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Lithostratigraphy and palynofacies appraisal of the northern depobelt onshore, Niger Delta

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Abstract

Palynological and lithological studies of two exploratory wells located within northern depobelt of the Niger Delta have been carried out. Seventy-six cutting samples were studied in order to determine the diverse lithofacies, biozonation, age, palaeoenvironment and palynofacies based on the recovered taxa. The main lithofacies identified are sandstones, shaly sand, sandy shale, silty shale, siltstone and shale of Benin and Agbada Formations. The sandstones are coarse to fine grain and sub-angular to sub-rounded. A total of one hundred and twenty pollen, one hundred and fifty spores, twenty algae and ten dinoflagellate cysts were recovered and identified. The palynological Zone of P500 and P520 Subzone (1,975m-2354m); P400 Zone and P470/P480 (2,179m-2,481m [Umutu-5]); (2,354m-2,793m [Umutu-2]); P450 (2,481m-3,060m) [Umutu-5]); (2,793m-3,163m [Umutu-2]); and P430 (3,060m- 3578m [Umutu-5]); 3,163m-3,380m [Umutu-2]). Subzones were established in the studied wells. The palynomorphstaxa show the occurrence of high species diversity of land derived palynoflora suggesting a near shore environment. The abundant land-derived palynomorphs and common dinoflagellate cysts recorded include *Polysphaeridium zoharyi, Lingulodinium machaerophorum* and *Spiniferite* ssp. suggesting shallow marine setting. The occurrence of *Psilamonocolpites marginatus*, *Doualaidites laevigatus, Echitriporites trianguliformis, Botryococcus braunii* and *Gemmamonoporites* sp. suggests middle Eocene to early Oligocene and middle to late Eocene ages respectively.

Keywords: Lithofacies; taxa; palynomorphs; palynofacies; palaeoenvironment; species; diversity.

Introduction

The Niger Delta is known to be the most prolific sedimentary basin in sub-Saharan Africa with respect to petroleum production, containing the 12th largest known accumulation of recoverable hydrocarbons with reserves exceeding 34 billion barrels of oil and 93 trillion cubic feet of natural gas [1]. The lithostratigraphy of the Niger Delta is divided into three units from oldest to youngest namely; the basal Palaeocene to Recent pro-delta facies of the Akata Formation, Eocene to Recent paralic facies of the Agbada Formation, and Oligocene-Recent, fluvial facies of the Benin Formation [2-4]. These formations become progressively younger farther into the basin, recording the long-term progradation of depositional environments of the Niger Delta on to the Atlantic Ocean passive margin.

The stratigraphy of Niger Delta is complicated by the syn-depositional collapse of the clastic wedge as shale of the Akata Formation mobilized under the load of prograding deltaic Agbada and fluvial Benin Formation deposits [1, 4]. In the oil industry, micro foraminifera and palynological analyses are very essential stratigraphic tools particularly useful in the study of rocks deposited in diverse depositional settings.

Several published works have appeared on deltaic environments since the late 1950s, with emphasis on lithofacies and the relationship between benthonic micro faunas, biozonations and the dynamic and hydro-chemical components of the environment [5-12]. Short

and Stauble [2] presented a detailed work on the lithostratigraphy of the Niger Delta. They delineated three diachronous and superimposed formations; the topmost Benin Formation comprising fluviate gravels and sandy clays, the paralic middle Agbada Formation which comprises interbedded sand and shales and the basal Akata Formation which is prominently composed of marine shales. Avbovbov [13] amongst others has also discussed the lithostratigraphy of the Niger Delta. A review of stratigraphy, sedimentation and structure of the Niger Delta was studied as well as the effects of long shore current on the delta [13]. Ekweozor and Daukoru [14] assessed the sandstone reservoirs of the Agbada Formation which composed of channel sands, barrier bars with occasional deep water turbidites. Boboye and Akaegbobi [15]; Orife and Avbovbo [16] and Petters [17] carried out a biostratigraphic analysis of the Akata and Agbada Shales and established the foraminifera palaeoecology based on diverse planktonic and benthonic foraminifera that led to the discovery of an ancient canyon system in the Western Niger Delta.

Detailed studies on the stratigraphy and petroleum geology of the Niger Delta were provided by some workers [4, 18, 19] while the effects of over-pressure in petroleum accumulation in Niger Delta subsurface was discussed by Boboye and Ogunkorode [20]. Boboye and Adeleye [21], defined provisional palynological zones from the stratigraphic distribution of pollen and spores in the late Miocene to Pliocene from a study of data from deep offshore wells in the Niger Delta. The proposed zones were correlated with the existing palynological zones for the onshore Niger Delta and the planktic foraminifera (N) and nannofossil (NN) zones. Their studies signified the reliability of palynostratigraphy as a biostratigraphy tool in the deep offshore Niger Delta.

