Geochemical and Palynological Characterization of Lignite Seams in Some Parts of South Eastern Nigeria

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DOI: 10.29322/IJSRP.9.09.2019.p9320
http://dx.doi.org/10.29322/IJSRP.9.09.2019.p9320

ABSTRACT

The main objective of the study is to carry out a geochemical and palynological characterisation of the lignite seams in some parts of South-eastern Nigeria. The study area is located within latitudes 5^0 27' N and 6^0 11'N and longitudes 6^0 52' E and 7^0 35' E, covering parts of Avodim, Nsukwe, Umudinkwa, and Nkpor. The study involves a detailed field study where outcrops of Ogwashi-Asaba Formations were described. Laboratory studies include playnological and proximate geochemical analysis. During field study, four lithofacies were identified in the studied sections namely: Mudstone facies A, Lignite facies B, Sandstone facies C, Ferruginized mudstone facies D. Characteristics of identified facies including colour, lithology, sedimentary structures and fossil contents suggest deposition in transitional sedimentary environments typical of flood plains and delta environments. The lignite facies B was preserved during a rise in the groundwater level. Corresponding to a transgressive phase. Identified palynomorphs are suggestive of proximal prodelta and near shore shallow shelf environments denoting the influx of terrigenous. Based on some index marker palynomorphs, an age range from Oligocene – Early Miocene is assigned to the lignite due to the presence of *Pachydermites diederixi, Verrrucatosporites usmensis, Inaperturopollenites hiatus, Psilatriporites rotundas, Magnastriatites howardi, Verrrucatosporites usmensis,* Zonocostites ramonae, *Retibrevitricolporites protrudens, Laevigatosporites ovatus* and *Psilatricolporites crassus, Retitricolporites irregularis.* Result of geochemical analyhsis showed that the average value of the moisture content at Avodim, Nsukwe, Umudinkwa and Nkpor are 7.2, 7.1, 6.55 and 6.1% respectively. The average ash contents (Dry Base) of lignite from the four study locations are 7.7, 7.1, 6.75 and 6.5 respectively. They recorded an average volatile matter contents of 49.4, 50.65, 50.6 and 49.24 respectively for the four study locations. The average fixed carbon contents of lignites from the study area are 72.6, 71.25, 72.55 and 73.6 respectively for Avodim, Nsukwe, Umudinkwa and Nkpor. A negative relationship exist between the fixed carbon and the other measured parameters. The fixed carbon decreased with increase in volatile matter, ash and moisture contents. It shows that lignite are gradually developing to sub-bituminous coal. The average values of hydrogen, oxygen, nitrogen and sulphur from the study area are relatively higher than those of bituminous coal from other coal deposits in Nigeria. This is because the coalification process results in loss of moisture (dehydration) and decarboxylation as the coalification process progresses; the carbon (rank) increase while the oxygen and hydrogen contents, decreases. Generally, the sulphur content of the lignite deposits are low and this makes them environmentally friendly in terms of industrial utilization. Economically, Lignite can be used for electricity generation, coal combustion and coal gasification by products. Lignite generated electricity is abundant, low cost, reliable and environmentally compatible. Although, lignites are ranked as low quality coals, its quality can be improved through beneficiation.

Keywords: *Palynological, geochemical, Ogwashi-Asaba, Lignite, Southeastern Nigeria.*

INTRODUCTION

Lignite also known as brown coal is the lowest quality and most crumbly coal due to its lowest heat content (Wendy, 2017). It is the first product of the coalification process which places it between peat and bituminous coal. According to Orajaka et al. (1990), lignite is one of the for fossil fuel resources found in substantial quantities in the Southeastern Nigeria and was first discovered by the Mineral Survey of Nigeria in 1908. Blatt et al (1972) described the process of formation of lignite begining as an accumulation of partially decayed plant material or peat. Burial by other sediments results in increasing temperature and pressure.This causes compaction of the material and loss of some of the water and volatile matter(primarily methane and carbon dioxide), a process known as coalification.

Although Nigeria is blessed with abundant lignite deposits, only few studies have been carried out on these Tertiary deposits (Simpson, 1955); Reyment, 1965; Okezie and Onukogu; Ahiarakwem, 2011; Ahiarakwem and Opara, 2012). The lignite deposits in the study area were used by locals for cooking purposes as reported by Ahiarakwem and Opara (2012). Although, lignite is classified as a low quality coal, it can be beneficiated and used for various industrial purposes.

There has been some controversies on the age of the Ogwashi Formation and the basin under which it belong. Nwajide, (1996), Hoque et al, (1977) assigned it to the Anambra Basin. Nwajide (2005) later re-assigned the Ogwashi Formation to the Niger Delta. The present studies tries to ascertain the age and stratigraphic disposition of the formation under study using detailed palynological analysis and field study respectively to either corroborate or criticize earlier studies.

Nigeria has abundant coal deposits that could be exploited to diversify the nation's economy. Nigerian coal include lignites, sub-bituminous coal and bituminous coal and are all found within the Southeastern sedimentary basins of Nigeria. The lignite deposits has however attracted limited attention which focused mainly on environment of deposition and age (Okezie and Onuogu, 1985, Oboh-Ikuenobe et al, 2005). Data on the geochemical properties which is necessary to characterize the lignite deposits for possible industrial use are scanty.

The Cretaceous and Tertiary coal and lignite deposits of the Lower Benue Trough and Niger Delta contain the largest and most economically viable coal and lignite resources (Obaje et al, 2004). These could be exploited for export to where they are put to use as sources of energy, in combustible engines and in industrial furnaces, as well as in liquefaction process plants where they could be converted to liquid hydrocarbons. They could constitute the bulk of the raw material for coke making consumable in the blast furnace of the Ajaokuta Steel Project.

Several studies have been carried out in the Niger delta sedimentary basin of Nigeria due to the petroleum potentials of the area. Most of these studies range from sedimentlogical/stratigraphic, biostratigraphic, paleontological, geophysical to petroleum geology. Generally, fewer works have been done and documented on the Nigerian lignite series of this basin. The lignite seams of southern Nigeria have been explored by mapping and drilling and thicknesses of the seams and shale associated with them in different locations recorded by Wilson (1925), Du Preez (1945), Da Swardt and Piper (1957).

Chene et al. (1978) carried out palynological study on the lignites and shales of the Ogwashi– Asaba Formation and assigned a Middle Eocene age for the basal part. Okezie and Onuogu (1985) presented data from chemical and gas analysis of lignites and showed that the lignite deposits have high calorific values, low sulphur but are generally rich in hydrocarbons, resins and waxes.

Obaje and Hamza (2000) investigated the liquid hydrocarbon potential of mid Cretaceous coals and coal measures in the middle Benue Trough of Nigeria and also subdivided the coal beds into three different coal facies, namely: a vitrinite-fusinite, a trimaceritic and shaly coal facies.

