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Palynofacies and sea level changes in the Upper Cretaceous of the Yola Basin, Northern Benue Trough, Northeastern Nigeria

[1]Yunis Boga Valdon, [2]Sadiq Abubakar Maigari
[1]Department of Geology,
Modibbo Adama University,
Yola.

[2]Department of Applied Geology,
Abubakar Tafawa Balewa University,
Bauchi.

Email: yunis.valdon@mautech.edu.ng

Abstract
Upper Cretaceous sediments (Numanha and Lamja Formations) in the Yola basin of Northern Benue Trough have been investigated in order to characterize the particulate organic matter (POM) in the samples. The aim is to understand the rapid facies changes in both vertical and lateral direction of the formations and the relative abundance of the different organic components within the sections. The investigation involved 62 samples from four outcrop sections. The analysis involved series of laboratory procedure ranging from sample preparation, chemical treatment with HCl and HF, sieving, slide cover and completion then the counting of 300 particles per sample. The samples yielded sufficient organic residues for detailed palynofacies analysis. The organic constituents observed in the studied samples have been classified into phytoclast, palynomorp and amorphous organic matter groups. The phytoclast group predominates in almost all the sections followed by the palynomorp group with little amount of amorphous organic matter (AOM). The palynofacies parameters used for the study are the continental/ marine and opaque/translucent ratios which led to the construction of the sea-level variation pattern for the formations using Tilia 2.0.2 program.

Keywords: palynofacies, eustatic, sea-level, phytoclast, opaque

INTRODUCTION
Upper Cretaceous rocks of the Yola Basin are well exposed in the Guyuk area. The study area falls within longitudes 11^0 00′to 11^0 56′ and latitudes 9^0 46′ to 9^0 54′ (Fig. 1). Research works in the basin include the works of Carter *et al.* (1963); Benkhelil, (1986); Ofogegbu and Okereke (1990); Braide (1992) and Guiraud (1993).These researchers discussed the sedimentation and tectonic history of the Yola Basin. Other works include, Allix (1983); Reyment (1965); Whiteman (1982); Hoque and Nwajide (1984); Obaje *et al.* (1999); Zaborski (1998 and 2000); Genik (1992). They studied the stratigraphy of the continental and marine sequences. Mamman *et al.* (2007) and Opeloye *et al.* (2012) examined the trace fossils of the Turonian

**Author for Correspondence*

Dukul and Jessu Formations and the microfossils of the Numanha Shale respectively. The textural characteristics of the limestone deposits in the basin was also studied by Opeloye (2003).

Studies on the stratigraphic and lateral distribution of sedimentary organic particles in marine depositional environments and the application of palynofacies analysis in the sequence stratigraphic interpretation of carbonate systems was first published by Gorin and Steffen (1991) and Steffen and Gorin 1993 who worked in the Lower Cretaceous of southern France. In this present study, palynofacies analysis is applied to detect sea level fluctuations within the Coniacian and Santonian sediments.

The Yola Basin is a rift related basin which occupies the eastern branch of the Northern Benue Trough and covers a total area of about 11,000 km^2 in its eastward orientation from Kaltungo inlier area. It extends into Cameroun Republic through the Douba rift to form a network of West and Central Rift system (Ofoegbu and Okereke, 1990). Braide (1992) used facies architecture to decifer the tectonic evolution of the Yola Basin. He concluded that the Yola Basin originated as a pull-apart basin following the high sedimentation rates, great structural complexity evidenced by the rapid facies changes in both vertical and lateral directions, great sedimentary thickness, evidence for strike-slip faulting as enumerated by Benkhelil (1982) as well as displaced fan/source relationship, overlap of the basement by sediments particularly on the northern margin which suggests the depocentre was migrating parallel to basin margin faults.

