

The Maiganga Coal Deposit: Bituminous, Sub-Bituminous or Lignite?

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Abstract: *There has been varying conclusions on the rank of coal at Maiganga over the years. This paper examined the Maiganga coal with the aim of establishing its actual rank. Proximate analysis was undertaken on some samples from Maiganga coal mine. The analysis determined the percentage moisture content, volatile matter, fixed carbon, ash content, and calorific value. Although not directly relevant for the determination of the rank of coal, the total sulfur of the coals was evaluated also. The Maiganga A1 and Maiganga A2 samples were from the first seam. Maiganga B1 and Maiganga B2 were collected from seam two of the coal deposit. From the result of the analysis the coal has high percentage ash content, moisture content, volatile matter, and low fixed carbon and calorific value. Based on the result of this analysis and on the coal classification by the American Society for Testing and Materials (ASTM), this paper establishes that the Maiganga coal falls within the lignite rank.*

Keywords: *Proximate analysis, Maiganga, Coal, Lignite, Fixed Carbon*

I. Introduction

The unconsolidated accumulation of debris [1] in geological conditions and time, under metamorphic process led to the formation of coal. The cycles of accumulation and sediment deposition continued [2], followed by diagenetic and tectonic [3] activity for coal to form. The extent of temperature, pressure, and time determines the degree of transformation the coal undergoes, which indicates the various ranks of coal. Depending on the degree of transformation [4-5], or metamorphism [6], coal is separated into four ranks, namely; lignite (brown coal), sub-bituminous, bituminous, and anthracite. Whereas anthracite, which is the hardest of the ranks, is established to have undergone a full cycle of metamorphism [7-8], lignite is established to be at the early stage of the metamorphic process. Hence, it is not well developed, as it is very soft, can ignite spontaneously under appropriate conditions, dusty, and has low calorific value.

Chemical analysis is undertaken to establish the rank of every coal occurrence, mostly to determine the quality of the coal. Proximate analysis [9] is used to determine the percentage of volatile matter, ash content, moisture (inherent water) content, and fixed carbon composition of coal sample. Fixed carbon, it must be noted is solid, combustible matter left in coal after the lighter, volatile, hydrogen-rich compounds are driven off during coalification [10-12]. This evaluation of coal quality [13] is majorly to ascertain coal use.

The Maiganga coal occurrence [14], which is formed in the Gombe sandstone has been a subject of investigation for decades with varying conclusions on the rank, quality of the coal [15]. Hence, the area was geologically mapped by this study, samples collected at the Maiganga coal mine were analyzed, using proximate analysis in order to establish the rank, and by extension its quality and use. Therefore, the aim of this study is to determine the rank of the Maiganga coal.

II. Geological Settings Of Maiganga

Maiganga lies within the Gombe sandstone, adjacent to and above the Pindiga Formation [16]. Whereas the Pindiga Formation was deposited under marine condition, the Gombe sandstone was laid down in non-marine, possibly delta plain condition. Geological mapping shows that actually being of the Upper Continental Sequence, the Gombe Sandstone is a sequence of estuarine and deltaic sandstones, siltstone, shale [17] and ironstones which overlie the sediments of the Zambuk ridge and the Chad Basin in the western part of the region. The restricted outcrop of the Gombe Sandstone suggests that these rocks were deposited in a basin which lay to the west of the Zambuk ridge in late Cretaceous times [18]. Siltstones and flaggy sandstones form greater part of Gombe Sandstone. These rocks are soft and light grey in colour when fresh, but on exposure give rise to dark red, flaggy debris which characteristically mantles the Gombe Sandstone hills. The Gombe Sandstone is the top member of a folded and eroded sedimentary sequence and it is not possible to determine its original thickness, at least 1,000 ft. of strata are

present in the area. An unconformity may exist below the Gombe Sandstone. Its contact with the Pindiga Formation and Fika shales is never satisfactorily exposed and in the field conclusive evidence of an unconformity has not been obtained. However, the presence of an unconformity is suggested by differences in structure between the Gombe Sandstone and the older Cretaceous rocks; the Gombe Sandstone is neither strongly folded nor does it reflect the east-west trends which are imposed on the earlier formation. Maiganga coal mine exposes the rock units of the Gombe Sandstone. And obviously the Gombe Sandstone is the formation that hosts most of the coal deposits found in Gombe State, especially that of Maiganga.

