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Geology and Petrography of Ibobo Coal, Anambra Basin, Nigeria

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Abstract

Coal is a combustible material consisting mainly of macerals and minor minerals. Macerals are the microscopic organic entities of coal while the inorganic components are the minerals. Maceral composition is vital for assessing the quality of coal and predicting its behaviour in metallurgical, combustion and other processes. It also helps to understand the geological history of coal deposits. Geological mapping of Ibobo coal deposit in the Anambra Basin of Nigeria was conducted and coal samples evaluated for maceral characteristics and vitrinite reflectance to determine the suitability of the coal for metallurgical processes and electricity generation. Petrographic analysis reveals the presence of the three maceral groups; vitrinite, liptinite and inertinite in all the samples. The proportion of the vitrinites and inertinites are higher than the liptinites in the samples. On mineral matter-free basis, the coal, on average, contains 60.80% vitrinite, 12.70% liptinite and 26.50% inertinite. With mineral matter counted, on average, it consists of 51.70% vitrinite,

11.40% liptinite, 23.10% inertinite and 13.80% mineral matter. The coal, on average, also contains 63.10% reactives (vitrinite + liptinite) and 36.90% inerts (inertinite + mineral matter). It has mean vitrinite reflectance measurement of 0.42 RoMax on average, which classifies the coal as sub-bituminous. These petrographic characteristics suggest that the coal does not possess coking qualities suitable for coke making for metallurgical processes thereby placing it on low quality and non-coking. However, it is good for electric power generation and as a domestic fuel.

Keywords: Ibobo Coal, Geology, Petrography, Sub-bituminous, Non-coking

Introduction

Coal is a combustible sedimentary deposit that is composed largely of carbon. It is a fossil fuel that is formed when dead plant matter decomposed into peat which is later converted into coal by the heat and pressure of overlying sediments. Coal is one of the cheapest and significant sources of energy, accountable for electricity production worldwide. Coal is the primary source of electricity and energy in many countries like India, China, Germany and USA.

Nigeria has large coal deposits most of which are reported to be within the Benue Trough and the Anambra Basin (Carter *et al.,* 1963; Obaje *et al.,* 1994; Fatoye *et al*., 2020). Though, the Anambra Basin is the main coal producing basin in Nigeria where thorough exploration and mining activities have been on since 1916 due to the discovery of commercial coal in Udi near Enugu in 1909 (Famuboni, 1996).

Coal was first discovered in the Mamu Formation (Lower Coal Measures) of the Anambra Basin and later reported in the Nsukka Formation (Upper Coal Measures). Lignites (brown coals) of Tertiary age and sub-bituminous coals (black coals) of Campanian–Maastrichtian age are distributed within the coal measures of the Mamu and Nsukka Formations in the Anambra Basin (Akande *et al.,* 1992a). However, the coal deposit at Obi-Lafia in the Middle Benue Trough is considered the oldest coal deposit (bituminous coal) in Nigeria so far discovered. The seams

belong to Awgu Formation of Turonian–Coniacian age which is dominantly shales, limestones, and sandstones (Offodile, 1972; 1980: Obaje and Hamza, 2000).

Apart from its use in electricity generation, coal can also be used in the production of coke for metallurgical processes and as a chemical source from which numerous synthetic compounds such as dyes, oils and waxes can be produced. It is used in heating boilers and ovens in industrial process heating. Coal is used for production of gas and automotive fuel.

Coal petrography is a microscopic method used to assess the organic and inorganic components of coal to determine its characteristics. It helps to determine coal rank, maceral composition and other properties that impact coal quality and appropriateness for various applications, such as steel production and power generation. Coal petrography is a vital tool in the characterization of coal deposits and coal products (Starch *et al*., 1982; Suarez-Ruiz, 2012).

Coal petrology reveals the geological and genetic conditions; it is used to obtain the range, distribution, lateral continuity, thickness, and organic and mineral matter composition, as the product of the different active processes during coal forming process (Guatame and Rincon, 2021).