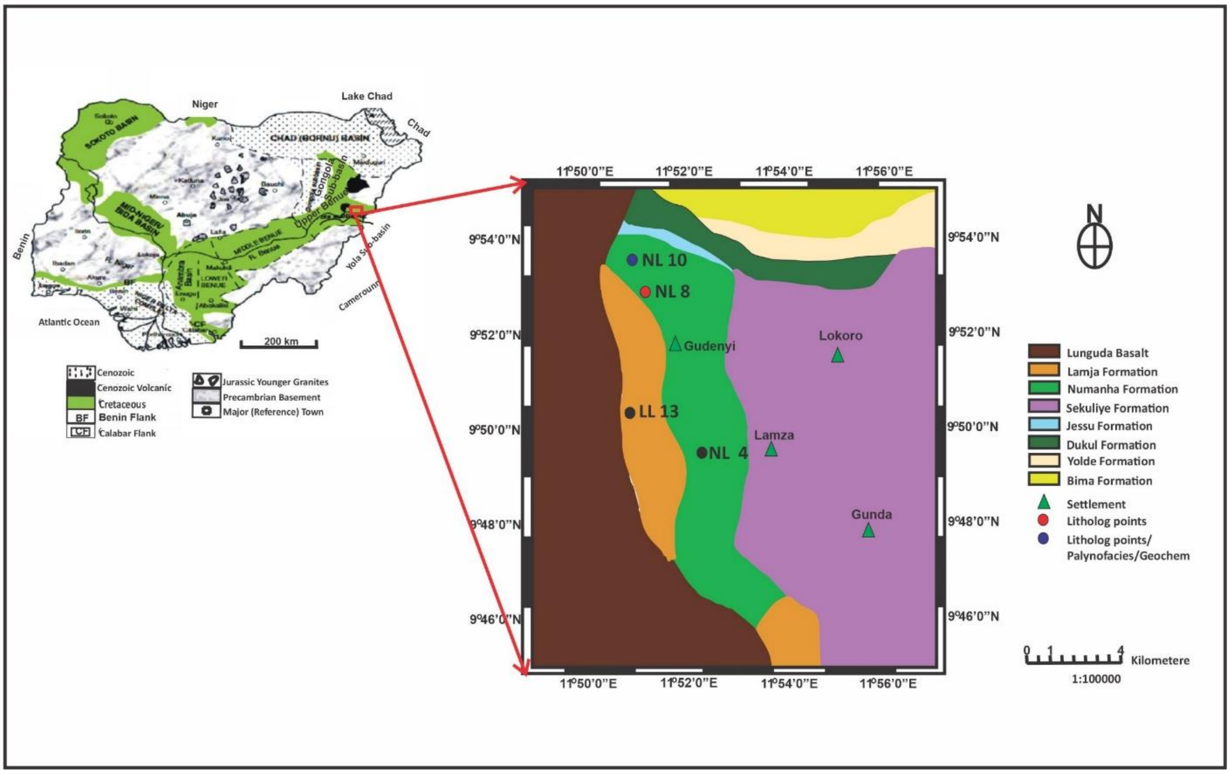

Fig.1: Geological map of the study area with location of sections studied.

MATERIALS AND METHODS

Samples

In the Guyuk area within the Dadinya syncline of the Northern Benue Trough, sixty two (62) representative outcrop samples were processed for palynofacies from three sections of Numanha and one section of Lamja Formations.

Palynofacies

The palynological processing performed in the Palynological Laboratory at the Missouri University of Science and Technology Rolla, USA involved digestion of 15-20g of samples in Hydrochloric(HCl) and Hydrofluoric (HF) acids to remove carbonates, silicates and fluorides resulting from Hydrofluoric acid treatment from the sediments (Traverse, 2007). Preparation of kerogen slides for palynofacies analysis followed the acid digestion. Three hundred particulate organic matter particles were point counted per kerogen slide and used for palynofacies analysis.

For palynofacies analysis the sedimentary organic matter of the studied Upper Cretaceous clastic and carbonate rocks were grouped into three: Palynomorphs (marine and terrestrial), Phytoclasts (structured, degraded and opaques) and Amorphous Marine Organic Matter (AMOM). From each sample, 300 specimens of organic particulate matter were counted and described with a Leica DM 1000 microscope using transmitted white light. The absolute relative abundance values were converted to percentage relative values and normalized to 100 percent. The qualitative and quantitative analysis from the organic particulate matter were synthesized in the form of percentage diagrams prepared by Tilia Gview 2.0.2 (Grim, 1992). Two palynofacies parameters were calculated to detect eustatic signals

1. The ratio of continental to marine particles (CONT/MAR ratio). The composition and relative abundance of the continental fraction reflects the hinterland vegetation and the source distance. Stratigraphic variations in the CONT/MAR ratio document prograding and retrograding coastlines. This ratio decreases basin-ward and increases stratigraphically in a shallowing –upward succession (Wood and Gorin, 1998).
2. The ratio of opaque to translucent phytoclasts (OP/TR rato). Opaque phytoclasts partly consist of charcoal originating from forest fires, but mainly develop by oxidation of translucent phytoclast. Another source of opaque phytoclast might be resedimentation of refractory particles. Generally the ratio of opaque to translucent phytoclasts increases basin-ward due to fractionation processes and the higher preservation potential of opaque particles (Tyson, 1993; Pittet and Gorin, 1997). Most of the oxidation is of subaerial, continental origin (Tyson, 1995).

RESULTS AND DISCUSSION

NL10 section

Eighteen samples of shale and mudstone were analysed for this section. Table 1 shows the relative percentage of the particulate organic matter. The opaque phytoclast dominates in all the samples throughout the section. This may be due to long distance transport of the particles. Figure 2 represents the synthesized diagram showing the continental/marine and opaque/translucent ratios.

Table 1. Relative Percentage of Palynofacies for Kurnyi (NL10) section

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL10s1	19.67	29.67	22.00	6.00	22.33	0.33	100.00
NL10s2	11.00	14.33	28.33	16.67	24.33	5.33	100.00
NL10s3	5.33	19.33	20.00	18.33	31.33	5.67	100.00
NL10s4	13.33	17.33	13.00	5.67	45.00	5.67	100.00
NL10s5	28.33	14.33	19.00	9.00	25.33	4.00	100.00
NL10s6	21.33	24.00	12.67	9.67	28.33	4.00	100.00
Nl10s7	11.33	17.67	19.33	7.33	42.00	2.33	100.00
NL10s8	6.94	52.78	1.39	5.56	29.17	4.17	100.00
NL10s9	19.67	37.67	20.67	7.67	10.00	4.33	100.00
NL10s10	3.33	42.00	1.67	19.33	30.00	3.67	100.00
NL10s11	8.00	31.33	11.00	25.33	19.67	4.67	100.00
NL10s12	8.00	19.00	6.67	20.33	43.67	2.33	100.00
NL10s13	24.33	12.00	17.67	13.33	27.33	5.33	100.00
NL10s14	6.33	17.00	6.00	36.67	30.67	3.33	100.00
NL10s15	30.33	12.67	6.33	18.33	24.33	8.00	100.00
NL10s16	7.00	13.33	2.33	41.33	30.33	5.67	100.00
Nl10s17	1.00	7.00	5.67	33.00	52.00	1.33	100.00
NL10s18	2.67	6.00	5.00	45.67	38.33	2.33	100.00

