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Paleoclimatic Cycles, Sea Level History and Sequence Stratigraphic Elements in Eocene–Oligocene Sediments of BIMOL-1 Well Northern Niger Delta Basin, Nigeria

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ABSTRACT: Lithofacies succession and palynomorph data trends in BIMOL-1 well in the north-western Niger Delta Basin have been investigated in order to unravel paleoclimatic influence on paleo-sealevel change and facies evolution. Eight lithologic cycles composed of sand and shale were identified. Miospore speciation revealed forty two miospore form species and ten dinoflagellate cyst species. Miospore and dinocyst trends revealed six climate driven sea level cycles that influenced sedimentation and facies distribution and characteristics. Miospore age determination of the succession revealed L-Eocene to L-Oligocene age range. Nine wet and eight dry climate driven transgressive and regressive events were identified, corresponding to sea level rise and to sea level fall correspondingly. Dry climate occasioned continental progradation that generated thick sand intervals, while wet climate triggered sea level rise, generating thinner sand bodies as transgressive sand reservoirs. Seven high stands (HSTs), eight transgressive (TSTs) and eight lowstand (LSTs) systems tracts, distributed within nine sequences were identified. Candidate MFSs, the 50.0 Ma, 48.9 Ma, 46.1 Ma, 43.2 Ma, 41.0 Ma, 34.0 Ma MFSs were identified. Candidate SBs identified include the 50.7 Ma, 48.4 Ma, 47.2 Ma, 44.4 Ma, 42.7 Ma, 40.1 Ma and 32.4 Ma SBs. Early Rupelian sequence boundaries were identified. Erosion/non-deposition of the Priabonian and parts of the Bartonian stage were revealed that inferred erosion/non-deposition of about 7 Ma of sediments in the well area. A synthesis of results of the evaluated proxies revealed that Paleoclimate-driven sea level and paleovegetation trends acted as key facies generators in the well area.

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Ancient sedimentary successions host a variety of records which may be important in unravelling past sea level and climatic fluctuations. Eocene-Oligocene sediments of the Niger Delta Basin are known to register varied sea level regimes reflected in the cyclic lithofacies pattern of the formational units (Reijers, 2011). The abundance and presence of palynotaxa preserved in sediments has been used as paleoclimatic and paleocenographic proxies for many decades (Jan du Chene and Adediran, 1984; Gregory and Hart, 1992; Lucas, 1992; Elsik, and Yancey, 2000; Adeonipekun, et al., 2012) and the influence of climate on paleovegetation cyclicity and sea level change is well documented (Van Der Hammen, 1957, 1961; Rull and Poumot, 1997; Rull, 2000). Studies have shown that paleoclimatic trends and fluctuations can be revealed by biosignals stored in sedimentary successions. The study of palynotaxa provides beyond age determination, fundamental contributions of our understanding of ancient climatic regimes. The biogeography and diversity of palynotaxa through geologic time varied depending on latitudinal zonation as well as climatic dynamics and variability (McIntyre and Bè, 1967; Findlay and Giraudeau, 2000; Boecked and Baumann, 2008). Changing climate as experienced in the present is observed to drive vegetation trends and global sea level change and patterns. The imprint of this process generates various sedimentary signatures registered as facies depending on the location where such process operates. Tertiary sediments of the Niger Delta Basin display various lithofacies components distributed within different lithostratigraphic units (Short and Stauble, 1967; Avbovbo, 1978, etc.), known to be products of oscillating sea level regimes through geologic time (Reijers, 2011). Several studies on the palynology, sedimentology, paleodepositional environment and sequence stratigraphy etc., on the Niger Delta have been carried out to contribute to the knowledge base of the geology and history of the Delta, but few have been directed towards paleoclimatic and paleooceanographic factors that can be related to sequence stratigraphic framework. In this study, we seek to use biosignals to unearth paleoclimatic cycles