Most research works on coal deposits in the northern Anambra Basin of Nigeria are focused on the common tests such as proximate analysis, ultimate analysis and calorific value determination. However, modern tests required petrographic analysis for an extensive characterization of coals for metallurgical processes and power generation, and to the best of our knowledge, these have rarely been carried out on coal deposits in the northern Anambra Basin.

Therefore, this study is aimed at investigating the geological and petrographic characteristics of Ibobo coal in the northern Anambra Basin of Nigeria in order to determine the utilization potential of the coal especially in metallurgical processes and electricity generation.

Location of the Study Area

Ibobo coal deposit is situated on Latitude 7^0 33' 01.0" N and Longitude 6^0 57' 16.4" E. It is located off Abocho town in Dekina Local Government Area of Kogi Staten (Fig. 1).

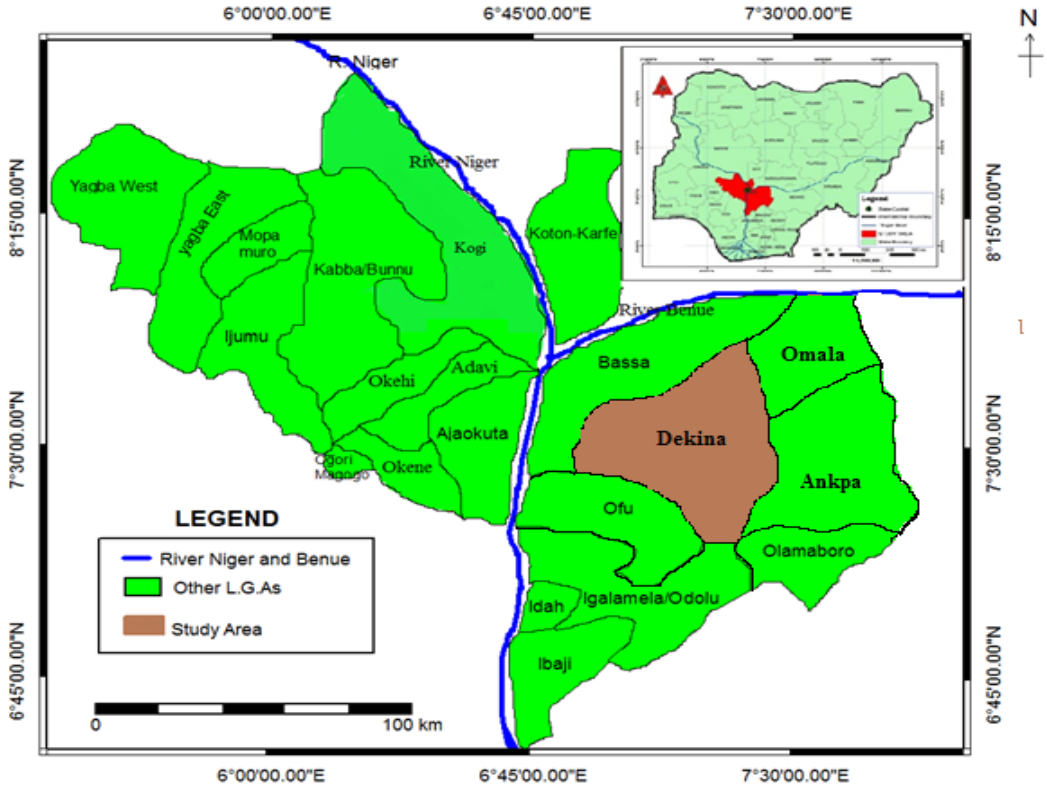


Figure 1: Location map of the study area.

Regional Geological Setting

Stratigraphic sequence of the Anambra Basin started with theNkporo Formation (Campanian), which is predominantly marine, overlain by the Mamu Formation (Maastrichtian), comprising paralic sandstones, mudstones and coals. The fluviodeltaic sandstones of theAjali Formation (Upper Maastrichtian) lie on the Mamu Formation and constitute its lateral equivalents in most places. Thereafter, a paralic coaly sequence of the Nsukka Formation (Paleocene) completes the succession in the Anambra Basin (Nwajide and Reijers, 1996; Obaje *et al*., 1999; Umeji, 2005).

