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Palynostratigraphy and Age of the Sequence Penetrated by the Kolmani River 1 Well in the Gongola Basin, Northern Benue Trough, Nigeria

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Abstract Sediments from the Kolmani River -1 well in the Gongola Basin, Northern Benue Trough, Nigeria, have been analyzed for palynomorphs from 900 ft to 9140ft. The main lithologies encountered in the well consist of sandstones, sandy shales, mudstones and siltstones. The result of the pollen analysis shows that angiospermous pollens and pteridophyte spores dominate the five palynological Assemblage Zones delineated in the well. Each zone represents a time stratigraphic unit.correlatable to the identified lithostratigraphic units penetrated by the well. The *Aquilapollenites minimus* Assemblage Zone (Late Maastrichtian) correlates with the Kerri Kerri Formation. The *Longapertites marginatus* Assemblage Zone (Early Maastrichtian – Late Campanian) correlates with the Gombe Formation. The *Dictyophyllidites harrisii* Assemblage Zone (Early Santonian), the *Syncolporites subtilis* Assemblage Zone (Coniacian*)* and upper part of the *Steevesipollenites binodosus* Assemblage correlate with the Pindiga Formation while the lower *Steevesipollenites binodosus* Assemblage Zone (Turonian – Cenomanian) correlates with the Yolde Formation. The absence of the Late Santonian confirms the presence of the Santonian unconformity in the northern Benue Trough. Based on quantitative and qualitative biostratigraphic and sedimentological analyses, the overall depositional environment of the analyzed interval of the well varies from coastal plain/estuarine to open marine.

Keywords: *palynostratigraphy, Benue Trough, palynomorphs, assemblage zones, late cretaceous, depositional environments, age dating and unconformity*

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1. Introduction

The study of the Cretaceous systems and Inland basins in Nigeria dated back to the early 1950s when exploration for oil began in the country. However, due to the huge petroleum deposit discovered in the Niger Delta area little or no attention has been given to petroleum exploration in these basins. This work is meant to rejuvenate research interest in these basins to increase Nigeria petroleum production and reserves to match with the increasingly world demand for fossil fuel. One of the inland basins believed to have petroleum potential is the Gongola Basin in the northern sector of the Benue Trough. The basin is a North-South trending Cretaceous basin that links the Benue Trough with the Bornu (Chad) Basin forming part of the West African Rift System [1]. The Gongola Basin has been the subject of several palynological studies but most of the samples used for the studies were surface outcrop samples. The limitations of using surface samples are that they can only be collected where the rocks are exposed and the time/stratigraphic resolution is very poor. The novelty of this work therefore is the fact that well samples were used and this will enhance better and systematic analysis of the basin stratigraphy, hence provide coherent data for higher stratigraphic resolution. This investigation is based on palynological analysis of 32 ditch cutting samples from the Kolmani River-1 well. The Kolmani River -1 well was drilled in the Gongola Basin in the Northeastern Nigeria at Latitude 10^{o} 07'03.9'' N and Longitude 10^{o} 42' 43.8''E (Figure 1). The key objectives of this study include identifying palynomorphs occurrences in the well samples and using them to analyze the stratigraphy of Gongola Basin, develop a palynological zonation and date the Formations penetrated by the well.

2. Geological Setting and Stratigraphy

The Benue Trough is an intracratonic Cretaceous Basin, underlying a large part of Nigeria and extending for about 1,000 km in length in a Southeast - Northeast direction,

from the Bight of Benin to Lake Chad and overlying the Precambrian Basement Complex of the West African Mobile belt. Its structural origin is related to the opening of the South Atlantic Ocean [3] and is part of series of Cretaceous rift basins that formed the West and Central African Rift System (WCARS) [1]. The Trough contains as much as 6000 m (20,000 ft) of Cretaceous –Tertiary sediments of which those predating the middle Santonian have been compressionally deformed, faulted, and uplifted in several places. Compressional folding during the middle Santonian tectonic episode affected the whole of the Benue Trough and was quite intense, producing more than 100 anticlines and synclines [3]. The Benue Trough is geographically sub-divided into lower, middle and upper Benue Trough [4]. The Upper Benue Trough is further sub-divided into three basins: the east–west trending Yola Basin (Yola Arm), the north – south trending Gongola Basin (Gongola Arm) and the northeast– southwest trending Lau Basin [5,6].

