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Visual Kerogen Analysis for Source Rocks Assessment: Case Study of Onshore Niger Delta Basin (Nigeria)

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Abstract

Microscopic observations for Visual Kerogen Analysis were conducted on twelve (12) core samples from eleven (11) wells in the onshore Niger Delta basin. The isolated kerogens were analysed under transmitted white, and fluorescence light for spore coloration index (SCI) and kerogen type description to estimate the relative abundances of vitrinite, inertinite, amorphous organic matter (AOM), define the maturity, and estimate the hydrocarbon generation potential of the source rocks. The samples analyzed come from the Akata and Agbada formations, which appear to be the main source rocks of the Niger Delta basin.

The results show that the kerogen particles from Agbada facies are dominated by amorphous kerogen (80 %), with marine microfossils (Dinoflagelated cysts) and some minor humic material (vitrinite and inertinite). This kerogen is classified as mixed Type II /III, and the organic matter is immature (SCI=4) to mature (SCI=7) according to thermal maturity parameters. Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows fair to Good preservation (FPI range between 2 to 4) for oil and gas-prone generation.

In Akata facies, the organic matter comprises vitrinite particles of more than 70% mixed with amorphous and inertinite. The SCI varies between 4 and 7.5 would indicate an immature to mature kerogen. Kerogen is classified as Type III and has low to medium generation potential for gas-prone. Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows weak preservation (FPI=2) for hydrocarbons generation.

Keywords*: Kerogen; Vitrinite; Amorphous Organic Matter; Source rocks assessment; Niger Delta Basin.*

1. Introduction

Kerogen is defined as the part of the organic matter present in sedimentary rocks which is insoluble in ordinary organic solvents [1]. Kerogen is formed during sedimentary diagenesis from the degradation of living matter which can include lacustrine algae, marine algae, and plankton, as well as higher-order land plants. Visual kerogen typing is the microscopic method for examining kerogen. It is based on the premise that optically classified kerogen particles can be related to the hydrocarbon generation potential of a source rock [2].

Combaz [3], Staplin [2], Burgess [4], and several others have developed different nomenclature schemes combining palynological and petrographic terms of coal for the visual description of recurrent kerogen types. These classifications have been generalized by most workers into four categories: woody, herbaceous, coaly, and amorphous. These categories are often not specific enough to help characterize the hydrocarbon generation potential of source rock, as they include several different types of organic particles in a generalized category, thus obscuring many details

Interpretation of visual kerogen data is based on each kerogen particle type having a specific hydrocarbon generation potential. According to [2], particles including spores, pollen, leaf cuticle, and thin cell wall structures are thought to be hydrogen-rich and should be oil-prone, while woody tissue, thick cell wall structures, and vitrinite were thought to be lignin-rich and should be gas prone. Coaly kerogen and inertinite are thought to be inert and have no real hydrocarbon-generating potential. Amorphous kerogen was originally thought to be derived almost exclusively from algae and therefore oil-prone [2, 5-7]

According to [2], the study of kerogen using transmitted light is derived from palynological examinations. The type of organic matter is identified using the translucency and shape of particles and, in some cases, their fluorescence. The results of transmitted light studies mainly give information on the type of organic particles present and their thermal maturity. The characterization of the origin of the organic matter and all aspects of the palynological organic matter assemblage in transmitted white light microscopy and fluorescence mode are achieved using a combination of the morphology and optical properties (qualitative fluorescence and translucency).

The optical microscopic method for kerogen typing has been widely used, and it can provide some relevant information that effectively supports the interpretation of Rock-Eval data, where kerogen mixtures can be generated by kerogen during the maturation process [8]. Visual kerogen analysis can also provide valuable information even when the techniques used are relatively "low-tech" and inexpensive, and it can be done with just a few grams of the sample [9]. But this analysis is a non-frequently used method, even unknown in the characterization of Niger delta basin source rocks.

This study aims to define the type of kerogen depending on the presence of different structured and amorphous assemblages to determine the thermal maturity and their hydro-carbon generation potential of the source rocks from the onshore Niger Delta Basin.

2. Study area

The Niger Delta is one of the most prolific petroleum provinces in the world. It is located in the Southern Nigeria margin of the Gulf of Guinea., with latitude 4°49′ N and longitude 6°0′ E [10]. The Niger Delta sedimentary basin covers an area of about 256,000 km^2 [11]. It is bounded to the south by the Gulf of Guinea and the north by older tectonic elements (Cretaceous), including the Anambra Basin, the Abakaliki uprising, and the Afikpo syncline, and to the east and west by the Cameroon volcanic line and the Dahomey basin respectively (Fig. 1b). The Niger Delta basin began to form in the Cretaceous when the African plate separated from the South American plate; the basin is delimited by rift faults on its northwest and northeast edges [12].

After the rifting, gravity tectonics became the main deformation process [13]. Pre- and syn-sedimentary tectonics described by [14-15] characterised the evolution of the Niger Delta basin. The regressive clastic sequence in the Niger Delta began to form in the Paleocene and has since formed sediments that now reach a thickness of 12,000 m [16]. The Niger Delta Basin consists of three main lithostratigraphic units of Cretaceous to Holocene origin (Fig. 2a). These units represent the prograding depositional environments which are distinguished mainly based on shale-sand ratios and are continental, transitional, and marine environments [17]. This Tertiary sequence in the Niger Delta consists of the three formations that are locally designated in ascending order (from the bottom) the Akata Formation, Agbada Formation, and Benin Formation [13, 18].

