EOCENE-OLIGOCENE STRATIGRAPHY AND INDUSTRIAL POTENTIALS OF LIGNITE DEPOSITS IN ANAMBRA STATE, NIGERIA.

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Abstract

The stratigraphy and geochemistry of the Eocene-Oligocene Ogwashi-Asaba Formation were studied to assess the industrial potentials of its lignite deposits in Anambra State, Nigeria. Methodology involved fieldwork and laboratory analysis. The analyses included proximate, ultimate and X-ray diffraction studies. Five lignitic seams were observed at different stratigraphic levels of the formation. Seam 1 is the lowest seam and includes lignites from Akpuchara and Ekulo streams at Oba, Enem, Ejighioku and Oruru streams at Oraifite, Obiakoloma, Amaiyi and Eze streams at Nnewi. The average moisture, dry ash, volatile matter and fixed carbon contents for seam 1 are respectively 17.20%, 25.64%, 31.84% and 25.12%. The average Carbon (C), Hydrogen (H), Nitrogen (N), Oxygen (O) and Sulphur (S) contents for seam 1 are respectively 35.91%, 2.99%, 1.51%, 9.10% and 0.12%. The calorific value of seam 1 ranges from 582.23 kcal/kg to 4583.79 kcal/kg (2.44-19.19 MJ/kg) with an average value of 3209.13 kcal/kg (9.77 MJ/Kg). Seam 2, 3, 4, 5 are lignites from Oduga stream, Anthill section, Ofala stream and Nneoru stream respectively. The moisture, dry ash, volatile matter and fixed carbon contents for seam 2 are respectively 6.10-11.40%, 63.40-67.60%, 15-19.70% and 6.6-9.83%. The C, H, N, O and S contents for seam 2 are 5.50%, 3.91%, 1.44%, 13.84% and 0.75%. The calorific value of seam 2 is between 1.281.55 and 1322.42 kcal/kg (5.37-5.54 MJ/Kg). Seam 3,4,5 are very thin lignite beds of less economic importance even though their calorific values vary between 984 kcal/kg and 3082.92 kcal/kg (4.12-12.91MJ/Kg). The lignites from the Eocene-Oligocene Ogwashi-Asaba Formation have potentials for use in thermal power generation, household and other industrial uses.

Keywords: ***Anambra lignite, Ogwashi-Asaba, Proximate Analysis, Ultimate Analysis, Caloric values***

1.1. Introduction

Coal, lignites, tar sand, petroleum and natural gas constitute Nigeria's fossil fuel resources. Coal including lignite is a hard, combustible sedimentary rock consisting mainly of elemental carbon (Ullah *et al* 2019), that formed from the decay of trees, bushes, ferns, mosses, vines and other forms of plants (Cheepurupalli and Anuradha 2019). Conversion of this plant to coal occurs due to the prolonged action of bacteria, fungi, temperature and pressure. Petroleum and natural gas are presently the focus of Nigeria's exploration and exploitation efforts whereas its abundant coal and lignite resources are largely neglected, unexploited and contribute little or nothing to the country's energy mix. Coal can be differentiated into two classes; low rank coals including lignite and sub-bituminous and high rank coals such as bituminous and anthracite. This subdivision is based on color, calorific values, and other factors such as moisture contents, ash contents and sulfur contents, etc. Lignite is usually brown in colour and is the lowest rank of coal. It is used mainly in electricity generation (Ullah *et al* 2019). Lignites constitute an enormous fossil fuel resource in several countries such as China, Greece, India, Germany, Slovenia, Turkey and Poland where it is used for commercial power generation, household and for industrial purposes.

Numerous works have discussed the occurrence, areal extent and economic importance of the lignites of the Ogwashi-Asaba Formation. The mineral survey of Nigeria discovered the lignites of Ogwashi-Asaba Formation between 1907 and 1908. Parkinson (1907) referred to the Ogwashi-Asaba Formation as the "lignite series, whereas in 1925, Wilson called it the "Lignite Group". Other pioneering discussions on the formation include the works of Du Preez (1945; 1946), Simpson (1955), De Swardt and Piper (1957), Short and Stauble (1967) and Okezie and Onuogu (1971; 1985). Reyment (1965) formalized the name to Ogwashi-Asaba Formation.

Obaje *et al* (2004) and Akande (1986) described Nigeria's coal and lignite resources as being large with indicated reserves of 2.75 billion tons and 70 million tons respectively. Orajaka *et al* (1990) and Ministry of Mines and Steel Development of Nigeria (MOMSD) (2007) suggested Nigerian lignite deposit as being the largest in Africa with proven reserves of more than 300 million tonnes. In southeastern Nigeria, coals occur in the Upper Cretaceous formations in the Anambra Basin, whereas lignites abound in the Tertiary sediments of the Niger Delta Basin. The lignite occurs within the Ogwashi-Asaba Formation. Reyment (1965) described the Ogwashi-Asaba Formation as consisting of white-pinkish clay, cross-bedded sandstones, carbonaceous black shale, lignite and coal. Whiteman (1982) described the lignite zone in southeastern Nigeria as a narrow belt of about 10 miles wide and 150 miles long trending northwest-southeast from the Niger in the west to the Nigerian-Cameroun frontier, east of Calabar. The lignite deposit stretches from Edo through Delta, Anambra, Imo, Akwa-Ibom and Cross River States.