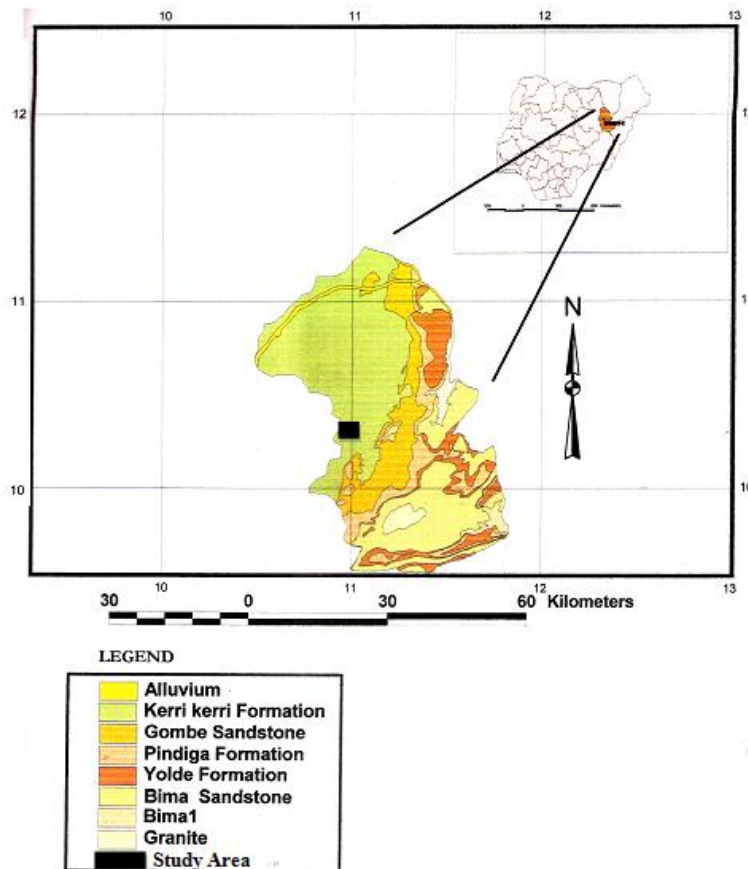


Fig. 2.1: Map of Nigeria showing the geological map of Gombe State

III. Materials And Methods

All necessary literatures and works published on the study area were acquired. Different maps were also acquired and carefully studied, thereby marking out the area of concern. With these, the mapping exercise was planned and carried out systematically [19-20]. Appropriate equipment necessary for the exercise were used throughout the geological mapping. Detailed geological mapping took place at Maiganga and environs (Fig. 4.1), and un-weathered *in situ* samples collected for further study. Stream channels and Wells served as the only means of exposure of the Gombe Sandstone until at the Maiganga coal mine where the formation is clearly exposed. Sandstone, shale and coal samples were all collected at various locations. Five coal samples were then analyzed for the chemical properties to determine their quality.

Two samples each were collected from the two coal seams; A and B being exposed and mined at the Maiganga coal mine. Particularly, the samples were collected at location 1 (L_1) and stops 1-4 (S_1 , S_2 , S_3 , and S_4) as indicated at fig. 4.1. The fifth sample, which was not from Maiganga was only used for correlation. Each of the seams is 3m thick, separated by clay. They lie in a lenticular form, trending north-west of Maiganga. Having pulverized each of the coal samples collected from various locations in the coal mine, they were packaged and well-labeled Maiganga A1, A2, B1 and B2; then analyzed. The Maiganga A1 and A2 are from different locations on seam A and Maiganga B1 and B2 are from seam B.