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locked in Eocene-Oligocene sediments of the Niger Delta accessed through well cutting samples retrieved from BIMOL-1 well in the northern Niger Delta Basin. This study is aimed at investigating the paleoclimatic cycles, sea level history and sequence stratigraphic elements in Eocene – Oligocene sediments of BIMOL-1 well northern Niger Delta basin, Nigeria. It is envisaged that the cycles can be related to and used to distinguish sedimentary packages that would reflect systems tracts. In the Niger Delta sedimentary pile, individual sea-level cycles are reflected in the various sedimentary sequences and interferences of cycles with different periods result in megasequences that are chronostratigraphically confined and sedimentologically characterised (Reijers, 2011).

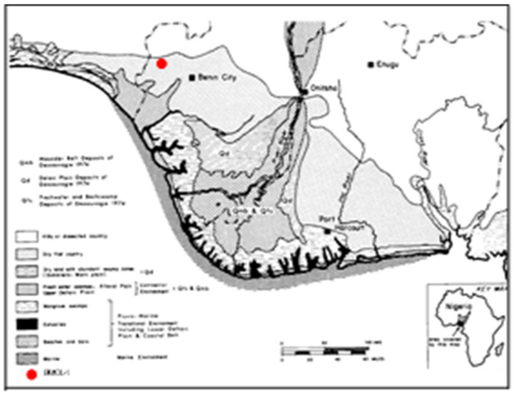

Fig. 1: Generalized map of the Niger Delta showing main sedimentary environments (Allen, 1965; Whiteman, 1982)

Geological Setting of the Niger Delta Basin: The Niger Delta Basin (Fig. 1) stands as one of the most prolific hydrocarbon provinces in the African continent. With a clastic wedge of just over 10 km thick, (Fig. 2), a very high concentration of petroleum per unit volume of rock is key note. known estimates of the ultimate recoverable hydrocarbons from the Niger Delta province range from 35 x 10^9 BBL of oil and 120 x 10^{12} SCF of gas (Ekweozor and Daukoru, 1994) to 66 x10^9 BBL of oil equivalent (BOE; Saugy and Eyer 2003). For many decades, exploration and production has been concentrated mostly on land or in shallow water, although since 1996 licensing rounds, major deep-water discoveries, of the order of 10^9 BOE, have been made (Agbami, Bonga, Bonga SW, Chota, Erha, Usan, Ukot, Zafiro, Ikija, Etan and Bobo). The sedimentary pile of the Niger Delta Basin has built out over the African Atlantic continental margin and adjacent oceanic crust since Eocene times (Evamy et al., 1978). The sedimentary pile of the basin is subdivided into a three-fold age diachronous stratigraphic subdivision, into the marine Akata, shallow marine Agbada and delta plain Benin formations, which reflects the distinguishing sedimentary environments of a regressive megasequence (Short and Stauble, 1967; Doust and Omatsola 1989; Morgan 2003).

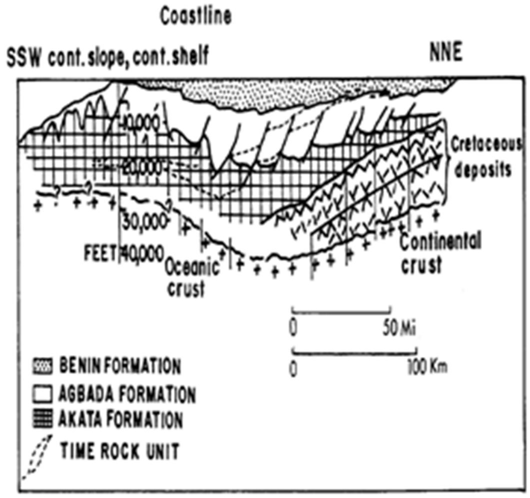

Fig. 2: Schematic subsurface cross section showing the main stratigraphic units of the Niger Delta Basin (after Ekweozor and Okoye, 1980)