Oboh-Ikuenobi et al (2005) carried out a research on the Lithofacies, Palynofacies and Sequence stratigraphy of the Palaeogene strata in the Okigwe, Isiukwuato, Umuahia and Ozuitem districts in Abia State, southeastern Nigeria.

Ahiarakwem and Opara (2012) evaluated the geochemical properties and Industrial Applications of Lignite Deposits around Orlu and environs, Imo State, Southeastern Nigeria using both proximate and ultimate analytical procedures. From the study the ash, volatile matter and moisture contents of the lignite deposits in the three locations decreases with increase in fixed carbon content. These results revealed that the lignite in these locations are of high economic value as they can be used for power generation, coal gasification by- products and other industrial uses.

The Study Area

The study area is located within latitudes 5^0 27' N and 6^0 11'N and longitudes 6^0 52' E and 7^0 35' E, and the villages covered include; Avodim, Nsukwe and Umudinkwa, all in Umuahia South local Government Area and also includes Ogbunike/Onitsha Toll gate, and they all fall within the South-eastern part of Nigeria (Fig 1).

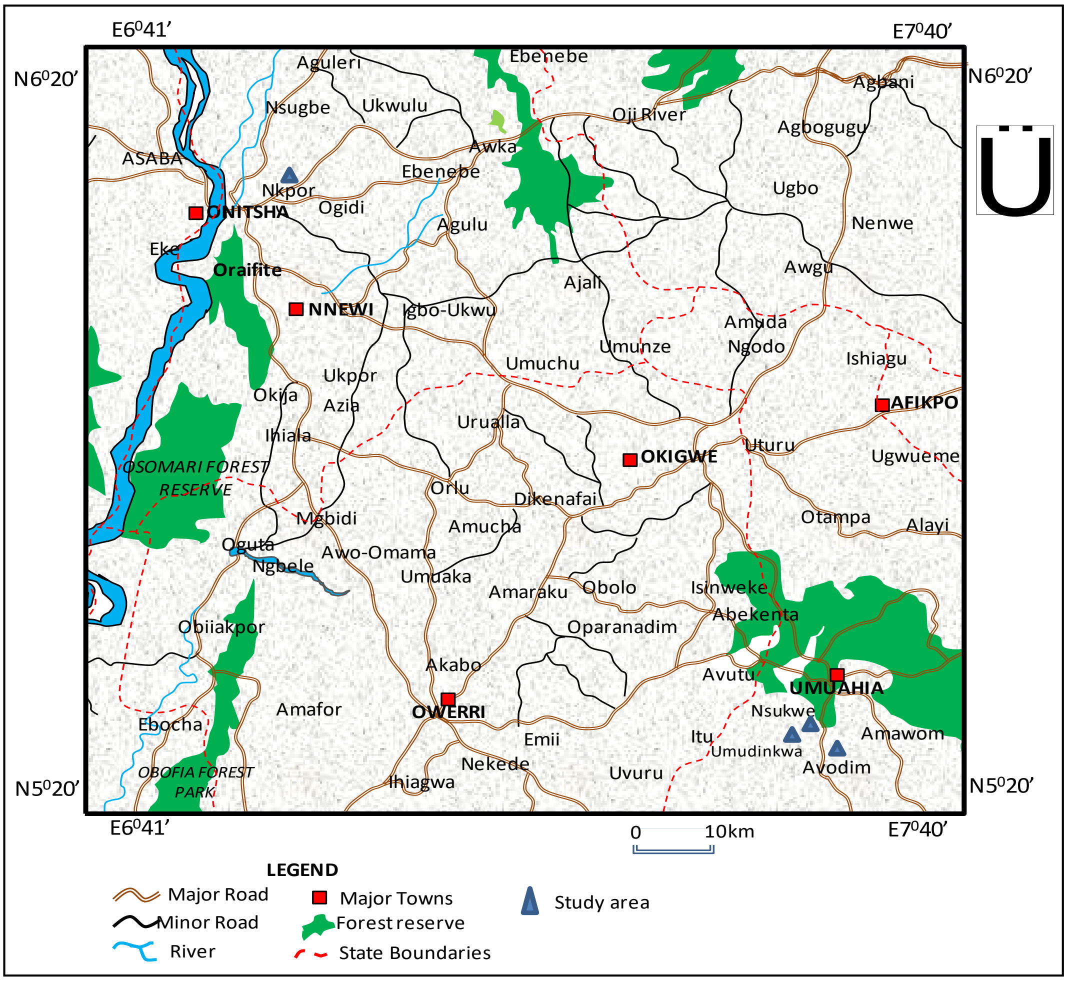


Fig 1 Location accessibility map of the study area

METHODOLOGY

Field Study

The field study entailed a geological mapping of the study area which includes bed-by-bed description and logging of lithosections while noting sedimentary features including texture, sedimentary structures, fossil content an lithology, description and sketching of lithologic logs of exposed rock sections to mimic grain size profiles and photographing of important features in the log sections.

Facies Analysis

Facies were described based on observed sedimentary features. The Markov model as described by Selly (1969) was utilized in the statistical analysis.

The Embedded Markov Matrix is utilized in the present study and involved the following:

i. Erection of transition count matrix (a two dimensional way of all possible vertical lithologic transitions) for each section.
ii. Tabulation of transition probability matrix,
iii. Tabulation of independent trial probability matrix,
iv. Erection of difference matrix,
v. A test of significance of resulting difference matrix (Selly, 1970; Walker, 1979).

Palynological Analysis

Lignite and organic rich shale samples were subjected to palynological analysis to ascertain their age. A total of ten samples were analysed; comprising of six lignite samples and four clay samples. Each sample was digested for 30 minutes in 40% hydrochloric acid to remove traces of carbonate and 72 hours in 40% hydrofluoric acid for removal of silicate. Approximately 100 g of cleaned rock sample, which has been crushed to pea-sized fragments, was placed into a large glass/pyrex beaker. 400 ml of hot/warm distilled/pure water was added into the beaker, stirred thoroughly and left overnight. The beaker was placed on a magnetic hot plate set at a moderate heat level with a plastic-coated magnetic stirrer and the mixture was agitated thoroughly. About 40 ml of sodium hexametaphosphate [(NaPO3)6] flakes was added to the sample vessel on the stirred hotplate. The mixture was stirred magnetically for about 15-20 minutes. The mixture was then sieved with 10 micro meter nylon mesh. The supernatant was mounted into already labelled glass slide using norland glue. The prepared palynological slides were analysed for the palynomorphs recovered in the sample preparation.

