Proximate and Ultimate Characteristics of Okobo Coal Deposit, Kogi State, North Central Nigeria

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Abstract
With rekindled interest in coal as a viable source of energy adequate to serve wide spectrum of industries in Nigeria, there is need for continuous appraisal of the coal deposits within the country. This study was geared towards enriching existing knowledge by investigating the proximate and ultimate characteristics of the Okobo coal deposit. The proximate analysis was carried in accordance with America Society for Testing and Materials standards while the ultimate composition was determined using NITON XL3 X-ray fluorescence (XRF) Analyzer. The analyses were carried out at the Centre for Minerals Research and Development, Kaduna Polytechnic, Nigeria. The field work reveals seven lithologic units; sandstone, siltstone, shale, sandy-shale, mudstone, carbonaceous shale and coal. On the average, the proximate result reveals moisture content of 15.20%, volatile matter of 48.42% and ash content of 19.89% with fixed carbon of 16.42%. These values place the Okobo coal at a disadvantage as metallurgical coking coal. However, favours its usage as feed for coal power systems and possibly liquefaction. The ultimate result showed the presence of C (42.16%), H (4.44%), N (1.16%), Al (0.23%), Si (1.37%), S (1.02%), Fe (1.16%), and Ca (0.24%) as major elements, while the trace elements are Ti (1610ppm), V (36ppm), Cl (110ppm), Sr (20ppm), Zr (42ppm), and Cd (20ppm). Aside, C, H and N some of the elements have low concentrations when compared with their Clark values except Fe, Ti, V, Zr and Cd with high values. In terms of mineralization, the Okobo coal is highly enriched in Cd, slightly enriched in Ti and depleted in other elements

Keywords: Okobo, Coal, Proximate, Ultimate, Anambra Basin

1. Introduction

Coal is a black to brown, heterogeneous sedimentary rock which contains varying proportions of combustible and incombustible materials (Say-Gee and Wan, 2011). The physicochemical alteration and compaction of plants under anaerobic conditions leads to the formation of coal. Beneath the soils of every continent, billion tonnes of coal have been reported with USA, the Soviet Union and China hosting the largest deposits. It has also been reported that Nigeria has the largest deposit of low rank coal (Lignite) in Africa (Adedosu *et al.*, 2007) in addition to sub–bituminous and bituminous coal grades. Previous works have shown that the Nigeria Coal deposits are geologically hosted within the inland Anambra Basin and the Benue Trough (Obaje, *et al.*, 1999, Reijiers and Nwajide, 1998, Akande, *et al.*, 1992 and Simpson, 1954), Also, various parameters such as moisture, volatile matter, ash, calorific value, vitrinite reflectance, cokeability, porosity, grindability, elemental composition amongst others have been used by diverse researchers to investigate the physical, chemical and biological alternations that took place within the precursors of the coal deposits thereby providing insights to the coal characteristics and its economic use. This recent study employs parameters such as moisture, volatile matter, ash and elemental composition to evaluate the quality and possible utilization of the newly discovered Okobo coal deposit.

2. Literature Review

Several works on the characterization of the Nigerian coal deposits have been well documented. Akande *et al.* (1992) reported that the Enugu, Orukpa, Okaba, Ihioma and Ogwashi-Asaba coal deposits are suitable as blends with coking coals of high grade based on their ranks and maceral composition. They also suggested that the Enugu (Onyeama) coal can serve as good feed for liquefaction plants on the basis of its petrological characteristics. Ezeh and Okeke (2016) also postulated that the Enugu and Benue coal based on their fixed carbon and ash contents fall within the sub-bituminous coal grade and can be utilized as feedstock for coal power plant. On the other hand, the assessment of the Qgwashi –Asaba coal reveals that it is a brown coal. Isaiah *et al.* (2015) reported the presence of potentially toxic elements such as Ba, V and Cr in the Okaba and Enugu Coal with U detected in Okaba and Th in both. They inferred that the quantities of some trace elements were as low as 3.09 ppm (Co), 0.79 ppm (Ta), and 0.22 ppm (Lu) thus; utilization of the coal for electricity generation must take into account proper control of the hazardous elements. Adekunle *et al.* (2015) evaluated the Okaba and Ogboyoga coal for their suitability as blend for biocoal briquettes on the basis of moisture, ash, volatile matter, fixed carbon and calorific contents. The results show that a ratio of 50:50 of the coal investigated and saw dust yielded biocoal briquettes that can be used as alternative composite fuel. The Ogboyoga biocoal briquette exhibited the most favourable quality with the highest calorific value of 29.55MJ/kg. The Lamja, Chikila, Lafia-Obi, Maiganga and Okaba coal from the middle and lower Benue Trough have also been studied by Usman (2015). From the investigation using biomarkers, heavy metals, mineral and proximate contents, it showed that the moisture, ash, volatile matter and fixed carbon content range from 1.02 to 4.23%, 10.07 to 17.53%, 30.35 to 41.66% and 44.04 to 51.10% respectively with presence of heavy metals that exceed the Federal Environmental Protection Agency (FEPA, 1999) limit. The biomarkers indicated that the coals originated from terrestrial organic matter deposited under oxic condition. The depositional condition is evidenced by the high Pristane/Phytane ratio (>3) and the high degree of waxiness (> 1) exhibited by the coals. Adedosu *et al.* (2007) conducted studies on the geochemical and mineralogical importance of trace elements in six coal samples (Ribadu, Okpara, Okaba, Orukpa, Ogboyoga and Ogwashi-Asaba lignite). The results show a positive correlation between Cr and Ni contents as well as V/Ni ratios for the coals. This suggests a terrestrial / marine source of organic matter and low maturity. They also inferred that the presence of iron and titanium elements in relatively high amount depicts possible occurrence of their bearing minerals such as pyrite, siderite, ankerite and ilmenite and rutile respectively. As low rank coal, they are adequate for electricity generation and the ash by-product could be source for some low inherent minerals such as nickel, iron, titanium and copper. In addition, Ogala (2012), evaluated the lignite of the Ogwashi-Asaba formation based on their petrology, chemical and mineralogical composition and the study revealed that the lignite have low ash yield, low telohuminite and high detrohuminite and liptinite contents with minute quantities of quartz and clay minerals. These minerals are indicative of the organic forming matter been accumulated in a continental basin with little influence of extraneous materials probably due to the large canopy of vegetation that prevailed in the paleoenvironment.

