSTEMS TRACT
TST - TRANSGRESSIVE SYSTEMS TRACT
MFS - MAXIMUM FLOODING SURFACE
SB - SEQUENCE BOUNDARY
TD - TERMINAL DEPTH OF WELL

Palynocycle 1 (CYL 1) (4000 – 2880 m)

Wet Phase 1 (4000 – 3030 m):

The common to abundant occurrence of the brackish-water species, *Pelliceria rhizophorae* (*Psilatricolporites crassus*) with fern spores such as *Microsonum aff. diversifolium* (*Verrucatosporites* sp.) and *Pallacea* sp. (*Laevigatosporites discordatus*) as well as fairly rich and diverse dinoflagellate cysts such as *Lingulodinium machaerophorum* and the acritarch, *Leiosphaeridium* sp., suggest a wet climate phase for this basal interval. The recognised 41.0Ma and 39.4Ma MFS at 3400 m and 2910 m respectively, characterized by peak abundance and diversity of identified benthic foraminifera, are associated with this phase.

Dry Phase 1 (3030 – 2880 m):

The low percentage of freshwater swamp species, lowland rainforest and brackish water swamp species recorded within this interval suggests a drier climatic condition.

Palynocycle 2 (CYL 2) (2880 – 2340 m)

Wet Phase 2 (2880 – 2450 m):

This phase is associated with increased percentage of brackish-water species such as *Pelliceria rhizophorae*, *Nypa fruticans* type (*Spinizonocolpites baculatus*); freshwater swamp forest species, *Ctenolophon englerianum* (*Ctenolophonidites costatus*) and pteridophyte spores as well as high presence of dinoflagellate cysts and a fair presence of the freshwater algae, *Pediastrum* sp. and *Concentricysts*, particularly towards the base.

Dry Phase 2 (2450 – 2340 m):

The rise in the percentages of savanna pollen with concomitant fall in those of wet climate indicators such as mangroves, pteridophyte spores and freshwater swamp forest suggests a dry climatic condition for the phase. The low recovery of dinoflagellate cysts recorded further corroborates the inference of a dry phase.

Palynocycle 3 (CYL 3) (2340 – 1720 m)

Wet Phase 3 (2340 – 2110 m):

There was a resurgent and appreciable increase in the percentages of wet climate indicators such as freshwater swamp forest: *Amanoa oblongifolia* (*Retitricolporites irregularis*) and *Ctenolophon englerianum*; brackish-water swamp species: *Nypa fruticans*; pteridophyte spores as well as dinoflagellate cysts and *Leiospaeridia* sp. The brackish water alga, *Botryococcus braunii*, exhibits a rich occurrence. The assemblage of this interval suggests a wet climatic phase.

Dry Phase 3 (2110 – 1720 m):

This interval witnessed a slight reduction in the percentage of the freshwater swamp forest, mangrove, fern spores as well as dinoflagellates cysts, *Leiospaeridia* sp. and *Botryococcus braunii*. The concomitant slight increase in the percentages of the savanna species such as *Anthonotha gilletii* (*Striaticolporites catatumbus*) is indicative of a dry climatic condition.

Palynocycle 4 (CYL 4) (1720 – 300 m)

Wet Phase 4 (1720 – 600 m):

The preponderance of freshwater swamp forest: *Amanoa oblongifolia* and *Symphonia globulifera* (*Pachydermites diederixi*); lowland rainforest *Psilastephanocolporites sapotaceae*; brackishwater swamp *Rhizophora* type (*Zonocostites ramonae*), Trilete spore (*Acrostichum aureum*); pteridophyte spores: *Microsonum aff. diversifolium*, *Pallacea* sp.; *Leiospaeridia* sp. and *Botryococcus braunii* within this interval suggests a wet climatic condition.

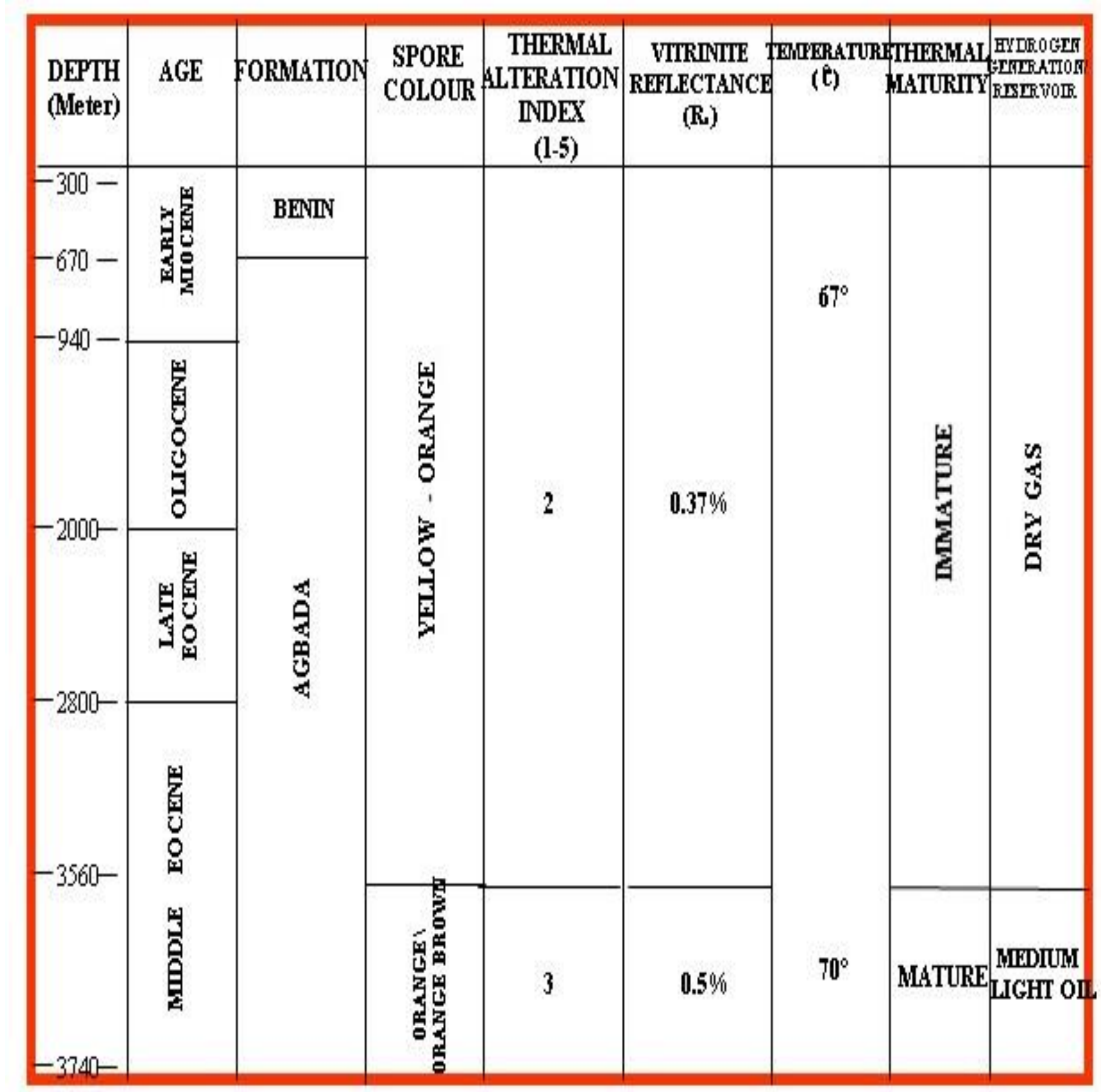
Dry Phase 4 (600 – 300 m):

The noticeable drop in the general recovery of palynomorphs in this phase is suggestive of a dry climatic condition.

4.4 Thermal Maturity of sediments in Oredo-2 Well

Table 4.4 depicts the results of the transmitted light microscopic analysis of spore colouration for thermal alteration indices in Oredo-2 well. The results yielded the recognition of two phases of organic matter maturity within the well studied. These were immature (300 – 2560 m) and mature (2560 – 4000 m).

Table 4.4: Thermal Maturation Index of Oredo-2 well



DEPTH (Meter)	AGE	FORMATION	SPORE COLOUR	THERMAL ALTERATION INDEX (1-5)	VITRINITE REFLECTANCE (R_o)	TEMPERATURE (°C)	THERMAL MATURITY	HYDROGEN GENERATION RESERVOIR
300 – 670	EARLY MIOCENE	BENIN	YELLOW - ORANGE	2	0.37%	67°	IMMATURE	DRY GAS
670 – 940		AGBADA						
940 – 2000	OLIGOCENE							
2000 – 2800	LATE EOCENE							
2800 – 3560	MIDDLE EOCENE							
3560 – 3740			ORANGE\ ORANGE BROWN	3	0.5%	70°	MATURE	MEDIUM LIGHT OIL

Immature (300 – 2560 m):

Spore colouration in this phase range from yellow to orange with the thermal alteration index (TAI) value of 2. This suggests deposits of immature organic matter. The hydrocarbon potential in this phase pointed to dry gas.

Mature (2560 – 4000 m):

The organic facies in this phase was made up of pteridophyte spores that were orange to orange brown in colour. The TAI value was 3, indicative of early mature organic matter with source potential of medium to light oil.

4.5 Multivariate Analysis of palynomacerals in Oredo-2 Well

Appendix 2a shows the percentage composition from the palynofacies analysis of the Oredo-2 well. These data formed the basis for the multivariate analyses conducted in the study.

4.5.1 Principal Component (PC) Analysis

The principal component (PC) analysis of the particulate organic matter recorded confirmed the preponderance of structureless organic matter (SOM) followed by the Phytoclasts and Palynomorphs (Sporomorphs) (See Table 4.5). Appendix 2d shows the PC scores values for the palynodebris.

By implication, SOM and Phytoclasts occur in significant abundance while Palynomorphs (Sporomorphs), though present, were not in a significant proportion. Furthermore, the result also depicts that the first component (PC1; the only component retained) accounted for 86.19% of the total variation in abundances of the particulate organic matter in the studied well (Table 4.6).

Table 4.5: PC Loading Values of Particulate Organic Matter in Oredo-2

	PC 1	PC 2	PC 3
Pal	-0.06166	0.81446	0.57694
Phy	-0.67387	-0.46038	0.57789
SOM	0.73627	-0.35315	0.57722

Table 4.6: PCA Summary Result of Oredo-2 Well

PC	Eigenvalue	% variance
1	483.579	86.193
2	29.9374	5.336
3	24.7846	4.4176
4	16.0183	2.8551
5	3.84688	0.68566
6	2.64791	0.47196
7	0.189754	0.033822
8	0.0164317	0.0029288
9	0.0141185	0.0025165
10	0.00405767	0.00072324
11	0.00302797	0.0005397
12	0.00091726	0.00016349
13	0.00052673	9.39E-05
14	0.00023415	4.17E-05

4.5.2 Cluster Analysis of palynofacies in Oredo-2 well

Figure 4.1 shows the results of the Principal Component Analysis (PCA) of the organic matter in Oredo-2 well. The pictorial illustration shows a linkage between the principal components; amorphous organic matter (AOM), black and brown wood (BBW) and Sporomophs in the cluster grouping across the depths of the well. It shows the distinct abundances of these particulate organic matter in contrast to other components. Figure 4.2 depicts the cluster hierarchies of the organic particulate matter.

4.6 Palynofacies Assemblages in Oredo-2 well

From the average linkage analysis of the percentage composition of the particulate organic matter, the Oredo-2 well sequence studied was divided into three discrete associations (Figure 4.2 and Enclosures 1 & 4). These associations are described in detail as follows:

Palynofacies Association I; PF-I: (4000 – 2340 m)

PF- I is dominated by abundant Amorphous Organic Matter (AOM) with percentage composition ranging between 23% and 90%, and relative percentage abundance (rpa) of 65% (Figure 4.3). This is followed by Black and Brown Wood ranging from 3-60% in percentage composition with rpa of 23.8%. Charcoal, with percentage composition ranging from~1 to 14% (rpa = 4.2%) constitutes the next main particulate organic matter within this interval. The other components being Gelified Matter with percentage composition ranging between~1 and 10% (rpa=2.5%, Sporomorphs in the range of ~1 and 7% (rpa =2.3% and Non – Cuticular Tissue with percentage composition between ~1 and 9% (rpa =1.6%).

The other palynodebris recorded within this palynofacies association interval, though in rare occurrences, with relative percentage abundance less than 1% include Epidermal Cuticles, Fungal Elements, Filaments, Hir and Tubes, Acritarchs Undifferentiated, Algal Elements, Charred Poaceae Cuticles, Microforaminiferal Wall Linnings (MWL), Resinous Matter and Tracheids.

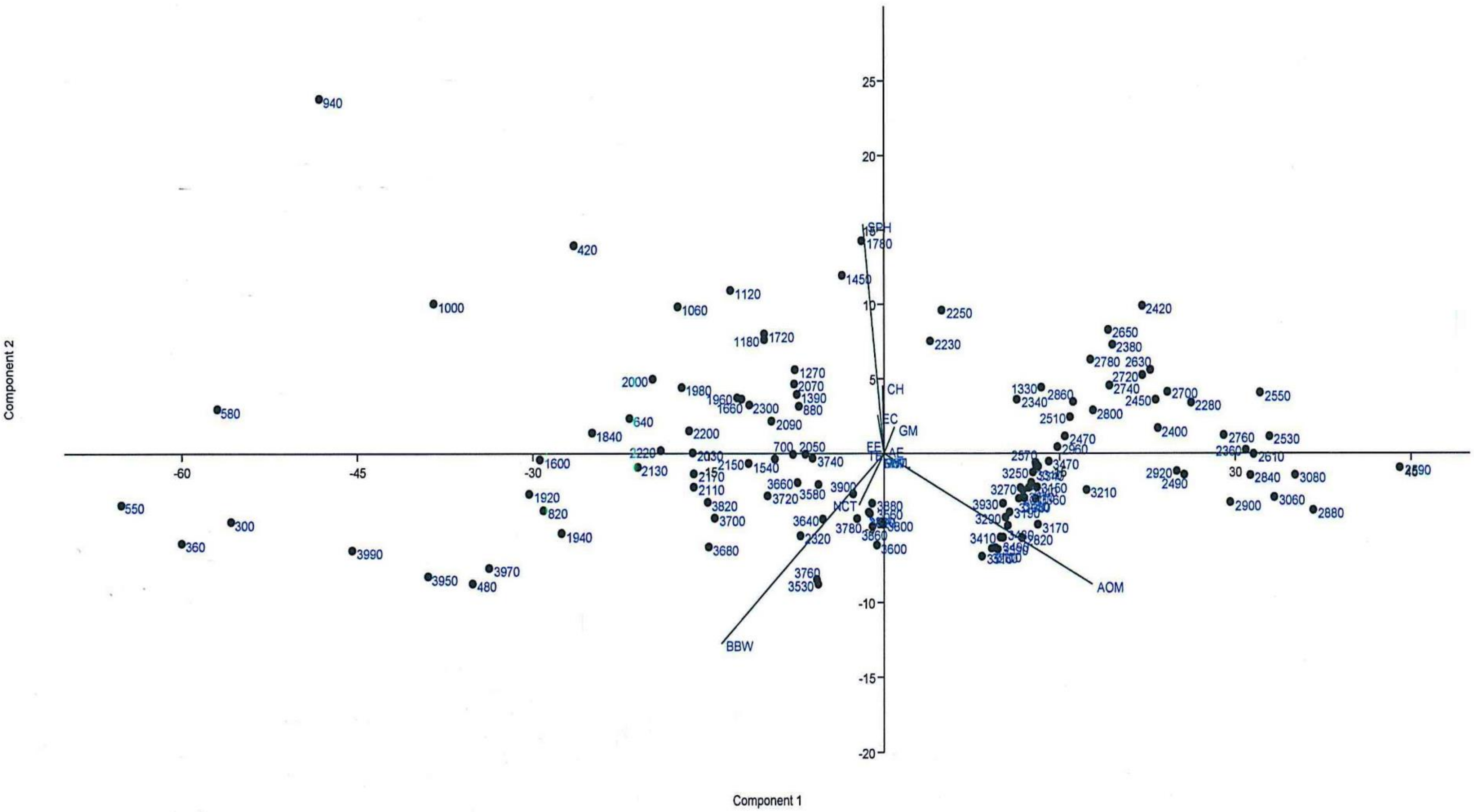


Figure 4.1: Principal Component Analysis results for the Organic Matter in Oredo-2 Well

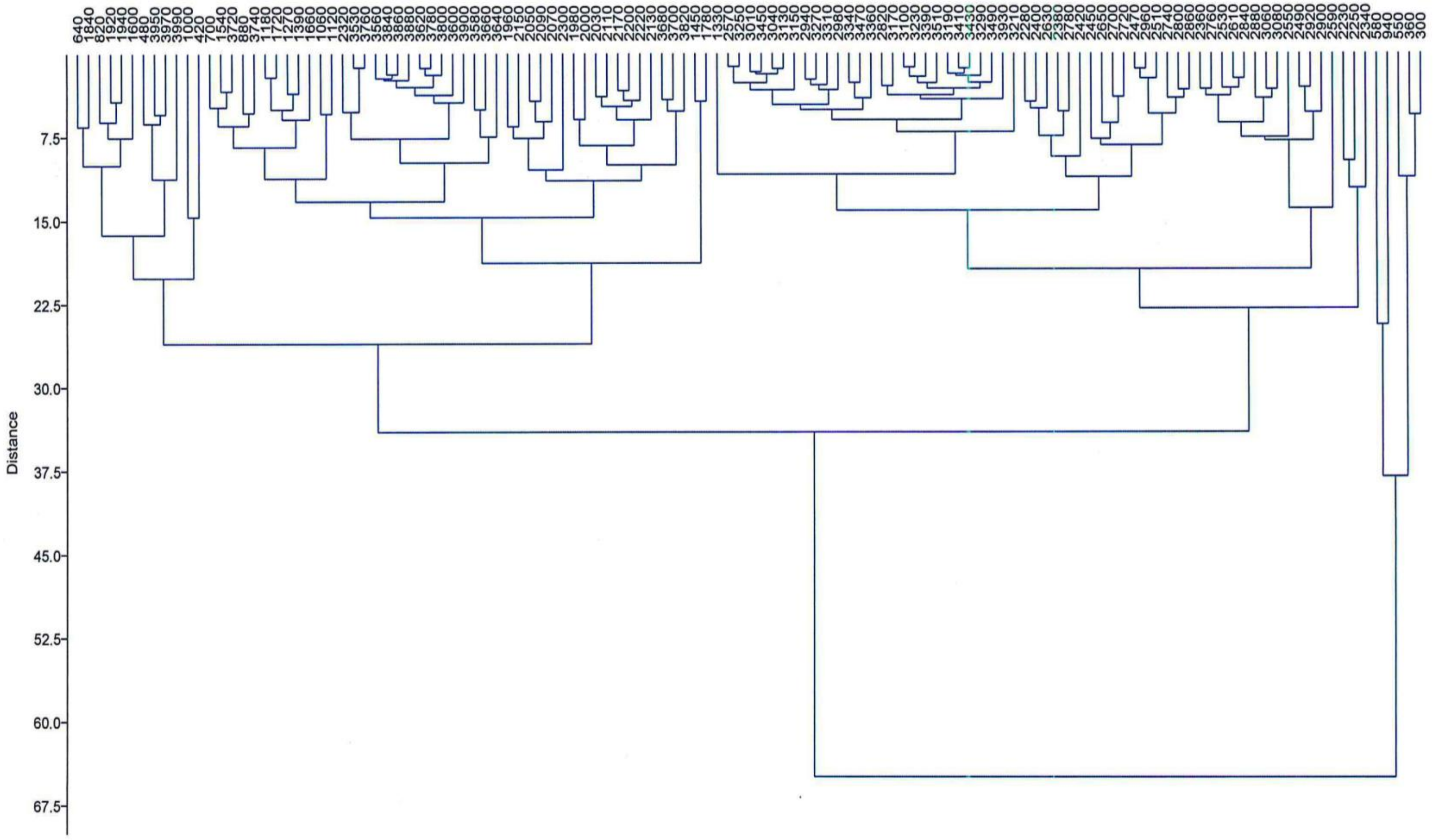


Figure 4.2: Dendogram of the hierachial Cluster Analysis of Organic Matter in Oredo-2 Well

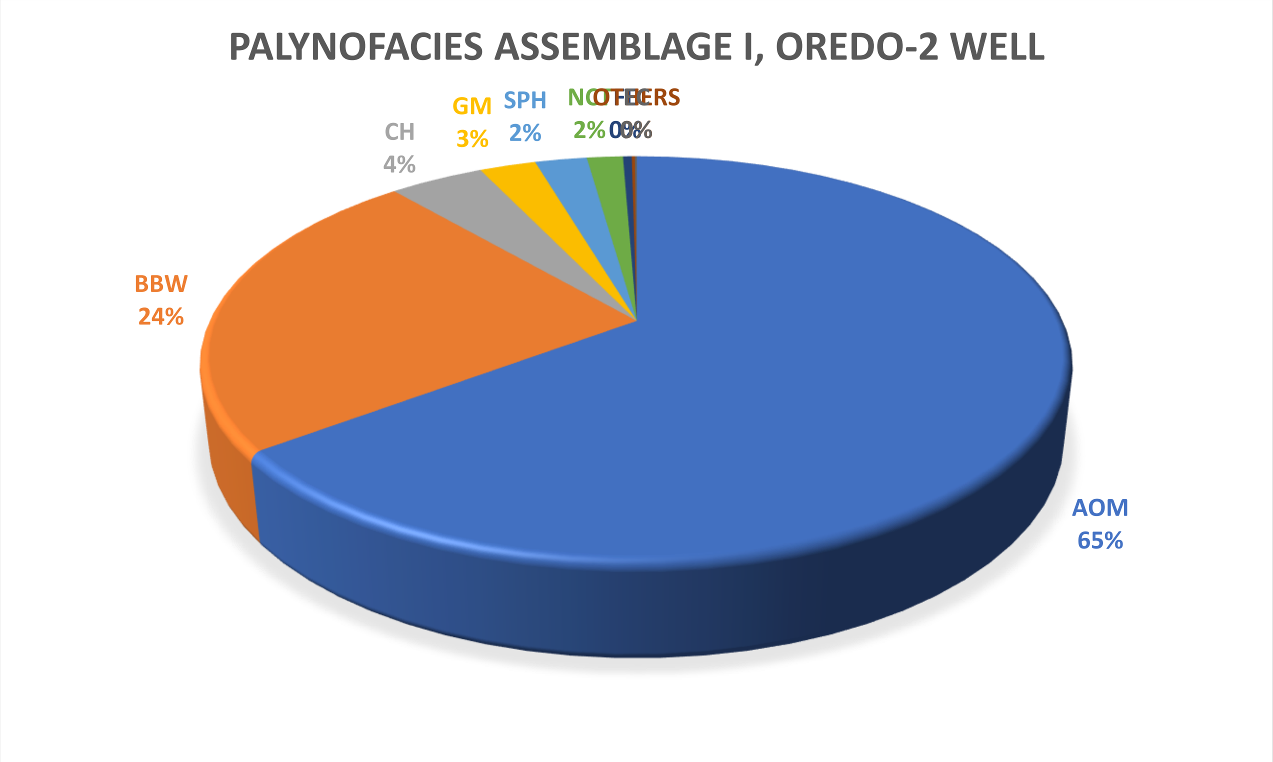


Figure 4.3: Percentage Composition of Particulate Organic Matter in PF-I, Oredo-2 Well

Key:

AOM – Amorphous Organic Matter
BBW – Black and Brown Wood
CH – Charcoal
GM – Gelified Matter
SPH – Sporomorphs
NCT – Non-Cuticular Tissues
FE – Fungal Elements
EC – Epidermal Cuticle
OTHERS

Palynofacies Association II; PF-II: (2340 – 640 m)

AOM, though still dominates the organic matter of PF-II, its percentage values (rpa. 42%) exhibit reduction relative to the underlying palynofacies association, with percentage composition in the range between 37 and 42% (Figure 4.4). Conversely, the most abundant phytoclast, Black and Brown Wood, witnessed increasing relative percentage abundance to 37.3% ranging in value between 10 and 50%. This assemblage is characterised by regular increase in the proportion of sporomorphs showing a range from~1 and 33% (rpa. of 7.9%) towards the upper part. The black debris, Charcoal, maintains its increasing proportion from the underlying association until depth 1900 m, when it starts gradual reduction to the top of the interval; it ranges between~1 and 24% (rpa. 5.7%).

Both Epidermal Cuticle and Gelified Matter have fairly regular frequency toward the basal part of the interval between 2340 m and 1900 m with percentage composition ranging between~1 and 10% (rpa.2.8%) and~1 and 6% (rpa. 1.4%) respectively. Non-Cuticular Tissue range from~1 to 4% (rpa. 1.3%). Occuring in subordinate proportions with relative percentage abundance of < 1% are Fungal Elements, Acritarchs Undifferentiated, Charred Poaceae Cuticle (CPC), Filaments, Hairs and Tube and Resinous Matter.

Palynofacies Association III; PF-III: (640 – 300 m)

Phytoclasts constitute the dominant organic matter component in PF- III. Black and Brown Wood with relative percentage abundance (rpa) of 55% and ranging between 40 and 64% make up the most abundant (Figure 4.5). This is followed by 17% Non-Cuticular Tissue ranging from~1-32%. Also, Charcoal and Epidermal Cuticles make up the other significant phytoclasts represented, ranging between~1 and 4% (rpa. 2%) and~1and 3% (rpa.1.6%) respectively.

AOM had its lowest values of 16% in the entire well sequence and ranged from~1 and 33%. Sporomorphs also constitute significant components of the palynofacies association with rpa of 5% with a range between~1 and 16%.

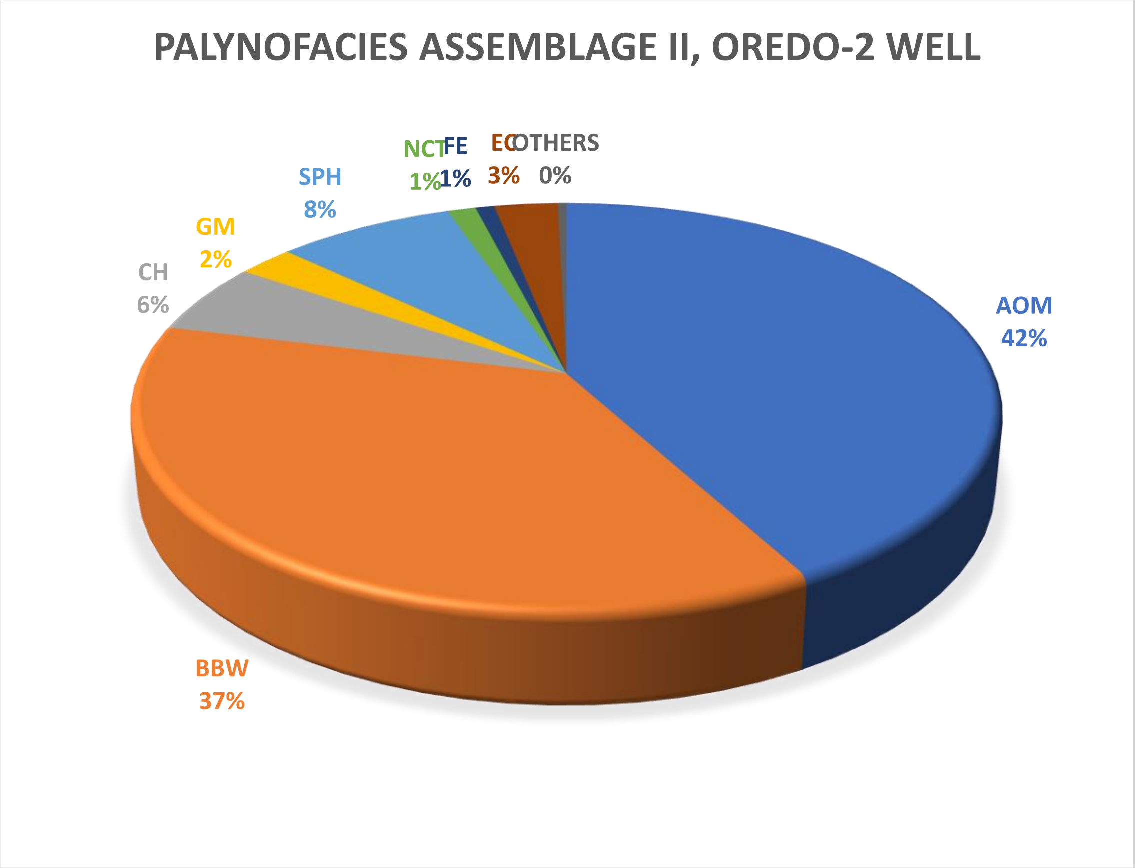


Figure 4.4: Percentage Composition of Particulate Organic Matter in PF-II, Oredo-2 Well

Key:

AOM – Amorphous Organic Matter
BBW – Black and Brown Wood
CH – Charcoal
GM – Gelified Matter
SPH – Sporomorphs
NCT – Non-Cuticular Tissues
FE – Fungal Elements
EC – Epidermal Cuticle
OTHERS

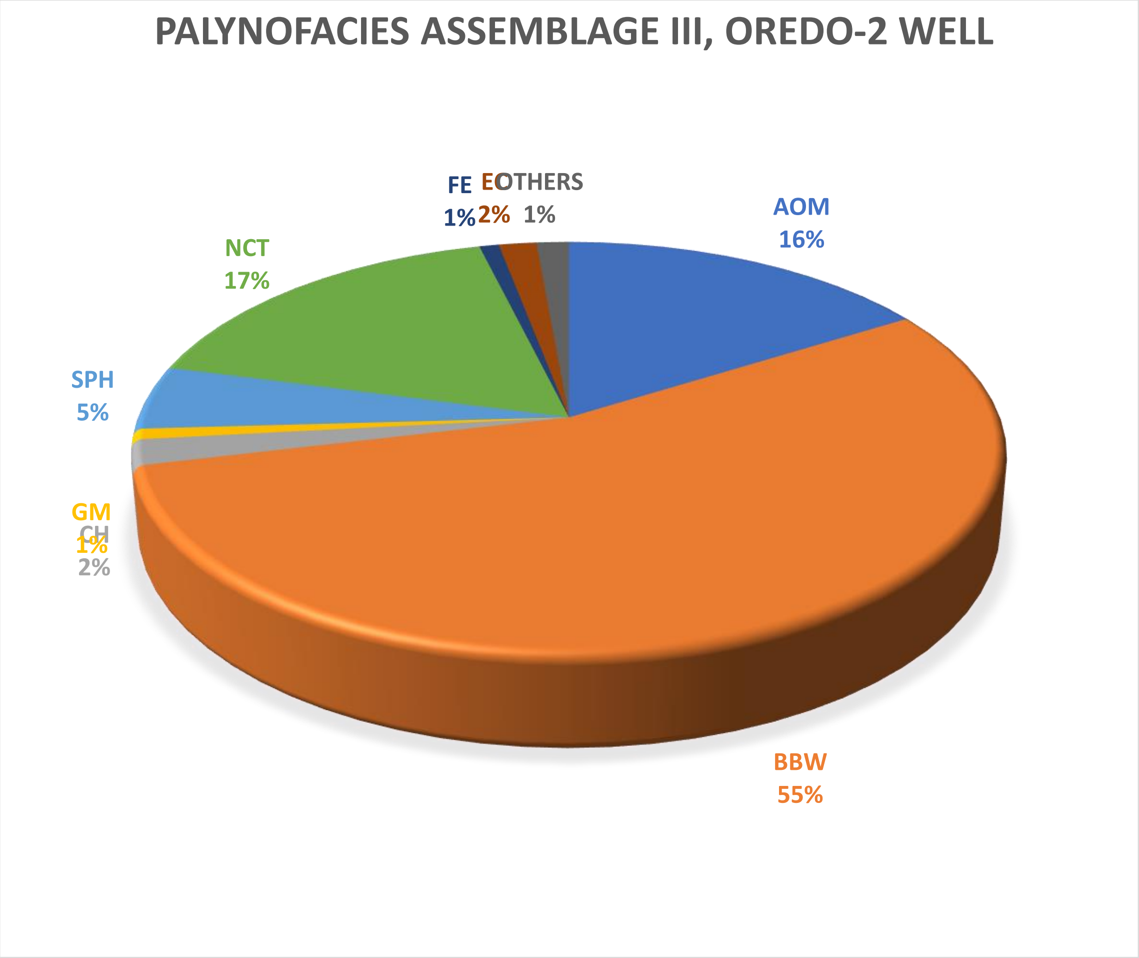


Figure 4.5: Percentage Composition of Particulate Organic Matter in PF-III, Oredo-2 Well

Key:

AOM – Amorphous Organic Matter

BBW – Black and Brown Wood

CH – Charcoal

GM – Gelified Matter

SPH – Sporomorphs

NCT – Non-Cuticular Tissues

FE – Fungal Elements

EC – Epidermal Cuticle

OTHERS

Other components of the palynofacies assemblage occurring in insignificant values of less than 1% of relative percentage abundance include Fungal Elements, Gelified Matter, Resinous Matter, Filaments, Hair and Tube, Tracheid Elements and Algal Elements.

4.7 Depositional Environments from Ternary Plot

The depositional environments and the relative proximity of terrestrial organic matter sources were inferred from the SOM – Phytoclasts - Palynomorphs Ternary Plot of Tyson (1995).

The plot reveals deposition in I, II, IV, VI, VII, VIII and IX fields (Figure 4.6).

Field I: Highly proximal Shelf or Basin

This field suggests deposition in highly proximal shelf or basin which is characteristic of Palynofacies III (PF III). According to Tyson (1995) this field is dominated by high phytoclast supply diluting all other components. A relatively high percentage abundance of terrestrial spores and very low records of microplankton respectively are associated with the field. The field depicts a gas-prone Kerogen Type III.

Field II: Marginal dysoxic-anoxic basin

Field II indicates deposition in a marginal dysoxic-anoxic basin and is characteristic of Palynofacies II (PF II) in the well. The field features the dilution of AOM by high phytoclast input, though still with fair representation of AOM. The relative percentage abundance of terrestrial spores is high with low records of microplankton. A Kerogen Type III which is gas prone is suggested by this field (Tyson, 1995).

Field IV: Shelf to basin transition

Field IV indicates a shelf to basin transition with Fields IVa and IVb representing dysoxic-suboxic and suboxic-anoxic conditions respectively (Tyson, 1995). The transition from shelf to basin occurs in time and space with the time factor mainly as a result of increased subsidence or space, while the space component is a result of basin slope.

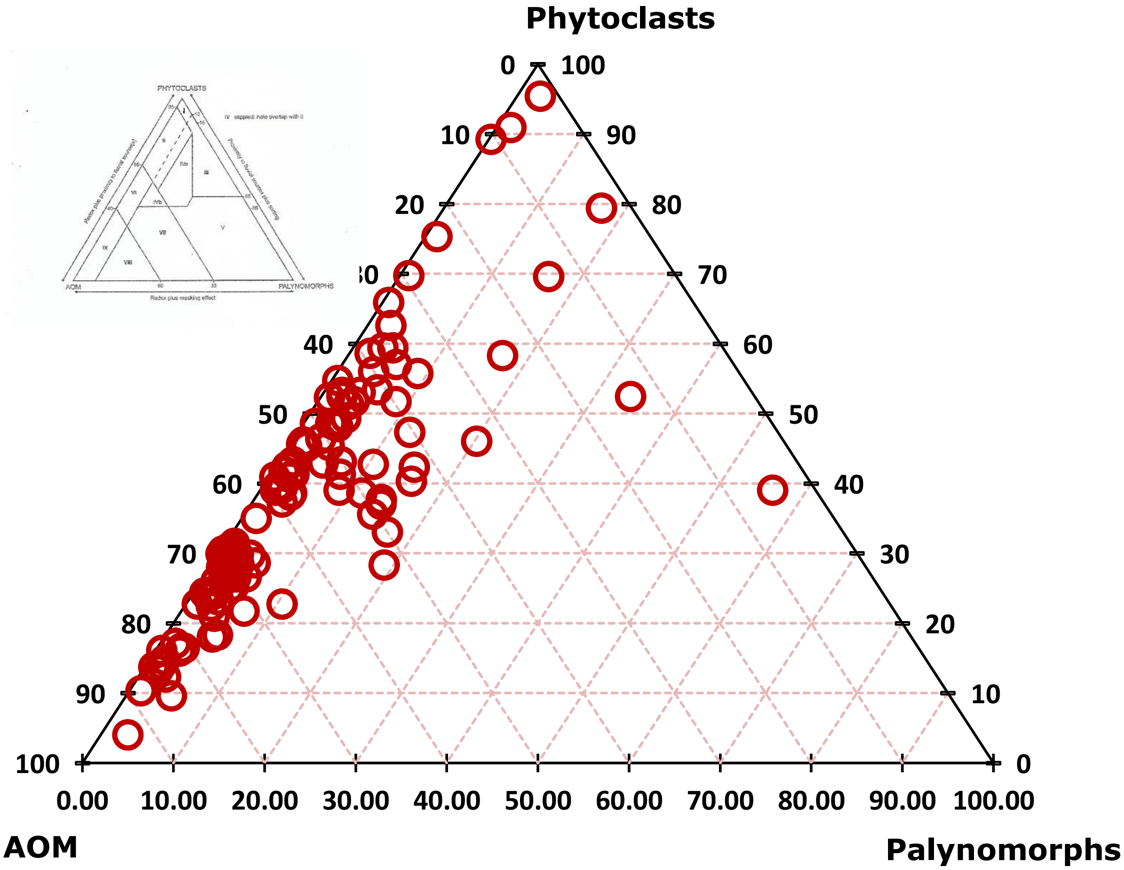


Figure 4.6: Ternary Plot, Oredo-2 well; Inset: Ternary Kerogen Diagram of Tyson (1995)

The abundance of phytoclast within this field is as a result of proximity and the extent of re-deposition. This field which characterizes palynofacies III (PF III) shows records of moderate to high spores with very low to low microplankton which point to Kerogen Types III/II, mainly gas prone for this field.

Field VI: Proximal suboxic-anoxic shelf

Field VI depicts deposition in a proximal suboxic-anoxic shelf condition, on the APP ternary plot of Tyson (1995). The field reflects good AOM preservation because of reducing basin conditions with the phytoclast content being moderate to high due to turbidity or proximity to the source. Low relative percentage abundance of sporomorphs and moderate to common marine elements characterize this field which infers an oil-prone Kerogen Type II.

Field VII: Distal dysoxic-anoxic shelf

Field VII points to deposition in a distal dysoxic-anoxic shelf condition on the APP ternary plot of Tyson (1995). Moderate to good AOM preservation and low to moderate palynomorphs characterize this field. Field VII characterizes Palynofacies I (PF I) suggesting oil-prone Kerogen Type II of Tyson (1995).

Field VIII: Distal dysoxic-oxic shelf

From Tyson (1995) APP ternary plot, Field VIII suggests deposition in a distal dysoxic-oxic shelf. The dominance of excellently preserved AOM, low to moderate sporomorphs characterize the field. The field characterizes Palynofacies I (PF I) inferring oil prone Kerogen Type II of Tyson (1995).

Field IX: Distal suboxic-anoxic basin

The depositional environment represented by this field is mostly rich in alginitic component, in deep basin/shelf sea deposits. Palynofacies I (PF I) in this well can also be classified into Field IX which is also characterized by the highly oil prone Kerogen Type II according to Tyson (1995).

4.8 Sedimentology and Lithostratigraphy of Oredo-2 well

Two hundred and fifty-five (255) samples of the Oredo-2 well were analysed lithologically and texturally. Detailed lithological and sedimentological analyses with log analytical data delineated two lithostratigraphic units of formational rank for well section in view. These are: Agbada Formation at the base (670 - 4000 m) overlain by the dominantly sandy Benin Formation (300 - 670 m).

The Agbada Formation is an intercalation of sandy mudstone/shale with sand with the sand assuming dominance up-section. The continental transitional (2440 – 670 m) and transitional paralic (2760 – 2440 m) sequences within this unit are assigned to the Agbada Formation largely based on log signatures. The lithofacies associations at the basal part of the well (4000 – 3190 m) is dominantly shale with sand interbeds. The shale/mudstones are dark grey, predominantly flaggy with some blocky and moderately hard. The sand interbeds are coarse to very coarse, sub-rounded to rounded, moderately sorted to well sorted. Abundant ferruginous materials, rare to few carbonaceous detritus and rare mica flakes and glauconites are the necessary minerals recorded within the lower part.

The upper part (3190 – 300 m) contains over 75 % sand with shale/mudstone making up the remaining 25 % of the gross lithology. Abundant ferruginous materials, common to abundant carbonaceous detritus, rare to few mica flakes and rare glauconites represent the accessory minerals. The Benin Formation (300 – 670 m), in this well, was identified solely from the lithologic descriptions of the continental sands since the wireline logs were not provided for the upper part of the well. Highlights of the lithostratigraphic analysis are presented in Table 4.7 and discussed as follows.

Table 4.7: Lithostratigraphic units recognized in Oredo-2 well

DEPTH (m)	THICKNESS (m)	FORMATION	LITHOFACIES	UNIT
300 - 670	370	Benin	Continental	V
670 - 2440	1770		Continental/Transitional	IV
2440 - 2760	320		Transitional Paralic	III
2760 - 3190	430	Agbada	Paralic	II
3190 - 4000	810		Marine	I

UNIT I: Agbada Formation: Marine (4000 – 3190 m)

This lower part of the Agbada Formation is made up of thick units of shale interbedded with thin units of sandy mudstone. The shales are mostly dark grey, flaggy to blocky, and moderately hard. The sandy mudstone interbeds are generally sub-rounded to rounded, very fine to fine grained with occasional coarse-grained fractions and moderately to well sorted. The accessory mineral association includes few to abundant ferruginous materials, rare to abundant carbonaceous detritus and rare to common mica flakes with spotty to rare gluconites. Moderate record of land-derived palynomorphs dominated by *Pelliceria rhizophora* (*Psilatricolporites crassus*), *Monoporites annulatus* and *Psilamonocolpites marginatus* with appreciable presence of dinocysts. The associated fauna are *Ammobaculites strathearnensis* and species of *Ammobaculites*, *Florilus* ex. gr. *costiferum and Valvulineria* sp. among others.

UNIT II: Agbada Formation: Paralic (3190 – 2760 m)

This unit consists of shale /sand intercalations with the shale/sand ratio approximately 60:40. The shales are grey, flaggy to blocky and moderately hard. The sands are white, sub-rounded to rounded, generally coarse to very coarse and moderately to well sorted. Abundant ferruginous materials, rare to common carbonaceous detritus and mica flakes with spotty gluconites make up the accessory mineral components of the unit. The floral assemblage, which witnessed a moderate increase in proportion and diversity, is still dominated by *Pelliceria rhizophora* (*Psilatricolporites crassus*) and *Monoporites annulatus*. Marine influence was recorded by increase presence of dinocysts such as *Lingulodinium machaerophorum* and *Polyspaeridium zoharyi*. Low records of benthonic foraminifera such as *Ammobaculites* sp. was recorded. Scaphopod spp., shell fragments and sponges are associated with this unit.

UNIT III: Agbada Formation: Transitional Paralic (2760 – 2440 m)

This unit is predominated by thick argillaceous sands, 280m thick, interbedded with 40m thick shales. The sands are white, very fine to coarse grained, sub-rounded to rounded, moderately to well sorted. The shales are dark grey, flaggy to block, occasionally platy and moderately hard. Index minerals within this unit include abundant ferruginous materials, few to common carbonaceous detritus and rare to few mica flakes. The unit recorded appreciable increase in the proportion of microflora with the highest diversity of dinocysts recorded within the well. *Ammobaculites* spp., *Florilus ex gr. costiferum* and scaphopods dominate the fauna assemblage.

UNIT IV: Agbada Formation: Continental/Transitional (2440 – 670 m)

This is a 1770m thick sequence of argillaceous sands. The sand/shale ratio approximates about 70:30. The sands are white, fine to very coarse pebbly, sub-rounded to rounded, moderately to well sorted. The shales are dark grey, predominantly blocky to flaggy, occasionally platy and moderately hard. Abundant to few ferruginous materials and carbonaceous detritus and few to rare mica flakes represent the accessory minerals composition within this unit. The floral assemblage recorded increased presence and high diversity of plant species. Scattered occurrences of dinocysts were recorded at the basal part of the unit with appreciable presence of *Botryococcus braunii* and *Leiosphaeridia* sp. No fauna presence was recorded.

UNIT V: Benin Formation: Continental (670 – 300 m)

This uppermost unit is dominated by massive, regressive upper shoreface sands. The sands are moderately and sorted, coarse to very coarse pebbly. Few to abundant carbonaceous detritus and ferruginous materials and very rare pyrites constitute the necessary minerals encountered. Brackishwater *Rhizophora* sp. dominate the floral assemblage. No fauna recovery was made within the unit.

4.9 Sequence Stratigraphy of Oredo-2 Well

The standard sequence stratigraphic interpretation procedures of Mitchum *et al*. (1990) of integrating high resolution biostratigraphic data obtained from foraminifera and palynomorphs with lithostratigraphic and well log data (Vail and Wornardt, 1991) have been adopted for the analysis of Oredo-2 well.

The sequence stratigraphic framework proposed here has been correlated with the Global Cycle Chart of Haq *et al*. (1988) as revised for the Pliocene-Pleistocene of the Gulf of

Mexico by Wornardt and Vail (1990). The recognized Maximum Flooding Surface (MFS) ages were also correlated with Gradstein *et al*. (2012) Geologic Time Scale and reported in parentasis subsequently.

Two Maximum Flooding Surfaces were recognized within the well sequence and dated in Ma using the marker benthic species and palynological subzones. These are 41.0 Ma (41.2 Ma) and 39.4 Ma (37.8 Ma) MFS at 3400 m and 2910 m respectively. One Sequence Boundary is recognized in the well sequence at 3100 m and dated 40.1 Ma. The proposed sequence stratigraphic framework for the well is summarized in Table 4.8 and briefly highlighted below:

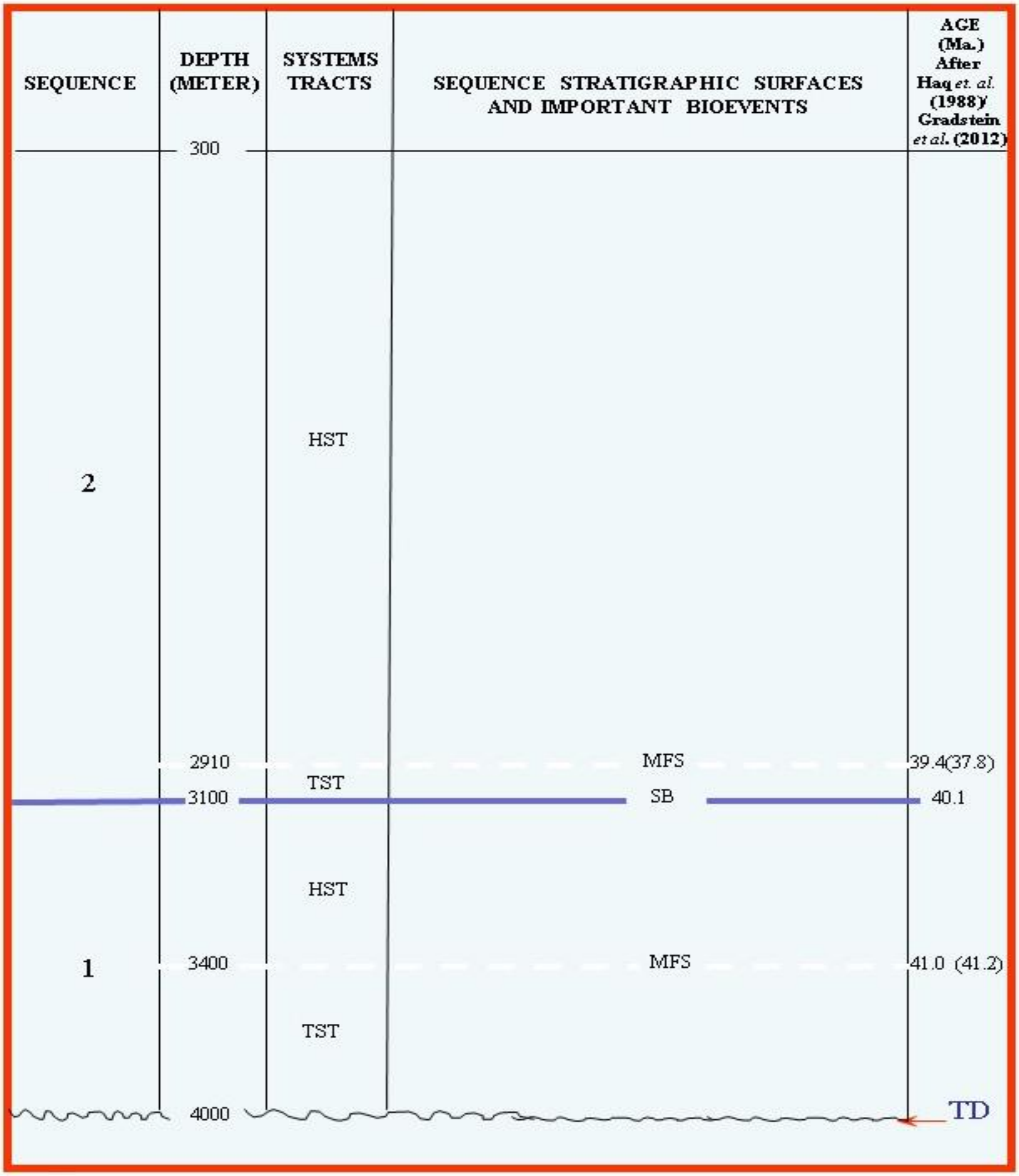
SEQUENCE 1 (4000 – 3100 m)

4000 – 3400m: Transgressive Systems Tract (TST)

Characteristics

- Increasing-upward faunal and dinocysts abundance and diversity
- Termination in a condensed section marked by foraminiferal abundance/diversity maxima at 3660 – 3460 m.

Table 4.8: Sequence Stratigraphic framework of the Oredo-2 well



SEQUENCE	DEPTH (METER)	SYSTEMS TRACTS	SEQUENCE STRATIGRAPHIC SURFACES AND IMPORTANT BIOEVENTS	AGE (Ma.) After Haq *et. al.* (1988)/ Gradstein *et al.* (2012)
	300			
2		HST		
	2910		MFS	39.4(37.8)
		TST		
	3100		SB	40.1
		HST		
1	3400		MFS	41.0 (41.2)
		TST		
	4000			TD

LEGEND

HST - HIGHSTAND SYSTEMS TRACT
TST - TRANSGRESSIVE SYSTEMS TRACT
MFS - MAXIMUM FLOODING SURFACE
SB - SEQUENCE BOUNDARY
TD - TERMINAL DEPTH OF WELL

Remarks

- The MFS at the top of the TST is defined at the gamma peak at 3400 m
- The MFS is dated 41.0 Ma of Haq *et al*. (1988), equivalent to 41.2 Ma of Gradstein *et al*. (2012). The age is assigned by virtue of its stratigraphic position within the foraminiferal zone ?P15 and the palynological subzone P450.

3400 – 3100 m: Highstand Systems Tract (HST)

Characteristics

- Decreasing-upward faunal and dinocysts abundance/diversity.
- Presence of brackishwater alga, *Botryococcus braunii*
- Stratigraphic position directly above a MFS.

Remarks

- The Sequence Boundary (SB) above this sequence is defined at 3100 m, the first significant sand above the 41.0 Ma (41.2 Ma) MFS.
- This SB is dated 40.1 Ma based on correlation to the Global Cycle Chart of Haq *et al*. (1988).

SEQUENCE 2 (3100 – 300 m)

3100 – 2910 m: Transgressive Systems Tract (TST)

Characteristics

- Fining-upward profile.
- Increasing-upward faunal and dinocyst abundance and diversity.
- Termination in a condensed section marked by foraminiferal abundance and diversity maxima at 3100 – 2800 m.

Remarks

- The MFS on top of the TST is defined at the gamma ray log positive deflection at 2910 m
- The MFS is dated 39.4 Ma. This age is assigned by virtue of its stratigraphic position with the palynological subzone P470.

2870 – 300 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile.
- Decreasing-upward foraminiferal and dinocyst abundance and diversity.
- Rich presence of *Botryococcus braunii*.
- Stratigraphic position directly above a Maximum Flooding Surface (MFS).

Remarks

- The top of the HST is suspected to lie shallower than the top of the analyzed well section

4.10 Palynostratigraphy of Oredo-4 Well

Ninety-seven ditch cuttings of the Oredo-4 Well, obtained between 70 m and 3770 m, were subjected to detailed palynological analyses. The rich palynofloral assemblages recorded in the well was dominated by pollen and spores such as *Retitricolporites irregularis*, *Retimonocolpites obaensis*, *Psilatricolporites crassus*, *Racemonocolpites hians*, *Retibrevitricolporites ibadaneensis*, *Psilatricolporites* sp., and pteridophyte spores such as *Acrostichum aureum*, *Verrucatosporites terellis* and *Laevigatosporites discordatus*.

A rich proportion of diverse fungal spores were also recorded. The dominant types among these are: *Exesisporites* sp., *Pleuricellaesporites* sp., *Basidiosporites* sp., and Form Type B. The recorded dinoflagellate cysts include *Lingulodinium machaerophorum*, *Pentadinium laticinitum*, *Selenophemphix nephroides*, *Spiniferites ramosus*, *S. pseudofurcatus*, *Lejeuncysta* sp., *Hystrichokolpoma salacium* and *H. rigaudae.* Few records of microforaminiferal wall lining (MWL) were made. The acritarch, *Leiospaeridia* sp., was recorded in high proportions throughout the well sequence. The brackish water alga, *Botryococcus braunii*, constitutes the dominant alga recorded with few freshwater species such as *Pediastrum* sp. and *Concentricyst*. Few Charred Poaceae Cuticle (CPC) and diatom frustules were also recorded.

The age diagnostic/significant pollen and spores encountered include: *Elaies guineensis, Verrutricolporites laevigatus, Verrutricolporites scabratus, Magnastriatites howardi, Cicatricosisporites dorogensis, Arecipites exilimuratus, Spirosyncolpites bruni, Verrustephanocolporites complanatus, Inaperturopollenites gemmatus, Spinizonocolpites echinatus, S. baculatus, Retimonocolpites obaensis, Praedapollis africanus, Proxapertites cursus, P. operculatus, Striamonocolpites rectostriatus, Retitricolpites bendeensis, Psilamonocolpites marginatus, Grimsdalea polygonalis, Psilatricolporites onitshaeensis, Peregrinipollis nigericus, Cinctiporipollis mulleri, Verrucatosporites usmensis, Retibrevitrocolporites ibadaneensis, Mauritiidites crassiexinus, Periretipollis spinosus, Doulaidites laevigatus, Auriculopollenites reticulatus, A. echinatus* and *A. simplex.*

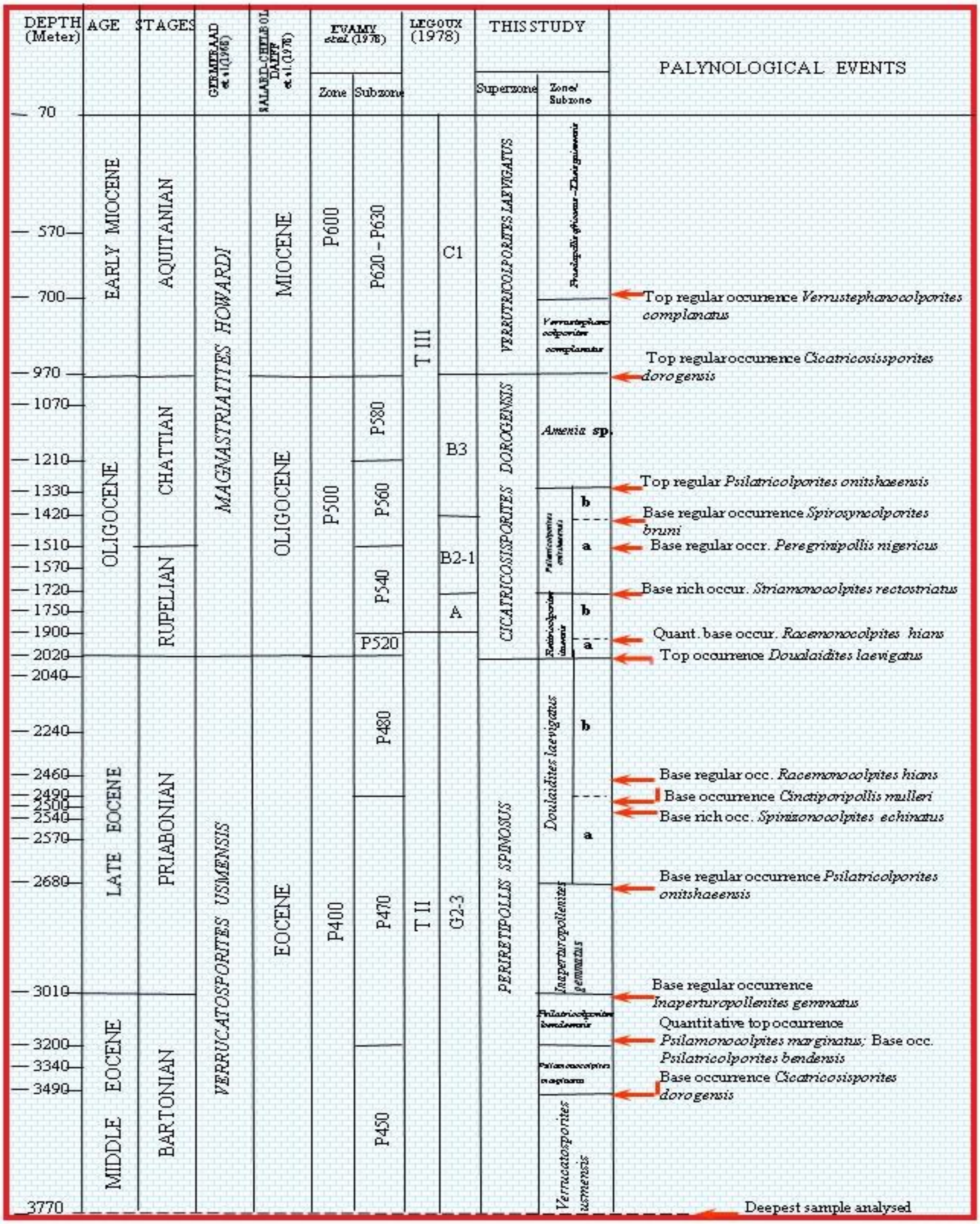
4.10.1 Zonation

The assemblage and stratigraphic distribution of recovered diagnostic species constitute the basis of the zonation of this well.

The recognized zones are: *Verrucatosporites usmensis* Zone, *Psilamonocolpites marginatus* Zone, *Retitricolpites bendeensis* Zone, *Inaperturopollenites gemmatus* Zone, *Doualaidites laevigatus* Zone, *Retitricolporites ituensis* Zone, *Psilatricolporites onitshaeensis* Zone, *Anemia* sp. Zone, *Verrustephanocolporites complanatus* Zone, *Praedapollis africanus* Zone and *Elaies guineensis* Zone (Table 4.9 and Enclosure 5).

Details of the different ages traversed as indicated by diagnostic palynomorphs are outlined as follows:

Table 4.9: Palynostratigraphic zonation of Oredo-4 well



Top regular occurrence *Verrustephanocolporites complanatus*

Top regular occurrence *Cicatricosissporites dorogensis*

Top regular *Psilatricolporites onitshaensis*

Base regular occurrence *Spirosyncolporites bruni*

Base regular occr. *Peregrinipollis nigericus*

Base rich occur. *Striamonocolpites rectostriatus*

Quant. base occur. *Racemonocolpites hians*

Top occurrence *Doualaidites laevigatus*

Base regular occ. *Racemonocolpites hians*

Base occurrence *Cinctiporipollis mulleri*

Base rich occ. *Spinizonocolpites echinatus*

Base regular occurrence *Psilatricolporites onitshaensis*

Base regular occurrence *Inaperturopollenites gemmatus*

Quantitative top occurrence *Psilamonocolpites marginatus*; Base occ. *Psilatricolporites bendensis*

Base occurrence *Cicatricosisporites dorogensis*

Deepest sample analysed

Superzone:	*Periretipollis spinosus*
Interval:	3770 - 2020 m
Age:	middle - late Eocene

Definition:

Base of the Superzone:	Probably below 3770 m, the lowest layer of the samples analysed.
Top of the Superzone:	Top occurrence of *Doualaidites laevigatus* at 2020 m.

Correlation: *Verrucatosporites usmensis* Zone of Germeraad *et al*. (1968); Zone P400 of Evamy *et al*. (1978) and TII of Legoux (1978).

The well sequence ranges from middle Eocene to early Miocene.

Description:

The *Periretipollis spinosus* Superzone comprises five Zones: the *Verrucatosporites. usmensis*, *Psilamonocolpites marginatus, Retitricolpites bendeensis, Inaperturopollenites gemmatus* and *Doualaidites laevigatus* Zones

Characteristic Features: This superzone is characterised by the top occurrences (Last Appearance Datums) of *Doualaidites laevigatus*, *Mauritiidites crassiexinus* and *Periretipollis spinosus*. The three are also restricted to the superzone.

Cicatricosisporites dorogensis, *Verrucatosporites usmensis*, *Monoporites annulatus, Peregrinipollis nigericus, Praedapollis africanus*, *Cinctiporipollis mulleri*, *Retitricolpites bendeensis* and *Praedapollis flexibilis* have their base occurrences (First Appearance Datums) within the superzone**.**

Zone:	*Verrucatosporites usmensis*
Interval:	3770 - 3490 m
Assigned Age	middle Eocene

Definition:

Zonal Base: Probably older than the terminal depth of samples provided, i.e., 3770 m.

Zonal Top: Base occurrence of *Cicatricosisporites dorogensis* at 3490 m.

Correlation: Zone P450 of Evamy *et al*. (1978) and G2-3 of Legoux (1978).

Characteristics:

- *Verrucatosporites usmensis* and *Striamonocolpites rectostriatus* are both present and have their base occurrences within the zone.
- Presence of *Doualaidites laevigatus*.

Psilatricolporites crassus and *Psilamonocolpites marginatus* constitute the dominant palynomorphs in the palynofloral assemblage within the zone.

Zone: *Psilamonocolpites marginatus*

Interval: 3490 - 3200 m

Assigned Age: middle Eocene

Definition:

Zonal Base: Base occurrence of *Cicatricosisporites dorogensis* at 3490 m

Zonal Top: Quantitative top occurrence of *Psilamonocolpites marginatus* at 3200 m

Correlation: Zone P450 of Evamy *et al*. (1978) and G2 -3 of Legoux (1978).

Characteristics:

- *Mauritiidites crassiexinus* is regularly present within the zone.
- Presence of *Grimsdalea polygonalis.*
- *Cicatricosisporites dorogensis* has its base occurrence (FAD) at the zonal base.

The dominant palynomorphs within the zone are *Psilatricolporites crassus*, *Retibrevitricolporites obodoensis* and *Psilamonocolpites marginatus*.

Zone: *Retitricolpites bendeensis*

Interval: 3200 - 3010 m

Assigned Age: middle Eocene

Definition:
Zonal Base: Quantitative top occurrence of *Psilamonocolpites marginatus* at 3200 m
Zonal Top: Base regular occurrence of *Inaperturopollenites gemmatus* at 3010 m

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Mauritiidites crassiexinus* has its top occurrence within the zone.
- *Praedapollis africanus* has its base occurrence at the basal boundary.
- *Retitricolpites bendeensis* also has its base occurrence within the zone or close to its basal boundary at 3200 m.

The palynofloral assemblage within this zone is dominated by *Psilatricolporites crassus* and *Retimonocolpites obaensis*.

Zone: *Inaperturopollenites gemmatus*

Interval: 3010 – 2680 m

Assigned Age: late Eocene

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Definition:

Zonal Base: Base regular occurrence of *Inaperturopollenites gemmatus* at 3010 m

Zonal Top: Base regular occurrence of *Psilatricolporites onitshaensis* at 2680 m.

Characteristics:

- *Praedapollis flexibilis* has its base occurrence within the zone.
- *Retibrevitricolpites triangulatus* has its quantitative base occurrence in the zone. *Psilatricolporites crassus* and *Retimonocolpites obaensis* still constitute the dominant palynomorphs of the zonal assemblage.

Zone: *Doualaidites laevigatus*

Interval: 2680 – 2020 m

Assigned Age: late Eocene

Definition:

Zonal base: Base regular occurrence of *Psilatricolporites onitshaeensis* at 2680 m.

Zonal Top: Top occurrence of *Doualaidites laevigatus* at 2020 m.

Correlation: Zones P470 - P480 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Racemonocolpites hians* has its base regular occurrence at 2460 m.
- *Cinctiporipollis mulleri* has its base occurrence 2490 m.
- *Striazonocolpites echinatus* has its base rich occurrence at 2500 m.
- *Retitricolporites ituensis* exhibits its base occurrence.

Psilatricolporites crassus, Retimonocolpites obaensis and pteridophyte spores such as *Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* dominate the palynofloral assemblage.

Remark:

The *Doulaidites laevigatus* Zone was further sub-divided into sub-zones a and b by the base occurrence of *Cinctiporipollis mulleri* at 2490 m.

The Eocene – Oligocene boundary was defined by the top occurrence of *Doualaidites dorogensis* at depth 2020 m.

Superzone: *Cicatricosisporites dorogensis*

Interval: 2020 – 970 m

Age: Oligocene

Definition:

Base of the Superzone: Top occurrence of *Doualaidites laevigatus* at 2020 m.

