Journal of Mining and Geology Vol. 56(1) 2020. pp. 23 - 30 1116-2775

Characterization of Coal Formations in the Middle Benue Trough and Anambra Basin, Nigeria Using Rock-Eval Pyrolysis

Ozoji, T.M.[1], Obaje, N.G.[1], Lar, U.A.[2], Amadi, A.N.[3], Umar, M.U.[1], Yenne, E.[2] and Nura, Y.A.[4]

[1]Ibrahim Badamasi Babangida University, Lapai, Nigeria.
[2]University of Jos, Jos, Nigeria.
[3]Federal University of Technology, Minna, Nigeria.
[4]Usman Danfodio University, Sokoto, Nigeria.
Corresponding E-mail: ozojitm@gmail.com

Abstract
Global energy demand has increased exponentially in the twenty first century with over dependence on few energy sources. These sources comprise oil and gas, renewable and nuclear energy. Nigeria suffers from acute energy deficiency especially in electric power availability; which has to a great extent, left the country behind in industrial and technological advancements. This has been attributed to huge dependence on few energy sources by a rapidly growing population. This study therefore evaluates the geochemical properties of coal deposits in the Middle Benue Trough and Anambra Basin, Nigeria as a strategy for addressing the energy shortfall in the country. Twenty five (25) coal samples from the study area were analyzed using Rock Eval Pyrolysis at the Federal Institute for Geosciences and Natural Resources, Hannover, Germany while combustion tests were carried out at the Ibrahim Badamasi Babangida University, Lapai, Nigeria. Results show that Okaba coal has an average TOC of 62.98%, HI of 278.22HC/gTOC, OI of 19.26mgCO_2/gTOC and Tmax of 420°C while Ogboyaga coal has average TOC of 63.4%, HI of 235.02HC/gTOC, OI of 38.47mgCO_2/gTOC and Tmax of 424°C. Omelehu coal on the other hand has an average TOC of 48.34%, HI of 224.74HC/gTOC, OI of 28.362mgCO_2/gTOC and Tmax of 421.8°C while Owukpa coal has an average TOC of 38.98%, HI of 234.2HC/gTOC, OI of 20.57mgCO_2/gTOC and Tmax of 427°C. The Lafia-Obi coal has an average TOC of 35.9%, HI of 56.12HC/gTOC, OI of 30.61mgCO_2/gTOC and Tmax of 451°C. Combustion test revealed that Okaba, Ogboyaga, Omelehu, and Owukpa coals took 10.00, 10.35, 11.37 and 13.22 minutes to boil equal volume of water respectively. Lafia-Obi coal did not bring the water to boiling point. Juxtaposing Rock Eval and combustion results revealed that Okaba coals have efficient combustion attributes of relatively high HI and low OI which resulted to fast boiling time and minimal smoke emission while the Lafia-Obi coals have the least combustion attributes with very low HI which made it difficult to combust. Ogboyaga coals have a good combustion attribute of high HI but the OI is also high. This explains the smoky combustion. Van Krevelen plot [HI versus OI] characterize the kerogens in Okaba, Ogboyaga, Omelehu, and Owukpa coal deposits as transitional Type II/III while Lafia-Obi coal as Type III. HI versus Tmax plot also characterize Okaba, Ogboyaga, Omelehu, and Owukpa coal deposits as immature for oil and gas generation although they possess relatively high HI while the Lafia-Obi coal as mature in the gas window although they have very low HI. Okaba, Ogboyaga, Omelehu, and Owukpa coal deposits show good prospect for clean bio-fuel extraction while Okaba coal can be used in its natural state to generate energy for industries with minimal smoke emission.

Keywords: *Coal Characterization, coal energy, middle Benue trough, Anambra basin, Rock Eval Pyrolysis*

Introduction

Energy is a vital instrument for sustaining human existence with applications ranging from industrial to transportation and domestic uses. Its demand globally is on an exponential increase in the twenty first century with over dependence on few energy brands; which include crude oil extracts (liquefied natural gas, premium motor spirit, kerosene, e.t.c), nuclear and renewable energies (solar, wind, biomass). Nigeria as a country suffers from acute energy deficiency especially in electric power availability; yet the country has far more resources of oil, gas and coals than it has demand for. This can be attributed to over dependence on few energy sources by a rapid growing population. Statistics show that ninety percent of Nigeria's current power generation is gas dependent while hydro driven sources constitute the remaining ten percent; leaving other sources underutilized. This has to a great extent, left the country behind in industrial and technological advancement.