Studies on the lignite-bearing Ogwashi-Asaba Formation are concentrated on environment of deposition and age (Okezie and Onuogu, 1985; Oboh-Ikhuenobe *et al*, 2005; Jan du Chene , 1978), petrographic classification (Akande *et al*, 1992), stratigraphic analysis (Bassey and Eminue, 2012; Onyekuru *et al* 2019), provenance and depositional settings (Acra *et al* 2014; Ejeh *et al*, 2015), source rock potential and thermal maturity (Olobaniyi and Ogala, 2011; Ogala, 2011; Akande *et al*, 2015, Okeke and Umeji, 2018). Others focused on geochemical studies (Nwadinigwe, 1982; Okezie and Onuogu, 1985, Ogala, 2012) and industrial applications (Ahiarakwem and Opara, 2012). Apart from Ahiarakwem and Opara (2012) who discussed geochemical properties and industrial applications of the lignites in the Orlu area, all other geochemical studies are localized, and only discussed the geochemistry of the lignites or its source rock potential and thermal maturity status. The present study discusses the stratigraphy, geochemistry and industrial potentials of the lignite deposits in Anambra State as a major contributor in industrial and domestic energy source in the Nigerian energy mix.

2.1. Geological Setting

The study area lies within the Paleocene-Quaternary Niger Delta Basin of south-eastern Nigeria (Nwajide, 2013) and covers an area of about 352 km^2. It is bounded by Latitudes 5° 46'N and 6° 06'N and Longitudes 5° 57'E and 7° 00'E (Fig. 1). Table 1 summarizes the Niger Delta

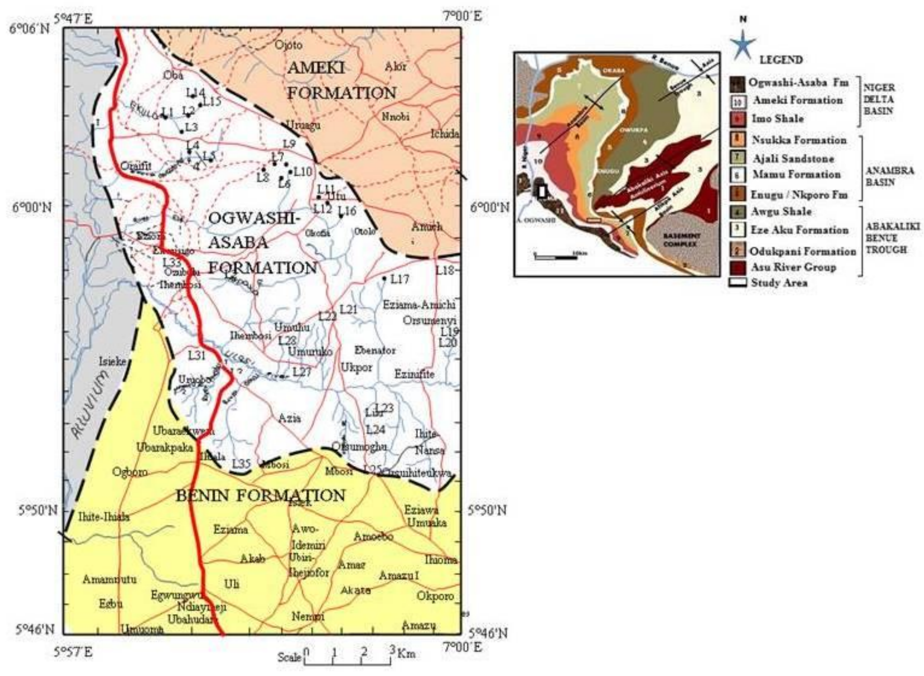

Fig. 1: Geologic map of the study area. Lignite outcrop locations are serially numbered

succession. In the present study area the outcropping formations include the Eocene Ameki Group (including the Ameki Formation, Nanka Sands, and Nsugbe Sandstone of Nwajide, 1979; 2013), the Upper Eocene-Oligocene Ogwashi-Asaba Formation and the Benin Formation (Miocene-Recent).

Table 1. Correlation of subsurface formations in the Niger Delta with their outcropping equivalents (After Short and Stauble, 1967; Avbovbo, 1978)

Age	Surface	Subsurface
Miocene-Recent	Benin Formation	Benin Formation
Upper Eocene- Oligocene	Ogwashi-Asaba Formation	Upper Agbada Formation
Mid-Lower Eocene	Nanka/Ameki Formation	Agbada Formation
Paleocene	Imo Formation	Akata Formation

In the sub-surface the Ameki Group and the Ogwashi-Asaba Formation are represented by the Agbada Formation (Short and Stauble, 1967; Avbovbo, 1978). The Ogwashi-Asaba Formation consists of alternation of coarse-grained sandstone, lignite seams, and light coloured clays (Kogbe, 1976).

Previous studies (e.g. Reyment, 1965; Murat, 1972; Nwajide and Reijers, 1996) have shown that the Niger Delta Basin resulted from Paleocene sea level rise which halted the filling of the Anambra Basin and ushered in the accumulation of the Imo Formation. The succeeding regression resulted in the formation of the overlying Ameki Group, Ogwashi Asaba and Benin Formations (Reyment, 1965; Murat, 1972; Nwajide and Reijers, 1996). The stratigraphic correlation for southern Benue Trough, the Anambra Basin and the Niger Delta Basin is shown in Table 2.

3.1. Methodology

Field and laboratory methods were utilized in this study. In the field, the logging of outcrops, description and collection of samples were done systematically. About 1 kg of sample was collected from each of the identified beds. Samples were carefully packed to prevent loss of moisture on transit and contamination.

Table 2: Stratigraphic subdivision of the Southern Benue Trough- Benue Ttough, Anambra Basin and Niger Delta Basin (Modified from Reyment (1965)

