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NIGERIAN MINING JOURNAL

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Opafunso Z.O. and Alaba O.C.(2015) Nigerian Mining Journal, 13(1) 1 - 7

Geophysical Investigation for Groundwater Potential of Oke-Isimi Layout, Akure, Nigeria

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Abstract
Electromagnetic (EM) profiling and geoelectric sounding were used to locate fissured, weathered or fractured zones and associated geoelectric parameters to identify groundwater potential at Oke-Isimi Layout. The VLF-EM data was collected at 10m intervals along six (6) profiles ranging from 70 to 100m while the VES data was acquired with ABEM SAS 4000 Digital Terrameter with current electrode spacing (AB/2) varied between 1m to 100m at a maximum spread length of 200m at locations of anomaly identified on the VLF-EM profiles. In all, a total of eleven VES were carried and the apparent resistivity values were calculated using the standard array constants. Points of positive VLF-EM filtered real anomalies are considered priority areas for resistivity sounding and groundwater development as they often suggest lithological variations within the unconsolidated overburden, and/or water-filled fissures in the bedrock. The Vertical Electrical Soundings interpretation delineated two groundwater target areas which are the weathered basement, and fractured basement within the VLF-EM localized zones. The most suitable points for groundwater abstraction are VES 2 and VES 5, which contain low to medium yield groundwater potential zones and possibly VES 7 but with lower yields when compared with VES 2 and 5.

Keyword: Electrical resistivity, geoelectric section, geophysical investigation, vertical electrical sounding, very low frequency electromagnetic,

Introduction

Water is a basic necessity of life that its scarcity or contamination could cause serious sickness or outbreak of epidemics. In the past, rain water, streams and lakes were the major source of water to human. Nowadays, these sources of water are not suitable for drinking due to human and industrial pollution or contamination (Olurunfemi *et al,* 1999). Though the access to quality water is greatly limited, its importance and usefulness cannot be overestimated. However, groundwater development offers cheap, clean and uncontaminated water for both domestic and commercial purpose. In order to access and harness groundwater, there is need to know pre-existing geologic formation of the area in question through geophysical investigation. The geophysical investigation of the interior of the earth involves taking measurements (at or near the surface), that are influenced by the internal distribution of physical properties. Analysis of these measurements can reveal how the physical properties of the earth subsurface vary vertically or laterally. Sometimes geophysical surveying is prone to some ambiguities of interpretation, yet it is only means of cost effective of getting accurate information about subsurface geology (Koefoed, 1972).

Available reports showed that there are a lot of abortive, abandoned and low yielding boreholes in various places of Oke-Isimi Layout. The reasons for this include: selection of wrong water points, poor data quality/incomplete information from the subsurface, lack of technical know- how and poor development of drilled holes among others, which are rampant in Basement Complex terrain. Electrical Resistivity method has become increasingly successful in solving the above problems. The method has been

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used extensively in groundwater investigation in the Basement Complex terrains (Olayinka and Olurunfemi, 1992; Olurunfemi et al, 1999 and Omusuyi, 2000) and in the sedimentary basin (Barker and Smith, 1996; Mbonu et al, 1991). Other geophysical methods that complement the use of the Electrical Resistivity method to ensure a high successful rate of groundwater development, especially in the basement terrain where aquifer characteristics cannot easily be predicted are the magnetic and the Very Low Frequency Electromagnetic (VLF-EM) prospecting methods. This method can be adopted as reconnaissance tool, the results of which will serve as guide for the Electrical Resistivity survey.

In this study, integrated use of the VLF-EM and the Electrical Resistivity prospecting methods were employed in evaluating the groundwater condition of Oke-Isimi Layout, Akure with a view of determining the geoelectric parameters of the superficial/overburden materials overlying the bedrock, the subsurface structural disposition of the bedrock and their hydrogeologic characteristics.

Materials and Methods

Site Location and Description

Oke –IsimiLayout is located in Akure, Akure South Local Government Area of Ondo State in the South Western Basement Complex of Nigeria. The study area is located outside the Orita-Obele Housing Estate in Akure municipal. It lies between longitude 0809164 E and 0809247 E and latitude 0740177 N and 0740246 N. Most of the inhabitant buildings in the study area depend on hand-dug wells as source of water supply. The study area is easily accessible through tarred major roads and untarred streets and footpaths connecting them. The base map of the study area is shown in Fig. 1.