Coal provides an alternative energy source but its application has been limited due to environmental concerns, few literature in Nigeria on the subject matter as well as technological insights and development for optimal utilization. In 1909, coal was first discovered in Eastern Nigeria near Udi. Further exploration for coal deposits led to several discoveries around the country including Abia, Adamawa, Anambra, Bauchi, Benue, Delta, Edo, Enugu, Gombe, Imo, Kogi, Niger and Plateau states. It is mainly used in hydropower plants (electricity generation), transportation (steam driven trains) and as industrial fuel (smelting/caking). Clean-energy technologies extract bio-fuel from coals with high hydrogen index as a strategy for achieving sustainable environments through reduced CO_2 emission.

The need to characterize Nigerian coal deposits cannot be over emphasized as a strategy for curbing the energy shortfall in the country. Only then, can Nigeria coal resources be put to optimum use.

Literature Review

The Benue Trough is an integral component of the sedimentary basins of Nigeria characterized by a major rift system extending NNE–SSW for about 800 km in length and 150 km width (Obaje, 2009). This basin was modified by a tectonic episode in the mid-Santonian resulting in an intense compressional fold formation which produced over a hundred anticlines and synclines (Benkhelil, 1989). This mid Santonian tectonic episode was accompanied by volcanism. The lower depositional axis of the Benue Trough was displaced westward following the mid-Santonian events, resulting in a major subsidence and the formation of the Anambra Basin. The Anambra Basin can therefore be referred to as an extension of the Lower Benue Trough with sediments of Campanian-Maastrichtian to Eocene ages.

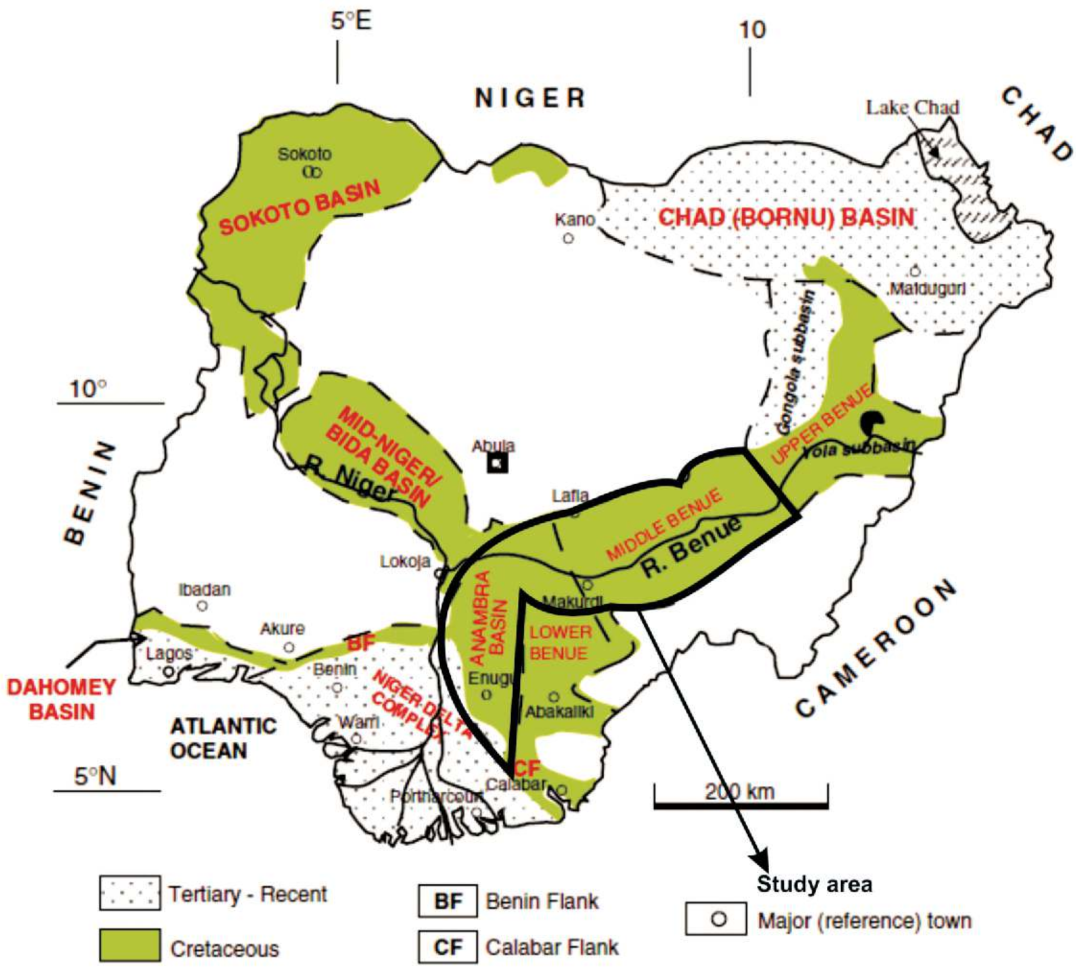

Fig 1: Sedimentary Basins of Nigeria showing the Middle Benue Trough and Anambra Basin (modified from Obaje, 2009)