The Akata Formation which consists of parallel-laminated mud has formed in deep water and, basin-floor, pro-delta setting. Generally the Akata Formation is viewed as the main source sediments for hydrocarbons in the Niger Delta. It is 3–4 km thick and overpressured (Short and Stauble, 1967; Doust and Omatsola 1989; Haack et al., 2000). The Agbada Formation consists of mixed clastic sediment, and is about 3 km thick or more. The Agbada Formation was formed in a paralic environment. Sediments of the Agbada Formation act as the main reservoir rocks for hydrocarbons generated in the basin. Capping the delta is the Benin Formation which is largely continental and fluvial in origin and consists of mainly sands.

MATERIALS AND METHODS

Sampling: A total of fifty non-composited ditch cuttings of sand and shale from a near-surface depth of 486 – 3216 m of the BIMOL-1 well located in the western reaches of the north-western area of the Niger Delta Basin (Fig. 1), were subjected to whole rock visual grain textural analyses using stereomicroscopic description to determine gross grain characteristic (mineralogy, morphology, sorting, presence of accessory materials, size distribution, and colour). The well under study belongs by Shell Petroleum Development Company (SPDC), but coded BIMOL-1well in this study for confidentiality reasons. For lithofacies description, a sampling range of 18 – 78 m (av. = 56.5 m) for the upper section of the well (depth range of 486 – 648 m), a sampling range of 18 – 108 m (av. = 66.71 m) for the mid-section (depth range of

828 – 1674 m) and a sampling range of 18 – 84 m with an average of 52.50 m for the lower section (1782 – 3216 m) of the well was achieved, with a general sampling range of 48.82 m for the well.

Palynological sample Preparation and Analysis: Thirty five (35) samples from the well section were subjected to series of acid treatment for palynological slide and analysis in accordance with techniques described by Traverse (1988), while age determination is based on earlier works by Muller (1959), Gemeraad (1968), Adegoke (1969), Legoux (1978), and Sowumi (1981b).

RESULTS AND DISCURSION

Lithostratigraphy: Whole rock lithologic sample description revealed eight distinct lithologic units/successions in the well section as detailed below (Fig. 3):

Unit 1 (3216 – 2970 m): This unit is composed of 246m thick black fossiliferous fissile shale and forms the basal unit of the succession.

Unit 2 (2970 – 2856 m): This unit is composed of 114m thick subangular to subrounded coarse grained sand, and unconformably overlies Unit 1.

Unit 3 (2856 – 2574 m): This sequence is composed of about 282m of black carbonaceous fossiliferous shale.

Unit 4 (2574 – 2484 m): This interval is composed of subrounded – rounded medium to coarse grained sand, sandwiched between thick shale of unit 3 below and unit 5 above.

Unit 5 (2484 – 1674 m): This unit is composed of 800m of black fossiliferous fissile shale. This unit occur as the thickest unit in the well section.

Unit 6 (1674 – 1404 m): This interval is composed of 730m thick subangular – rounded medium to coarse grained sand unconformably overlying shale of unit 5.

Unit 7 (1404 – 648 m): This unit is characterized by 756m of shale and sand interbeds. The shale interbeds are fossiliferous and displays medium the dark grey colour. The sand interbeds are characteristically composed of subangular – rounded very fine to medium grained sand.

Unit 8 (648 – 486 m): this unit caps the well section and is also composed of sand and shale interbeds. It is distinguished as a different unit based on the morphological characteristics of the sand components which displays subrounded to well-rounded fine to medium grains and light to medium grey shale interbeds.

