

# Geology and Geochemical Assessment of Maastrichtian Coal Quality in Abocho area, Northern Anambra Basin, Nigeria

A. A. Zakari<sup>1\*</sup> and B. S. Jatau<sup>2</sup>

<sup>1</sup>Department of Geology, School of Physical Sciences, Federal University of Technology, Minna, Nigeria.

<sup>2</sup>Department of Geology, Faculty of Natural Sciences, Sciences, Nasarawa state University, Keffi, Nigeria.

## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

## Article Information

DOI: 10.9734/JGEESI/2021/v25i730294

### Editor(s):

(1) Anthony R. Lupo, University of Missouri, USA.

### Reviewers:

(1) Hassan Rahmanpour, Islamic Azad University, Iran.

(2) Daniel E. Azunna, Clifford University, Nigeria.

Complete Peer review History: <https://www.sdiarticle4.com/review-history/71492>

Original Research Article

Received 14 May 2021  
Accepted 19 July 2021  
Published 20 July 2021

## ABSTRACT

Detailed geologic mapping and geochemical analysis of coal samples around Abocho area, northern Anambra Basin, Nigeria was conducted in order to assess the quality of the coals in the area. Proximate and ultimate analyses were carried out on coal samples from the Mamu Formation to determine its chemical characteristics. Physical analysis was also carried out on the coal samples to determine the specific gravity, density and hardness. Geochemical analysis was also carried out on the associated rocks in the study area (Abocho), particularly Shales and Clays to determine their major oxides composition. The area is composed of the Maastrichtian Mamu Formation overlain by the Ajali Sandstone of the same age both dipping between 16°E and 19°E. The geologic mapping of Abocho area revealed two mappable lithologic units: The Mamu Formation and the Ajali Sandstone. The Proximate analyses indicates that the coal contains an average 7.15%, 35.53%, 36.24% of moisture content, volatile matter and fixed carbon respectively. These burns to generate 4,339 kcal/kg calorific value with 20.80% ash yield. The result of the ultimate analysis shows 57.81% organic carbon, 4.15% hydrogen, 8.41% oxygen, 1.39% nitrogen

\*Corresponding author: E-mail: [attahzakari001@gmail.com](mailto:attahzakari001@gmail.com), [attahzakari@gmail.com](mailto:attahzakari@gmail.com), [attzak@yahoo.com](mailto:attzak@yahoo.com);

and 0.3% Sulphur. The physical analysis revealed that, the coal has an average specific gravity of 1.5g/cm, average density of 1.4g/cm<sup>3</sup> and average hardness of 1.2. These characteristics qualify the coal to be ranked as high volatile sub-bituminous to marginal lignite. The coal is thus, suitable for combustion, gasification, electric power generation and industrial uses. Geochemical results show that the Shale contains 60% Silica (SiO<sub>2</sub>) and 26% Alumina (Al<sub>2</sub>O<sub>3</sub>) constituting 86% of bulk chemical composition. The Clay contains 70% Silica (SiO<sub>2</sub>) and 25% Alumina (Al<sub>2</sub>O<sub>3</sub>), constituting 95% of bulk chemical composition. The occurrences of CaO, NaO and K<sub>2</sub>O which are the major component of feldspar in clay suggests the clay to be of granitic origin possibly from Oban massif, east of the Anambra Basin. It also suggests low feldspar content.

*Keywords: Coal; proximate analysis; ultimate analysis; geochemical analysis; anambra basin.*

## 1. INTRODUCTION

### 1.1 Background to the Study

Coal is an organic, combustible rock substance formed from the accumulation of plant matter that has undergone great physical and chemical changes through varied geological processes [1]. Coal is a general name given to stratified accumulations of carbonaceous materials derived from vegetation that were accumulated in swamps near seas. Coal is mainly composed of carbon, but it also has Oxygen, Sulphur, hydrogen, and nitrogen and includes some inorganic minerals and water. Coals are classified into ranks ranging from Peat through sub-bituminous, bituminous and anthracite coals depending on the level of coalification undergone by the vegetal matter. Coal varies in colors ranging from brown-black, with properties like luster, dull too shiny. Coals are generally layered and tends to break into blocks or tabular form. The specific gravity of coals falls between 0.7-1.8g/cm<sup>3</sup>. This depends on the amount of alteration and compaction by due to temperature and pressure, the amount of incombustible (inorganic mineral) matter it contains [2].

In Nigeria, coal deposits have been identified within the Cretaceous series of the Upper, Middle and Lower sections of the Benue Trough as well as the Anambra Basin. The coal deposits of Anambra Basin in the South-eastern Nigeria and the Southern portion of the Benue Trough contains the largest and most economically viable coal resources [3] which are made up of lignite and sub-bituminous coals hosted within the Middle Campanian–Late Maastrichtian Mamu Formation [4]. Nigeria has about 1.2 billion tons of coal in proven, probable and inferred reserves [5].

Recently, the Nigerian Government, in a bid to diversify her economy from oil, announced a

renewed interest in the mining sector particularly the use of coal to replace gas in powering the electricity turbines. This also has been adopted in several nations of the world as coal has found applications as fuel for cooking, cement factories and electricity generation stations. It has also found applications in steel production and synthetic fuels.

Coal has been utilized both for domestic and industrial purposes. For coal to be suitable in any application, it must possess certain minimal physical and chemical properties that are collectively obtained through inorganic geochemical analysis. Quality assessment of coal resources of Nigeria has been conducted by the Nigerian government and other researchers on the suitability of the Nigerian coal for different purposes. One of such assessment was done in the 1950 [6] another was done by Geological survey of Nigeria in 1973 [7]. Both of these were aimed at determining the suitability of the coals for rail transport and coke production, preparatory for the take-off of Ajaokuta iron and steel company. Within the Kogi coal district, detailed quality assessment of coal has been reported around Ogboyaga and Okaba. In the former, 27 drilled core samples and 15 outcrops samples were analyzed while in the later, 17 core samples were obtained from a more than 2 m thick extensive coal seam [8]. Unfortunately, mention was only made of coal seam outcrops along stream channels in Dekina without a comprehensive quality assessment. This research therefore seeks to assess the quality of coal resources around Abocho area using geological mapping, physical and inorganic geochemical analysis.

### 1.2 Regional Geological Setting of the Study Area

The geologic evolution of the Anambra basin started in the Lower Cretaceous with the

separation of the South American and African Plates which led to the formation of the Benue Trough as a failed arm of the rift's triple junction. The morphology of Anambra basin is roughly triangular. It is located in the south-central part Nigeria and covers about 40,000 km<sup>2</sup> (Fig. 1). The Anambra basin represents one of the sub-basins of the Benue rift structure which is flanked by the Basement Complex rocks and the Bida basin on the western side, while the eastern portion is bounded by Abakaliki/Benue Basin. The northern and southern side is bound by the middle Benue Trough while the northern part is bound by the Niger Delta basin [9].

The Lower Maastrichtian Mamu Formation has been reported to be exposed as long narrow ridges in Anambra Basin trending in a NE-SW orientation (Fig. 1). The Mamu Formation comprises alternating lithologies of sandstones, sandy shales and mudstones with interbedded coal seams. Mamu formation is underlain by the Campanian Enugu/Nkporo Shales (lateral equivalents), and overlain by Middle Maastrichtian Ajali Sandstone and Upper Maastrichtian to Danian Nsukka Formation (Fig. 1). Five sedimentary units have been delineated in the Mamu Formation consisting of shale or sandy shale (basal unit), sandstone, sometimes interbedded with shale, carbonaceous shale, coal and sandy shale [10,11]. The succession is paralic as demonstrated by the alternating marine and continental facies, and is considered to represent part of the "third marine cycle" in southern Nigeria and these are deposited mainly in the Campanian – Maastrichtian times in Anambra and Afikpo Basins (Fig. 1) [12-14].

