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PETROGRAPHIC EVALUATION OF OKOBO COAL, NORTHERN ANAMBRA BASIN, NIGERIA

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ABSTRACT

Petrographic studies have been carried out on coal samples from Okobo coal deposit in the northern Anambra Basin of Nigeria. The studies were carried out primarily to determine the petrographic characteristics of the coal based on its composition and vitrinite reflectance. Maceral characterization reveals the presence of the three maceral groups; vitrinite, liptinite and inertinite in all the samples. Generally, 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 65.10 % vitrinite, 11.30 % liptinite and 23.60 % inertinite. With mineral matter counted, on average, it consists of 57.10 % vitrinite, 10.20 % liptinite, 21.50 % inertinite and 11.20 % mineral matter. The coal, on average, also contains 67.30 % reactives (vitrinite + liptinite) and 32.70 % inerts (inertinite + mineral matter). It has mean vitrinite reflectance measurement of 0.54 % R_{omax} on average. These petrographic characteristics suggest that the coal does not possess coking qualities suitable for coke making blends for metallurgical processes such as iron and steel manufacture thereby placing it on low quality and non-coking. However, it is good for electricity generation. The coal is appropriate in heating boilers and ovens in industrial heating process. The cement, glass, ceramics, paper and brick industries can use it for this purpose.

Keywords: Okobo coal, Petrography, Low quality, Non-coking

INTRODUCTION

Coal is one of the fossil fuels found in abundance in Nigeria. In countries like USA, China, India and South Africa coal is their primary source of electricity and it has sustained their economy. Nigeria is endowed with large deposits of coal that if well managed, will improve the economy of the nation.

Apart from sparsely reported occurrences of lignites and minor sub-bituminous coals in the Sokoto Basin, in the Mid-Niger (Bida) Basin and in the Dahomey Embayment, all the coal deposits of Nigeria occur in the Benue Trough and the Anambra Basin (Fatoye *et al*., 2020). However, Anambra Basin appears to contain the largest and most economically viable coal resources in the country.

Coal mining commenced in Nigeria in 1916 at Enugu in a drift mine. Coal production was initially concentrated in Enugu where four mines (Iva Valley, Onyeama, Okpara and Ribadu) were worked by the Nigerian Coal Corporation (Orajaka *et al*., 1990). Two other mines were later opened at Okaba in Kogi State and Orukpa in Benue State. Production started from a modest beginning (24,500 tonnes in 1916) and gradually rose to an annual output of about 700,000 tonnes in 1966 just before the outbreak of the Nigerian civil war (Famuboni, 1996). During this period of growth, coal played a significant role in Nigeria's economic development. Coal was mainly utilised by the Nigerian Railway Corporation to operate its locomotives, by the Electricity Corporation of Nigeria (ECN) for the generation of electricity; and by the Nigerian Cement Company (NIGERCEM) at Nkalagu for firing its kilns.

However, coal production has steadily declined in the last few decades due to the loss of two of its traditional customers, who switched from coal to diesel, natural gas and hydro resources for the generation of electricity and for transportation services. Coal has been relegated to the background especially after oil was discovered in commercial quantity in Nigeria, and the country became over-dependent on it as its primary source of energy.

Despite the abundant coal deposits in Nigeria it does not contribute to Nigeria's electricity generation (Sambo *et al*, 2009), and it will be tantamount to economic short-sightedness, if the importance of coal in the industrial development of the country is judged by its present low level of its utilisation. The Nigerian Coal Industry must be seen as a long neglected economic frontier that needs urgent resuscitation. It is one major area that can change the economic fortune of this great country. Its potential for growth is on the upward swing.

Currently, it has been confirmed that there is a large deposit of coal beds within the sedimentary succession of the Anambra Basin of Nigeria (Obaje, 1994) especially the Mamu Formation in the Okobo area of the Basin. However, literature is scanty on the petrographic characteristics of this coal deposit.

Therefore, the present study is designed to implement petrographic characteristics and applications of Okobo coal deposit in the northern Anambra Basin of Nigeria.