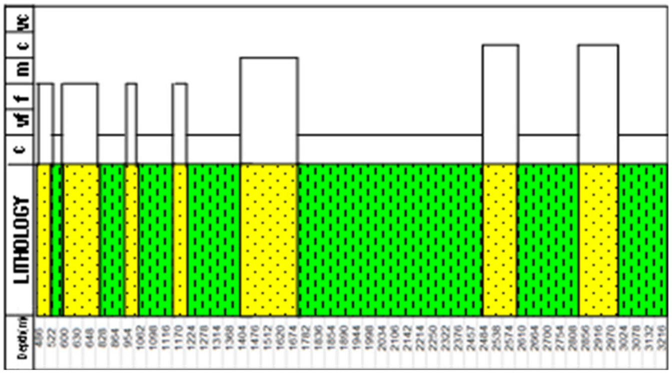

Fig. 3: Lithologic of BIMOL-1 well showing the two main lithologies, sand and shale, in the sections.

Quantitative Distribution of Palynological Constituents: The palynological constituents recovered from the well were initially classified according to their biological origin as continental and marine forms and further sub-classified into Miospore, fungi which together constitute the allochthonous forms and dinocyst (Fig. 5) which makes up the authochthonous fraction. Quantitative miospore counts in the well ranged from thirty seven (37) to one thousand four and sixty nine (1469), while dinoflagellate cyst species count ranged from one (i) to forty nine (49) at various depth intervals and complete absence in some depth intervals. Quantitative depth distribution of the various form species are presented in Table 1. A total of forty two (42) miospore species and ten (10) dinoflagellate cyst species were identified in this study.

Table 1: Quantitative depth distribution of miospores and dinocysts from BIMOL-1 well

S/N	Depth (m)	Pollen	Spore	Total Miospore	Dinocyst
1	486	100	16	116	0
2	522	1434	35	1469	0
3	600	196	16	212	0
4	630	440	13	453	0
5	648	347	44	391	1
6	828	77	15	92	2
7	864	160	16	176	7
8	954	200	55	255	1
9	1062	163	08	171	0
10	1098	266	54	320	3
11	1116	241	88	329	0
12	1170	281	120	401	0
13	1224	281	180	461	1
14	1278	320	105	425	3
15	1314	346	116	462	1
16	1368	333	96	429	3
17	1404	292	36	328	1
18	1476	330	120	450	5
19	1512	41	02	43	0
20	1620	345	126	471	5
21	1674	360	53	413	1
22	1782	281	50	331	27
23	1836	32	05	37	8
24	1854	41	12	53	3
25	1890	59	01	60	2
26	1944	50	23	73	0
27	1998	370	6	435	4
28	2034	59	20	79	5
29	2106	45	02	47	49
30	2142	100	18	118	9
31	2214	72	02	74	22
32	2250	47	10	57	0
33	2322	54	02	56	2
34	2376	137	61	198	3
35	2457	113	12	125	39
36	2484	96	53	149	3
37	2538	65	05	70	6
38	2574	33	23	56	0
39	2610	47	03	50	5
40	2664	82	36	118	5
41	2700	110	12	122	2
42	2754	38	22	60	0
43	2808	467	39	506	9
44	2856	353	85	438	1
45	2916	231	38	269	3
46	2970	116	14	130	0
47	3024	113	03	116	0
48	3078	100	37	137	2
49	3132	174	03	177	0
50	3216	111	44	155	0

Sea level history, Paleoclimate and Climatic cycle: The integration of sedimentological and palynological results from the well enabled valid inferences to be made regarding the age of the sediments, changes in sea level through time and paleoclimatic regime. From graphical analysis of miospore and dinocyst abundance (Fig. 4), inferences concerning sea level history, paleoclimatic changes and cycles were made. This analysis revealed a climate driven cyclic sea level pattern that influenced sedimentation and facies distribution and characteristics.

Sea Level History And Paleoclimatic Changes: Seal level history which is the record of the rise and fall of global sea level above and below its mean datum in past geologic times and driven by paleoclimatic indices which refers to past climatic conditions that prevailed in a given region is defined in this work.

The importance of this record is seen as a rise in sea level is marked by transgression of the sea, during which a landward shoreline shift is recorded and vice versa, thus important in erecting sequence stratigraphic framework for sedimentary columns.