3. Materials and Method

The method employed in the study includes field work, sample preparation and laboratory work.

3.1 Fieldwork

The field work involved observation and description of the different lithological units and their sedimentary features within the coal mine. Five sections within the available mine pit was selected based on rock stability and exposure of the representative sedimentary strata. During the field work, global positioning system (GPS) was used to take and record the spatial data of each section studied. The geographic coordinates were identified and marked on the base topographic map. Detailed description of the units in terms of rock type, grain size, colour and thickness were represented in the field as graphic logs. Within each section, 5 kg coal sample was collected, placed in a plastic bag and properly labelled.

3.2 Sample Preparation

The coal sample preparation and analyses were carried out at the Mineral Processing and Assay Laboratory and the Centre for Minerals Research and Development in Kaduna Polytechnic, Kaduna, Nigeria. Initially, each block of the coal samples was disintegrated with the aid of a sledge hammer into smaller lumps. The smaller fragments were collected in a container and carefully labelled and taken to the gyratory crusher. At the crushing section, the samples were further reduced to 2 to 4 mm size fractions and then packaged for the proximate and ultimate analyses.

3.3 Proximate Analysis

The coal sample preparation method used was in compliance with the American Society for Testing and Materials Standards (ASTM, 2004). To carry out the analysis, each of the crushed coal samples was weighed, coned and quartered until one fourth (1.25kg) of the original mass (5kg) was obtained. From the obtained sample, 1kg was weighed out and subjected to sieving through the use of mesh sizes ranging from 425 m to 180 m. Materials retained within 250-micron mesh were set aside, packaged and labelled for the proximate analysis. This test evaluates the moisture, volatile matter, ash and fixed carbon contents of the Okobo coal.

a) Moisture content determination

The moisture content was determined based on ASTM test method D-3173. 1 g of each of the coal samples was weighed into a previously weighed silica crucible. The silica crucible plus sample was placed in the muffle furnace and heated to temperature between 104°C to 110°C for thirty minutes to evaporate the moisture. The silica crucible was then cooled in a desiccator and weighed and the percentage moisture content was determined using the formula below,

$$\text{Moisture } \% = \frac{\text{loss in weight due to removal of moisture}}{\text{weight of coal sample taken}} x100 \quad (1)$$

b) **Ash content determination**

1g of each of the coal samples was weighted into a clean silica crucible. The silica crucible and its content was placed in the muffle furnace which was heated gradually to an initial temperature of 500°Cand later increased to a maximum temperature of 700°C. The pre-heating and attainment of the peak temperature lasted for four hours thereafter; the crucible and its contents were extracted from the furnace, cooled and covered in a desiccator. The weight was taken and the percentage ash content was determined using the formula below. The test was conducted in accordance with ASTM D-3174.

$$\text{Ash content } \% = \frac{\text{weight of ash formed}}{\text{weight of dry coal taken}} \text{ x } 100 \quad (2)$$

c) **Volatile matter content determination**

1 g of the moisture free coal sample was weighed into a silica crucible covered with its lid. The crucible and its content was placed in a pre-heated muffle furnace of 900°C and removed after nine minutes residency in the high temperature zone. The crucible is then cooled in a desiccator with its content weighed and expressed as the percentage weight loss volatile matter. The test was conducted in accordance with ASTM D-3175 standard procedures.