Top of the Superzone: Top regular occurrence of *Cicatricosisporites dorogensis* at 970 m.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone 500 of Evamy *et al*. (1978) and TII - TIII of Legoux (1978).

Descrption:

The *Cicatricosisporites dorogensis* Superzone is made up of the *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis* and *Anemia* sp. Zones.

Characteristic Features:

- The superzone is characterised by the top occurrences (last appearance datums) of *C. dorogensis, Verrustephanocolporites complanatus, Inaperturopollenites gemmatus, Spinizonocolpites echinatus, Retimonocolpites obaensis* and *Praedapollis africanus.*
- *Magnastriatites howardi* has its base occurrence in the superzone.
- Types with top rich occurrences in the superzone are: *Proxapertites cursus, Proxapertites operculatus, Striamonocolpites rectostriatus, Retitricolpites bendeensis and Retimonocolpites obaensis.*

- *Arecipites exilimuratus*, *Psilatricolporites okeizei*, *Verrustephanocolporites complanatus* and *Grimsdalea polygonalis* have their top regular occurrences.

Zone: *Retitricolporites ituensis*

Interval: 2020 – 1720 m

Assigned Age: Oligocene

Definition:

Zonal Base: Top occurrence of *Doualaidites laevigatus* at 2020 m.

Zonal Top: Base rich occurrence of *Striamonocolpites rectostriatus* at 1720 m.

Correlation: Zonse P520 and P540 of Evamy *et al*. (1978) and G2-3 – A of Legoux (1978).

Characteristics:

- *Retitricolporites ituensis* has its top occurrence.
- *Retimonocolpites obaensis* and *Spinizonocolpites echinatus* show top rich occurrences.
- *Grimsdalea polygonalis and Proxapertites cursus* exhibit top regular occurrences.
- *Peregrinipollis nigericus* has a base regular occurrence.

Retimonocolpites obaensis, Psilatricolporites crassus, Acrostichum aureum, Verrucatosporites terellis and *Laevigatosporites discordatus* dominate the microfloral assemblage.

Remark:

The *Retitricolporites ituensis* Zone was further sub-divided into sub-zones a and b by the quantitative base occurrence of *Racemonocolpites hians* at 1900 m.

Zone: *Psilatricolporites onitshaeensis*
Interval: 1720 – 1330 m
Assigned Age: Oligocene

Definition:

Zonal Base: Base rich occurrence of *Striamonocolpites rectostriatus* at 1720 m.
Zonal Top: Top regular occurrence of *Psilatricolporites onitshaeensis* at 1330 m

Correlation: Zones P540 and P560 of Evamy *et al*. (1978) and B2-1 – B3 of Legoux (1978).

Characteristics:

- *Cicatricosisporites dorogensis* occurs in rich proportions.
- *Arecipites exilimuratus* and *Psilatricolporites okeeizei* both exhibit top regular occurrences.
- *Striamonocolpites rectostriatus* has its top rich occurrence.
- *Retitricolpites bendeensis* shows regular presence.
- *Psilatricolporites onitshaeensis* exhibits regular occurrence.

Retitricolporites irregularis, Psilatricolporites crassus, Monoporites annulatus, Zonocostites ramonae, Racemonocolpites hians, Acrostichum aureum, Verrucatosporites terellis and *Laevigatosporites discordatus* dominate the assemblage within the zone.

Zone: *Anemia* sp.
Interval: 1330 – 970 m
Assigned Age: Oligocene

Diagnosis:

Zonal Base: Top regular occurrence of *Psilatricolporites onitshaeensis* at 1330 m.
Zonal Top: Top regular occurrence of *Cicatricosisporites dorogensis* at 970 m.

Correlation: Zone P580 of Evamy *et al*. (1978) and B3 of Legoux (1978).

Characteristic:

- *Retitricolpites bendeensis* exhibits its top rich occurrence.

The palynofloral assemblage is dominated by *Retitricolporites irregularis*, *Racemonocolpites hians*, *Zonocostites ramonae*, *Acrostichum aureum*, *Verrucatosporites usmensis* and *Laevigatosporites discordatus*.

Remark:

The Oligocene – Miocene boundary was defined by the top occurrence of *Cicatricosisporites dorogensis* at depth 970 m.

Superzone: *Verrutricolporites laevigatus*

Interval: 970 – 70 m

Age: early Miocene

Definition:

Base of the Superzone: Top regular occurrence of *Cicatricosisporites dorogensis* at 970 m.

Top of the Superzone: Placed at the last sample analysed at 70 m.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P600 of Evamy *et al*. (1978) and TIII of Legoux (1978).

Description:

The *Verrutricolporites laevigatus* Superzone is made up of the *Verrustephanocolporites complanatus* and the *Praedapollis africanus* - *Elaeis guineensis* Zones.

Characteristics:

The superzone is characterised by the top occurrence of *Praedapollis africanus*.
Elaeis guineensis has its first appearance datum within the superzone.
Verrutricolporites laevigatus shows base regular or rich occurrence within the superzone.

Zone: *Verrustephanocolporites complanatus*
Interval: 970 – 700 m
Assigned Age: early Miocene

Definition:
Zonal Base: Top regular occurrence of *Cicatricosisporites dorogensis* at 970 m.
Zonal Top: Top regular occurrence of *Verrustephanocolporites complanatus* at 700 m.
Correlation: Zone P620 – P630 of Evamy *et al*. (1978) and C1 of Legoux (1978).

Characteristics:

- *Verrustephanocolporites complanatus* shows its top regular occurrence.
- *Verrutricolporites laevigatus* has its base regular or rich occurrence.

Zonocostites ramonae, Monoporites annulatus, *Retitricolporites irregularis* and pteridophyte spores such as *Acrosticnum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* constitute the dominant microfloral of the zone.

Zone: *Praedapollis africanus - Elaeis guineensis*
Interval: 700 – 70 m
Assigned Age: early Miocene

Definition:
Zoanl Base: Top regular occurrence of V*errustephanocolporites complanatus* at 700 m.
Zonal Top: Tentatively marked by the top regular occurrence of at the first sample analyzed at 70 m.

Correlation: Zone P620 – P630 of Evamy *et al*. (1978) and C1 of Legoux (1978).

Characteristics:

- *Psilastephanocolporites malacanthoides* has its top regular occurrence.
- *Elaeis guineensis* has its base occurrence.

Zonocostites ramonae, Monoporites annulatus, *Acrostichum aureum, Verrucatosporites usmensis* and *Laevigatosporites discordatus* dominate the zonal assemblage.

Remarks:

The zonal boundary between *Praedapollis africanus* and *E. guineensis* Zones could not be defined due to the near rarity of the zonal marker, *P. africanus*.

The zone had the lowest recovery of palynomorphs in the entire well section studied.

Age Designation:

A middle Eocene to early Miocene age is inferred from the index marker species of palynomorphs recorded in the sequence of the Oredo-4 well.

4.11 Foraminiferal Biostratigraphy of Oredo-4 Well

4.11.1 Introduction

Ninety-seven composited ditch cutting samples between intervals 3770 m and 70 m of the Oredo-4 well were processed and analysed for their foraminiferal and accessory microfauna contents.

Foraminiferal recovery within the studied section was generally low except in the interval 3510-3470 m where moderate to high abundant foraminifera, low in diversity, were recovered. However, samples within interval 2470-70 m were barren of foraminifera. Sixteen (16) foraminiferal species were recovered. Of these, two (13%) were planktic, eight (50%) were calcareous benthic while the remaining six (37%) were arenaceous benthic. Ostracods, scaphopods, shell fragments, gastropods, echinoid remains, sponges and pelecypods were the accessory microfauna recorded. Samples in the interval 2470 - 70m were barren of foraminifera.

The microfauna distribution chart, containing the foraminiferal abundance and diversity plots and paleobathymetric data, are presented in Enclosure 4.10.

4.11.2 Planktic Foraminiferal Zones

Paucity of planktics affected the delineation of the planktic foraminiferal zones. However, the planktic foraminiferal zones recognized in this study are based on the revised Cenozoic Geochronologic and Chronostratigraphic Schemes of Berggren *et. al*., (1995) and Blow (1969, 1979). These zones are summarized in Table 4.10 and briefly described below.

Stratigraphic Interval: 3770 - 3490 m

Planktic Foraminiferal Zone: ? P15

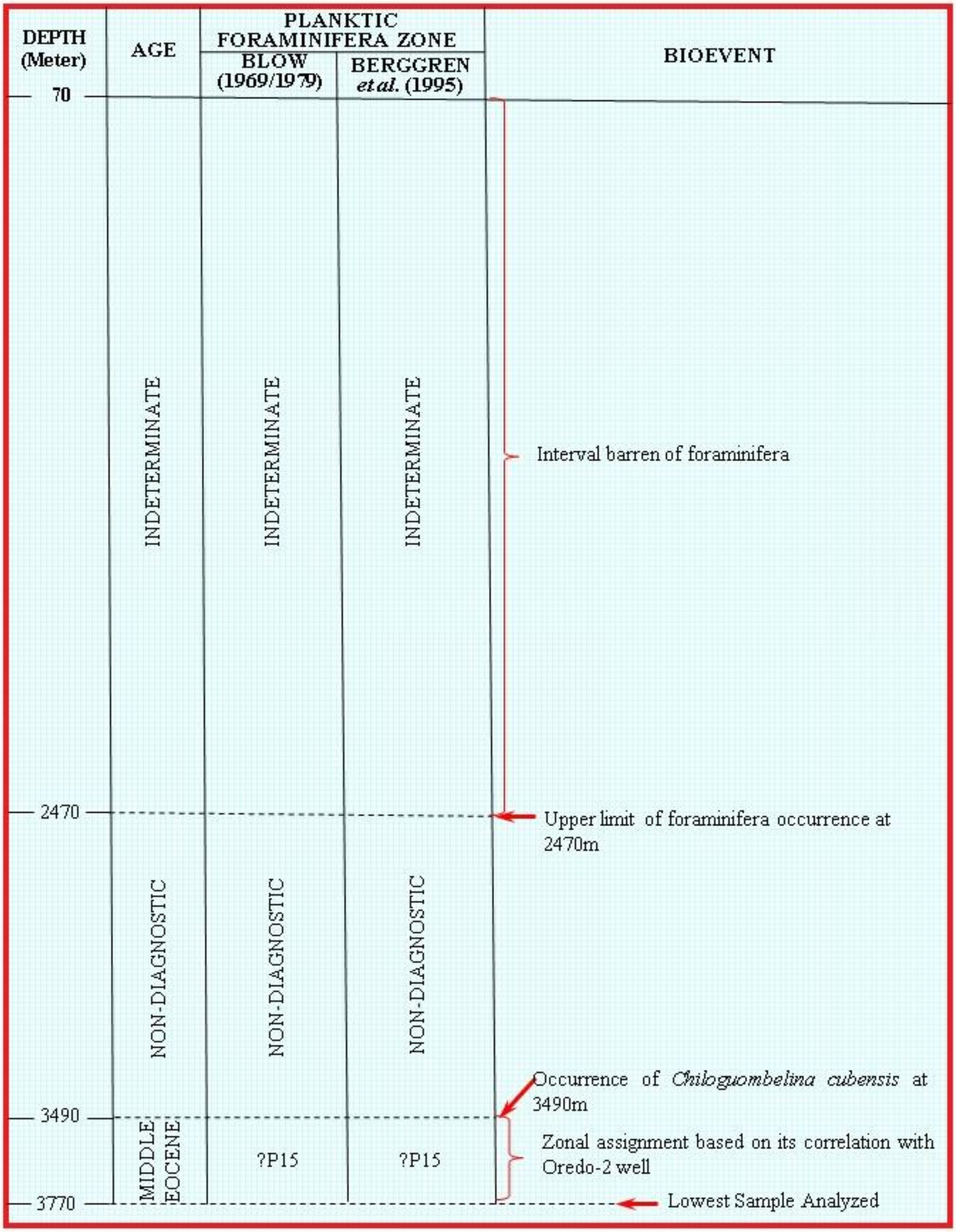
Age: middle Eocene

Diagnosis:

- The zonal base is tentatively placed at TD (3770 m). Its zonal top is approximated at 3490 m, the depth where *Chiloguembelina cubensis* was recovered.
- Paucity of planktics characterizes this zone. Recorded plantic species were grouped as indeterminate.
- *Ammobaculites strathearnensis* and *Ammobaculites* sp. constitute the dominant arenaceous benthics.
- Rare and sporadic calcareous benthics such as species of *Epinoides, Quiqueloculina, Nonion* were recorded.
- Shell fragments, gastropods and sponges and pelecypods were the accessory minerals recovered.

Remarks: The zone was assigned based on its correlation with Oredo-2 well. Also, the definition of the zonal top by the sole occurrence of *Chiloguombelina cubensis*, necessitates the assigned probable P15 Zone.

Table 4.10: Foraminiferal Biozonation of Oredo-4 well



DEPTH (Meter)	AGE	PLANKTIC FORAMINIFERA ZONE		BIOEVENT
		BLOW (1969/1979)	BERGGREN *et al.* (1995)	
70				
	INDETERMINATE	INDETERMINATE	INDETERMINATE	Interval barren of foraminifera
2470				Upper limit of foraminifera occurrence at 2470m
	NON-DIAGNOSTIC	NON-DIAGNOSTIC	NON-DIAGNOSTIC	
3490				Occurrence of *Chiloguembelina cubensis* at 3490m
	MIDDLE EOCENE	?P15	?P15	Zonal assignment based on its correlation with Oredo-2 well
3770				Lowest Sample Analyzed

Stratigraphic Interval: 3490 - 2470 m

Planktic Foraminiferal Zone: Non-diagnostic

Age: Non-diagnostic

Diagnosis:

- The zonal base is approximated at 3490 m, the depth where *Chiloguembelina cubensis* was recovered. Zonal top marked at 2470 m, the depth of initial recovery of foraminifera.

- Paucity of planktic characterizes this interval. *Chiloguembelina cubensis* and planktic indeterminate species were the only planktic recovered.

- Arenaceous benthics dominated the microfloral assemblage. These include: *Ammobaculites strathearnensis*, *Saccammina complanata*, *Eggerella scabra* and species of *Ammobaculites* and *Textularia*.

- *Florilus ex gr*. *costiferum*, *Quinqueloculina rhodiensis*, *Q*. *seminulum* were the associated calcareous benthics present.

- The associated accessory minerals were echinoid remains, shell fragments, ostracods, gastropods, sponges and pelecypods.

Stratigraphic Interval: 2470 - 70 m

Planktic Foraminiferal Zone: Barren

Age: Barren

Diagnosis:

- Zonal base: depth of the initial recovery of foraminifera at 2470 m; zonal top: tentatively marked at the top of the analyzed section at 70m.

- Barren of foraminifera.

4.12 Palynological Climate Cycle in Oredo-4

From the quantitative and qualitative analysis of palynomorphs recovered from the Oredo-4 well, deductions of sea level trends, climate change and the depositional sequences were made. Based on the phytoecological groups recognized in the well, four (4) informal local climate cycles were defined (Table 4.11 and Enclosures 5 & 8). These are described below:

Palynocycle 1 (CYL 1)

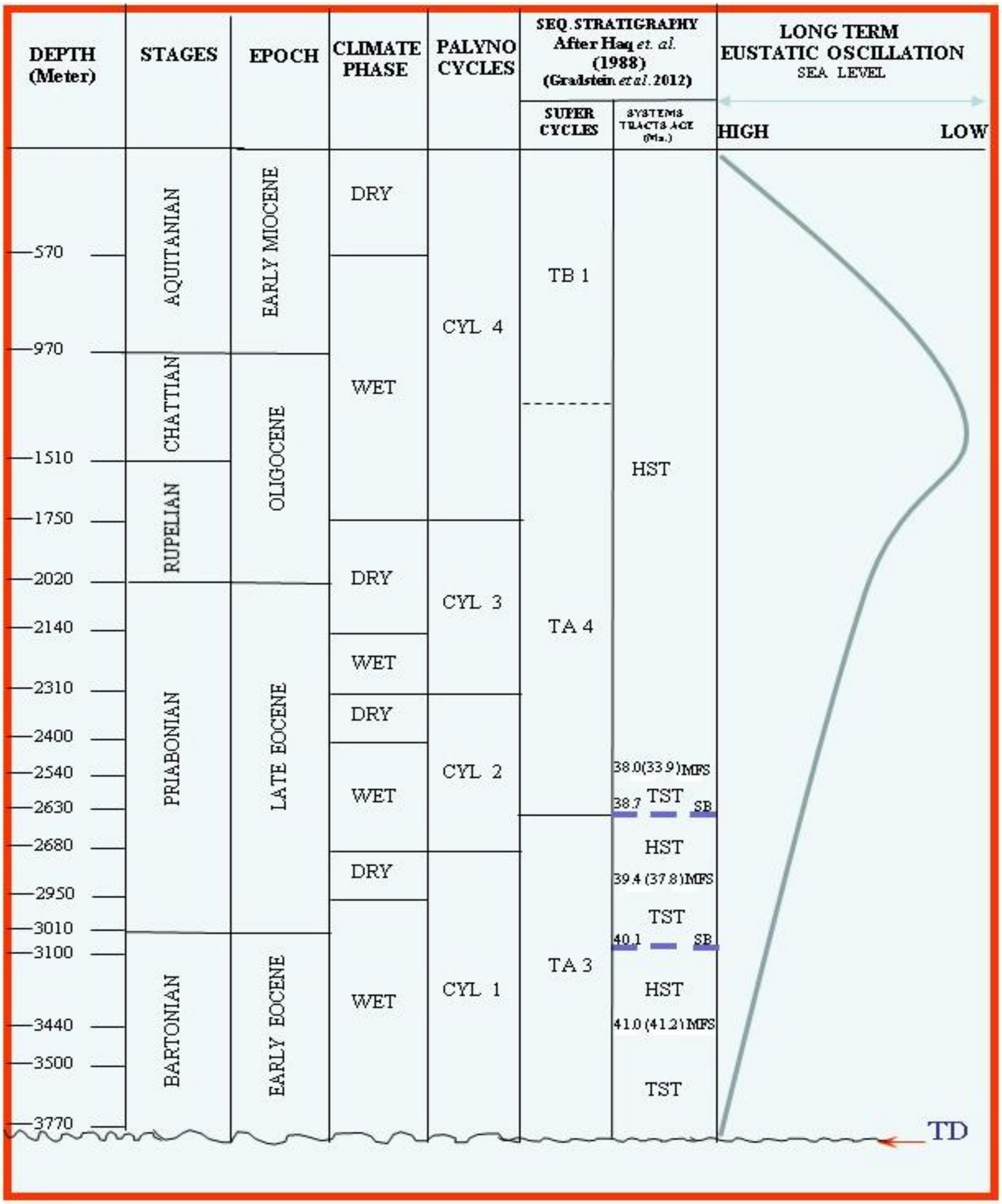
Wet Phase 1 (3770 – 2930 m):

Abundant percentages of freshwater swamp forest species such as *Amanoa oblongifolia*, *Ctenolophon englerianum*; brackish-water species: *Pelliceria rhizophorae* and *Acrostichum aureum*; pteridophytes spores: *Microsonum aff. diversifolium*, *Pallaea* sp. as well as common dinoflagellate cysts such as *Lingulodinium machaerophorum*, species of *Spiniferites*; *Leiosphaeridia* sp. and alga elements dominate this phase. The proposed 41.0 Ma MFS Condensed Section, characterized by peak abundant and diversity of foraminifera, is associated with this wet phase.

Dry Phase 1 (2930 – 2680 m):

There is a marked reduction in the percentage of wet climate indicators such as freshwater swamp forest, brackish-water swamp species and fern spores as well as a slight increase in the percentage representation of savanna species. The brackish water alga, *Botryococcus brauni* and acritarch, *Leiosphaeridia* sp. remain high in percentages. This assemblage suggests a dominant dry climatic condition during this phase.

Table 4.11: Paleoclimate Cycle in Oredo-4 well



LEGEND

HST - HIGHSTAND SYSTEMS TRACT
TST - TRANSGRESSIVE SYSTEMS TRACT
MFS - MAXIMUM FLOODING SURFACE
SB - SEQUENCE BOUNDARY
TD - TERMINAL DEPTH OF WELL

Palynocycle 2 (CYL 2)

Wet Phase 2 (2680 – 2400 m):

The percentage composition of freshwater swamp forest species which include *Amanoa oblongifolia* and *Ctenolophon englerianum*; brackish-water swamp species of *Pelliceria rhizophorae* and *Acrostichum aureum*; pteridophyte spores such as *Microsonum* aff. *diversifolium*, *Pallaea* sp. increased. The dinoflagellate cysts had their highest percentage values while *Botryococcus braunii* retained its high percentage level. Presence of microforaminiferal wall lining (MWL) was also recorded. This assemblage of phytoecological groups is suggestive of a wet climatic condition. The proposed 39.4Ma and 38.0Ma MFS Condensed Sections, characterized by peak abundance/diversity of foraminifera, are associated with this phase.

Dry Phase 2 (2400 – 2310 m):

The drop in the percentages of the freshwater swamp forest, the brackish water swamp species and the alga, *Botryococcus braunii* in association with increase in savanna species is indicative of a dry climatic condition.

Palynocycle 3 (CYL 3)

Wet Phase 3 (2310 – 2140 m):

Wet climate indicators such as freshwater swamp forest *Amanoa oblongifolia*, brackish-water swamp species such as *Pelliceria rhizophorae* and *Acrostichum aureum* and freshwater pteridophyte spores dominate this phase. Few to common *Rhizophora* type and dinoflagellate cysts were also recorded. This assemblage suggests a wet climatic phase.

Dry Phase 3 (2140 – 1750 m):

The increase in the percentage composition of savanna species *Anthonotha gilletii* in association with the relative drop in the percentages of wet climate indicators suggests dry climate at deposition.

Palynocycle 4 (CYL 4)

Wet Phase 4 (1750 – 570 m):

Wet climate indicators such as brackish-water swamp species of *Pelliceria rhizophorae*, *Acrostichum aureum*, *Rhizophora* type, and *Crenea* type (*Verrutricolporites laevigatus*); lowland rainforest species, *Psilastephanocolporites sapotaceae*; pteridophyte spores together with the brackish water alga, *Botryococcus braunii*, were recorded in high percentages within the interval. *Leiospaeridia* sp. also had high percentages, particularly toward the top of the interval.

Dry Phase 4 (570 – 130 m):

There is a general reduction in the percentages of palynomorphs within this interval. The regular presence of charred Poaceae cuticle (CPC) supports the inference of a dry climatic phase during this interval.

4.13 Thermal Maturation Index of Oredo-4 Well

Results of the visual observation of thermal alteration indices on pteridophyte spores in unoxidized slides of Oredo-4 well are shown in Table 4.12. Two phases of organic matter were identified in the well sequence as follows:

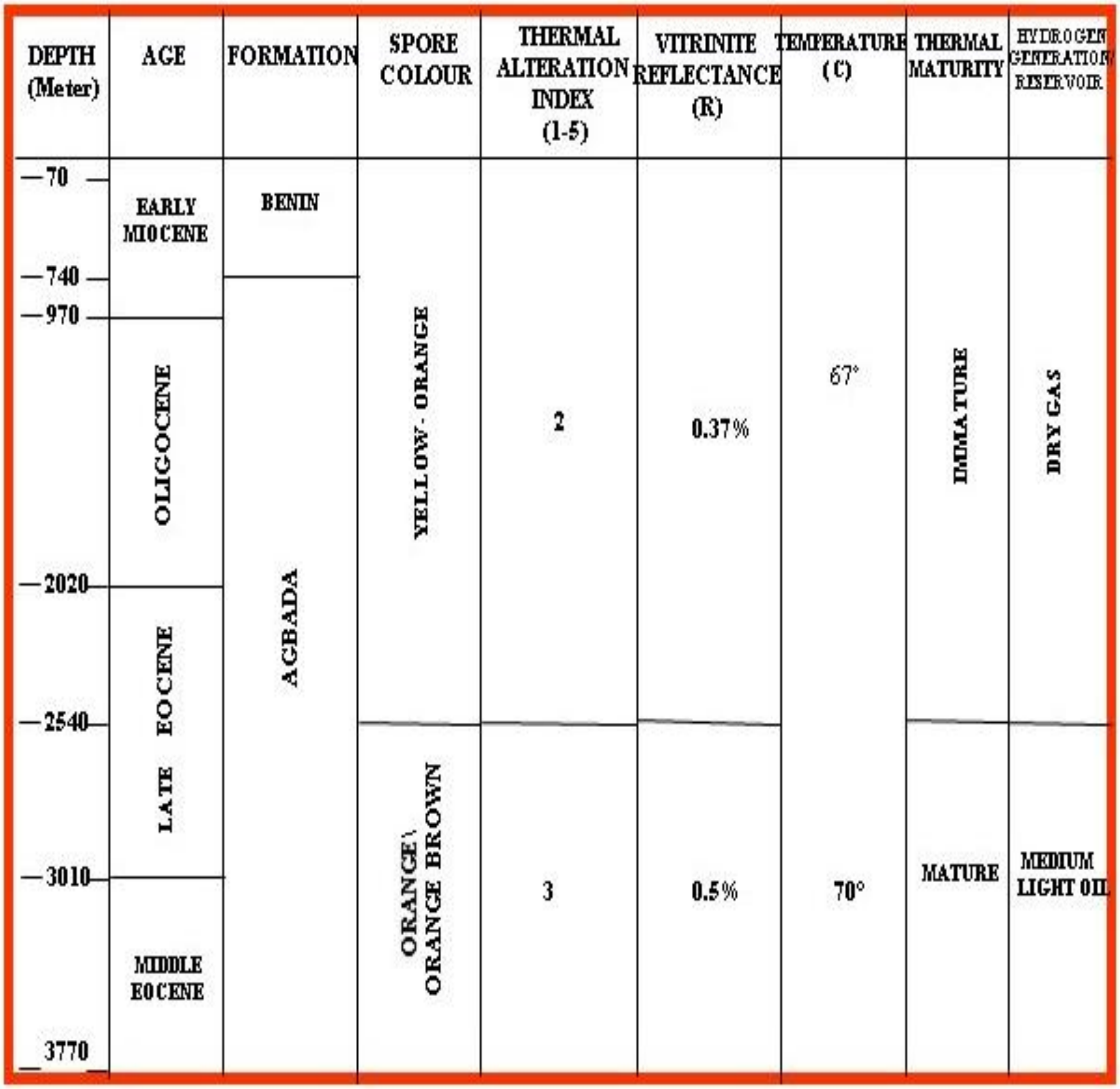
Immature (70 – 2540 m):

Yellow – orange coloured spores characterized the organic facies of this phase with a TAI value of 2. An immature thermal maturation index with dry gas hydrocarbon potential is suggested.

Mature (2540 – 3750 m):

Pteridophytes spores mostly of orange to orange-brown colouration were encountered within this phase. The TAI value of 3 suggests early mature organic facies with medium to light oil hydrocarbon potential.

Table 4.12: Thermal Maturation index of Oredo-4 well



DEPTH (Meter)	AGE	FORMATION	SPORE COLOUR	THERMAL ALTERATION INDEX (1-5)	VITRINITE REFLECTANCE (R)	TEMPERATURE (C)	THERMAL MATURITY	HYDROGEN GENERATION/ RESERVOIR
70	EARLY MIOCENE	BENIN	YELLOW - ORANGE	2	0.37%	67°	IMMATURE	DRY GAS
740		AGBADA						
970	OLIGOCENE							
2020	LATE EOCENE							
2540			ORANGE\ ORANGE BROWN	3	0.5%	70°	MATURE	MEDIUM LIGHT OIL
3010	MIDDLE EOCENE							
3770								

4.14 Multivariate Analysis of the Oredo-4 Well

Appendix 2b shows the percentage composition from the palynofacies analysis of the Oredo-4 well. These data formed the basis for the multivariate analyses conducted in the study.

4.14.1 Principal Component (PC) Analysis

The three groups, structureless organic matter (SOM, Phytoclast and Palynomorph) show significant contribution in the Principal Component (PC) analysis loading of the components (Table 4.13). This implies that, these three particulate organic matters are significantly present in Oredo-4 Well. The Principal Component (PC) analysis score values of Oredo-4 well are shown in Appendix 2e.

Furthermore, the PCA summary results (Table 4.14) shows that the first three components, PC1, PC2 and PC3, accounted for 55.68%, 24.81% and 14.06%, respectively, of total variation in abundances of the particulate organic matter in the Oredo-4 well. From the component loadings (abundance of each group), SOM, Phytoclast and Sporomorphs (Palynomorph) groups constitute the most abundant of all the particulate organic matter recorded.

4.14.2 Cluster Analysis

Figure 4.7 shows the results of the Principal Component Analysis (PCA) of the palynomacerals in Oredo-4 well. The pictorial illustration shows a linkage between the principal components, structureless organic matter (SOM), black and brown wood (BBW) and Sporomophs in the cluster grouping across the depths of the well. It shows the distinct abundances of these particulate organic matters in comparison with those from other components. Figure 4.8 depicts the cluster hierarchies of the organic particulate matters.

4.15 Palynofacies Assemblages in Oredo-4 Well

From the average linkage analyses the sequence of Oredo-4 well is sub-divided into three discrete palynofacies associations (Figure 3.8 and Enclosures 5 and 8). A description of these associations is provided as follow:

Table 4.13: PC Loading Values for the Particulate Organic Matter in Oredo-4

	PC 1	**PC 2**	**PC 3**
Pal	0.11752	-0.80736	0.57824
Phy	-0.75804	0.30323	0.57743
SOM	0.64154	0.50619	0.57637

Table 4.14: PCA Summary Result of Oredo-4 Well

PC	Eigenvalue	% variance
	143.206	55.681
2	63.8002	24.807
3	36.1635	14.061
4	8.90918	3.4641
5	2.92847	1.1386
6	1.56512	0.60855
7	0.505864	0.19669
8	0.0739856	0.028767
9	0.0145613	0.0056617
10	0.00889395	0.0034581
11	0.00608132	0.0023645
12	0.00534402	0.0020779
13	0.0025282	0.00098301
14	0.00037345	0.0001452

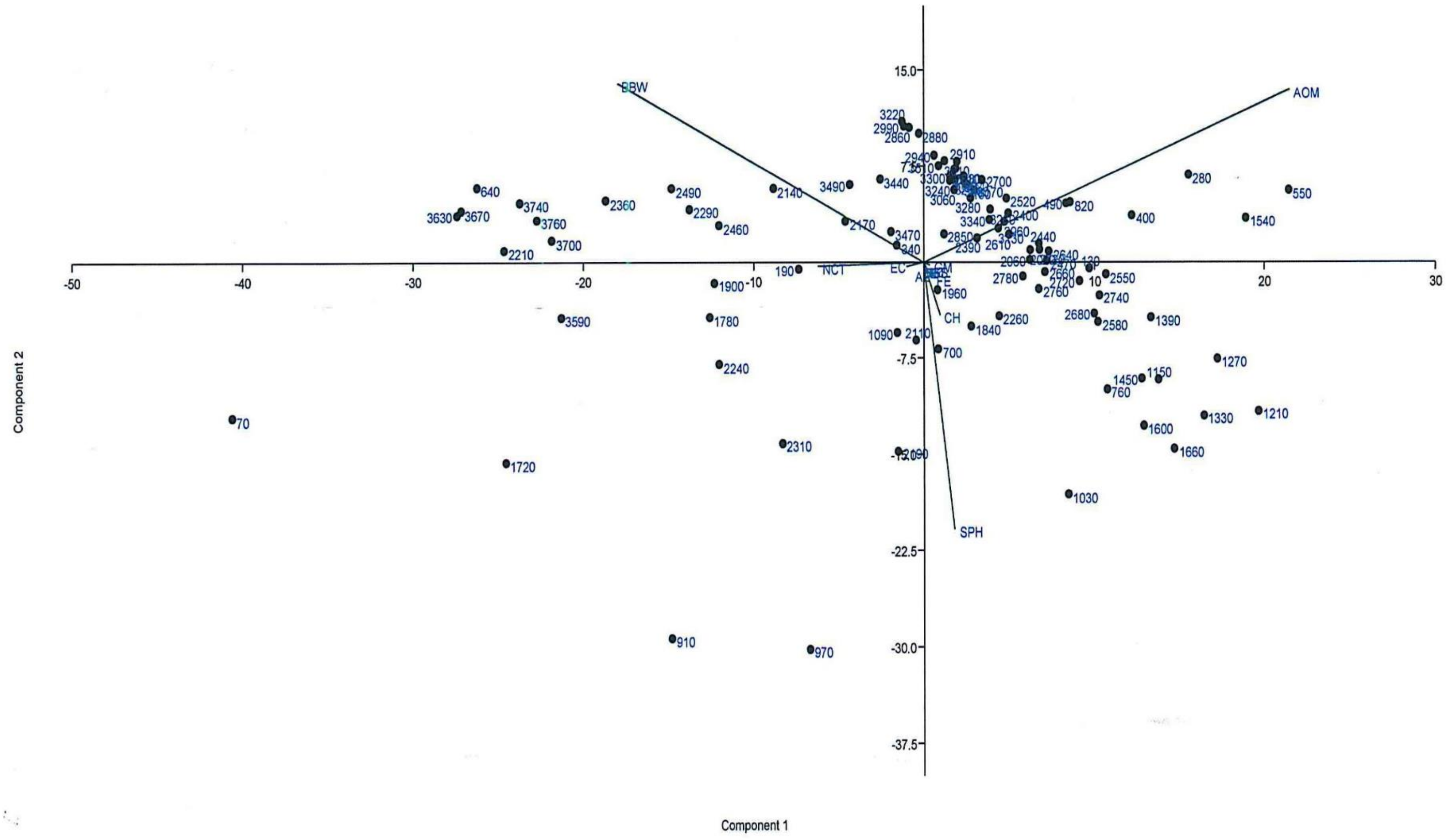


Figure 4.7: Principal Component Analysis results for the Organic Matter in Oredo-4 Well

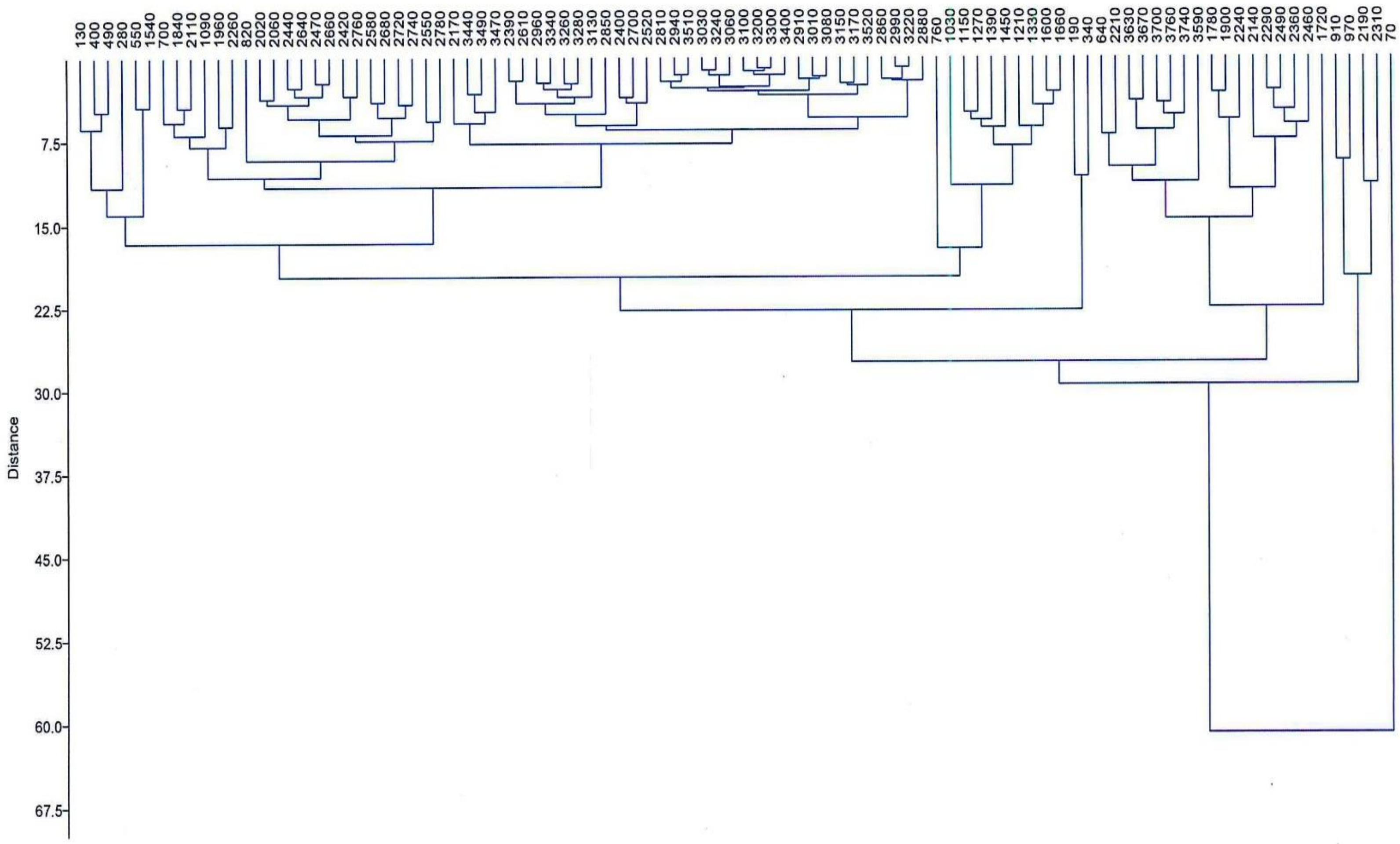


Figure 4.8: Dendogram of the Hierachial Cluster Analysis of Organic Matter in Oredo-4 Well

Palynofacies Association I; PF-I (3750 – 2370 m)

The Palynofacies Association I (PF-I) shows predominance of AOM with a relative percentage abundance (rpa) of 52%, ranging from 42 – 72% (Figure 4.9). This is followed by the commonest type of phytoclasts, the Brown and Black Wood ranging between 12 and 40% (rpa.31%). Non-Cuticular Tissue with rpa value of 5.4%, ranging from ~1 to 10% as well as Sporomorphs in the range between ~1 to 10% constitute the next significant organic matter within the palynofacies association. Non-Cuticular Tissue decreases upward from the interval base to the top.

Others are Charcoal (rpa.2.5%) ranging from ~1 to 8%, Gelified Matter (rpa.1.8%) with values ranging between ~1 and 8%, Epidermal Cuticle (rpa.1.6%) with values ranging between ~1 and 3%. Both Charcoal and Gelified Matter are marked by regular upward increase within the interval. Other organic matters encountered in the palynofacies association with relative percentage abundance less than 1% are Alga Elements, Acritarch Undifferentiated, Dinoflagellate Cysts, and Tracheid Elements.

Palynofacies Association II; PF-II (2370 – 700 m)

AOM which still dominates the organic matter assemblage shows an upward increase in values from the preceding palynofacies association (Figure 4.10). Its relative percentage abundance rose to 56% with percentage range from 37 – 77%. The next dominant component of the facies assemblage, Black and Brown Wood, exhibits an increasing to decreasing to increasing pattern from the base of the interval through the middle to the upper part. It ranges between 4 and 40% and has a relative percentage abundance of 19%.

Sporomorphs, with relative percentage abundance value of 13.5% (3 – 31%), constitute another key component of the palynofacies association. It exhibits a regular increase from the base to the upper part of the interval and then decrease at the top. Charcoal also shows an increase – decrease – increase trend in its occurrence with a relative percentage abundance of 5.6% (~1 – 17%). Epidermal Cuticle, Gelified Matter and Fungal Elements, with the first two components increasing towards the top of the interval, make up the next important organic matter with the following respective values: rpa. 1.8% (~1 – 7%), rpa. 1.9% (~1 – 8%) and rpa. 1.4% (~1-3%).

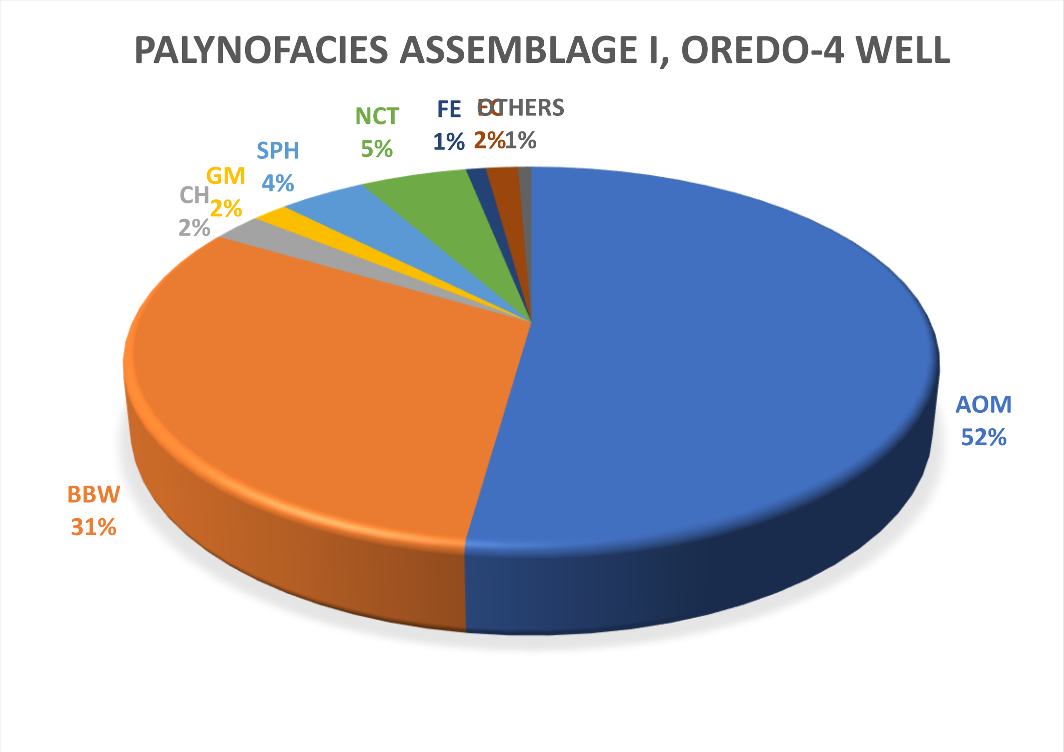


Figure 4.9: Percentage Composition of Particulate Organic Matter in PF-I, Oredo-4 Well

Key:

AOM – Amorphous Organic Matter
BBW – Black and Brown Wood
CH – Charcoal
GM – Gelified Matter
SPH – Sporomorphs
NCT – Non-Cuticular Tissues
FE – Fungal Elements
EC – Epidermal Cuticle
OTHERS

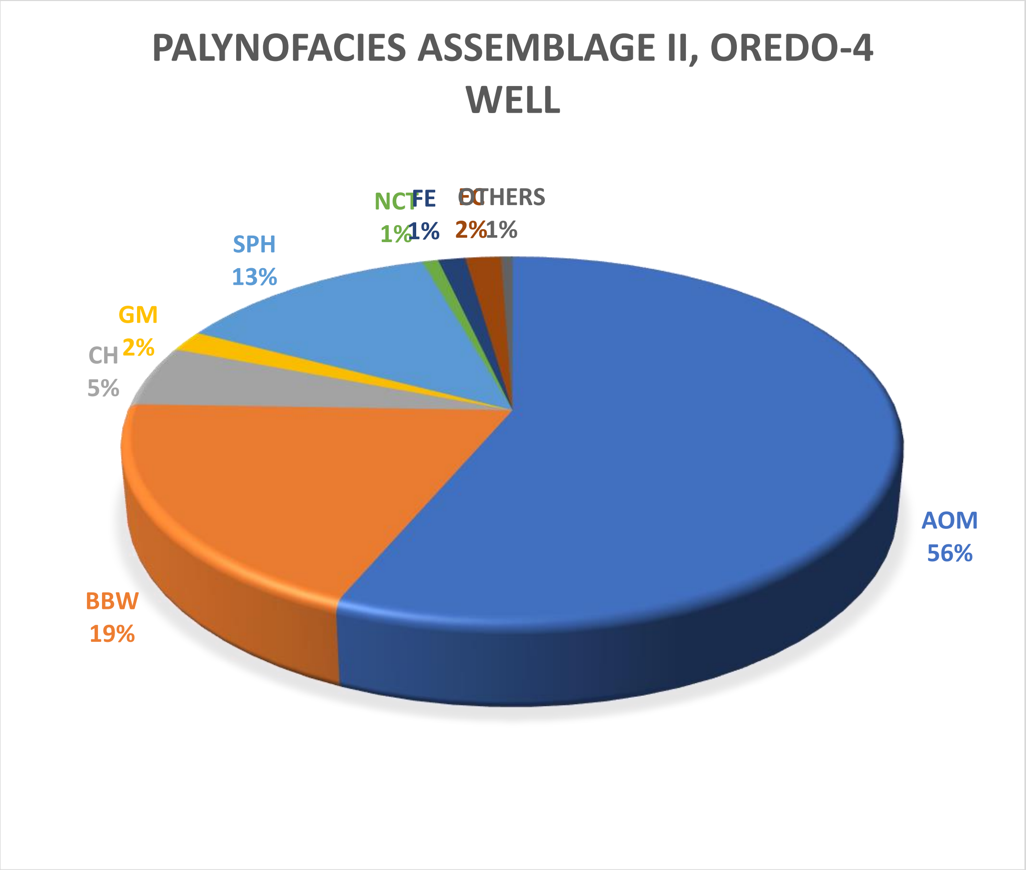


Figure 4.10: Percentage Composition of Particulate Organic Matter in PF-II, Oredo-4 Well

Key:

AOM – Amorphous Organic Matter

BBW – Black and Brown Wood

CH – Charcoal

GM – Gelified Matter

SPH – Sporomorphs

NCT – Non-Cuticular Tissues

FE – Fungal Elements

EC – Epidermal Cuticle

OTHERS

Occurring as subordinate elements with relative percentage abundance less than 1% are: Non-Cuticular Tissue, Alga Elements, Tracheid Elements, Acritarch Undifferentiated and Filaments, Hair & Tube.

Palynofacies Association III; PF-III (700 – 150 m)

This interval is still dominated by AOM with its percentage abundance further rising to 64% (45-91%) from its former value in the underlying association (Figure 4.11). Conversely, Black and Brown Wood further witnessed reduction in its relative percentage abundance (rpa. 16%) ranging from 42 to 9%. Non-Cuticular Tissue makes up the next abundant organic matter, ranging between 1 and 23% (rpa.9%). Charcoal (rpa.3.8%) ranging between 1 and 9%, Epidermal Cuticle (rpa. 2.6%) ranging from ~1 to 18% and Sporomorphs (rpa.1.7%) in the range between ~1 and 4% make up the other significant palynodebris recorded.

Other organic matter recorded but less than one percent in relative percentage abundance are: Fungal Elements, Gelified Matter, Tracheid Elements, Filaments, Hair & Tube and Miscellaneous.

4.16 Depositional Environments from Ternary Plot of Oredo-4 Well

From the SOM – Phytoclasts - Palynomorphs Ternary Plot of Tyson (1995) for the Oredo-4 well, deposition in five fields is revealed. These are II, VI, VII, VIII and IX Fields (Figure 4.12).

Field II: Marginal dysoxic-anoxic basin

A marginal dysoxic-anoxic basin sedimentation is indicated by Field II. High influx of phytoclast dilutes the concentration of well-preserved AOM. There is high relative percentage abundance of sporomorphs with very low proportion of marine elements (Tyson, 1995) in this well. The field characterizes palynofacies III (PF III). A gas-prone Kerogen Type III is suggested for this field.

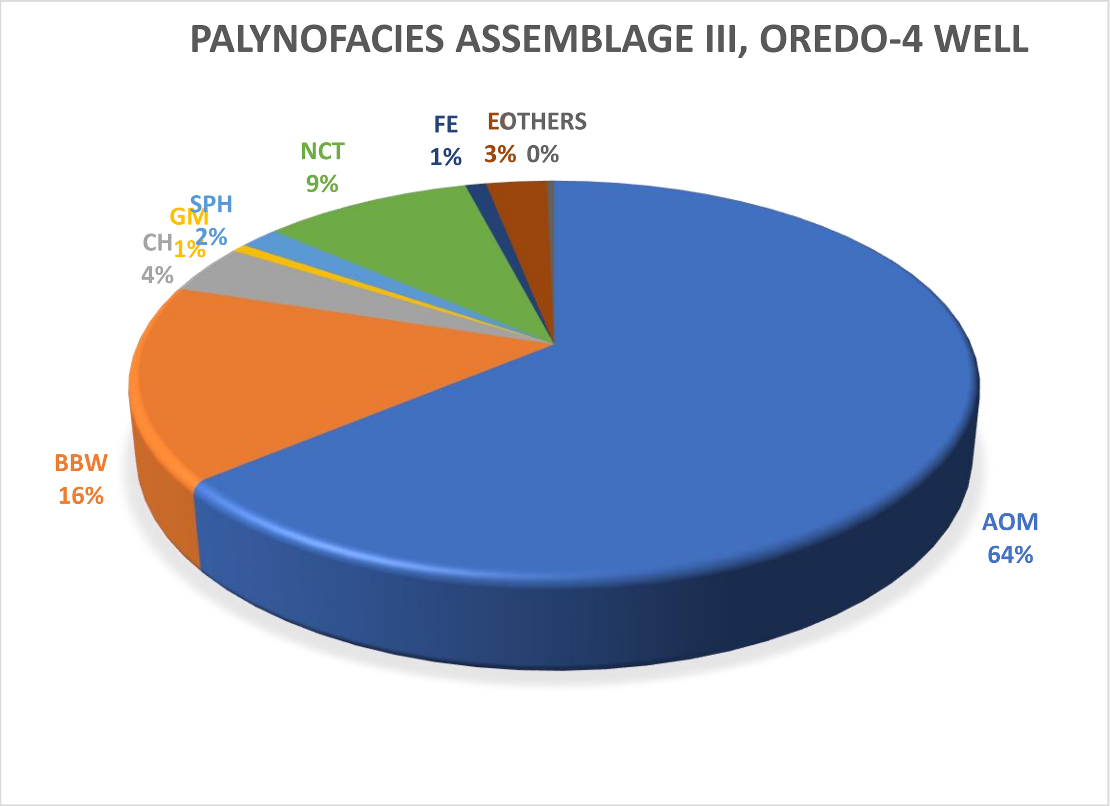


Figure 4.11: Percentage Composition of Particulate Organic Matter in PF-III, Oredo-4 Well

Key:

AOM – Amorphous Organic Matter
BBW – Black and Brown Wood
CH – Charcoal
GM – Gelified Matter
SPH – Sporomorphs
NCT – Non-Cuticular Tissues
FE – Fungal Elements
EC – Epidermal Cuticle
OTHERS

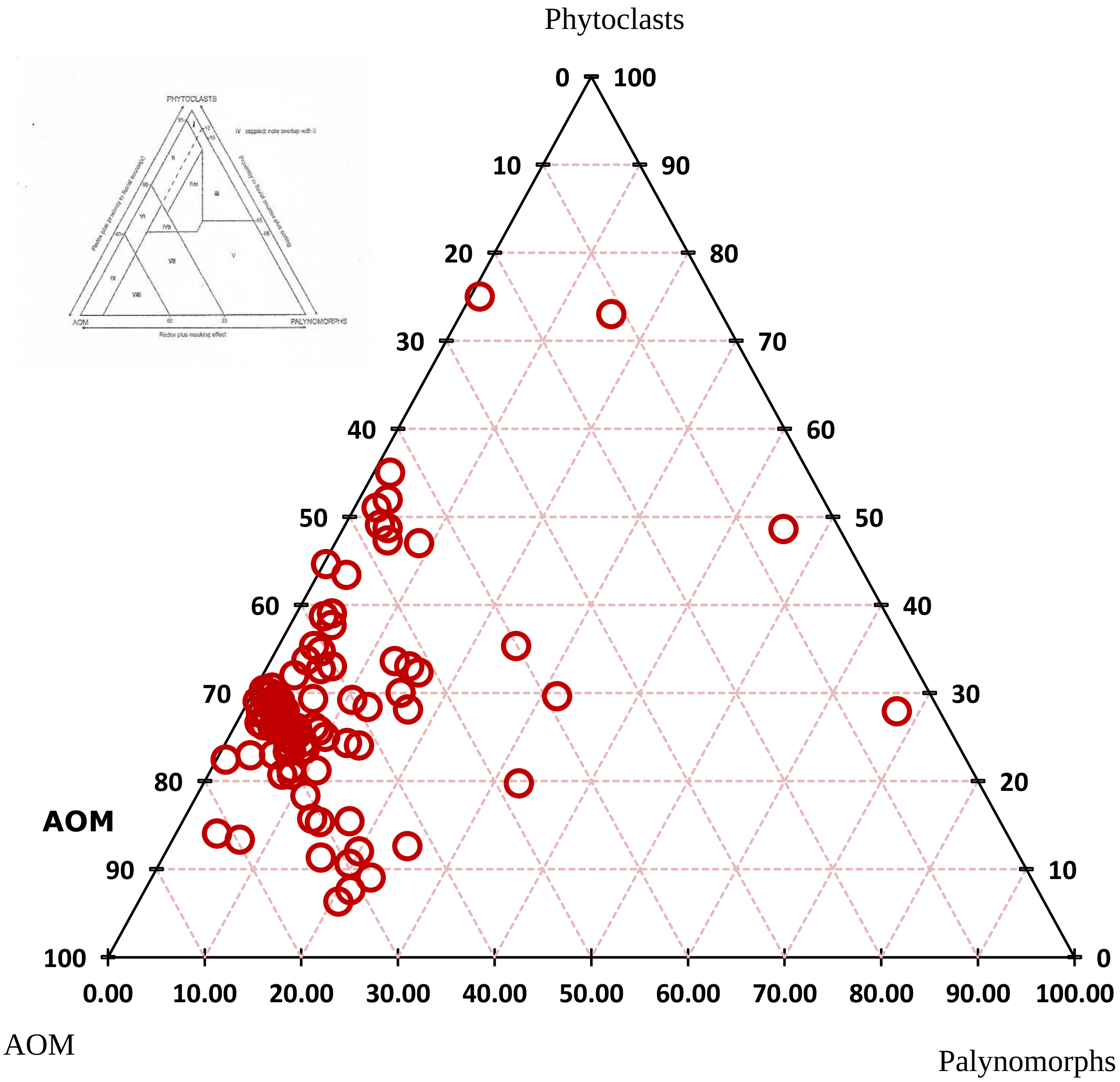


Figure 4.12: Ternary Plot, Oredo-4 well; Inset: Ternary Kerogen Diagram of Tyson (1995)

Field VI: Proximal suboxic-anoxic shelf

Proximal dysoxic-anoxic shelf condition is indicated by Field VI. High preservation of AOM in reducing basin conditions and moderate to high proportion of phytoclast due to turbidite influx or nearness to source characterize this field (Tyson,1995). Field VI characterizes Palynofacies II (PF II) assemblage in this study. Reduced proportion of sporomorphs and moderate to common marine indicators also characterize this field which suggests oil prone Kerogene Type II.

Field VII: Distal dysoxic-anoxic shelf

A distal dysoxic-anoxic shelf deposition in Field VII is indicated. It is characterized by moderate to well preserved AOM content as well as low to moderate sporomorphs. The field is typified by Palynofacies I (PF I) and indicates Kerogene Type II, rich in oil.

Field VIII: Distal dysoxic-oxic shelf

A distal dysoxic-oxic shelf deposition typical of Field VIII is indicated. Excellently preserved and dominant AOM with low to moderate sporomorphs characterize this field typifying Palynofacies I (PF I) which exhibits Kerogene Type II and is oil prone.

Field IX: Distal suboxic-anoxic basin

A distal suboxic-anoxic basin deposition which is dominated by AOM in association with low proportion of sporomorphs of Field IX is suggested (Tyson, 1995). The depositional environment is commonly rich in alginites and shelf sea deposits within starved basins. Palynofacies I (PF I) can also be related with Field IX. The field typifies highly oil prone Kerogene Type II.

4.17 Sedimentology and Lithostratigraphy of Oredo-4 Well

Lithologic and textural descriptions were carried out on the 183 ditch cuttings available for study (Appendix 4b). The lower part of the well sequence (3800 – 3410 m) has its lithofacies dominated by thick shale interbedded with a sand package. The shales are dark grey, predominantly flaggy, blocky to moderately hard. The interbedded sands grains fine with some coarse, sub-rounded to rounded, poorly sorted components. The accessory mineral content consists of abundant ferruginous materials, rare to common carbonaceous detritus and spotty and rare mica flakes and glauconites.

The upper segment of the well sequence (3410 – 70 m) is characterized by sand/shale intercalations in the ratio of approximately 75/20. The accessory mineral composition within this part consists of abundant ferruginous materials, rare to abundant carbonaceous detritus with few mica flakes and glauconites.

The sedimentological and wireline log analytical data indicate two lithological units of formational ranks for the studied section of the Oredo-4 well. These are the Agbada Formation lying below the continental Benin Formation (Table 4.15) (Short and Stauble, 1967; Whiteman, 1982).

The Agbada Formation (3800 – 740 m) is shale at the base overlain by the intercalated shale/mudstone with sand, with the sand attaining dominance up-section. This formation is further classified into marine (3800 – 3410 m), paralic (3410 – 2740 m), transitional/paralic (2740 – 2410 m) and continental/transitional (2410 – 740 m). The Benin Formation (70 – 740 m), in this well, was identified solely from the lithologic descriptions of the continental sands since the wireline logs were not provided for the upper portion of the well. Highlights of the lithostratigraphic analysis are presented in Table 4.15 and discussed below.

UNIT I: Agbada Formation: Marine (3800 – 3410 m)

This basal unit shows very thick homogenous shale interbedded with thin units of sandy mudstone. The shales are dark grey, predominantly flaggy to blocky and moderately hard. The sand interbeddeds are fine with some coarse, sub-rounded to rounded and poorly sorted.

Table 4.15: Lithostratigraphic units recognized in the Oredo-4 well

DEPTH (m)	THICKNESS (m)	FORMATION	LITHOFACIES	UNIT
70 - 740	670	Benin	Continental	V
740 - 2410	1670		Continental/Transitional	IV
2410 - 2740	330		Transitional Paralic	III
2740 - 3410	430	Agbada	Paralic	II
3410 - 3800	810		Marine	I

Abundant ferruginous materials, rare to common carbonaceous detritus and spotty and rare mica flakes and glauconites make up the accessory mineral content. Moderate records of microflora dominated by *Pelliceria rhizophorae* (*Psilatricolporites crassus*), *Psilamonocolpites marginatus* and pteridophytes spores with high dinoccysts representation. The macrofaunal assemblage is low in abundance and diversity. Accessory microfauna recorded are ostracods, scaphopods, shell fragments, gastropods, echinoid remains, sponges and pelecypods.

UNIT II: Agbada Formation: Paralic (3410 – 2740 m)

The unit is characterized by sand/shale intercalation. The sands are white, very fine to pebbly sized, sub-rounded to rounded and poorly sorted. The shales are dark grey, predominantly flaggy to blocky with some platy and moderately hard. Accessory mineral contents include abundant ferruginous materials, common carbonaceous detritus and rare mica flakes with glauconites. Backswamp species of *Pelliceria rhizophorae* (*Psilatricolporites crassus*) and pteridophyte spores such as *Acrostichum aureum* and *Polygodium vulgare* (*Verrucatosporites* sp.) dominate the floral assemblage. Dinocysts increase in abundance towards the upper part of the unit but with reduce diversity. Rich presence of Microforaminiferal Wall Lining (MWL) was recorded. Record of microfauna was low.

UNIT III: Agbada Formation: Transitional/Paralic (2740 – 2410 m)

A 280m thick argillaceous sand deposits, interspersed with 50m shales. The sands are white, fine to very coarse grained, sub-rounded to rounded and moderately sorted. The shales are dark grey, flaggy/blocky, occasionally platy to moderately hard. Ferruginous materials and carbonaceous detritus occur in abundant proportions. Palynomorphs recorded a general increase in abundance and diversity with few dinocysts and MWL. However, microfauna record was low.

UNIT IV: Agbada Formation: Continental/Transitional (2410 – 740 m)

A 1315 m thick sequence of argillaceous sands interbedded with an incised valley filled shale/mudstone deposits, 355m thick. The sands are white, very coarse pebbly, surrounded to rounded and moderately sorted. The shales are dark grey, blocky/flaggy, and occasionally platy, and moderately hard. Index minerals over this interval include abundant ferruginous materials and carbonaceous detritus with very rare mica flakes and glauconites. The unit is made up of rich presence of land-derived palynomorphs with few dinocysts limited to the basal part. Botryococcus braunii and Leiosphaeridia sp. are well represented. No record of microfauna.

UNIT V: Benin Formation: Continental (740 – 300 m)

This uppermost litho-unit is essentially (100%) composed of clean, coarse to very coarse pebbly, moderately sorted sands. The poorly recovered accessory minerals in the unit are represented by rare record of mica flakes and carbonaceous detritus at 640 – 670 m. The microflora representation of this unit is low with no record of microfauna content.

4.18 Sequence Stratigraphy of Oredo-4 Well

The standard sequence stratigraphic interpretation procedures of Mitchum *et al*. (1990) of integrating high resolution biostratigraphic data obtained from foraminifera and palynomorphs with lithostratigraphic and well log data (Vail and Wornardt, 1991) have been applied in the in the study.

Three Maximum Flooding Surfaces (MFS) were recognized in the well sequence, which are dated in Ma using the marker benthic species and palynological subzones. The recognized MFSs are 41.0 Ma (41.2 Ma), 39.4 Ma (37.8 Ma) and 38.0 Ma (33.9 Ma) at 3440 m, 2905 m and 2540 m respectively. Two (2) Sequence Boundaries are recognized within the well sequence at 3100 m and 2610 m. These are dated 40.1Ma and 38.7Ma, respectively.

The proposed sequence stratigraphic framework for the well is summarized in Table 4.16 and briefly highlighted below:

SEQUENCE 1 (3800 – 3100 m)

3800 – 3440 m: Transgressive Systems Tract (TST)

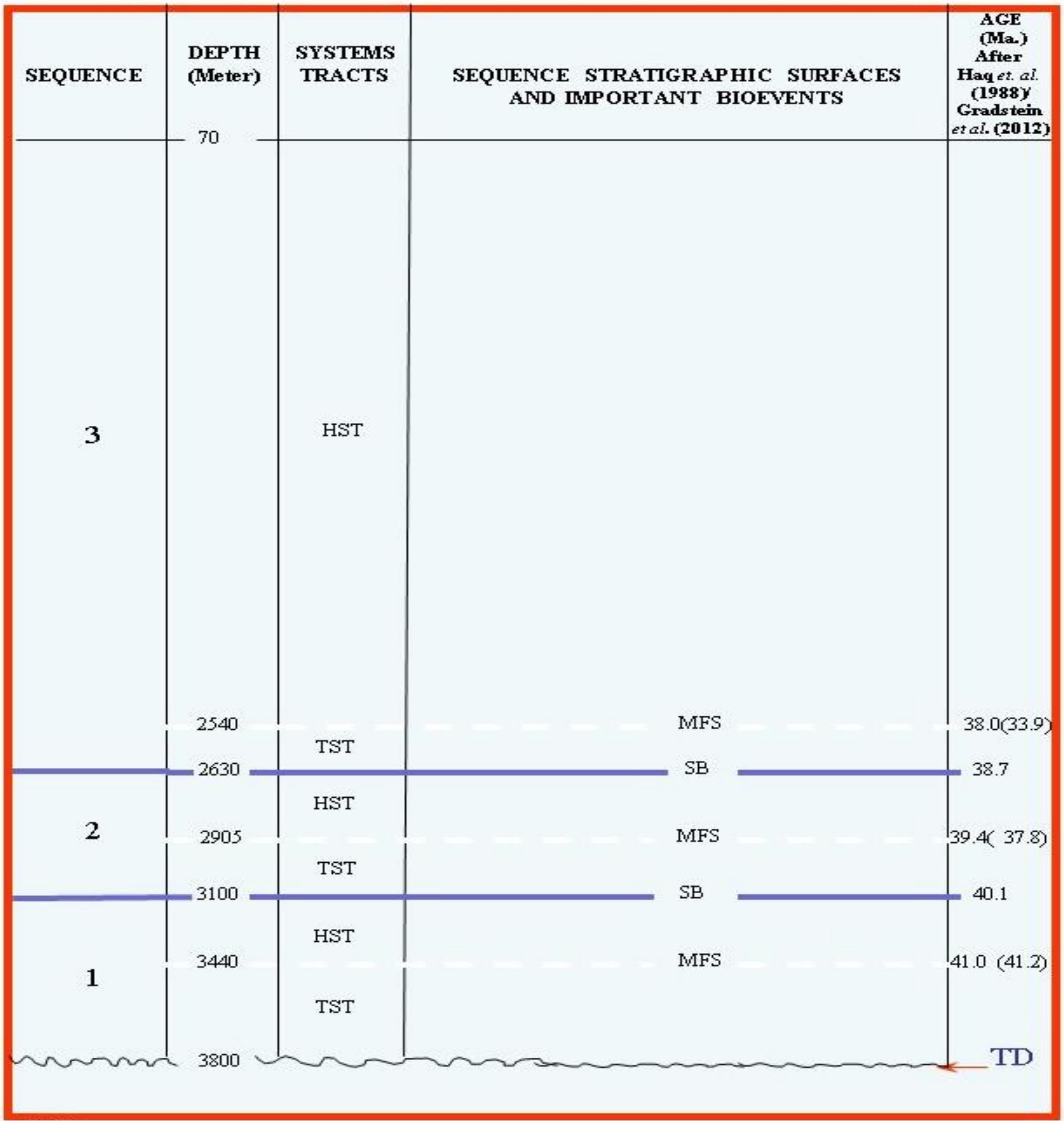
Characteristics

- Increasing-upward faunal and dinocysts abundance and diversity
- Termination in a condensed section marked by foraminiferal abundance/diversity maxima at 3510 – 3300 m.