AGE		Formation	Lithology	Depositional Environment	Basin
Quarternary		Benin Formation	Sandstones, Clays, Shales	Continental	NIGER DELTA BASIN
TERTIARY	Pliocene				
	Miocene				
	Oligocene	Ogwashi-Asaba Formation	Clays, Shales, Sandstones, Lignite	Continental	
	Eocene	Ameki Group	Sandstones, Clays, Shales, Limestones	Estuarine, Shallow Marine	
	Paleocene	Imo Formation	Clays, Shales, Limestones, Sandstones, Marl	Shallow Marine, Deltaic	
UPPER CRETACEOUS	Maastrichtian	Nsukka Formation	Sandstones, Clay, Shales, Coal, Marl	Fluvio Deltaic	ANAMBRA BASIN
		Ajali Formation	Sandstones, Claystones	Fluvio Deltaic	
		Mamu Formation	Sandstones, Clays, Coals	Shallow Marine, Deltaic	
	Campanian	Enugu / Nkporo / Owelli Formation	Shales, Sandstones, Clay, Ironstones, Siltstones	Shallow Marine, Deltaic	
		Major Unconformity			
	Santonian	Awgu Formation	Sandstones, Limestones, Clays, Coals, Siltstones	Shallow Marine, Deltaic	BENUE TROUGH
	Coniacian				
MIDDLE CRETA -CEOUS	Turonian	Eze-Aku Group	Shales, Limestones, Sandstones	Shallow Marine	
	Cenomanian	Odukpani Formation	Sandstones, Limestones, Shales	Shallow Marine	
L.Creta -ceous	Albian	Asu River Group	Shales, Limestones, Sandstones	Shallow Marine	
LOWER PALEOZOIC		Major Unconformity			
		Basement	Granites, Gneisses, Schists, Migmatites	Igneous, Metamorphic	

The laboratory analyses were carried out at the National Geosciences Research Laboratory, Kaduna. Laboratory analysis did include proximate, ultimate analysis and bomb calorimetry of the brown coal (lignite) samples. About 1 kg of each coal sample were grounded and passed through a 210 micron sieve. The powdered brown coals are then used for proximate and ultimate analysis following some specific procedures.

3.1.1. Proximate analysis

The proximate parameters determined in this study include moisture content, volatile matter, ash content, fixed carbon and calorific values. Proximate analysis is a simple method of evaluating the components of coal that is released when coal is heated under specified conditions. Proximate parameters were determined in this study and it includes;

(i) moisture content

(ii) volatile matter, consisting of gases and vapours released during pyrolysis

(iii) fixed carbon, the non volatile fraction of coal (lignite)

(iv) Ash content, the inorganic residue remaining after combustion and

(v) Calorific values

3.1.1.1. ***Moisture content determination (M):***

Moisture content (MC), is a very important property of coals. The procedure of determination involves weighing 1 gram of finely grounded coal sample in a silica crucible, heated in an electric hot air oven to about 110 °C for 1.5 hour. The crucible is taken out with the sample, cooled in desiccators for 15 min and weighed. The moisture content of the sample is the loss in weight on percentage basis. The process of heating, cooling and weighing was repeated until a consistent weight of coal sample was achieved. The MC% was determined according to the following

MC% = Loss in weight of coal / Initial weight of coal taken * 100

%MC = (Y-Z) / (Y-X) * 100-- (1)

Where X = weight of empty crucible

Y = weight of crucible + coal sample before heating, (gm)

Z = weight of crucible + coal sample after heating, (gm)

Y-X = weight of coal sample, (gm)

Y-Z = weight of moisture, (gm)

3.1.1.2. ***Ash content determination****:*

The non-combustible matter that remains after water has been expelled during combustion is referred to as the ash content. In order to determine the ash content, 1 gm of brown coal sample is weighed into a crucible incinerated in a special furnace at a temperature of about 450 °C for about 30 minutes. The temperature of the furnace is then increased to about 850 °C and heated for another one hour. The crucible is afterwards removed; placed in desiccators and weighed. The ash content is the residue on percentage basis which is the difference between the initial weight and the final weight.

% AC = Weight of residue of ash formed / Initial weight of coal taken * 100

% AC= (Z –X / Y-X) * 100-- (2)

Where X = weight of the empty crucible, (gm)

Y = weight of coal sample + weight crucible (gm) before heating

Z = weight of coal sample + weight of crucible (gm) after heating

3.1.1.3. Determination of volatile matter:

The component of coal (except moisture) that is expelled at temperature in the absence of air is the volatile matter. It consists of mixtures of short to long chain hydrocarbons, aromatic hydrocarbons and some sulphur. Volatile matter is determined by heating about 1 gm of crushed coal sample in a minimum air at 900 °C for seven minutes. The sample heated is then cooled in a desiccator and weighed. Repeat the process until a consistent weight of the sample is recorded. The loss in weight (%) is reported as volatile matter.

Volatile matter (%) = (loss in weight due to removal of volatile matter/wt of coal sample used) x 100. Volatile matter is expressed as follows;

$$\%VM = \text{Loss in weight of moisture formed} / \text{Initial weight of coal taken} * 100$$

$$\%VM = (Y-Z) / (Y-X) * 100 - \% MC \text{--} (3)$$

Where X = weight of empty crucible, (gm)

Y = weight of crucible + weight of coal sample before heating, (gm)

Z = weight of crucible + weight of coal sample after heating, (gm)

Y – X = weight of coal sample, (gm)

Y – Z = weight of volatile matter + moisture, (gm)

3.1.1.4. Fixed carbon determination

The carbon found in the material when volatile matter has been driven off is known as fixed carbon. To determine the percentages of fixed carbon, 1 gm sample of brown coal is ground to pass a 0.2 mm in a current of oxygen. The carbon dioxide and water formed were absorbed by soda asbestos and magnesium per chlorate respectively. This level of carbon content is then determined gravimetrically. Alternatively, fixed carbon is determined on air dry basis by subtracting the sum of the other parameters from 100 and is expressed thus;

$$\% FC = 100 - (\%MC + \% AC + \% VM) \text{---} (4)$$

Where

MC = Moisture Content (%)

VM = Volatile Matter (%)

A = Ash content (%)

3.1.2. Ultimate analysis

The chemical approach to characterize coal based on the amount of chemical elements present such as carbon, hydrogen, nitrogen, oxygen and sulfur is known as ultimate analysis. Ultimate analysis involves the determination of the hydrogen, oxygen, sulfur, and nitrogen contents of the weight (percent) of these elements under specified laboratory conditions.

3.1.3. Calorific value

The Net Calorific Value (NCV) of the brown coals was determined using the Bomb Calorimeter.