Most of the previous studies carried out in the Niger Delta made use of form generic names, which essentially are illustrated or systematic descriptions [6, 7, 8-10]. However, this study is based on the identification of fossil palynomorphs using botanical nomenclature where possible. Identification of the possible botanical affinity is essential in order to make palaeoecological inferences, provided the limitations of this procedure are taken into cognizance. Such data will be useful in the present search of the operating oil industries for information on the flora and the environmental changes as reflected by vegetation particularly during the late Tertiary period [7, 8, 22]. According to Whiteman [4], the Niger Delta certainly stands among the world's best studied delta complexes, but its superficial deposits are among the poorest known. However, present study aims at determining the lithofacies of the sequence; identify the palynomorphs taxa present, biozonation and correlation based on the recovered fossils and palaeoenvironmental reconstruction.

Location of the study-area and geology

The Niger Delta Basin is situated on the continental margin of the Gulf of Guinea between Latitude 03^0 and 06^0N and Longitude 05^0 and 08^0E. The areal extent of the Niger Delta is about 75,000 km^2 with a clastic fill of about 12,000 m. It ranks amongst the world's most prolific petroleum-producing Tertiary Deltas that together accounts for about 5% of the world's oil and gas reserves [23]. It is bounded on the west and northwest by the Western African Shield, which terminates at the Benin hinge line to the east, by the Calabar hinge line. The Anambra Basin and the Abakaliki anticlinorium mark its northern limit while it is bounded by the Gulf of Guinea towards the south (Figure 1).

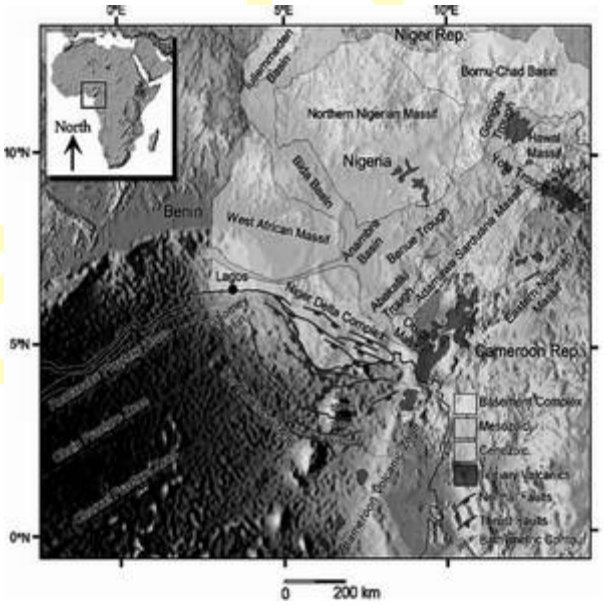

Figure 1. Geologic map of Nigeria showing Niger Delta. Inset: Map of Africa showing the position of the Niger Delta [5].

Stratigraphy of Niger Delta Basin

Differential subsidence, fluvial actions, coastal and marine depositional processes by transgressive and regressive cycles have greatly influenced and modified the lithologies of the Niger Delta [1]. A major transgression, Sokoto transgression, began with the

Imo Shale being deposited in the Anambra Basin to the northeast and Akata Shale in the Niger Delta Basin to the southwest [1]. During the Eocene, the deposition of paralic sediments had begun in the Niger Delta Basin as the coastline shape become convexly curvilinear, though the long shore drift cells switched to divergent which cause a change in sedimentation pattern to wave-dominated [1]. As sediments prograded southward, the coastline becomes progressively more convex seaward. But from Campanian to Palaeocene, the shoreline was concave into the Anambra Basin, resulting in convergent long shore drift cells that produce tide dominated deltaic sedimentation during transgressions and river-dominated sedimentation during regressions [1 and 14].

However, lithologies of Cretaceous rocks deposited in the Niger Delta Basin have not been penetrated beneath the Niger Delta Basin (i.e. the youngest, southernmost Benue-Abakaliki sub-basin) but can be studied from the exposed Cretaceous section in Anambra Basin [1]. The stratigraphy of Niger Delta from oldest to youngest include: Akata, Agbada and Benin formations [1].

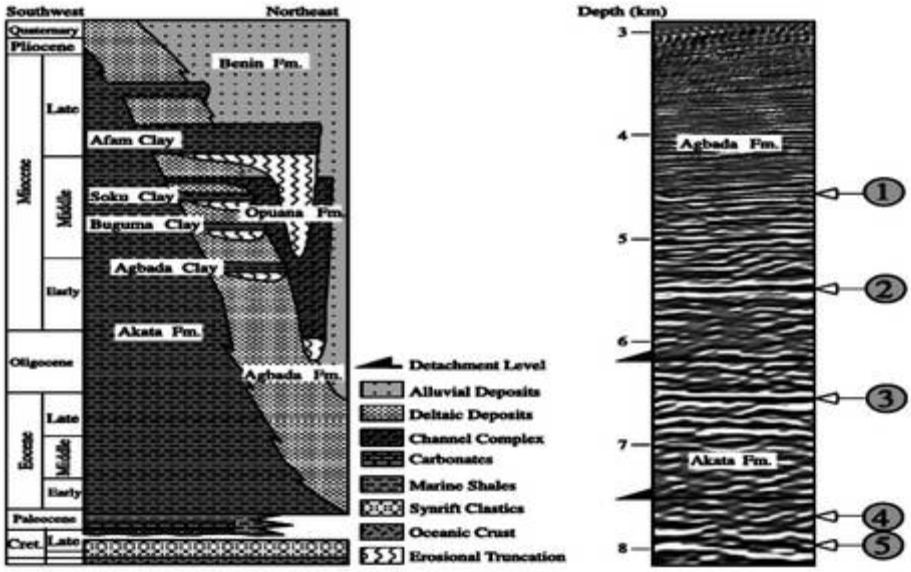

Figure 2. Schematic diagram of the regional strati-graphy of the Niger [24].