Location of Study Area

Okobo coal deposit is situated on Latitude 7^0 30' 24.1" N and Longitude 7^0 42' 38.8" E. It is located south of Okaba coal mine about 12km east of Ankpa town in Ankpa Local Government Area of Kogi State (Fig. 1). Drainage is generally that of the dendritic pattern. The area is well drained with rivers and their tributaries occupy wide valleys. Most of these rivers are tributaries to the Anambra River. The area is generally undulating lowland with a few isolated hills. It has an average elevation of 280 m above sea level.

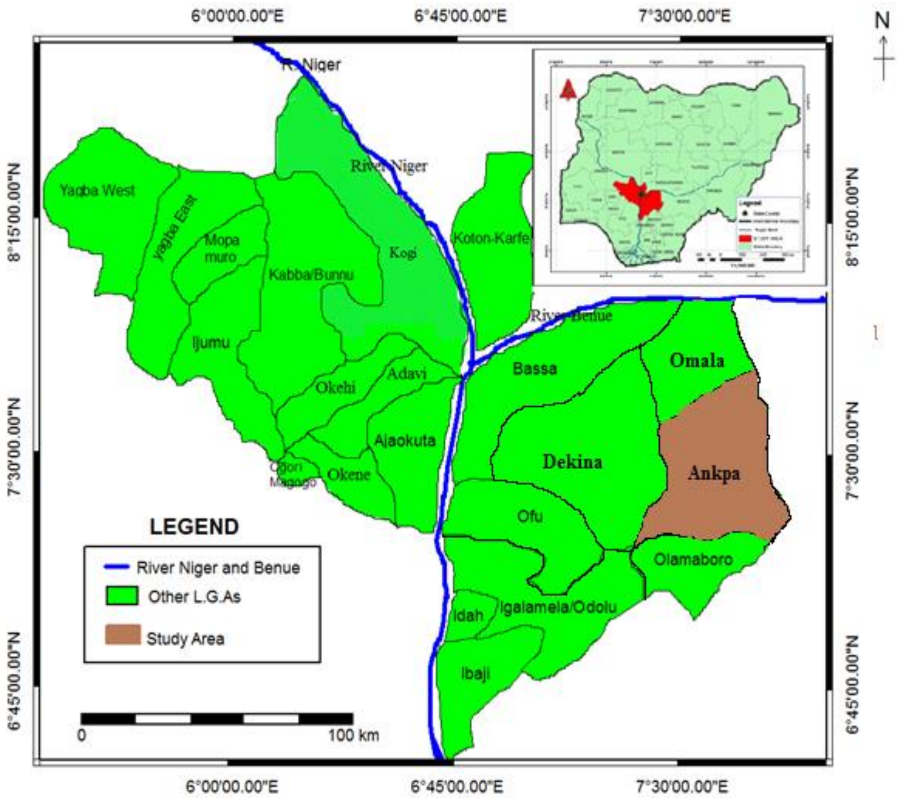

Figure 1: Location map of the study area (modified from map of Nigeria)

Regional Geological Setting

The study area lies within the Anambra Basin of Nigeria. The structural setting and general geology of the Anambra Basin have been documented by various workers (Umeji, 2005; Obaje, 2009) among others. Sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine and paralic shales of the Nkporo Formation (Fig. 2), overlain by the Early – Late Maastrichtian coal measures of the Mamu Formation, comprising paralic sandstones, mudstones and coals. The Middle – Late Maastrichtian fluviodeltaic sandstones of the Ajali Formation lie on the Mamu Formation and constitute its lateral equivalents in most places. In the Paleocene, the marine shales and paralic coaly sequence of the Nsukka Formation were deposited to complete the succession in the Anambra Basin (Umeji, 2005).