The Lower Benue Trough comprise centers of deposition, which include areas around Abakaliki and Nkalagu, while the Anambra Basin depositional centers are around Awka, Okigwe and Enugu. The Middle Benue Trough areas of deposition extend from Makurdi to Yandev, Obi, Lafia, Jangwa to Wukari. The Upper Benue Trough deposition centers that make up the Gongola Arm include Gombe, Nafada, Pindiga, Ashaka and Tula, while the Yola Arm consists of Bambam, Lakun, Jessu, and Numan. This has recorded oil and gas discovery by the Nigerian National Petroleum Corporation with reserves not yet established.

The Middle Benue Trough comprise of the Asu River Group, Ezeaku Formation, Keana/Awe Formation, Agwu Formation and the Lafia Sandstone. The Asu River Group is the oldest and while the Lafia Sandstone is the youngest in age succession. The Asu River Group is mid- Albian while the Ezeaku Formation, Keana/Awe Formation, Agwu Formation and the Lafia Sandstone are Turonian to early Maastrichtian in age.

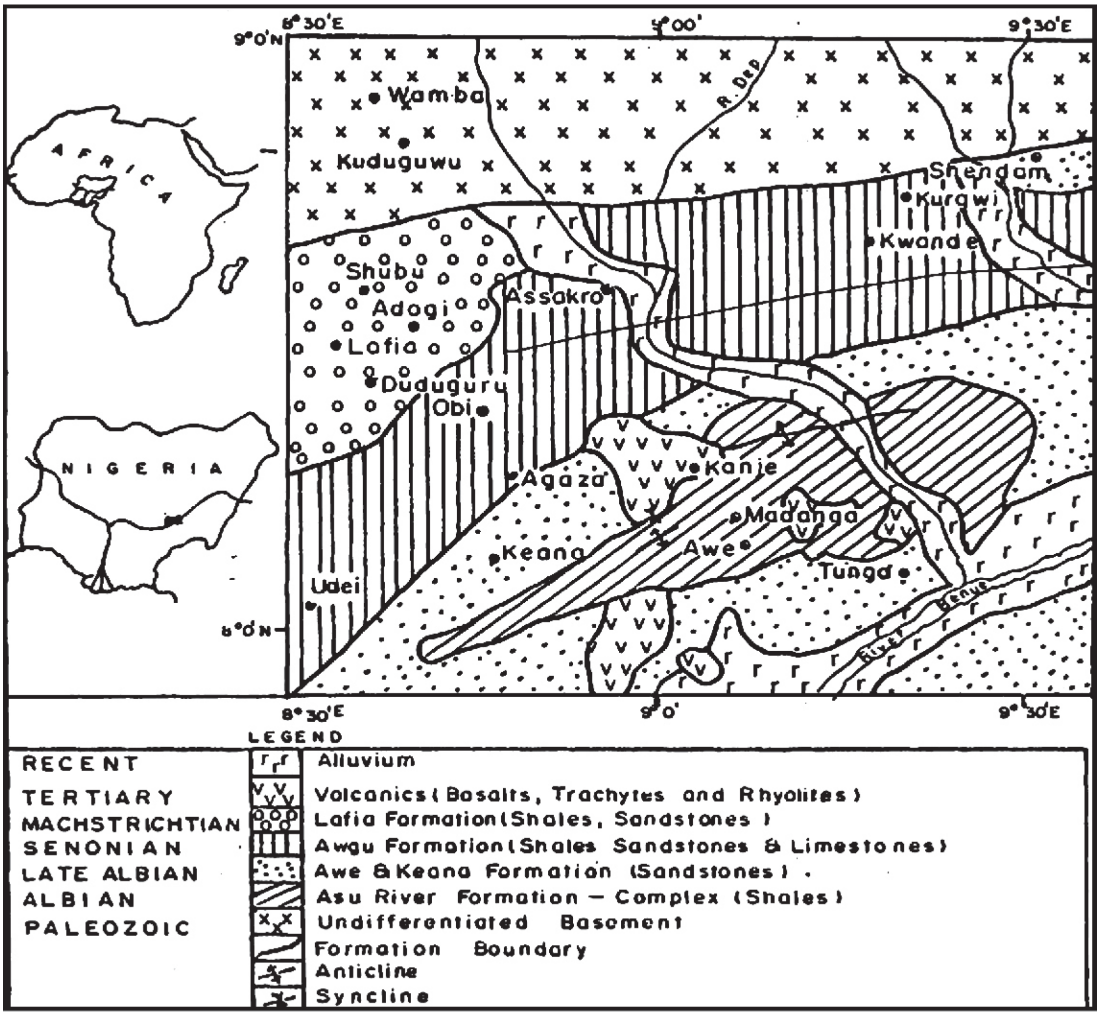

Fig. 2: Geological Map of the Middle Benue Trough showing a sample location (Geological Survey of Nigeria, 1984).