NB: Pal=Palynomorphs, Struc. Phyto= Structured phytoclast, Degr Phyt= Degraded phytoclast, Opaq. Phyt= Opaque Phytoclast, AOM= Amorphous Organic Matter

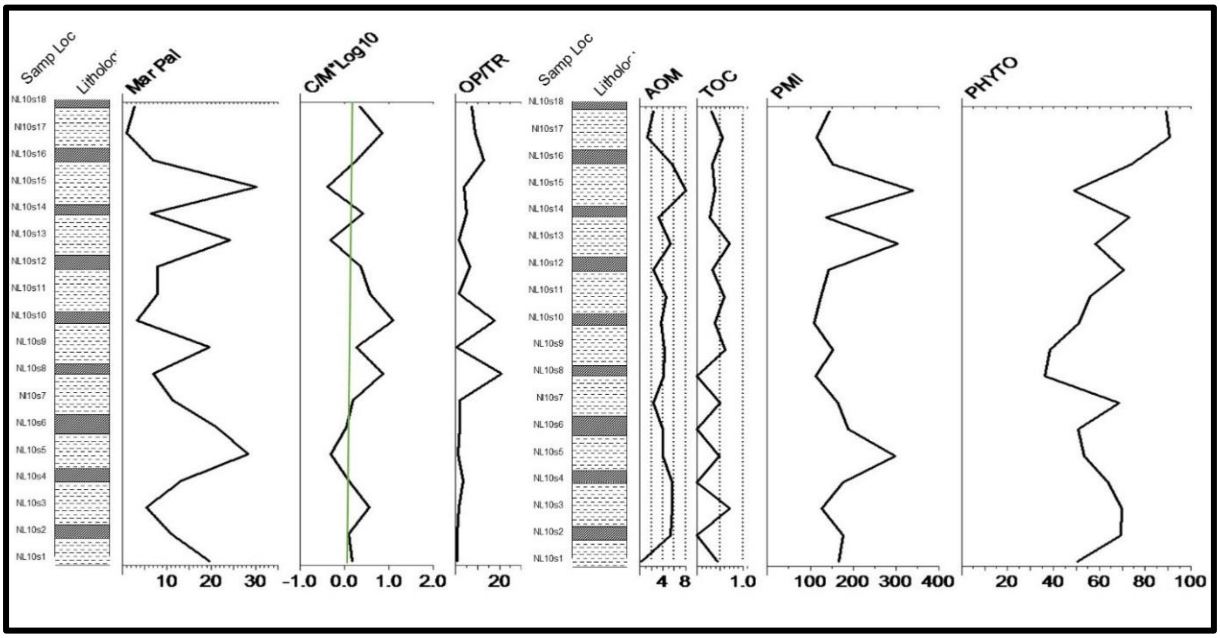

Fig. 2: Relationship between palynofacies and sea level parameters for Kurnyi section (NL10)

NL8 section

This section is composed of shale, calcareous mudstone and limestone. Eighteen samples were analysed (Table 2). The organic matter indicated the presence of both the terrestrial and marine sourced characteristics based on the carbon/nitrogen ratio. Figure 3 is the diagram showing the relationship between the palynofacies and sea-level changes as synthesized by Tilia.

Table 2: Relative Percentage of Palynofacies for Gundenyi 1 (NL8) section

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL8s1	5.67	1.67	19.00	5.33	65.33	3.00	100.00
NL8s3	22.00	5.67	55.33	6.00	11.00	0.00	100.00
NL8s4	5.00	2.33	48.67	17.33	25.67	11.00	110.00
NL8s6	6.33	8.00	60.67	3.33	21.00	0.67	100.00
NL8s7	5.00	4.00	55.33	3.67	31.67	0.33	100.00
NL8s8	16.33	5.67	44.00	5.67	27.67	0.67	100.00
NL8s9	7.67	6.33	54.33	2.00	25.33	4.33	100.00
NL8s10	2.67	5.00	64.00	4.33	22.33	1.67	100.00
NL8s11	5.00	2.33	51.00	5.67	34.67	1.33	100.00
NL8s12	1.67	1.33	61.33	2.67	32.00	1.00	100.00
NL8s13	13.00	2.33	54.00	0.67	29.33	0.67	100.00
NL8s14	5.00	3.33	43.67	6.33	40.33	1.33	100.00
NL8s16	0.67	0.33	20.00	34.67	43.33	1.00	100.00
NL8s17	0.33	1.67	34.00	6.67	57.00	0.33	100.00
NL8s18	0.67	1.33	12.33	61.00	24.67	0.00	100.00