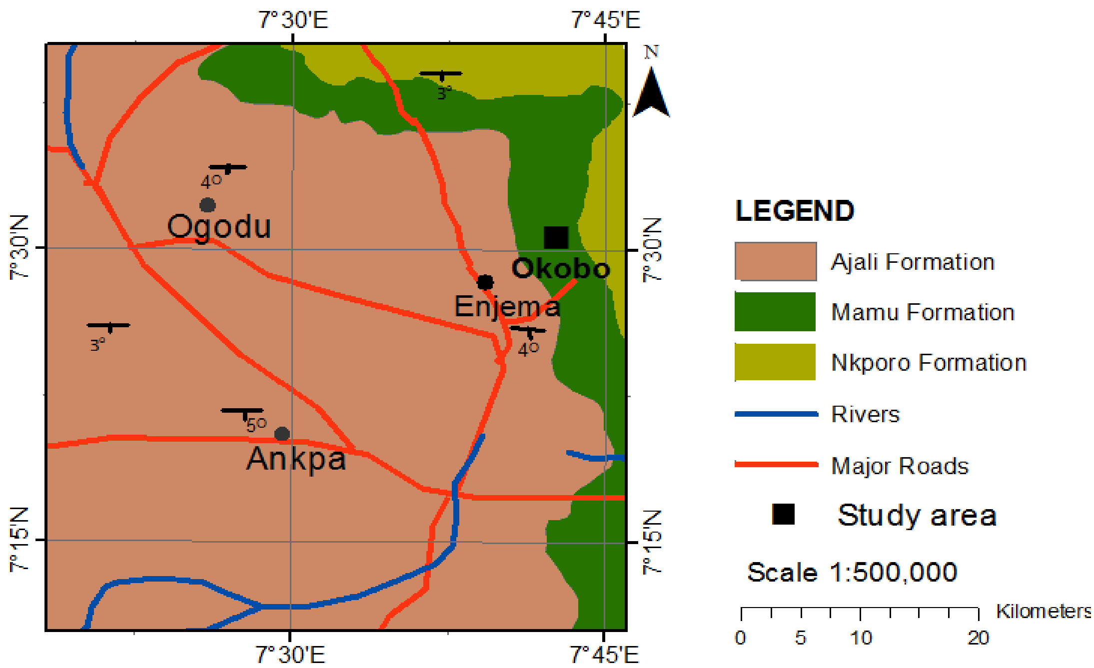

Figure 2: Geological map of the study area.

MATERIALS AND METHODS

Sampling

Ten coal samples were collected from Okobo coal deposit. Samples collected were kept in an airtight polyethylene bags prior to analyses. The coal samples were pulverized and sieved to pass through a 10 mm sieve size. All sample analyses were carried out at Pearson Coal Petrography Laboratory, South Holland, Illinois, USA.

Petrographic Analysis

Petrographic analysis based on maceral composition and vitrinite reflectance was carried out on the coal samples.

Maceral Analysis

A Leitz MPV 2 microscope photometer was used for the petrographic work. Maceral analyses were carried out under the microscope using reflected white light with X10 ocular and X50 oil-immersion objective lenses. The maceral characterization was done by point counting using a mechanical stage attached to the microscope stage, under the reflected white light excited by ultraviolet (UV). The components V (vitrinite), L (liptinite), I (inertinite), and M (mineral matter) are expressed in volume percent (vol. %) for V + L + I + M = 100%. Maceral analyses were carried out using International Standards ASTM D2799 and ISO7404/5.

Vitrinite Reflectance Analysis

The vitrinite reflectance of the samples was measured under oil-immersion, using a monochromatic non-polarized light (calibrating against two sets of reference standards) in conjunction with the X10 ocular and X50 objective lenses. Measurements were made of the percentage of incident light reflected from the vitrinite particles in the samples using a wavelength of 546 nm. Mean maximum vitinite reflectance (Rm max %) 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, ISO7404.

RESULTS AND DISCUSSION

Macroscopic Description of the Coal Seams (Lithotypes)

The International Committee for Coal and Organic Petrology (ICCP) Handbook (1963) defined lithotypes as "the macroscopically recognizable bands of humic coals", and named four of them as vitrain, clarain, fusain and durain.
Macroscopic observation shows that all the coal samples are banded and show dull to shiny black in appearance. Clarain is the most common macroscopic ingredient in most of the samples followed by durain. The dominance of durain in samples 1, 3 and 10 imparts a dull appearance to the coals.