Remarks

- The MFS on top of the TST is defined at the gamma ray peak at 3440 m
- The MFS is dated 41.0 Ma of Haq *et al*. (1988), correlated to 41.2 Ma of Gradstein *et al*. (2012). The age is assigned using its stratigraphic position within foraminiferal zone ?P15 and palynological subzone P450.

Table 4.16: Sequence Stratigraphic framework of the Oredo-4 well



SEQUENCE	DEPTH (Meter)	SYSTEMS TRACTS	SEQUENCE STRATIGRAPHIC SURFACES AND IMPORTANT BIOEVENTS	AGE (Ma.) After Haq *et. al.* (1988)/ Gradstein *et al.* (2012)
	70			
3		HST		
	2540		MFS	38.0(33.9)
		TST		
	2630		SB	38.7
		HST		
2	2905		MFS	39.4(37.8)
		TST		
	3100		SB	40.1
		HST		
1	3440		MFS	41.0 (41.2)
		TST		
	3800			TD

LEGEND

HST - HIGHSTAND SYSTEMS TRACT
TST - TRANSGRESSIVE SYSTEMS TRACT
MFS - MAXIMUM FLOODING SURFACE
SB - SEQUENCE BOUNDARY
TD - TERMINAL DEPTH OF WELL

3440 – 3100 m: Highstand Systems Tract (HST)

Characteristics

- Presence of *Botryococcus braunii*;
- Decreasing-upward faunal and dinocyst abundance and diversity.
- Termination in a foraminiferal and dinocyst abundance and diversity minima.

Remarks

- The Sequence Boundary (SB) capping the HST is marked at 3100 m, top of sand intertwined within a thick shale section.
- SB is dated 40.1 Ma based on its stratigraphic position below the 41.0Ma Maximum Flooding Surface

SEQUENCE 2 (3100 – 2630 m)

3100 – 2905 m: Transgressive Systems Tract (HST)

Characteristics

- Increasing-upward foraminiferal abundance and diversity.
- Fining-upward log profile.
- Termination in a condensed section (3080 – 2960 m**).**

Remarks

- The MFS occurring within this condensed section is defined at the gamma ray peak at 2905 m.
- This MFS is dated 39.4 Ma (Haq *et al.*, 1988), correlated to 37.8 Ma of Gradstein *et al*. (2012).
- The age is assigned based on the palynological subzone P450.

2905 – 2630 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile.
- Decreasing-upward foraminiferal abundance and diversity.
- Directly overlying an MFS.
- Regular occurrence of *Botryococcus braunii*.

Remarks

- The SB on top of this sequence is defined by 2630 m, top of the argillaceous sand.
- This SB is dated 38.7Ma based on correlation with the Global Cycle Chart of Haq *et al*. (1988).

SEQUENCE 3 (2630 – 70 m)

2630 – 2540 m: Transgressive Systems Tract (TST)

Characteristics

- Fining-upward profile.
- Increasing-upward faunal abundance and diversity.

Remarks

- The MFS on top of the TST is defined by the gamma ray log positive deflection at 2540 m.
- The MFS is dated 38.0 Ma (Haq *et al.*, 1988), correlated to 33.9 Ma of Gradstein *et al*. (2012).
- The age is assigned by its stratigraphic position within the palynological subzone P470.

2540 – 720 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile.
- Decreasing-upward dinocysts abundance and diversity.
- Barren faunal assemblage.
- Shallowing-upward trend.
- Stratigraphic position directly above a MFS.
- Abundance occurrence of *Botryococcus braunii*.

Remarks

The Sequence Boundary (SB) on top of this HST is believed to lie shallower than the top of the analysed section.

4.19 Palynostratigraphy of Oredo-8 Well

A total number of 80 ditch cuttings of the Oredo-8 Well, between depths 320 m and 3650 m, were subjected to detailed palynological analyses. Angiosperm pollen and pteridophyte spores dominate the rich palynofloral assemblage recorded in the well. These include: *Retitricolporites irregularis*, *Retimonocolpites obaensis*, *Psilatricolporites crassus*, *Iriartea* sp., *Psilatricolporites* sp., and pteridophyte spores such as, *Acrostichum aureum*, *Verrucatosporites terellis* and *Laevigatosporites discordatus*.

A rich proportion and diverse forms of fungal spores were also recorded. The dominant types among these are: *Exesisporites* sp., *Pleuricellaesporites* sp., *Basidiosporites* sp., and Form Type B. The recorded dinoflagellate cysts include *Lingulodinium machaerophorum, Spiniferites ramosus, S. membranacoeus, Tuberculodinium vancampoae, Hystrichokolpoma rigaudae. Homotryblium abbreviatum, H. plectilum, Polyspaeridium zoharyi and cf. Lejeuncysta serrata.* Few microforaminiferal wall lining (MWL) were recovered, particularly at the basal section of the well. The acritarch, *Leiosphaeridia* sp., was recorded in high proportions throughout the well sequence. The brackish water alga, *Botrycoccus braunii*, constitutes the dominant alga recorded with a few freshwater forms, i.e.., *Pediastrum* sp. and *Concentricyst*. Charred Poaceae Cuticles (CPC) were common while an unusually high number of diatom frustules was also recorded.

The age diagnostic/significant pollen and spores encountered include: *Elaies guineensis, Verrutricolporites laevigatus, V. scabratus, Magnastriatites howardi, Cicatricosisporites dorogensis*, *Arecipites exilimuratus*, *Spirosyncolpites bruni, Verrustephanocolporites complanatus*, *Inaperturopollenites gemmatus, Spinizonocolpites echinatus, S. baculatus, Retimonocolpites. obaensis, Praedapollis africanus*, *Proxapertites cursus*, *P. operculatus, Striamonocolpites rectostriatus, Retitricolpites bendeensis, Psilamonocolpites marginatus, Grimsdalea polygonalis, Psilatricolporites onitshaeensis, Peregrinipollis. nigericus, Cinctiporipollis mulleri, Verrucatosporites usmensis, Retibrevitricolporites ibadaneensis, Mauritiidites crassiexinus, Periretipollis spinosus, Doualaidites laevigatus, Auriculopollenites reticulatus, A. echinatus* and *A. simplex.*

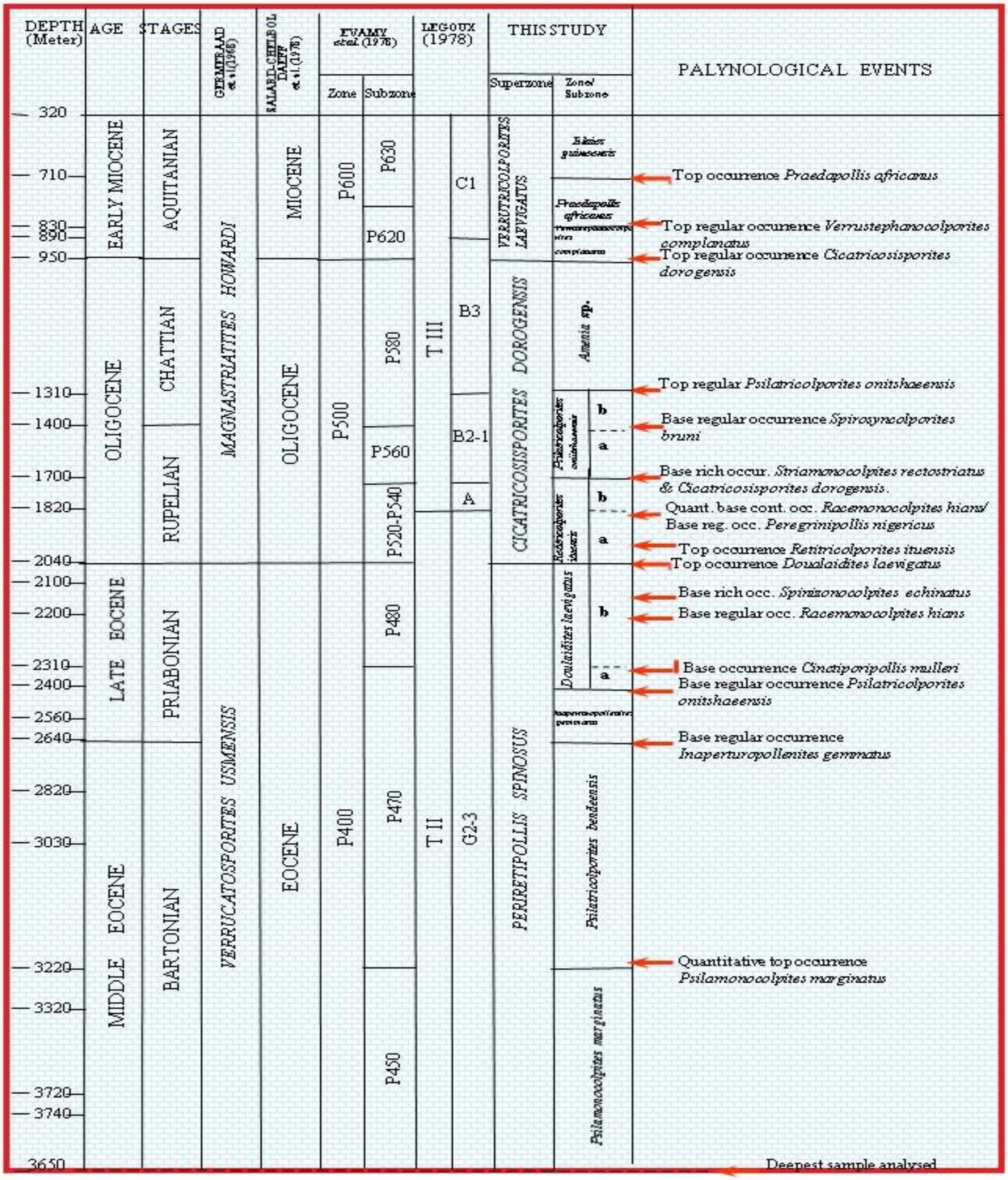
4.19.1 Zonation

Results of detailed palynological analyses of 80 ditch cuttings of the Oredo-8 well, between interval 320 m and 3650 m, are presented in Enclosure 7. The assemblage and stratigraphic distribution of the diagnostic species recovered were used for the zonation of the well.

The recognized zones in this well are: *Psilamonocolpites marginatus*, *Retitricolpites bendeensis*, *Inaperturopollenites gemmatus*, *Doualaidites laevigatus*, *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis*, *Anemia* sp., *Verrustephanocolporites complanatus*, *Praedapollis africanus* and *Elaeis guineensis* (Table 4.17 and Enclosure 9).

Details of the different ages traversed as indicated by diagnostic palynomorphs are discussed below:

Table 4.17: Palynostratigraphic zonation of Oredo-8 well



Superzone:	*Periretipollis spinosus*
Interval:	3650 - 2040 m
Age:	middle - late Eocene

Definition:

Base of the Superzone:	Probably not penetrated by last sample analysed at 3650 m.
Top of the Superzone:	Top occurrence of *Doualaidites laevigatus* at 2040 m.
Correlation:	*Verrucatosporites usmensis – Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P400 of Evamy *et al*. (1978) and TII of Legoux (1978).

Description:

The *Periretipollis spinosus* Superzone comprises the *Psilamonocolpites marginatus*, *Retitricolpites bendeensis*, *Inaperturopollenites gemmatus* and *Doualaidites laevigatus* Zones.

Characteristics Features: The superzone is characterised by the top occurrences (Last Appearance Datums) of *Doualadites laevigatus*, *Mauritiidites crassiexinus*, *Periretipollis spinosus.* These three are also restricted to the superzone.

Cicatricosisporites dorogensis, *Verrucatosporites usmensis*, *Monoporites annulatus*, *Peregrinipollis nigericus*, *Praedapollis africanus*, *Cinctiporipollis mulleri*, *Retitricolpites bendeensis* and *Praedapollis flexibilis* have their base occurrences (first appearance datums) within the superzone.

Zone:	*Psilamonocolpites marginatus*
Interval:	3650 - 3220 m
Assigned Age:	middle Eocene

Definition:

Zonal Base: Probably deeper than 3650 m which was the last sample analyzed.

Zonal Top: Quantitative top occurrence of *Psilamonocolpites marginatus* at 3220 m.

Correlation: Zone P450 of Evamy *et al*. (1978) and G2 -3 of Legoux (1978).

Characteristics:

- *Mauritiidites crassiexinus* is regularly present within the zone.

The dominant palynomorphs within the zone are *Psilatricolporites crassus*, *Psilamonocolpites marginatus, Acrostichum aureum* and *Verrucatosporites terellis*.

Zone: *Retitricolpites bendeensis*

Interval: 3220 - 2640 m

Assigned Age: middle Eocene

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Definition:

Zonal Base: Quantitative top occurrence of *Psilamonocolpites marginatus* at 3200 m.

Zonal Top: Base regular occurrence of *Inaperturopollenites gemmatus* at 2460 m.

Characteristics:

- *Mauritiidites crassiexinus* has its top occurrence within the zone.
- *Praedapollis africanus* has its base occurrence towards the basal boundary.
- *Retitricolpites bendeensis* also has its base occurrence within the zone or close to its basal boundary.

The palynofloral assemblage within this zone is dominated by *Psilatricolporites crassus, Acrostichum aureum* and *Verrucatosporites terellis*.

Zone: *Inaperturopollenites gemmatus*
Interval: 2640 – 2400 m
Assigned Age: late Eocene
Definition:
Zonal Base: Base regular occurrence of *Inaperturopollenites gemmatus* at 2640 m.
Zonal Top: Base regular occurrence of *Psilatricolporites onitshaeensis* at 2400 m.

Correlation: Zone P470 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristic:

- *Praedapollis flexibilis* has its base occurrence within the zone.
- *Retibrevitricolpites triangulatus* has its quantitative base occurrence in the zone.

Psilatricolporites crassus, Acrostichum aureum, Verrucatosporites terellis and *Laevigatosporites discordatus* make up the dominant palynomorphs of the zonal assemblage.

Zone: *Doualaidites laevigatus*
Interval: 2400 – 2040 m
Assigned Age: late Eocene

Definition:
Zonal Base: Base regular occurrence of *Psilatricolporites onitshaeensis* at 2400 m.
Zonal Top: Top occurrence of *Doualaidites laevigatus* at 2040 m.

Correlation: Zones P470 - P480 of Evamy *et al*. (1978) and G2 - 3 of Legoux (1978).

Characteristics:

- *Racemonocolpites hians* has its base regular occurrence at 2200 m.
- *Cinctiporipollis mulleri* has its base occurrence at 2310 m.

- *Spinizonocolpites echinatus* has its base rich occurrence 2100 m.

Psilatricolporites crassus, Retimonocolpites obaensis, Spinizonocolpites echinatus and pteridophyte spores such as *Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* dominate the palynofloral assemblage of this zone.

Remark:

The *Doulaidites laevigatus* Zone was further sub-divided into sub-zones a and b by the base occurrence of *Cinctiporipollis mulleri* at 2310 m.

The Eocene – Oligocene boundary was defined by the top occurrence of *Doualaidites dorogensis* at depth 2040 m.

Superzone:	*Cicatricosisporites dorogensis*
Interval:	2040 – 950 m
Age:	Oligocene

Definition:

Base of the Superzone: Top occurrence of *Doualaidites laevigatus* at 2040 m.

Top of the Superzone: Top regular occurrence of *Cicatricosisporites dorogensis* at 950 m.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P500 of Evamy *et al*. (1978) and TII - TIII of Legoux (1978).

Description:

The *Cicatricosisporites dorogensis* Superzone is made up of the *Retitricolporites ituensis, Psilatricolporites onitshaeensis* and *Anemia* sp. Zones.

Characteristic Features:

- The superzone is characterised by the top occurrences (Last Appearance Datums) of *Cicatricosisporites dorogensis, Verrustephanocolporites complanatus Inaperturopollenites gemmatus, Spinizonocolpites echinatus, Retimonocolpites obaensis* and *Praedapollis africanus.*
- *Magnastriatites howardi* has its base occurrence in the superzone.

- Types with top rich occurrences in the superzone are: *Proxapertites cursus, Proxapertites operculatus, Striamonocolpites rectostriatus, Retitricolpites bendeensis and Retimonocolpites obaensis*.

Arecipites exilimuratus, Psilatricolporites okeizei, Verrustephanocolporites complanatus and *Grimsdalea polygonalis* have top regular occurrences.

Zone:	*Retitricolporites ituensis*
Interval:	2040 – 1700 m
Assigned Age:	Oligocene

Definition:

Zonal Base:	Top occurrence of *Doualaidites laevigatus a*t 2040 m.
Zonal Top:	Base rich occurrence of *Striamonocolpites rectostriatus* at 1700 m.

Correlation: Zone P520 - P540 of Evamy *et al*. (1978) and G2-3 – A of Legoux (1978).

Characteristics:

- *Retimonocolpites obaensis* and *Spinizonocolpites echinatus* show top rich occurrences.
- *Grimsdaleae polygonalis* exhibits top regular occurrences.
- *Peregrinipollis nigericus* has its base regular occurrence.

Retimonocolpites obaensis, Psilatricolporites crassus, Retitricolporites irregularis, Acrostichum aureum, Verrucatosporites terellis and *Laevigatosporites discordatus* dominate the microflora assemblage.

Remark:

The *Retitricolporites ituensis* Zone was further sub-divided into sub-zones a and b by the quantitative base occurrence of *Racemonocolpites hians* and/or base regular occurrence of *Peregrinipollis nigericus* at 1820 m.

Zone: *Psilatricolporites onitshaeensis*

Interval: 1700 – 1310 m

Assigned Age: Oligocene

Definition:

Zonal Base: Base rich occurrence of *Striamonocolpites rectostriatus* marks at 1700 m.

Zonal Top: Top regular occurrence of *Psilatricolporites onitshaeensis* at 1310 m.

Correlation: Zones P540, P560 and P580 of Evamy *et al*. (1978) and B2-1 – B3 of Legoux (1978).

Characteristics:

- *Cicatricosisporites dorogensis* occurs in rich proportions.
- *Arecipites exilimuratus* and *Psilatricolporites okeeizei* both exhibit top regular occurrences.
- *Striamonocolpites rectostriatus* has its top rich occurrence.
- *Retitricolpites bendeensis* shows regular occurrence.
- *Psilatricolporites onitshaeensis* exhibits regular occurrence.

Retitricolporites irregularis, Psilatricolporites crassus, Psilastephanocolporites spp., *Zonocostites ramonae*, *Racemonocolpites hians, Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* dominate the assemblage within the zone.

Remark:

The *Psilatricolporites onitshaeensis* Zone was sub-divided into sub-zones a and b by the base regular occurrence of *Spirosyncolporites hians* at 1400 m.

Zone: *Anemia* sp.

Interval: 1310 – 950 m

Assigned Age:	Oligocene
Definition:	
Zonal Base:	Top regular occurrence of *Psilatricolporites onitshaeensis* at **1310** m.
Zonal Top:	Top regular occurrence of *Cicatricosisporites dorogensis* at 950m.

Characteristics:

- *Retitricolpites bendeensis* exhibits its top rich occurrence.

The palynofloral assemblage is dominated by *Retitricolporites irregularis, Psilatricolporites crassus, Psilastephanocolporites spp., Racemonocolpites hians, Zonocostites ramonae*, *Psilatricolporites* spp., *Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus.*

Remark:

The Oligocene – Miocene boundary was defined by the top occurrence of *Cicatricosisporites dorogensis* at depth 950 m.

Superzone:	*Verrutricolporites laevigatus*
Interval:	950 – 320 m
Age:	early Miocene

Base of the Superzone:	Top regular occurrence of *Cicatricosisporites dorogensis* at 950 m.
Top of the Superzone:	Tentatively marked at 320 m, the depth of the last sample analysed.

Correlation: *Magnastriatites howardi* Zone of Germeraad *et al*. (1968); Zone P600 of Evamy *et al*. (1978) and TIII of Legoux (1978).

Description:

The *Verrutricolporites laevigatus* Superzone is made up of the *Verrustephanocolporites complanatus, Praedapollis africanus* and *Elaeis guineensis* Zones.

Characteristic:

The superzone is characterised by the top occurrence of *Praedapollis africanus*.
Elaeis guineensis has its base occurrence (FAD) within the superzone.
Verrutricolporites laevigatus shows base regular or rich occurrence within the superzone.

Zone: *Verrustephanocolporites complanatus*
Interval: 950 – 830 m
Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Cicatricosisporites dorogensis* at 950 m.
Zonal Top: Top regular occurrence of *Verrustephanocolporites complanatus* at 830m.

Correlation: Zone P620 of Evamy *et al*. (1978) and B3 - C1 of Legoux (1978).

Characteristics:

- *Verrustephanocolporites complanatus* shows its top regular occurrence.
- *Verrutricolporites laevigatus* has its base regular or rich occurrence.

Zonocostites ramonae, Retitricolporites irregularis and pteridophyte spores such as *Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* constitute the dominant microflora of the zone.

Zone: *Praedapollis africanus*
Interval: 830 – 710 m

Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Verrustephanocolporites complanatus* at 830 m.

Zonal Top: Top occurrence of *Praedapollis africanus* at 710 m.

Characteristic:

- *Psilastephanocolporites malacanthoides* is present.

Zonocostites ramonae, Acrostichum aureum, Verrucatosporites terellis and *Laevigatosporites discordatus* dominate the floral assemblage.

Zone: *Elaeis guineensis*

Interval: 710 – 320 m

Assigned Age: early Miocene

Definition:

Zonal Base: Top regular occurrence of *Praedapollis africanus* at 710 m.

Zonal Top: Suspected to be above the depth of the first sample analysed at 320 m.

Characteristics:

Elaeis guineensis exhibits its regular occurrence within the zone.

Psilastephanocolporites spp., Zonocostites ramonae, *Retitricolporites irregularis*, *Acrostichum aureum, Verrucatosporites terellis* and *Laevigatosporites discordatus* pollen constitute the dominant microflora within the zone.

The well sequence ranges from middle Eocene to early Miocene.

4.20 Foraminiferal Biostratigraphy of Oredo-8 Well

4.20.1 Introduction

Seventy-nine (79) composited ditch cutting samples from 3650 m to 320 m of the Oredo-8 well were processed and analysed for their foraminiferal and accessory microfaunal contents. Recovery of foraminifera within the studied section was generally low except in the interval 3600 - 3620 m where abundant foraminifera, but of low diversity, were recovered. Samples in the interval 2460 - 320 m were barren of foraminifera.

Twenty-three (23) foraminiferal species were recovered. Two (9%) were planktic foraminifera, twelve (52%) were calcareous benthics with the remaining nine (39%) species arenaceous benthic species. Sponges, scaphopods, echinoid remains, ostracods, shell fragments and gastropods were the accessory microfauna recovered.

The microfaunal distribution chart, the foraminiferal abundance and diversity plots and paleobathymetric data are presented as Enclosure 10.

4.20.2 Planktic Foraminiferal Zones

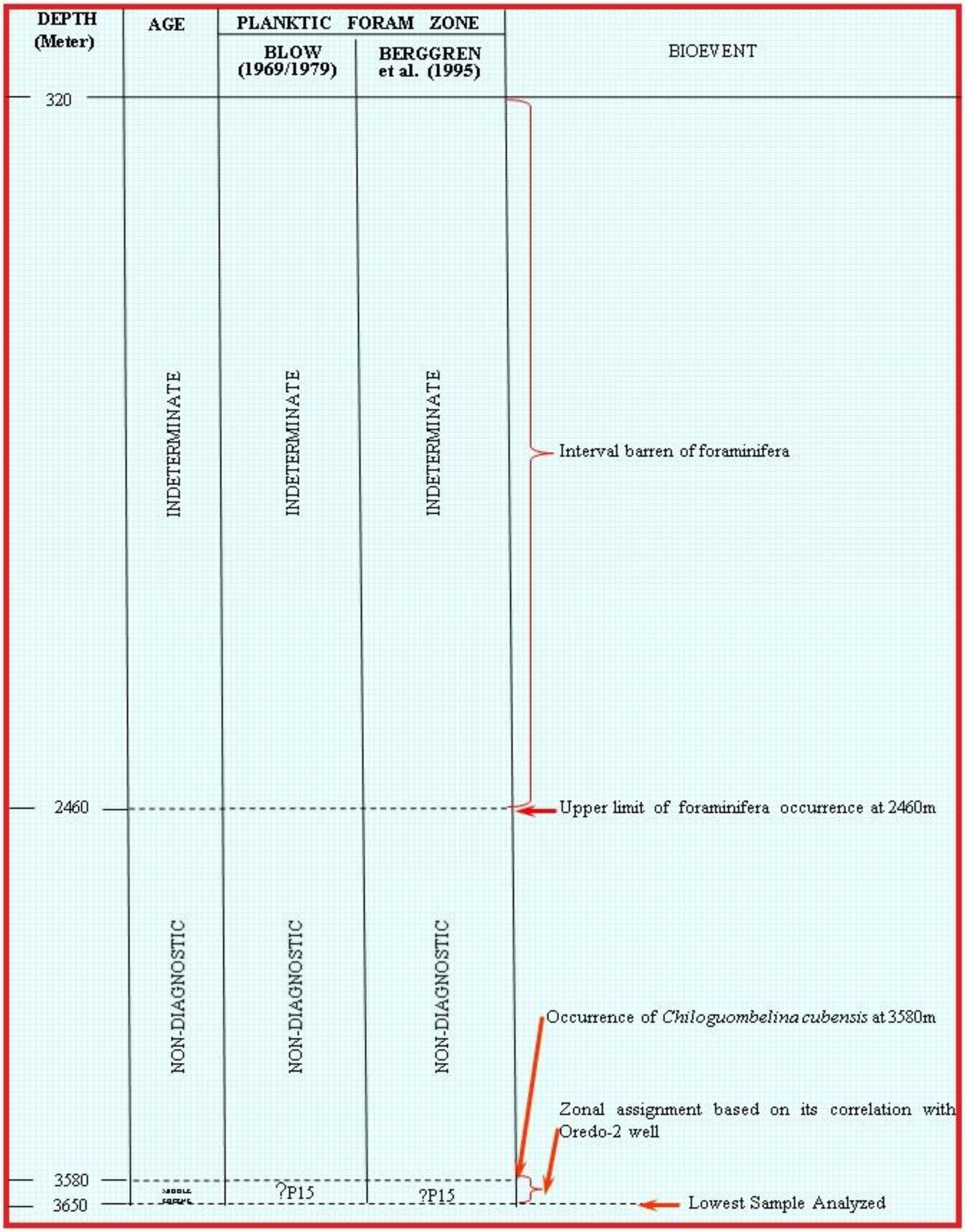
Paucity of planktic affected the delineation of the planktic foraminifera zones. However, the planktic zones recognized in this study are based on the revised Schemes of Berggren *et al*. (1995) and Blow (1969, 1979). These zones are summarized in Table 4.18 and briefly described below.

Stratigraphic Interval:	3580 - 3650 m
Planktic Foraminiferal Zone:	?P15
Age:	middle Eocene

Diagnosis:

- The zonal base is tentatively placed at TD (3650 m) with its top approximated at 3580 m, where *Chiloguembelina cubensis* was recovered.
- Paucity of planktic species characterizes this zone.

Table 4.18: Foraminiferal biozonation of Oredo-8 well



DEPTH (Meter)	AGE	PLANKTIC FORAM ZONE		BIOEVENT
		BLOW (1969/1979)	BERGGREN et al. (1995)	
320 – 2460	INDETERMINATE	INDETERMINATE	INDETERMINATE	Interval barren of foraminifera
2460				Upper limit of foraminifera occurrence at 2460m
2460 – 3580	NON-DIAGNOSTIC	NON-DIAGNOSTIC	NON-DIAGNOSTIC	Occurrence of *Chiloguombelina cubensis* at 3580m
3580 – 3650	[illegible]	?P15	?P15	Zonal assignment based on its correlation with Oredo-2 well
3650				Lowest Sample Analyzed

Remarks: Zonal assignment was based on its correlation with Oredo-2 well. Also, the definition of the zonal top by the sole occurrence of *Chiloguombelina cubensis*, necessitates the assigned probable P15 zone.

Stratigraphic Interval:	3650 - 2460 m
Planktic Foraminiferal Zone:	Non-diagnostic
Age:	Non-diagnostic

Diagnosis:

- The zonal base is approximated at 3580 m, depth where *Chiloguembelina cubensis* was recovered; the zonal top is defined at 2460 m, by the upper limit recovery of foraminifera occurrence in the well.
- Paucity of planktic characterizes this interval. *Chiloguembelina cubensis* and planktic indeterminate species were the only planktic recorded.
- Arenaceous benthics recovered were *Eggerella scabra*, *Saccammina complanata*, *Ammobaculites strathearnensis*, species of *Ammobaculites* and *Textularia*.
- Associated calcareous benthics recorded were *Florilus* ex gr. *costiferum*, *Quinqueloculina rhodiensis*, *Q. seminulum*, species of *Cibicides*, *Nonion*, *Quinquloculina* and *Eponides*.
- Accessory microfaunas present were ostracods, scaphopods, shell fragments, echinoid remais sponges and pelecypods.

Stratigraphic Interval:	2460 - 320 m
Planktic Foraminiferal Zone:	Barren
Age:	Barren

Diagnosis:

- The zonal base placed at the upper limit of foraminifera occurrence at 2460 m. The zonal top marked at 320 m, top of the analyzed section
- The interval is barren of foraminifera.

4.21 Palynological Climate Cycles in Oredo-8

Sea level and climate changes with depositional sequences within the well section of Oredo-8 analysed were determined from quantitative and qualitative evaluation of the palynomorph groups recovered. The assemblage components of environmentally important palynomorphs recovered aided the delineation of the well sequence into four (4) informal local climate cycles. (Table 4.19 and Enclosures 9 and 12). Descriptions of the cycles are provided below:

Palynocycle 1 (CYL 1)

Wet Phase 1 (3650 – 3220 m):

Brackish-water palynomorphs such as *Pelliceria rhizophorae, Acrostichum aureum* and freshwater pteridophyte spores constitute the dominant groups within this interval. Common dinoflagellate cysts were also recorded. This palynofloral assemblage is suggestive a wet climatic phase. The recognized 41.0 Ma and 39.4 Ma MFS Condensed Sections are associated with this wet phase.

Dry Phase 1 (3220 – 3060 m):

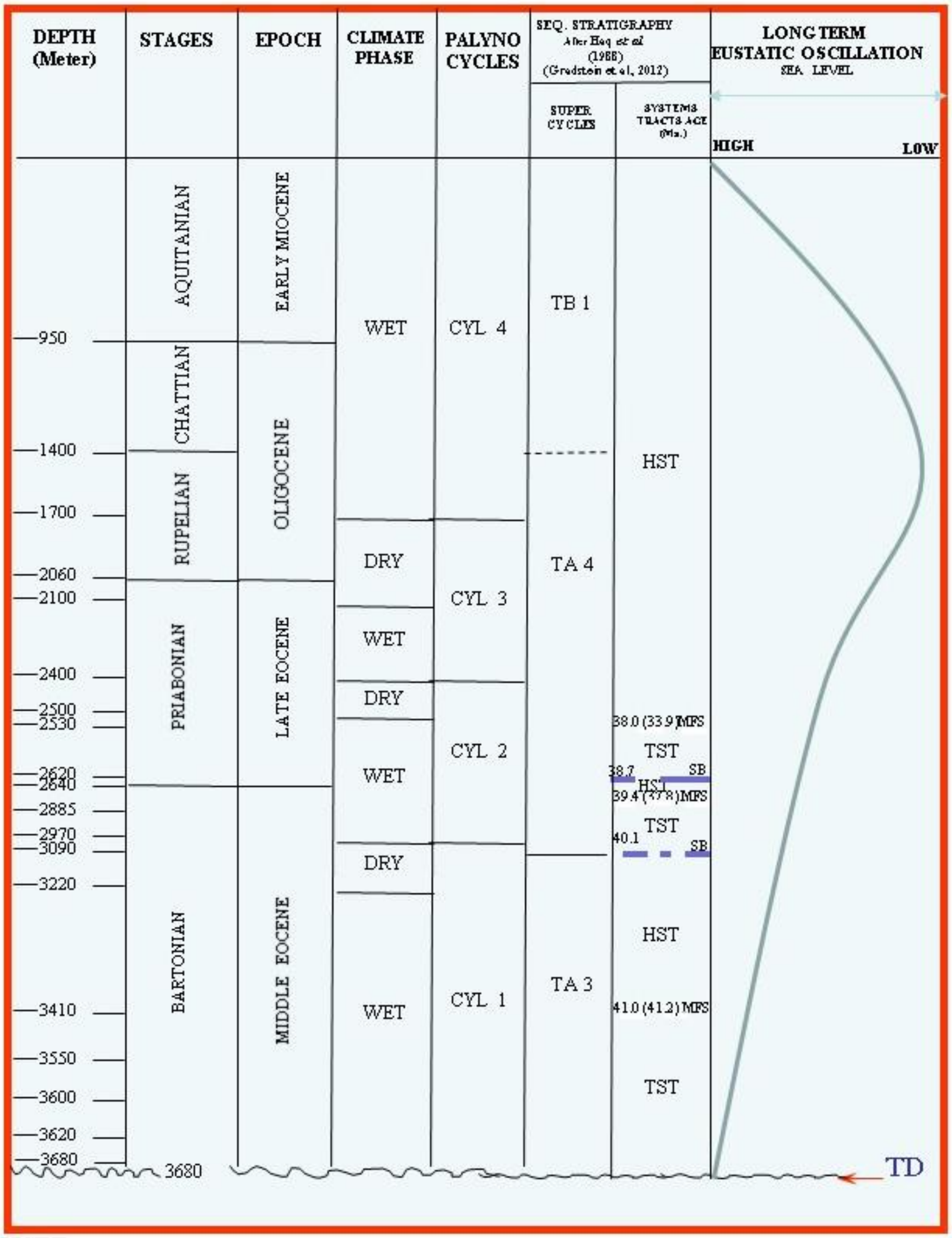
The increase in the percentage of savanna species concomitantly with reduction in the percentage composition of wet climate indicators such as *Pelliceria rhizophorae*, *Acrostichum aureum* and *Microsonum aff. diversifolium* suggested that a dry climatic condition prevailed during this phase.

Palynocycle 2 (CYL 2)

Wet Phase 2 (3060 – 2500 m):

This interval exhibits increase in percentages of freshwater swamp species: *Amanoa oblongifolia*; brackish-water swamp palynomorphs such as *Pelliceria rhizophorae* and *Acrostichum aureum* and fern spores. The highest abundance /diversity of dinoflagellate cysts and MWL were also recorded. *Botryococcus braunii* shows increasing percentages. The assemblage within this interval suggests a wet climate phase. The proposed MFS Condensed Sections, 38.0Ma MFS, characterized by peak abundance and diversity of foraminifera, are associated with the wet phase.

Table 4.19: Paleoclimate Cycle in Oredo-8 well



LEGEND

HST - HIGHSTAND SYSTEMS TRACT
TST - TRANSGRESSIVE SYSTEMS TRACT
MFS - MAXIMUM FLOODING SURFACE
SB - SEQUENCE BOUNDARY
TD - TERMINAL DEPTH OF WELL

Dry Phase 2 (2500 – 2400 m):

This short interval witnessed reduction in the percentage compositions of wet climate indicators with scanty dinoflagellate cysts suggesting a dry climate condition for the phase.

Palynocycle 3 (CYL 3)

Wet Phase 3 (2400 – 2100 m):

Increased percentages of brackish-water species such as *Pelliceria rhizophorae*, *Nypa fruticans* and *Rhizophora* sp., freshwater swamp forest species: *Amanoa oblongifolia*; lowland rainforest *Psilastephanocolporites sapotaceae*; pteridophyte spores dominate this interval. *Botryococcus braunii* and the acritarch, *Leiosphaeridia* sp., were also well represented. This palynofloral assemblage suggests a wet climatic phase.

Dry Phase 3 (2100 – 1700 m):

The concomitant increase in the percentage composition of savanna species with a slight reduction in that of wet climate indicators suggests a dry climate phase. The high record of charred Poaceae cuticle (CPC), the highest throughout the entire well, further corroborates this inference.

Palynocycle 4 (CYL 4)

Wet Phase 4 (1700 – 330 m):

High percentages of brackish-water species: *Pelliceria rhizophorae* and *Rhizophora* sp.; freshwater swamp species: *Amanoa oblongifolia*; *Psilastephanocolporites sapotaceae;* pteridophyte spores constitute the dominant elements of this assemblage. This, in association with the rich presence of *Botryococcus braunii* and *Leiospaeridia* sp., with few microforaminiferal wall lining (MWL), together with decreasing percentages of savanna species indicate a wet climatic condition within the interval.

4.22 Thermal Maturation Index of Oredo-8 Well

Table 4.20 shows the thermal alteration indices based on spore colouration as observed with transmitted light microscope. The result shows that the entire well sequence can be classified into two organic facies phases as follows:

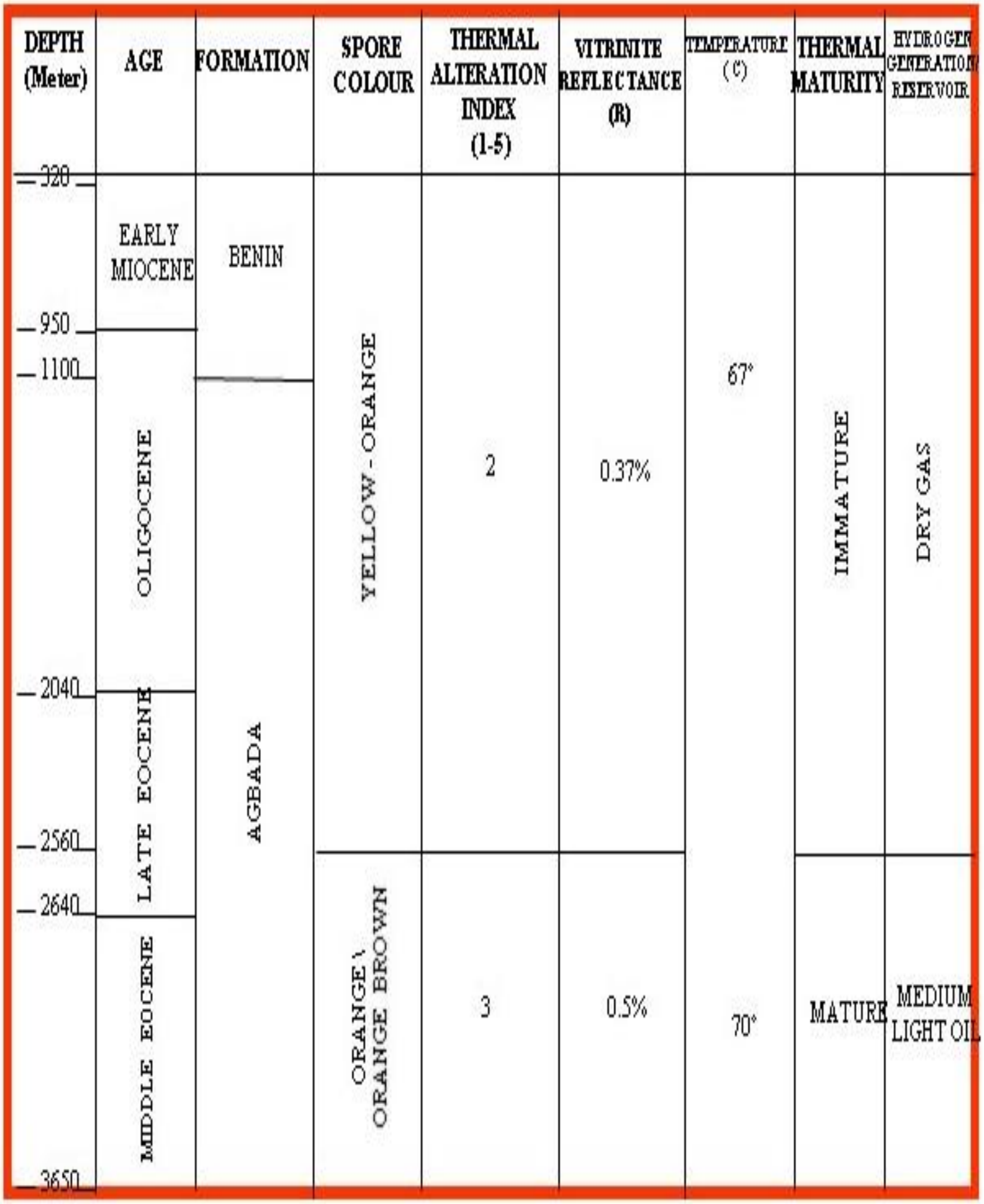
Immature (320 – 2560 m):

The spore colouration of this facies is yellow – orange with TAI value of 2 This indicates that the organic matter is immature with a dry gas hydrocarbon potential.

Mature (2560 – 3650 m):

Spores in this phase are mainly orange to orange brown in colour with TAI value of 3 indicating mature organic matter with medium to light oil hydrocarbon potential.

Table 4.20: Thermal Alteration Index of Oredo-8 well



DEPTH (Meter)	AGE	FORMATION	SPORE COLOUR	THERMAL ALTERATION INDEX (1-5)	VITRINITE REFLECTANCE (R)	TEMPERATURE (°C)	THERMAL MATURITY	HYDROGEN GENERATION RESERVOIR
320	EARLY MIOCENE	BENIN	YELLOW - ORANGE	2	0.37%	67°	IMMATURE	DRY GAS
950	OLIGOCENE							
1100		AGBADA						
2040	LATE EOCENE							
2560			ORANGE \ ORANGE BROWN	3	0.5%	70°	MATURE	MEDIUM LIGHT OIL
2640	MIDDLE EOCENE							
3650								

4.23 Multivariate Analysis of the Oredo-8 Well

The recorded palynodebris are shown as percentage compositions in Appendix 2c. These percentages were made use of in the multivariate analysis carried out in the study. The results are provided below.

4.23.1 Principal Component Analysis (PCA)

The PCA loading (Table 4.21) reveals abundance of structureless organic matter (SOM) evident at all depths relative to other groups of particulate organic matter in the well. Phytoclasts constitute next in abundance with high values in virtually at every depth. Thus, SOM and Phytoclasts constitute the dominant forms within the well section analysed, though SOM is more in abundance. The PCA Scores are shown in Appendix 2f.

The PCA summary results shows that, the first two components (PC1 and PC2) accounted for 87.84% of the total variation in the abundances of the particulates organic matter in Oredo-8 (Table 4.22).

4.23.2 Cluster Analysis

Figure 4.13 shows the results of the Principal Component Analysis (PCA) for the particulate organic matter in Oredo-8 well. Amorphous organic matter (AOM), black and brown wood (BBW) and Sporomorphs (SPH) are clearly distinguished from other particulate matters. The dendrogram plot depicts the cluster hierarchies of the particulate organic matter in the well. From the figure, AOM of SOM group has the highest abundances (is highly significant in abundances) followed by BBW of the Phytoclast group. Figure 4.14 also shows the clustering pattern of the particulate matter across the depths of the well.

Table 4.21: PC Loading Values for the Particulate Organic Matter in Oredo-8

	PC 1	**PC 2**	**PC 3**	**PC 4**
Pal	0.0090613	-0.72614	0.68729	0.016241
Phy	0.71459	0.48562	0.50326	0.01633
SOM	-0.69948	0.48669	0.52298	0.018706
OT	0.0012687	0.0052432	-0.029176	0.99956

Table 4.22: PCA Summary of Oredo-8 well

PC	Eigenvalue	% variance
1	957.604	87.849
2	84.9506	7.7932
3	26.2679	2.4098
4	14.153	1.2984
5	3.26416	0.29945
6	2.33195	0.21393
7	0.926818	0.085025
8	0.383663	0.035197
9	0.0741642	0.0068037
10	0.0526686	0.0048317
11	0.0240859	0.0022096
12	0.0185838	0.0017049
13	0.00171754	0.00015756
14	0.00107482	9.86E-05
15	8.39E-32	7.69E-33

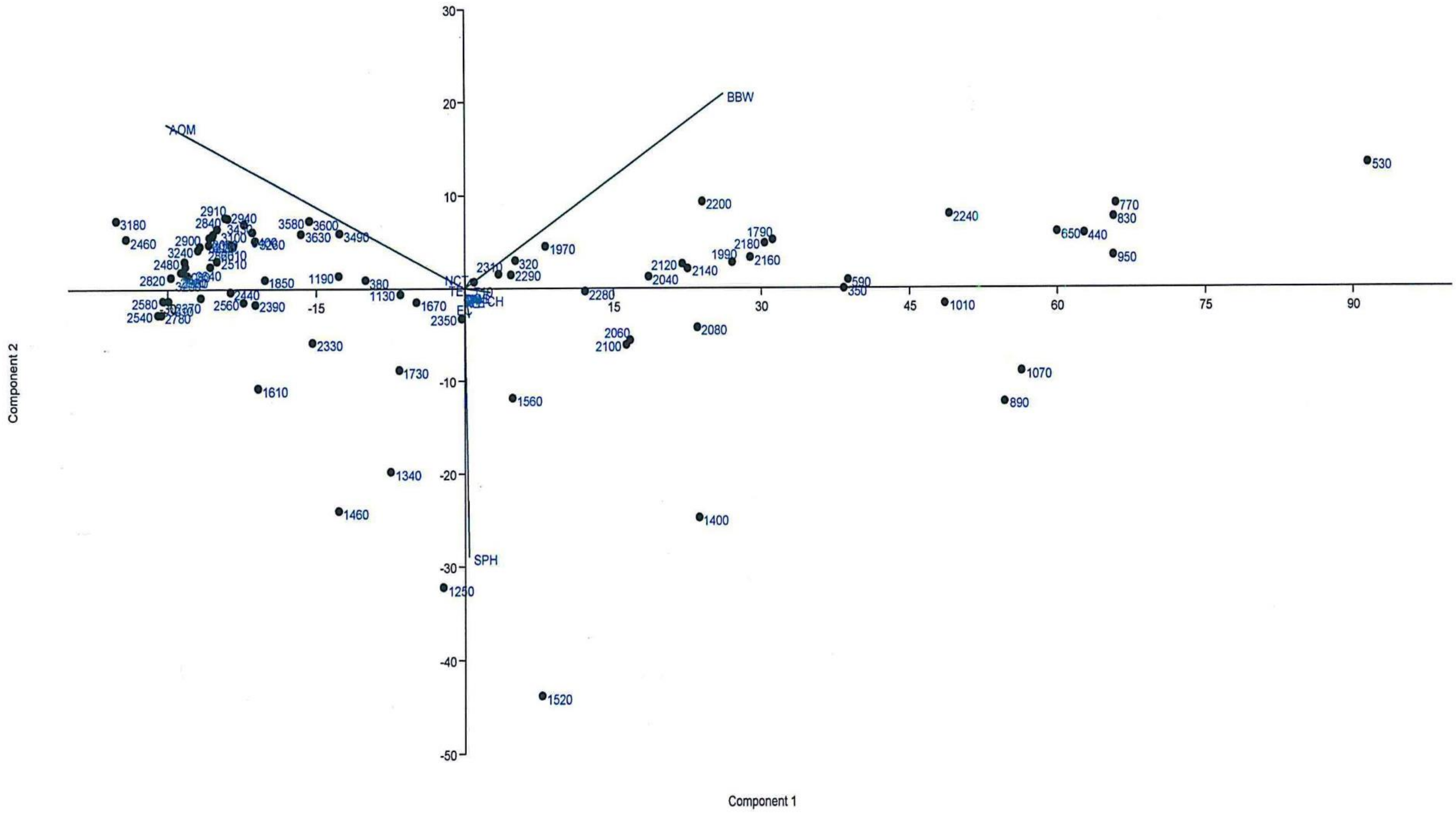


Figure 4.13: Principal Component Analysis results for the Organic Matter in Oredo-8 Well

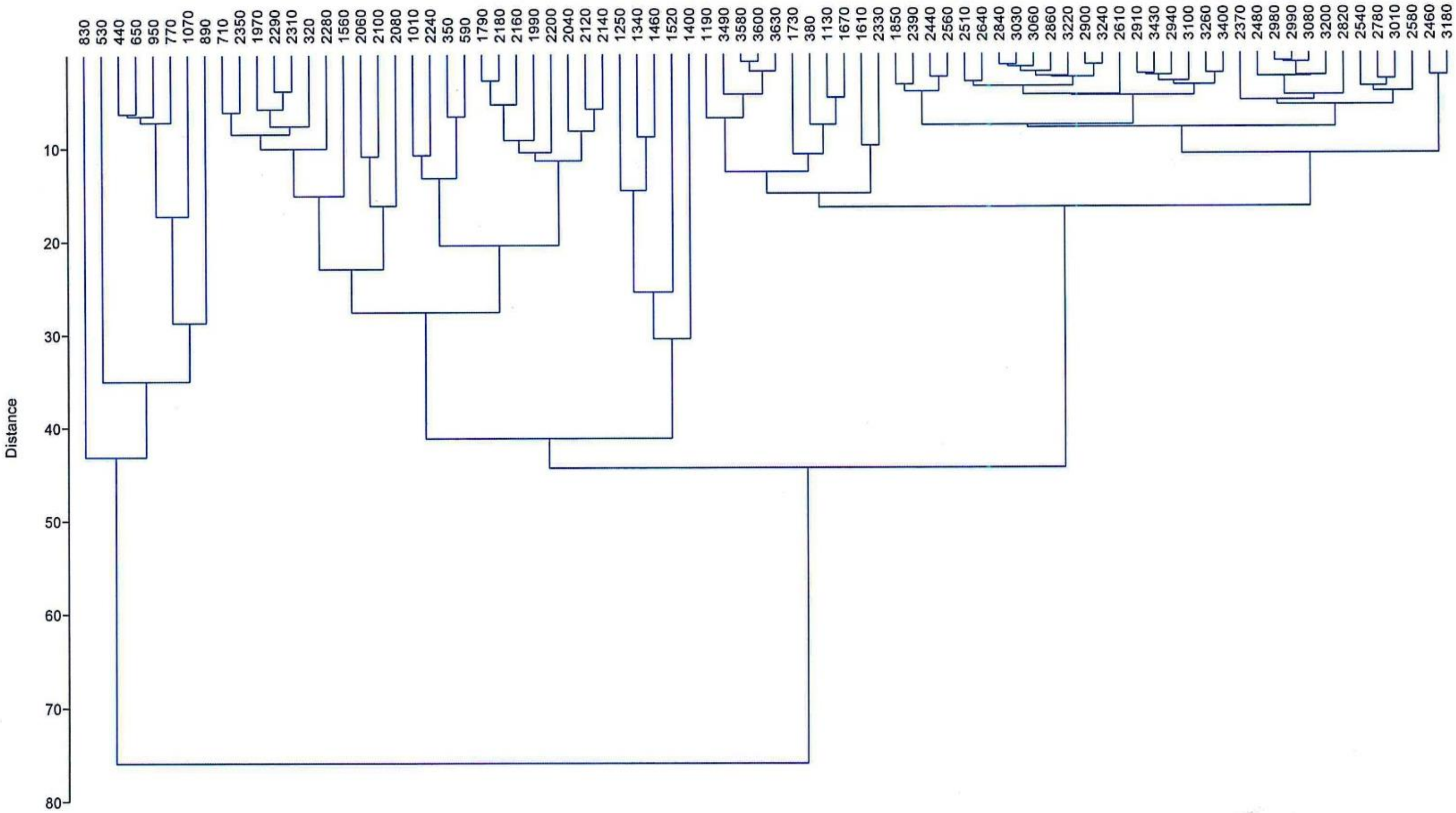


Figure 4.14: Dendogram of the hierachial Cluster Analysis of Organic Matter in Oredo-8 Well

4.24 Palynofacies Assemblages in Oredo-8 Well

The average linkage analysis of the percentage composition of the particulate organic matter reveals the sub-division of the well sequence into three palynofacies associations (Figure 4.15 and Enclosures 9 and 12). These palynofacies associations are described as follows.

Palynofacies Association I; PF-I (3650 – 2400 m)

Amorphous organic matter (AOM) makes up the dominant organic matter within this palynofacies association. It has a relative percentage abundance (rpa) of 82% and ranges between 72 and 90% (Figure 4.15). This is followed by Black and Brown Wood with 11.2% relative percentage abundance and a range between 4 and 21%. Sporomorphs with relative percentage abundance of 2.4% and ranging from ~1 to 7% comes next. Gelified Matter (rpa.1.4%), Non-Cuticular Tissues (rpa. 1.3% and Charcoal (rpa.1.2%) make up the next substantial organic matter. Making up the sub-ordinate components with relative percentage abundance less than 1% are Fungal Elements, Microforaminiferal Wall Linings (MWL), Diatom Frustules and Algal Elements.

Palynofacies Association II; PF-II (2400 – 1100 m)

Amorphous organic matter (AOM) remains predominant with a relative percentage abundance (rpa) of 55% and ranges from 30 – 80% (Figure 4.16). Black and Brown Wood recorded an increase in its relative percentage abundance to 28% with percentage range of 6 – 62%. Sporomorph recorded an increase to decrease to increase trend with relative percentage abundance of 7.9 % and ranges between ~1 and 37%. Epidermal Cuticle recorded relative percentage abundance of 3.2% and percentage range between ~1 and 12%. Next to this is Charcoal with rpa of 2.9% in the range between ~1 and 22%. Non-Cuticular Tissue (rpa.1.8%), Gelified Matter rpa.1.2%) and Fungal Elements (rpa. 1.1%) constitute the other significant organic debris recorded within this palynofacies association. Other components recorded, albeit in non-significant percentages (less than 1%) include Filaments, Hair and Tube, Diatom Frustules, Tracheid Elements and Algal Elements.

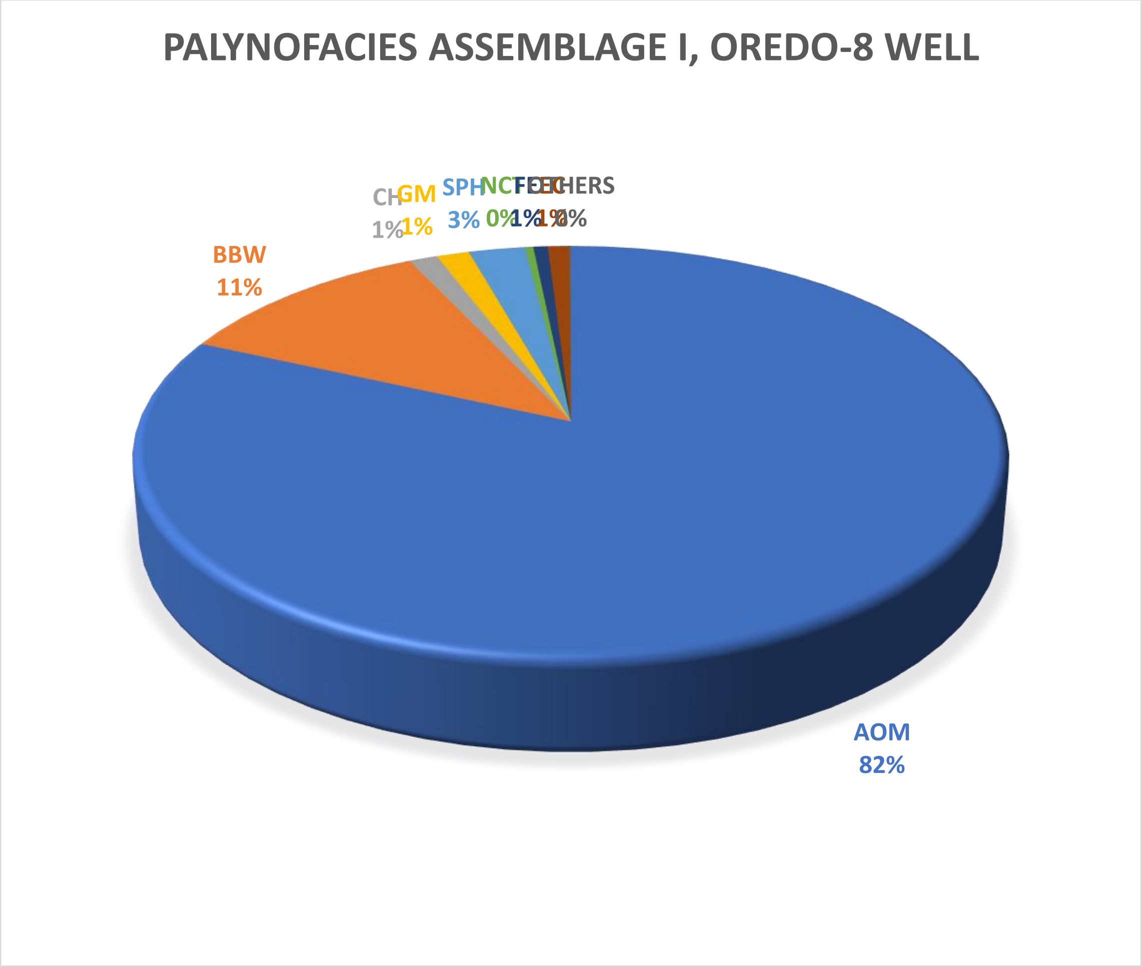


Figure 4.15: Percentage Composition of Particulate Organic Matter in PF-I, Oredo-8 Well

Key:

AOM – Amorphous Organic Matter
BBW – Black and Brown Wood
CH – Charcoal
GM – Gelified Matter
SPH – Sporomorphs
NCT – Non-Cuticular Tissues
FE – Fungal Elements
EC – Epidermal Cuticle
OTHERS

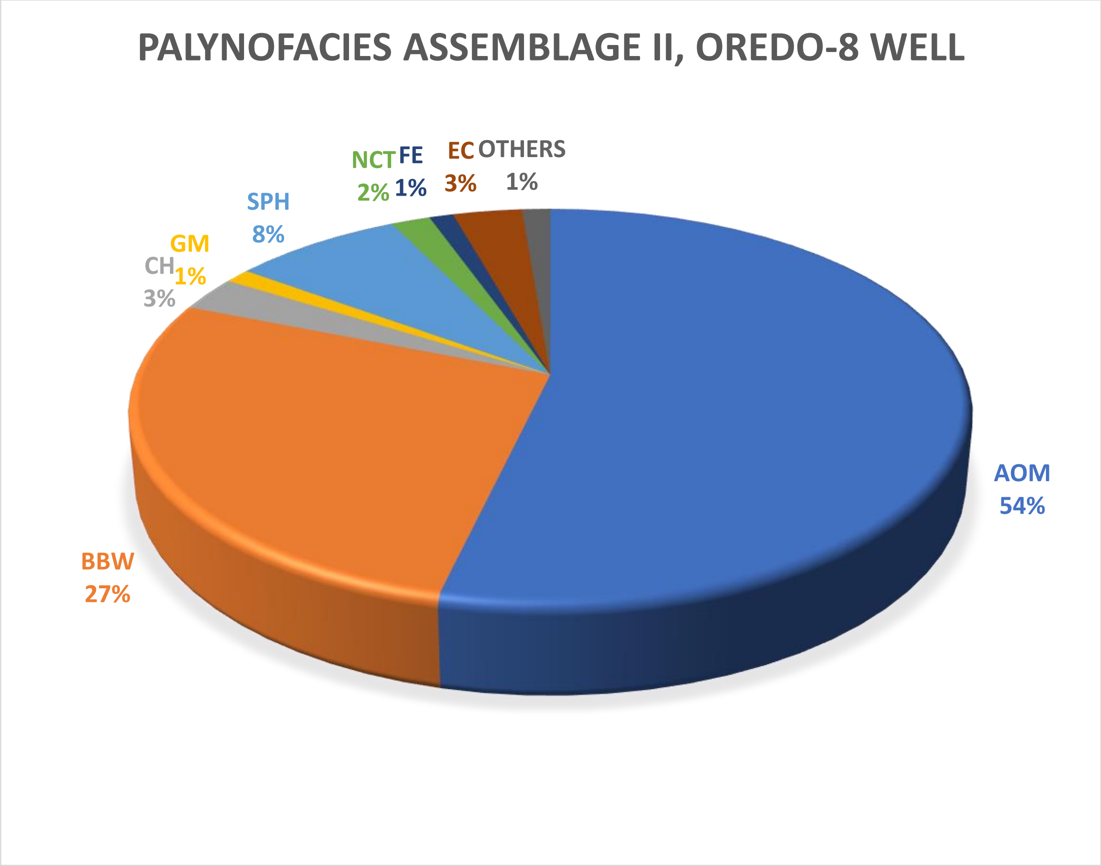


Figure 4.16: Percentage Composition of Particulate Organic Matter in PF-II, Oredo-8 Well

Key:

AOM – Amorphous Organic Matter

BBW – Black and Brown Wood

CH – Charcoal

GM – Gelified Matter

SPH – Sporomorphs

NCT – Non-Cuticular Tissues

FE – Fungal Elements

EC – Epidermal Cuticle

OTHERS

Palynofacies Association III; PF-III (1100 – 350 m)

The phytoclast, Black and Brown Wood dominate the organic matter assemblage of this palynafacies association with a relative percentage abundance of 59%, ranging between 17 and 95% (Figure 4.17). This shows an upward increase in its percentage abundance/composition from the underlying assemblage. AOM, which has been dominating the previous two palynofacies associations, recorded a sharp drop in percentage composition to 25% with a range between ~1 and 89%. Charcoal with rpa. of 6% comes next and has percentage range of ~1 to 42%. Sporomorph makes up relative percentage abundance of 4.5% with a range between ~1 and 14%. Non-Cuticular Tissue and Gelified Matter make up 1.9% and 1.2% relative percentage abundance respectively.

Other recorded organic matter components with less than 1% relative percentage abundance include Fungal Elements, Epidermal Cuticle, Diatom Frustules, Tracheid Elements and Acritarch Undifferentiated.

4.25 Depositional Environments from Ternary Plot of Oredo-8 Well

The Oredo-8 well AOM – Phytoclasts - Palynomorphs (APP) Ternary Plot reveals deposition in seven fields: I, II, IV, VI, VII, VIII and IX fields (Figure 4.18).

Field I: Highly proximal shelf or basin

This field is associated with high phytoclast input diluting all other components. It is also represented by a usually high abundance of terrestrial spores and low marine species. The field is typified by Palynofacies III (PF III) suggesting gas-prone Kerogen Type III.

