Proximate and Ultimate Characteristics of Some Nigerian Coal Deposits in Benue Trough and Anambra Basin

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ABSTRACT

Forty coal samples (4 samples per deposit) from ten Nigerian coal deposits that span over Anambra basin and Benue Trough were sampled and analyzed for their proximate, ultimate and elemental characteristics. These coal deposits include Onyema, Okpara, Ogboyoga, Okaba, Owukpa, Ibobo, Udane Biomi and Iva Valley in the Anambra basin and Lafia-Obi and Maiganga in the Benue Trough. The conventional proximate and ultimate analysis methods of American Standard Test Methods (ASTM) were employed in this study. The moisture contents of the coals range from 2.45 at Udane Biomi to 11.02 % at Maiganga coal. The ash contents of the coals range from 7.30-40.65 %, with Lafia-Obi recording the highest of 40.65 % and Iva Valley with the lowest (7.30 %). Volatile matter for the coals ranges from 11.12 -74.22 % with Iva Valley having the highest value of 74.22 % while Lafia Obi recorded the lowest of 11.12 %. The fixed carbon content for the coals also range from 10.52 to 57.85 % with Udane Biomi recording the highest value of 57.85 % while Ogboyoga has 10.50 % as the lowest. The coals are generally low in N_2 and have fairly high P and S.

1. INTRODUCTION

Nigerian coals were major source of power generation and income to the country until the advent of the oil boom in the early seventies when emphasis was shifted to oil. This brought a nearly complete halt to research and continuous exploration and appreciation of the country's coal resources. However, with current dwindling power supply and decreasing reliance on oil all over the world, coal is positioned to regain its past glory in the energy mix of Nigeria.

Nigerian coal reserves are in the excess of three billion (3,000,000,000) tons of indicated reserves spread over seventeen coal fields and over six hundred million (600,000,000) tons of proven reserves (RMRDC, 2015). As more new coal deposits are being discovered in the country, there more be continuous and up to date analyses to determine the qualities of these coal deposits (Laminga, 2018). These coal deposits and resources are spread over 13 states of the Federation but geologically restricted to the Benue Trough (Northern, Central-, and Southern-Benue Troughs) and the adjacent Anambra Basin.

Some of the notable coal deposits in Nigeria include the Okaba, Owukpa, Inyi, Ogboyoga, Udane Biomi, Ibobo, Onyeama, Okpara, Iva Valley, Kwangshir-Jangwa along River Dep, Maiganga and Gidan Sidi and studies including the reserve estimations have been carried out on these coal deposits and the results well documented.

Coal is known to be a multi-purpose geo-material being a bulk mineral with various uses which depends on its physiochemical, mineralogical and other inherent properties. Coals generally and the Nigerian Coals in particular find uses primarily in heat and electricity generation for homes, locomotives and factories. The bituminous coals are used to produce coke for steel-making and other industrial process heating. Coal gasification and coal liquefaction (coal-to-liquids) are other possible uses of coal for producing Synthetic fuel and finally, the exportation of coals to earn foreign exchange.

The proximate analysis of coal is an assay of the moisture, ash, volatile matter and fixed carbon as determined by series of prescribed or standard test methods. The ultimate analysis of coal on the other hand, involves the determination of the elemental composition of coal. These elements include sulfur, nitrogen, carbon and oxygen as well as the trace elements that occur in coal. The ultimate carbon determine in coal includes carbon present as organic carbon as well as carbon present in the form of inorganic (carbonate minerals). The hydrogen content of coal includes the hydrogen in all the water associated with coal. The nitrogen is assumed to exist within the organic matrix of coal. Sulfur occurs as organic sulfur compounds, inorganic sulfides e.g. pyrite and marcasite (FeS_2) and as inorganic sulfides e.g. Na_2SO4, $CaSO4$. In this study, proximate and ultimate characteristics of the coals were determined in order to characterize the coal deposits and infer the best comparative uses the various coal deposits can be applied.

2. Geological Setting of Benue Trough and Anambra Basin

2.1. The Benue Trough

The Benue Trough is one of Nigeria's inland basins that are bounded in the north by Chad Basin and in the southwest by the Anambra Basin (Figure 1). The Benue trough is a fundamental tecteno sedimentological feature in the evolution of the Cretaceous and Tertiary geology of Nigeria (Nwajide, 2013). The trough is a part of the extensive West and Central

Africa plate consequent upon the initiation of proto-equatorial Atlantic (Nwajide, 2013). According to Nwajide (2013), the precise bounds and dimensions of the Benue Trough are yet to be accurately determined and defined. This he attributed to the burial of its limits under the younger basins, the Anambra and the Niger Delta basins in the South-West and the Chad basin in the North East.

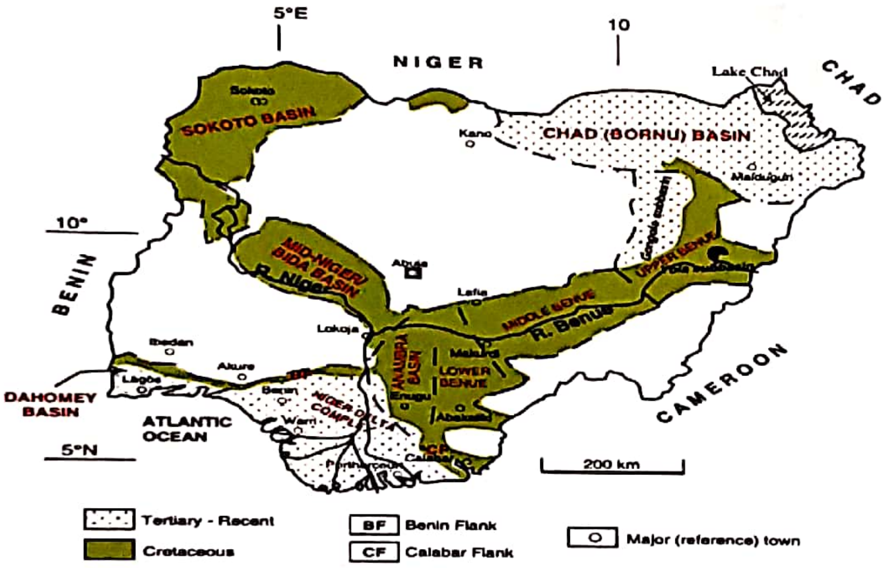

Figure 1: Sedimentary basins of Nigeria (Adopted from Obaje, 2009).