$$\text{Volatile matter } (\%) = \frac{\text{loss in weight due to removal of VM}}{\text{weight of coal sample used}} \text{x}100 \quad (3)$$

d) **Determination of Fixed Carbon**

The fixed carbon content of the representative coal samples is what is left after the ash, volatile and moisture components of the sample have been separated (Speight, 2005). It was calculated with the formular;

$$FC = 100 - MC+VM+AS \quad (4)$$

Where;

FC = Fixed Carbon

MC = Determined Moisture content of the coal sample

VM = Determined Volatile matter of the coal sample

Ash = Determined Ash content of the coal sample

3.4 Ultimate Analysis

This test evaluates the elemental contents of the Okobo coal. For the ultimate test, each of the crushed coal samples was passed through a 100-micron sieve. The undersize was collected and sub-divided using a riffle box to obtain a 60g sample. The 60g sample size is further pulverized and screened with a 150-micron mesh. 5g of the undersize sample was measured into a beaker and thoroughly mixed with 1g of cellulose to form compressed pellets. The coal pellets were placed in NITON XL3 XRF Analyzer to determine the elemental composition of the coal. The carbon, hydrogen and nitrogen content of the coal samples were determined empirically using the formula below as proposed by Kumar and Saxena, 2014.

% Carbon = 0.97FC + 0.7(VM – 0.1Ash) – M (0.6 – 0.01M) (5)

% Hydrogen = 0.036FC + 0.086 (VM - 0.1 x Ash) - 0.0035*M*2* (1 - 0.02M) (6)

% Nitrogen =2.10 -0.020 VM (7)

Where: -
FC = Fixed Carbon
M = Determined Moisture content of the sample
VM = Determined Volatile matter of the sample
Ash = Determined Ash content of the sample

4. Results and Discussion

4.1 Lithostratigraphy of the coal deposit

The field work showed five lithologic strata namely carbonaceous shale, sandstone, mud/claystone, sandy-shale and coal. At each of the section sampled, the thickness and other observable features of these units were documented as graphic logs as shown in figures 1 to 5.

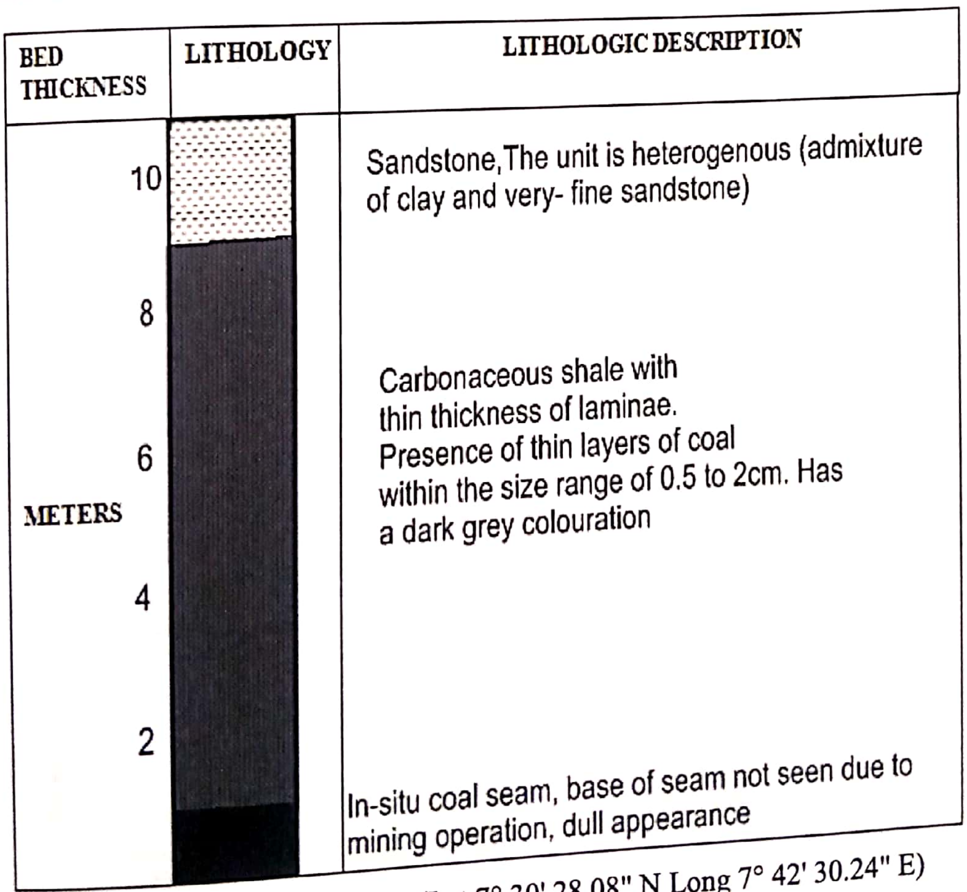

Figure 1: Log of section one (Lat 7° 30' 28.08" N Long 7° 42' 30.24" E)