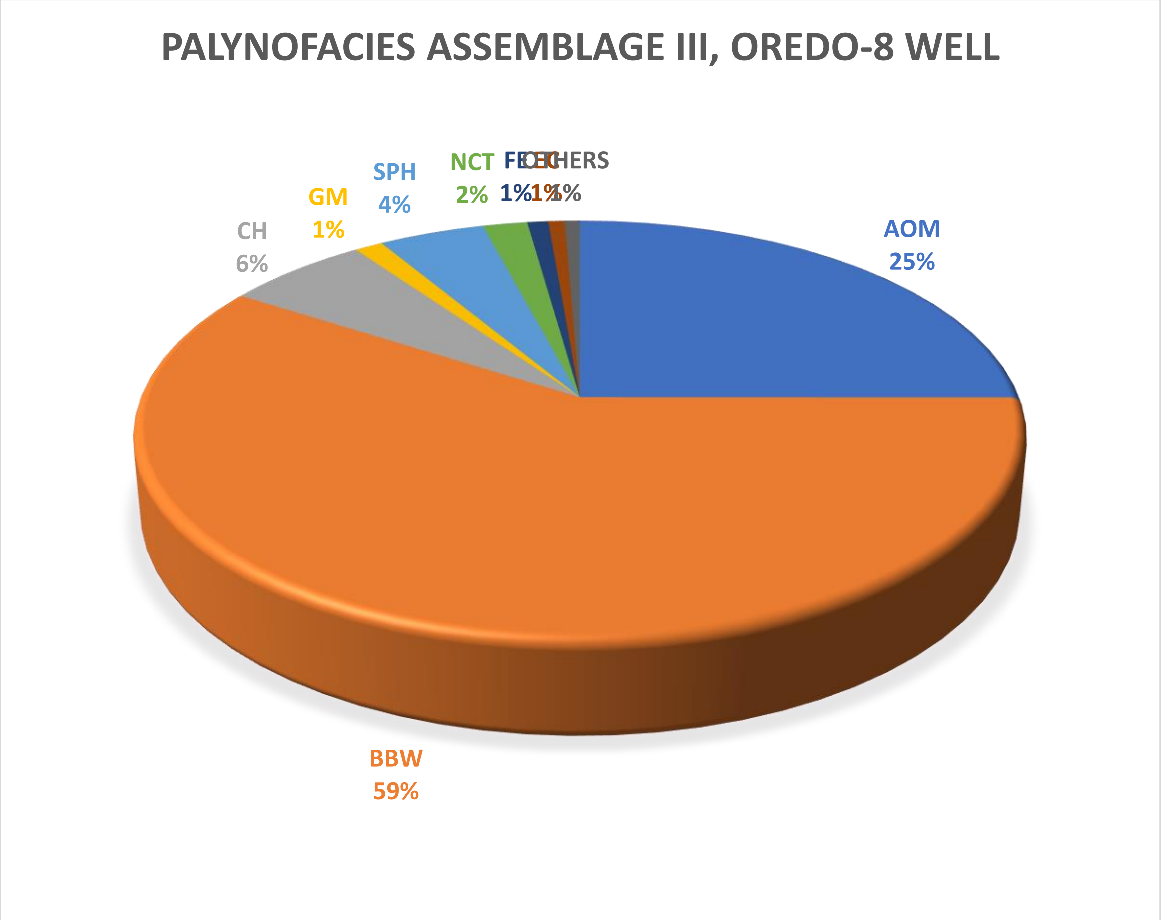


Figure 4.17: Percentage Composition of Particulate Organic Matter in PF-III, Oredo-8 well

Key:

AOM – Amorphous Organic Matter

BBW – Black and Brown Wood

CH – Charcoal

GM – Gelified Matter

SPH – Sporomorphs

NCT – Non-Cuticular Tissues

FE – Fungal Elements

EC – Epidermal Cuticle

OTHERS

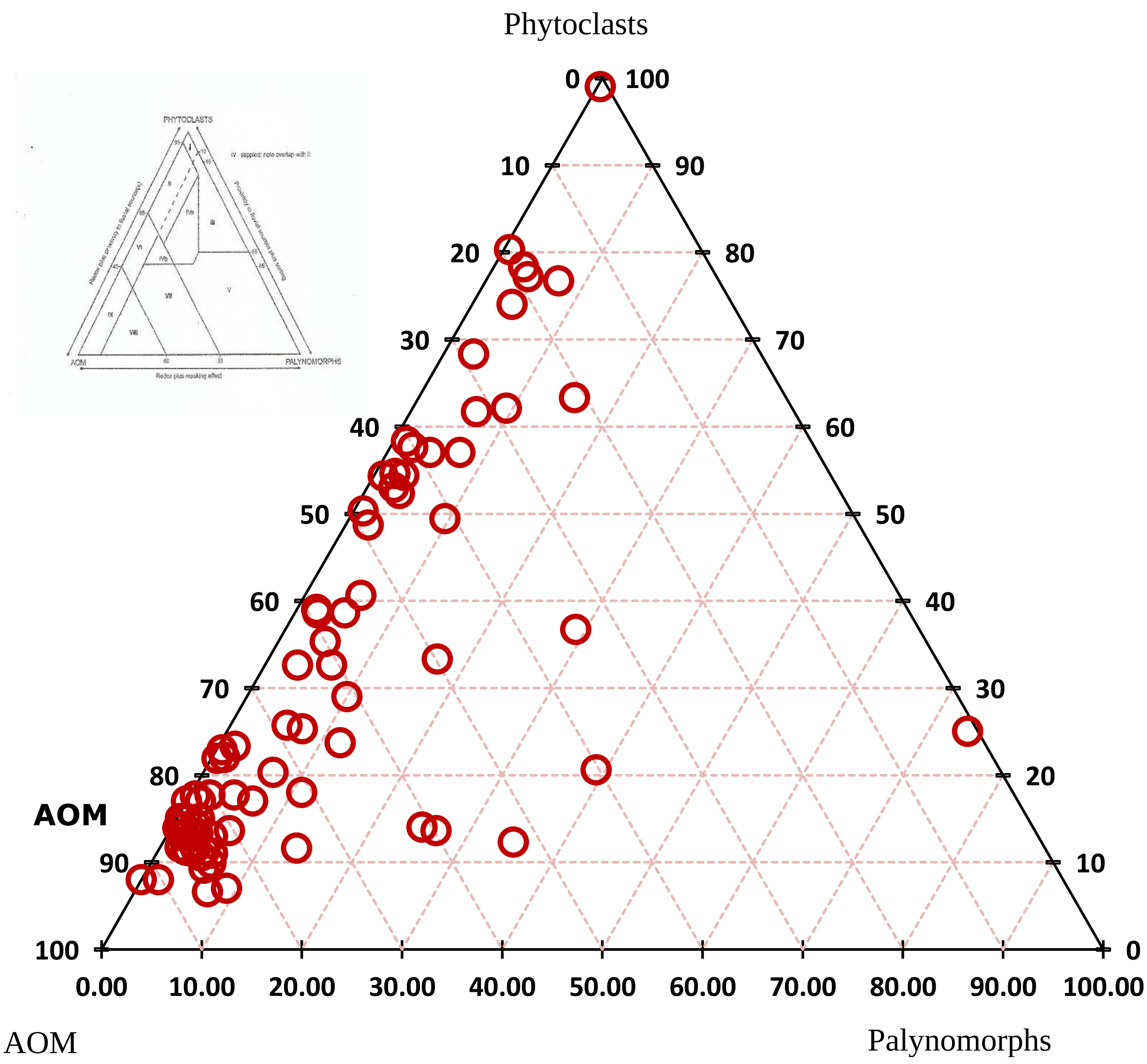


Figure 4.18: Ternary Plot, Oredo-8 well; Inset: Ternary Kerogen Diagram of Tyson (1995)

Field II: Marginal dysoxic-anoxic basin

This field is characterized by the dilution of AOM by high phytoclast influx, albeit with good preservation of the former. There is high relative percentage abundance of terrestrial sporomorph and low marine indicator. The field typifies Palynofacies II (PF II) in the studied well and exhibits gas prone Kerogen Type III (Tyson, 1995).

Field IV: Shelf to basin transition

Field IV represents transition from a shelf to basin deposition. Fields IVa and IVb stand for dysoxic-suboxic and suboxic-anoxic conditions, respectively. The abundant phytoclast recorded within this field are resultant of proximity and the level of redeposition. Only Field IVa was tested in this well and characterizes Palynofacies III (PF III). The moderate to high sporomorphs in association with microplankton suggests gas-prone Type III/II Kerogen (Tyson, 1995).

Field VI: Proximal suboxic-anoxic shelf

High preservation AOM largely due to reducing basin conditions and moderate to high phytoclast resulting from turbidite influx or nearness to source is exhibited within the field. This field characterizes Palynofacies II (PF II) and suggests oil prone Kerogen Type II (Tyson, 1995).

Field VII: Distal dysoxic-anoxic shelf

Field VII of distal dysoxic-anoxic shelf deposition which is typified by Palynofacies I (PFI) is characteristic of oil prone Kerogen Type II.

Field VIII: Distal dysoxic-oxic shelf

Well preserved dominant AOM and low to moderate sporomorphs are characteristic of the field. The field characterizes Palynofacies I (PF I) suggesting oil prone Kerogen Type II.

Field IX: Distal suboxic-anoxic basin

The depositional environment of this field is predominated by AOM in association with reduced proportion of sporomorphs. Palynofacies I (PF-I) typifies this field in this well and is characterized by highly oil prone Kerogene Type II>I (Tyson, 1995).

4.26 Lithostratigraphy and Sedimentology of Oredo-8 Well

The one hundred and forty-six ditch cutting samples provided were analysed lithologically and texturally. The basal part of the well sequence (3680 – 2510 m) is consists of shale/sand intercalation of shale/sand ratio approximately 70/30. The shales are grey, flaggy to blocky with some platy to moderately hard. The sands are white, fine-very coarse-grained, poorly to moderately sorted. The accessory minerals of this section include abundant ferruginous materials, common carbonaceous detritus and rare mica flakes.

The upper part of the sequence (2510 – 320 m) is predominantly sand and argillaceous sands. The accessory mineral components of this section include abundant ferruginous materials and carbonaceous detritus with rare to few mica flakes, pyrites and gluconites.

Two lithological units of formational ranks are defined from the sedimentological and wireline log analyses for the studied section of the well. These are the Agbada and Benin Formations. The Agbada Formation (3680 – 1100 m) is sub-divided into paralic unit (3680 – 2510 m) at the base with an intercalation of sand and shale and the upper continental/transitional unit (2510 – 1100 m) which is predominantly composed of argillaceous sands.

The continental sand deposits at the upper part of the well sequence is identified to be Benin Formation. The highlights of the lithostratigraphic analytical data are summarised in Table 4.23 and described as follows.

UNIT I: Agbada Formation: Paralic (3680 – 2510 m)

This unit is an intercalation of shale and sand in the ratio 70/30. The shales are grey, flaggy to blocky with some platy to moderately hard. The sands are white, fine to coarsely grained, poor to moderately sorted. Dominant ferruginous materials with common carbonaceous detritus and rare mica flakes constitute the accessory minerals within the unit. *Peliceria rhizophorae* (*Psilatricolporites crassus*), *Retimonocolpites obaensis* and pteridophyte sporesdominate the floral assemblage. There is an increase occurrence of dinocysts and MWL. The faunal assemblage was low with dominant *Ammobaculites* sp.

Table 4.23: Lithologic units recognized in Oredo-8 well

DEPTH (m)	THICKNESS (m)	FORMATION	LITHOFACIES	UNIT
320 - 1100	780	Benin	Continental	III
1100 - 2510	1410		Continental/Transitional	II
2510 - 3680	1170	Agbada	Paralic	I

UNIT II: Agbada Formation: Continental /Transitional (2510 – 1100 m)

The 1410 m thick sequence consists of entirely argillaceous sand deposits. The sands are white, very fine, medium to very coarse-grained, sub-rounded to rounded, moderately to well sorted. The shaly components are grey, flaggy to blocky or platy, fissile. Abundant ferruginous materials and carbonaceous detritus with rare to few mica flakes and spotty pyrites make up the accessory minerals within the unit. The floral content was dominated by land-derived palynomorphs and fungal spores with sporadic records of dinocysts. A singular presence of *Ammobaculites strathearnensis* was recorded at depth 2470 m.

UNIT III: Benin Formation: Continental (1100 – 320 m)

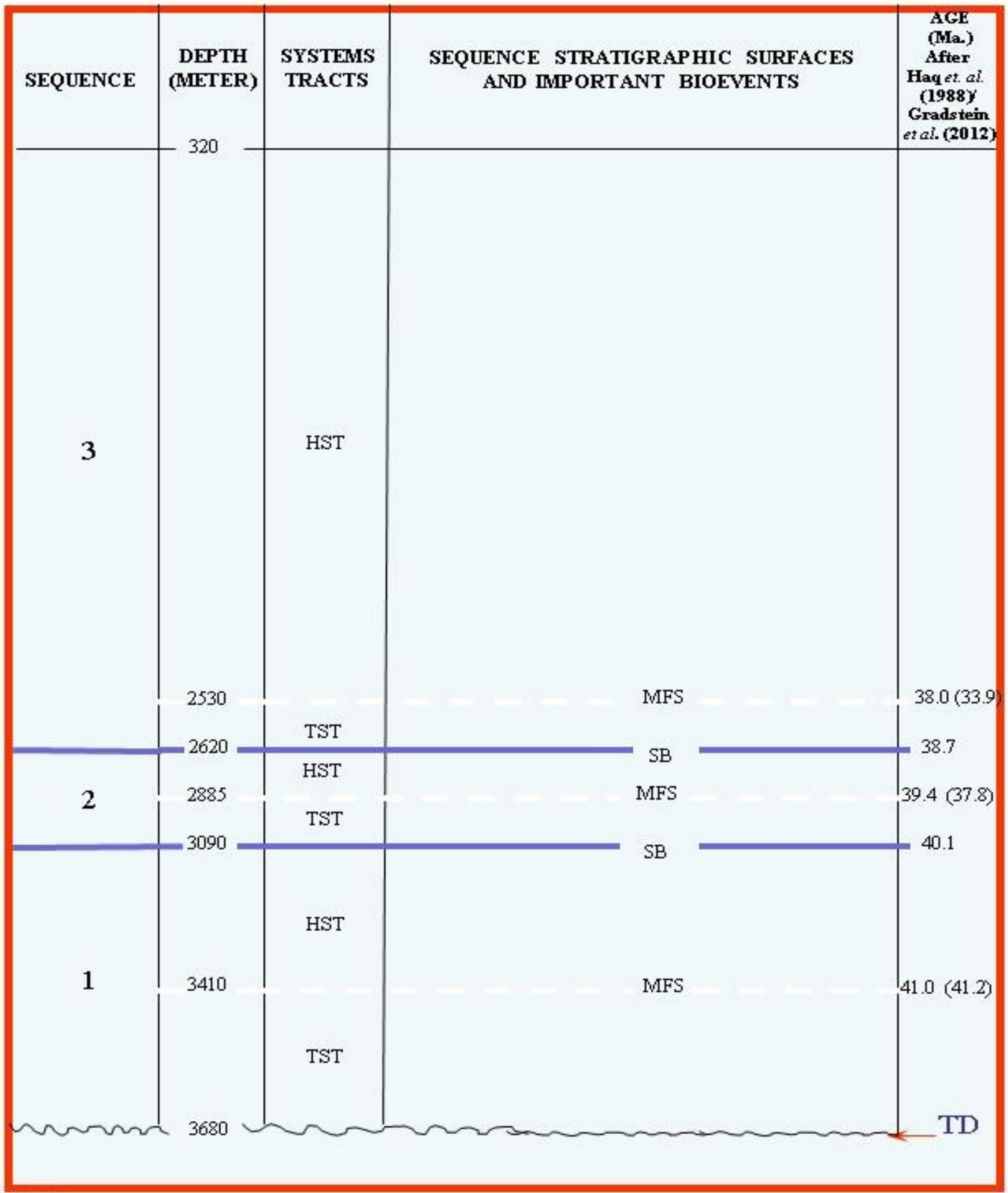
Massive regressive shoreface sands, suspected to be Benin sands (wireline logs not available) dominate the lithofacies of this uppermost unit. The sands are mostly white, very coarse pebbly, subrounded to rounded, moderately to well sorted. Accessory minerals association includes abundant carbonaceous detritus and ferruginous materials and very rare mica flakes. High representation of *Rhizophora* sp. dominate the floral assemblage with few Botryococcus braunii and Leiosphaeridia sp. There was no foraminifera recorded.

4.27 Sequence Stratigraphy of Oredo-8 Well

High resolution biostratigraphic data obtained from foraminifera and palynomorphs integrated with lithostratigraphic and well log data were adopted in the sequence stratigraphic analysis of Oredo-8 well. Three Maximum Flooding Surfaces are recognized in the well sequence at 3410 m, 2885 m and 2530 m and dated 41.0 Ma (41.2 Ma), 39.4 Ma (37.8 Ma), and 38.0 Ma (33.9 Ma) respectively. Two Sequence Boundaries were also recognized at 3090 m and 2620 m which have been dated 40.1Ma, and 38.7Ma respectively.

The sequence stratigraphic framework proposed here has been correlated with the Global Cycle Chart and is summarized in Table 4.24 and briefly highlighted below:

Table 4.24: Sequence Stratigraphic framework of the Oredo-8 well



SEQUENCE	DEPTH (METER)	SYSTEMS TRACTS	SEQUENCE STRATIGRAPHIC SURFACES AND IMPORTANT BIOEVENTS	AGE (Ma.) After Haq *et. al.* (1988)/ Gradstein *et al.* (2012)
	320			
3		HST		
	2530		MFS	38.0 (33.9)
		TST		
	2620		SB	38.7
2		HST		
	2885		MFS	39.4 (37.8)
		TST		
	3090		SB	40.1
		HST		
1	3410		MFS	41.0 (41.2)
		TST		
	3680			TD

LEGEND

HST - HIGHSTAND SYSTEMS TRACT

TST - TRANSGRESSIVE SYSTEMS TRACT

MFS - MAXIMUM FLOODING SURFACE

SB - SEQUENCE BOUNDARY

TD - TERMINAL DEPTH OF WELL

SEQUENCE 1 (3680 – 3090 m)

3680 – 3410 m: Transgressive Systems Tract (TST)

Characteristics

- Fining-upward profile
- Termination of interval within a condensed section (3490 – 3300 m).

Remarks

- The MFS associated with this condensed section has been picked by the gamma peak at 3410m. This MFS is dated 41.0 Ma of Haq et al (1988) and correlated to 41.2 Ma on the Geologic Time Scale of Gradstein *et al*. (2012). This age is assigned on the basis of the association of the MFS with foraminiferal zone ?P15 and palynological subzone P450.
- A sample gap truncates the condensed section between 3380 m and 3280 m.

3410 – 3090 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile.
- Directly overlying an MFS.
- Presence of *Botryococcus braunii*.

Remarks

- The SB above this HST has been marked at 3090 m to coincide with the base of a sand package. It is dated 40.1Ma.
- This age is based on its stratigraphic position between the dated 41.0 Ma (41.2 Ma) and 39.4 Ma (37.8 Ma) Maximum Flooding Surfaces.

SEQUENCE 2 (3090 – 2620 m)

3090 – 2885 m: Transgressive Systems Tract (TST)

Characteristics

- Fining-upward profile.
- Termination in a condensed section (2960 – 2820 m).

Remarks

- The MFS associated with this condensed section is marked by the gamma peak at 2885 m. This MFS is dated 39.4 Ma (Haq *et al*., 1988), correlated to 37.8 Ma of Gradstein *et al*. (2012). The age is assigned based on stratigraphic position relative to the older MFS

2885 – 2620 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile
- Directly overlying the MFS
- Presence of *Botryococcus braunii*
- Decreasing-upward dinocysts abundance and diversity.

Remarks

- The SB on top of this HST has been recognized at 2620 m, the point of left shifting on the log. The SB is dated 38.7 Ma.
- The assigned age is based on the stratigraphic position of the SB between the adjoining 39.4 Ma (37.8 Ma) and 38.0 Ma (33.9 Ma) Maximum Flooding Surfaces.

SEQUENCE 4 (2620 – 320 m)

2620 – 2530 m: Transgressive Systems Tract (TST)

Characteristics

- Fining upward profile
- Increasing-upward faunal abundance and diversity

Remarks

- The MFS associated with this condensed section has been marked by the gamma peak at 2530 m. This MFS is dated 36.8 Ma.
- This age assignment is based on its stratigraphic position at the upper part of the palynological subzone P470 – P480.

2530 – 320 m: Highstand Systems Tract (HST)

Characteristics

- Coarsening-upward profile.
- Shallowing-upward trend.
- Abundance occurrence of *Botryococcus braunii*;
- Stratigraphic position directly above MFS.

Remarks

The SB over this HST probably lies shallower than the top of the analysed section.

4.28 Correlation of the Three Wells

A comparison of the sequences in the three wells in Oredo Field was carried out using erected palynological, foraminiferal and sequence stratigraphic correlation panels (Enclosures 13-15). The depths of the wells were used as datum for the correlation. The rich palynological data and the relatively poor foraminiferal data made possible comparison of the well sections using palynomorphs and foraminifera (Enclosure 13-14). The recognized datable sequence stratigraphic Maximum Flooding Surfaces (MFS), Sequence Boundaries (SB) and Systems Tracts were correlated across in the three well (Enclosure 15).

To compare or correlate the studied sections of the three wells of Oredo-2, Oredo-4 and Oredo-8, resort was made to the floral and faunal events as well as sequence stratigraphic criteria. These criteria include:

- Correlating three palynological boundaries across the three wells.
- Correlating two foraminiferal boundaries across the wells.
- Tying two MFS(s) and one SB across the three wells and one MFS and SB across Oredo-4 and Oredo-8 wells.
- Correlating the Systems Tracts across the three wells.

Using the above criteria, the following observations were made.

1. The quantitative top occurrence of *Psilamonocolpites marginatus* was recorded at depth 3190 m of the Oredo-2 well. The same event was recorded at depths 3200 m and 3220 m of the Oredo-4 and Oredo-8 wells, respectively.
2. Top occurrence of *Doualaidaites laevigatus* recorded at depth 2000 m of the Oredo-2 was also recorded at depths 2020 m and 2060 m of Oredo-4 and Oredo-8, respectively.
3. The base rich occurrence of *Striamonocolpites rectostriatus* /and *Cicatricosisporites dorogensis*, the top boundary marker(s) of *Retitricolporites ituensis* Zone, was recorded at depth 1720 m, 1720 m and 1700 m in Oredo-2, Oredo- 4 and Oredo-8 respectively.
4. The quantitative base occurrence of *Racemonocolpites hians*/and base regular occurrence of *Peregrinipollis nigericus*, the upper boundary marker for ‘Subzone a’

of *Retitricolporites ituensis* Zone, was defined at depths 1960 m, 1900 m and 1820 m in Oredo-2, Oredo-4 and Oredo-8 respectively.

5. Base regular occurrence of *Spirosyncolporites bruni*, the boundary marker used in delineating *Psilatricolporites onitshaeensis* Zone into Subzones a and b, was recorded at depths1450 m, 1420 m and 1400 m in Oredo-2, Oredo-4 and Oredo-8 wells respectively.
6. Top regular occurrence of *Cicatricosisporites dorogensis* recorded at 940 m of Oredo-2 well was recorded at depths 970 m and 950 m of Oredo-4 and Oredo-8 wells, respectively.
7. The top occurrences of *Chiloguombelina cubensis* and *Turborotalia pseudomayeri* were recorded at 3530 m of the Oredo-2 well. Top occurrence of *Chiloguombelina cubensis* was recorded at depths 3490 m and 3580 m of Oredo-4 and Oredo-8 wells, respectively.
8. The depths of the last recovery of foraminifera were recorded at 2450 m, 2470 m and 2460 m in Oredo-2, Oredo-4 and Oredo-8 wells, respectively.
9. Two depositional sequences were recognized in Oredo-2 well while three sequences were identified in Oredo-4 and Oredo-8 wells.
10. The top of Sequence 1 recognized on top of Highstand Systems Tracts (HST) at 40.1 Ma Sequence Boundary (SB) was marked at 3100 m, 3100 m and 3090 m in Oredo-2, Oredo-4 and Oredo-8 respectively.
11. The top of Sequence 2 was recognized in Oredo-4 and Oredo-8 wells. It was placed on top of HST at 38.7 Ma at 2630 m and 2620 m for Oredo-4 and Oredo-8 wells, respectively.
12. The 41.0 Ma (41.2 Ma) and 39.4 Ma (37.8 Ma) MFS(s) associated with Bartonian in the middle Eocene were recognized at depths 3400 m and 2910 m respectively in the Oredo-2 well. These two MFS(s) were also tested at depths 3440 m and 2905 m respectively in Oredo-4 and at depths 3410 m and 2885 m respectively in Oredo-8.
13. The 38.0 Ma MFS associated with the Priabonian age in the late Eocene of Haq *et al*. (1988) (33.9 Ma of Gradstein *et al*. 2012), though not recognized in Oredo-2, was recognized at depths 2540 m and 2530 m in Oredo-4 and Oredo-8 wells respectively.

On the basis of the above-mentioned events associated with the three wells (see Enclosures 13-15), it is suggested that the studied section of the Oredo-2 well (4000 – 300 m) compares/correlates with intervals (3770 - 70 m) and (3650 -320 m) of the Oredo-4 and Oredo-8 wells. This indicates that the three well intervals are equivalent and co-eval.

CHAPTER FIVE
DISCUSSION

5.1 Introduction

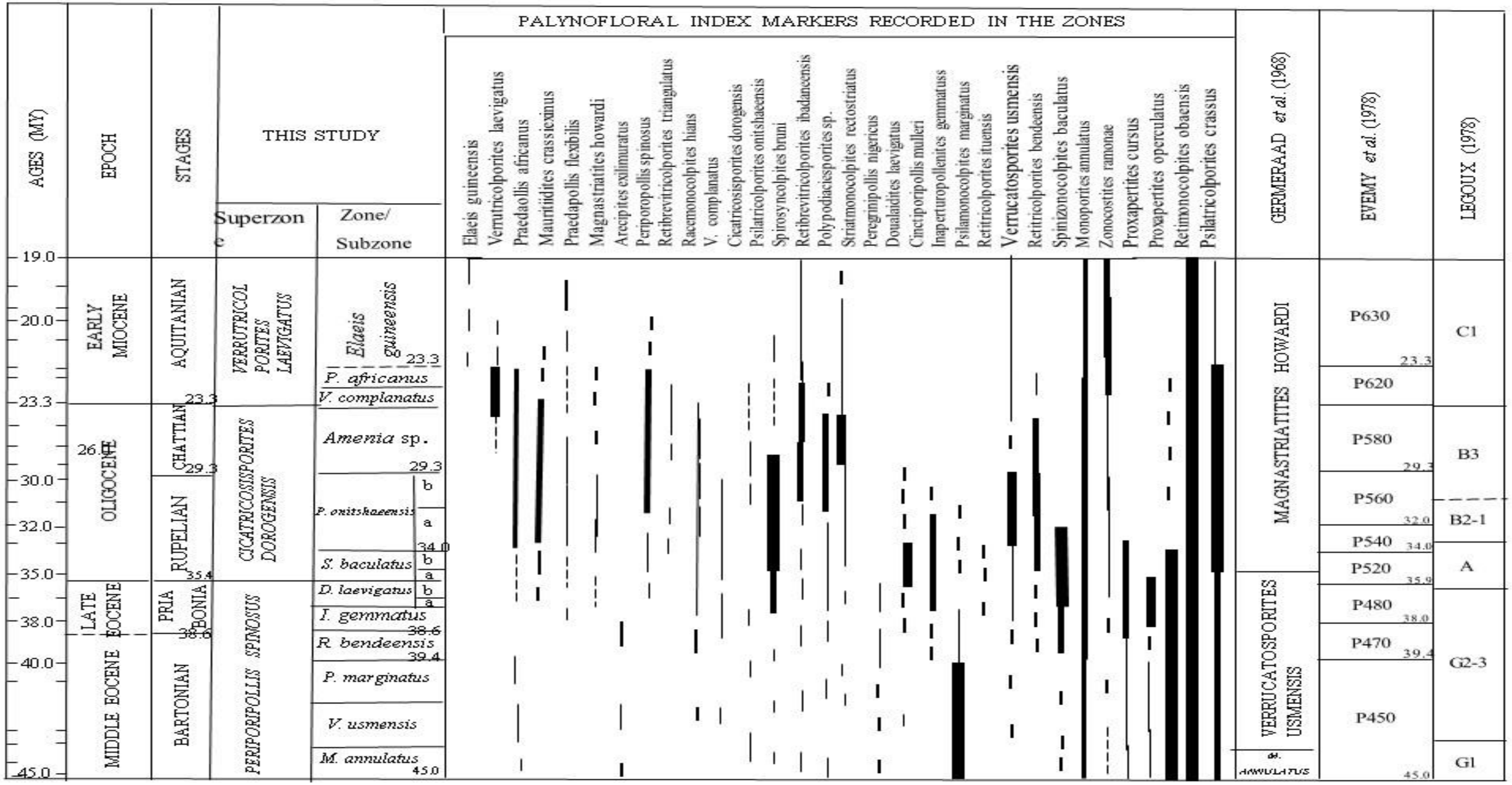
The biostratigraphic analysis and bio-zonal interpretation of occurrences of fossil pollen, spores and foraminifera have traditionally provided time-stratigraphic control for the Niger Delta basin (Stacher *et al*., 1993). This is facilitated by characteristic rich variety of pollen, spores, dinocysts, planktonic and benthonic foraminifera associated within the sedimentary basin. The established biostratigraphic zonation schemes have contributed largely to exploration successes recorded in the country (Germeraad *et al*., 1968; Stacher *et al*., 1993).

However, as important as these zonation schemes are in stratigraphy, there is need for their refinement aimed at achieving better and higher biostratigraphic resolutions. As mentioned earlier, most existing zonation schemes in use for the Niger Delta stratigraphic interpretations are beset with challenges of wide zones/subzones. This necessitates the need to improve on these zonation schemes aimed at achieving improved resolutions in basin evaluation.

5.2 Palynostratigraphic Zonation

Based on the stratigraphic distribution of significant and index palynomorphs of middle Eocene to earliest Miocene identified in the three wells studied from the Oredo Field, a palynological zonation scheme has been defined and it is here proposed (Table 5.1). The oldest of the three proposed superzones, the *Periretipollis spinosus* Superzone, is characterized by the top occurrences (Last Appearance Datums) (LAD) of *Doualaidites*

Table 5.1: Stratigraphic Ranges of important palynomorphs recorded in the study



laevigatus, *Mauritiidites crassiexinus* and *Periretipollis spinosus*. The base of the superzone is believed to terminate at the base of the *Monoporites annulatus* Zone.

All the six divisions of the *Periretipollis spinosus* Superzones were recognized in Oredo-2 well, while Oredo-4 and Oredo-8 wells have five and four zones respectively (Tables 4.1, 4.9 and 4.17).

The upper part of the superzone was marked at top occurrence of *Doualaidites laevigatus.* This boundary lies at near the same depths in the three wells: Oredo-2 (2000 m), Oredo-4 (2020 m) and Oredo-8 (2060 m) (See Tables 4.1, 4.9 & 4.17). Jan du Chene *et al*. (1978), AGIP (1987), Evamy *et al*. (1978), Salard-Cheboldaeff (1979 and 1990) all assigned the beginning of *Doualaidites laevigatus* to the basal part of the Eocene. These authors are also in agreement that the extinction point of this pollen is in the late Eocene.

Cicatricosisporites dorogensis Superzone, the second superzone defined, has associated with it, the base occurrences (Last Appearance Datums) of *C. dorogensis* (*Anemia* sp.), *Verrustephanocolporites complanatus*, *Inaperturopollenites gemmatus*, *Spinizonocolpites. baculatus/echinatus*, *Retimonocolpites obaensis*, *Praedapollis africanus* and *Proxapertites crassus*. This superzone, which completely lies within the Oligocene in all the three wells, is defined at its base by the top occurrence of *Doualaidites laevigatus* and at its upper limit by the top regular occurrence of *Cicatricosisporites dorogensis.* As observed for the top of the preceding superzone, the *Cicatricosisporites dorogensis* Superzone also has its top defined at close depths in all the wells: Oredo-2 (940 m), Oredo-4 (970 m) and Oredo-8 (950 m) (Tables 4.1, 4.9 & 4.17). The three zones delineated within the superzone are all recognized in all the wells.

The youngest superzone recognized, the *Verrutricolporites laevigatus* Superzone, features the last appearance of *Praedapollis africanus* and base regular occurrence of *Verrutricolporites laevigatus*. Its upper boundary was tentatively marked by the top of *Verrucatosporites* sp. at the highest sample depth in the three wells: Oredo-2 (300 m), Oredo-4 (70 m) and Oredo-8 (320 m) (Tables 4.1, 4.9 and 4.17). This is based on Evamy *et al*. (1978) that also recognized the top of their P630 in the early Miocene using the same event. However, it needs be stressed that the real top of this superzone may still lie shallower than it was recognized. The superzone straddles the Oligocene and early Miocene. The top of *Praedapollis africanus* defines the boundary between Oligocene and early Miocene in this study. This event, that is, the top occurrence of *P. africanus*, was recognised in two of the wells, Oredo-2 and Oredo-8.

A detailed study of the palynological zonation proposed in this study revealed the recognition of nearly all the palynological events used in the three wells studied. The exceptions to this observation include instances where zones were not recognized. For example, *Monoporites annulatus* and *Verrucatosporites usmensis* Zones, both recognized in Oredo-2 well (Table 4.1 and Enclosure 1), were not recognized in Oredo-8 well (Table 4.17 and Enclosure 9). *Monoporites annulatus* Zone was also not recognized in Oredo-4 well (Table 4.9 and Enclosure 4). The three wells have different terminal depths (TD): Oredo-2: 4000 m; Oredo-4: 3770 m and 3650 m for Oredo-8 well.

The top occurrence of *Praedapollis africanus* used in defining the upper boundary of the *Praedapollis africanus* Zone in both Oredo-2 and Oredo-8 wells was not identified in Oredo-4 well. This was due to the non recovery of since the boundary marker species, *Praedapollis africanus*. This may be attributed to facies control of the marker species particularly within the sandy lithofacies of the interval.

The recognition of similar stratigraphic sequences in the three wells is further demonstrated by the recognition of some of the significant bioevents in nearly the same depths across the wells as revealed from the correlation of the biostratigraphic events (Enclosures 13 and 14). This similarity of recognized bioevents across the three wells in the active, faulted, and tectonic basin (Reijers *et al*., 1996) is better explained by the proximity of the wells to one another. As reported in Chapter Three, the distance between Oredo-2 and Oredo-8 is 1.192 km while Oredo-4 is 2.0 km from Oredo-8; that is, all lie within 3.5km radius.

As mentioned earlier in Chapter Four, the assemblage and stratigraphic distribution of diagnostic species form the basis for the zonation of the the three wells. This necessitated correlation of the proposed zonation with the existing ones. The geologic age of the sequences of the three wells lie within the *Monoporites annulatus*, *Verrucatosporites* *usmensis* and *Magnastriatites howardi* Zones of the Pantropical Zones of Germeraad *et al*. (1968).

The *Periretipollis spinosus* Superzone corresponds to the *Verrucatosporites usmensis* Zone particularly in Oredo-2 well (Table 4.1 and Enclosure 1). However, the superzone top, marked by the top of *Doualaidites laevigatus* at 2020 m and 2040 m, lies slightly at the base of *Magnastriatites howardi* Zone of Germeraad *et al*. (1968) in Oredo-4 and Oredo-8 wells respectively (Tables 4.9 and 4.17 and Enclosures 5 and 9). This is, however, still tolerable as the *Verrucatosporites usmensis* and *Magnastriatites howardi* Zones boundary is probable. This means that the boundary between the two zones may shift up or down. The base of *Doualaidites laevigatus* Superzone, marked by the base occurrence of *Verrucatosporites usmensis*, was recognized only in Oredo-2 well.

The *Cicatricosisporites dorogensis* and *Verrutricolporites laevigatus* Superzones were defined within the *Magnastriatites howardi* Zone of Germeraad *et al*. (1968). This suggests a finer refinement of the latter. The *Cicatricosisporites dorogensis* Superzone lies entirely in the Oligocene with its base boundary at the top of *Doualaidites laevigatus* and its top at the top regular occurrence of *Cicatricosisporites dorogensis*. The *Verrutricolporites laevigatus* Superzone correlates with early Miocene in the three wells.

A comparison of the palynological zonation scheme proposed in this study with existing zonation schemes such as those of Evamy *et al*. (1978) and its unpublished version, Boom (1977), and Legoux (1978) reveals a refinement of the latter schemes, particularly in the Eocene and Oligocene Periods. For example, the P450 Subzone of Evamy *et al*. (1978) was subdivided into three zones, namely *Monoporites annulatus*, *Verrucatosporites usmensis* and *Psilamonocolpites marginatus* in Oredo-2 well (Table 4.1 and Enclosure 1).

Though not marked in the only well that the zone was recognized, the Oredo-2, the base *Monoporites annulatus* Zone is hypothetically marked at the evolutionary point of *Monoporites annulatus*. Germeraad *et al*. (1968) used the base occurrence of *Monoporites annulatus* to define the boundary between their *Proxapertites operculatus* and *Monoporites annulatus* Zones. The zonal top was defined by the base occurrence of *Verrucatosporites* *usmensis* at 3740 m in Oredo-2. This oldest zone, albeit the only one recognized in this study, lies at the basal part of the P450 subzone.

The succeeding *Verrucatosporites usmensis* Zone, was recognized in both Oredo-2 and Oredo-4 wells. Its basal boundary was defined by the base of *Verrucatosporites usmensis* at 3720 m in Oredo-2. Its basal boundary could not be defined in Oredo-4 as it probably lies deeper than the last sample analyzed. The zonal top was, however, defined by the base of *Cicatricosisporites dorogensis* at depths 3390 m and 3490 m in both Oredo-2 and Oredo-4 wells, respectively.

The last zone delineated within the upper part of the P450 subzone is *Psilamonocolpites marginatus* Zone. The zone was identified in all the wells in the study, though its base probably lies below the last sample analyzed in Oredo-8 well. The zonal base was defined by the base of *Cicatricosisporites dorogensis* at 3390 m and 3490 m in Oredo-2 and Oredo-4 wells, respectively. Its upper limit was marked by the quantitative top of *Psilamonocolpites marginatus* at 3190 m, 3200 m and 3220 m in Oredo-2, Oredo-4 and Oredo-8 wells, respectively.

The recognition of the bioevents discussed above enabled the refinement of P450 subzone into three finer zones in the middle Eocene. Also, the P470, straddling mid-late Eocene, was subdivided into the *Retitricolporites bendeensis, Inaperturopollenites gemmatus* and the basal part of *Doualaidites laevigatus* Zones in the three wells (Tables 4.1, 4.9 and 4.17). This was possible with the recognition and use of hitherto unrecognized events such as the base regular of *Inaperturopollenites gemmatus* and the base regular of *Psilatricolporites onitshaeensis* in the existing zonation scheme of Evamy *et al*. (1978). A further subdivision of the *Doualaidites laevigatus* Zones into subzones (a) and (b) was made possible by the base occurrence of *Cinctiporipollis mulleri* in all the three wells. This further subdivisions places subzone (a) within the P470 and subzone (b) in the P480. This has facilitated the refinement of P470 into two zones and one subzone in the palynological zonation proposed.

A further attempt at the refinement of P500 Zone, in the Oligocene, resulted was also successful. The entire P500 Zone which was delineated into four subzones of P520, P540, P560 and P580 was subdivided into three zones: the *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis* and *Anemia* sp. Zones. The identification of significant bioevents such as the quantitative base occurrence of *Racemonocolpites hians* or base regular occurrence of *Peregrinipollis nigericus* facilitated the subdivision of the *Retitricolporites ituensis* Zone into Subzones (a) and (b). This refinement of the *Retitricolporites ituensis* Zone assigned Subzone (a) to be equivalent to the P520 Zone. Subzone (b) correlates with the basal part of P540 and Zone A of Legoux (1978). Further critical and careful interpretation of the palynostratigraphic data resulted in the subdivision of *Psilatricolporites onitshaeensis* Zone into subzones (a) and (b) by the base regular occurrence of *Spirosyncolpites bruni*. This further subdivison assigned subzone (a) to Zone B2-1 of Legoux (1978) with the subzone straddling P540 and P560 Zones (Tables 4.1, 4.9 and 4.17).

Further refinement of existing zones was also carried out in the early Miocene where the P620 subzone was delineated into two zones: *Verrustephanocolporites complanata* and *Praedapollis africanus* Zones, in two of the wells, Oredo-2 and Oredo-8 (Tables 4.1 & 4.17). In Oredo-4 (Table 4.9), the upper boundary of the *Praedapollis africanus* Zone could not be defined necessitating a composite *Praedapollis africanus – Verrutricolporites laevigatus* Zone.

It has also been possible to refine the entire G2-3 Zone of Legoux (1978) by subdividing it into six zones as represented in two of the wells, Oredo-2, and Oredo-4. The first two oldest zones, *Monoporites annulatus* and *Verrucatosporites usmensis,* were not penetrated in Oredo-8 well. The zones defined in this study that were found corresponding to the G2-3 Zone are: *Verrucatosporites usmensis*, *Psilamonocolpites marginatus*, *Psilatricolporites bendeensis*, *Inaperturopollenites gemmatus*, *Doualaidites laevigatus* and the basal part of *Retitricolporites ituensis*. These zones were based on bioevents as discussed above. The C1 Zone of Legoux (1978) was further refined into three zones: *Verrustephanocolporites complanata*, *Praedapollis africanus* and *Elaies guineensis* Zones.

As experienced in the attempt at refinement of P500 zonation scheme, improved refinement of TIII Zone of Legoux (1978) was also attempted (Tables 4.1, 4.9 and 4.17). This resulted in assigning Subzone (a) of *Retitricolporites ituensis* Zone to the upper part of Zone G2-3 and Subzone (b) to Zone A of Legoux (1978). Subzone (a) of *Psilatricolporites onitshaeensis* Zone was found equivalent to B2-1 while subzone (b) lies within the P560.

5.2.1 Foraminiferal Zonation

Each of the three wells analyzed in this study exhibits a general low recovery of fauna (Enclosures 2, 6 and 10). Benthonic foraminifera dominate with an average value of 87%, while planktonic foraminifera constitute 13% of the fauna assemblage on the average. This observed trend of general paucity of planktonic foraminifera and dominance of benthics have been reported by several authors from the delta basin as alluded to in Chapter One (Petters, 1982; Ozumba, 1995; Adeniran, 1997; Okosun and Liebau, 1999; Adegoke, 2002 and Akaegbobi *et al*., 2009). Most benthonic species are thick walled and tend to be more resistant to dessication relative to planktonics making them better preserved than the latter (Douglas, 1973).

The paucity of faunal species, particularly the planktonic foraminifera, recorded in this study greatly impaired the foraminiferal zonation of the wells. However, the few recorded planktonic foraminifera were used to delineate the well sections into three segments: ?P15, Non-Diagnostic, and Indeterminate.

The basal section, from the deepest sample analyzed (Oredo-2: 4000 m; Oredo-4: 3770 m and Oredo-8: 3650 m) to the depth of occurrence of *Chiloguombelina cubensis* (and *Turborotalia pseudomayeri* in Oredo-2 well) (Oredo-2: 3530 m; Oredo-4: 3490 m and Oredo-8: 3580 m), though characterized by paucity of planktonic foraminifera, is assigned to ?P15 A spot occurrence of an unidentified species of *Globigerina* was recorded in Oredo-2 well while spotty occurrences of indeterminate species of planktics were recorded in both Oredo-4 and Oredo-8 within the interval. *Globigerina* is a genus of planktonic foraminifera which has populated the ocean waters since the Middle Jurassic till Recent (Wikipedia, 2017).

Chiloguombelina cubensis ranges from Middle Eocene to Late Oligocene with its extinction level being a widespread marker in the Late Oligocene (Kucenjak *et al*., 2014 and King and Wade, 2017). Ozumba (1997, 2011) used the interval of the range of another species of

Chiloguembelina, *C. martini* or *C. multicellaris* to define the Upper Eocene which he correlated with P15 of Blow (1969, 1979). However, King and Wade (2017) cautioned on basing the extinction of *C. cubensis* as a correlation event for the Chattian (Upper Oligocene; ca 28 Ma) base suggesting it is controversial and remains unclear. Ozumba (2011) characterized his *Chiloguembelina cubensis* Partial Range Zone with *Globigerina ciperoensis* and *G. augustiumblicata* along with some other identified species. Also, Okosun and Liebau (1999) identified *Globigerina tapurrensis*, *G. ampliappetura* and *G. ciperoensis* in a Late Oligocene interval of their study. The occurrence of *Turborotalia pseudomayeri* in Oredo-2 confirmed the penetration of Eocene age. This was extrapolated to the other two wells. Berggren *et al*. (1995) used FAD of *Turborotalia cunialensis*, the extinction of *T. cerrozulensis*/*T. cunialensis*, the LAD of *T. cerroazulensis*, the LAD of *T. ampliapertura* in the definition of foraminiferal zones P15, P16, P17, P18, P19 and P20 from late Eocene and early Oligocene. However, caution needs be exercised in the use of these bioevents as a result of the poor recovery in this study.

The rarity of planktonic foraminifera in sediments with marine lithofacies, though against the general expectation, as planktics are expected in appreciable proportions in marine sediments, is not totally strange. Such trends have been observed in biostratigraphic studies conducted by the author’s company for the Nigerian Agip Oil Company (NAOC) in nearby fields to Oredo Field in the Northern Depobelt of the delta (GEC, 2007a, b, c, d, e, and f). Furthermore, sedimentation in northern depobelt has been known to be mostly dominated by fluvial activities according to Short and Stauble (1967). This fact has been corroborated by subsequent workers as pointed out earlier. Esedo and Ozumba (2005) opined that the development of the delta in the northern depobelt during the Eocene is different from that of succeeding periods due to the separation of the Niger Delta system from the eastward Cross River delta basin by the Abakaliki High, which significantly controls the sedimentation of the former basin. These two factors resulted in the dilution effect on carbonaceous floating planktics and likewise dinoflagellate cysts, attributable to the dominating fluvial activities on the sea water, giving rise to the paucity of such forms. From the foregoing, the intervals discussed above are assigned Middle Eocene (?P15).

Sections between the depths of occurrence of *Chiloguembelina cubensis* (Oredo-2: 3530 m; Oredo-4: 3490m and Oredo-8: 3580 m) and the upper limit of foraminifera occurrence (Oredo-2: 2450 m; Oredo-4: 2470 m and Oredo-8: 2460 m) are assigned Non - diagnostic. This is based on the paucity or absence of planktics making the assignment of the section to a definite planktonic foraminiferal zone impossible. However, a spot occurrence of *Globorotalia opima nana* (3430 m) was recorded in Oredo-2 well. Petters (1979) had used this characteristic Oligocene planktonic species, together with another species of the genus, *Globorotalia opima opima*, to define one of his two horizons for which he suggested a Late Oligocene age. However, **s**ince no foraminifera was recorded or the few recorded within the interval are long ranging, this section could not be assigned a definite foraminiferal zone and no age could be assigned. Hence, the interval is referred to as Non-diagnostic.

The upper sections identified in the study (Oredo-2: 2450-300 m; Oredo-4: 2470-70 m and Oredo-8: 2460-320 m) are barren of foraminifera. The sections are defined from the depths of the topmost recovery of foraminifera to the top of the analyzed sections. This section lies mostly in the continental lithofacies (coastal deltaic environment). This observation is in tandem with the general belief that continental facies are most often devoid of foraminifera. Douglas (1973) reported the absence of foraminifera in hard limestone deposits. Thus, the barren nature of the interval precludes any age or zonal assignment.

5.2.2 Age Determination

From the foregoing, it is evident that palynological zonation offers better resolution than foraminiferal zonation in this study. As pointed out above, the general poor recovery of foraminifera, particularly the dearth of planktic marker/index species, has greatly impaired the expected use of the latter to correlate the identified palynological zones and in mapping the MFSs. Planktonic foraminifera are usually significant age indicators largely due to their floating nature which makes them preponderant in open marine environment (Whittaker *et al*.,1991). Furthermore, their short stratigraphic ranges, make them significant and reliable for biostratigraphic studies (Postuma, 1971). However, as pointed out by many workers, the dilution effect of the clastic influx within the deltaic environment has impacted on the population of the planktonic species within the delta (Adeniran, 1997; Adegoke, 2002; Esedo and Ozumba, 2005; Okosun and Liebau, 1999).

This limitation, due to preferential accumulation of sediments in shallow marine to shelfal settings, has directed attraction to benthic foraminifera for age dating and determination of paleobathymetry in the Niger Delta (Ozumba, 2011). Ozumba (2011) also observed that the oil producing companies apply routine benthonic foraminiferal study with that of pollen and spores for the identification of depositional environments and subdivision of penetrated sequences into zones for their immediate biostratigraphic requirements.

As a matter of fact, phenomenon such as this resulted in the original introduction and application of palynology in petroleum exploration (cf. Traverse, 2008). In Nigeria, exploration companies such as SPDC carried out most of their strata correlation with the aid of palynology (Sowunmi, 1989, pers. comm.).

The recovery of *Turborotalia cubensis* in Oredo-2, which was extrapolated to the other two wells, led to the assignment of a Middle Eocene (?P15) and a 41.0Ma for the only datable MFS Condensed Sections using foraminifera. Subsequent MFS Condensed Sections were derived by the principle of stratigraphic positioning. This has necessitated the use palynological zones to correlate the proposed zones and identify the possible ages of MFS(s) for the succeeding younger sections in the wells. From the biostratigraphical analyses conducted on the three wells provided for this study, a middle Eocene (Paleogene) to early Miocene (Neogene) is inferred for the studied sections.

5.3 Reconstruction of Depositional Environments

Paleoenvironmental deductions from the analysed sections of the three Oredo wells relied on the integration of palynological, micropaleontological and sedimentological data. Sedimentological inferences were based on log motifs, textural and lithological attributes as well as the distribution of index minerals and accessories.

Palynologically, the abundance and diversity of pollen and spores and marine indicators such as microforaminiferal wall linings (MWL) and dinoflagellate cysts as well as the occurrences of brackishwater palynomorphs were used for paleoenvironmental deductions. Results of the palynofacies analysis were also integrated to enhance paleoenvironmental interpretations of the investigated samples in the wells (Enclosures 1, 5 and 9).

Micropaleontologically, paleoenvironmental deductions were based on faunal criteria such as the trends in foraminiferal species abundance and diversity, planktic/benthic relationships, established depth ranges of some bathymetric indicator benthic species and the nature and types of faunal accessories recovered. Environments of deposition over the analysed sections of the wells are generally discussed under the lithofacies sequences shown in Tables 4.7, 4.15 and 4.23. The results suggest that the depositional environments in the three wells range. The strata penetrated were deposited in an essentially shallow, nearshore marine waters with occasional deepening to Middle Neritic at the base and shallowing to Coastal Deltaic up section.

5.3.1 Marine Lithofacies Sequence

This sequence was encountered in both Oredo-2 (4000-3190 m) and Oredo-4 (3800-3410 m) wells (Enclosures 3 and 7). The high proportion of shale and presence of ferruginous materials, carbonaceous detritus, mica flakes and glauconites within this unit is indicative of oxic moderate-energy marine depositional conditions. The coarse nature of the sands within the unit may represent occasional fluvial inflow into a quiet marine setting.

A moderate proportion of sporomorph population and diversity was recorded in this lithologic unit. Dominant among these are *Pelliceria rhizophorae* (*Psilatricolporites crassus*), *Retimonocolpites obaensis*, *Psilamonocolpites marginatus* as well as pteridophyte spores such as *Acrostichum aureum* and *Polygodium vulgare* (*Verrucatosporites* sp.). However, there is high marine dinoflagellate cysts population and diversity. Dinoflagellate cysts are renowned marine environment indicators (Lorente *et al.*, 2014). Presence of microforaminiferal wall linings (MWL) was registered at the basal part of the unit in Oredo-2 but limited to a spot occurrence at 3670 m in Oredo-4. MWL, relicts of benthic foraminifera, have been associated with marine environments, though they have also been recorded in estuarine settings (Tyson, 1995; Batten, 1996). This palynological representations suggest deposition in a marine environment. The records of moderate to few freshwater algae, *Botryococcus braunii* and *Pediastrum* sp., *Concentricyst* as well as brackishwater acritarch, *Leiosphaeridia* sp. suggest estuarine inflow into the marine setting. The few CPC recorded in Oredo-4 also confirms influent from fluvial environments into marine deposits.

Micropalaeontologically, the lower part of this unit in Oredo-2 (4000 – 3880 m) recorded sparse occurrences of agglutinating foraminifera, mostly species of *Ammobaculites* and spot occurrence of *Florilus ex gr. costiferum*. While intervals between 3860 and 3680 m were completely devoid of foraminifera. However, from depth 3680 m, there is gradual up-hole increase in the abundance and diversity of foraminiferal fauna which attained a maximum development over interval 3560 – 3510 m. This bloom is succeeded by decrease in microfauna from 3510 – 3190 m. Arenaceous benthic species dominated most of the intervals except interval 3560 – 3510 m where calcareous benthic were dominant. In Oredo-4, the microfaunal content of this unit is made of low abundance and diversity of benthic. However, moderate to abundant but low in diversity foraminiferal species were recovered within intervals 3690 – 3670 m and 3510 – 3470 m.

Generally, the arenaceous benthics recovered were *Saccamina complanata*, *Ammobaculites strathearnensis,* species of *Ammobaculites* and *Textularia*. *Florilus ex gr. costiferum*, *Heterolepa pseudoungeriana*, *Quinqueloculina lamarckiana*, *Q. seminulum* and *Brizalina ihuoensis* are among the calcareous benthics recorded. Accessories microfauna recorded were ostracods, scaphopods, shell fragments, gastropods, echinoid remains, sponges and pelecypods. The sediments of this lithofacies sequence were deposited in environments which alternated between Inner Neritic and Coastal Deltaic with minor deepening into Middle Neritic.

The basal part of Palynofacies Association I, typified by abundant Amorphous Organic Matter (AOM) and Black and Brown Wood alongside Non-Cuticular Tissues and Sporomorphs characterize the organic matter components of this sequence. The dominance of AOM, throughout the entire sequence, points to sediments deposition in marine environment. AOM, being usually associated with distal depositional low energy setting, far from fluvial deposits. Tyson (1995) and Batten (1996) have suggested that high percentage of AOM is related with sediment deposition in marine and anoxic environments. Black and Brown Wood is an indicator of possible inflow of fluvial organic inputs into sediments (Boussafir *et al.*, 2012). Based on the palynofacies data discussed here, sedimentary deposits that probably accumulated in a marine environment depicting deposition in distal setting are inferred.

The integration of palynological (palynofacies), micropalaeontological and sedimentological inferences above suggests that this lithofacies sequence largely represents a shelfal facies composed of nearshore sands and shallow marine shales. The log signatures suggest the sands are of distributary channel origin.

5.3.2 Paralic Lithofacies Sequence

The paralic lithofacies sequence was encountered in all the three wells studied: Oredo-2 (3190 -2760 m), Oredo-4 (3410 – 2740 m) and Oredo-8 (3680 – 2510 m) wells (Enclosures 3, 7 and 11). Thick sections of shale intercalated with very fine to pebbly-sized sands developed over this sequence. The predominance of shales, together with the very fine to coarse nature of the intercalated sands, with records of glauconite pellets suggests shallow marine environment. On the GR logs, the sediments exhibit irregular log motifs with the sands constituting hybrid units exhibiting upward coarsening characteristic of subaqueous mouth bars and channels. These sediments indicate deposition in a high energy setting as suggested by the coarse sands with recorded carbonaceous detritus.

The palynological assemblage within this lithologic unit exhibits a slight upward increase in the sporomorph population and diversity values from the underlying units. *Pelliceria rhizophorae* (*Psilatricolporites crassus*), *Retimonocolpites obaensis*, pteridophyte spores: *Acrostichum aureum* and *Polygodium vulgare* (*Verrucatosporites* sp.) continue to dominate. However, moderate recovery of sporomorphs with dominance of *P. rhizophorae* and Poaceae pollen continue to dominate the assemblage in Oredo-2.

The dinoflagellate cysts occurrence shows an increase in abundance, particularly up section, though with a reversal in diversity. Examples include *Lingulodinium machaerophorum* and *Polysphaeridum zoharyi* among others. In addition, the rich presence of Microforaminiferal Wall Lining (MWL) recorded, particularly in both Oredo-4 and Oredo-8, suggests marine depositional environment. Brackishwater influence in the lithofacies is suggested by records of *Botryococcus braunii* (Batten and Lister, 1988; Tyson, 1989) and the acritarch, *Leiosphaeridia* sp. *Botryococcus braunii*, a freshwater alga, albeit tolerant to salt, has been found also associated with brackish water environment (Adeonipekun et al., 2023).

Leiospheres have been found associated with AOM-rich deposits with anoxic and low nutrients (Habib and Knapp, 1982; Batten, 1996).

The faunal assemblage of this sequence featured low records of benthonic species. Arenaceous benthics: *Ammobaculites strathearnensis* and *Ammobaculites* sp. dominate the low macrofaunal assemblage. Accessories microfauna recorded in the underlying lithofacies sequence, such as scaphopod spp., shell fragments and sponges, are also associated with this sequence. The sediments of this sequence were generally deposited in environments which alternate between Inner Neritic and Coastal Deltaic with minor deepening into Middle Neritic as witnessed in Oredo-2 (3560 – 3510 m) and Oredo-8 (3650 – 3480 m).

The organic matter components within this sequence is dominated by abundant AOM with common Black and Brown Wood and have been classified still into Palynofacies Assemblage 1. This assemblage also points to environments varying between marine and fluvial deltaic setting. Generally, a synthesis of the foregoing discussions suggests deposition in a nearshore marine (Inner Neritic, occasionally Middle Neritic environment) shoaling to Coastal Deltaic at the upper part.

5.3.3 Transitional/Paralic Lithofacies Sequence

The transitional/paralic lithofacies sequence was recognized in Oredo-2 (2760 – 2440 m) and Oredo-4 (2740 – 2410 m). The sand/shale ratio of the lithofacies suggests high and low-energy sedimentation probably resulting from well-known frequent shifting of depositional axis and/or different subsidence characteristic of the Niger Delta (Doust and Omatsola, 1990: Reijers *et al*., 1996). Ferruginous materials, carbonaceous detritus and mica flakes recorded within this sequence indicates shallow marine/ coastal deltaic sedimentation largely prevailed during deposition.

Palynological evidence suggests a gradual increase in the sporomorph abundance and diversity within this lithofacies relative to the underlying one. This rise in proportion is noticeable in most of the recorded floral species such as *Amanoa oblongifolia* (*Retitricolporites irregularis*), *Ctenolophon englerianum* (*Ctenolophonidites costatus*), *Retimonocolpites obaensis*, *Pelliceria rhizophorae*, *Rhizophora* sp. (*Zonocostites ramonae*), *Anthonotha gilletii* (*Striatricolporites catatumbus*), *Retibrevitricolpites triangulatus*, *Alstonia brooni* (*Retibrevitricolporites ibadaneensis*) as well as the pteridophyte spores such as *Polypodium vulgare*, *Pallacea* sp. (*Laevigatosporites* sp.) and brackish-water *Acrostichum aureum*.

High record of sporomorph suggest proximity to source of vegetation (Batten, 1996; Lorente *et al*., 2014). Evidence of marine incursion was suggested by few dinoflagellate cysts and MWL. The highest diversity of dinoflagellate cysts in the Oredo-2 was recorded within this sequence. Brackishwater influence was also established with the high values of *Botryococcus braunii* and acritarch, *Leiosphaeridia* sp. recorded. In general, low abundance and diversity of benthic characterize this sequence. The foraminiferal assemblage is still dominated by *Ammobaculites* spp., and *Florilus ex gr*. *costiferum* with *Scaphopod* sp. This suggests sediment deposition in alternating Coastal Deltaic and Inner Neritic environments.

The organic matter components within this sequence is still dominated by AOM in association with Black and Brown Wood, Gelified Matter, Charcoal with increasing percentage of Sporomoph representing the upper part of Palynofacies Assemblage I. Increased value of phytoclasts have been associated with flourishing land vegetation during conducive climatic periods (Kholeif and Ibrahim, 2010). Gelified Matter, a precursor of amorphous humic gels, may result from the “complex process of decay and degradation of plant tissues that can result in either the preservation of original features or homogenization of structure” (Batten, 1996, p.1038). The relative abundance of Charcoal has also been associated with high energy situations ranging from channels deposits, proximal delta-front, estuarine to nearshore marine environments. The palynofacies assemblage represented in this sequence is typical of Shallow Marine/Coastal Deltaic environment (Batten, 1996).

Integration of palynological, micropalaeontological and sedimentological inferences above suggests that the unit largely represents a shelfal facies made up of nearshore shallow water and non-marine sands and shales. The sands are interpreted as being mostly of distributary channel and point bar origins with a few units of crevasse splay. While the interbedded shales are interpreted to be essentially of interdistributary and flood plain origins.

5.3.4 Continental/Transitional Lithofacies Sequence

Oredo-2 (2440 - 670 m), Oredo-4 (2410 – 740 m) and Oredo-8 (2510 – 1100 m) wells all penetrated the continental/transitional lithofacies sequence (Tables 4.7, 4.15 and 4.23). The predominantly sandy nature of this sequence is indicative of high energy depositional conditions. This position is corroborated by the coarse to very coarse-grained character of the sands. This thick succession of sands probably represents a shallow water non-marine environment. This possibly explains the abundant to few quantities of ferruginous materials and carbonaceous detritus as well as the few to rare mica flakes recorded within the unit.

This lithofacies unit exhibits gradual and steady appreciation in the general recovery and diversity of land-derived palynomorphs. Dominant among these are *Amanoa oblongifolia*, *Retimonocolpites obaensis*, *Pelliceria rhizophorae*, *Iriartea* sp. (*Racemomocolpites hians*), *Alstonia brooni*; pteridophyte spores such as *Acrostichum aureum*, *Polypodium vulgare* and *Pallacea* sp. as well as fungal spores such as *Exesisporites* sp., *Pleuricellaesporites* sp., *Basidiosporites* sp., *Dicellaesporites* sp., *Dyadosporites* sp. and *Involutisporites* sp. among others.

Scanty and scattered dinoflagellate cysts were generally encountered within the sequence with few recorded limited to the basal part in both Oredo-2 (2440 – 1450 m) and Oredo-4 (2410 – 2245 m). The noticeable reduction in abundance and diversity of dinoflagellate cysts suggests deposition in stressed or restricted environments such as “estuaries, coastal mud plains and on delta-tops” (Batten, 1996, p.1029). This points to a marginal or shallow marine influence and dysoxic-anoxic conditions (Marshall and Batten, 1988, Batten and Marshall, 1991; Batten, 1996).

Brackish water indicators such as *Botryococcus braunii* and the acritarch, *Leiospaeridia* sp. are appreciably represented, recording their most abundant values within this lithofacies sequence in Oredo-2, suggesting a brackish water depositional environment. An unusual recovery of significant quantity of diatom frustules was recorded in Oredo-8. This lithofacies sequence is virtually bereft of foraminifera in all the three wells, except in Oredo-8 where just a singular occurrence of *Ammobaculites strathearnensis* was recorded at depth 2470 m. This suggest sediments recovered within this sequence were deposited in Coastal

Deltaic environment, except between interval 2470 m and 2450 m in Oredo-8 where Inner Neritic is inferred.

The organic matter composition identified within this interval has been classified as Palynofacies Assemblage II, dominated by AOM with Black and Brown Wood in association with Epidermal Cuticle, Charcoal and Non-Cuticular Tissue.

The presence of Epidermal Cuticle recorded within this lithofacies sequence suggests deposition in a high energy submarine fan phase of channel sediments (Boulten and Riddick, 1986). Thus, their presence has been taken by many authors to infer fluvial flow into nearshore fluvio-deltaic environments (Habib, 1983; Tyson, 1993). Oboh-Ikuenobe *et al*. (2005) observed high percentages of both structured and unstructured phytoclasts together with terrestrial and marine components characterizing estuarine/lagoonal facies. Thus, from these suites of palynofacies assemblage, a nearshore, transitional environment with proximity to fluvio-deltaic settings is suggested.

Overall, the inferences from the synthesis of the palynological, micropaleontological and sedimentological discussions above indicate deposition in a lower deltaic plain, fluviatile environment or deltaic littoral setting.

5.3.5 Continental Lithofacies Sequence

This uppermost lithofacies was recognized in all the three wells studied: Oredo-2 (670 – 300 m), Oredo-4 (740 – 70 m) and Oredo-8 (1100 – 320 m). The succession of sands in this lithofacies unit is suggestive of high-energy conditions of deposition. The predominantly coarse-grained nature of sands in the sequence supports this interpretation. This in association with fairly persistence occurrence of carbonaceous detritus and ferruginous materials within the sequence may be indicative of continental environment of deposition.

There is a general and noticeable decline in the population of land-derived palynomorphs as well as fungal spores within this sequence. However, *Rhizophora* sp. appears to deviate from this trend in Oredo-8 as it maintains its high value. Few and scattered alga *Botryococcus braunii* and acritach, *Leiosphaeridia* sp. were recorded, though high values of the latter and diatom frustules were recorded in Oredo-8. This observed reduction in the palynological contents within this lithofacies suggests deposition within the continent with some brackish-water influence.

No foraminifera were recorded within this sequence thereby suggesting a Coastal Deltaic environment of deposition. This lithofacies sequence corresponds to Palynofacies Assemblage III. The increased abundance of phytoclasts and tremendous reduction in the value of AOM recorded in this palynofacies association reflect strong/massive terrestrial influence during facies deposition. Sporomorphs, though showing a reduction in its percentage composition from the underlying sequence, still shows appreciable value to suggest deposition in a fluviatile environment. This is further corroborated by the complete absence of dinoflagellate cysts and MWL.

According to Batten (1996), facies dominated by brown and black wood with minor inputs of spores, pollen, tissue with rare resin suggests non-marine deposits. This corroborates deposition in a continental environment. From the summation of the floral, faunal, and lithological evidence described above, this lithofacies sequence largely represents continental sand deposits (? braided channels) characteristics of the Benin Formation.

5.4 Palaeo-Cyclicity

Following the approaches of Adojoh *et al*. (2015) and Essien and Beka (2016) from their adaptations of palynocycles of Poumot (1989), an alternating wet and dry phase is constituted into a palynological cycle or palynocycle. The resultant alternations in the internal vegetations of the well sediments analysed resulted in the recognition of four wet phases and alternating four dry climatic phases for the Oredo-2 and Oredo-4 wells. These alternating wet and dry phases have been classified into Cycles 1, 2, 3, and 4. However, in Oredo-8 well, four wet phases and three dry phases which were also classified into four cycles were recognized.

Noted fluctuations in the proportions of wet climate indicators such as mangrove species, freshwater swamp species, lowland rainforest, spores and marine forms and dry climate phytoecological groups such as savanna constitute the basis for the paleoclimatic deductions made in this study. Abundant and rich proportions of the former group were associated with wet climatic conditions with their low recovery coupled with increase in the savanna group suggestive of dry paleoclimatic conditions. As highlighted earlier in the results, the wet phases are generally characterized by high relative percentage representations of wet climatic phytoecological groups. Most of these wet phases have identified MFS associated with them as reported in the results. On the other hand, the corresponding dry climate phases are commonly denoted by high proportions of savanna species with lower percentages of wet phase indicators.

This approach is based on the premise that vegetation constitutes significant reflection of the prevailing climatic condition of an area or region as posited by Birks and Birks (1980). The composition and structure of the vegetation in a region have been known to respond to climate changes for over a century (Jensen *et al*., 2007). Of the components of an environment, plants are the best indicators of the prevailing climate. Morley and Richards (1993) and Van der Zwan and Brugman (1999) averred that climate change in tropical equatorial region is marked by alternating wet and dry climate phases as reflected by variations in vegetation between rainforest (wet) and savanna (dry). Thus, according to them, a dry climate reflects the dominance and increase in savanna species while rise in abundance of mangrove, freshwater swamp, riverine and rain forests along with marine elements indicate wet climates.

The vegetation zones shift depending on the prevailing climatic condition: in the dry phase there is drastic reduction of forests to refugia and expansion of savannas and the desert. The reverse occurs in wet phase (Elenga *et al*., 2004; Sykes, 2009; Pietsch and Gautam, 2013). According to Pietsch and Gautam (2013), the Central African rainforest region is renowned to have witnessed alternating phases of decrease in forest zone during drier conditions with expansion during wetter periods.