Fig. 3.1: Coal in the Maiganga Coal mine-Seam A



Fig. 3.2: coal intercalated with clay at the Maiganga coal mine

3.1 Coal Proximate Analysis

The objective of coal proximate analysis is to determine the amount of fixed carbon, volatile matter, moisture content, and ash content within the coal sample. The variables are measured in weight percent (wt. %) and are calculated in several different bases. The most widely used in industrial applications is the as received (AR) basis. All variables are put into consideration and the total weight is used as the basis of measurement in the AR basis. The presence of moistures other than inherent moisture in the air dried basis (AD) are neglected, while all moistures, including inherent moisture, surface moisture, and other moisture are left out in the dry-basis (DB). All moistures and ash constituent [21] in the coal are neglected in the dry, ash-free (DAF) [22], while the presence of moisture and mineral matters in coal such as quartz, calcite, pyrite, etc are left out in dry, mineral-matter-free (DMMF). Based on the ultimate and proximate analysis, mineral matter [23] is not directly measured but may be obtained by one of number of empirical formula. The various proximate analyses require a significant amount of laboratory equipment and is time consuming.

3.1.1 Moisture Content

This is determined by heating an air-dried coal sample at $105^{\circ}\text{C} - 110^{\circ}\text{C}$ ($221^{\circ} - 230^{\circ}\text{F}$) under specified conditions until a constant weight is obtained.

Materials: Crucible, oven, balance, tong, desiccators and 5 prepared coal samples.

Method:

1. Weigh empty clean crucible as W_{t_1} .
2. Weigh 1g of coal sample, W_{t_2} into the crucible. Weight of crucible + sample is recorded as W_{t_3} .
3. Introduce the crucible + sample into the oven at 110°C and leave for one hour.
4. Remove from oven, cool in the desiccators and re-weigh. This is recorded as W_{t_4} .

$$\text{Weight of moisture content} = W_{t_3} - W_{t_4}$$

$$\text{Percentage of moisture} = \frac{W_{t_3} - W_{t_4}}{W_{t_2}} \times 100$$

3.1.2 Volatile Matter

The volatile matter of coal is determined by rigidly controlled standards. This involves heating the coal sample to $900\pm 5^{\circ}\text{C}$ ($1650\pm 10^{\circ}\text{F}$) for 7 minutes in a cylindrical silica crucible in a muffle furnace in Australian and British laboratories. American standard procedures involves heating to $950\pm 25^{\circ}\text{C}$ ($1740\pm 45^{\circ}\text{F}$) in a vertical platinum crucible. These two methods give different results and thus the method used must be stated. Here, the former is used.

Materials: Crucible, furnace, tong, balance, desiccators, and 5 prepared coal samples.

Method:

1. Weigh empty clean crucible as W_{t1}
2. Weigh 1g of coal sample, W_{t2} into the crucible. Weight of crucible + sample is recorded as W_{t3} .
3. Introduce the crucible + sample into the furnace at a temperature of 900°C and leave for 7 minutes
4. Remove from furnace, cool in the desiccators and re-weigh, record as W_{t4}

$$\text{Weight of volatile matter} = W_{t3} - W_{t4}$$

$$\text{Percentage of volatile matter} = \frac{W_{t3} - W_{t4}}{W_{t2}} \times 100$$

3.1.3 Ash Content

Coal sample is thoroughly burnt and the ash material indicated as a percentage of the original weight, hence making the analysis a fairly straight forward one.

Materials: Crucible, furnace, tong, balance, desiccators, and 5 prepared coal samples.

Method:

1. Weigh empty clean crucible as W_{t1} .
2. Weigh 1g of coal, sample, W_{t2} into the crucible. Weight of crucible + sample is recorded as W_{t3} .
3. Introduce the crucible + sample into the furnace at temperature of 825°C and leave for one hour.
4. Remove from furnace, cool in the desiccators and re-weigh, record as W_{t4} .

$$\text{Weight of ash content} = W_{t4} - W_{t1}$$

$$\text{Percentage of ash} = \frac{W_{t4} - W_{t1}}{W_{t2}} \times 100$$

3.1.4 Fixed Carbon

This is simply arithmetic. It is determined by subtracting the percentages of moisture, volatile matter, and ash from the samples, i.e. $100\% - \% \text{moisture} + \% \text{volatile matter} + \% \text{ash}$.