Materials and methods

A total of seventy-six cuttings samples were retrieved from Umutu-2 and Umutu-5 exploratory wells in the onshore northern depobelt of Niger Delta Basin within the Latitudes 4^0 30′ to 5^0 2′ North and Longitudes 3^0 9′ East at 36 m intervals within the depths of 1,975m-3,380 m and 2,179 m-3,578 m respectively. Samples were selected and subjected to lithological and palynological analyses. The wells were made available by the Chevron Nigeria Limited via the Department of Petroleum Resources (DPR), Nigeria.

Lithofacies description

The descriptions of the lithofacies were carried out in the sedimentology laboratory, Department of Geology, University of Ibadan. This was done with a hand lens and stereo-binocular microscope with standard sedimentological charts to delineate the diverse lithofacies' units within the study wells. The samples were described in terms of texture, colour, grain sizes and lithology.

Palynological preparation

This was done at the University of Ibadan, Ibadan, and Crystal Age Laboratory, Lagos. Fifteen grammes (15 g) each of the cutting samples was treated with dilute hydrochloric acid (HCL) to remove carbonates. Each sample was sieved, washed, centrifuged and treated with hydrofluoric acid (HF) for complete digestion in gentle agitation of the acid/sample mixture. The samples were then treated with hot hydrochloric acid (HCL) and later wet-sieved over a 5 µm mesh size polypropylene sieve. The Branson Sonifier 250 was routinely employed during sieving to facilitate complete removal of silt and clay particles. The sieved residue was given controlled oxidation using

concentrated nitric acid (HNO_3). LOCTITE (Impruv) was used as the mounting medium. The slides were stained to enhance the visibility of some dinoflagellate cysts present. The residues were then sieved via 10 µm sieve size to recover the palynomorphs. The slides were carefully studied using a binocular microscope (Leitz Diaplan) and the dating was based on STRATCOM Schemes, Evamy, Germeraad and other workers [3, 25]. Taxa identification were done using reference slides, Chevron and Shell (SPDC) albums while the distribution charts were prepared using a STRATABUG software (Figures 3-7).

