PALYNOFACIES ANALYSIS AND THERMAL MATURATION STUDY OF SEDIMENTS OF IDM 4 AND IDM 5 WELLS OF NIGER DELTA BASIN, NIGERIA

BY

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ABSTRACT

Palynofacies analysis and thermal maturation study was carried out on IDM-4 and IDM-5 wells of the Niger Delta Basin. The location of the studied area lies within Latitude 04º 08’ 02’’ N and longitude 06º 08’ 06’’ E for IDM-4 and latitude 04º 08’ 0’’ N and longitude 06º 07’ 06’’ E for IDM-5. The studied depth of the well is 10030 ft– 11700 ft at 30 ft interval. Palynological processing, analysis and interpretations were carried out on forty-nine and forty-seven ditch cutting samples from the IDM-4 and IDM-5 wells, respectively. Kerogen analysis was also carried out on the part samples. Simple acid method of sample preparation was used during the palynofacies analysis. Physical observation and Gamma Ray log were used in determining the lithology of the sedimentary succession. The lithology consists of the fine to medium sized sandstones and sandy mudstones. Abundant species of palynomorphs and palynomacerals were recovered. Some of which are biomarkers such as *Zonocostites ramonae, Pachydermites diederixii, Sapotaceodaepollenites sp., Psilatricolporites cassus. Crassoretitriletes vanraadshooveni, Laevigatasporites sp.* This is correlatable to early-Miocene to middle-Miocene stratigraphic ages. Two zones were established in IDM-4well. They are *Pachydermites diederixi*zone which falls within the 7000 ft and 7990 ft and *Crassoretitrites vanraadshooveni*Zone which falls within the interval 6030 ft and 7000 ft. Three zones were established in IDM-5 well. They are *Polypodiaceoisporites* sp. Zone, Magnastriatites *howardi* Zone and *Pachydermites diederixi* Zone. The palynofacies associations show the depositional environment of *Pachydermites diederixii* to be mangrove swamp *while Crassoretitrites vanraadshooveni* Zone indicates mangrove- shoreface depositional environment for IDM-4 while the depositional environment of the studied interval is interpreted to predominantly range between Mangrove and Channel depositional environments for IDM-5. For IDM-4 well, the intervals such as 6050 ft, 6150 ft, 6400- 6600 ft, 6900- 6950 ft are the intervals that show the mature phase of liquid oil while intervals 6100 ft, 6200- 6400 ft, 6600- 6900 ft, 6950- 7950 ft are the phase of dry gas. For IDM-5 well, intervals 10000 -10950 ft are the phases of dry gas while intervals 10950- 11025 ft and 11450-11700 ft are the phases of mature liquid oil.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Palynofacies encompasses the total complement of acid-resistant organic matter recovered from a sediment or sedimentary rock by palynological processing techniques, using hydrochloric acid and hydrofluoric acid, as seen under a microscope (Combaz, 1964). Powell *et al.* (1990) redefined the term as “a distinctive assemblage of palynoclasts whose composition reflects a particular sedimentary environment”. Tyson (1995), however, added that apart from reflecting a specific set of environmental conditions, it is also associated with a characteristic range of hydrocarbon-generating potential. Other workers have referred to organic components in sediments as organic matter, palynodebris, palynomaceral, and kerogen (Mudie, 1992; Staplin, 1969; Whitaker, 1984; Boulter and Riddick, 1986; Traverse, 1988; Lorente, 1990; Tyson, 1995).

Polynofacies is the total complement of acid resistant particulate organic matter recovered from sediments by palynological processing techniques (Tyson, 1995). Tyson (1995) provided that one of the most widely use definition of the palynofacies as the total particulate organic matter assemblage contained in a body of sediments is indicative of a particular type of environmental condition or is associated with a characteristic range of hydrocarbon generating potential.

According to Lucas (2017) palynofacies is a relatively new aspect of palynology; the term connotes the global microscopic image of the organic constituents of the rock after proper carrying out of maceration and mounting under standard conditions of preparation. In other words, palynofacies involves the examination of the total acid insoluble component of the sedimentary samples (outcrops, cores or ditch cuttings) with focus on the constituent elements, their proportions, diversity of palynomorph, types, sorting and size characteristics and evidence for biological and physical degradation.

Muhammed *et al*. (2008) reported that in source rock quality, palynofacies and the thermal history of the Niger Delta Basin will give a detailed picture of the hydrocarbon generation and the source rock potential of the basin.

Tyson (1995) classified palynofacies into phytoclasts, opaques (black debris), Amorphous organic matter (AOM) and palynomorphs. Kholeif and Mudie (2010) has extensively described the palynofacies that include spores, pollen, dinoflagellates, acritarchs, chitinozoans, prasinophytes, foraminiferal linings and marine algae. These are abundant in fine grained muds, shales, clays, and sometimes in sandstones and limestones (Mudie, 1992).

Pollen and spore assemblages from superficial sediments provide useful information that can aid the proper understanding of depositional environments and stratigraphy of geologic formation. Therefore, it is a means of elucidating the environment represented by a particular lithological sequence. Onoduku (2014) noted that the study of fossil remains in sedimentary succession had become a valuable tool which is universally accepted to understand the stratigraphy and source rock potential of sedimentary basins. Palynofacies study is advantageous over other fossils studies because, palynofacies are widely distributed, they can be found in their terrestrial, freshwater, saltwater, or estuarine source of sedimentary rocks.

Organic diagenesis or maturation is one of the parameters to be considered in the evaluation of hydrocarbon producing potentials of sediments. Maturation is considered to be controlled by various factors including the temperature, pressure and time. Some other parameters include geothermometry state of preservation of organic matter, vitrinite reflectance studies, organic geochemical studies, clay mineralogy and microscopic studies can be integrated to define a maturation scale or the thermal alteration index.

Thermal alteration index is established specifically relating to the physical alteration observed in the kerogens evaluated. The state of preservation of the organic matter has been used to characterize the degree of organic maturity. Additional to the alteration states of palynomorphs, the zonation has been based on the vitrinite reflectance values, clay mineralogic compositions and pyrolysis.

Tyson (1995), the main uses of palynofacies include:

i. Determining magnitude and location of terrigenous inputs (proximal-distal relationships with respect to source).
ii. Determining depositional polarity (onshore-offshore axes).
iii. Identifying relative shallowing-deepening and regressive-transgressive trends in stratigraphic sequences (and hence Sequence Tracts and Flooding Surfaces).
iv. Characterizing and to subdividing sedimentologically uniform facies, especially shales.
v. Determining hydrocarbon source rock potential and to qualify the bulk rock geochemical

parameters.

vi. Estimating differences in primary productivity and water mass stratification (using absolute and relative abundance of different types of organic-walled microplankton).
vii. Discriminating among environments, for example: oxic open marine, dysoxic-anoxic marine, and brackish freshwater.

1.2 Statement of the Research Problem

An accurate identification of thermally matured sediments/source rocks is a challenge to petroleum exploration (Okeke and Umeji, 2016).

Researchers like Inyang *et al.* (2016), Lucas (2017), Chukwuma-Orji *et al* (2017) and a lot of others have carried out researches on palynofacies and depositional environment of the Niger Delta Basin, but did not work on thermal alteration indices of the rocks.

Few works have been done on the use of palynomorphs to identify oil bearing zones, (Okeke and Umeji, 2016) more work still need to be done to provide more accurate data on the thermal alteration in identifying productivity levels of oil wells in the Niger Delta Basin.

Evamy *et al*. (1987) used Alpha-numeric method to establish biozone which is not in line with the international standard. Therefore, biozone established in line with international standard is needed.

1.3 Justification for the Study

Biostratigraphy studies in the Niger Delta Basin is a very important aspect of research as regards oil exploration. Thermal alteration studies useful in delineating matured source rocks. Biozone done in line with international standard is essential in oil industry for accurate relative dating and correlation of reservoirs.

1.4 Aim

The aim of this research is to carry out palynofacies analysis of the sedimentary succession penetrated by IDM- 4 and IDM-5 wells in order to identify the palynomorph maker species and palynomacerals which would be related to palyzones and sediment maturity of the successions.

1.5 Objectives

The objectives of this research are as follows:

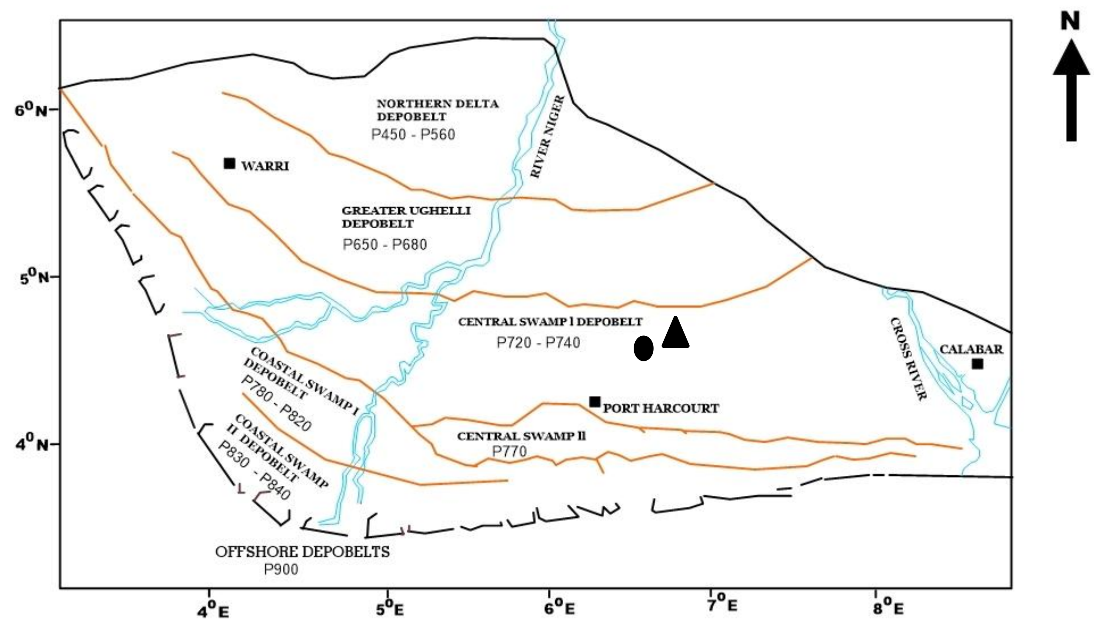
- Establish the palynofacies associated with the strata within the field using the recovered palynomorphs and palynomacerals.
- Determine the environment of deposition of the succession using the palynofacies association.
- Deduct the maturity of the potential source rock intervals (shales) using palynofacies.

1.6 Scope of Work

The work covers palynofacies analysis, depositional environment and thermal maturation analyses of IDM-4 and IDM-5 wells in the Niger Delta Basin.