Also the co-existence and continuity of the Trough's structures with those of the Niger Republic's basin (Termit basin) to the North added to the complicity of determining the Northern boundary and dimension of the Benue Trough (Figure 2).

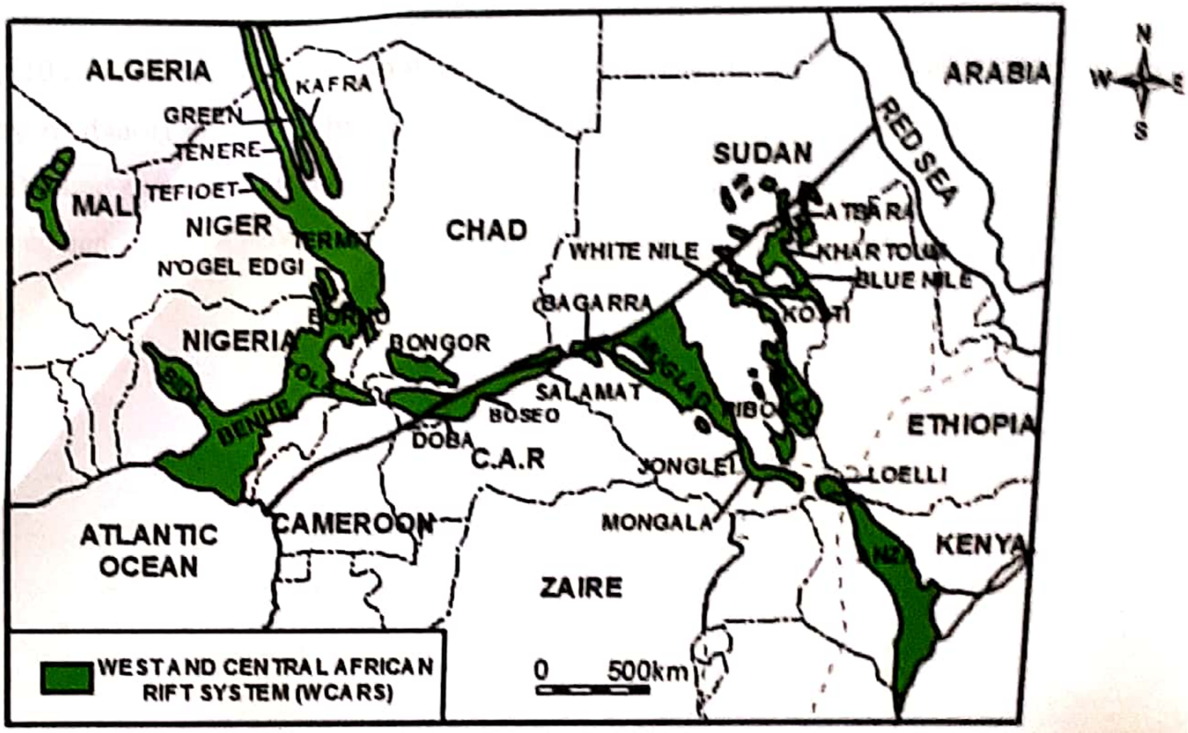

Figure 2: Location and extent of the Benue Trough within the West and Central African Rift System (after Nwajide, 2013).

From Figure 2, the Trough can be arbitrarily taken to extend to and terminate at the right angular bend into the Termit Basin in Niger Republic and this will make an estimated total length of the Trough in Nigeria to be roughly 1,300km and an estimated narrowest and broadest width of 125km at the immediate South East of the Jos Plateau and 250km across Auchi to Gboko axis respectively (Nwajide, 2013). In the Northeastern part where the Trough bifurcates into two arms (the Northern Gongola arm and the Southern Yola arm), the width of the trough is estimated at over 200km. The sediment thickness across the trough range from 5km in the Northeast to over 12km in the Southwest (Nwajide, 2013).

Nwajide (2013) adapted the Northern, Central and Southern segments as the subdivisions for the Benue Trough as against the hitherto Upper, Middle and Lower Benue Trough (Nwajide, 2013). The gross characteristics of the Trough are defined by its structural orientation, configuration and the inherent lineaments.

The stratigraphic successions of the Benue Trough have been identified and described on the basis of the three-fold subdivisions of the trough as shown in Figure 3.

