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Research Article

PALYNOFACIES ANALYSIS, ORGANIC THERMAL MATURATION AND KEROGEN TYPE OF UPPER CREATACEOUS-PALEOCENE ROCKS IN AUCHI SHEET 266, BENIN FLANK, WESTERN EXTENSION OF THE ANAMBRA BASIN, SOUTHWESTERN NIGERIA

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Abstract

Thirty four (34) samples collected from Outcrops and ditch- cutting from Borehole in Benin Flank, Western Extension of the Anambra Basin, South-western Nigeria were investigated to deduce the kerogen type and maturity stage. Twenty Four (24) outcrop and Ten (10) ditch- cutting samples were subjected to palynofacies analysis. Palynofacies were analyzed to determine the kerogen type and maturity stage of Mamu and Nsukka Formation. The result from the palynofacies analysis reveals the presence of miospores (pollen and spores), woody plant materials (black wood and phytoclast), amorphous organic matter, which were used to characterize the samples of its kerogen type and maturity. The borehole well samples was divided into three palynofacies zones which are palynofacies zones A,B and C ,based on cluster analysis of the palynomacerals while The outcrop samples were subdivided into two (2) palynofacies zones A and B based on cluster analysis of the palynomacerals. The Ternary plot of AOM- Phytoclasts- Palynomorphs indicated predominantly type III kerogen with perhaps limited occurrence of type II kerogen. The spore colour observations indicated that the kerogen of Mamu and Nsukka Formation are immature to early mature but may generate gas on maturity.

Keywords: Palynofacies, Thermal maturation, Kerogen, Mamu Formation and Nsukka Formation..

INTRODUCTION

Once there is a depression as a result of tectonic activity, a basin is created and thus sedimentation starts in such a basin. The Anambra Basin is a Cretaceous/ Tertiary basin which is a structural link between the Benue Trough and the Niger- Delta Basin. The evolution of the Benin flank in South Western Nigeria is known to have started with a series of tectonic activities which accompanied the initial opening of the South-American and African plates in late Jurassic to Cretaceous time; (Burke *et al.,* 1972). These events created the interior fracture basin of the Benin flank and part of the Benue Trough Complex and the Benin Basin. The later Santonian-Campanian tectonics which produced the Abakaliki Anticlinorium and the other fold sequence along the Benue Trough Complex also produced the Synclinal basins of the Anambra and Afikpo Syncline. The Niger Delta Basin developed as the Benue Trough feed out sediments, just filling the Anambra Basin and led to the outward growth of the delta; (Burke *et al.,* 1972; Nwajide, 2013). Field mapping involves the study of 56 outcrops in Auchi Topographic Sheet (266), across Benin Flank in the neighborhood of Edo State. Outcrops where available, remain the best and most direct source of information on the rock record, having played a good role in building the primary data set which largely helped in understanding and establishing a stratigraphic architecture in various depositional settings in the flank. Field investigation was used to carry out a detailed field mapping with emphasis on Lithofacies and Palynofacies distribution and their palaeoenvironmental significance. Palynofacies represents a geological interpretation of sedimentary dispersed organic material which together with lithofacies studies can provide the key to identification of depositional environments.

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Each lithofacies has individual physical characteristics such as grain size, structure and mineral assemblage, sorting variations, which are largely dependent upon depositional processes such as energy conditions and sediment supply source. Lithofacies alone cannot be used solely to reconstruct precise paleoenvironments, but a palynofacies approach in conjunction with sedimentologic analyses can enable accurate paleoenvironmental appraisal as seen in works by Lucas *et al.* 2021. This work was carried out with the aim of giving a detailed documentation of palynofacies constituents of the formational units exposed on the Benin Flank. It involved sampling of outcrops and subsurface formations from a number of boreholes drilled within the flank.

Location of the Study Area

The study area is geographically located in the Southwestern Nigeria, and defined by Latitudes 07^0 $00^!$ N and 07^0 $15^!$ N and Longitudes 006^0 $00^!$ E and 006^0 $30^!$ E, which constitutes part of the Auchi Sheet 266 (1:100,000). It covers an area of about 2,400km^2. Major access roads into the area include Auchi – Fugar Road, Auchi- Igarra Road, Ayogwiri- Apana Road, Iyora- Uzaire Road, Apana- Iyora Road, Auchi Ukpilla Road, Ugbekpe- Ekperi Road, Ogbonna- Okpekpe Road, Auchi-Ohame Road, as well as Ogbonna- Imiegba Road. The major towns are Auchi, Fugar, Jattu, Imiegba, and Okpekpe; (Fig 1.)

The Stratigraphic Fill of the Anambra Basin

Sedimentation within the Anambra Basin consists of deltaic complexes (2500m thick) ranging from Late Cretaceous to Late Eocene in age. Two major transgressions occurred within the basin resulting in the Nkporo depositional cycle during the Late Campanian to Early Maastrichtian, and the Nsukka depositional cycle during the Late Maastrichtian to Late Paleocene, (Reijers *et al.,* 1997).