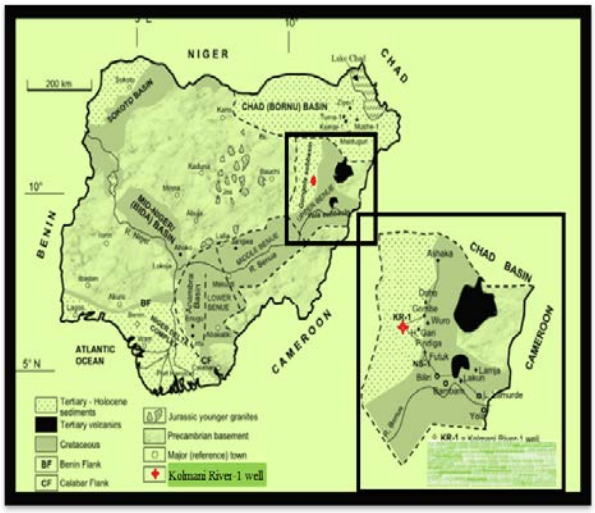


Figure 1. Geological Map of Nigeria showing the Gongola basin and Kolmani River-1 Well [2].

Sedimentation in the Gongola basin began with the deposition of the continental Bima Sandstone which unconformably overlies the Precambrian Basement Complex. The Bima Sandstone was derived from the granitic Basement Complex. It consists of feldspathic-sandstones and clays which pass upwards into medium to coarse grained sandstones with less feldspar. Guiraud [5] subdivided the sandstone into three members namely; the Upper Bima (B_3), the Middle Bima (B_2) and the Lower Bima (B_1). The palynological analysis of the outcropping beds of the Bima Sandstone dated the formation Late Aptian - Early Albian [7]. The Bima Sandstone is conformably overlain by the Yolde Formation. This consists of a variable sequence of sandstones and shales. The sandstones are thin-bedded at the base, followed subsequently by alternations of sandy mudstones and shelly limestone [8]. The Yolde Formation is followed by Pindiga Formation which is dominantly a marine shale facies with limestones at the base. The formation is believed to be deposited under marine conditions that prevailed during the early – late Turonian and Coniacian times in the Northern Benue Trough. The Gongila and the Fika Formations are the lateral equivalents of the Pindiga Formation [9]. The Pindiga Formation is overlain by the Gombe Formation made up of three major lithofacies: (1) alternating beds of silty shales and fine-medium grained sandstones with ironstone intercalations, overlain by (2) medium grained quartz arenite with occasional and iron oxide cement and (3) brick-red coloured, fine - medium grained sandstone, with tabular cross-bedding highlighted by layers and streaks of pure white sandstones [9]. The youngest formation in the Gongola basin is the Kerri-Kerri Formation. It is represented by the gently dipping continental conglomerates, sandstones, siltstones and clays which overstep into the Gombe Formation. Due to the faulted and folded nature of the Gombe Formation, the continental clastics of the Kerri-Kerri Formation reaches a thickness of over 320 meters as a result of sediments infill into the tectonic structures [9]. Adegoke et al., [10] assigned Paleocene age to the Formation using pollen evidence. The stratigraphic succession of the Northern Benue Trough is shown in Figure 2.

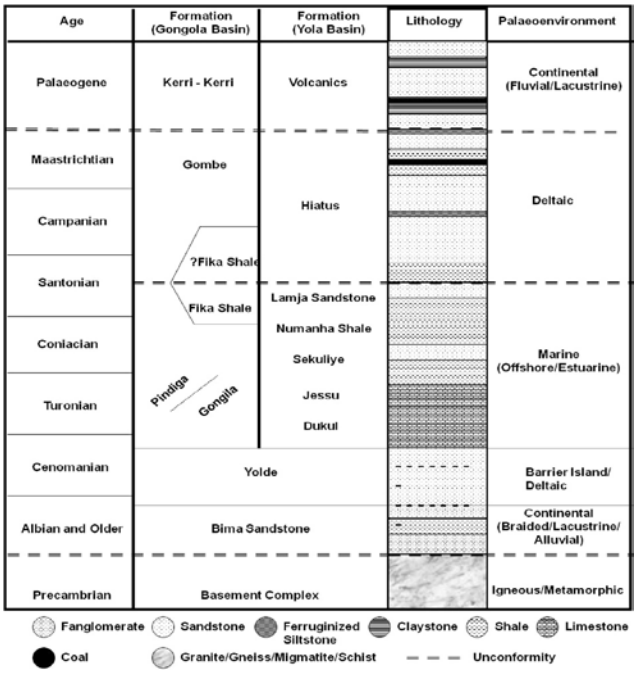


Figure 2. Stratigraphic units of the Upper Benue Trough [11]

