Palynofacies and Thermal Maturity Studies of Kudu-3 Well, Northern/Central Bida Basin, Nigeria

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Abstract
Petroleum prospection in the Bida Basin is still in its initial stage of exploration. Palynofacies and thermal maturation studies are key parameter for early basin evaluation by improving exploration success and understanding of the potential hydrocarbon source rock. The purpose of this study is to carry out palynofacies characterization of the sediments retrieved from Kudu-3well, Northern/Central Bida Basin, to determine the sediment maturity. These were accomplished by processing 19 ditch cutting samples within the depth interval of 31 – 58 m using acid maceration technique. Microscopic analysis of both palynological and palynofacies slides yielded diverse pollen, spores, dinoflagellate and palynomacerals. The palynomaceral types recovered include 51% of dark brown to orange, brown structureless resinous cortex material of palynomaceral 1, 32% of brown to orange platy like structured plant materials of palynomaceral 2, 14% of pale-coloured small to medium-sized stomata bearing plant materials of palynomaceral 3 and 3 % of black equant needle shaped plant materials of palynomaceral 4. Thermal maturation was determined from microscopic observation of exine wall colour of the palynomorph and the palynomacerals, which range from orange-brown, light-brown, and light-medium brown to dark brown. The estimated values for thermal alteration index (TAI), vitrinite reflectance (%Ro) and burial temperature extrapolated from correlation of the observed palynomorphs/palynomacerals colour changes with other calibrated scale yielded 3/4–5 TAI, 0.55–0.95% and 60–120°C respectively. These values indicate early mature to mature stage of petroleum generation. The abundance records of palynomacerals 1, 2 and 3, and terrestrial palynomorphs in the studied section are an indication of more gas prone than oil. This work suggests possible potential of hydrocarbon accumulation in the Bida Basin and that the Enagi Siltstone is a potential hydrocarbon source rock.
Keywords: Palynofacies, thermal maturity, palynomorph, palynomacerals, Kudu-3 well, Bida Basin

INTRODUCTION

Palynofacies analyses studies particulate organic matter assemblage in sedimentary deposits. Palynofacies studies have several applications in exploration geology: they have been utilized in oil industries to delineate zones of hydrocarbon potential by identifying and correlating rock sequences, reconstruction of paleoenvironmental and paleoclimatic conditions, determining relative ages and estimating the degree of thermal maturation of sediments (Zobaa, 2011). Certain palynomorphs (bisacate pollens and psilate spores) tend to become darker and darker with increasing thermal maturation and hence the colour variation of palynomorphs exine (wall) serve as tool for determining the thermal maturation level of their enclosing source rock (Staplin, 1969). The colour changes of palynomorphs with depth are extremely useful in assessing thermal maturation history of sedimentary sequence. The extent of maturation of hydrocarbon source rock, vitrinite reflectance and hydrocarbon generation can be inferred from the degree of thermal alteration of spores and pollen grains extracted from sedimentary rocks. Palynofacies and thermal maturation studies are key parameter for assessment of oil and gas accumulation of a source rock at initial stages of exploration. They play an important role in early basin evaluation by improving exploration success. Hence, the knowledge of palynological analysis of the source rock is invaluable for assessing the hydrocarbon prospectivity of the basin.

Alkali et al. (2017) carried out palynostratigraphy, age determination and paleoenvironmental studies on samples obtained from exposed section of Patti Formation at Ahoko area of the Bida Basin. The authors assigned Maastrichtian age to the section and delineated both terrestrial and marine derived palynomorph from the sequence. Onoduku et al. (2017) described the environment of deposition of kudu-1 well using the palynomorphs contents as terrestrial to near shore dominated environment but paid no attention to the palynomaceral contents and thermal maturity. This work considers the use of palynofacies (palynomorphs and palynomacerals) in assessing the thermal alteration of organic matter content of the sedimentary succession penetrated by Kudu-3 well, which is important in basin evaluation and successful exploration of mineral resources especially hydrocarbon. Nigeria's economy is mostly dependent on export and domestic sales of hydrocarbon products from the Niger Delta Basin, hence reducing the hydrocarbon reserve in the basin. This has motivated the shift in hydrocarbon exploration to other frontier inland sedimentary basins of Nigeria to balance the resource distribution of the Nation's wealth (Tsepav and Mallam, 2017). The Bida Basin is one of the inland basins of Nigeria that might have significant hydrocarbon accumulation potential as well as other mineral deposits of economic interest. The aim of this study is to assess the thermal maturation and burial temperature of the sediments by observing palynomorph and palynomacerals colour variation at each depth interval of the ditch cuttings. This will in turns help to infer the grade or economic status of the potential hydrocarbon source rock.

Geologic Setting

The studied well is in Kudu town (Figure 1) which lies in northern Bida Basin with GPS coordinates of latitude 9° 21′ 12″ N and longitude 5° 05′ 21″E. Four mappable stratigraphic units recognized in the northern/central Bida Basin are; Bida Sandstone, Sakpe Sandstone, Enagi Siltstone and Batati Formation (Adeleye and Dessauvagie, 1972; Obaje, 2009; Goro et al., 2017). The Bida Sandstone is divisible into two members, namely the Doko Member and the Jima Member. The Doko Member is the basal unit and consists mainly of very poorly sorted pebbly arkoses, sub-arkoses and quartzose sandstones. The Jima Member is dominated by cross-stratified quartzose sandstones, siltstones and claystones. The Sakpe Ironstone comprises mainly of oolitic and pisolitic ironstones with sandy claystones locally at the base, which is followed by dominantly oolitic ironstone which exhibits rapid facies changes across the basin at the top. The Enagi Siltstone consists mainly of siltstones. Other subsidiary lithologies include mixture of sandstone-siltstone with clay stones. The Batati Formation consist of argillaceous, oolitic and goethitic ironstones with ferruginous claystone and siltstone intercalations and shaly beds occurring in minor proportions, some of which have yielded nearshore shallow marine to freshwater fauna (Obaje et al., 2011).