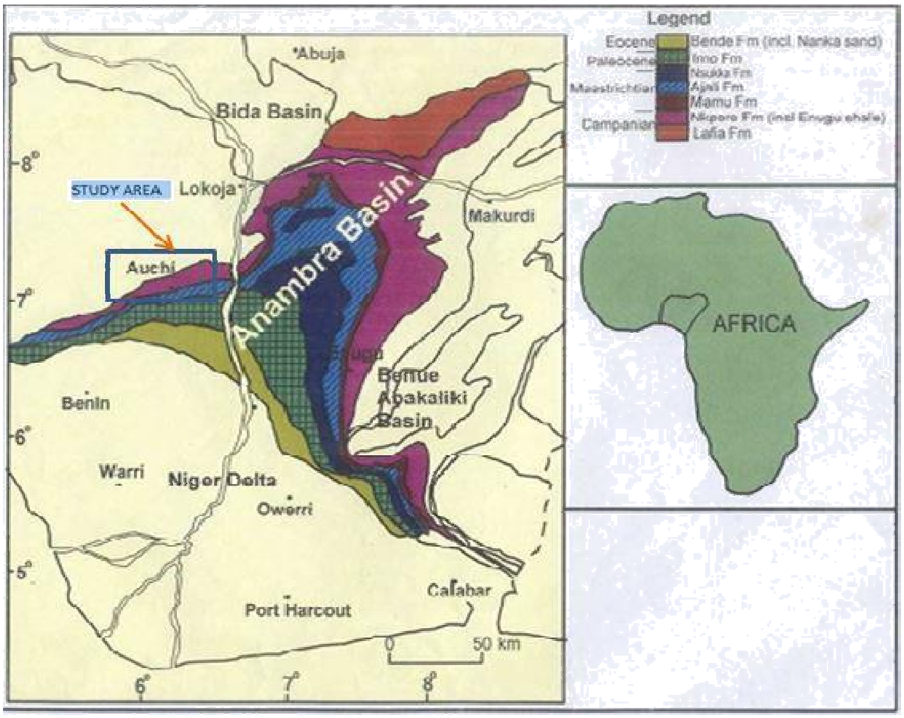

Fig .1. Map of Anambra Basin showing the location of the study area. (Drawn from the Geological Map of Nigeria, GSN 1994)

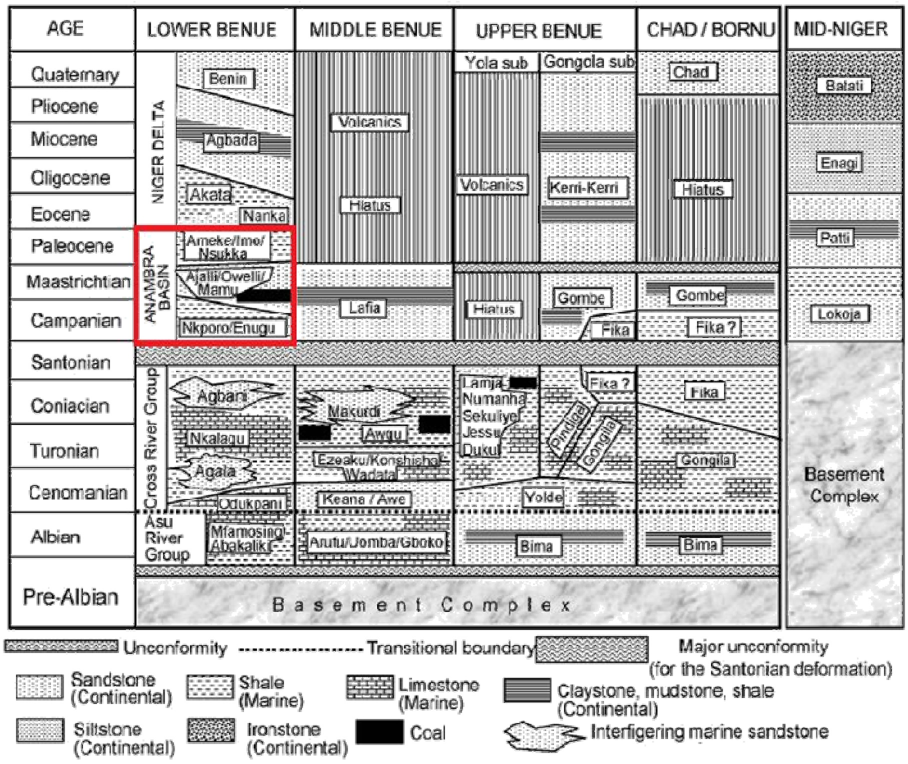

Fig .2. Stratigraphy of the Anambra basin in relation to the Benue Trough complex (Adapted from Obaje *et.al.* 2006)

The formations that make up the Nkporo cycle are the Agbani, Owelli, Mamu and Ajali Formations. The Ajali Formation marks the height of the regression before the beginning of the Nsukka depositional Cycle. The Enugu Shale and Nkporo Shale sequences represent brackish marsh and fossiliferous prodeltaic facies, respectively. The Nsukka Formation marks the beginning of the Nsukka cycle, and is interpreted to be a fluvio-deltaic phase of deposition. This cycle ended with the deposition of the Imo Shale, which is interpreted to be shallow marine shelf sediments. The deposition of the Ameki Group and its laterally equivalent Nanka Formation represents the start of the Eocene regression.

The shape, closeness of sediment source areas, transgression and regression cycles, and paleo-circulation patterns are all factors that had major impact on the depositional patterns in the Anambra Basin (Reijers *et al.,* 1997).

MATERIALS AND METHOD

This study was carried out in two(2) phases as follows:

- Field investigation
- Laboratory analysis

Table 1. Lithostratigraphic framework for the Early Cretaceous-Tertiary period in Southeastern Nigeria (after Nwajide, 1990)

m.y	AGE	ABAKALIKI – ANAMBRA BASIN	AFIKPO BASIN
30	Oligocene	Ogwashi-Asaba Formation	Ogwashi-Asaba Formation
54.9	Eocene	Ameki/Nanka Formation/ Nsugbe Sandstone (Ameki Group)	Ameki Formation
65	Palaeocene	Imo Formation Nsukka Formation	Imo Formation Nsukka Formation
73	Maastrichtian	Ajali Formation Mamu Formation	Ajali Formation Mamu Formation
	Campanian	Npkoro Oweli Formation/Enugu Shale	Nkporo Shale/ Afikpo Sandstone
83 87.5	Santonian		Non-deposition/erosion
88.5	Coniacian	Agbani Sandstone/Awgu Shale	
	Turonian	Eze Aku Group	Eze Aku Group (incl. Amasiri Sandstone)
93 100	Cenomanian – Albian	Asu River Group	Asu River Group
119	Aptian Barremian Hauterivian	Unnamed Units	
	Precambrian	Basement Complex	

Field Investigation

This involves field mapping and lithologic logging of outcrop sections to provide data for lithofacies studies and palynofacies studies which will aid in identifying the kerogen types and source rock maturity. Outcrops were studied lithologically with their attributes and characteristics recorded with representative samples taken in places. Selected ditch cutting samples collected from the Out crop were utilized for palynofacies slide preparation.

