Determination of Coking Properties and Heat Values of Coals from Parts of Benue Trough and Anambra Basin for their Industrial and Domestic Uses

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ABSTRACT

A total of six coal samples labeled (AGB, EHA, INY, LAF, OHN, and SHJ) were collected within our map area and sent to the laboratory for standard proximate analyses for ranking of the coals based on ASTM D388 – 05 standard classifications of coal ranks. The coal parameters obtained from the laboratory are moisture content (Mc), volatile matter (Vm), fixed carbon (Fc), ash content (Ac), sulphur content (Sc), mineral content (Mc), heating values (Hv), calorific values (Cv), fuel ratio (Fr), and free swell index (Fsi). The values of these parameters show that two (LAF, SHJ) of the six coal samples are of high ranking and are of bituminous grade while the other four (AGB, EHA, INY, and OHN) coal samples are of lower rank and are of sub-bituminous grade. The bituminous coals in Lafia-Obi and Shankodi-Jangwa areas are of large quantities and are used for production of coke used in blast furnaces for production of steel. It can also be used for domestic heating especially where anthracite is not available. The sub-bituminous coals located in Agbogugu, Eha-Etiti, Inyi, and Ohandiagu are of very large quantity and are used in generating steam for the production of electricity in power plants. In addition, sub-bituminous coals can be liquefied and converted to petroleum and gas. However, the use of sub-bituminous coal can lead to hazardous emissions into the environment especially harmful smoke, soot, sulphur oxides, nitrogen oxides and mercury. The low sulphur content is attributed to shallow marine depositional environment, which restricted sea water incursion during peat formation in the Coalification process.

Keywords: Coking Properties - Heat Values – Coals – Bituminous – Sub-Bituminous – Fixed Carbon - Fixed Carbon – Benue Tough - Anambra Basin.

INTRODUCTION

The present global concern for alternative sources of energy for economic development and industrialization has rekindled interest in coal. In today's choice of alternative sources of energy, industrialized countries have invested in the exploration and exploitation of coal. In these developed countries, coal has since been used for industrial and domestic sources of energy. Available literatures show that Nigeria has a lot of coal reserves in the different levels of exploration and exploitation. The detail of which is shown in Table 1. There are about twenty-two (22) coal deposits spread in thirteen (13) states of Nigeria. The proven reserves are 639 million tonnes and estimated or inferred reserves are about 2.75 billion tonnes. The total reserves are made up of 49% sub-bituminous, 39% bituminous and 12% lignitic coals (Kibiya, 2012). In Nigeria, coal was used for rail transportation, electricity generation and coal briquettes. Currently coal is only utilized in few private industries and minimal briquettes making. Globally, with the development of cleaner coal utilization technologies such as carbon capture and storage (CCS), coal has continually been utilized in electricity generation and other energy generation in many developed countries.

Available records show that Nigeria has vast deposits of high quality and environmentally friendly coal. The

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exploration and exploitation of which can make large reserve of coal available for industrial and domestic uses. Coal forms through Coalification process which involves some biochemical and geological processes that take place for a long geological time. The main objective of this paper is to ascertain the ranks/grades of the coal deposits within our study area through an elaborate field and laboratory studies. These will enable us to determine their proximate and ultimate properties. The study area is located within the Benue Trough and Anambra Basin and is bounded by latitude 6009'21"N to 8028'18"N and longitude 7016"45"E to 9012'56"E.

Table 1: Coal Deposits in Nigeria showing their Locations, Ranks, and Estimated/Proven Reserves in Million Tonnes (Kibiya, 2012)