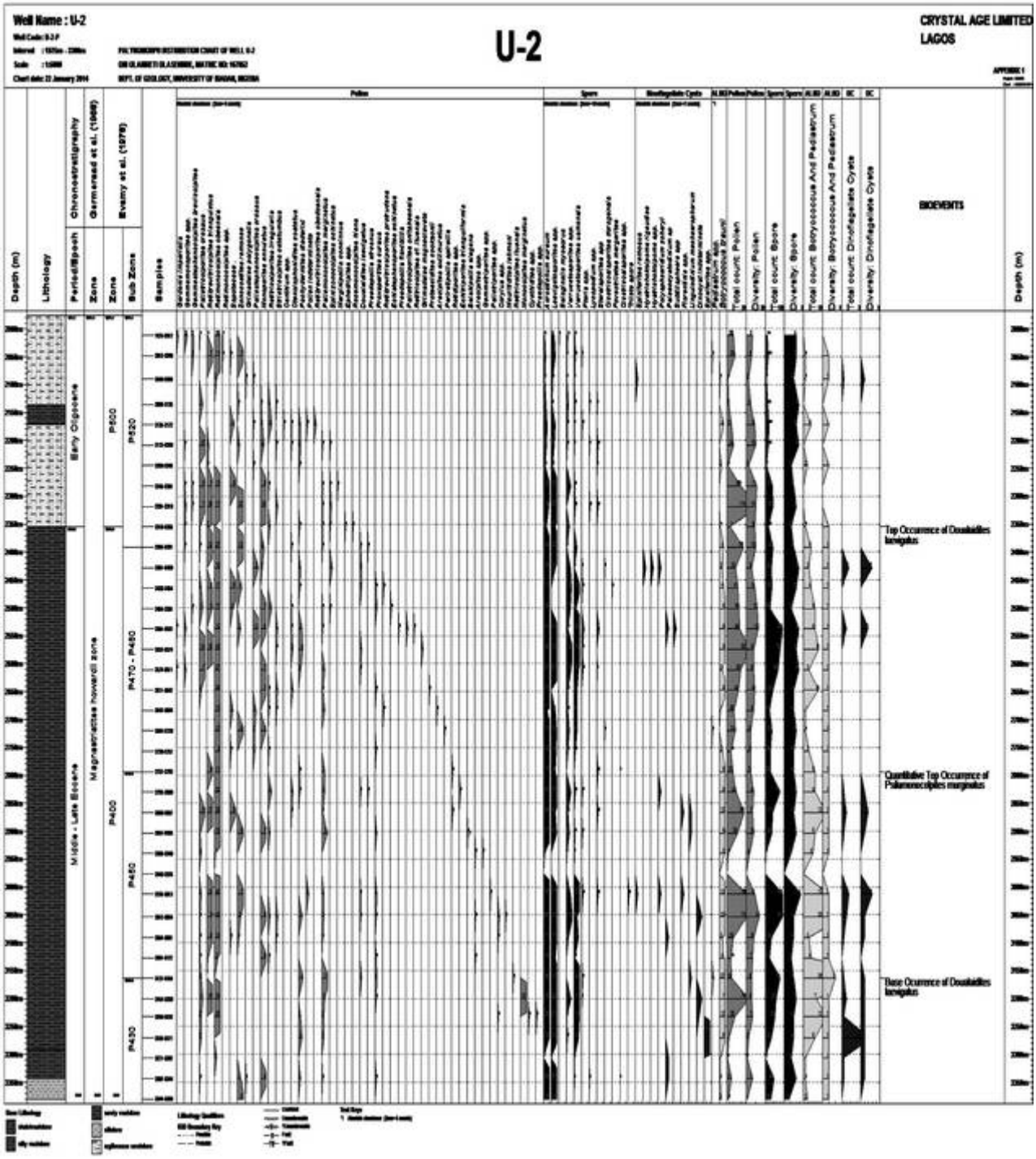

Figure 3. Palynological distribution chart of U-2 (Umutu-2) Well.

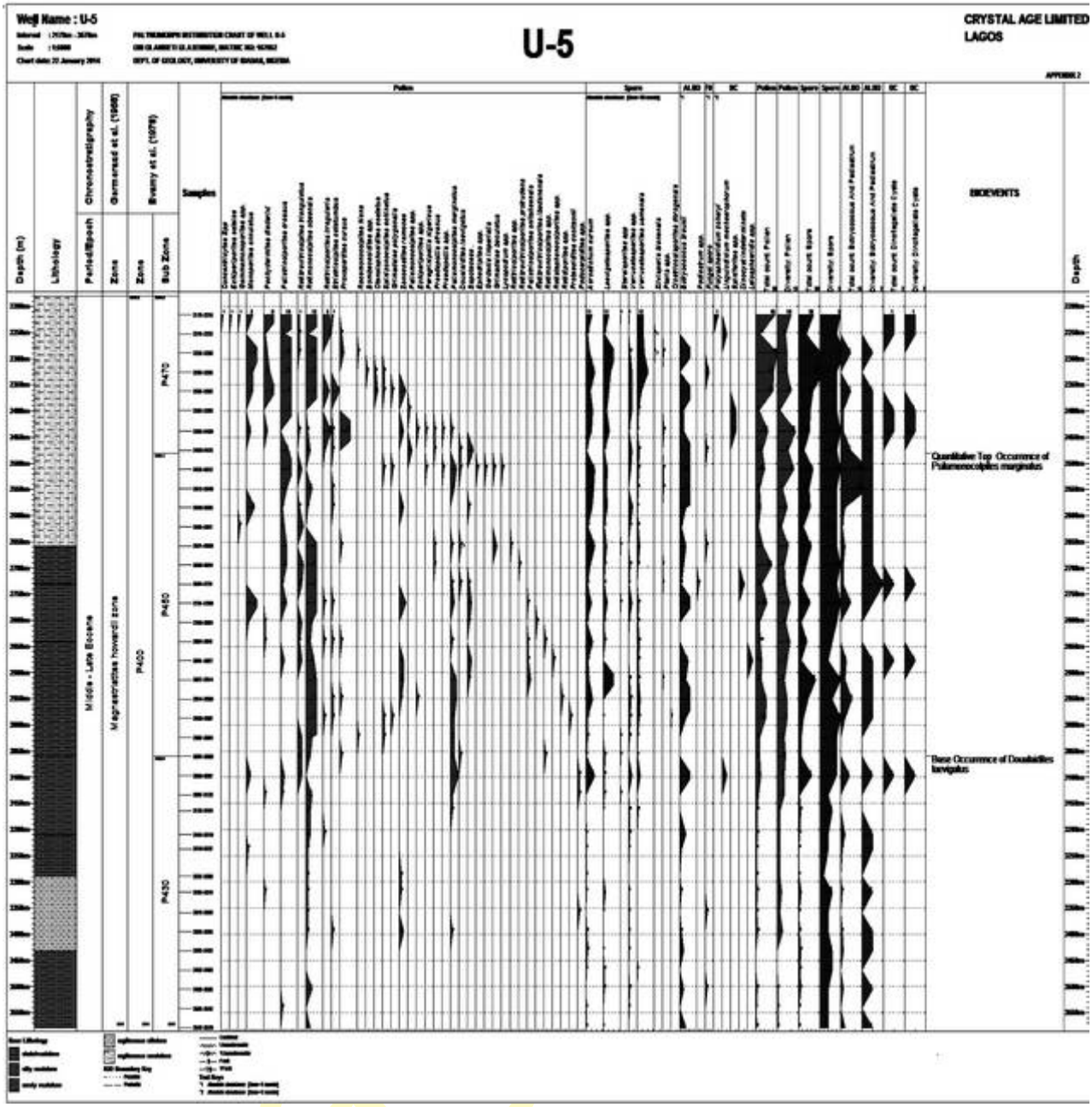

Figure 4. Palynological distribution chart of U-5 (Umutu-5) Well.