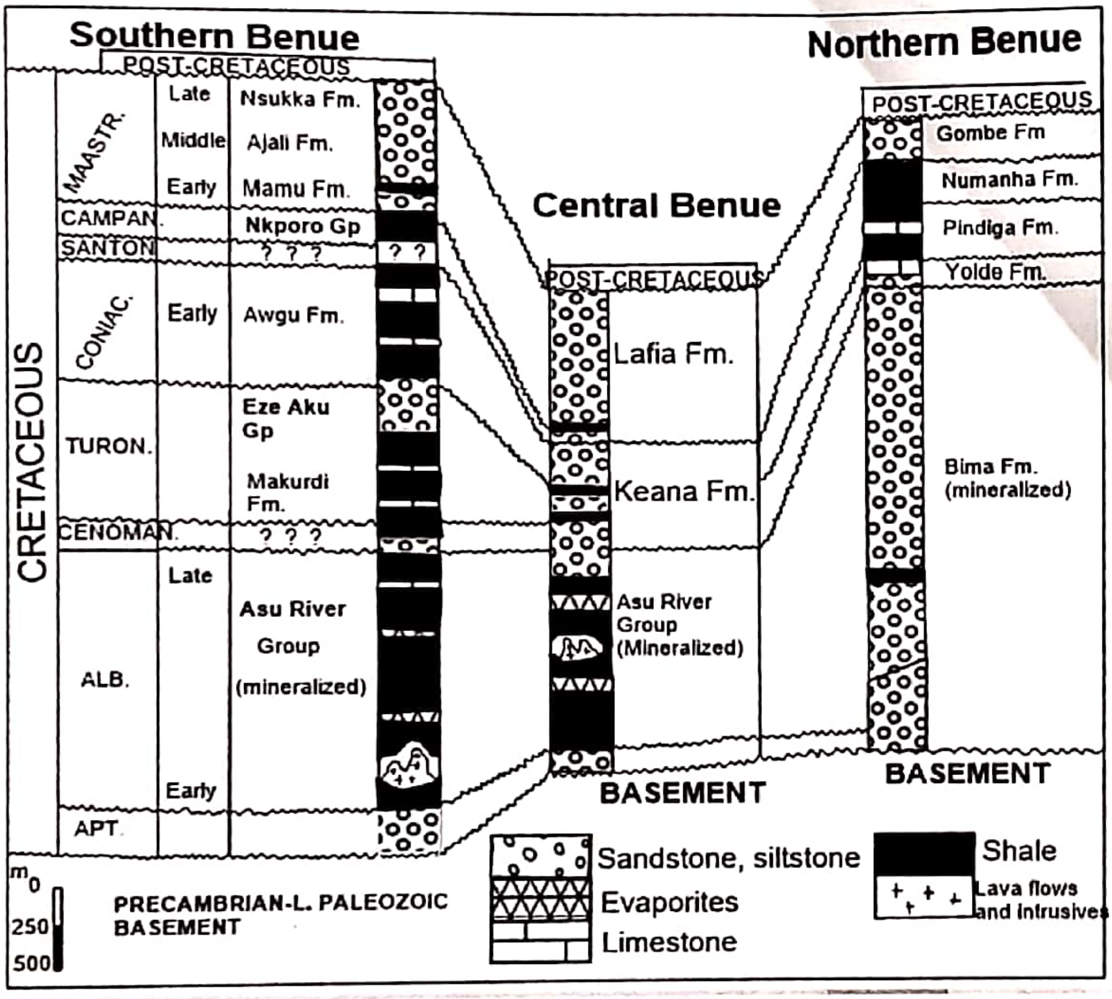

Figure 3: Generalized Cretaceous Stratigraphy of the Benue Trough (after Nwajide, 2013)

Coal resources within the Benue Trough are stratigraphically restricted to the Mamu, Ajali and Nsukka formations, Lafia Formations and the Gombe Formation of the Southern, Central and Northern Benue Trough segments, respectively.

2.2. The Anambra Basin

Nwajide (2013) as adapted from Wright *et al.*, 1985) defined the Anambra Basin as "the upper Senonian-Maastrichtian to Paleocene depositional area located at the Southern end of the Benue Trough, within which the Nkporo Group and younger sediments accumulated. It extended towards the Southwest as the Niger Delta Basin". This definition is both geologic and geographic and it refers to the sediments-filled area between the southernmost end of the Benue Trough and the Northern end of the Niger Delta. There seems to be a sort of sedimentological continuity among the three interrelated basins, their respective different lithological characteristics notwithstanding (Figure 4).

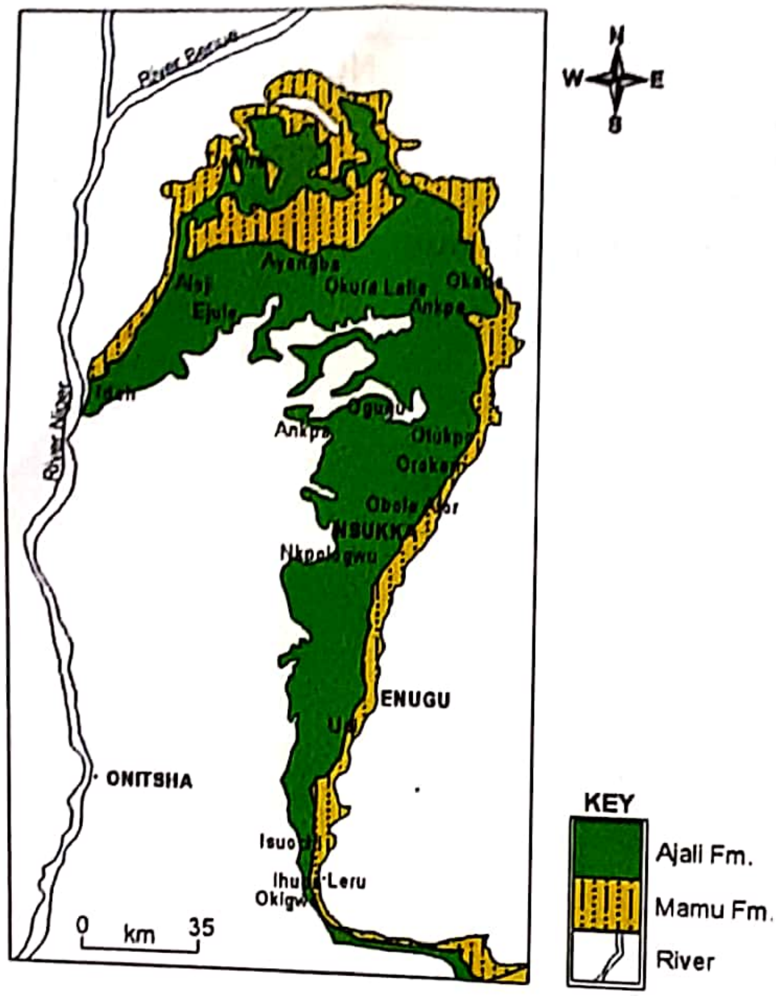

Figure 4: Geological map of Anambra Basin (after Chiaghanam *et al.*, 2013)

Stratigraphically, the Anambra Basin consists of the uppermost coal measures which are made of the Nsukka, Ajali and Mamu Formations, underlain by the Awgu Formation as shown in Figure 5 (Chiaghanam *et al.*, 2013).