Clues about sea level history and paleoclimate in the well area have been obtained from miospore and dinocysts abundance as proxy indicators, such that a climate driven rise in sea level is marked by wet climatic conditions leading to lush vegetation and high preservation of forms, while the reverse is obtained for seal level fall.

The result of the graphical analysis of the plot of miospore and dinocysts quantitative signatures with depth (Fig. 4) reveals changes in the paleo sea level and paleoclimate in the well section in which sea level rise alternates with seal level fall at various depths, revealing a cyclic pattern. In this signature, a rise and fall in sea level corresponds to wet and dry climatic conditions respectively (Table 2, Fig. 7).

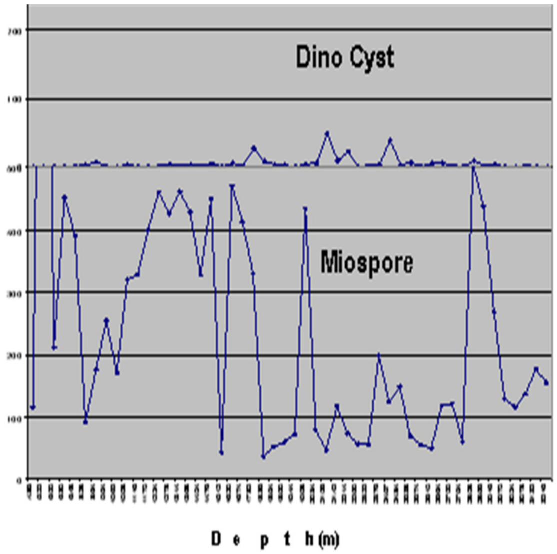

Fig. 4: Graphical depth plots of miospore and dinoflagellate cysts in BIMOL-1 well

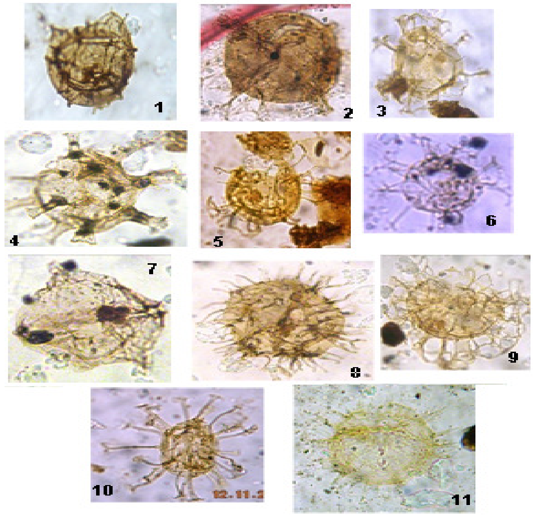

Fig. 5: Photomicrograph of some of the age-significant and paleoenvironment diagnostic dinocyst species recovered from the well section. (1. *Kenleyia lophophora,* 2. *Muratodinium fimbratum,* 3. *Homotryblium tenuispinosum,* 4. *Homotryblium palladium,* 5. *Systematophora,* 6. *Spiniferites pseudocatus,* 7. *Palaeoperidinium,* 8. *Apectodinium homomorphum,* 9. *Adnatosphaeridium vittatum.* 10. *Distatodinium.* 11. *Lingulodinium macphaerophorum.*)

Climatic Cycles and Reservoir Typing: A sequence of wet-dry-wet climatic index or dry-wet-dry climatic index gives a complete climatic cycle. Based on the miospore signal in figure 7, six climatic cycles have been identified: first climatic cycle ranged from 3216 to 2797 m, second cycle ranged from 2797 to 2567 m, third cycle ranged from 2567 to 2286 m, fourth cycle ranged from 2286 to 1634 m, fifth cycle ranged from 1634 to 1107 m and the sixth cycle ranged from 1107 to 486 m. The climatic cycles stands as facies generators in the sedimentary sequence. In this vain, sand bodies formed during a rise indicates a transgressive reservoir, as a rise in sea level corresponds to transgression while sand bodies formed during a fall in sea level corresponds to regressive sands such as lowstand sand wedge. The importance of this differentiation is appreciated in systems tract reservoir characterisation, in which reservoirs formed in different systems tract are known to possess different reservoir characteristics that ultimately determine the exploration and production philosophy of each reservoir type (Catuneanu, 2006).