Results and discussion

Lithostratigraphy

This study reveals sandstone, shaly-sand, sandy-shale, silty-shale, shaly-siltstone and shale as the main constituents of the two wells. The textural parameters of the sandstones are coarse grained, sub-angular to sub-rounded (Tables 1 and 2).

Palynostratigraphy

Umutu-2 and Umutu-5 Wells have yielded high abundance and diversity of palynomorphs. The forms recovered are well preserved micro flora dominated by abundant pollen, spores and fungal spores. The total number of seventy (70) pollen, one hundred (100) spores, eight (8) dinoflagellate cysts, ten (10) algae were recovered from Umutu-2 Well. Those recorded from Umutu-5 well are fifty (50) pollen, two (2) dinoflagellate cysts, fifty (50) spores and fifteen (15) algae. The recovered forms include; *Zonocostites ramonae, Retimonocolpites obaensis, Retibrevitricolpites obaensis, Retibrevitricolpites triangulates, Psilatricolporites crassus, Psilamonocolpites marginatus, Striatricolpites*

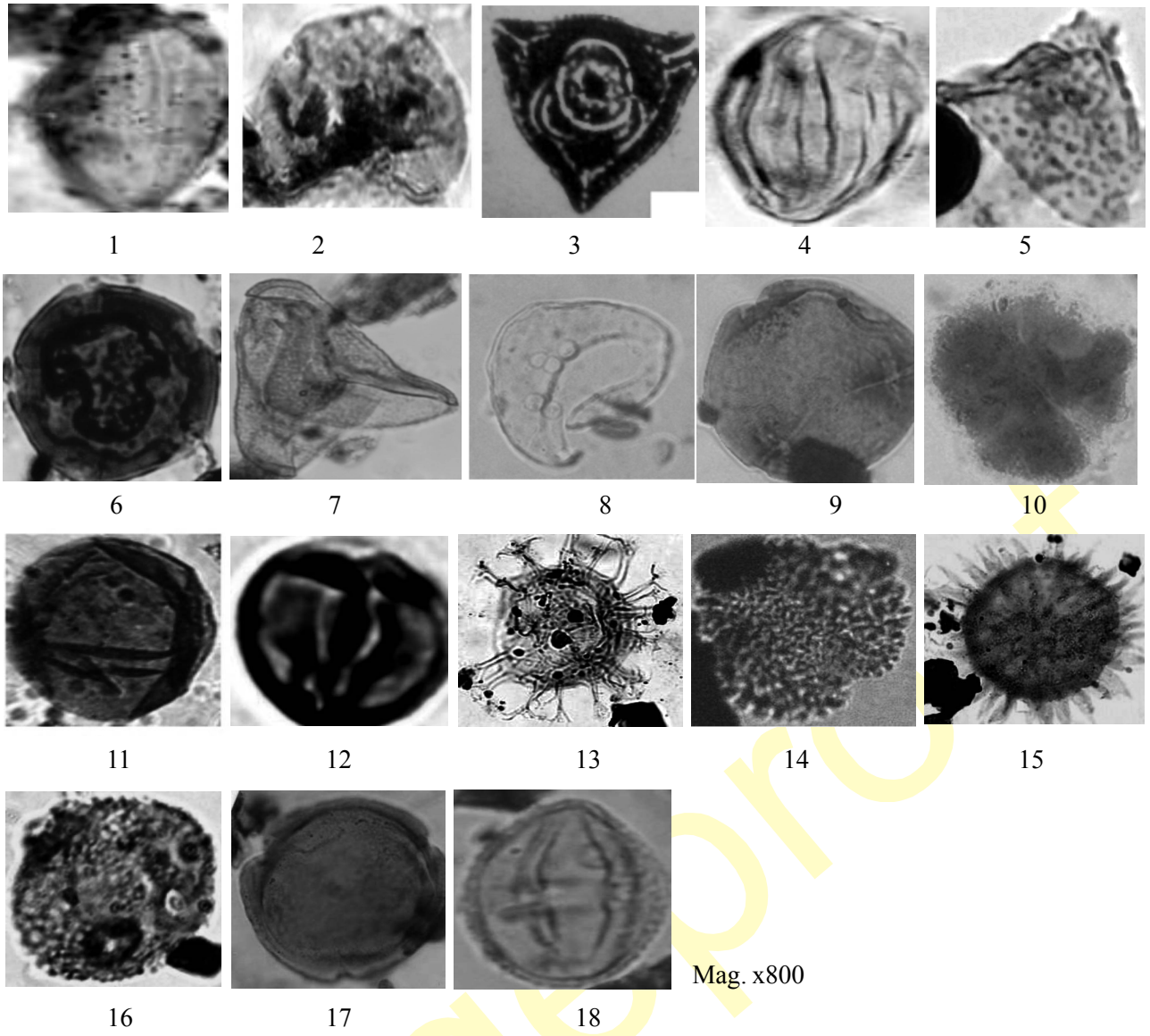

Figure 5. Some palynomorphs taxa identified from the studied-wells.