These alternating wet and dry phases result in correlated cyclicity within a region, according to Van der Zwan and Brugman (1999). However, as pointed out by Rull (2000), caution needs to be taken in the application of phytoecological groupings in the sense of Poumot (1989) in the Paleogene of the Niger Delta. This must do largely with the relatively unknown botanical affinity of some of the palynomorphs encountered, particularly in the Eocene.

The early Eocene of sub-tropics is replete with diverse angiosperm pollen of unknown extant affinities (Jacobs *et al*., 2010). Though, the same authors alluded to evidence for the existence, albeit not unequivocal, of low-latitude tropical forest since the Palaeocene as suggested by some plant fossils akin to tropical forests. Also, there was a significant decline in the record of grass pollen in the mid-Eocene and its complete absence in mid-Oligocene of West Africa (Jacobs *et al*., 2010). Grass cuticles has been a significant signal in the recognition of dry climatic phases in palynological studies of the Neogene in the tropics (Morley and Richards, 1993; Morley, 1995b).

Nonetheless, Poumot's approach was still adopted in this study since identifiable or known taxa constitute a significant proportion of recorded palynomorphs. The adoption of this approach is a further corroboration of Rull (2000) in his testing of palynological cyclic pattern in the Palaeocene/Eocene transition in western Venezuela. Rull (2000) delimited and correlated minimum of eight palynological cycles with third-order global eustatic cycles in a Late Palaeocene/Early Eocene sequence by applying palynocycles and ecologs. From his study, Rull (2000) detected and related recurrent climate oscillations and linked cyclicity of high-frequency period of about 220,000 – 260,000 year to Milankovitch cyclicity.

A major upsurge in the diversity of pollen involving many extant genera and families in the tropical lowland forest was reported from late Eocene to Oligocene by Salard-Cheboldaeff (1978, 1979, 1981). As a matter of fact, most extant plant genera had evolved by the end of the late Eocene in lowland tropical forests (Jacobs *et al*., 2010). Muller,1981, cited in Poumot (1989) showed that 75% of the extant species were present in the Oligocene. Also, there is unanimity on the existence of coastal estuarine habitat since the earliest Paleogene. As a matter of fact, the dominance of pollen types of *Spinizonocolpites* and *Proxapertites* in the Paleogene has been recorded by different authors (Van Hoeken-Klinkenberg,1966; Medus, 1975; Kogbe and Sowunmi, 1975; Salard-Cheboldaeff, 1978,1979; Kaska, 1989). Estuarine palms in general are ubiquitous in Palaeocene and Eocene sediments (Frederiksen, 1985; Sowunmi, 1986; Jacobs *et al*., 2010).

Palynocycle 1 (CYL 1) lies within the middle Eocene in both Oredo-2 and Oredo-8 but straddles the middle to late Eocene in Oredo-4 (Tables 4.3, 4.11 and 4.19). Palynocycle 2 (CYL 2) straddles the Middle to Late Eocene in both Oredo-2 and Oredo-8 wells and lies within the late Eocene in Oredo-4 well. Palynocycle 3 (CYL 3) straddles late Eocene to Oligocene, while the youngest, Palynocycle 4 (CYL 4), straddles the Oligocene to early Miocene in all the wells. In Oredo-2, the four recognized palynocycles belong to two depositional cycles of sediments bounded by one Sequence Boundary, 40.1 Ma at 3100 m (Table 4.3). Thus, the palynological cycles correlated reasonably well with the Niger Delta Cenozoic Chronostratigraphic Chart (1998) and Haq *et al*. (1987) Third Order Cycle Chart (Figure 5.1). However, the wide range of cycle in terms of age noticed in Oredo-4 from the other two wells may be due to facies control as earlier alluded to.

Palynocycle 1 correlates with the upper part of TA3 Supercycle, Palynocycles 2 and 3 lie within the TA4 Supercycle and Palynocycle 4 straddles the TA4 and TB1 Supercycles (Table 4.3 and Enclosure 3). This study shows that Palynocycles 1-3 and the basal part of Palynocycle 4 span the falling limb of the long-term eustatic oscillations with durations between >41.0 Ma and ca 29.3 Ma. The upper part of Palynocycle 4 lies within the rising limb of the eustatic oscillation from~ca. 29.3 Ma to ca. 23.3 Ma**.**

The palynocycles in the Oredo-4 well belong to three depositional cycles of sediment deposition bounded by two sequence boundaries, 40.1Ma and 38.7Ma at 3100 m and 2630 m respectively (Table 4.11). Correlation with Niger Delta Chronostratigraphic Chart (1988) and Third Order Cycle Chart of Haq *et al*. (1987) reveals that Palynocycle 1 and the basal part of Palynocycle 2 correlate with the upper part of TA3 Super Cycle, the larger chunk of Palynocycle 2 and Palynocycle 3 lied within the TA4 Supercycle with Palynocycle 4 straddling the TA4 and TB1 Supercycles (Table 4.11 and Enclosure 5). Palynocycles 1-3 and the lower portion of Palynocycle 4 are associated with the falling limb of the long term eustatic oscillation ca. 41.0 Ma to ca. 29.3 Ma, while the upper part of Palynocycle 4 belongs to the rising limb of the eustatic oscillation between ca. 29.3 Ma and 23.3 Ma.

The recognized four palynocycles in Oredo-8 well have been associated with three depositional cycles of sediment deposition bounded by two sequence boundaries, 40.1 Ma and 38.7 Ma at 3090 m, and 2620 m respectively (Table 4.19). The entire portion of Palynocycle 1 (CYL 1) and the lowest part of Palynocycle 2 (CYL 2) correspond to the upper part of TA3 Supercycle. Most part of CYL 2 and the entire Palynocycle 3 (CYL 3) lie within the TA4 Supercycle while Palynocycle 4 (CYL 4) straddles the TA4 and TB1 Supercycles of Haq *et al*. (1987) (Table 4.19 and Enclosure 9). Detailed correlation of the palaeoclimate signals of the well depicts Palynocycles 1 – 3 and the lower portion of Palynocycle 4 span the falling limb of the long term eustatic oscillation from between 41.0 Ma to ca. 29.3 Ma and the upper section of Palynocycle 4 is associated with the rising limb of from ca 29.3 Ma to 23.3 Ma.

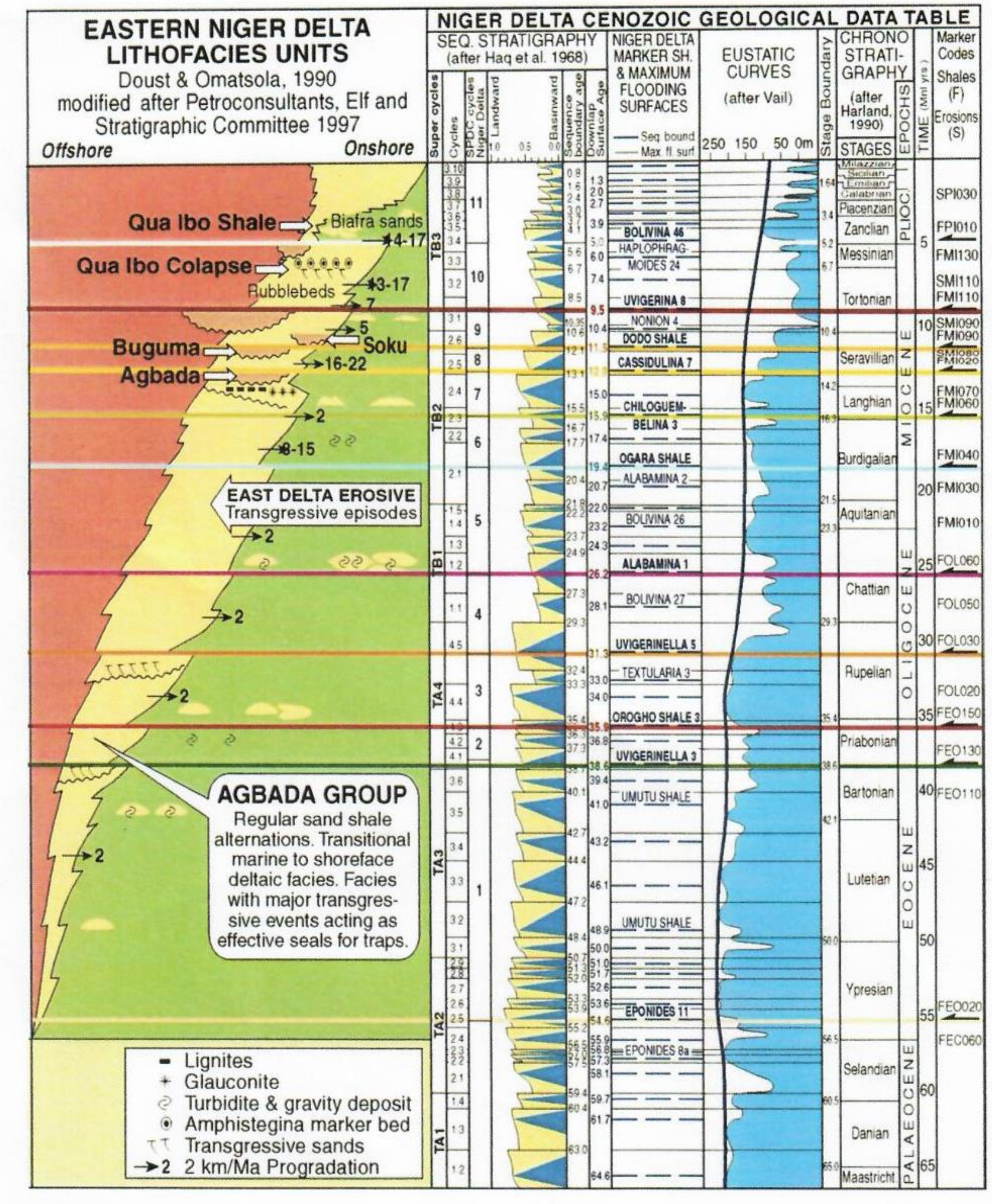


Figure 5.1: Niger Delta Chronostratigraphic Chart (Culled from Reijers, 2011)

In agreement with the affirmation of Birks and Birks (1980) that climate changes with time, there is a definite, consistent, and correlated trend in the chronostratigraphic recognition of the four palynocycles in the three wells in this study. Based on this consistent trend, the climatic indicators used in determining the respective palynocycles are discussed as follows.

Palynocycle 1 (CYL 1) penetrated the thick shale Marine lithofacies in Oredo-2 well, the Paralic lithofacies shale /sand intercalations in Oredo-8 and straddled the Marine-Paralic lithofacies in Oredo-4 well within the Agbada Formation. The interval representing Palynocycle 1 in the three wells commenced with abundance of brackish-water swamp species and freshwater pteridophytes spores with rich representation of dinoflagellate cysts. Common recovery of freshwater swamp forest species was also made. The preponderance of brackish-water (Frederiksen, 1985) and presence of shallow marine dinoflagellate cysts such as *Lingulodinium machaerophorum* and species of *Spiniferites* among others (Muller, 1959; Durugbo *et al*., 2010b) suggest a wet climate phase for the sediments representing this interval. Associated with this wet climate phase is the 41.0 Ma (41.2 Ma) MFS in the wells. This MFS lies on top of the youngest Transgressive Systems Tract (TST).

The brief succeeding drier phase interval in all the three wells featured reduction of the wet climate indicators witnessed in the previous interval. The concomitant decline in the representation of dinoflagellate cysts indicates a drier climate phase completing a wet-dry cycle making up Palynocycle-1. The reduction in brackish-water swamp species as well as that of shallow marine dinoflagellate cysts from higher percentages in the preceding interval is an indication of an alternating drier climate condition. The dry phase of this cycle lies in close association with the 40.1 Ma Sequence Boundary (SB) in the wells. The reduction of the wet climate indicators probably resulted from the decrease in sea level and initial sea-level drop typical of the Highstand Systems Tracts (HST) within the Palynocycle 1 dry phase.

Palynocycle 2 (CYL 2) lies from the Paralic to Continental/Transitional lithofacies (ranging from intercalated shale/sand unit to a predominant of thick argillaceous sands with thick shales interbeds at the base) in the three wells. The inception of the Palynocycle 2 saw the resurgence of brackish-water swamp species, freshwater pteridophytes spores with high representation of dinoflagellate cysts and microforaminiferal wall lining (MWL) with occurrence of the alga, *Botryococcus brauni*. This interval represents sea-level rise suggesting a wet climate phase. It is closely associated with the 39.4 Ma (37.8 Ma) MFS in the three wells as well as the 38.0 Ma (33.9 Ma) MFS in Oredo-8. Sediments of this wet climatic phase were deposited in the Paralic – Transitional Paralic lithofacies in Oredo-2 and Oredo-4 wells (Paralic in Oredo-8 well). Overlying the wet phase is an interval represented by reduction in the proportion of the wet climate indicators and rare occurrence of dinoflagellate cysts and *Botryococcus braunii*. This interval probably indicates period of sea-level fall within the Highstand Systems Tract (HST).

Palynocycle 3 (CYL) consists of thick sequence of argillaceous sands of the Continental/Transitional lithofacies. In addition to the abundance of brackish-water swamp species and freshwater pteridophyte spores that dominated the earlier wet phases in the two previous palynocycles, the initial phase of this cycle witnessed abundant representation of freshwater swamp forest species such as *Amanoa oblongifolia* and *Ctenolophon englerianum*. Also, regular presence of lowland rainforest such as *Psilastephanocolporites sapotacea* and mangrove *Rhizophora* type pollen were recorded. There was still high presence of dinoflagellate cysts.

The vegetation within this interval depicts diversification from the previous brackish-water swamp and freshwater swamp forests of the previous cycles to a richer forest vegetation with evidence of lowland rainforest representation. This vegetation diversification between the Eocene and Oligocene has been reported (Strauss, 2019). The record of *Rhizophora* type pollen probably suggests gradual establishment of *Rhizophora* flora into the vegetation. Hitherto, mangrove vegetation was assumed to be alien in the Nigerian (West African) tropics until the Early Miocene (Germeraad *et al.*, 1968; Salard-Chelboldaeff, 1990; Asadu and Ofuyah, 2017). However, mangrove vegetation had been established in the Asian/Borneo since the Eocene and in South American region by the Oligocene (Frederiksen, 1985; Germeraad *et al*., 1968). These representations of plant taxa that signify wet paleoenvironmental conditions indicate a wet climate phase heralding Palynocycle 3 in the three wells. This wet phase is associated with the aggradation lithofacies of the highstand in the sea level.

Succeeding the wet phase in this cycle is interval characterized by high representation of a dry climate indicator, *Anthonotha gilletii* (*Striatricolporites catatumbus*). The reduction in the records of the wet climate indicators such as freshwater spores, near absence of dinoflagellate cysts corroborates the suggestion of a third, dry climatic phase.

Palynofacies 4 (CYL 4) represents interval within the upper part of the Continental/Transitional lithofacies and heralded by abundant mangrove species such as, *Rhizophora* sp. and *Verrutricolporites laevigatus* as well as lowland rainforest pollen such as *Psilastephanocolporites sapotacea*. Also recorded in abundance were freshwater swamp forest pollen, brackish swamp species, freshwater pteridophyte spores and the alga, *Botryococcus braunii*. The floral assemblage represented in this interval is suggestive of a wet climate related to sea level rise. This inference is corroborated by the expansion in mangrove or coastal swamp vegetation (Adojoh, *et al*. 2015). However, it needs be mentioned that the rise in sea level within this wet phase probably contributed to the incised valley filled shale/ mudstone deposits within the Continental/Transitional unit of the wells.

Identified in the Benin Continental lithofacies is the succeeding dry phase of the cycle, Palynocycle 4. This interval is generally characterized by the poor recovery of palynomorphs. While the generally poor record of palynomorphs might be because of the sandy nature of the continental lithofacies of the Benin Formation which could have led to most of the deposited palynomorphs being oxidised, a harsh climatic condition of increased dryness and very high temperature could also be responsible for the paucity of palynomorphs recorded. In addition, the Miocene is noted to be warmer than its preceding and succeeding epochs and heralded the expansion of grasslands associated with dry weather conditions (Kazlev, 2002b).

As mentioned above, there exists consistency and correlation in the chronostratigraphy of the four palynocycles in the three wells. While Palynocycles 1 and 2 lie within the Bartonian and Priabonian Stages of middle-late Eocene in all the wells, Palynocycle 3 straddles the Priabonian and Rupelian Stages of the late Eocene and Oligocene (Tables 4.8, 4.11 and 4.19). Palynocycle 4 ranges from the Rupelian to Aquitanian Stages.

Furthermore, correlation of designated palynological cycles with Third Order sequence stratigraphic ages suggests correlated relationship. Palynocycle 1 is associated with Sequences 1 and 2 penetrating 41.0 Ma (41.2 Ma) and 39.4 Ma (37.8 Ma) MFS(s) in both Oredo-2 and Oredo-4 wells. However, in Oredo-8 it is limited to the 41.0 Ma (41.2 Ma) MFS. Palynocycle 2 penetrated 38.0 Ma (33.9 Ma) in Oredo-4 and 39.4 Ma (37.8 Ma) and 38.0Ma (33.9 Ma) MFS(s) in Oredo-8. Palynocycles 3 and 4 could not be tied to any associated MFS. They are both recognized within the Highstand Systems Tract (HST) above the youngest Maximum Flooding Surfaces (MFSs): 39.4Ma (37.8 Ma) in Oredo-2 and 38.0 Ma (33.9 Ma) in Oredo-4 and Oredo-8 wells.

The association of more than one stratigraphic sequence with Palynocycles 1 and 2 confers the status of megapalynocycle on them. According to Poumot (1989) a megapalynocycle is ascribed to sequences with frequency longer than palynocycles. Rull (2000) had also identified two mega palynocycles in his study. As Reijers (2011:135) puts it "interference of cycles with different periods result in megasequences that are chronostratigraphically confined and sedimentologically characterized".

The upper part of Palynocycle 2, Palynocycle 3 and Palynocycle 4 are all identified within the extensive HST of the youngest sequence in all the wells. These segments in the three wells are all within the transitional/continental and continental lithofacies sequences. The recognized Sequence Boundaries (SB) in most cases are marked very close to the dry phases of the palynocycles (Table Tables 4.8, 4.11 and 4.19). Instances where they have been found lying within a wet phase is at the sea-level regression associated with HST. Sequence boundaries (SB) are unconformities which correspond to low sea-level and used in delineating the basal and upper boundaries of a complete sequence (Haq *et al.*, 1987; Vail, 1987; Vail and Wornardt,1991).

Though, Reijers (2011) averred that sequence boundary bounded sequences are recognized in specific areas of the Niger Delta, genetic sequences delineated by maximum flooding surfaces in transgressive shales of Galloway (1989) are common in the delta. The latter approach is more relevant in this study as it facilitates better correlation of the recognized palynocycles with the conventional systems tracts; though, a sequence is usually bounded by sequence boundary.

The four palynological cycles recognized in this study have been found to correlate with three of the seven second-order global eustatic Supercycles, TA3, TA4 and TB1, cited by Haq *et al*. (1987) (Tables 8, 17 and 26). In all the wells, Palynocycle 1 corresponds to Supercycle TA3; Palynocycle 2 straddles Supercycle TA3 and TA4 (except in Oredo-2, where its base coincides with the base of TA4). Palynocycle 3 lies within Supercycle TA4 while Palynocycle 4 straddles Supercycle TA4 and TB1. This attempt facilitates the identified palynocycles to be situated in the way they reflect in sediment packages (Reijers, 2011). Based on the assigned ages from both palynological and foraminiferal data, the dated palynocycles in Oredo-2 occur within a period of *ca* 1.6 Ma giving an average of *ca* 0.8Ma per palynocycle. In Oredo-4 and Oredo-8, the two dated megapalynocycles have durations of 4.7 Ma and 4.2 Ma giving an average of about 2.35 Ma and 2.1 Ma for each palynocycle respectively.

The recognized palynological cycles in the study were related to the long-term eustatic oscillation recognized by Haq *et al*. (1987) (Figure 5.2). The Eocene arm of the eustatic curve showing a global sea-level drop, was identified from the basal parts in the three wells studied spanning top Supercycle TA3. The curve shows a continuous shallowing trend through Supercycle TA4 until the Chattian at *ca* 29.3Ma in the basal part of TB1 when it deepened into the Early Miocene. This observed trend in the Cenozoic Era has been well documented and reported in literature (Jenkins, 1971; Ozumba and Amajor, 1999a; Adojoh and Osterloff, 2010; Jaramillo *et al*., 2010; El Beialy *et al*., 2005; Traverse, 2008; Francis *et al*., 2009; Digbehi *et al*., 2012).

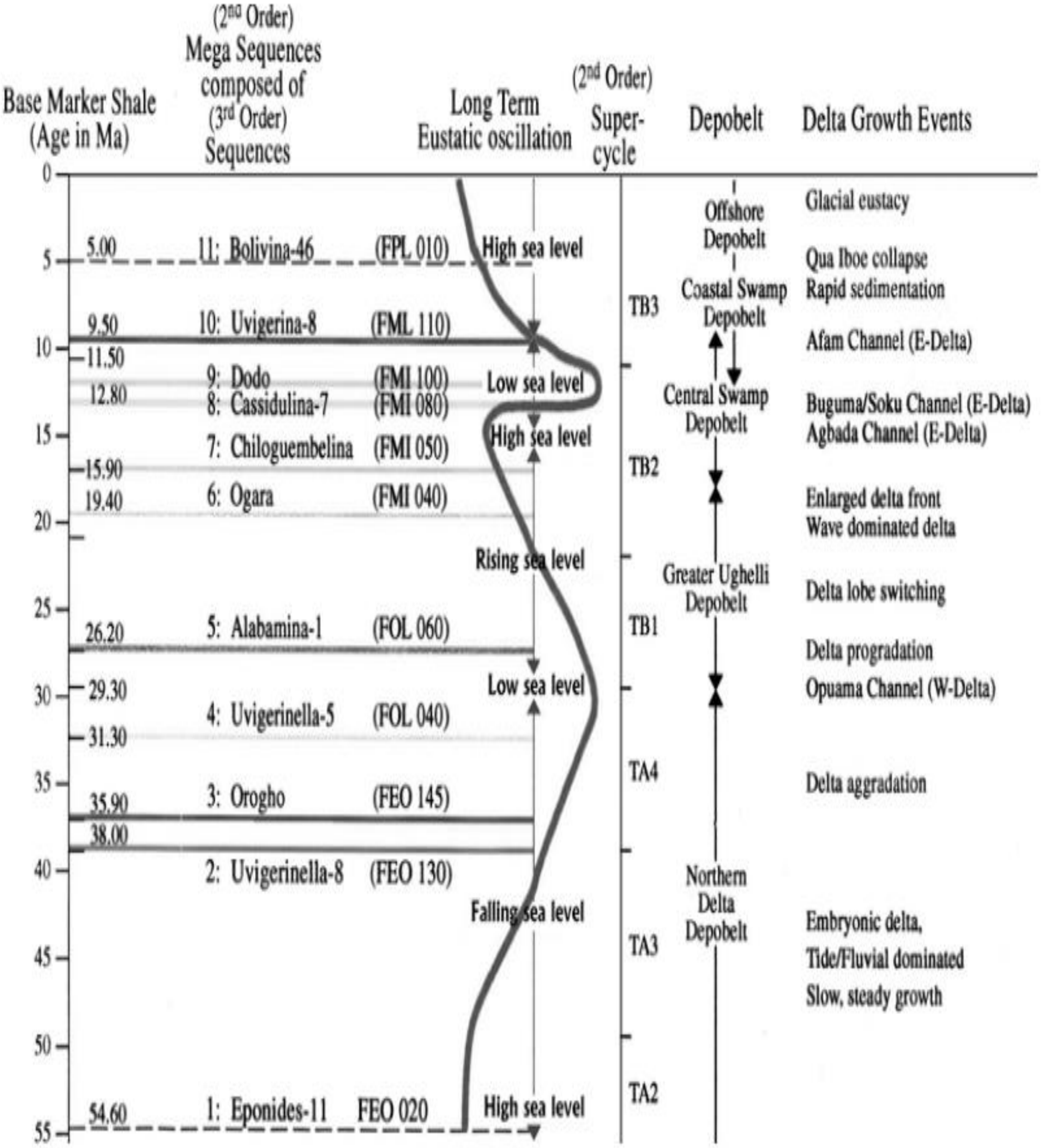


Figure 5.2: Phases of Delta evolution and some of their characteristics (After Reijers, 2011)

The late Palaeocene and early Eocene have been identified to be mostly warm and characterized by tropical and warm temperate flora with maximum tropical conditions recorded between early and middle Eocene. The early Eocene marked period of greatest expansion of palaeotropical flora in the Northern Hemisphere resulting in it being referred to as the palaeotropical maximum (Traverse, 2008). Drastic changes in flora leading to the advent of contemporary plant species are believed to have started in the Oligocene, a period synonymous with pronounced cooling (expansion of temperate deciduous forests, appearance of grasses and Asteraceae (Compositae) families (Francis *et al*., 2009; Adojoh and Osterloff, 2010). The overall climate trend in the Cenozoic depicts a progressive fluctuation to cooling in the Pleistocene (Traverse, 2008).

The floral assemblages encountered in the quantitative palynological analyses carried out on the Oredo Field sediments suggested distinct differences in the compositions between the Eocene and Oligocene periods. The Eocene intervals were dominated by estuarine coastal plant species such as *Pelliceria rhizophorae* with *Nypa* types species (*Spinizonocolpites baculatus* and *S. echinatus*), most especially in the Late Eocene. High representations of dinoflagellate cysts and microforaminiferal wall linings (MWL) in numbers and diversity were also recorded. The Oligocene period exhibited greater abundance and diversity of plant species such as the freshwater swamp *Amanoa* sp. (*Retitricolporites irregularis*) and *Symphonia globulifera* (*Pachydermites diederixi*) becoming established. Evidence of change in coastal swamp environment from estuarine to mangrove was shown by the improved representation of the mangrove swamp species, *Rhizophora*. These changes in vegetations are reflections of global climate change from the greenhouse conditions in the Eocene to a much cooler phases in the Oligocene.

From the foregoing, it has become manifest that signals from the palaeoecological data analysis of the three Oredo wells indicated about eight alternating wet and dry phases. These phases have been classified into four correlated palynological cycles or palynocycles across the wells from middle Eocene to early Miocene. This paleoclimatic study has revealed that the Eocene, though generally known for its astronomical temperatures and low sea levels, still recorded wet phases which may not be pronounced as reflected by the three wet phases reported. This assertion is supported by the well documented record of brackish-water coastal plant communities and the coastal-plain peat-forming freshwater swamp communities associated with the period (Frederiksen, 1985). The increase in floral diversity and abundance in the tropics of the Eocene also corroborates this (Jaramillo and Dilcher, 2000; Jaramillo *et al*., 2006, 2010).

According to Strauss (2019), the climate of the Eocene period took over from the increasing global temperature from the Palaeocene. The prevailing high temperature and humidity in the early Eocene created conducive environments for thick rainforest in both the north and south hemispheres. The rise in temperature later experienced decrease in the late Eocene resulting in the global cooling largely due to the reduction in the atmospheric levels of carbon dioxide. The climate change recorded in the late Eocene resulted in the disappearance of neotropical forest and the succeeding deciduous forest with better tolerance for seasonal temperature changes in the succeeding Oligocene. However, rainforests continued its existence in tropical equatorial South America, Africa, India, and Australia (Wikipedia, 2020).

The extended wet phases recorded within the Oligocene are very much in agreement with the well-recognized cooling and resultant high sea-level which commenced at the threshold between the Eocene and Oligocene (Jaramillo, 2010; El Beialy *et al*., 2005; Francis *et al*., 2009; Digbehi *et al*., 2012; Kaslev, 2002a). The Oligocene signalled the beginning of a generalized cooling of global temperature. For the first time, glaciers were formed during this epoch in the Cenozoic. The rise in the ice sheets resulted in sea-level fall, reduction in the tropical zones succeeded by cooler woodlands and grasslands (Kaslev, 2002a).

The Oligocene/Miocene threshold is noted for a significant global cooling event linked with a development of glacial in Antarctica (Essien and Beka, 2016). Relative to the preceding and succeeding epochs, the global climates were warmer in the Miocene. The formation of the modern atmospheric and ocean circulations patterns was initiated during this period (Kaslev, 2002a). The Miocene recorded two major ecosystems: forests and grasslands. The period witnessed the expansion of grasslands which was related to dryness of the continental interiors and global cooling. The cooling in the late Miocene gave room to expansion of grasslands savanna vegetations in place of the tropical forests (Kaslev, 2002a).

This study has been able to relate paleoclimatic variations with specific absolute MFS(s) ages in middle Eocene – early Miocene sediments of the delta for the very first time and link them across wells. The poor recovery of foraminifera, which ensured the sole use of palynological data in this study, lends credence to the independent of palynology in its application to sequence stratigraphy Without doubt, an extensive application of this model will be required to fine-tune it and bring it to perfection. The succession of alternating wet and dry phases recorded in this study indicate the cyclic nature of palynological events during sedimentation processes on the onshore Niger Delta. These alternating sequences of palaeoflora assemblages have been shown to fit reasonably well into the sea-level changes defined by Haq *et al*. (1987). This agrees with results of earlier workers (Poumot, 1989; Rull, 2000; Essien and Beka, 2016).

The data of Poumot's (1989) study showed correlation between the palynocycles and the eustatic cycles of Haq *et al*. (1987) in the Neogene. However, Poumot (1989) concentrated his research solely on the Neogene of the Niger Delta. Rull (2000) correlated identified palynological cyclic pattern with third-order global eustatic cycles in the Paleocene/Eocene transition in Western Venezuela. Also, Essien and Teka (2016) found out that palynocycles influenced by climate changes correlated with phases of sea level oscillations and depositional systems from their studies of offshore wells from the Neogene sediments of the Niger Delta basin.

This concept of palynology in sequence stratigraphy constitutes a significant contribution to the advancement of exploration activities in the Niger Delta using the third order cyclic packages. Its application will ultimately facilitate the erection of models towards the actualization of improved hydrocarbon predictions. However, as various authors in the area pointed out (Poumot, 1989) additional studies need to be carried out towards a better refinement of the model.

5.5 Thermal Maturation

Evaluation of organic thermal maturation for hydrocarbon potentials of sediments in the three wells studied was carried out by adopting the thermal scale modified after Gaupp and Batten (1985). The TAS reflects the maturation colour of spores identified in the unoxidized kerogen samples. Results of the thermal alteration index are shown in Tables 4.4, 4.12 & 4.20 and Enclosures 1, 5 and 9. From the results, the three well sequences exhibit similar trends in their thermal alteration indices. Older sediments (4000 – 3560 m) in Oredo-2 well, (3750 - 2540 m) in Oredo-4 well and (3650 – 2560 m) for Oredo-8 recorded Thermal Alteration Index (TAI) value of 3 representing early maturity in the oil-window maturation.

As a result of over-burden pressure of deposited sediments over time with increasing temperature, the spore colour in the TAI transformed into orange\orange brown colour depicting mature facies for hydrocarbon generation. According to Leythaeuser (2005), source rocks require to be buried at deeper depths allowing for adequate underneath temperatures for the initiation of the petroleum generation process. Increase in subsurface temperature over geologic period results in the generation of hydrocarbon from source materials in a process\ called maturation (Tissot and Welte,1984). The principal driving force in petroleum maturation and generation is high temperature from burial heat generated in the subsurface because of increasing depth. Thermal alteration/degradation of kerogen resulting in the cracking or breaking down of carbon-carbon bonds yields oil and gas (Makenzie and Quigley, 1988 cited in Leythaeuser, 2005).

The mature facies intervals in the study lie in the Eocene in the three wells. Apart from the Oredo-2 well where it was limited to the Middle Eocene, the mature facies straddle middle/ late Eocene in both Oredo-4 and Oredo-8 wells. The mature facies interval lies either in the Agbada Formation marine lithofacies in Oredo-2 well (Table 4.7) or marine-paralic lithofacies in both Oredo-4 and Oredo-8 wells (Tables 4.15 and 4.23).

From the above, results of the biostratigraphic and lithostratigraphic investigation corroborate the inference of source rock potential in the shale portion of Agbada Formation in Eocene intervals of the three wells. A school of thought posited that the Agbada Formation shales in the Niger Delta constitute major source rocks in the basin (Reed, 1969).

Subsequent workers such as Lambert-Aikhionbare (1982) and Lambert-Aikhionbare and Ibe (1984) affirmed the Agbada shales to be a significant hydrocarbon source.

However, another school of thought averred that Akata Formation shales are the source rocks in the delta suggesting Agbada shales are essentially immature (Ekweozor and Daukoru, 1984). But according to Ejedawe, 1981 cited in Nwachukwu and Chukwura (1986), hydrocarbon in the Agbada Formation sandstone reservoirs are concentrated at different levels in the Niger Delta. The productive sand intervals range in age from Eocene to Pliocene.

Nevertheless, it seems possible that both Akata and Agbada Formations are sources of hydrocarbon with varying contributions in the Niger Delta (Nwachukwu and Chukwura, 1986). According to Reijers *et al*. (1996), matured shales from the Eocene to Miocene within the Akata and Agbada formational sequences dominate the source rocks of the delta basin.

Results of paleoenvironmental, palynofacies and sequence stratigraphic analyses in this study also corroborate the hydrocarbon generation potential of the basal matured facies in the three wells. The marine and paralic lithofacies sequences within which the mature facies lie are dominated by thick shale (or sections of shale intercalated with very fine sands, in case of the paralic sequence) with the records of ferruginous materials, carbonaceous detritus, mica flakes and gluconites suggest deposition in marine setting as discussed earlier. Marine transgression in dysoxic or anoxic basins is significant for “the preservation of oil-prone organic matter in sediments” according to Batten (1996:1014).

The dominance of Amorphous Organic Matter (AOM) witnessed in this basal interval of mature facies is typical of anoxic marine conditions according to Tyson, 1987 as cited in Batten (1996). This preponderance of AOM gives supportive evidence to the source rock potential of the mature facies. AOM in anoxic marine environments are known to be good source of hydrocarbon generation with the facies often classified as Type II kerogens. Thakhur and Dogra (2011) used the preponderance of AOM to corroborate the measured TAI values of 3.00 in suggesting an optimum source-rock potential for sediments in Marhighat, India.

The mature facies interval in Oredo-2 well is associated with the Transgressive Systems Tract (TST) shale of Sequence 1 between depths 4000 and 3400 m. This shale is suspected to be the source rock in the well with the Maximum Flooding Surface (MFS) at 41.0 Ma (41.2 Ma) as the seal. The overlying Highstand Systems Tract (HST) between 3400 and 3100 m appears to be the reservoir. In Oredo-4 and Oredo-8 wells, the mature facies intervals extend between Sequences 1 and 2. The TST shales are believed to be the source rock while the adjoining HST sand packages are believed to be the reservoir. The MFS between the TST and HST serves as the reservoir seal.

Sediments of upper interval in the three wells studied (Oredo-2: 3560-300 m; Oredo-4: 2540 – 70 m and Oredo-8: 2560 – 320 m) suggest immature thermal alteration phase. The Thermal Alteration Index (TAI) value of 2 indicates dry gas reservoir. The studied spores in these facies indicate yellow – orange colouration. The immature facies interval ranges from late Eocene to early Miocene in both Oredo-4 and Oredo-8. However, in Oredo-2 it straddles middle Eocene and late Miocene. According to Ojo *et al*. (2012), the Oligocene and Miocene sandstones of the Niger Delta serve as clastic reservoir.

The immature facies intervals extend between Paralic lithofacies in Oredo-2; Transitional-Paralic lithofacies in Oredo-4 and Continental/Transitional lithofacies in Oredo-8 to the Benin Continental lithofacies. According to Petters (1991), the delta front intercalated Agbada Formation serves as the hydrocarbon reservoir of the delta. In the words of Short and Stauble (1967:769), “the Agbada Formation is the main objective in the exploration for oil in the southern Nigeria”. The porous intercalated sands of the formation serve as reservoirs. However, the continental upper deltaic plain Benin sands and sandstones are generally freshwater- bearing formation devoid of hydrocarbon deposits.

The Transitional/Paralic to Continental lithofacies of the immature facies has been ascribed to marginal or shallow water to non-marine environment. The increasing records of the phytoclasts such as the black and brown wood together with epidermal cuticle, charcoal and sporomorph encountered between Palynofacies Assemblages II and III within the facies point to gas production. Abundant phytoclasts such as structured woods and other plant materials and palynomorphs in sediments largely point to significant gas production.

Environments such as this with the hydrogen indices lesser than the Amorphous Organic Matter (AOM) dominated facies are classified as poor hydrocarbon sources and are grouped as Type III kerogen (Batten, 1996).

The immature facies interval mostly lies within the Highstand Systems Tract (HST) in the three wells studied. These prograding sediments packages of sand and shales associated with the HST serve as reservoir for the dry gas generated from the source rock in the underlying Transgressive Systems Tract (TST). The 39.4 Ma (37.8 Ma) Maximum Flooding Surfaces (MFS) picked at 2910 m in Oredo-2 well and 38.0 Ma (33.9 Ma) MFS picked at 2540 m and 2530 m in both Oredo-4 and Oredo-8 wells respectively serve as seals for the reservoir rocks.

The results of Thermal Alteration Index (TAI) carried out in this study conform with the generally recorded increase in maturation as the sediments get older. This is adduced to either increases or decreases in absorbance or transmittance respectively with increasing depths (Oboh, 1995; Ibrahim, 1996; Odedede *et al*., 2012). From visual and quantitative spore colouration study on a 50 m long middle Miocene cores from two boreholes, Oboh (1995) indicated immature to marginally mature facies. Also, results of colour indices with predominance of orange to brownish coloured *Botryococcus braunii* on sediments aged middle Eocene from the E-12 well by Odedede *et al*. (2012) inferred a mature organic source rock.

Results of Thermal Alteration Index (TAI) carried out on sediments of the three wells studied agrees with the conclusion drawn by Ojo *et al*. (2012). Ojo *et al*. (2012) from the results of their study affirmed that the Palaeocene and Eocene source rocks reached optimum thermal levels for hydrocarbon generation into the Oligocene and Miocene clastic reservoirs in north-western Niger Delta.

5.6 Sequence Stratigraphy

5.6.1 Conventional Sequence Stratigraphic Framework

Conventional sequence stratigraphy carried out facilitated the subdivision of the section of the wells in this study into packages of sequences delimited by key chronostratigraphic surfaces.

From the identified dated sequence boundaries and maximum flooding surfaces, two depositional sequences have been delineated in the Oredo-2 well (Table 4.8) while three sequences were defined in Oredo-4 and Oredo-8 wells (Tables 4.16 and 4.24).

As a result of the paucity of foraminifera, particularly planktonic ones, the age assignment to the picked MFS(s) were based on the stratigraphic position within the palynological subzones or the foraminiferal zones, wherever applicable, rather than the conventional index foraminiferal markers. This challenge has been recognized by earlier workers such as Garzon *et al*. (2012) who reported possible difficulty in the identification of maximum flooding surfaces and sequence boundaries in some settings such as homogenous fine-grained deposits as was the case in the Colombian sediments they studied. Garzon *et al*. (2012) constructed a sequence-stratigraphic framework by using cyclic pattern in palynofloral abundances and changes in lithology from two sections. Data integration from both palynology and lithology resulted in the recognition of systems tracts and maximum flooding surfaces (MFS) in both sections.

The non-availability of gamma-ray logs, particularly for the upper section of the three wells, limited sequence stratigraphic interpretations in the affected portion of the wells. Though wireline log data have been variously identified as *sine qua non* in the interpretation of lithology and identification of sequence boundaries, maximum flooding surfaces and systems tracts (Mitchum *et al*., 1990; Wornardt *et al*., 1992), many researchers have integrated palynological studies with sedimentology in identifying depositional systems tracts and maximum flooding surfaces (Poumot, 1989; Jones *et al*., 1993; Hart *et al*., 1994; Nichols, 1995; Oboh, 1996; Morley, 1995b, Garzon *et al*., 2012).

In the two depositional sequences recognized in Oredo-2, two systems tracts: transgressive systems tract and highstand systems tract were distinctively identified. The general non recognition of the third systems tract, the lowstand systems tract, in all the wells can be attributed to the shefal nature of the depositional setting. Sequence 1 contains the TST and HST associated with the 41.0 Ma (41.2 Ma) maximum Flooding Surface (MFS) of Haq *et al*. (1987) (Table 4.8). Sequence-2 is associated with 40.1Ma Sequence Boundary and 39.4Ma (37.8 Ma) MFS.

As shown in Tables 4.16 and 4.24, three sequences, 1, 2, and 3 were recognized in Oredo-4 and Oredo-8 wells. Sequence 1 of Oredo-4, made up of the TST and HST, is associated with 41.0Ma (41.2 Ma) MFS, penetrated the oldest chronostratigraphic horizon in the two wells. The succeeding two sequences in both Oredo-4 and Oredo-8 wells, Sequences 2 and 3, contain the TST and HSTa cyclic and succeeding order. The sequences are associated with 39.4Ma (37.8 Ma) and 38.0Ma (33.9 Ma) MFS(s) and bounded by 40.1Ma and 38.7Ma SB(s) respectively at the base.

Sequence 1, the oldest of the four depositional sequences recognized in Oredo-8 well, contains the transgressive systems tract and highstand system tract with an associated 41.0 Ma (41.2 Ma) MFS. The studied section of the well probably did not penetrate the sequence boundary at the last sample analysed. Sequence 2 is made up of transgressive and highstand associated with 40.1Ma SB and 39.4Ma (37.8 Ma) MFS. The succeeding overlying Sequences 3 is made up of a cyclic and succeeding transgressive systems tract and highstand systems tract with associated 38.7 Ma and SB and 38.0 Ma (33.9 Ma) MFS of Haq *et al*. (1988) respectively.

As can be deciphered from Tables 4.7, 4.15 and 4.24, the extensive uppermost highstand systems tract in all the wells (largely due to the continental sandy Benin Formation lithology at the upper sections of the wells) has its base coeval in the P470 palynological subzone within the paralic lithofacies in Oredo-2 and Oredo-8 or the transitional/paralic lithofacies. This suggests fast rate of sedimentations in the basal Eocene segments of the wells and rapid regression with increasing volumes of sediments deposition in the Oligocene and younger. Thus, the overlying regressive transitional – continental sequence progressively prograde.

The Niger Delta basin, which started its growth in late Palaeocene/Eocene with sediments build-up in northern flank of contemporary delta region, has been impacted in its structure and stratigraphy by the joint activities of sediment supply and subsidence. This resulted into sediment prograding southwards into the ocean intimately related to the sedimentation pattern in a regressive sedimentary sequence. This sedimentation rate, according to them, are largely influenced by sea-level variations and climate change (Doust and Omatsola, 1990).

The delta development in the northern depobelt is different from that of succeeding periods due to the separation of the Niger Delta system from the eastwards Cross River Delta basin by the Abakaliki High, thus significantly controlling the sedimentation of the delta (Esedo and Ozumba, 2005). The sedimentation in the northern depobelt was mostly dominated by fluvial activities (Short and Stauble, 1967), while paralic facies deposits of the Agbada Formation characterize the post Eocene (Evamy *et al*., 1978). Also, Pacht and Hall (1993) opined that increased sedimentation rate, big growth faults, toe thrusts, massive slumping and shale diapirs have all been associated with the delta complex strata deposited on an unstable progradation continental margin.

As can be gleaned from the foregoing, the application of sequence stratigraphic principle in this study facilitated the recognition of chronostratigraphic time bounds within the identified sequences which correlate with the Global Cycle Chart of Haq *et al*. (1988). These age assignments, when related among the three wells in the context of their locations in the field show that Oredo-2 lies in the downthrown to Oredo-4 and Oredo-8 which are located almost parallel to each other (Figure 11). As Doust and Omatsola (1990: 201) put it "the delta sequence is extensively affected by synsedimentary and postsedimentary normal faults, the most important of which can be traced over considerable distances along strike. The resultant fault trends lie parallel to the paleogeographic position of the delta front at each stage of its developments".

This is a good reflection of one of the key attributes of sequence stratigraphy in hydrocarbon exploration: "to correlate sedimentary strata within the context of sequence stratigraphy by using the concepts of maximum flooding surfaces condensed sections, sequence boundaries and system tracts on the basis of integration of high resolution biostratigraphic, well-logs and seismic data" (Wornardt, 1993: 4).

5.6.2 Palynological Characterization in Sequence Stratigraphy

Despite the considerable studies conducted on the application of palynological assemblages in the identification of depositional systems tracts and flooding surfaces in recent times, the sequential characterization of fossil palynofloral assemblages is still developing on the

Niger Delta basin (Adojoh *et al*., 2015). This necessitates the need to explore this concept/model further using palynological suites recovered in this study and apply them in middle Neogene – early Neogene of the basin using mainly the approaches of Morley (1995a, b) and Holz and Dias (1998).

Oboh (1996), Holz and Dias (1998) and Garzon *et al*. (2012) applied the model on Cretaceous and post-Cretaceous rock sections. Most of the studies from South-America are largely on Paleogene sediments (Rull and Poumot, 1997; Rull, 2000, 2002; Jaramillo and Oboh-Ikuenobe, 1999). All the attempts made at implementing the model in Niger Delta have been in the Neogene (Poumot, 1989; Morley, 1995a, b; Adojoh *et al.*, 2015).

However, this attempt calls for caution in its application bearing in mind the documented differences in the plant ecology of the period from that of the Neogene (Frederiksen, 1985). For instance, though quite a number of modern-day plant groups had been in existence by *ca.* 80my BP with most of the families being in existence by about 45my BP (Raven, 1983), botanical affinities of most pollen and spore taxa before Oligocene are limited (Frederiksen, 1985).

In addition, it is well known that the ecological adaptation or tolerances of present-day plants could have been slightly different from the Paleogene. Poaceae pollen, believed to have evolved in the Paleocene in most parts of the world, has rare or sparse occurrences prior to the Neogene in Nigeria (Frederiksen,1985). The same evolutionary path is also ascribed to the Cyperaceae. Even at that, there is yet no strong or conclusive evidence of the existence of savanna in most regions of the world during the early Tertiary as the vegetation was dominantly forest (Jacobs *et al*., 2010), suggesting that the climate, at the time, was not dry enough (Germeraad *et al*., 1968).

Also, unlike in the Neogene when the mangrove vegetation was dominated by *Rhizophora* spp., the Paleogene mangrove communities were dominated by extinct species. These species are represented by *Proxapertites*, *Echitriporites trianguliformis*, among others (Jacobs *et al*., 2010) as well as *Acrostichum aureum*, *Brevitricolpites* spp., *Pelliceria* sp. and *Verrutricoporites rotundiporus* (Frederiksen, 1985).

Consideration of modern-day affinities of the fossil palynomorphs and their appropriate classification into the phytoecological groups are very essential in the application of palynological data in sequence stratigraphic studies of the Paleogene and Neogene. Incidentally, much of this has been resolved with about 30% of Eocene and 70% of Oligocene pollen and spores identified. This has facilitated the classification of significant proportion of the recovered palynomorphs into the appropriate phyto-ecological groups, as shown in Appendix 1, a requirement for systems tracts characterization.

In addition to the impact of plant taphonomic factors alluded to earlier in Chapter Two, which include the production, rate of production, preservation, dispersal and sedimentation of palynomorphs, other factors influencing the preservation of depositional sequences in sedimentary basins are also of great significance. According to Oboh (1996), these factors include sediment supply, sediment type, subsidence, changes in sea-level and climate.

Prominent among the recognized sequences of the three wells studied is the Transgressive Systems Tract (TST). This system of sediment retrogradation is generally characterized by the dominance of spores, common mangrove species, dinoflagellate, acritarch and the alga, *Botryococcus braunii* with few freshwater swamp forest species and intermittent records of microforaminiferal wall lining (MWL).

The dominance of spores recorded in this study contrasts with the fewer records of spores obtained in earlier sequence stratigraphic models such as those of Morley (1995b) and Holz and Dias (1998). Adeonipekun (2006, pers. comm.) similarly noted such dominance in his studies of three wells from the western Niger Delta in which higher values of spores were recorded in the HST and TST. He opined that the high values of spores within the two systems tracts could be adduced to climatic factors since the two are often synchronous with wet paleoclimate, a phase during which the hydromorphic fern spores blossom.

Since the TST is flooded in a marine transgression, the vegetation is expected to have been drowned, limiting the extent of pteridophytes spore deposition offshore. However, in shelfal environments that dominate the wells studied, proximity to the source of parent plants probably resulted in preponderance of spores in the transgressive phase. According to

Meyer *et al*., 2005, cited in (Lorente *et al*., 2014), the relative high proportion of pteridophyte spores is suggestive of growth of pteridophytic vegetation close to the depositional environment. The prevalence of mangrove species, dinoflagellate cysts and acritarch confirms the occurrence of extensive flooding of the brackish, mangrove vegetation into marine sediments within the TST.

The Highstand Systems Tract (HST) occupies the largest extent in the stratigraphic sequences of all the wells studied (Enclosures 3, 6 and 9). As previously reported by earlier researchers (Oboh, 1996; Morley, 1995b), the HST is dominated by terrestrial palynomorphs within the studied wells in the field. The rich records of pteridophytes spores as recorded in virtually all the HST(s) in the three wells, which contradicts those from earlier studies, could have been as a result of the proximity of the depositional environment to the vegetation as earlier discussed.

Nevertheless, this high level of recorded pteridophyte spores may not be out of place for the HST since the systems tract is associated with consistent presence of terrestrial palynomorphs (Oboh, 1996; Garzon *et al*., 2012). Generally, within the Highstand Systems Tract (HST) mangrove and freshwater swamp forest depict an increasing upward trend. Whereas marine indicators such as dinoflagellate cysts, MWL and acritarch show decreasing upward trend. This observed trend in the records of these marine indicators reflects the generally progressive shoaling of sea level that is synonymous with the HST. As Morley (1995b) posited, the highstand systems tract exhibits maximum representation of miospores from freshwater and alluvial swamps provenances in the upper delta plain. However, increase in representation of mangrove pollen is expected at the lower delta plain due to marine intrusion transporting miospores from mangrove into proximal freshwater swamp environments.

The increasing trends in the proportion of dinoflagellates and acritarch beyond the Transgressive Systems Tracts (TST) appear to suggest preservation succeeding the end of the flooding at a time shoreline retreat ceased and gradually migrate basinward at the end of the transgression preceding the HST (Holz and Dias, 1998). Garzon *et al*. (2012) also noted that the HST is represented by gradual decline in open marine dinoflagellate, presence of estuarine dinoflagellates and regular presence of terrestrial palynomorphs. *Botryococcus braunii*, the freshwater alga, is frequently associated with the HST in very high percentages, though it is also recorded in the TST, albeit in few to common occurrences. In this study, its occurrence was mostly restricted to the Continental/Transitional lithofacies in all the wells and Transitional Paralic as noted in Oredo-4. This observed trend in the occurrence of *Botryococcus braunii* is a confirmation of the affinity of the alga to a brackish water environment as affirmed by Adeonipekun *et al*., (2023).

Though, Morley (1995b) noted an abundance of what he referred to as freshwater algae associated with the Lowstand Systems Tract (LST) in late Miocene and late Pliocene of Niger Delta, he however recorded increased abundance of the algae in the Transgressive Systems Tract and especially in the HST in Natuna Sea and Maley Basin. In the same vein, Holz and Dias (1998) recorded abundant *Botryococcus*, hitherto thought to be of freshwater environment, within the transgressive systems tract. Although, Morley (1995b) concluded that freshwater alga, *Botryococcus*, exhibit characteristic and distinctive trends from one basin to another and at different time intervals reflecting different systems tracts, it can be reasonably concluded here that from the studied wells and from evidences obtained from previous works cited above, abundant *Botryococcus braunii* characterize the Highstand Systems Tract.

Acritarch, mostly represented by *Leiosphaeridia* sp. in this study, can serve as significant sequence stratigraphic elements as suggested by Holz and Dias (1998). Though Holz and Dias (1998) opined that acritarch and dinocysts are of different taxonomic groups and share the same habitat and palaeoenvironmental significance, the former is generally taken to suggest brackishwater environments (Tyson, 1995). This group is well represented within the Highstand Systems Tract (HST) where palaeoecological conditions seem to suit their development and preservation, albeit the group is also recorded in the Transgressive Systems Tract (TST). This observed trend in distribution of acritarchs in the systems tract sequence is in perfect agreement with results of earlier studies where maximum presence was recorded often in the Highstand Systems Tract (HST) (Holz and Dais, 1998; Jan du Chene *et al*., 1993; Turner *et al*., 1994). As opined by Turner *et al*. (1994), favourable nutrient and salt-water level could be the driver in determining the representations of the acritarch within a sequence. Also, as suggested by Holz and Dias (1998), improved study and understanding of the trends of this group can be usefully employed in differentiating the TST from the HST.

As fall-out from the foregoing, the use of palynomorphs has proved to be invaluable in differentiating systems tracts in stratigraphic sequences by the characterization of the flora components. This becomes particularly significant in depositional settings where marine microfossils are lacking. Though, “palynodebris and palynomorphs do not always conform to strict definitions of systems tracts”, according to Oboh (1996: 1291), however, sediments from a particular systems tract are often characterized by specific palynofacies assemblages. Nevertheless, there is need to exercise caution in the application of palynofacies and palynomorphs in systems tracts characterization. Its application in “high-resolution sequence stratigraphic interpretations can only be achieved if the dataset is integrated with sedimentological, paleontological and paleomagnetic data” in the words of Oboh (1996: 1292). With this in mind, the application of palynology in sequence stratigraphic studies needs to be integrated with palaeontological and sedimentological data (including wireline log) for optimum results in systems tracts characterization (Morley, 1995b; Oboh, 1996; Holz and Dias, 1998).

5.7 Source Rock Potentialities

The identification of systems tracts which are pointers to potential reservoirs, source rocks and seals facilitates the determination of the play concept for reservoir sands (Wornardt, 1993). Sequence stratigraphic applications in most sedimentary basins of the world, including Niger Delta, have resulted in the exploration and exploitation of huge hydrocarbon reservoirs (Momta and Odigi, 2015). As depicted in Tables 4.4, 4.12 and 4.20, Sequences 1, 2 and 3, lying mostly within the Eocene, at the basal parts of the three wells (except Oredo-2 that penetrated two sequences, 1 and 2), are prospective. Sequences with abundant prospects lie approximately around the same depth range across the Oredo Field and are found within 4000 – 2870m in Oredo-2, 3800 – 2540m in Oredo-4 and 3680 – 2530m in Oredo-8.

Hemipelagic shales within the transgressive systems tract (TST) are renowned excellent source rocks (Wornardt, 1993). Sangree *et al*. 1990, cited in Bassey *et al*. (2014) reported that shales associated with early progradation in the highstand systems tract are gas prone. Doust and Omatsola (1990) posited that shales encountered within the paralic Agbada and marine Akata sequences have high source rock potentials with more within the former. Admixture of land plant-derived and marine components constitute the organic content of most source rock sediments. A source rock potential is determined by the relative composition of its organic materials. Source rocks predominated by algal or bacterial biomass tend to be rich in hydrocarbon while those dominated by land plant-derived organic matter are rich in oxygen largely due to high level of cellulose and lignin derivatives through leaves cuticles and spores are often hydrogen rich (Leythaeuser, 2005).

From the high representation of palynomorphs in particular, the marine and the alga, *Botryococcus braunii*, which characterizes the TST as well as the HST as discussed in the last section, the source rock potentials of the TST and, to some extent, the HST is firmly established. Studies conducted by Shell Petroleum Development Company (SPDC) researchers for the Tertiary and Holocene of the Niger Delta suggested that forest swamps, freshwater swamps and mangrove swamps environments result in potentially rich source beds (Doust and Omotsola, 1990).

The Transgressive Systems Tracts (TST), in this study, are excellent source rocks while the Highstand Systems Tracts (HST) may be potential source rocks depending on the petrophysical attributes of associated shales. The accumulated petroleum is kept in place within the source rock by the associated maximum flooding surfaces (MFSs) which serve as regional seals and could be good source sediments on their own (Wornardt, 1993). Reservoirs which are typically developed within the sandy sequences of the paralic unit of the delta (Doust and Omatsola, 1990) are associated with HST in this study. The HST(s), characterized by thick prograding packages of sediments as a result of limited space for sediment deposition (Wornardt,1993) constitute the bulk of reservoirs among the three wells. Hydrocarbon reserves in the delta basin occur mainly within the sandstone reservoirs trapped in rollover anticlines of the growth faults within the Agbada Formation (Reijers *et* *al*., 1996). The reservoir rocks of the sedimentary strata form traps which provide a lid for the accumulated hydrocarbon.

From the fore-going discussion there is an indication that the Eocene sequence in this field of study possesses higher hydrocarbon potential than the younger Oligocene and early Miocene. This is in perfect agreement with results obtained from the spore colouration indices conducted which suggest oil generation from matured sediments within the Eocene stratigraphic column for all the three wells. Sediments within the Oligocene and early Miocene are immature from the thermal alteration studies conducted.

According to Reijers *et al*. (1996), matured shales from the Eocene to Miocene within the Akata and Agbada formational sequences dominate the source rocks of the Niger Delta basin. Berggren 1978 cited in Esedo and Ozumba (2005) opined that the warm climate resulted in the expansion of the organic level leading to increased organic content of most shales in the Eocene. This development is attributed to the source rock potentiality of Eocene and older sediments in the Niger Delta (Petters and Ekwezor, 1982).

The organic-rich shale unit is a massive hydrocarbon source in the Niger Delta basin. This shale source unit is located within the oil and gas windows with hydrocarbon generation starting in the Eocene (Oluwajana, 2016). As Oluwajana (2016) concluded, a perfect appreciation of hydrocarbon generation is key in revealing the Eocene paralic facies hydrocarbon potentials. Results of biostratigraphic, sedimentological and sequence stratigraphic studies conducted on the three wells available in this study affirm that the shale units (and the paralic shale in Oredo-8 well) identified within the Transgressive Systems Tracts in the Eocene are hydrocarbon source rock potentials.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary

The matured Niger Delta basin has a reserve of about 40 billion barrels of petroleum in Nigeria. The onshore Niger Delta (Paleogene-Neogene), where exploration activities commenced and were mostly concentrated before activities shifted to the offshore and deep-offshore (Neogene-Quaternary), remains not fully exploited. The re-direction of exploration focus created gaps in available information on the Paleogene palynology/biostratigraphy of the basin. This present work is a palyno-sequence stratigraphic study of three onshore wells undertaken in an attempt to fill these gaps. It is aimed at a further elucidation of the application of biostratigraphy, chronostratigraphy, palaeoenvironment reconstruction and sequence stratigraphy in petroleum exploration.

Five hundred and eighty-five ditch cuttings from three Oil Wells (Oredo-2: 244; Oredo-4: 195 and Oredo-8:146 samples) drilled in Oredo Field, OML 111, of the Niger Delta by the Nigeria Petroleum Development Company (NPDC) Benin, were subjected to conventional palynological maceration procedures for carbonate, silicate, and silicofluoride gel removal, followed by heavy liquid separation and oxidation. Two sets of organic residues - unoxidized kerogen and oxidized – were mounted per sub-sample, and microscopic slides made from them. The slides were analysed quantitatively and qualitatively using a transmitted light binocular microscope with a digital camera attachment. Percentage compositions of the particulate organic matter were analysed using multivariate statistical analyses. The samples were also subjected to standard micropaleontological sample preparation and analysis. Lithologic descriptions of the samples were carried out following procedures in AAPG Sample Description manual.

Twelve palynological zones were established based on the stratigraphic distribution of significant palynomorphs. These are: *Monoporites annulatus*, *Verrucatosporites usmensis*, *Psilamonocolpites marginatus*, *Retitricolpites bendeensis*, *Inaperturopollenites gemmatus*, *Doualaidites laevigatus*, *Spinizonocolpites baculatus*, *Psilatricolporites onitshaeensis*, *Amenia* sp., *Verrustephanocolporites complanatus*, *Praedapollis africanus* and *Verrutricolporites laevigatus* Zones. This new palynological zonation is a refinement of schemes currently in use in the region. A general low recovery of microforaminifera, constituted by 87% benthic and 13% planktic and typifies by *Chiloguombelina cubensis* and *Turborotalia pseudomayeri*, was recorded. Two lithostratigraphic units: Agbada and Benin Formations, were also delineated. The integration of palynological events and foraminiferal data suggests a middle Eocene (Paleogene) to early Miocene (Neogene) age for the analyzed intervals. Average linkage analysis of the organic matter revealed the dominance of amorphous organic matter (AOM) with phytoclasts and palynomorphs which aided the subdivision of the wells into PF-I, PF-II and PF-III Palynofacies Associations. Integration of these Palynofacies Associations with other biostratigraphic data suggests palaeoenvironments shoaling from marine to terrestrial/continental. Four palynocycles of alternating wet and dry climatic regimes were identified, based on ecological indicator plant species. Two distinct organic facies represented by orange to orange-brown (TAI 3) and yellow to orange (TAI 2) indicating early mature and immature hydrocarbon potentials, respectively, were recognized. Sequence stratigraphic interpretations revealed the mapping of 41.0Ma, 39.4Ma and 38.0Ma Maximum Flooding Surfaces with associated 40.1Ma and 38.7Ma Sequence Boundaries. Characteristic palynological assemblages were used to determine the Transgressive Systems Tract (TST) and Highstand Systems Tract (HST). Marine lithofacies with their associated TST in the Eocene are mature and lie within the oil and gas “windows”.

This study has produced for the Niger Delta Paleogene to Neogene, a refined palynostratigraphic zonation; proposed four cycles of alternating wet and dry phases inferred mature hudrocarbon generation for the Eocene shales in the Agbada formation within the Oredo Field

6.2 Conclusion

Biostratigraphic and environmental data have been derived from palynological, foraminiferal and sedimentological studies of 585 ditch-cutting samples from three onshore wells in the Oredo Field, northern depo-belt of the Niger Delta. For the first time, records of *Rhizophora*-type pollen were established from the Eocene in the Niger Delta sediments. This is contrary to the earlier held post-Oligocene existence by various authors such as Germerrad *et al*. (1968), Asadu and Ofuyah (2017).

The palynological data offer better resolution in the stratigraphic zonation of the wells than foraminiferal data due to the paucity of the planktic markers or index species. The stratigraphic distribution of significant and diagnostic palynomorphs, identified in the study, resulted in the erection of twelve informal zones, i.e., *Monoporites annulatus*, *Verrucatosporites usmensis, Psilamonocolpites marginatus*, *Retitricolpites bendeensis, Inaperturopollenites gemmatus*, *Doualaidites laevigatus*, *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis*, *Amenia* sp., *Verrustephanocolporites complanatus*, *Praedapollis africanus*, and *Elaies guineensis* Zones within the proposed *Periretipollis spinosus*, *Cicatricosisporites dorogensis* and *Verrutricolporites laevigatus* Superzones.
Three of the erected zones were further subdivided, that is; *Doualaidites laevigatus*, *Retitricolporites ituensis*, *Psilatricolporites onitshaeensis* Zones were further subdivided into subzones (a) and (b).

The potentials for further subdivision of existing palynological zones have been established from the recognized palyno-events in the study. This is demonstrated in the finer subdivisions of the P450 and P470 subzones into three zones each. Also, the P620 subzone was subdivided into two zones. The proposed palynological zonation thus represents an improvement on the scheme in use for the Niger Delta basin. This will provide a better age control in the stratigraphic interpretation and correlation of the basin. The integration of palynological and foraminiferal data suggests a stratigraphic age which range between middle Eocene (Neogene) and early Miocene (Neogene) for the relevant sections of the well.

The palynofacies analysis reveals a rich organic matter generally dominated by amorphous organic matter (AOM) with phytoclasts, mostly black and brown wood (BBW), and palynomorphs. From the average linkage analysis of the percentage composition of the particulate organic matter, the sequences of the wells were subdivided into three palynofacies associations designated as PF-I, PF-2 and PF-III. These were integrated with palynological, micropaleontological and sedimentological data in all the wells to infer depositional environments shoaling from marine through nearshore – transitional to continental setting towards the top.

The results of the thermal alteration index (TAI) conducted in the study conforms with the generally recorded increase in maturation as the sediments get older resulting from either increases or decreases in absorbance or transmittance respectively with increasing depth (Oboh, 1995; Ibrahim, 1996). Transmitted light microscopic analysis of spore colouration for the thermal alteration indices conducted suggests early mature facies with hydrocarbon potentials for the Transgressive Systems Tract intervals in marine lithofacies in the Eocene in the Oredo Field. The overlying paralic to continental lithofacies mostly within the Highstand Systems Tracts (HST) intervals in the younger segments of the field point to immature organic facies with limited or dry gas hydrocarbon potentials.

Data obtained from the biostratigraphic, palaeoenvironmental, palynofacies, lithologic and sequence stratigraphic analyses conducted in the study all corroborate hydrocarbon generation potential of the Eocene shale facies in the three wells. This is in conformity with the school of thought that posited that Agbada Formation shales in the Niger Delta constitute the major source rocks of the basin (Frankl and Cordry, 1967; Reed, 1969; Lambert-Aikhionbare, 1982; Lambert-Aikhionbare and Ibe, 1984).

