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Kerogen Characterization, Organic Thermal Maturation and Source Rock Potential of Paleogene Strata in Bende-Umuahia Area, Niger Delta Basin, Southeastern Nigeria

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Abstract

Sediments of Paleogene age in up-dip series of Niger Delta Basin, around Bende-Umuahia axis, where approximately 260 m thick sequences were exposed, have been systematically logged from base to top. This paper aims at evaluating the petroleum source rock potential and organic thermal maturation status of the sediments. Seventeen (17) selected outcrop samples of shale and mudstone were subjected to palynological sample processing using conventional method of acid demineralization for recovering acid-free unoxidized organic residue (kerogen) from sediments. The formations encountered in the study area include, Imo, Ameki, and Ogwashi Formations. Results obtained generally reveal three (3) main palynofacies groups (A, B, and C), based on significant change in the particulate organic matter constituents of the examined kerogen samples. *Palynofacies A* is mainly characterized by abundant Amorphous Organic Matter (AOM) and frequent opaque debris followed by phytoclasts and palynomorph, while *Palynofacies B* constituted mostly of abundant opaque debris and frequent phytoclasts followed by AOM and palynomorph, whereas *Palynofacies C* is dominated by abundant AOM and frequent phytoclasts followed by opaques and palynomorphs. Kerogen type II/III with oil-gas-prone material is suggested for the Imo Formation, having immature thermal maturation status, with spores/ pollen exine color ranging from colourless - pale yellow, while Kerogen type III with gas-prone material is suggested for the Ameki Formation, with immature - slightly mature thermal status, with spores/ pollen exine color ranged from pale yellow – brown. Ogwashi Formation however constituted kerogen type III with gas-prone material, thermally immature with spores/ pollen exine color range of colourless - pale yellow. The kerogen data generated in this work, using transmitted light microscopy, have proven the method as a reliable tool for evaluating petroleum potential in any given sedimentary basins.

Keywords: *Palynofacies; Kerogen; Niger Delta Basin; Paleogene; Spores/Pollen grain.*

1. Introduction

Niger Delta Basin overlies Anambra Basin in the southern parts (Fig. 1), and forms one of the seven sedimentary domains of Nigeria [1-2]. The basin is a Cenozoic gross offlap clastic succession built out atop the Anambra Basin and forms part of the western African miogeocline that spread out onto the cooling and subsiding oceanic crust generated as the African and the South American lithospheric plates separated [3-4].

In recent past, palynological study was meant solely for the study of spores and pollen. It now encompasses investigations on all kinds of microscopic organic particles [5], ranging from palynomorphs with well defined morphology, such as dinoflagellates cysts and chitinozoans, to particles of woods and cuticles, structured and unstructured algal remains, and tissues of uncertain origin which are more difficult to categorize [6]. Palynofacies and kerogen studies in the Niger delta basin have been widely undertaken by workers, most of which were concentrated on the southern down dip section towards the offshore, due to the availability of data from well logs generated through extensive oil drilling activities in the region [6-9].

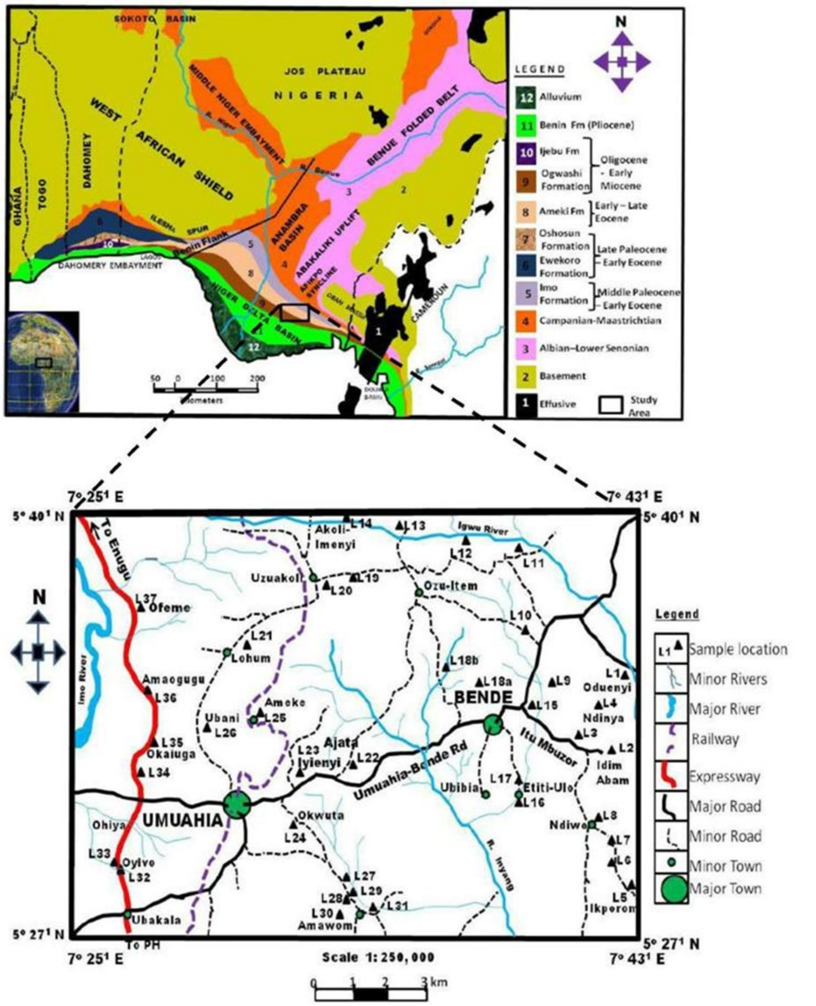


Fig. 1. General geological map of Nigeria showing the Cenozoic succession of the Niger Delta Basin, and location and access route of the study area (modified after [1])