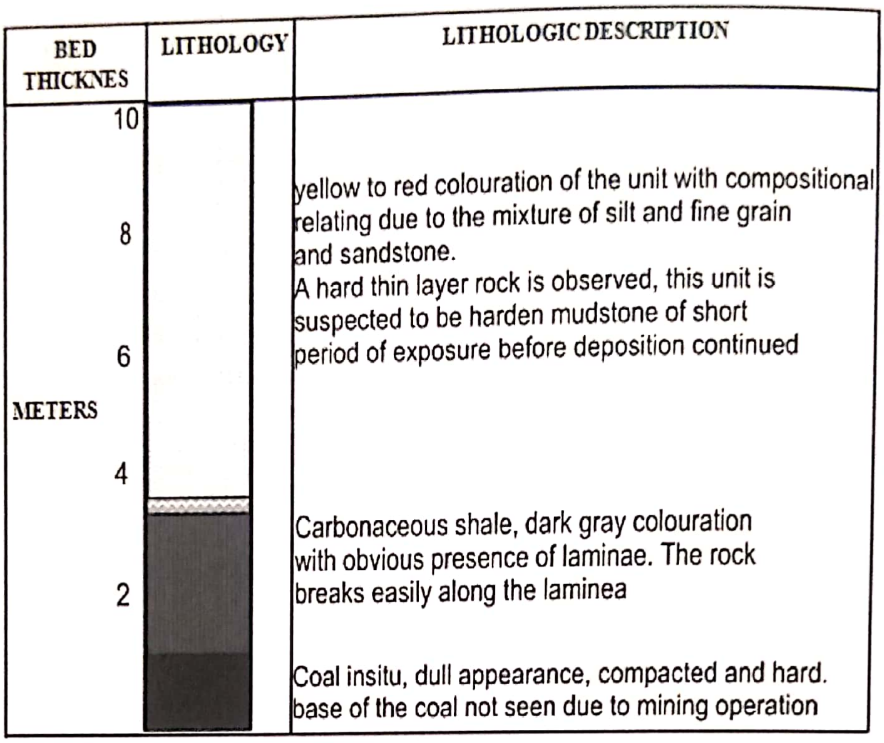

Figure 2: Log of section two (Lat 7° 30' 28.8" N Long 7° 42' 30.96" E)

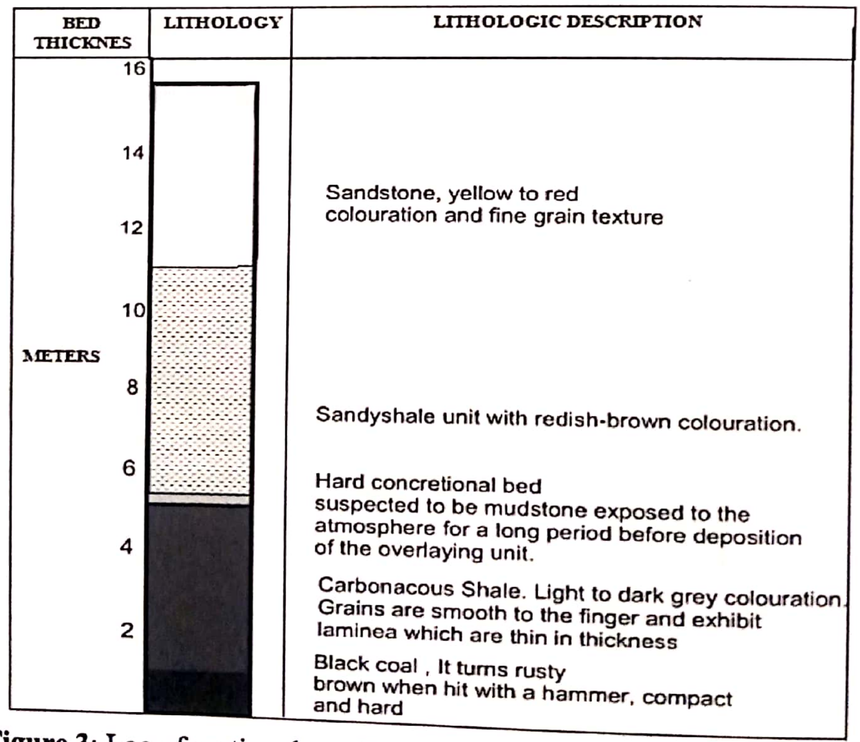

Figure 3: Log of section three (Lat 7° 30' 29.88" N Long 7° 42' 32.04" E)