The following are the recovered palynomorph taxa presented (Figure 6):

1. *Retimonocolpites* sp.
2. *Laevigatosporites* sp.
3. *Doualaidites laevigatus*
4. *Monocolpites marginatus*
5. *Echitriporites trianguliformis*
6. *Psilamonocolpites marginatus*
7. *Cyathidites* spp.
8. *Gemmamonoporites* sp.
9. *Psilatricolporites crassus*
10. *Botryococcus braunii*
11. *Monoporites annulatus*
12. *Zonocostites ramonae*
13. *Spiniferites* sp.
14. *Retitricolporites irregularis*
15. *Lingulodinium machaerophorum*
16. *Retibrevitricolporites protrudens*
17. *Psilatricolporites crassus*
18. *Retitricolporites* sp.

catatumbus, Sapotaceae, *Monoporites annulatus, Ctenol ophonidites costatutus, Retitricolporites irregularis, Pachydermites diederixi, Acrostonum aureum, Laevigatosporites* sp., *Verrucatosporites usmensis, Polypodiaceiorporites* sp.(pteris), *Verrucatosporites* sp. And *Stereisporites* sp. (Figure 6). There are occurrences of marine dinoflagellate cysts within the middle (2427m- 2537m) and basal sequences (2,793m-3,380m) of Umutu-2 Well (Figures 4 and 5).

Palynological biozonation of the studied wells

The studied wells' sequences are within the broad Pan-Tropical *Magnastriatites howardi* Zone of Germeraad and others [25] and the P400 and P500 Zones of Evamy

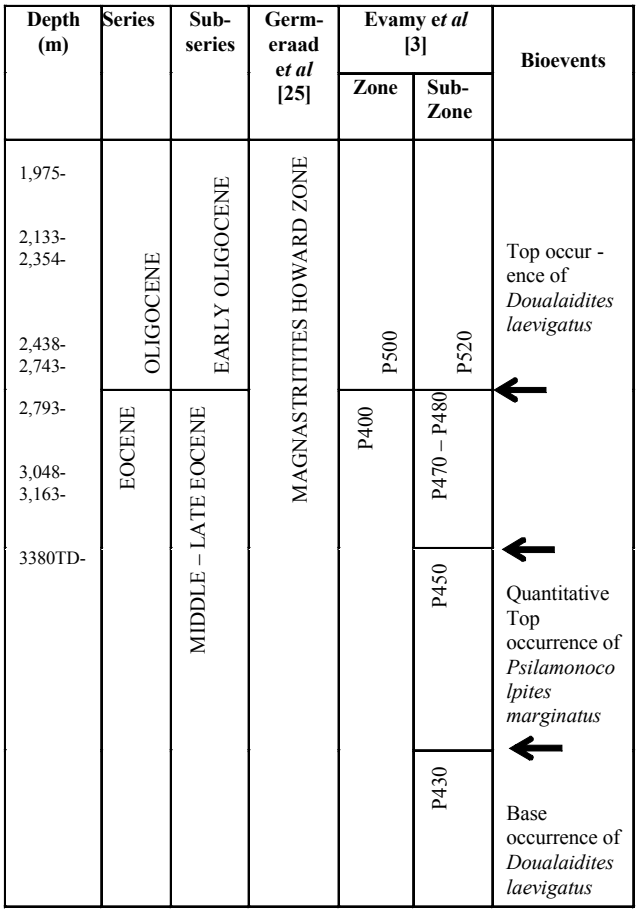

Figure 6. Palynomorph biozonations recognised in Umutu-2 Well.

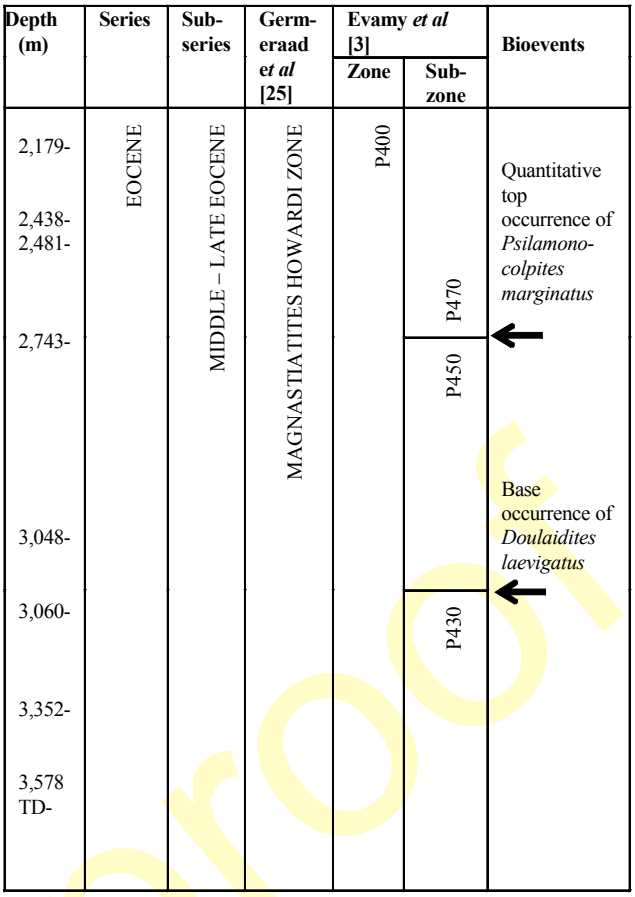

Figure 7. Palynomorph biozonations recognised in the Umutu-5 Well.