3. Materials and Methods

The samples for this research were collected from Kolmani River-1 well, drilled in the Gongola Basin, Northern Benue Trough. Thirty two (32) ditch cutting samples were collected from the Shell Nigeria Exploration and Production Company (SNEPCo) Kolmani River-1 well and were used for this study. The sampled depths ranged from 900 ft – 9140 (total depth of well). The samples were carefully arranged from the top to the base of the well. Each sample was recorded in a manifest (Log Book). Checks for possible missing depths were done. A detailed sedimentological description using the petrological microscope was carried out documenting the sand-silt-shale percentages, texture (grain size, sorting, and roundness), environmentally sensitive accessory minerals, faunal and floral contents of the samples.

The samples for palynological analysis were processed using the conventional acid maceration, alkali treatment and staining methods. These helped to concentrate and

recover the acid insoluble organic microfossils. The oxidized residues were sieved with 5 micron nylon sieve using digital Sonifier 450 machine and mounted on glass slides with Norland adhesive gel. Laborlux 12 (Ernst Leitz) transmitting light microscope was used for identification and counting of the palynomorphs. The counting and logging were done by straight transects across each slide and coordinates for important markers were recorded with England finder. The recovered palynomorphs species were identified with the aid of relevant publications and manuals such as Shell palynological photo album and web-based albums [12]. Morphological characters of the pollens and spores such as the size, exine, structure, shape, and sculpture and aperture type provided the basis for the identification of the forms. Species name and the number of times they were encountered were recorded in the analysis data sheets. All the palynomorphs with features that could not be distinguished due to corrosion, fungal attack or mechanical damage were recorded as indeterminate pollen, spore or algae and their abundance recorded accordingly. Photomicrographs were prepared with Scopetek MDC560 digital camera.

4. Results

4.1. Lithostratigraphy

The result of the sedimentological description of the samples is presented in Figure 3. The lithostratigraphic units penetrated by Kolmani River 1 well and their environments of deposition are shown.

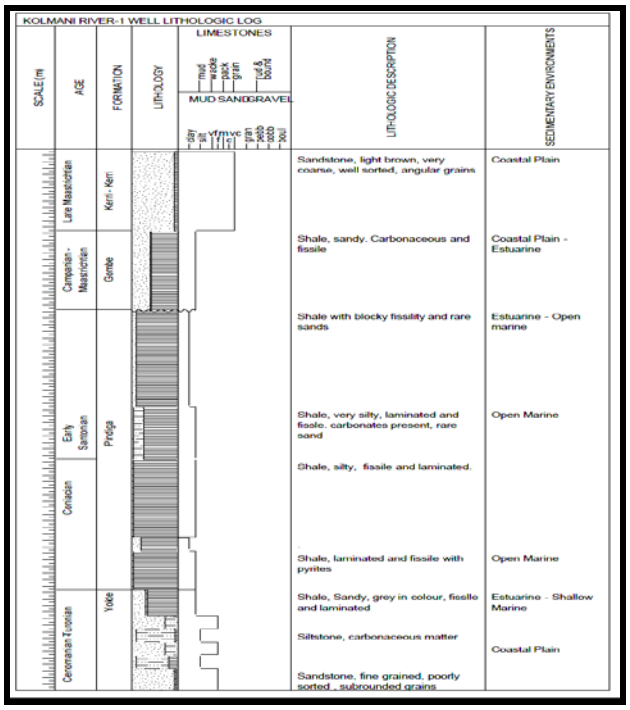


Figure 3. The lithostratigraphic Units penetrated by of Kolmani River-1

4.2. Palynostratigraphy

4.2.1. Palynomorph Count

The analysis of the palynological slides yielded one hundred (100) palynomorphs species. Most of the recovered palynomorphs are long ranging except for few forms which are restricted to their stratigraphic ranges. Angiospermous pollens are the most abundant group in the analyzed slides, followed by spores and few dinoflagellate cysts. The recovered palynomorphs are listed below and shown on the distribution chart (Figure 4).