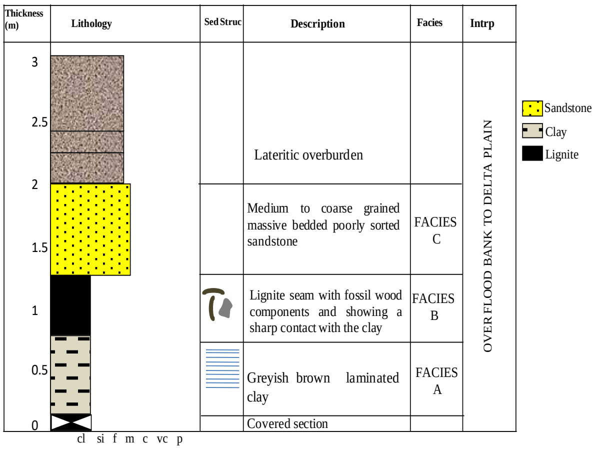
Geochemical Analysis

Eight representative lignite samples were obtained at each location with the aid of geologic hammer. Sampling was done at a minimum distance of 5m in each location. The samples were analysed within 24 hours of collection for analysis. Both Proximate and Ultimate Analysis were employed in the determination of the geochemical properties of the lignite. The proximate analysis of lignite/coal was developed as a simple means of determining the distribution of products obtained when the lignite/coal sample is heated under specified conditions. It separates the products into four groups:

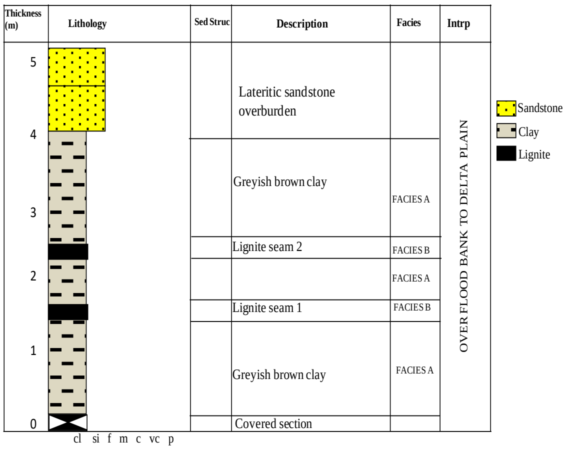
i. Moisture content
ii. Volatile matter, consisting of gasses and vapours driven off during pyrolysis
iii. Fixed carbon, the non-volatile fraction of lignite/coal.
iv. Ash, the inorganic residue remaining after combustion The ultimate analysis was carried out to determine the hydrogen, oxygen, sulphur and nitrogen contents of the lignite.

RESULTS

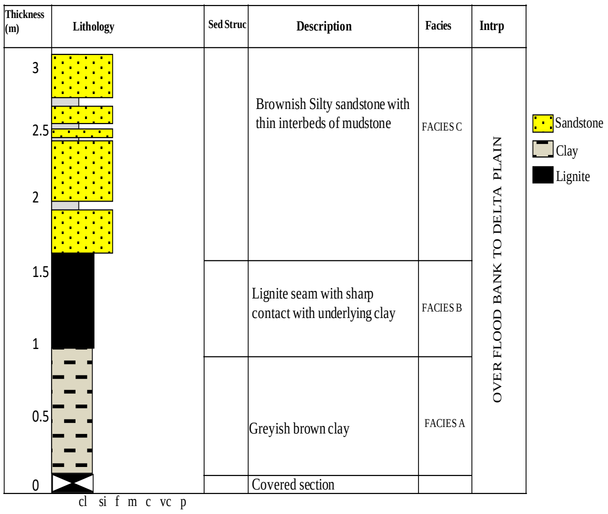
Lithofacies Description



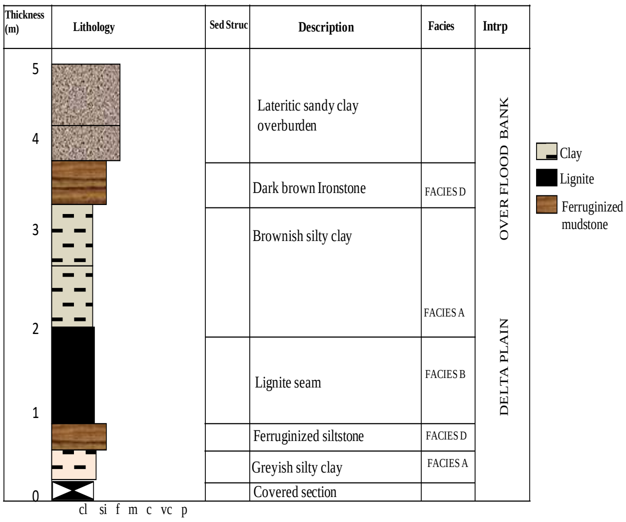
Lithosection of outcrop at Avodim



Lithosection of outcrop at Nsukwe



Lithostratigraphic profile of outcrop at Umudinkwa



Lithosection of outcrop at Nkpor

Fig 2. Lithostratigraphic profiles of outcrops in the study area

Mudstone Facies A

This facies is fine-graineded whose original constituents were clays or muds. The facies was recognized in association with the lignite units in all the locations exhibiting a sharp contact with the overlying or underlying lignite seam. This facies however lacks fissility usually associated with shale.

Lignite Facies B

This facies was recognized in all the studied sections. It occurred as dark grey slightly indurated seams with thickness of 1-2m. The thickest seam occurred at Nkpor overlying ferruginized siltstone. In lies sandwiched between mudstone facies in all occurrence

Sandstone Facies C

This facies is medium to coarse grained, poorly sorted and massive bedded. It occurred only at the section at Avodim. The contact between this facies and underlying units is sharp showing an abrupt transition in energy regime

Ferruginized mudstone Facies D

This facies occurs as hardground as observed at the outcrop at Nkpor. It was either deposited directly as a ferruginous sediment or created by chemical replacement, that contains a substantial proportion of an iron compound.

Light brown claystone facies A at Avodim

Lowermost part of Greyish brown clay facies A at Nsukwe

Ferruginized siltstone facies D depicting sharp contact with overlying lignite facies B at Nkpor

Lignite seam facies B at Umudinkwa

Fine grained greyish brown sandstone facies C at Umudinkwa

Ferruginized siltstone facies D at Nkpor

Fig 4. Described facies in the study area

Markov Chain Analysis

Individual facies relationship diagrams for the various sections studied in the field were erected based on the observed facies transitions (Fig 5). The composite facies relationship diagram for the respective formations were constructed by combining their respective individual FRDs (fig 6). A facies model was also constructed based on the composite FRD which summarizes the stacking signature of the strata in the area. Table 1 on the other hand show the summary table, computed statistical matrixes for lithofacies in the study area.