Palynofacies Sample Preparation

The sample preparation was carried out following the international standards given below: 10g of sample was crushed between aluminum pie dishes, collected and tested for limestone (CaC03) using HCl, while effervescence occurred, the limestone was eliminated by further addition treatment with concentrated HCl. After two or three hours, the sample was decanted and the waste solution transferred to one special waste container bottle. The broken down mineral material and fossils were removed and centrifuged for about 1-2 minutes and decanted repeatedly until a neutral reaction was reached. Concentrated HNO3 was used for oxidization and heated over bunsen burner. KOH of 10% solution was added to the sample and transferred to styrofoam cups and HF added and let to stand overnight. The sample was then washed with water until a neutral reaction was reached and decanted. Sodium hypochlorite (Purex) as well as some drops of HCl was added, agitated and let for about 15 minutes. Two drops of Ammonium Hydroxide concentrate was added and diluted with water. At this stage, separation of the organic matter from the inorganic material (silica) was done by floatation using diluted zinc bromide (ZnBr). The residues were sieved through a 10-µ mesh and washed using ultrasonic cleaning for preparing slides. Polyvinyl Alcohol (PVA) was used as a mounting medium. For discriminating among the different palynofacies characteristics, particulate organic matter and palynomorph particles were counted and used to calculate relative abundances. The slides were analyzed under the microscope for palynofacies content.

RESULTS AND DISCUSSION

Lithofacies Distribution

A lithostratigraphic map identifying the various formations in the study area, their sedimentary structures as well as roads and rivers linking the area was established.

Palynofacies Description and Distribution

The palynofacies constituents identified from 34 samples analyzed have been classified according to Oyede, (1992). Palynological constituents recognizable are sporomorphs, marine palynomorphs, palynomaceral 1,2,3,4 and structureless organic matter (SOM).

- **Sporomorphs** constitutes the allochthonous fraction and they include pollen and spores
- **Marine palynomorphs** reprents the autochthonous fraction and they include dinoflagellate cysts and foraminiferal test- linings.
- **Palynomaceral 1** usually orange- brown or dark brown more or less structureless material. It is of heterogenic origin and may include palnt debris (mainly resinous cortex material), humic gel- like substances and resinous substances. It is mainly of higher plant origin.
- **Palynomaceral 2** brown- orange structured material of irregular shape. It may include structured plant material such as leaf, stem, or small rootlet debris, algal detritus. Its buoyancy is considered higher relative to palynomaceral 1 because of its thinner often lath- shaped character.
- **Palynomaceral 3** is pale, relatively thin irregularly shaped, usually structured material occasionally bearing stomata. It includes structured plant material mainly of cuticularorigin and degraded aqueous plant material. It is considered the most buoyant of palynomacerals 1-3.
- **Palynomaceral 4** is black or almost black equidimensional blade or needle shaped material, which is usually uniformly opaque and structureless. The constituents are of many different origins and include compressed humic gels, charcoal resulting from forest fires, blade shaped palynomaceral 4 can be extremely buoyant, and often transported over long distances. It is usually concentrated in high energy environments.
- **Structureless organic matter (SOM)** is characterized by essentially structure less material bearing a granular appearance. SOM is preserved mainly where conditions are anoxic or disaerobic.

Palynomaceral 1, 4 and SOM are not structured and have been classified under the amorphous debris, while palynomacerals 2 and 3 are structured and have been classified under the phytoclasts.

Palynofacies Zones of Borehole Samples

The well was divided into three palynofacies zones based on cluster analysis of the palynomacerals.