1.7 Location of the Study Area

The studied wells are part of the Niger Delta Basin's Central Swamp Depobelt (Figure 1). The Niger Delta lies within latitudes 04° and 07° N and longitudes $03^{\circ}$and 09° E (Figure 2). IDM 4 and IDM 5 wells are situated in IDM field of the Niger Delta Basin. IDM 4 well is situated on latitude 04° 08' 02" N and longitude 06° 08' 06" E, while IDM 5 is located within latitude 04° 08' 00" N and longitude 06° 07' 06" E



Key: ■ – **City** ● - **IDM 5** ▲ - **IDM 4**

Figure 1: Location of the studied wells (Modified after Doust and Omotsola, 1989)

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Regional Geology of the Niger Delta Basin

The Niger Delta Basin, also referred to as the Niger Delta province, is an extensional rift basin located in the Niger Delta and the Gulf of Guinea on the passive continental margin near the western coast of Nigeria (Tuttle *et al.,* 2015). This basin is very complex, and it carries high economic value as it contains a very productive petroleum system. The Niger Delta Basin is one of the largest subaerial basins in Africa. It has a subaerial area of about 75,000 km^2, a total area of 300,000 km^2, and a sediment fill of 500,000 km^3 (Tuttle *et al.,* 2015). The sediments fill has a depth between 9-12 km. It is composed of several different geologic formations that indicate how this basin could have formed, as well as the regional and large scale tectonics of the area (Fatoke, 2010). The Niger Delta Basin is an extensional basin surrounded by many other basins in the area that all formed from similar processes. The Niger Delta Basin lies in the south westernmost part of a larger tectonic structure, the Benue Trough. The other side of the basin is bounded by the Cameroon Volcanic Line and the transform passive continental margin. (Fatoke, 2010).

The Niger Delta Basin was formed by a failed rift junction during the separation of the South American plate and the African plate, as the South Atlantic began to open. Rifting in this basin started in the late Jurassic and ended in the mid Cretaceous. As rifting continued, several faults formed many of the thrust faults. Also, at this time syn-rift sands and then shales were deposited in the late Cretaceous. This indicates that the shoreline regressed during this time.

The Niger Delta stratigraphic sequence comprises an upward-coarsening regressive association of Tertiary clastics up to 12 km thick (Weber and Daukoru, 1975; Evamy *et al.,* 1987). It is informally divided into three gross lithofacies: (i) marine claystones and shales of unknown thickness at the base; (ii) alternation of sandstones, siltstones and claystones, in which the sand percentage increases upwards; (iii) alluvial sands, at the top (Doust and Omatsola, 1990). Three lithostratigraphic units have been recognized in the subsurface (Short and Stauble, 1967) which are the basal and oldest Akata Formation that compose primarily of dark shale with occasional sand and considered the hydrocarbon producing unit. The middle Agbada Formation considered the main petroleum bearing unit and consisting of interbedded sandstone and shale. Lastly, is the topmost Benin Formation which consists of continental sand (Short and Stauble, 1967) (Figure 2). These formations were deposited in environments which are marine, transitional and continental respectively; forming a thick, progradational passive-margin wedge.

Three major depositional cycles have been identified within Tertiary Niger Delta deposits (Short and Stauble, 1967; Doust and Omatsola, 1990). The first two, involving mainly marine deposition, began with a middle Cretaceous marine incursion and ended in a major Paleocene marine transgression. The second of these two cycles, starting in late Paleocene to Eocene time, reflects the progradation of a “true” delta, with an arcuate, wave- and tide-dominated coastline. These sediments range in age from Eocene in the north to Quaternary in the south (Doust and Omatsola, 1990). Deposits of the last depositional cycle have been divided into a series of six depobelts (Doust and Omatsola, 1990) also called depocenters or megasequences) separated by major synsedimentary fault zones (Figure 2). These depobelts formed when paths of sediment supply were restricted by patterns of structural deformation, focusing sediment accumulation into restricted areas on the delta. Such depobelts changed position over time as local accommodation was filled and the locus of deposition shifted basinward (Doust and Omatsola, 1990).

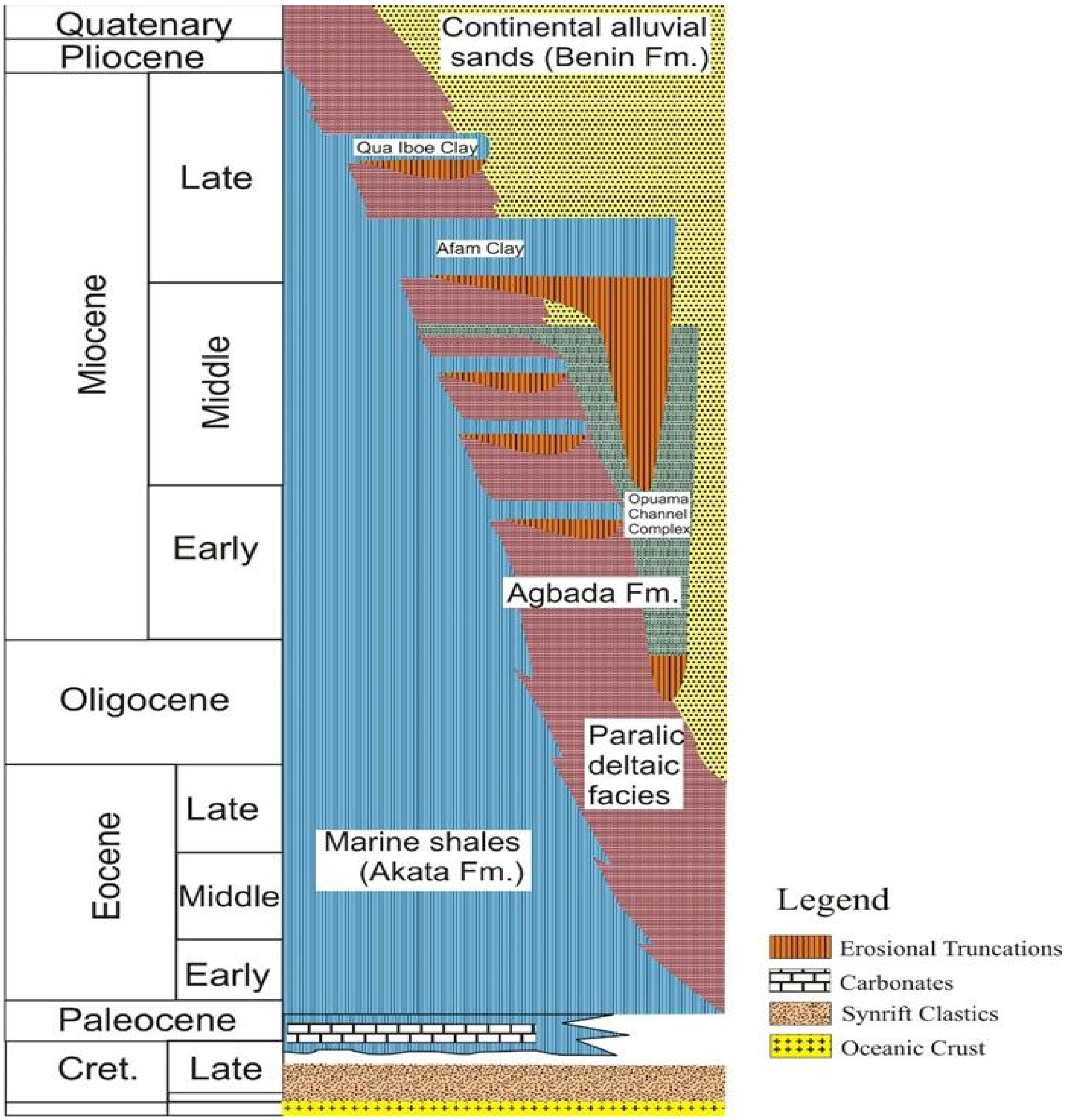


Figure 2: Geology and Stratigraphy of Niger Delta (Lawrence *et al*., 2002)

2.1.2 Review of other works

Hughes and Moody-Stuart (1967) proposed the term palynological facies in the same general sense as "palynofacies" of Combaz (1964) to include all organic elements. These authors and Batten and Stead (2005) also applied the term to refer to the general aspect of kerogen preparation. Quadros (1975) took the words Organopalynology and Organopalynofacies for the investigation of organic matter in sedimentary rocks using techniques of microscopy. Leopold (1982) showed that a palynofacies does not necessarily reflect the Biologic environment of the area near the basin of deposition but instead can be produced by a variety of geological and geochemical taphonomic processes associated with sedimentation. This sort of palynofacies is a product of the total sedimentary environment and is unlikely to be a palynobiofacie.

Hoshaw and McCourt (2005) defined palynofacies as a “distinctive assemblage of HCl- and HF-insoluble particulate organic matter (palynoclasts) whose composition reflects a particular sedimentary environment”. Tyson (1995) defined a palynofacies as “the assemblage of palynomorphs *taxa* in a portion of a sediment, representing local environmental conditions and not typical of the regional palynoflora”. Tyson (1995) published a pioneering contribution in the area of palynofacies analysis. Tyson (1995) reported that since 1960 used the term palynofacies to refer to a more or less local concentration of particular palynomorphs, indicating a sort of biofacies. The author believes that the application of the word since then has been geologically oriented, and palynofacies is used primarily to indicate information about the enclosing *rock*, especially its environment of depositionshould be called palynolithofacies.

Tyson (1995) published summation of the geochemical aspects of organic facies analysis. The work integrates the geological and biological aspects of palynofacies research. The modern palynofacies concept was introduced by Tyson (1995) and definition of palynofacies is: “a body of sediment containing a distinctive assemblage of palynological organic matter thought to reflect a specific set of environmental conditions or to be associated with a characteristic range of hydrocarbon-generating potential" and the definition of palynofacies analysis is: "the palynological study of depositional environments and hydrocarbon source rock potential based upon the total assemblage of particulate organic matter".

Furthermore, the third volume of Jansonius and McGregor's (1996) compendium of palynology include two chapters (Batten and Stead, 2005) with succinct and profusely illustrated summaries and exposition of the subject, including its application to petroleum exploration.

The palynofacies term refers to the study of the particulate organic matter presents in sediments and sedimentary rocks using the organic matter isolationmethods for sample preparation (kerogen concentration) and applying microscopy techniques as a principal tool for acquiring data and statistical methods for its interpretation (Mendonça Filho *et al.,* 2002). In Brazil, Mendonca Filho *et al.* (2002) was the first to use the organic facies concept (Organic Geochemistry associated to Palynofacies) based on the Tyson (1995) in the study of Upper Paleozoic rocks from the Paraná basin.

Batten and Stead (2005) described palynofacies as "associations of palynological matter (PM) in sediments, considered primarily in terms of the reasons for the association, which is usually geological, but may be connected to the biological origin of the particles". Spores, pollen, dinocysts, acritarchs and all other palynomorphs are of course included in a palynofacies, but so are all other visible organic particles in the palynological size range (roughly 2–250 µm) that occur in palynological maceration residues. Such non-palynomorph PM is often referred to collectively as palynodebris.