Table 1. Computed statistical matrix

Transition Count Matrix					
	A	B	C	D	Rt
A	0	4		2	6
B	3	0	2		5
C			0		0
D		1		0	1
Transition Probability Matrix					
	A	B	C	D	
A	0.00	0.66	0	0.33	
B	0.6	0.00	0.4	0.00	
C	0.00	0.00	0	0.00	
D	0.00	1.00	0.00	0.00	
Random Probability Matrix					
	A	B	C	D	
A	0	0.55	0.22	0.22	
B	0.63	0	0.18	0.18	
C	0.5	0.36	0	0.14	
D	0.5	0.36	0.14	0	
Difference Matrix					
	A	B	C	D	
A	0	0.11	-0.22	0.11	
B	-0.63	0	0.22	-0.18	
C	-0.5	-0.36	0	-0.14	
D	-0.5	0.64	-0.14	0	

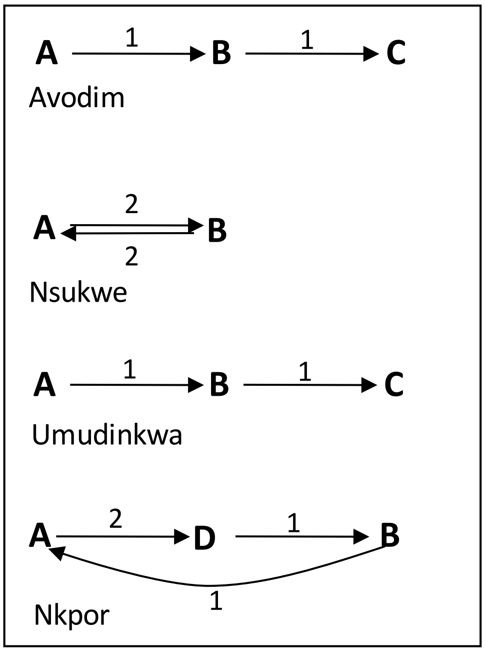


Fig 5. Facies relationship diagram

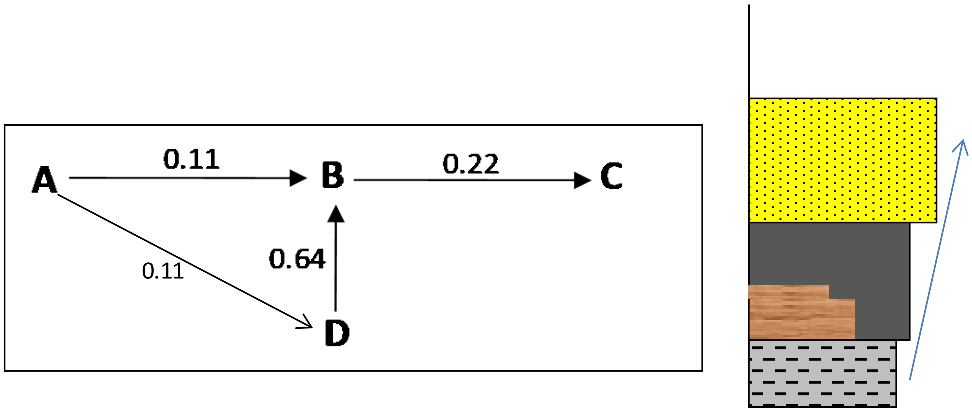


Fig 6. Composite FRD and 2D model

4.3 Result of Palynological Study

Nine (9) shale, mudstone and clayey sandstones samples were processed for their palynological contents. Several types of dispersed organic matter and palynomorphs were identified including spores and pollen, freshwater algae, structured phytoclasts (wood, cuticles, parenchyma), unstructured phytoclasts (communited and degraded fragments), and black debris. The study area is characterised by forms such as *Classopollis sp*, *Monoporites annulatus*, *Retitricolporites irregularis*, *Echiperiporites Icacinoidi*, *spachydermites diederixi*, *Striatricolporites catatumbus*, *Polypodiaceoisporites spp.*, *Bombacacidites spp.*, *Verrustephanocolporites complanatus*, *Deltoidspora minor*, *Laevigatosporites haarditii*, *Pilososporites sp*, *Verrucatosporites tenellis*, *Retitricolporites sp*, *Triorites africaensis*, *Classopollis sp*, *Monocolpites marginatus*, *Striatricolporites undulates*, *Longapertites marginatus*, *Mauritidites crassiexnius* and *Retibrevitricolporites triangulates* The assemblages were compared with stratigraphic chart of selected key sporomorphs for age determination.

