Elemental Characteristics of some Nigerian Coal Deposits: Implications for the origin of the coals

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ABSTRACT

Forty coal samples (4 samples per deposit) from ten coal deposits that span over Anambra Basin and Benue Trough were sampled and analyzed for their elemental characteristics. These coal deposits include Onyema, Okpara, Ogboyoga, Okaba, Owukpa, Ibobo, Udane Biomi and Iva Valley in the Anambra Basin and Lafia Obi and Maiganga in the Benue Trough. The conventional Atomic Absorption Spectroscopic method of elemental analysis was employed in this study. The coals are depleted in V, Cr, Co, Ni, Cu, Zn; elements with no clear trend are Pb, W and Rb; those that are slightly enriched in the coals are P, K, Ti and Mn whilst elements that are highly enriched in the coals are Al, S, Ca, Fe and Si. The concentrations of the PHTEs could be reduced by coal washing and other appropriate coal cleaning methods or emission control measures in order to minimize their impacts on the environments and health.

1. INTRODUCTION

Nigerian coals were major source of power generation and income to the country before the advent of the oil boom in the early seventies when emphasis was shifted to oil (Obaje, 2009). This brought a nearly complete halt to research and continuous exploration and appreciation of the country's coal resources. However, with current dwindling power supply and decreasing reliance on oil all over the world, coal is positioned to regain its past glory in the energy mix of Nigeria but with its attendant environmental concerns in terms of usage. These reserves are in the excesses of three billion (3,000,000,000) tons of indicated reserves spread over seventeen coal fields and over six hundred million (600,000,000) tons of proven reserves (RMRDC, 2015). This shows that more new coal deposits are being discovered in the country and this trend must be matched with continuous and up to date analyses to determine the qualities of these coal deposits. These coal deposits and resources are spread over 13 states of the Federation but geologically restricted to the Benue Trough (Northern, Central-, and Southern-Benue Troughs) and the adjacent Anambra Basin. Some of the notable coal deposits in Nigeria include the Okaba, Owukpa, Inyi, Ogboyoga, Udane Biomi, Ibobo, Onyeama, Okpara, Iva Valley, Kwangshir-Jangwa along River Dep, Maiganga and Gidan Sidi Coal deposits. The concentration of elements in coal depends on the properties of their host rocks, environments of deposition, diagenetic activities and coalification processes, mineralization processes, as well as hydrological/hydrogeological conditions (Sia and Abdullah, 2011).

Consequently, the concentration of the elements can differ greatly between and within coal seams and coalfields. The elements contained in coal can generally be classified into three groups based on their concentrations: (1) major elements, with concentrations higher than 1000 ppm, consisting of the coal forming elements (C, H, O, and N) and S; (2) minor elements, with concentration between 100 and 1000 ppm, comprising the mineral matter forming elements (Si, Al, Ca, Mg, K, Na, Fe, Mn and Ti) and halogens (F, Cl, Br, I); and (3) trace elements, with concentrations below 100 ppm (Sia and Abdullah, 2011).

In this study, we determined the concentrations of elements in ten Nigerian coal deposits. The elements determined are mostly the potentially hazardous trace elements (PHTEs) with the aim of assessing the environmental and health impacts of the coals' usage. This will facilitate the use of the coals in an environmentally-friendly manner through (a) selective mining and utilizations to avoid coal deposits with high concentrations of PHTEs, (b) coal cleaning processes to remove the inorganically associated PHTEs, and/or (c) the installation of emission control devises (Sia and Abdullah, 2011).

2. GEOLOGICAL SETTING OF BENUE TROUGH AND ANAMBRA BASIN

2.1. The Benue Trough

The Benue Trough is one of the Nigeria's inland basins that are bounded in the north by the Chad basin and in the south by the Bida Basin (Figure 1). The Benue Trough is a fundamental tectnosedimentological feature in the evolution of the Cretaceous and Tertiary geology of Nigeria (Nwajide, 2013). The trough is a part of the extensive West and Central Africa plate consequent upon the initiation of proto-equatorial Atlantic (Nwajide, 2013). According to Nwajide, 2013, the precise bounds and dimensions of the Benue Trough are yet to be accurately determined and defined. This he attributed to the burial of its limits under the younger basins, the Anambra and the Niger Delta basins in the South-West and the Chad basin in the North East. Also theco-existence and continuity of the Trough's structures with those of the Niger Republic's basin (Termit basin) to the North added to the complicity of determining the Northern boundary and dimension of the Benue Trough (Figure 2).