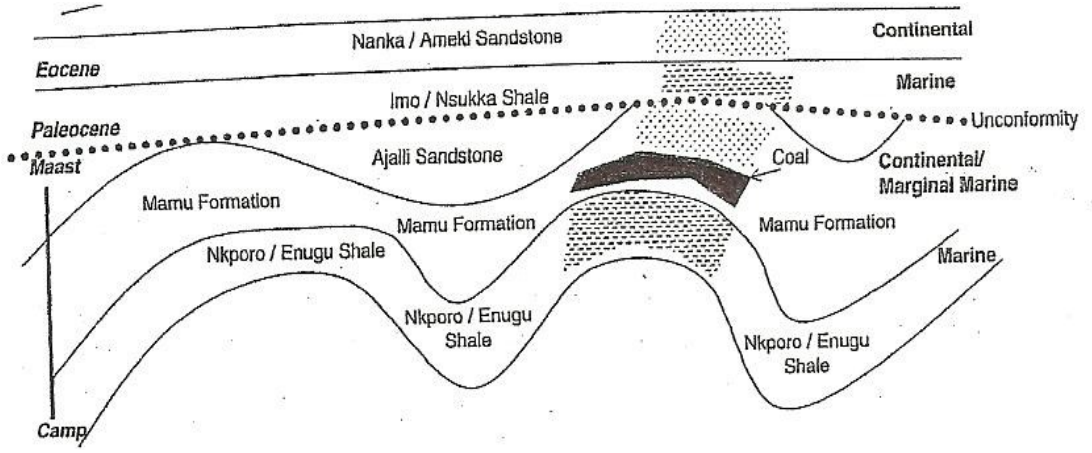


Figure 2: Stratigraphic succession in the Anambra Basin (after Obaje, 2009).

MATERIALS AND METHODS

Seven coal samples were collected from Ibobo coal deposit. The coal samples were pulverized and sieved to pass 10 mm sieve size. All sample analyses were carried out at Pearson Coal Petrography Laboratory, South Holland, Illinois, USA.

Petrographic Analysis

Petrographic analysis was carried out on coal samples based on maceral composition and vitrinite reflectance. Coal maceral analysis is important because it helps to determine the microscopic composition of coal, which directly influences its quality, behaviour and potential applications. Vitrinite reflectance analysis of coal is also crucial because it provides a reliable measure of coal rank and thermal maturity, which are key indicators of coal quality and potential for various uses.

Maceral Analysis

Pulverized coal sample was embedded in an epoxy to create a solid and polished block for microscopic examination. For clear observation under the microscope, the embedded sample was later polished to a high level of smoothness. The polished sample was examined under a Leitz MPV–2 microscope photometer using reflected white light with X10 ocular and X50 oil-immersion objective lenses. The macerals were identified and counted using a point-counter method, where a grid is superimposed on the microscope field and each point falling on a maceral was

counted. Macerals identification was based on their optical properties such as colour, shape, and reflectance characteristics. The relative proportions of each maceral group (vitrinite V, liptinite L, inertinite I and mineral matter M) were expressed in volume percent (vol. %) for V + L + I + M = 100%. Maceral analyses were carried out using International Standard ASTM D2799 – 05 (2005a).

Vitrinite Reflectance Analysis

The vitrinite reflectance measurements of the coal samples were performed using a microscope, shining a beam of monochromatic light (546 nm) onto a polished vitrinite surface. The reflected light was measured with a photometer. Mean maximum vitinite reflectance (RoMax) determinations were carried out based on an average of at least 100 individual measurements for each studied sample. Vitrinite reflectance analyses were carried out using International Standards ASTM 2798 – 21 (2021) and ISO7404 – 5 (2009).