The Lafia-Obi coal is part of the Agwu Formation exposed by denudation at Obi. The Awgu Formation represents a significant hiatus as it marks the end of marine sedimentation in the Middle Benue Trough. They are denoted by a bluish-grey to dark-black calcareous shales, carbonaceous shales, shaley limestones, limestones, siltones, sandstones and coal seams. The major exposure of the coal-bearing Awgu Formation in the study area is located at the bank of River Dep in Shankodi, near Jangwa village. This exposure can be traced laterally along the bank of River Dep for approximately 500m and confirmed to be of bituminous rank (Obaje, 1994; Obaje *et al,* 1996). The Awgu Formation recorded numerous depositional oscillations between shallow marine and continental deposits with marine marls or shales enclosing coals and associated non-marine beds (Offodile, 1976). Evidence from Miospore Proteacidites correlation reveals that almost all the Santonian and Campanian depositional stages are missing in the Middle Benue Trough. Several researchers including Offodile (1976), Offodile and Reyment (1977) and Obaje (1994) attribute this hiatus to the Santonian compression which led to the formation of the NE-SW trending Keana anticline.

The Anambra Basin stands as a structural link between the Cretaceous Benue Trough and the Tertiary Niger Delta basin comprising of the Enugu/Nkporo Shale, Mamu Formation, Ajali Sandstone and Nsukka Formation ranging from Campanian to Paleocene in age. Coal deposits in the Anambra Basin are believed to be of sub-bituminous rank occurring principally at two levels, the upper coal facies of the Nsukka Formation and the lower coal facies of the Mamu Formation. However just below the Mamu Formatiion, we find the brackish marsh and fossiliferous Enugu/Nkporo Shales. The Anambra Basin is believed to host the largest and most economically viable coal resource in the study area covering about 1.5 million hectares and constrained by the Benue River to the north, the Enugu escarpment to the east and the River Niger to the west.