S/N	DEPOSIT	LOCATION	RANK	EST. RESERVE	PROV. RESERVE	METHOD
1	Okpara Mine	Enugu	Sub-Bituminous	100 estimated	24 proven	Underground
2	Onyeama	Enugu	Sub-Bituminous	150 "	40 "	Underground
3	Ihioma	Imo	Lignite	40 "	N.A	Open-cast
4	Ogboyoba	Kogi	Sub-Bituminous	427 "	107 "	Opencast/Underground
5	OgawashiAzagba/ Obomkpa	Delta	Lignite	250 "	63 "	Opencast/Underground
6	Ezimo	Enugu	Sub-Bituminous	156 "	56 "	Opencast/Underground
7	Inyi	Enugu	Sub-Bituminous	50 "	20 "	Opencast/Underground
8	Lafia/Obi	Nasarawa	Bituminous (Cokable)	156 "	21.42"	Opencast/Underground
9	Oba/Nnewi	Anambra	Lignite	30 "	N.A	Underground
10	Afikpo/Okigwe	Ebonyi/Imo	Sub-Bituminous	50 "	N.A	Underground
11	Amansiodo	Enugu	Bituminous (Cokable)	1000"	N.A	Underground
12	Okaba (Odagbo)	Kogi	Sub-Bituminous	250 "	3"	Opencast/Underground
13	Owukpa	Benue	Sub-Bituminous	75 "	75 "	Open
14	Ogugu/Awgu	Enugu	Sub-Bituminous	N.A	N.A	Underground
15	Afuji	Edo	Sub-Bituminous	N.A	N.A	Underground
16	Ute	Ondo	Sub-Bituminous	N.A	N.A	Underground
17	Doho	Gombe	Sub-Bituminous	N.A	N.A	Underground
18	Kurumu	Gombe	Sub-Bituminous	N.A	N.A	Underground
19	Lamja	Adamawa	Sub-Bituminous	N.A	N.A	Underground
20	Garinmaigungu	Bauchi	Sub-Bituminous	N.A	N.A	Underground
21	GindiAkwati	Plateau	Sub-Bituminous	N.A	N.A	Underground
22	Jamata Koji	Kwara	Sub-Bituminous	N.A	N.A	Underground

Geologic Framework

The Benue Trough of Nigeria Figure 1 is a fundamental tectono-sedimentological feature in the evolution of the Cretaceous and Tertiary geology of Nigeria. It may be assumed that prior to its inception; no part of the Nigerian landmass had any sedimentary cover. In other words, the entire surface of the Pan-African crystalline basement, at least within Nigeria, was exposed. The various regions of the basement known today as the Ibadan Craton, Jos Craton, the Bamenda Massif, and even the Brazil Craton were one large expanse that might as well have been named the Central Gondwana Shield. However, it had its weak zones, and the Benue Trough is thought to be one such zone, only reactivated by tectonics during Gondwana break-up. The high sea levels and warm climate of the Cretaceous imply that large areas of the continents were covered by warm, shallow seas, providing habitat for many marine and terrestrial organisms. The Benue Trough is an intra-continental basin in Africa and covers over 1000 km in length and exceeds 150 km in width (Abubakar, 2014).

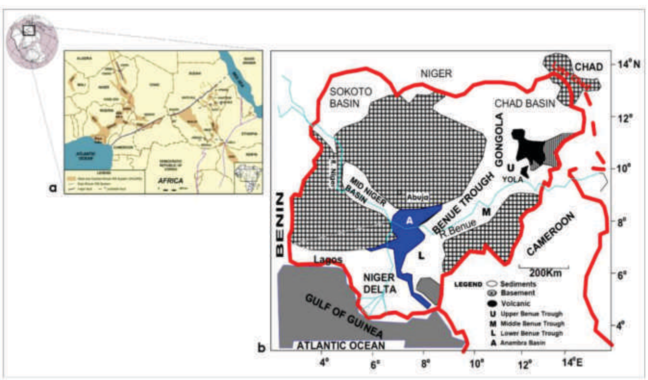

Figure 1: WCARS showing the Benue Trough. (b) Generalized Geological Map of Nigeria showing the Benue Trough, Blue Area represents the Anambra basin (Jauro et al., 2007)

NB: The Anambra Basin is a separate Sedimentary Basin.

The trough originated from Early Cretaceous rifting of the central West African basement uplift, which accounts for the hosting, production and development of deposition of the largest coal deposits in Nigeria. Regionally, the Benue Trough is part of an Early Cretaceous rift complex known as the West and Central African Rift System. Olade, (1975) and Wright, (1976) considered the Benue Trough as the third failed arm (or aulacogen) of a three-armed rift system related to the development of hot spots (Figure 2). Its southern outcrop limit is the northern boundary of the Niger Delta Basin, while the northern outcropping limit is the southern boundary of the Chad Basin separated from the Benue Trough by an anticlinal structure termed the "Dumbulwa-Bage High". The Benue Trough is filled with up to 6000m thick of Cretaceous sediments associated with some volcanics. It is part of a mega-rift system termed the West and Central Africa Rift System (WCARS). The WCARS includes the Termit Basin of Niger and western Chad, the Bongor, Doba and Doseo Basins of southern Chad, the Salamat Basin of Central African Republic and the Muglad Basin of Sudan (Figure 3). The Benue Trough is geographically subdivided into Southern (lower), central (middle) and northern (upper) parts.

