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Oil Shale Prospects of Imo Formation Niger Delta Basin, Southeastern Nigeria: Palynofacies, Organic Thermal Maturation and Source Rock Perspective

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ABSTRACT

The search for oil and gas in the Nigerian inland basins and efficacy of the unconventional oil shale in hydrocarbon generation have necessitated the palynofacies characterization, thermal maturation and source rock evaluation of the Imo Formation, updip Niger Delta basin to determine its palynofacies constituents and oil shale potential. The standard acid maceration technique, palynofacies description as well as palynomorph colour index chart systematically compared to thermal alteration index and vitrinite reflectance index values were utilized for the study.

The palynofacies components of the Imo Formation is dominant of yellow and brown amorphous organic matter, marine taxa, opaque particles, with few dark brown structured phytoclasts and terrestrial microflora. The source rock content is interpreted as Kerogen Type II - oil prone with abundant marine palynomorphs, amorphous organic matter and few terrestrial microfossils. The spore/pollen colour of the strata is light brown signifying mature and oil generation zone. This correlates to thermal alteration index (TAI) 2+ to 3 and vitrinite reflectance index (%R_o) values of 0.5% to 1.0%.

The abundance of the amorphous organic matter of marine origin suggests good source rock which indicates good oil shale prospects. The oil shale prospects of the Imo Formation in the study area are hindered by the low abundance of the palynofacies associations. Field evidence indicate that the grey to slightly light grey shales in hand specimen, as against black carbonaceous shales rich in organic matter suggests that the environmental conditions affected the quality of the organic kerogen. The oil yields may be compensated by the great volume of marine shale deposited in the formation and the abundance of amorphous organic matter of marine origin which is known to be an excellent indicator of oil. The palynofacies model enhances the understanding of palynofacies events and oil shale quality which can be tied to the development of unconventional oil shale, oil fields and subsequent exploration drive in the area.

INTRODUCTION

The application of palynology in reconstructing ancient stratigraphy, palaeoenvironment, vegetation distribution, climatic changes and hydrocarbon potentials of both conventional and unconventional source rocks have positioned it as a topical research area in earth and natural sciences. The palynofacies model of the outcropping sections of the Imo Formation, Niger Delta demonstrates the efficacy of kerogen analysis in both conventional and unconventional oil and gas. Zelenin and Ozerov (1983) and Zhao et al. (1991) attempted a definition of oil shale. Although there is no general accepted oil shale definition but any good definition must take into cognizance, quantity and quality of kerogen (organic matter), textures and depositional environment. However, oil shale was initially viewed by Colorado School of Mines Research as a rock that contains kerogen, that breaks down into combustible liquids and gases at 900°F.

Palynological studies in the Niger Delta basin were mostly in the southern section (subcroping formations) (Fig.3) towards the offshore (Oboh-Ikuenobe, 1992, Nwachukwu and Chukwura, 1986, Bustin, 1988 and Batten, 1982, Okeke et al. 2014) due to its potential as a petroliferous province in conventional and unconventional resources alike. Works on the up-dip Niger Delta basin (outcrop sections) were concentrated in the southern part around Bende and Umuasua area (Oboh-Ikuenobe et al., 2005; Germeraad et al. 1968) mostly on palynostratigraphy. Although palynological studies were carried out in the northern portion around Oba and Onitsha axis (Okeke and Umeji, 2016; Umeji, 2003 and Jan du Chêne et al., 1978.), this work illustrates detailed palynofacies characterization, source rock evaluation, organic thermal maturity and oil shale potential of the formation.

Many researchers, (Combaz, 1964; 1977; Bujak et al., 1977; Masran and Pocock. 1981; Tyson 1993, 1995; Whitaker, 1982; 1984) proposed different palynofacies classification schemes to establish a high resolution palynofacies model. The diversity in classification schemes is as a result of different processing techniques and specific scope of study (Okeke, 2017). The scheme used here is that proposed by Tyson (1993, 1995) which described palynofacies in a practical sense as the quantitative and qualitative study of the total particulate organic matter present in a sedimentary rock. Palynofacies analysis reflect depositional environment and cycles associated with progradation and retrogradation.

Nwachukwu and Chukwura, (1986) reported that amorphous organic matter of Agbada Formation constitutes 63% of the kerogen, 30% of terrestrial organic matter (woody remains, herbaceous material), recycled or coaly organic matter consists of 7%. The organic matter in the Niger Delta is mainly a mixture of type II and III kerogen (Bustin, 1988, Nwachukwu and Chukwura, 1986).

The organic matter content of sedimentary rock is dependent on the environmental control prevalent during the sediment deposition and diagenetic processes. The quantity and quality of the organic matter constituents are very pivotal in the interpretation of palynofacies and oil shale prospects of the Formation. This is because classification and quality of the individual organic matter present in clastic sediments is key to effective palynofacies analysis of any clastic rock. The palynofacies model of the Imo Formation will enhance the understanding of palynofacies events and oil shale prospects of the formation which can be tied to the development of oil fields and subsequent exploration in the area.

PREVIOUS WORK

Several palynological studies were carried out in the northern portion of the Niger Delta basin (Germeraad et al., 1968; Jan du Chêne

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et al., 1978, Legoux, 1978). Regional correlation (Short and Stauble, 1967; Avbovbo, 1978 and Nwajide and Reijers, 1996) shows that overlying Nanka and Ogwashi formations are equivalents of the hydrocarbon generating Akata, Agbada and Benin formations respectively.

The organic matter in the Niger Delta is mainly a mixture of types II and III kerogen (Bustin, 1988). The main palynofacies are structured woody materials, opaque organic matter, cuticles, pollen and spores and minor amorphous organic matter (Batten, 1982; Bustin, 1988). Oboh (1992), concluded that abundant yellowish gel-like AOM from well samples probably indicated terrestrial origin, whereas gray AOM has been interpreted as marine in origin by others.

The palynological composition (Okeke and Umeji, 2016) is marked by abundance of dinoflagellate cysts in the Imo Formation (Selandian to Thanetian), dominance of spores and pollen over dinoflagellate in the Nanka Formation (Ypresian to Bartonian), and overwhelming amounts of spore and pollen in the Ogwashi Formation (Pariabonian to Aquitanian). Van Hoeken-Klinkenberg (1966) documented the occurrence of some late Paleocene-early Eocene sporomorphs from Inyi-1 borehole of Geological Survey of Nigeria. Germeraad et al. (1968), established palynological zonations for the Pantropical *Proxapertites operculatus* - Maastrichtian to lower Eocene and Atlantic *Retidiporites magdalenensis* – Paleocene zones of the Cenozoic and correlated sediments of tropical and sub-tropical countries.