### 1.3 Stratigraphy of Anambra Basin

The various lithostratigraphic units resulting from these depositional cycles are here presented (Fig. 2). These include the Nkporo/Enugu shale, Mamu Formation, Ajali Sandstone and Nsukka Formation. Others include Imo Shale, Ameki group and Ogwashi Asaba formation.

#### 1.3.1 Nkporo/Enugu shale

The Campanian Enugu Formation consists of coarsening upward sequences with thick, dark grey shale at the base, grading upward through siltstones into thin, texturally mature sandstone [15]. The lithologic assemblage suggests deltaic progradation during active delta growth. The carbonaceous shale at the base is interpreted as full marine pro-delta subfacies while the upper

part of the section represents shallow water shoreface subfacies. The Enugu Formation is considered as lateral equivalent to Owelli sandstone, Nkporo Shale, and Afikpo Formation [16].

#### 1.3.2 Mamu formation

The Maastrichtian Mamu Formation is about 400 m thick and consists of rhythmic sequences of sandstones, shales, siltstones, mudstones, sandy shales with interbedded coal seams suggesting deposition under paludal to possibly marginal marine [17,18]. It was considered by earlier workers as Lower Coal Measures.

#### 1.3.3 Ajali sandstone

Ajali Sandstone consist of entirely of cross bedded sandstones with drapes of clay stones extending as stacks of sheet-like bodies from the Calabar flank northwards towards Enugu and measures about 300m in thickness. The Ajali Sandstone was referred to by earlier workers as false bedded sandstone. It is a regressive phase conformably overlying the Mamu Formation. The lithology of this Formation consists of white, friable, coarse-grained, moderately to poorly sorted, with thin beds of whitish clay stone as well as numerous bands of variegated rarely carbonaceous shale [9]. Depositional environment of the Maastrichtian sediment was interpreted to be tidal due to several occurrences of herringbone cross-bedding and bioturbations [14,1].

#### 1.3.4 Nsukka formation

The Danian Nsukka Formation marks the onset of the transgression and a return to paludal conditions. The fluvio-deltaic formation overlies the Ajali Sandstone and is made up of Sandstones interbedded with blue Clays, Sandstones that are fine-grained in texture, as well as Carbonaceous Shales, thin bands of Limestones and thin Coal seams (Upper Coal Measure) [19,20].

#### 1.3.5 Imo shale

The marine Imo Shale is the outcropping type of the Akata Formation within the subsurface Niger Delta. It contains an important amount of organic matter and may be a good source for hydrocarbon within the northern part of the Niger delta. The authors [21,22] gave the age of the Imo Formation to be of Paleocene and its

depositional environment to be mainly marine with littoral to neritic environments.

### 1.3.6 Ameki group

The Ameki Group comprises of the Nanka Sand, Nsugbe Formation, and Ameki Formation [17]. These formations mark the return to transgressive conditions. The outcropping deposits of the Eocene regression, which marked the onset of the Niger delta progradation, consists of the “Ameki Group” which includes tidal facies and backshore as well as pro-deltaic facies. The Formation is predominantly alternating shale, sandy shale, clayey sandstone, and fine-grained fossiliferous sandstone with thin limestone bands [23,21].

### 1.3.7 Ogwashi asaba formation

The Oligocene – Miocene Ogwashi Asaba Formation consist of interbedded successions of lignite, shale, sandstone, siltstone, and claystone facies. It is the outcropping equivalent of the Agbada Formation in the subsurface Niger Delta. Depositional environment has been interpreted to be continental [24].

## 2. MATERIAL AND METHODS

### 2.1 Geological Mapping and Sample Collection

Geological mapping was carried out around Abocho and environs within the northern part of Anambra Basin to produce a comprehensive geological map and to obtain good quality samples for analytical studies in accordance with minimal geological standards as demonstrated in other reports [25-28]. Several traverses were taken across the three localities namely: Ibobo, Okatakpokpo and Emewe. At every outcrop encountered, the rock type(s), bed thicknesses, textural features, sedimentary structural features were recorded and possible depositional environments proposed. A total of twenty samples were collected. Although two lithologic units: Lower Maastrichtian Mamu Formation, and upper Maastrichtian Ajali Sandstone Formation were encountered in the area, only samples from the Mamu Formation were collected and analyzed. These include fifteen coal, two shale and three clay samples.

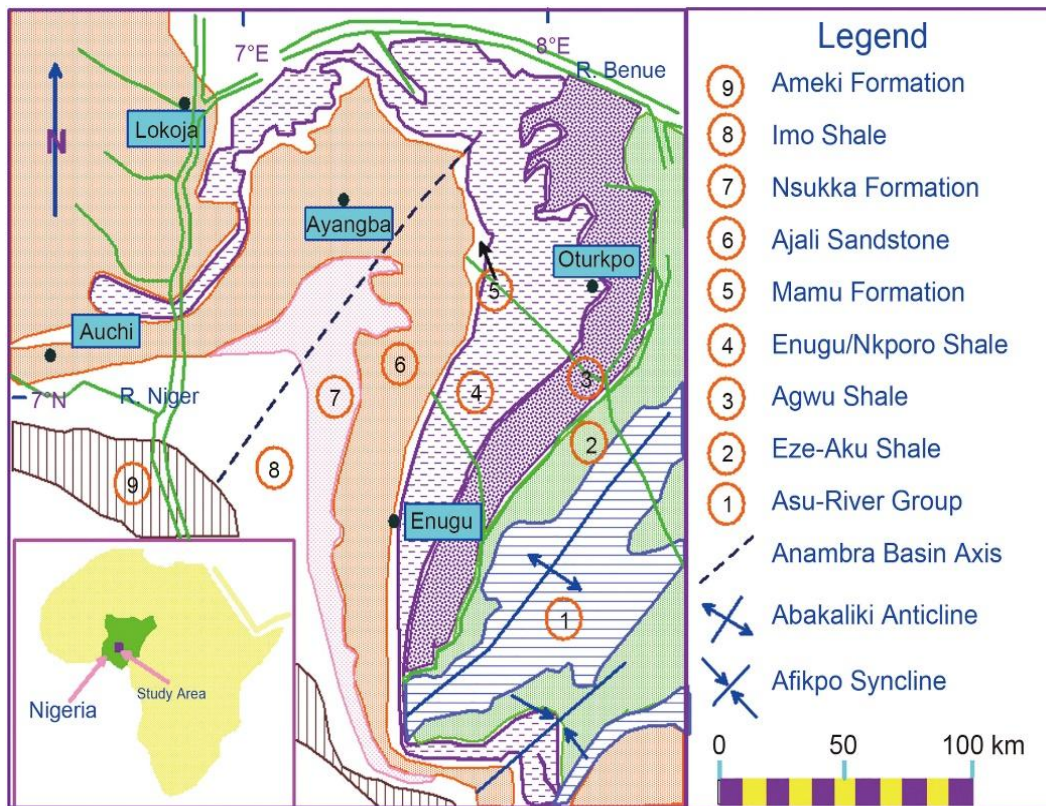


Fig. 1. Geological map of the anambra basin showing location of study area [15]