Palynofacies is a powerful analytical tool when used in conjunction with geological and geophysical information. It can be applied in the determination of kerogen types and their abundance, providing clues concerning depositional environment and hydrocarbon-generating potential. Palynofacies analysis involves the integrated study of all aspects of the palynological organic matter assemblage, which include the identification of the individual particulate components, assessment oftheir absolute and relative proportions, particle sizes, and their preservation states. It can be used indiverse studies, such as: geology (stratigraphy, sedimentology, and palaeoenvironmental studies), paleontology (biostratigraphic studies), petroleum exploration, environmental studies, etc. (Tyson, 1995). According to Fleisher and Lane (1999), palynofacies data can be still combined with ancillary biostratigraphic information in a sequence-stratigraphic framework to help recognize reservoir–source rock geometry.

Lucas and Ebahili (2017) also conducted a research on palynofacies studies of sedimentary succession in Ogbabu-1 well, Anambra Basin, Nigeria with the aim of giving a detailed palynofacies study of the Ogbabu-1 Well, Anambra Basin using sedimentology and palynology as geologic tools. Two main environments of deposition were delineated from palynofacies analysis and they are shelfal and shallow marine environments.

2.2 Kerogen Groups

Kerogen is generally defined as disseminated organic matter in sediments that is insoluble in normal petroleum solvents (Selley, 1985). It is a mixture of organic compounds (longchain biopolymers) that contain carbon, hydrogen and oxygen with minor amounts of nitrogen and sulphur. The term is applied to organic matter in oil shales that yield oil upon heating and is regarded as the prime source for petroleum generation (Durand, 1980). Thus, it is used for organic matter that converts to petroleum (crude oil and natural gases) after burial and heating in sedimentary basins. Kerogen is distinguished from bitumen because it is insoluble in normal petroleum solvents whereas bitumen is soluble (Selley, 1985). Kerogen has four sources: lacustrine, marine, terrestrial, and recycled. It is not in equilibrium with the surrounding liquids (Tissot and Welte, 1978; Selley, 1985). Most oil has been formed from lacustrine and marine kerogen. Terrestrial organic matter generates coal and the cycle is inert (Tissot and Welte, 1978; Selley 1985; Hunt, 1995). In petroleum studies, kerogens are classified into three basic types (I, II, and III) based on the ratio between their C, H, and O content, (Tissot and Welte, 1978; Selley, 1985). Types I and II are referred to as sapropelic kerogen, and type III is known as humic kerogen. Sapropelic kerogen is formed through decomposition and polymerization products of fatty, lipid organic material, such as algae and spores, and is used to designate finely disseminated kerogen, exhibiting an amorphous structure after destruction by acids (Tissot and Welte, 1978; Selley, 1985; Hunt, 1995). Humic kerogen is largely produced from the lignin of higher land plants. Types I and II predominantly generate oil, type III primarily generates gas and some waxy oil.

The generation of petroleum by kerogen maturation depends on a combination of temperature, as a function of the depth of burial, and time. Kerogen is mostly formed in shallow subsurface environments. With increasing burial depth in a steadily subsiding basin, the kerogen is affected by increased temperature and pressure. After burial and preservation, organic matter can go through three phases leading to kerogen degradation:

i. **Diagenesis** – This phase occurs in shallow subsurface environments at low temperatures and near-normal pressures. It includes two processes, biogenic decay supported by bacteria, and abiogenic reactions (Selley, 1985). Diagenesis results in a decrease of oxygen and a correlative increase of the carbon content. It is also characterized by a decrease in the H/O and O/C ratios (Tissot and Welte, 1978).

ii. **Catagenesis** – This phase is marked by an increase in temperature and pressure, and occurs in deeper subsurface environments. It results in a decrease of the hydrogen content due to generation of hydrocarbons. Petroleum is released from kerogen during this stage. Oil is released during the initial phase of the catagenesis, at temperatures between 60 and 120 ºC. With increasing temperature and pressure (approximately 120–225 ºC), wet gas and subsequently dry gas are released along with increasing amounts of methane (Tissot and Welte, 1978 & Selley, 1985). Catagenesis is characterized by a reduction of aliphatic bands due to a desubstitution on aromatic nuclei with increased aromatization of naphthenic rings.

iii. **Metagenesis** – This is the last stage in the thermal alteration of organic matter. It occurs at high pressures and temperatures (200 to 250 ºC) in subsurface environments leading to metamorphism and a decline of the hydrogen-carbon ratio. Generally only methane is released until only a carbon-rich solid residue is left. At temperatures over 225 ºC, the kerogen is inert and only small amounts of carbon remain as graphite (Selley, 1985). The vitrinite reflectance is used to indicate metagenesis because this stage leads to rearrangement of the aromatic nuclei (Tissot and Welte, 1978).

The temperature that leads to maturation of kerogen can be estimated by many techniques, such as the colour and reflectance of organic matter in the rocks, measuring of the carbon ratio, analysis of clay l mineral diagenesis, and fluorescence microscopy (Selley, 1985; Hunt, 1995). The colour of kerogen is dependent on the degree of maturation and its chemical composition and structure (Selley, 1985). Pollen and spores are for instance originally colourless. With increasing burial depth and temperature, they change from light to dark (Hunt, 1995). One commonly used system is the Spore Colour Index of Barnard et al. (1976) and the Thermal Alteration Index developed by Staplin (1969).

The reflectance of vitrinite is widely used for determining the maturation of organic matter in sedimentary basins and the maturity of potential source rocks. The reflectance is measured optically and only on vitrinite group macerals, since other macerals mature at different rates (Hunt, 1995). The vitrinite macerals are separated from the sample by solution of hydrofluoric and hydrochloric acids (Selley, 1985). There are two hypotheses describing how petroleum is generated, an organic and an inorganic. The inorganic or abiogenic hypothesis postulates that oil forms by reduction of carbon or its oxidized form at elevated temperatures deep in the Earth (Selley, 1985; Hunt, 1995). Thus, methane can form through various types of metamorphic and igneous processes, and is found trapped in some minerals. Although there is some evidence for a biogenic origin of some methane, overwhelming geochemical and geological evidence shows that most petroleum is formed from accumulation of organic matter trapped and altered in sedimentary rocks. According to the organic theory, the origin of the petroleum follows two pathways from living organisms and goes through three stages (diagenesis, catagenesis and metagenesis). The first pathway represents petroleum formed directly from hydrocarbons synthesized by living organisms or from their molecules (Hunt, 1995). This pathway involves an accumulation of hydrocarbons formed by dead organism and other hydrocarbons formed by bacterial activity and chemical reactions at low temperatures (Hunt, 1995). The second pathway involves thermal maturation of converted organic matter, such as lipids, proteins and carbohydrates, into kerogen during diagenesis (Selley, 1985; Hunt, 1995). With increasing burial depth and temperature, the organic matter progressively cracks to bitumen and liquid petroleum (Selley, 1985; Hunt, 1995).

As pointed out above, oil is mainly formed during the catagenetic phase, which is also known as the oil window or oil zone. With increasing temperature more molecular bonds are broken (H/C or O/C) and hydrocarbon molecules and aliphatic chains are formed from the kerogen. The hydrocarbons generated are C15 to C30 biogenic molecules, which have low to medium molecule weight (Tissot and Welte, 1978). When burial and temperature increase, light hydrocarbons are generated due to cracking, and increase the proportion of source rock hydrocarbons and petroleum (Tissot and Welte, 1978; Hunt, 1995). Subsequently, the hydrocarbons convert to wet gas with an increased amount of methane. The temperature in which oil is generated and expelled from the source rock ranges from 60 to 160 ºC. This temperature interval is known as the oil window (Hunt, 1995). The oil window corresponds to the depth interval 3.0 to 4.9 km. At 2.5 km there is an exponential increase in the C6–C7 hydrocarbons generated and there is a peak at about 4.0 km (Hunt, 1995). The stratigraphic interval above and below the oil window is referred to as immature and postmature for oil generation, respectively (Hunt, 1995).

Different studies have shown that the zone of intense oil generation and the peak for oil-yield differ from basin to basin because the oil generation is influenced by several factors, such as migration of oil out of the source rock and conversion of oil to gas (Hunt, 1995). When the generation of oil is more than the migration out of the source rock + the conversion of oil, the yield increases, but when the migration and conversion of oil to gas is greater than generation of oil, the yield will decrease (Hunt, 1995).

The classification of organic particles has always been rather subjective. Classifications often

have a particular objective. Particles have been divided by their modification and thermal alteration, their depositional environments, botanical classification, degree of terrigenous supply and thereby distance from land, degree of degradation, and all ochthonous and autochthonous fractions. It is essentially a morphological classification but it also incorporates the broad areas of provenance of particles (Tyson, 1995).

A generally acceptable terminology for transmitted light work has proved elusive and they differ by the degree of emphasis placed on different aspects of kerogen assemblage providing more detailed subdivisions of the palynomorph, phytoclast and amorphous organic matter components by greater attention to botanical source, morphology, and/or preservation states. The much more standardized and systematic maceral terminology used by organic petrologist (in reflected light studies) should never be used in transmitted light work (Tyson, 1995). Macerals can only be properly defined on reflected light characteristics; any other usage can produce pseudo-accuracy, unnecessary confusion and futile controversy.

However, regarding the kerogen groups and subgroups it is important to use a classification system which gives the maximum information about the variables involved. This means the classification system shall also emphasize the most relevant factors having in mind the objectives of the study. In that case, a rigorous subdivision of the categories should be present to identify any quantitative variation related to the main controls on the distribution of the organic matter and thus use those factors in the determination of the palaeoenvironmental meaning. In the case of palynofacies the main objectives of microscopy are to (Tyson, 1995):

2.2.1 Criteria used in Optical Kerogen Classification

The main criteria used in optical kerogen classification are:

i. **Origin:** biological source (based on definitive biostructure) and process of formation.
ii. **Structure:** structureless or structured

Type of structure (3 classes):

i. **Morphology (descriptive):** shape and fabric
ii. **Measurable optical properties:** reflectance, translucency, and fluorescence
iii. **Geochemical composition:** indirect evidence only, fluorescence is essential

Preservation state: Environmental oxidation, environmental biodegradation, and thermal alteration. In transmitted white light microscopy, the three main groups of morphologic constituents recognized within kerogen assemblage are: Palynomorphs (organic walled constituents that remain after maceration using HCl and HF acids), Phytoclasts (fragments of tissues derived from higher plants or fungi), and Amorphous Organic Matter - AOM (structureless material derived from non-fossilizing algae, or advanced tissue biodegradation, phytoplankton or bacterially derived AOM, higher plants resins and amorphous products of the diagenesis of macrophyte tissues).

The three classes of structured particles are: Palynomorphs (discrete, coherent, recognizable, individual or colonial entities), biostructured Clasts (fragments which at least partially preserve definitive original botanical features that indicate the original type of tissue from which they were derived), and (non-bio) Structured Clasts (coherent angular to irregular particles with distinct outlines that although not clearly attributable to a specific biological source, have a definite structure, shape or fabric which indicates they are fragment of larger organized bodies or tissues and they often larger than palynomorphs and lacking organic inclusions) (Tyson, 1995).

In the case of structureless particles observed in transmitted white light microscopy, they

present no botanical features, no organized internal structure or fabric, and no consistent shape. Now, they may be internally heterogeneous or homogeneous, hyaline (as in resin) or non-hyaline (as in Amorphous Organic Matter), and they may be fluorescent or non-fluorescent depending on source and preservation (Tyson, 1995).