NB: Pal=Palynomorphs, Struc. Phyto= Structured phytoclast, Degr Phyt= Degraded phytoclast, Opaq. Phyt= Opaque Phytoclast, AOM= Amorphous Organic Matter

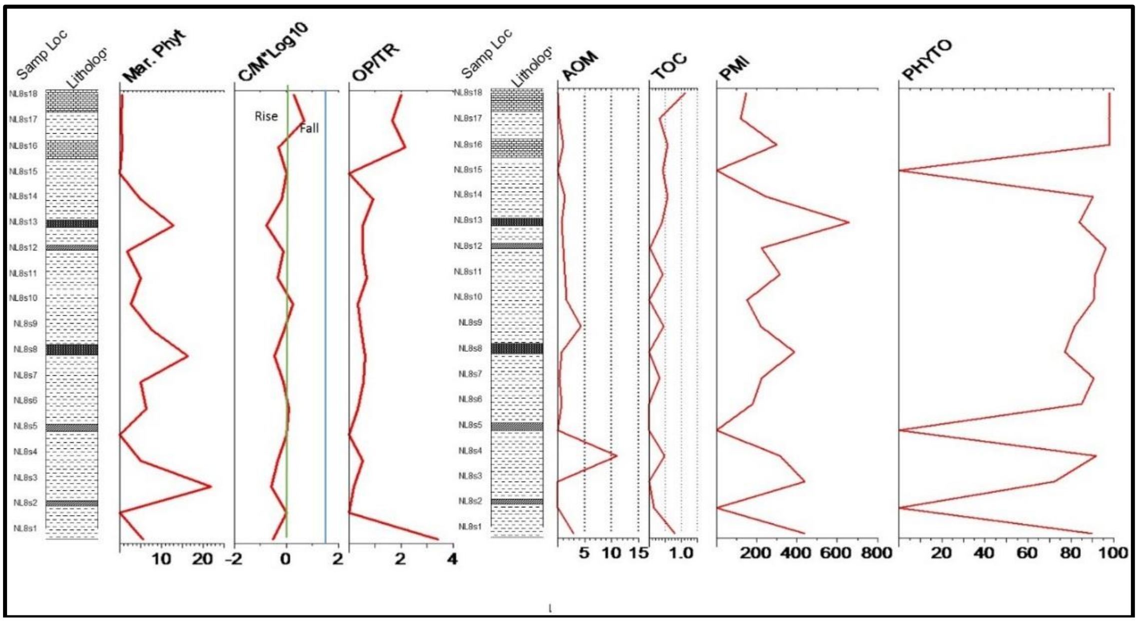

Fig. 3: Relationship between palynofacies and sea level parameters for Gundenyi section (NL8)

NL4 section

This section is the thickest of the sections studied with 21 samples of shale, limestone and calcareous mudstone. Table 3 shows the relative percentage of the organic components. The opaque phytoclast dominates generally. Dinoflagellate cyst, foraminiferal lining and fresh water algae are abundant depicting a proximal estuarine environment. The relationship between the palynofacies and the sea level parameters are on Fig. 4.

Table 3. Relative Percentage of Palynofacies for Tsintsire (NL4) section

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
NL4s1	11.00	8.67	31.00	9.00	38.00	2.33	100.00
NL4s2	1.00	1.33	39.00	12.33	41.33	5.00	100.00
NL4s3	0.00	6.67	53.33	7.00	30.00	3.00	100.00
NL4s4	0.67	19.33	48.00	6.00	25.33	0.67	100.00
NL4s5	0.33	27.67	40.00	5.33	26.33	0.33	100.00
NL4s6	35.67	8.67	21.67	13.00	18.67	2.33	100.00
NL4s7	19.67	2.00	23.33	16.33	37.33	1.33	100.00
NL4s9	7.33	22.67	9.67	22.00	26.33	12.00	100.00
NL4s10	10.00	20.33	10.33	17.33	38.67	3.33	100.00
NL4s11	11.00	37.00	15.33	11.00	22.33	3.33	100.00
NL4s12	29.00	28.00	10.00	10.33	20.00	2.67	100.00
NL4s13	8.33	45.00	5.00	5.67	35.67	0.33	100.00
NL4s14	16.00	34.33	5.00	18.33	25.00	1.33	100.00
NL4s15	11.67	12.33	19.00	5.67	52.67	0.00	101.33
NL4s17	25.67	30.67	10.00	20.67	12.33	0.67	100.00
NL4s19	24.00	14.67	10.67	12.00	36.00	2.67	100.00
NL4s20	13.33	40.67	4.33	18.67	23.00	0.00	100.00
NL4s21	5.00	5.67	31.67	4.67	52.33	0.67	100.00
NL4s22	2.67	9.33	19.33	2.00	66.00	0.67	100.00
NL4s23	2.33	16.00	7.33	40.33	33.67	0.33	100.00
NL4s24	12.67	12.00	17.33	12.33	44.67	1.00	100.00

NB: Pal=Palynomorphs, Struc. Phyto= Structured phytoclast, Degr Phyt= Degraded phytoclast, Opaq. Phyt= Opaque Phytoclast, AOM= Amorphous Organic Matter