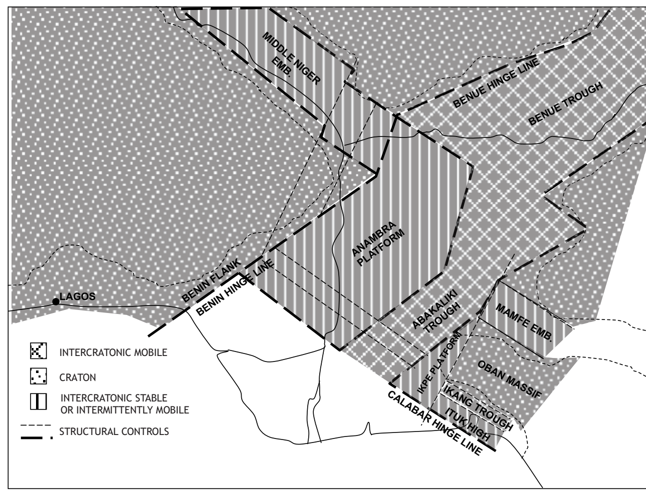

Figure 2: Cenomanian Tectonic Framework for the Benue Trough (Akande and Erdtman, 1998)

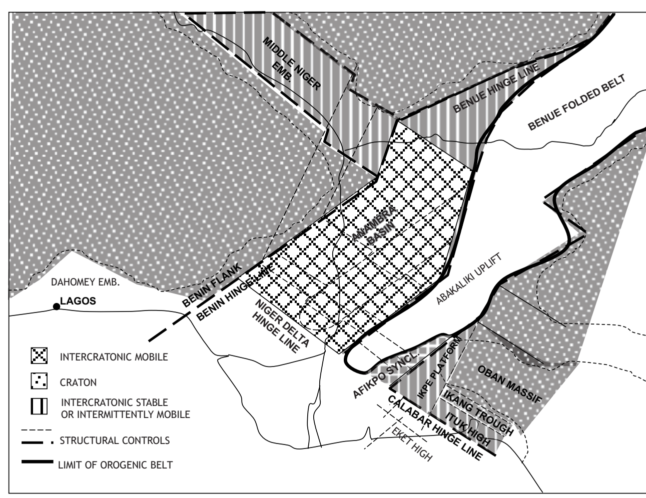

Figure 3: Santonian Tectonic Framework for the Benue Trough (Akande and Erdtman, 1998)

Over geologic times, the Benue Trough has been subjected to various tectonic episodes (Burke, et al. l970). These episodes of tectonic events were initiated by the opening of the South Atlantic Ocean and were the major controlling factors for the deposition of sediments in the trough. In essence, the tectonic events created different depocentres through the uplift of adjacent areas. The depositional history of the Benue Trough is dominated by repetitive transgressive/regressive sedimentary cycles interspersed with three main episodes of tectonism during the Cenomanian, Santonian and Eocene events. The Cenomanian episode caused the initial rifting of the southern continental margin of Nigeria resulting in the opening of the Benue Trough which is flanked by the Anambra Basin to the East and the Afikpo Syncline to the Southwest (Figure 2). This phase produced two principal sets of faults, trending NE-SW and NW-SE. The NE-SW set of faults bounded the Benue Trough, while the NW-SE sets are characteristic of the Calabar Flank. The Asu River Group, the Eze-Aku Group and Awgu Group in the Southern Benue Trough were deposited in the rift structure so created. The sediment thickness deposited during this episode is over 3000m. The second phase of tectonism started in the mid-Santonian and affected all pre–Santonian sediments within the rift basin. The Santonian deformation was characterized by compressive folding, faulting and uplift generally along a NE–SW direction, parallel to the trough margin. The uplift resulted in the formation of the Abakaliki Anticlinorium and also created the complementary Afikpo Syncline. The major fracture is in the NE-SW direction, defining axial planar structures. These NE-SW trending fractures were intruded by magmatism in the Southern Benue Trough. The tectonic episodes shifted the depositional axis to the Anambra Basin at the northwestern part of the Abakaliki Anticlinorium; the depositional axis also shifted to the Afikpo Syncline at the southeastern side of the Abakaliki Anticlinorium. The Santonian tectonic episode (Figure 3) totally obscured the Cenomanian episode. Thus, structural features pointing to the Santonian event is well preserved and documented more than the Cenomanian episode. The last tectonic phase–the Eocene phase–involved rapid subsidence and the uplifting of the Anambra Basin; this forced the depositional axis into the Niger Delta.