In recent times, due to the government policy to discovering more reserves in frontier regions through increased exploration, the quest for oil and gas has shifted to the inland basins. Works on the outcropping up-dip series in northern parts of the Niger delta basin around, Bende, Oba and Onitsha area, have been carried out [10-16]. These works centered mostly on palynostratigraphy and paleoenvironmental studies. Very few works have been able to demonstrate the usefulness of palynofacies and kerogen studies, and other geochemical methods, in assessing petroleum source rock potential and organic thermal maturation within the inland sector of the basin [4,11,17-18].

Okeke and Umeji [18] studies palynofacies, organic thermal maturation and source rock evaluation of Nanka and Ogwashi Formations exposed at Umunya and Tollgate sections. They remarked that palynofacies constituents of the Nanka and Ogwashi Formations reflect Kerogen

(Type II / III) with Gas/Oil prone, and (Type III) kerogen with Gas prone, respectively, whereas the thermal alteration index and vitrinite reflectance index (% Ro) values of the formations are consistent with each other. Oboh-Ikuenobe *et al.* [11] carried out lithofacies, palynofacies and sequence stratigraphy of the Paleogene strata in southeastern Nigeria, and concluded that the kerogen organic contents of the Imo, Ameki, and Ogwashi Formations are mainly constituted of Type III Gas prone dominated by structured phytoclasts, and with few Type II Oil prone material of marine origin. Nzekwe and Okoro [17] investigated hydrocarbon generating potential of the Ameki Formation in Umuahia, southeastern Nigeria using the organic and trace element geochemistry. They noted that the Ameki Formation contains mainly the inert Type IV kerogen and insignificant gas prone Type III kerogen, with low hydrocarbon generative potential; is immature and was deposited under oxic conditions. Oguanya *et al.* [4] examined source rock geochemistry of the Paleogene strata in Bende-Umuahia and environs, using Walkley black wet oxidation and rock-eval pyrolysis techniques. Their result generally reveals a source rock geochemistry of type IV Kerogen with thermal immature status and fair petroleum potential for the formations. This study, therefore, attempts to present a detailed kerogen characterization to evaluation petroleum source rock potential and organic thermal maturation status of Paleogene up-dip outcropping strata in Bende–Umuahia Area, Niger Delta Basin, southeastern Nigeria, using organic-walled microfossils. Different kerogen and palynofacies classification schemes have been proposed by various researchers [19-23]. These classification schemes were as result of different preparation techniques and scope of study. The scheme employed here includes Tyson [21], Ibrahim *et al.* [23], and Zobaa *et al.* [24] for quick kerogen assessment.

The study area covers approximately 235 km^2 between latitudes of 5°27′N–5°40′N and longitudes of 7°25′E–7°43′E, within the Niger Delta Basin in southeastern Nigeria (Fig. 2). Three Cenozoic formations, including the Imo Formation, the Ameki Formation and the Ogwashi Formation, were encountered in the study area (Figs. 1 and 2).

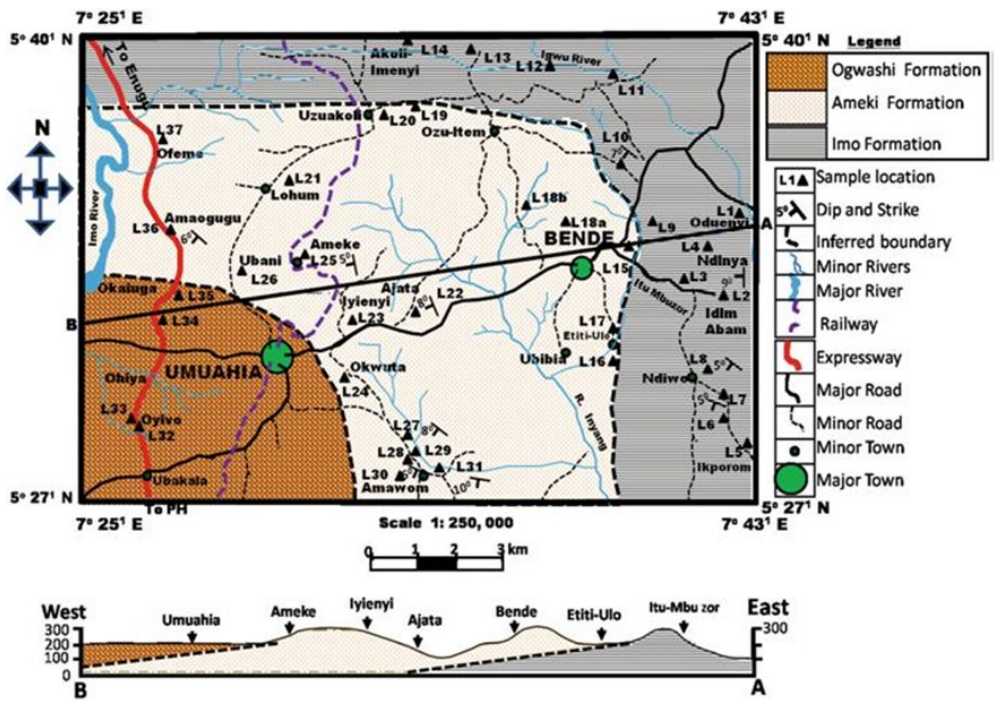


Fig. 2. Geological map of the study area showing location, accessibility and sample locations.