At the base of the system are the Akata Formation, a sequence of planktonic foraminifera-rich non-compacted transgressive Paleocene-to-Holocene marine shale, clays, and silt. The Akata formation at the base of the delta is of marine origin and consists of sequences of thick shale (potential source rock), turbiditic sand (potential deepwater reservoirs), and small amounts of clay and silt. The Paleocene and the recent Akata formation were formed during the lowlands when terrestrial organic matter and clays were transported to deep water areas characterized by low energy conditions and a deficiency in oxygen [19]. It is estimated that the formation can reach 7,000 meters thick [10]. The Akata Formation is covered by more than 4,000 m of alternating sandstones and shales of paralic facies [18, 20]. This interstratified unit of sandstone and shale is called the Agbada Formation (Recent Eocene). The Agbada Formation represents the delta system (delta front, fluvial-deltaic facies) of the sedimentary sequence [13]. The Agbada Formation is overlain by the third formation, the Benin Formation, a last continental deposit from the Eocene to Recent alluvial and upper coastal plains that sums up to 2000 m thick [20]. This study is based on twelve (12) different wells located in the onshore part of the Niger Delta basin.

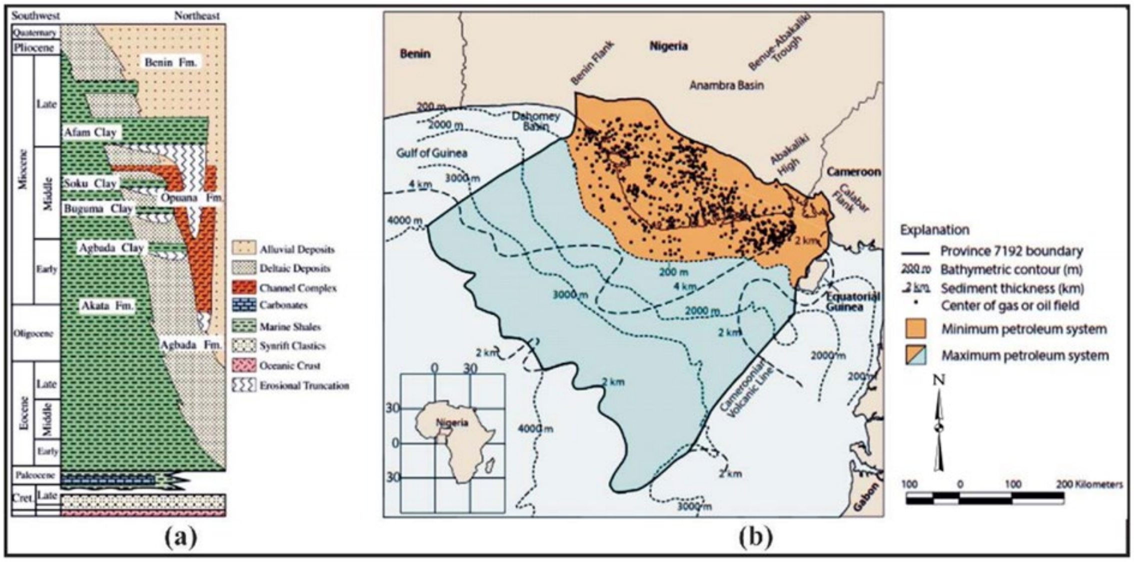

Figure 1. (a) Stratigraphic column showing the three formations of the Niger Delta [17]. (b) Niger Delta Map showing Province outline (petroleum system) and bounding structural features (*Source: From USGS Open File Rpt No. 99-501*)

3. Materials and methods

Twelve (12) core samples of eleven (11) wells in the onshore Niger Delta basin for visual kerogen analysis were treated with 37% hydrochloric acid (HCl) and 70% hydrofluoric acid (HF) in order to remove respectively carbonates and silicates minerals. The isolated kerogen was then washed and mounted on a glass slide for analysis under transmitted white and fluorescence light for spore coloration index and kerogen type description to estimate the relative abundances of vitrinites, inertinites, Amorphous Organic Matter (AOM), and maturity. The analysis was carried out in the laboratory of PETROCI (Société National d'Opération Pétrolière de la Cote d'Ivoire), using a transmitted light and fluorescent light microscope (Axioskop 40 FL).

The combination of transmittance and fluorescence microscopy makes possible the distinction of the different individual organic constituents from the kerogen assemblage. The observation of kerogen particles is an integrated analysis of all the aspects of the organic assembly of rock. Several particulars of organic matter will then be described [9, 21]. Kerogen assemblages are classified according to each type of kerogen particle, having a special hydrocarbon generation capacity [2] and counted to determine the relative percentages of three groups: amorphous organic matter (non-fluorescence and fluorescence amorphous), vitrinites (materials from land-plant),) and inertinites (recycled and plant materials) [9]. The results of transmitted light studies mainly give information on the type of organic particles present and their thermal maturity.

The Spore Coloration Index (SCI) is determined by the coloration of the miospores in the geochemical slides under a transmitted light microscope. Colors vary from yellow to black, orange, and brown. We call miospore all spores and pollens that have a diameter of fewer than 200 µm, regardless of biological functions [22]. The color of the miospores is determined using a chart called "FRL Spore Colour Index (1-10)" (Fig. 2), which is used at PETROCI. The determination of the colours of the miospores makes it possible to define the degree of maturity of the organic matter and hydrocarbon-generating capacity.