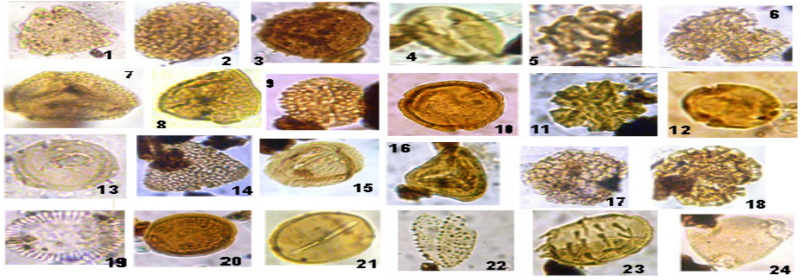

Fig. 6: Photomicrograph of some of the age-significant and paleoenvironment diagnostic miospore species recovered from the well section. (*1. Retribrevitricolpites triangulates,* 2. *Cleistophollis patens,* 3. *Mauritiidites lehmani,* 4. *Monocolpites sp.,* 5. *cf. baculatus,* 6. *Retitricolporites irregularis,* 7. *Fenestrate pollen,* 8. *Filtrotrilete nigerensis,* 9. *Retricolpites sp.,* 10. *Psilatricolporites crassus,* 11. *Ctenolophonidites costatus,* 12. *Psilatriporites sp.* 13. *Sporopollenites pollen*. 14. *Syndemicolpites typicus,* 15. *Striatricolpites catatumeus,* 16. *Polypodiacesporites sp.,* 17. *Praedapollis africanus,* 18. *Praedapollis flexibilis,* 19. *Ancillary microfossil,* 20. *aff. Nymphea lotus linn,* 21. *Psilamonocolpites marginatus,* 22. *Echimonocolpites rarispinosus,* 23. *Spinizonocolpites echinatus,* 24. *Retribrevitricolporites. Obodensis.*)

Table 2: Sea level and climatic index versus depth recognized in the well section

Depth (m)	Sea Level History	Climatic Index
600 – 486	Rise	Wet
648 – 600	Fall	Dry
1107 – 648	Rise	Wet
1197 – 1107	Fall	Dry
1503 – 1197	Rise	Wet
1654 – 1503	Fall	Dry
1971 – 1654	Rise	Wet
2016 – 1971	Fall	Dry
2286 – 2016	Rise	Wet
2363 – 2286	Fall	Dry
2565 – 2363	Rise	Wet
2637 – 2565	Fall	Dry
2727 – 2637	Rise	Wet
2795 – 2727	Fall	Dry
2997 – 2795	Rise	Wet
3153 – 2997	Fall	Dry
3216 – 3153	Rise	Wet

Age Calibration and Lithostratigraphic Differentiation: The geologic age of the sediments was determined by index forms identified among the many pollen and spores recovered from the well. These include: *Cleistopholis patens, Pachydermites diederixi, Grimsdalea polygonalis, Grimsdalea magnaclavata, Cyathidites sp., Verrucatosporites sp., Retibrevitricolporites triangulates, Retibrevitricolporites obodoensis, Praedopollis africanus, Praedopollis flexibilis, Polypodiaceisporites sp., Racemonocolpites hians, Cinctiperiporites mulleri, Arecipites exilimuratus* and *Proxapertites cursus.*

An age evaluation of these forms revealed a Lower Eocene to Lower Oligocene age range for the sediments as detailed below:

Lower Eocene 3216 – 2832 m: The low abundance and subsequent disappearance of *Cyathidites sp.,* at this depth interval indicate Lower Eocene. This age is also confirmed by the interval being immediately below the first appearance datum of Middle Eocene markers – *Cleistophollis patens* and *Pachydermites diederixi* (Fig. 6). Other forms that occur within this interval include *Zonocostites ramonae, Laevigatosporites sp.* and Monolete spores.