2. Geological setting and stratigraphy

Niger Delta Basin is situated between latitudes of 3°N and 6° N and longitudes of 5°E and 8°E, and occupies the continental margin of the Gulf of Guinea in equatorial West Africa [1] (Fig. 1). It has a total area of about 75,000 km^2, and an entirely clastic sedimentary-fill up to 12,000 m thick. The basin fill was supplied by large continental drainage systems which constructed arcuate and bird-foot deltaic wedges prograde basinward into the oceanic crusts [25]. The Imo, Ameki, and Ogwashi Formations have been found to exhibit similar microfloral assemblages with those in the subsurface Niger Delta [14,16]. These formations form the up-dip series of the Niger Delta Basin and are the lateral equivalents of the down-dip Akata and Agbada Formations (Fig. 3). The Imo Formation forms the basal stratigraphic unit in the inland part of the Niger Delta Basin. It consists of blue-grey clay and black shale, with bands of calcareous sandstone, limestone, and marl [26]. And, the northward lateral variations into sandstone facies (members) occur in some places such as Ebenebe, Umuna, and Igbabu [26] (Fig. 3).

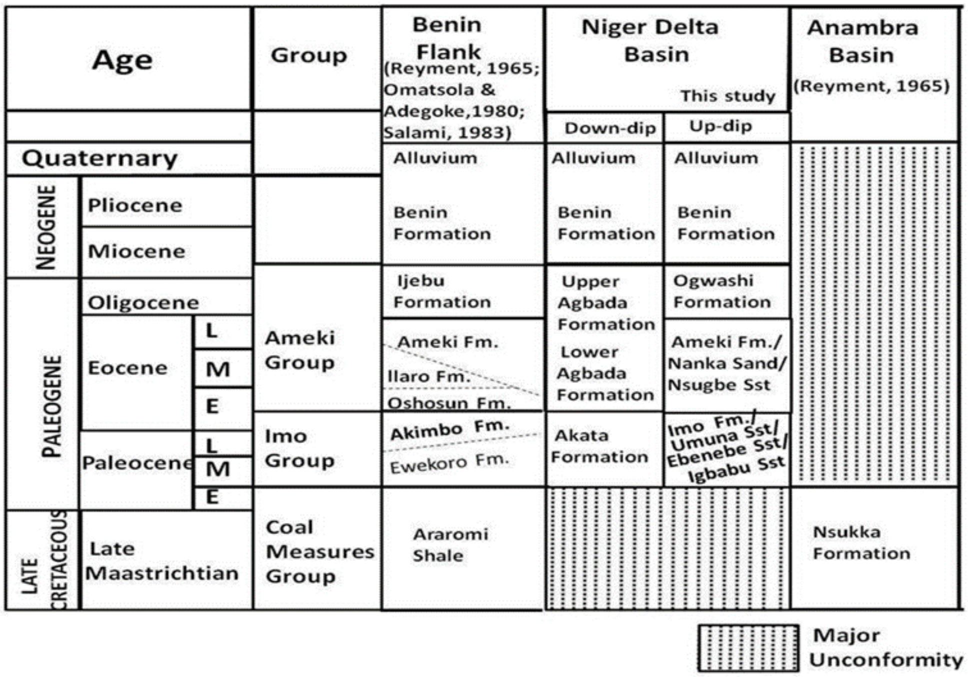


Fig. 3. Stratigraphic synopsis of southern Nigerian sedimentary basins (from given authors)

In western Nigeria, the Imo Formation cut across partially into a thick shaly and in places, arenaceous limestone (the Ewekoro Formation). In the east, the Imo Formation unconformably overlies the Nsukka Formation, exposes at Oduenyi village extending westward through Ndiwo, and terminates at Itu-Mbuzor where it is conformably overlain by the Ameki Formation [16]. The Ameki Formation dominantly consists of alternating shale, sandy shale, clay sandstone, and fine-grained fossiliferous sandstone, with thin bands of limestone [26-28]. It exposed at Bende-Idima road in Itu-Mbuzor town extending northwestward through Ozu-Item to Uzuakoli town and terminates at Amogugu town where it is completely overlain by the Ogwashi Formation [16] (Fig. 3). The Ogwashi Formation consists of alternating coarse-grained conglomeritic sandstone, lignite, and light-colored clays of continental origin [29]. The Benin Formation consists of massive coarse- to fine-grained sandstones and gravels, with minor shale interbeds. The formation is deposited in coastal or alluvial plain setting following a southward shift of the delta into a new depobelt [30].

3. Materials and methods

This involves outcrop logging and sampling, and laboratory analysis of collected samples. Exposures in the study area around Bende-Umuahia and environs were systematically sampled from bottom to top at different localities, from Oduenyi village (Loc. 1) in the eastern part (Fig. 2), along Bende-Umuahia road, to Location 35, near Oyivo stream, toward the southwestern end.

Seventeen (17) selected shale and mudstone samples were processed in the laboratory for their kerogen contents, using standard conventional method of acid demineralization for recovering the acid-insoluble organic residue extract (Fig. 4). Each sample was thoroughly cleaned to remove field contaminants. 10 g of each shale and mudstone sample was weighted out and gently crushed with agate mortal and piston. The crushed sample was passed through 36 % conc. hydrochloric acid treatment for 30 minutes to get rid of calcite. The calcite-free sample was digested for 72 hours in 48 % conc. hydrofluoric acid for removal of silicates. The sample was diluted with distil water to neutralize the acid, and then sieve-washed through 10 microns nylon mesh to enable the organic residue be free from mud and acid. The sieve-washed 10 g residue equivalent was partitioned into two parts, 5 g each, for oxidation and the other 5 g for kerogen studies.

