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PALYNOFACIES STUDIES OF THE LATE CRETACEOUS (TURONIAN-MAASTRICHTIAN) STRATA FROM JAURO JATAU, GONGOLA SUB-BASIN, NORTHERN BENUE TROUGH, NIGERIA

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ABSTRACT

Geographically located within Gombe, Bauchi, and Yobe states, the Gongola Sub-basin has drawn attention from several academics looking to increase Nigeria's oil reserves relative to the inland frontier basins. This paper's goal is to determine the thermal maturity of strata from drill samples of the Fika shales in Nigeria's Northern Benue Trough, Gongola Sub-basin. To predict the well section's maturity and kerogen type, this study uses optical and organic facies studies. Twenty-seven samples of ditch cuttings were prepared using the universally accepted acid palynological procedure. The dispersed mounted slides revealed a variety of pollen, spores, and palynomacerals upon microscopic inspection. The well section under study exhibits a range of thermal maturation from mature to late mature, indicating the possibility of producing oil and gas. This corresponds to a range of thermal alteration values of 4 – 6 and equivalent vitrinite reflectance (%Ro) values of 0.6% – 1.35%. The total recovered Sedimentary Organic Matter (SOM) in this study was classified into Palynomorphs, Amorphous Organic Matter (AOM) and Phytoclasts and plotted on a ternary graph. The Percentage frequencies of AOM, Phytoclast and Palynomorphs were compared with the zones of the Tyson Ternary diagram. Most of the distribution frequencies lie within zones II, IX, VI and Iva suggesting Kerogen types III (gas-prone) and II (oil-prone).

Keywords: Palynofacies, Thermal maturity, Kerogen Type, Gongola Basin

INTRODUCTION

Palynomorphs can be used successfully for a wide range of geological studies apart from biostratigraphy, including sediment provenance Studies (Vecoli and Samuelsson, 2001), Structural geology (Delcaillau et al., 1998; Dorning1986), geo-thermometry (Pross et al., 2007) and source rock potential (Jiang et al., 2016), because organic matter (OM) is known for its high sensitivity to thermal evolution. Palynomorphs, such as sporomorphs and acritarch, are composed of impervious organic polymers, the precise nature of which is still unknown. One noteworthy feature of these polymers is the internal reorganization of their molecular structure, which is brought about by processes that occur during burial (such as depth and duration, geothermal flux, and fluid geochemistry). These processes result in colour alteration that is directly related to the maximum temperature attained. Furthermore, weathering-related post-depositional oxidation can brighten the colour of palynomorphs in addition to corroding or even destroying them (Traverse, 2008 and references therein). Visual kerogen typing, a form of organic petrography, is the microscopic technique used to examine kerogen. It is based on the idea that optically categorized kerogen particles can be connected to the hydrocarbon-generating potential (Staplin, 1969) of a source rock. These microscopic observations are Mostly done using concentrated kerogen with refractory minerals prepared on a slide. At the same time, the Thermal Alteration Index (TAI) is a maturity indicator based on observations of the progressive change in the colour of spore and pollen particles in kerogen with increasing maturity (e.g., Gutjahr, 1966; Correia, 1969; Staplin, 1969). Staplin (1969) created the first formal scale, which was a 1–5 scale with + and − notations to indicate intermediate steps. In contrast to other geochemical methods for studying the thermal alteration of sediments, these are sophisticated but rather costly procedures.

A few numbers of researchers, including Obaje (2004) and Abubakar (2008), conducted investigations on the petroleum potential of the Gongola Sub-basin following Chevron Nigeria Ltd.'s drilling attempt in 1992. They use the organic geochemical approach to study the source rock maturity of the basin. Abubakar, (2014) also reviewed the petroleum potentials of the Benue Trough and Anambra Basin making comparisons with other West and Central African basins. Recent works include the work of Raji, (2015) who used borehole samples from the Gongola Sub-basin to study the Rock-Eval pyrolysis, vitrinite reflectance, and infrared spectroscopy to evaluate their organic richness, thermal maturity, and petroleum-generating potential.

The purpose of this paper is to study the source rock potential of the strata penetrated at Borehole Jauro Jatau community at the outskirt of Gombe Town (Figure. 1) by using Spore/Pollen colour changes and Organic Facies to determine the maturity of the sediments. This study determines thermal alteration by visually evaluating palynomorph colour (i.e., Spore Color, Thermal Alteration, and Palynomorph Darkness). This method is less expensive and reasonably easy to use when compared to the costly methods used by previous authors.