2.3. The Coal Measures

The Nigerian coals are sub-bituminous (black coals) of Cretaceous age and lignites (brown coals) of Tertiary age (NGSA, 1987). However, the coal deposit at Obi, near Lafia in Nasarawa state has been described as coking coal. Black coals occur in strata of two different ages in the Lower and Upper Coal Measures and are almost entirely restricted to the Benue Trough and the Anambra basin of Nigeria. The Upper Coal Measures are hosted by the Nsukka Formation while the Lower Coal Measures are hosted by the Mamu Formation. The Mamu Formation consists of alternations of sandstones, siltstones, mudstones, coal seams and rare shales. This is overlain by the Ajali Formation which is mainly sandstone. The Ajali Formation is in turn overlain by the Nsukka Formation typically comprising of sandstones, black shales, coal, mudstones and marine limestones. The coals of the lower measures are of medium quality, non-coking sub-bituminous and they are excellent for gas making. They produce high tar-oils, self-binding under pressure and suitable for production of liquid fuels. Conversely, the coals of the upper measures are thinner and of poorer quality.

Age	Basin	Stratigraphic units							
Thanctian	Niger Delta	Imo Formation							
Danian									
	Anambra Basin	Coal Measures	Nsukka Formation						
Maastricthtian									
			Ajali Formation						
Campanian									
			Mamu Formation						
			Nkporo FM	Nkporo Shale	Enugu FM	Owelli Ss	Afikpo Ss	Otobi Ss	Lafia Ss
Santonian	Southern Benue Trough		Awgu Formation						

Figure 5: Stratigraphic Sequences of Anambra Basin (Adopted from Chiaghanam *et al*, 2013)

3. MATERIALS AND METHODS

3.1 Field Work and Samples Collection

Ten coal locations were selected within the country for this study. The ten locations were chosen to cover the whole length of Benue Trough and parts of the Anambra Basin. Coal samples from Ibobo, Udane-Biomi and Ogboyoga (Kogi State), Iva Valley and Okpara (Enugu State) were obtained from coal seams exposed on the field either along river banks, beds, or in areas where the coal seams or beds have been exposed by erosion. Samples from Onyema (Enugu State), Owukpa (Benue State) and Lafia-Obi (Nassarawa State) were obtained from old and abandon coal mines while in Okaba (Kogi State) and Maiganga (Gombe State) the samples were obtained from the recent mine sites.

Four representative coal samples were obtained at each of the ten study sites. The sampling was done randomly. During sampling, a bulk sample of about 300g each of coal was collected from four points within each of the study areas. The samples collected were sealed in polythene bags and were subsequently transferred into polyvinyl chloride (PVC) canisters and labeled appropriately for laboratory analyses. The coordinates and elevations of the sampling locations were taken with an Etrex Garmin model of GPS (Global Positioning Satellite). Location maps of the coal deposits were prepared from the GPS coordinates using ArcGis version 10.2.2.

3.2. Laboratory Analyses

The methods of analyses employed generally followed the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). The proximate and ultimate analyses were carried out at the Department of Earth Sciences, Kogi State University, Anyagba. For each of the samples the analysis was in quadruplicates and their average values computed. This was to ensure good reliability of the analytical results.

3.2.1 Proximate Analyses (ASTM)

3.2.1.1 Moisture Content

The moisture content was determined on the bases of American Society for Testing and Materials Standards (ASTM- D3173, Montgomery, 1978). A gram of the sample was weighed into a previously weighed crucible. The crucible plus the sample was positioned in cold muffle furnace and heat is applied to 104°C for an hour for the moisture to be given off. The crucible was subsequently cooled in desiccators and weighed. The percentage moisture was calculated as percentage weight loss (moisture content, Mc).

$$\text{Mc}(\%) = \frac{\textit{loss in weight after drying}}{\textit{initial samples weight}} X\ 100$$

3.2.1.2 Volatile Matter

The volatile matter was determined on the bases of American Society for Testing and Material Standards (ASTM- D3175). One gram of the coal sample was measured into a tarred crucible, enclosed with the lid; and the crucible and its constituent positioned in the muffled furnace and heat raised to 925°C. It was taking away after precisely 7 minutes residence in the hot region of the kiln immediately before reaching the temperature of ignition and was then cooled in desiccators. The crucible and its constituent were weighed and the percentage volatile matter (Vm) calculated as:

$$\text{Vm}(\%) = \frac{\textit{weight before heating} - \textit{weight after heating}}{\textit{weight before heating}} X\ 100$$

3.2.1.3 Ash Content

The ash content was determined on the bases of American Society for Testing and Materials Standards (ASTM- D3174). One gram of the coal sample was measured into a dirt free crucible. The exposed crucible was positioned in cold muffle furnace and heat is gradually applied so that the temperature rose to 500°C in one hour and 750°C within two hours. The crucible was thereafter cooled and enclosed in desiccators and weighed. The percentage ash content was then calculated.

3.2.1.4 Fixed Carbon Determination

The fixed content of the coal is the carbon content in the coal which is remaining following the given off of volatile matters. According to ASTM D3172-07a and ISO 17246: 2005, fixed carbon is used as an approximation of the quantity of coke that will be produced from a coal sample. Fixed carbon was obtained by deducting the weight of volatiles determined by test of volatility from the initial weight of the sample of coal.

3.2.2 Ultimate Analysis

3.2.2.1 Determination of Carbon and Hydrogen by Liebig Method

The carbon and hydrogen content values were determined based on ASTM- D3178standards. A 2 g of sample was placed in a platinum crucible and put into the combustion tube where it was burnt in oxygen at the temperature of 1300°C. The combustion products surge across a heated lead chromate and copper oxide and into the absorption train. The copper oxide makes sure there is total combustion of the hydrogen and carbon in the coal, while the lead chromate takes up the oxides of sulphur. The pre weighed absorbers within the absorption train absorbed carbon dioxide and water, and the percentage of hydrogen and carbon in the sample was computed from the increase in the absorbers weight. The hydrogen as water and carbon as carbon dioxide were computed from the raise in weight of the absorbents which was used to gather the carbon dioxide and water. An Oxide of sulphur which was removed was released from combustion gases by passage over silver at about 600°C while nitrogen dioxide was removed by lead chromate.