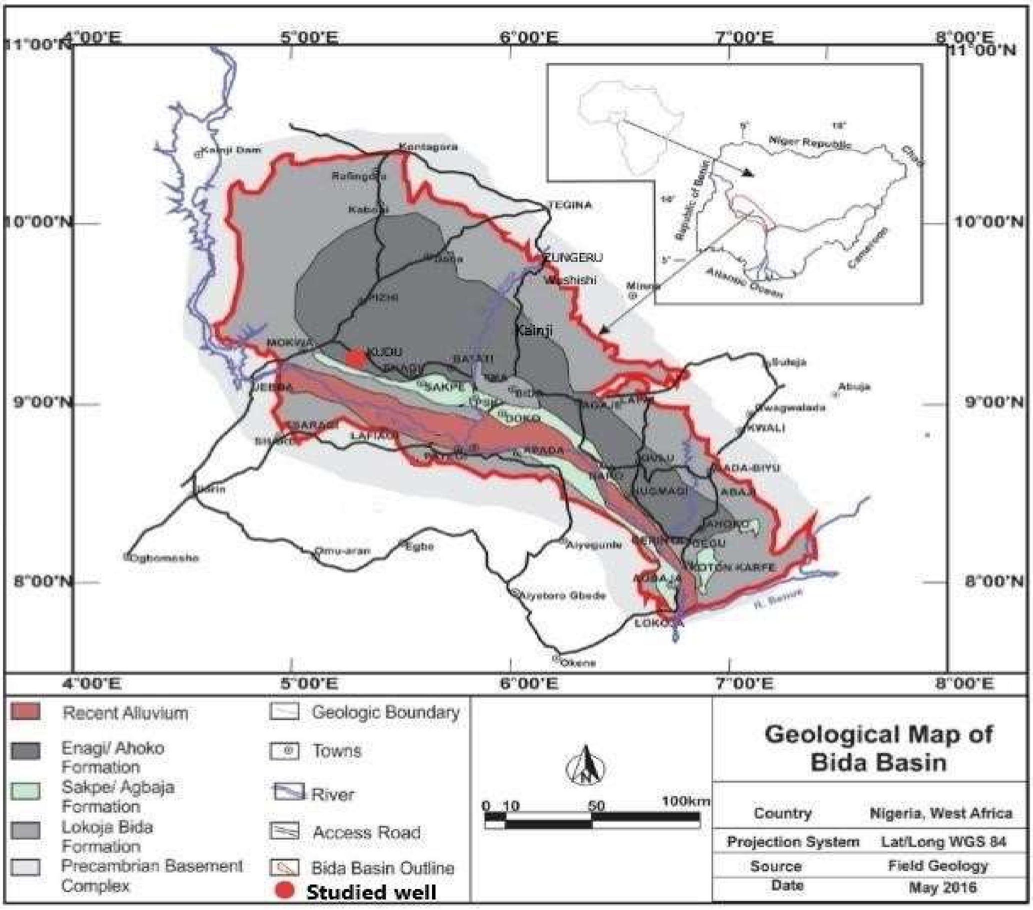

Figure 1: Geological map of Bida Basin showing the studied well (Modified after Rahaman et al., 2018).

METHODS

The lithologic description was carried out by visual examination of each sample using munsell colour chart to establish the colour, and a magnifying hand lens and grain size chart was use for the grain-size description

Nineteen ditch cutting samples within the depth interval of 31 – 58 m were subjected to the palynological acid maceration technique (Batten and Stead, 2005) to recover the palynomorphs from the sediments. Fifteen grams of each sample was treated with 10% HCl under a fume cupboard for the complete removal of carbonates present in the samples. This was followed by complete washing with distilled water before the next procedure. Then 40% HF was added to the sample and kept for 24 hours to ensure a complete dissolution of the silicates present in the samples. Thereafter, the HF was diluted with water and carefully decanted, then followed by complete washing with distilled water to remove fluoro-silicate compounds usually formed from the reaction with HF. The whole wet solution was then sieved and separated using Brason Sonifier 250. Brason Sonifier is an electric device used with the aid of 5 μm sieve to filter away the remaining inorganic matter (silicates, clay, and mud) and heavy minerals to recover organic matters. The sieved residue was given controlled oxidation using concentrated nitric acid (HNO_3). This treatment selectively removed amorphous organic matters that often co-exist with the palynomorphs, and to lighten the dark-hued palynomorphs. The residues for preparation of palynological slides were then stained with safranin-O. The same procedure for sample preparation for palynomorphs recovery was followed for the palynomacerals, except that the oxidation process with HNO_3 was omitted in order not to bleach the palynomacerals (palynodebris). The analyses were carried out at Crystal Age Laboratory Ltd, Ikorodu Road, Lagos. Few drops of the residue (recovered organic matters) were then uniformly strewed over a rectangular cover slip of 22 mm by 40 mm and allowed to dry on a hot plate. Loctite (*impruv*) was used as the mounting medium. Glass slides of 25 mm by 75 mm were then used to permanently mount the cover slips by curing them with ultraviolet light for 2 minutes.

Both palynology and palynomacerals (kerogen) slides were examined under the Olympus CX41 Binocular light transmitted microscope. Identification of palynomorphs and palynomacerals were done with aid of palynological albums and the published works of previous researchers such as (Germeeraad *et al*., 1968; Ige, 2009; Bankole, 2010; Ige *et al*.,2011; Ajaegwu *et al*., 2012; Durugbo and Aroyewun, 2012; Eisawi, 2015). The slides were subjected to quantitative analysis of palynomorphs and palynomacerals (types 1, 2, 3, and 4) as well as structureless organic matter (SOM). Microphotographs of well persevered palynofacies were taken with camera (Olympus DP 12) attached to the microscope.

The exine wall colouration of the identified palynomorphs and palynomacerals for each sample was compared with thermal alteration scale for palynomorphs coloration developed by Batten (1980) which is ranked from 1-7 (Table 1). This was in turn correlated with thermal alteration index, vitrinite reflectance and degree of maturation of the source rock in order to estimate the thermal maturity of the sediments.

Table 1: Scale of palynomorphs colour (After Batten, 1980)

Palynomorphs thermal alteration scale	Observed colour of palynomorphs	Significance
1	Colourless, pale yellow, yellowish orange	Chemical change negligible; Organic matter immature, having no source potential for hydrocarbon.
2	Yellow	Some chemical change, but Organic matter still immature.
3	Light brownish yellow, yellowish orange	Some chemical change, marginally mature but not likely to have potential as a source
4	Light medium brown	Mature, active volatilization, oil generation.
5	Dark brown	Mature, production of wet gas and condensate transition to dry gas phase.
6	Very dark brown, Black	Over mature; source potential for dry gas
7	Black(opaque)	Trace of dry gas only

RESULTS

The result from the lithologic description of the studied well (Fig. 2) extrapolated from the ditch cutting samples consists of siltstone, silty mudstone, and sandy mudstone. The grain sizes range from particle size smaller than 0.002 to 0.006 mm and no fissility was observed. Visual comparison of the ditch cutting samples with munsell colour chart indicates that the siltstone and silty sandstone range from light gray to greenish gray colour occurring at a depth interval of 37 – 58 m of the well section. Occurring within this interval is smaller depth intervals, at the bottom of the well section, of greenish-gray, fine grained silty mudstone (49 – 50 m) and grayish sandy mudstone. The top of the section (32 – 37 m) is fine grained to very fine-grained silty mudstone and sandy mudstone of greenish gray to light gray colour. The lithologic description shows that the studied interval is from Enagi Siltstone (Obaje, 2009).