The organic sediments are classified as marine and non-marine which can be linked to the depositional and post-depositional history.

Multivariate statistical analysis of palynodebris from Niger Delta (Oboh-Ikuenobe, 1992) revealed that mudstone and muddy heteroliths from low energy depositional settings are characterised by small-sized lath-shaped woody debris and high concentration of buoyant components of cuticle and palynomorphs. Reservoir scale depositional environment (Okeke, 2014) suggests that the Alakiri-wells were predominantly deposited within fluctuating low and intermediate energy fluvial conditions in conjunction with minor crevasse splay setting, based on the buoyancy and percentage abundances of the palynomaceral and palynomorph components. Batten (1999) suggested that palynofacies is very useful in identifying potential source rocks for petroleum exploration, and that some of the best source rocks coincides with the maximum flooding surfaces (condensed surfaces).

GEOLOGY

The Niger Delta basin lithostratigraphy units comprises the Imo, Ameki, Ogwashi and Benin formations (Fig. 2). Offshore, the lateral stratigraphic equivalent of these formations in the sub-surface include the Akata, Agbada, and Benin formations while top of Agbada and base of Benin formations correlate to Ogwashi Formation (Fig.3). The formations decrease in age southwesterly. The delta complex, is defined onshore by the contact between Imo and Nsukka formations, (Fig.2) in the offshore by the Cameroun volcanic line on the southeast, the Okitikpukpa ridge to the west and Guinea Abyssal plain in the southwest (Nwajide, 2013).

The oldest lithostratigraphic unit is the Imo Formation with Ebenebe, Umuna and Igbakwu Sandstone members. Imo Formation is composed of grey sandy shale, siltstone and sandstone with lenses

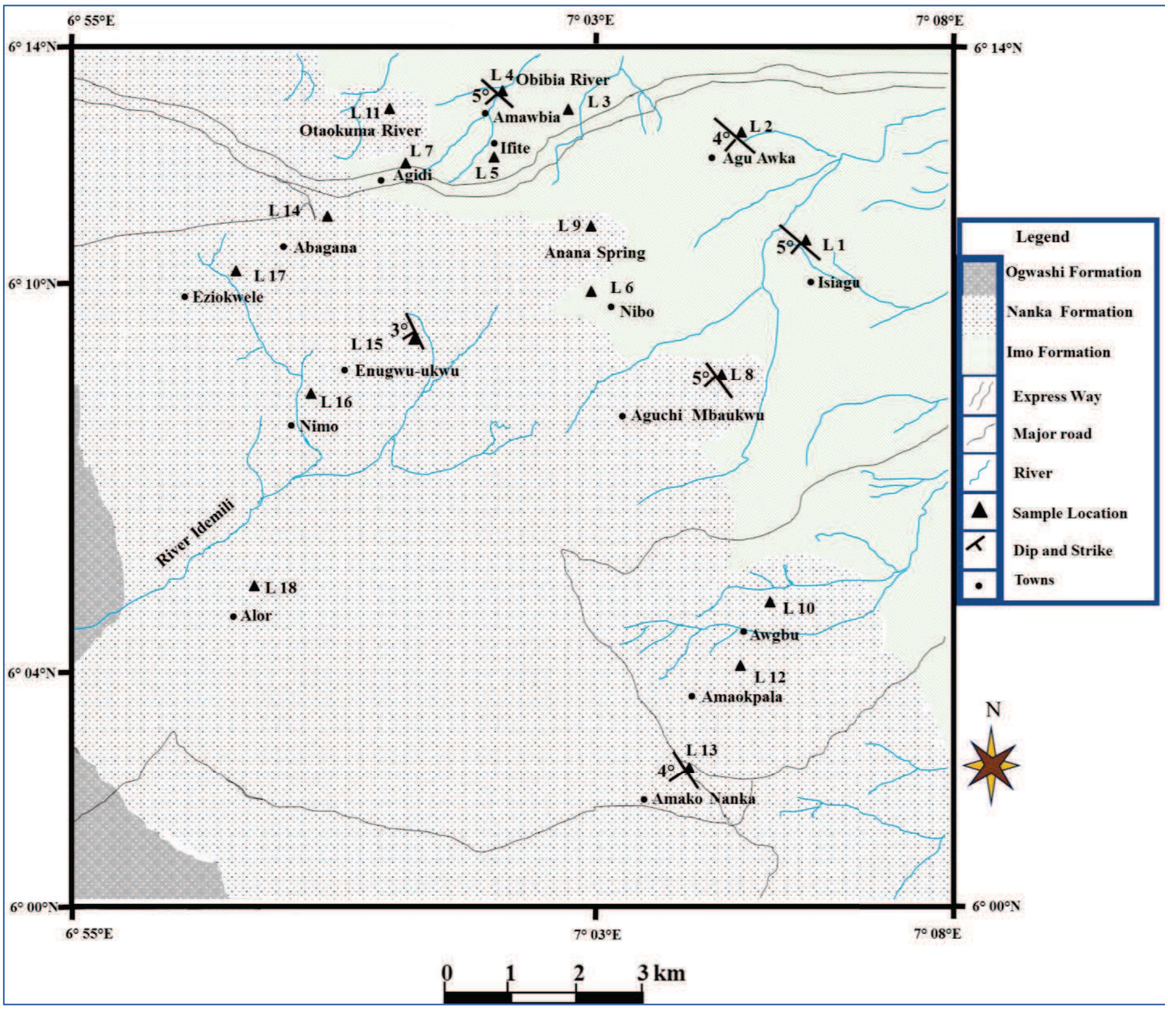

Fig.1. Geological map of the study area showing location and accessibility, sample location and dip and strike.