RESULTS AND DISCUSSION

Geology of the Study Area

The geographical co-ordinates of sample locations were used to produce a geological map of the study area (Fig. 3).

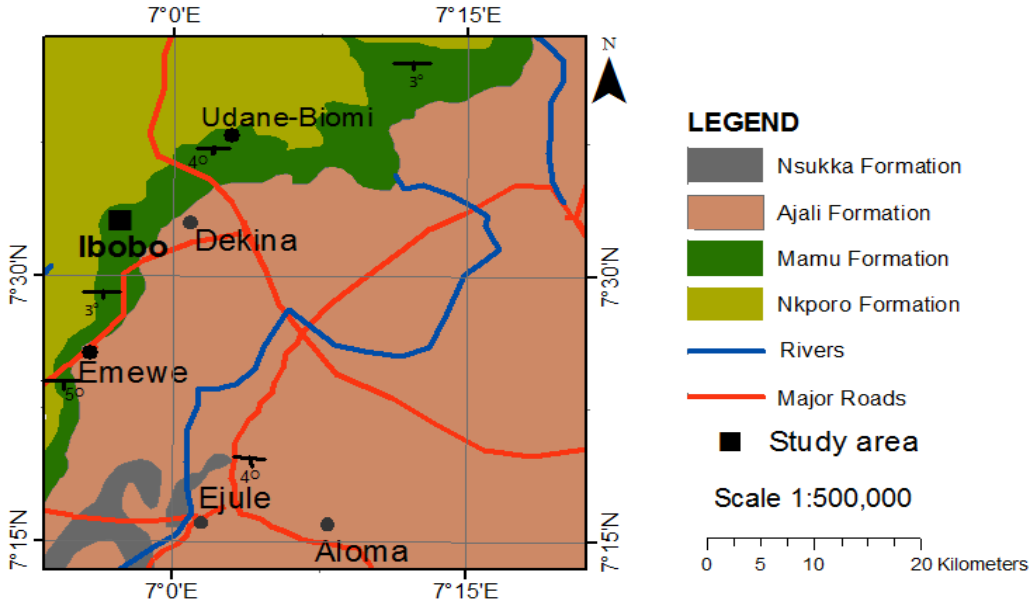


Figure 3: Geological map of the study area.

The sedimentary sequence of the coal formation was examined stratigraphically. It was established that the coal occurs in the Maastrichtian Mamu Formation, a sequence of paralic sandstones, shale and coals (Fig. 4). The coal seam is about 0.4 – 0.7m thick. It is underlain by about 0.3m thick layer of clay and overlain by about 2.0m thick layer of shale intercalated with clay (Fig. 4). About 0.8m thick layer of fine-grained sandstones lies conformably on the shale layer then capped with about 0.1m thick layer of coarse-grained laterite. The coal seam is black, shinny, hard and banded.



Figure 4: Section of the exposed part of Ibobo coal within the stratigraphic Mamu Formation.