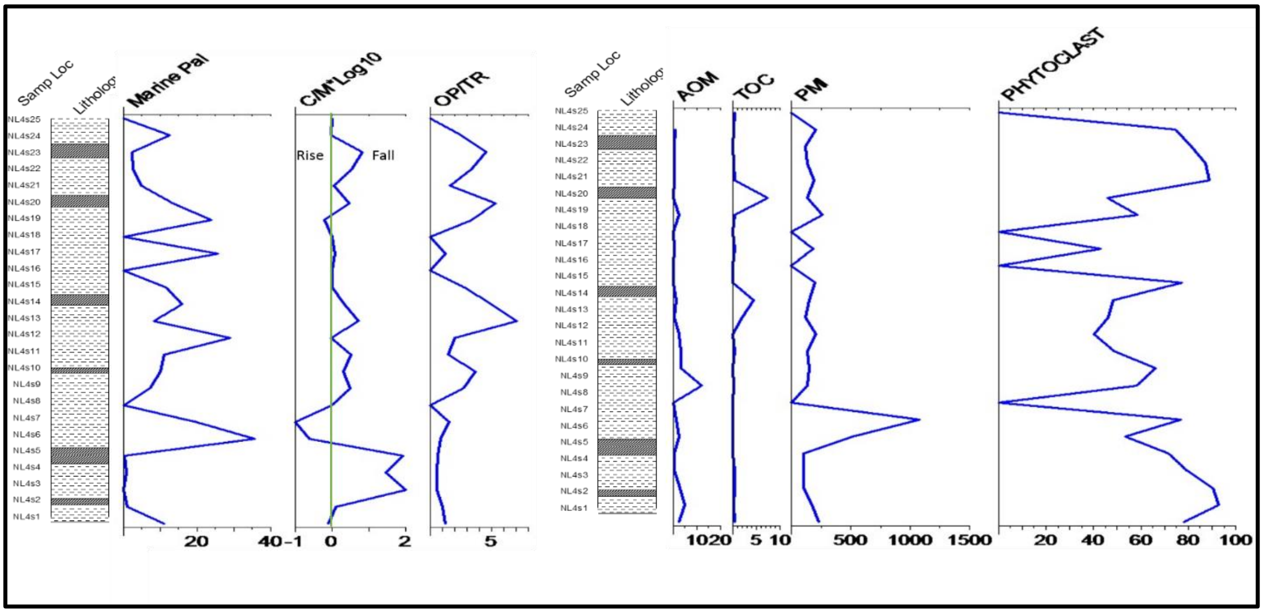

Fig. 4: Relationship between sea level and Palynofacies parameters for Tsintsire section (NL4)

LL 13 section

Sixteen samples were analysed for this section but majority of the samples were barren of particles except for the eight samples that were productive (Table 4). Stuctured translucent phytoclast are the dominant particles, suggesting transport under well oxygenated conditions and the transport distance from the source were not long enough to result in complete degredation and oxidation of the phytoclast fragments. The opaque contribution to the organic matter maybe due to wild fires from nearby continents brought in by run-offs.Fig. 5 shows the relationship between palynofacies and the sea level parameters.

Table 4. Relative Percentage of Palynofacies for Lamja Sama 1 (LL13) section

Sample No	Marine pal	Terrestrial pal	Struc. Phyto	Degr. Phyt	Opaq Phyt	AOM	Total
LL13s1	0.00	16.00	18.00	12.67	53.00	0.33	100.00
LL13s4	0.00	20.67	38.00	12.00	29.00	0.33	100.00
LL13s5	0.00	28.00	25.67	10.00	36.00	0.33	100.00
LL13s6	0.33	21.33	40.00	11.00	23.67	3.67	100.00
LL13s8	2.00	32.67	42.67	8.67	14.00	0.00	100.00
LL13s10	0.00	27.33	31.67	13.67	27.33	0.00	100.00
LL13s13	0.67	18.00	51.33	9.33	20.67	0.00	100.00
LL13s15	5.00	18.67	34.00	11.00	24.33	7.00	100.00