The Trough can be arbitrarily taken to extend to and terminate at the right angular bend into the Termit Basin in Niger Republic and this will make an estimated total length of the Trough in Nigeria to be roughly 1,300km and an estimated narrowest and broadest width of 125km at the immediate SouthEast of the Jos Plateau and 250km across Auchi to Gboko axis respectively (Nwajide, 2013). In the Northeastern part where the Trough bifurcates into two arms (the Northern Gongola arm and the Southern Yola arm), the width of the trough is estimated at over 200km. the sediment thickness across the trough range from 5km in the Northeast to over 12km in the Southwest.

Nwajide (2013) has adopted the Northern, Central and Southern segments as the subdivisions for the Benue Trough as against the hither to Upper, Middle and Lower Benue Trough used by previous authors. The gross characteristics of the Trough are defined by its structural orientation, configuration and the inherent lineaments.

Various theories that culminated into the origin of the Trough have been summarized and discussed by several authors (Nwachukwu, 1972; Wright *et al*, 1985; Wright, 1989; Genik, 1992; Obaje, 2009; Nwajide, 2013). According to these authors, two geologic events viz, the rift fault system and plate tectonics were postulated for the origin of the Benue Trough. The stratigraphic successions of the Benue Trough have been identified and described on the basis of the three-fold subdivisions of the trough as shown in Figure 3.

Coal resources within the Benue Trough are stratigraphically restricted to the Mamu, Ajali and Nsuka formations, Lafia Formations and the Gombe Formation of the Southern, Central and Northern Benue Trough segments respectively.

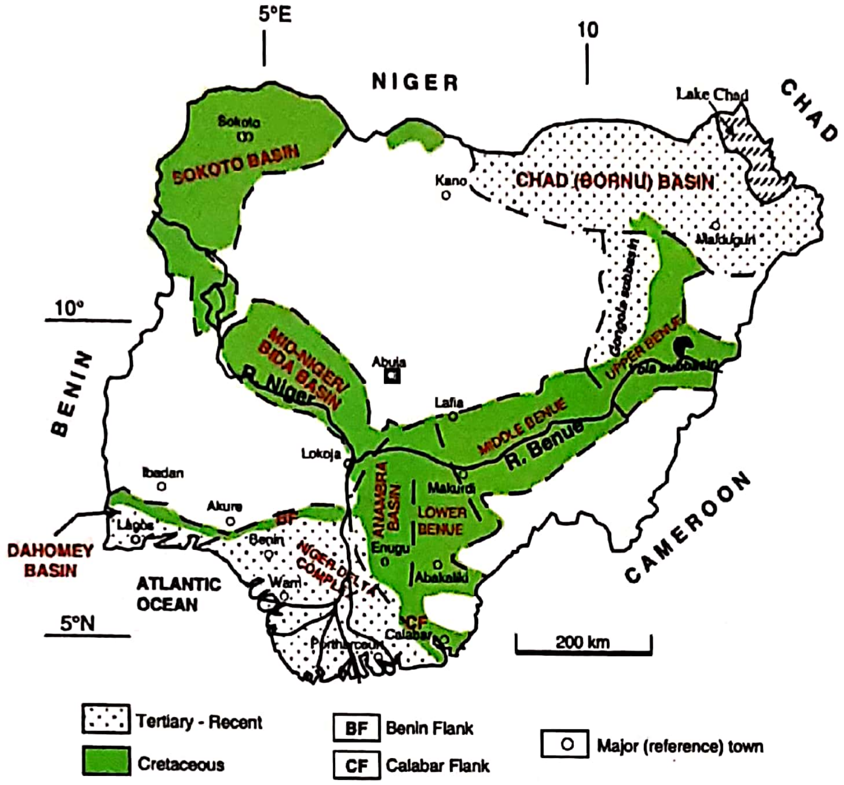

Figure 1: Sedimentary basins of Nigeria (Adopted from Obaje, 2009).