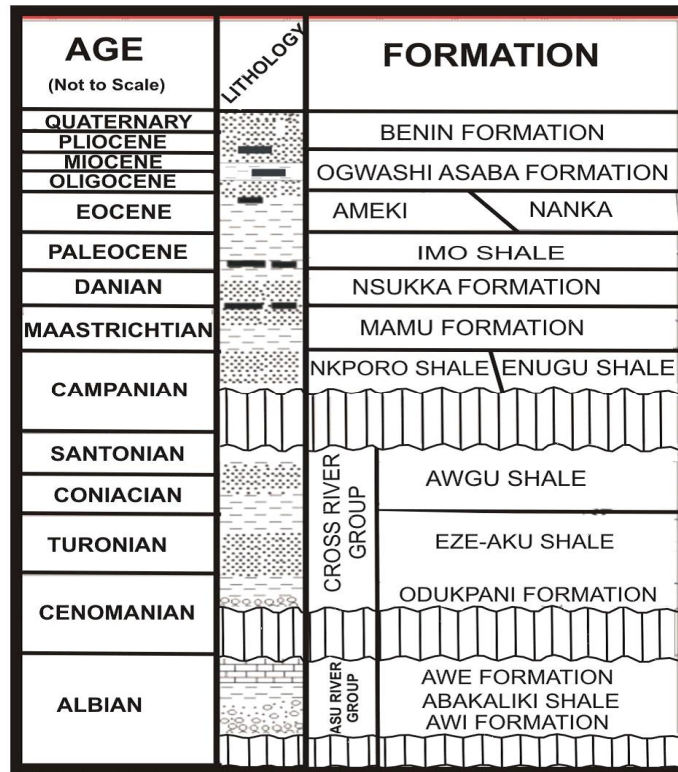


Fig. 2. Stratigraphic and lithologic section of southern benue trough and anambra basin from [16]

## 2.2 Laboratory Methods

### 2.2.1 Sample preparation

All analyses were carried out at Nigerian Geological Survey Agency, Kaduna, Nigeria. Sample preparation was carried out in accordance with American Society for Testing and Materials Development (ASTMD) 2013-86 standard methods. Samples were grinded to fine powder, using auger grinding machine and passed through a 150 micro mesh sieves in order to ensure homogeneity of the samples. These were then used for proximate and ultimate analyses. Also, pulverized shale and clay samples were processed to produce pellets and packaged for x-ray florescence analysis.

### 2.2.2 Proximate analysis

Proximate analysis determines the moisture content, volatile matter, Ash content and, by difference, the fixed carbon within the coal sample as well as the Calorific value of the coal all expressed in percentages. Proximate analyses form the basis upon which the

performance prediction index of coals is determined. Proximate analysis of the samples was carried out using ASTMD 3172-73 (84) Standard.

### 2.2.3 Ultimate analysis

Ultimate Analysis was carried out on the coal to determine the percentage of Carbon, Hydrogen, Oxygen, Nitrogen and Sulphur. The Carbon, Hydrogen and Nitrogen contents of the coal were determined using instrumental method according to ASTM D5373-08. During this test, 0.5g of ground coal was fed into combustion chamber of the instrument at accelerated temperature of 1350°C in an atmosphere of oxygen. During combustion, the components of coal (Carbon, Hydrogen and Nitrogen) were converted to their corresponding gases (CO<sub>2</sub>, H<sub>2</sub>O, N<sub>2</sub>/NO<sub>x</sub>). The Nitrogen oxide was further converted to elemental nitrogen and together with other gases is detected by the gas ionization detector (GID). The Sulphur content was determined by high temperature combustion test method. 0.5g of coal were accurately measured and burned in a tube furnace at a minimal temperature of 1350°C



in a stream of oxygen to ensure complete oxidation of Sulphur in the coal to Sulphur dioxide (SO<sub>2</sub>). The amount of Sulphur dioxide produced was measured using infrared absorption detection device [29].

#### 2.2.4 Physical analysis

The samples were analyzed physically to determine the density, Specific Gravity and hardness. Sample specimen was weighed in air, then submerged in distilled water at 23°C using a sinker and a wire to hold the specimen completely submerged. The loss in weight was determined which is directly proportional to the mass of the fluid displaced.

$$\text{Specific gravity S.G} = a/(a+w)-b \quad (1)$$

a=mass of specimen in air,  
b=mass of specimen and sinker in water,  
w=mass of totally Immersed sinker + wire;  
Density (kg/m<sup>3</sup>) = s.g x 997.6.

#### 2.2.5 Geochemical analysis

X-ray Fluorescence spectrometry is a method of quantitative analysis that obey the law of electromagnetic radiation which states that a body surface can absorb incident radiation and reflect the incident radiation and emit the radiations [30]. Energy dispersive X-ray Fluorescent (EDXRF) spectrometer of model "Minipal 4" was used for the analysis. The pellets were carefully placed in the respective measuring positions on a sample changer of the machine. Time of measurement for each sample was 100 seconds and the medium used was air throughout the duration of the measurement. The machine was calibrated by the machines gain control, after which the respective samples were measured by clicking the respective positions of the sample changer. Loss of Ignition (LOI) was determined gravimetrically by heating 1g of the powdered sample in a cleaned weighed crucible at 1000°C. After which the crucible and the content was weighed to get the difference in weight before and after heating.

$$\text{LOI} = (a - b/1) \times 100\% = \text{H2O}+ \quad (2)$$

Where

a = weight of crucible + 1g of the sample before heating,  
b = weight of crucible + 1g of the sample after heating.

### 3. RESULTS AND DISCUSSION

#### 3.1 Geology of the Study Area

The study area is underlain by two mappable lithologic units trending N-S. These units belong to the older Mamu Formation (Lower Coal Measures) occupying about 60% of the study area and overlain by the Ajali Sandstone formation, having a comfortable contact (Fig. 3). The Mamu Formation dip on an average of 18°E, while the Ajali sandstone dips between 16°E - 18°E. Several structures have been mapped in the formations. These include laminations, burrows, cracks and fissures. Thin but visible laminations occur in the shale having thicknesses of about 2 cm have exhibiting a variety of colors from white, brown, grey or red. Visible cracks or fissures occur in the rock sequence exposed at the coal site, sometimes running vertically from top to bottom. Burrows occur frequently and randomly throughout the formations.

#### 3.2 Laboratory Analysis

##### 3.2.1 Proximate analysis

The result of proximate analysis conducted on the coal samples indicate that the coal at Ibobo have moisture content that ranges from 4.29% to 20.96% with an average of 7.86%, This is within the standard range for sub-bituminous to bituminous coal [31]. Generally high moisture content in coal negatively affects its calorific value but with this minimal moisture content, the Ibobo coal is expected to burn at reasonably high calorific value. Ash content range from 6.82% – 28.08% with an average of 14.51% which is considerably high. The high ash content in Ibobo coal suggests that the coal contains high non-combustible matter like silt, clay and other inorganic mineral matters. This suggests a shallow marine/marshy swamps to fluvial transitional depositional environment. Ibobo coal have volatile matter of 37.68%, fixed carbon content of 39.64%, Sulphur content 0.31% while the calorific value is 4722.96 Kcal/Kg. The low Sulphur content is a good indication that the coal will not pose an environmental threat when use as fuel.

In a similar vein, analysis of coal obtained from Okatakpokpo area shows results with the same trend. Here, moisture content of the coal ranges from 4.43 to 6.98% with an average of 5.88 which is close to that of Ibobo series. The ash content

range between 32.36 to 54.13% with an average 39.45% while volatile matter, fixed carbon and Sulphur content averages 29.59%, 24.81% and 0.26% respectively. The result for coal designated as Emewe series is not different either. Moisture content here ranges between

7.00% and 8.50% with an average of 7.71%, likewise, the ash content averages 8.42 while volatile matter averages 39.31%. Fixed Carbon is relatively high here with values that range from 37.34 to 46.58 with an average of 44.26% while Sulphur content is as low as 0.30% (Table 1).