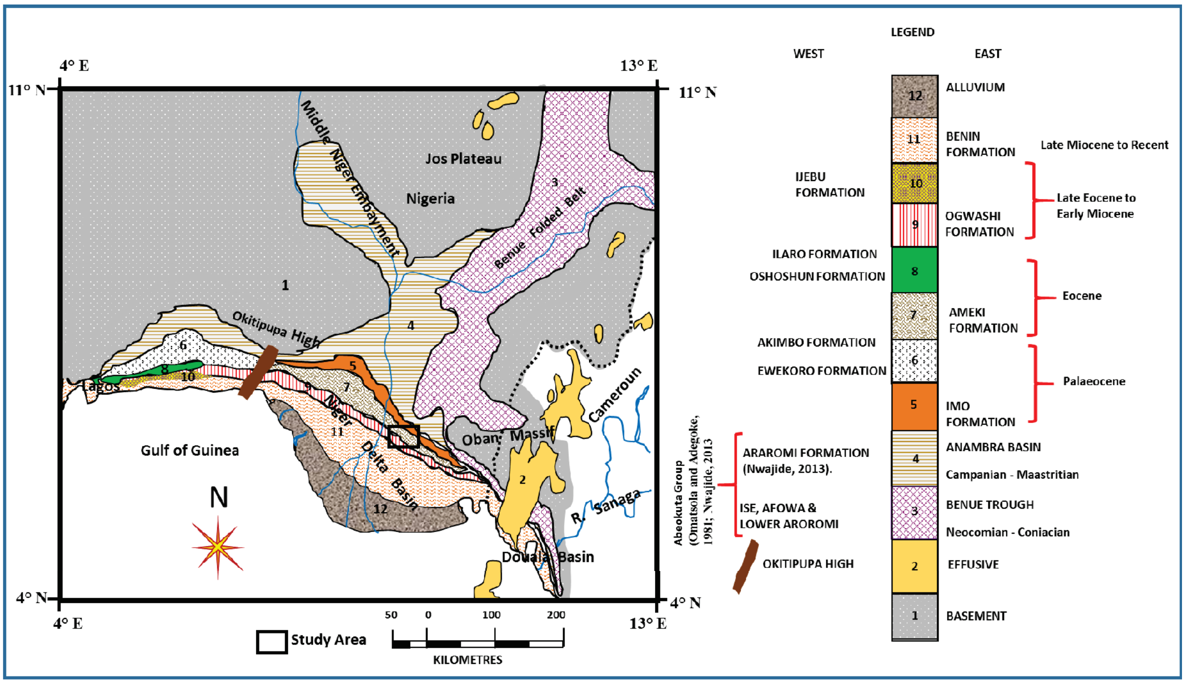

Fig.2. Geological map of some parts of Nigeria showing Cenozoic succession of Niger Delta Basin.

of coal and limestone. The Imo Formation contains Cenozoic microflora, foraminifera and trace fossils which are correlatable to those in the sub-surface. In some places, lateral variations in sandstone facies have been reported due to fluctuating environmental events associated with progradation and retrogradation. The works of Ezeofor, (2004) and Samuel, (2014) documented authentic outcrops of bituminous sands at Ogbagirigiri spring in Umulolo, at the Okigwe area. The Formation continues southwards (basinward) without break into the Akata Formation in the sub-surface.

The Ameki Group simultaneously overlies the Imo Formation unconformably. It is predominantly sandy lithology with Nsugbe and Nanka formations (Nwajide, 1980) as its lithostratigraphic equivalents. Nanka Formation consists of fluvial friable cross bedded sandstones with abundant ichnofossils, micaceous grey shale and kaolinitic clays, siltstone, lenses of coal and fossiliferous limestone. Agbada Formation (down dip) is correlatable with the updip Ameki Formation. The Agbada Formation consists of alternating sand and shales indicating sediments of the transitional lower delta plain (mangrove swamps, floodplain, marsh) and the coastal barrier and fluviomarine settings. It is the main petroleum bearing unit of Niger Delta petroleum system. They represent the actual portion of the succession that accumulated in the delta front, delta top set and fluvio-deltaic environment. The Nanka Formation is conformably overlain by the Ogwashi Formation which extends laterally westwards where it is correlatable with Oshoshun Formation.

The Ogwashi Formation (Reyment, 1965) was initially called as Lignite Series by Parkinson (1907). It consists of cross bedded sandstones, carbonaceous black shales, lignites, and coal. The lignite seams within the Ogwashi Formations are commonly brown to black and vary in thickness from few centimetres to a maximum of six meters. They are thinly laminated and fissile with leaf and woody fragments. It extends eastwards beyond the Niger to the east of Calabar and Cameroon frontiers (Fig.2.) (Okezie and Onuogu, 1985). The Ogwashi Formation is regarded as a boundary formation which is mapable in the sub-surface from the top of Agbada at its base to the base of Benin formation at its top. It does not outcrop, being covered by Benin Formation. Its exposures are only along stream sections and quarries.

Benin Formation is the uppermost lithostratigraphic unit in the Niger Delta. The type section is at the Elele 1 Well, drilled almost 38 km NNW of Port Harcourt (Avbovbo, 1978). It consists of late Miocene to Recent alluvial and upper coastal plain deposits that are up to 2,000 m thick (Avbovbo, 1978). It overlies the Ogwashi Formation whose topmost unit is regarded as the base of the formation. In the onshore and some coastal regions, the Benin Formation overlies the Agbada Formation. Short and Stauble (1967) defined the contact between the Agbada and Benin formations as the highest shale, bearing marine fauna in the Agbada Formation. However, the contact is more practically defined at the base of the massive sandstone depicting Benin Formation, and generally corresponds to the base of fresh water bearing strata. The Benin Formation is barren of foraminifer, macrofossils and microflora. This characteristic of the formation inhibits accurate age-dating.

Stratigraphic Description of Studied Sections

Sedimentological field logging of outcrop thicknesses, grain size, bedding plane contacts and sedimentary structures were systematically carried out. The study area is part of the Niger Delta basin. It is within Lat. 06°00' to 06°14' and Long. 6°50' to 7°08' (Fig.1). The area

PERIOD	EPOCH	AGE	NIGER DELTA BASIN	
			SUBSURFACE	OUTCROP
Quaternary			Alluvium	
NEOGENE	Pliocene			Benin Formation?
	Miocene	Messinian	Benin Formation ?	
		Tortonian	Upper Agbada Formation ?	
		Serravallian		
		Langhian		
		Burdigalian		
		Aquitanian		Ogwashi Formation
PALEOGENE	Oligocene	Chattian		
		Rupelian		
	Eocene	Priabonian		
		Bartonian	Lower Agbada Formation?	Ameki Fm/Nanka Fm/Nsugbe Fm
		Lutetian		
		Ypresian		
	Paleocene	Thanetian	Akata Formation?	Imo Fm/Ebenebe /Umuna/Igbakwu Ssts
		Selandian		
		Danian		

Fig.3. Stratigraphic column of the Niger Delta basin showing the age of the diachronous outcropping and subcropping formations of the basin.

is accessible through footpaths, tarred and untarred roads. Stream sections, gully sites, road cuts and quarries provided good exposures from which the samples for this work were collected.