The palynomorphs and palynomaceral constituents recovered at various depth intervals are, generally, abundant, and diverse (Figs. 2 and 3). A total of 37 species of palynomorphs were recorded from microscopic observation of the strew-mounted palynological slides. The miospores (pollen and spores) constituents recovered occur in abundant quantity with few counts of dinoflagellate cysts and others. The pollens, which are the predominant sporomorphs, consist of *Monoporites annulatus, Zonocostites ramonae, Ephredripites* sp., *Longapatites* sp., *Milfordia jardinei, Monocolpites marginatus, Racemonocolpites hians, Retidiporites* sp., *Striatricolporites irregularis, Arecipites* sp., *Psilatricolporites crassus, Alnipollenites verus, Retimonocolpites obaensis, Verrutricolporites rotundiporus, Pachydermites diederixi, Striamonocolpites rectostriatus* and *Arecipites eximularatus*. The spores recovered include *Cythidites minor, Cyathidites* sp., *Distaverrusporites simplex, Zlivisporites blanensis, Pteris* sp., *Acrostichum aureum, Magnastriatites howardii, Caudospora* sp. and the long ranging forms such as *Laevigatosporites* sp., *Verrucatosporites* sp., and *Verrucatosporites usmensis*. Dinoflagellate cysts recovered, which are indicative of marine incursion, include *Oligosphaeridium complex, Leiosphaeridia* sp., *Paleocystodinium* sp., *Achomosphaera* sp., *Oligosphaeridium* sp. and some dinocysts that cannot be determine to their genus or species level denoted as indeterminate. Other palynofacies constituents recovered in appreciable quantity include algae such as *Botryococcus braunii* and *Pediastrum* sp. The microphotographs of some recovered palynomorphs are presented in figure 4.

Visual microscopic inspection of the sporomorphs and palynomacerals colour under transmitted light microscope revealed the following results (Table 2). The palynomorphs/palynomacerals colouration ranges from orange, brown through light brown, light medium brown to dark medium brown.

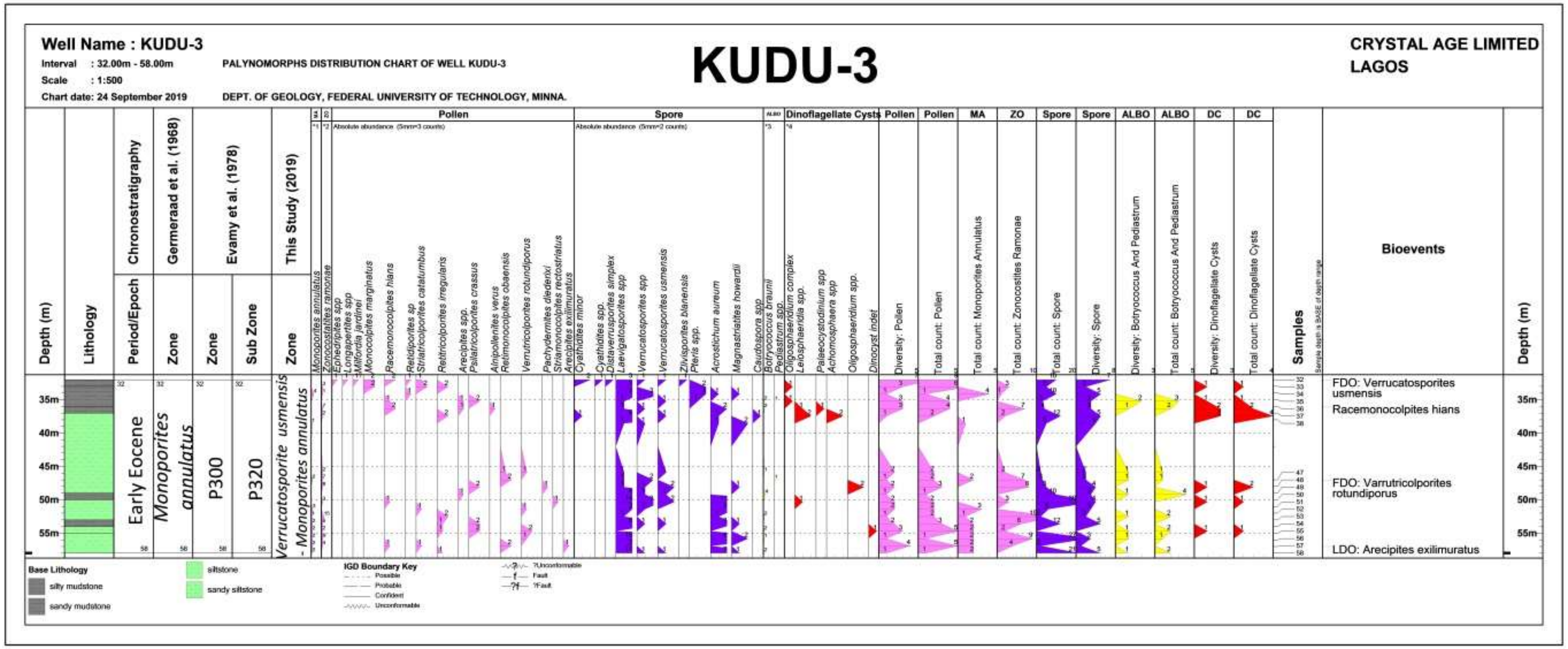

Figure 2: Palynormorphs distributions of Kudu-3 well.