2.2. The Anambra Basin

Nwajide (2013) and Wright *et al.* (1985) defined the Anambra Basin as "the upper Senonian-Maastrichtian to Paleocene depositional area located at the Southern end of the Benue Trough, within which the Nkporo Group and younger sediments accumulated, and which extended towards the Southwest as the Niger Delta Basin". This definition is both geologic and geographic and it refers to the sediments-filled area between the southernmost end of the Benue Trough and the Northern end of the Niger Delta. There seems to be a sort of sedimentological continuity among the three interrelated basins, their respective different lithological characteristics notwithstanding (Figure 4).

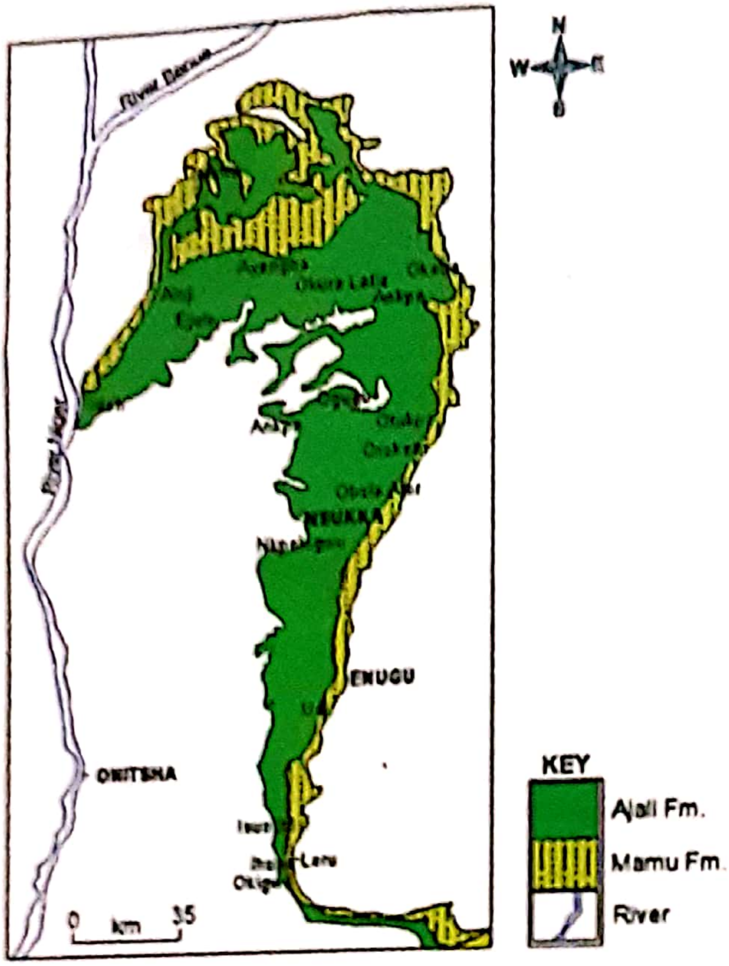

Figure 4: Geological map of Anambra Basin (Adopted from Chiaghanam *et al.*, 2013)

Stratigraphically, the Anambra Basin consists of the uppermost coal measures which are made of the Nsukka, Ajali and Mamu Formations, underlain by the Awgu Formation (Chiaghanam *et al.*, 2013).

2.3. The Coal Measures

The Nigerian coals are sub-bituminous (black coals) of Cretaceous age and lignites (brown coals) of Tertiary age (Nigerian Geological Survey Agency, NGSA bulletin, 2nd edition, 1987). However, the coal deposit at Obi, near Lafia in Nasarawa state has been described as coking coal. Generally, the quality of a coal depends largely on its geological age, hence the Nigerian coals and lignites which are dated Cretaceous to Tertiary age are believed to be of poorer quality than the older Carboniferous coals of Europe and America. The black coals occur in strata of two different ages in the Lower and Upper Coal Measures and are almost entirely restricted to the Benue Trough and the Anambra basin of Nigeria. The Upper Coal Measures are hosted by the Nsukka Formation while the Lower Coal Measures are hosted by the Mamu Formation.The Mamu Formation consists of alternations of sandstones, siltstones, mudstones, coal seams and rare shales. This is overlain by the Ajali Formation which is mainly sandstone. The Ajali Formation is in turn overlain by the Nsukka Formation typically comprising of sandstones, blackshales, coal, mudstones and marine limestones. The coals of the lower measures are of medium quality, non-coking and sub-bituminous. They are excellent for gas making and produces high tar-oils, self-binding under pressure, suitable for production of liquid fuels. Conversely, the coals of the upper measures are thinner and of poorer quality.