Microscopic Description of Constituent Macerals

The organic components of coal which are called macerals are the basic and relatively homogeneous organo-petrographic entities of coal which by their chemical composition and physical characteristics determine its properties and utilisation (Fatoye *et al*., 2020). Many different types of macerals occur in coal. The identification of the original plants and their parts (such as bark, roots, spores, or seeds) that produced individual coal macerals is helpful in determining coal quality. In coals, they are normally classified into three groups; namely, vitrinite, liptinite, and inertinite. This classification is based either on similar origin (e.g. the liptinite group) and/or on the differences in preservation (e.g. the vitrinite and inertinite groups). Chemical and physical properties of the macerals such as elemental composition, moisture content, hardness, density and petrographic characteristics differ widely and are also subject to changes in the course of diagenesis and coalification (Obaje, 1994).
Vitrinite Group: The vitrinites are massive and cellular types with dark gray to light gray colour exhibiting moderate to low reflectivity. These are considered as telocollinite. It is frequently intermixed with exinite (liptinite), and fragmental bits of fusinite. In all the samples discrete grains of pyrite and siderite are found to be embedded in vitrinite. Telocollinite is the dominant vitrinite group in all the samples.
Liptinite (Exinite) Group: The liptinite group of macerals observed in the coal samples is mainly sporinite, cutinite and resinite. Sporinite and cutinite are the major liptinite macerals (Fig. 3). Vitrinites admixed with liptinites contain small oval bodies of resinite.
Inertinite Group: Inertinites are the group of macerals which show highest reflectivity and are very bright in incident light. The micro components of the inertinite group include semi-fusinite, fusinite, macrinite, micrinite, sclerotinite, and intertodetrinite. Semi-fusinite is by far the most dominant maceral in all the coals (Fig. 5). Semi-fusinite, macrinite, micrinite and inertodetrinite are found in decreasing order of abundance. Sclerotinite occurs as a rare component. Micrinite occurs as granular form and is opaque in transmitted light. Fusinite cell lumens are filled with inorganic minerals like pyrite, quartz and siderite. Fusinite and semi-fusinite occur as lensoid bodies and are crossed at many places (Figs. 4 and 5).

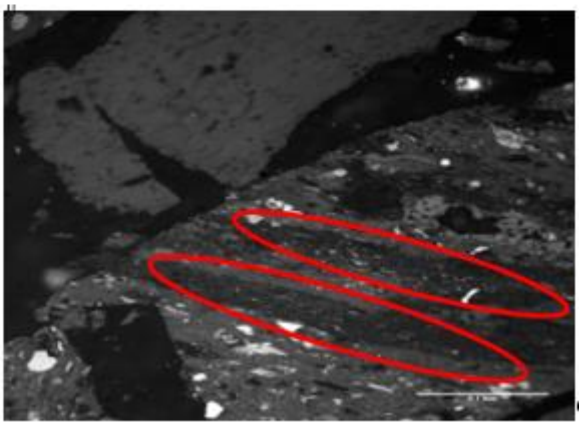

Figure 3: Photomicrograph showing the maceral composition of Okobo coal sample comprising sporinite with dots of pyrite under reflected white light

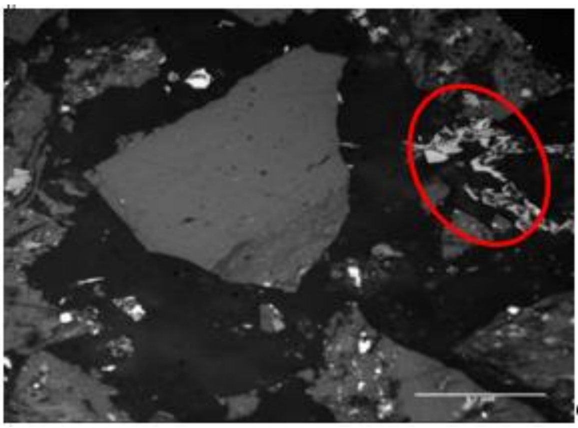

Figure 4: Photomicrograph showing the maceral composition of Okobo coal sample with fusinite and spots of pyrite under reflected white light.