MATERIALS AND METHODOLOGY

A total of six coal samples from six different locations within the study area namely: Agbogugu (AGB), Eha-Etiti (EHA), Inyi (INY), Eha-Ndiagu (EHA), Shankodi-Jangwa (SHJ) and Lafia-Obi (LAF) were sent to the National Geosciences Research Laboratory of Nigeria, Kaduna (NGRLN), a subsidiary of Nigerian Geological Survey Agency, Kaduna (NGSA) for proximate and ultimate laboratory analyses. The geologic map of the study area showing the sample locations is shown in Figure 4 and the regional stratigraphy of the Benue Trough is shown in Figure 5. The stratigraphic section of four of the six sample locations are shown in Figures 6 to Figure 9. The methods of analyses employed are in compliance with International Organization for Standardization (ISO), formerly American Society for Testing and Materials (ASTM).

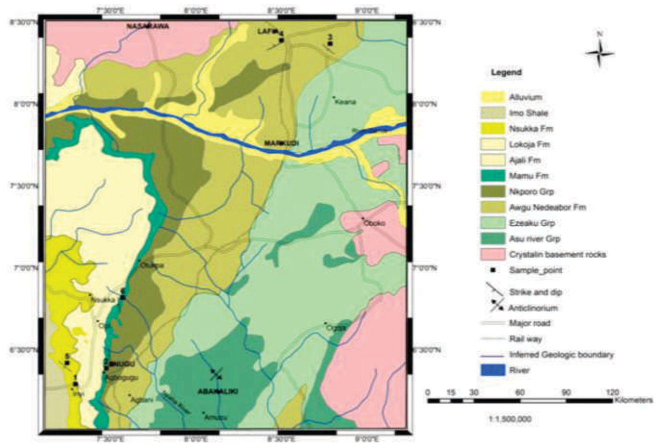

Figure 4: Geologic Map of the Study Area Showing Sample Locations

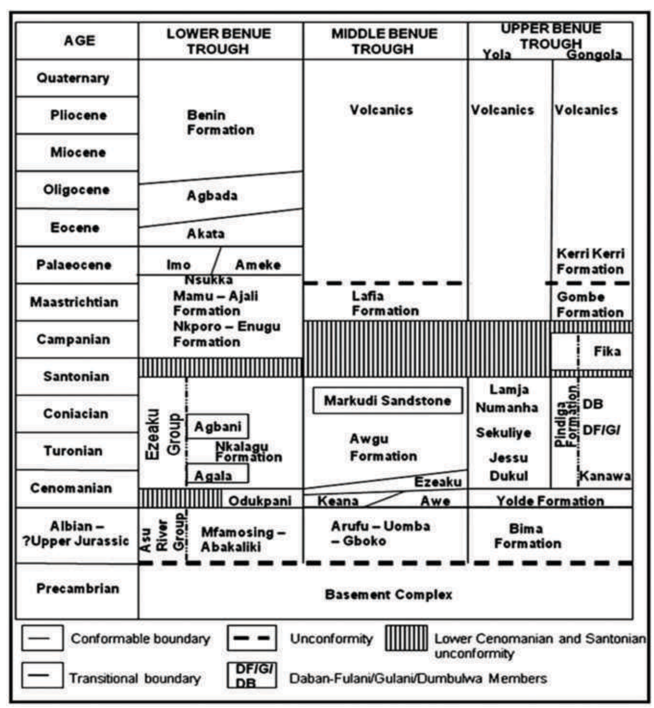

Figure 5: The Regional Stratigraphic Succession of Lithologies in Benue Trough. (Adapted from Abubarkar, 2014)