Geomorphology and Geology of the Study Area

The area of concentration is bounded few meters at the Northern part by a massive mountainous outcrop almost carrying the study area on its limb. About 300m away from its southern end, the study area is bounded by a structurally controlled stream which flows approximately in the east-west direction. The elevation of the area varies between 365 to 399m.The area is situated within the tropical rain forest region, with a climate characterized by dry and wet seasons. Annual rainfall ranges between 100mm and 1500mm, with average wet days of about 100. The annual temperature varies between 180°C to 340°C (Ileoje, 1980). The study area is underlain by the Precambrian Basement complex rocks of South-western Nigeria. The local lithologic units identified in the study area are the migmatite-gneiss, biotite-gneiss and granites. The migmatite-gneiss is the most widespread rock unit in the area, covering more than half of the area and occurring in north-eastern and south-eastern parts of the area. The biotite-granite occurs in several locations, mostly in the central part of the study area. They are porphyritic and of medium coarse grained texture. Granites occur as intrusive in low-lying outcrops within the biotite-gneiss and occur mostly in the south-western part of the study area (Rahaman, 1976).

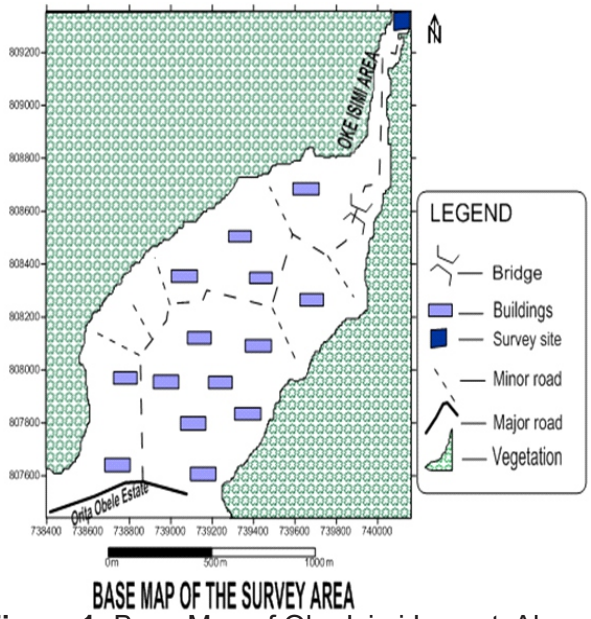


Figure 1: Base Map of Oke-Isimi Layout, Akure, Showing the Study Area

Method of Geophysical Approach

The geophysical investigation was carried out in two stages. The first stage involved the Very Low Frequency (VLF)

electromagnetic method that was used as reconnaissance survey to delineate area with fractures and other conductive features. The VLF survey (profiling) was achieved with ABEM WADI 300. The VLF measurements were made at 10m intervals along the six (6) traverses as shown in Fig. 2.Vertical electrical sounding (VES) was used to measure apparent electrical resistivity of ground using Schlumberger electrode array configuration. The VES data was acquired with ABEM SAS 4000 Digital Terrameter with current electrode spacing (AB/2) varied between 1m to 100m at a maximum spread length of 200m.

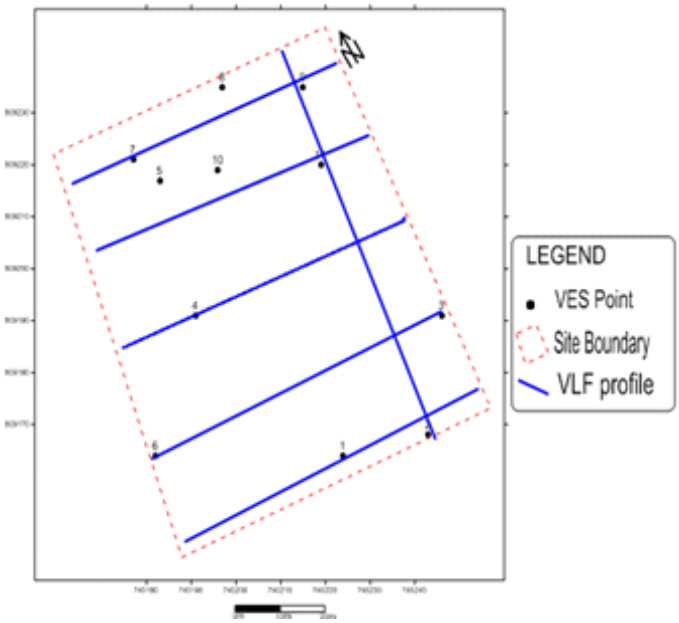


Figure 2: Survey Layout of the Study Area

Results, Interpretation and Discussion

Electromagnetic VLF

The VLF-WADI traverse data of the investigated area is shown in Table 1 while Fig. 3 shows the VLF-EM profiles. The interpretation of the VLF-WADI data was qualitative which involved inspection of the VLF-WADI anomaly curves for diagnostic signatures (the coincidence of inflections on raw real component anomaly curves with positive peaks on filtered real anomaly curves which were infer as faults or fractured zones).