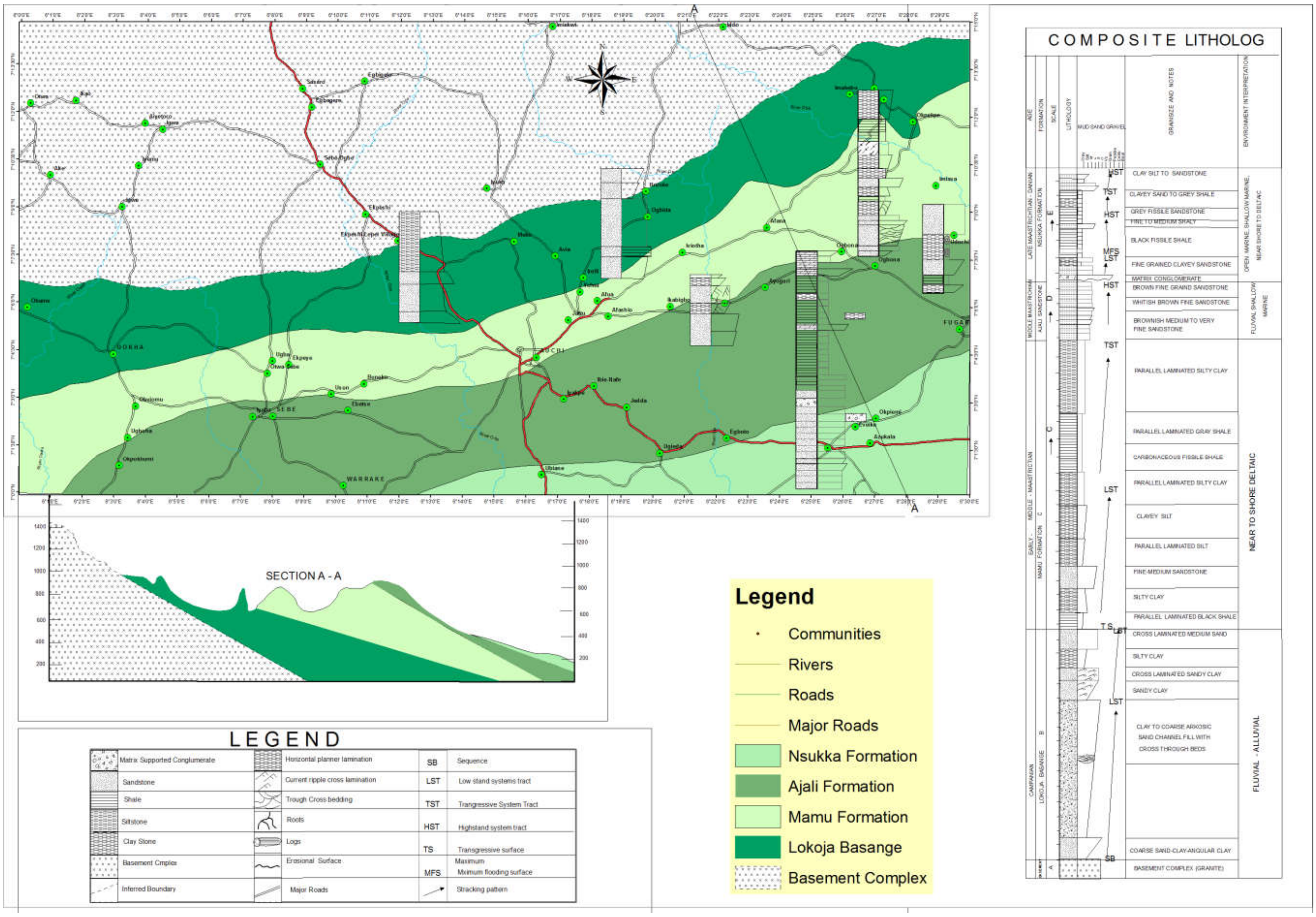

Fig. 3. Lithostratigraphic Map of Auchi Sheet 226 (ONYEACHONAM .N and FREGENE T.J present study)

- **Palynofacies Zone A:** This zone is the oldest of the analyzed section (82-92m below sea level) and the distribution of organic matter is shown in table 2 below:

Table 2. Classification of the Palynomacerals of zone A

Depth (m)	Palynomaceral 1 (P1)	Palynomaceral 2 (P2)	Palynomaceral 3 (P3)	Palynomaceral 4 (P4)	Pytoclasts (P2+P3)	Amophous Organic Matter (P1+P4)	Pollen	Spores	Dinoflagellate Cyst	Total Palynomorph
82-92	12	14	70	4	84	16	13	13	83	109

- **Palynofacies Zone B:** Palynofacies zone B extends from 2- 72m below sea level and 0-58m above sea level. Table 5.9 shows the distribution of the analyzed particulate organic matter.

Table 3. Classification of palynomacerals of Zone B

Depth (m)	Palynomaceral 1 (P1)	Palynomaceral 2 (P2)	Palynomaceral 3 (P3)	Palynomaceral 4 (P4)	Pytoclasts (P2+P3)	Amophous Organic Matter (P1+P4)	Pollen	Spores	Dinoflagellate Cyst	Total Palynomorph
48-58	16	23	34	27	57	43	6	2	5	13
18-28	21	18	16	45	34	66	7	7	10	24
8-18.	56	18	13	13	31	69	6	2	5	13
2-12.	33	39	16	12	55	45	7	7	10	24
22-32	36	30	20	14	50	50	18	24	3	45
32-42	53	25	8	12	33	65	29	27	24	80
52-62	21	42	23	14	65	35	15	23	1	39
62-72	41	38	17	4	55	45	14	7	2	23

Table 4. Classification of Palynomacerals of Zone C

Depth (m)	Palynomaceral 1 (P1)	Palynomaceral 2 (P2)	Palynomaceral 3 (P3)	Palynomaceral 4 (P4)	Pytoclasts (P2+P3)	Amophous Organic Matter (P1+P4)	Pollen	Spores	Dinoflagellate Cyst	Total Palynomorph
58-68	50	21	17	12	38	62	73	27	2	102

Palynofacies Distribution of Outcrop Studies

The outcrop samples are subdivided into 2 palynofacies zones based on cluster analysis of the palynomacerals.

- **Palynofacies Zone A:** The distributions of the particulate organic matter are shown in table 5.below:

Table 5. Distribution of the various Palynomacerals in the outcrop studies

Sample No.	Palynomaceral 1 (P1)	Palynomaceral 2 (P2)	Palynomaceral 3 (P3)	Palynomaceral 4 (P4)	Pytoclasts (P2+P3)	Amophous Organic Matter (P1+P4)	Pollen	Spores	Dinoflagellate Cyst	Total Palynomorph
L7E3	17	88	84	9	172	26	56	17	1	74
L7E5	55	18	11	15	29	70	4	4	0	8
L7H2	80	100	5	15	105	95	56	11	3	70
L7F5	77	88	11	24	99	101	24	13	0	37
Shales 25cm	83	35	70	10	105	93	9	2	0	11
Gwoligwo 85cm	70	28	12	90	40	160	5	0	2	7
Lokoja Clay	75	27	8	90	35	165	0	1	0	1
Ajali Idah	100	34	10	56	44	156	3	1	0	4
Ferrugized	78	45	15	62	60	140	37	6	1	44
Okpatse 263cm	24	6	60	110	66	134	23	3	1	27
Burrow Pit Shale	22	57	11	110	68	132	25	30	0	55

- **Palynofacies Zone B:** The distribution of the particulate organic matter are shown In table 5.12 below:

Table 6. Distribution of the various Palynomacerals in the outcrop studies

Sample No.	Palynomaceral 1 (P1)	Palynomaceral 2 (P2)	Palynomaceral 3 (P3)	Palynomaceral 4 (P4)	Pytoclasts (P2+P3)	Amophous Organic Matter (P1+P4)	Pollen	Spores	Dinoflagellate Cyst	Total Palynomorph
L6D1	47	16	5	13	21	60	116	92	1	209
L3C	174	26	38	26	64	200	117	87	1	205
L7F1	59	94	34	35	128	94	71	76	0	147
Coaly Shale	82	71	36	11	107	93	103	42	0	145
Shales 45cm	46	49	13	92	82	138	160	65	3	228
Ripple Shale	34	55	11	100	66	134	104	60	0	164
Shales 35cm	37	65	11	87	76	124	70	37	1	108
Shales 93cm	16	39	70	75	109	91	101	29	2	132
Silty Clay	46	14	60	80	74	126	295	57	5	357

PLATE 1

Palynofacies Zone A (82-92m bsl)

A. - Amorphous organic matter = 8%
B. - Phytoclasts = 40%
C. - Miospores =12%
D. – Dinocysts =40%

1. Dinocysts and Amorphous Organic Materials
2. Dinocysts and Amorphous Organic Materials
3. Amorphous Organic Materials and Phytoclsts
4. Miospores and Phytoclasts
5. Spore colour index = 4.8

PLATE 2

Palynofacies Zone B (2-72m bsl, 0-58m asl)

A. - Amorphous organic matter = 37%
B. - Phytoclasts = 39%
C. - Miospores =18%
D. – Dinocysts =6%

1. Dinocysts and Phytoclasts
2. Miospores, Amorphous Organic Materials and Phytoclasts
3. Amorphous Organic Materials and Phytoclsts
4. Miospores
5. Spore colour index = 4.5- 5.5

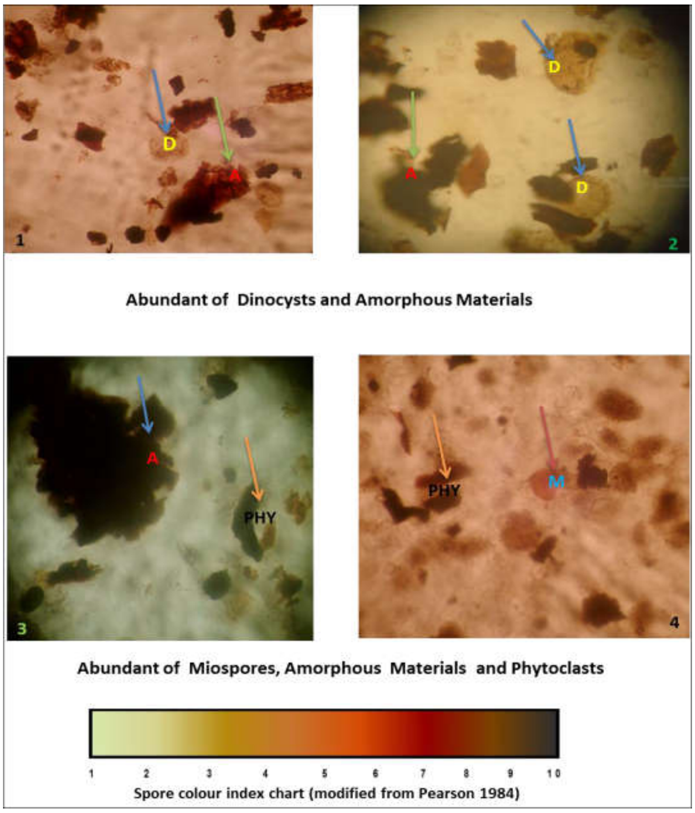

PLATE 1

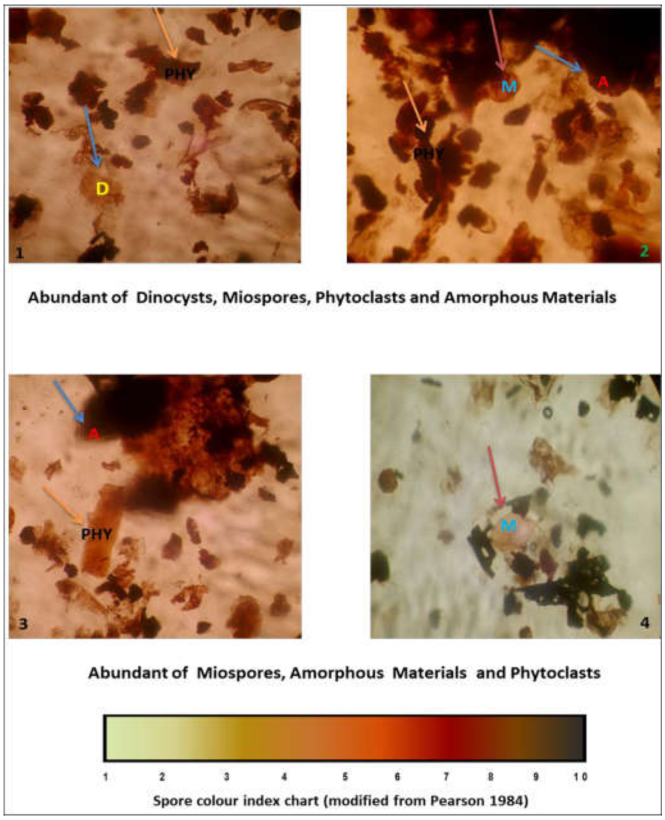

PLATE 2

PLATE 3

Palynofacies Zone C (58-68m asl)

A. - Amorphous organic matter = 31%
B. - Phytoclasts = 19%
C. - Miospores =49%
D. – Dinocysts =1%

1. Miospores and Phytoclasts
2. Miospores, and Amorphous Organic Materials
3. Miospores
4. Phytoclasts
5. Spore colour index = 5.3