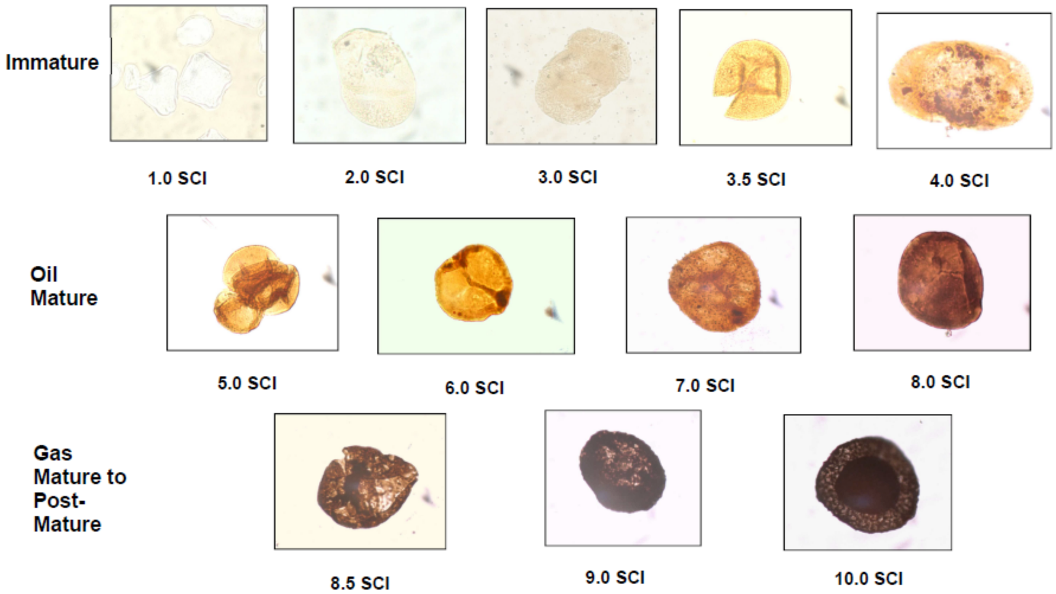

Figure 2. Fugro Robertson Limited (FRL) spore colour standards

4. Results and discussion

The maceral composition and content of the selected samples are listed in Table 1 and illustrated in Figure 3 and Figure 4. Based on the change of the number of amorphous assemblages and vitrinite particles in the whole section, the interpretation is divided into two (2) assemblages.

- *Assemblage 1*: from 6760 ft to 8680 ft, the core samples are from three (3) wells drilled in the Agbada formation.
- *Assemblage 2*: from 9555 ft to 1340 ft, the core samples are from nine (9) wells drilled in the Akata formation.

***Assemblage 1*: Agbada Formation**

Kerogen particles analysis indicates that the facies are dominated by amorphous kerogen (80 %), resulting in large part from the decomposition of particles of terrestrial origin (Fig. 4), with some minor humic material. The woody organic matter is composed primarily of structured, derived from land plants, in the form of degraded phytoclasts (vitrinite) and was found in low quantities (15 to 20%) of the total organic matter. Inertinite is virtually absent (0 to 5% in places).

In the well Benin West (7840 ft), the marine microfossils (dinoflagellates cysts) also make a significant contribution to these facies (Fig. 7). This organic matter appears as non-fluorescent kerogen (FPI=2), which gives it an average quality of generation of hydrocarbons and to a dysoxic to oxic depositional environment. The SCI (4) based on the coloration of the spores would indicate immature kerogen (Fig. 5). This kerogen is classified as mixed Type II/III and has medium potential for gas and oil-prone.

The AOM of Well Isan 9 appears as fluorescent to weakly fluorescent kerogen (Fig. 6 and Fig. 8). We also note a presence of spore and fairly rich contribution from the very fluorescent lacustrine algae (Botryococcus). The colonial freshwater alga *Botryococcus* occurs widely in lagoonal and lacustrine facies (they occur in marine sediments only by redeposition or transportation, e.g., prodeltaic facies) [9]. *Botryococcus was* also occurring in a wide range of freshwater to brackish aquatic environments [23]. The sedimentary environment of the Niger Delta shows that the area where the well Isan 9 was drilled is a fresh water swamp. A part of this kerogen is represented by a weak presence of marine algae. Kerogen is classified as Type

II/III and currently has average to good potential for the generation of liquid and gaseous hydrocarbons. The SCI (varies between 3 and 4) would indicate immature kerogen for the well Isan 9 (6760 ft), and the SCI (varies between 7 and 8) for the well Isan 9 (8680 ft) would indicate a kerogen in the oil window (Fig. 5).

Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows fair to good preservation (FPI range between 2 and 4) for hydrocarbons generation (Fig. 4).

Table 1. Visual kerogen data from Akata and Agbada formations

FORMATIONS	WELLS	DEPTH	%MOA	% VITRINITE	% INERTINITE	Fluorescence Preservation Index (FPI)	SCI(Spor Colour Index)
AGBADA	ISAN 9	6760	80	20	0	4	4
	BENIN WEST	7840	80	15	5	2	4
	ISAN 9	8680	80	15	5	2	7
AKATA	IYEDE 1	9555	0	70	30	1	5
	UBEFAN	9800	10	90	0	2	4
	UGHELLI	11120	20	80	0	2	5
	APPARA	11800	10	80	10	2	5
	KOKORI	12140	20	70	10	2	5
	ERIEMU	12200	30	70	0	2	7
	WARRI RIVER	12260	15	70	15	2	7
	UDEDUMA CREEK	12340	15	70	15	2	7
	ISOKO	13400	10	70	20	2	7,5