3.1.4. X-ray diffraction

X-ray diffraction (XRD) technique was used for the identification of minerals present in the lignite so as to assess the purity or quality of the lignite samples. The XRD analysis was done at the National Geoscience Research Laboratory (NGRL) Kaduna.

4.1. Results

4.1.1. **Field characteristics**

A total of thirty seven outcrop sections of the Ogwashi-Asaba Formation were logged and described. Table 3 shows the locations of the lignite outcrops. Most of the lignite outcrops occur deep into valleys and are associated with springs which discharge at several points from the scarp face. The basal contact between Ogwashi-Asaba Formation and the Ameki Formation occurs at the contact between the mudstones underlying the lignite seam and overlying the topmost sandstones of the Ameki Formation. The lithologic succession at this basal part consists of alternation of carbonaceous mudstone, lignite (brown coal), clayey sandstone, and sandy claystone, heteroliths of sandstone/shale or siltstone and fine, medium to coarse grained pebbly sandstones. The thickness of the lignite seams varies from 0.3 m to about 4 m. In some locations such as Obiakoloma stream at Nnewi (Plate 1), the seams are overlain by 0.1 to 0.3 m thick bed of ferruginized sandstone. The beds dip at 4 ° in the southwest direction and strike in a NW-SE direction.

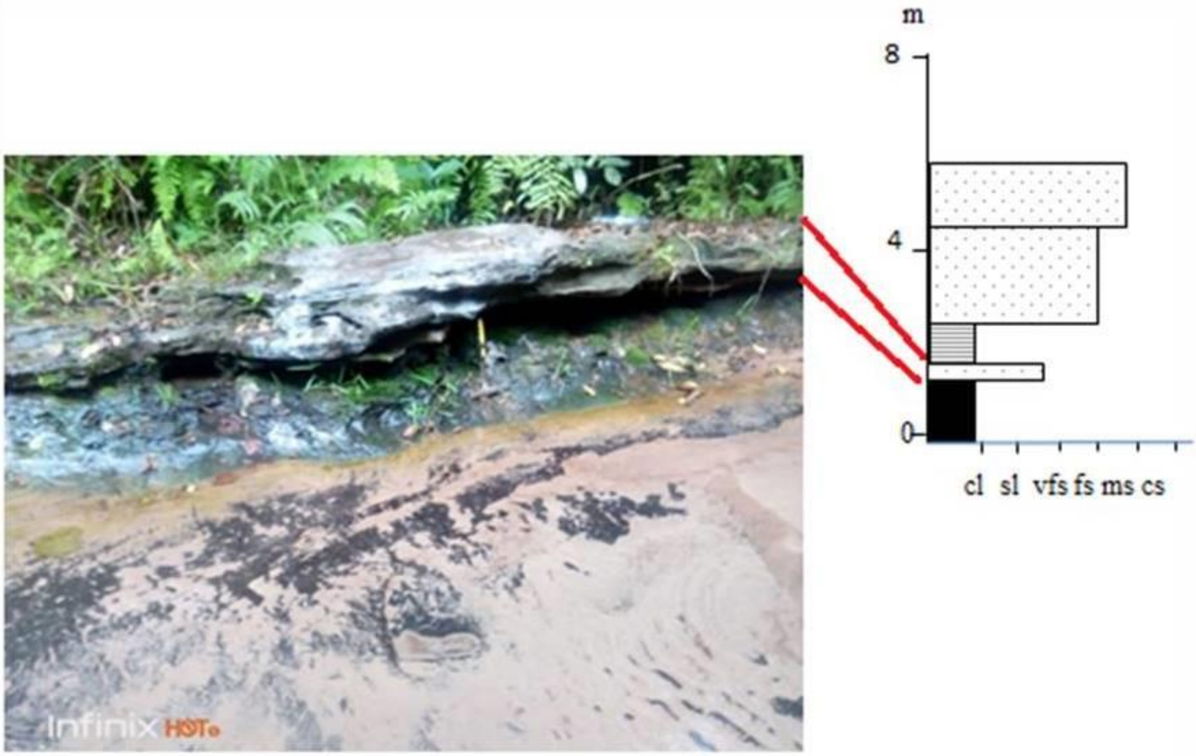

Plate 1: Lignite section at Obiakoloma stream, Okpunoeze Nnewi

The lignite seams which vary in colour from brown, dark brown and black, are inter-bedded with carbonaceous mudstones, sandy clays, clayey sandstones and are overlain by fine and medium to coarse grained sandstones.. The lignite is thinly laminated and mostly fissile in nature. They have leafy and woody fragments on fresh cleats. The lignite beds are considered as belonging to five stratigraphic intervals within a composite stratigraphic section of the Ogwashi-Asaba Formation. The overburden thickness of the lignite seams averages 27.7 m, but varies from about 12 m to a maximum of about 50 m at the various locations. At Ochi stream section in Amichi, a basal 1 m thick black carbonaceous mud rock was observed alternating with 0.3m thick black fissile shale and 0.5m thick heterolith of clay and fine grained sandstone. The section at Gwogwo stream in Ezinifite consists of about 6 m of dark grey micaceous claystones that is moderately burrowed. The middle section of the formation was observed at Umuhu Ukpor, Umuruko Ukpor, Akpata stream section, Lilu sections and along Okija-Ihiala expressway (Fig. 1; Table 3). Here, the Ogwashi-Asaba Formation consists of massive laminated kaolinitic clay and cross-bedded clayey sandstones. Evidence from the outcrop section described at Ekulo stream (Fig. 1, Plate 3) reveals that the lignite occurs at two different levels in the study area. However the lowest seam (Seam-1) which is the thickest was traced to Obiakoloma, Akpuchara, Eze Stream,Ejighioku, Enem, Ant Hill and the Oduga lignite sections (Plates 1, 4, 5, 6-9) respectively.