The directions of VLF-EM profiles one to five are east – west while that of VLF-EM profile six is north – south direction. Two positive peak amplitudes were obtained in profiles one, three and five while one was obtained in profiles two, four and six. The positive peak amplitude indicates the presence of conductive zone while negative peak amplitude indicates presence of a resistive material.

Table 1: VLF-EM Data of Oke-Isimi Layout, Akure

		0	1	2	3	4	5	6	7	8	9	10
TR 1	RR	0.0	5.4	-3.6	1.0	0.4	1.3	-15.2	6.1	2.5	6.4	
	FR	4.3	0.9	-2.1	2.1	-2.2	-12.1	-5.0	10.0	6.8	6.4	
TR 2	RR	0.0	-1.2	-0.8	-0.2	0.7	-1.2	-4.6	-12.3	-8.9	-0.7	8.7
	FR	-1.3	-1.7	-0.5	0.3	-1.5	-7.5	-16.5	-17.5	-4.5	8.4	8.7
TR 3	RR	0.0	-8.5	4.0	0.8	0.8	-2.6	4.0	2.1	3.3	-5.2	
	FR	-7.2	-2.7	3.3	-1.3	-0.7	2.3	6.0	3.0	-2.6	-5.2	
TR 4	RR	0.0	-3.4	-3.2	-3.1	-13.6	-6.2	-2.7	5.6	7.2	6.6	
	FR	-3.9	-6.2	-8.0	-16.4	-16.6	-5.9	4.7	12.4	11.5	6.6	
TR 5	RR	0.0	7.3	1.4	-2.3	-12.2	-8.7	-0.8	10.9			
	FR	7.3	6.3	-4.9	-15.3	-17.2	-3.9	10.6	10.9			
TR 6	RR	0.0	3.7	-0.8	3.0	2.3	-1.7	-4.4	-2.9			
	FR	3.3	2.8	2.5	4.4	-1.1	-6.2	-5.9	-2.9			