Signals from wet climate indicators such as mangrove species, freshwater swamp, lowland rainforest, spores and marine species as well as dry climate phyto-ecological groups such as savanna result in the recognition of alternating wet and dry phases classified into Cycles 1, 2, 3, and 4. This classification was fashioned after the model of Poumot (1989). The succession of alternating wet and dry phases recorded indicates the cyclic nature of palynological events during sedimentation processes onshore Niger Delta. These alternating sequences of palaeofloral assemblages have been shown to fit into the sea-level oscillations defined by Haq *et al*. (1988). The four palynocycles also correlate with three of the seven second-order global eustatic Supercycles TA3, TA4 and TB1 of Haq *et al*. (1987) (Fig. 5.2).

This study revealed that the Eocene, most often associated with high temperatures and low sea levels, had intermittent wet phases. The well-documented record of coastal brackish-water plant communities and the coastal-plain freshwater peat-forming swamp communities associated with the period (Frederiksen, 1985) with the increased diversity and abundance of flora in the tropics of the Eocene (Jaramillo and Dilcher, 2000; Jaramillo et al., 2006, 2010) corroborate this assertion. The extended wet phases recorded which were inferred within the Oligocene supports the cooling and sea-level rise associated with the boundary between the Eocene and Oligocene (Jaramillo, 2010; El Beialy *et al*., 2005; Francis *et al*., 2009; Digbehi *et al*., 2012). This concept of palynocycles represents a significant contribution of palynology in the advancement of exploration activities about facilitating the formulation of models for the actualization of improved hydrocarbon predictions. However, further and extensive studies are required to improve on the model.

As a result of the paucity of planktonic foraminifera, mapping of the Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB) were based on the stratigraphic position of the palynological subzones of the Evamy *et al*. (1978). The application of sequence stratigraphic principle facilitated the recognition of chronostratigraphic time boundaries within the identified sequences. These correlate with the Global Cycle Chart of Haq *et al*. (1988) associated with the 41.0 Ma (41.2Ma), 39.4 Ma (37.8Ma) and 38.0 Ma (33.9Ma) Maximum Flooding Surfaces (MFS) and their corresponding Sequence Boundaries: 40.1 Ma and 38.7 Ma. As a result of shefal environments dominating the wells studied, two systems tracts - Transgressive Systems Tract (TST) and Highstand Systems Tract (HST) - were recognised. The recognised ages are well correlated among the three wells. This is a good reflection of a key attribute of sequence stratigraphy of correlating sedimentary strata using maximum flooding surfaces condensed sections, sequence boundaries and the system tracts.

For the first time, to the best of the knowledge of the author, palynological assemblages were used to characterize systems tracts in the Paleogene in the Niger Delta. The Transgressive Systems Tract (TST) is generally characterized by the dominance of spores, common mangrove species, dinoflagellates, acritarch and the alga *Botryococcus braunii* as well as a few swamp forest species and sporadic microforaminiferal wall lining (MWL). The HST is dominated by terrestrial palynomorphs within the studied wells in the field. The increasing trends in the proportion of dinoflagellates and acritarch beyond the Transgressive Systems Tracts (TST) appear to suggest preservation succeeding the end of the flooding at a time shoreline retreat ceased and gradually migrate basinward at the end of the transgression preceding the Highstand Systems Tracts (HST). Although *B. braunii*, occurring in very high percentages, is frequently associated with the Highstand Systems Tract (HST), it was also recorded in the Transgressive Systems Tract (TST), but in comparatively low percentages. This pattern of occurrence of *B. braunii* is a confirmation that the freshwater alga is is salt tolerant making brackishwater environment habitable for it. Acritarch, mostly represented in this study by *Leiosphaeridia* sp., is well represented within the Highstand Systems Tract (HST), though may be recorded in the Transgressive Systems Tract (TST).

The use of palynomorphs has proved advantageous in characterizing systems tracts in stratigraphic sequences, most especially in non-marine environments. However, there is need for caution in its application. As has been recognized by different authors, palynology in sequence stratigraphic studies needs to be integrated with palaeontological and sedimentological data for optimization of results in systems tracts characterization (Morley, 1995b; Oboh, 1996; Holz and Dias, 1998).

6.3 Limitations

There are some inherent limitations that are experienced during routine palynological/biostratigraphic studies. These limitations include, but not limited to, the nature of palynomorphs (pollen productivity, differential preservation, dispersal mechanism); over-and under-representation, post-depositional alteration; drilling mud contamination and human subjectivity. The incomplete lithological gamma ray and resistivity logs, non-availability of seismic profile and geothermal analytical data also constitute some other limitations in this study. These limitations are discussed in the context of this study below.

(i) The nature of palynomorphs (pollen productivity, differential preservation, and dispersal mechanism) does have bearing on the conclusions drawn on their stratigraphic importance. Factors such as: vegetational composition of the pollen sources, individual plant species pollen production proficiency, pollen dispersion, pollen sedimentation and preservation have been identified in determining the fossil pollen floral composition in soil deposits (Havinga, 1967).

Plants have different rates of pollen production with prolific producers expected to be adequately represented in pollen samples, albeit, different factors such as climatic conditions and hierarchy within the vegetation determine the production rate in a given species (Williams *et al*., 1998). According to Campbell (1999: 245), 'pollen grains are affected by various processes from the time of dehiscence to the time of recovery and analysis'

Pollen production, estimated in the millions and billions of grains per square metres, varies with the source of vegetation. The preponderance of pteridophytes spores such as *Microsonum aff. diversifolium* (*Verrucatosporites* spp.) and *Pallaea* sp. (*Laevigatosporites discordatus*) and brackish water *Acrostichum aureum* recorded generally throughout this study (Enclosures 1, 4 and 9) is suggestive of provenance very close to littoral swampy environment conducive to ferns growth. This is further corroborated by the rich presence of the freshwater swamp forest pollen of *Amanoa oblongifolia* (*Retitricolporites irregularis*). Spores are renowned for possessing very strong exine to withstand dessication and corrosion.

(ii) The autochthonous and allochthonous nature of producing plants as well as the resistance or susceptibility to decay of different pollen species may result in over-representation or under-representation in the pollen spectra (Havinga, 1967). To the extent that usually high or low percentage representation of a plant species in a pollen diagram can serve as indications of resistance or susceptibility. The high records of pteridophytes spores recorded in the three wells of this study could be ascribed to the coastal deltaic environment setting and the resistance of spores to corrosion. The fluvial transport mechanism of fern spore dissemination may also be a contributory factor that aided the preponderance of spores over flowering plants' pollen grains in the pollen spectra of the wells in the Oredo Field.

(iii) Germeraad *et al*. (1968) cited the absence or scarcity of determinable pollen and spores as some of the limitations encountered in the application of correlation techniques. Germeraad *et al*. (1968) noted that this may be because of sediment types and destruction by oxidation, high temperature effects from deep burial, volcanic activity, among others. It is imperative to appreciate the effect of corrosion on pollen composition in deposited samples towards deriving maximum benefit in data interpretation (Havinga, 1963, 1964; Delcourt and Delcourt, 1980; Williams *et al*., 1998).

Havinga (1964) opined that oxidation of embedded pollen predates their chemical or biochemical attack by bacteria and fungi. This suggests that knowledge of oxidation susceptibility of different pollen and spores will offer clue to the differential corrosion susceptibility *in situ*. Pollen grain corrosion may result from diverse causes such as microbial attack, oxidation, mechanical forces, and high temperature (Havinga, 1967; Williams *et al*., 1998; Traverse, 2008). These may be impacted on the pollen and spores in-situ or during laboratory preparation of the samples (Havinga, 1967).

Microbial activity has been identified as a common cause of pollen corrosion predominant in environments with high oxygen and alkalinity with attendant biological activity (Havinga, 1967; Williams *et al*., 1998). Bush fire can also serve as source of oxidation on soil pollen thereby inflicting rapid damages on the pollen grains and reducing their frequency. Chemical oxidation of pollen and spores from oxidizing agents may also occur during laboratory preparations (Havinga, 1967; Campbell, 1999). Mechanical pressure exerted during laboratory sample preparation with the application of ultrasonic machine such as the Sonifier may have destructive mechanical effects causing break-up of pollen into fragments (Havinga, 1967).

Sediments with poorly preserved pollen include well-sorted sandy soils, claystone, and eutrophic peats in oxidized states (Havinga, 1967; Traverse, 2008). However, contrary to the general assumption of poor recovery of palynomorphs from well-sorted sandy deposits, prolific recovery was made from the upper continental Benin Formation relative to the basal paralic Agbada Formation in all Oredo wells studied. The autochthonous nature of the source vegetation resulting in proximal provenance, as opined above, may be largely responsible for the preponderance of the littoral vegetation representatives.

While not totally ruling out the effect of post-depositional alteration of palynomorphs in the studied samples, the results of the analysis of the samples revealed this to be very limited in significance. Most recovered palynomorphs are well preserved with well distinct marker/index species available for easy identification. This facilitated the recognition of necessary marker species for interpretation and zonation.

In addition, slight oxidation with 40% HNO_3 was applied on the samples for palynomorphs study during laboratory preparation to produce clearer slides for easy identification without destroying the recovered palynomorphs. Also, the ultrasonic machine, the Sonifier, was excluded from the laboratory preparation to avoid destruction to the pollen and spores.

(iv) Ditch cutting samples are liable to caving of deposits from up hole of the bit during drilling as well as recycled samples unremoved by mud recovery systems and contamination from drilling mud additives from lost circulation material (LCM), barite and other mud condition drilling lubricants (Woodson, 1997). Caving, reused mud and mud additives make ditch cutting samples not very reliable materials for palynological and paleoenvironmental interpretations relative to sidewall or core samples. The use of ditch cutting samples can result in contamination or unrecognized or misinterpreted stratigraphic events provided by the fossil groups. However, because of the huge cost of procuring the latter two types of samples by the drilling operating companies, ditch cuttings are more readily available for biostratigraphic studies. However, quality results are still obtainable from ditch cuttings by proper handling of samples and adequate information with incorporation of log-study. Nevertheless, a critical study of the checklist of the biostratigraphic analysis of the three Oredo wells revealed no incidence of caving or mud additives in the study.

(v) Instances when older and non-negligible fraction of a pollen assemblage are re-deposited into younger sediments are referred to as reworking. However, reworked pollen is often easily recognized from deposits based on their incompatible stratigraphic occurrence. For example, records of Cretaceous pollen in the Eocene. Such occurrences may lead to complexities in biostratigraphic interpretations particularly when the reworked pollen is not distinctly older in age than the embedding sediments (Germeraad *et al*., 1968; Cambell, 1999).

Resolving the quagmire posed by reworked pollen and spores required adequate "knowledge of the basic floral succession in the area of investigation" according to Germeraad *et al*. (1968: 221). Though the Oredo Field is situated in more of a proximal shallow marine to continental environments which are active due to deposition, erosion and re-deposition of clastic materials, few evidences of reworked samples were recorded. Evidence of reworking was only observed in Oredo-8 well with the records of *Buttinia andreevi* and *Elateropsporites klaszii* at samples 2310-2330 m and 2080-2100 m respectively.

(vi) Human subjectivity and limitation of knowledge may have negative impact on the inferences drawn in palynological studies. Palynological study is subject to the maxim of 'garbage in – garbage out' (GIGO) right from the drilling rig when the samples are being cached, through the laboratory preparation procedures, microscopic analysis of prepared slides to interpretation of data. Painstaking efforts and caution are required to ensure that samples are not subjected to contamination during laboratory preparation.

The palynologist needs to be very analytical and well experienced during analysis by identifying the recovered palynomorphs to specific levels where possible. Accurate identification of palynomorphs will ensure better result and interpretation. Every necessary step was made, and time taken at ensuring optimum result during laboratory, analysis, and result interpretation of all the three wells used in this study.

(vii) The virtual absence or paucity of foraminifera species encountered in the three wells studied (Tables 4.2, 4.10 and 4.18, and Enclosures 2, 6 and 10) limited age determination of the well sequences to age deductions based on palynological interpretation. Also, relative ages of the palynological zones were relied upon for the identification of Maximum Flooding Surfaces (MFSs) and Sequence Boundaries (SBs). This may leave open the deducted ages and recognized MFS and SB to confirmation from independent sources.

(viii) The available logs for the three wells are limited to the shale basal parts of the wells. Also, there is no seismic profile provided for the studied part of the OML 111. The non-availability of these important geological materials made the conclusion drawn on the sequence stratigraphy tentative.

Nevertheless, regardless of the inherent limitations identified in the study, high level of reliability is still placed on the generated data and interpretations derived thereof.

6.4 Recommendations

1. The incorporation of the newly erected palynological zones into the existing palynological scheme will bring about better resolutions and precision.
2. There is need for further palynological studies particularly on Paleogene sediments in the Niger Delta. This will ensure a broader scope of the application of the proposed zonation.

3. The results of the thermal alteration indices carried out on the Oredo Field samples suggests the Eocene sections of the wells (Oredo-2: 4000 - 3560 m; Oredo-4: 3570 – 2540 m; Oredo-8: 3665 - 2560 m) as potential hydrocarbon source rocks.
4. An integration of the results of the thermal alteration indices with vitrinite reflectance and geochemical studies will ensure optimum evaluation of hydrocarbon potentials of the recognized source rocks.
5. The significant advantage of application of palynology, in a wide range of environments, from terrestrial through estuarine to the deep marine should be well exploited particularly in correlating sediments from diverse environments.
6. Palynology should be more incorporated in sequence stratigraphic studies, the mapping of Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB) and in the characterization of Systems Tracts.
7. This work has provided a basis for further studies in the application of palynology in hydrocarbon exploration and exploitation. Further studies are recommended particularly in other fields of the delta.

6.5 Contributions to Knowledge

1. Establishment of a new palynological zonation scheme with additional eight zones between Middle Eocene and Early Miocene onshore Niger Delta.
2. The new zonation scheme constitutes better resolution and refinements of the zonation scheme currently being used in the delta basin, such as those of Evamy *et al*. (1978) and Legoux (1978).
3. For the first time, records of *Rhizophora*-type pollen were established from the Eocene in the Niger Delta sediments. This is contrary to earlier held post-Oligocene existence by various authors such as Germerrad *et al*. (1968); Asadu and Ofuyah (2017).
4. Palynofacies analysis was carried out on Paleogene samples in the Niger Delta.
5. The hydrocarbon potential of source rocks was determined based on the estimation of the level of thermal maturity of the sediments as indicated by the qualitative spore colours.

6. There has been a successful use of palynological zones/subzones and events in confirming the ages of recognized Maximum Flooding Surfaces (MFS) and Sequence Boundaries (SB) and the characterization of Systems Tracts in the Paleogene of the Niger Delta.

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APPENDICES

APPENDIX 1

Morphogeneric nomenclature of palynomorphs recorded and their botanical affinities and inferred environment

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
THALLOPHYTA			
Botryococcus braunii	Botryococcaceae	*Botryococcus*	Fresh water – brackishwater
Concentricus sp.		*Concentricyst circulus*	
Pediastrum spp.	Hydrodictyaceae	*Pediastrum*	Fresh water
PTERIDOPHYTA			
Cicatricosisporites dorogensis Potonie and Gelletica 1933	Schizaeaceae	*Anemia* spp.	Scrub Forest on hills
Crassoretitriletes vanraadshooveni Germeraad *et al*. 1968	Schizaeaceae	*Lygodium microphyllum*	Fresh water Swamp
Fitrotriletes nigeriensis	Adianthaceae	*Acrostichum aureum*	Mangrove Swamp
Laevigatosporites discordatus		*Pallaea* sp.	
Lycopodiumsporites fastiginoides	Lycopodiaceae	*Lycopodium cernuum*	Lowland Rain Forest
Magnastriatites howardi Gonzalez 1967	Adiantaceae	*Ceratopteris cornuta*	Fresh/Brackish Swamp
Polypodiaciesporites retirugatus Kedves 1961	Adiantaceae	*Pteris mohasiensis*	Lowland Rainforest
Verrucatosporites usmensis (Van der Hammen 1956) Germeraad *et al*. 1968	Polypodiaceae	*Stenochlaena palustris*	Lowland Rainforest
Verrucatosporites terellis Plug 1952 *ex*. Potonie 1956	Polypodiaceae	*Polypodium vulgare*	Lowland Rainforest
???	Selaginellaceae	*Selaginella myosurus*	Secondary Forest

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
SPERMATOPHYTA			
ANGIOSPERMA			
Adenantherites sp.	Fabaceae-Mimosoideae	*Calpocalyx* sp.	
Alnus sp.	-	*Alnipollenites verus*	Deltaic Floodplain
Arecipites exilimuratus Legoux *et al*. 1978	Arecaceae/Palmae	*Knema attenuate*	Evergreen Forest
Anacolosidites luteoides Cookson and Pike 1954	Olacaceae	*Anacolsa unicifera*	
Auriculopollenites echinatus Legoux *et al*. 1978	-	Unknown	
Auriculopollenites reticulatus Salard-Cheboldaeff 1978	-	Unknown	
Auriculopollenites simplex Legoux *et al*. 1978	-	Unknown	
Balanopollis minutus Salard-Cheboldaeff 1978	Balanophoraceae	*Balanophora* sp.	
Bombacacidites annae Leidelmeyer 1966	Bombacaceae	Unknown	
Bombacacidites sp.	Bombacaceae	*Bombax buonopezense*	Open Forest/Forest Outlier
Brevicolporites guinetii Salard-Cheboldaeff 1978	Mimosaceae	*Pentaclethra macrophylla*	Lowland Rain Forest
Cinctiporipollis mulleri Salard-Cheboldaeff 1975	-	Unknown	
Corsinipollenites jussiaeensis Jan du Chene 1978	Onagraceae	*Ludwigia stenorraphe/repens*	Fresh Water Swamp
Crototricolpites densus Salard-Cheboldaeff 1978	Euphorbiaceae	*Klaineanthus gaboniae*	Lowland Rainforest
Ctenolophonidites costatus Van Hoeken Klinkenberg 1966	Ctenolophonaceae	*Ctenolophon englerianum*	Freshwater Swamp Forest
Cyperceaepollis sp.	Cyperaceae	*Cyperus rotundus*	Freshwater Swamp

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
Doualaidites laevigatus	-	Unknown	
Echiperiporites estelae Germerrad *et al*. 1968	Malvaceae-Convolvulaceae	*Thespesia populnea*	Coastal Areas
Echitricolporites spinosus Germerrad *et al*. 1968	Asteraceae	*Eclipta prostrata*	Open Vegetation; Coastal Area
???	Arecaceae (Palmae)	*Elaies guineensis*	SecondaryLowland Rain Forest
Gemmamonoporites sp.	-	Unknown	Freshwater Swamp
Gemmastephanocolporites brevicolpites	-	Unknown	
Gemmatricolporites pilatus Jan du Chene 1978	-	Unknown	
Gemmatriporites sp.	-	Unknown	
Gemmatriporites ogwuashiensis Jan du Chene *et al*. 1978	-	Unknown	
Grimsdaleae polygonalis Germerrad *et al*. 1968	Arecaceae (Palmae)??		
Inaperturopollenites gemmatus	-	Unknown	
Loranthacites nataliae Salard-Cheboldaeff 1978	Loranthaceae	*Sindora klaineana*	
Marginipollis concinnus Clarke & Frederiksen 1968	Lecythidaceae	*Combretodendron macrocarpa*	Lowland RainForest
Margocolporites foveolatus Jan du Chene *et al*. 1978	Fabaceae-Caesalpinioideae	*Caesalpinia welwitchiana*	
Margocolporites rauvolfia	Apocynaceae	*Rauvolfia vomitora*	Secondary Lowland Rainforest
Margocolporites umuhiaensis Jan du Chene 1978	Fabaceae-Caesalpinioideae	Unknown	
Mauritiidites crassiexinus Jan du Chene 1978	Arecaceae (Palmae)	*Mauritia vinifera*	Freshwater Swamp Forest

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
Monoporites annulatus (Van der Hammen 1956) Potonie 1960	Poaceae	Poaceae type	Savanna, Open vegetation, Freshwater lakes/ponds
Multiareolites formosus	Acanthaceae	*Justicia glabra*	
Nummulipollis neogenicus	Acanthaceae	*Isoglossa lacteal*	?Montane Forest
Pachydermites diederixi Germerrad *et al*. 1968	Clusiaceae	*Symphonia globulifera*	Freshwater Swamp Forest, Creek
Perfotricolpites digitatus Gonzalez 1967	Convolvulaceae	*Merremia hederacea*	Lowland Rain Forest
Peregrinipollis nigericus Clarke 1966	Fabaceae-Caesalpinioideae	*Brachystegia nigerica*	Savanna
Periporopollenites agboensis	?Amaranthaceae	Unknown	
Periporopollenites reticulatus Jan du Chene *et al.* 1978		Unknown	
Periretipollis spinosus Legoux *et al*., 1971		Unknown	
Praedapollis flexibilis		Unknown	
Praedapollis africanus Boltenhagen & Salard 1973	?Lecythidaceae	?*Napoleonaca imperialis*	Lowland Rain Forest
Praedapollis flexibilis Legoux 1978	-		Lowland Rain Forest
Praedapollis protrudentiporatus Legoux 1978	-	Unknown	
Proteacidites cooksooni Salard-Cheboldaeff 1978	Proteaceae	*Protea* sp./*Faurea* sp.	
Proteacidites dehaani	Proteaceae	*Guevina avellane*	Freshwater Swamp Forest
Proteacidites otamiriensis Germerrad *et al*. 1968	Proteaceae	Unknown	

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
Psilamonocolpites marginatus		Unknown	
*Psilastephanocolporites malacanthoides*Jan du Chene 1978	Sapotaceae	*Malancantha alnifolia*	Lowland Rainforest
Psilastephanocolporites sapotace Van der Hammen 1956 (Van der Hammen & Wijmstra 1964)	Sapotaceae	??	Lowland Rainforest
Proxapertites cursus van Hoeken-Klinkenberg 1966	Annonaceae	cf. *Nipa*	Fluvial Deltaic
Proxapertites operculatus Van der Hammen 1956	Annonaceae	*Annonidium* sp.	Fluvial Deltaic
Psiladiporites nnewiensis Jan du Chene 1978	Apocynaceae	*Dictyostega/Alyxia??*	
Psilatricolpites cf. hammenii		Unknown	
Psilatricolpites okeziei Jan du Chene *et al.* 1978		Unknown	
Psilatricolporites annuliporis	Leguminosae-Mimosoideae	*Pentaclethra ectweldiana*	Lowland Rain Forest
Psilatricolporites crassus Van der Hammen & Wijmstra 1964	Theaceae	*Pelliceria rhizophorae*	Mangrove Swamp (Estuarine bank)
Psilatricolporites ifeensis Jan du Chene 1978	Ebenaceae	*Diospyros canaliculate*	??
Psilatricolporites benueensis Jan du Chene 1978	Ebenaceae	*Diospyros mesipiliformis*	Lowland Rain Forest
Psilatricolporites igboensis Jan du Chene *et al.* 1978		Unknown	
Psilatricolporites magnoporatus Jan du Chene *et al.* 1978		Unknown	
Psilatricolporites onitshaeensis Jan du Chene *et al.* 1978		Unknown	
Psilatricolporites operculatus Van der Hammen and Wijmstra 1964	Euphorbiaceae	*Alchornea* spp.	Freshwater Swamp Forest
Psilatricolporites rotundiporus		Unknown	
Psilatriporites annulatus		Unknown	

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
Psilatriporites rotundus Jan du Chene *et al.* 1978		Unknown	
Psilatriporites owerriensis Jan du Chene *et al.* 1978	Proteaceae/Persoonioideae	Unknown	
Racemonocolpites racematus Gonzalez 1967		Unknown	
Retibrevitricolpites triangulatus Van Hoeken Klinkenberg 1966		Unknown	
Retibrevitricolporites ibadaneensis	Apocynaceae	*Alstonia booeni*	Lowland Rain Forest
Retibrevitricolporites obodoensis Legoux 1978		Unknown	
Retidiporites magdalensis	?Arecaceae (Palmae)	*Dryandra longifolia*	Freshwater Swamp
Retitricolpites bendeensis	Rubiaceae	*Psychotria calva*	Forest outlier, Savanna
Retimonocolpites asabaensis Jan du Chene *et al*. 1978	Arecaceae (Palmae)		
Retimonocolpites irregularis	Arecaceae (Palmae)	Areca sp.	
Retimonocolpites obaensis Jan du Chene *et al*. 1978		Unknown	
Retimonocolpites pluribaculatus Salard-Cheboldaeff	Arecaceae/Palmae	*Areca* sp.	
Retistephanocolpites williamsi	Ctenolophonaceae	*Ctenolophon parvifolius*	Lowland Rain Forest
Retitricolporites crassireticulatus Jan du Chene *et al.* 1978	Turneraceae/Nyctaginaceae	Unknown	
Retitricolporites brevis		Unknown	
Retitricolporites clavensis		Unknown	
Retitricolporites irregularis Van der Hammen and Wijmstra 1964	Euphorbiaceae	*Amanoa oblongifolia*	Scrub wood along creeks
Retitricolporites ituensis Jan du Chene *et al.* 1978	?Turneraceae/Nyctaginaceae	Unknown	

Morphogeneric Nomenclature	**Family**	**Botanical Affinity**	**Habitat**
	Rubiaceae	*Canthium* sp.	Evergreen Forest/Riverine Vegetation
Saturna enigmaticus Salard-Cheboldaeff 1978	-	Unknown	
Scabraperiporites asymmetricus Jan du Chene *et al.* 1978	-	Unknown	
Spinizonocolpites baculatus Muller 1968	Arecaceae (Palmae)	*Nypa* aff. *fruticans*	Tidal Creek
Spinizonocolpites echinatus Muller 1968	Arecaceae (Palmae)	*Nypa* aff. *fruticans*	Tidal Creek
Spinizonocolpites microechinatus Muller 1968	Arecaceae (Palmae)	*Nypa* aff. *Fruticans*	Tidal Creek
Spirosyncolpites bruni Gonzalez 1967	Fabaceae-Caesalpinioideae	*Afzelia bella* var. *gracilior*	Lowland Rain Forest
Striamonocolpites undatostriatus Legoux 1978	-	Unknown	
Striamonocolpites rectostriatus Legoux 1978	-	Unknown	
Striatricolpites catatumbus Gonzalez and Guzman 1967	Fabaceae-Caesalpinioideae	*Anthonotha gilletii*	Savanna
Striatricolporites undulatus Jan du Chene 1978	Fabaceae-Caesalpinioideae	*Gilbertiodendron mayombese*	Riverine Forest
Verrustephanocolporites complanatus Salard-Cheboldaeff 1978	Fabaceae-Caesalpinioideae	*Bauhinia gossweilleri*	???
Verrutricolporites irregularis Jan du Chene *et al.* 1978		Unknown	
Verrutricolporites laevigatus Legoux 1978	Lythraceae	*Crenea* Type	Coastal Swamp
Verrutricolporites microporus Legoux 1978	Lythraceae	*Crenea* Type	Coastal Swamp
Verrutricolporites rotundiporus Van der Hammen & Wijmstra 1964	Lythraceae	*Crenea maritama*	Coastal Swamp
Verrutricolporites scabratus Legoux 1978	Lythraceae	*Crenea* Type	Coastal Swamp
Zonocostites ramonae Duena 1980	Rhizophoraceae	*Rhizophora* spp.	Mangrove Swamp Forest

APPENDIX 2a: PERCENTAGE COMPOSITION OF ORGANIC MATTER IN OREDO-2 WELL

TOP	BASE	AE	AOM	BBW	CH	DC	EC	FHT	FE	GM	MWL	NCT	RM	SPH	TE
300	360	0	9.7	58.3	4.3	0	0.3	0.3	0	0.7	0	25.7	0.3	0.3	0
360	420	0	7.3	62.3	2.3	0	1	0.7	1.3	0	0	24.3	0	0.3	0.3
420	480	1	32	40	1	0	3	0	0.7	0.7	0	1	0.3	20.3	0
480	520	0	33.3	58.3	3.3	0	0.3	0	0.3	1	0	0.7	0.3	2.3	0
550	580	0	1.3	61.7	0	0	2	0	0.3	0.7	0	31.7	0	2.3	0
580	640	0	13.3	66.7	0.3	0	2	0.3	0.7	0.7	0	0.3	0	15.7	0
640	700	0	40	43.3	0	0.3	0.7	0	0.3	0.3	0	3.3	0	11.7	0
700	760	0	51.7	36.3	1.7	0	0	0	0.7	0.7	0	0.7	0.3	8	0
820	850	0	36.3	51.7	4	0	0.3	0	0.3	0.7	0	1	0	5.7	0
880	940	0	50	33.3	7	0	0.3	0	0	1	0	0.7	0	7.7	0
940	1000	0	13.3	50	0	0	0.7	0	0.7	0.3	0	1.7	0	33.3	0
1000	1060	0	24	50	6.7	0.3	1.3	0	0	0.7	0	0.3	0	16.7	0
1060	1120	0	40	36.7	5	0	0.3	0	0.3	2.3	0	0.3	0	15	0
1120	1150	0	43.3	33.3	5	0	1.7	0	0.3	0.3	0	0.3	0	15.7	0
1180	1240	0.7	46.7	33.3	2.7	0	1.7	0	1	0.7	0	0	0	13.3	0
1270	1330	0	50	33.3	2	0	0.3	0	1.7	0	0	0	0	12.7	0
1330	1390	0	66.7	20.3	0	0	1.7	0	0.3	0	0	0.7	0	10.3	0
1390	1450	0	50	33.3	3.3	0	1.7	0	1.7	0	0	0.3	0	9.7	0
1450	1510	0	50	26	2	0	3.7	0.3	1.3	0	0	1	0	15.7	0
1540	1600	0.3	50	36.7	2.7	0	2.7	0	0.3	0	0	1	0	6.3	0
1600	1660	0	35	50	0	0	5	0	0	0.3	0	0.7	0	9	0
1660	1720	0	46.7	36.7	1.7	0	4	0	0.3	0	0	0.3	0	10.3	0
1720	1780	0.3	46.7	33.3	1.7	0	2	0	0	2	0	0	0	14	0
1780	1840	0	50	23.3	1	0	3	0	2	2.7	0	1	0	17	0
1840	1900	0	36.7	45	1.7	0	3	0	0.3	3	0	2	0	8.3	0
1920	1940	0	33.3	50	2.7	0	5	0	0.7	3	0	1.7	0	3.7	0
1940	1960	0	36.7	50	3.3	0	3.3	0	0.3	2.3	0	2	0	2	0

TOP	BASE	AE	AOM	BBW	CH	DC	EC	FHT	FE	GM	MWL	NCT	RM	SPH	TE
1960	1980	0	43.3	33.3	8	0	4	0	0	3	0	4	0	4.3	0
1980	2000	0	40	36.7	7	0	7.7	0	0	1	0	2	0	5.7	0
2000	2030	0	36.7	36.7	10	0	10.7	0	0	0.7	0	2	0	3.3	0
2030	2050	0	43.3	40	6	0	5.7	0	0	1	0	0	0	4	0
2050	2070	0	50	33.3	10.3	0	2.3	0	0.3	2.3	0	0	0	1.3	0
2070	2090	0	46.7	30	10	0	7	0.3	0.3	1.3	0	1	0	3.3	0
2090	2110	0	46.7	33.3	10.3	0	3.3	0	0	1.7	0	1.7	0	3	0
2110	2130	0	43.3	40	6.3	0	6.7	0	0	1.3	0	1.7	0	0.7	0
2130	2150	0	40	43.3	5.3	0	6.7	0	0	0.3	0	0.7	0	3.7	0
2150	2170	0	46.7	36.7	4.7	0	3.3	0	0	4	0	1.7	0	3	0
2170	2200	0	43.3	40	6.7	0.3	3.3	0	1	1.7	0	1.3	0	2.3	0
2200	2220	0	41.7	38.3	6.7	0	3.3	0	1	2.7	0	2	0	4.3	0
2220	2230	0	40	40	5	0	4.7	0	0.7	3	0	3.3	0	3.3	0
2230	2250	0	53.3	20	15.3	0	2.7	0	0	6	0	1	0	1.7	0
2250	2280	0	52.7	17.7	23.7	0	1.7	0	1.3	2.7	0	0	0	0.3	0
2280	2300	0	74	10	11.7	0	0.3	0	0.3	2	0	0.7	0	1	0
2300	2320	0	44	33.3	17	0	1	1	0.7	1	0	0.7	0	1.3	0
2320	2340	0	53	38	2.3	0	0.7	0.3	1.3	3	0	0	0	1.3	0
2340	2360	0	62	18.7	14.3	0	0	0	0.3	1.3	0	2	0	1.3	0
2360	2380	0	80.7	10.7	4.7	0	1	0	0	0.3	0	0	0	2.7	0
2380	2400	0	66.7	11.3	14.3	0	2	0	0.3	1.7	0	1	0	2.7	0
2400	2420	0	73	13.3	9.3	0	1	0	0	1.3	0	0.7	0	1.3	0
2420	2450	0	66.7	7.7	13.7	0	1	0	0	8	0	0	0	3	0
2450	2470	0	71.3	12	3.7	0	0.3	0	0	10	0	0	0	2.7	0
2470	2490	0	66.7	18.7	4.3	0	0.7	0	0	7.7	0	0	0	2	0
2490	2510	0	76.7	14.7	1.7	0	0.7	0	0	4.7	0	0	0	1.7	0
2510	2530	0	66.7	17.7	4	0	1	0.3	0	6.7	0	0.3	0	3.3	0
2530	2550	0	81.3	8.3	2.7	0	1	0	0.3	3.3	0	0.3	0	2.7	0

TOP	BASE	AE	AOM	BBW	CH	DC	EC	FHT	FE	GM	MWL	NCT	RM	SPH	TE
2550	2570	0	79	6.7	2.3	0	0.3	0	0.7	6.3	0	0.3	0	4.3	0
2570	2590	0	66.7	22.3	5	0	1.3	0	0	2	0	0	0	2.7	0
2590	2610	0	91.7	3.3	0	0	0	0	0.3	1.3	0	0.7	0	2.7	0
2610	2630	0	80.7	10	4	0	0	0	0	3.7	0	0	0	1.7	0
2630	2650	0	70	10.3	11	0	1.7	0	0	3	0	1.7	0	2.3	0
2650	2670	0.3	66.7	11.7	5	0	4.7	0	0.3	4.7	0	0.3	0	6.3	0
2700	2720	0	73.3	12	2.7	0	3	0	0	3.3	0	0.3	0	5.3	0
2720	2740	0	70.3	11.7	3	0	2.3	0	0.7	5.3	0.3	1.3	0	5	0
2740	2760	0	68.3	14	5	0	2	0	0	6	0	0.7	0	4	0
2760	2780	0	78.3	10.7	3.7	0	1.3	0	0.3	2	0	0.7	0	3	0
2780	2800	0	66.7	14.3	10.7	0	1.3	0	0	2	0	0.3	0	4.7	0
2800	2820	0	67.7	15.3	5.7	0	1.7	0	1	3.7	0	2.3	0	2.7	0
2820	2840	0	68.7	26.7	0	0	0.3	0	0.7	0.7	0	1	0	2	0
2840	2860	0	81	10.7	3.7	0	0.7	0	0	2.3	0	1	0	0.7	0
2860	2880	0	66.7	17	6.7	0	1.3	0	0.3	4	0	0.3	0	3.7	0
2880	2900	0	87.3	10	0.3	0	0	0	0	1	0	0	0	1.3	0
2900	2920	0	81.3	14	0.7	0	0	0	0	2.3	0	0	0	1.7	0
2920	2940	0	76.7	15.3	0.3	0	1	0	0	2.7	0	0.7	0	3.3	0
2940	2960	0	66.7	23	2	0	0.3	0	0.3	4.3	0	1	0	2.3	0
2960	2980	0	66.7	19.7	3.7	0	0.7	0	0.3	7	0	0	0	2	0
2980	3010	0	66.7	24.3	1	0	0.7	0	0	5.7	0	0	0	1.7	0
3010	3030	0	66.7	23.3	4	0	0	0	1	2.3	0	1	0	1.7	0
3040	3060	0	66.7	24.3	4	0	0	0	0	3	0	0	0	2	0
3060	3080	0	83.7	10.7	1	0	0.7	0	0	1.7	0	1.3	0	1	0
3080	3100	0	84.7	9	2.7	0	1.3	0	0	0.3	0	0.3	0	1.7	0
3100	3130	0	66.7	28.3	1.3	0	0.7	0	0	2.7	0	0	0	0.3	0
3130	3150	0	66.7	24.7	4.3	0	0	0	0	2	0	0.7	0	1.7	0
3150	3170	0	66.7	22.3	6	0	0.3	0	0	3	0	1.3	0	0.3	0

TOP	BASE	AE	AOM	BBW	CH	DC	EC	FHT	FE	GM	MWL	NCT	RM	SPH	TE
3170	3190	0	69	25	2	0	0.7	0	0	1.3	0	0.7	0	1.3	0
3190	3210	0	66.7	26	2	0	0.3	0	0	2.3	0	0.7	0	2	0
3210	3230	0	71	20.7	2.7	0.3	1	0	1	1	0	0.3	0	2	0
3230	3250	0	66.7	28.7	1.7	0	0	0	0	2	0	0.3	0	0.7	0
3250	3270	0	66.7	22.7	4.7	0	0.7	0	0.7	2	0	0.3	0	2.3	0
3270	3290	0	66.7	24.3	1	0	0.3	0	0.3	3	0	1	0	3.3	0
3290	3310	0	66.7	26.3	1	0	0.7	0	0	1.3	0	1.7	0	2.3	0
3310	3330	0	66.7	22	0.3	0	1.3	0	0.3	4	0	1.7	0	3.7	0
3340	3360	0	66.7	21.7	3	0	0	0	0	3.3	0	2.3	0	3	0
3360	3390	0	66.7	21.7	1.3	0	1	0	0	2.3	0	5.7	0.3	1	0
3390	3410	0	66.7	27.7	2	0	0.3	0	0	1.7	0	1.7	0	0	0
3410	3430	0	66.7	27.3	1	0	0.3	0	0	2.3	0	1.3	0	1	0
3430	3450	0	66.7	26.3	1	0	0	0	0.3	3	0	1.3	0	1.3	0
3450	3470	0	66.7	24	3.3	0	0	0	0	2.7	0	1.7	0	1.7	0
3470	3490	0	66.7	20	3.3	0	0.7	0	0	3	0	4	0	2.3	0
3490	3510	0	66.7	26.7	0.7	0	1.7	0	0.3	1	0	2.3	0	0.7	0
3510	3530	0	66.7	30	0.7	0	0	0	0	1.3	0	0	0	1.3	0
3530	3560	0	56.7	40	1	0	0	0	0	0.3	0	0.7	0	1.3	0
3560	3580	0	58.7	33.3	2	0	0	0	0.3	0.7	0	2	0	3	0
3580	3600	0	51.7	33.3	9	0	0.3	0	1.3	1	0	2.7	0	0.7	0
3600	3620	0	58.3	33.3	3.3	0	0	0	0	0	0	4.3	0	0.7	0
3620	3640	0	57.3	33.3	5	0.3	0.3	0	0	0.3	0	1.3	0	2	0
3640	3660	0	53	33.3	3.3	0	0	0	0	0	0	9	0	1.3	0
3660	3680	0	50	33.3	8.3	0	0	0	0	0	0	7	0	1.3	0
3680	3700	0	46.7	41.7	3.3	0	1.3	0	0	0	0	6	0	1	0
3700	3720	0	47.3	41.7	2.7	0	0	0	0	0.7	0	3.7	0	4	0
3720	3740	0	50	38	3.7	0	1.7	0.3	0.7	0.3	0	1.7	0	3.7	0
3740	3760	0	51.7	33.3	5	0	0.3	0	0.3	0	0	4.3	0	5	0

TOP	BASE	AE	AOM	BBW	CH	DC	EC	FHT	FE	GM	MWL	NCT	RM	SPH	TE
3760	3780	0	56.3	39.7	2	0	0	0	0.3	0	0	0.7	0	1	0
3780	3800	0	56.7	34.3	5	0	0.3	0	0.3	0	0	1.3	0	2	0
3800	3820	0	58.7	33.3	5	0	0.3	0	0	0	0	1	0	1.7	0
3820	3840	0.3	45	39.7	6.7	0	0.7	0	0.3	0.3	0	5.3	0	1.7	0
3840	3860	0	57.3	33.3	3.3	0	0.3	0	1	0.3	0	1.7	0	2.7	0
3860	3880	0.3	57.7	33.3	3.3	0	0.3	0	0	0.7	0	2.7	0	1.7	0
3880	3900	0	57.7	33.3	2.7	0	1.3	0	0	0.3	0	1	0	3.7	0
3900	3930	0	56	33.3	2	0	0	0	0	0.3	0	3.7	0	4.7	0
3930	3950	0	66.7	26.7	3	0	0	0	0.3	0	0	0	0	3.3	0
3950	3970	0	29.7	60	8.3	0	0.3	0	0	0	0	0.7	0	1	0
3970	3990	0	33.3	56	8.3	0	0.3	0	0	0	0	1.3	0	0.7	0
3990	4000	0	23.3	62.3	11.7	0	0	0	0.3	0	0	1.3	0	1	0

APPENDIX 2b: PERCENTAGE COMPOSITION OF ORGANIC MATTER IN OREDO-4 WELL

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MSS	NCT	SPH	TE
70	130	0	23.7	25	2.3	0	0	1	0	0	0.3	0	46.7	1	0
130	190	0	67.7	11.7	7	0	0	2.7	0	0.3	1	0	5.7	4	0
190	250	0	55	17.3	4	0	0	0	0	0.3	0	0	23.3	0	0
280	340	0	76.7	10.7	0.7	0	0	0	0	0.7	0	0	11	0.3	0
340	400	0	60	17.3	3.7	0	0	0	0	3	0	1	14.3	0.7	0
400	460	0	71.3	11.3	9	0	0	0	0.3	0.3	0.3	0	7.3	0	0
490	550	0	69.3	15	6.7	0	0	0	0	0.7	0.7	0	7.3	0.3	0
550	580	0	81	10	1.3	0	0	0.7	0	0	0.7	0	1.7	4.3	0.3
640	700	0	44.7	43.3	5.3	0	0	1.7	0	0.3	2	0	0.7	2	0
700	760	0	58.3	17.3	9.3	0	0	2.3	0	0.7	1.7	0	0.3	10	0
760	820	0	63.3	8	16.7	0	0	0.3	0	0	1.7	0	0	10	0
820	880	0	70	18.3	8	0	0	0	0	0.3	0.7	0	0	2.7	0
910	970	0	38	19.7	7	0	0	1.3	0	1.7	0.7	0	1.3	30	0.3
970	1030	0	43.3	13.3	5	0	0	0.7	0	2	4.3	0	0.7	30.7	0
1030	1090	0	60	8.3	4	0	0	0	0	3	2.7	0	0	21.7	0.3
1090	1150	0	58	20.7	1.7	0	0	1.3	0	2.3	4	0	0.3	11.7	0
1150	1210	0.7	68.3	9	1.3	0	0	0	0.3	3.3	1.3	0	0	15.7	0
1210	1270	2.3	71.7	3.7	2.3	0	0	0.3	0	0.7	1	0	0.3	17.7	0
1270	1330	0	72	7.7	3.3	0	0	0	0	1.7	0.3	0	0.3	14.7	0
1330	1390	0.3	70	7	0.3	0	0	0.3	0	1.3	1	0	0	19.7	0
1390	1420	0.3	70	11.3	3	0	0	1	0	2.7	0.3	0	0	11.3	0
1450	1510	0.7	66.7	8.7	6.7	0	0	0	0	3.3	0.7	0	0	13.3	0
1540	1600	0	78.3	11.7	1.3	0	0	0.3	0	0.3	1.3	0	0	6.7	0
1600	1660	0.7	66.7	8.7	2.7	0	0	0.3	0	1	0.3	0	0.3	19.3	0
1660	1720	1	66.7	6	2.3	0.7	0	0.7	0	1.7	1	0	0	20	0
1720	1750	0.3	38.3	35	0	0	0	0	0	1.3	1.7	0	0.3	23	0
1780	1840	0	51.7	30.7	0.3	0	0	1	0	1.7	0.7	0	0.7	13	0.3

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MSS	NCT	SPH	TE
1840	1900	0	61.7	18.3	4.7	0	0	1.3	0	1.3	1	0	0	11.3	0.3
1900	1960	0.3	53.3	32.3	1	0	0	0.3	0	1.3	0	0	0	11.3	0
1960	2010	0	60	18	6	0	0	7.3	0	1	0.3	0	1.7	5.7	0
2020	2060	0	66.7	17.7	4.3	0	0	3	0	0	1.3	0	1	6	0
2060	2100	0.3	66.7	17.3	1.3	0	0	2.7	0	1	1	0	2.3	7.3	0
2110	2140	0	58.3	19	4.7	0	0	4	0	1.7	0.7	0	0.7	11	0
2140	2170	0	58.3	32	1.7	0	0	1	0	0.7	2.3	0	0	4	0
2170	2190	0	60	26.7	2	0	0	2.3	0	0.7	1.7	0	1.7	5	0
2190	2210	0	53.3	15	6.7	0	0	4.7	0	1.3	0.7	0	1.7	16.7	0
2210	2240	0	43.3	39	3.3	0	0	5.3	0	0.3	2.3	0	1	5.3	0
2240	2260	0	50	28.3	2.3	0	0	1.7	0	1	1.7	0	0	15	0
2260	2280	0	61.7	15	5.7	0	0	4.3	0	1.3	3.7	0	0.7	7.7	0
2290	2310	0	53.3	33.3	2.7	0	0	1	0	0	4	0	2	3.7	0
2310	2320	0	46.7	18	8	0	0.7	2.3	0	1	8.3	0	1.7	13.3	0
2360	2370	0	50	36.7	2	0	0	1.7	0	0	3.7	0	3	3	0
2390	2400	0	65	20.7	2.3	0	0.3	1.3	0	0.7	2.7	0	1	6	0
2400	2420	0	66.7	19.7	4.7	0	0	0.7	0	0.3	3.7	0	1	3.3	0
2420	2440	0	66.7	17	6.7	0	0	1	0	0.7	2	0	1	5	0
2440	2460	0	66.7	16.7	3.3	0	0	2.7	0	2	2.7	0	1.3	4.7	0
2460	2470	0	53.3	30	1.7	0	0	3	0	1	4.7	0	3	3.3	0
2470	2490	0	66.7	16.7	2.7	0	0	1.3	0	2	4	0	0	6.7	0
2490	2500	0	53.3	35	1.7	0	0.3	0.3	0	1.7	3.3	0	1.7	2.7	0
2520	2540	0	66.7	20	2.3	0	0	0.3	0	1	7	0	0.3	2.3	0
2550	2580	0	70	15.3	0	0	0	0.3	0	0.7	3.7	0	0	10	0
2580	2610	0	66.7	12	1.7	0	0	1.3	0	3	4.3	0	0.7	10.3	0
2610	2620	0	66.7	20	2	0	0	1	0	0.7	3	0	0.3	6.3	0
2640	2660	0	66.7	16	4	0	0	2	0	0.7	4.7	0	1	5	0
2660	2680	0	66.7	16.7	2.7	0	0	1.3	0	0.3	3.7	0	0.7	8	0

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MSS	NCT	SPH	TE
2680	2700	0	66.7	12.7	5	0	0	0	0.3	2	3.7	0	0	9.3	0.3
2700	2720	0	66.7	22.3	3.3	0	0	1	0	0.7	4.3	0	0	1.7	0
2720	2740	0	66.7	13	4.7	0	0	1	0	1.7	5	0	2	6	0
2740	2760	0	66.7	12	4.3	0	0	0.3	0	1.3	8.3	0	0	7	0
2760	2780	0	65	15.7	8	0	0	0.7	0	1	2.7	0	0	7	0
2780	2810	0	66.7	18.3	0.3	0	0	0.3	0	1	1	0	2.3	10	0
2810	2820	0	66.7	24.3	1	0	0.7	1.3	0	1.3	1	0	1.3	2.3	0
2850	2860	0	63.3	21.7	0.7	0	0	2.7	0	3	2.3	0	0.7	5.3	0.3
2860	2880	0	66.7	28.3	0.3	0	0	0	0	0.3	2	0	1.7	0.7	0
2880	2900	0	66.7	28	1	0	0	0.7	0	0.3	2.3	0	0	1	0
2910	2930	0	66.7	24.3	2	0	0	0.7	0	0.7	3.7	0	0.7	1.3	0
2940	2960	0	66.7	26.3	0.3	0	0	1	0	1.3	1	0	1	2.3	0
2960	2990	0	66.7	19.7	0	0	0.3	2	0	2	2.7	0	1.7	5	0
2990	3010	0	66.7	29.3	0	0	0	0.3	0	0.7	1.3	0	0.3	1.3	0
3010	3030	0	66.7	25.3	1.7	0	0	0.3	0	0.3	2.3	0	1.3	2	0
3030	3050	0	66.7	24.7	0	0	0	0.3	0	0.7	2.7	0	1.3	3.7	0
3060	3080	0	66.7	24.7	0.3	0	0	0.3	0	0.7	1.3	0	1	5	0
3080	3100	0	66.7	24	1.3	0	0	0.3	0	0.7	3	0	2	2	0
3100	3130	0	66.7	24	1	0	0	0.3	0	0.7	1.7	0	3	2.7	0
3130	3150	0	66.7	19.3	1	0	0	1	0	1.3	0.7	0	4.7	5.3	0
3150	3170	0	66.7	23.7	2.3	0	0	1.7	0	0.7	1.3	0	0.3	3.3	0
3170	3200	0	66.7	22.3	2	0	0	1.7	0	1.3	1	0	2	3	0
3200	3220	0	66.7	24	0.7	0	0	0.7	0	0.7	1.7	0	2.3	3.3	0
3220	3240	0	66.7	29.3	0.3	0	0	0.3	0	1	1	0	0.7	0.7	0
3240	3260	0	66.7	25	0	0	0	0.7	0	0.3	2	0	1	4.3	0
3260	3280	0	66.7	20.3	0.7	0	0	1	0	1	2.7	0	3.7	4	0
3280	3300	0	66.7	22.3	0	0	0	0.3	0	0.7	2.3	0	3.3	4.3	0
3300	3320	0	66.7	24.3	0	0	0	0.7	0	0.3	2	0	2.7	3.3	0

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MSS	NCT	SPH	TE
3340	3360	0	66.7	21	0.3	0	0	1	0	1	2	0	2.3	5.7	0
3400	3440	0	66.7	23	1.3	0	0	0.7	0	1	2	0	2.7	2.7	0
3440	3470	0	63.7	26.7	0	0	0	1	0	0	1	0	4.3	3.3	0
3470	3490	0	61.7	23.3	0	0	0.3	1	0	1	2.3	0	5	5.3	0
3490	3510	0	62	26.7	0	0	0	0.3	0	1	0.7	0	6.7	2.7	0
3510	3520	0	66.7	25.7	0.7	0	0	1	0	0.3	1	0	1.7	3	0
3520	3560	0.3	66.7	23.3	3.3	0	0	0.7	0	0.3	1.3	0	2	2	0
3590	3610	0.3	43.3	31.3	5	0.3	0	1.7	0	0.7	1.3	0	9	7	0
3630	3670	0.3	43.3	40	0.3	0	0	1.3	0	1.3	0.3	0	10.3	2.7	0
3670	3690	0	43.3	40	3.3	0	0	2.7	0	0	0	0	9	1.7	0
3700	3730	0	46.7	36.7	1	0	0	3.3	0	0.3	0.3	0	6.3	5.3	0
3740	3760	0.3	46.7	40	0	0	0.3	4	0	0.3	0	0	4.7	3.7	0
3760	3770	0	46.7	36.7	0	0	0	2.7	0	0.3	0.7	0	9.7	3.3	0

APPENDIX 2c: PERCENTAGE COMPOSITION OF ORGANIC MATTER IN OREDO-8 WELL

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MWL	MSS	NCT	SPH
320	330	0	58	30	5	0.7	0	0.3	0	3.3	0	0	0	3.3	1.7
350	380	0	31.7	50.3	6.7	0.3	0.3	1.7	0	2	0.3	0	0.3	3	4.3
380	410	0	67.3	18	1	2	0	1	0	0	0	0	0	3.3	1.7
440	470	0	17.3	71.7	1	0	0	0	0	1	4.7	0	0	1.3	3
530	590	0	0.7	96.3	3.7	0	0	0	0	0	0	0	0	1.7	0.3
590	650	0	33.3	53.3	2	0.3	0	0.7	0	1	0.3	0	0	1	6.3
650	710	0	20	70.3	3.3	0	0	1.3	0	0.7	0	0	0	2.3	3.3
710	740	0	61.7	28	4.3	0	0	0.3	0	1	0	0	0	0	5.7
770	800	0	16	75	1.3	0	0	0	0	0.3	0	0	0	4	0.3
830	890	0	18.7	73.7	41.7	0	0	1	0	0.7	0	0	0	2.3	2.3
890	920	0	5.3	45.3	3	1.3	0	0	0	1	0	0	0	3.7	1.7
950	1010	0	15	73.3	2.7	0	0	0	0	1.3	0.3	0	0	0.7	6
1010	1070	0	25	58.7	2.7	0	0	0	0	0.7	3.7	0	0	0.7	8.7
1070	1100	0	16	60.3	1	0	0	0.7	1	1.3	3.3	0	0	0.3	14.3
1130	1190	0	66.7	22.7	0.7	0	0	1.3	0.3	0.7	0.3	0	0	0.3	6.7
1190	1250	0	72.3	19.7	0.3	0	0	0	0.3	1.7	0	0	0	0	5.3
1250	1310	0	51.7	11.7	0	0	0	0.3	0.3	1.7	0.7	0	0	0	33.3
1340	1400	0.7	60	13.3	0	0.7	0	0.7	0	2	0.3	0	0	0	22.3
1400	1440	0	35.7	32.7	2	0	0	1	0.3	0.7	0.3	0	0	0.7	28.3
1460	1520	1.3	61.7	6.7	5	0	0	1.3	0.3	1	1	0	0	0.3	24.3
1520	1560	0.7	36.7	9.3	1.7	0	0	8	0.3	0.7	0.3	0	0	1.3	37.7
1560	1610	0.3	53.7	24.3	6.7	0.7	0	1.3	0.3	1.3	0	0	0	0.7	15.3
1610	1670	0	71.7	6	5	0.3	0	0.3	0.3	2	0	0	0	0	11.7
1670	1700	0	63.3	21.3	0.7	1	0	1.7	2	1	0	0	0	0	4.7
1730	1790	0	61.7	16.7	0	0	0	6.7	0	2	2	0	0	0.3	10
1790	1820	0	40.7	50.3	0.7	0	0	2	0	0.3	1	0	0	3	2.7
1850	1900	0	76.7	13.3	1	0	0	2.7	0	0.7	1.7	0	0	0.7	3.7

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MWL	MSS	NCT	SPH
1970	1990	0	57.3	34.3	0.7	0	0	3.3	0	0.3	1.3	0	0	0.3	2
1990	2000	0	40.3	43.3	1.7	0.3	0	2.3	0	0.3	0	0	0	11	1
2040	2060	0	46	36.7	4.3	0.3	0	8	0	0	1	0	0	5.3	1
2060	2080	0	43.3	30	11	0.3	0	12.3	0.7	1	1.7	0	0	3	3.3
2080	2100	0	38.3	33.7	2.7	0	0	11	0	0.3	2.7	0	0	2	1
2100	2120	0	40.7	27.3	4.3	0	0	5	0.7	0.3	1.3	0	0	1.7	1.3
2120	2140	0	45.3	41	7	0	0	1.3	0	1.3	1	0	0	3	2.3
2140	2160	0	43.3	40	2	0	0	2.7	0.3	1.3	0.7	0	0	3.7	1
2160	2180	0	40	45.7	3.3	0.3	0	4.3	0	1	1	0	0	4.3	1.3
2180	2200	0	40	48.3	0.3	0	0	2.3	0	0.7	0.3	0	0	3.7	1.3
2200	2230	0	48.3	48.3	0.3	0	0	0.7	0	0.7	0	0	0	1	0.3
2240	2260	0	29.7	65	1.3	0	0	1.7	0	0.3	0	0	0	0.3	2.7
2280	2290	0	51.3	33.3	2.3	0	0	3.3	0	1.3	3.3	0	0	1.7	4.3
2290	2310	0	58.3	30	2	0	0	3.3	0	1	1.3	0	0	0	3.7
2310	2330	0	58.3	28.3	0	0	0	4	0	1	3.7	0	0	0.3	2.3
2330	2350	0	70.7	13.7	0.3	0	0	3	0.3	1.3	0.7	0	0	0.7	9.7
2350	2370	0	60	24.3	1.7	0	0	2	0	2.7	2.3	0	0	1	7.3
2370	2390	0	80	7.3	0	0	0	3.3	0	0.7	2.3	0	0	0.7	4
2390	2400	0	76.7	11.7	2	0	0	2.3	0	0.3	1.7	0	0	1	6.3
2440	2460	0	78.3	10	0	0	0	0.7	0	1.3	3	0	0	0.3	4.3
2460	2480	0	90	7.3	0.7	0	0	0	0	0	1	0	0	0	1.7
2480	2500	0	83.7	9	1	0	0	1	0	0.7	2.3	0	0	0.3	2.3
2510	2540	0	81.7	11.7	1	0	0	0.3	0	1.3	0.7	0.3	0	0	3
2540	2560	0	83.3	4.3	1.7	0	0	0	0	2.3	1.3	0	0	1	6.7
2560	2580	0	76.7	10	1.3	0	0	2	0	1.3	3.3	0	0	0.3	4.7
2580	2600	0.3	83.3	5	2.7	0	0	1.3	0	0.3	3	0	0	0.3	5
2610	2640	0	80	12.3	0.3	0	0	1.3	0	0.7	3	0	0	0	0
2640	2680	0	81.7	10.7	0.7	0	0	1.7	0	0	2.7	0	0	0	3

TOP	BASE	AE	AOM	BBW	CH	DT	DC	EC	FHT	FE	GM	MWL	MSS	NCT	SPH
2780	2820	0	83.3	5	0	0	0	0.3	0	0	2	0	0	1.3	7.3
2820	2840	0	83.3	6.3	1	0	0	0.7	0	0.3	1.7	0	0	5	2.7
2840	2860	0	83.3	13.7	0.3	0	0	0	0	0.3	1	0	0	0	0.7
2860	2900	0	83.3	12.3	1	0	0	0.7	0	0.3	0.7	0	0	0.3	2
2900	2910	0	83.3	11	0.3	0	0	1	0	0.3	1	0	0	1	1.3
2910	2940	0	83.3	15	0	0	0	0	0	0	1.3	0	0	0	0
2940	2960	0	81.7	16	0.3	0	0	0	0	0.7	0.3	0	0	0.7	0.7
2980	2990	0	83.3	8.3	0.3	0	0	1	0	0.3	1.3	0	0	2	3.3
2990	3010	0	83.3	8	0	0	0	1.3	0	0	1.7	0	0	2.3	3
3010	3030	0	83.3	6	0.3	0	0	0.3	0	0	1	0	0	3.3	6
3030	3060	0	83.3	13	0	0	0	0	0	0.3	1.7	0	0	0	1.3
3060	3080	0	83.3	13	1	0	0	0.3	0	0	1.7	0	0	0.7	1
3080	3100	0	83.3	8.7	0	0	0	1	0	0	1.7	0	0	1.7	2.7
3100	3180	0	81.7	14	0	0	0	0	0	0.3	0.7	0	0	1	2.3
3180	3200	0	91.7	7.7	1.3	0	0	0	0	0	0.3	0	0	0	0.3
3200	3220	0	83.3	9	0.7	0	0	0.3	0	0.3	0.7	0	0	0.7	4.3
3220	3240	0	83.3	12.3	2	0	0	0.3	0	0	0.7	0	0	1.7	1
3240	3260	0	83.3	10.7	0.3	0	0	0	0	0.3	1.3	0	0	0.7	1.7
3260	3280	0	80	15.7	0.3	0	0	0	0	0	0.3	0	0	1.7	2
3400	3430	0	80	15.3	0	0	0	1	0	0.3	0.3	0	0	2.3	0.3
3430	3490	0	83	15	0	0.3	0	0	0	0	0	0	0	1.7	0
3490	3580	0	73.3	21	0	0	0	0.3	0	0	0.7	0	0	4	0.7
3580	3600	0	76.7	20.3	0.3	0	0	0.3	0	0.3	0	0	0	2	0.3
3600	3620	0	76.7	20.3	0	0	0	0.3	0	0.3	0.3	0	0	1.3	0.3
3630	3650	0	76.7	19	0	0	0	0.7	0	0	0	0	0	2.3	1.3

APPENDIX 2d: PC Score Values of Particulate Organic Matter in Oredo-2

	PC 1	PC 2	PC 3
300	-69.771	-10.414	-0.01752
360	-73.279	-9.0427	-0.074483
420	-25.108	19.595	0.0049837
480	-34.593	-4.8727	-0.09332
550	-80.276	-8.4282	0.043662
580	-54.906	10.451	0.022668
640	-20.262	8.0905	-0.048674
700	-5.5375	4.7064	0.062287
820	-28.839	-0.34086	0.017255
880	-8.0565	3.3275	0.0063712
940	-44.695	32.845	0.0063
1000	-39.45	12.363	0.01501
1060	-15.605	12.129	-0.052835
1120	-13.343	13.161	-0.054358
1180	-8.7313	12.202	0.059646
1270	-5.3649	11.762	0.00070199
1330	15.858	8.708	-0.0067734
1390	-7.2015	7.9372	0.0035372
1450	-3.7731	15.076	-0.0017552
1540	-9.9564	2.2004	0.0077899
1600	-29.4	3.3014	0.015547
1660	-12.345	6.5635	0.00648
1720	-7.2593	11.495	0.001658
1780	1.2587	17.915	-0.0054345
1840	-23.44	3.2632	0.013009
1920	-30.873	-2.5017	0.07702
1940	-28.217	-4.7972	-0.038362
1960	-16.698	-1.4648	-0.04509
1980	-23.45	-0.34044	0.072677
2000	-29.996	-3.7861	0.07733
2030	-19.77	-2.1078	0.014308
2050	-9.8231	-4.2175	-0.1043
2070	-14.73	-2.1749	-0.045555
2090	-14.6	-2.943	0.012536
2110	-21.367	-6.2825	0.017228
2130	-25.594	-2.9191	0.017242
2150	-11.424	-2.7424	0.0688
2170	-18.96	-2.4966	-0.043567
2200	-18.833	-0.43976	0.013013
2220	-21.603	-2.2472	0.015169
2230	-0.02561	-3.4315	0.0065414
2250	-5.6538	-4.0232	0.067009

2280	23.279	-2.1507	-0.0041472
2300	-20.007	-4.5824	0.015734
2320	-4.0607	-2.5919	-0.049911
2340	5.6211	-3.084	-0.053803
2360	31.119	0.12414	0.049005
2380	13.603	-0.79843	-0.00071747
2400	20.949	-2.287	-0.060809
2420	22.419	-0.16894	0.052896
2450	31.61	0.20235	-0.0089824
2470	21.384	-1.4759	0.05404
2490	31.004	-1.1538	0.10747
2510	20.837	0.12016	-0.0043143
2530	36.514	0.98469	-0.069241
2550	38.726	3.6094	-0.071595
2570	13.842	-1.1487	-0.00063275
2590	48.292	1.8394	-0.017019
2610	35.302	-0.78612	0.047697
2630	19.661	-1.1976	-0.0031042
2650	20.221	4.4951	-0.0063912
2700	26.641	3.059	-0.066114
2720	25.66	3.8441	-0.066112
2740	22.535	1.109	-0.0055723
2760	30.567	0.86002	-0.0088867
2780	15.066	1.401	-0.0025229
2800	18.194	0.3696	0.054422
2820	14.762	-1.1197	0.056692
2840	33.138	-2.1789	0.049371
2860	17.458	0.72303	-0.0031867
2880	40.691	-0.78579	-0.070087
2900	34.241	-0.82586	-0.0095615
2920	29.298	0.76352	-0.0082903
2940	17.091	-0.98353	-0.059851
2960	20.58	-1.1685	0.054221
2980	18.38	-2.0728	0.055649
3010	14.265	-1.1165	-0.00083155
3040	14.824	-1.9339	-0.00063388
3060	36.283	-1.5713	0.047696
3080	36.215	-0.67574	-0.010489
3100	13.36	-4.1333	0.0011715
3130	13.162	-2.4696	0.058101
3150	13.85	-4.055	-0.056816
3170	15.241	-2.7619	-0.00036994
3190	13.836	-2.0089	-0.00017002
3210	18.863	-0.029962	-0.0033866

3230	12.55	-3.7444	0.059046
3250	13.958	-0.8123	0.056872
3270	15.87	0.1519	-0.059935
3290	12.61	-1.7337	0.00020914
3310	17.458	0.72303	-0.0031867
3340	15.859	-0.62687	-0.0017777
3360	13.224	-3.2838	0.00077504
3390	11.699	-4.669	0.059906
3410	13.292	-3.2377	-0.057014
3430	14.646	-2.3978	-0.058044
3450	14.149	-2.3945	0.057637
3470	15.007	-1.5514	-0.0009174
3490	11.324	-3.4692	0.059425
3510	11.998	-3.0085	0.0011542
3530	-3.5138	-4.188	0.0084435
3560	1.0949	-1.381	0.004963
3580	-9.1489	-3.7567	0.010631
3600	-1.9806	-4.7675	-0.049639
3620	-1.9208	-2.7568	-0.10848
3640	-9.087	-4.5709	-0.046694
3660	-13.317	-4.8926	-0.044706
3680	-18.222	-5.6749	0.015553
3700	-14.62	-1.7571	0.069645
3720	-11.131	-1.0005	0.067742
3740	-8.4714	0.38903	-0.049613
3760	-4.5009	-4.2631	0.0089074
3780	-3.2573	-2.8993	-0.050091
3800	-0.8717	-3.4958	0.006939
3820	-19.4	-4.1678	0.015252
3840	-1.131	-1.0181	-0.052011
3860	-1.1111	-3.1455	0.0068543
3880	-0.63438	-1.0212	0.0055127
3900	-2.4194	0.07134	0.0056942
3930	11.573	-0.21582	-0.00015797
3950	-42.194	-7.4978	0.026818
3970	-37.234	-7.4482	-0.033073
3990	-50.968	-7.7555	-0.027013