Table 3: Outcrop locations and their various coordinates				
S/N	Outcrop locations	Latitude	Longitude	Elevation (m)
1	Enem stream	06° 01 12' N	006° 51 36' E	90
2	Ejighioku Amakom Oraifite	06° 01 613' N	006° 51 615' E	110
3	Oruru Awor Ifite Oraifite	06° 01 252' N	006° 51 804' E	106
4	Mkpazi Akamiri Umudim Nnewi	06° 00 435' N	006° 53 527' E	91
5	Location 3	06° 02 041' N	006° 51 481' E	71
6	Amaiyi Okpunoeze Umudim Nnewi	06° 00 917' N	006° 53 796' E	129
7	Obiakoloma	06° 00 914' N	006° 53 726' E	129
8	Ekulo Uruezeakwa Oba	06° 02 585' N	006° 50 763' E	66
9	Eze Ezumeri stream Oraifite	06° 00 762' N	006° 53 954' E	120
10	Ekulo Umuezegbogu	06° 02 880' N	006° 51 557' E	112
11	Ogba	06° 03 153' N	006° 51 251' E	128
13	Akpuchara	06° 02 860' N	006° 51 408' E	103
14	Ezema Ojoto	06° 04 972' N	006° 53 101' E	64
15	Eze stream Okpunoeze Uruagu Nnewi	06° 00 847' N	006° 54 055' E	132
16	Anthill	06° 59 951' N	006° 55 218' E	99
17	Anthill block industry Nnewi	06° 00 059' N	006° 55 242' E	105
18	Oduga stream Otolo Nnewi	06° 01 12' N	006° 51 36' E	80
19	Amawom ifite Oraifite	06° 02 044' N	006° 50 479' E	73
20	Ofalla River Utuh	06° 57 222' N	006° 57 773' E	63
21	Gully erosion Okija/Ihembosi	05° 55 380' N	006° 51 461' E	28
22	Okija-Onitsha Owerri expressway	05° 54 752' N	006° 52 081' E	39
23	Nneolu Okija	05° 53 394' N	006° 50 889' E	70
24	Akpata stream Ozubulu	05° 57 687' N	006° 52 290' E	73
25	Okpu river Okija	05° 53 766' N	006° 51 553' E	40
26	Ulasi river Okija	05° 55 380' N	006° 51 461' E	28
27	Umuroko Ukpor	05° 54 654' N	006° 54 784' E	46
28	Opposite Mac-Peter Oil	05° 56 2551' N	006° 56 017' E	115
29	Nnewi – Ukpor road	05° 55 756' N	006° 56 034' E	100
30	Akaba Mgborogwu Umunze Orsumoghu	05° 53 539' N	006° 55 612' E	54
31	Lilu road	05° 52 933' N	006° 55 836' E	70
32	Mbara Ozalla Orsumoghu	05° 52 581' N	006° 55 651' E	110
33	Mmirioma Amichi	05° 57 709' N	006° 59 923' E	78
34	Nwaota Osumenyi	05° 55 970' N	006° 59 202' E	117
35	Gwogwo stream Awor Ezinifite	05° 55 969' N	006° 59 219' E	92
36	Omado stream Orsuifite-Ukwa	05° 51 406' N	006° 57 596' E	116
37	Toll gate Ogbunike	06° 10 823' N	006° 51 903' E	108