Now in the case of phytoplankton-derived "AOM", the most common type of structureless material in marine or lacustrine sediments, the particles appear typically heterogeneous and microparticulate when viewed under fluorescence, they may have common inclusions (Pyrite), they may show a lack of regular shape or size, they may have no internal structure or fabric, often somewhat diffuse edges (but varies), less angular than phytoclasts or zooclasts, and a "gritty gel" appearance. “AOM" may sometimes show "craters" or imprints where mineral grains were once located but have been removed by acid treatment and it may often adhere to the outside of other particles (Tyson, 1995).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

The materials used for this work were supplied by Shell Nigeria Exploration and Production Company (SNEPCO) through The Directorate of Petroleum Resources (DPR) are:

i. Ditch cuttings

ii. Gamma-ray logs

3.2 Methods

3.2.1 Lithologic description

Physical observation of ditch cuttings and gamma ray logs were used in describing the stratigraphic intervals studied. The parameters observed are the rock types, the colour and the sorting of the samples at each interval.

3.2.2 Palynological Preparation Method

Palynological analyses was carried out at Earth Search and Services Limited, Lagos. Samples were prepared using the standard palynological acid technique of (Ridings *et al*., 2007). Palynological processing, analysis and interpretation were carried out on forty-nine (49) ditch cutting samples of the IDM-4 well. Laboratory processing was done to extract the palynomorphs from the sediments with the use of inorganic reagents such as hydrochloric acid (HCl), hydrofluoric acid (HF) and nitric acid (HNO_3) at specific concentrations in a fume cupboard.

All analytical procedures discussed below are conducted under strict adherence to safety requirements such as:

i. Restricting all operations to an efficient fume chamber.

ii. Use of personal protective safety equipment (safety boots, laboratory coats, face shield, gloves and PVC apron).

iii. Accurate observation throughout the procedure is also undertaken.

3.2.3 Acid Digestion/Cleaning

Samples are arranged sequentially in batches composited in 30 ft interval. The samples were washed with water in beakers.

The steps involved are given below:

i. 25 grams of sample is placed in a 250 ml polypropylene beaker.

ii. A 10 solution of HCl was added, watching for an overtly violent reaction that is dampened with an atomized spray of distilled water from a spray bottle. This minimizes the dilution of the acid.

iii. The samples were kept for three hours to allow the carbonates to dissolve.

iv. The HCl was decanted. Distilled water was added and allowed to settle and decanted again. The sample was diluted and decanted three times to remove any remaining calcium ion that can produce a precipitate when HF is added.

v. 70 HF was added and watched for any violent reaction, which is dampened with distilled water as above. The sample in HF was stirred and left overnight to enable digestion.

vi. The digested sample is poured into a 50 ml polypropylene test tube and centrifuge for five minutes at 2,000 RPM. The top of the used HF was carefully decanted.

vii. Distilled water was added while vortexing and centrifuging ware done for two minutes, (repeated until neutral).

viii. To allow for a better heavy liquid separation, a few drops of concentrated HCl are added to the sample after which water was added and centrifuged for four minutes.

3.2.4 Oxidation

i. 3 ml. of 70 concentrated HNO_3 was placed on to the residue and it was stirred gently.

The tube was placed in a hot water bath for a few minutes.

ii. The acid was removed by washing and centrifuging until neutral. Smear of residue was checked to see if oxidation is sufficient (the level of oxidation required by each sample is closely monitored under a palynological microscope).

iii. 10 solution of KOH was added (and placed in hot water bath) for two minutes. It was centrifuged and washed three times. This ensured the removal of humic acid.

iv. The residue was examined to determine if the desired level of oxidation has been achieved. If further oxidation is required, the procedure repeated.

v. Sample was then sieved using polypropylene sieve frames with 5 and 150-micron nitex screen clothe (sieve) which is discarded after each sample.

vi. Staining of residue with Safranin was done to enhance photomicrography.

3.3 Palynofacies Slides:

One third of the floating organic matter obtained during palynological processing is removed and sieved with 5-micron disposable sieves. One slide of the unoxidised sample residue is prepared using the procedures stated below.

3.3.1 Mounting of Slides

i. The 5 microns sieved fractions are pipetted off and mixed in one drop of polyvinyl alcohol with a glass rod.

ii. When the polyvinyl alcohol/residue has dried, one drop of clear casting (Petropoxy-154) resin was added and the 32x22mm cover slip was turned and sealed. Permanent curing occurs in approximately one hour.

3.4 Observation of Kerogen Colours

In order to get the colour maturity indices of the sediments, Pearson's colour chart was used (Figure 3). The colour ranges show the different phases of hydrocarbon in the sedimentary section.

3.5 Data Capturing

The data generated from the analysis are captured in the database in Stratabug and saved in readable format as CSV, which is accessible to other numerical software.

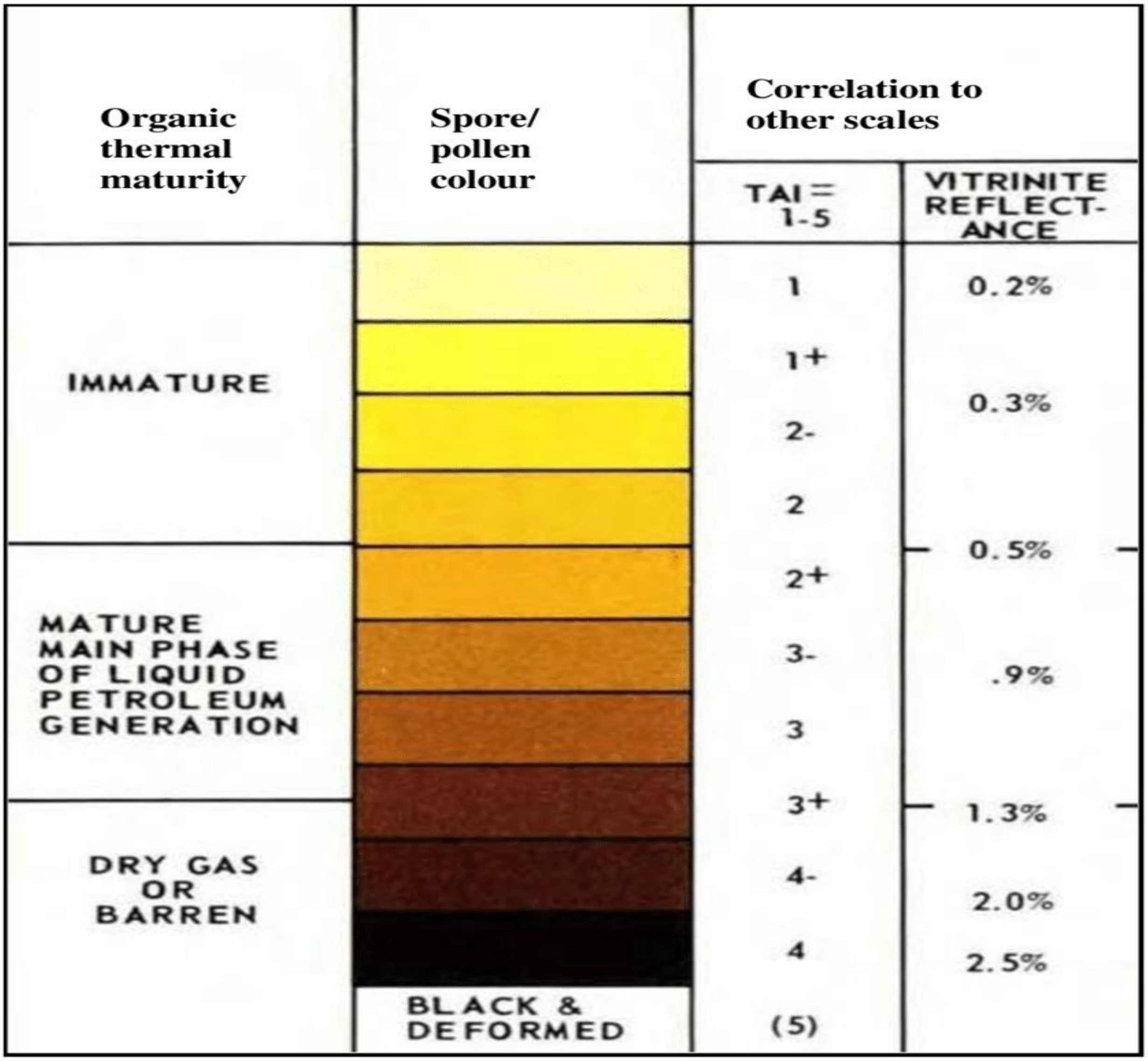


Figure 3: Pearson's colour chart compared with organic thermal maturity, TAI and vitrinite reflectance (Traverse, 1994).

CHAPTER FOUR

4.0 PRESENTATION AND DISCUSSION OF RESULTS

4.1 Data Presentation

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

4.2 Palynostratigraphy of the IDM-4 Well (6030-7990 ft)

Moderately abundant and diverse palynomorphs were recovered and used to deduce the age and possible environment of deposition of the studied interval.

Continental and transitional environments species such as *leoitriletes adriensis, Laevigatosporites* sp.*, Verrucatosporites* sp.*, Sapotaceoidaepollenites* sp.*, Zonocostites ramonae* and *Retitricolporites irregularis* quantitatively dominated the assemblage.

4.2.1 Biozonation of IDM-4

Based on the stratigraphic occurrence of marker species, two (2) formal biozones were erected: *Pachydermites diederixi* (Assemblage) *Z*one and *Crassoretitriletes vanraadshooveni* (Taxon range) *Z*one for IDM 4. These were correlated with the P680 and P720 Zones of Evamy *et al*., (1978) and the *Verrutricolporites rotundiporus* - *Crassoretitriletes vanraadshoveni* palynological zones of Germeraad *et al*. (1968). Thus, an Early to Middle Miocene age is interpreted for the Idama-4 well (6030-7990ft.). Details are succinctly discussed below and shown as figure 1.

***Pachydermites diederixi Z*one (Assemblage Zone)**

Interval: 7000-7990 ft.

Age: Early Miocene

Related palynological zone: P680 (Evamy *et al*., (1978)

Discussion: The zone is an assemblage zone because of the abundant presence *Magnastriatites howardi. Verrutricoporite rotundiporus* and *Racemonocolporites usmensis*. The top of this zone is marked by the base occurrence of *Crassoretitriletes vanraadshoveni* at 7000 ft. The base is marked by the top occurrence of the sample analysed. It is the oldest zone and is further characterised by the moderately abundant occurrence of *Praedapollis flexibilis* at 7450 ft., common *Zonocostites ramonae, Sapotaceoidaepollenites* sp. *Retitricolporites irregularis* and fresh water algae-*Botryococcus braunii*. This zone also relates to the *Verrutricolporites rotundiporus* Zone of Germeraad *et al*., (1968).

***Crassoretitriletes vanraadshooveni* Zone**

Interval: 6030-7000 ft.