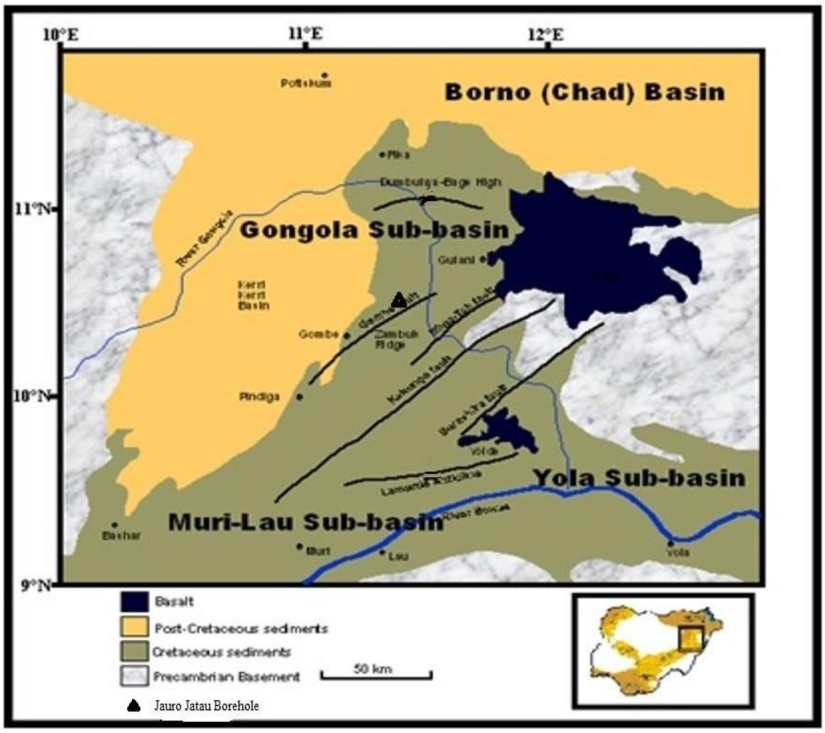


Figure 1: Map showing the geology of the Northern Benue Trough with borehole location. (Modified after Goro et al., 2021)

The Benue Trough, a rift basin that stretches 800 km in length and 150 km in width and contains up to 6,000 meters of Cretaceous-Tertiary sedimentary strata, the Gongola sub-basin is situated northeast of the Benue Trough. According to (Akande and Erdtmann, 1998), both post-deformational strata of Campanian-Maastrichtian to Eocene ages are found in the Gongola Sub-basin. Additionally, a lot of anticlines and synclines have been created by folding, faulting, and local uplift of strata that predate the mid-Santonian compressional phase (Benkhelil, 1989). In the aftermath of mid-Santonian magmatism and tectonism, the Benue Trough's depositional axis was moved. The Northern Benue Trough is composed of the Gongola Sub-basin and the Yola Sub-basin. The Lau-Gombe Sub-basin is the third basin; while it is not well-known, some have acknowledged it (Akande et al; 1998 Whiteman, 1982). The stratigraphic succession in the Gongola and Yola Basins is illustrated in (Figure. 2**)**. The lacustrine and fluvial Bima were unconformably deposited in the Precambrian basement during Albanian time. The formation contains carbonaceous clay, shales, and mudstones. The Bima was divided by Carter et al. (1963) into lower, middle, and upper units. The Middle Bima is said to be Shales with some limestones and is thought to have been deposited under more aqueous anoxic conditions (lacustrine, briefly marine). The Yolde Formation is Cenomanian and rests conformably on the Bima Sandstone. This formation represents the beginning of a marine incursion into this part of the Benue Trough and was deposited in a transitional/coastal marine environment made up of clays, claystone, shales, limestones, and sandstones. In the Gongola Sub-basin, the Pindiga Formation rest conformably on the Yolde Formation. This formation, which was deposited in a transitional/coastal marine environment, marks the start of a marine transgression into the Benue Trough. It is made up of clays, claystones, shales, limestones, and sandstones. From the Turonian to the Late Maastrichtian period, a total marine invasion of the Northern Benue Trough is represented by this Formation. Lithologically, the Kanawa Member is represented by Shales, pale limestones, and minor sandstones that are intercalated with dark or black carbonaceous limestones. The Middle Marine Sandstones Members of Dumbulwa, Daben Fulani, and Gulani are then deposited on top of this formation in some areas. The Fika Shale consist of extremely fissile, bluish-green carbonaceous, occasionally pale-coloured gypsiferous shales associated with rare limestones. The Late Cretaceous strata are represented by the Gombe Sandstone and followed by the almost fully continental Kerri-Kerri Formation. The Gombe sandstone is dominantly composed of sandstones, clay, coal, lignite and coaly shale intercalations. The Gombe sandstone is mostly made up of intercalations of clay, lignite, coal, and sandstones with coaly shale. The Tertiary Kerri-Kerri Formation consists of sandstones, claystones, and siltstones.