PLATE 4

Palynofacies Zone A (Outcrop)

A. - Amorphous organic matter = 54%
B. - Phytoclasts = 33%
C. - Miospores =12%
D. – Dinocysts =1%

1. Miospores and Amorphous Organic Materials
2. Dinocysts and Amorphous Organic Materials
3. Miospores and Amorphous Organic Materials
4. Phytoclasts
5. Spore colour index = 4.5

PLATE 5

Palynofacies Zone B (Outcrop)

A. - Amorphous organic matter = 30%
B. - Phytoclasts = 23%
C. - Miospores =46%
D. – Dinocysts =1%

1. Phytoclasts
2. Dinocysts and Miospores
3. Amorphous Organic Materials and Phytoclasts
4. Phytoclasts
5. Spore colour index = 5.5

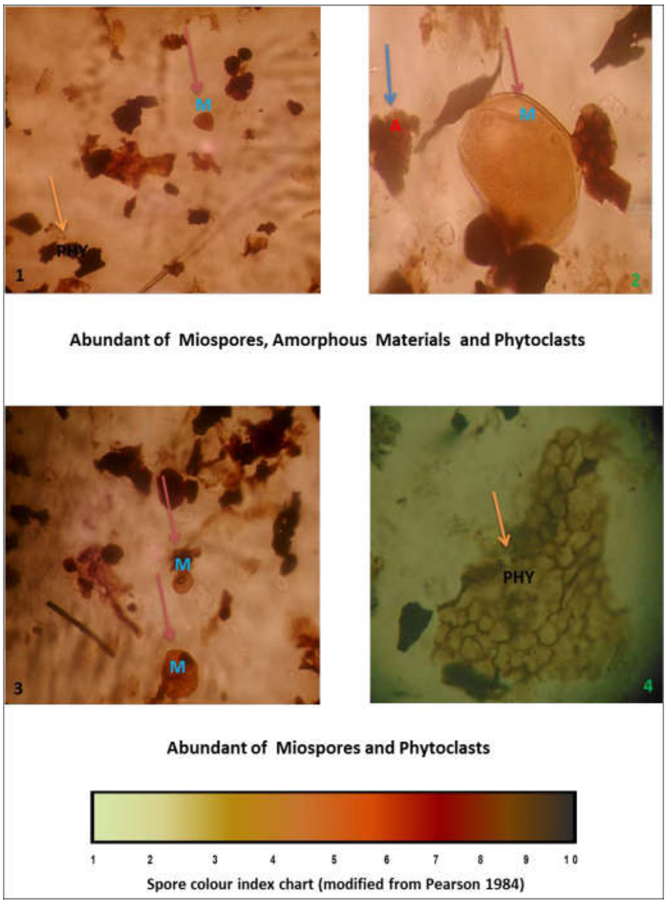

PLATE 3

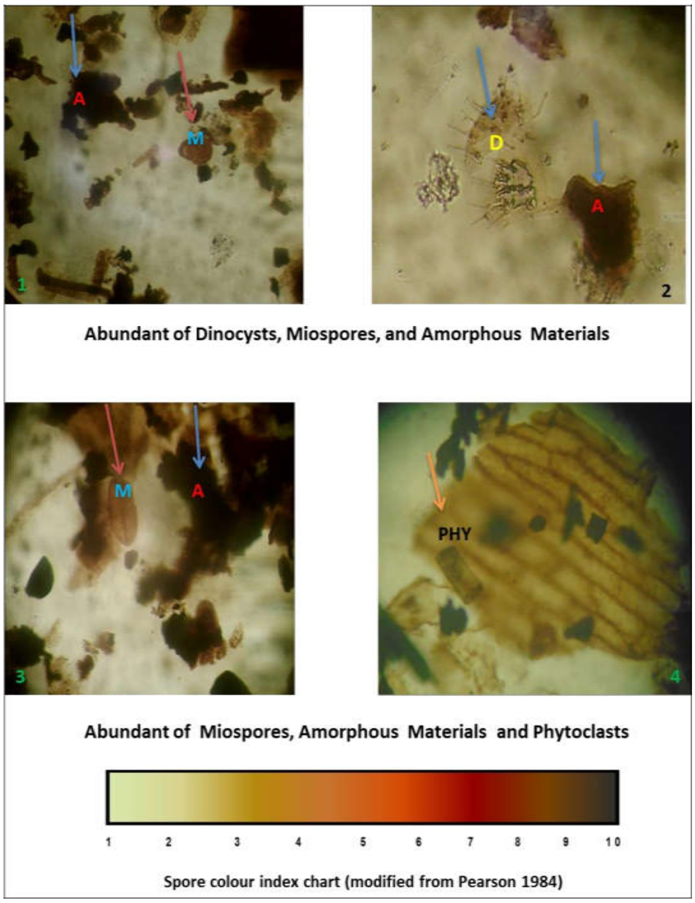

PLATE 4

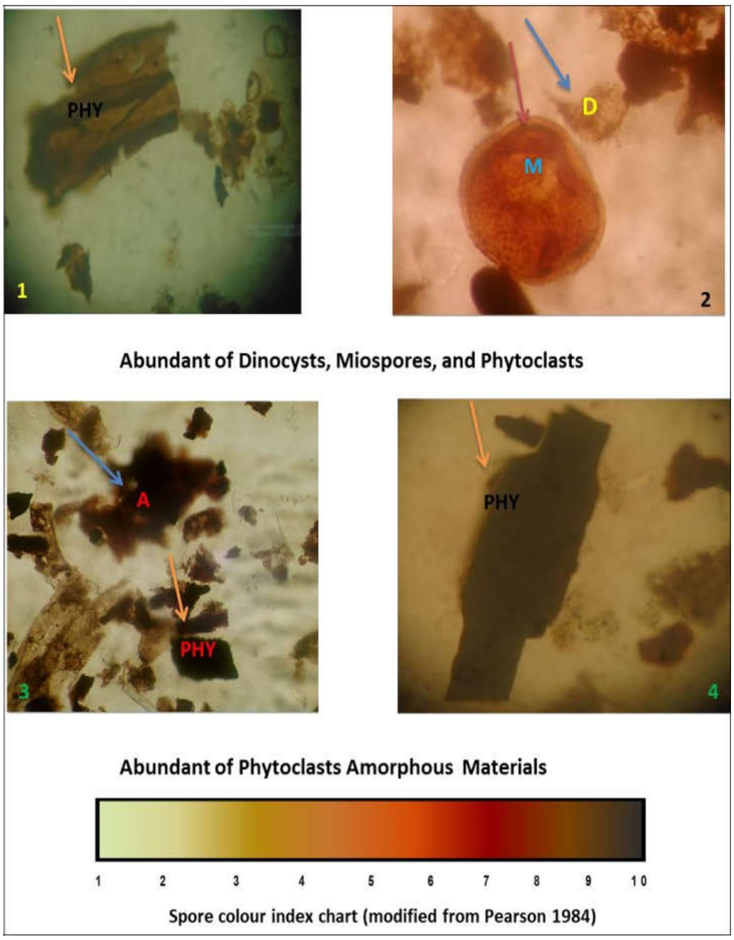

PLATE 5

Palynofacies and Kerogen types

The cluster analysis of the particulate organic matter (POM) revealed three cluster for the Nsukka Formation (ditch cuttings), and two cluster for the Mamu Formation (outcrop samples). This is represented in (Fig. 4 and 6) and is described as follows:

Nsukka Formation

Palynofacies cluster A: It is characterized by moderate abundant of phytoclast (40.1%), low abundances of Amorphous organic matter and miospores (7.6%, 12.3%) respectively, and high abundant of dinocyst (40%). The sample of this cluster is plotted in field III of Tyson Ternary Diagram, Fig 6.8. The Kerogen is expected to be gas prone type 3. The colour index value of 5.3 suggests that it is immature to generate hydrocarbon (plate 1).