Age: Middle Miocene

Related palynological Zone: P720 (Evamy *et al*., (1978))

Discussion: It is a taxon range zone. The top of the zone marked by last appearance occurrence of *Crassoretitriletes vanraadshoveni* at 6030 ft while the base is marked by the base occurrence of *Crassoretitriletes vanraadshoveni* at 7000 ft. Common to abundant occurrences of *Magnastriatites howardi* (makes a possible quantitative top occurrence at 6190 ft). *Psilatricolporitescrassus, Laevigatosporites* sp., *Leoitriletes adriensis* and

Polypodiaceoisporites sp. also characterized this zone. This zone also relates to the *Crassoretitriletes vanraadshoveni* Zone of Germeraad *et al*., (1968).

4.2.2 Biozonation of IDM-5 Well

Two (2) formal palynological zones are defined for the studied interval namely *Spirosyncoporite bruni -Polipodiaceoisporites* sp (interval) Zone and *Sapotaceoidaepollinites* sp – *Arecipites exilimuratus (interval)* Zone. These are based on the stratigraphic occurrences and distribution of diagnostic palynomorphs. These zones correlate with the P650 and P670 - P680 palyzones of Evamy *et al.,* (1978) and the *Verrutricolporites rotundiporus* zone of Germeraad *et al*., (1968). Thus, an Early Miocene age is interpreted for the Idama-5 well (10000-11700ft.). Details are given below and graphically shown as figure 6.

***Spirosyncoporite bruni -Polipodiaceoisporites* sp (interval) Zone**

Interval: 11050-11700 ft

Age: Early Miocene

Related palynological zone: P650 (Evamy *et al*., (1978)).

Discussion: The top of this zone is defined by the quantitative base occurrence of *Spirosyncoporite bruni* at 11110 ft while the top is marked by the quantitative first downhole occurrence of *Polipodiaceoisporites* sp. The zone is further defined by the occurrence of *Verrucatosporites usmensis, Praedapollis flexibilis* and moderately abundant *Zonocostites ramonae*. This zone is also related to the Verrutricolporites rotundiporus Zone of Germeraad *et al*., (1968).

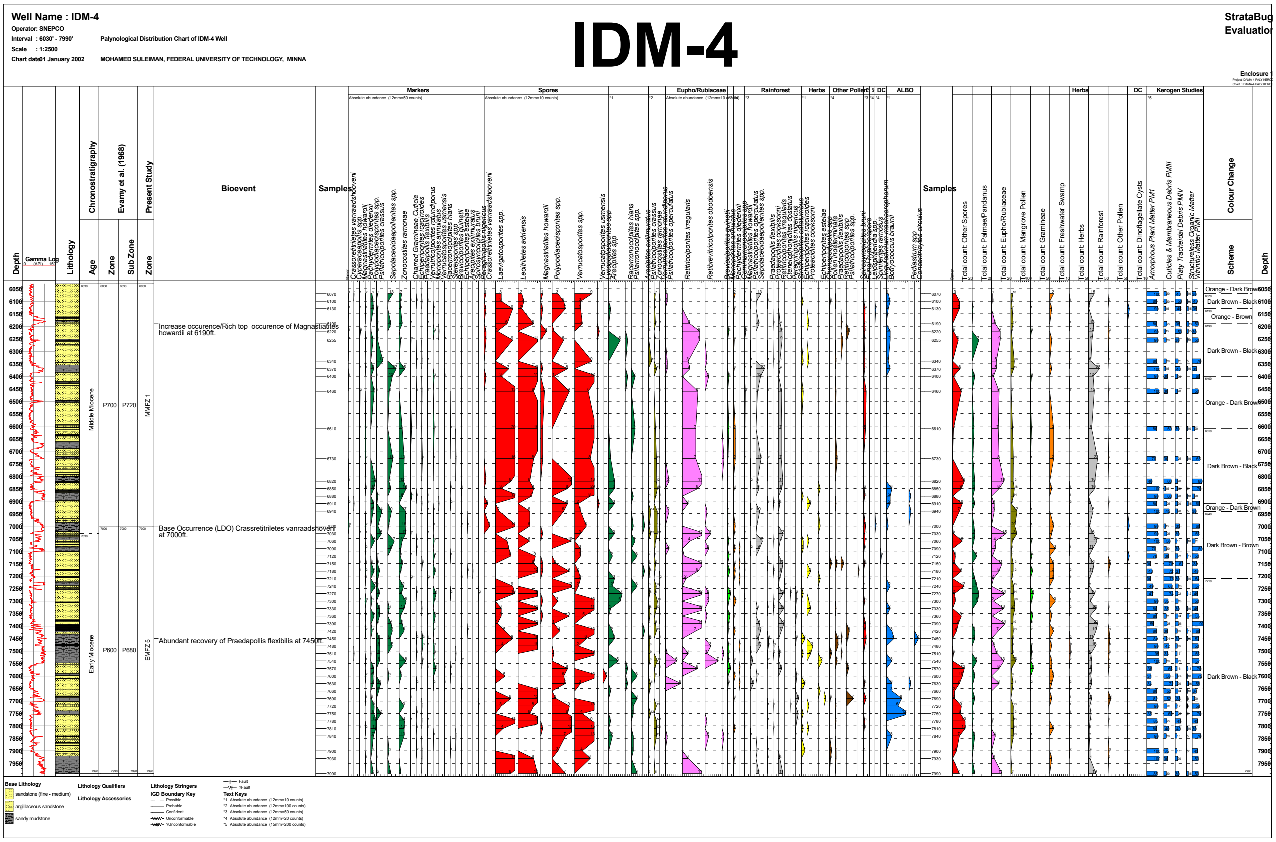


Figure 4: Palynofacies distribution chart of IDM-4 well of the Niger-Delta

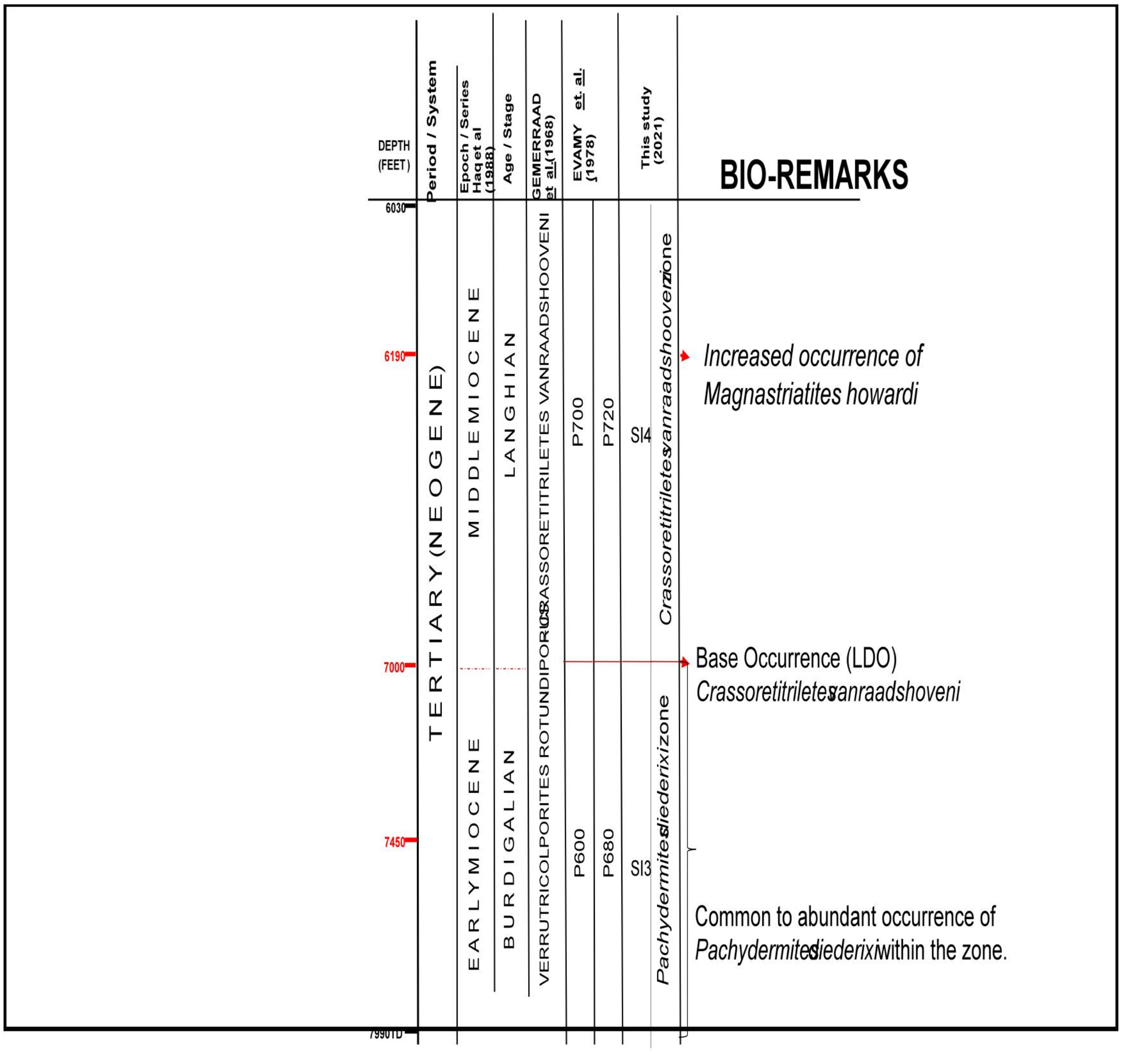
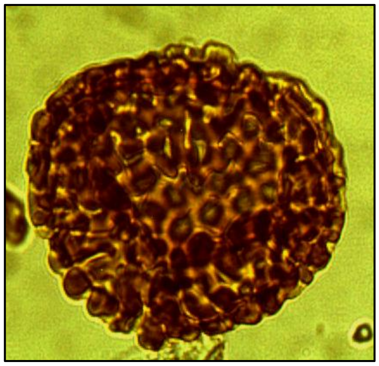
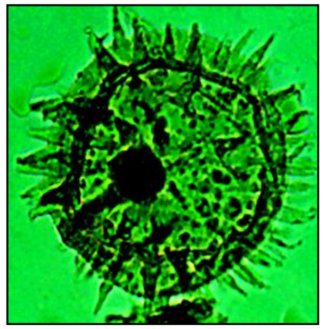


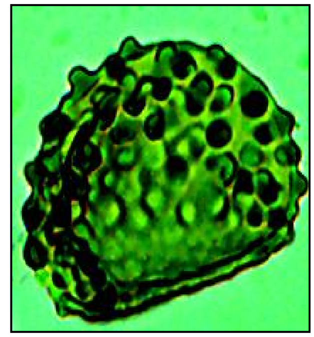
Figure 5: Palynozones identified in the IDM-4 well (6030-7990ft.)