Auriculiidites reticulates, Auriculiidite sspp., Araucariacites australis, Aquilapollenites minimus Clavatipollenites hughesii., Clavainaperturapollenites spp., Clavatricolporites spp. Syndemicolpites typicus, Constructipollenites ineffetus, Cupuliferoidaepollenites quietus,Cupanieidites sp.B, Cycadopites spp., Echitriporites trianguliformis, Ephedripites spp., Ephedripites sp., Foveotricolporites spp., Longaperties microfoveolatus, Longapertites spp., Longapertites marginatus, Longapertites inornatus, Leoisphaeridia spp., Lycopodiumsporites spp., Mauritiidites spp., Momipites africanus, Monocolpites marginatus, Monocolpopollenites spherodites, Proteacidites miniporatus, Proxapertitesoperculatus, Proxapertites marginatus, Proxapertites spp., Pollen indeterminate, Psilabrevitricolporites simpliformis, Psilamonocolpites spp, Psilastephanocolpites spp., Psilastephanocolporites spp., Racemonocolpites racematus, Retibrevitricolpites triangulates, Retimonocolpites spp., Retimonocolpites perireticulatus, Retimonocolpites variplicatus, Retitricolpites vulgaris, Retitricolpites spp., Retidiporites magdalensis, Psilatriporites spp., Psilatricolporites spp., Retitriletes spp., Rugulatisporites maculosus, Steevesipollenites binodosus, Steevesipollenites orbiculatus, Stephanocolporites recticulatus, Striatricolporites spp., Psilatricolporites spp.,Striatopolli spp., Syncolporites subtilis, Tricolpites microreticulatus, Tricolporites spp, Tricolpites psilatus Triporopollenites sp. A , and Verrutriletes spp. Cyathidites australis, Cyathidites spp., Cyathidites congoensis, Cyathidites minor, Cicatricosisporites spp., Cingulatisporites spp., Dictyophyllidites spp. Dictyophyllidites harrisii, Distaverrusporites simplex, Gleicheniidites senonicus, Foveotriletes margaritae, Foveotriletes microfoveolatus, Gleicheiniidites delicates, Matonisporites sp.2, Laevigatosporites spp., Laevigatosporites ovatus, Polypodiaceosporites spp., Verrucatosporites spp., Leotriletes sp. A, Leoitriletes spp. and Psilatriletes sp.A

Sixty-six (66) pollens, thirty (30) spores, and a few dinoflagellate cysts were recognized and counted in Kolmani River-1 well. Taxonomical identification of the recovered palynomorphs was done to the genera and species levels. The assemblages are dominated by angiospermous pollen and laevigate pteridophytic spores, few dinocysts and fungal spores. The palynofloral assemblages identified in this well closely relate to those previously described in Nigeria [13,14,15,16,17,11], Senegal and Ivory Coast [18,19], Egypt [20,21,22], Malaysia [23], Ghana [24], and New Zealand [12].

4.3. Interpretation and Discussion

4.3.1. Assemblage Zones and Age

The stratigraphic sequence penetrated by Kolmani River-1 well has been zoned using age-diagnostic marker palynomorphs species and the abundance and diversity of recovered palynomorphs. Five palynological assemblage zones were recognized from the Late Maastrichtian - Late Cenomanian (65 - 95 my) as follows:

The *Aquilapollenites minimus* Assemblage Zone (Interval 900 ft – 2100 ft)

Age: Late Maastrichtian

This zone is characterized by the occurrence of *Constructipollenites ineffectus, Aquilapollenites minimus, Gemmastephanocolpites gemmatus, Brevimonosulcites corrugatus, Gleicheniidites delicatus, Monocolpites marginatus, Cyathidites* spp. *Psilamonocolpites medius, Cyathidites minor, Distaverrusporites simplex, Retimonocolpites perireticulatus, Proxapertites miniporatus, Taxadiaceapollenites hiatus, Mauritiidites* spp. and *Longapertites percrasus*. Acme event of *Laevigatosporites ovatus* and the first down-hole occurrence (FDO) of *Arauculidites australis* were recorded in this interval. Most of these palynofloral assemblages have been previously described in in other sedimentary basins in Nigeria [13,14,25,15,26,24].