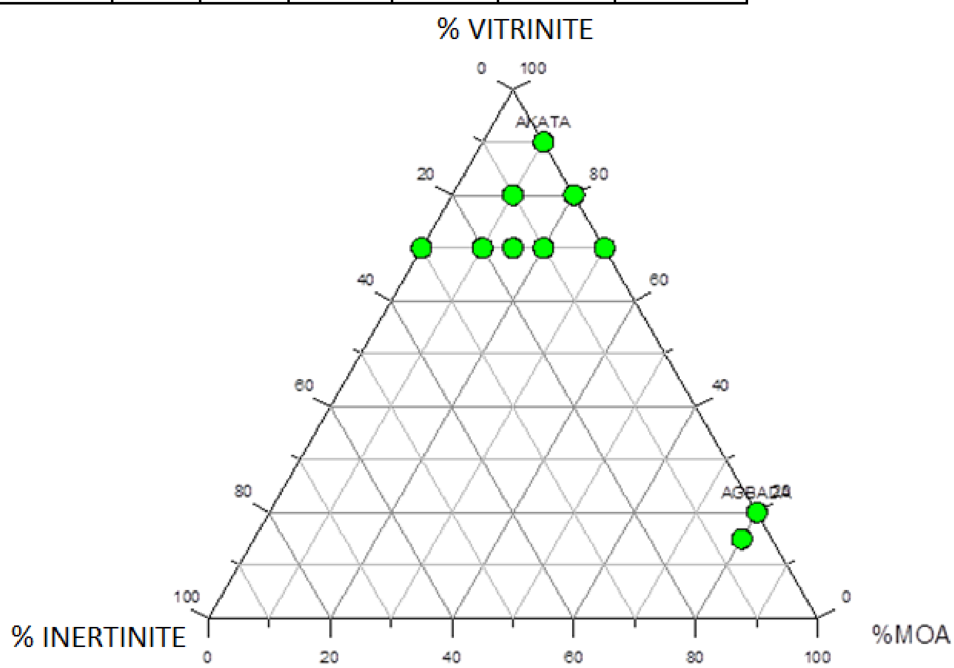

Figure 3. Ternary diagram showing the maceral group composition

***Assemblage 2*: Akata Formation**

This kerogen is dominated by the organic matter of terrestrial origin (structured debris) varies from 70 to 90 % (Fig. 4). Some woody particles degrade into amorphous (0 to 30%), sometimes oxidized (Fig. 12), with an absence of fluorescence. There is also a presence of opaque particles (inertinite) ranging between 0 to 20% (Fig. 9, Fig.10, Fig. 11, and Fig. 12). These facies represent terrestrial organic matter deposited in the marine environment and in deltaic deposits. The types of environments in which these facies occurs often correspond to the transgressive and early highstand systems tracts where some oxidation occurs and where different kerogen components can be deposited together [9]. The OM, apart from a few miospores is not fluorescent in its entirety, which gives it an average quality of hydrocarbon generation (Fig. 9, Fig. 10, Fig. 11, and Fig. 12). This absence of fluorescence is probably due to its state of preservation. The SCI varies between 4 and 7.5 would indicate an immature to mature kerogen (Fig. 5). Kerogen is classified as Type III and has low to medium potential for gas-prone. Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows weak preservation (FPI=2) for hydrocarbons generation.

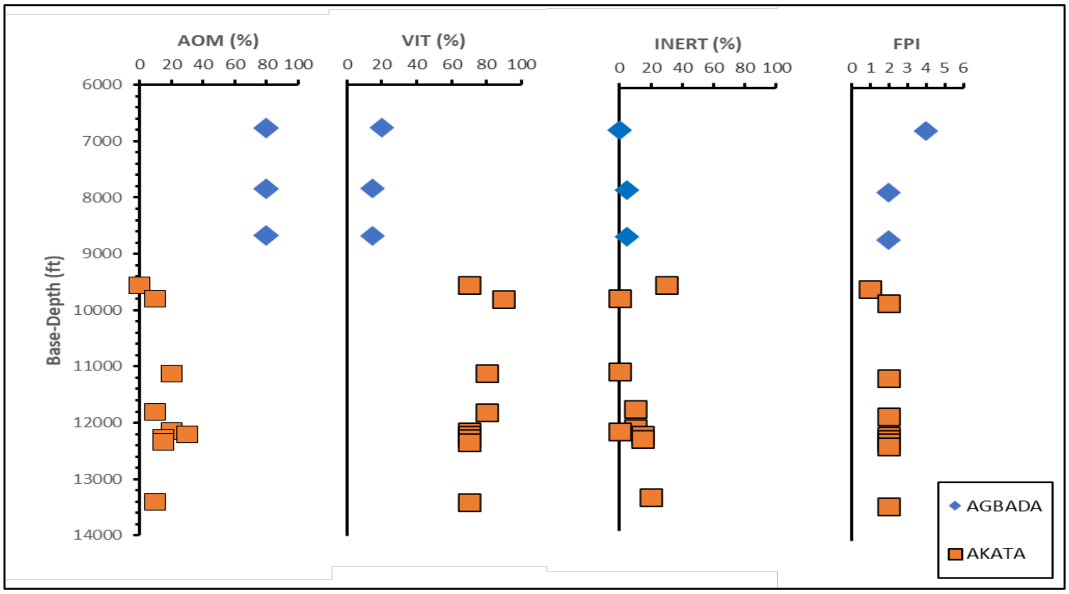

Figure 4. Source rock screening kerogen type vs. depth of studied well colored by the formation