3. MATERIALS AND METHODS

3.1 Field Work and Samples Collection

During field work, ten coal locations were selected within the country for this study. The ten locations were chosen to cover the whole length of Benue Trough and parts of the Anambra basin. Coal samples from Ibobo, Udane-Biomi and Odu-OkpalakiAfe (Ogboyoga) (Kogi State), Iva Valley and Okpara (Enugu State) were obtained from coal seams exposed on the field either along river banks and/or beds, or in areas where the coal seams or beds have been exposed by erosion. Samples from Onyema (Enugu State), Owukpa (Benue State) and Kwaghshir (Lafia-Obi) (Nassarawa State) were obtained from old and abandon coal mines while in Okaba (Kogi State) and Maiganga (Gombe State) the samples were obtained from the recent mine sites.

Four representative coal samples were obtained at each of the ten study sites with the aid of a geological hammer. The sampling was done randomly but in areas where the coal seams were well exposed as in Maiganga, the samples were collected at the various coal seams seen in the mine site. During the sampling, a bulk sample of about 300g each of coal was collected from four points within each of the study areas. The samples collected were sealed in polythene bags and were subsequently transferred into polyvinyl chloride (PVC) canisters and labeled appropriately for later transport to the laboratory for the various analyses. The coordinates and elevations of the sampling locations were taken with an Etrex Garmin model of GPS (Global Positioning Satellite). Coal samples were collected from freshly exposed mine faces (at Maiganga, Okaba, Ibobo), exposed seams as a result of weathering (at Ogboyoga, Onyema, Iva Valley, Udane Biomi and Okpara) and core samples at Lafia Obi coal deposits. Location maps of the coal deposits were prepared from the GPS coordinates using ArcGis version 10.2.2.

3.2 Laboratory Analyses

Pulverized coal samples were analyzed for trace and major elements. The detailed procedures for the samples preparation for the analysis are described thus. A 5.00g of each sample was weighed and kept in a dried clean conical flask. The samples were digested in different ratio of acid mixtures (5ml HNO3, 3ml HClO4 and 2ml HF). They were placed on hot plates for some minutes and were later transferred to the fume cupboard where they remained for overnight. The cooled solutions were made up to 100ml in volumetric flasks with de-ionized water and were later stored in the refrigerator prior to the elemental analysis using Atomic Absorption Spectrophotometry with a Perkin Elmer 3110 instrument. Absorbances were read in quadruplets for reproducibility. The elemental analysis was carried out at the Engineering Materials Development Institute (EMDI) of National Agency for Science and Engineering Infrastructure (NASENI), Akure, Nigeria.

4. RESULTS AND DISCUSSION

4.1Field Results

Forty coals samples (four per sample site) obtained from ten coal deposits were used for the various analyses carried out in this study (Figure 5). The coal samples were obtained from the various coal fields (active and non-active mining) spread across the Nigerian coal-bearing sedimentary facies.

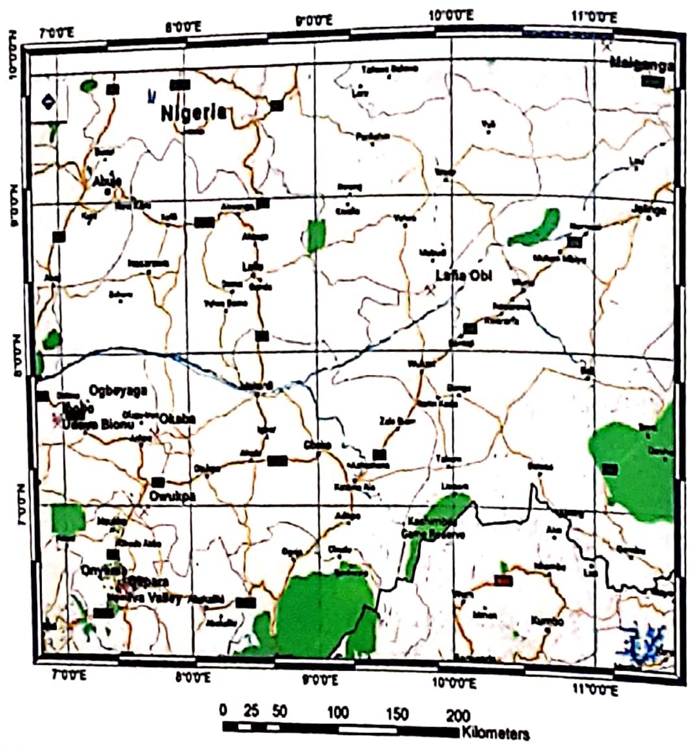

Figure 5: Location map of the coal fields where samples were taken for the study

Table 1: Information on the coal sampling points (sample origin, latitude and longitude)