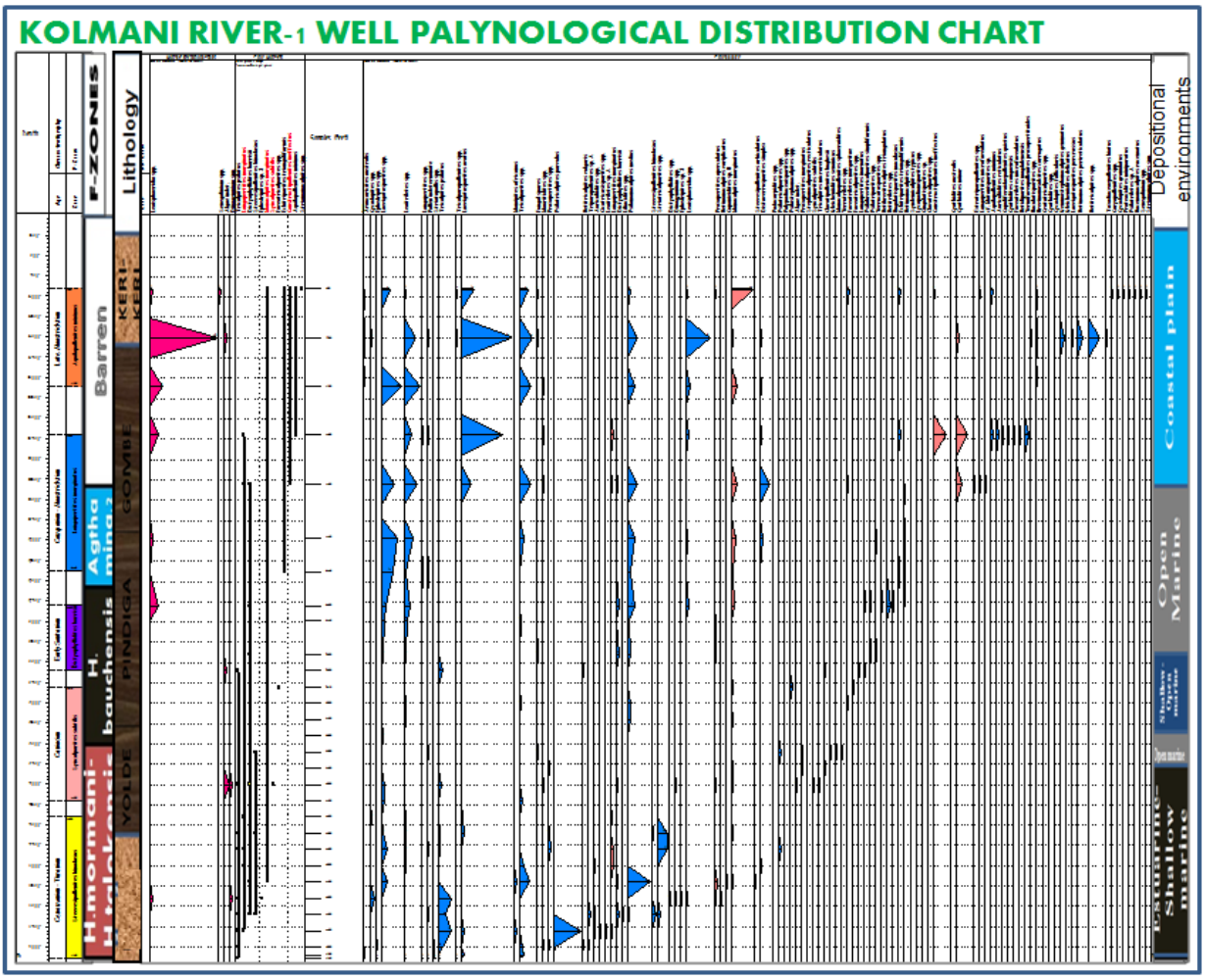


Figure 4. Palynological distribution chart and interpretations for Kolmani River-1 well

An equivalent zone was described by Oloto [25] in the Anambra Basin where she characterized the zone with *Constructipollenites ineffectus, Aquilapollenites minimus* and *Araucaricites australis*. All the forms she used to describe this zone were recovered in this study. The zone is equivalent to P190 Subzone of Wilschut [27] who used *Constructipollenites ineffectus, Spinizonocolpites echinatus, Monocolpopollenites sphaeroidites, Longapertites marginatus, Retimonocolpites pluribaculatus, Crototricolpites densus* and the absence of *Cingulatisporites ornatus* to date equivalent zone as Late Maastrichtian. In this study, *Constructipollenites ineffectus* and *Retimonocolpites perireticulatus* are present while *Cingulatisporites ornatus* is absent in within this interval.