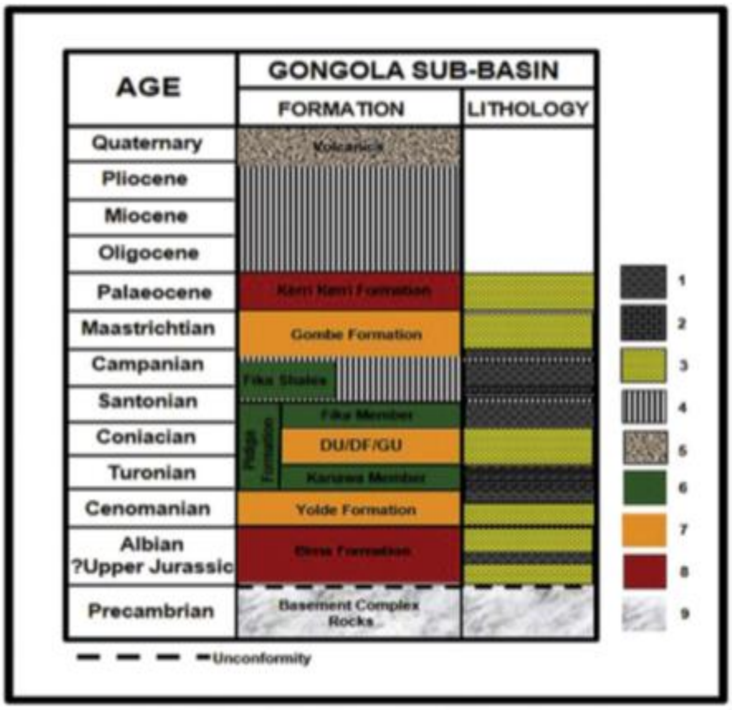


Figure 2: Stratigraphy of the Gongola Sub-basin, Northern Benue Trough, Nigeria (adopted from Goro et al., 2021). 1-Mudstone, 2-Limestone, 3-Sanstone, 4-Hiatus, 5-Basalt, 6-Marine sediments, 7-Transitional-marine sediments, 8-Continental sediments, 9-Basement Complex (DU-Dumbulwa Member, DF-Deba Fulani Member, GU-Gulani Member)

MATERIALS AND METHODS

The lithologic description was done by visual assessment of each sample during drilling using a colour chart to establish the colour, a grain size chart and magnifying hand lens were used for the grain-size description. The borehole site is located within the outcrop of Fika Shale at 10° 14' 54.35"N and 11° 9' 34.87"E. The borehole was drilled to a total depth of twenty-seven meters and sampled at 1m intervals. The samples were subjected to the palynological preparation technique of (Batten and Stead, 2005) to recover the palynomorphs from the sediments. The analyses were carried out at the National Centre for Petroleum Research and Development (NCPRD), located at the Abubakar Tafawa Balewa University Bauchi Palynological Laboratory. Twenty grams of each sample was treated with 35% HCL acid under a fume cupboard for the removal of carbonates. The residues were completely washed with distilled water. Then 48% HF acid was added to the sample and kept for 24 hours to dissolve the silicates present in the samples. Thereafter, the residue was diluted with distilled water and carefully decanted, then followed by complete washing with distilled water to remove fluoro-silicate compounds which are usually formed from the reaction with HF. The residue is now sieved and separated. The sieved residue was not oxidized using concentrated nitric acid (HNO_3), because this treatment will selectively remove amorphous organic matters that often co-exist with the palynomorphs, but can lighten the dark-hued palynomorphs. The residues for palynological slides were then stained and prepared with glycerin jelly. The Olympus CX41 Binocular Light Transmitted Microscope was used to examine the slides. The identification of palynomorphs and palynomacerals was accomplished with the help of palynological albums and the published works of earlier researchers, including Chukwuma-Orji (2018), Oboh-Ikuenobe (1998), Abubakar (2011), and Njoh (2017). The visual pollen and spore colouration of the identified palynomorphs for each sample was compared with the thermal alteration scale developed by Batten (1980). This was also correlated with the thermal alteration index, vitrinite reflectance and degree of maturation as suggested by Batten (1980). The total recovered Palynomacerals in this study were classified into Palynomorphs, Amorphous Organic Matter (AOM) and Phytoclast groups and plotted on a ternary diagram of Tyson 1995. The Percentage frequencies of sedimentary organic matter (AOM), Phytoclast and palynomorphs were compared with the zones of the ternary diagram.