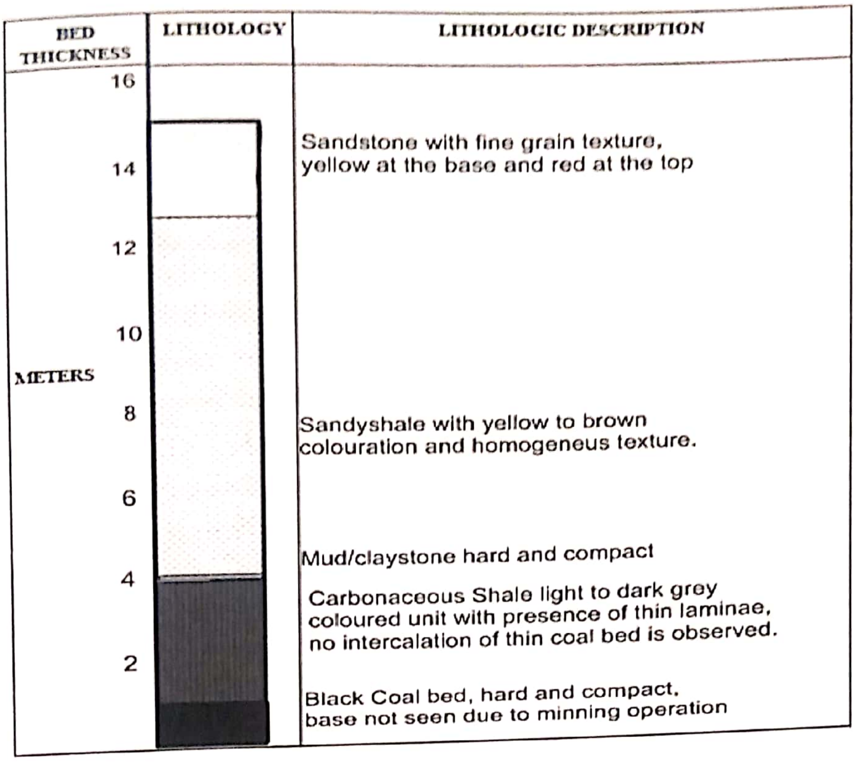

Figure 4: Log of section four (Lat 7° 30' 29.16" N Long 7° 42' 32.4" E)

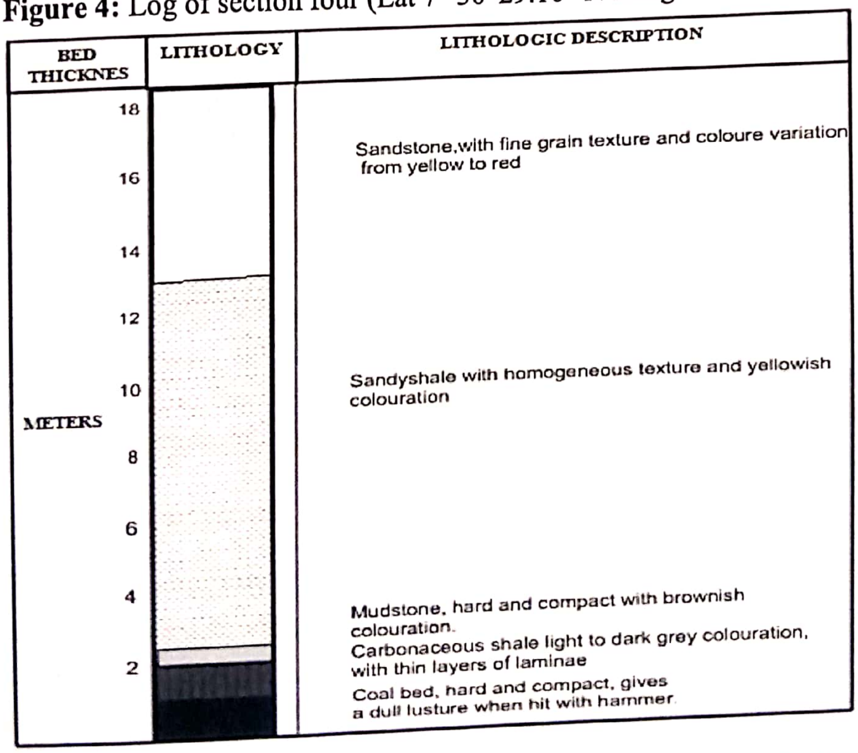

Figure 5: Log of section five (Lat 7° 30' 29.88" N Long 7° 42' 32.4" E)

4.2 Characterization of the Okobo Coal

Proximate Result

The proximate result (Moisture, MC, Volatile Matter, VC, Ash and Fixed Carbon, FC)) of the Okobo coal reported on as received basis is presented in Table 4.1.