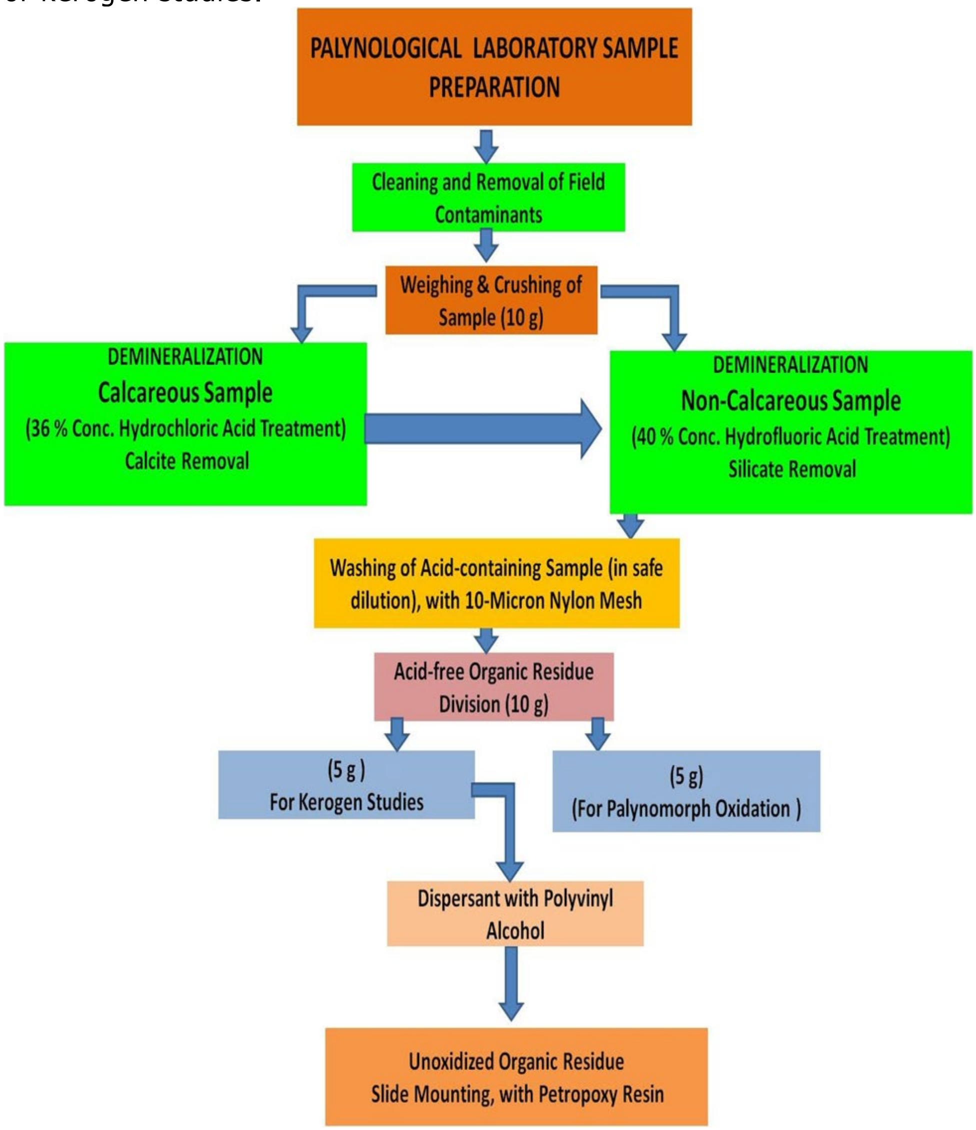


Fig. 4: Flow chart for palynological laboratory (kerogen) sample processing

Each 5 g kerogen residue extract from each sample was mounted on a glass slide and critically studied using transmitted light microscopy at x10 and x40 magnifications, in order to carry out a qualitative as well as a quantitative analysis of disperse particulate organic matter (POM), determine the palynofacies association and kerogen types, examine spore/pollen exine color, and estimate Thermal Alteration Index (TAI), Vitrinite Reflectance (Ro %), as well as the degree of organic thermal maturation. Each slide was scanned and counted for its (POM) contents, in which the first 200 particles were considered in terms of ***rare*** (<5 %), ***common*** (5-15 %), ***frequent*** (16-35 %), and ***abundant*** (>35 %) [31-34].

4. Results

Unoxidized acid-insoluble organic matter was classified into four main groups similar to those identified by [21,31,33], for quick kerogen assessment. These include:

- Phytoclasts, refer to all structured and dispersed clay to fines and size particles of plant derived kerogen.

- Opaques, defined as all structured dark or carbonized particles of plant-derived kerogen.
- Amorphous organic matter (AOM), refers to all structureless particles of plant-or marine-derived kerogen.
- Palynomorphs, refer to all HF acid resistant organic-walled plants remains.

A total of 17 kerogen samples from Locations 2, 8 (Imo Formation), 16, 22, 23, 25 (Ameki Formation) and 33 (Ogwashi Formation) (Fig. 2) were examined for their petroleum source rock potential.

Imo Formation

Table 1 shows the percentage frequency distribution of the total POM present in the samples. From the illustration given in the histogram (Fig. 5), it is evident that organic constituents of the kerogen samples L2/01, L2/02, L2/03, L2/04 from black shale and L8/01, L8/02 from the blue-grey shale are mostly dominated by amorphous organic matter (AOM) and opaque debris, followed by phytoclasts and then palynomorphs.