3.2.2.2 Determination of Nitrogen Content by Kjeldahl Method

The nitrogen content was determined using ASTM- D3179 standard. 2 g of sample was measured into a Kjeldahl flask of Kjeldahl. Sulphuric acid of 20 ml and copper sulphate of 1 g each and catalysts of potassium sulphate were poured inside the flask. Heat was applied to the flask quietly till boiling; the mixture was afterward diluted with 100 ml of distilled water and left to lower the temperature. The flask was then attached to the distillation equipment of Kjeldahl and adding solution of sodium hydroxide to the mixture and then heated to boiling. There is the condensation of the ammonia gas into the receiving flask consisting 2% boric acid. Indicators of methyl red and bromocresol green were added drop-wise and alkaline concentrate was titrated on the 0.1 M hydrochloric acid. The method was replicated for the 13 samples and the nitrogen proportion was computed as thus.

$$\%N = \frac{\{(VH_2SO_4 \, X \, NH_2SO_4) - (VBK \, X \, NNaOH) - (VNaOH \, X \, NNaOH)\}}{1.4007 \, X \, W} X \, 100$$

3.2.2.3 Phosphorus Determination

The coal samples were grounded into fine powder and sieved through 2mm sieve mesh into different vertical crucible containers. The sample was heated in a muffle furnace for an hour at 550°C and left to cool to room temperature. A 30 ml of 0.1M H_2SO_4 was then added to each sample, stirred and filtered into 100 ml standards flask and the volume was prepared to 100 ml which was used to determine the phosphorus content of the coal.

Standard solutions were prepared by pipetting 0.5, 1, 2, 4, and 10 ml from 10 ppm into separate 50 ml volumetric flask and 8 ml of 0.53% ascorbic acid solution and made the volume up to 50 ml mark with deionized water. The solutions gave 1, 0.2, 0.4, 0.8, and 2 ppm respectively. The blank was prepared by making 8 ml ascorbic acid up to 50 ml mark on the volumetric flask with deionized water. Thereafter, 5 ml of each of the sample extract was pipetted into 50 ml volumetric flasks. An 8 ml of ascorbic acid solution prepared up to 45 ml indication on standards flask with distilled water and allowed to stand for 30 minutes. The absorbance of standard solution was read at 660 nm and for each sample at same wavelength. The phosphorus concentration of each sample was determined from the graph of absorbance against concentrations.

3.2.2.4 Determination of Sulphur by the Eschka Method

Sulphur content was determined using ASTM-D 3177 standard. A 1.0 g weight of sample of coal was put into a ceramic crucible and blended with 3 g of Eschka mixture. The mixture was then mixed with 1 g of Eschka mixture. The crucibles were then put in a cold muffle heater and heated steadily to 800°C for 60 minutes. Digestion was done in hot water for 45 minutes with intermittent stirring. The content in every beaker was afterward discharged using a

Watman no. 540 filter paper into a beaker of 400 ml. Three drops of methyl orange indicator were added drop-wise till colour turned to neutral. Then 1 ml hydrochloric acid was added, followed by addition of 25 ml potassium sulphate solution. Heat was subsequently applied to the sample till boiling and 10 ml of solution of 10% barium chloride was gradually added while stirring. The solution was boiled for 30 minutes and filtered with Watman no. 42 filter paper after it was cooled down. The entrapped remains were thoroughly washed with hot water. The total content of sulphur was computed from the formula:

$$\text{Total sulphur} = \frac{A - \quad X\ 13.738}{C}$$

Where:

A = the barium sulphate mass from the sample

B = the barium sulphate mass from the blank

C = the sample mass

4. RESULTS AND DISCUSSION

4.1 Field Studies

The field locations of the coal deposits studied is shown in figure 6 and table 1.

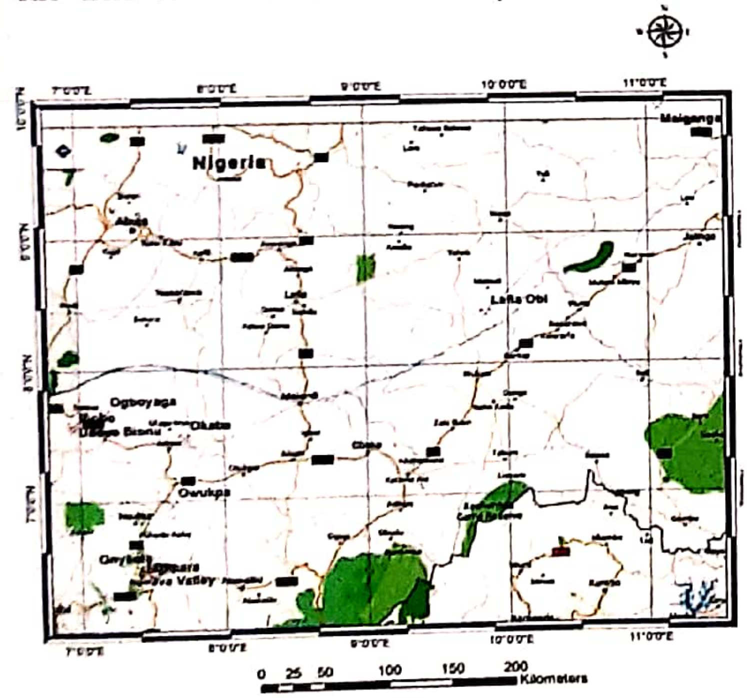

Figure 6: Location map of the coal fields where samples were taken for the study

Table 1: Information on the coal sampling points (sample origin, latitude and longitude)