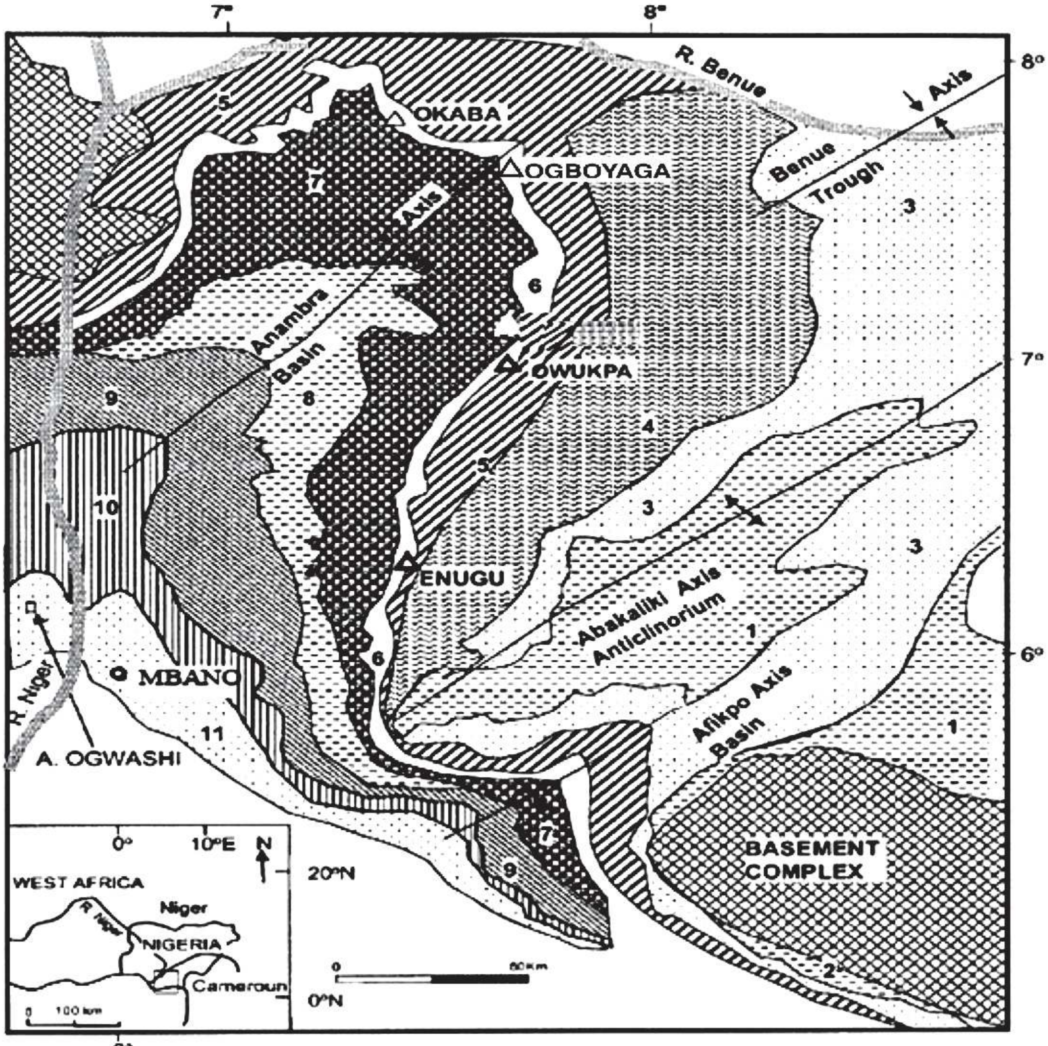

Fig. 3: Generalized geological map of the Anambra Basin showing some sample locations. Numbers below indicate Cretaceous and Tertiary formations. **1.** Asu River Group; **2.** Odikpani Formation; **3.** Eze-Aku Shale; **4.** Awgu Shale; **5.** Enugu/Nkporo Shale; **6.** Mamu Formation; **7.** Ajali Sandstone; **8.** Nsukka Formation; **9.** Imo Shale; **10.** Ameki Formation and **11.** Ogwashi-Asaba Formation (modified from Akande *et al.*, 2007).

Okaba, Omelehu, Ogboyaga and Owukpa coal deposits form part of the Mamu Formation while parts of the Owukpa Formation show a transitional facies into the Enugu/Nkporo Formation. The Enugu and the Nkporo Shales represent the brackish marsh and fossiliferous pro-delta facies of the Late Campanian-Early Maastrichtian depositional cycle (Reijers and Nwajide, 1998). Deposition of the sediments of the Nkporo/Enugu Formations reflects a funnel-shaped shallow marine setting that graded into channeled low-energy marshes and accumulated during the regression of the Nkporo cycle (Obaje, 2009). However, the Mamu Formation occurs as a narrow strip trending north–south from the Calabar Flank, swinging west around the Ankpa plateau and terminating at Idah near the River Niger. It is made up of different lithologic units which include shales, siltstones, sandstones and coal. The shales of the Mamu Formation are generally interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north (Akande et al., 1992). However, the coal deposits of the Mamu Formation are of fluvio-deltaic to fluvio-estuarine environments.

Methods of Study

The scope of study comprises geochemical evaluation and characterization of coal deposits in the Middle Benue Trough and Anambra Basin while the adopted methodology comprises:

a. Geologic fieldwork and sample collection.
Geologic fieldwork was carried out with the aim of identifying lithologies as well as sample collection. Twenty five (25) samples were collected from five (5) identified coal deposits in the study area. These comprise the Okaba, Omelehu and Ogboyaga coal deposits in Kogi State, Owukpa coal deposit in Benue State and Lafia-Obi coal deposit in Nasarawa State.

b. Preparation and analysis.
Coal samples collected were air dried, pulverized and labeled appropriately. This was carried out at the geology laboratory of the Ibrahim Badamasi Badamasi University, Lapai, Nigeria.
Rock Eval pyrolysis was carried out at the Federal Institute for Geosciences and Natural Resources, Hannover, Germany. Three milligram (3mg) of pulverized sample was weighed using a high precision scale and fed into the Rock-Eval device in crucibles. The samples were exposed to an initial temperature of 100°C then increased gradually to 300°C and finally to the temperature of 850°C. The Temperature at Maximum Rate of Pyrolysis (Tmax), Pyrolysable Hydrocarbon Content (S2) and amount of CO_2 (S3) were determined as the temperature was increased.
Combustion tests were also carried out on coals from the study area. This comprise evaluation of the combustion efficiency based on the time it took thesame weight of coal to bring equal volume of water to boiling point and combustion pathway based on the temperature readings at two minutes interval.

c. Data analysis and interpretation.
Data generated from the fore-mentioned analysis were analyzed using Microsoft Excel and Microsoft PowerPoint softwares. Graphic illustrations are interpreted in relation to referenced standards.

Results and Discussion

Rock Eval Pyrolysis result of coal samples from the study area are presented in Table 1.