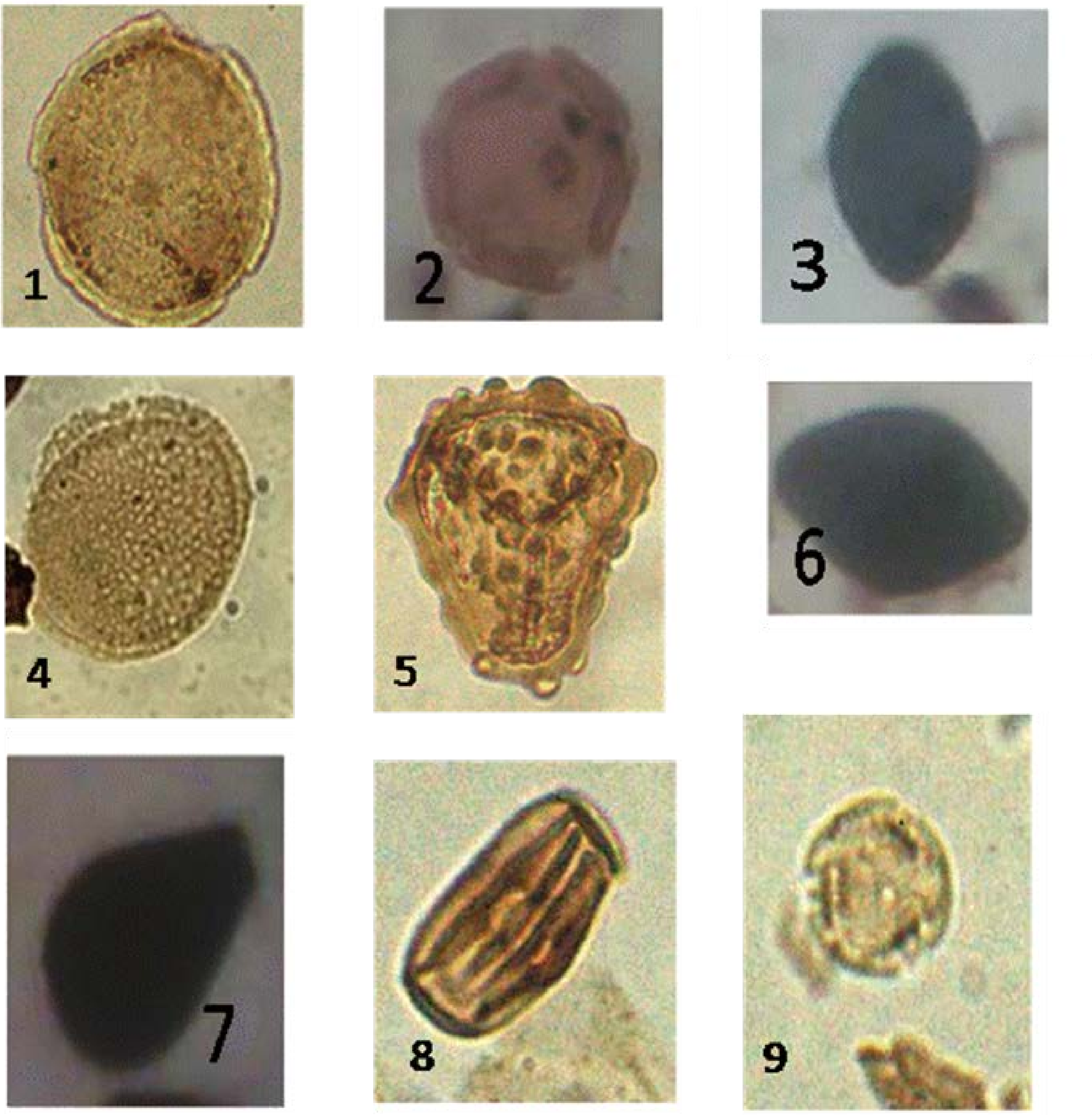


Fig 7a. Photomicrograph of some palynomorph assemblages

1. Psilatricolporites crassus 2. Pachydermites diederixi, 3. Fungal spore, 4. Proxapertites Cursus, 5. Polypodiaceisporites spp. 6,7. Fungal spores, 8. Psilastephanocolporites, 9. Psilatricolporites operculatus

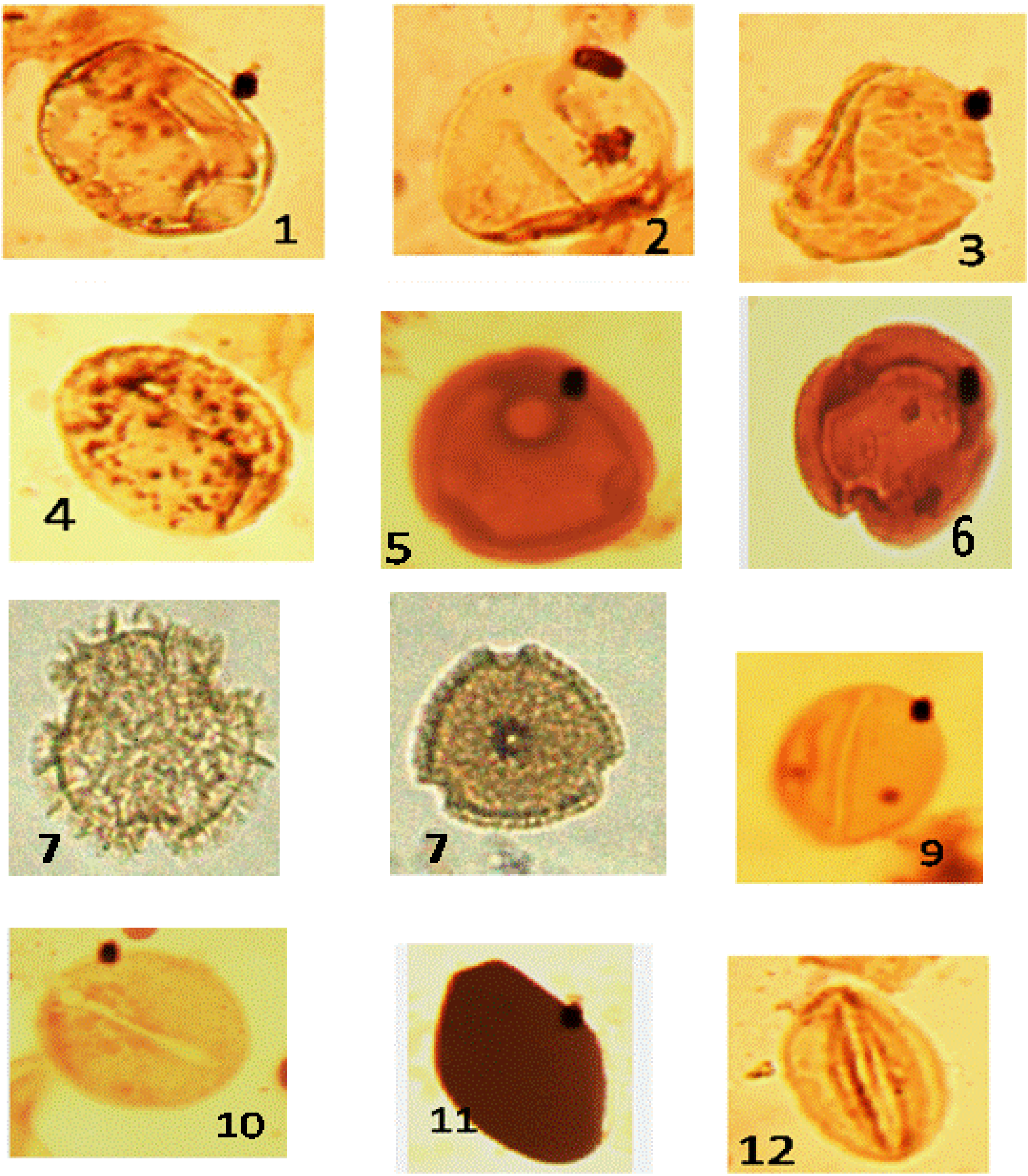


Fig 7b. Photomicrograph of some palynomorph assemblages

1,4, Laevigatosporites haarditi, 2. Pilosporites sp, 3. Verrucatosporites tenelis, 5,6, Retricolporites sp. 7, Retitricolporite irregularis, 8.. Retitricoporites heterobrochatti, 9,10. Monocolporites marginatus, 11. Fungal spore, 12. Striatricolporites undulates

Result of Geochemical Analysis of Lignite.

The result of the geochemical analysis is shown in Table 2 while comparison of the average value with those of sub-bituminous coals in some parts of Nigeria is shown in Table 3.

From the results, the moisture content ranges from 6.0 to 9.5 with an average value of 6.74. The ash content ranges from 6.1 to 8.0 with an average of 7.01. The volatile matter recorded a value of 48.5 to 52.0 with an average of 49.9. The fixed carbon showed a value range of 70.0 to 74 % with an average value of 72.5%. The percentage hydrogen of the lignite samples showed values of 6.5 to 7.5 with an average value of 7.09. Oxygen showed a range of 4.9 to 6.8, while sulphur ranges from 0.7 to 1.1 with an average of 1.0.

Bivariate plots of some of these parameters against each other were generated to show the trend relationship (Fig 8-10).