Coal Deposit	Sample origin	Latitude	Longitude
Ibobo	Run-off-mine	N 07 33 01.1	E 006 57 15.5
Udane Biomi	River channel	N 07 34 51.2	E 006 57 07.5
Ogboyoga	River bank	N 07 40 15.2	E 007 10 26.1
Okaba	Mine face	N 07 28 43.2	E 007 43 33.9
Owukpa	Abandoned mine	N 06 58 04.9	E 007 38 04.9
Onyema	Coal outcrop	N 06 28 19.9	E 007 26 43.2
Okpara	Coal outcrop	N 06 24 00.2	E 007 27 05.5
Iva Valley	Coal outcrop	N 06 27 02.0	E 007 27 09.2
Maiganga	Mine face	N 09 57 08.1	E 011 05 15.2
Lafia Obi	Core sample	N 08 23 13.2	E 009 50 39.9

4.2 Proximate Characteristics of the Coal Deposits

The results of the various proximate analyses of the coals are shown in Table 2

4.2.1 Moisture Content

The moisture contents (average) for the studied coals are 6.63%, 5%, 7.99%, 11.01%, 2.45%, 7.04%, 9.24%, 7.24%, 4.01% and 3.63% for Lafia-Obi, Onyema, Okaba, Maiganga, Udane Biomi, Okpara, Ibobo, Owukpa, Iva Valley and Ogboyoga coal deposit respectively (Tables 2). Table 3 shows the mean, standard deviation, minimum and maximum concentration of moisture in the studied coals.

These values are higher than the Polish coals with 0.58% and the American coals with 1.07% moisture contents (Akinyemi *et al.*, 2012). The moisture contents for the coals decrease in order of Maiganga (11.01) > Ibobo (9.24)> Okaba (7.99) >Owukpa (7.24) > Okpara (7.04) > Lafia-Obi (6.63) > Onyema (5) > Iva Valley (4.08) > Ogboyoga (3.63) > Udane Biomi (2.45). This trend implies that Maiganga coal with the highest moisture content is considered least matured while Udane Biomi coal deposit with the least moisture content is considered most matured and other coal deposits followed in that trend. Hence, the quality of the coals increases in the same order because moisture affects the calorific value and the concentration of other constituents in coals (Akinyemi *et al.*, 2012).

Table 2: Proximate (average) characteristics of the studied coal deposits

LOCATIONS	LAFIA OBI	ONYEMA	OKABA	MAIGANGA	UDANE BIOMI	OKPARA	IBOBO	Owukpa	IVA VALLEY	OGBOYOGA
Moisture Content	6.62	5	7.98	11.01	2.45	7.03	9.23	7.23	4.07	3.62
Ash Content	40.65	8.52	10.85	7.82	20.1	42.47	15.42	14.7	7.3	40.27
Volatile Matter	11.12	67.6	63.9	67.35	19.6	22.5	62.97	56.6	74.22	45.57
Fixed Carbon	41.6	18.87	17.26	13.81	57.85	27.98	12.36	21.46	14.4	10.52
Organic Carbon	2.08	3.16	3.23	2.91	2.91	2.95	2.86	2.82	3.29	3.01
Total Nitrogen	0.42	0.63	0.65	0.58	0.58	0.59	0.57	0.57	0.66	0.61
Phosphorus	0.47	0.93	0.77	0.73	0.63	0.87	0.85	0.77	0.87	0.75
Sulphur	0.74	1.27	1.9	0.96	1.58	1.24	2.03	1.74	1.9	1.36

The total moisture content is very important in assessing and controlling the commercial processing of coals. It is used to determine the amount of drying that is needed to reach given moisture content and the amount of freeze-proofing (Ahiarakwem and Opara, 2012). When coals are used as coking coals, coal with high moisture content (as is the case with Maiganga, Ibobo, Okaba, Owukpa, and Okpara coals) require more heat for vaporization of the moisture which lead to longer coking cycles and decreased production as against coals with low moisture content which will require less heat and hence less time for the vaporization of the moisture during coking process. Lafia-Obi and Onyema coals have moderate moisture contents. The moisture content of coal depends on the degree of its maturity. The less the moisture content, the more matured is the coal and vice versa. Hence, the Udane-Biomi coal with the lowest moisture content (2.45%) may be the most matured of all the studied coal deposits, followed by Ogboyoga (3.625%), Iva Valley (4.075%), Onyema (5%), Lafia -Obi (6.625%), Okpara (7.038%), Owukpa (7.238%), Okaba (7.988%) and then the Maiganga coal deposit (11.013%). Furthermore, moisture content is an indication of the quality of a coal; it dictates both the calorific value and the concentration of other constituents in coal in terms of its cokability. High moisture content is disadvantageous because it decreases the capacity of a furnace and increases operational cost (Solomon *et al.*, 2012). The moisture content required for a good coking coal is 1.5% (Ryemshak and Jauro, 2013, Jauro, 2011), therefore, the values of the moisture contents recorded for all the studied coal deposits are much higher than the value stipulated for a good coking coal.

Table 3: Mean, Standard deviation, Minimum and Maximum Concentration of Moisture in the studied coals

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Lafia obi	4	6.6250	.27538	.13769	6.1868	7.0632	6.35	6.95
Onyeama	4	5.0000	1.38384	.69192	2.7980	7.2020	3.85	7.00
Okaba	4	7.9875	1.58555	.79277	5.4645	10.5105	5.95	9.80
Maiganga	4	11.0125	.36142	.18071	10.4374	11.5876	10.50	11.35
Udane-Biomi	4	2.4500	.27988	.13994	2.0046	2.8954	2.20	2.80
Okpara	4	7.0375	1.27696	.63848	5.0056	9.0694	6.35	8.95
Ibobo	4	9.2375	.73979	.36990	8.0603	10.4147	8.55	9.95
Owukpa	4	7.2375	.91413	.45706	5.7829	8.6921	6.25	8.20
Iva valley	4	4.0750	.56051	.28025	3.1831	4.9669	3.50	4.75
Ogboyoga	4	3.6250	.61847	.30923	2.6409	4.6091	2.90	4.40
Total	40	6.8443	2.88592	.43507	5.9669	7.7217	2.20	11.95

4.2.2 Ash content

The average ash contents of the analyzed coal samples are 40.65, 8.53, 10.85, 7.83, 20.10, 42.48, 15.43, 14.70, 14.70, 7.30 and 40.28 percents for Lafia-Obi, Onyema, Okaba, Maiganga, Udane Biomi, Okpara, Ibobo, Owukpa, Iva Valley and Ogboyoga, respectively (Tables 1 and 4). These values show that the coal deposits have ash content values that decrease in the following order: Okpara > Lafia Obi > Ogboyoga > Udane Biomi > Ibobo > Owukpa > Okaba > Onyema > Maiganga > Iva Valley.