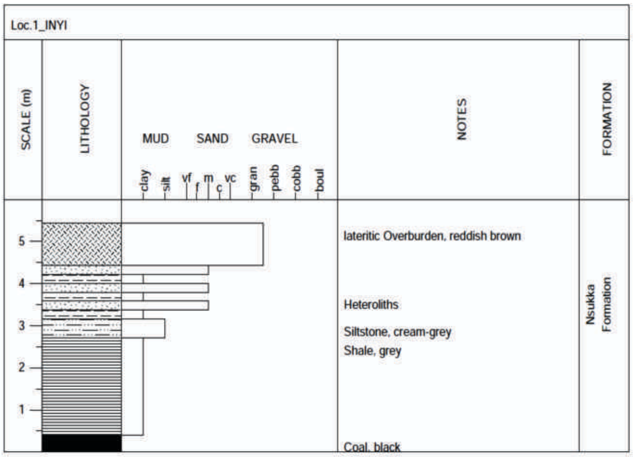

Figure 6: Geologic Map of the Study Area Showing Sample Locations

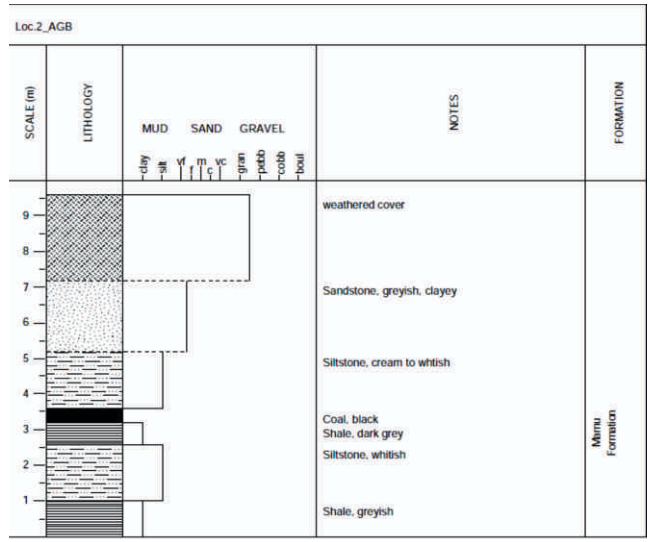

Figure 7: The lithologic section of coal sample location at AGBOGUGU

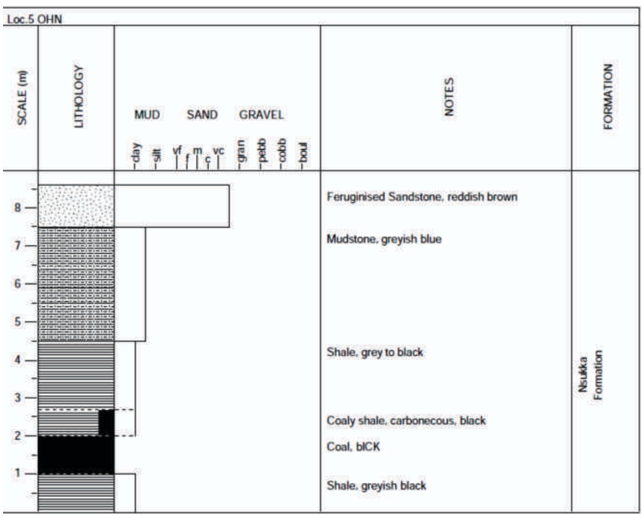

Figure 8: The Lithologic Section of Coal Sample Location at OHNDIAGU

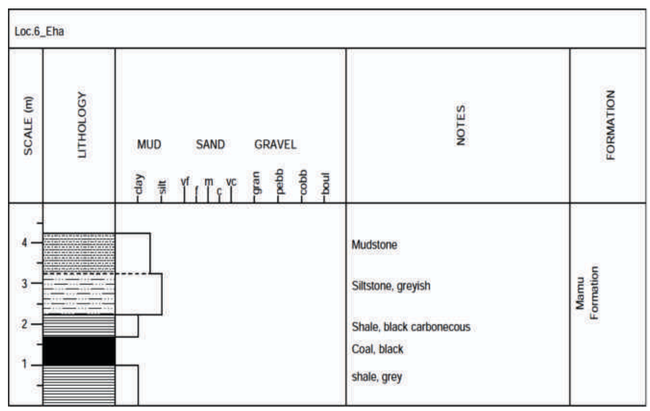

Figure 9: The Lithologic Section of Coal Sample Location at EHA-ETITI

RESULTS AND INTERPRETATION

Proximate Analysis Results

The results obtained from proximate Analysis and the calculated Mineral matter of the Six Coal Samples are shown on Table 2.

Table 2: The results for the proximate Analysis and the Mineral matter of the Six Coal Samples.

Properties and Symbols		**Samples**					
		AGB	**EHA**	**INY**	**LAF**	**OHN**	**SHJ**
Moisture Content (%)	MC	3.5	3.50	3.30	2.40	3.70	2.40
Volatile Matter (%)	VM	40.3	40.1	40.5	30.1	38.5	30.2
Fixed Carbon (%)	FC	48.17	45.20	42.50	56.22	40.94	56.07
Ash Content (%)	AC	13.00	13.30	13.80	8.10	13.40	8.40
Sulphur Content (%)	SC	0.91	0.98	0.95	0.91	0.93	0.92
Mineral Content (%)	Mc	15.62	15.01	16.44	10.38	15.42	10.66

Heating (Calorific) Value

The results obtained from the gross calorific value determination carried out on the Six Coal Samples along with their calculated fuel Ratios are shown in Table 3.