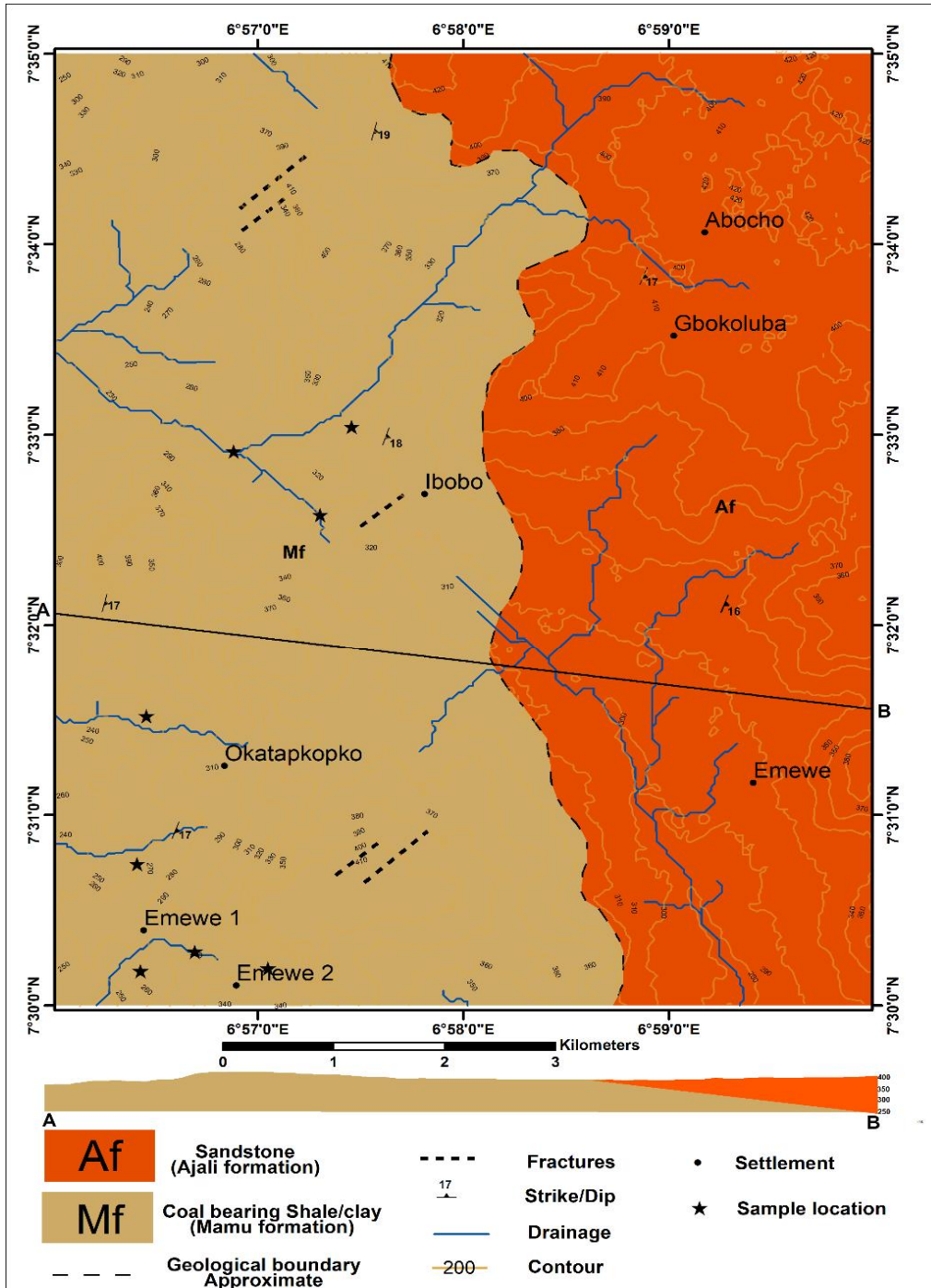


Fig. 3. Geology map of abocho and environs part of Ikoja sheet 247SE

Comparatively, the coal at Emewe have the highest fixed carbon (44.26%) and volatile matter (39.31%) while the coal at Okatakpokpo have the highest ash content (39.45%) with the lowest fixed carbon (24.81%) (Table 1, Fig. 4). In terms of calorific value, the Emewe coal have the highest calorific value (5185 Kcal/Kg) followed by Ibobo and then Okatakpokpo (Fig. 5). This observation agrees completely with international rule of thumb that coals which have high ash content burn with low calorific values. Generally, the coals in the study area shows similar characteristics which is an indication that they have undergone the same extent of coalification or are possibly obtained from the same seam which outcropped at different locations.

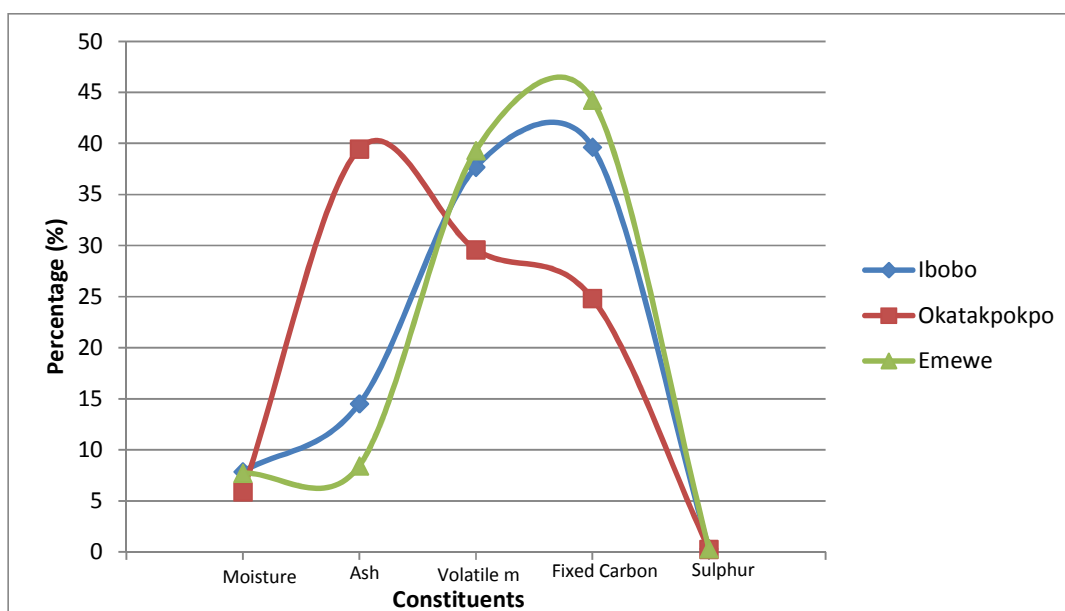
### 3.2.2 Ultimate analysis

The Ultimate analysis revealed that the carbon content of the coal is higher than the other constituent such as hydrogen, oxygen, Nitrogen

and Sulphur. The carbon content is at an average of 57% which is considered low and indicated that the Abocho coal is sub-bituminous in rank. The oxygen content of the coal is higher next to the carbon content with an average of 8.3% which is considered a bit high and indicated that the coal is relatively young and still undergoing maturation. The hydrogen content of the coal is considered to be too low with an average of 4.1%. The Nitrogen content is relatively low with an average of 1.4%. This place the coal at an advantage in terms of usage either as coking or non-coking coal since the environment will be less polluted as consequence of burning the coal. The Sulphur content is very low with an average of 0.30% which is commendable and also places the coal at a high recommendation for industrial use [23]. Summarily, the results of the ultimate analysis (Table 2) shows that Abocho coal, on the average, contains 57% carbon, 4% hydrogen, 8% oxygen, 1.4% Nitrogen, and 0.3% Sulphur.