3.1.5 Calorific Value

Calorific value, strictly speaking is neither part of the proximate analysis nor part of the ultimate analysis. It is in fact, one of the many physical properties of coal and is therefore discussed under it in several instances. For the analysis of coal, the calorific value is determined in a bomb calorimeter by either a static (isothermal) or an adiabatic method. In the isothermal method (ASTM D 3286; ISO 1928), a weighed sample of coal is burned in oxygen under controlled conditions and the calorific value is computed from temperature observation made before, during and after combustion, with appropriate allowances made for the heat contributed by other processes. The adiabatic method (ASTM D2015; ISO 1928) consists of burning the coal sample in an adiabatic bomb calorimeter under conditions. The calorific value is calculated from observations made before and after the combustion. The computed value for the calorific value of coal is usually expressed in British thermal units per pound, kilocalories per kilogram, or kilojoules per kilogram ($1.8\text{Btu/lb} = 1.0\text{Kcal/kg} = 4.187\text{Kj/kg}$).

Materials: Crucible, bomb calorimeter (Leco AC-350), balance, 200ml water, and 5 prepared coal samples.

Method:

1. Weigh 1g of sample into the crucible.
2. Introduce into the combustion chamber, the crucible does not touch the bottom of the combustion chamber.
3. Put the combustion chamber + crucible + sample into the bomb and place into the container that has the 200ml of water inside the calorimeter. The stirrer under the cover of the bomb calorimeter ensures even distribution of the heat as it automatically stirs.
4. After 8 minutes, the reading is taken from the computerized readings by a side of the bomb calorimeter.

3.1.6 Total Sulfur

The samples were analyzed for total sulphur with the computerized XRF equipment. And the press method was employed.

Materials: Computerized XRF, sample cups, sample tray, printer, pistil, and 5 prepared coal samples.

Method:

1. Put on the computer and the printer after which you turn the key of the XRF clockwise. The machine will take about 2 hours to butt. Then click MINIPAL (the model of the machine) on the monitor to open.

2. Measure about ¾ of the sample into the sample cup. Use the pistil to press it in order to remove any air, cover and put on one of the sample positions in the tray (the tray has 12 sample positions). Select the sample position and label name on the screen.
3. Click MEASURE, as the tray appears, click the sample position, the 1% position on the system is selected for it to start the analysis. The result is displayed as it gets to the 100% mark.
4. Then the result recorded..

Note: Before you open the x-ray tube, it must be on the reference, R mark if not it will leak and kill the person instantly. And make sure the machine is not analyzing another sample at the moment

IV. Result And Discussions

The results obtained in proximate and sulfur analysis from the coal samples are presented in table [4.1] and Table [4.2] below.

Table 4.1: Proximate Analysis of Maiganga Coal

S/N	Coal source	Moisture content (wt. %)	Ash content (wt. %)	Volatile matter (wt. %)	Fixed carbon (wt.%)	Calorific value (j/g)
1.	Maiganga A1	5.51	19.30	42.53	32.66	4981.5
2.	Maiganga A2	4.41	31.34	35.53	28.71	4237.5
3.	Maiganga B1	3.77	44.00	31.92	20.31	3200.3
4.	Maiganga B2	3.12	48.48	25.61	22.79	2248.8

Table 4.2: Total Sulfur Determination of Maiganga Coal

Coal Source				
Maiganga A1		Maiganga A2	Maiganga B1	Maiganga B2
Total Sulfur(wt. %)	0.35	0.96	0.79	0.77