Coal Deposit	Sample origin	Latitude	Longitude
Ibobo	Run-off-mine	N 07 33 01.1	E 006 57 15.5
Udane Biomi	River channel	N 07 34 51.2	E 006 57 07.5
Ogboyoga	River bank	N 07 40 15.2	E 007 10 26.1
Okaba	Mine face	N 07 28 43.2	E 007 43 33.9
Owukpa	Abandoned mine	N 06 58 04.9	E 007 38 04.9
Onyema	Coal outcrop	N 06 28 19.9	E 007 26 43.2
Okpara	Coal outcrop	N 06 24 00.2	E 007 27 05.5
Iva Valley	Coal outcrop	N 06 27 02.0	E 007 27 09.2
Maiganga	Mine face	N 09 57 08.1	E 011 05 15.2
Lafia Obi	Core sample	N 08 23 13.2	E 009 50 39.9

The coal deposits where the samples were obtained are Lafia Obi, Okpara, Onyema, Okaba, Maiganga, Udane Biomi, Ibobo, Owukpa, Iva Valley and Ogboyoga. The samples are grab samples (Ibobo and Owukpa coals), channel samples (other coals deposits) except for Lafia Obi coal where core samples were obtained from the Nigerian Coal Corporation site office at Obi, Nasarawa State (Table1).

4.2 Elemental concentrations of the coals

The results of the trace elements analysis are shown in Table 2. The results revealed that the concentrations of Mg, As and Au were not detected in all the coal samples whereas Ag was below the detection limit. Hence, these elements were excluded from the statistical analyses, and not discussed subsequently in this thesis.

Researches have shown that coals can contain 76 of the 92 naturally occurring elements of the periodic table (Schweinfurth, 2003, Sia and Abdullah, 2011). According to Sia and Abdullah, 2011, the concentration of elements in coal depends on the properties of the country rocks, depositional environments, diagenesis and coalification processes, syngenetic and epigenetic mineralization as well as hydrological and hydrogeological conditions. Hence, the concentration of the elements can vary both intra and inter coal seams and coal deposits. There are three basic classes of elemental concentrations in coals: (1) major elements, usually with concentrations higher than 1000 ppm (0.1 wt. %), (2) minor elements, usually with concentrations between 100 to 1000 ppm (0.01 to 0.1 wt. %) and (3) trace elements, usually with concentrations below 100 ppm (0.01 wt. %) (Sia and Abdullah, 2011). In coal, the major elements include the coal forming elements (C, H, O and N) and S. The minor elements include the mineral matter forming elements (Si, Al, Ca, Mg, K, Na, Fe, Mn, and Ti) and halogens (F, Cl, Br, I). The major elements are treated under the ultimate characteristics of the coals in this study. Hence, in this study, all elements with concentrations within the range of 0.01 wt.% to above 0.1 wt.% are considered and discussed as minor elements while those of elements with concentrations below 0.01 wt.% are regarded and discussed as trace elements.

Table 2: Average elemental characteristics of the coals (wt %)

Minor Elements	LAFIA OBI	ONYEM	OKABA	MAIGANGA	UDANEBIOMI	OKPARA	OKOBO	WUKP	IVA VALLEY	OGOBYOGA
Mg	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Al	8.71	1.63	5.17	5.17	5.17	4.29	4.95	4.89	4.83	4.74
Si	26.35	2.28	14.32	14.32	14.32	11.31	13.57	13.38	13.14	12.85
P	0.28	0.13	0.21	0.21	0.21	0.19	0.21	0.20	0.20	0.20
S	1.24	6.30	3.77	3.77	3.77	4.40	3.92	3.96	4.01	4.07
K	1.60	0.05	0.83	0.83	0.83	0.63	0.78	0.76	0.75	0.73
Ca	7.23	0.06	3.64	3.64	3.64	2.75	3.42	3.36	3.29	3.23
Fe	18.45	0.71	9.58	9.58	9.58	7.36	9.03	8.89	8.72	8.50
Trace Element										