**Table 1. Summary of proximate analysis on the coal in Abocho**

Sample ID	Moisture cont. (%)	Ash Cont. (%)	Volatile matter (%)	Fixed carbon (%)	Sulphur cont. (%)	Calorific value Kcal/Kg
Ibobo	7.86	14.51	37.68	39.64	0.31	4722.96
Okatakpokpo	5.88	39.45	29.59	24.81	0.26	3110.45
Emewe	7.71	8.42	39.31	44.26	0.31	5184.9
Average	7.15	20.79	35.53	36.24	0.29	4339.44

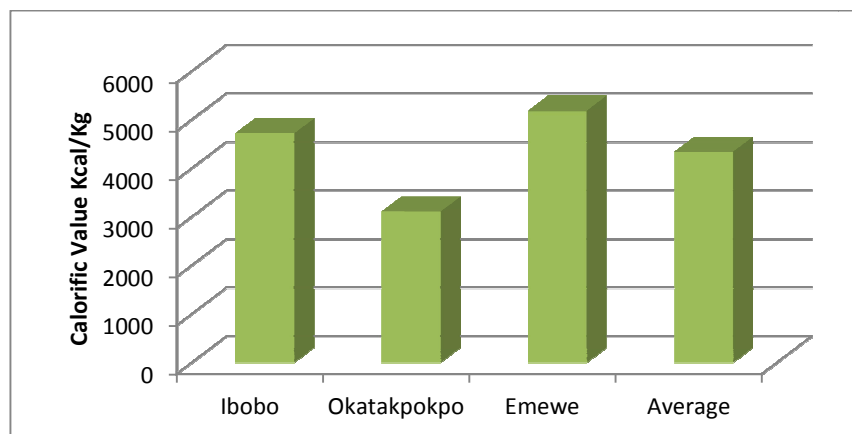


**Fig. 4. Comparative plot of percentage content of various constituents in (Ibobo, Okatakpokpo and Emewe) coals in the study area**



**Table 2. Average values of ultimate analysis results for Abocho coals.**

Sample ID	% Carbon	% Hydrogen	% Oxygen	% Nitrogen	% Sulphur
Ibobo	61.9176	4.5416	9.5123	1.3465	0.314
Okatakpokpo	44.3707	3.0988	5.4284	1.5081	0.254
Emewe	67.1458	4.8272	10.2781	1.3139	0.3125

**Fig. 5. Distribution and average calorific values of the three coal series in Abocho.**

### 3.2.3 Physical analysis

Mechanical tests subjected to the various coal samples to determine some of its physical properties show an average specific gravity of 1.5, average density of 1.4 (Apparent Relative Density (ARD)) and average hardness of 1.2 (Mohr's hardness scale). Higher specific gravity and density were recorded for Ibobo and Emewe and less for Okatakpokpo. This is an indication that the coal seams at Ibobo and Emewe are deep seated and more compact than those of Okatakpokpo. According to [2], coals with densities between 1.25 - 1.50 can be graded as Sub-bituminous or bituminous. On this basis, the Abocho coal falls within the Sub-bituminous coal rank. Apart from ranking, density of a coal helps in making accurate coal resources and reserve estimates. On the basis of hardness, the coal at Abocho could be generally described as soft coal with an average hardness of 1.2(Hm), because, lignite and bituminous coal have a hardness range of 2-2.5(Hm) while anthracite has a hardness of 4 [2].

### 3.2.4 Major oxides analysis on shale and clays

Geochemical studies using energy dispersive X-ray fluorescence (EDXRF) analysis revealed that the shale has major elements abundance with silica ( $\text{SiO}_2$ ) ranging from 58.73% to 60.33%,

$\text{Al}_2\text{O}_3$  25.93% to 26.92%,  $\text{TiO}_2$  1.55% to 1.74% constituting more than 86% of bulk chemical composition. The  $\text{TiO}_2$  here is higher than that of the clay as well as the  $\text{Al}_2\text{O}_3$ . The silica content is however relatively lower compared to the clay. The  $\text{Fe}_2\text{O}_3$  content is also higher here when compared to the clay. The shale is low in CaO, MgO,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$  and such low content indicates low amount of Illite or K-feldspar present. The MgO, MnO and  $\text{Na}_2\text{O}$  content values were very low in both samples, collectively only accounting for less than 1%. The shale thus did not indicate associated carbonates or dolomitization. The shale and the clay alumina to silica ratio  $\text{Al}_2\text{O}_3/\text{SiO}_2 = 3:5$ , and  $2:6$  respectively and this means that on the bulk elemental constituent of the rocks (shale and clay) which silica and alumina constitutes over 70% in shale has a lesser silica content (60%) compared to the clay which has 70.2% while the clay has a lesser constituent of Alumina (25%) compared to the shale which has over 26.4%.

The shale has over 10% average loss on ignition (LOI) which is higher than that of clay and indicated great shale potential for carbonaceous compounds. The shale and the clay are highly silicious. Table 3 shows the major oxides composition of the clay as analyzed. Abundances of major oxides show that  $\text{SiO}_2$ (69.52 – 71.12%) and  $\text{Al}_2\text{O}_3$  (23.62% - 25.37%) constitutes over 90% of the bulk

chemical compositions, the high content of SiO<sub>2</sub> shows that the source rocks are rich in quartz and silica – rich minerals confirming the grittiness of the clay. Other oxides are present in relatively very small amounts.

The occurrences of CaO, NaO and K<sub>2</sub>O which are the major component of feldspar in clay suggests the clay to be of granitic origin possibly from Oban massif, east of the Anambra Basin. It also suggests low Feldspar content. Although, notable disparities exist in the SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> contents of the clay, the clay is more siliceous and less Aluminous. The clay has more Silica contents than the shale while less Alumina contents compared to the shale. The lesser content of alumina in the clay suggests a lesser degree of weathering activities. The alkalis (K<sub>2</sub>O, Na<sub>2</sub>O) as well as MgO and MnO occur in relatively insignificant proportions in the range 0.01 to 0.2%, that is indicative of weathering under tropical conditions from which the clay bodies resulted.

### 3.2.5 Coal rank

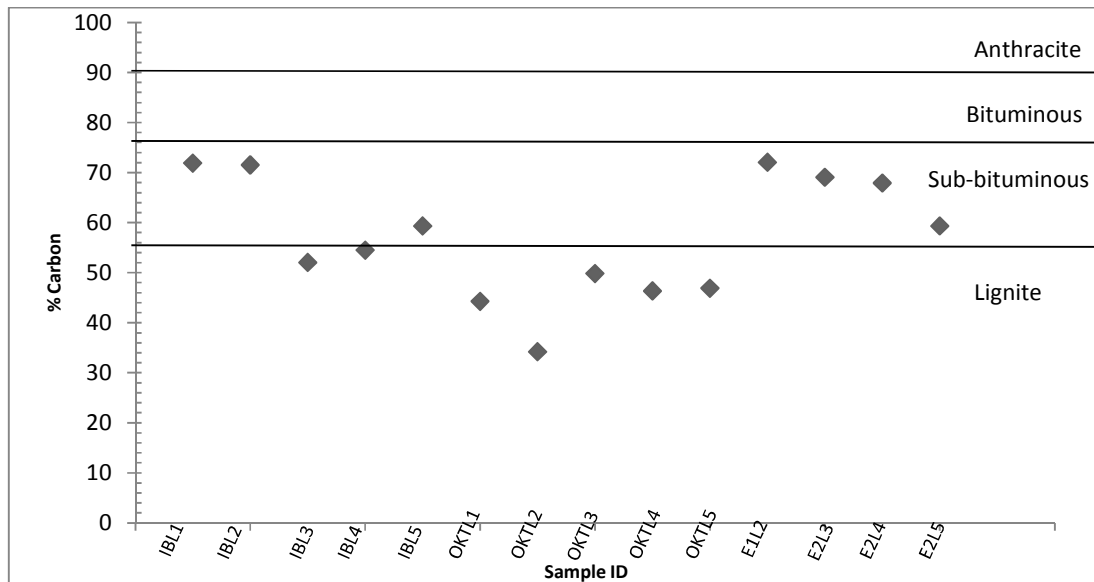
World over, coals are ranked according to the approximate carbon content, moisture content, elemental composition especially Sulphur and the amount of heat it can generate per unit weight when combusted (Calorific value) [32,33]. To determine the rank of Abocho coal, percentage carbon values were plotted against