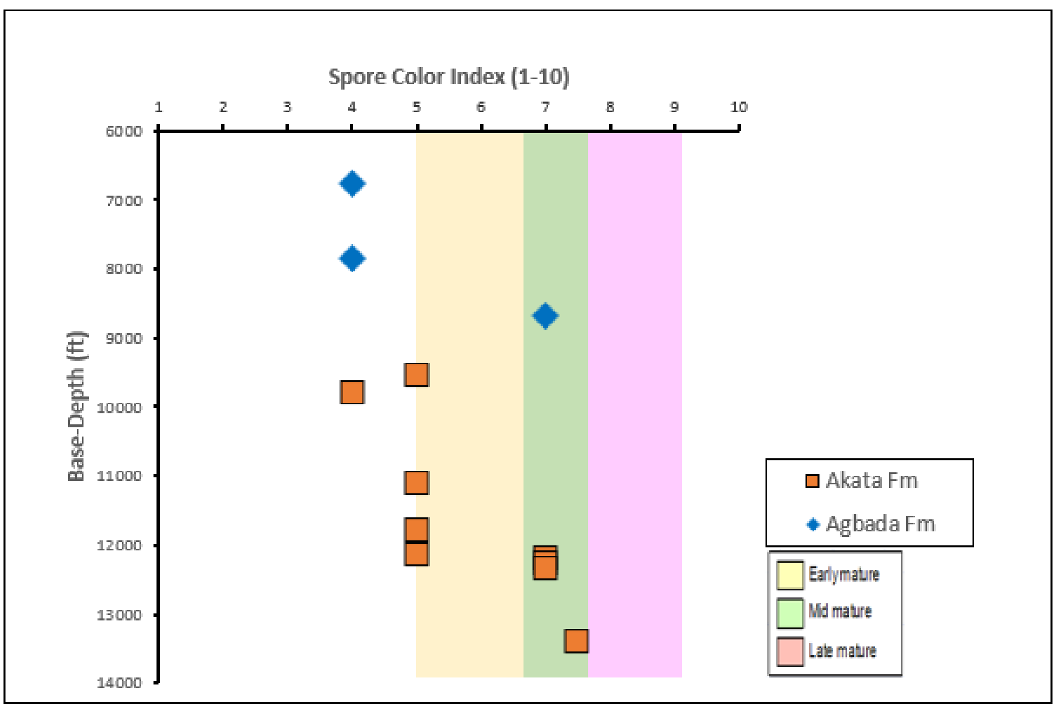

Figure 5. SCI vs. depth diagram of studied wells colored by the formation

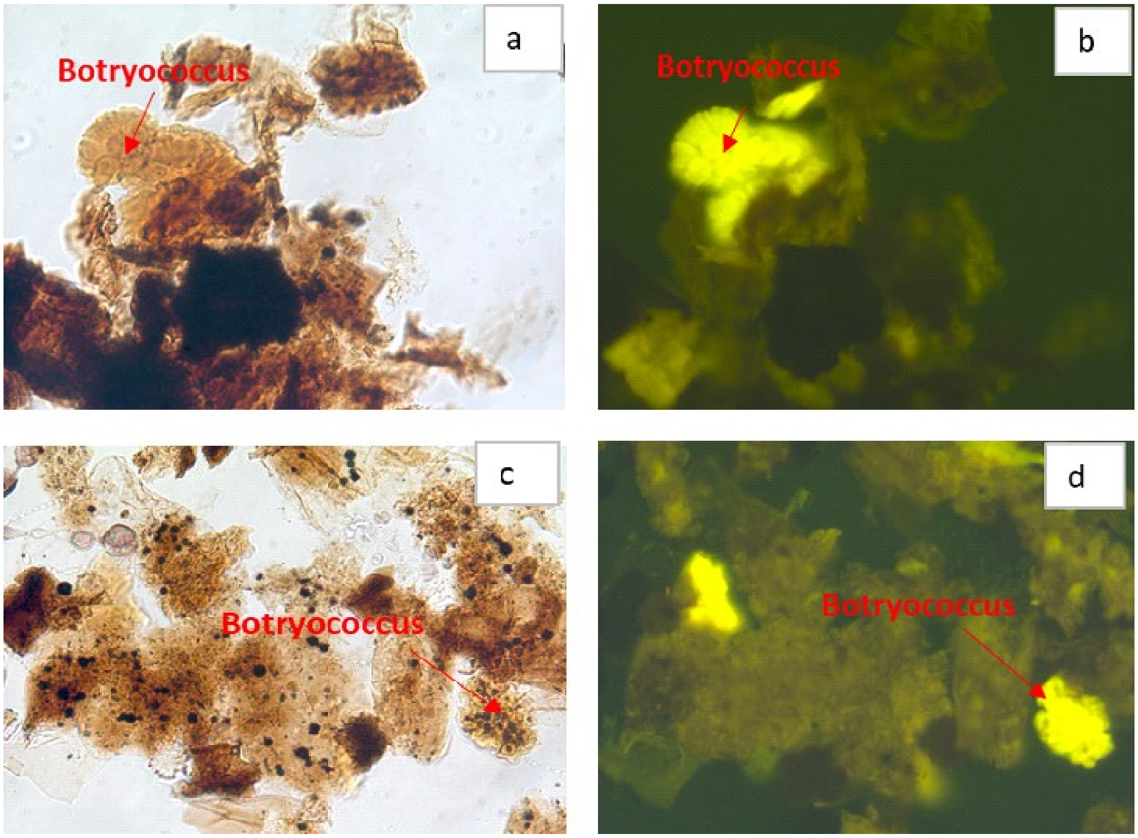

Figure 6. Photomicrographs of immature kerogen in Agbada formation (Well Isan 9 ‘6760 ft’**)** under transmitted white light (photo a, c) and in fluorescence mode (photo b, d): Kerogen is largely composed of amorphous organic matter which appears as fluorescent to weakly fluorescent kerogen. The fairly rich presence of fluorescent lake algae (*Botryococcus*)