RESULTS AND DISCUSSION

Lithology organic matter Composition and colour variation

The lithologic composition and organic matter variation of the studied well (Fig. 3), consists of shales, fine-grained sandstone, and sandy mudstones. Visual observations of the ditch cutting samples with the Munsell colour chart indicate that the shale has fissility, and has a colour range from light grey to greenish grey, occurring at a depth interval of 0 – 20 m of the well section. The palynomorphs and palynodebris constituents recovered at various depth intervals are generally, abundant, and diverse (Fig. 4). A total count of 526 palynomorphs were recovered. The pollen and spores' constituents occur in abundance with few counts of dinoflagellate cysts and others. The Pollens, Spores and *dinoflagellates* which are the predominant sporomorphs, consist of *Monoporites annulatus, Zonocostites ramonae, Ephredripites sp., Longapatites sp., Tricolporopollenites sp., Cingulatisporites Ornatus, Stephanocolporate zonorate, Leotrilete adriensis Droseridites senonicus, Cretacaeiporites scabratus, Longapertites microfoveotus, Cyathidites sp, Zlivisporites blanensis,* , Dinoflagellate cysts recovered, are indicative of marine incursion, include *Cribroperidinium orthocera. Leiosphaeridia sp., Paleocystodinium sp., Achomosphaera sp., Oligosphaeridium sp.* and some *dinocysts* that cannot be determined by their genus or species levels denoted as indeterminate. Other palynofacies constituents recovered in appreciable quantities are *Marine Parasinophyte, Foraminiferal test linings, and Tasmanites* including (phycomata) of Parasinophyte algae. The microphotographs of some recovered palynomorphs are presented in Plate 1. Visual microscopic inspection of the polymorphs and palynodebris colour under a transmitted light microscope revealed the dominance of Light medium brown – dark brown and a minor Dark Brown-Very dark brown, Black colours (Table 2). Other Palynological materials of interest in the sampled depths include palynodebris like Phytoclast, Amorphous Organic Matter (AOM), *Marine Parasinophyte, Foraminiferal test linings*, and *Tasmanites*. Their distribution and influence are stratigraphically presented in Figure 3.