Ti	0.23	0.01	0.12	0.12	0.12	0.09	0.11	0.11	0.11	0.11
V	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cr	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mn	0.34	0.00	0.18	0.18	0.18	0.13	0.17	0.16	0.16	0.16
Co	0.13	0.00	0.07	0.07	0.07	0.05	0.06	0.06	0.06	0.06
Ni	0.06	0.10	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08
Cu	0.05	0.90	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07
Zn	0.09	0.14	0.11	0.11	0.11	0.12	0.12	0.12	0.12	0.12
As	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pb	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
W	0.03	0.01	0.02	0.02	0.02	0.02	0.02	0.025	0.02	0.02
Au	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ag	bdl	Bdl	bdl	Bdl	bdl	Bdl	Bdl	Bdl	Bdl	Bdl
Rb	0.06	Bdl	0.03	0.03	0.03	0.02	0.03	0.03	0.03	0.03

Table 3: Enrichment/depletion ranking of the minor and trace elements of the studied coals

Enrichment/Depletion factor (EDF) Limit	Explanation	Elements
Elements <0.1	Depleted	V, Cr, Co, Ni, Cu, Zn,
Elements 0.1-2	No trend	Pb, W, Rb
Elements 2.0-10	Slightly enriched	P, K, Ti, Mn
Elements >10.0	Highly enriched	Al, S, Ca, Fe, Si

Note: - < - less than; > - greater than (Modified after Onyemali *et al*., 2017)

From Table 3, the coals are depleted in V, Cr, Co, Ni, Cu, Zn; elements with no clear trend are Pb, W and Rb; those that are slightly enriched in the coals are P, K, Ti and Mn whilst elements that are highly enriched in the coals are Al, S, Ca, Fe and Si.

3.4.1 Geochemistry of the Elements

(i) Aluminum

The Al concentrations of the analyzed coals in wt.% are Lafia Obi (8.71), Onyema (1.63), Okaba (5.17), Maiganga (5.17), Udane Biomi (5.17),Okpara (4.29), Ibobo (4.95), Owukpa (4.89), Iva Valley (4.83) and Ogboyoga (4.74). These Al concentrations for the coals are considered relatively high compared with that of the world average of 1 wt% Al contents for coals. Lafia Obi recorded the highest Al content and progressively followed by Maiganga, Udane Biomi and Okaba with equal values of Al, Ibobo, Owukpa, Iva Valley, Ogboyoga, Okpara and Onyema with the least concentration of Al (Table 2). High Al in coals is related to the presence of clay minerals (Sia and Abdullah, 2011). This suggests that clay minerals make up substantial portion of the constituent minerals that make up the coals.

(ii) Potassium

The K concentrations of the analyzed coals in wt.% are Lafia Obi (1.60), Onyema (0.05), Okaba (0.83), Maiganga (0.83), Udane Biomi (0.83),Okpara (0.63), Ibobo (0.78), Owukpa (0.76), Iva Valley (0.75) and Ogboyoga (0.73). The K content of all the analyzed coals are higher than that of the world average K content of 0.01 wt.% in coals. Lafia Obi coal recorded the highest variation of K from the average world K content of coals while the other analyzed coals have slightly higher variations from the world K contents for coals. Higher K concentrations in coals are due to the enrichment of mixed layer clay in the coals as opposed to the enrichment of kaolinites in most of the world coals (Vassilev and Vassileva, 1996, Sia and Abdullah, 2011).

(iii) Iron

The Fe concentrations in the analyzed coals are Lafia Obi (18.45), Onyema (0.71), Okaba (9.58), Maiganga (9.58), Udane Biomi (9.58),Okpara (7.36), Ibobo (9.03), Owukpa (8.89), Iva Valley (8.72) and Ogboyoga (8.50). The Fe contents of the analyzed coals are higher than the world average Fe content on coal except for the Onyema coals with lesser Fe content than 1 wt.% which is the world average. Iron in coals exist in various forms e.g. Fe sulphides, (pyrite and marcasite), Fe carbonates e.g. siderite and ankerite, Fe -bearing clays, Fe sulphates e.g. ferrous sulphate and jarosite and organically bound Fe (Wang *et al.*, 2008, Sia and Abdullah, 2011). This element is highly enriched in the analyzed coals (Table3).