Table 1. Percentage frequency distribution of the total particulate organic matter (POM) present in samples from the Imo Formation

Particulate organic matter	L2/01	L2/02	L2/03	L2/04	L8/01	L8/02	L8/04	L8/05	L8/06
Palynomorphs									
Spores & pollen	5	2	7.5	6	1.5	2	4.5	2.5	12.5
Dinoflagellate cyst	1.5	3	-	-	17.5	3.5	-	1.5	5
Forams test lining	-	-	0.5	-	1	-	0.5	-	0.5
Phytoclast (structured) Plant tissues:									
Tracheids	4	3.5	10.5	10	0.5	1.5	6.5	20	15
Cuticles	-	0.5	-	0.5	1	-	2.5	1	1
Phytoclast (structured)									
Degraded wood	5	6	0.5	1	-	-	2.5	6.5	2.5
Resin	-	-	-	-	-	-	-	-	0.5
Amorphous organic matter (AOM)									
Fluffy - Transparent	53	52	16	9.5	45.5	44.5	10	5.5	12.5
Yellow – brown	2	3	2	0.5	3	2.5	1	0.5	2.5
Black brown	-	-	-	-	-	-	-	-	-
Opaque debris	30	30	63	72	30	46	72.5	62.5	48

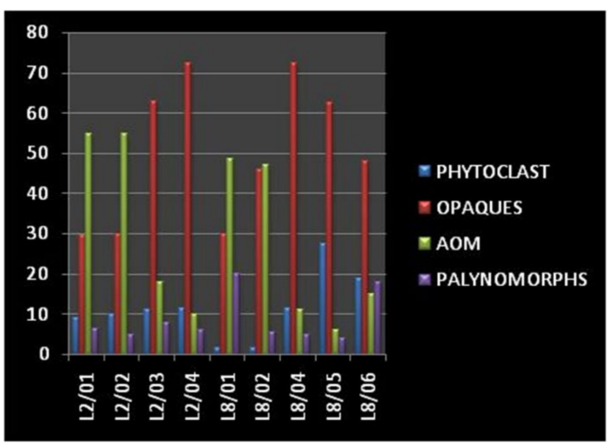


Fig. 5. Histogram of % frequency distribution of the total Particulate Organic Matter (POM) present in the samples from the Imo Formation

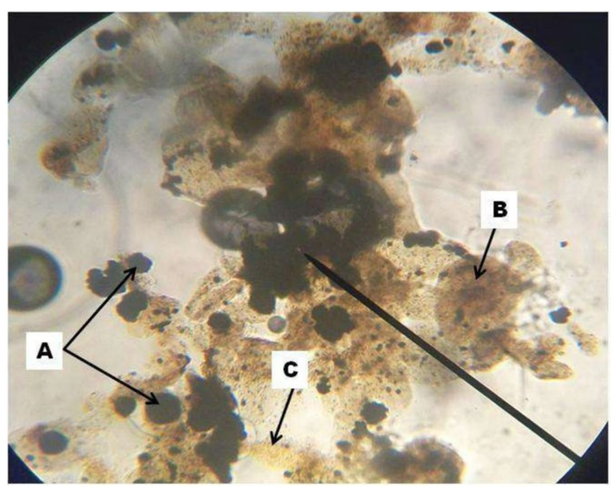


Fig. 6: Micrograph of POM from the black shale at Loc 2, (Imo Formation). (A) opaques; (B) amorphous organic matter; and (C) microfossil (spore)

The AOM was predominantly transparent (coloureless) with few dark fluffy ones. The exine colours of spores and pollen are generally in arrange of colourless to pale yellow. In terms of maturation, the POM was generally immature (Fig. 6). However, samples L8/04, L8/05, L8/06 from the blue-grey shale are dominated by opaques and phytoclasts followed by AOM and palynomorphs. The exine colours of spores and pollen of the samples ranged from colourless to pale yellow and are also immature.

Ameki Formation

Table 2 presents the percentage frequency distribution of the total POM present in the samples. The illustration given in the histogram (Fig. 7) shows that organic constituents of the kerogen sample L16 from the calcareous grey shale at the base of Ameki Formation are dominated by amorphous organic matter (AOM) (56 %) and opaque debris (40 %) followed by phytoclasts (3%) and palynomorphs (1 %). The AOM was dominantly transparent (coloureless) with few dark fluffy ones. The exine colours of spores and pollen are generally in a range of colourless to pale yellow. In terms of maturation, the POM is generally immature.

Meanwhile, kerogen sample L22 from the calcareous laminated grey shale at the middle of Ameki Formation is mostly constituted of AOM (42 %) and phytoclasts (33 %) followed by opaque debris and palynomorphs. The exine spores/pollen colouration ranged from colourless to pale yellow and tends to be immature (Fig. 8a).