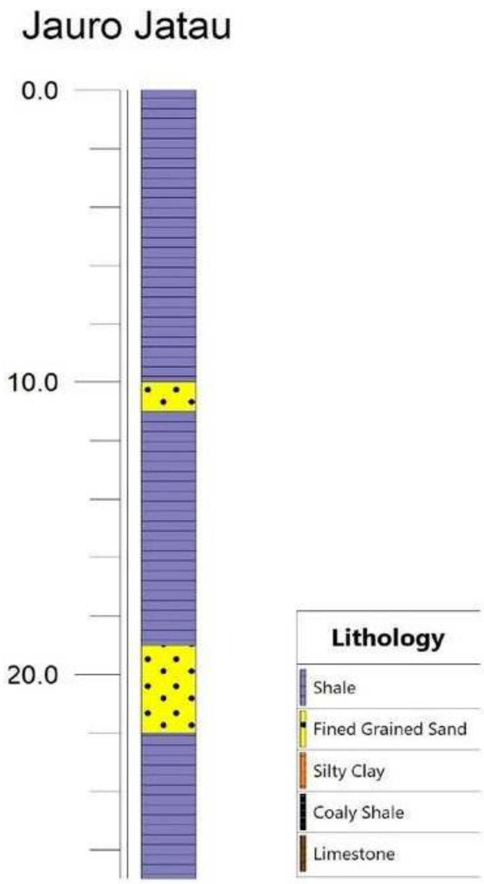


Figure 3: Arawa Borehole lithology Log

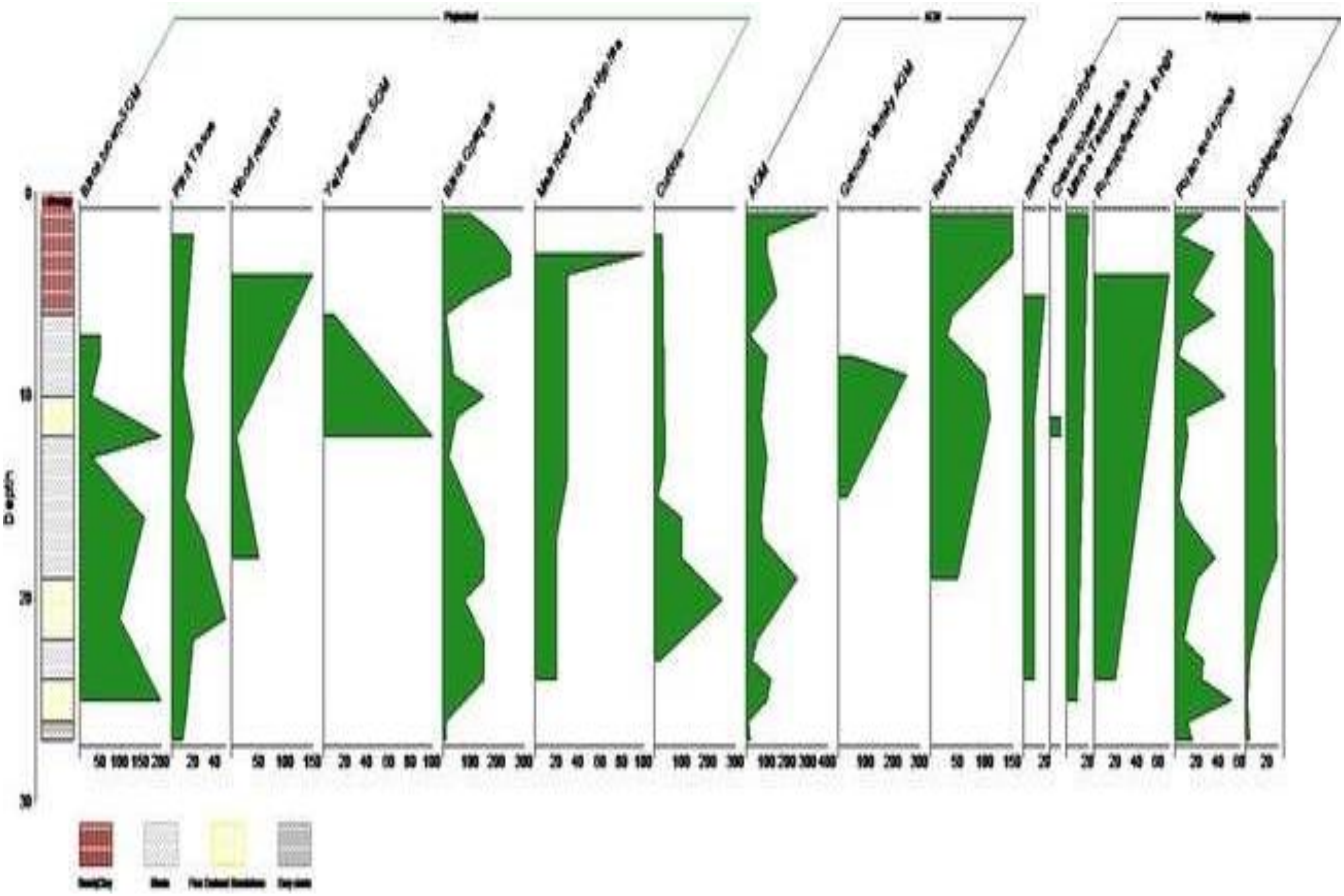
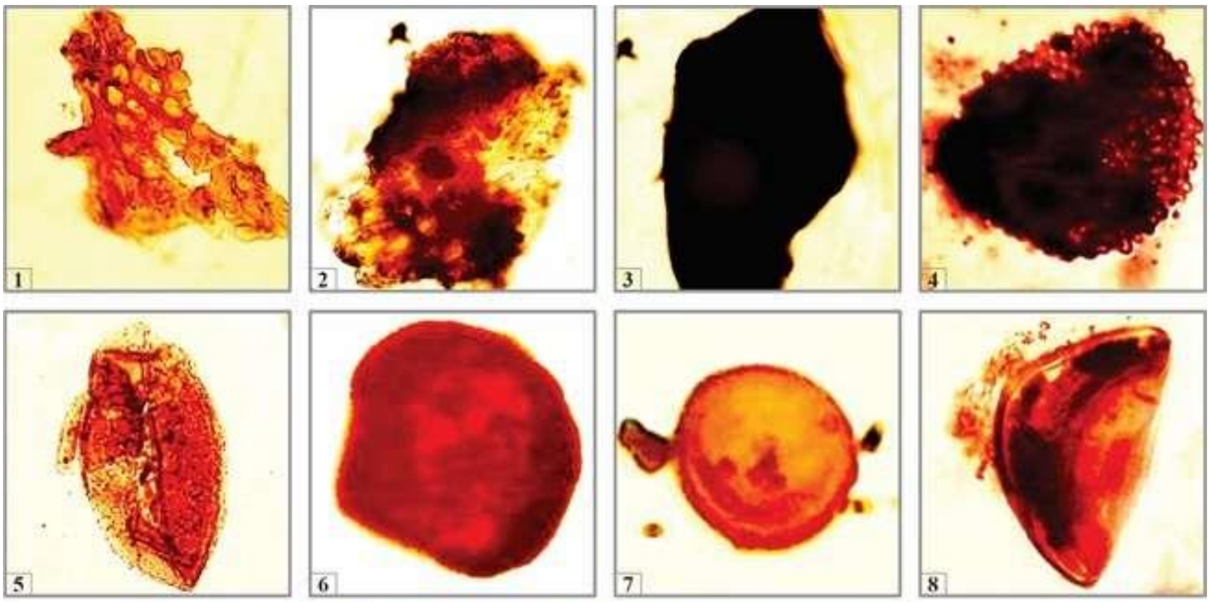