Various wells drilled at the Maiganga coalfield shows that the coal occurrence has different depths at which it is encountered. Two seams, A and B being exposed and mined at the Maiganga coal mine. The seam A (L₂, S₁ of fig. 4.1) is about 3m thick. It is generally of low quality compared to seam B (L₂, S₂ of fig. 4.1) judging by its woody nature and brown coloration. Its hardness increases towards the basaltic hill, north of the mine, which suggests of the effect of the volcanic activity with peculiar characteristics in its geological setting of excessive tectonic shattering and deformation resulting from tensile and compressive stresses [24] typical of the Benue trough. Seam B (L₂, S₂ of fig. 4.1), which lies about 5m to seam A is an improvement in quality to that of the former, in that it is much darker in colour and less woody. Obviously the thickness of the coal occurrence here is not uniform, hence difficult to give a general, uniform thickness.

Table (4.1) shows a non-uniform coal quality even among the samples from the same seam. This, notwithstanding, the result shows that the Maiganga A1, A2 and Maiganga B1 and B2 are within the same rank. Based on the classification of laboratory analysis by the American Society for Testing and Materials (Table 4.3), coals are classified based on fixed carbon content, volatile matter content, moisture and ash [25]. By this they are grouped into different ranks; lignite, sub-bituminous, bituminous, and anthracite. Each of these ranks have value limit within which a coal sample falls into. In some cases however, the fixed carbon and calorific values are strictly used. For instance, a result of analysis of a coal sample that falls within 8,300 Btu/lb to 6,300 Btu/lb is placed as lignite A (Table 4.3) whereas the sample that has a calorific value of less than 6,300 Btu/lb is lignite B. The fixed carbon of lignite is normally 60% and less.

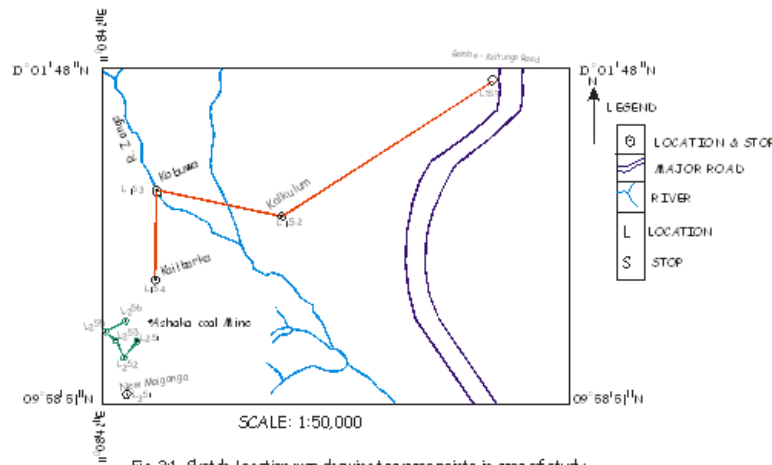


Fig. 31 Sketch Location map showing traverse points in area of study (Maiganga and environs)

Table 4.3: Coal Classification by ASTM D388 (1997)

Class	Group	Fixed Carbon Limits, % (Dry, Mineral-Matter-Free Basis)		Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis)		Gross Calorific Value Limits, Cal/g (Moist ^a , Mineral-Matter-Free Basis)		Agglomeration Character
		Equal or Greater than	Less than	Greater than	Equal of Less than	Equal or Greater than	Less than	
1. Anthracite	1. Meta-anthracite	98	2	nonagglomerating
	2. Anthracite	92	...	2	8	...	...
	3. Semianthracite	86	...	8	14	...	...
2. Bituminous	1. Low volatile bituminous coal	78	86	14	22	commonly agglomerating
	2. Medium volatile bituminous coal	69	78	22	31	...	...
	3. High volatile A bituminous coal	...	69	31	...	7,777 ^a	...	
	4. High volatile B bituminous coal	...	...	...	...	7,222 ^a	7,777
	5. High volatile C bituminous coal	...	...	...	...	6,389 5,833	7,222 6,389
3. Subbituminous	1. Subbituminous A coal	5,833	6,389	nonagglomerating
	2. Subbituminous B coal	...	...	...	...	5,277	5,833
	3. Subbituminous C Coal	...	...	...	...	4,611	5,277
4. Lignite	1. Lignite A	3,500	4,511	nonagglomerating
	2. Lignite B	...	...	...	...	...	3,500

a. Coals having 69% or more carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of gross calorific value