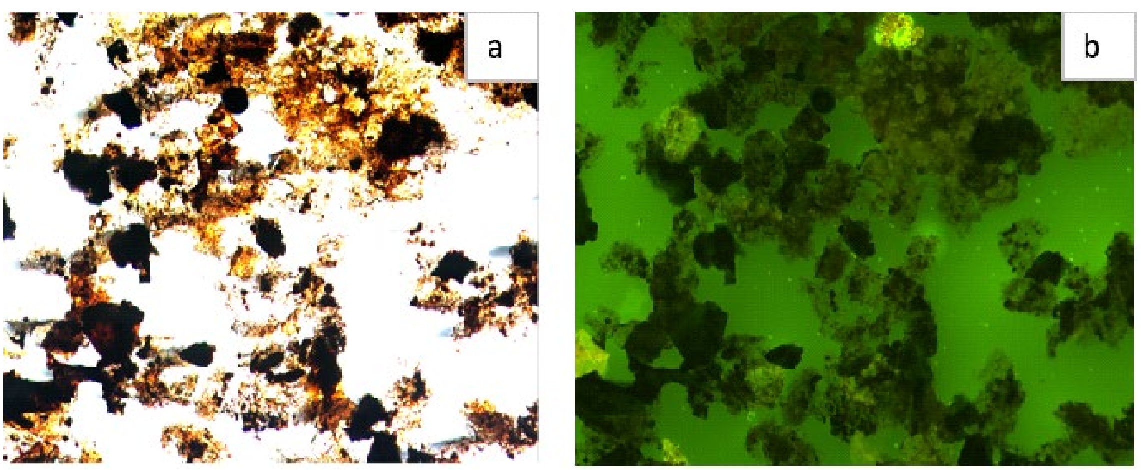

Figure 7. Photomicrographs of immature Kerogen in Agbada formation (Well Benin west ‘7840 ft’**)** under transmitted white light (photo a) and in fluorescence mode (photo b): Facies dominated by amorphous kerogen resulting in large part from the decomposition of particles of terrestrial origin. Dinoflagellates cysts also make a significant contribution to these facies

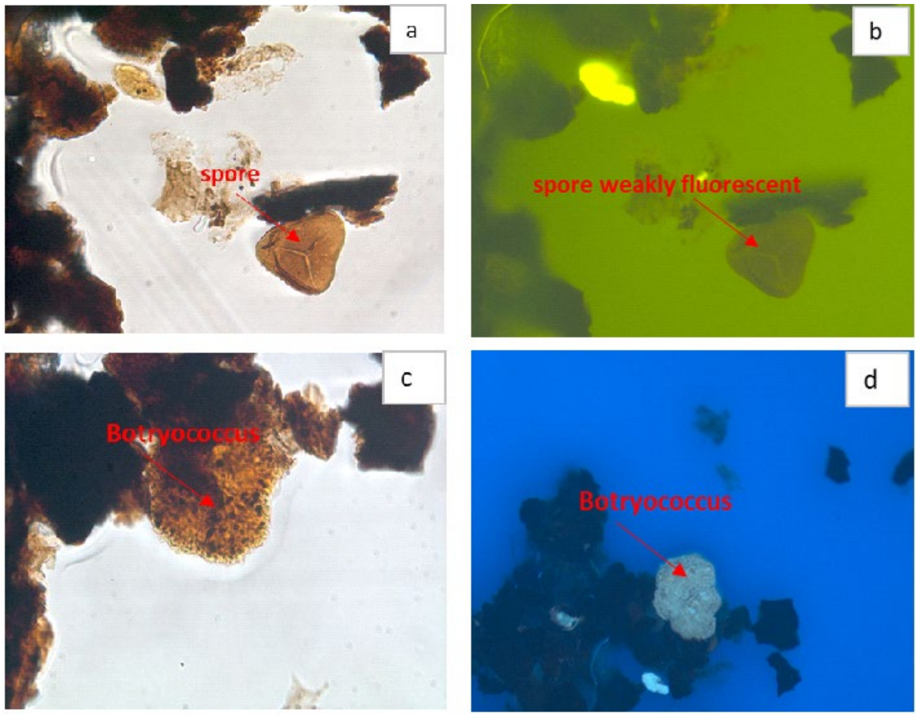

Figure 8. Photomicrographs of mature Kerogen in Agbada formation (Well Isan 9 '8680 ft'**)** under transmitted white light (photo a, c) and in fluorescence mode (photo b, d): Kerogen contains a fairly large amount of amorphous organic matter. This organic material appears as a weakly fluorescent to non-fluorescent kerogen. Fairly rich contribution from lake algae (*Botryococcus*) (photo c, d) and the weak presence of marine algae and spores (photo a, b)