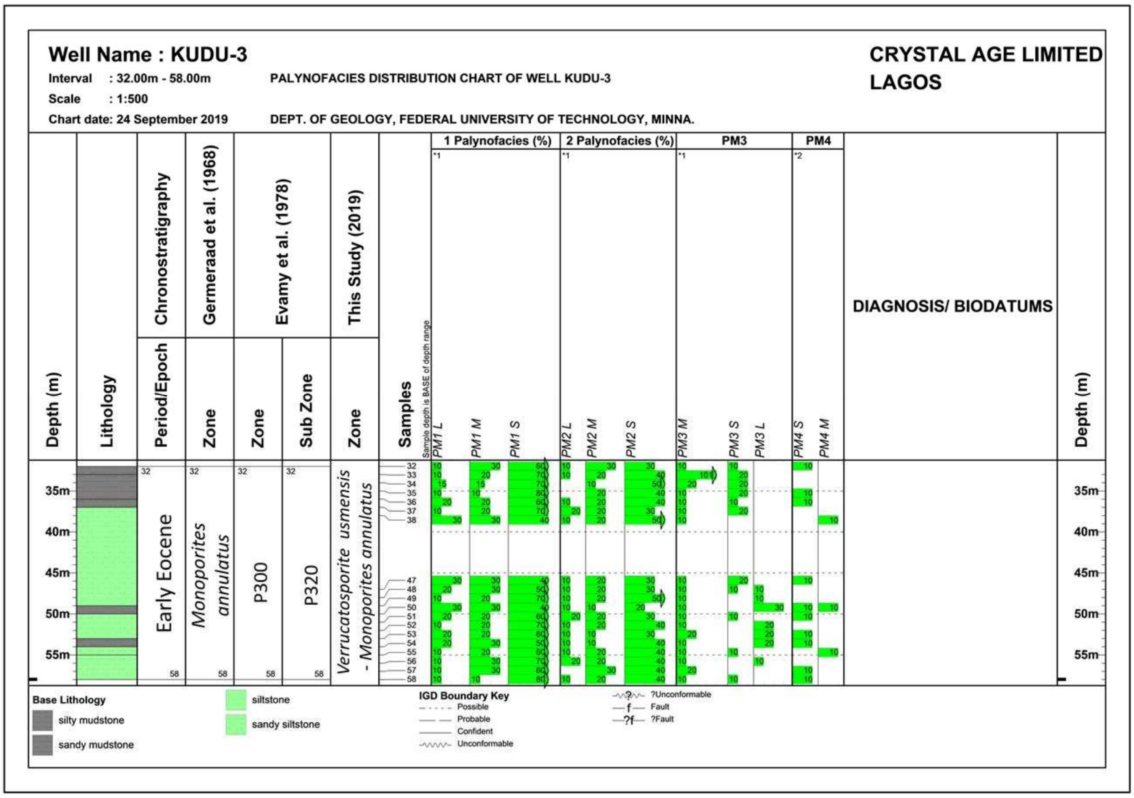

Figure 3: Palynomacerals distributions of Kudu-3 well.

Characterisation of Palynomacerals Constituents in Kudu-3 Well

Various classification schemes have been used by different authors to categories/group palynomacerals constituents observed under transmitted light microscope (Tyson, 1995; Batten and Stead, 2005). The organic matter classification scheme adopted here is that of Whitaker et al. (1992) which involve four basic numbered palynomaceral classifications under transmitted light microscopic characterizations vis-a-vis the buoyancy and degree of degradation of the identified macerals.

Palynomceral 1 (PM1)

The observed Palynomceral 1 (PM1) encompasses structured and unstructured (or structureless) dark brown to orange brown colour and "dense" in appearance resinous cortex tissues. Their state of preservation is variable and possess irregular outline. They are the most abundant palynomacerals type consisting of 51 % of the palynomacerals assemblage (Fig. 5). Counts of palynomacerals type occur in variable sizes (Figs. 3 and 6) ranging from predominantly 61% of small, 23% medium to 15% large particles. On the whole, there is predominant occurrence of small and medium particle size. They have heterogeneous origin that have been ascribed to different plant materials (such as resinous cortex materials, resinous substances, and humic gel-like substances) with mainly higher plant origin, including exudation products resulting from gelification of plant debris in the sediment (Oyede, 1992). They are characterized by low buoyancy (due to their "dense" appearance, waterlogging, size) and low resistance to physical abrasion (Batten and Stead, 2005).

Table 2: Microscopic observation of spore/pollen and palynomacerals colour changes and their corresponding thermal alteration (TAI) and degree of maturation in Kudu-3 well

S/N	Depth interval (m)	Spore/pollen and palynomacerals Colour	Thermal alteration index (TAI)	Degree of maturation
1	31 – 32	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
2	32 – 33	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
3	33 – 34	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
4	34 – 35	Light medium brown – dark brown	4 – 5	Mature stage
5	35 – 36	Light medium brown – dark brown	4 – 5	Mature stage
6	36 – 37	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
7	37 – 38	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
8	46 – 47	Light medium brown – dark brown	4 – 5	Mature stage
9	47 – 48	Light medium brown – dark brown	4 – 5	Mature stage
10	48 – 49	Light medium brown – dark brown	4 – 5	Mature stage
11	49 – 50	Light medium brown – dark brown	4 – 5	Mature stage
12	50 – 51	Light medium brown	3/4 – 4	Early to mature stage
13	51 – 52	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
14	52 – 53	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
15	53 – 54	Orange, brown – light medium brown	3/4 – 4	Early to mature stage
16	54 – 55	Light medium brown – dark brown	4 – 5	Mature stage
17	55 – 56	Light medium brown – dark brown	4 – 5	Mature stage
18	56 – 57	Light medium brown – dark brown	4 – 5	Mature stage
19	58 – 59	Light medium brown – dark brown	4 – 5	Mature stage