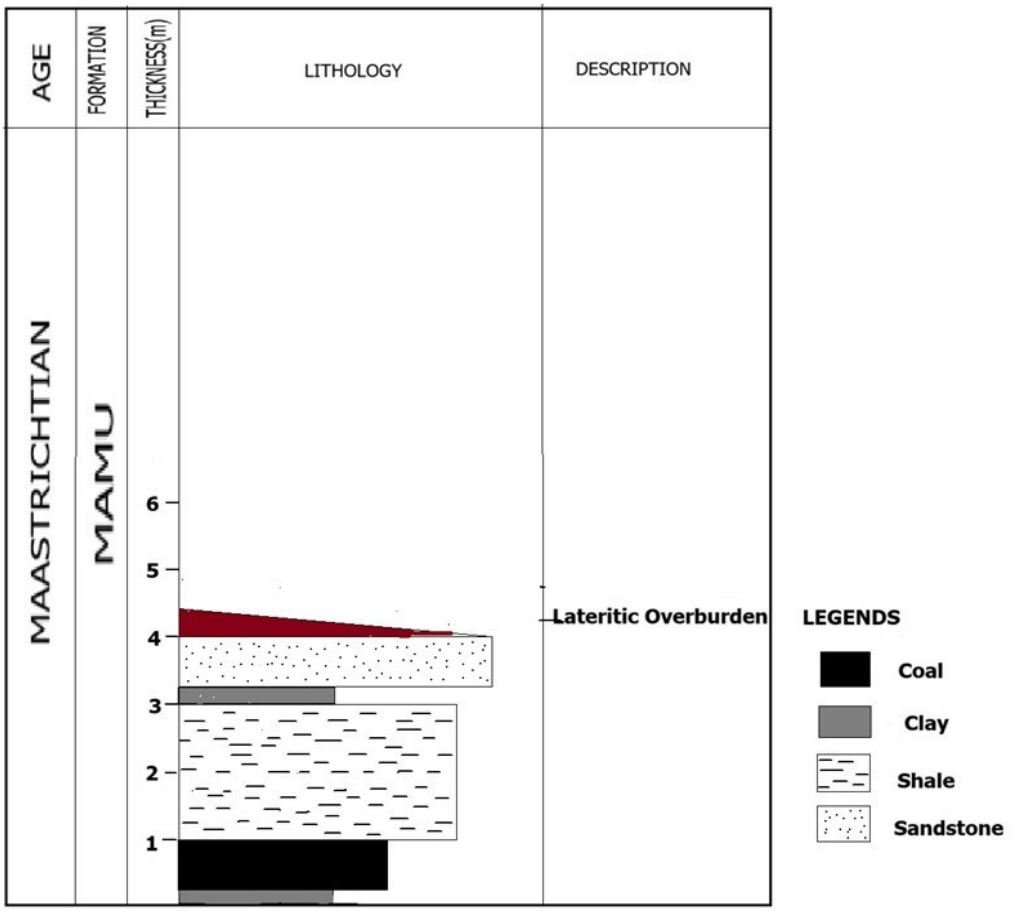


Figure 5: Lithologic section of the Mamu Formation at Ibobo coal mine.

Macroscopic Description of the Coal Seam

Four macroscopically recognizable bands of humic coals were recognizable by the International Committee for Coal and Organic Petrology (ICCP) Handbook (2001), these include; vitrain, clarain, fusain and durain. Out of these, only two were identified in the samples. They are clarain and durain. However, clarain is the most common macroscopic ingredient in the samples followed by durain. The dominance of durain in samples2 and 5 imparted a dull appearance to the coal. Macroscopic observation shows that all the coal samples are banded and show dull to shiny black in appearance.

Microscopic Description of Constituent Macerals

Macerals are the organic components of coal which by their chemical composition and characteristics determine its quality and utilisation (Diessel, 1992). The identification of the original plants and their parts (such as bark, roots, spores, or seeds) that produced individual coal macerals is useful in determining coal quality. Macerals are classified into three groups on the basis of their optical microscopic properties; namely, vitrinite, liptinite, and inertinite (Stach *et al*., 1982). This classification is based either on similar origin and/or on the differences in preservation. The three maceral groups were identified in all the samples on the basis of relative reflectance in white light.

Vitrinite was moderately reflecting (intermediate gray). Telocollinite is the dominant vitrinite group in all the samples commonly intermixed with fragmental bits of fusinite (Fig. 6). It appears as light grey in reflected light microscopy. Telocolinite is mainly found in coals formed from woody plant material, and it is always associated with the primary cell walls of these plants. Isolated grains of pyrite and siderite are found to be embedded in vitrinite in all the coal samples.

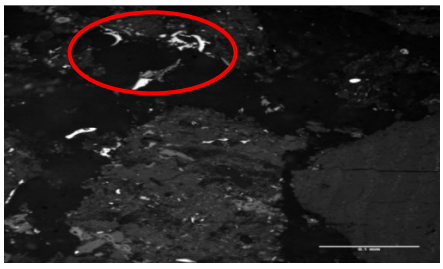


Figure 6: Photomicrograph showing the maceral composition of Ibobo coal sample with telocollinite (in the circle) and specks of pyrite under reflected white light.