Palynofacies cluster B: It is characterized by moderate abundances of phytoclasts (18.5%- 50.4%), moderate abundances of Amorphous Organic Matter (25.2%- 61.1%), low abundances of Miospores (7.1%- 31.5%), and very low abundances of Dinocysts (0.7%- 13.5%). A part of the Amorphous Organic Matter is dark brown and sharp edged and is considered as degraded phytoclasts. The samples of this cluster are plotted in fields IV, V, VI, and VII of Tyson Ternary Diagram (Fig 4). The kerogen is expected to be gas prone type 3 and 4. The colour index value between 4.5- 5.5 suggests that it is immature- early mature to generate hydrocarbon (plate 2).

Palynofacies cluster C: It is characterized by low abundant of phytoclasts (18.8%), moderate abundant of Amorphous Organic Matter (30.7%), high abundant of miospores (49.5%), and very low abundant of dinocysts (1%). The sample of this cluster is plotted in field V of Tyson Ternary Diagram (Fig 4). The kerogen of this cluster is Gas prone type 3. The colour index value of 5.3 suggests that it is immature- early mature to generate hydrocarbon (plate 3).

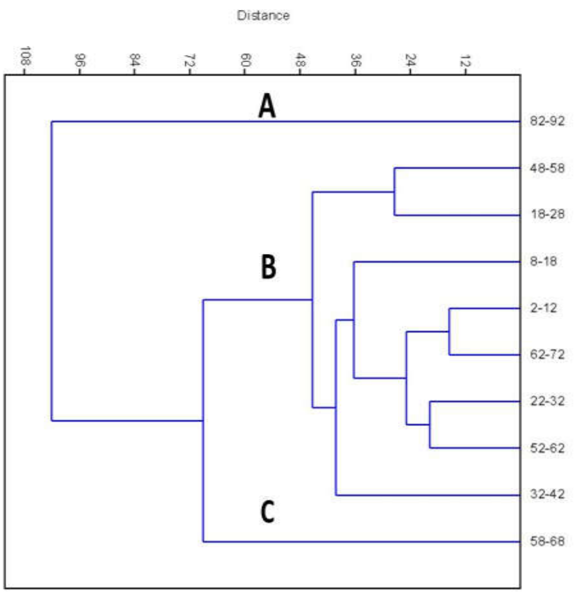

Fig 4. Cluster Analysis of the Studied Palynofacies Categories from Nsukka Formation (After Walid *et al.*, 2013)

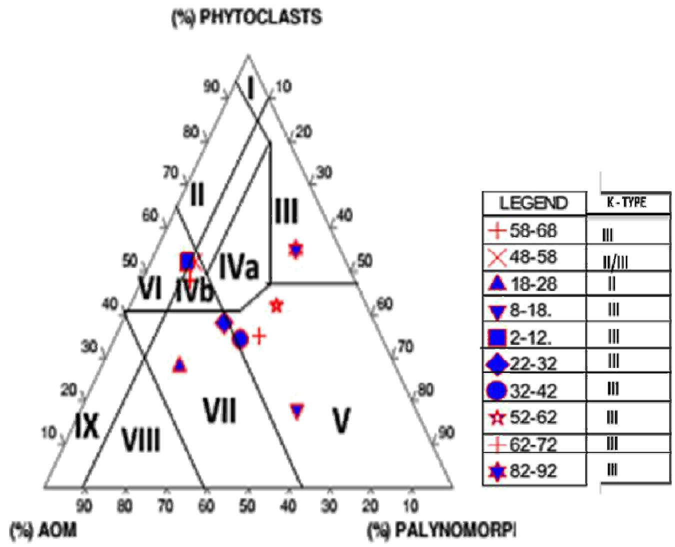

Fig. 5. A Ternary Diagram/Kerogen Plot showing AOM, Phytoclasts and Palynomorphs (after Tyson 1993). Field I= kerogen type 3, Field II= Kerogen type 3, Field III= kerogen type 3or4, Field IV= kerogen type 3or2, Field V= kerogen type 3>4, Field VI= kerogen type 2. Field VII= kerogen type 2, Field VIII= kerogen type 2>1, Field IX= kerogen type 2or1