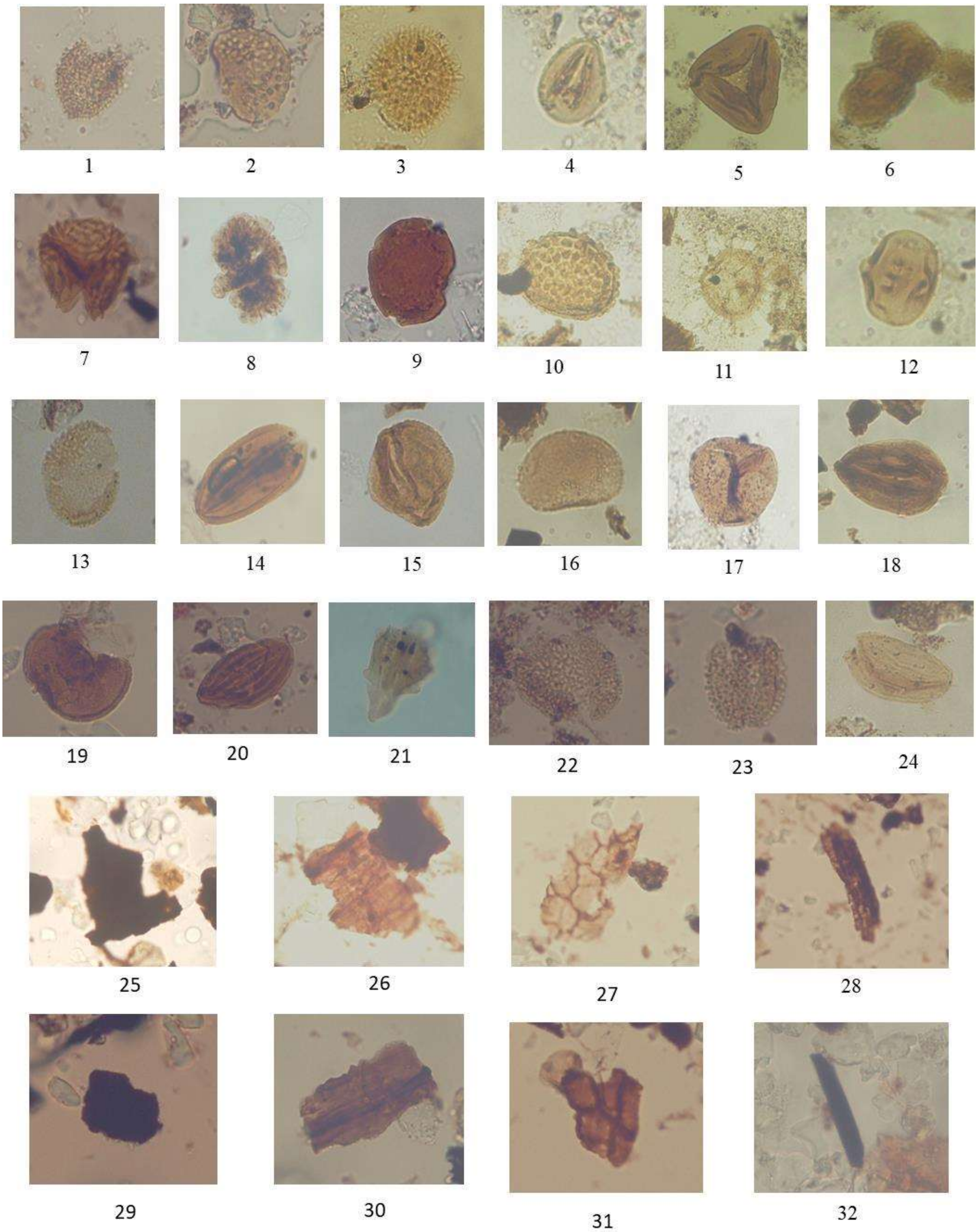

Figure 4: Recovered palynomorphs photomicrographs from Kudu-3 well, Bida Basin (×400). *1 Racemonocolpites hians, 2 Verrucatosporites usmensis 3 Retitricolporites irregularis, 4 Verrutricolpites rotundiporus 5 Pteris sp. 6 Zonocostites ramonae, 7 Magnasriatites howardi, 8 Botryococcus braunii, 9 Pachydermites diederixi, 10 Verrucatosporites sp., 11 Oligosphaeridium complex, 12 Sapotaceae13 Arecipites exilimuratus, 14 Monocolpites marginatus, 15 Psilatricolporites crassus, 16 Laevigatosporites sp., 17 Acrostichum aureum, 18 Striatricolpites catatumbus, 19 Psilatricolporites crassus, 20 Ephedripites sp., 21*

Botryococcus braunni, 22 Arecipites exilimuratus, 23 Racemonocolpites hians, 24 Striamonocolpites rectostriatus; palynomaceral types (×400): 25 & 29 palynomaceral 1 (PM1); 26 & 30 palynomaceral 2 (PM2); 27 & 31 palynomaceral 3 (PM3) and 28 & 32 palynomaceral 4 (PM 4).