TR = Traverse, RR = Raw Real, FR = Filtered Real

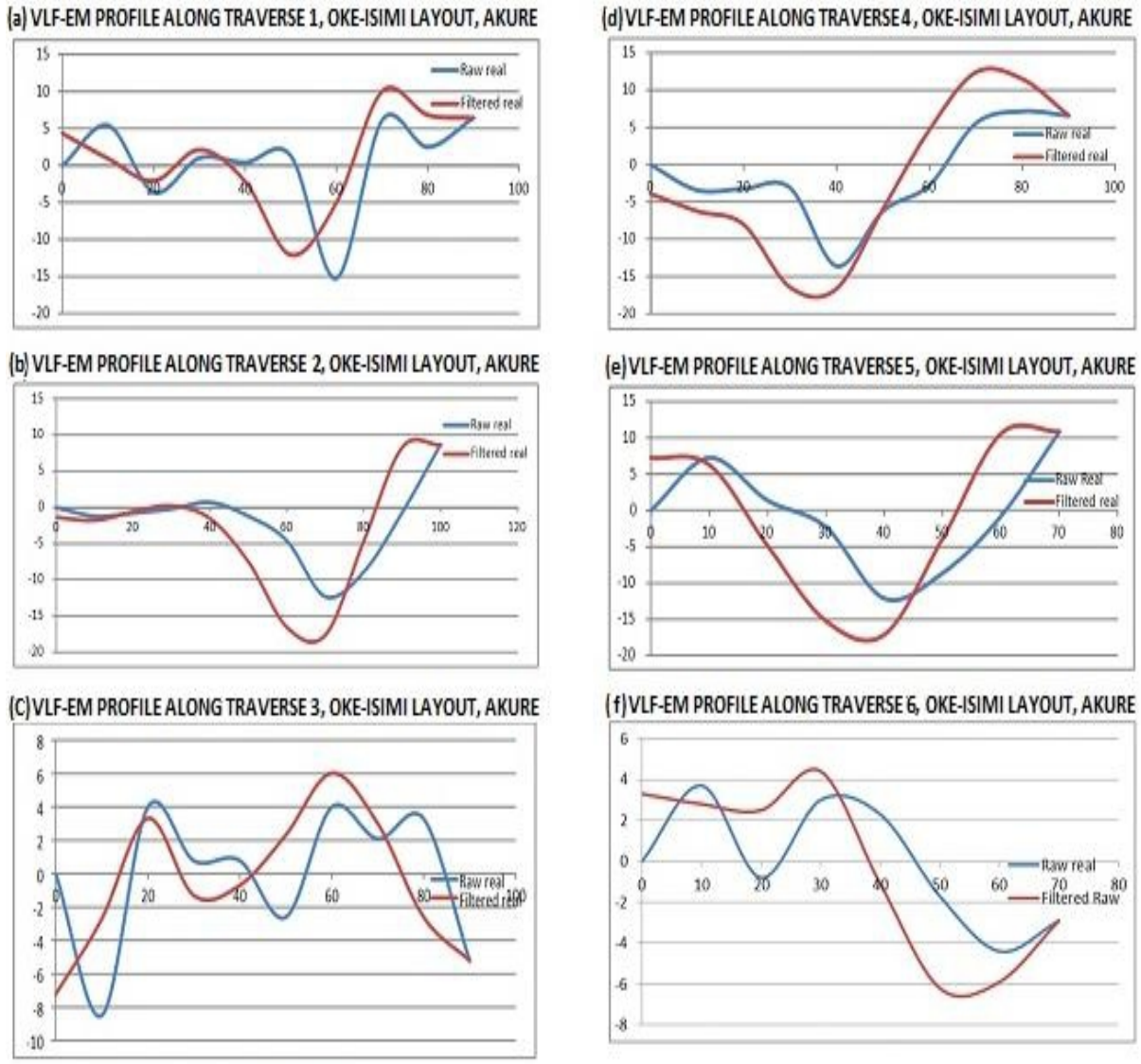


Figure 3 (a – f): VLF – EM Profile Vertical Electrical Sounding (VES)

The resistivity data for occupied VES was shown in Table 2 and VES curves are presented as sounding curves in Figs. 4(a and b).Apparent resistivity values were determined by combined factors such as: geometry of electrode arrays, thickness and angle of dip of layers, anisotropic properties of the earth materials, resistivities of rocks and electrode spacing. Quantitative interpretation involves partial curve matching technique and interpretation involves computer iteration by using Resist software packages. The depth sounding curves were classified into five curve types which were the H, HA, HKH, QH and A (Koefoed, 1972). For this study, quantitative method was used for data interpretation

Six different curve types were identified in the study area as shown in Fig. 4a and 4b. These curves are A, K, AK, KH, HK and HAK with KH type dominating the area (Koefoed, 1972). The curves show three to five subsurface geoelectric sequences with the weathered layer (overburden) between 2 and 12m depth. These weathered layers (overburden) are very thin. The points that are most suitable for groundwater abstraction are VES 2 and VES 5 which has low to medium yield of groundwater potential. Also VES 7 may be drilled but has less yield of groundwater potential when compared with VES 2 and VES 5.

Table 2: Apparent Resistivity Values of VES Points

AB/2 (m)	RESISTIVIT (Ohm– m)										
	V1	V2	V3	V4	V5	V6	V7	V8	V9	V10	V11
1	153	232	6.0	219	138	191	242	366	113	198	142
2	174	294	24	247	169	191	207	291	141	258	182
3	166	295	56	261	187	186	209	331	180	266	196
4	164	287	91	251	184	182	118	398	238	256	212
6	145	248	205	240	195	225	248	416	313	270	252
6	127	223	174	259	188	216	268	413	318	312	312
8	94	353	305	123	167	239	247	433	405	316	328
12	92	166	654	145	177	308	252	506	460	226	338
15	106	171	750	141	184	348	295	580	573	220	360
15	106	182	107	156	212	334	274	578	715	222	420
25	149	295	438	255	255	408	335	786	705	290	614
32	195	272	643	370	290	435	405	667	705	406	268
40	229	314	1084	428	381	462	488	630	677	520	486
40	207	283	534	432	271	515	509	638	665	588	568
65	390	287	1742	505	292			588	667	914	
100		302	683								