The ash content of coal is an empirical quantity which is useful as index of coal uses (Ahiarakwem and Okpara, 2012). Ash content of a coal is the total organic residue produced from the burning of the combustible fractions of coal. Coals with high ash content are considered not good for power generation, briquettes making and coke production (Ryemshak and Jauro, 2013, Onyemali *et al*, 2017).

Table 4: Mean, Standard deviation, Minimum and Maximum Concentration of Ash in the studied coals

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Lafia obi	4	40.6500	1.06615	.53307	38.9535	42.3465	39.30	41.90
Onyeama	4	8.5250	.66018	.33009	7.4745	9.5755	7.80	9.40
Okaba	4	10.8500	.62450	.31225	9.8563	11.8437	10.10	11.50
Maiganga	4	7.8250	.63966	.31983	6.8072	8.8428	7.30	8.70
Udane-Biomi	4	20.1000	.52915	.26458	19.2580	20.9420	19.40	20.60
Okpara	4	42.4750	2.26918	1.13459	38.8642	46.0858	39.10	44.00
Ibobo	4	15.4250	.09574	.04787	15.2727	15.5773	15.30	15.50
Owukpa	4	14.7000	.21602	.10801	14.3563	15.0437	14.40	14.90
Iva valley	4	7.3000	.34641	.17321	6.7488	7.8512	7.00	7.80
Ogboyoga	4	40.2750	.23629	.11815	39.8990	40.6510	40.10	40.60
Total	40	22.6909	14.64623	2.20800	18.2380	27.1438	7.00	44.00

The ash content of coal is an empirical quantity which is useful as index of coal uses (Ahiarakwem and Okpara, 2012). Ash content of a coal is the total organic residue produced from the burning of the combustible fractions of coal. Coals with high ash content are considered not good for power generation, briquettes making and coke production (Ryemshak and Jauro, 2013, Onyemali *et al*, 2017). High ash content in coal increases the volume of slag and its composition during combustion in blast furnace as well as constituting problem of high cost of disposal. The ash content of coal also determines the best cleaning method for raw coals. From this study, Lafia Obi, Udane Biomi, Okpara, Ibobo, Owukpa and Ogboyoga coal deposits have markedly higher ash contents than the 10% generally specified for good metallurgical coke making (Ryemshak and Jauro, 2013) while Onyema, Okaba, Maiganga and Iva Valley coals have ash contents that are considered optimum or below the specified value for coke making.

However, the India Ministry of Environment and Forestry (MoEF) considered 40% limit of ash content for coals that can be used for power generation and coal briquette making (Onyemali *et al*, 2017). This means that if the conditions outlined by the MoFT are applied, some of the studied coals may be useful for power generation and briquette production except for the Lafia Obi, Okpara and Ogboyoga coals with more than 40% of ash content.

4.2.3 Volatile Matter Content

The Lafia Obi, Onyema, Okaba, Maiganga, Udane Biomi, Okpara, Ibobo, Owukpa, Iva Valley and Ogboyoga coals have on average volatile matter of 11.16%, 67.60%, 63.90 %, 67.35%, 19.60%, 22.50%, 62.98%, 56.60%, 74.23% and 45.58%, respectively (Tables 1 and 5).

These values show that Iva Valley coal has the highest volatile matter, followed by Onyema coal, Maiganga coal, Okaba coal, Ibobo coal, Owukpa coal, Ogboyoga coal, Okpara coal, Udane Biomi coal and the Lafia Obi coal with the least volatile matter. The volatile matter content of a coal depends on its rank; it decreases with increase in coal rank and vice versa. It is an important coal parameter to evaluate as far as coal uses are concerned. In metallurgical coke making, volatile matter does not usually form part of the coke, but rather evolves as coal tar during coal carbonization (Ryemshak and Jauro, 2013). High volatile coals usually generate high pressure during coal burning and this can damage the coke oven walls (Obaje, 1997). Medium volatile coals (27.70% to 30.30%) are known to be good coke-making coals (Adeleke *et al*, 2011 as reported in Ryemshak and Jauro, 2013).

These suggest that only Lafia Obi, Udane Biomi and Okpara coal deposits with volatile matter contents that fall within the specified range are good for metallurgical coke making while Onyema, Okaba, Maiganga, Ibobo, Owukpa, Iva Valley and Ogboyoga coals are not good coke forming coals. However, the non-coking coals as a result of their high volatile matter content can be employed in other economic uses such as power generation and domestic energy sources since such high volatile coals will readily ignite and agglomerate well.

Table 5: Mean, Standard deviation, Minimum and Maximum Concentration of Volatile Matter in the studied coals.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Lafia obi	4	11.125	0.66521	0.3326	10.0665	12.1835	10.3	11.9
Onyeama	4	67.6	1.06458	0.53229	65.906	69.294	66.5	68.7
Okaba	4	63.9	1.37356	0.68678	61.7144	66.0856	62.1	65.4
Maiganga	4	67.35	1.5	0.75	64.9632	69.7368	65.4	69
Udane-Biomi	4	19.6	0.3559	0.17795	19.0337	20.1663	19.1	19.9
Okpara	4	22.5	0.1633	0.08165	22.2402	22.7598	22.3	22.7
Ibobo	4	64.275	1.98725	0.99363	61.1128	67.4372	62.1	66.9
Owukpa	4	67.35	1.5	0.75	64.9632	69.7368	65.4	69
Iva valley	4	74.225	1.39613	0.69806	72.0035	76.4465	73.1	76.2
Ogboyoga	4	45.575	2.52108	1.26054	41.5634	49.5866	42.4	47.7
Total	40	51.7182	22.2722	3.35766	44.9468	58.4896	10.3	76.2

4.2.4 Fixed carbon Content

The average fixed carbon contents of the analyzed coal deposits are 41.60%, 18.88%, 17.26%, 13.81%, 57.85%, 27.99%, 12.37%, 21.47%, 14.40%, 10.53% and 4.38% for Lafia Obi, Onyema, Okaba, Maiganga, Udane Biomi, Okpara, Ibobo, Owukpa, Iva Valley and Ogboyoga coals respectively (Table 1). These show that the Udane Biomi coal has the highest carbon content, followed by Lafia Obi, Okpara, Owukpa, Onyema, Okaba, Iva Valley, Maiganga, Ibobo and Ogboyoga with the least fixed carbon content (Tables 1 and 6).