Table 4.1: Proximate Result of the Okobo Coal Samples

	Parameters (As received basis)				
Sample Name	**MC (wt %)**	**VM (wt %)**	**Ash (wt %)**	**FC (wt %)**	**Fuel Ratio**
OKC 1	14.7	47.35	19.8	18.25	0.385428
OKC 2	13	49.75	20.65	16.6	0.333668
OKC 3	15.8	49.22	20.09	14.89	0.302519
OKC 4	16.78	40.22	17.89	25.11	0.624316
OKC 5	15.6	48.03	21.01	15.36	0.3198
Average	**15.18**	**46.91**	**19.89**	**18.04**	**0.393146**

a. Moisture Content

The moisture content analysis shows that the Okobo coal has moisture content range of 13% to 16.78% with an average value of 15.18%. The acceptable moisture content range for anthracite coal grade is less than 15%, bituminous coal grade 2-15%, sub-bituminous grade 10% to 45% and for lignite coal 50% to 60% (Brian and Marty, 2008). For the Okobo coal, the moisture content falls within the acceptable value range of 10% to 45% for sub-bituminous coal. However, in comparison with the moisture values obtained for Okaba (5.99%) and Ogboyoga (6.93%) coal in Kogi state, the moisture content of the Okobo coal is high. Also Onyeama (5.87%), Maiganga (5.28%) and Afuze (1.67%) coal in Enugu, Gombe and Edo states respectively, have less moisture content compared to the Okobo coal. The high moisture content suggests that the coal was formed under minimal temperature and high-pressure impact upon the organic matter (Larry, 2002). In terms of usage, the coal can be utilized for power generation and production of domestic energy such as coal briquettes. However, it is unsuitable as feed for metallurgical coke because the moisture content exceeds the 1-4% limit.

b. Ash Content

The ash content of the Okobo coal varies from 17.89% to 21.01% with an average of 19. 89%. In comparison with Okaba, Ogboyoga and Onyeama coals with ash content of 3.32%, 8.63% and 1.25% respectively, the ash content of the Okobo coal is considered high. However, when compared with the Maiganga (21.05%) and Afuze (30.99%) coal as reported by Bemgba (2015), the ash composition of the coal is low. Generally, coals containing high ash content are considered problematic in power generation, coal briquette and coke production. From the result, it can be inferred that the Okobo coal has an optimum as content which favours its usage as feed in coal plants and coal briquette making. This is evidenced by the <40% limit stipulated by India Ministry of Environment and Forestry (MoEF) for coals to be used for power generation and coal briquette making (Anjaja, 2012). Inversely, the ash content places the Okobo coal at a disadvantage for coke production because it exceeds the 1-2% limit required for the Ajaokuta Steel Plant in Kogi State (FMPS, 1992).

c. Volatile Matter Content

From the proximate result, the volatile matter content of the Okobo coal range from 40.22% to 49.75% with an average value of 46.91%. According to Speight (2005), the acceptable volatile matter content range for anthracite coal grade is 2% to 12%, bituminous coal grade 15-45%, sub-bituminous grade 28% to 45% and for lignite coal 24% to 32%. For the Okobo coal, the volatile matter can be closely ranked under the sub-bituminous to bituminous grade. In comparison with some known coals in Nigeria such as Okaba, Ogboyoga, Onyeama and Afuze with volatile matter contents of 32.56%, 30.41%, 29.61% and 45.80%, the volatile matter of the Okobo coal is considered high except for Maiganga coal with a higher value of 51.16%. In terms of economic use, the high volatile matter of the Okobo coal implies that the coal will readily ignite and agglomerate hence favours its use for power generation and domestic energy. However, the Okobo coal is not suitable as blend for coking coals because it exceed the Gray et al. (1978) volatile matter content limit of 31-0 to 36.0 %.

d. Fixed Carbon Content

As shown in Table 1, the Okobo coal on average has fixed carbon content of 18.04% with a range of 14.89% to 25.11%/ This value is relatively low compared to that of Okaba (58.13%), Ogboyoga (54.33%), Onyeama (63.27%), Maiganga (22.52%) and Afuze (21.24%). The fixed carbon content indicates that a high pressure and low temperature was responsible for the coal formation since this property of coal increases with deep burial of the peat matter. The fuel ratio (proportion of fixed carbon content to volatile matter content) of approximately 0.4 (Table 4.1) on the average indicates that the Okobo Coal is of the sub-bituminous rank (www.mindat.org/glossary/coal_fuel_ratio) thus, its suitability for electricity generation.