Okaba, Omelehu, Ogboyaga and Owukpa coal deposits form part of the Mamu Formation while parts of the Owukpa Formation show a transitional facies into the Enugu/Nkporo Formation. The Enugu and the Nkporo Shales represent the brackish marsh and fossiliferous pro-delta facies of the Late Campanian-Early Maastrichtian depositional cycle (Reijers and Nwajide, 1998). Deposition of the sediments of the Nkporo/Enugu Formations reflects a funnel-shaped shallow marine setting that graded into channeled low-energy marshes and accumulated during the regression of the Nkporo cycle (Obaje, 2009). However, the Mamu Formation occurs as a narrow strip trending north–south from the Calabar Flank, swinging west around the Ankpa plateau and terminating at Idah near the River Niger. It is made up of different lithologic units which include shales, siltstones, sandstones and coal. The shales of the Mamu Formation are generally interbedded with chamositic carbonates and overlain by bioturbated siltstones, sandstones and coal units in coarsening upward cycles towards the north (Akande et al., 1992). However, the coal deposits of the Mamu Formation are of fluvio-deltaic to fluvio-estuarine environments.

Okaba coals have the highest HI average of 278.22 and lowest OI average of 19.26 with a Tmax average of 420. Ogboyaga coals have the second highest HI average of 235.02 as well as the highest OI average of 38.47 with Tmax average of 424. Owukpa coals have an average HI of 234.2 and OI average of 20.57 with Tmax of 427 while Omelehu coals have an average HI of 224.74 and OI of 28.36 with Tmax average of 422. Lafia-Obi coals have the lowest HI average of 56.12 and the second highest OI average30.61. It also records the highest Tmax average of 451.

Results from Rock Eval pyrolysis were interpreted using the Van Krevelen diagram and HI versus Tmax plots. The Van Krevalen plot (Fig 4) was used to characterize the kerogen types while HI versus Tmax plot (Fig 5) was used to ascertain the maturity and petroleum generative potential of coal deposits in the study area.

Table 1: Rock-Eval pyrolysis result of study samples

Sample ID	Coal Deposit	S2 mg/g	S3 mg/g	Tmax	TOC	S	HI	OI
LBI-001	Lafia-Obi	20.72	11.36	451	36.075	0.540	57.4	31.49
LBI-002	Lafia-Obi	19.57	10.85	451	36.05	0.493	54.2	30.10
LBI-003	Lafia-Obi	19.76	11.04	452	36.20	0.508	54.6	30.50
LBI-004	Lafia-Obi	20.56	10.71	451	34.90	0.498	58.9	30.69
LBI-005	Lafia-Obi	20.16	10.99	450	36.30	0.543	55.5	30.28
OGB-001	Ogboyaga	150.06	23.80	425	63.40	0.620	236.7	37.54
OGB-002	Ogboyaga	133.89	25.65	423	62.10	0.713	215.6	41.30
OGB-003	Ogboyaga	153.36	24.12	424	63.70	0.638	240.8	37.86
OGB-004	Ogboyaga	154.59	24.05	424	64.00	0.663	241.5	37.58
OGB-005	Ogboyaga	153.44	24.28	424	63.80	0.636	240.5	38.06
OKB-001	Okaba	170.92	12.14	421	62.90	1.280	271.7	19.30
OKB-002	Okaba	174.84	12.11	420	62.80	1.080	278.4	19.28
OKB-003	Okaba	178.08	12.05	423	62.90	1.180	283.1	19.16
OKB-004	Okaba	177.36	12.14	419	63.10	1.080	281.1	19.24
OKB-005	Okaba	174.95	12.22	419	63.20	1.100	276.8	19.34
OML-001	Omelehu	92.73	13.47	421	45.00	0.639	206.1	29.93
OML-002	Omelehu	123.78	14.11	420	52.50	0.794	235.8	26.88
OML-003	Omelehu	111.62	13.49	423	48.90	0.753	228.3	27.59
OML-004	Omelehu	103.76	13.71	423	46.60	0.713	222.7	29.42
OML-005	Omelehu	112.42	13.63	422	48.70	0.736	230.8	27.99
OWU-001	Owukpa	93.23	8.03	426	39.55	0.374	235.7	20.30
OWU-002	Owukpa	92.12	8.13	427	38.85	0.363	237.1	20.93
OWU-003	Owukpa	90.01	7.77	427	39.10	0.378	230.2	19.87
OWU-004	Owukpa	91.32	8.14	427	39.00	0.384	234.2	20.87
OWU-005	Owukpa	89.76	8.01	428	38.40	0.357	233.8	20.86