Middle Eocene 2832 – 1782 m: The interval is characterized by the first appearance of *Cleistophollis patens, Praedopollis Africans* and *Pachydermites diederixi* (Fig. 6), which indicate Middle Eocene (Legoux, 1978). The occurrence of *Grimsdalea polygonalis* within this interval further confirms s this age. Other palynomorphs that characterize this interval include *Retibrevitricolporites obodoensis*, *R. triangulates*, *Retitricolporite*s *irregularis*, and *Laevigatosporites sp.* These forms, according to Adegoke, (1969) are common in the Middle Eocene but not endemic to it.

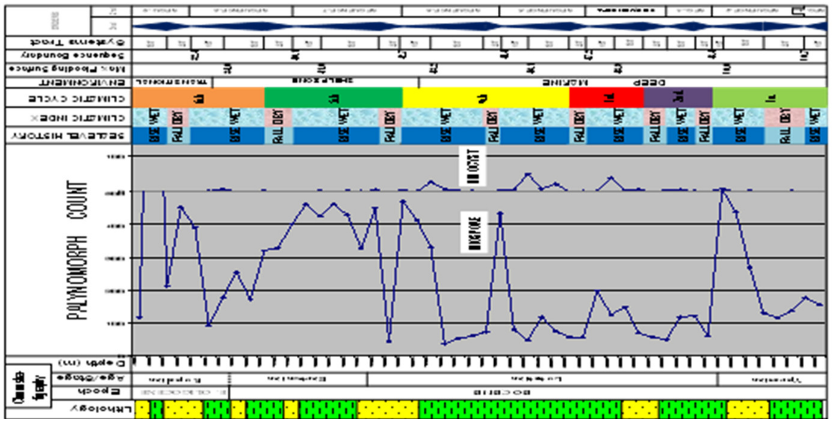

Fig. 7: Quantitative Plots of miospore and dinocyst reflecting changes in sea level, paleoclimate, paleoenvironment and sequence stratigraphic elements recognized in the well section