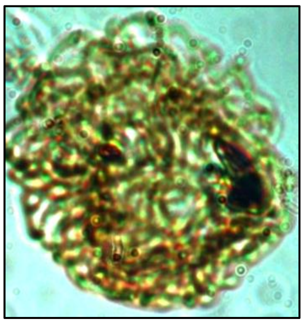
1. *Crassoretitrilet es*



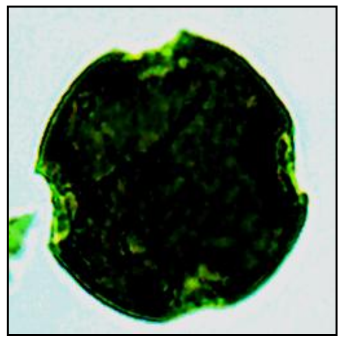
2. *Lingulodinium machaerophorum.*



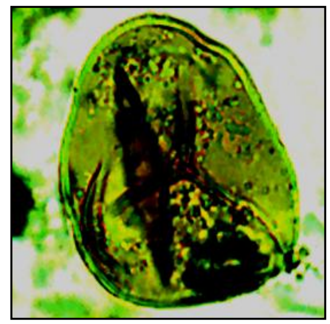
3. *Verrucatosporites*



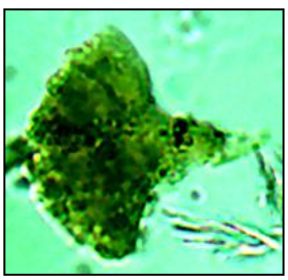
4. *Praedapollis flexibilis.*



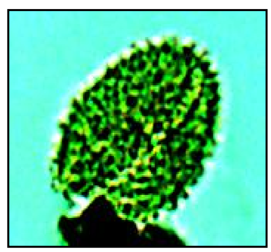
5. *Pachydermites diederixi.*



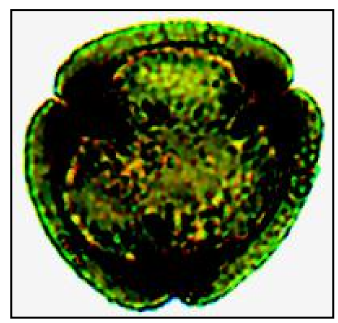
6. *Acrostichum*



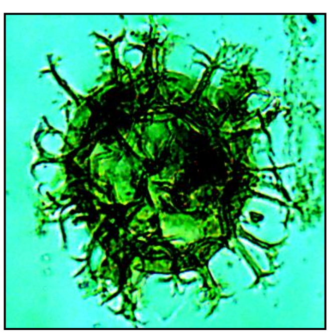
7. *Botryococcus braunii.*



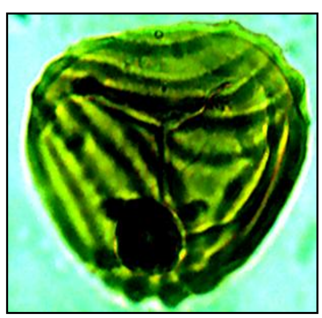
8. *Racemonocolpites hians.*



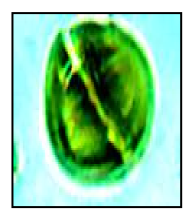
9. *Psilatricolporites crassus.*



10. *Spiniferites sp.*



11. *Magnastriatites howardi.*



12. *Zonocostites ramonae.*

PLATE I: Photomicrograph of IDM-4 Well

***Sapotaceoidaepollenite* sp. - *Arecipites exilimuratus* (interval) Zone**

Interval: 10000- 11050 ft

Age: Middle Miocene

Related palynological zone: P670-P680 (Evamy *et al.,* (1978)).

Discussion: The top of this zone is marked by the last downhole occurrence of *Sapotaceoidal pollenites* sp. at 10000 ft. The base is marked by first downhole occurrence of *Arecipites exilimuratus* at 11050 ft. The zone is also defined by the occurrence of *Striamonocolpites rectotriatus, Magnastriatites howardi, Pachydermites diederixi, Psilatricolporites incacinoides*. This zone is also related to *Verrutricolporites rotundiporus* of Germeraad *et al.*, (1978).

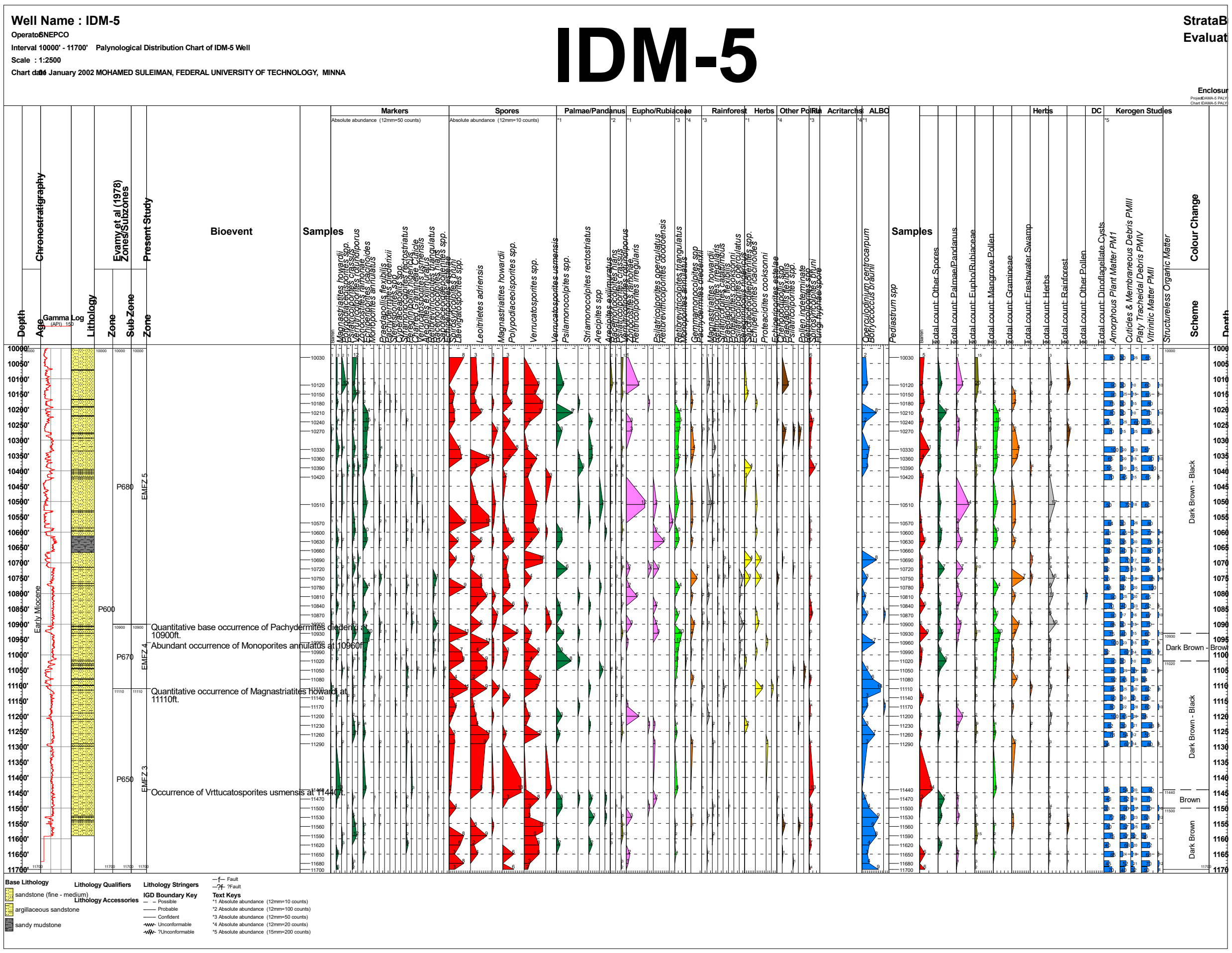


Figure 6: Palynofacies distribution chart of IDM-5 well of the Niger-Delta.

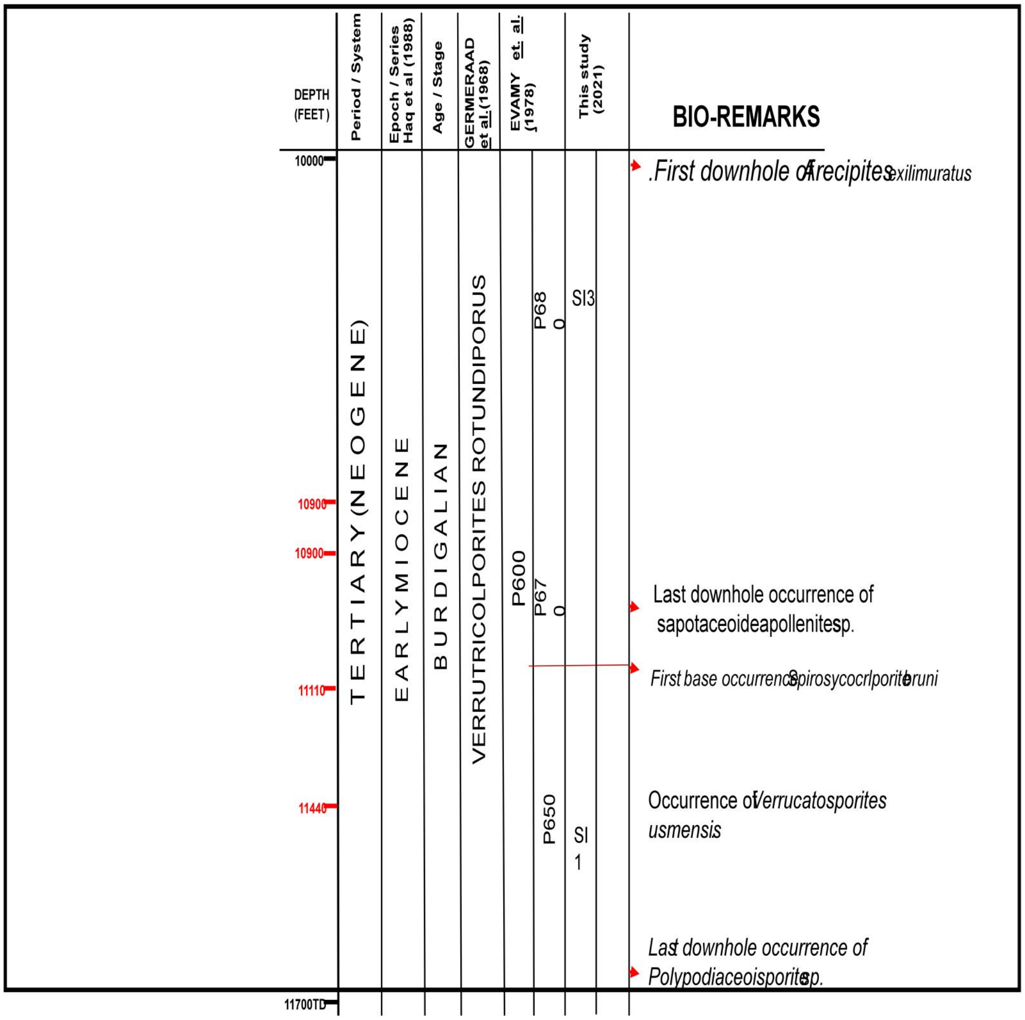
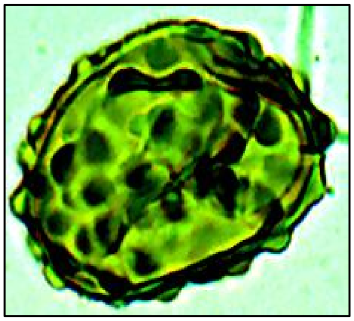
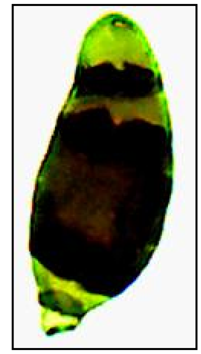


Figure 7: Palynozones identified in the IDM-5 well (10000- 11700 ft)



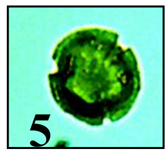
1. Verrucatosporites usmensis.