Table 3: Calorific Values and the Fuel Ratio Values of the Six Coal Samples

Fuel Quality Parameters	Symbol	AGB	EHA	INY	LAF	OHN	SHJ
Gross Calorific Value (Kcal/Kg)	GCV	6.46	6.66	6.10	8.42	6.63	8.62
Btu/Ib		25.62	26.41	24.19	33.39	26.29	34.19
MJ/Kg		20.2	20.1	20.5	30.2	22.1	30.1
Fuel Ratio	FR	1.2	1.13	1.05	1.87	1.06	1.86

Free Swell Index

The results obtained from the free swell index determination carried out on the Six Coal Samples are shown in Table 4.

Table 4: The Free Swell Index of the Six Coal Samples

Sample Location	Free Swell Index
Agbogugu	3.1
Eha-Etiti	3.2
Inyi	3.5
Lafia –Obi	6.2
Ohandiagu	3.2
Shankodi –Jangwa	6.1

Proximate Analysis

The proximate analysis of the six coal samples is presented in Table 2. The following values are for moisture content (Mc), volatile matter (Vm), fixed carbon (Fc), Ash content (Ac) and calculated values for the Mineral content (Mc) respectively. The values of moisture content (Mc) are lowest for Lafia-Obi (LAF) 2.40wt% and Shankodi-Jangwa (SHJ) 2.4wt% coals; the values for the other four samples range from 3.30 to 3.70wt%.

The volatile matter (Vm) values are lowest for Lafia-Obi (LAF) 30.1wt% and Shankodi-Jangwa (SHJ) 30.2wt% coals; other four coal samples range from 38.5 to 40.5wt%.

The Fixed Carbon (Fc) values are highest for Lafia-Obi (LAF) 56.22wt% and Shankodi- Jangwa (SHJ) 56.07wt% coals; other four coal samples range from 40.94 to 48.17wt%.

The Ash content (Ac) values are highest for Lafia-Obi (LAF) 28.1wt% and Shankodi-Jangwa (SHJ) 28.4wt% coals; the other four coal samples range from 13.00 to 13.8wt%.

The sulphur content (Sc) values for the six coal samples are low and range from 0.91 to 0.98wt%. A variation of sulphur in coals is related to the depositional environment of coal seams. In our study area is attributed to the shallow marine environment of deposition where there was little influence of sea water during peat formation.

The Mineral matter (Mm) values are lowest for Lafia-Obi (LAF) 10.38wt% and Shankodi-Jangwa (SHJ) 10.66wt% coals; the other four coal samples range from 15.01 to 16.44wt%.

Table 3 show values of heating, calories and fuel ratios. The coals of Lafia-Obi and Shankodi-Jangwa show highest values; while the other four coal samples show lower values.

Table 4 show lowest values of free swell index for the coals of Lafia-Obi and Snankodi-Jangwa; while the other four coal samples show higher values.

DISCUSSION

Coal ranking applied in this paper is based on American Society for Testing and Material ASTM D388 – 05 standard classifications of coal ranks. The coal ranking depends on levels of geological metamorphosis/ Coalification process, fixed carbon and calorific values.

The following parameters: moisture content (Mc), volatile matter (Vm), fixed carbon (Fc), ash content (Ac), sulphur content (Sc), mineral matter (Mm), heating values (Hv), calorific values (Cv), fuel ratio (Fr), and free swell index (Fsi) indicate that two (LAF,SHJ) of the six coal samples are higher in ranking compared with the remaining four (AGB,EHA,INY,OHN) coal samples.

The values of volatile matter, ash content, fixed carbon and calories indicate that the coals of Lafia-Obi and Shankodi-Jangwa are bituminous and coking; while those of Agbaogugu, Eha-Etiti, Inyi, and Ohandiagu are sub-bituminous and non-coking. These agree with the works of Akpabio, etal. (2008); Chukwu, etal. (2012) and Akubo, etal. (2013) and Ryemshak and Jauro. (2013).

Bituminous coal is mainly used for making coke hence it can be called coking coal or metallurgical coal. The produced coke is used in blast furnaces for iron reduction in steel production. Bituminous coal can be used for domestic heating in the absence of anthracite. These high ranking coals (Lafia-Obi, Shankodi-Jangwa) within our study area has less moisture, less ash content and higher fixed carbon than the four other coal samples. Records show that about 1.5 metric tons of bituminous coals are required to produce 1 metric tons of coke. In Nigeria the coking coal in Lafia-Obi area has an estimated reserve of 156 million tons and proven reserve of 21.42 million tons (Kibiya. 2012). There is no data on same bituminous coal in Snankodi-Jangwa.