samples (Fig. 6) according to [34]. The plot shows that Abocho coal is predominantly sub-bituminous in rank. Although, some samples (mainly the Okatakpokpo series plot within lignite field.

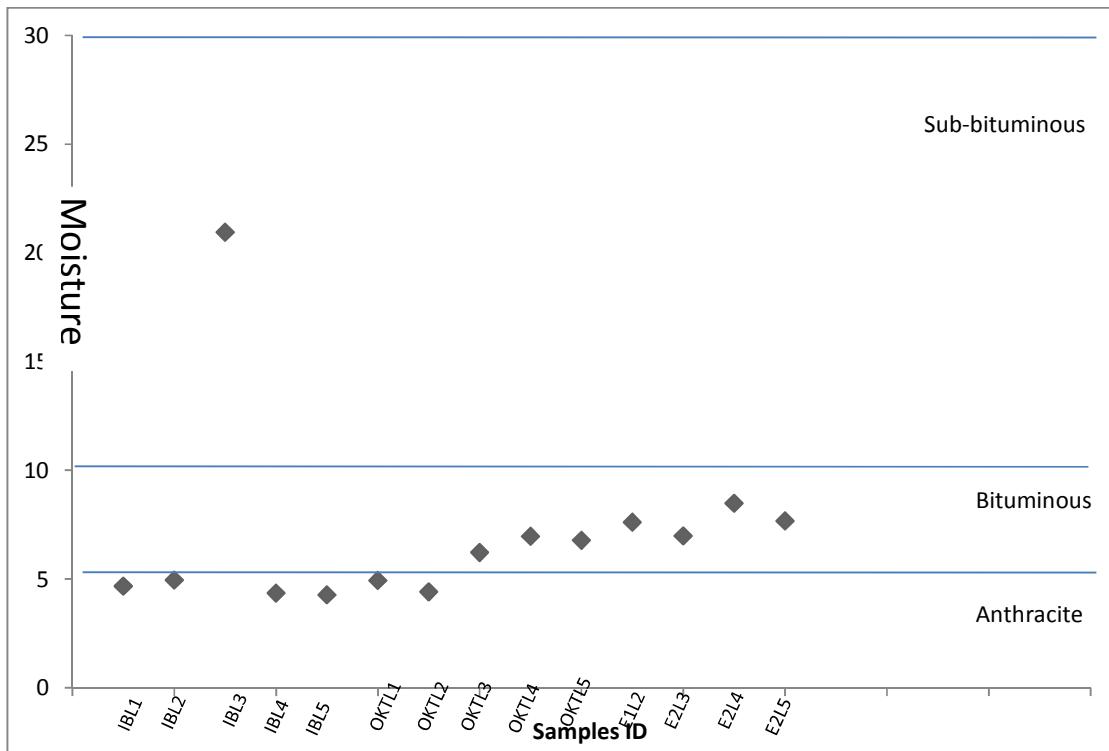
The moisture content in Abocho coal was also plotted against samples to determine the rank of the coal and result is contrary to the previous trend with 29% of the samples lying within the Anthracite region, 64% within bituminous coal while only 7% shows sub-bituminous coal rank (Fig. 7).

Due to the discrepancy between the two plots, the only convincing interpretation is that Abocho coal is actually Sub-bituminous in rank but with exceptional low moisture content, this quality is advantageous in the any application of the coal because it will ensure high calorific value.

On the basis of thermal heat production, the Abocho coal can generate heat within the ranges of 2,149 – 5,446 Kcal/Kg, equivalent to 3,870 – 9,808Btu/lb (Table 4) which is within the range of sub-bituminous to lignite coals according to Bowen and Irwin (2008). The calorific values were then plotted against samples and result shows that 42.85% of samples are sub-bituminous in rank while others are at marginal end of lignite rank (Fig. 8). This implies that, the coal seams situated at deeper levels will be conveniently sub-bituminous in rank.



**Fig. 6. Plot of percentage carbon against samples according to Schweinfurth 2009 shows that Abocho coal is 57% sub-bituminous in rank**



**Fig. 7. Plot of moisture content against samples indicates that the Abocho coal is predominantly bituminous to anthracitic in rank**

**Table 3. Summary of the calorific values of Abocho Coals in Kcal/Kg and Btu/lb**

Sample ID	Average calorific value (Kcal/Kg)	Btu/lb
Ibobo	4722.964	8506.056
Okatakpokpo	3110.446	5601.916
Emewe	5184.903	9338.01

42.85% of samples are sub-bituminous while others are at marginal end of lignite rank. To further classify the Abocho coal, results of ultimate analysis were compared to that of other standardized coal deposits. It was discovered that the values are similar to those of Wyoming (USA) sub-bituminous coal, Dietz (USA) coal, and Okaba (Nigeria) Sub-bituminous coal (Table 4, implying that Abocho coal is also sub-bituminous coal (Fig. 9). Ultimate Analysis of some coal in comparison with Abocho coal.

In a similar vein, the result of proximate analysis on coal samples around Abocho and environs compares favorably with coals of Indiana district and Power River Basin (USA) Okaba, Owukpa and Ogboyoga (Nigeria) both of which are sub-bituminous in rank (Fig. 9). This also is an indication that the Abocho coal is equally sub-bituminous in rank and can be used for the same purposes as the USA coals.

**Table 4. Ultimate analysis of some coal in comparison with abocho coal**

Property/Locality	% Carbon	% Hydrogen	% Nitrogen	% Sulphur
Abocho	57.14	4.11	1.39	0.3
Wyoming (USA) [35]	67.6	4.8	1.2	0.8
Dietz (USA) [35]	73.66	5.12	0.98	0.76
Okaba (Nig.) [36]	76.36	5.95	0.81	0.71