Ultimate result: The results of the ultimate test are presented in Tables 2 and 3

Table 2: The carbon, hydrogen and nitrogen composition of Okobo Coal (wt %)

	Parameters (Calculated)		
Sample Name	**Carbon (wt%)**	**Hydrogen (wt%)**	**Nitrogen (wt%)**
OKC 1	42.80	4.49	1.15
OKC 2	43.37	4.63	1.11
OKC 3	40.51	4.52	1.12
OKC 4	44.01	4.13	1.30
OKC 5	40.12	4.43	1.14
Average	**42.16**	**4.44**	**1.16**

From table 1, the average values for carbon, hydrogen and nitrogen for the Okobo coal are 42.16%, 4.44% and 1.16% respectively. These values rank the Okobo coal as sub-bituminous coal grade and suggest a low degree of coalification when compared with figure 1. Also, the hydrogen and carbon content influence the application of the coal for power generation as both elements account for the combustibility of any coal. Other major elements detected in the Okobo coal as shown in table 2 include Aluminum, Silicon. Calcium, Sulphur and Iron and their average values are 0.227%, 1.375%, 0.240%, 1.161% and 1.019% respectively. The detection of aluminum in the coal samples indicates that alumino-silicates minerals (clay) may be associated with the coal. However, the enrichment/depletion (EDF) value of 0.23 suggest the element is depleted when compared to Ruch *et al*. (1974) limit shown in Table 4. The presence of silicon in the coal samples may be indicative of the presence of feldspars and mica minerals which are mostly derived from the disintegration of transported alkaline silicates. Additionally, the silicon may be of biogenic origin, since plants have the capacity to take up and store elements even though some of them are not useful for growth and development. The EDF of 0.49 further justifies the low concentration of the element in the coal because the element falls within the depleted group of elements in Table 4.

	← Low Rank		→ ← High Rank	→
Rank:	Lignite →	Sub-bituminous	Bituminous	→ Anthracite
Age:	increases			
% Carbon:	65-72	72-76	76-90	90-95
% Hydrogen:	~5	decreases		~2
% Nitrogen:	~1-2			
% Oxygen:	~30	decreases		~1
% Sulfur:	~0 increases	~4	decreases	~0
%Water:	70-30	30-10	10-5	~5
Heating value (BTU/lb):	~7000	~10,000	12,000–15,000	~15,000

Figure 1: Selected properties of coal varying with coal rank (Retrieved from http://www.ems.psu.edu/~radovic/Chapter7.pdf)

Table 3: Concentration of major (%) and trace (ppm) elements in Okobo Coal and their enrichment/depletion coefficient

Sample No	Al (%)	Si (%)	S (%)	Fe (%)	k (%)	Ca (%)	P (ppm)	Ti (ppm)	V (ppm)	Cr (ppm)	Mn (ppm)	Cl (ppm)	Sr (ppm)	Zr (ppm)	Cd (ppm)	W (ppm)
OKC 1	0.193	1.469	0.991	1.028	Bdl	0.232	Bdl	1460	30	Bdl	Bdl	90	20	40	20	Bdl
OKC 2	0.185	1.513	1.023	1.021	Bdl	0.244	Bdl	1640	40	Bdl	Bdl	90	20	50	20	Bdl
OKC 3	0.212	1.031	0.763	0.841	Bdl	0.234	2170	1390	30	Bdl	Bdl	190	20	40	Bdl	Bdl
OKC 4	0.395	1.767	1.533	1.771	0.01	0.284	490	2230	50	30	190	130	20	40	20	120
OKC 5	0.151	1.093	0.786	1.144	Bdl	0.207	Bdl	1330	30	Bdl	200	50	20	40	20	Bdl
Average	0.227	1.375	1.020	1.161	NC	0.2402	NC	1610	36	NC	NC	110	20	42	20	NC
World Coal	1	2.8	2	1	0.01	1	220	500	22	15	100	120	130	30	0.24	6
EDF	0.23	0.49	0.51	1.16	NC	0.24	NC	3.22	1.64	NC	NC	0.92	0.15	1.4	83.33	NC

Note: -

Bdl- below detection limit, NC- Not computed

Major and trace elements compared with world coal average and Clark's values (Ketris and Yudorich, 2006)

EDF- Enrichment/depletion factor is the relationship between the identified element in the coal to the World coal / Clarke value

The detection of sulphur in the Okobo coal infers that pyrite, marcasite, calcite and gypsum minerals may be present in the coal environment because of the high affinity of the element to these minerals (Vassilev *et al.*, 2010). Although, the EDF value of 0.51 indicate that the host minerals of the sulphur element is depleted. The presence of iron implies that the coal is slightly enriched in iron bearing minerals, but the enrichment shows no define trend according to the EDF value of 1.16.

Table 4: Enrichment/depletion ranking of the major and trace elements in Okobo Coal

Enrichment/Depletion factor (EDF) Limit	Explanation	Elements
Elements <**0.1**	Depleted }	Al, Si, S, Ca, V, Cl,
Elements 0.1-2	No trend }	Fe, Sr, Zr
Elements 2.0-10	Slightly enriched	Ti
Elements >**10.0**	Highly enriched	Cd

Note: - < - less than; > - greater than (Ruch *et al.*, 1974)