Furthermore, the palynological assemblage in this zone is comparable to those in the Sequence II of Jardine and Magloire [18] which he dated Late Maastrichtian and the upper part of the *Proteacidites* Assemblage Zone also dated upper Maastrichtian by Germeraad et al. [28]

The *Longapertites marginatus* Assemblage Zone (Interval: 2700 ft – 4380 ft)

Age: Early Maastrichtian – Late Campanian

This zone is marked by the FDO of *Auriculidites reticulatus, Foveotriletes microfoveolatus, Longapertites marginatus, Retidiporites magdalensis, Syndemicolpites typicus, Clavatricolporites* spp., *Cyathidites australis, Matonisporites* spp. and the LDO of *Constructipollenites ineffectus, Aquilapollenites minimus, Cyathidites minor, Distaverrusporites simplex* and *Echitriporites trianguliformis.* This zone is similar to the P170 Subzone of Wilschut [27] which he characterized with *Longapertites marginatus, Retidiporites magdalensis* and *Cingulatisporites ornatus*.

Previously, Edet & Nyong [13]; Umeji [15]; Ojo and Akande [29]; Attah-Petters & Salami [24], Muller [23], Okoro et al. [30] and Onuigbo et al. [31] used most of the forms recorded in this interval to date the Campanian sequence in their study areas.

The presence of Auriculidites reticulatus, Longapertites marginatus, Distaverrusporites simplex, Echitriporites

trianguliformis and Retidiporites magdalensis has been used to confirm an Early Maastrichtian – Early Campanian age for this interval in this study.

The *Dictyophyllidites harrisii* Assemblage Zone (Interval: 4800 ft – 5600 ft)

Age: Early Santonian

The top of this zone is marked by the FDO occurrence of *Psilabrevitricolporites simpliformis, Psilatriporites* spp. and the last down-hole occurrence (LDO) of

Retimonocolpites spp. The base is marked by the FDO of Momipites africanus, Retitricolpites vulgaris, Longapertites inonatus and Clavatipollenites hughesii and the continuous acme events of Dictyophyllidites harrisi and Retibrevitricolpites triangulates, Momipites africanus, Retitriletes spp., Rugulatisporites maculosus, Psilabrevitricolporites simpliformis are restricted to this zone. The presence of the Santonian in this zone shows that not all the sediment deposited in the early Santonian were eroded following the Santonian epeirogenic uplift and erosion of the Benue Trough.

The *Syncolporites subtilis* Assemblage Zone (Interval: 5810 ft -7200 ft)

Age: Coniacian

The section from 5810 ft-7200 ft in Kolmani River-1 well has been dated Coniacian due to the presence of Syncolporites subtilis, Monocolpopollenites sphaeroidites, Gleicheniidites senonicus, Tricolporites psilatus, and the FDO of Steveesipollenites binodosus, Ephredipites spp., Psilatricolpites spp., and Foveotricolporites spp. This zone was first established by Wilschut et al., [27]. They noted that Syncolporites subtilis is restricted to this zone which is also true in this well. They assigned a Coniacian age to the Zone. It is also equivalent to the Droseridites senonicus Zone (Coniacian) of Lawal and Moullade [34]. These palynofloral assemblages have also been recorded in other Nigeria sedimentary basins [11, 15, 32] and in the Senegal basin [33].

The *Steevesipollenites binodosus* Assemblage Zone (Interval: 7400 ft – 9140 ft)

Age: Turonian - Cenomanian

The interval 7400ft - 9140ft has been dated Turonian - Cenomanian in Kolmani River 1 using the following palynomorphs; *Steevesipollenites orbiculatus, Retimonocolpites variplicatus, Leoitriletes* sp. A, *Dictyophylidites* spp., *Cupanieidites* spp, *Epheripites* sp. 3, *Striatopollis* spp., *and Liliacidites* spp. The zone is also characterized by the acme event of *Striatricolporites* spp., *Steevesipollenites binodosus* and *Tricolporites psilatus*.