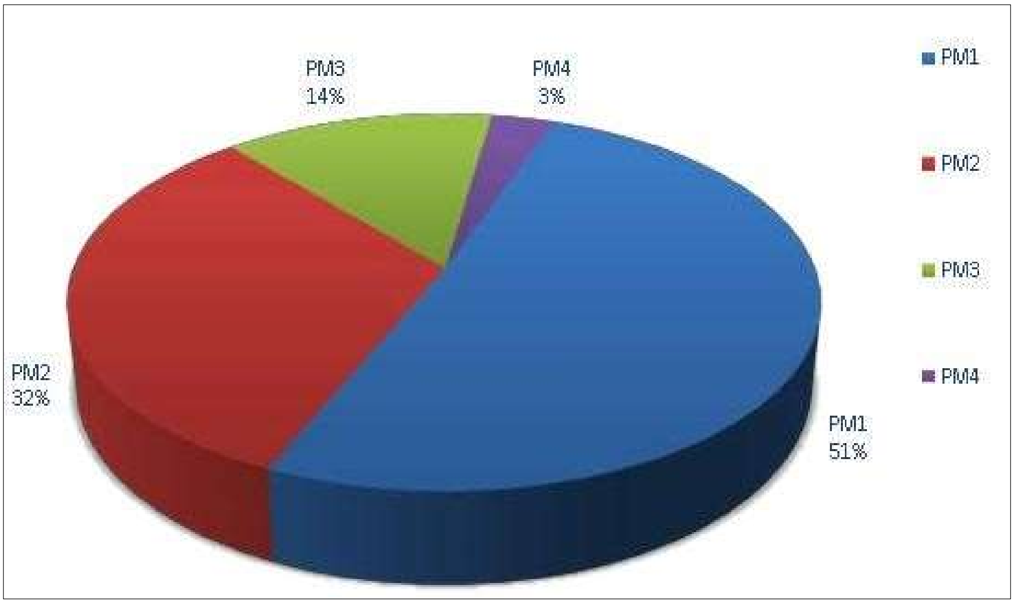

Figure 5: Percentage of palynomacerals recovered from Kudu-3 well

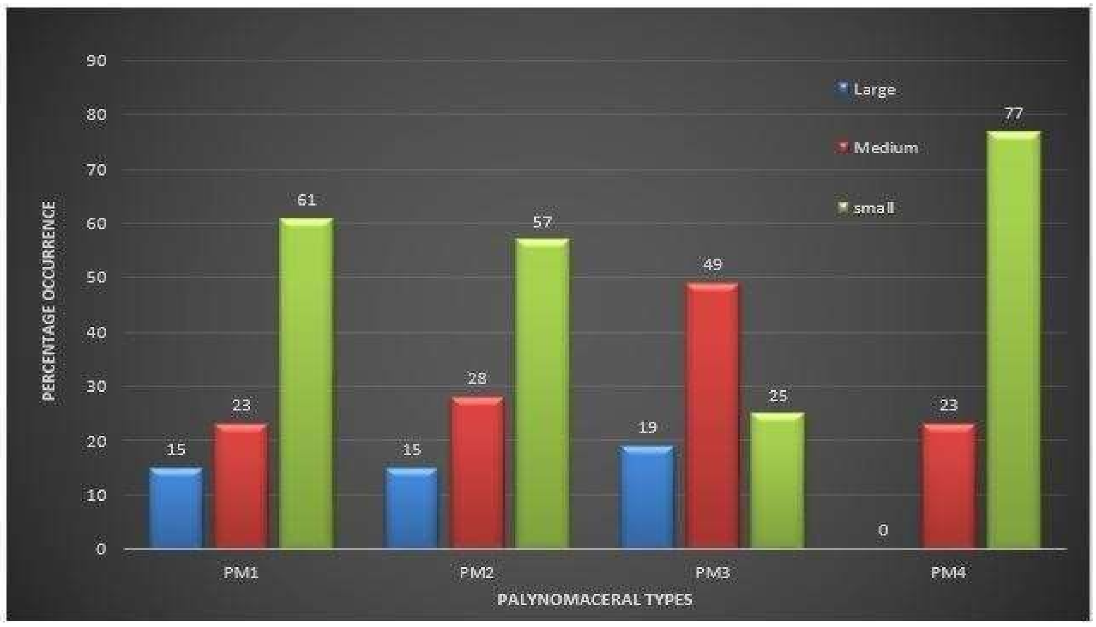

Figure 6: Distribution of the various sizes of palynomaceral types from Kudu-3 well

Palynomaceral 2 (PM 2)

They are made up of platy-like brown-orange plant materials (or woody tissues) with cellular structuring and irregular in shape (Figure 4). They account for about 32% of the palynomacerals assemblage in the ditch cutting samples of Kudu-3 well (Fig. 5). Small particle sized palynomaceral 2 are predominant with moderate medium size and few large size particles (Figs. 3 and 6). The particles appear thinner in transmitted light microscopy than those of palynomaceral 1 and hence possess higher relative buoyancy than palynomaceral 1. They are product of plant derived materials such as stem, leaf, and small rootlet debris and to a lesser degree humic gel and resinous substances (Tyson, 1995).

Palynomaceral 3 (PM3)

They have pale-coloured appearance, relatively thin, with pronounced cellular structuring and irregular shape (Figure 4). This palynomaceral type is the third most abundant (14%) of palynomaceral constituents of the Kudu-3 well ditch cutting samples (Fig. 5). They are mainly degraded, aqueous stomata-bearing plant materials with predominantly small to medium size particles (Fig. 4). They are mostly cuticular (leaf debris) in origin and are considered to have higher buoyancy compared to palynomaceral 1 and 2 (Battenand Stead, 2005; Chukwuma-Orji et al., 2017a & b; Chukwuma-Orji et al., 2019).

Palynomaceral 4 (PM4)

The maceral type is opaque to semi-opaque black equidimensional needle shaped (or blade shaped) plant derived materials (Fig. 4). Low counts of this maceral type were recorded, which account for 3% of palynomaceral assemblage recovered from the well (Fig. 5). They consist predominantly of about 77% of small particle size with very few medium size particles (Fig. 6). PM4 are heterogeneous ranging from compressed humic gels (derived from forest fires), geothermally fussinized material to reworked charcoal (Oyede, 1992). They are regarded as the most buoyant palynomaceral PM4 is highly resistant to physical degradation and hence mostly abundant in high energy settings (Tyson, 1995; Thomas et al. 2015; Chukwuma-Orji et al., 2019).

DISCUSSION

Thermal Maturation

Different spore colour charts and their corresponding thermal alteration index (TAI) and vitrinite reflectance (%Ro) values have been developed for the purpose of thermal maturation determination (Staplin, 1969; Collins, 1990; Batten, 1980). However, the result presented here (Table 2; Fig. 7) is based on thermal alteration scale for spore coloration developed by Batten (1980) which is ranked from 1-7 and represent sporomorphs colour variation from yellow, orange, brown to black (Table 2).

From the depth interval of 31 – 34 m in the studied well (Table 2), spore/pollen colour shows orange – light medium brown with corresponding TAI value as 3/4; this indicates early to mature stage of hydrocarbon generation based on Batten (1980) spore colour chart (Table 1; Fig. 7). At the depth interval of 34 – 36 m, the observed miospores exhibited light medium brown – dark brown colour yielding a TAI value of 4 – 5 which is equivalent to mature stage of maturation. At depth interval of 36 – 38 m, the palynofacies colour observed is orange brown – light medium brown and have TAI value of 3/4 – 4 which is indicative of early to mature stage of maturation. Among the spore-pollen assemblage observed at this interval is the long ranging *Laevigatosporites* sp. which consistently exhibits this coloration. Within the penetrated depth interval of 46 – 50 m, sporomorphs show light medium brown – dark brown and have TAI value of 4 – 5; this indicates mature stage to transition to dry gas phase of maturation. At the depth interval of 51 – 54 m, spore-pollen colour ranges from orange brown – light medium brown and have TAI value ranging from 3/4 – 4 which correspond to early to mature stage of degree of maturation. Observed *Acrostichum areum* exhibit this colour throughout this interval. The bottom section of the penetrated well interval of 54 – 59 m shows consistent spore/pollen colour of light medium brown to dark medium brown and have TAI value of 4 – 5, this indicates early mature stage of maturation.

Generally, the entire depth interval has palynomorphs/palynomacerals colouration ranging from orange brown through light brown, light medium brown to dark medium brown. This is attributed to increase in burial temperature with depth. The average orange to medium brown colouration of spore/pollen reflects mature organic matter with an estimated burial temperature ranging from 60 –120°C (Jiang et al., 2015). The degree of thermal maturation of the studied interval of the well can be interpreted as mature stage of maturation, hence prone to oil and gas production. This corresponds to a range of thermal alteration value of 3/4 – 5 and equivalent vitrinite reflectance (%Ro) value of 0.55% – 0.95% (Figure 7).