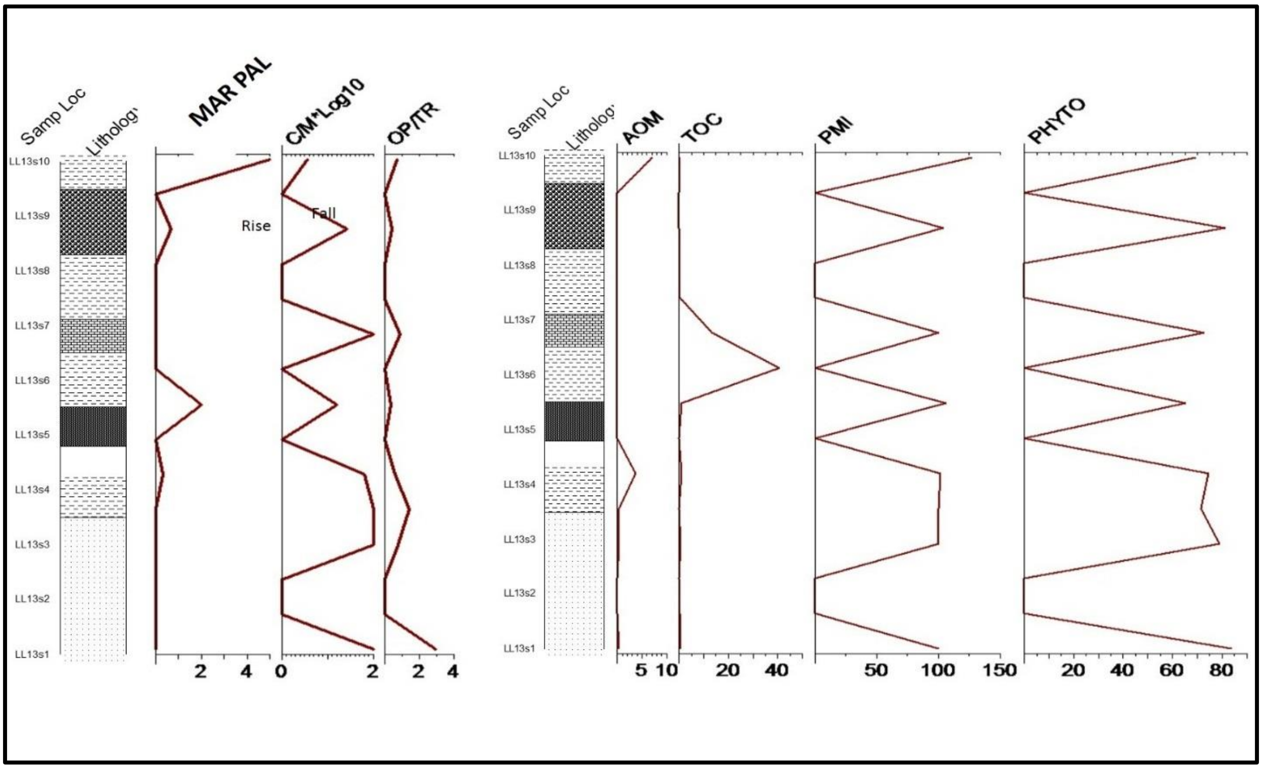

Figure 5: Relationship between sea level and Palynofacies parameters for Lamja section (LL13)

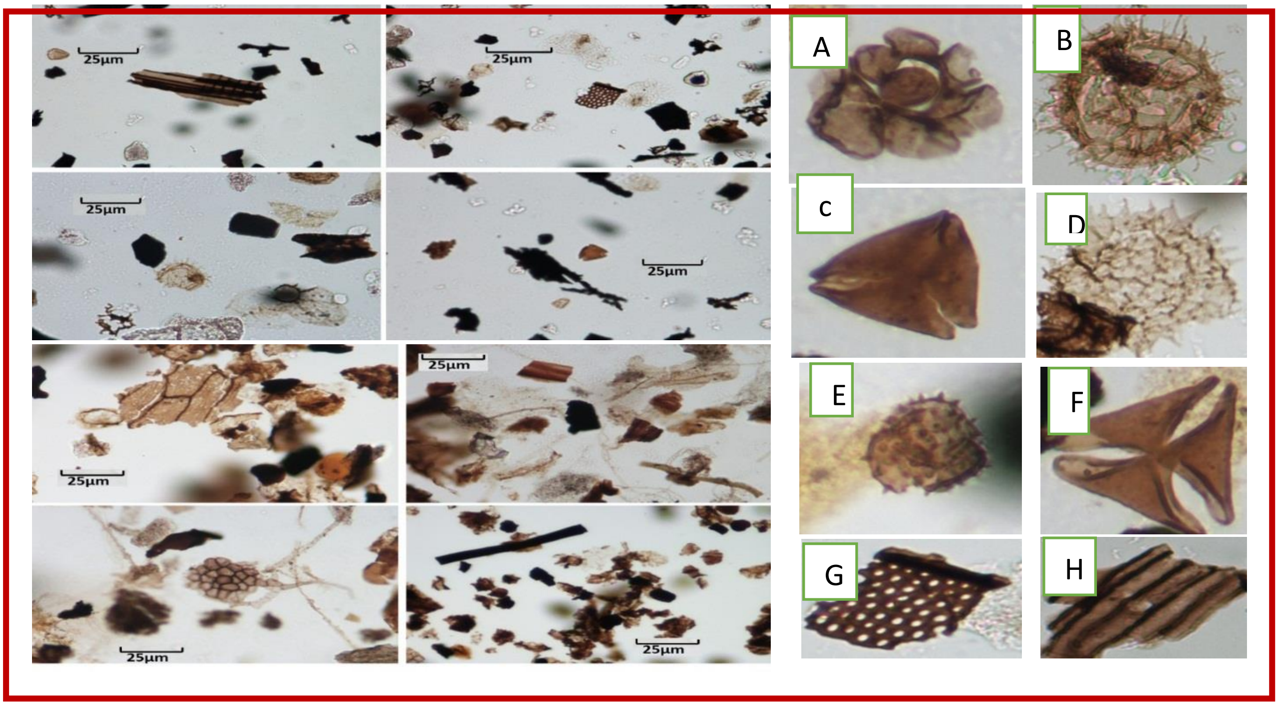

Plate 1: Photomicrograph of palynofacies and some palynomorphs recovered from the samples.
A. Foraminiferal test lining. B. Dinoflagellate cyst (*spiniferites sp.*), C, F.*Dityophilidites harrisii*, D. fresh water (*pediastrum*), E. *Droseridites senonicus*. G. Tracheid particles with visible pitings H. Well preserved wood.