Appendix 2e: PC Score Values of Particulate Organic Matter in Oredo-4

	PC 1	PC 2	PC 3
70	-61.847	-0.30468	0.049247
130	3.5271	5.1331	0.062179
190	-18.998	6.7342	-0.041996
280	11.834	10.422	0.051006
340	-8.3407	3.7001	-0.56424
400	4.311	10.073	-0.11737
490	2.533	9.0315	0.00037976
550	21.797	7.7412	-0.0093747
640	-28.939	2.8588	0.026186
700	-2.8941	-3.8011	-0.038878
760	3.4151	-1.9786	0.012986
820	5.2638	6.9524	0.0012572
910	-14.394	-31.416	0.058513
970	-1.0623	-30.72	0.049869
1030	13.067	-18.771	0.027344
1090	2.7186	-7.0298	0.019415
1150	18.422	-11.848	-0.041782
1210	23.56	-12.299	0.013479
1270	19.236	-7.6047	0.010418
1330	21.782	-13.341	-0.041973
1390	14.674	-5.7087	-0.046903
1450	13.09	-9.5684	0.074097
1540	21.298	4.2861	-0.062699
1600	15.845	-13.789	0.019777
1660	18.768	-15.717	-0.32605
1720	-18.715	-23.297	-0.0063658
1780	-10.18	-9.7253	0.087924
1840	2.5484	-5.3632	-0.040207
1900	-10.269	-7.6345	-0.087721
1960	-6.0522	0.73246	0.015304
2020	4.1116	3.0727	0.006557
2060	6.044	0.09393	-0.04876
2110	-2.6941	-6.1646	0.079292
2140	-7.3835	3.0145	0.013364
2170	-5.0442	2.1575	0.07075
2190	-5.0515	-13.065	0.088899
2210	-27.437	-1.0901	-0.085458
2240	-9.9459	-11.341	0.031978
2260	3.0236	-0.75647	0.069494
2290	-12.878	3.4553	0.01606

2310	-6.2028	-9.5611	0.027662
2360	-18.605	3.5324	0.07706
2390	4.5673	1.9012	0.0076862
2400	5.2934	6.2555	0.059806
2420	4.7528	3.5782	0.063314
2440	6.6081	2.6097	0.06338
2460	-11.373	2.9311	0.015802
2470	10.179	0.6524	0.06362
2490	-12.982	2.2027	0.017614
2520	9.801	7.1978	-0.05943
2550	16.204	-0.99021	0.0043111
2580	14.702	-4.4257	0.0092867
2610	7.3664	2.3071	0.0055615
2640	8.5317	4.1262	0.060445
2660	9.4086	1.0357	0.063615
2680	12.111	-2.3263	0.0083031
2700	5.1583	7.6797	0.00045215
2720	10.703	1.9659	0.061748
2740	15.998	1.9087	-0.056758
2760	5.367	0.82093	0.06624
2780	8.1453	-2.5715	-0.046815
2810	2.2791	4.8694	-0.052246
2850	2.7664	0.031211	0.010971
2860	0.71353	8.7677	0.0017608
2880	1.3961	8.4954	0.0016852
2910	3.8926	8.0324	0.058509
2940	1.6662	5.6469	-0.052813
2960	7.1334	1.9434	0.063867
2990	0.68519	7.4847	-0.054428
3010	2.3474	7.3545	-0.055248
3030	4.5943	5.1641	0.061516
3060	3.8489	3.4058	0.0063138
3080	3.6015	7.0826	0.0020763
3100	2.3192	6.0717	0.061768
3130	3.7972	2.2845	0.0076807
3150	2.3605	5.2938	0.0049359
3170	2.2033	4.8998	0.0054978
3200	2.8445	5.4053	0.062254
3220	-0.073155	7.7873	0.0033905
3240	3.8655	4.7696	0.0046786
3260	5.1197	4.4977	0.062003
3280	4.7114	4.3559	-0.053059
3300	2.99	5.8801	0.0038681
3340	5.7042	2.4373	0.0063807

3400	3.0017	5.7994	0.061693
3440	-2.871	5.4015	0.0078743
3470	-0.88554	1.5641	-0.046451
3490	-5.3957	4.5816	0.068066
3510	1.2519	6.0407	0.062431
3520	1.2105	6.8183	-0.053942
3590	-26.584	-4.0191	-0.19794
3630	-31.375	-0.052229	-0.084387
3670	-34.223	2.8351	0.029311
3700	-25.554	-0.7756	-0.029202
3740	-26.925	0.30442	0.02805
3760	-26.897	1.5874	0.084239

Appendix 2f: PC Score Values of Particulate Organic Matter in Oredo-8

	PC 1	PC 2	PC 3	PC 4
320	7.9187	1.7828	0.65727	0.60499
350	43.127	-0.47475	0.13996	0.43332
380	-9.548	1.2685	-4.4849	1.7749
440	58.387	2.1826	-1.0215	-0.20627
530	93.046	7.9545	-0.76361	-0.21246
590	38.155	-2.8251	-1.251	0.086569
650	62.072	2.7632	-0.457	-0.19143
710	1.0575	-0.56094	0.76155	-0.095856
770	67.055	4.7908	-3.3256	-0.27085
830	92.628	23.01	19.061	0.4457
890	54.337	-15.691	-21.758	0.4004
950	65.247	-2.0176	-0.7476	-0.22902
1010	45.245	-4.2566	0.20506	-0.18757
1070	52.734	-12.751	0.15415	-0.24312
1130	-7.8599	-2.0348	0.34064	-0.10455
1190	-15.144	-1.593	0.32122	-0.093559
1250	-6.687	-35.495	5.1319	-0.14171
1340	-11.088	-23.567	3.2257	0.57112
1400	22.381	-27.125	4.8619	-0.14258
1460	-13.039	-23.751	5.3996	-0.06423
1520	10.053	-41.937	4.073	-0.22765
1560	7.4613	-11.379	4.0709	0.63617
1610	-20.165	-10.491	0.72841	0.17816
1670	-5.0001	-2.4121	-2.5907	0.80472
1730	-6.6533	-7.7581	0.97112	-0.1177
1790	31.735	3.7554	-0.46474	-0.14795
1850	-21.292	2.0012	0.41597	-0.064136

1970	7.4736	4.0391	-0.86421	-0.12732
1990	34.843	5.7638	-0.86427	0.14711
2040	26.795	6.9601	0.068185	0.19082
2060	30.154	4.9016	2.6491	0.25109
2080	41.07	10.671	4.2412	0.01384
2100	19.365	-3.3374	-9.8255	-0.44268
2120	26.093	3.9074	0.64226	-0.10768
2140	24.903	1.8381	-3.4168	-0.2355
2160	33.362	4.6985	-0.51546	0.15359
2180	31.705	3.1204	-2.5888	-0.21324
2200	23.242	5.7976	-1.1053	-0.14515
2240	48.918	3.8883	-0.5504	-0.17156
2280	11.731	0.66727	0.31845	-0.11589
2290	4.4377	1.1805	-0.35249	-0.12353
2310	0.81689	2.054	-1.4183	-0.14546
2330	-16.122	-6.0525	1.4422	-0.08299
2350	-1.9048	-4.4134	1.5317	-0.089826
2370	-28.591	0.57351	-0.55909	-0.090821
2390	-21.772	0.063759	1.5757	-0.039837
2440	-28.097	-0.71239	-0.61449	-0.09981
2460	-37.062	5.3836	0.26821	-0.030691
2480	-31.194	3.6087	0.20755	-0.049219
2510	-27.447	1.5203	0.28003	-0.062814
2540	-33.233	-3.5177	1.4351	-0.048182
2560	-25.327	-0.37295	0.28903	-0.075174
2580	-32.81	0.8955	1.1449	-0.034041
2610	-27.259	5.0814	-1.6337	-0.10023
2640	-28.789	3.7041	0.27665	-0.049755
2780	-34.024	-2.1368	0.43148	-0.069229
2820	-29.28	3.9476	0.54011	-0.040164
2840	-28.094	5.5448	-0.69729	-0.069409
2860	-27.658	4.6005	0.19027	-0.04901
2900	-28.589	4.7692	-0.6372	-0.071096
2910	-27.598	6.9025	-0.72443	-0.063708
2940	-24.338	5.5918	-0.11545	-0.056947
2980	-29.995	2.6373	0.038728	-0.060764
2990	-30.28	3.2677	-0.16445	-0.063026
3010	-30.978	-0.076967	0.67579	-0.055159
3030	-29.293	4.9642	-0.42209	-0.062901
3060	-27.869	6.3711	0.17205	-0.039986
3080	-30.426	3.3884	-0.47129	-0.071164
3100	-26.036	3.9439	-0.088033	-0.062636
3180	-37.059	7.3725	0.33225	-0.018392
3200	-30.209	1.1821	-0.040706	-0.070443

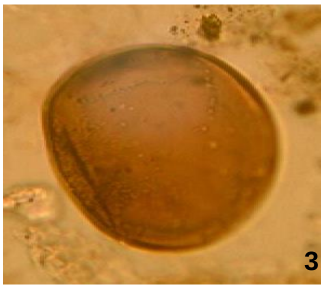
3220	-26.24	6.5157	0.30331	-0.037463
3240	-29.938	3.8477	-1.0106	-0.085116
3260	-22.643	4.6687	-0.23986	-0.067572
3400	-22.012	6.1223	-0.74913	-0.075612
3430	-25.264	6.9478	-0.71441	0.23399
3490	-12.817	6.2372	-0.60334	-0.082425
3580	-16.422	6.4584	-0.46784	-0.072735
3600	-17.346	6.1188	-0.81421	-0.083453
3630	-17.058	5.513	-0.43967	-0.076063

APPENDIX 3

PHOTOMICROGRAPHS SHEET 1


1


2


3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10


11

LEGEND **Magnification X400**

1-2 *Laevigatosporites discordatus* (Oredo-2: 1120-1150 m); 3 *Laevigatosporites* sp. (Oredo-4: 2490-2510 m);
4 *Verrucatosporites usmensis* (Van der Hammen 1956) Germeraad *et al*. 1968 (Oredo-2: 1120-1150 m)
5-6 *Verrucatosporites usmensis* (Van der Hammen 1956) Germeraad *et al*. 1968 (Oredo-2: 1840-1900 m)
7-8 *Acrostichum aureum* (Oredo-2: 420-480 m & 1120-1150 m)
9 *Polypodiaciesporites retirugatus* Kedves 1961. (Oredo-2: 420-480 m)
10-11 *Magnastriatites howardi* Gonzalez 1967. (Oredo-2: 970-1030 m)

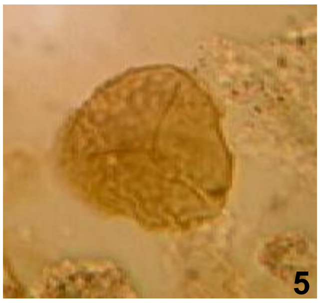
PHOTOMICROGRAPHS SHEET 2


1


2


3


4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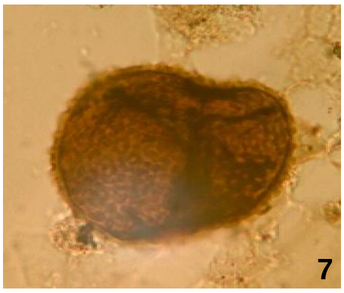
6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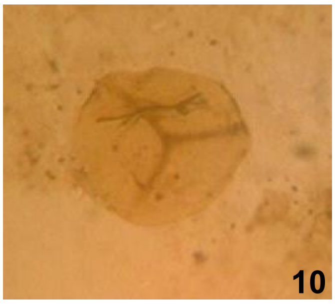
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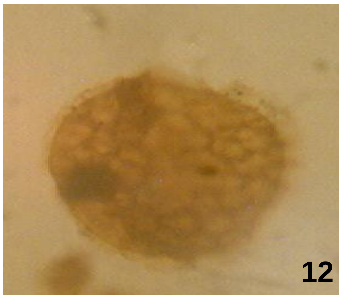
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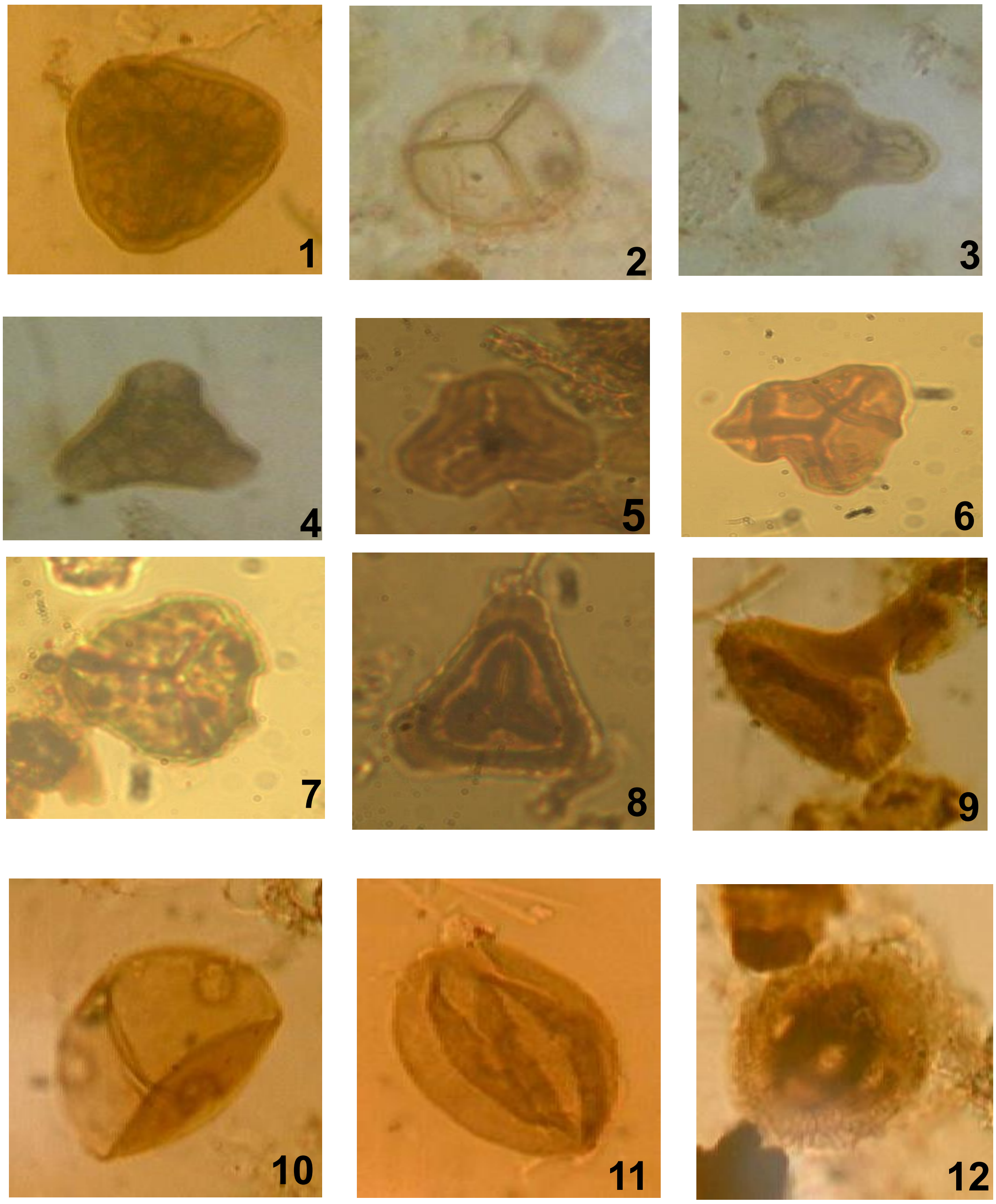
LEGEND **Magnification X400**

1-3 *Polypodiaciesporites retirugatus* Kedves 1961. (Oredo-2: 1120-1150 m)
4-5 *Lycopodiumsporites fastiginoides* (Oredo-2: 420-480 m; 1120-1150 m)
6 *Cicatricosisporites dorogensis* Potonie and Gelletica 1933. (Oredo-2: 1540-1600 m)
7-8 *Cicatricosisporites dorogensis* Potonie and Gelletica 1933. (Oredo-2: 1120-1150 m)
9 *Laevigatosporites* sp. (Oredo-2: 1120-1150m)
10-11 *Ricciaesporites transdanubiscus* (Oredo-4: 2460-2470 m & 2490-2510 m)
12 Trilete Spore (Oredo-4: 2080-2100 m)

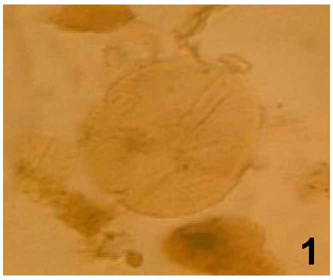
PHOTOMICROGRAPHS SHEET 3



LEGEND **Magnification X400**

1-7 Trilete Spore (Oredo-8: 2080-2100 m; Oredo-2: 420-480 m, 1270-1330 m, 1450-1510 m, 1120-1150 m, 2720-2740 m); 8 *Polypodiaciesporites* (Oredo-2: 1120-1150 m); 8 *Auriculopollenites simplex* Legoux *et al*. 1971. (Oredo-2: 2050-2080 m); *9 Psilatricolporites* (Oredo-2: 1120-1150 m); 10 *Psilatriporites* sp. (Oredo-2: 2170-2200 m); 11 *Psilatricolporites* sp. (Oredo-2: 1120-1150 m); 12 *Retitricolporites* sp. (Oredo-2: 2170-2200)

PHOTOMICROGRAPHS SHEET 4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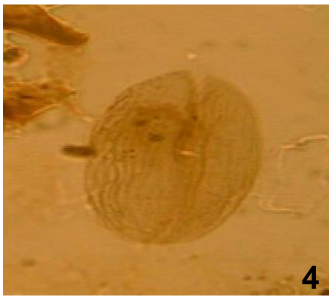
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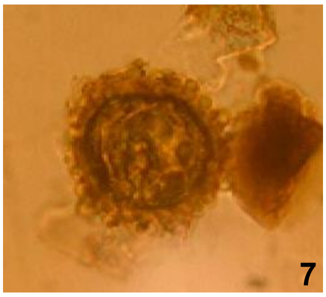
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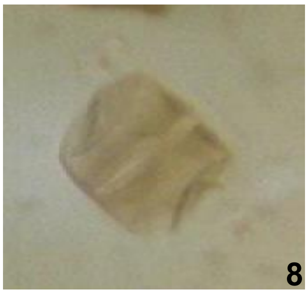
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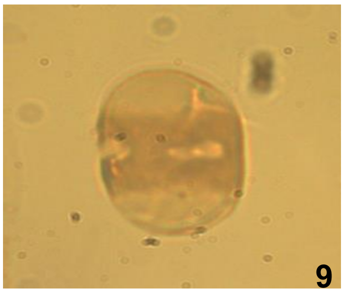
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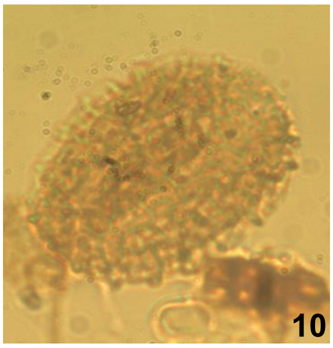
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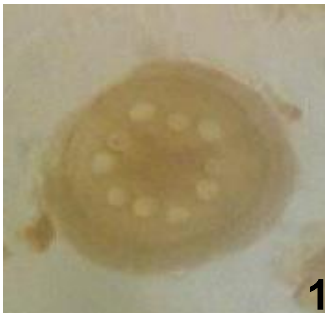
LEGEND **Magnification X400**

1 *Psilamonocolpites marginatus* (Oredo-4: 2390-2400 m); 2-3 *Psilamonocolpites marginatus* (Oredo-2: 1120-1150 m & 2170-2200 m); 4-5 *Striamonocolpites rectostriatus* (Oredo-2: 420-480 m & 1840-1900 m); 6-7 *Inaperturopollenites gemmatus* (Oredo-2: 1840-1900 m); 8-9 *Psilatricolporites onitshaeensis* Jan du Chene *et al.* 1978. (Oredo-2: 1660-1820 m & 1840-1900 m); 10 *Retitricolporites ituensis* Jan du Chene *et al.* 1978. (Oredo-2: 1840-1900 m); 11-12 *Retitricolpites bendeensis* (Oredo-2: 420-480 m & 1120-1150 m)

PHOTOMICROGRAPHS SHEET 5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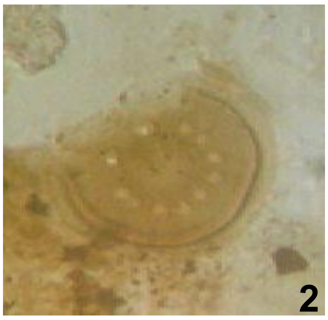
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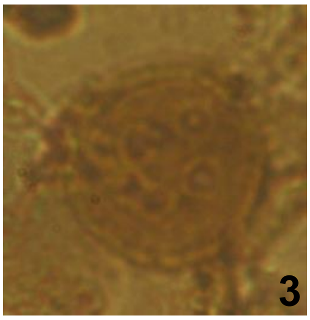
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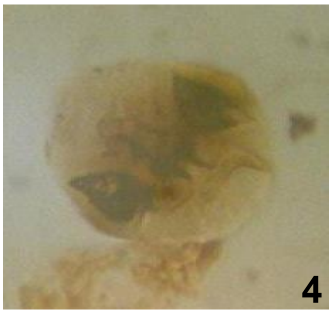
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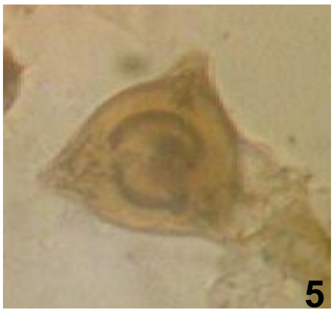
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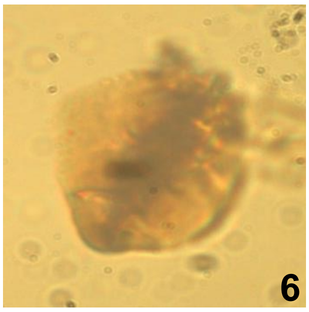
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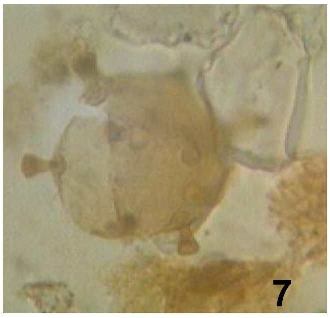
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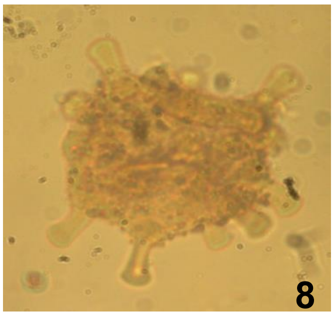
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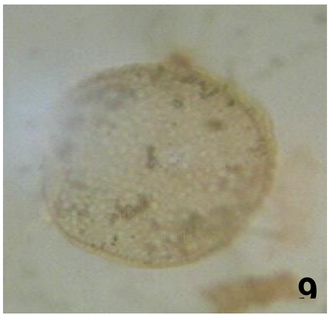
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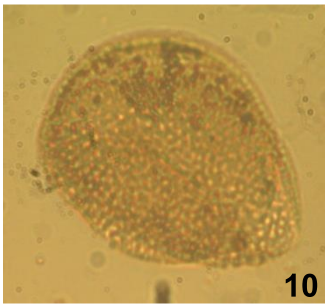
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LEGEND **Magnification X400**

1-3 *Cinctiporipollis mulleri* (Oredo-2: 1120-1150 m; 1270-1330 m & 2180-2200 m); 4 *Doualaidites laevigatus* (Oredo-4:2390-2400 m); 5-6 *Doualaidites laevigatus* (Oredo-4:1840-1900m & 2220-2230 m); 7-8 *Grimsdaleae polygonalis* Germerrad *et al.* 1968. (Oredo-2: 1780-1840 & 1840-1900 m); 9. *Proxapertites cursus* (Oredo-2: 1780-1840 m); 10. *Proxapertites operculatus* Van der Hammen 1956. (Oredo-2: 420-480 m); 11-12 *Retimonocolpites obaensis* Jan du Chene *et al.* 1978 (Oredo-4:1840-1900m & 2220-2230 m)

PHOTOMICROGRAPHS SHEET 6


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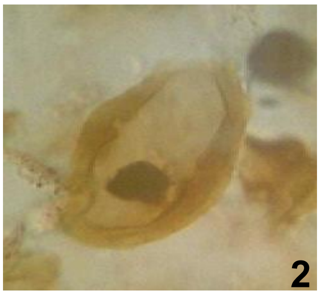
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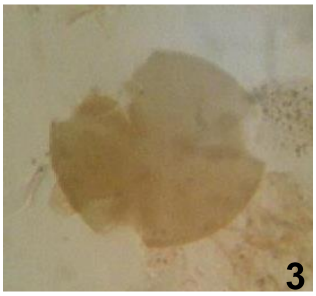
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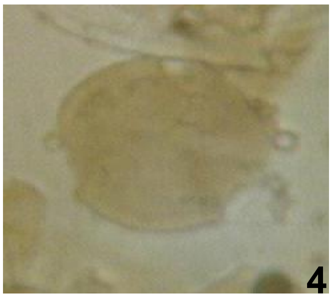
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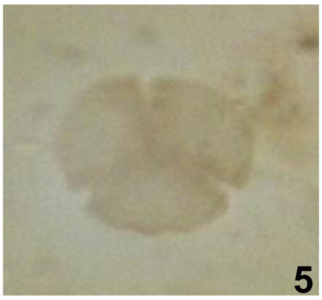
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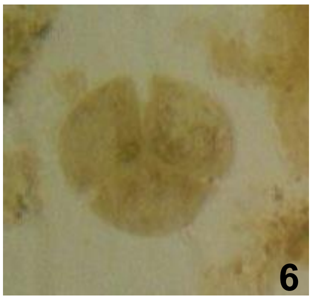
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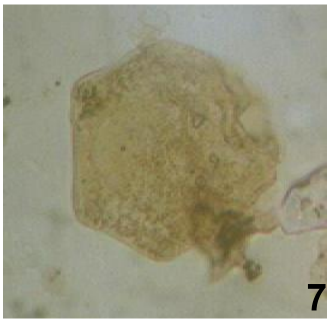
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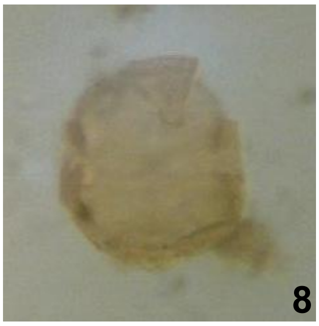
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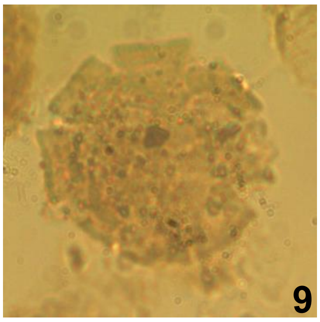
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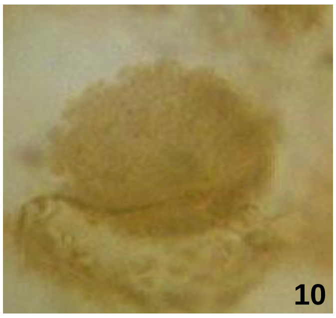
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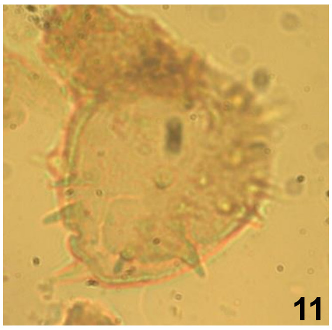
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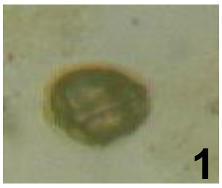
LEGEND **Magnification X400**

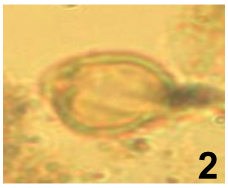
1 *Psilatricolporites magnoporatus* Jan du Chene *et al.* 1978 (Oredo-2: 1270-1330 m);

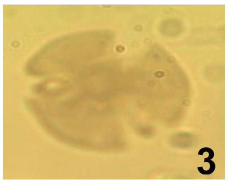
2 *Psilatricolporites igboensis* Jan du Chene *et al.* 1978 (Oredo-2: 1270-1330 m); 3-4 *Psilatricolpites okeziei* Jan du Chene *et al.* 1978 (Oredo-2: 1270-1330 m & 1450-1510 m); 5-6 *Retitricolporites clavensis* (Oredo-2: 1600-1660 m); 7 *Proteacidites otamiriensis* Germerrad *et al*. 1968 (Oredo-2: 1780-1840 m);

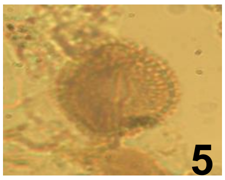
8 *Psilatricolporites magnoporatus* Jan du Chene *et al.* 1978 (Oredo-2: 2360-2380 m); 9-10 *Retistephanocolpites williamsi* (Oredo-2: 1720-1780 m); 11-12 *Spinizonocolpites baculatus* Muller 1968 (Oredo-2: 1720-1780 m & 1840-1900m)

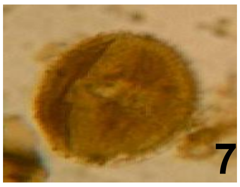
PHOTOMICROGRAPHS SHEET 7

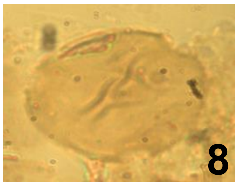


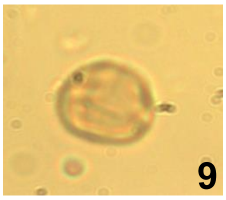


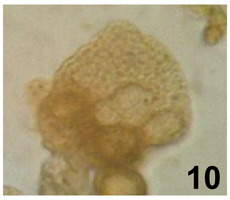


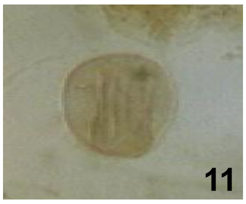


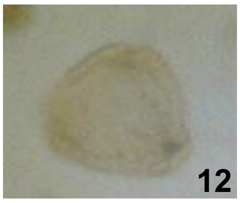


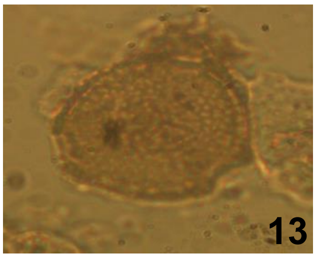


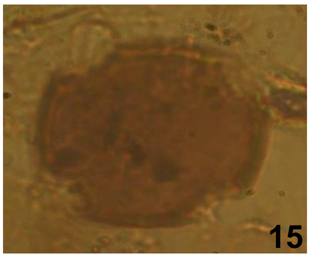


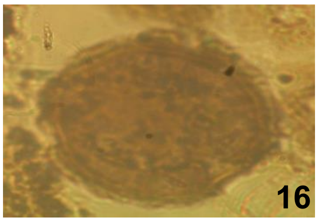


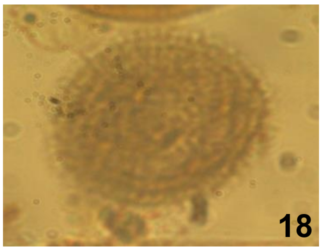








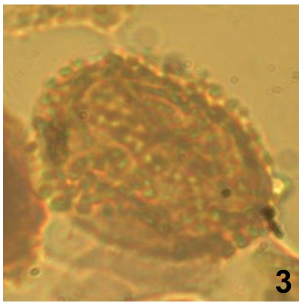


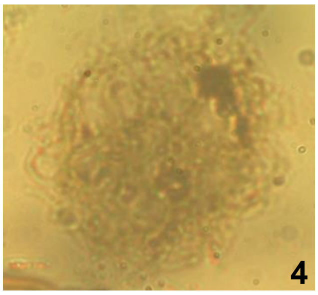


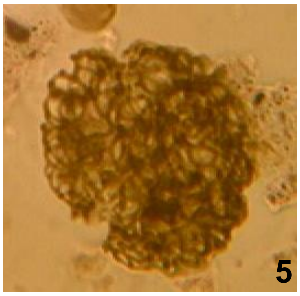
LEGEND **Magnification X400**

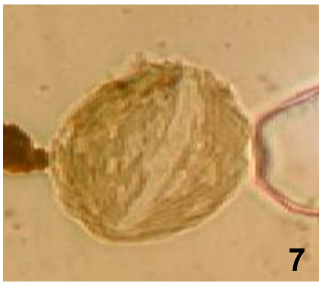
1 *Zonocostites ramonae* Duena 1980 (Oredo-4: 700-760 m); 2&9 *Zonocostites ramonae* Duena 1980 (Oredo-2: 420-480 m & 1120-1150 m); 3 *Psilatricolporites operculatus* Van der Hammen and Wijmstra 1964. (Oredo-2: 420-480 m); 4 *Retibrevitricolpites triangulatus* Van Hoeken Klinkenberg 1966. (Oredo-2: 1840-1900 m); 5*Verrutricolporites scabratus* Legous,1978. (Oredo-2: 1840-1900 m); 6 *Psilatricolporites operculatus* Van der Hammen and Wijmstra 1964. (Oredo-4: 700-760 m); 7 *Retitricolporites* sp. (Oredo-2: 1840-1900 m); 8*Psilatriporites rotundiporis* (Oredo-2:1840-1900 m); 10 *Auriculopollenites reticulatus* Salard-Cheboldaeff 1978. (Oredo-8: 2510-25400 m); 11 *Retitricolpites kigwensis* (Oredo-8: 1850-1900 m); 12 *Retibrevitricolpites triangulatus* Van Hoeken Klinkenberg 1966. (Oredo-8: 1850-1900 m); 13 Canthium sp. (Oredo-2: 420-480 m); 14&15 *Psilastephanocolporites boureaui* Salard-Cheboldaeff 1975. (Oredo-2: 420-480 m);16&17 *Psilatricolporites crassus* Van der Hammen & Wijmstra 1964. (Oredo-2: 1840-1900 m); 18 *Ctenolophonidites costatus* Van Hoeken Klinkenberg 1966. (Oredo-2: 1840-1900 m)

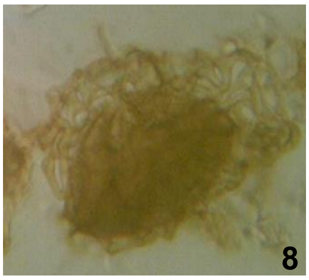
PHOTOMICROGRAPHS SHEET 8

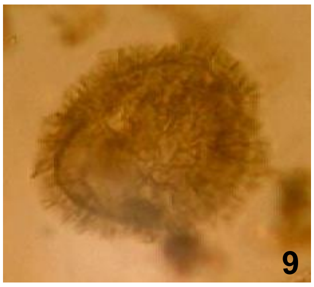


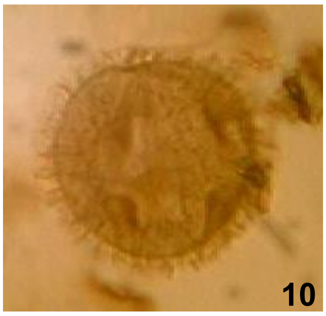


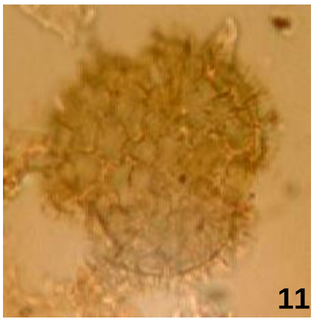


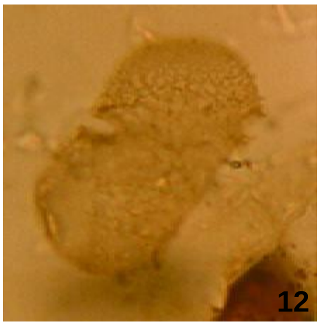








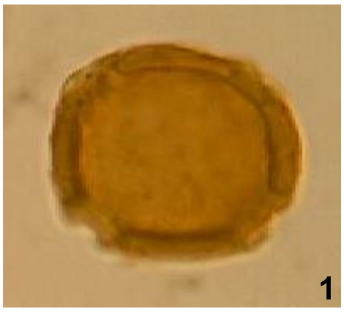




LEGEND **Magnification X400**

1 *Gemmatriporites* sp. (Oredo-2: 2170-2200 m); 2 *Gemmamonoporites* sp. (Oredo-4: 1720-1750 m); 3. *Gemmatricolporites Pilatus* (Oredo-2: 1840-1900 m); 4&5 *Praedapollis flexibilis* (Oredo-2: 1120-1150 m); 4&5 *Praedapollis flexibilis* (Oredo-2: 1120-1150 m); 6&7 *Striatricolpites catatumbus* Gonzalez and Guzman 1967. (Oredo-2: 2170-2200 m); 8 *Praedapollis africanus* Boltenhagen & Salard 1973 (Oredo-2: 1540-1600 m); 9-11 *Retitricolporites irregularis* Van der Hammen & Wijmstra 1964 (Oredo-2: 1120-1150 m); 12 *Bombacacidites* sp. (Oredo-2: 1120-1150 m)

PHOTOMICROGRAPHS SHEET 9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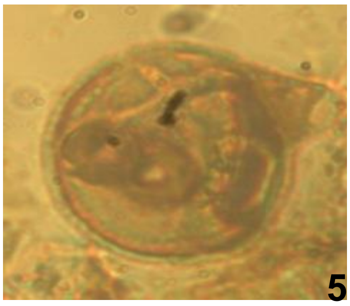
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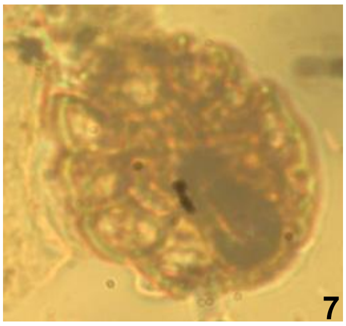
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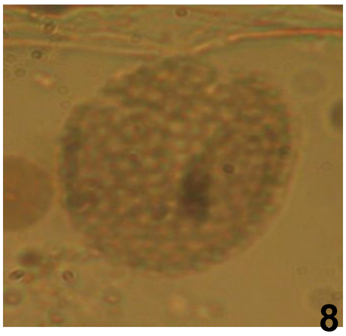
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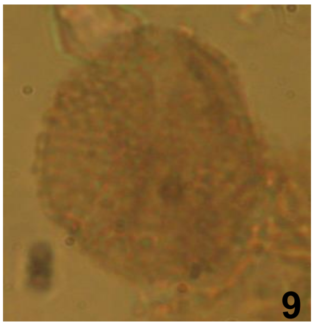
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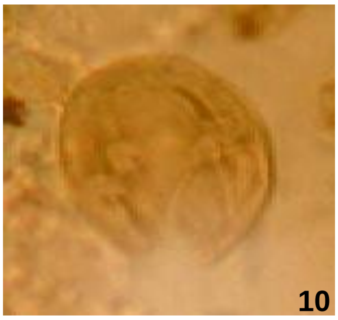
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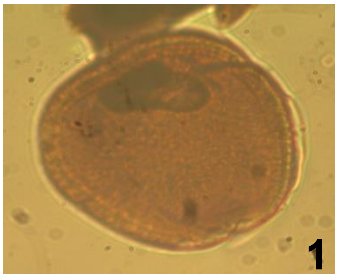
12

LEGEND **Magnification X400**

1&2 *Pachydermites diederixi* Germerrad *et al*. 1968. (Oredo-2: 1840-1900 m; 2170 – 2200 m);

3-5 *Retibrevitricolporites ibadaneensis* (Oredo-2: 1540 – 1600 m & 1840-1900 m); 6 *Retibrevitricolporites protrudens* (Oredo-2: 420 – 480 m); 7 *Peregrinipollis nigericus* Clarke 1966. (Oredo-2: 420 – 480 m); 8 *Arecipites crassimuratus* (Oredo-2: 1120 – 1150 m); 9 *Arecipites exilimuratus* (Oredo-2: 420 – 480 m); 10&11 *Psilastephanocolporites sapotace* Van der Hammen 1956 (Van der Hammen & Wijmstra 1964) (Oredo-2: 1120 – 1150 m); 12 *Anacolosidites luteoides* Cookson and Pike 1954. (Oredo-2: 2170 – 2200 m)

PHOTOMICROGRAPHS SHEET 10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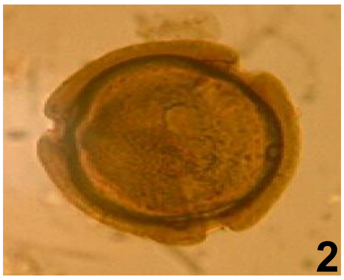
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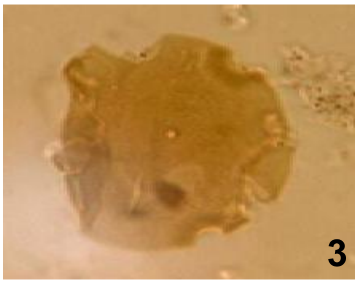
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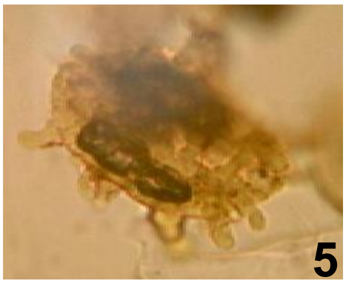
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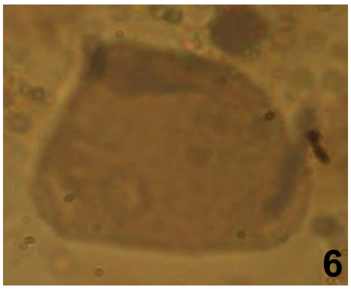
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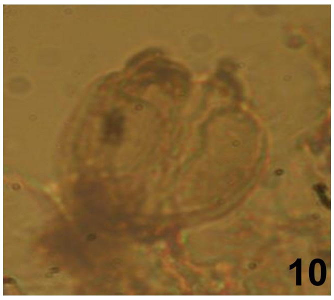
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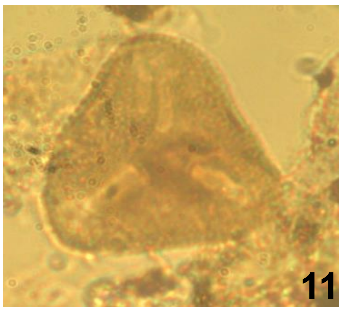
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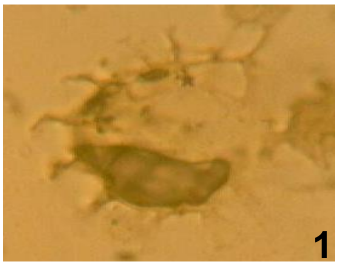
13

LEGEND **Magnification X400**

1&2 *Psilatricolporites crassus* Van der Hammen & Wijmstra 1964. (Oredo-2: 1840-1900 m; 2720 – 2440 m) 3 *Brevicolporites guinetii* Salard-Cheboldaeff 1978. (Oredo-2: 1540-1600 m); 4 *Racemonocolpites hians* (Oredo-2: 1120-1150 m); 5 *Grimsdaleae magnaclavata* (Oredo-2: 2170 – 2200 m); 6 *Proteacidites cooksooni* Salard-Cheboldaeff 1978. (Oredo-2: 1120-1150 m); 7 *Cyperus* Type (Oredo-2: 380-410 m); 8 *Elaies guineensis* (Oredo-2: 380-410 m); 9 *Verrustephanocolporites complanatus* Salard-Cheboldaeff 1978. (Oredo-4: 970-1030 m); 10 *Marginipollis concinnus* Clarke & Frederiksen 1968. (Oredo-2: 1120-1150 m); 11 *Loranthacites nataliae* Salard-Cheboldaeff 1978. (Oredo-2: 420-480 m); 12 *Caryapollenites* sp. (Oredo-2: 2740-2760 m); 13 *Verrutricolporites laevigatus* (Oredo-2: 2170-2200 m).

PHOTOMICROGRAPHS SHEET 11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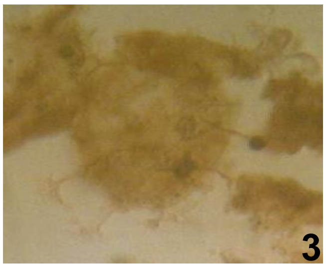
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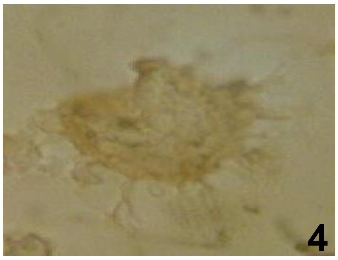
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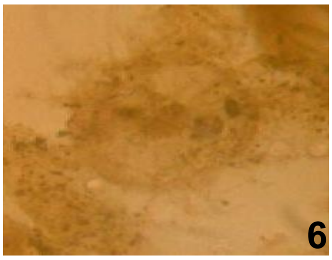
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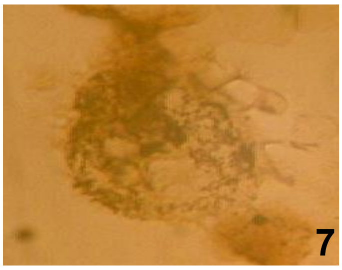
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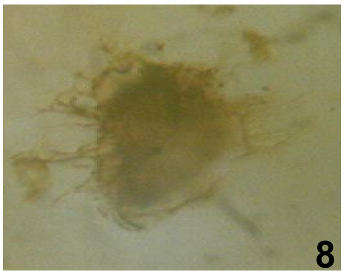
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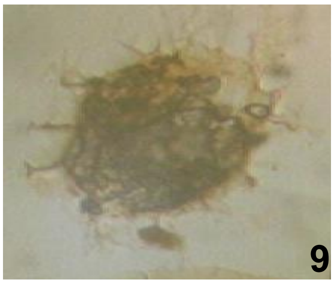
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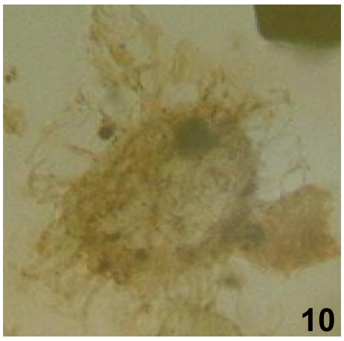
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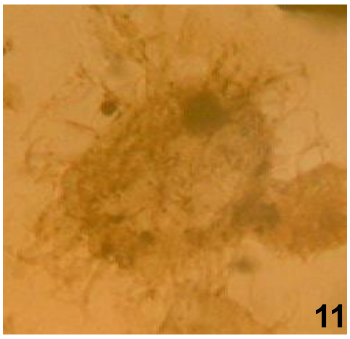
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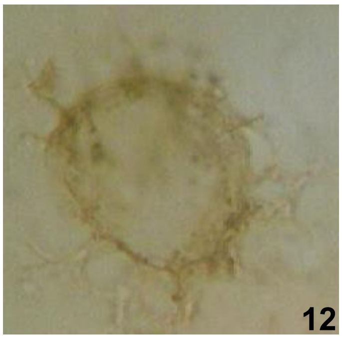
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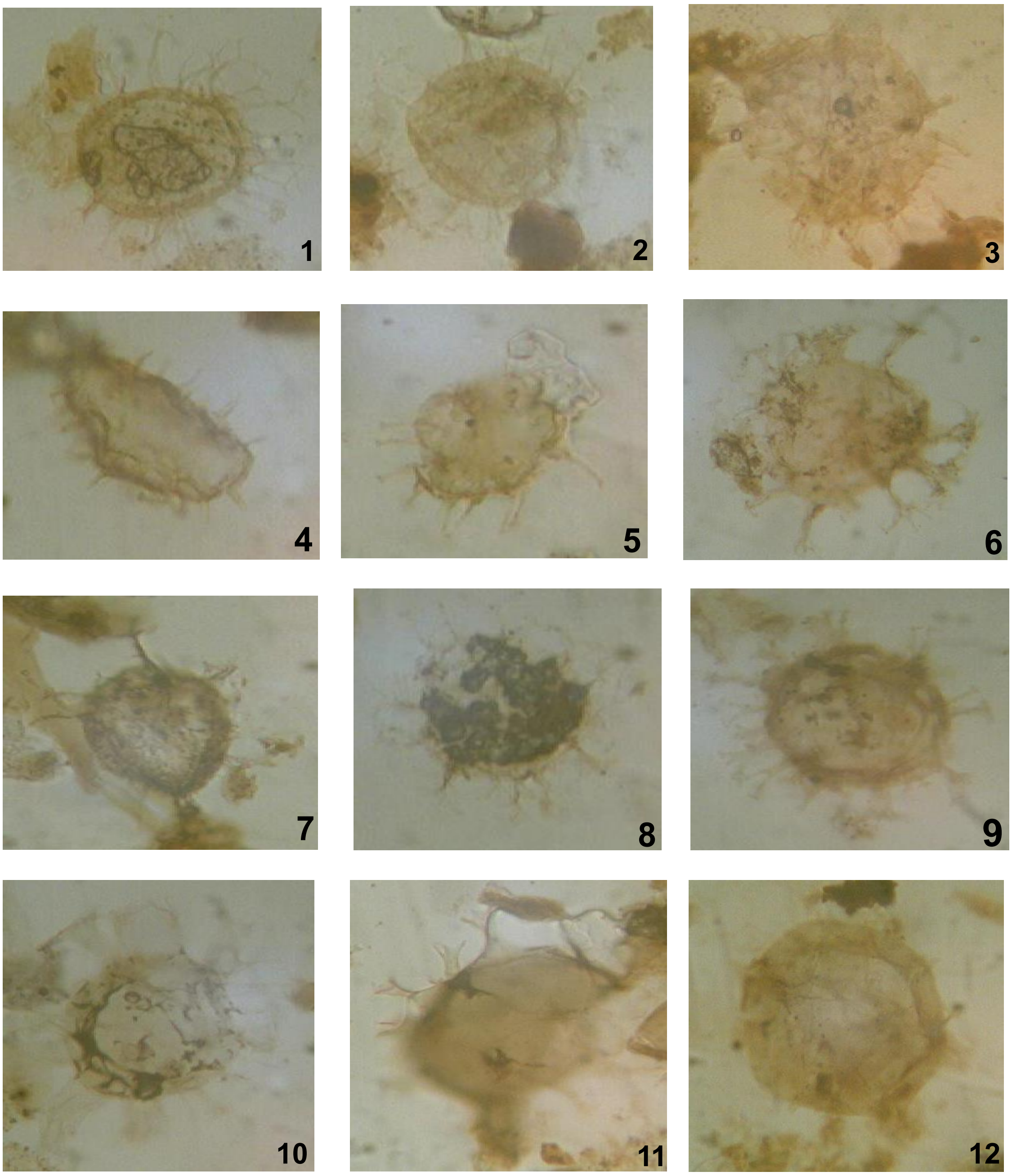
LEGEND **Magnification X400**

1 *Spiniferites* sp. (Oredo-4: 760-820 m); 2 *Hystrychokolpoma salacium* (Oredo-4: 1720-1750 m);
3&12 *Spiniferites pseudofurcatus* (Oredo-4: 2310-2320; 3670-3690 m);
4,8,10-11 *Spiniferites membranaceous* (Oredo-4: 2390-2400 m; 2520-2540 m);
5,6&9 *Spiniferites ramosus* (Oredo-4: 2390-2400; 2440-2460 m);
7 *Spiniferites* sp. (Oredo-4: 2440-2460 m).

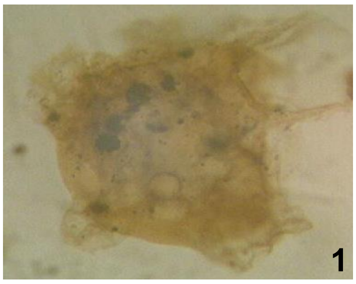
PHOTOMICROGRAPHS SHEET 12



LEGEND **Magnification X400**

1 *Spiniferites membranaceous* (Oredo-8: 380-410 m); 2. *Lingulodinium machaerophorum* Deflandre & Cookson) Wall, 1967. (Oredo-8: 2640-2680 m); 3 *Spiniferites membranaceous* (Oredo-2: 2510-2530 m); 4 *Lingulodinium machaerophorum* (Deflanre & Cookson) Wall, 1967. (Oredo-2: 2720-2740 m); 5 *Polysphaeridium zoharyi* (Oredo-2: 2900-2920 m); 6 *Homotryblium floripes* (Oredo-2: 2490-2510 m); 7 *Spiniferites ramosus* (Oredo-2: 2650-2670 m); 8 *Spiniferites* sp. (Oredo-2: 2650-2670 m); 9 *Spiniferites pseudofurcatus* (Oredo-2: 3840-3860 m); 10*Hystrichokolpoma rigaudae* (Oredo-2: 1780-1840 m); 11 *Homotryblium pallidium* (Oredo-2: 1600-1660 m); 12*Homotryblium abbreviatum* (Oredo-2: 1600-1660 m).

PHOTOMICROGRAPHS SHEET 13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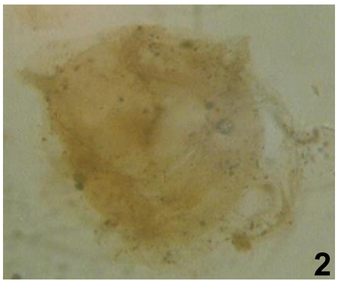
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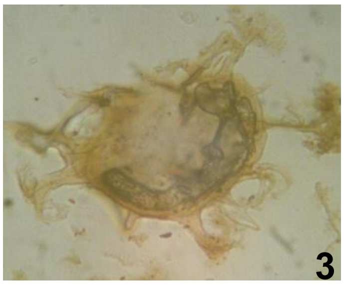
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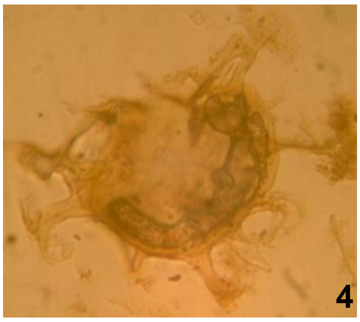
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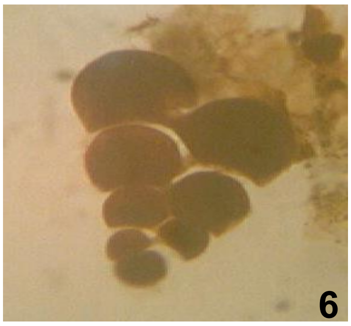
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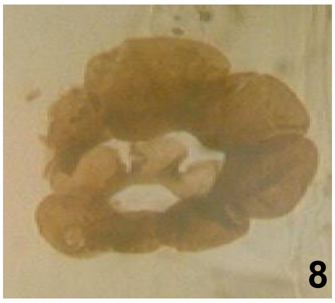
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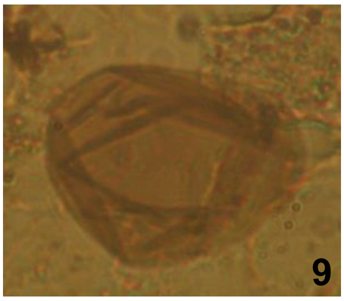
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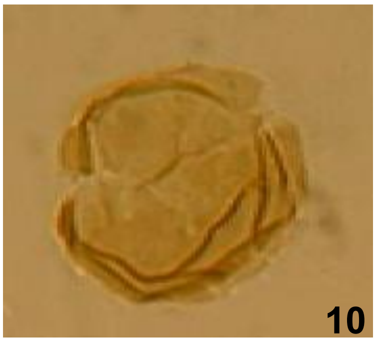
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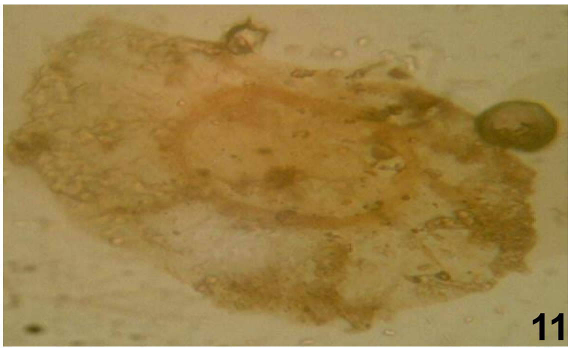
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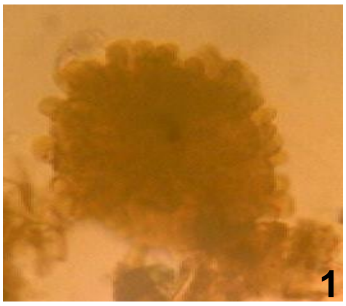
LEGEND **Magnification X400**

1&2 *Pentadinium laticintum* (Oredo-4: 2310-2320 m); 2&4 *Homotryblium* sp. (Oredo-4: 2480-2500 m); 5 *Selenopemphix nephroides* (Oredo-4: 3630-3670 m); 6&8 Microforaminiferal Wall Lining (MWL) (Oredo-4: 2660-2680 m; 3670-3690 m); 7 Microforaminiferal Wall Lining (MWL) (Oredo-8: 2480-2500 m); 9&10 *Leiospaeridium* sp. (Oredo-2: 1840-1900 m; 2050-2070 m); 11 *Pterospermopsis heliantoides* (Oredo-4: 2460-2470 m).

PHOTOMICROGRAPHS SHEET 14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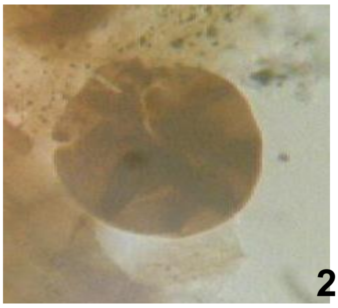
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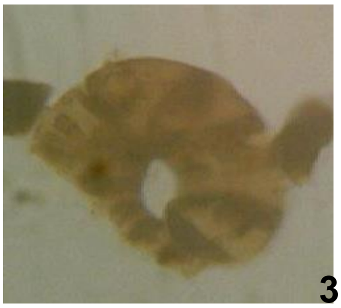
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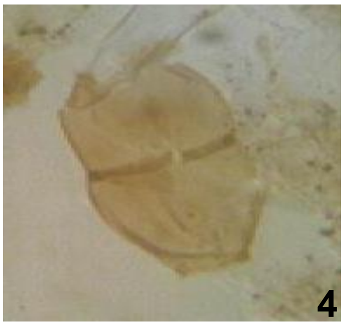
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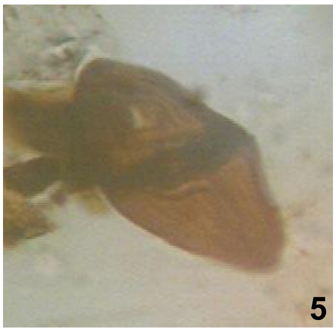
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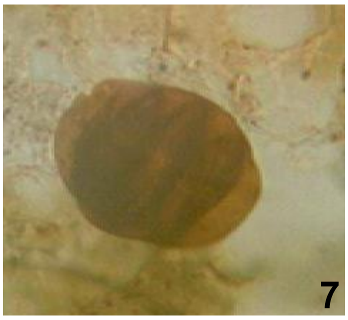
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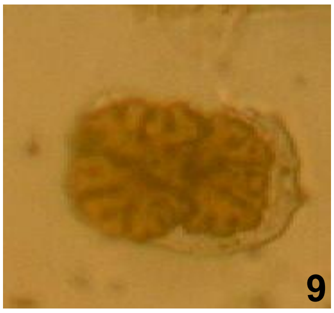
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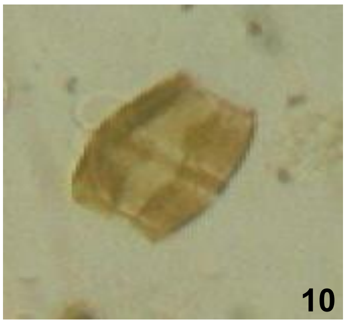
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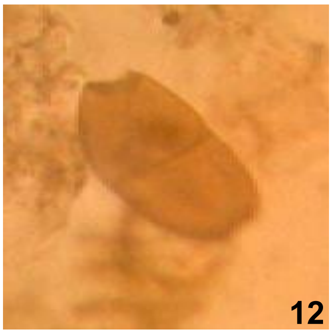
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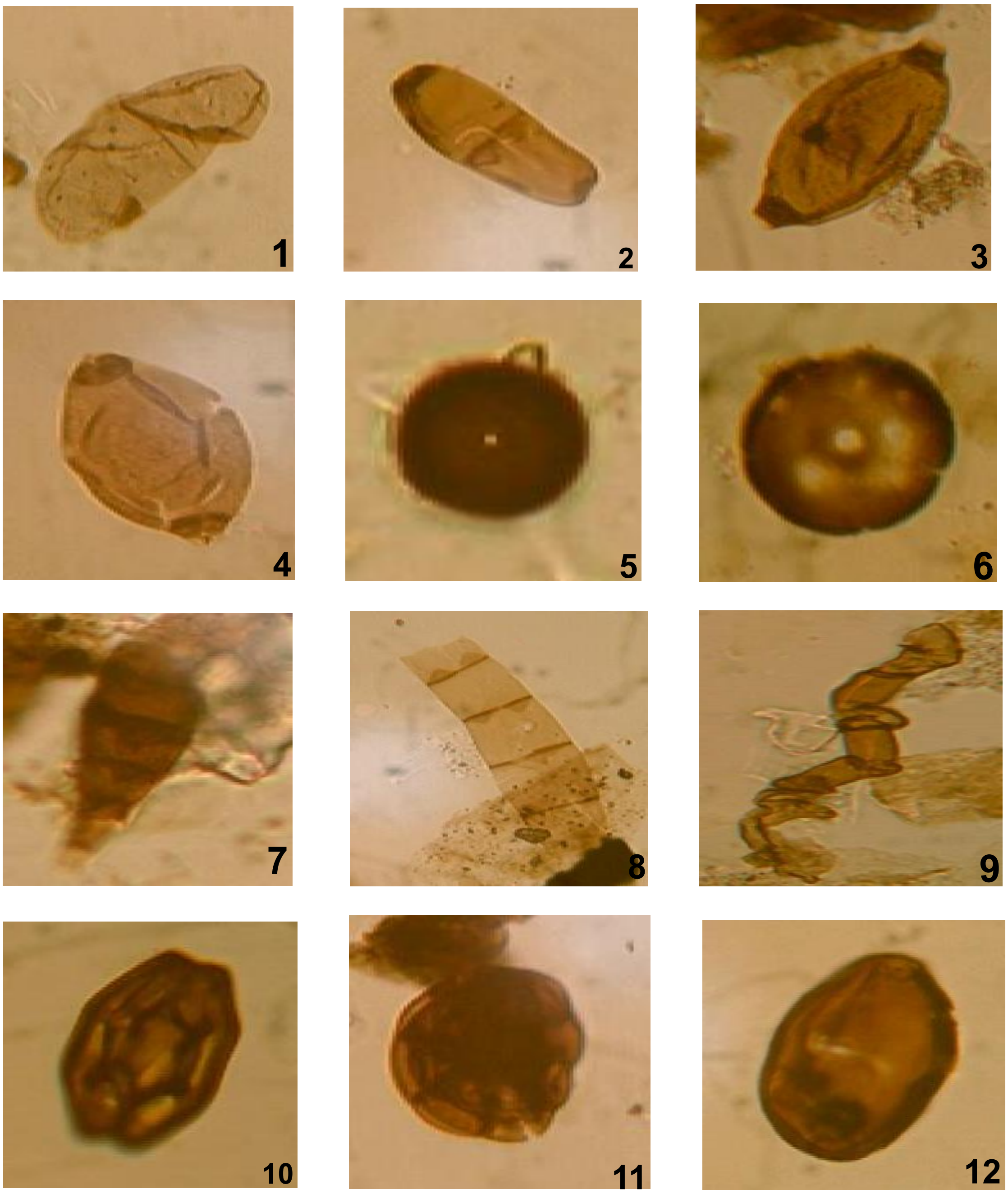
LEGEND **Magnification X400**

1 *Aletisporites* sp. (Oredo-4: 3700-3730 m); 2&3 *Pesavis tagliensis* (Oredo-2: 2220-2230 m); 4 *Trichodochium*-type (Oredo-2: 1540-1600 m); 5 *Diacellasporites* sp. (Oredo-2: 2220-2230 m); 6 *Coniechaeta*-type (Oredo-2: 1540-1600 m); 7 *Pleospora*-type (Oredo-2: 1270-1330 m); 8 *Glomus* sp. (Oredo-2: 2360-2380 m); 9 *Hyphopodium* sp. (Oredo-4: 1330-1390 m); 10&12 *Dyadosporites* sp. (Oredo-4: 700-760; 3670-3690 m); 11 ? Fungal Element (Oredo-4: 700-760).