The remaining four other coal samples (Agbaogugu, Eha-Etiti, Inyi, and Ohandiagu) are sub-bituminous coals based on coal assessment parameters done in the laboratory. These are again correlated to the works of Akpabio, etal. (2008); Chukwu, etal. (2012); Akubo, etal. (2013) and Ryemshak and Jauro (2013).
These sub-bituminous coals are used for generating steam for electricity production in power plants. In addition, sub-bituminous coals can be liquefied and converted to petroleum and gas. However, the use of this bituminous coal can lead to hazardous emissions, especially harmful, smoke, soot, sulphur oxides, nitrogen oxides and mercury. Records show that estimated reserve of bituminous coal in Enugu area is well over 300 million tons while the proven reserve is over 84 million tons Kibiya, (2012).

CONCLUSIONS

A total of six coal samples labeled (AGB, EHA, INY, LAF, OHN, and SHJ, were taken to the laboratory for standard proximate analyses for ISO ranking of the coals. Based on the values of coal parameters obtained, two of the coal samples (LAF, SHJ) are bituminous coals while the remaining four coal samples (AGB, EHA, INY, and OHN) are sub-bituminous coals. The low sulphur content of all the coal samples is attributed to shallow marine depositional environment, which restricted marine influence during peat formation in the Coalification process.

The bituminous coals are used in making coke for blast furnace in steel production. In addition, they can be used for domestic heating especially in the absence of anthracite.

The sub-bituminous coals are used for generating steam for electricity production. They are also liquefied and converted to petroleum and gas. The industrial use of sub-bituminous coals can lead to hazardous emissions, especially harmful smoke, soot, sulphur oxides, nitrogen oxides and mercury.

REFERENCES CITED

Abubakar M.B. (2014). Petroleum Potentials of the Nigerian Benue Trough and Anambra Basin: A Regional Synthesis. Natural Resources, vol. 5, pp. 25-58.

Abubakar, M. B., Maigari, A. S., Babangida, S. Y. D., Abdullah, W. H., Ahmed, I. H., John, S. J., Bappah, U. A. and Abdulkarim, H. A.(2014). A re-focus on the tectono-stratigraphic evolution of the Upper Benue Trough, northeastern Nigeria: implications on petroleum exploration. Nigerian Association of PetroleumExplorationists Bulletin, vol. 26(1), pp. 27-33

Adedosu T. A., Adedosu, H. O., and Adebiyi, F. M. (2007). Geochemical and Mineralogical Significance of Trace Metals in Benue Trough Coal: Nigeria. *Journal of Applied Sciences*, vol. 7(20), pp. 3101 – 3105.

Adekola F. A., Baba, A. A. and Buhari, S. (2012). Physico-Chemical Characterization and Speciation of Sulphur of Nigerian Coal Samples. Journal of Minerals and Materials Characterization and Engineering, vol. 11, pp. 965-969

Afonja, A.A. (1996). Production of Metallurgical Coke from Non-

Coking Coals in: Nigerian Coals: A Resource for Energy and Investments, Afonja, A.A. (Ed.). RMRDC, Abuja, Nigeria, pp: 89-105.

Afu, D.J., Ifelola, E.O., and Adesida, P.A (2018). Omelewu Coal Characterization for Powering Power Plant at Dangote Cement Factory, Obajana, Kogi State, Nigeria. American Journal of Engineering Research (AJER), vol. 7(3), pp.143-152.

Akande, S. O. and B. D. Erdtman. (1998). Burial Metamorphism (thermal maturation) in Cretaceous Sedimentsof the Southern Benue Trough and Anambra Basin, Nigeria. American Association of Petroleum Geologists, Bulletin, V.82, no.6, P.1191-1206.

Akpabio, I. O., Chagga, M. M. and Jauro, A. (2008). Assessment of Some Nigerian Coals for Metallurgical Applications. Journal of Minerals & Materials Characterization & Engineering, Vol. 7(4), pp. 301-306.

American Society for Testing and Materials. (1992). Annual Book of ASTM Standards, Section 5.05, Petroleum Products, Lubricants and Fossil Fuels.

Benkhelil, J. (1989). The Origin and Evolution of the Cretaceous Benue Trough (Nigeria) Journal of African Earth Sciences (and the Middle East), vol.–8, Issues 24, pp. 251-282.