Figure 4: Lithology and palynofacies distributions



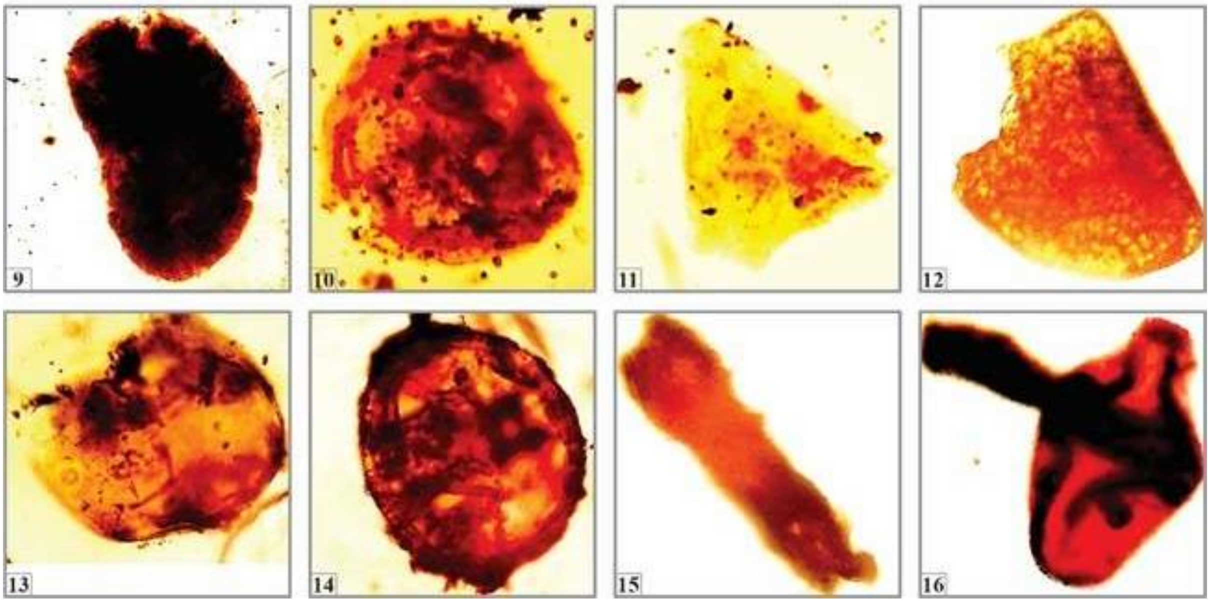


Plate 1: A selection of Palynomorphs and Palynodebris Recovered from The Borehole all images are at a magnification of x600. 1. Plant Cuticle 2. Granular AOM 3. Black brown SOM 4. Echitriporites trianguliformis Van Hoeken-Klinkenberg, 1964 5. Monosulcite Sp 1. Lawal and Moullade 1986. 6. Rugulatisporites caperatus Van Hoeken-Klinkenberg, 1964 7. Classopollis sp. Jardiné and Magloire, 1965 8 Monosulcite sp. Lawal and Moullade 1986. 9. Longapertites sp. 3, Lawal and Moullade, 1986 10. Cretacaeiporites scabratus Herngreen, 1973. 11. Proteacidites sp. P. cf. dehaanii Germeraad et al., 1968 12. Resin Particle 13. Marine Phycoma 14. Zlivisporites blensis Pacltova, 1961 15. Wood remains 16. Pseudotricolpites reticulatis.

Thermal Maturation

Pollen and Spore colour and their corresponding thermal alteration index (TAI) and vitrinite reflectance (%Ro) values have been developed by several academics, including (Staplin, 1969; Collins, 1990; Batten, 1980), for the goal of determining thermal maturation. However, the results presented here (Table 1; Fig. 5) are based on the Batten (1980) thermal alteration scale for spore colouring, which is scored from 1 to 7 and indicates the colour change of polymorphs from yellow, orange, brown, to black. The palynomorphs/palynodebris colouration ranges from light brown, light medium brown to dark medium brown (4-5) for the first 20m of the borehole which signifies a matured oil generation stage and a dark brown through very dark brown to black which is represented by numbers 5-6 ranking on the Batten classification table indicating Mature to late matured stages respectively. Special consideration was given to long-ranging species like *Longapertites sp., Tricolporopollenites sp., and Cingulatisporites Ornatus,* and they all show this colour changes with increasing burial. The degree of thermal maturation of the studied samples can be interpreted as matured to Late Matured stage and, hence prone to oil and gas production. This corresponds to a range of thermal alteration values of 4 – 6 and an equivalent vitrinite reflectance (%Ro) value of 0.6% – 1.35% (Fig 5).