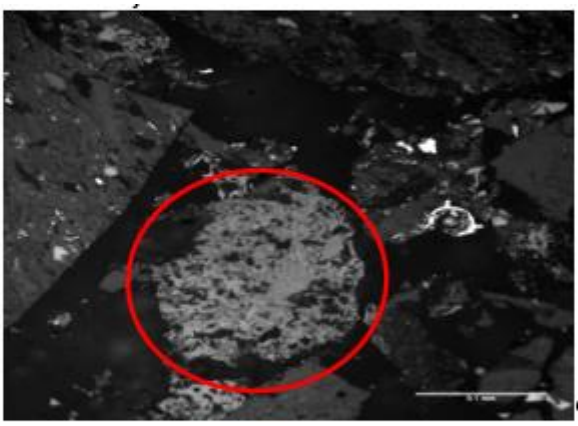

Figure 5: Photomicrograph showing the maceral composition of Okobo coal sample with dominance of semi-fusinite and with specks of pyrite under reflected white light.

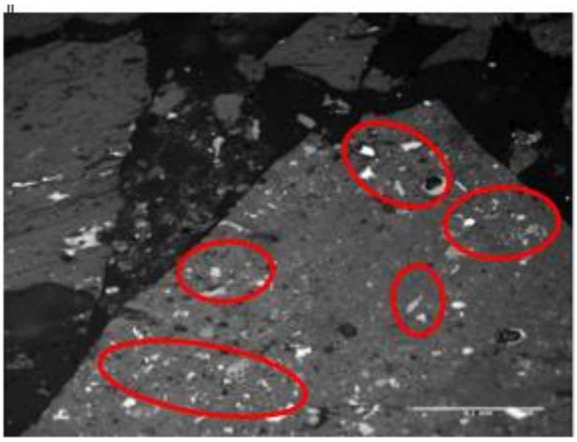

Figure. 6: Photomicrograph showing the maceral composition of Okobo coal sample comprising of inertodetrinite with spots of pyrite under reflected white light

Table 1: Petrographic composition (maceral) of Okobo coal samples

Sample Number	Vitrinite (%)	Liptinite (%)	Inertinite (%)	Total Macerals (%)
Okobo 1	64.40	11.10	24.50	100.00
Okobo 2	65.20	11.40	23.40	100.00
Okobo 3	64.00	11.20	24.80	100.00
Okobo 4	65.10	12.00	22.90	100.00
Okobo 5	66.40	10.50	23.10	100.00
Okobo 6	65.60	11.60	22.80	100.00
Okobo 7	65.70	10.90	23.40	100.00
Okobo 8	65.30	11.30	23.40	100.00
Okobo 9	65.00	11.20	23.80	100.00
Okobo 10	64.30	11.80	23.90	100.00
Average	**65.10**	**11.30**	**23.60**	**100.00**
X	**53.00**	**17.00**	**30.00**	**100.00**
Y	**80.50**	**10.20**	**9.30**	**100.00**
Z	**80.00**	**0.00**	**20.00**	**100.00**

X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

Table 2: Petrographic composition (maceral and mineral matter) of Okobo coal samples

Sample Number	Vitrinite (%)	Liptinite (%)	Inertinite (%)	Total Macerals (%)	Total Minerals (%)
Okobo 1	57.40	11.40	20.00	88.80	11.20
Okobo 2	57.00	11.10	20.30	88.40	11.60
Okobo 3	55.60	9.20	24.10	88.90	11.10
Okobo 4	57.30	11.60	20.30	89.20	10.80
Okobo 5	58.10	8.90	21.70	88.70	11.30
Okobo 6	57.20	9.00	22.60	88.80	11.20
Okobo 7	56.60	10.80	22.10	89.50	10.50
Okobo 8	58.20	8.70	20.60	87.50	12.50
Okobo 9	57.10	10.30	21.00	88.40	11.60
Okobo 10	56.50	11.00	22.30	89.80	10.20
Average	**57.10**	**10.20**	**21.50**	**88.80**	**11.20**
X	**51.00**	**17.00**	**29.00**	**97.00**	**3.00**
Y	**80.07**	**10.23**	**9.30**	**99.60**	**0.40**
Z	**79.70**	**0.00**	**19.90**	**99.60**	**0.40**