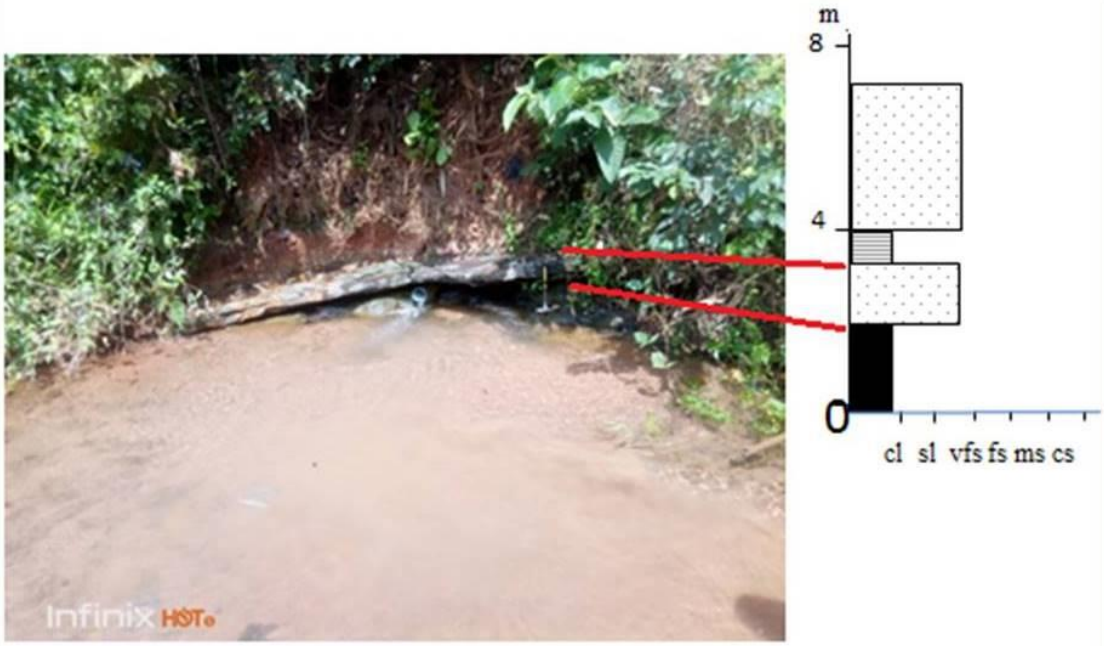

Plate 2: Lignite section at Amaiyi stream, Okpunoeze, Nnewi

Plate 2. Lignite section at Amaiyi Stream, Okpunoeze, Nnewi

Plate 3. Lignite section at Ekulo Stream, Oba

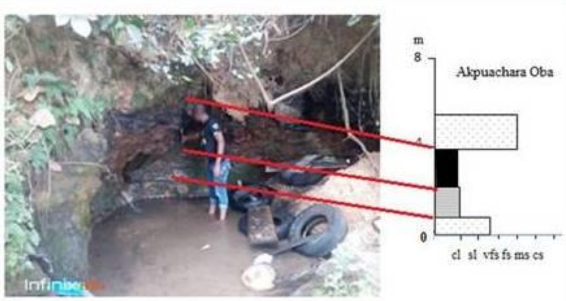

Plate 4. Lignite section at Akpuchara, Oba

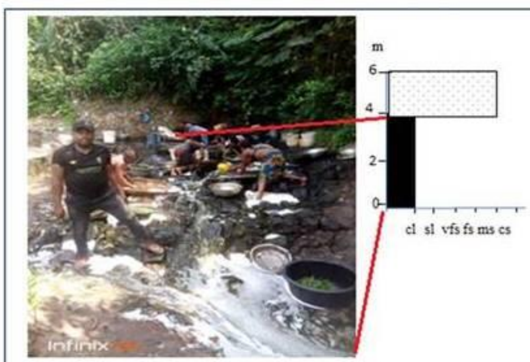

Plate 5. Lignite section at Eze Stream, Nnewi

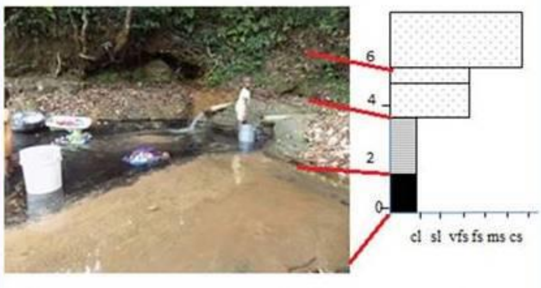

Plate 6. Lignite section at Ejighioku Stream, Oraifite

Plate 7. Lignite section at Enem Stream, Oraifite

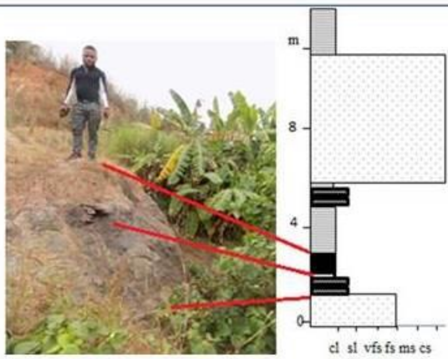

Plate 8. Lignite section at Anthill, along Nnewi-Okigwe Road

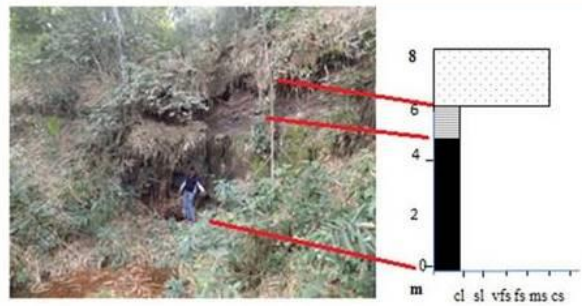

Plate 9. Lignite section at Oduga Stream, Otolo Nnewi

4.1.2. Elemental composition

Seam 1

Seam 1 includes the lignites from Akpuchara, Ekulo, Enem, Ejighioku, Oruru, Obiakoloma, Amaiyi and Eze streams. The moisture contents of the lignite samples range from 12.10 to 37.50 %, while that of Obiakoloma and Amaiyi streams are 7.2% and 7.3% respectively (Table 4). The dry ash contents of the lignite range from 8.3 to 36.6% whereas that of Ejighioku is 70.75%. The volatile matter content of the lignite varies from 27.55 to 39.92% (d.a.f.) and Ejighioku is 15.55% (d.a.f.). Fixed carbon content varies from 23.08 to 37.50% (d.a.f.), while that for Ejighioku is 1.6% (d.a.f.). The carbon and hydrogen contents range between 11.59 to 56.33% (d.a.f.) and 0.13 to 4.59% (d.a.f.) respectively (Table 5). Nitrogen content varies between 1.30 and 1.80 (d.a.f.). Elemental sulfur is low in all samples with values between 0.04 and 0.30%. The oxygen contents vary from 3.07 to 14.52%. The calorific values of the lignites vary between 582.23 and 4583.79 kcal/kg (2.44 – 19.19 MJ/Kg) (Table 4). This coal is classified as lignite using the coal classification scheme whereby calorific values less than 4,600 kcal/kg is grouped

Table 4; Results of Proximate Analysis for lignite from Ogwashi-Asaba Formation (2 samples per section)

	Outcrop	Fixed Carbon %	Volatile Matter %	Moisture %	Ash %	Sulfur %	Calorific values % Kcal/kg	MJ/Kg
Seam 1	Akpuchara Sream, Oba	24.35	27.55	16.50	31.30	0.30	3023.46	12.659
	Ekulo stream, Oba	37.50	38.40	17.30	6.60	0.20	4583.79	19.191
	Enem stream, Nnewi	23.21	33.63	30.70	12.40	0.06	3188.76	13.351
	Ejighioku Stream, Oraifite	1.60	15.55	12.10	70.75	0.04	582.23	2.436
	Oruru Stream, Oraifite	30.40	39.92	20.20	9.40	0.08	4035.64	16.896
	Obiakoloma Stream, Nnewi	23.08	33.04	7.20	36.60	0.08	3210.74	13.442
	Amaiyi Stream, Nnewi	29.20	33.60	7.30	29.80	0.10	3661.02	15.328
	Eze Stream, Nnewi	31.65	33.05	26.80	8.30	0.20	3387.47	14.183
	Average	36.12	31.84	17.20	25.64	0.13	3209.1	13.436
Seam 2	Oduga stream, Otolo Nnewi 1	6.6	19.7	6.1	67.6	0.08	13.22.42	5.537
	Oduga Stream, Otolo Nnewi 2	9.83	15.30	11.40	63.4	0.07	1281.55	5.366
	Average	8.22	17.5	8.75	65.5	0.75	1301.99	5.451
Seam 3	Anthill B.I. Nnewi	15	13	5	67	0.06	984	4.120
Seam 4	Ofala Stream, Utuh	24.40	28.05	34.80	12.60	0.15	3082.92	12.908
Seam 5	Nneoru Stream, Okija	12	23	43	22	0.11	2031.22	8.504