- b. This classification applies to coals composed mainly of volatile. Coal rich in liptinite or inertinite do not fit into this classification
- c. Moist refers to containing its natural inherent moisture but not including visible water on the surface coal
- d. if agglomerating, classify in low-volatile group of the bituminous class
- e. It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and that there are notable exceptions in high volatile C bituminous group

Source: ASTM Standards D388 (1997)

4.1 The Rank of Maiganga Coal

Looking closely at the result (Table 4.1) and based on ASTM coal classification (Table 4.3), the Maiganga coal apparently falls within the lignite rank [26-27], as this is the range of its calorific value and fixed carbon. Samples from locations A1 and A2 have 4981.5 j/g and 4237.5 j/g calorific values. Their fixed carbon values are 32.66% and 28.71% respectively. The locations B1 and B2 have 3200.3j/g and 2248.8j/g respectively as their calorific values, whereas 20.31% and 22.48% are their respective fixed carbon values. By far, the most important property of coal is that it burns. When pure carbon and hydrocarbons found in coal burn completely only two products are formed: carbon-dioxide and water. During the chemical reaction, a relatively large amount of heat energy is released, the very reason why coal has been used as energy source. This is the reason why carbon content of coal is very important and its quantity in a coal determines how it would burn, long or short. The higher its quantity the better the quality and the longer it burns. Of course, the heating energy value would equally be high. Hence, the fixed carbon and calorific value are strictly the parameters of placing coals into different ranks. The volatile matter is equally important as it is given off as gas and vapour. It consists mainly of combustible gases such as hydrogen, carbon-monoxide, and methane, plus other hydrocarbons. Tar and incombustible gases such as carbon dioxide and steam are also evolved. The proportion of volatile constituents to fixed carbon in the result (Table 4.1) is high and this means that the fuel would burn quickly with a long smoky flame that is difficult to control. The high content of the volatile matter in the result (Table 4.1) demonstrates that the coal of the study area is of low rank. This is because the content of the volatile matter decreases with increase in coal rank [28].

The moisture content and ash content of coals are counter-productive. The higher the moisture and ash contents, especially the ash content the lesser the quality. They are contained in some measures in the various ranks of coal, though high to extreme in low rank coals. This may be due to their porous nature [29]. In the high rank coals they are very minimal. Also, this may be based on their little to no porosity. A common characteristic of lignite coal is the presence of abundant inherent moisture [30] within its carbonaceous matrix [31]. Moisture held within the coal itself is known as inherent moisture and is analyzed. The inherent moisture [32] is that fraction of the moisture content that is structurally contained in the material [33]. Moisture may occur in four possible forms within the coal, namely; surface moisture- water held on the surface of coal particles or macerals, hygroscopic moisture- water held by capillary action within the micro-fractures of the coal, decomposition moisture- water held within the coal's decomposed organic compounds, and mineral moisture - water which comprises part of the crystal structure of hydrous.

V. Conclusion

In determining the rank of coal, the percentage of fixed carbon and calorific value is very critical. It has been established in this study that the degree of coalification a coal deposit undergoes would normally determine its percentage of fixed carbon and calorific value, and the quality. Having undergone maximum coalification, anthracite has the highest percentage of fixed carbon and calorific value, and is the best quality of coal. However, the reverse is true for lignite. This paper has established from the proximate analysis carried out on each of the samples collected from various locations at Maiganga coal mine that the Maiganga coal deposit has high percentage ash content, high percentage moisture content, and low percentage fixed carbon and low calorific value. The implication of this is that the Maiganga coal deposit belongs to a lower coal rank. Judging by the American Society for Testing Materials (ASTM) coal classification (Table 4.3), the values of the result of the analysis (Table 4.1) places the Maiganga coal in the lignite rank.

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