The shales outcrop around Awka, Enugwu-Agidi, Umuawulu and Mbaukwu (Fig. 1) area. The studied outcrops of Imo Formation are composed of grey siltstone, mud rocks, shale and sandstone (Fig.4). The siltstones are dark grey in some places. The shales are grey (Fig.5A) with a maximum thickness of 50 m around Ugwugama Isiagu. The sandstones are coarse to fine grained, (Fig.5B) heterolithic with planar cross beds. The beds have sharp contact with each other, strike NNW – SSE and dip SSW with an average dip amount of 3°. The field observations were used to determine the quantity and quality of the oil shale in the study and infer the depositional facies change of the formation.

MATERIALS AND METHOD

Since the samples were not calcareous, HCl treatment was not necessary. After cleaning and crushing, each sample, 10 g was used for acid digestion, immersed in hydrofluoric acid for removal of silicates. The samples were sieve-washed with a 10 µm mesh and the residue was divided into two (5 g equivalent) aliquots, one for palynofacies analysis and the other for oxidation. The residue used for palynofacies analysis was dispersed in polyvinyl alcohol before being mounted on glass slides and analyzed with the aid of transmitted light microscope. A minimum count of 200 palynomaceral particles was undertaken for each sample.

A modified spore/ pollen colour chart of Pearson (1984) adapted from Traverse (2007) was used in the determination of palynomorph colour index and compared to the thermal alteration index (TAI) and vitrinite reflectance index (%R_0) to establish the petroleum maturity. Palynomorphs (only psilate and ornamented pollen and spore) were used to delineate the geothermal maturation level since there is no colour difference when both palynomorph groups were compared. The vitrinite reflectance index (%R_0) values were obtained by correlating it to the thermal alteration index (TAI) values while the later was generated from the spore/pollen chart previously discussed above.

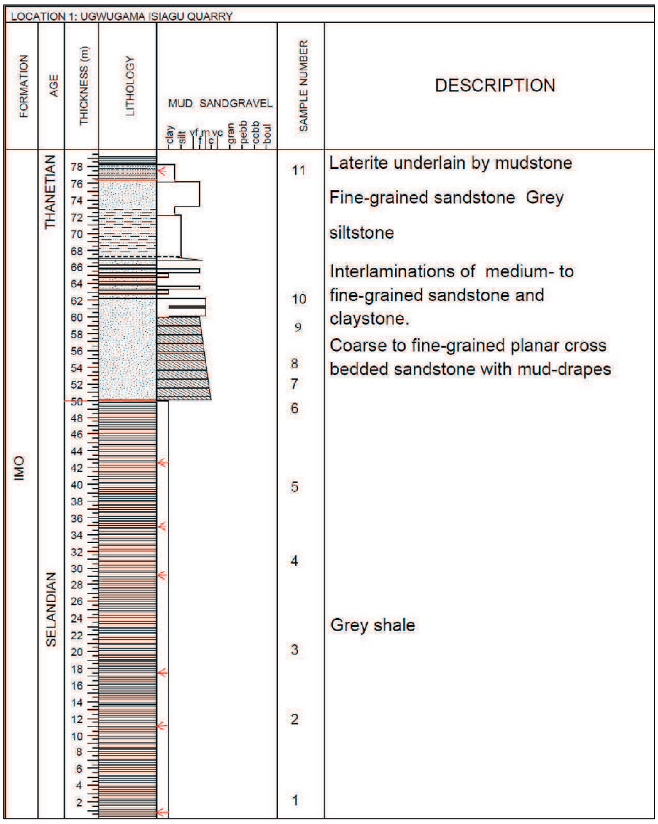

Fig.4. Litholog of the representative section of Imo Formation at Isiagu. Red arrows represent sample points.

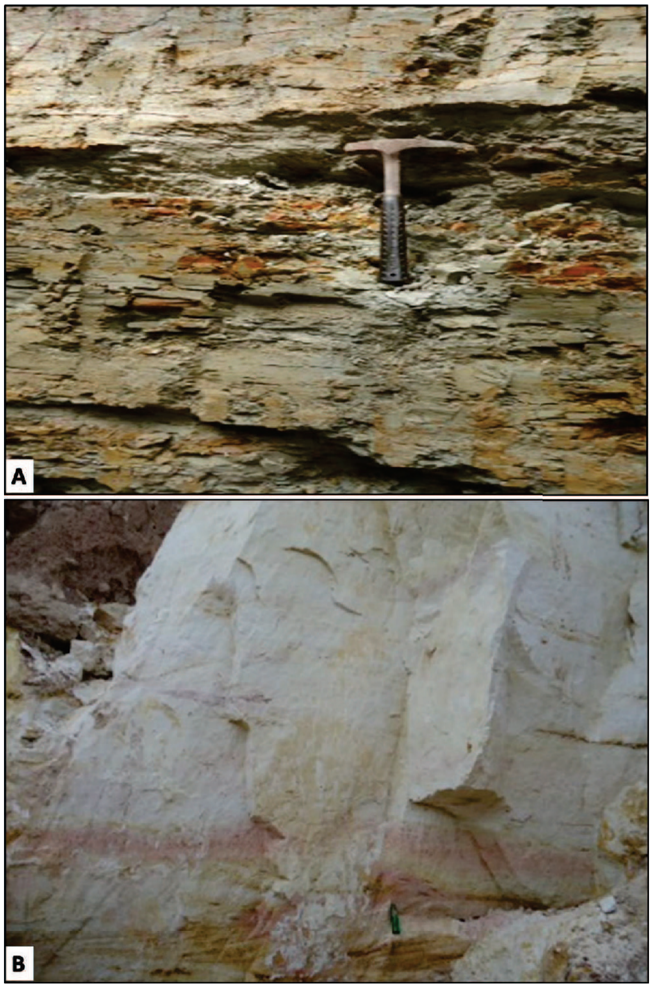

Fig.5. (A) The Imo shale at an open shale mining, Enugwu-Agidi. **(B)** Sandstone outcrop of Imo Formation at Isiagu.

PALYNOFACIES DESCRIPTION

The scheme used here is that proposed by Tyson (1993, 1995) which described palynofacies in a practical sense as the quantitative and qualitative study of the total particulate organic matter assemblages present in a sedimentary rock. The scheme provides for the origin, character and degrees of preservation of the total organic matter present in a clastic rock. The various palynofacies groups are described below.

Amorphous organic matter (AOM): The amorphous organic matter of Imo Formation occurs as fluffy, yellow-amber and brown structureless dense humic gel-like substances of different sizes, degrees of preservation and shape. The amorphous organic matter is dominated by 20 µm to 70 µm sized fluffy (light) and dark brown particles and few yellow types (Fig. 11).