Palynofacies and relative sea level variation

Two palynofacies parameters were calculated to detect eustatic signals in the study area which are: Continental/Marine (CONT/MAR) and Opaque/Translucent (OP/TR) ratios. This is similar to Tyson and Follows (2000) who studied the transportation pathway and relative sea level variation based on palynofacies interpretations as sea level change which control the nature of organic matter, palynomorphs and other fossils incorporated in the sediment (Oboh and Yepes, 1996).)

The characteristic palynofacies patterns displayed a long-term transgressive trend within the Numanha Shale (Figs. 2-4) and a short term regressive trend characterized by the occurrence of parallic coals rich in continental organic matter are within the Lamja Sandstone (Fig. 5). However the Numanha Shale at NL10, NL8, NL4 sections show sea-level variations based on the continental/marine ratios of palynomorphs. The ratio of continental to marine particles expressed to $\log_{10}$ at the Kurnyi (NL10) section shows variable increases representing sea-level fall; and occasional decreases representing sea-level rise. The sea-level rise horizons corresponds with high values of marine palynomorphs (Fig. 2). The abundant marine palynomorphs are foraminifera test linings and dinoflagellates cysts mostly *Spiniferites* (plate 1*)*. Abundances of these species indicates a well-oxygenated open marine neritic environment (Marshall and Batten, 1988; Li and Habib, 1996). The opaque/translucent (OP/TR) ratio at Kurnyi section remained at relatively low values except for sample numbers NL10s7 and NL10s10 where values increased to 20 and 15 respectively. Low amounts of opaques suggest low salinity due to close proximity to active fluvio-deltaic sources (Kholeif and Ibrahim, 2010). Generally, the ratio of opaque to translucent phytoclast increases basin-ward due to fractionation processes and the higher preservation potential of opaque particles (Tyson, 1993; Pittet and Gorin, 1997; Bombardiere and Gorin, 1998). The palynological marine index (PMI) indicates marine condition for the Kurnyi section (Fig. 2).

The Gundenyi (NL8 section) is characterized by sea-level variations based on the continental/marine ratio. There is a fluctuation of the motif as seen on Figure 3, but there was a general sea-level rise stratigraphically except for sample NL8s17. The opaque/translucent particles also maintained low values indicating a reduction in salinity. The PMI indicated a marine condition with values generally above 200. Samples NL8s2, NL8s5 and NL8s15 however were barren (Table 2).

The continental/marine ratio indicated sea-level fall for the Tsintsire (NL4) section except for samples NL4s5 and NL4s6 where there was marked increase in sea-level and an increase in the abundance of marine palynomorphs. The overwhelming low sea-level at NL4s2-NL4s4 was supported by the low abundance of marine palynomorphs and opaque particles. The PMI however remained marine with appreciable increase of marine influence (Fig. 4).

The Lamja section (LL13) representing the Lamja Sandstone is characterized by high continental/marine ratio indicating sea-level fall during the deposition of the sediments (Fig. 5). High values for translucent particles is characteristic of marine regression and indicates fresh- water influx. This is supported by the presence of the fresh water algae *Paediastrum* that are abundant in the samples. The PMI also supports fresh water influence with values below 100, the minimum value for marine waters.

The composite sedimentary cycle in Figs. 6 and 7 show the sea-level variations for the two formations (Numanha and Lamja) and the correlation with PMI values of the formations. The repeated sea-level rise and fall are due to local tectonic forces within the third-order cyclicity.