The palynomorphs assemblages in this interval and the presence of long ranging Albian to Turonian forms present a challenge in comprehensive characterization of this section as Turonian – Cenomanian. However, the Albian Stage cannot be confirmed due to the absence of Elater-bearing pollens such as *Elaterocolpites castelainii, Elaterosporites africaensis, Elaterosporites klaszii* and *Elaterosporites protensis* which are typical Albian marker species in low latitude West African basins. The presence of some marker species such as *Steevesipollenites orbiculatus, Retimoncolpites variplicatus* and *Ephredipites* sp.3 which were reported by Schrank and Ibrahim [21] in Egypt and Abubakar *et al*. [11] in Nigeria lends confidence to dating this interval as Turonian – Cenomanian in age.

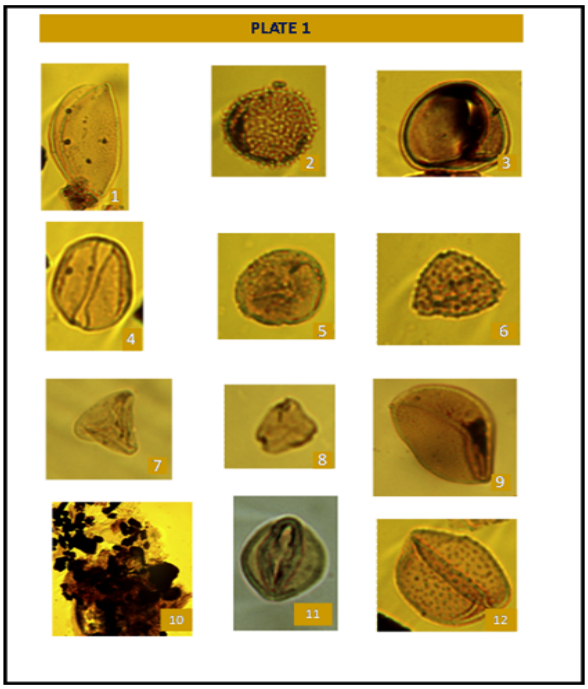
The *Steevesipollenites binodosus* Assemblage Zone (Cenomanian - Turonian) correlates to the Yolde and Gongila Formations. The Yolde has previously been dated Cenomanian – Turonian [34]. The palynofloral assemblage recovered from this zone corroborates this age.

The Pindiga Formation was dated Turonian – Maastrichtian by Zaborski et al., [9] but in this study the interval is characterized by palynological association of Turonian- Maastrichtian age represented by (*Longapertites marginatus* Assemblage Zone), Early Maastrichtian – Late Campanian (*Dictyophyllidites harrisii* Assemblage Zone), Early Santonian (*Syncolporites subtilis* Assemblage Zone), Coniacian and part of *Steevesipollenites binodosus* Assemblage Zone. This work has therefore provided a finer dating of the Formation by palynological zonations.

The Gombe Formation is dated Early Maastrichtian - Campanian and this correlates with the *Aquilapollenites minimus* Assemblage Zone (Late Maastrichtian) and part of *Longapertites marginatus* Assemblage Zone (Early Maastrichtian – Late Campanian). This formation was dated Maastrichtian in the Gongola basin by Lawal and Moullade [34] and Zarboski et al, [9]. The sections penetrated by Kolmani River-1 well in the Gongola Basin are characterized by Cenomanian - Maastrichtian palynormorphs. The results from this study therefore show that the analyzed well did not penetrate the Albian sequence as the elater bearing pollens characteristic of the Albian age is absent.