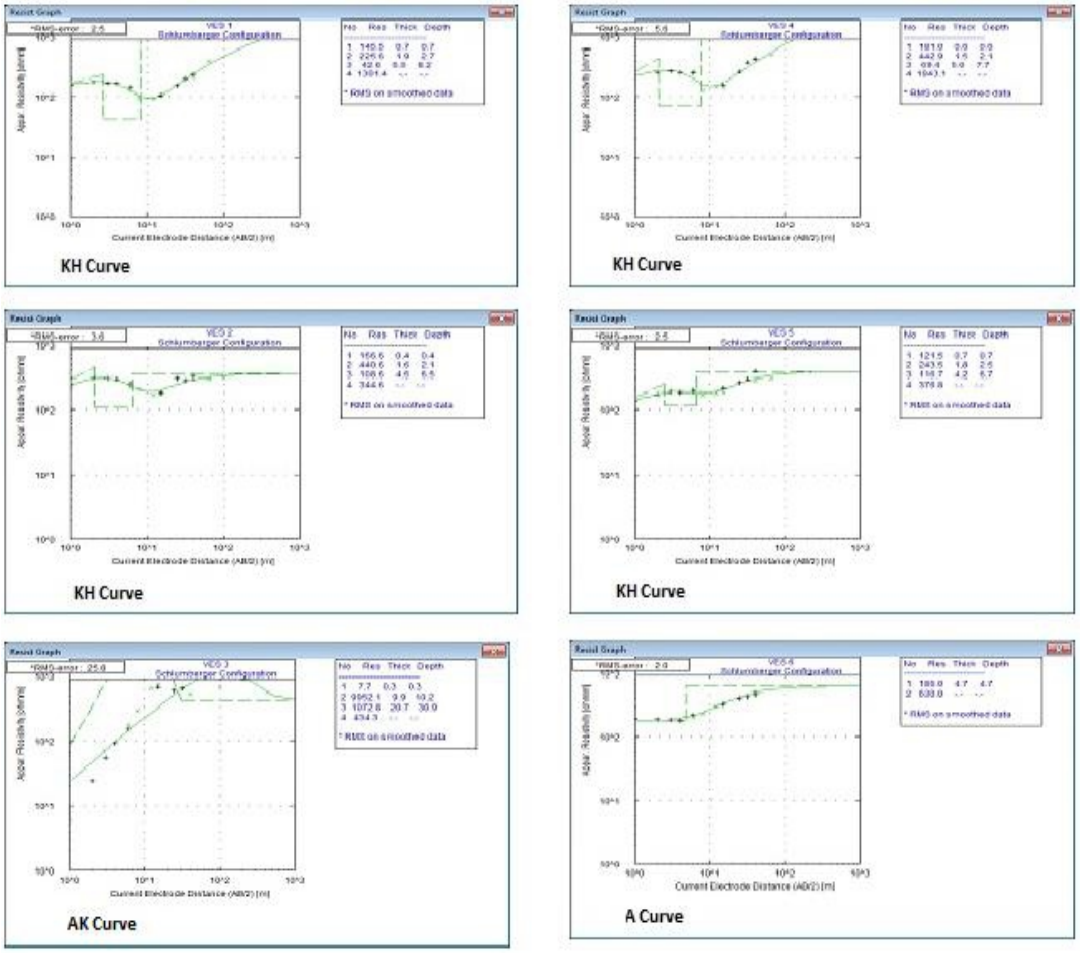
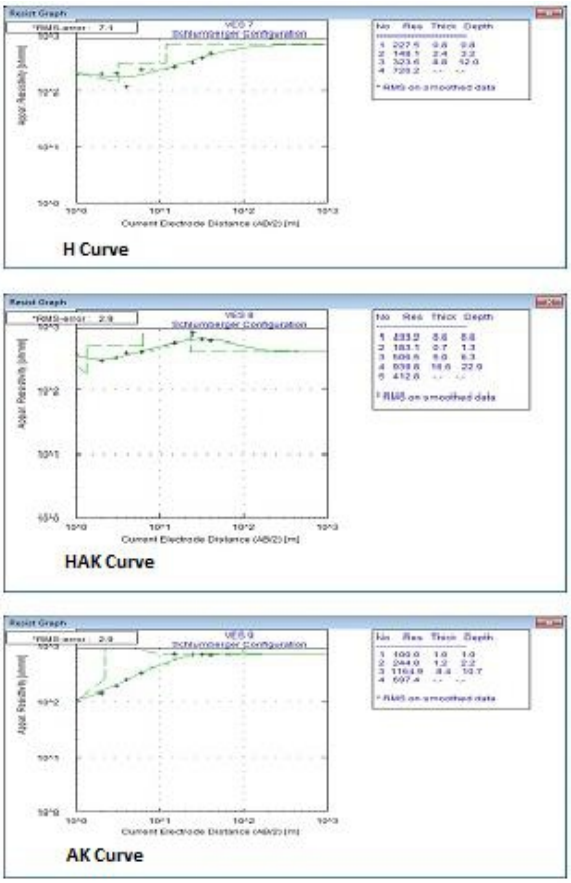