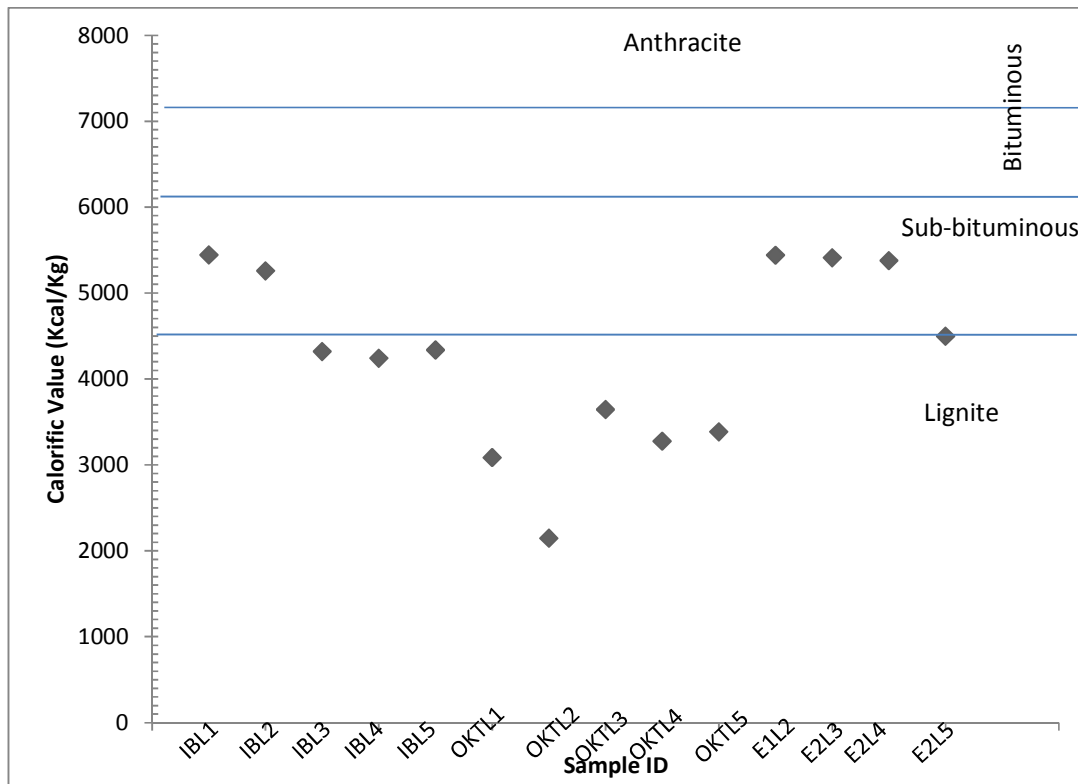


Fig. 8. Plot of calorific values of abocho coal against samples

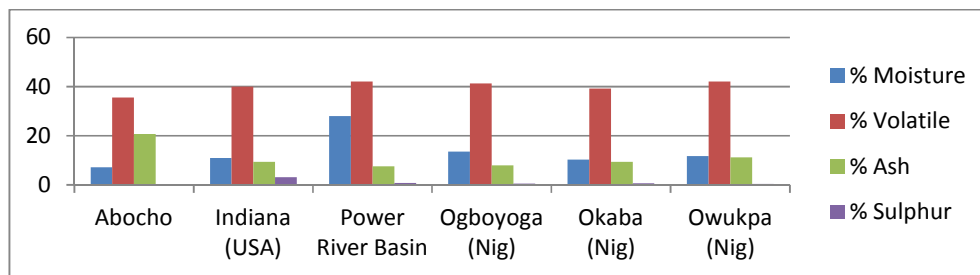


Fig. 9. Comparative result of proximate analysis between abocho coal and other coals

Table 5. Calorific values of abocho coal in comparison with other coals

Area	% Moisture	% Ash	% Sulphur	Calorific value	
				Btu/lb	Kcal/Kg
Abocho	7.15	20.79	0.3	7814	4339
Okaba (Nigeria) [35]	10.3	9.3	0.65	10280	5710
Enugu (Nigeria) [35]	7.6	6.7	0.93	11900	6610
Power River Basin (USA) [34]	28	7.6	0.72	8088	4490
Indiana (USA) [34]	11	9.4	3.13	11386	6322

### 3.2.6 Industrial applications of abocho coal

The suitability of coal for any industrial application is a function of its calorific value, i.e., the amount of heat it could generate per unit

weight and Sulphur content. The calorific value depends on the percentage fixed carbon, moisture content, amount of volatiles and non-combustible inorganic mineral matter. Coals with high carbon content, low moisture, low volatile

content and low amount of non-combustible materials produce high calorific values with little ash when burnt. Although, coals that contain high amount of volatiles are easy to ignite but burn with lesser heat value. High Sulphur coals on the other hand poses danger to the environment when burnt.

Coals around Abocho area produces heat values that are comparable to other coals that have been used for various applications (Table 5). The calorific value of an air-dried sample of coal from Abocho area range from 2149 to 5446 Kcal/Kg, though other authors report values usually between 7,000 and 8,000 kca/kg for Nigerian coals [37]. [38] in his work opined that the calorific value of Onyeama, Orukpa, Okaba and Gombe coals ranges between 7,000 – 8,000 kcal/kg, while that of the Obi/Lafia coal ranges between 7,500 –8,500 kcal/kg. The low moisture content and reasonably high calorific value makes Abocho coal suitable for combustion, though the high ash residue makes the coal less suitable as a domestic fuel. Other applications of the Abocho coal include electric power generation, gasification, liquefaction and industrial chemicals extraction.

#### 4. CONCLUSION

The study of the geology of Abocho and Environs within the Anambra Basin shows two lithologic units that outcrop within the area: the Mamu Formation and the Ajali Sandstone Formation. Study on the coal seams within the Mamu Formation rank the coal as lignite to sub-bituminous with high moisture and volatile content while Sulphur content is low. Characteristics of the coal show that it is most suitable for power generation, gasification and industrial manufacture of chemicals. On the other hand, the coal is unsuitable as domestic fuel because of high ash yield. It is equally unsuitable for metallurgical coke making due to low fixed carbon except it is blended with other high rank coals or is carbonized. In a similar vein, Abocho coal is not good for liquefaction due to low rank and high content of inertinite maceral.

Hence, since the coal can be applied for industrial purposes, geophysical investigation, drilling and test-pitting should be carried out around Abocho and environs in order to determine the actual depth and thickness of the coal seams in order to carry out reserve evaluation of the coal in order to determine the resource tonnage and its mining potentials.

#### DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

1. Oti W, Eze ON. Proximate Analysis and Ranking of a Suspected Sample of Coal from Afikpo and Enugu. *International Journal of Biology, Pharmacy and Applied Sciences*. 2017;6(2):326-332.
2. Xie KC. *Structure and Reactivity of Coal*. Springer. 2015;413.
3. Fatoye FB, Yomi BG. Appraisal of the Economic Geology of Nigerian Coal Resources. *Journal of Environment and Earth Sciences*. 2013;3(11):25-31.
4. Odoma AN, Obaje N, Omada JI, Idakwo SO, Erbacher J. Paleoclimate Reconstruction during Mamu Formation (Cretaceous) Based on Clay Mineral Distributions. *IOSR Journal of Applied Geology and Geophysics*. 2013;1(5):40–46. Available: <https://doi.org/10.9790/0990-0154046>.
5. Sobamowo GM, Ojolo SJ. Techno-economic analysis of biomass energy utilization through gasification technology for sustainable energy production and economic development in Nigeria. *Journal of Energy*. 2018;1–16. Available: <https://doi.org/10.1155/2018/4860252>
6. Usuanlele U. Development and education in British colonial Nigeria, 1940–55. *Developing Africa*. 2014;251–269. Available: <https://doi.org/10.7228/manchest er/9780719091803.003.0011>
7. Oyedepo SO, Babalola OP, Nwanya SC, Kilanko O, Leramo RO, Aworinde AK, et al. Towards a sustainable electricity supply in Nigeria: The Role of Decentralized