Table 5. Results of ultimate analysis for lignite samples from Ogwashi-Asaba Formation

	Sample	C	H	N2	O2	S wt.%
Seam 1	Akpuchara	37.92	2.97	1.55	9.46	0.30
	Ekulo	56.33	4.59	1.33	13.64	0.20
	Enem	37.93	3.62	1.43	13.87	0.06
	Ejighioku	11.59	0.13	1.79	3.60	0.04
	Oruru	50.05	4.44	1.30	14.52	0.08
	Obiakoloma	44.27	3.36	1.44	7.05	0.08
	Amaiyi	50.08	3.68	1.43	7.61	0.10
	Eze	19.14	1.12	1.80	3.07	0.07
	Average	35.91	2.99	1.51	9.10	0.12
Seam 2	Oduga	45.50	3.91	1.44	13.84	0.20
Seam 3	Ofala	18.89	1.31	1.64	13.15	2.48
Seam 4	Anthill	16.21	1.00	1.84	8.95	2.50
Seam 5	Nneoru	35.42	3.18	1.54	12.32	0.15

as lignite, 4,600 – 6,400 (sub-bituminous), 5,800 – 8,300 (bituminous), and for Anthracite. There is no specific limit under ASTM.

Seam 2

Seam 2 is the lignites from Oduga stream in Nnewi. The moisture contents of the lignite range from 6.10 to 11.40%. The dry ash content of the lignite is very high and ranges from 63.40 to 67.60%. The volatile content of the lignite varies from 15.30 to 19.70% (d.a.f.). The fixed carbon content of the lignite is low and ranges from 6.6 to 9.83% (d.a.f.). The carbon and hydrogen contents are 45.50 and 3.91 respectively. The nitrogen content is 1.44% (d.a.f.). Elemental sulfur is low at an average value of 0.075%. The oxygen content is 13.84%. The calorific value of the lignite varies between 1281.55 and 1322.42 kcal/kg (5.37 – 5.54 MJ/Kg).

Seam 3

Seam 3 is the lignites from Anthill section. The moisture content is about 5%. The dry ash content is very high at about 67%. The volatile matter content is 13%. The fixed carbon content is 15%. The carbon and hydrogen contents are 16.21% and 1.00% respectively. Nitrogen content is 1.84%. Elemental sulfur is low at about 0.0%. The oxygen content is about 8.95%. The calorific value (984 kcal/kg or 4.12 MJ/Kg) is the lowest

Seam 4

Seam 4 is a very thin lignite seam from the Ofala River section at Utuh. The moisture content is about 43%. The dry ash content is about 22%. The volatile matter content is 23%. The fixed carbon content is 12%. The carbon and hydrogen contents are 18.89% and 1.31% respectively. Nitrogen content is 1.64%. Elemental sulfur is low at about 2.48%. The oxygen content is about 13.15%. The calorific value is 2031.22kcal/kg (8.504 MJ/Kg).

Seam 5

Seam 5 is lignite samples collected from Nneoru stream section at Okija. The moisture content is about 34.80%. The dry ash content is about 12.60%. The volatile matter content is 28.05%. The fixed carbon content is 24.40%. The carbon and hydrogen contents are 35.42% and 3.18% respectively. Nitrogen content is 1.54%. Elemental sulfur is low at about 0.15%. The oxygen content is about 12.32%. The calorific value is about 3082.92 kcal/kg (12.91 MJ/Kg). The most common inorganic minerals in all the lignites are oxides; silica (Quartz), feldspar (Kaolinite), sulfurs (Pyrite) (Table 6).

Table 6. Minerals identified in lignite samples from the Ogwashi-Asaba Formation

Mineral	Sample Localities										
	Akpuchara	Enem	Ejighioku	Oruru	Mkpazi	Amaiyi	Obiakoloma	Eze	Anthill	Nneoru	Ekulo
Quartz	59.6	70.0	76.5	51.1	44.0	xx	73	xx	61.2	xx	49.4
Kaolinite	40.4	29.7	xx	48.9	21.0	45.0	27.0	100.0	38.8	xx	8.05
Pyrite	xx	xx	23.5	xx	35.0	55.0	xx	xx	xx	xx	xx
Cristobalite	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	42.5
Graphite	xx	xx	xx	xx	xx	xx	xx	xx	xx	100.0	xx