Resin: The resin particles are yellowish to amber colored stem tissues associated with higher vascular plant with variable sizes. They range in sizes from 30 µm to more than 60 µm.

Structured wood: They are terrestrially derived components of palynofacies which constitute preserved structured and relatively structureless light brown to dark brown phytoclasts. They show well preserved conducting tissues and are generally lath-shaped with occasional equidimensional forms. Cellular structures and fringes of structured wood parts can be easily observed under the transmitted light microscope. They vary in size (50 ìm to > 90 ìm), degree of preservation and abundance. The structured phytoclasts have various colour shades of yellow-brown, brown and dark brown (Fig.11).

Cuticle: The cuticles are flat, platy, relatively thin and well preserved with 30 µm to 50 µm sizes while some are poorly preserved and almost degraded. Well preserved cuticle show clear outline of epidermal cells that define their boundaries with distinct upper and lower epidermis still intact. The poorly preserved forms have very faint epidermal outline (Fig.11). The well and poorly preserved cuticle outline also shows that they have not undergone much thermal alteration.

Unstructured phytoclasts: This is basically degraded phytoclasts which can be brown to dark brown (Fig. 9). They are irregularly shaped structureless to partly structured phytoclasts without any observable cell structure.

Opaque Debris: They are opaque particles classified as equidimentional opaque particles, lath- shaped opaque particle and opaque debris. Lath-shaped opaque particles are needle and blade shaped with irregularly shaped sizes while the opaque particle are those without any defined shape. These palynodebris are products of oxidation of translucent woody material during prolonged transport and post-depositional alteration of other terrestrial phytoclast. It is also produced as charcoal during natural wildfires (Tyson, 1993). The abundance and sizes of the opaque debris suggests that they are of plant origin and their unique opaque nature is a result of natural sedimentological diagenesis and not majorly as a result of fire. Nevertheless, some opaque debris show characteristics of recycled (coal) debris or charcoal from forest fires.

Pollen and spores: There is paucity of pollen and spores in the Imo Formations with *Retitricolporites irregularis* and *Proxapertites cursus* as the only terrestrial palynomorph in the palynofacies assemblage.

Dinoflagellate cysts: They are the most abundant marine components of the palynofacies assemblages recovered from the study and includes *Glaphyrocysta ordinata, G. exuberans, Homotryblium tenuispinosum* and *Leiosphaeridea* sp.

Marine microfossils: The trochospiral foraminifer text linings are the only microforaminifer recovered. They are mostly brown and dark brown in colour with an average 65 µm to more than 100 µm.

RESULTS

Figure 6 shows the palynofacies results from the various samples studied in Imo Formation. Palynofacies analysis was undertaken to illustrate a detailed kerogen evaluation model of the Imo Formation, to enhance the understanding of palynofacies events which can be tied to the development of oil fields and subsequent exploration drive in the area. Changes in the abundance of palynofacies assemblages is linked to environmental and climatic mechanism prevalent during sediment deposition.

The organic components (Fig.11) from of the middle Paleocene interval of the Imo Formation is made up of yellow and brown amorphous organic matter (64%), marine species (0.8%), opaque particle and absence of equant and lath-shaped opaque particles (Fig. 6). There are also few brown and dark brown structured phytoclasts (1%) and terrestrial microflora (2%). A slight drop in yellow and light dark brown amorphous organic matter to (49%), brown and dark brown structured phytoclast (0.6%), opaque particle (17%) and increase in marine species to (21%) in which *Glaphyrocysta ordinata* and *G. exuberans* predominate was observed in the late Paleocene unit (Fig. 8).

DISCUSSION

Figure 9 shows the palynofacies types and organic thermal maturity of the Imo formation. The changes in the colour of organic matter reflect the degrees of thermal alteration of sedimentary rocks. The kerogen types were based on palynofacies compositions which reflect

Particulate Organic Matter	LI						
	1	2	3	4	5	6	11
Palynomorphs							
Pollen	1	-	5	-	-	-	0.3
Spores	-	-	1	-		-	-
Dinoflagellate cysts	0.8	-	-	-	-	-	21
Forams test lining	-	-	1	-	-	-	0.9
Phytoclast (structured)							
Tracheids	0.4	-	0.3	-	-	-	-
Cuticles	-	-	3	-	-	-	-
Plant tissues	-	-	-	-	-	-	0.6
Phytoclast(unstructured)							
Degraded wood	2	-	2	-	-	-	5
Resin	-	-	-	-	-	-	5
Amorphous Organic Matter							
Fluffy- Transparent	10	45	25	-	-	-	20
Yellow - brown	26	40	15	-	-	-	15
Black brown	20	-	11	-	-	-	13
Opaque debris (Opaque)							
Opaque	37	13	35	-	-	-	3
Equant opaque	-	-	-	-	-	-	14
Lath Shaped Opaque	-	-	-	-	-	-	-

Fig.6. Distribution of the particulate organic matter (POM) abundance from the Imo Formation

the parent source material which is an indicator of conventional and unconventional oil and gas quality and prospects of the formation.

The organic components of the Middle Paleocene strata of the formation are made up of dark brown amorphous organic matter with few yellow forms, opaque particles and marine species. There are also few structured phytoclasts and terrestrial microflora. A decrease in amorphous organic matter (49%), in which the fluffy amorphous predominated was observed in the upper Paleocene unit. Although the drop in the amorphous component of the upper unit does not have any significant effect in the kerogen type, it points to fluctuation in the paleoenvironment. This may be due to facies changes during the sediment deposition because the type and abundance of palynofacies in a sedimentary rock is a product of the environmental settings prevalent during sediment deposition. There is structured phytoclast, opaque particle, paucity of terrestrial palynomorphs (0.3%) and increase in marine species to (21%) at the upper unit (Fig.6). These attributes of the palynofacies components suggests Kerogen Type II -

Observed colour of palynomorph	Significance
Colourless, pale yellow, yellowish orange	Chemical change negligible; organic matter immature, having no source potential for hydrocarbon
Yellow	Some chemical change, but organic matter still immature
Light brownish yellow, yellowish orange	Some chemical change, marginally mature but not likely to have potential as a commercial source
Light medium brown	Mature, active volatilization, oil generation
Dark brown	Mature, production of wet gas and condensate, transition to dry gas phase
Very dark brown-black	Overmature; source potential for dry gas.
Black (opaque)	Traces of dry gas only

Fig.7. Batten (1980) scale for palynomorph colours (reproduced from Traverse, 1988)