- Renewable Energy System. *European Journal of Sustainable Development Research*. 2018;2(4). Available: <https://doi.org/10.20897/ejosdr/3908>
8. Metu AG, Nwokoye E. Entrepreneurship development in Nigeria: Prospects and challenges. *SSRN Electronic Journal*; 2014. Available: <https://doi.org/10.2139/ssrn.2622222>
  9. Adebayo OF, Adegoke AK, Mustapha KA, Adeleye MA, Agbaji AO, Abidin NS. Paleoenvironmental reconstruction and hydrocarbon potentials of Upper Cretaceous sediments in the Anambra Basin, south-eastern Nigeria. *International Journal of Coal Geology*. 2018;192:56–72. Available: <https://doi.org/10.1016/j.coal.2018.04.007>.
  10. Reyment RA. The Stratigraphy of the cretaceous and Cenozoic Deposits, In: *Aspects of the Geology of Nigeria*. University of Ibadan Press, Nigeria. 1965;145.
  11. Faboya OL, Sonibare OO, Abimbade SF, Liao ZW. Shale gas prospect of different source rock types from Early Maastrichtian Mamu Formation, Anambra Basin, Nigeria. In *IOP Conference Series: Earth and Environmental Science*. IOP Publishing. 2020;600(1):012011.
  12. Short KC, Stauble AJ. Outline of Geology of the Niger Delta. *American Association of Petroleum geologists Bulletin*. 1967; 51:761–779.
  13. Tijani MN, Nton ME, Kitagawa R. Textural and geochemical characteristics of the Ajali Sandstone, Anambra Basin, SE Nigeria: implication for its provenance. *Comptes Rendus Geoscience*. 20103; 42(2): 136-150.
  14. Chiaghanam OI, Chiadikobi KC, Ikegwuonu ON, Omoboriowo AO, Onyemesili OC, Acra EJ. Palynofacies and kerogen analysis of upper cretaceous (early campanian to Maastrichtian) Enugu shale and Mamu Formation in Anambra basin, south-eastern Nigeria. *International Journal of Scientific & Technology Research*. 2013;2(8):87-97.
  15. Nton ME, Bankole SA. Sedimentological characteristics, provenance and hydrocarbon Potential of post Santonian sediments in Anambra Basin, south-eastern Nigeria. *RMZ-Materials and Geoenvironment Journal*. 2013;60(1):47-66.
  16. Akaegbobi IM, Nwachukwu JI, Schmitt M. Aromatic Hydrocarbon Distribution and Calculation of Oil and Gas Volumes in post-Santonian Shale and Coal, Anambra Basin, Nigeria: In M. R. Bello and B. J. Katz, eds., *Petroleum Systems of South Atlantic Margins*. Amer. Assoc. Petrol. Geol. Memoir. 2000;73:233-245.
  17. Nwajide CS. Anambra Basin of Nigeria: Synoptic basin analysis as a basis for evaluating its hydrocarbon prospectivity. In: Okogbue, C. O. (ed) *Hydrocarbon potentials of the Anambra Basin: Geology, Geochemistry and Geohistory perspectives*. Proceedings of the first seminar organized by the Petroleum Technology Development Fund (PTDF) chair in geology. University of Nigeria. 2005;1–46.
  18. Akande SO, Ogunmoyero IB, Petersen HI, Nytoft HP. Source rock evaluation of coals from the Lower Maastrichtian Mamu Formation, SE Nigeria. *Journal of Petroleum Geology*. 2007;30:303-324.
  19. Adamu ML, Rufai A, Atabo NO, Tope SA. Sedimentology and Depositional Environment of the Mid-Maastrichtian Ajali Sandstone in Idah and Environs, Northern Anambra Basin, Northcentral Nigeria; 2017.
  20. Obi GC, Okogbue CO, Nwajide CS. Evolution of the Enugu Cuesta: A tectonically driven erosional process. *Global Journal of Pure and Applied Sciences*. 2001;7:321–330.
  21. Oboh-Ikuenobe FE, Obi CG, Jaramillo CA. Lithofacies, palynofacies, and sequence stratigraphy of Paleogene strata in south-eastern Nigeria. *Journal of African Earth Science*. 2005;41:79-101.
  22. Ekwenye O, Nichols GJ, Nwajide CS, Obi G. A paleogeographic model for the sandstone members of the IMO shale, south-eastern Nigeria. *Journal of African Earth Sciences*. 2014;96. DOI: 10.1016/j.jafrearsci.2014.01.007
  23. Mastalerz M, Drobnik A, Rupp J, Shaffer N. Assessment of the quality of Indiana coal for integrated gasification combined cycle performance (IGCC), Indiana Geological Survey, Indiana University; 2005.
  24. Kogbe CA. Paleogeographic history of Nigeria from Albian times. In: Kogbe,

- C.A. (Ed.), Geology of Nigeria. Elizabethan Publishers, Lagos. 1976;237–252.
25. Adeigbe OC, Salufu AE. Geology and Depositional Environment of Campanian-Maastrichtian Sediments in the Anambra Basin, South-eastern Nigeria: Evidence from Field Relationship and Sedimentological Study. Earth Science Journal. 2009;13(2):148-166.
26. Onuigbo EN, Etu-Efeotor JO, Okoro AU. Palynology, paleoenvironment and sequence stratigraphy of the Campanian-Maastrichtian deposits in the Anambra Basin, South-eastern Nigeria. European Journal of Scientific Research. 2012; 78(3):333–348.
27. Zhu Q. Coal sampling and analysis standards. IEA Clean Coal Centre, London, United Kingdom. 2014;143.
28. Akande SO, Lewan MD, Egenhoff S, Adekeye O, Ojo OJ, Peterhansel A. Source rock potential of lignite and interbedded coaly shale of the Ogwashi–Asaba Formation, Anambra basin as determined by sequential hydrous pyrolysis. International Journal of Coal Geology. 2015;150:224-237.
29. Speight JG. Handbook of coal analysis. In: Chemical analysis, a series of monographs on analytical chemistry and its applications. 166. Wineforder J.D (ed), Hoboken, NJ, USA, John Wiley and Sons, Inc. 2005;238.
30. Loudon R. The Quantum Theory of Light (third ed.). Cambridge University Press; 2000,1973. ISBN 0-19-850177-3.
31. Bowen BH, Irwin MW. Coal Characteristics. The Energy Center at Discovery Park Purdue University; 2008.
32. Ekwenye OC, Nichols GJ, Collinson M, Nwajide CS, Obi GC. A paleogeographic model for the sandstone members of the Imo Shale, south-eastern Nigeria. Journal of African Earth Sciences. 2014;96:190-211.
33. Dunnington L, Nakagawa M. Fast and safe gas detection from underground coal fire by drone fly over. Environmental Pollution. 2017;229:139-145.
34. Schweinfurth SP. An introduction to coal quality. The National Coal Resource Assessment Overview: US Geological Survey Professional Paper 2009.
35. Gross D, Gross A, Schoenfeld M, Simmons W, Patrick B. Jupiter oxygen combustion technology of coal and other fossil fuels in boilers and furnaces. In 28th International Technical Conference on Coal Utilization and Fuel Systems, Clearwater, FL, USA; 2003.
36. Fatoye FB, Omada JI, Olatunji JA. Quality assessments and industrial usages of cretaceous Okaba coal, Anambra Basin, Nigeria. Journal of Mining and Geology. 2012;48(1):81-87.
37. Orajaka IP, Onwuemesi G, Egboka BCE, Nwankor GI. Nigerian Coal. Mining Magazine. 1990;447-448.
38. Mackowsky MTh The Application of Coal Petrography in Technical Processes. In: Stach's Textbook of Coal Petrology (Edited by Stach E, Mackowsky MTh, Teichmuller M, Taylir GH, Chandra D, Teichmuller R), Gebruder Borntraeger, Berlin. 1982;413–483.

© 2021 Zakari and Jatau; This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:

The peer review history for this paper can be accessed here:  
<https://www.sdiarticle4.com/review-history/71492>