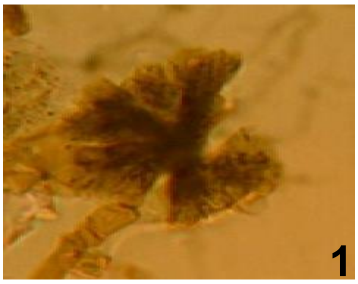
PHOTOMICROGRAPHS SHEET 15

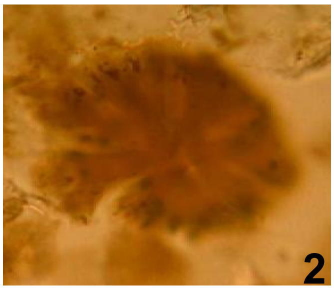


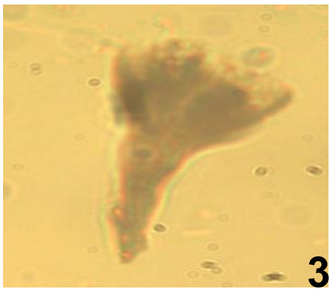
LEGEND **Magnification X400**

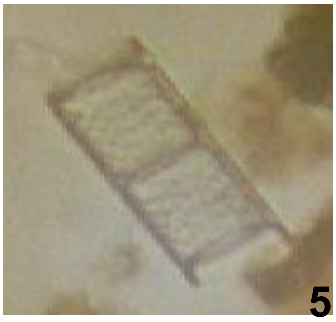
1&2 *Dicellaesporites* sp. (Oredo-2: 2170-2200 m); 3&4 *Diporisporites* sp. (Oredo-2: 2050-2070 m); 5&6 *Exesisporites* sp. (Oredo-2: 2170-2200 m); 7 *Alternaria*-type (Oredo-2: 2170-2200 m); 8 *Pluricellaesporites* sp. (Oredo-2: 2170-2200 m); 9 Fungal Hypha (Oredo-2: 2050-2070 m); 10 Fungal Spore Indeterminate (Oredo-2: 2050-2070 m); 11 *Polyadosporites* sp. (Oredo-2: 2170-2200 m); 12 *Polyporisporites* sp. (Oredo-2: 2170-2200 m).

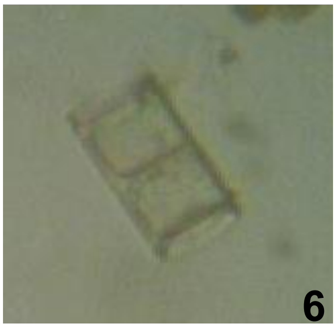
PHOTOMICROGRAPHS SHEET 16

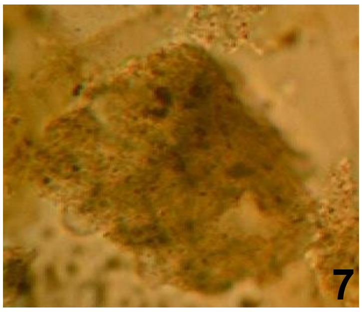


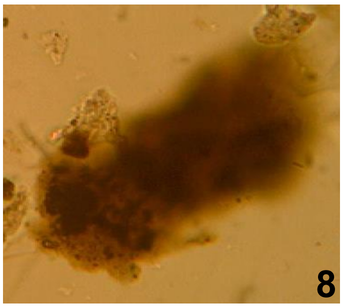


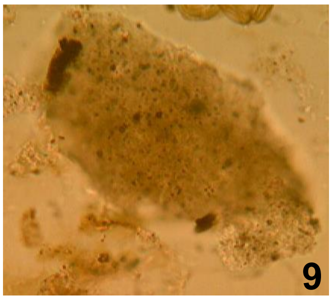


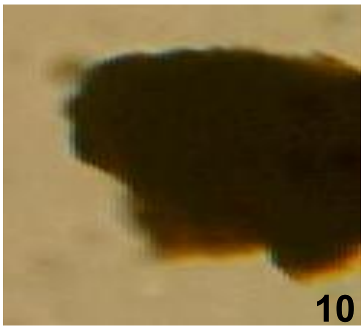


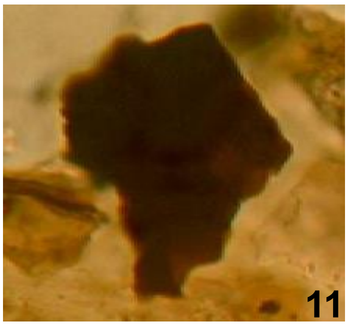


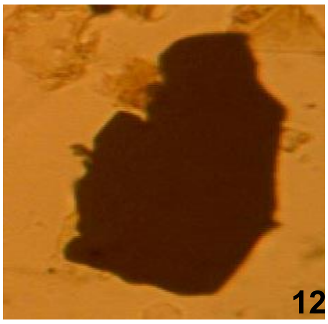








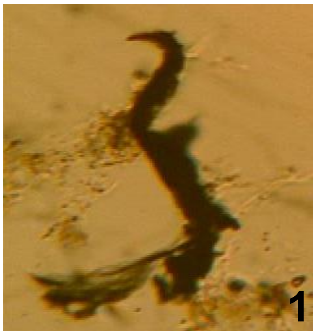


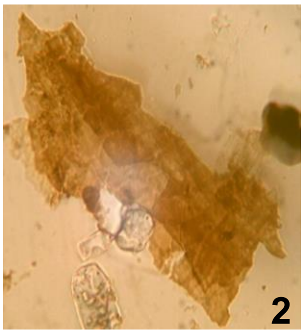


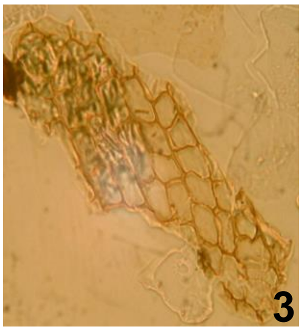
LEGEND **Magnification X400**

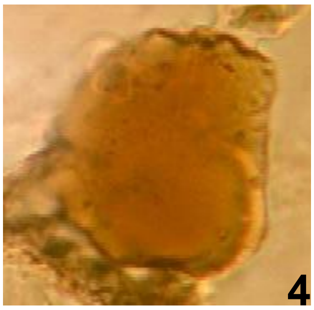
1-3 *Botryococcus braunii* (Oredo-2: 420-480 m); 4 *Concentricytes* (Oredo-2: 420-480 m); 5 Diatom (Oredo-4: 3700-3730 m); 6 Diatom (Oredo-2: 2220-2230 m); 7-9 Amorphous Organic Matter (AOM) (Oredo-2: 1120-1150 m); 10&11 Black and Brown Wood (BBW) (Oredo-2: 1120-1150 m; 2170-2200 m); 12 Charcoal (Black Debris) (Oredo-2: 2170-2200 m).

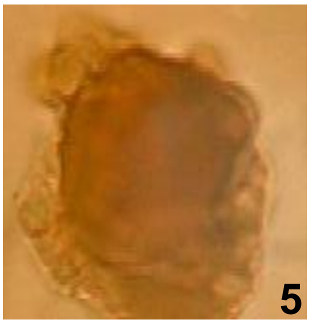
PHOTOMICROGRAPHS SHEET 17

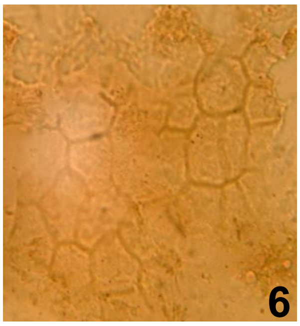


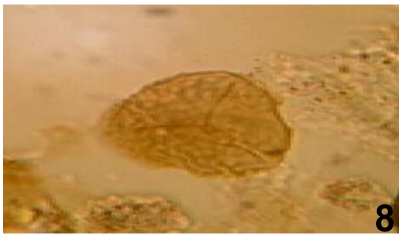


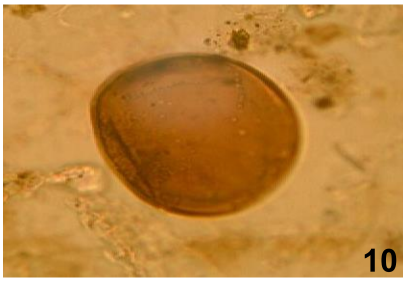








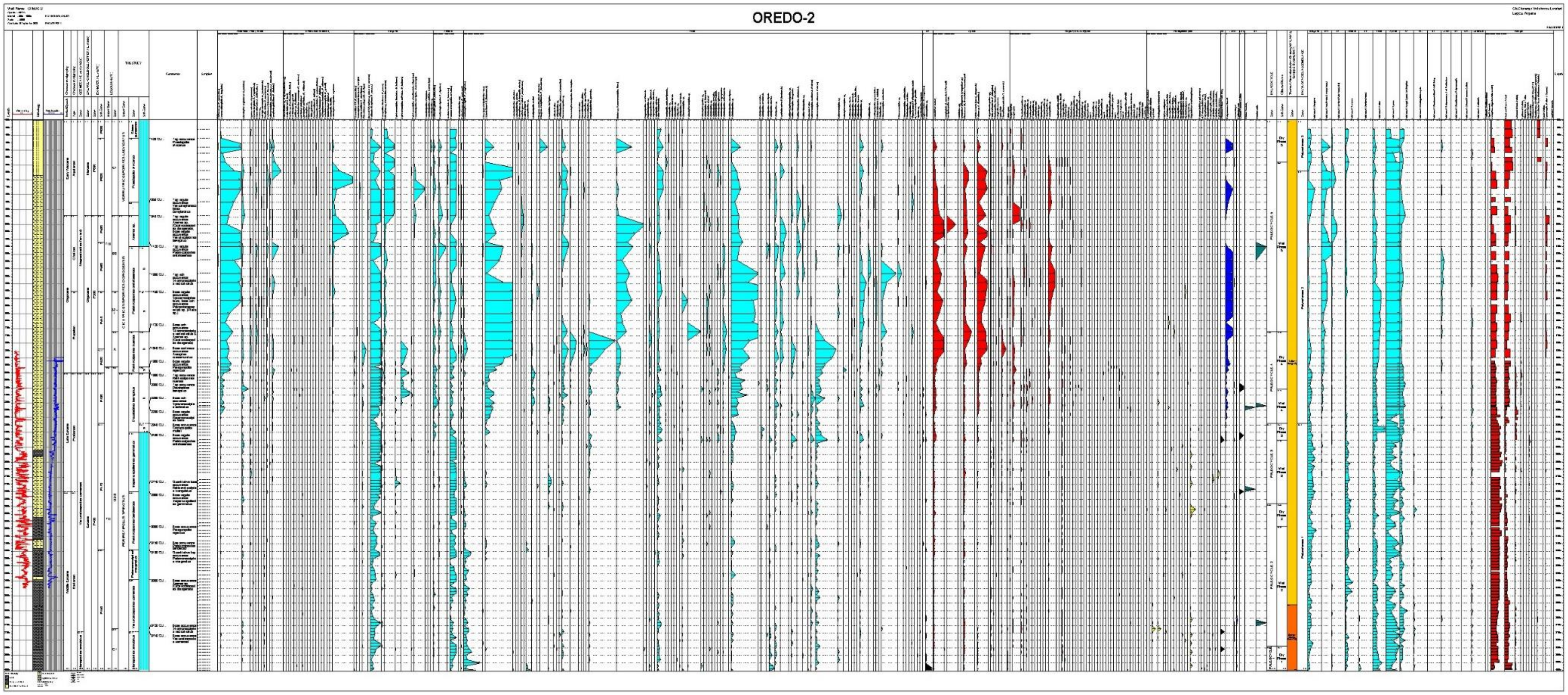


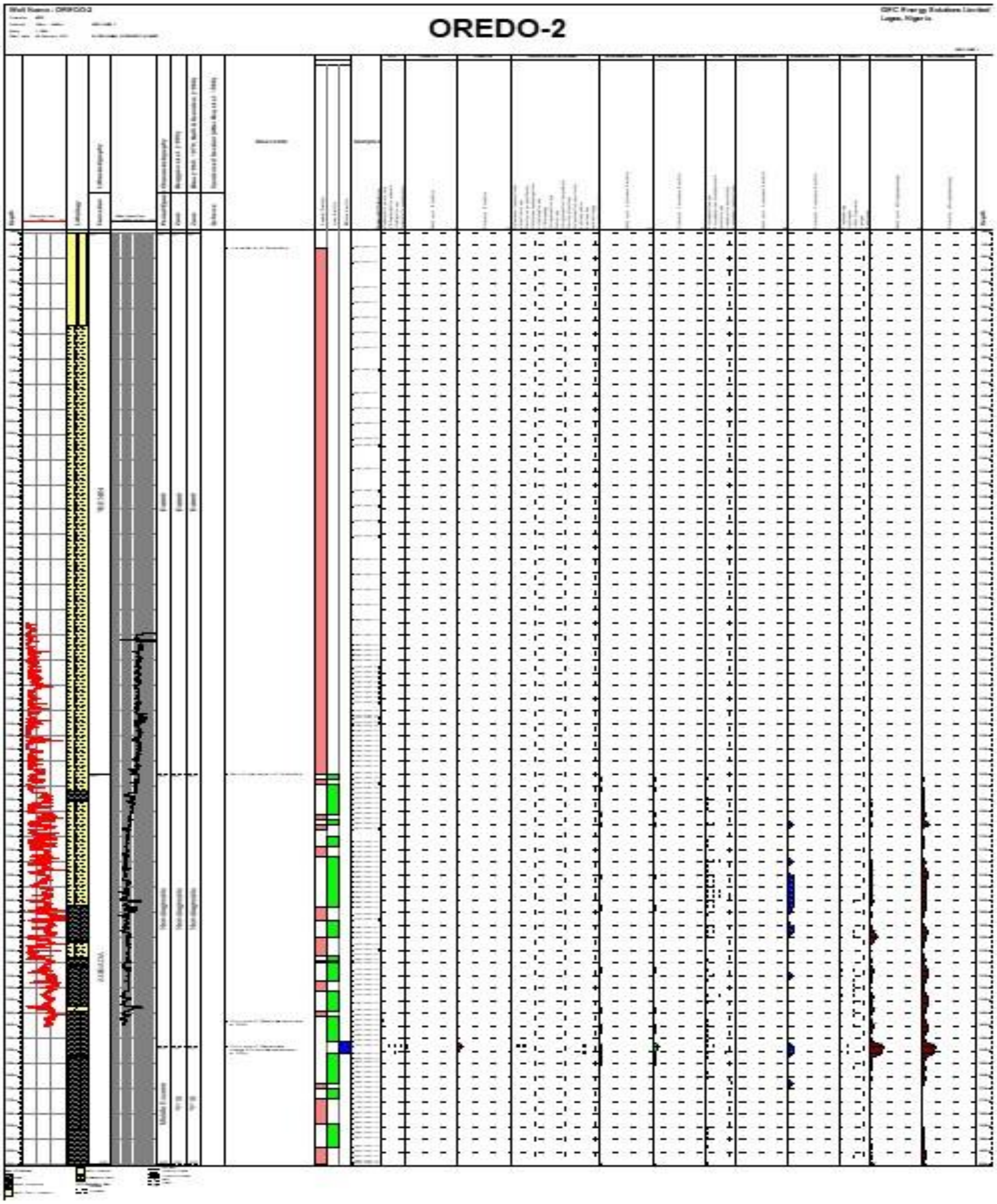


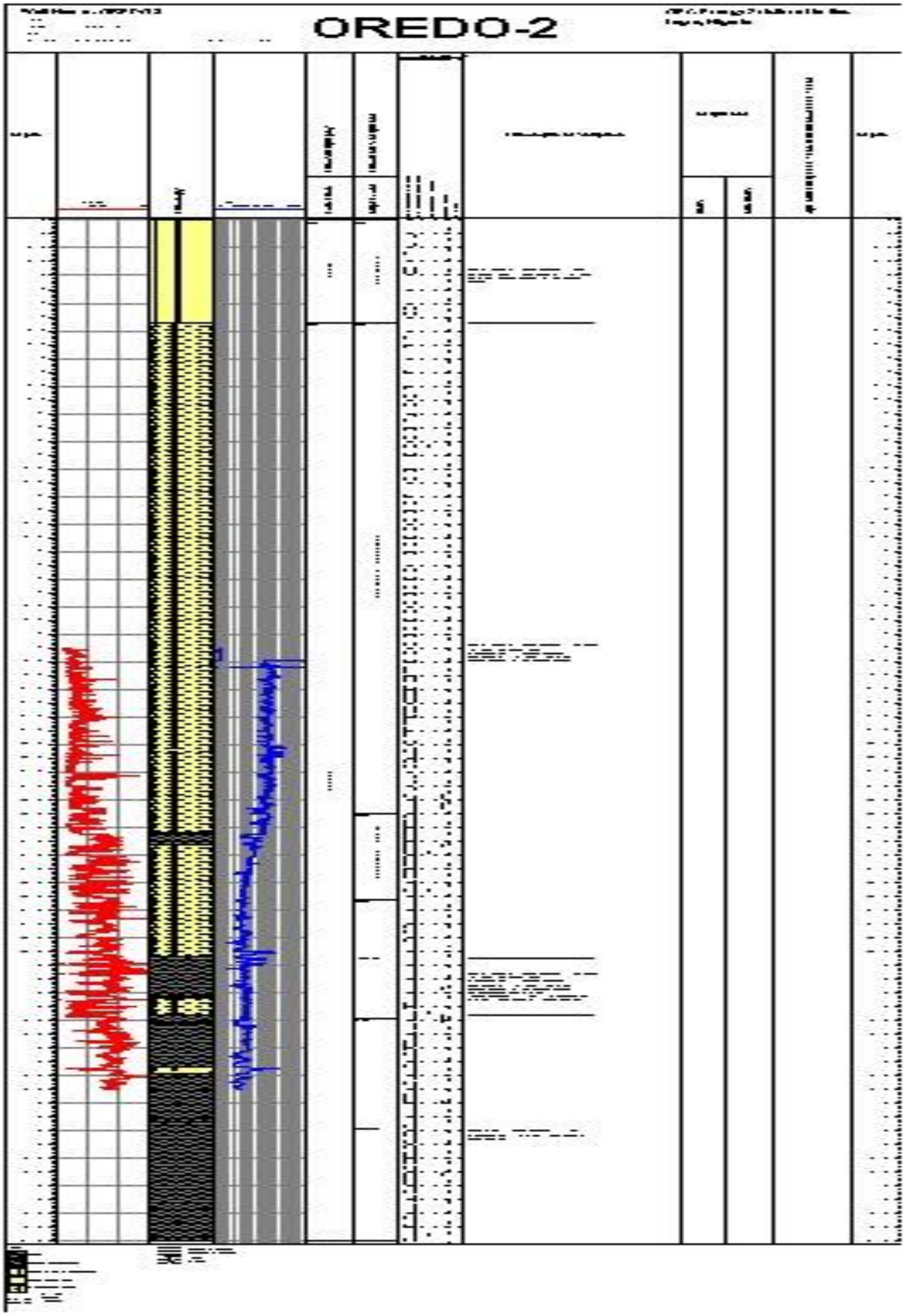
LEGEND **Magnification X400**

1 Charcoal (Black Debris) (Oredo-2: 1120-1150 m); 2 Tracheid (Oredo-2: 2740-2760 m); 3 Epidermal Cuticle (Oredo-2: 550-580 m); 4&5 Gelified Matter (Oredo-2: 2740-2760 m); 6 Epidermal Cuticle (Oredo-2: 1120-1150 m); 7 *Laevigatosporites discordatus* Yellow Orange (Oredo-2: 1120-1150 m); 8 *Lycopodiumsporites fastiginoides* Yellow Orange (Oredo-2: 1120-1150 m); 9 Trilete Spore Orange/Orange Brown (Oredo-2: 2720-2740 m); 10 *Laevigatosporites* sp.Orange/Orange Brown (Oredo-4: 2490-2510 m).

ENCLOSURES




Well Name : OREDO-2
OREDO-2
GFC Energy Solutions Limited
Lagos, Nigeria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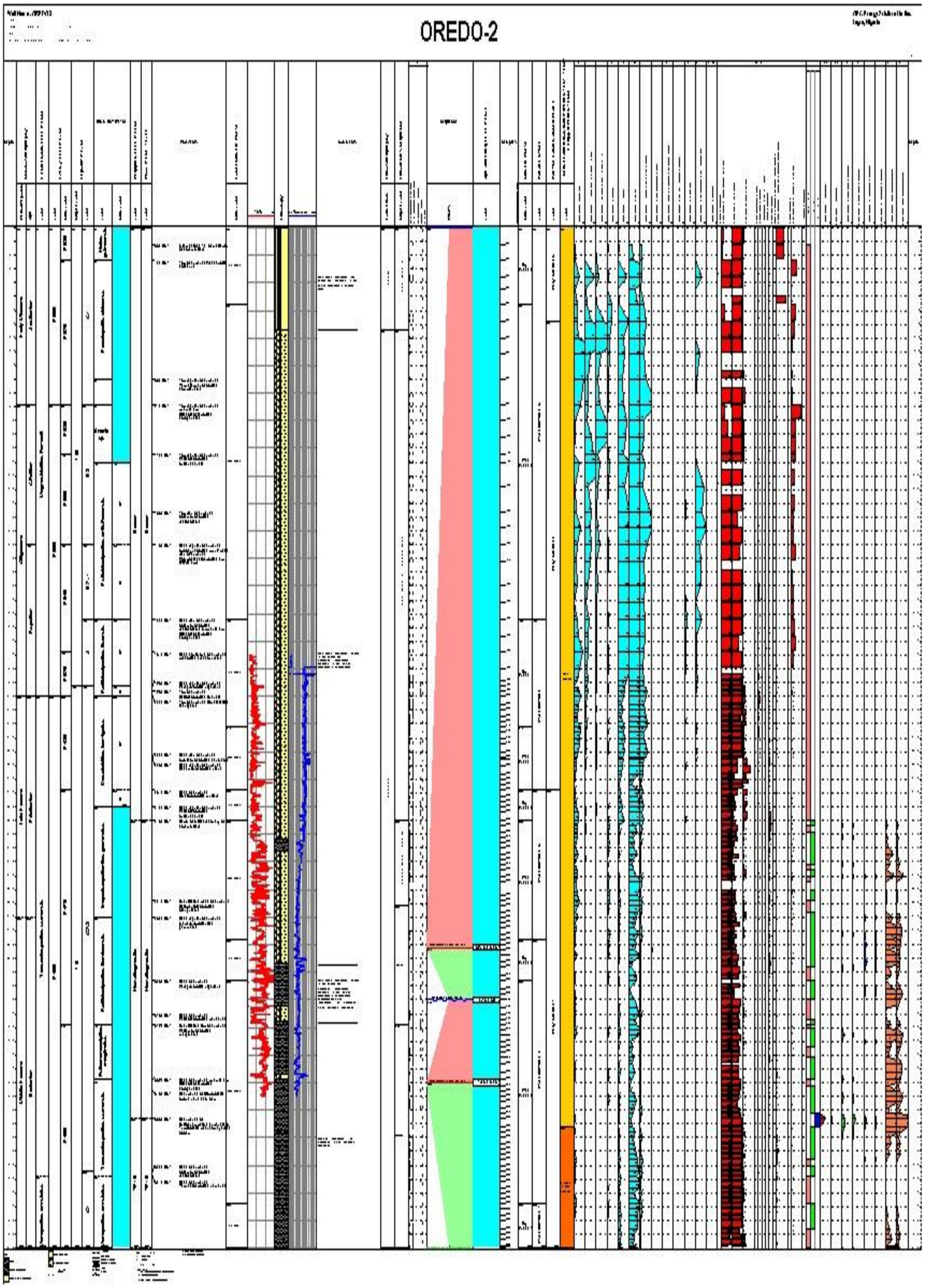
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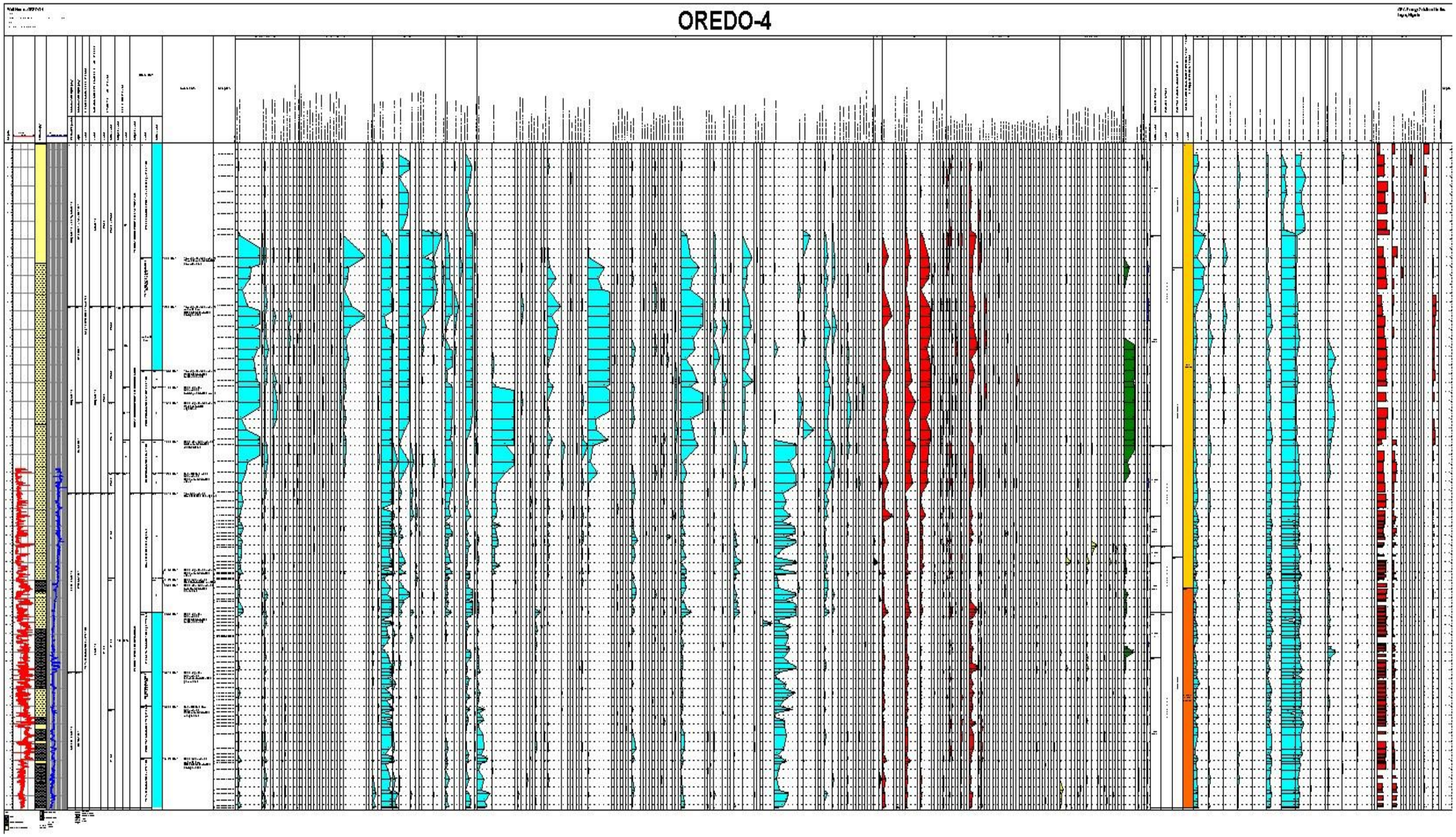
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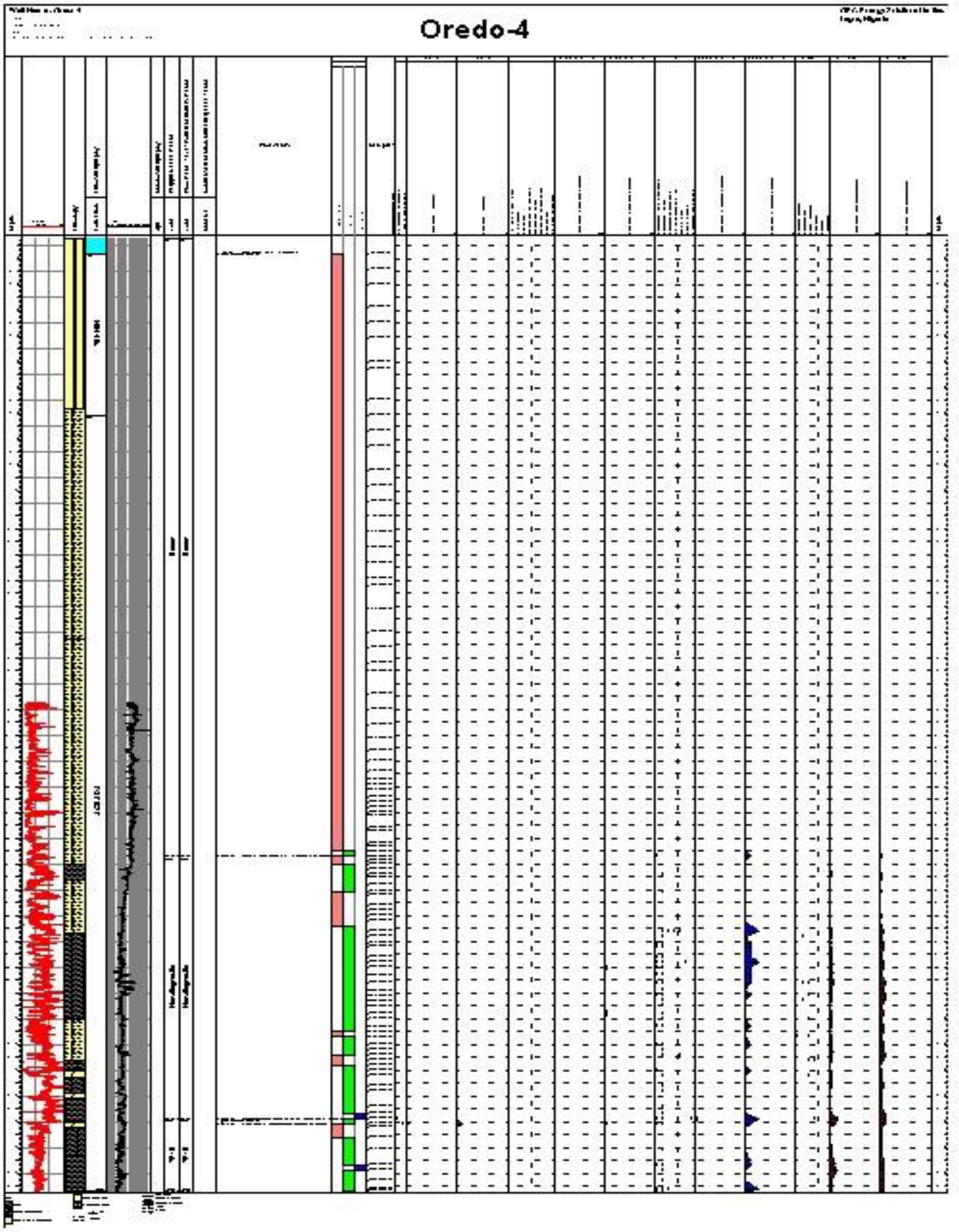
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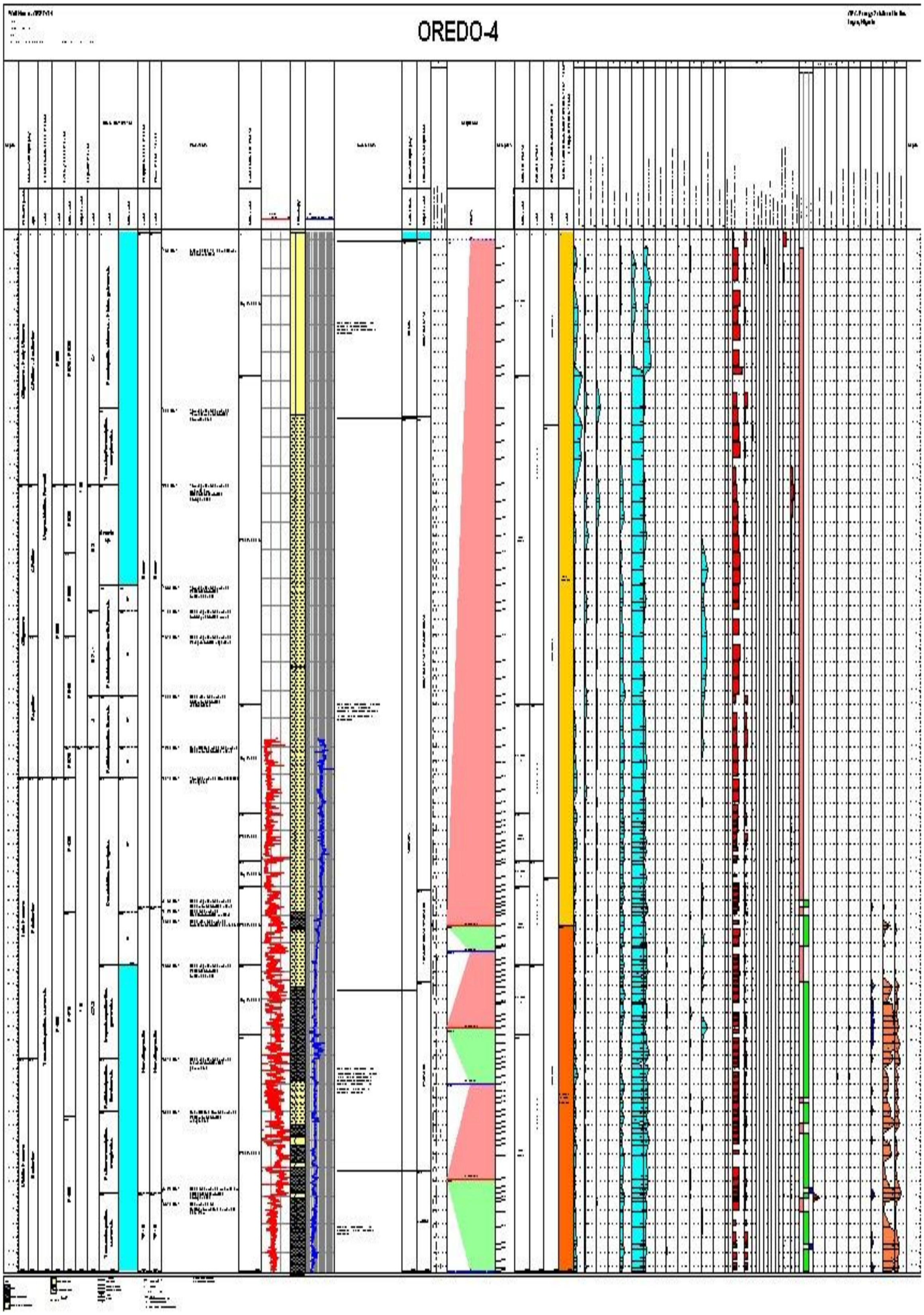
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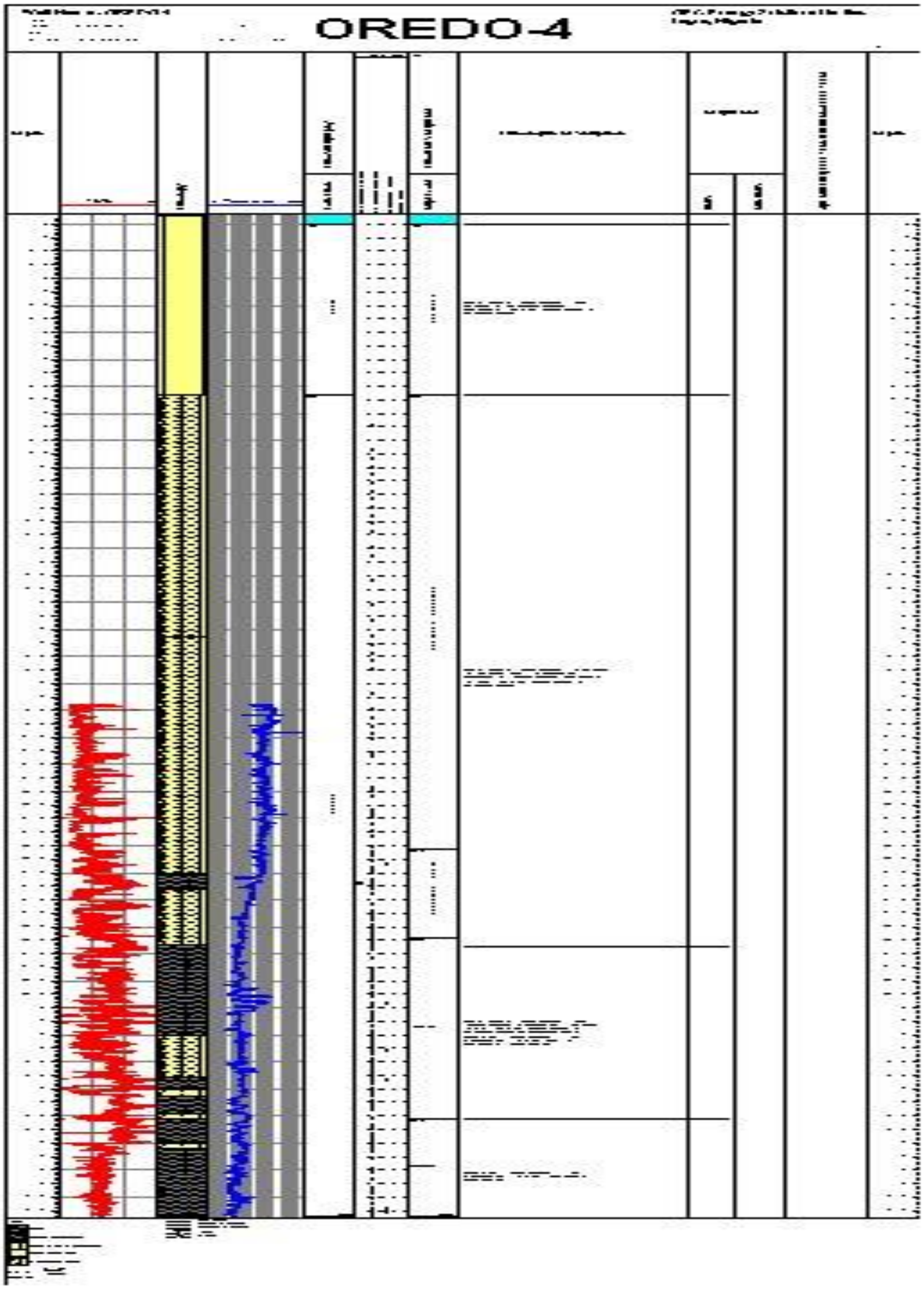
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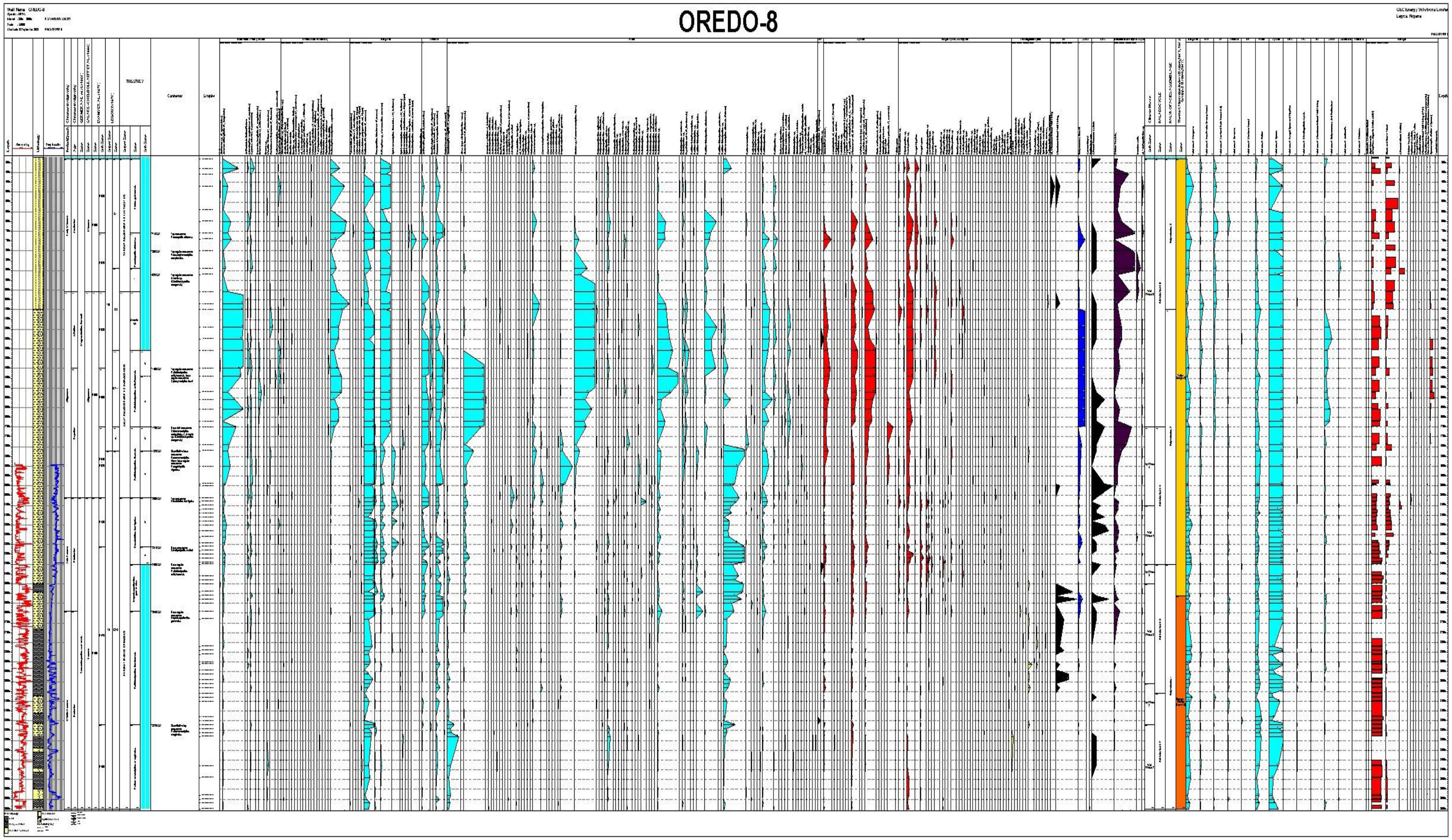
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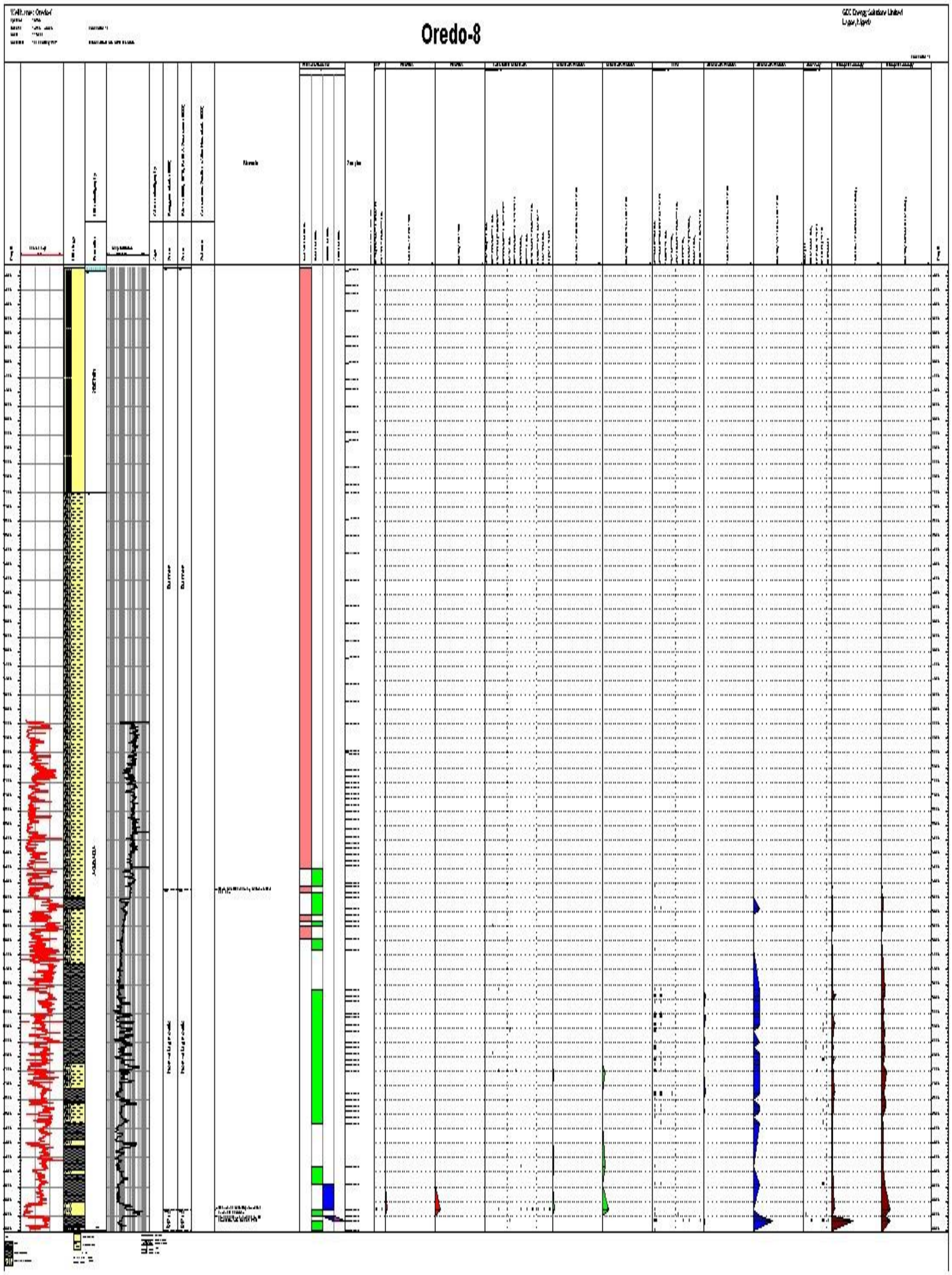
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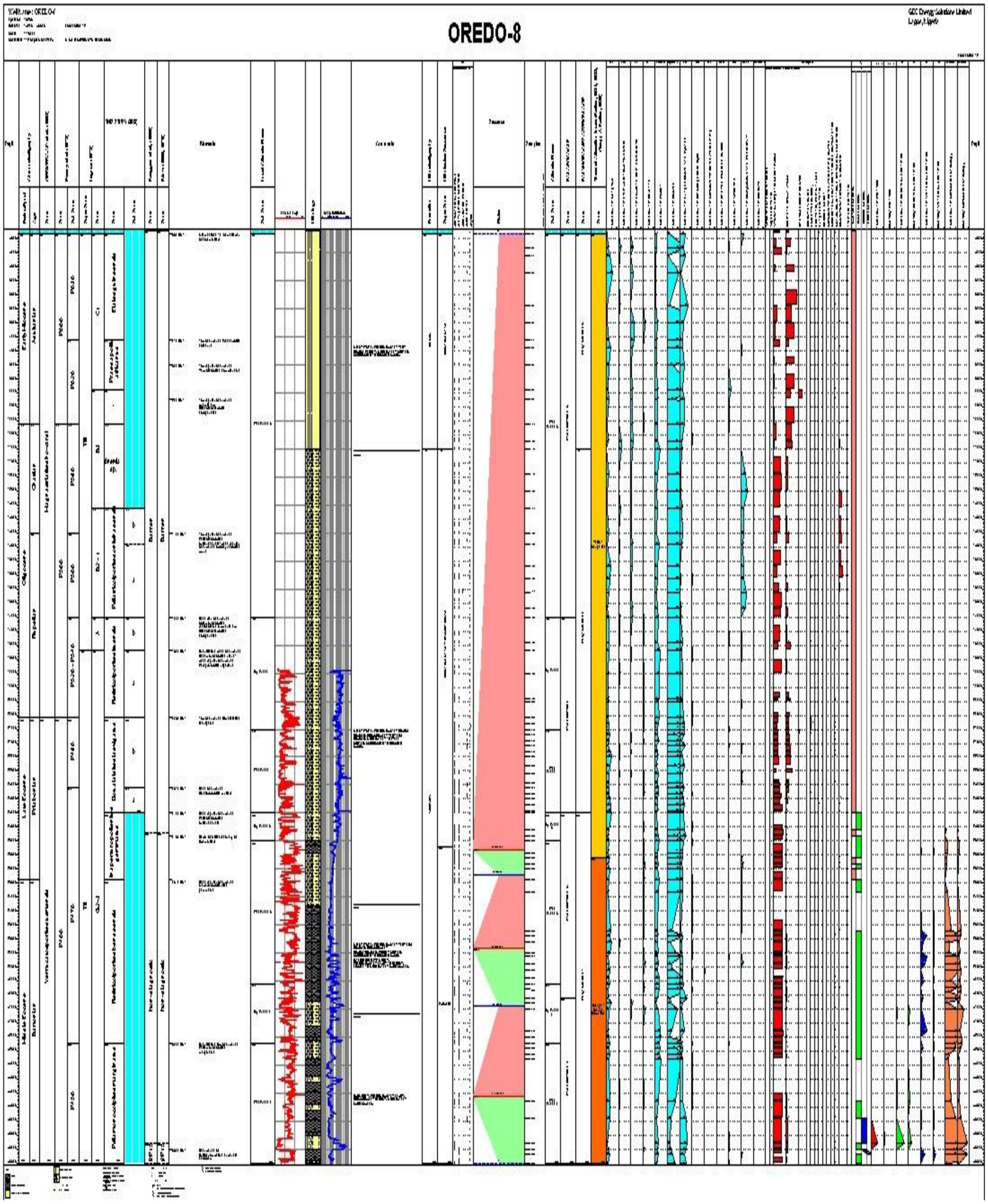
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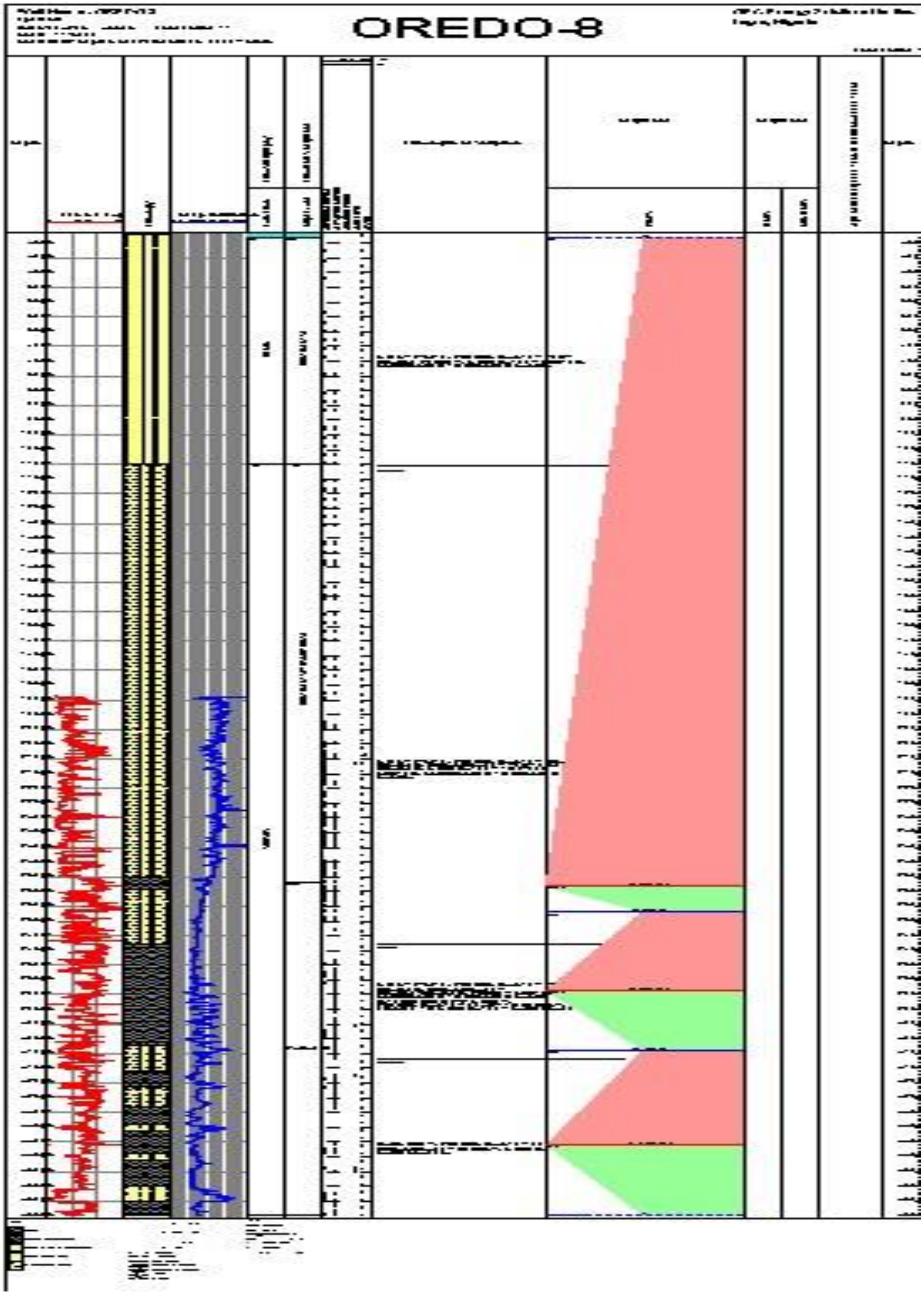
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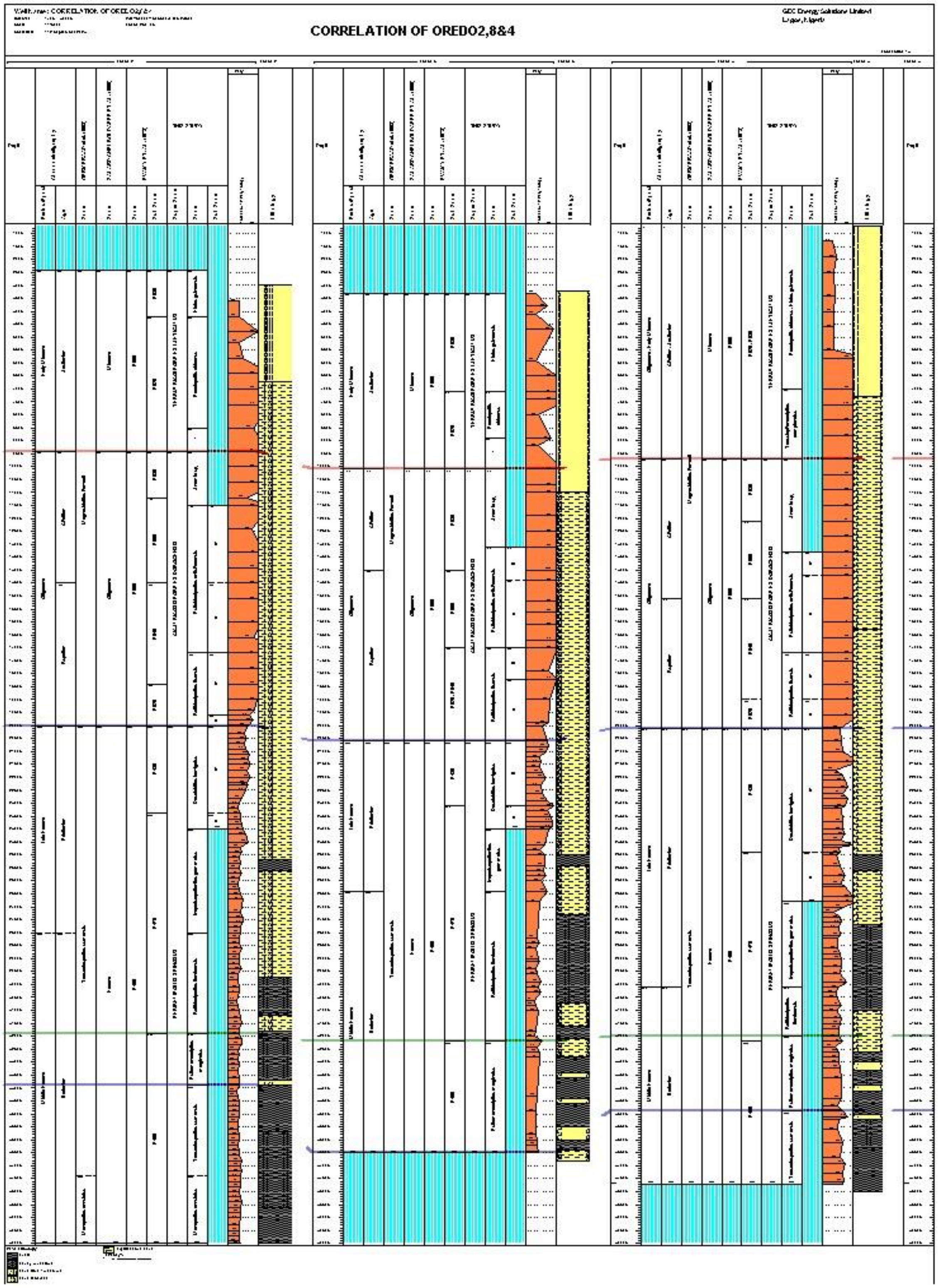
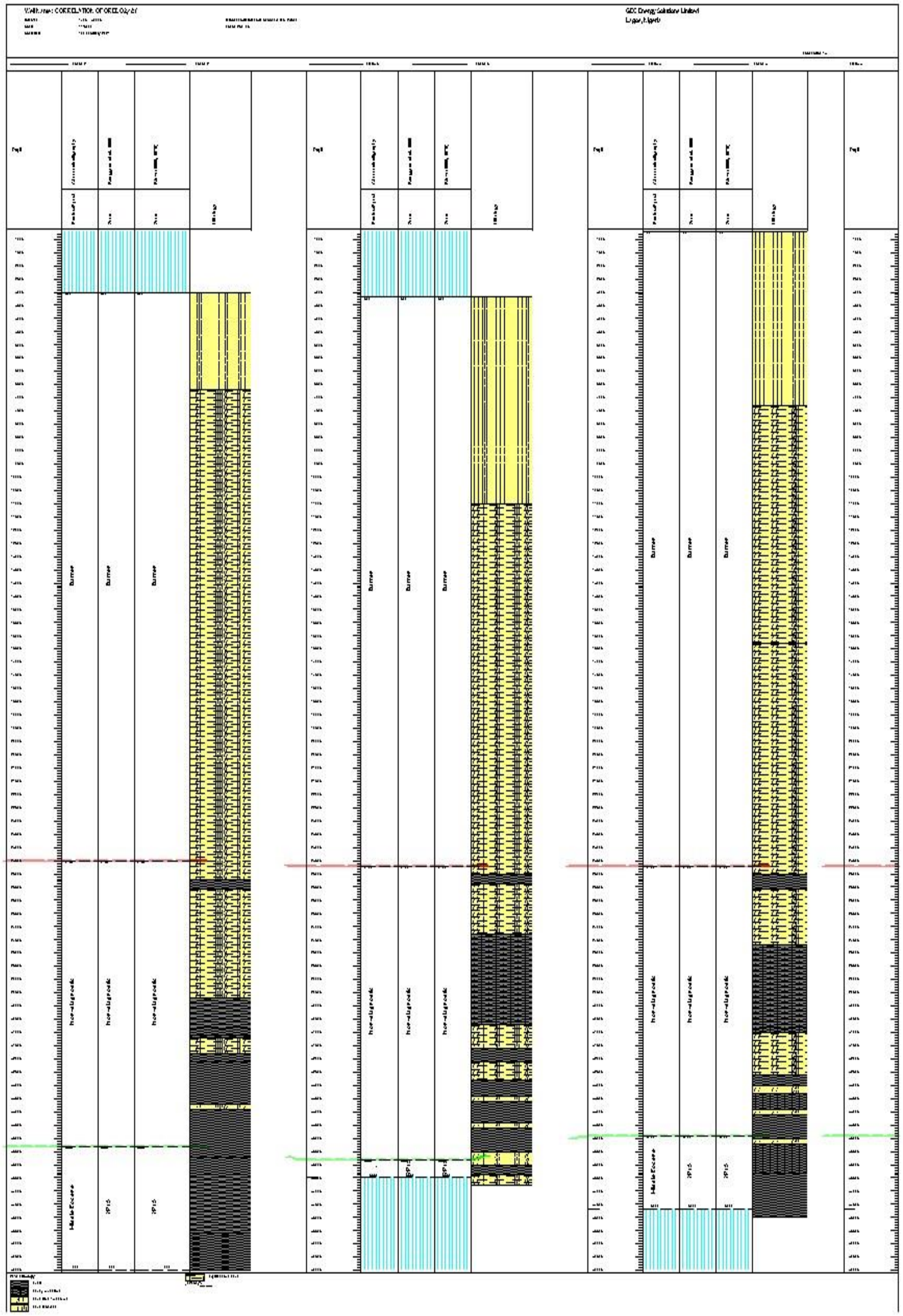
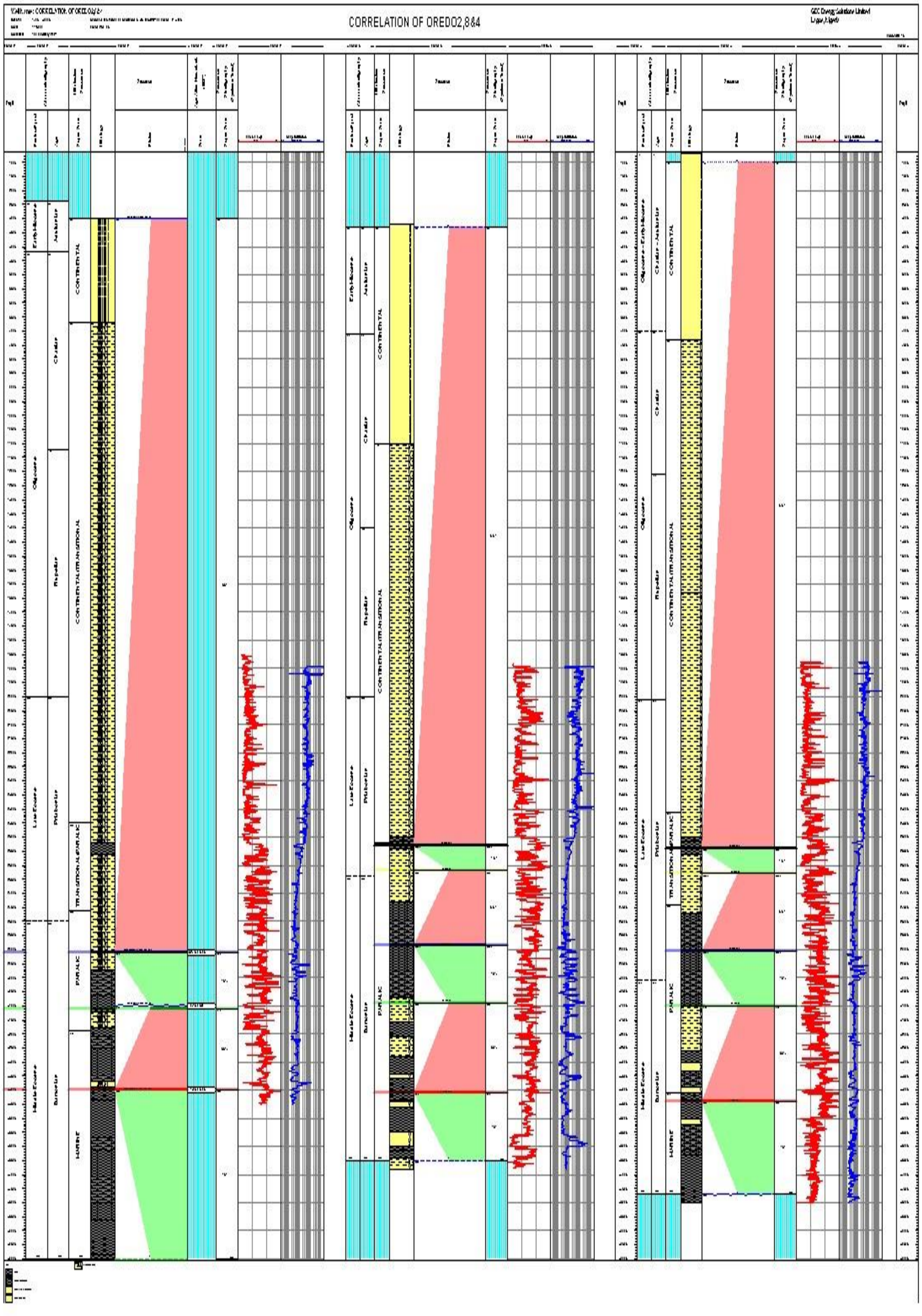

CORRELATION OF OREDO2,8&4
GDC Energy Solutions Limited
Lagos, Nigeria


Wellname: CORRELATION OF OKEL 02/ 07
GDC Energy Solutions Limited
Lagos, Nigeria
Barren
Non-diagnostic
Middle Eocene


CORRELATION OF OREDO2,8&4
GEC Energy Solutions Limited
Lagos, Nigeria
Early Miocene
Aquitanian
Oligocene
Chattian
Rupelian
Late Eocene
Priabonian
Middle Eocene
Bartonian
CONTINENTAL
CONTINENTAL/TRANSITIONAL
TRANSITIONAL/PARALIC
PARALIC
MARINE