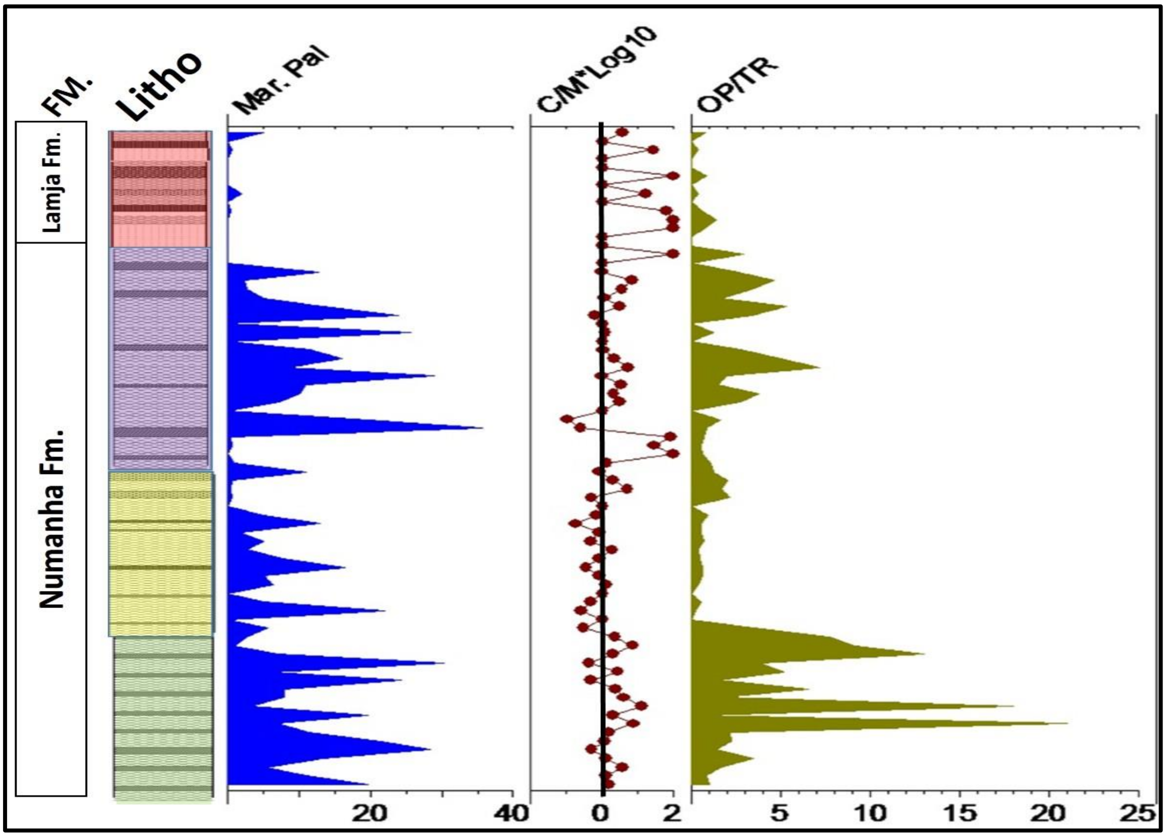

Figure 6: Composite relationship between sea level and Palynofacies parameters for the Upper Cretaceous in the Yola Basin (Numanha Shale and Lamja Sandstones)

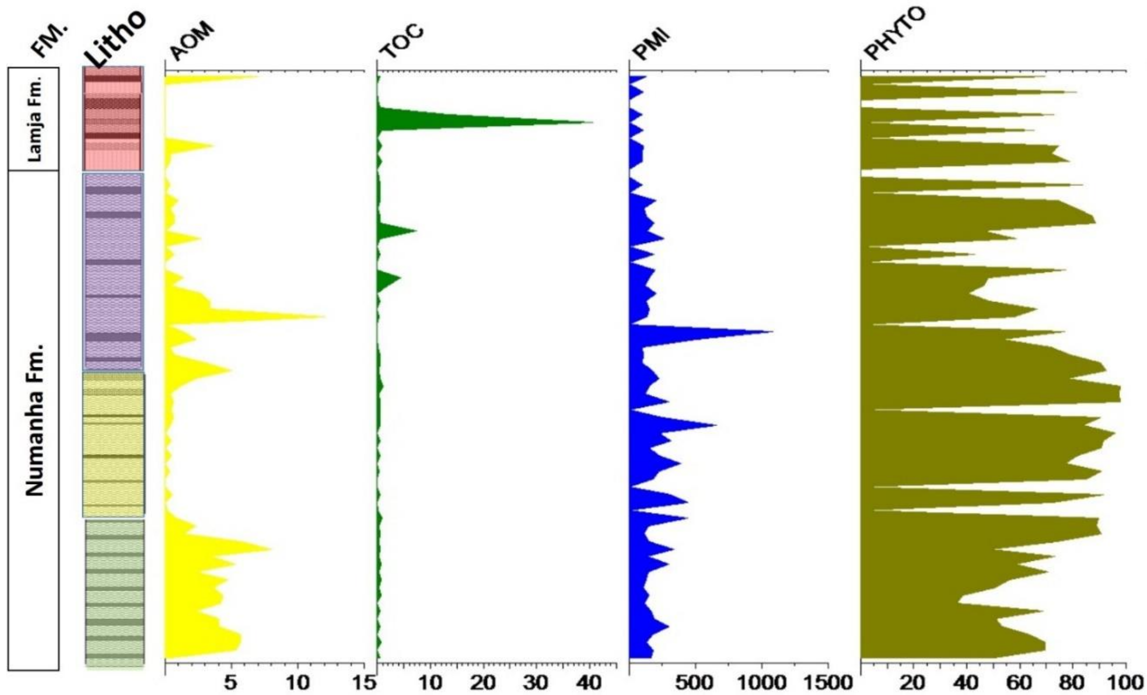

Figure 7: Composite relationship between sea level and Palynofacies parameters for the Upper Cretaceous in the Yola Basin (Numanha Shale and Lamja Sandstones)

CONCLUSION

This work focused on the study of palynofacies in the Upper Cretaceous sediments in the Yola Basin and the following attributes emanated from the study:

I. The phytoclast group predominates the other organic matter groups. This condition is usually related to shallow water depositional conditions resulting from short distances over which the particles have been transported.

II. Evaluation of the palynofacies (Continental/marine ratio and the opaque/translucent ratios)have confirmed repeated sea level fluctuations. The sea level rise positively correlated with the marine palynomorp abundance (foraminferal test linig and dinoflagellate cyst).

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