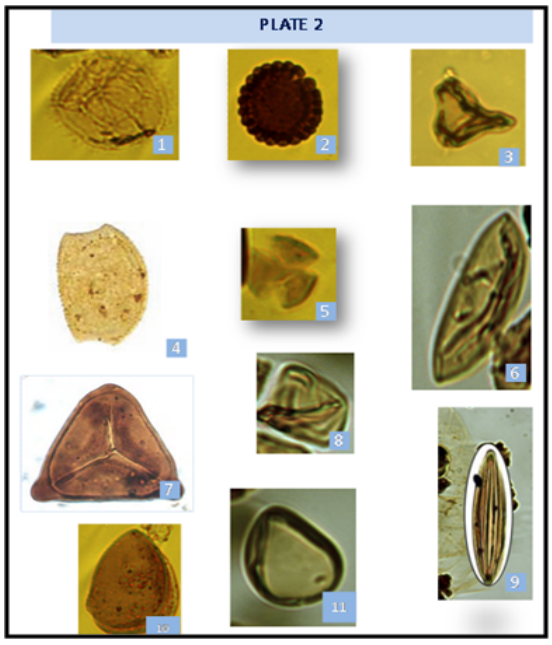
5. Summary and Conclusions

Palynological analysis of Kolmani River-1 well yielded about one hundred (100) palynomorphs species. The assemblages are dominated by angiosperm pollen and laevigate pteridophyte spores, few dinocysts and fungal spores. Five palynological assemblage zones were delineated from the Kolmani River-1 well and was correlated as follows: *Aquilapollenites minimus* Assemblage Zone *(Late Maastrichtian), Longapertites marginatus* Assemblage Zone *(Early Maastrichtian – Late Campanian), Dictyophyllidites harrisii* Assemblage Zone *(Early Santonian), Syncolporites subtilis* Assemblage Zone *(Coniacian) and Steevesipollenites binodosus* Assemblage Zone *(Turonian – Cenomanian).* The palynofloral assemblages identified in this well closely relate to those previously described in Nigeria, Ghana, Senegal and Ivory Coast, Egypt, Malaysia and from other low latitude settings around the World. The well penetrated Kerri-Kerri, Gombe, Pindiga and Yolde Formations in the Gongola basin. The Kerri-Kerri Formation comprising well sorted coarse - medium grained sandstones deposited in a coastal plain setting is dated Late Maastrichtian in age. The Gombe Formation, composed of grey shale, sandstone and coal deposited in environments ranges from coastal plain - estuarine is dated Maastrichtian – Campanian in age. The Pindiga Formation consisting dominantly of shales with minor silt and Limestone and deposited in estuarine – open marine and the Yolde Formation is composed of interbedding of sandstone, sandy shale and siltstone. The shales are pyritic, fissile and laminated. The sandstone is fine-grained, sub-angular and well sorted with carbonaceous materials. The upper part is interpreted as open marine environment while the lower part is interpreted as coastal plain deposit.



1. Longapertites microfoveolatus
2. Constructipollenites ineffectus
3. Leotriletes sp.
4. Monocolpites marginatus
5. Foveotriletes margaritae
6. Echitriporites trianguliformis
7. Dityophyllidites harrisii
8. Syncolporites subtilis
9. Longapertites marginatus
10. Kerogen
11. Distaverrusporites simplex
12. Mauritiidites sp.

Figure 5. Some of the palynological photomicrographs used for interpretations



1. Leosphaeridia sp.
2. Incerta sedi
3. Gleicheniidites senonicus
4. Retidiporites magdalensis
5. Retitricolporites vulgaris
6. Laevigatosporites sp.
7. Matonisporites sp.
8. Dinogymnium sp.
9. Steevesipollenites orbiculatus
10. Proxapertites operculatus
11. Laevigatosporites sp.

Figure 6. Some of the palynological photomicrographs used for interpretations

Acknowledgement

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Appendix 1

Auriculiidites reticulates Elsik, 1964
Araucariacites australis Cookson ex Couper, 1953
Aquilapollenites minimus Rouse ,1957
Clavatipollenites hughesii Couper, 1958
Constructipollenites ineffectus Van der Hammen, 1956
Cupuliferoidaepollenites quietus Muller etal, 1955
Cyathidites minor Couper, 1958
Dictyophyllidites harrisii Couper, 1958
Distaverrusporites simplex Van Hoeken-Klinkenberg, 1964
Echitriporites trianguliformis Van Hoeken Klinkenberg, 1964
Ephedripites spp Couper, 1956
Gleicheniidites senonicus Couper, 1958
Foveotriletes margaritae Germeraad et al., 1968
Matonisporites Couper, 1958
Leiotriletes sp. 1 Van der Hammen, 1956
Striatopollis sp. Krutzsch, 1959
Monocolpate marginatus Van Der Hammen , 1954
Longapertites marginatus Van Hoeken-Klinkenberg, 1964
Longapertites microfoveolatus Adegoke and Jan du Chene, 1975
Proxapertites operculatus Van der Hammen, 1956
Steevesipollenites obiculatus Stover, 1964
Tricolpites psilatus Couper, 1958
Retimonocolpites variplicatus Schrank & Mahmoud, 1998
Retitricolpites vulgaris Pierce, 1961
Mauritiidites spp Van Hoeken-Klinkenberg, 1964
Retidiporites magdalenensis Van der Hammen and Garcia 1966