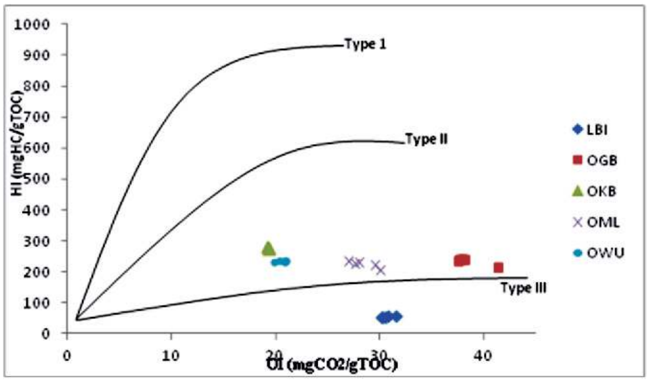

Fig 4: Van Krevalen plot [HI (mg HC/g TOC) over OI (^{o}C)] showing that the Kerogens are generally Type II & Type III

Interpretations from the Van Krevalen plot ranks Okaba, Ogboyaga, Omelehu, and Owukpa coals as transitional Type II / III while Lafia-Obi sample as Type III.

The HI versus Tmax plot of Obaje et al. (2004) show that coal deposits in the study area are predominantly immature (Fig 5) to generate either oil or gas although they possess relatively high HI. However these are surface to near surface samples; the scenario with respect to maturity may be different where they lie at deeper sections of the basin. The Lafia Obi coal on the other hand is mature at the current depth and falls in the gas window but has very low HI.

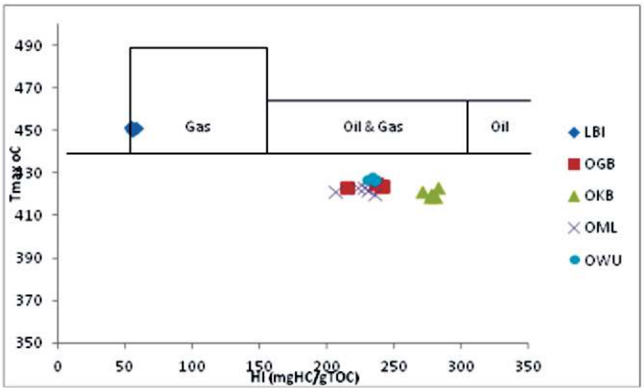

Fig. 5: HI (mg HC/g TOC) over Tmax (^{o}C) plot indicating the kerogen maturity and hydrocarbon proneness of coal deposits of the study area.

Combustion evaluation of coal deposits in the Middle

Benue Trough and Anambra Basin was also carried out to ascertain their combustion efficiency and results are presented in Table 2 below.

Table 2: Combustion efficiency test of coals from the study area

S/N	COAL DEPOSIT	TIME TO BOILING POINT (Minutes)
1	Okaba	10.00
2	Ogboyaga	10.35
3	Omelehu	11.37
4	Owukpa	13.22
5	Lafia-Obi	Did not bring to boiling point

Results show that Okaba coal is the most efficient with a boiling time of 10 mins.; followed by Ogboyaga coal (10.35mins), Omelehu coal (11.37mins) and Owukpa coal (13.22mins) while Lafia-Obi coal did not bring the water to boiling point. Although the evaluation did not record the volume of smoke produced, Okaba coals burned with minimal smoke emission (Fig. 6) while Ogboyaga coal burned with significant amount of smoke emission to turn the glass beaker black (Fig. 7).

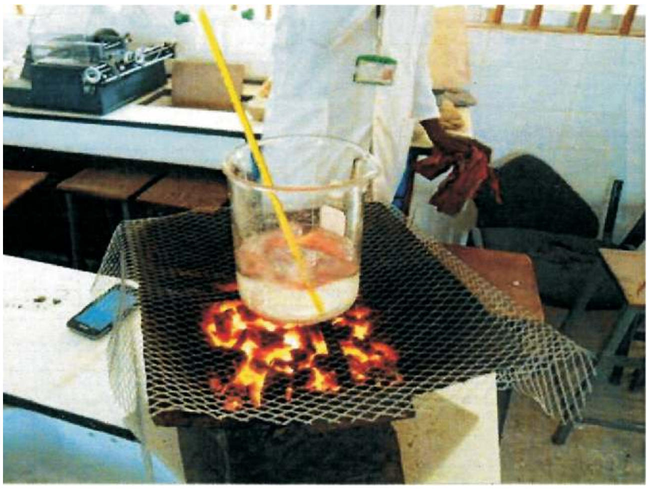

Fig. 6: Okaba coal combustion showing clean beaker with minimal smoke emission

Fig. 7: Ogboyaga coal combustion showing stained beaker (A) and significant smoke emission(B)

Generally, coals with high hydrogen index (HI) and low oxygen index (OI) combust efficiently with minimal smoke emission. Furthermore, high OI and sulphur content (S) in coal causes smoky combustion with negative impacts on the environment.