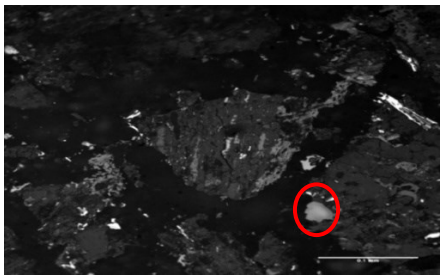


Figure 7: Photomicrograph showing the maceral composition of Ibobo coal sample comprising sporinite (in the circle) with specks of pyrite under reflected white light.

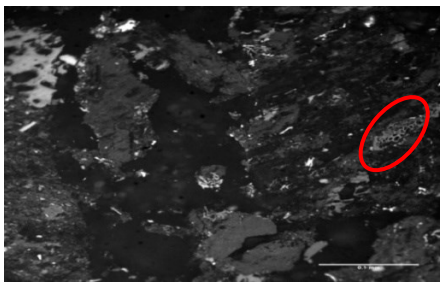


Figure 8: Photomicrograph showing the maceral composition of Ibobo coal sample with semi-fusinite (in the circle) and dots of pyrite under reflected white light.



Figure 9: Photomicrograph showing the maceral composition of Ibobo coal sample with resinite (in the circle) with specks of pyrite under reflected white light.

Liptinite was poorly reflecting (black to dark grey). Sporinite, resinite and cutinite were mainly the liptinite group of macerals observed in the coal samples. Sporinite exhibited oval forms that reflected the cross-sectioning of a hollow body. In other hand, cutinite frequently exhibited reticulation in planar section and a serrated edge

in cross section whereas resinite occurred as rod-like bodies filling cracks in the coal (Fig, 9). However, sporinite and resinite were recorded more (Figs. 7 and 9). Inertinite was highly reflective (light gray to white). Semi-fusinite is the most dominant inertinite maceral in the coal samples (20.10%) followed by fusinite (6.00%) and inertodetrinite (0.40%) on mineral matter-free basis. It also consists of 14.60% semi-fusinite, 6.40% fusinite and 2.10% inertodetrinite with mineral matter counted. Inertodetrinite consists of fragments of fusinite, semifusinite and other inertinite macerals that have been worn and re-deposited. They are resistant to degradation. Both semi-fusinite and inertodetrinite occurred in the coal samples as fragments within the binder matrix (Fig. 8).

Table 1: Table of petrographic composition of Ibobo coal samples on mineral matter-free basis

Sample Number	Vitrinite (%)	Liptinite (%)	Inertinite (%)
Ibobo 1	60.60	12.80	26.60
Ibobo 2	59.90	12.30	27.80
Ibobo 3	60.80	12.70	26.50
Ibobo 4	61.30	11.20	26.90
Ibobo 5	60.70	12.50	26.80
Ibobo 6	61.50	13.40	25.10
Ibobo 7	60.80	13.40	25.80
Average	**60.80**	**12.70**	**26.50**

Table 2: Table of petrographic composition of Ibobo coal samples with mineral matter counted.

Sample Number	Vitrinite (%)	Liptinite (%)	Inertinite (%)	Total Macerals (%)	Total Minerals (%)
Ibobo 1	50.80	10.00	24.30	85.10	14.90
Ibobo 2	52.50	13.10	20.60	86.20	13.80
Ibobo 3	50.50	10.50	23.60	84.60	15.40
Ibobo 4	52.70	12.50	21.10	86.30	13.70
Ibobo 5	51.50	11.00	24.70	87.20	12.80
Ibobo 6	52.20	11.30	24.00	87.50	12.50
Ibobo 7	51.70	11.40	23.40	86.50	13.50
Average	**51.70**	**11.40**	**23.10**	**86.20**	**13.80**

On mineral matter-free basis, the coal, on average, contains 60.80% vitrinite, 12.70% liptinite and 26.50% inertinite (Table 1). With mineral matter counted, on average, it consists of 51.70% vitrinite, 11.40% liptinite, 23.10% inertinite and 13.80% mineral matter (Table 2).