Table 1. Lithologic description of Umutu-2 Well.

Depth (m)	Age	Formation	Lithology	Lithologic description
621-1,207	Early Tertiary – Recent	Benin	Sandstone	Light brown, coarse, loose, moderately sorted, sub-rounded to sub-angular
1,207-1,975	Early Tertiary – Recent	Benin	Shaly sand	Light grey, coarse, earthy, sub-spherical, sub-rounded to sub-angular, moderately sorted, brittle
1,975-2,354	Early Tertiary – Recent	Agbada	Sandy shale	Light grey, coarse, loose, earthy, brittle, sub-angular, dusty, moderately sorted.
2,354-3,182	Early Tertiary – Recent	Agbada	Shale	Light grey, sub-blocky to blocky, hard, compact to firm, earthy

Table 2. Lithological description of Umutu-5 Well.

Depth (m)	Age	Formation	Lithology	Lithologic description
1,676-1,972	Early Tertiary – Recent	Benin	Sandstone	Light brown, soft, medium, sub-spherical, sub-angular to sub-rounded, moderately sorted.
1,972-2,179	Early Tertiary – Recent	Benin	Shaly sand	Light brown, coarse to medium, sub-rounded to sub-angular, moderately sorted, brittle, earthy
2,179-2,657	Early Tertiary – Recent	Agbada	Sandy shale	Grey, coarse to medium, soft, sub-rounded to sub-angular, moderately sorted, brittle, blocky to sub-blocky
2,657-2,731	Early Tertiary – Recent	Agbada	Shale	Grey, sub-blocky to blocky, moderately hard.
2,731-2,877	Early Tertiary – Recent	Agbada	Sandy shale	Grey, coarse to medium, sub-angular to sub-rounded, loose, moderately sorted, blocky to sub-blocky, brittle
2,877-3,078	Early Tertiary – Recent	Agbada	Shale	Grey, brittle to moderate, earthy, sub-blocky to blocky.
3,078-3,468	Early Tertiary – Recent	Agbada	Shale	Grey, brittle, sub-blocky to blocky, well sorted, rounded, dusty.

and others [3]. The P520, P480-P470, P450 and P430 Subzones were recognised within the Umutu-2 Well while the P470, P450 and the P430 Subzones are within the Umutu-5 Well (Figures 7 and 8).

P500 Zone
P520 Sub-zone
Interval: 1975m-2354m.
Age: Early Oligocene.
Top: The top of this subzone was tentatively placed at 1,975 m depth.
Base: This is marked by the first down hole occurrence of *Doualaidites laevigatus* form.

Diagnostic Criteria: The P520 sub-zone was only recognised within the P500 Zone [3] in the Umutu-2 Well but absent in Umutu-5 Well. This is the youngest sub-zone recognised within the two wells (Umutu-2 and Umutu-5). The top of this sub-zone was tentatively placed at the depth of 1,975 m while the base was placed at 2354 m depth which was defined by the top occurrence of *Doualaidites laevigatus*.

P400 Zone
P470/P480 Sub-zone
Intervals: 2,354m-2,793 m (Umutu-2), 2,179 m-2,481 m (Umutu-5)
Age: Late Eocene.

Top: The top of this sub-zone was placed at the depth of 2,354 m (Umutu-2) and 2,179 m (Umutu-5) marked by the first appearance datum (FAD) of *Doualaidites laevigatus* species with the co-occurrence assemblages of *Retimonocolpites obaensis* and *Psilatricolcolporites crassus.*

Base: The base of this sub-zone could not be delineated in Umutu-2 well due to the absence of *Cinctiperipollis mulleri* but it was marked by quantitative top occurrence (FAD) of *Psilamonocolpites marginatus* at 2,481 m in Umutu-5 Well. Other pollen occurring in abundance with this sub-zone are *Retimonocolpites obaensis, Verrucatosporites usmensis* which co-occurred with *Psilamonocolpites marginatus.*

Diagnostic criteria: This sub-zone was delineated within the Umutu-2 Well but could not be substantiated within the Umutu-5 Well due to the absence of diagnostic species for this zone within the Umutu-5 well at this horizon. However, the top of this sub-zone placed at 2,354 m depth is defined by the top occurrence of *Doualaidites laevigatus* forms. These are of the P470 sub-zone and the top of the P480 sub-zone could not be delineated because of the absence of *Cinctiperipollis mulleri* diagnostic species. This is the youngest sub-zone recognised within Umutu-5 Well with the top of this sub-zone placed at the depths of 2179 m (Umutu-5 Well), and 2,481m (Umutu-2 Well).

The top of the composite sub-zones were defined by the quantitative top occurrence of *Psilamonocolpites marginatus.* This sub-zone is further characterized by the abundant recovery of *Retimonocolpites obaensis, Verrucatosporites usmensis* co-occurring with *Psilamonocolpites marginatus.*

P450 Sub-zone
Intervals: 2,793m-3,163m (Umutu-2), 2,481m-3,060 m (Umutu-5)
Age: Middle – Late Eocene.