Okaba coal shows the best combustion attribute with relatively high HI and low OI as well as fast boiling time, while Lafia-obi coal shows the least combustion attribute of having relatively low HI as well as not been able to bring water to boiling point. Ogboyaga coal shows a relatively good combustion attribute (high HI) but possess a relatively high OI. This explains the smoky combustion illustrated in Fig. 7 above.

Integrating results above, Okaba coal has the best energy conversion efficiency and therefore is most suitable for use as industrial fuel in its present form with negligible negative impacts on man and the environment. Ogboyaga, Owukpa and Omelehu coal deposits can be harnessed for the extraction of bio-fuel due to their relatively high HI; thereby limiting environmental pollution from carbon dioxide and sulphuric gas emissions.

Conclusion

The geochemical properties and combustion attributes of coal deposits in the Middle Benue Trough and Anambra Basin have been assessed with the aim of proffering sustainable energy substitutes that are capable of ensuring energy mix, thereby reducing the epileptic power supply in the country. Results ranked Okaba coal deposit as the most suitable for clean energy generation due to relatively high HI and low OI. This is followed by the Ogboyaga, Owukpa, Omelehu and Lafia-Obi coal deposits.

The results further indicate that the some coal deposits in the study area can be harnessed and utilized in ensuring energy mix in the country, thereby addressing energy deficiency. This can be achieved through the construction of a processing plant at Okaba for the production of clean coal pellets and the development of a bio-fuel power plant in Ogboyaga to drive industries in the geo-political region.

References

Akande, S.O., and Erdtmann B.D. (1998). Burial metamorphism (thermal maturation) in Cretaceous sediments of the Southern Benue Trough and Anambra Basin, Nigeria. AAPG Bull 82: pp1191–1206.

Akande, S.O., Hoffknecht A., and Erdtmann, B.D. (1992). Rank and petrographic composition of selected Upper Cretaceous and Tertiary coals of Southern Nigeria. International Journal of Coal Geol Vol. 20: pp 209–224.

Akande, S.O., Ogunmoyero I.B., Petersen, H.I. and. Nytoft, H.P. (2007). Source rock evaluation of coals from the Lower Maastrichtian Mamu Formation, S.E. Nigeria. Journal of Petroleum Geology, Vol. 30(4), pp 303-324.

Benkhelil, J. (1989). The Origin and Evolution of the Cretaceous Benue Trough, Nigeria. Journal of African Earth Science Vol. 8:pp 251–282.

Geological Survey of Nigeria (1984). Geological Map of the Middle Benue Trough. GSN: Lagos, Nigeria.

Mohammed, Y. (2005). Predictive petroleum systems of prospective Anambra Basin, Nigeria. NAPE/AAPG.

Obaje, N.G. (1994). Coal Petrology, Microfossils and Palaeo-environments of Cretaceous Coal Measures in the Middle Benue Trough of Nigeria. Tubinger Mikropalaontologische Mitteilugen. Vol. 11: pp 1-150.

Obaje, N.G., Wehner, H., Scheeder, G., Abubakar, M.B., Jauro, A. (2004). Hydrocarbon prospectivity of Nigeria's inland basins: from the viewpoint of organic geochemistry and organic petrology. AAPG Bull. Vol. 87. Pp 325–353.

Obaje, N.G. (2009). Geology and Mineral Resources of Nigeria. Springer Dordrecht Heidelberg London New York, pp 158-162.

Obaje, N.G., Funtua I.I., Ligouis, B., and. Abaa, S.I. (1996). Maceral Associations, Organic Maturation and Coal-derived Hydrocarbon Potential in the Cretaceous Awgu Formation, Middle Benue Trough, Nigeria. Journal of African Sciences. Vol. 23: pp 89-94.

Offodile, M.E. (1976). The Geology of the Middle Benue Nigeria. Cretaceous Research, Paleontological Institute: University of Uppsala Special Publication. Vol. 4: pp 1-166.

Offodile, M.E. and Reyment, R.A. (1977). Stratigraphy of the Keana-Awe area of the Middle Benue Region of Nigeria. Geology of deltas. Postma G (eds) Vol. 19. pp 219–235.

Petters, S.W. (1986). Foraminiferal biofacies in the Nigerian rift and continental margin deltas.

Reijers, T.J.A. and Nwajide, C.S. (1998). Geology of the Southern Anambra Basin. Unpublished Report for Chevron Nigeria Limited. Field Course Note pp 66.

Reyment R.A. (1965). Aspects of the Geology of Nigeria. Ibadan University Press, pp 133.