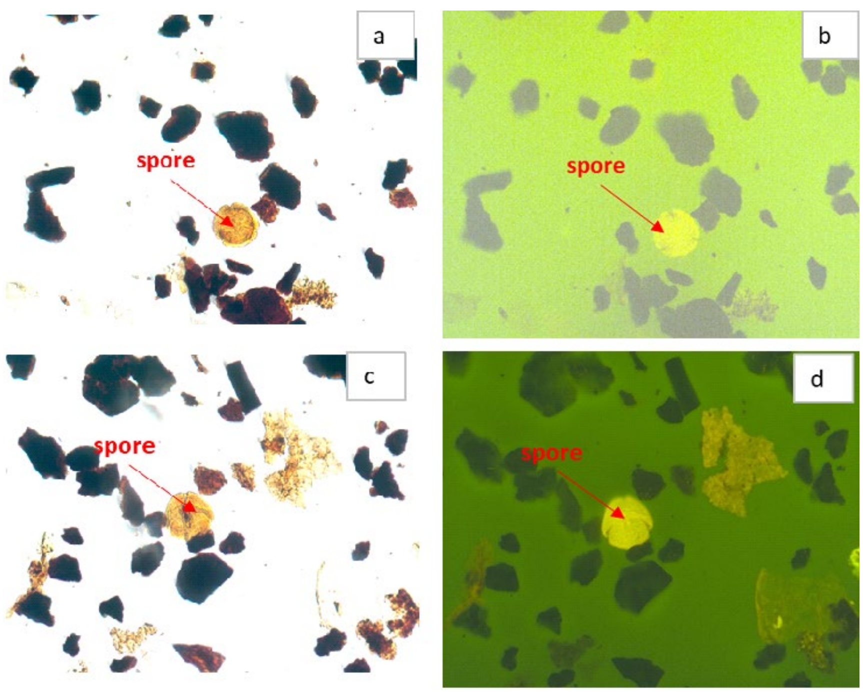

Figure 9. Photomicrographs of early mature Kerogen in Akata formation (Well Iyede 1 '9555 ft') under transmitted white light (photo a, c) and in fluorescence mode (photo b, d): Kerogen is largely composed of structured debris of terrestrial origin that is brown to black in color. The OM, apart from a few miospores is not fluorescent in its entirety

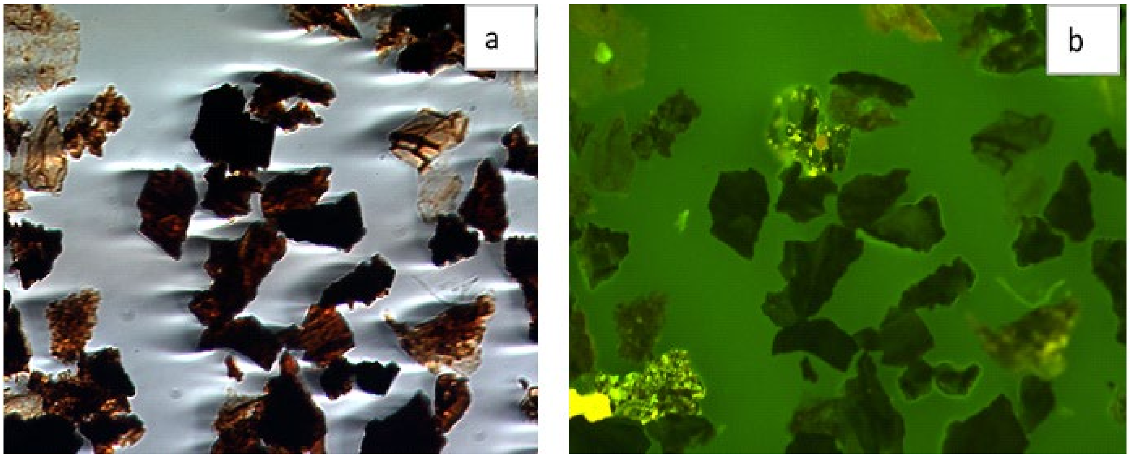

Figure 10. Photomicrographs of immature Kerogen in Akata formation (Well Ubefan '9800 ft') under transmitted white light (photo a) and in fluorescence mode (photo b): Kerogen is largely composed of structured debris of terrestrial origin. OM is not fluorescent in its entirety