Table 2: Some Geochemical Properties of Lignite in the Study Area

LOCATION / PARAMETERS	AVODIM			NSUKWE			UMUDINKWA			NKPOR TOLL GATE		
	1	2	AVERAGE	1	2	AVERAGE	1	2	AVERAGE	1	2	AVERAGE
MOISTURE	7.50	6.90	7.20	6.70	7.5	7.10	6.9	6.20	6.55	6.19	6.00	6.10
ASH(db)	8.00	7.40	7.70	6.70	7.5	7.10	7.00	6.50	6.75	6.90	6.10	6.50
VOLATILE MATTER (afb)	50.3	48.5	49.40	49.30	52.0	50.65	51.20	50.00	50.60	49.47	49.00	49.24
FIXED CARBON (%)	72.00	73.20	72.60	72.50	70.00	71.25	71.60	73.5	72.55	73.20	74.00	73.60
HYDROGEN (%)	6.50	7.00	6.75	6.90	7.20	7.05	7.23	7.50	7.37	7.19	7.20	7.20
OXYGEN (%)	4.90	5.70	5.30	6.80	6.60	6.70	5.47	5.00	5.24	5.68	5.60	5.64
NITROGEN (%)	1.50	1.30	1.40	1.34	1.50	1.42	1.27	1.00	1.14	0.73	0.80	0.77
SULPHUR (%)	0.70	1.10	0.90	1.30	1.41	1.36	1.10	0.80	0.95	0.90	0.70	0.80

Table 3. Comparison of some geochemical properties of lignite from the study area with some other lignites and sub-bituminous coal deposits in Nigeria

LOCATION / PARAMETERS	Average values from present study				Other lignite deposits in Nigeria (Ahiarakwem and Opara, 2012)			Other sub-bituminous coal deposits in Nigeria (ASWEN, 1987)	
	AVODIM	NSUKWE	UMUDINKWA	NKPOR	UBAHA (Imo)	IHIOMA (Imo)	Umuhu-Okabia (Imo)	ONYEAMA (Enugu)	OKABA (Benue)
MOISTURE	7.20	7.10	6.55	6.10	6.19	7.57	6.47	5.80	3.50
ASH(db)	7.70	7.10	6.75	6.50	6.50	7.33	6.73	6.00	5.30
VOLATILE MATTER (afb)	49.40	50.65	50.60	49.24	49.4	60	51.2	44.50	43.00
FIXED CARBON (%)	72.60	71.25	72.55	73.60	72.6	71.33	71.60	75.40	80.50
HYDROGEN (%)	6.75	7.05	7.37	7.20	6.75	7.13	7.13	5.40	6.00
SULPHUR (%)	0.90	1.36	0.95	0.80	0.9	0.83	1.1	0.70	0.90

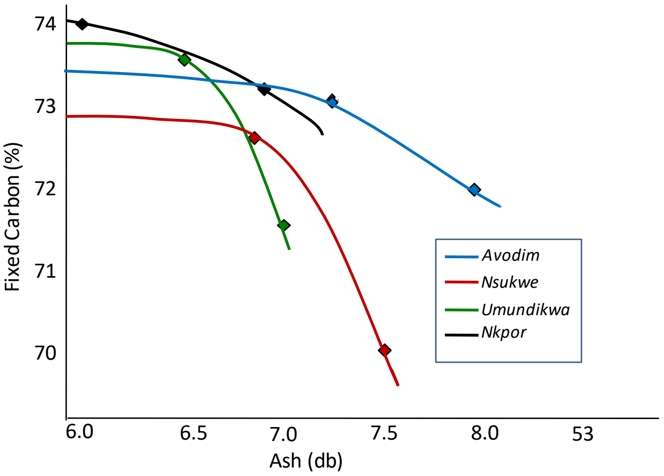


Fig 8. Fixed carbon-Ash content relationship

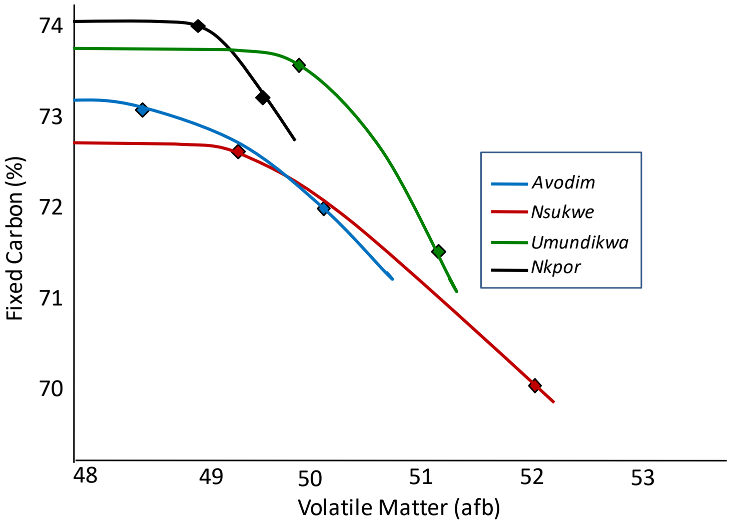


Fig 9. Fixed carbon-Volatile matter relationship

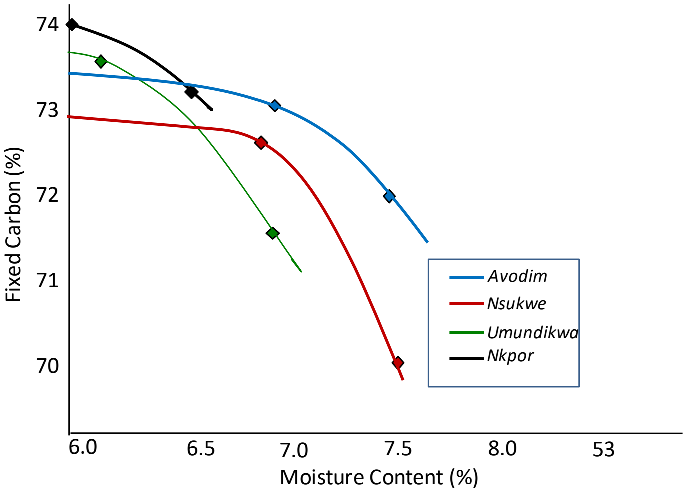


Fig 10. Fixed carbon-moisture content relationship

DISCUSSION

Environment of Deposition and Depositional Model

Three lithofacies were identified in the studied sections namely: Mudstone facies A, Lignite facies B, Sandstone facies C, Ferruginized mudstone facies D.

Colours of the various lithologies provide important field evidence of depositional setting (Boggs, 2006). Generally, the colour of sedimentary rocks provides useful clues to the depositional environment. Red (often more of a maroon or a pink), and brown, purple, or orange colouration in sedimentary rocks indicates the presence of iron oxides (Nichols, 2009). In well-oxygenated continental sedimentary environments, the iron in the sediments is oxidized to form hematite or ferric iron oxide (Fe_2O_3), which colours the sediment red, brown, or purple such as that which is obtainable in the study area.

The reddish-brown colourations of the ferruginized mudstone facies as observed in the study area typically indicate deposition in continental (or transitional) sedimentary environments such as flood plains, alluvial fans, and deltas (Reineck and Singh, 1980. The lignite facies B was deposited during a rise in the groundwater level. Inland from tidal influence the change from the lowstand to the transgressive phase may be marked by a change in fluvial style or by the development of coal beds. Coal commonly occurs during an initial increase in accommodation, before this is balanced out by an increase in clastic supply (Catuneanu, 2002).