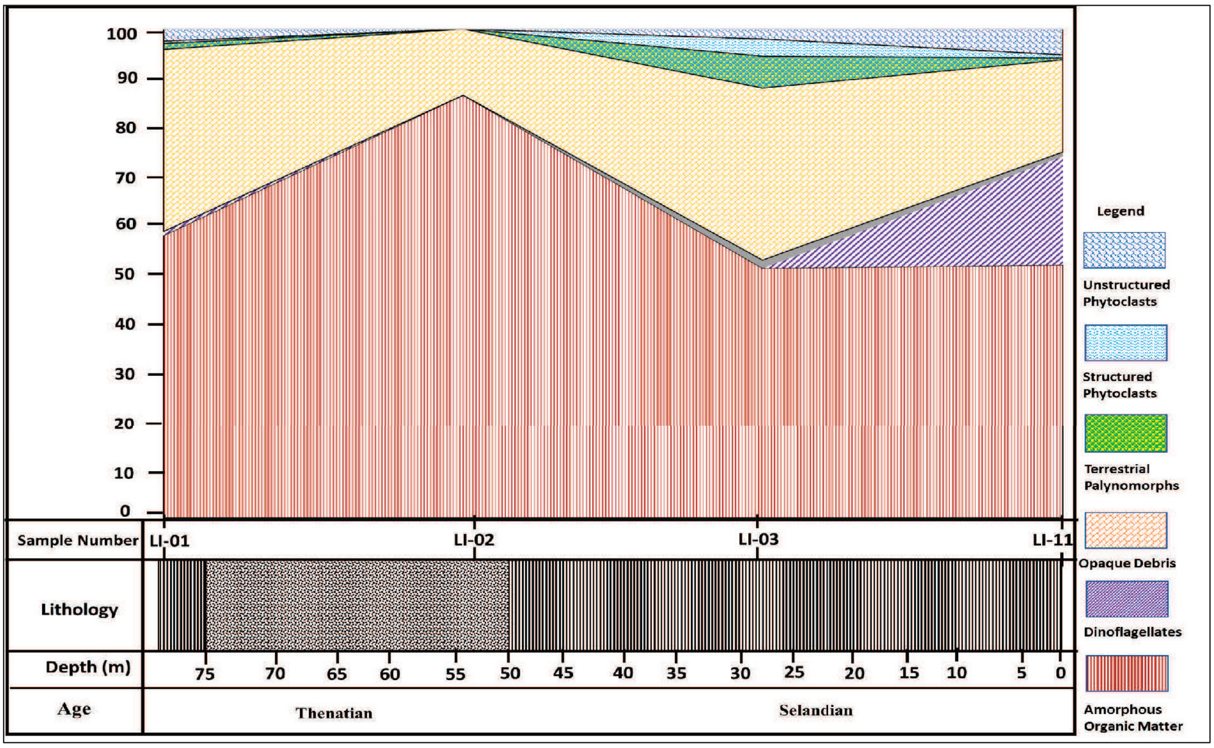

Fig.8. The percentage distribution of palynofacies components from the Imo Formation

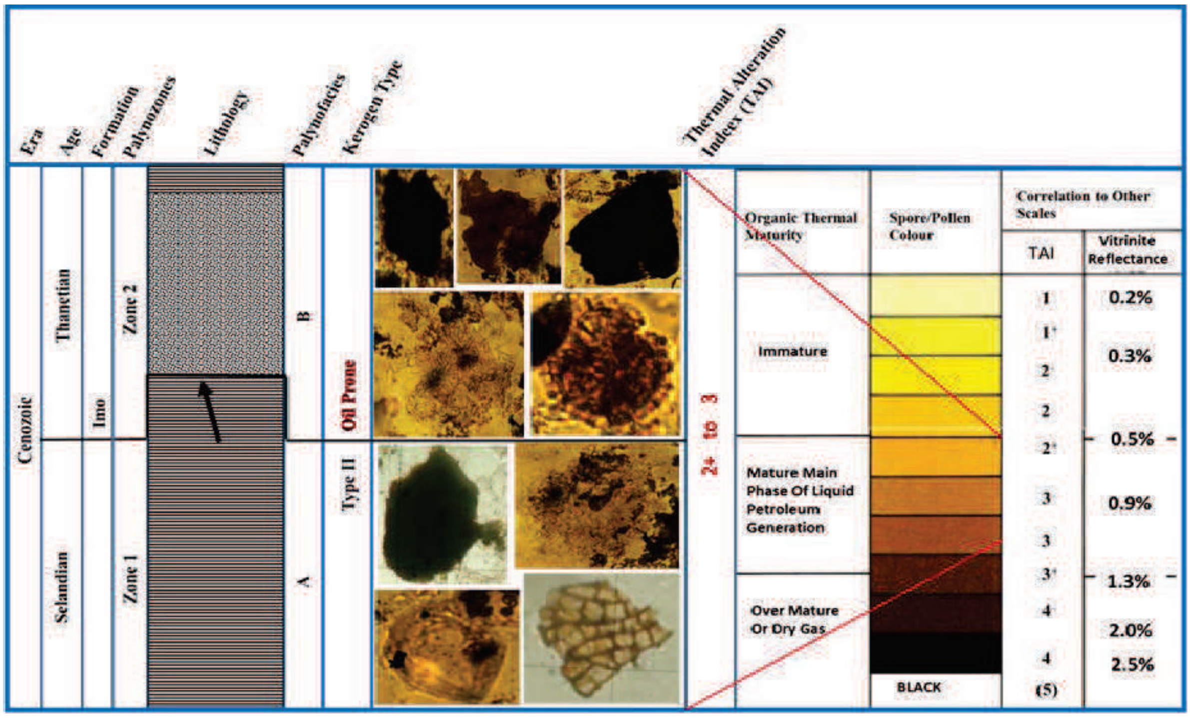

Fig.9. Palynofacies, kerogen types and organic thermal maturation of the Imo Formation

oil prone for the formation.

The abundance of the amorphous organic matter of marine origin suggests good source rock which indicates good oil shale prospects. Tyson (1996) suggested that the best source rock coincides with the maximum flooding surfaces identified in sequence stratigraphy. Traverse (2007) pointed out that a small percentage of TOC consisting of AOM of marine algal origin similar to that interpreted for the AOM in the shales of Imo Formation is a much better indicator of good source rock. Moreover, Mehrota, *et al*. (2002) argued that high total carbon does not necessarily mean high petroleum source potential, as the carbon could consist of dark woody material, which is very poor indicator for oil. Batten (1996) indicated that abundant structured matter (STOM) such as phytoclasts and sporomorphs are poor indicators for source rocks while brown-black woody matter and evidence of reworking in the palynofacies of non-marine sediments are also very negative indicators of oil.