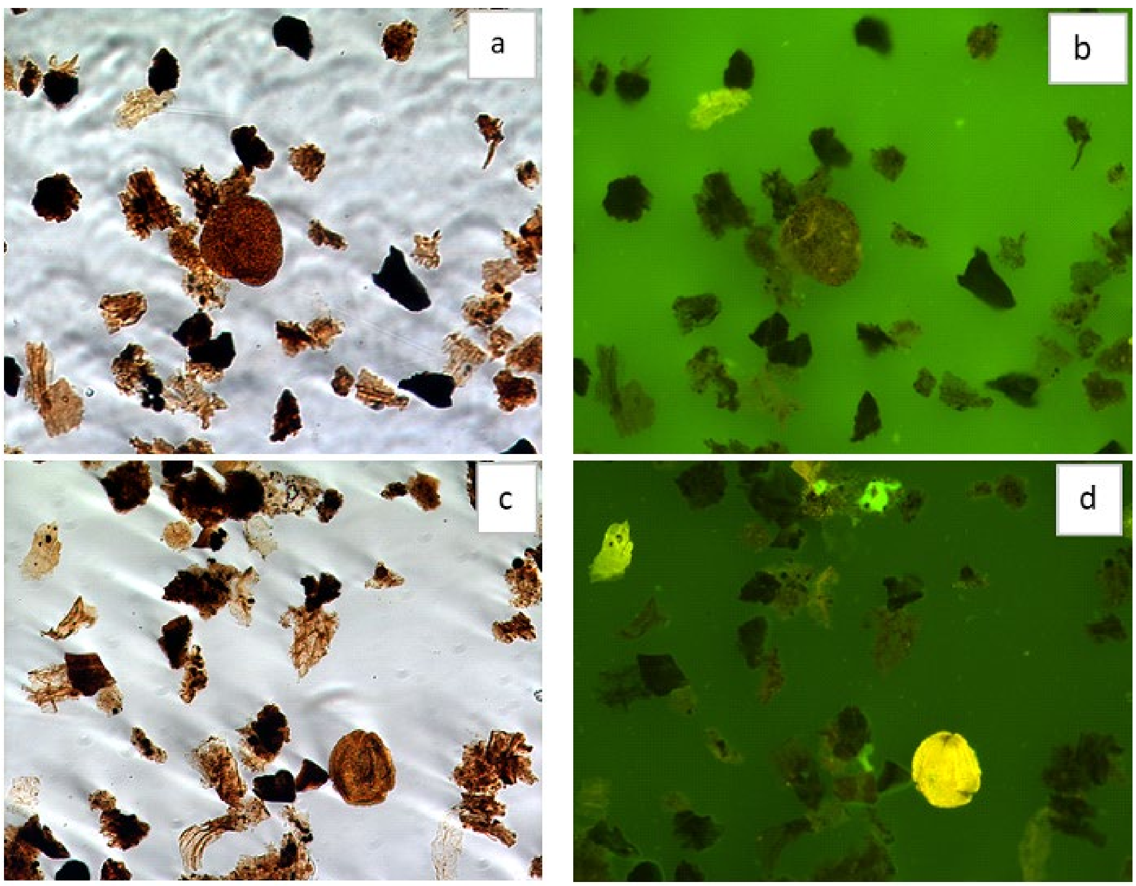

Figure 11. Photomicrographs of mature Kerogen in Akata formation (Udeduma Creek '12340 ft') under transmitted white light (photo a, b) and in fluorescence mode (photo c, d): Kerogen is mainly composed of structured debris. Woody particles are the most abundant. Some of these woody fragments degrade into amorphous with an absence of fluorescence

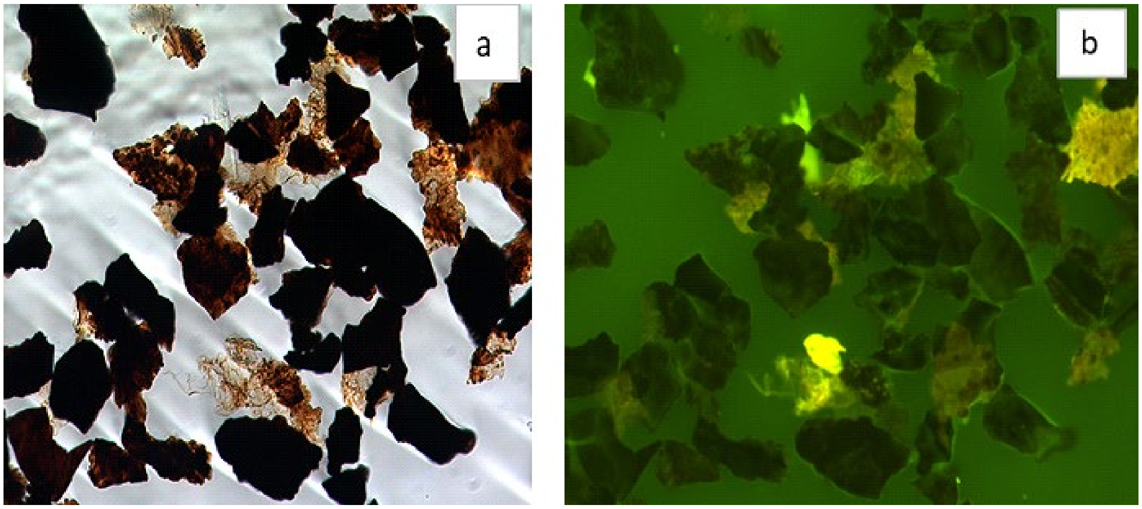

Figure 12. Photomicrographs of mature kerogen in Akata formation (Well Isoko '13400 ft') under transmitted white light (photo a) and in fluorescence mode (photo b): This kerogen is dominated by the organic matter of terrestrial origin (structured debris). Some woody particles degrade into amorphous with an absence of fluorescence. Presence of opaque particles (photo a; b)

5. Conclusion

Visual analysis of the kerogen contained in the formations of the onshore wells of the Niger Delta, based on optical analyses, revealed two assemblages of organic matter particles. One group from the Akata formation and the other from the Agbada formation. Visual Kerogen analyses were classified on the basis of vitrinite, inertinite, and amorphous organic matter (AOM).

The average percent count of AOM is about 80%, that of Vitrinite and Inertinite is about 20% in the Agbada Formation, with marine microfossils (Dinoflagelated cysts) and the presence of spore and fairly rich contribution from the very fluorescent lacustrine algae (Botryococcus) in two (2) wells (Well Isan 9). The kerogen of this formation is classified as Type II /III, and the organic matter is immature (SCI=4) to mature (SCI=7) according to thermal maturity parameters. Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows fair to good preservation (FPI range between 2 to 4) for oil and gas-prone generation.

The Akata formation is characterized by Vitrinite particles (70 to 90%), with low to moderate percentages of AOM and Inertinite (0 – 30%). This assemblage is classified as Type III kerogen. The SCI ranging from 4 to 7.5 would indicate an immature to mature kerogen and has low to medium generation potential for gas-prone. Under fluorescent light, the Fluorescence Preservation Index (FPI) of this kerogen shows weak preservation (FPI=2) for hydrocarbons generation. As this optical analysis can often be compromised by the low presence of kerogen particles in the samples, it is suggested that combine study with geochemical analysis, for example, Rock-Eval, for better characterization of the source rocks and assessment of the oil generation potential of the formations.

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