Results of the analysis showed that the assemblage indicates dominance of sporomorphs. The vascular tissue sporomorphs are suggestive of proximal prodelta and near shore shallow shelf environments (Ojo et al., 2009). This denotes the influx of terrigenous organic matter in response to deltaic progradation on the shallow shelf (Habib, 1970).

The co-existence of the structured organic palynomorphs debris in the units as shown in palynological data suggests swampy conditions within a predominantly fluivial setting (Eisawa and Schrank, 2008).

Observed facies and sedimentary characteristics from the studied section are suggestive of fluvial operative processes which vary from fluvial deltaic to beach and shallow agitated marine. This is represents a mixed environment typical of fluvio-deltaic to shallow marine depositional settings. This is in agreement with the suggested paralic delta front facies model for the *Agbada* Formation (Ejeh et al, 2005, Short and Stauble, 1967) as well as the universally accepted models of growth and development of the Niger Delta Basin.

In this depositional model (Fig 11), lignite is present at the base of the short marine interval and forms the base of the cycle in a majority of cases. Less frequently, lignite is underlain by a thin interval of nonmarine deposits that form the base of the cycle. In both situations, the lignite is part of a thin transgressive interval. Cycles are separated by an exposure surface, usually marked by plant rooting and/or development of ferruginized units. Peat accumulated on top of these exposure surfaces and lignite is preserved where marine flooding allowed ocean waters to cover the peat deposits with fine grained sediments, producing high-ash lignite horizons of good lateral extent but variable thickness. Same depositional model was observed in the Late Eocene lignite-bearing strata, east-central Texas (Yancey, 1996).

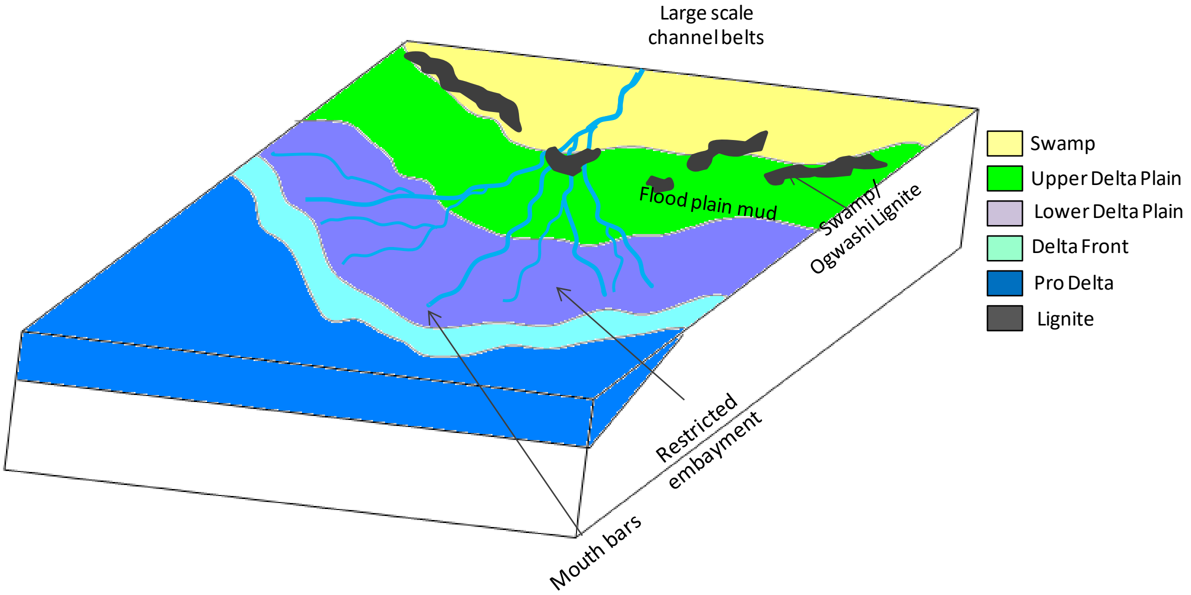


Fig 4.22. Proposed depositional model for lignite in the study area

4.5.2 Age Determination

The pollen and spores, dinoflagellates and other particulate organic matter which can be recognized and identified from a succession of rocks can be used effectively to define precisely the age and palaeoenvironment that prevailed during the deposition of the rocks. The palynofacies types and abundance provide information regarding the interpretation of the age and environment of deposition of the sediments in this area. Pollen and spores play a major role in dating and palaeoenvironmental determination due to their abundance and good preservation. The definition of the proposed age and palaeoenvironment is based on the data gathered from both the abundance and distribution of range species of the Palynomorphs.

The age of the sediments was assigned based on identified age diagnostic pollen and spore markers species according to the zonation schemes of Evamy *et al.*, (1978) and Legoux (1978). An age range from Oligocene – Early Miocene is assigned due to the presence of *Pachydermites diederixi, Verrrucatosporites usmensis, Inaperturopollenites hiatus, Psilatriporites rotundas, Magnastriatites howardi* in the samples.

It is pertinent to note that the study area at the time of deposition was dominated by diverse forest plant species. Some of these forest species include *Verrrucatosporites usmensis,* Zonocostites ramonae, *Retibrevitricolporites protrudens, Laevigatosporites ovatus* and *Psilatricolporites crassus, Retitricolporites irregularis,* etc.

The percentage abundance of the different species at a particular time, gives rise to the different depositional environments, thus generally it was assigned fresh water swamp forest.

Adegoke et al., (1978) had used the presence of Monocolpites marginatus, P. Operculatus, to assign a Paleocene age to the Kerri-Kerri Formation in Northern Nigeria. Also, Salard (1979) had listed Monocolpites spp., under the Late Paleocene P. Operculatus zone, while the Eocene assemblage is composed of Retibrevitricolpites triangulates, Silatricolporites operculatus, Monoporites annulatus among othrs, of which majority were present at some sections of the study area.

Furthermore, Elsawi and Shrank (2008) had also associated Monocolpites marginatus, L. Marginatus and Syncolporites marginatus with the Paleocene. Elsawi and Shrank (2008) also associated Poperculatus, Echiperiporites icacinoidis, Echitriporites protudens, Retistephanocolpites williamsi with the Eocene of the Melut Basin in Sudan.

Again, Salami (1983) in studying the Upper Senonian(Maastrichtian) and Lower Tertiary (Paleocene-Eocene) pollen grains from Southern Nigeria had recorded L. Marginatus, Retibrevitricolpites triangulates, Retistephanocolpites williamsi among the recovered palynomorphs from Okigwe samples.

This study has shed more light on the palynology of the Formation encountered in the study area, thereby confirming the age as late Paleocene-Early Miocene. The palynoflora revealed an assemblage similar to the Palm province of (Herngreen and Chlonora, 1981; Herngreen et al., 1996 and Jaramilloet al., 2007).

Geochemical Properties and Industrial Applications

Moisture Content

Moisture in coal must be transported, handled and stored. Since it replaces combustible matter, it decreases the heat content per kg of coal. Typical range is 0.5 to 10% (Thomas, 2013).