Fixed carbon contents in coals serve as the measure of their rank and quality. High carbon content is essential for the coking of coals since it is the mass that forms the coke when coals undergo carbonization (Jauro, 2011). This suggests that the Udane Biomi coal with the highest fixed carbon content has most carbon for coke formation, followed by Lafia Obi, Okpara, Owukpa, Onyema, Okaba, Iva Valley, Maiganga, Ibobo and Ogboyoga with the least fixed carbon content. The maturity of the studied coals will follow the same trend as for the fixed carbon content of the coals since the two parameters of coal are directly related to one another.

Hence the Lafia Obi coal is most matured of the studied coals and the Ogboyoga coal as the least matured.

Table 6: Mean, Standard deviation, Minimum and Maximum Concentration of Fixed carbon in the studied coals.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Lafia obi	4	41.6000	.99833	.49917	40.0114	43.1886	40.85	43.05
Onyeama	4	18.8750	1.89934	.94967	15.8527	21.8973	16.70	21.30
Okaba	4	17.2625	2.72928	1.36464	12.9196	21.6054	13.60	19.65
Maiganga	4	13.8125	1.50686	.75343	11.4148	16.2102	12.15	15.60
Udane-Biomi	4	57.8500	.24833	.12416	57.4549	58.2451	57.50	58.05
Okpara	4	27.9875	3.11110	1.55555	23.0370	32.9380	24.55	32.10
Ibobo	4	12.3625	1.76464	.88232	9.5546	15.1704	10.05	14.15
Owukpa	4	21.4625	3.08420	1.54210	16.5548	26.3702	18.30	25.00
Iva valley	4	14.4000	1.37417	.68708	12.2134	16.5866	12.50	15.65
Ogboyoga	4	10.5250	2.40468	1.20234	6.6986	14.3514	8.40	13.80
Total	44	21.8648	15.04693	2.26841	17.2901	26.4395	2.55	58.05

4.3 Ultimate Characteristics of the Coals

The results of the ultimate analysis of the studied coals are presented in Tables 1. The results show that Iva Valley coal has the highest organic carbon content (3.30%), successfully followed by Okaba (3.23%), Onyema (3.16%), Ogboyoga (3.02%), Okpara (2.96%), (Udane Biomi and Maiganga, 2.92% each), Ibobo (2.87%), Owukpa (2.82%) and Lafia Obi (2.09%). Organic carbon is one of the major combustible constituents of coal. From the above, the Iva Valley coal can be considered most matured of all the analyzed coals while the Lafia Obi is considered the least matured. The nitrogen values for all the analyzed coals are generally low. Ibobo coal has the highest sulfur content of 2.03%, followed by the Okaba and Iva Valley (1.90%), Owukpa (1.74%), Onyema (1.27%), Udane Biomi (1.58%), Okpara (1.24%), Ogboyoga (1.36%), Maiganga (0.96%) and Lafia Obi with the lowest sulfur content (0.74%). The maximum acceptable limit of sulfur in coals is 1.5% to 1.6% (Ryemshak and Jauro, 2013). Sulfur is one of the major undesirable elements in coal as far as coal utilizations are concerned. Its content in coals however contributes to the heating value on combustion of coals. It produces acids of sulfur dioxide and sulfur trioxide which corrodes combustion equipment and also cause atmospheric pollution which can be lethal to human life. The addition of calcium hydroxide used as a desulphurizer can further reduce the sulfur content in all the coals.

5. CONCLUSION

The proximate results of the studied coals indicate that the Udane Biomi coal had the lowest and acceptable values of moisture content (2.45%) for metallurgical coke production. This is followed by Ogboyoga with moisture content of (3.62%) for the production of metallurgical coke. Appropriate blending of Onyema and Lafia Obi coals with coals of moisture contents of (5.00%) and (6.62%) respectively could improve on their usage as metallurgical coals. The other studied coal deposits have relatively high moisture contents that are greater than those required for metallurgical coke production and hence may not be useful as metallurgical coals.

The Onyema, Okaba, Maiaganga, Ibobo, Owukpa and Iva Valley coal deposits with low to medium ash contents will be good sources of coking coals for metallurgical applications. Their ash content values fall within most of the specified values of ash by the major coal marketing companies as listed in appendix B. Conversely, the Lafia Obi, Udane Biomi, Okpara and Ogboyoga coal deposits with high to very high ash contents are not good sources of coking coals for metallurgical makings. Such coals will however be useful in power utilization and non-core sector consumers. These coals will also not be acceptable in coal washeries due to their high ash contents.

In terms of volatile matter contents, the studied coal deposits can be grouped into two classes; those with high to very high volatile matter which include Onyema, Okaba, Maiganga, Ibobo, Owukpa, Iva Valley and Ogboyoga coal deposits and those with low volatile ma tters viz Lafia Obi, Udane Biomi and Okpara coal deposits. Those with high to very high volatile matters will not form cokes and are not used as sources of house warming while the coals with low volatile matters are good for coke making and sources of heat generation for homes.

Lafia Obi and Udane Biomi coal deposits have high fixed carbon contents which would transform into more carbon for formation of coke (Onoduku, 2014, Ryemshak and Jauro, 2013).

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