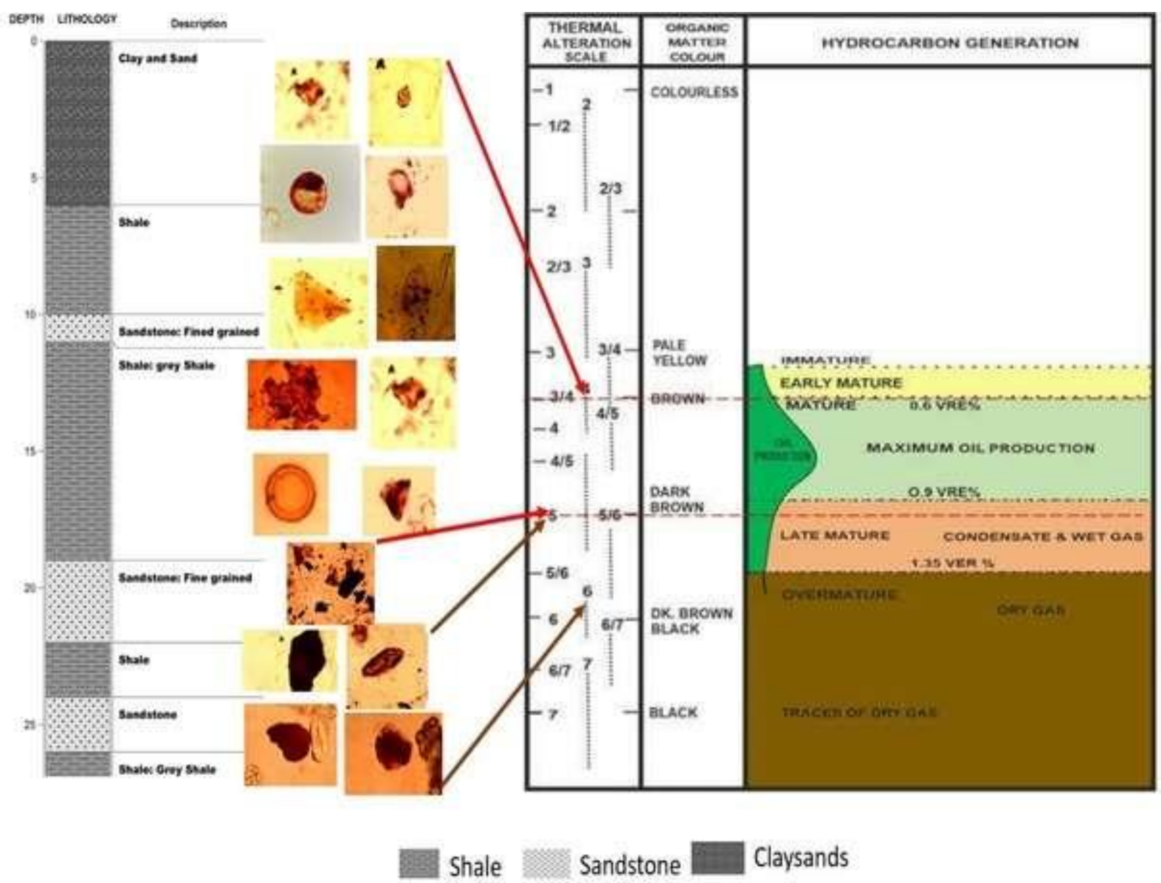


Figure 5: Correlation of pollen/spore exine wall colour from Jauro Jatau sediments with palynomorphs colour chart and there corresponding thermal alteration index and vitrinite reflectance of Batten (1980).

Table 1: Microscopic observation of spore/pollen and palynodebris colour changes and their corresponding thermal alteration index (TAI) and degree of maturation in Jauro Jatau borehole

Depth (M)	Lithology	Spore/pollen color	Thermal alteration index	Degree of maturation
0-1	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
1-2	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas
2-3	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas
3-4	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
4-5	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
5-6	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
6-7	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
7-8	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
8-9	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
9-10	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
10-11	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
11-12	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
12-13	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
13-14	Grey Shale	Light medium brown – dark brown	4-5	Mature stage

14-15	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
15-16	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
16-17	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
17-18	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
18-19	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
19-20	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
20-21	Fine Grained Sandstone	Light medium brown – dark brown	4-5	Mature stage
21-22	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
22-23	Grey Shale	Light medium brown – dark brown	4-5	Mature stage
23-24	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas
24-25	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas
25-26	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas
26-27	Grey Shale	Dark brown-Very dark brown, Black	5-6	Mature-Over Mature Stage source potential for dry gas

Organic Facies

A complex fossilized organic matter found in sedimentary rocks is known as kerogen. Tyson (1984, 1995) proposed a ternary kerogen plot consisting of kerogen categories, AOM (Amorphous organic Matter), Phytoclast and Palynomorphs. Based on the ternary plot, Late Jurassic sediments and other Mesozoic-Cenozoic rocks have been studied and found that palynological kerogen having similar composition and paleoenvironmental settings (from different geologic times) tends to occupy the same position in the ternary plot. The total recovered Sedimentary Organic Matter in this study was classified into Palynomorph, AOM and Phytoclast groups and plotted on a ternary diagram of Tyson 1995. The Percentage frequencies of sedimentary organic matter (AOM), Phytoclast and palynomorphs were compared with the zones of the ternary diagram (cf. Tyson 1995) (fig 6). Most of the distribution frequencies fall under zones II, IX, VI and IVa areas which indicate Kerogen type II (Oil Prone), and III (gas prone), respectively (Table 2.).