Top: The top of this sub-zone is marked by quantitative appearance (FAD) of *Psilamonocolpites marginatus* at 2,793 m (Umutu-2) and 2,481 m (Umutu-5 Well) with the absence of *Cinctiperipollis mulleri* forms.

Base: This was characterized by the basal occurrences of *Doualaidites laevigatus* at 3,163 m (Umutu-2 Well) and 3,060m (Umutu-5 Well) depths. This co-occurred with *Psilatricolporites crassus* and *Monoporites annulatus* forms in Umutu-2 Well, while it co-occurred with the abundance of *Retibrevitricolporites triangulates* and the persistent records of *Doualaidites laevigatus* form in Umutu-5 Well.

Diagnostic criteria: The top of this sub-zone was placed at the depth of 2,793 m marked by the quantitative top occurrence of *Psilamonocolpites marginatus,* while the base is defined by the basal occurrence of *Doualaidites laevigatus* at 3,163 m depth. The sub-zone is characterised by the consistent records of *Psilamonocolpites marginatus* species.

P430 Sub-zone
Intervals: 3,163m-3,380 m (TD) (Umutu-2); 3,060m-3,578m (TD) (Umutu-5)
Age: Middle Eocene.
Top: The top was marked by the appearances of basal occurrence of *Doualaidites laevigatus.*

Top: The top of this sub-zone in Umutu-2 and Umutu-5 Wells are characterized by the basal occurrence of *Doualaidites laevigatus* species at 3,163 m and 3,578m depths respectively. This is accompanied by the occurrence of *Retimonocolpites obaensis* and *Retibrevitricolpites trangulatus* species within the Umutu-5 Well.

Base: The base was tentatively placed at 3,380 m (TD) and 3578 m (TD) interval depths.

Diagnostic criteria: This is the oldest and the last sub-zone recognized within Umutu-2 and Umutu-5 Wells. The top of the sub-zone was marked by the basal occurrence of *Doualaidites laevigatus* at 3,163 m (Umutu-2) and 3060 m (Umutu-5) depths while the base were tentatively placed at 3,380 m and 3,578 m (TD) depths.

Palaeodepositional environment

The interval of 2,011 m-2,354 m depth in the Umutu-2 Well consists of abundant land derived palynomorphs which include *Retibrevitricolpites triangulates, Psilatricolporites crassus, Retimonocolpites obaensis, Acrostichum aureum, Laevigatosporites* sp., *Verrucatosporites* sp., freshwater algal (*Botryococcus braunii*) and a singular record of dinoflagellate cyst within the sequence. These assemblages suggest a near shore environment of deposition [21, 26]. There was a slight increase in the dinoflagellates cysts with abundant pollen, spores and fungal spores (2,354 m-2,793 m). However, high abundant of fresh water algae, *Botryococcus braunii,* was also recovered throughout this interval. The sediments of this interval were deposited within the shallow marine settings with high influx of freshwater [26]. There was appreciable increase in the abundance of dinoflagellates cysts and freshwater algae (*Botryococcus braunii)* at 2,793 m-3,380 m depth. The recorded dinocysts include *Spiniferites ramosus, Hystrichokolpoma* sp., *Palaeocystodinium* sp., *Florentinia* sp., *Lingulodinium machaerophorum* and *Spiniferites* sp. with abundant pollen and spores. These assemblages suggest a marine depositional environment with high influx of freshwater. The abundant land derived palynomorphs and ubiquitous dinoflagellate cysts in Umutu-5 Well amongst which are *Polysphaeridium zoharyi, Lingulodinium machaerophorum* and *Spiniferites* sp. recorded within the shallow marine depth of 2,179 m-2,694 m intervals. Abundant numbers of pollen and pteridophyte spores were recorded with low numbers of dinoflagellate cysts. Abundant freshwater algae, *Botryococcus braunii,* were also recorded at the interval of 2,694 m-3,133 m depth suggesting a shallow marine environment with high influx of freshwater. Dinoflagellate cysts were also recovered at 3,133 m-3,578 m intervals. This assemblage is suggestive of a coastal deltaic environment of deposition [21, 25, 26].

Conclusions

Lithological and palynological studies of Umutu-2 and Umutu-5 Wells located within the Niger Delta have

been carried out. Seventy-six (76) cutting samples belonging to Benin and Agbada Formations were analyzed for their lithofacies and palynomorphs. They constitute sandstone, shaly sand, sandy shale, silty shale, shaly siltstone and shale. The sandstones are coarse to fine grained and sub-rounded to sub-angular. The wells show abundant and diverse microflora. The established biozonation based on the diagnostic forms are P500 and P400 Zones, P520, P470/P480, P450 and P430 Sub-zones.

The recovered forms suggest middle Eocene to early Oligocene and middle to late Eocene ages for Umutu-2 and Umutu-5 Wells respectively. The occurrence of the microflora assemblages which co-occurred with *Spiniferites ramosus, Hystrichokolpoma rigaudiae, Polysphaeridium zoharyi, Lingulodinium machaerophorum, Florentinia* sp. and *Botryococcus braunii* suggest a shallow marine depositional environment (Umutu-5) and marine environment with high influx of fresh water (Umutu-2).

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