(iv) Calcium

Concentrations of Ca in the analyzed coals are Lafia Obi (7.23), Onyema (0.06), Okaba (3.64), Maiganga (3.64), Udane Biomi (3.64),Okpara (2.75), Ibobo (3.42), Owukpa (3.36), Iva Valley (3.29) and Ogboyoga (3.23) wt.% as against the 1 wt.% world average for Calcium in coals (Table 4.6). The Ca concentrations in all the coals except Onyema are considerably higher than that of the world average of 1 wt%. The higher Ca content suggests that these coals were deposited in mire supplied by calcium-rich water (Stach *et al.*, 1982, Sia and Abdullah, 2011). Ca in coals can either be organically or inorganically bonded.

(v) Vanadium

Vanadium (V) is not listed among the PHTEs nor as a regulated constituents of coals by the US Public law, 1990 and the US EPA,1976 (Sia and Abdullah,2011). This element can however be leached from coal ash and constitute adverse health and environmental impacts. According to Sia and Abdullah, 2011, there has not any report of adverse health or environmental impacts of V contained in coal or coal ash. Anomalous V content has been reported in coals from Western Kentucky and Guangxi province, Zhijin, Guizhou, Yanshan, Yunnan in China without any cases of adverse impacts from their mining and usage (Sia and Abdullah, 2011). Vanadium is depleted in the analyzed coals (Table3).

(vi) Chromium

Chromium (Cr) is listed as one of the PHTEs as well as regulated constituents of coals by the US Public law, 1990 and the US EPA,1976 (Sia and Abdullah,2011). Though, there has so far been little evidence of adverse effects from the element in coal mining and utilization (Swaine, 1990), Ren *et al.* (2004) reported that the lung cancer in the Shengbei coalfield of China was associated with high Cr and other toxic trace elements in lignite. Chromium is also depleted in the analyzed coals (Table3).

(vii) Manganese

Although Manganese (Mn) is listed as one of the PHTEs, there is no reported health or environmental problems from Mn in coals (Sia and Abdullah, 2011). Mn in coal is usually associated with carbonate minerals, particularly with iron carbonate (Sia and Abdullah, 2011). Manganese and Mg are known to substitute for Fe in siderite ($FeCO_3$) forming a complete solid solution between siderite and rhodochrosite ($MnCO_3$) and between siderite and magnesite ($MgCO_3$) (Sia and Abdullah, 2011). Table 3 shows that the manganese has no clear trend in terms of enrichment/depletion.

(viii) Nickel

Nickel (Ni) is depleted in the analyzed coals. Despite being listed among the PHTEs, there has been no reported health or environmental problems associated with Ni in coal mining and utilization (Swaine, 1990). The modes of occurrence of Ni in coals are still skeptical and not well understood, previous works suggests the association of Ni with clays, carbonates, sulphides, as well as organically bound Ni (Sia and Abdullah, 2011). Ni is depleted in the analyzed coals (Table 3).

(ix) Copper

Copper (Cu) is neither a PHTE nor a regulated constituent of coal (US Public law, 1990, US EPA, 1976, Sia and Abdullah, 2011). Cu is depleted in the analyzed coals. The trace element is not of environmental and health treats because it is depleted in the coals. Cu occurs in coal mostly as chalcopyrite ($CuFeS_2$) and can either be inorganically or organically bounded to coals.

(x) Zinc

Zinc (Zn) is not listed as PHTE and also not a regulated constituent of coal (US Public law, 1990, US EPA, 1976, Sia and Abdullah, 2011). It has not been documented that Zn poses any deleterious health or environmental impacts from its usage (Swaine, 1990). Table 3 shows that Zn is depleted in the analyzed coals and has been reported to constitute no environmental or health hazard because of its low toxicity (Sia and Abdullah, 2011). Zinc is usually present in coals as sphalerites (ZnS).

(xi) Lead

Lead (Pb) is both a PHTE and a regulated constituent of coal as solid wastes (Sia and Abdullah, 2011). The dispersion range of lead is wide and varies from 0.01 to 0.02 in the analyzed coals

(Table 2). It is depleted in the analyzed coals which imply that its content in the coals may constitute little or no health or environmental problem as a result of the coals' usage. Lead occurs mainly as sulphides minerals such as galena (PbS), selenide (PbSe) and crocoite ($PbCrO_4$).