Table 2. Percentage frequency distribution of the total Particulate Organic Matter (POM) present in samples from the Ameki Formation

Particulate organic matter	L16	L22	L23/01	L23/02	L25/01	L25/02	L25/03	L16	L22
Palynomorphs									
Spores & pollen	1	5.5	0.5	0.5	3.5	4.5	3	1	5.5
Dinoflagellate cyst	-	2.5	-	0.5	1.5	0.5	-	-	2.5
Forams test lining	-	2.5 %	-	-	-	-	-	-	2.5 %
Phytoclast (structured) Plant tissues:									
Tracheids	2	24	17.5	31	17.5	15.5	35	2	24
Cuticles	-	2.5	0.5	3	2	5	11	-	2.5
Phytoclast (structured)									
Degraded wood	1	6	5.5	10	2.5	2	5	1	6
Resin	-	0.5	-	-	2	3	3	-	0.5
Amorphous organic matter (AOM)									
Fluffy - Transparent	49	38	12.5	13.5	1.5	1	1.5	49	38
Yellow – brown	7	4	1	0.5	15	9	11.5	7	4
Black brown	-	-	-	1	0.5	1	0.5	-	-
Opaque debris	40	14.5	62.5	40	54	58.5	50	40	14.5

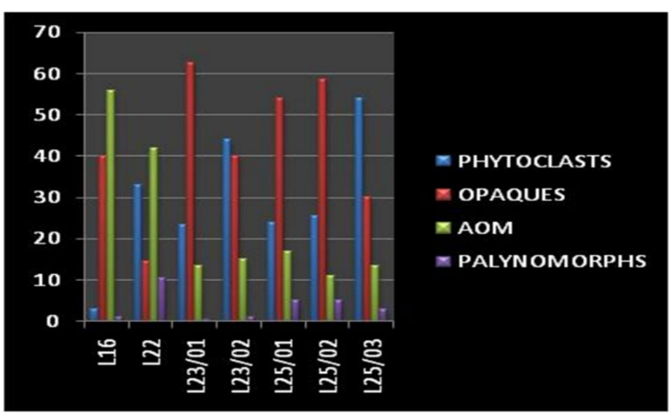
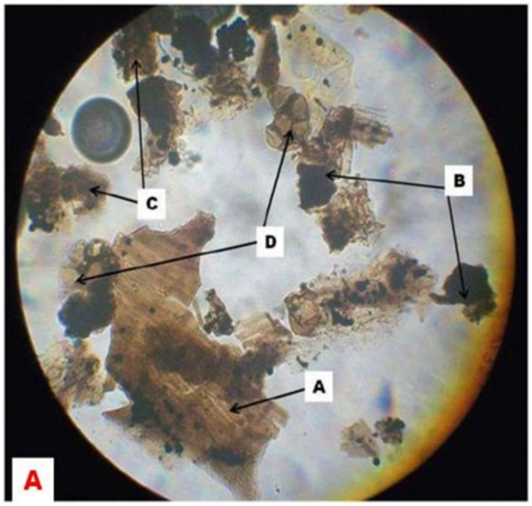


Fig. 7. Histogram of % frequency distribution of the total Particulate Organic Matter (POM) present in the samples from the Ameki Formation

Moreover, the kerogen samples L23/01, L23/02 and L25/01, L25/02, L25/03 from the mudstones towards the top of Ameki Formation are dominated by opaques and phytoclasts followed by AOM and palynomorphs. However, the exine colours of spores and pollen of kerogen samples L23/01, L23/02 ranged from colourless to pale yellow and are immature, while kerogen samples L25/01, L25/02, L25/03 from the fossiliferous mudstone ranged from yellow-brown to brown and tend to be immature - slightly mature (Fig. 8b).



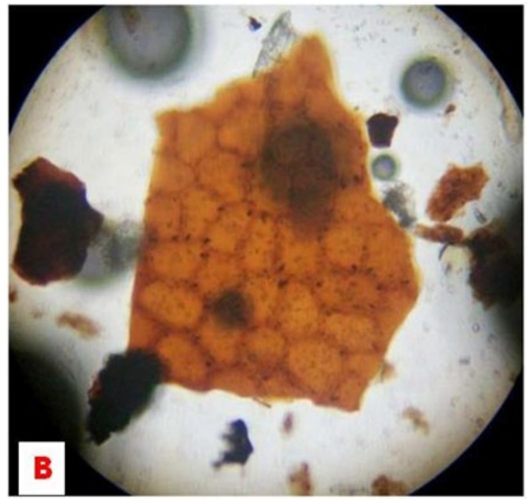


Fig. 8A: Photomicrographs of POM from the calcareous grey shale at Loc 22, (Ameki Formation). (A) Structured phytoclast; (B) opaques; (C) AOM; and (D) foraminifer linings.
B: Micrograph of mature POM from the fossiliferous mud stone at Loc 25, (Ameki Formation).

Ogwashi Formation

The histogram (Fig. 9) shows the percentage frequency distribution of the total POM present in the samples. The kerogen sample L33/03 from grey to dark shale of Ogwashi Formation are dominated by phytoclasts (55 %) and opaques (34%), followed by AOM (7 %) and palynomorphs (4 %) (Fig. 9).The exine colours of spores and pollen ranged from colourless to pale yellow and tends to be immature (Fig. 10 and Fig. 11).