X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

The three maceral groups namely, vitrinite, liptinite and inertinite were represented in all the samples. The mineral matter content was also considered in conventional maceral analysis. Vitrinite, however, is the predominant group in the samples (Tables 1and 2). On mineral matter-free basis, the coal, on average, contains 65.10 % vitrinite, 11.30 % liptinite and 23.60 % inertinite (Table 1). With mineral matter counted, on average, it consists of 57.10 % vitrinite, 10.20 % liptinite, 21.50 % inertinite and 11.20 % mineral matter (Table 2).

The studied coal is characterized by low content of vitrinite and high content of inertinite to satisfy Mackowsky (1982) rating of 60 – 80 % vitrinite and 5 – 15 % inertinite for coking potential. However, it satisfies the rating of 30 – 60 % vitrinite and < 40 % inertinite for steam or thermal coals also proposed by Mackowsky (1982). These imply that Okobo coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries. Mackowsky (1982) also proposed greater than 30 % vitrinite and lesser than 40 % inertinite for coals used in the manufacture of organic chemicals. Based on this proposal, Okobo coal with 65.10 % vitrinite and 23.60 % inertinite can also be used in the manufacture of products such drugs, dyes, plastics, synthetic rubbers, insecticides, antiseptics, paint products, solvents, synthetic fibres, flavourings, perfumes, varnishes, adhesives and numerous other organic chemicals.

Comparing the values of maceral composition of the studied coal with those reported for other coals, Okobo coal is similar to sub-bituminous coal in Ib-Valley (India) reported by Senapaty and Behera (2015) but contrast with the values of bituminous coals in North-East (India) and Obi-Lafia (Nigeria) reported by Sharma *et al*., (2012) and Afonja (1996) respectively (Tables 1 and 2) thereby placing Okobo coal in sub-bituminous rank. Vitrinite is the most abundant material group in most coals and hence plays an important role in determining the properties of the coal. Vitrinite and liptinite are both reactives. They enhance the rate of combustion. Inertinite has a low reactivity, which retards combustion (Schapiro, *et al.*, 1961). The studied coal, on average, contains 67.30 % reactives (vitrinite + liptinite) and 32.70 % inerts (inertinite + mineral matter) (Table 3).

Table 3: Table of Percentage of reactives and inerts in Okobo coal samples

Sample Number	Reactives (V + L) %	Inerts(I + M) %	Total(V + L + I + M) %
Okobo 1	68.80	31.20	100.00
Okobo 2	68.10	31.90	100.00
Okobo 3	64.80	35.20	100.00
Okobo 4	68.90	31.10	100.00
Okobo 5	67.00	33.00	100.00
Okobo 6	66.20	33.80	100.00
Okobo 7	67.40	32.60	100.00
Okobo 8	66.90	33.10	100.00
Okobo 9	67.40	32.60	100.00
Okobo 10	67.50	32.50	100.00
Average	**67.30**	**32.70**	**100.00**
X	**68.00**	**32.00**	**100.00**
Y	**90.30**	**9.70**	**100.00**
Z	**79.70**	**20.30**	**100.00**

V = Vitinite, L = Liptinite, I = Inertinite M = Mineral matter
X: Ib-Valley (India) Sub-bituminous coal (after Senapaty and Behera, 2015)
Y: North-East (India) Bituminous coal (after Sharma *et al*., 2012)
Z: Obi-Lafia (Nigeria) Bituminous coal (after Afonja, 1996)

Generally, the studied coal contains low amount of reactives and high amount of inerts to agree with Composition Balance Index (CBI) of reactives greater than 70 % and inerts lesser than 30 % stated by Schapiro *et al*. (1961) and Rentel (1987) for coking coals (Table 3). However, it satisfies the Composition Balance Index (CBI) of reactives greater than 40 % and inerts lesser than 60 % for steam or thermal applications also proposed by Schapiro *et al*. (1961) and Rentel (1987). These imply that Okobo coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries. The cement, glass, ceramic, paper and brick industries can use it for this purpose.