Nevertheless, the oil shale prospects of the Imo Formation in the study area is hindered by the low abundance of the palynofacies associations (TOC) which is a resultant effect of environment of deposition. This is because the quality of oil shale is dependent on depositional environment. Middle to outer neritic paleoenvironment with terrestrial influences and transgressive systems tracts was

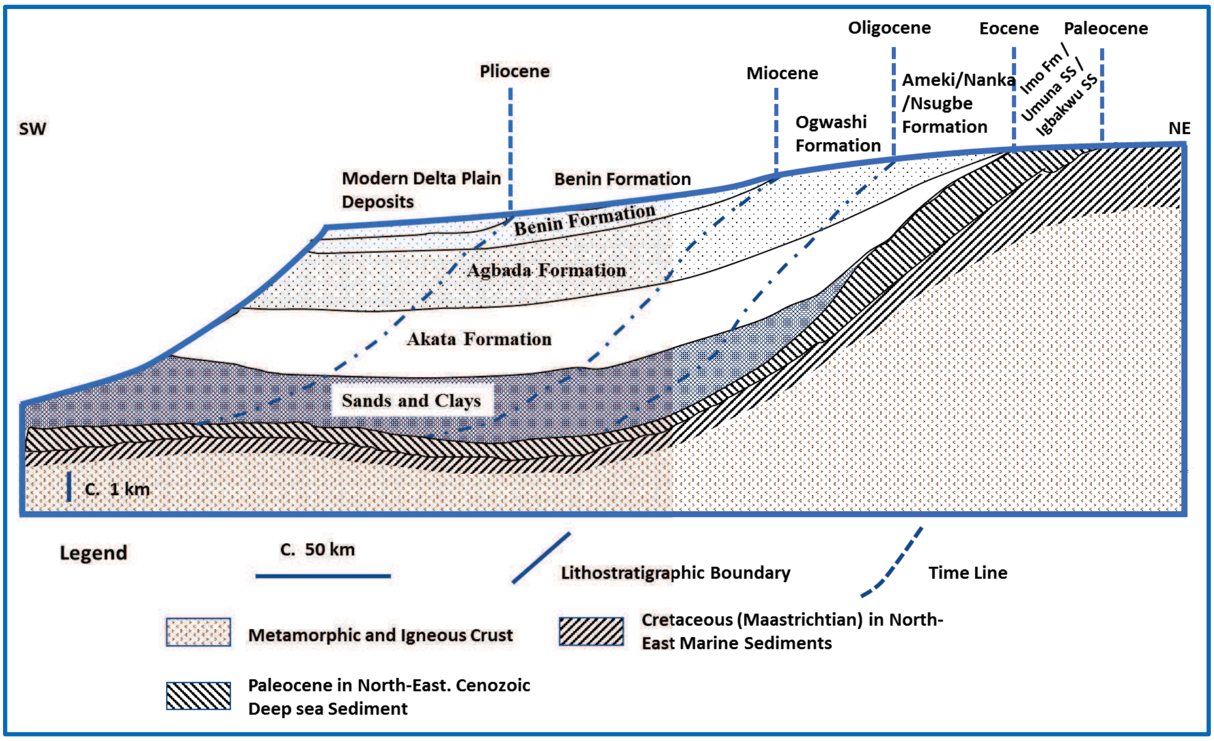

Fig.10. Stratigraphic equivalences between the outcropping and subsurface Niger delta (modified after Wright et al. 1985).

associated with the Imo Formation from palynomorphs occurrences. Batten (1999) suggested that palynofacies is very useful in identifying potential source rocks for petroleum exploration, and that some of the best source rocks coincides with the maximum flooding surfaces (condensed surfaces). Based on field evidence, the grey to slightly light grey shales in hand specimen as against black carbonaceous shales which are known to be rich in organic matter suggests that the environmental conditions affected the quality of the organic kerogen materials. The darker the colour the higher the quality of oil shale. In China, Zhaojun *et al*. (2017) revealed that the organic carbon content can be used as one of the indicators for judging oil shale quality, being especially suitable for evaluating oil shale in oil- and gas-bearing basins. In the same way Bujak et al. (1977) indicated that the kinds of organic particles in sedimentary rocks also partially controls the production of hydrocarbons from the rock during thermal maturation in conventional oil and gas resources. It was observed that the southern section of the Imo Formation around Umuahia - Bend - Umuasua area is more with black carbonaceous shale than the northern portion of the same formation around Awka – Mbaukwu area. The poor oil shale prospects may be compensated by the great volume of marine shale of 1000 m given by Reyment (1965) and 490 m by Dessauvagie (1975) and the abundance of amorphous organic matter of marine origin which is known to be an excellent indicator of oil.

The spores/pollen colouration of the biological remains were used to estimate the thermal maturity of the organic matter in Imo Formation. Pearson (1984) spore/pollen colour standard chart, calibrated to other organic thermal maturity parameters in Traverse (2007) was used to determine the thermal alteration index (TAI) and vitrinite reflectance (%R_0) of the formation. Batten (1980) Thermal Alteration Scale (TAS) (Fig.7) was correlated to Pearson's spore/pollen chart for palynomorph colour and their significance for hydrocarbon maturity. The spore/pollen colour is light brown signifying mature and oil generation. This correlates to thermal alteration index (TAI) 2+ to 3 and vitrinite reflectance index (%R_0) values of 0.5% to 1.0% (Fig.9). The range of vitrinite reflectance index (%R_0) falls within 50 – 150 catagenic range (R_0 : 0.5 – 2.0) of Hayes et al. (1983).

Bustin (1988) pyrolysis study of some 3,300 samples spread across 63 wells mostly from the Agbada - Akata transition or uppermost Akata Formation suggested that organic matter in the offshore Niger Delta is majorly a mixture of Types II and III. These kerogen types are mainly products of structured woody materials, opaque organic matter, cuticles, pollen and spores and minor amorphous organic matter (Claret et al., 1981; Bustin, 1988).

There is a striking difference in the diversity and abundances of palynofacies of the Imo and Akata formations (Fig. 10). Bustin (1988) basin wide kerogen studies suggested that the geochemistry, petrology, palynofacies distribution of the formations in the subcroping Niger Delta basin (including the top of Akata Formation) indicate a predominantly terestrial detrital source for the organic matter irrespective of age and formation. This is a sharp deviation from the source of the palynofacies asemmblages recorded in the equivalent of Akata Formation; the Imo Formation which indicated a predominant marine (alginite) origin with minor terestrial influences (Fig. 9).