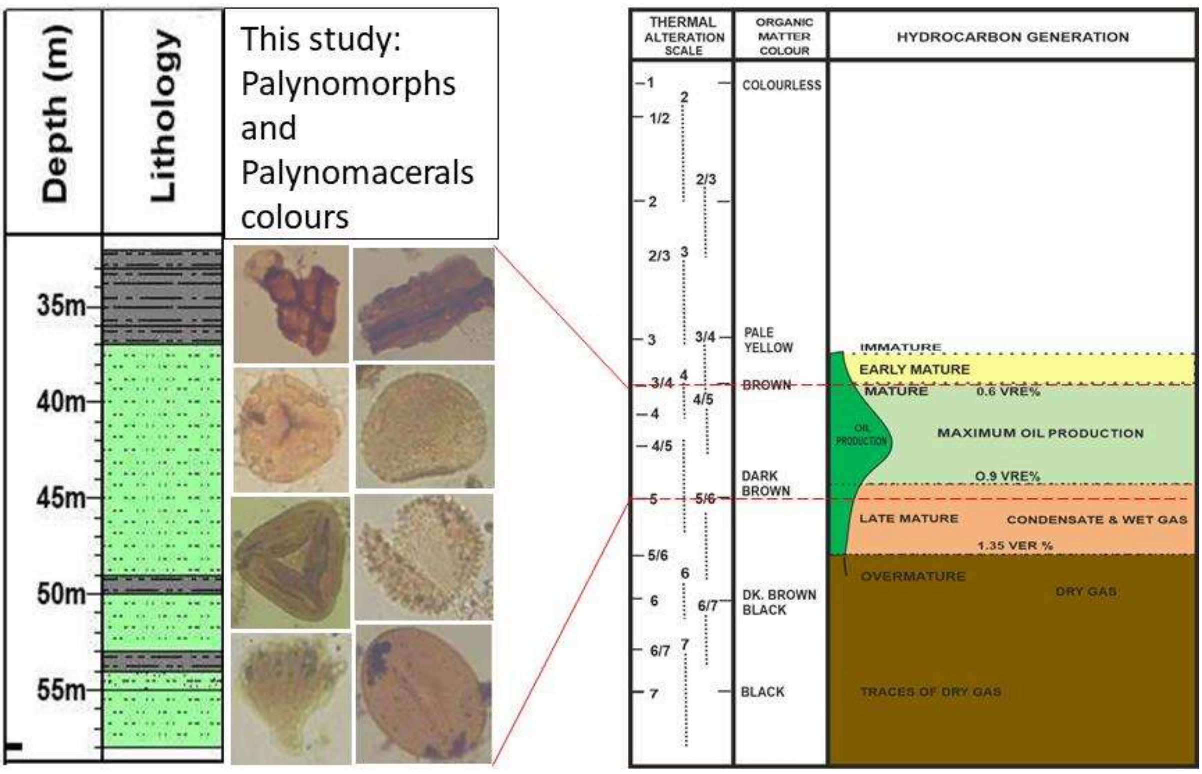

Figure 7: Correlation of pollen/spore exine wall colour from Kudu-3 well with sporomorph colour chart and the corresponding Thermal Alteration Index and Vitrinite Reflectance of Batten (1980).

CONCLUSION

The need to understand the hydrocarbon prospectivity and contribute to the pre-requisite knowledge required to attract investors to the inland Bida Basin necessitated the palynofacies study and thermal maturation analysis. This was done by subjecting 19 cuttings samples to standard acid palynological preparation method. Microscopic analysis of the strewn mounted slides yielded diverse pollen, spores and palynomacerals. The palynomaceral types recovered from the studied well include dark brown orange structureless resinous cortex material of palynomaceral 1 (making up 51% of the recovered macerals), brown- orange platy-like structured plant materials of palynomaceral 2 (32%), pale-colour small to medium sized stomata bearing plant material of palynomaceral 3 (14%) and black equidimensional needle shaped plant materials of palynomaceral 4 (3%). Lithology of the studied interval consists of silty mudstone, sandy mudstone, siltstone, and sandy siltstone units, indicating Enagi Siltstone.

Transmitted light microscopic observation of the recovered palynomorphs colour (ranging from orange brown, light brown, light medium brown to medium brown) and their equivalent thermal alteration index (TAI), vitrinite reflectance(%Ro) and burial temperature yielded an estimated value of 3/4 –5, 0.55 – 0.95% and 60 – 120°C respectively. The values indicate that the organic matter enclosed in the sediments from the Kudu-3 well can be considered as mature and hence prone to hydrocarbon generation. The grade of the hydrocarbon source rock has been inferred from correlation of the palynomorph colour with other calibrated scale as early mature to mature stage. The interpretation above was restricted to the observation of exine wall colour of terrestrial pollen and spores which according to Njoh and Tembi (2017) shows more consistent colour variation with increasing burial temperature during maturation than other particulate organic matter. The abundance of palynomacerals 1, 2 and 3, and terrestrial sporomorphs in the studied section is an indication of gas prone than oil. This work suggests possible potential of hydrocarbon accumulation in the Bida Basin, and Enagi Formation is also a potential hydrocarbon source rock.

The results obtained from this study have indicated a good prospectivity of the Kudu-3 well. However, prediction of the hydrocarbon potential of the Bida Basin using spore/pollen colour is not sufficient to conclude for successful accumulation of oil and gas, other geological factors must be considered. Hence, the result for this research should merely serve as reconnaissance of the hydrocarbon prospectivity of Bida Basin and should be supplemented by detailed geochemical analytical techniques (such as Rock-Eval pyrolysis, Vitrinite reflectance (%Ro), Total organic carbon (TOC) and numerical thermal alteration index) for more reliable determination of the bulk source rock potential.

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REFERENCES

Ajaegwu, N. E., Odoh, B. I., Akpunonu, E. O., Obiadi, I. I. & Anakwuba, E. K. (2012). Late Miocene to Early Pliocene Palynostratigraphy and Paleoenvironments of ANE-1 Well, Eastern Niger Delta, *Nigeria Journal of Mining and Geology,* 48, 31–43.

Alkali, Y. B., Oluwafemi, O. O., Chukwuma-Orji, J. N., & Taiwo, O. F. (2017). Palynostratigraphy of the Exposed Section of Patti Formation Ahoko Quarry, Southeastern Bida Basin, Nigeria. Minna Journal of Geosciences (MJG) 1(2), 116 –123.