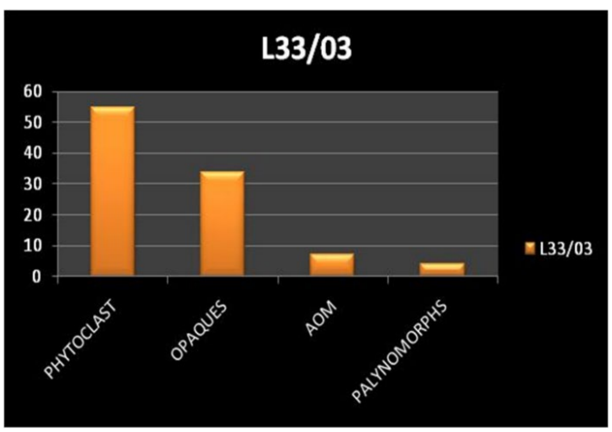


Fig. 9. Histogram of % frequency distribution of the total Particulate Organic Matter (POM) present in the samples from the Ogwashi Formation

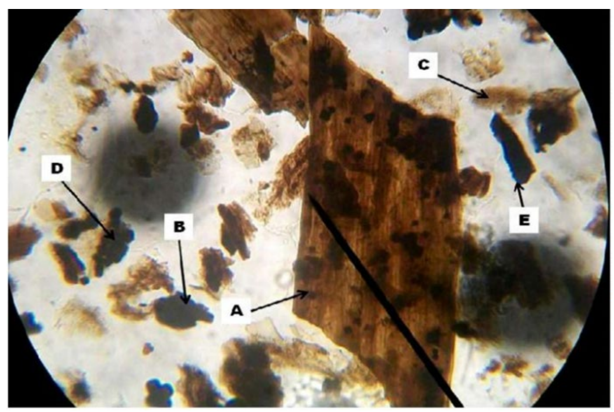


Fig. 10. Micrograph of POM from grey shale at Loc 33, (Ogwashi Formation). (A) Structured phytoclast; (B) opaques; (C) AOM; (D) degraded wood; and (E) opaque wood

5. Interpretation and discussion

5.1 Palynofacies association, kerogen type, thermal maturation and source rock potential

Table 3 shows the summary of kerogen analysis, with some interpretation. Residue extracts from kerogen samples were examined to estimate the color change of fossil exine and compare them using the Pearson's color chart (Fig 12). The distribution of different kerogen components throughout the sections from the oldest to the youngest units, show a significant change in the particulate organic matter (POM) (Fig 12).These changes were recognized in the three formations encountered. Three (3) main palynofacies associations were recognized from the 17 kerogen samples, which include palynofacies (A, B and C).

Table 3. Summary of kerogen analysis, with some interpretation

FORMATION	SAMPLE NO	PALYNOFACIES ASSOCIATION	S/P COLOUR	TAI	VITRINITE REFLECTANCE (Ro%)	THERMAL MATURATION	KEROGEN TYPE	SOURCE ROCK POTENTIAL
OGWASHI FM	L33/03	Abundant phytoclast & Frequent opaques	Pale yellow - yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE III	Gas prone
AMEKI FORMATION	L25/03	Abundant opaque & Frequent phytoclast	Yellow brown - brown	2 to 2-	0.4 % - 0.5 %	Immature to slightly mature	TYPE III	Gas prone
	L25/02	Abundant opaque & Frequent phytoclast	Yellow brown - brown	2 to 2+	0.4 % - 0.5 %	Immature to slightly mature	TYPE III	Gas prone
	L25/01	Abundant opaque & Frequent phytoclast	Yellow brown - brown	2 to 2+	0.4 % - 0.5 %	Immature to slightly mature	TYPE III	Gas prone
	L23/02	Abundant opaque & Frequent phytoclast	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE III	Gas prone
	L23/01	Abundant opaque & Frequent phytoclast	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE III	Gas prone
	L22	Abundant AOM & Frequent phytoclast	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L16	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
IMO FORMATION	L8/06	Abundant opaque & Frequent phytoclast	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE III	Gas prone
	L8/05	Abundant opaque & Frequent phytoclast	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE III	Gas prone
	L8/04	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L8/02	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L8/01	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L2/04	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L2/03	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L2/02	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone
	L2/01	Abundant AOM & Frequent opaque	Colourless - Pale yellow	1 to 1+	0.2 % - 0.3 %	Immature	TYPE II/III	Oil-Gas prone

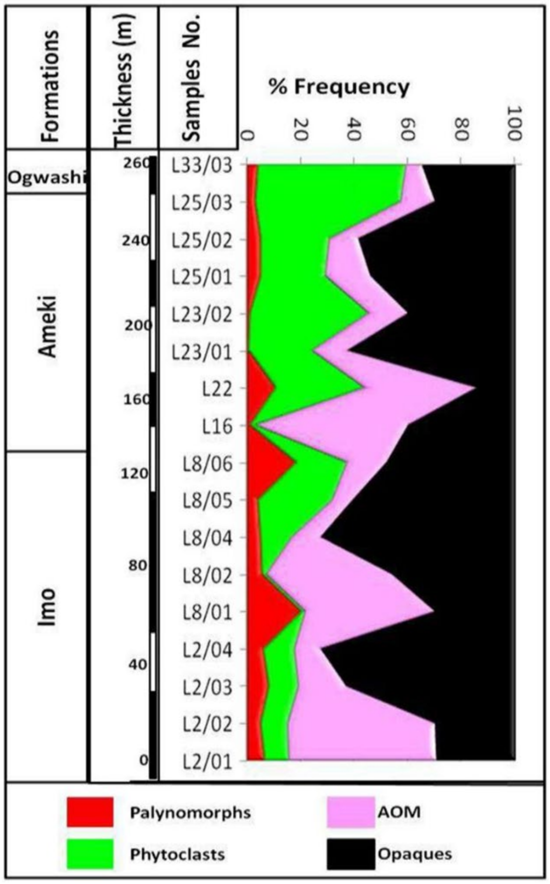


Fig. 11. Graphs of percentage frequency distribution of the (POM) in the studied area

Palynofacies A constituted mostly the amorphous organic matter (AOM) and opaque debris, followed by phytoclasts and palynomorphs; *palynofacies B* characterized by opaques and phytoclasts followed by AOM and palynomorphs; and *palynofacies C* dominated by AOM and phytoclasts followed by opaques and palynomorphs.