5. CONCLUSION

The ten major Nigerian coals are situated within the Benue Trough and Anambra Basin.The depleted elements in the analyzed coals are V, Cr, Co, Ni, Cu, Zn, Pb, W and Rb, elements with no clear trend are P, K, Ti and Mn, those that are slightly enriched in the coals are Al, S and Ca whilst elements that are highly enriched in the coals are Fe and Si. The concentrations of the PHTEs could be reduced by coal washing and other appropriate coal cleaning methods or emission control measures in order to minimize their impacts on the environments and health.

REFERENCES

Chiaghanam, O.I., Chiadikobi, K.C., Ikegwuonu, O.N., Omoboriowo, A.O., Onyemesili, O.C., Acra E.J., (2013). Palynofacies and Kerogen Analysis of Upper Cretaceous (Early Campanian to Maatrichtian) Enugu Shale and Mamu Formation in Anambra Basin, south-eastern, Nigeria

Genik, G.J. (1992). Regional Framework, Structural and Petroleum aspects of Rifts Basin in Niger, Chad and the Central African Republic (CAR). *Tectonophysics*, Elsevier. ISO 1172. *Journal of Mining and Geology*, 44, 11–18.

Nigerian Geological Survey Agency, NGSA bulletin, 2nd edition, 1987

Nwajide, C. S. (2013). Geology of Nigeria's Sedimentary Basins. CSS Bookshop LTD., Lagos, 1 – 565

Obaje, N. G. (2009). Geology and Mineral Resources of Nigeria. Springer Dordrecht Heidelberg London New York, 221 pp.

Onyemali, P.I., Onoduku, U.S.and Ogunbajo, M.I. (2017). Proximate and Ultimate characteristics of Okobo coal Deposit, Kogi state, North Central Nigeria. Research Journal of the Department of Geology, Federal University of Technology, Minna, Nigeria. *Minna Journal of Geosciences, Vol. 1, No 2,* pp. 124-139.

Nwachukwu, S.O. (1972). The Tectonic Evaluation of the Southern Portion of the Benue Trough. *Geological Magazine*, 109(5), 411-419.

Raw Materials Research and Development Council (RMRDC), 2015.

Ren, D., Xu,d., Zhao, F.(2004). A preliminary study on the enrichment mechanism and occurrence of hazardous trace elements in the Tertiary lignite from the Shenbei coalfield, China. International Journal of Coal Geology 57, 187-196.

Schweinfurth, S.P. (2003). Coal-a complex natural resource, an overview of factors affecting coal quality and use in the United States. U.S. Geological Survey Circular, 1143 (39 pp).

Sia, S. and Abdullah, W.H. (2011). Concentration and association of minor and trace elements in Mukah coal from Sarawak, Malaysia, with emphasis on the potentially hazardous trace elements. International journal of coal Geology 88 (2011), pp.179-193

Stach, E., Mackowsky, M.Th., Teichmuller, M., Taylor, G.H., Chandar, D. and Teichmuller, R. (1982). Stach's textbook of coal petrology, 3rd edition, Gebruder Borntraeger, Berlin, 535pp.

Swaine, D.J. (1990). *The Contents and Some Related Aspects of Trace Elements In Coals*. London, Springer Butterworths, 278p.

US EPA (1976). Subtle D of Resource Conservation and Recovery Act.

US Public law (1990). Clean Air Act Amendments of 1990 Public Law, pp. 101-549 (441 pp.).

Vassilev, S.V. and Vassileva, C.G. (1996). Occurrence, abundance and origin of minerals in coals and coal ashes, Fuel Processing Technology 48, pp. 85-106

Wang, X., Xu, C. & Zhu, J. (2008). Graphene-metal Particle Nanocomposites. *The Journal of Physical Chemistry,* C, - ACS Publications

Wright, J.B., Hastings, D.A. & Williams, H.R. (1985). *Geology and Mineral Resources of West Africa*. London, George Allen and Unwin, 187p.

Wright, J.B. (1989). Review of the Origin and Evolution of Benue Trough in Nigeria. In: C. A. Kogbe (ed) Geology of Nigeria, A Standard Test Method for Gross Calorific Value of Coal and Coke. Rock View (Ltd) Nigeria, 359 – 364.