The average value of the moisture at Avodim, Nsukwe, Umudinkwa and Nkpor are 7.2, 7.1, 6.55 and 6.1% respectively. It is quite imperative to note that moisture content decreases as the coalification process progresses. A comparison of the average moisture contents of the four lignite deposits in the study area with those of other lignites studied by Ahiarakwem and Opara (2012) showed similar trend, however comparision with other sub-bituminous coals in some parts of Nigeria indicates that lignite are gradually tending towards sub-bituminous coals; the moisture content decreases as the fixed carbon increases. The total moisture content is important in assessing and controlling the commercial processing of lignite. It is used to determine the amount of drying that is needed to reach a giver moisture content; it is also used to determine the amount of freeze-proofing agents to be added. In cooking process, lignite with high moisture content (as is the case with the study area) requires more heat for vaporization of the moisture, and this leads to longer cooking cycles and decreased production. It is possible to use standard furnace to rapidly drive off the moisture content and thus reduce the long looking cycles (Ahiarakwem and Opara, 2012, Famuboni, 1996, Fatoye et al, 2012).

Ash (Dry Base)

The average ash contents (Dry Base) of lignite from the four study locations (Avodim, Nsukwe, Umudinkwa and Nkpor) are 7.7, 7.1, 6.75 and 6.5 respectively. These values are also relatively higher when compared with those of sub-bituminous coals. Compared with lignites of Ahiarakwem and Opara (2012), the values from the study area is slightly higher, however, the variation is not a marked one. The ash content decreases as the fixed carbon increases. The ash value is an empirical quantity, but it is quite useful for many practical applications. In combustion, high ash content reduces the amount of heat obtainable from a given quantity of lignite (Thomas, 2013). High ash content also leads to the problem of handling and disposing of large amount of ash produced during combustion. The ash content of raw coal/lignite is often used to select the best cleaning method and the ash content of the cleaned coal/lignite is used to measure the effectiveness of the cleaning process (Davies et al, 1976; Ahiarakwem and Opara, 2012)

Volatile Matter

Volatile matters are the methane, hydrocarbons, hydrogen and carbon monoxide, and incombustible gases like carbon dioxide and nitrogen found in coal. Thus the volatile matter is an index of the gaseous fuels present. Typical range of volatile matter is 20 to 35% (Thomas, 2013). The lignite samples from the four study location have average volatile matter contents of 49.4, 50.65, 50.6 and 49.24 respectively. This is similar to the Ihioma, Umuhu-Okabia and Ubaha lignite deposit studied by Ahiarakwem and Opara (2012). It should be noted that the volatile matter content of lignite varies from 45 to 65 (Martin et. al., 1983). The average lignite values of the

study area are also high when compared with those of sub-bituminous coal. This is because volatile matter content of a carbonaceous material decreases as the rank of the material increases (Fig. 4.13). Volatile matter values are important in choosing the best match between a specific type of lignite/coal burning equipment and the lignite/coal to use with the equipment. Volatile matter values are also used as an indication of the amount of smoke that may be emitted from furnaces or other types of coal burning equipment. The volatiles can be properly handled if standard furnace is used; appropriate pollution mitigation strategies are usually put in place in such a situation (Ahiarakwem, 2011). This enables the use of lignite for industrial purposes in sustainable manner.

Fixed Carbon

Fixed carbon is the solid fuel left in the furnace after volatile matter is distilled off. It consists mostly of carbon but also contains some hydrogen, oxygen, sulphur and nitrogen not driven off with the gases. Fixed carbon gives a rough estimate of heating value of coal.

The average fixed carbon contents of lignites from the study area are 72.6, 71.25, 72.55 and 73.6 respectively for Avodim, Nsukwe, Umudinkwa and Nkpor. These values are within the fixed carbon range of 60 to 75% for lignite deposits (Martin et. al., 1983). The fixed carbon value is one of the parameters used in determining the efficiency of lignite/coal burning equipment. It is also a measure of the solid combustible material that remains after the volatile matter in coal/lignite has been removed. For this reason, it is also used as an indication of the yield of coke in cooking process (Thomas, 2013). The relationship between the fixed carbon and the volatile matter, fixed carbon and ash contents and fixed carbon-moisture content of the lignites from the for study locations are similar. The fixed carbon decreased with increase in volatile matter, ash and moisture contents. The fixed carbon content shows that

lignite are gradually developing to sub-bituminous coal. The beneficiation of the lignite can enable its use for production of coal briquettes (Ahiarakwem and Opara, 2012).

Hydrogen, Oxygen Nitrogen And Sulfur

The average values of hydrogen, oxygen, nitrogen and sulphur from the study area compared similarly the lignites of Ahiarakwem and Opara (2012). These values are relatively higher than those of bituminous coal (Table 4.7), as expected. The coalification process results in loss of moisture (dehydration) and decarboxylation as the coalification process progresses; the carbon (rank) increase while the oxygen and hydrogen contents, decreases. Generally, the sulphur content of the lignite deposits are low and this makes them environmentally friendly in terms of industrial utilization.

Economic Significance of Lignite

Lignite can be used for electricity generation, coal combustion and coal gasification by products (Aiarakem et al., 2012). Lignite generated electricity is abundant, low cost, reliable and environmentally compatible.

Although, lignites are ranked as low quality coals, its quality can be improved through beneficiation (Ahiarakwem et al., 2012). When beneficiated, lignite can be used for powering of trains, production of briquettes, cements, iron and steel. The use of lignite hole briquettes for cooking purposes is cheaper and less hazardous when compared to gas and even kerosene (Ahiarakwem et al.,2012).

The low sulphur contents of lignite are advantageous for its use in various purposes. It is important to note that Peat which is the precursor of coal Formation is an important industrial resource in Ireland and Finland. Although, peat is of lower quality when compared with lignite, it is being beneficiated and used for various industrial purposes in these countries (Ahiarakwem et al., 2012). In Indonesia as well as Australia, prolific oil fields have been discovered which are known to be sourced by coals (Shanmugam, 1985; Noble et al., 1991). Obaje et al, (2004) has also characterized the Cretaceous coals as possible source rock.

More recently, several workers have used Rock-Eval pyrolysis and vitrinite reflectance data to demonstrate that Western U.S. coals are capable of generating hydrocarbon liquids at least at the local scale (Barker, 1989; Clayton etal., 1989; Law et al., 1990; Rice et al., 1992).

CONCLUSION

Lithofacies, palynological and geochemical studies has been utilized in the present study to characterize the lignite deposits in parts of southeastern Nigeria. The environment of deposition has been interpreted as a fluvially dominated parallic shallow marine. Palynological evidence attest to terrestrial inputs.

Based on some index marker palynomorphs, an age range from Oligocene – Early Miocene is assigned to the lignite

The lignite deposits are characterized by relatively high moisture, ash and volatile matter contents. These high values make the lignite less appreciated for industrial application. However, the lignites are characterized by low sulphur content making them more environmentally friendly

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