5.1. Discussions

An examination of the geological map of the study and the stratigraphic sections suggests the lignite field in the study area extends in a NW-SE direction from Oba town through Nnewi to Utuh in the southeastern part of the study area. The lignite seams vary laterally in thickness from about 1m at Enem stream to 4 metres at Eze stream. The quality of the lignite is also variable laterally. The lignite from Eze stream may possess the best quality of lignites because of its thickness and lack of silica (quartz) and very little sulfur content of about 0.20 % (pyrite) (Table 6). The lignites from Amaiyi stream is also of good quality apart from its apparent thickness and sulfur content (0.10%). The next in good quality is the lignites from Oruru stream because of its moderate composition of silica. All other lignites contain higher quantity of silica which will slow its heating rate. Apart from the lignites from Ekulo, Oruru and Eze streams with lower ash content, all the other locations possess high ash contents which give rise to high slag volume and low blast furnace efficiency. High ash content affects the performance of blast furnace coke negatively and is influenced by the abundance of detrital materials in the lignite, whereas low ash lignites are dominated by authigenic and biogenic inorganics. The volatile matter content of the lignites vary from 15.55 to 39.92 wt.%, with an average value of 31.84, which falls within the threshold of 20 to 32 % suggested by Afonja (1996) for lignites with appreciable coking coal characteristics. These lignites can all be utilized for various purposes if they are properly beneficiated. The lignites from the Ogwashi-Asaba Formation can be employed in several industrial applications ranging from power generation, steel production, household and industrial uses. The lower calorific value of lignites of Ogwashi-Asaba Formation makes it suitable for use in power generation because the lignite takes a longer time to burn and thus longer electricity production. However, the lignite from the Ogwashi-Asaba Formation may not be suitable for high-energy generation or the blast furnace because of its high moisture content which averages 19.14 wt. %. The moisture content of lignite generally reduces its heating value. Less than thirty percent of the lignites has calorific value less than 10.46 MJ/Kg, while over 70 % of the lignites have their calorific values above 10.46 MJ /Kg. Inaner (2005) have advocated that lignites with calorific values lower than 10.46 MJ as being consumed in power plants while those with calorific values higher than 10.46 MJ /Kg as more suitable for household and industrial uses. Lignites are generally less expensive than other sources. Domestically, lignites are used for the heating of residential buildings during winter. These lignites can also be useful for steel production because of its lower sulfur content. The ash-fusion temperature is usually reduced to lower levels especially in the form of ferrous sulphide (pyrite), of about 900°C, when high amounts of sulfur is present in a coal. High amounts of sulfur as compared with black coals especially in the form of ferrous sulphide (pyrite) reduce the ash-fusion temperature to lower levels like 900°C. This characteristic gives lignite high potential for slagging in steel production. This process creates synthetic natural gas that delivers more power and it is easier to operate in commercial scale electric generations. The process of breaking down lignites through coal gasification produces syngas from coal along with water, air and/or oxygen. No data exists to resolve the lignite reserve calculation in the study area. Suggestions include the drilling of several boreholes to assess the reserves. The lignites of the Ogwashi-Asaba Formation may likely be worked as open mines if developed, which may be besieged with a lot of environmental problems, resulting from the removal of the thick overburden required to exploit the resource.

5.2. Environmental Hazards

The use of lignite for thermal power plants, home and other industrial uses in parts of Anambra State is likely to present some health and environmental hazards. Heal (2018) discussed the implications of lignite combustion and burning for electricity and suggested the health effect of coal power plants to stem from the release of harmful air pollutants that contribute to poor air quality with impacts on heart and lung health. Combustion of coal and lignites releases particulate matter (pm), sulfur dioxide (SO_2), nitrogen oxides (NO_2), heavy metals and other pollutants to the air (Heal, 2018). Burning of coal for electricity is regarded as one of the biggest industrial sources of CO2 emissions, fueling climate change. Premature death has also been linked to the impact of three main pollutants – particulate matter regarded as the most harmful, groundwater ozone and nitrogen oxide on the cardiovascular or respiratory system. Lignites and coal are also known as influencing the soil and water characteristics such as acid mining lakes resulting from mining operations in these parts of Anambra State is likely as a result to these problems enumerated.

Lignite seam fire occurred at Oduga Stream in Nnewi in December 2017 and lasted for over eight months causing some environmental degradation. Possible causes of lignite fire include bush burning and exothermic-oxic reactions or spontaneous combustion (thermodynamics and geothermal alteration) (Song and Kuenzer, 2014; Chidera *et al* 2019). Potential hazards associated with such fires include emission of harmful gases such as Mercury, Methane, Sulfur I Oxide, and greenhouse gases (Carbon monoxide, Nitrogen oxides, and hydrogen sulphide) into the atmosphere (Kim, 2007; Chidera *et.al* 2019). Geological and environmental hazards resulting from lignite fires include sinkholes, valleys, slump blocks and chemically altered rocks and minerals. Major health hazards caused by lignite fires include carbon monoxide poisoning, bronchitis, stroke, lung cancer, chronic pulmonary obstructive disease (Kroonenberg and Zhong, 1997; Stracher *et al* 2010; Finkelmann *et al* 2002; Pone *et al* 2007 and Hower *et al*, 2009).

5.3. Conclusion

The purpose of this study is to assess the industrial potentials of the lignite deposits in the study area by analyses of the chemical composition using proximate and ultimate analysis. Five lignite seams were observed at different stratigraphic levels of the formation. Seam 1 is the lowest and includes the lignites from Akpuchara and Ekulo streams from Oba, Enem, Ejighioku and Oruru streams from Oraifite and Obiakoloma, Amaiyi and Eze streams from Nnewi. Seam 1 has an average moisture, dry ash, volatile matter and fixed carbon contents of 17.20%, 25.64%, 31.84% and 21.22% respectively. Analytical results shows that seam 1 has an average carbon ©, Hydrogen (H), Nitrogen (N), Oxygen (O) and Sulphur (S) content of 35.91%, 2.9%, 1.51%, 9.10% and 0.12% respectively. Gross calorific value for seam 1 in the study area is 3209.14 kcal / kg (9.77 MJ /Kg) on average. Seams 2, 3, 4 and 5 include lignites from Oduga stream, Anthill section, Ofala stream and Nneoru stream respectively. The average moisture, dry ash, volatile matter and fixed carbon content for seam 2 are respectively 8.75%, 65.5%, 17.35% and 8.22%. Analytical results show that seam 2 has an average C, H, N, O and S content of 45.50%, 3.91%, 1.44%, 13.84% and 0.75%. Gross calorific value for seam 2 in the study area is 1302 kcal / kg (5.46 MJ/Kg) on average. The other seams are very thin beds and are of less economic importance although their calorific values are between 984 kcal/kg and 3082.92 kcal/kg (4.12 – 12.91 MJ/Kg). The lignites of the Eocene Ogwashi-Asaba Formation has potentials for use in thermal generation, household and several other industrial uses if properly beneficiated.

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