The coal has low vitrinite content and high inertinite content to gratify Mackowsky (1982) rating of 60 – 80% vitrinite and 5 – 15% inertinite for coking potential. However, the values obtained for vitrinite and inertinite maceral groups fall within the rating of 30 – 60% vitrinite and <40% inertinite for steam or thermal coals also proposed by Mackowsky (1982).

Also, by comparison with North-East Indian coal which is considered coking (a bituminous coal) with 80.07% vitrinite, 10.23% liptinite and 9.3% inertinite and 0.4% mineral matter contents (Sharma *et al*., 2012), the studied coal has low vitrinite and high mineral matter contents to possess coking potential. However, it is similar to Ib-Valley (India) sub-bituminous coal which has 51.00% vitrinite, 17.00% liptinite, 29.00% inertinite and 3.00% mineral matter contents (Senapaty and Behera, 2015). Table 3 also shows similarity between the studied coal and Enugu and Effin-Okai coals which are considered sub-bituminous.

Table 3: Maceral analysis of some coals in Nigeria in comparison with Ibobo coal

Coal Deposit	Vitrinite (%)	Liptinite (%)	Inertinite (%)	Vitrinite Reflectance (RoMax)
Enugu Coal	61.4	8.4	30.2	0.45
Effin-Okai Coal	58.6	8.6	32.8	0.38
Obi-Lafia Coal	80.0	0.0	20.0	0.46

Source: Fatoye, *et al*. (2020)

Table 4: Table of percentage of Reactives and Inerts in Ibobo coal samples.

Sample Number	Reactives (V + L) %	Inerts (I + M) %	Total (V + L + I + M)
Ibobo 1	60.80	39.20	100.00
Ibobo 2	65.60	34.40	100.00
Ibobo 3	61.00	39.00	100.00
Ibobo 4	65.20	34.80	100.00
Ibobo 5	62.50	37.50	100.00
Ibobo 6	63.40	36.60	100.00
Ibobo 7	63.20	38.60	100.00
Average	**63.10**	**36.90**	**100.00**

Vitrinite and liptinite enhance the rate of combustion and are therefore considered reactives. Inertinite retards combustion because of its low reactivity (Schapiro, *et al.,* 1961). The coal, on average, contains 63.10% reactives (vitrinite + liptinite) and 36.90% inerts (inertinite + mineral matter) (Table 4).

The coal contains low amounts of reactives and high amount of inerts to satisfy the Composition Balance Index (CBI) of reactives $\geq$ 70% and inerts $\leq$ 30% ratings proposed for coals with coking potential (Schapiro *et al*., 1961; Rentel, 1987) (Table 4). However, it satisfies the CBI of reactives $\geq$ 40% and inerts $\leq$ 60% for steam or thermal coals also proposed by the same authors.

Mineral matter in coal includes minerals and other inorganic materials associated with macerals. Most of the minerals in coal were added to the coal deposit by groundwater or wind during coalification (coal forming process). Many of these minerals occur in close association with the coal matrix either as infillings or cleats, cell lumens or as partial metasomatic replacement of organic matter (Beeston, 1981), while others are concentrated in concretions, lenses or dirt bands (Davis, 1982). The mineral matters were also formed from metals that accumulated in the living tissues of the ancient plants. Occasionally some of the mineral matters are formed either as chemical precipitates or as inorganic products of diagenesis (Jensen and Bateman, 1979).

Minerals commonly found in coal include; clay minerals (illite, kaolinite, montmorillonite and smectite), sulphide minerals (pyrite, marcasite and sphalerite), carbonate minerals (calcite, dolomite and siderite), oxide minerals

(quartz, hematite and magnetite), sulphate minerals (gypsum and baryte), phosphate minerals (apatite) and other minerals such as feldspar and zircon.