Bizualem, W. and Busha, A. (2017). Physicochemical Characterization of Coal and its alternative use as a Source of Energy (in case of Yayo Coal Mining Industry). Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT) Vol.11, (5), PP 44-50

Burke, K. C., Dessauvagie, T. F. L. and Whiteman. A. J. (1970). Geological History of the Benue Valley and Adjacent Areas.In: African Geology (ed.) T.F.J. Dessauvagie and A.J. Whiteman. Pp.187-205. Ibadan (Nigeria): Dept. of Geology, University of Ibadan.

Chukwu, C. J., Obasi, N. A., Jauro, A., Ezeribe, A. I., Nwachukwu, C. B. and J. D. Putshak'a. (2012). Physical and elastic properties of three Nigerian coals. Asian Journal of Materials Science, V.4, no.2, P.45-51

Diez, M. A., Alvarez, R. and Barriocanal, C. (2002). Coal for Metallurgical Coke Production: Prediction of Coke Quality and Future Requirements for Coke Making. Int. J. Coal Geology, Vol. 50, pp. 289-412.

Fatoye, F., B. and Mepaiyeda, S. (2020). Quality Assessment of Igaliwo and Olokwu Coals in the Northern Anambra Basin of Nigeria. International Journal of Geology and Mining,vol. 6(1), pp. 309-317.

International Energy Agency, (2007). Fossil fuel-fired power generation: case studies of recently constructed coal- and gas-fired power plants. http://www.iea.org/publications/freepublications/publication/fossil-fuel-fired-power-generation.html.

Jauro, A., Obaje, N., Agho, M., Abubakar, M. and Tukur, A., 2007. Organic geochemistry of Cretaceous Lamza and Chikila Coals, upper Benue trough, Nigeria. Fuel, vol. 86, pp. 520–532.

Kibiya, M. M. (2012) Properties of some Nigerian coals for power generation (M.S. thesis), Ahmadu Bello University, Zaria, Nigeria.

Makan, S. Alexander, J. Solomon, R., Manasseh, A., Mbaya, I. and Julius, P. (2017). Physicochemical Characterization of Coal Tar Produced by Pyrolysis of Coal from Garin Maiganga and Shankodi Deposits. Journal of Minerals and Materials Characterization and Engineering, vol. 5, pp. 288-297.

McCabe, P. J. (1991). Geology of coal; Environments of deposition, in Gluskoter, H.J., Rice D.D., and Taylor, R.B., eds., Economic Geology, U.S.: Boulder, CO, Geological Society of America, The Geology of North America, vol. 2, pp. 469-482.

Nasirudeen, M. B. and Jauro, A. (2011). Quality of Some Nigerian Coals as Blending Stock in Metallurgical Coke Production. Journal of Minerals & Materials Characterization & Engineering, vol. 10(1), pp.101-109.

Nyakuma B. B. and Jauro A. (2016). Physicochemical Characterization and Thermal Decomposition of Garin Maiganga Coal. Geoscience Engineering Volume LXII, No. 3 http://gse.vsb.cz p. 6-11, ISSN 1802-5420.

Nyakuma B.B., (2016). Physicochemical characterization and thermal analysis of newly discovered Nigerian coals. Bulgarian Chemical Communications, vol. 48(4), pp. 746 – 752.

Obaje, N.G. (1997). Petrographic evalution of the coking potential of the Cretaceous Lafia-Obi coal deposits in the Benue trough of Nigeria. Nigerian Journal of Mining Geology, vol. 43, pp. 4-7.

Olade, M. A. (1975). Evolution of Nigeria's Benue Trough (Aulacogen): A Tectonic Model. Geology Magazine, Vol. 112, pp.575-583.

Onoduku, U. S. (2014). Chemistry of Maiganga Coal Deposit, Upper Benue Trough, North Eastern Nigeria. Journal of Geosciences and Geometrics, vol. 2(3), pp. 80 – 84.

Oni, S. O. and Ehinola, O. A., (2017a) Estimation and assessment of free swelling index and some petro graphic properties from chemical analysis of coals across river Niger. Petroleum and Coal, vol. 59(3), pp. 273-287.

Ryemshak, S. A. and A. Jauro. (2013). Proximate analysis, rheological properties and technological applications of some Nigerian coals. International Journal of Industrial Chemistry. V.4, no.7

Speight, J. G. (2012). The Chemistry and Technology of Coal. 3rd ed. Boca Raton, FL (USA): CRC pp1-801

Speight, J. G. (2005). Handbook of coal analysis. John Wiley & Sons, Inc., Hoboken, New Jersey. ISBN 0-471-52273-2. 238 p.

Wright, J. B. (1976). Volcanic Rocks in Nigeria. In: Geology of Nigeria (ed.) Kogbe, C. A. Elizabethan Publications, Lagos, Nigeria. pp.93-141.