Mamu Formation

Palynofacies cluster A: It is characterized by moderate abundances of phytoclasts (19.3%- 63.2%), low to high abundances of Amorphous Organic Matter (9.6%- 82.1%), poor occurrences of Miospores (2.0%- 26.8%), and very low occurrences of dinocysts (0%- 0.9%). The samples of this cluster are plotted in fields IV, V, VI and VII of Tyson ternary diagram Fig 6.10. The kerogen is expected to be gas prone type 2 and 3. The colour index value of 4.5 suggests that it is immature- early mature to generate hydrocarbon (plate 4).

Palynofacies cluster B: It is characterized by moderate abundances of phytoclasts (10.6% - 34.7%), moderate abundances of Amorphous Organic Matter (22.6%- 42.6%), high occurrences of miospores (34.7%- 63.2%), and very low occurrences of dinocysts (0%- 0.9%0). The samples of this cluster are plotted in fields III, IV, and V of Tyson ternary diagram Fig 6. The kerogen is expected to be predominantly gas prone type 3. The colour index value of 5.5 suggests that it is immature- early mature to generate hydrocarbon (plate 5).

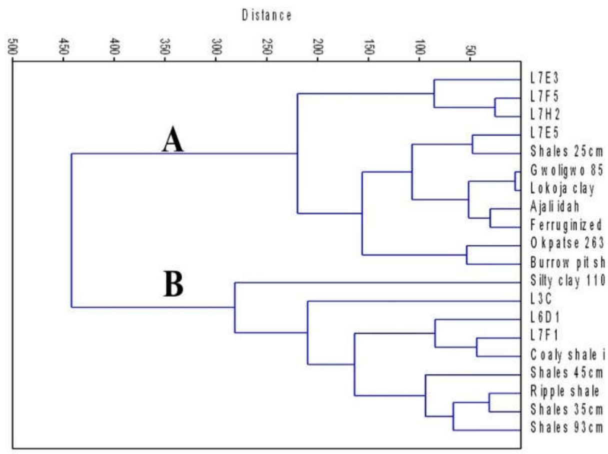

Fig. 6. Cluster Analysis of the Studied Palynofacies Categories from Nsukka Formation (After Walid et al., 2013).

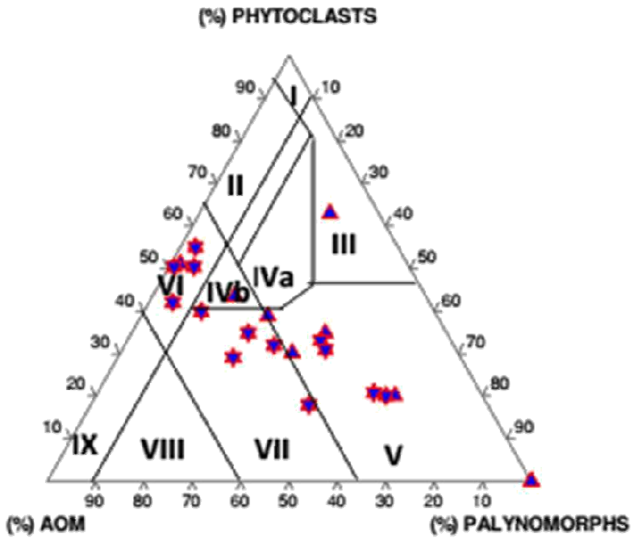

Fig. 7. A Ternary Diagram/Kerogen Plot showing AOM, Phytoclasts and Palynomorphs (after Tyson 1993). Field I= kerogen type 3, Field II= Kerogen type 3, Field III= kerogen type 3or4, Field IV= kerogen type 3or2, Field V= kerogen type 3>4, Field VI= kerogen type 2. Field VII= kerogen type 2, Field VIII= kerogen type 2>1, Field IX= kerogen type 2or1

Hydrocarbon potential of the Basin

Depending on the proportions of the different palynomorphs, the palynofacies analysis is a successful tool to determine the kerogen types, Tyson, (1993). On the other hand, the thermal maturation is indicated from the spore colouration. The fields of Tyson ternary diagrams are indicating the kerogen types (Tyson 1993), (Fig 4 and 6). The outcrop samples from the Mamu Formation are plotted in the fields of (III, IV, V, VI and VII) which indicate gas prone kerogens type 2 and 3. The colours of the miospore grains are immature yellow to yellowish orange which is indicating a thermal alteration index (TAI) of 2 to 2.40 and vitrinite reflectance (R_o%) of 0.40-0.52, Pearson, (1984). The borehole samples from the Nsukka Formation are plotted in the fields of (III, IV, V, and VI) which indicate gas prone type 2 and The colours of the miospore grains are immature, yellow in colour which indicates a thermal alteration index (TAI) range between 2.0- 2.3 and vitrinite reflectance of 0.40%-0.50% Peason, (1984). From the above established fact, the studied sediments contain particulate organic matter (POM) that is still immature to generate hydrocarbon but may generate gas on maturity.

Conclusion

Palynofacies data recovered from the outcrop and borehole samples were integrated to determine the Kerogen type and maturity stage. This present research work has shown: That Mamu and Nsukka Formation indicate predominantly type III kerogen with perhaps limited occurrence of type II kerogen. The shales are immature to early mature but may generate mainly gas on maturity.

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