The calorific values of coals tend to decrease with increasing mineral matter content. This is due to endothermic reactions of decomposition of the mineral matter as well as the heat capacities of such minerals (Shirazi, 1995). It should be noted also that high mineral matter in coal is detrimental because mineral reduces coal plasticity (Afonja, 1996). Mineral matter also causes slagging and fouling in the boilers, thereby reducing their efficiency and causing corrosion. The lesser the mineral matter in coal the better the quality of the coal (Peng, 2002).

The average value of mineral matter recorded in the studied coal is above the value of <5% mineral matter content recommended for coking coals but within the value of <15% mineral matter content proposed for steam or thermal coals (Thomas, 2002).

Vitrinite reflectance values of Ibobo coal samples

Table 5: Table of mean vitrinite reflectance values (RoMax) of Ibobo coal samples.

Sample Number	Vitrinite Reflectance (RoMax %)
Ibobo 1	0.41
Ibobo 2	0.43
Ibobo 3	0.41
Ibobo 4	0.43
Ibobo 5	0.42
Ibobo 6	0.42
Ibobo 7	0.42
Average	**0.42**

Vitrinite reflectance analysis measures the reflectance of incident light from vitrinite in coal. The reflectance of vitrinite in coals is dependent on the level of coalification, thus, vitrinite reflectance increases with increasing rank. The level of coalification dictates economic potential and technological applications of the coal. The mean vitrinite reflectance measurement value of 0.41 RoMax recorded in the studied coal (Table 5) placed the coal in sub-bituminous rank based on Taylor *et al*. (1998) vitrinite reflectance rating of 0.10 – 0.60 RoMax for sub-bituminous

coals (Table 6). Also, Zimmerman (1979) in Thomas (2002) gave the same rating for the same type of coal.

Table 6: Rank classes in terms of vitrinite reflectance

Coal Rank	Vitrinite Reflectance (RoMax)
Sub-bituminous Coals	0.10 – 0.60
Bituminous Coals	0.60 – 1.80
Anthracites	> 1.80

Source: Taylor *et al*. (1998)

CONCLUSION

Field and petrographic studies of Ibobo coal in the northern Anambra Basin of Nigeria have been undertaken. Geological field studies revealed that the coal occurs in the Maastrichtian Mamu Formation, a sequence of paralic sandstones, shale and coals. The coal seam is thin, between 0.4 – 0.7m thick, black, shinny, hard and banded.

The petrographic composition in terms of maceral analysis and vitrinite reflectance measurement is fundamental for understanding the properties and quality of coal. Petrographic studies indicated the dominance of vitrinite maceral group in the coal followed by liptinite and inertinite groups. However, the coal has low vitrinite, low reactives and high mineral matter contents with low vitrinite reflectance. Comparison with high rank coals shows that disparity petrographic profiles are developed in them.

These characteristics suggest that Ibobo coal does not possess coking qualities suitable for coke making for metallurgical processes thereby placing it on low quality, non-coking and sub-bituminous. However, it is good for electricity generation. The coal is also appropriate in heating for manufacturing processes. For example, it can be used to heat kilns in the production of cement, glass, ceramic, paper and bricks. In addition to generating electricity and heating, the coal is important source of raw materials for manufacturing. Nevertheless, additional metallurgical and combustion efficiency tests can be carried out on the coal to further ascertain its suitability for metallurgical, combustion and other processes.

RECOMMENDATIONS

For effective exploration, exploitation and utilization of this coal and other coal deposits in the country, the following recommendations are proposed:

- Adequate funding of Nigerian coal industry
- Well-articulated and investors friendly national energy policy and/or policy on solid minerals
- Provision of technological know-how for Nigerian coal industry
- Public enlightenment on coal potential, especially in metallurgical and combustion processes
- More research work should be carried out on coal upgrading or blending for industrial utility.

Without doubt, the implementation of the above recommendations to ensure maximum coal production and utilization will have a considerable impact on the economic development of the country.

Conflicts of Interests

The authors declare that they have no conflicting interests.

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