Mineral matter in coal includes minerals and other inorganic materials in, and associated with, macerals. Mineral matter is an undesirable constituent of coal as it contributes to producing brittle steel, causes slagging and fouling in the boilers thereby impeding their function, reduces the calorific (heating) values of coal and reduces coal plasticity. The lesser the mineral matter in coal the better the quality of the coal (Peng, 2002). The studied samples are characterized by high mineral matter compared with known high rank coals. The mineral matter content in different samples varied from 10.20 % in sample 10 to 12.50 % in sample 8 (Table 2). According to Thomas (2002) recommendation which suggested that the mineral matter in coal suitable for coking purpose should be less than 5 %, therefore, Okobo coal with 18.90 % mineral matter may not be suitable for the manufacture of coke meant for reduction of iron ore in the blast furnace. However, the mineral matter content of the coal falls within the rates of less than 15 % proposed for steam or thermal coals by Thomas (2002). This implies that Okobo coal is also good for generation of electricity and heating purposes. The cement, glass, ceramic, paper and brick industries can use it for this purpose. Comparing the values of the mineral matter composition of the studied coal with the values of other coals elsewhere, Okobo coal is similar to sub-bituminous coal in Ib-Valley (India) reported by Senapaty and Behera (2015) but contrast with bituminous coals reported in North-East (India) and Obi-Lafia (Nigeria) by Sharma *et al*., (2012) and Afonja (1996) respectively (Table 2).

Vitrinite Reflectance Values

Table 4: Summary Table of mean vitrinite reflectance values (R_{omax} %) of Okobo coal samples

Sample Number	(R_{omax} %)
Okobo 1	0.54
Okobo 2	0.55
Okobo 3	0.55
Okobo 4	0.53
Okobo 5	0.54
Okobo 6	0.53
Okobo 7	0.54
Okobo 8	0.54
Okobo 9	0.53
Okobo 10	0.55
Average	**0.54**
X	**0.50**
Y	**0.88**

X: Enugu (Nigeria) Sub-bituminous coal (Ugwu, 1988)
Y: Obi/Lafia (Nigeria) Bituminous coal (Obaje, 1997)

Vitrinite analysis is a measure of the percentage of incident light reflected from the surface of vitrinite particles in a coal. The reflectance of vitrinite in coals is dependent on the level of coalification. The level of coalification dictates economic potential and technological applications of the coal. The mean vitrinite reflectance measurements of the studied coal samples varied from 0.53 % R_{omax} in samples 4, 6 and 9 to 0.55 % R_{omax} in samples 2, 3 and 10 (Table 4). According to Thomas (2002) and Taylor *et al*. (1998), vitrinite reflectance rating of 0.10 – 0.60 % R_{omax} is applicable to sub-bituminous coals. This rating therefore placed Okobo coal in sub-bituminous rank. By comparison, the vitrinite reflectance value of the studied coal is similar to that of sub-bituminous coal in Enugu (Nigeria) reported by Ugwu (1988) but contrast with the value of bituminous coal in Obi-Lafia (Nigeria) reported by Obaje (1997).

Based on vitrinite reflection classification, Okobo coal is unsuitable for metallurgical processes such as in iron and steel production but appropriate for generation of electricity and for heating in manufacturing industries such as cement, glass, ceramic, paper and brick industries.

CONCLUSION

Petrographic studies revealed that Okobo coal generally is low in vitrinite, low in reactive, high in mineral matter and low in vitrinite reflectance.

These characteristics suggest that Okobo 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 a good producer of gas fuel, and is suitable for complete gasification using oxygen enriched steam blast process. It can also be processed to produce automotive fuel. The coal and its by-products can as well be used as components of many different products like soaps, detergents, fertilizer, shampoo, etc.

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