2. Polypodiaceoisporites sp.

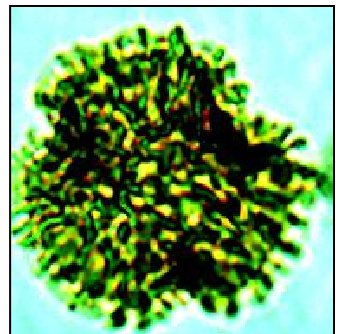


3. Fungal spore.

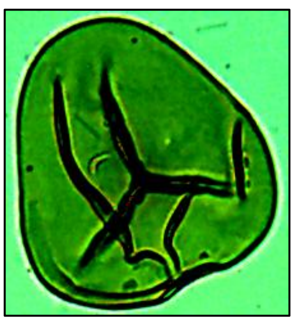
4. Monoporites annulatus.



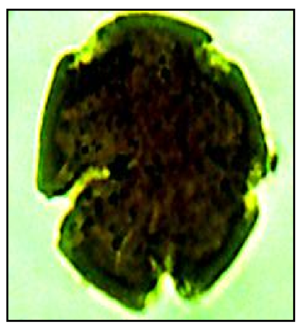
5. Zonocostites ramonae.



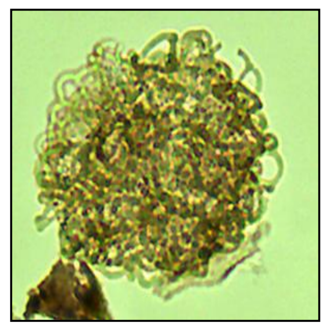
6. Retitricolporites irregularis.



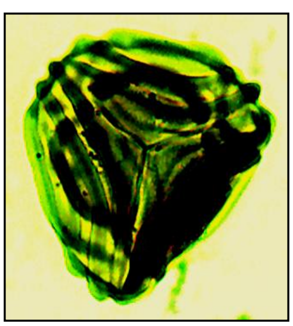
7. Acrostichum aureum.



8. Pachydermites diederixi.



9. Praedapollis flexibilis.



10. Magnastriatites howardi.

11. Striamonocolpites

12. Sapotaceae.

PLATE II: Photomicrograph of IDM-5 Well

4.3 Palynomacerals of IDM-4 and IDM-5 Wells

Five categories of palynomacerals were determined in IDM-4 and IDM-5 wells. They are:

i. Amorphous Plant Matter (PM I)
ii. Cuticle and Membranous Debris (PM III)
iii. Platy Tracheidal Debris (PM IV)
iv. Vitrinitic Matter (PM II)
v. Structureless Organic Matter

Figures 8 and 9 show the percentage occurrence of the palynomacerals in IDM-4 and IDM-5 respectively.

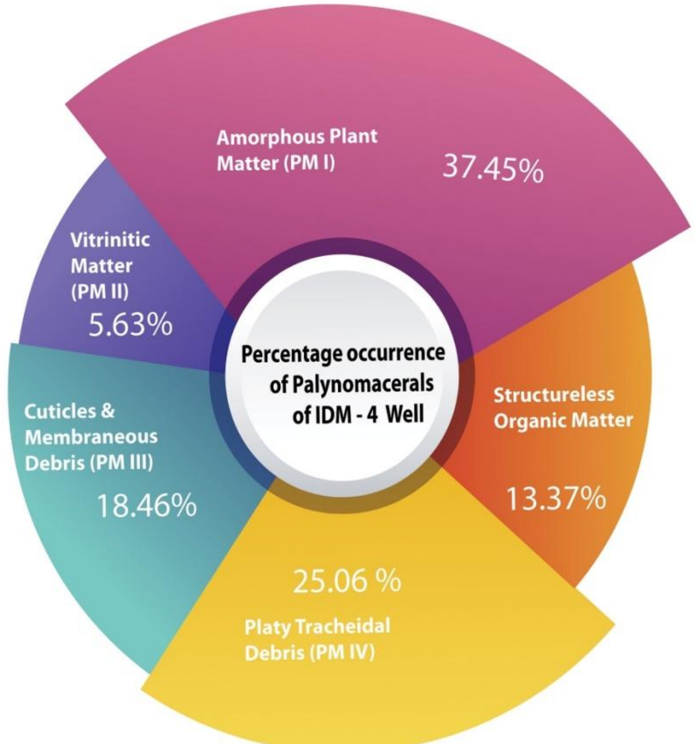


Figure 8: Percentage occurrence of Palynomacerals of IDM-4 Well.

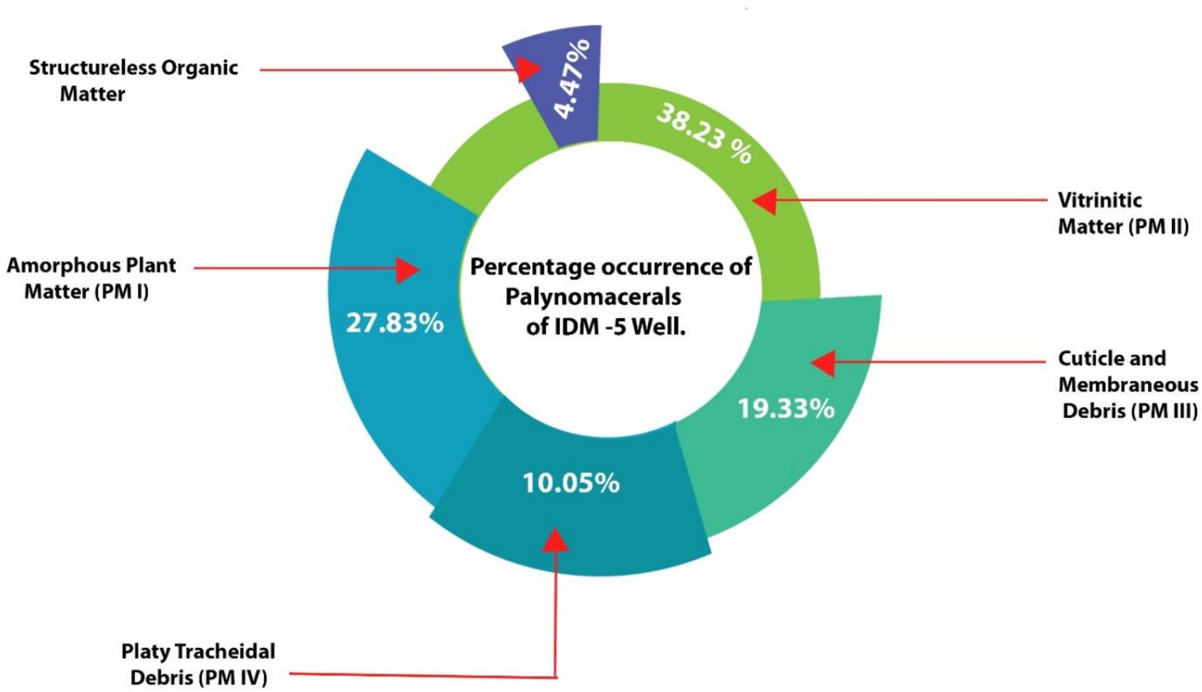


Figure 9: Percentage occurrence of Palynomacerals of IDM-5 Well.

4.4 Paleoenvironmental Interpretations

4.4.1 Paleoenvironmental Interpretation of IDM-4 Well

Unoxidized slides were produced for palynofacies studies of the Idama-4 well.. The results were integrated with abundances of mangrove species and fresh water algae to suggest possible environment of deposition.

The depositional environment of the studied interval is interpreted to range between Mangrove and Shoreface environments.

6030-6450 ft. – Shoreface Depositional Environment.

This environment is characterized by the following:

i. Abundant occurrence of Palynomaceral IV and I.

ii. Common occurrence of Palynomaceral II and III

iii. Common occurrence of fresh water algae – *Botryococcusbraunii* and

iv. Common occurrence of Mangrove species – *Zonocostites ramonae*.

6450-6730 ft – Channel Depositional Environment

This depositional environment is characterised by the following:

i. High records of Palynomaceral I and II

ii. Low counts of Palynomaceral IV

iii. Relatively low occurrence of Palynomaceral III and

iv. Common occurrence of Rainforest species.

6730-7990 ft. – Mangrove – Shoreface Depositional Environment.

i. Common to abundant occurrence of *Zonocostites ramonae*

ii. Common presence of sporomorphs

iii. Moderately abundant *Botryococcus braunii*

iv. Abundant Palynomaceral I and II

v. Common occurrence of Palynomaceral III and IV.

Figure 10 shows the palynofacies associations which was used to determine the environment of deposition of IDM-4 well of the Niger-Delta.

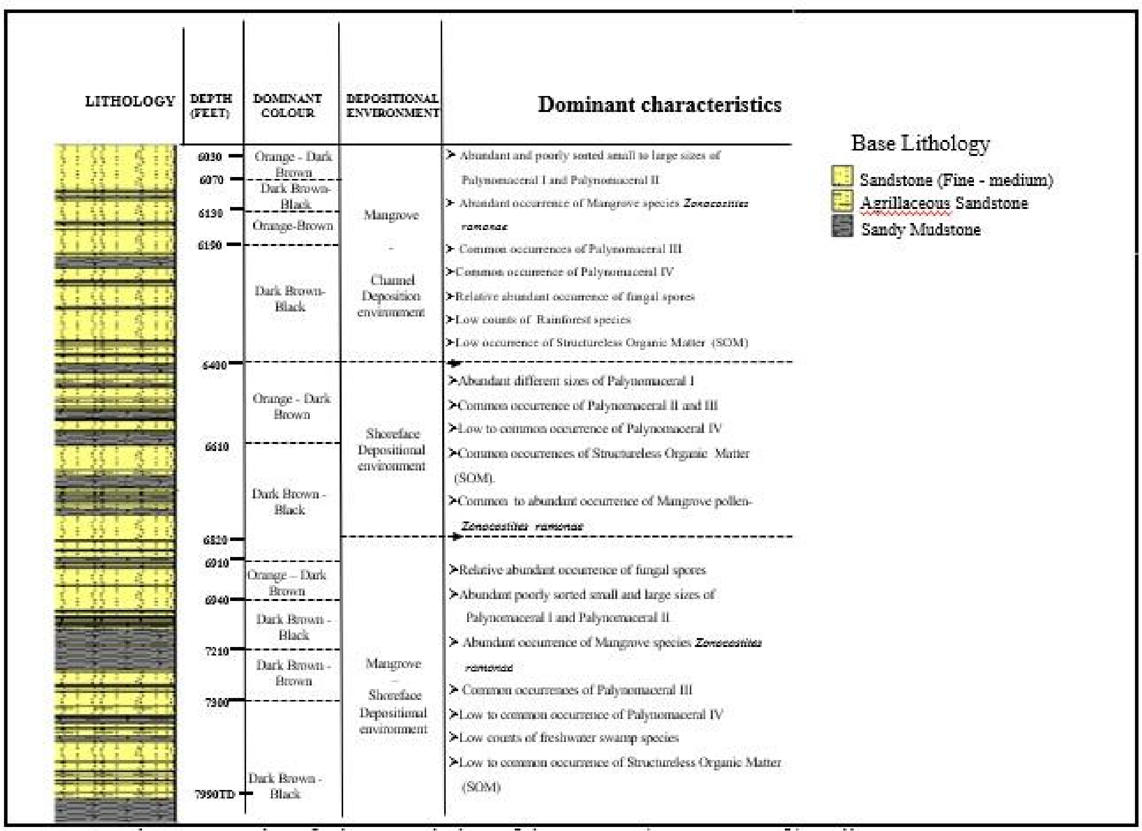


Figure 10: Palynofacies association of the IDM-4 (6070-7990 ft)