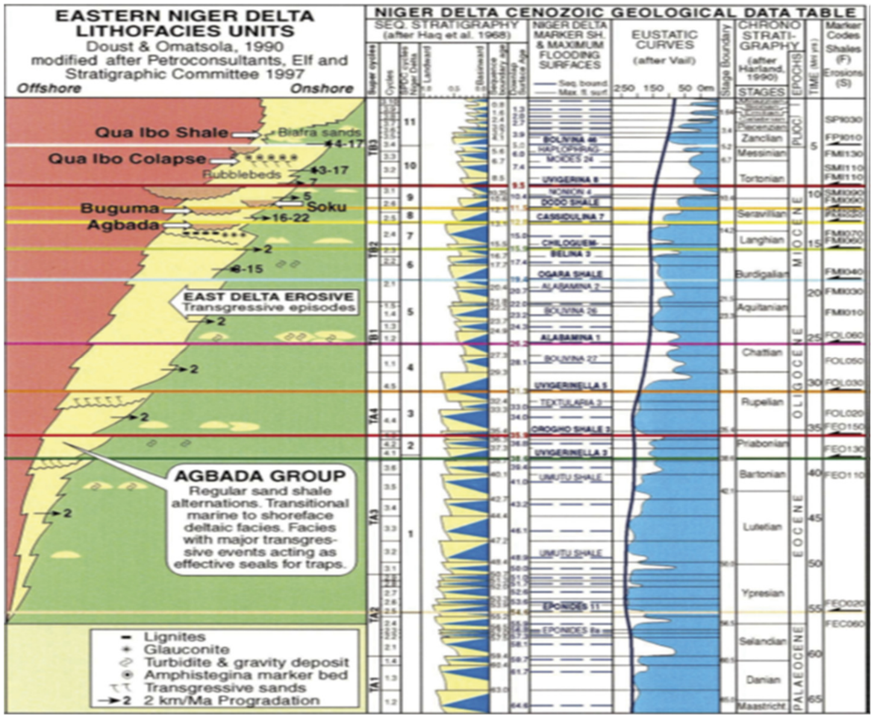

Fig. 8: Chrono-Stratigraphic data sheet (west and east halves combined) of the Niger Delta (SCiN Chrono Chart in Reijers, 2011).

Upper Eocene 1782 – 954 m: This interval is characterized first by the stratigraphic appearance of *Racemonocolporites hians* and *Cinctiperiporites mulleri* which indicate Upper Eocene. Muller (1959) asserted these forms to be characteristic of this age. Other formsrecovered from this interval include *Polypodiaceisporites sp.*, *Retibrevitricolporites obodoensis* and *Retimonocolpites obaensis*, (Fig. 6). These forms according to Sowumi (1981) are characteristics of Upper Eocene, but not restricted to it.

Lower Oligocene 954 – 486 m: This interval is characterized by regular and increased occurrence of *Arecipites exilimuratus*. The regular and increased occurrence of this form indicates that this interval is Lower Oligocene. Other Forms recovered from this interval include *Retitricolporites irregularis* and *Verrucatosporites sp.*

Sequence Stratigraphy: Twenty three systems tracts made up of seven high stands and eight transgressive and eight lowstand systems tracts, distributed within nine sequences have been identified. Six candidate maximum flooding surfaces (MFS) based on age dates defined by age significant palynotaxa and constrained with the Shell Company in Nigeria (SCiN) Chronochart (Reijers, 2011), include the 50.0 Ma Late Ypresian MFS which marks the close of the Ypresian stage; the 48.9 Ma, 46.1Ma and 43.2 Ma MFSs of Lutetian stage (Figs. 7 and 8). Others include the 41.0 Ma Bartonian and the 34.0 Ma Rupelian MFSs. The Priabonian and parts of the Bartonian stage in the well seems to have experienced some form of erosion/non-deposition. This observation is made visible by the systems tracts and the age of the sediments formed within that section of the well, as four maximum flooding surfaces (MFS 39.4, 38.6, 36.8 and 35.9 Ma) are absent in the well section, thus indicates the non-existence of the upper Bartonian and the entire Priabonian stage of the Late Eocene which accounts for the erosion/non-deposition of about 7 Ma of sediments in the well area and probably marking a major sequence boundary dated 40.1 Ma in this well (Figs. 7 and 8). Seven candidate sequence boundaries (SB) dated 50.7 Ma and of Ypresian stage, 48.4 Ma of Early Lutetian, 47.2 Ma and 44.4 Ma of Mid Lutetian, and 42.7 Ma Late Lutetian were recognized (Figs. 7 and 8). Others include the 40.1 Ma Bartonian and the 32.4 Ma Early Rupelian sequence boundaries.

*Conclusions***:** Palynotaxa record reveals paleovegetational trends which reflect paleoclimatic records and consequent sea level cycles. These correlated with paleovegetational change signatures, indicating that paleovegetational change is occasioned by paleoclimatic change in ancient geologic history that correspondingly affected sea level cycles. Acting as key facies generating elements, in that the thicker sand intervals/successions are closely related to dry climatic periods (sea level fell) and progradation which heralded the sedimentation pattern and vice versa. Sea level trends and climatic conditions correlated with different systems tracts depending on the climatic regime, thus this technique would enable tracking of significant events in the sedimentary history.

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