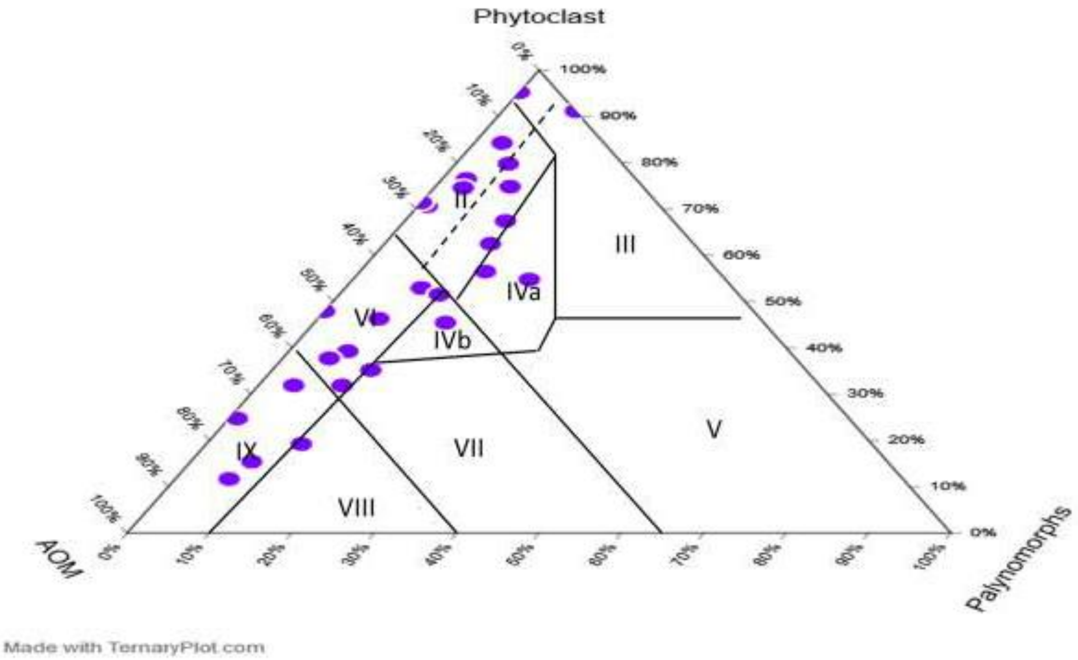


Figure 5: Ternary-diagram-showing-AOM-Phytoclasts-and-palynomorphs for the studied strata (after Tyson,1995).

Table 2: Palynofacies fields defined in the ternary kerogen diagram of Tyson, (1995)

Palynofacies Field	Jauro Jatau		Kerogen Type
I	⊗	→	III gas prone
II			III gas prone
III			III or IV gas prone
IVa	⊗	→	III or II mainly gas prone
IVb			III or II mainly gas prone
V			III>II gas prone
VI	⊗	→	II oil prone
VII			II oil prone
VIII			II>> I oil prone
IX	⊗	→	II≥I highly oil prone

Discussion

The use of thermal maturation as a tool for accessing the Petroleum Potentials of sedimentary basins has been underrated by different scholars and oil exploration companies, this method has been one of the most reliable methods as shown by this research when we crosscheck with those researchers that employed the conventional methods which include Rock-Eval pyrolysis and Vitrinite reflectance, the two major studies carried out by earlier researches in this basin indicates an immature kerogen type for the Pindiga formation why also suggesting a more deeper formation for oil exploration, that was why this study was carried out on only the Fika shale within the Pindiga formation in order to increase the resolution of the results and the results shows a different characteristics for the Fika shale. Considering the cost of using those methods, palynology is a cheaper and more reliable substitute. This research was done to support and add to the existing knowledge with regards to the Late Cretaceous Petroleum System in the Gongola Sub-basin, after the successful exploration of oil from the early Cretaceous system all efforts are to develop a reliable system for the late Cretaceous units of the basin, from the thermal maturation and organic facies results from these studies, the Fika shale has shown to be oil and gas prone which we believe will attract more government interest in the basin.

CONCLUSION

The need to understand the hydrocarbon prospectivity and contribute to the pre-requisite knowledge required to attract investors to the inland Gongola Sub-basin necessitated this palynofacies study and thermal maturation analysis. Twenty-seven (27) cuttings samples were subjected to the standard acid palynological preparation method. Microscopic analysis of the strewn mounted slides yielded diverse pollen, spores and palynomacerals. The palynomorphs/palynodebris colouration ranges from light brown, light medium brown to dark medium brown (4-5) for the first 20m of the borehole which signifies a matured oil generation stage. Also, there was a 7m of Dark brown through Very dark brown to Black colouration which is represented by numbers 5-6 ranking on the classification table and represents a late Matured Stage which indicates a more gas-prone stage. The total recovered sedimentary organic matter in this study was classified into Palynomorph, AOM and Phytoclast groups and plotted on a ternary graph. The Percentage frequencies of sedimentary organic matter (AOM, Phytoclast and palynomorphs) were compared with the zones of the ternary diagram. Most of the distribution frequencies are coming under the zone II, IX, VI and IVa areas, which indicated Kerogen type III (gas prone), and II (Oil Prone), respectively. The results obtained from this study have indicated a good prospectivity of the Jauro Jatau borehole. However, prediction of the hydrocarbon potential of the Gongola Sub-basin using spore/pollen colour and organic facies is not sufficient to conclude for successful accumulation of oil and gas, other geological factors must be considered. Hence, the result of this research should serve as a preliminary view of the hydrocarbon potential of the Fika shales Gongola Sub-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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