Bankole, S. I. (2010). Palynology and stratigraphy of three deep wells in the Neogene Agbada Formation, Niger Delta, Nigeria. Implications for petroleum exploration and paleoecology, PhD thesis, der Technischen Universität Berlin, 1-190.

Batten, D. J. (1980). Use of transmitted light microscopy of sedimentary organic matter for evaluation of hydrocarbon source potential. In Proceedings of 4th International Palynological Conference, 2, 589–594.

Batten, D. J. & Stead, D. T. (2005). Palynofacies Analysis and its Stratigraphic Application. In E. A. M. Koutsoukos (ed), Applied Stratigraphy. Netherland, Springer, 203- 226.

Chukwuma-Orji, J. N., Okosun E.A., Alkali Y.B., Taiwo O.M. & Fadiya L.S., (2017a). Palynofacies analysis of Ida 5-well, Niger Delta Basin, Nigeria. *Nigeria Journal of Engineering and Applied Sciences,* 4, 95–112.

Chukwuma-Orji, J. N., Okosun E. A., Goro I. A. & Waziri S. H. (2017b). Palynofacies, sedimentology and paleoenvironment evidenced by studies on IDA-6 well, Niger Delta, Nigeria. *Paleoecology of Africa*, 34, 87–105.

Chukwuma-Orji, J. N., Okosun, E. A. & Gana, F. D. (2019). Palynofacies analysis of Ida4 well, Niger Delta Basin, Nigeria, Journal of Geology, Geophysics and Environment vol. 45 (3): 219–230.

Collins, A. (1990). The 1-10 Spore Colour Index (SCI) scale: a universally applicable colour maturation scale, based on graded, picked palynomorphs. Mededelingen Rijks Geologische Dienst, 45, 39–47.

Durugbo, E. U. & Aroyewun, R. F. (2012). Palynology and Paleoenvironments of the Upper Araromi Formation, Dahomey Basin, Nigeria. *Asian Journal of Earth Sciences,* 5, 50-62. doi:10.3923/ajes.2012.50.62

Eisawi A. A. M., (2015). Palynological Evidence of a Campanian-Maastrichtian Age of the Shendi Formation (Shendi Basin, Central Sudan). *American Journal of Earth Sciences*, 2, 206–210.

Germeraad, J. J., Hopping, G. A. & Muller, J. (1968). Palynology of Tertiary sediments from tropical areas. *Review of Paleobotany and Palynology,* 6, 189-348. doi: 10.1016/0034-6667(68)90051-1

Goro, A. I., Okosun, E. A., Akande, W. G. & Salihu, H. D. (2017). Anastomosing River Deposits: A case study of Enagi Siltstone, Northern Bida Basin, Central Nigeria. *Minna Journal of Geosciences* (MJG), 1, 121-134.

Ige, O. E., Datta, K., Sahai, K. & Rawat, K. K. (2011). Palynological Studies of Sediments from North Chioma-3 Well, Niger Delta and its Palaeoenvironmental Interpretations. *American Journal of Applied Sciences,* 8, 1249-1257.

Jiang, D., Robbins, E I., Wang, Y. & Yang, H. (2015). Petrolipalynology. Springer Heidelberg New York Dordrecht London.

Njoh, O. A. & Tembi, A. (2017). Spores and Pollen Colour Changes and Thermal Maturation of Mid-Cretaceous Lacustrine Organic-rich Sediments in the Mamfe Basin, S.W. Cameroon. *Journal of Geography and Geology*, 9, 22 – 32.

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. Springer-Verlag Berlin Heidelberg.

Obaje, N. G., Moumouni, A., Goki, N. G. & Chanda, M.S. (2011). Stratigraphy, Paleogeography and Hydrocarbon Resource Potentials of the Bida Basin in North Central Nigeria. *Journal of Mining and Geology*, 47, 97-114.

Onoduku, U.S., Okosun, E.A., Obaje, N. G., Goro, A. I., Salihu, H. D. & Chukwuma-Orji, J. N. (2017). Palynological Evidence of a Campanian-Maastrichtian Age of the Central Bida Basin, Nigeria: Implication for Paleoenvironment, Paleoclimate and Hydrocarbon Prospectivity. *Minna Journal of Geosciences* (MJG), 1, 165-178.

Oyede, A. C. (1992). Palynofacies in Deltaic Stratigraphy. *Nigerian Association of Petroleum Explorationists Bulletin*, 7, 10 – 18.

Rahaman, M. A. O., Fadiya, S. L., Adekola, S. A., Coker, S. J., Bale, R. B., Olawoki, I. J. Omada, O. A., Obaje, N. G., Akinsanpe, O. T., Ojo, G. A. & Akande, W. G. (2018). A revised stratigraphy of the Bida Basin, Nigeria. *Journal of African Earth Sciences*,151, 67 – 81

Staplin, F. L. (1969). Sedimentary organic matter, organic metamorphism, and oil and gas occurrence. *Canadian Petroleum Geology, Bulletin*, 17, 47 – 66.

Thomas, M. L., Pocknall, D. T., Warney, S., Bentley, S. J. Sr., Droxler, A. W. & Nittrouer, C. A. (2015). Assessing palaeobathymetry and sedimentation rates using palynomarceral analysis: a study of modern sediments from the Gulf of Papua, offshore Papua New Guinea. *Palynology*, 1 – 24. doi: org/10.1080/01916122.2015.1014526

Tsepav, M. T. & Mallam, A. (2017). Evaluation of Depth to Magnetic Basement over some parts of the Nupe Basin, Nigeria by Source Parameter Imaging Method using Aeromagnetic Data. *International Journal of science and Research Technology*, 8, 120 – 136.

Tyson, R. V. (1995). Sedimentary Organic Matter, Organic facies and Palynofacies. 1stedition, Chapman and Hall, 203 – 239.

Whitaker, M. F., Giles, M. R., & Cannon, J. C. (1992). Palynological review of the Brent Group, UK sector, North Sea. In: Morton, A. C., Haszeldine, R. S., Giles, M. R., Brown, S. (editors). Geology of the Brent Group. Geological Society of America Special Publications, 61, 169 – 202.

Zobaa, M. K. (2011). Applied palynology: Multidisciplinary case studies from Egypt, Gulf of Mexico and USA. Doctoral Dissertations, 1 – 87.