However, the dominance of terestrial source attributed to the subcroping Akata Formation (Claret *et al*., 1981, Bustin, 1988) may be as a result of its age and facies change since the formations are diachronous (Fig. 10). This implies that facies changes offshore (which was associated with age as indicated above) is suggested as the influencial factor responsible for the variable palynofacies constituents in the formations. The facies changes downdip is expected becaause the marine transgression that deposited the Imo Formation during the Paleocene, was succeeded by the Eocene to Recent regression in the subcropping units which is responsible for the heavy load of sediments and associted bulk terestrial phytoclasts of the formations.

It is also observed that the diversity and abundance of the microfloral taxa in the older sediments culminated in the favorable environment associated with the shallow marine deposition of Akata and shallow to non-marine Agbada formations hence, the terrestrial and detrital source attributed to these formations (especially the upper Akata Formation since the middle and basal part is still a mystery due to overpressure except at the flanks – Awaizombe-1 well of Nwajide, 2013, p.393). This suggests that the Imo Formation was deposited in middle to outer neritic settings while the drilled Akata Formation is of

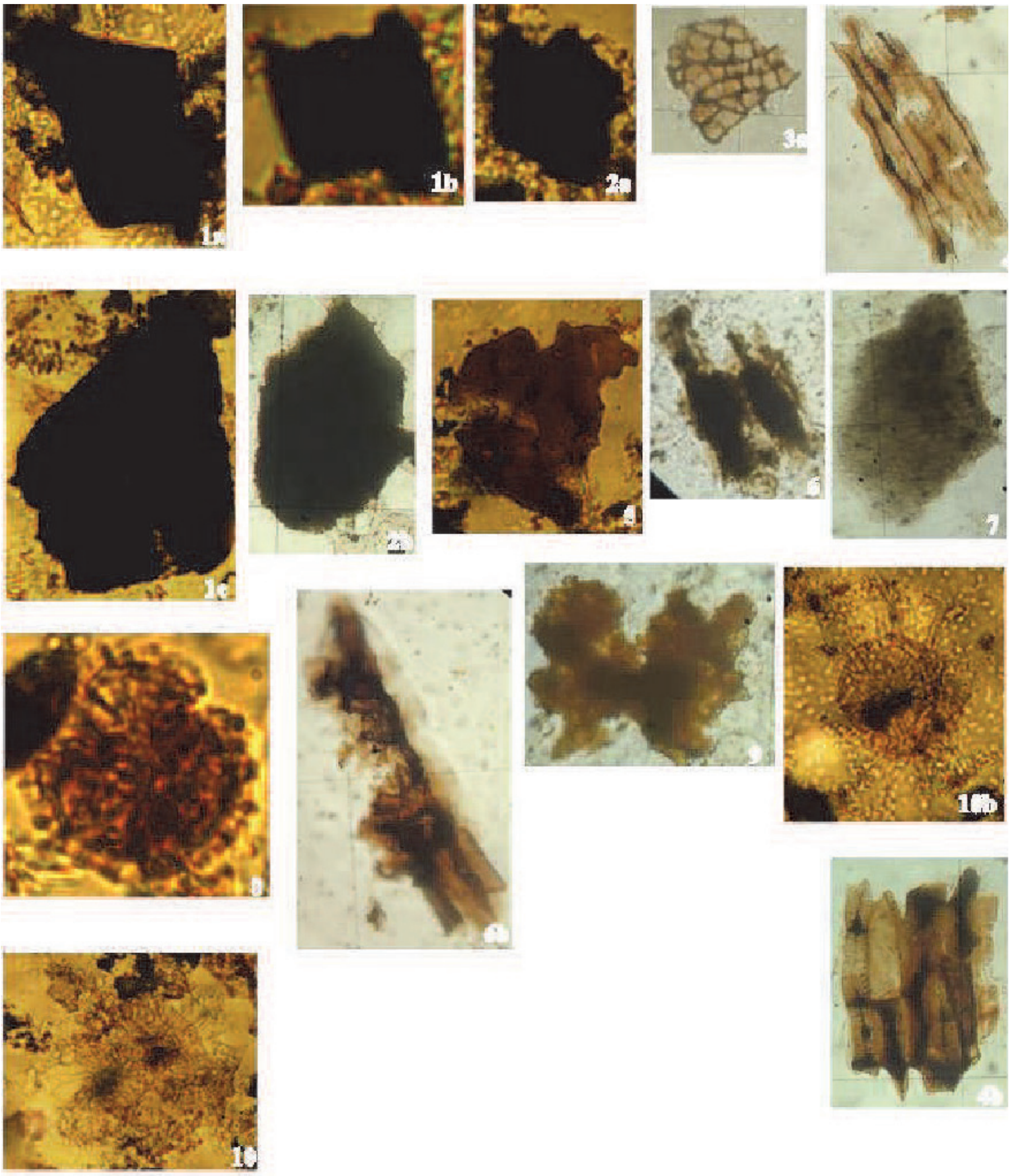

Fig.11. Palynofacies assemblages from the Imo Formation. (Magnifications: (x100) oil immersion. Scale bar represents 30¼). **(1)** Equidimentional opaque particles. **(2)** Black amorphous organic mater. **(3)** Dispersed cuticle showing regular rectangular outline. **(4)** Disperesed cuticle. **(5)** Resin particle. **(6)** Degraded structured phytoclasts. **(7)** Fluffy amorphous organic matter. **(8)** *Retitricolporites irregularis* Van der Hammen et Wymstra. **(9)** Yellow brown amorphous organic matter. **(10)** *Adnatosphaeridum multispinosum* Williams & Downie in Davey et al. (1966). **(11)** Dinoflagellate sp.

shallow marine environmnet and thus, the microflora and microfaunal components may be different due to its time transgrssive nature and variable facies. The shallow marine environmnet of the Akata Formation was supported by the planktonic foraminifera occurence which indicated shallow marine shelf deposition (Nwajide, 2013) thereby rulling out deep water (Short and Stauble, 1967) associted with the Imo Formation.

These may have been observed by Nwachukwu and Chukwura (1986) when they suggested that the shales in different parts of the Niger Delta basin differ in terms of maturity and source. These must have prompted Wright et al. (1985) to consider the Akata Formation as having no surface counterpart, being the continental slope shales and fine sands deposited in the delta front. These different observations are yet to be resolved.

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