The trace elements present with their average values are Chlorine (110ppm), Titanium (1610ppm), Vanadium (36ppm), Cadmium (20ppm), Zirconium (42ppm), and Strontium (20ppm). According to Ward *et al.* (1999) and Yudorich and ketris (2002), Cl accumulation in coal could either be associated with influx of weathered alkali igneous rocks (detrital origin) transported into the coal formed environment or syngenetic and/or epigenetic processes (authigenic origin) and may be plant derived (organic origin) because of its high affinity with the marine environment. It has also been put forward by these researchers that the syngenetic origin could be related with marine transgression and volcanism while the epigenetic origin could be associated with inclusion of Cl into the peat phase from salt bearing strata occasioned by saline fluids. Based on the above facts, the detrital, syngenetic and biogenic source may hold true for the chlorine in Okobo coal. The detrital origin agrees with the suggestion of Hogue (1978) that part of the lithic sediments of the Anambra basin originated from the weathered sediments of the Cameroon granitic complex rocks whereas, the syngenetic origin is evidenced by the Nsukka marine transgression that prompted partly the facies of the coal bearing formations of which the Okobo coal belongs. The EDF value of 0.92 indicates that the chlorine is depleted in the Okobo coal. The high concentration of iron and titanium may indicate the presence of titanium rich minerals such as ilmenite (Ipinmoti and Ayesanmi, 2001) and rutile (Zang *et al.*, 2004) within the rocks hosting the coal deposit. More so, the high value of vanadium suggests that the Okobo coal environment host rocks contain vanadium-rich minerals or those with close association for instance, the clay minerals. It has also been reported that vanadium can be organically associated with coal depending on the genetic configuration of the plant matter and coalification processes (Dai *et al.*, 2008). The mean value of cadmium when compared with the Clark value of 0.24 ppm indicates abundance of the element in the Okobo coal. On the other hand, the EDF value of 83.33 (Table 4) confirms the enrichment of the element in the coal. It has been reported that cadmium have positive relationship with the organic matter of coal, thus, the high enrichment could probably be related to the selective adsorption and complex interaction of the vegetal/humic compounds (Fergusson, 1990). In other words, the enrichment could be attributed to influx of organic rich shale sediments or other marine cadmium- rich minerals such as manganese and phosphorite (Fergusson, 1990). More so, the detection of cadmium in the Okobo coal validates the reports of Adaikpoh *et al.*

(2005); Ezeh and Okeke (2016); and Usman *et al.* (2016) wherein they reported the enrichment of cadmium in Enugu, Benue, Delta and Maiganga coal. The presence of the element zirconium suggests the occurrence of zircon, which is the ore bearing mineral of the element. Probably, the mineral has its origin from the detrital materials derived from the Cameroon granitic rocks that provided sediments for the Anambra basin (Hogue, 1978). In comparison with the world coal average, iron, titanium, vanadium, cadmium and zirconium exceed the world average values while the other elements fall below the limit as shown in table 2.

From the ultimate result, it can be inferred that the Okobo coal will be a good feedstock for coal plants and coal briquette production because most of the elements occur in minute quantities except cadmium which is enriched in the coal. Also, the elemental constituents could provide guide in the design of the combustion system and process to which the Okobo coal will be utilized.

5. Conclusion

The field work conducted in the Okobo coal mine revealed five lithologic units namely carbonaceous shale, sandstone, mud/claystone, sandy-shale and coal. The carbonaceous shale unit revealed dark grey colouration with thickness between 0.14m and 8.5m. The unit exhibited thin laminae of less than 1m thickness with a powdery texture synonymous to that of the clay/mudstone. The sandstone units showed light to grey and yellow to brown colouration with thickness between 0 1.2 m to 6m with silt to fine sand grained texture. Also, the mud/claystone units showed dark grey colouration and thickness range of 0.05m to 0.14m with a homogeneous texture. The sandy- shale units exhibited brown colouration with imprints of yellow stains. The thickness of the unit varied between 6.5m to 11m with homogeneous texture. The coal units showed black colouration with a brownish luster when hit with a hammer. The thickness of the units varied from 1m to 1.5m. The proximate result revealed that the Okobo coal have on the average moisture, volatile matter, ash and fixed carbon contents of 15.18%, 46.91%, 19.89% and 18.04% respectively. These content value favours the usage of the Okobo coal as feed for power generation and domestic energy but unsuitable for metallurgical coke production. In addition, the ultimate result showed the presence of C (42.16%), H (4.44%), N (1.16%), Al (0.23%), Si (1.37%), S (1.02%), Fe (1.16%), and Ca (0.24%) as major elements, while the trace elements are Ti (1610ppm), V (36ppm), Cl (110ppm), Sr (20ppm), Zr (42ppm), and Cd (20ppm). Other trace elements detected in one or two samples are W, Mn, P and Cr. Aside, C, H and N some of the elements have low concentrations when compared with their Clark/world values (Ketris and Yudorich, 2009) except Fe, Ti, V, Zr and Cd with high values. In terms of mineralization, the Okobo coal is highly enriched in Cd, slightly enriched in Ti and depleted in other elements.

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