In the Imo Formation, palynofacies A and B were identified. Kerogen samples L2/01, L2/02, L2/03, L2/04, L8/01 and L8/02, fall within the palynofacies A and interpreted as type II/III kerogen with oil gas prone material, while samples L8/04, L8/05 and L8/06 are grouped under palynofacies B and interpreted as type III kerogen with gas prone material. In terms of maturation, they are generally immature, with exine spores/pollen colour ranged of colourless to pale yellow (Fig 12). Meanwhile, in Ameki Formation, palynofacies A, B and C were recognized. Kerogen sample L16 was characterized by palynofacies A while sample L22 falls within the palynofacies C, and both were interpreted as type II/III kerogen with oil gas prone material. Moreover, samples L23/01, L23/02, L25/01, L25/02 and L25/03 from mudstone are grouped under palynofacies B and interpreted as type III kerogen with gas-

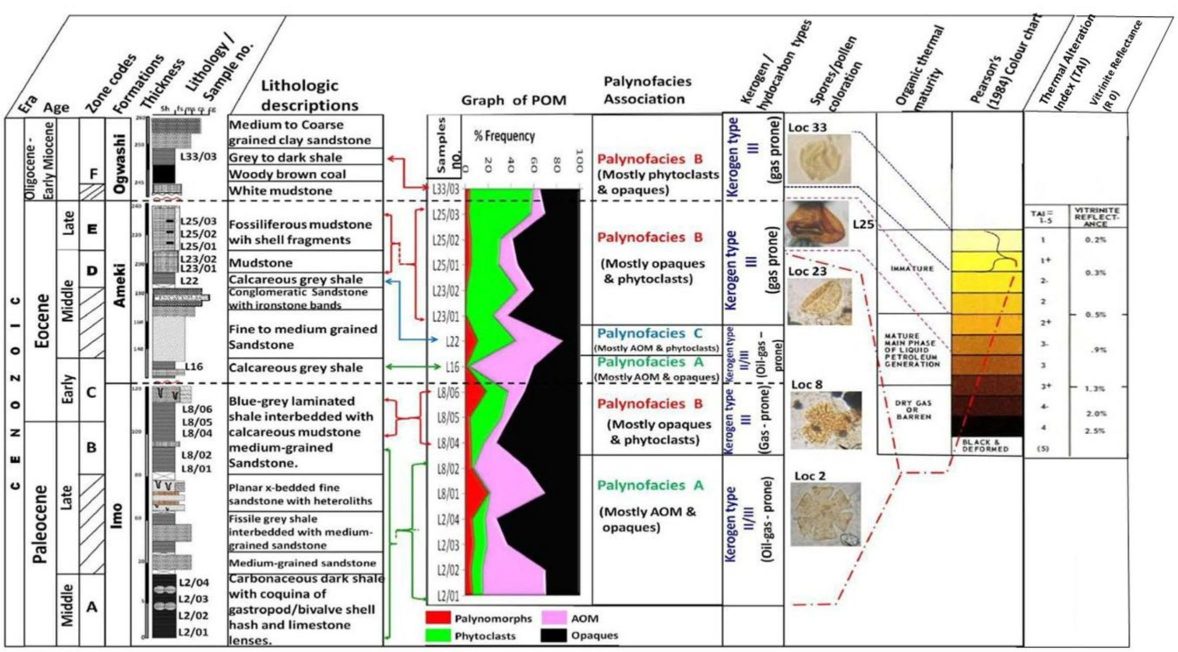


Fig. 12. Composite chart of the studied sequence showing litho-sections & sampling points, lithologic description, palynofacies and kerogen type, and thermal maturation status

prone material. Based on maturation, kerogen samples from fossiliferous mudstone at Loc 25 fall in the mature zone, with exine spores/pollen colour range of yellow-brown to brown (Fig. 12). Other kerogen samples from Locations16, 22 and 23 fall within the immature zone, with exine spores/pollen colour range of colourless to pale yellow. In Ogwashi Formation, palynofacies B was recognized in sample L33/03 from grey to dark shale, and interpreted as type III kerogen with gas-prone material. In terms of maturation, the exine spores/pollen colour ranged from colourless to pale yellow and falls within the immature zone.

6. Conclusions

Kerogen data generated in this study have revealed three (3) main palynofacies associations namely; *palynofacies A* and *palynofacies B, and palynofacies C* based on significant change in the constituent organic particle of the examined kerogen samples. *Palynofacies A* constituted mostly the amorphous organic matter (AOM) and opaque debris; *palynofacies B* characterized mostly the opaques and phytoclasts; while *palynofacies C* is dominated by AOM and phytoclasts.

In the Imo Formation, *palynofacies* A and B were identified, with exine color range of colourless – pale yellow and thermally immature; while in Ameki Formation, *palynofacies* A, B and C were recognized, with exine color ranging from colourless – pale yellow at the base to yellowish brown – brown at the top of the section; whereas In Ogwashi Formation, palynofacies B was recognized, with exine color range of colourless – pale yellow, and thermally immature. These indicate a type of organic matter content that is thermally immature to slightly mature but with a potential to generate mainly gas and less oil.

Kerogen analysis using transmitted light microscopic technique has shown some significant level of confidence, as a reliable tool, and a proxy for more expensive geochemical parameters, such as Rock-Eval pyrolysis. Despite its subjectivity, the method is relatively cheap, quick and, surprisingly accurate for evaluating petroleum source rock potential and thermal maturity status of any given sedimentary basin.

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