4.4.2 Paleoenvironmental Interpretation of the IDM-5 Well

The paleoenvironmental synthesis was carried out by integrating the results of the analysis of the unoxidized slides. with the abundances of *Zonocostites ramonae*, fresh water algae and sporomorphs.

Based on the published work of Oyede (1991), the depositional environment of the studied interval is interpreted to predominantly range between Mangrove and Channel depositional environments, however a period of Shoreface depositional environment was interpreted for the upper section of the well. Details are given below;

10000-10420 ft – Shoreface Depositional Environment

- Abundant occurrence of Palynomaceral I and IV
- Common occurrence of Palynomaceral II and III
- Abundant *Botryococcus braunii*
- Common occurrence of mangrove species – *Zonocostites ramonae*

10420-10600 ft. – Channel Depositional Environment

- Low occurrence of Palynomaceral IV and III
- High frequencies of Palynomaceral I and II
- Low records of *Zonocostites ramonae*.

10600-11290 ft. – Mangrove Depositional Environment

- Abundant occurrence of Palynomaceral I and II
- Common Palynomaceral III

- Low counts of Palynomaceral IV
- Common occurrence of *Botryococcus braunii*
- Abundant *Zonocostites ramonae*

11290-11700 ft. – Mangrove – Channel Depositional Environment.

- High records of Palynomaceral I and II
- Common Palynomaceral IV
- Low counts of Palynomaceral IV
- Common occurrence of rainforest species
- Abundant *Botryococcus braunii*and *Zonocostites ramonae*
- Common Structureless Organic Matter (SOM)

Figure 11 shows the palynofacies associations which determines the environment of deposition of IDM-5 well of the Niger-Delta.

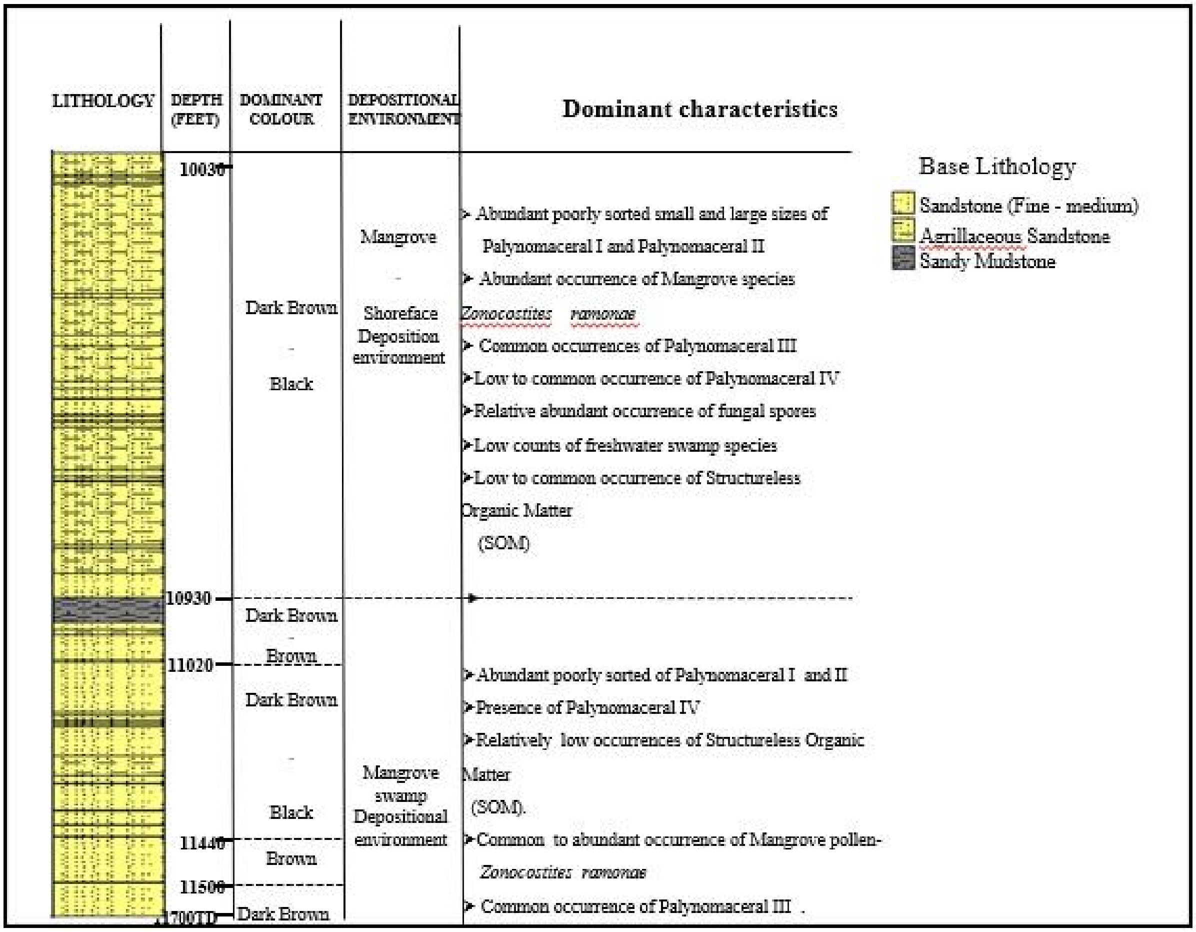


Figure 11: Palynofacies association of the IDM-5 (10030- 11700 ft)

4.5 Thermal Maturation

Thermal maturity is the extent of heat-driven reactions that alter the composition of organic matter (conversion of sedimentary organic matter to petroleum or cracking of oil to gas). When standard Pearson's colour chat was used to compare the colour changes, the colour and the corresponding organic products of recoverd palynofacies at different depth intervals for IDM-4 and IDM-5 wells are given as in table 1 and table 2 below.

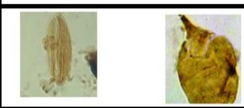
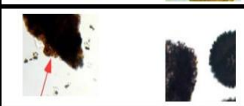
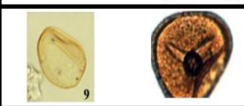
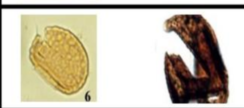
DEPTH INTERVAL (FT)	DOMINANT COLOUR	RECOVERED PALYNOFACIES	TAI	INTERPRETATION	DEGREE OF MATURATION
6050	Orange - dark brown		3+	Phase of liquid petroleum	Matured stage
6100	Dark brown - black		4	Phase of dry gas	Very matured to almost deformed
6150	Orange - brown		2+	Phase of liquid oil	Early matured stage
6200 - 6400	Dark brown - black		4	Phase of dry gas	Very matured to almost deformed
6400 - 6600	Orange - dark brown		3+	Mature phase of liquid oil	Matured stage
6600 - 6900	Dark brown - black		4	Phase of dry gas	Very matured to almost deformed
6900 - 6950	Orange - brown		2+	Mature phase of liquid oil	Early matured stage
6950 - 7200	Brown - dark brown		3	Phase of dry gas	Matured stage
7200 - 7950	Dark brown - black		4	Phase of dry gas	Very matured to almost deformed

Figure 12: Interpretation of the thermal maturation of the kerogen for IDM-4 Well.

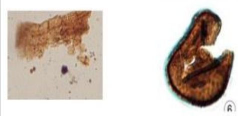
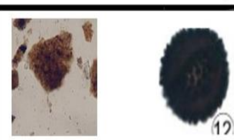
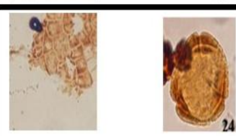
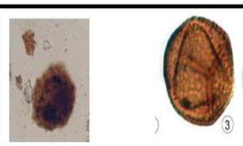
DEPTH (FT)	DOMINANT COLOUR	RECOVERED PALYNOFACIES	TAI	INTERPRETATION	DEGREE OF MATURATION
10000 - 10950	Dark brown - black		4	Phase of dry gas	Very matured to almost deformed
10959 - 11025	Brown - dark brown		3	Main phase of liquid oil	Matured stage
11025 - 11450	Dark brown - black		4	Dry gas	Very matured to almost deformed
11450 - 11500	Brown		3-	Phase of liquid petroleum	Matured stage
11500 - 11700	Dark brown		4	Phase of liquid petroleum	Very matured stage

Figure 13: Interpretation of the thermal maturation of the kerogen for IDM-5 Well.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Based on the outcome this study, the following conclusions were reached:

- Formal biozonation were reached for the two wells. They are *Pachydermites diederixi (Assemblage)* Zone and *Crassoretitriletes vanraadshooveni (*Taxon range) Zone for IDM-4 and *Spirosyncoporite bruni -Polipodiaceoisporites* sp (Interval Range) Zone and *Sapotaceoidaepollenite* sp. - *Arecipites exilimuratus* (Interval) Zone for IDM-5.

- The depositional environment of IDM-4 is interpreted to range from Mangrove to Shoreface environments while the depositional environment of the studied interval is interpreted to predominantly range between Mangrove and Channel depositional environments.

- For IDM-4 well, the intervals such as 6050, 6150, 6400- 6600, 6900- 6950 ft are the intervals that show the mature phase of liquid indicating early stages of maturity while intervals 6100, 6200- 6400, 6600- 6900, 6950- 7950 ft are the phase of dry gas indicating very high stages of maturity. For IDM-5 well, intervals 10000 -10950 are the phases of dry gas indicating very high stages of maturity while intervals 10950- 11025 ft and 11450-11700 ft are the phases of mature liquid oil indicating early stages of maturity.

5.2 Recommendation

It is recommended that other methods such as seismic method, sedimentological examination be incorporated to palynofacies analysis in order to make more accurate and reliable deductions for petroleum prospection.

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