Figure 4a: Vertical Electrical Sounding (VES) Curves of VES 1 to VES 6



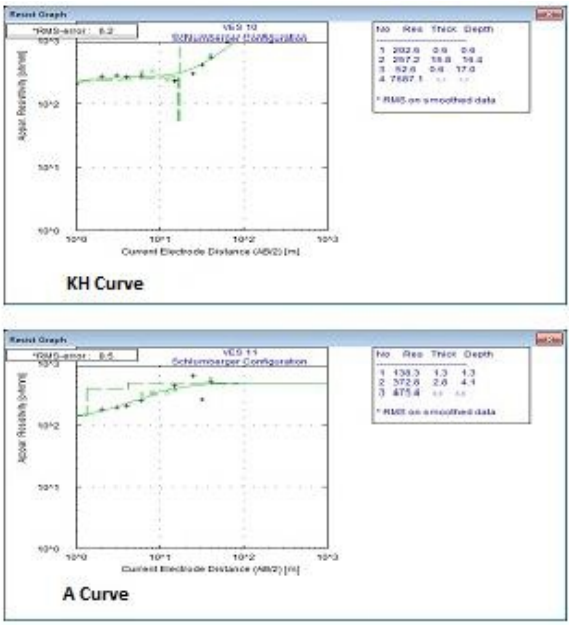


Figure 4b: Vertical Electrical Sounding (VES) Curves of VES 7 to VES 11

Geoelectric Sections

The geoelectric sections generated from the study area depict four subsurface geoelectric sequences as shown in Figs. 5 (a – c). The layers are:

(i) Top soil –generally the topsoil of the area are thin and composed mainly of sandy clay, clayey sand and clay materials with resistivity ranges from 100-433Ωm and thickness ranges from 0.4-1.3m

(ii) Weathered layer –These are characterised with the resistivity values varying from 43-507 Ωm and thickness between 0.6 - 8.8m

(iii) Weathered basement - These are characterised with the resistivity values varying from 183-630Ωm and thickness between 0.7-15.8m

(v) Bed rock –This is the last layer with the resistivity ranges from 335-7767 Ωm and thickness tending to infinity.

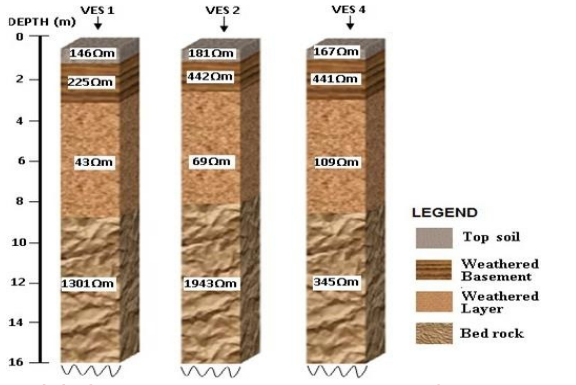


Fig. 5 (a): Geoelectric section along VES 1, 2, and 4

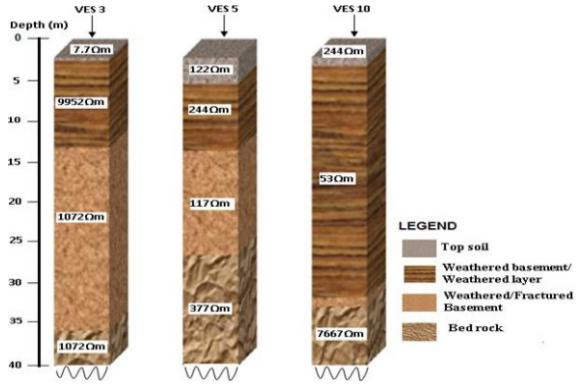


Fig. 5 (b): Geoelectric section along VES 3, 5, and 10

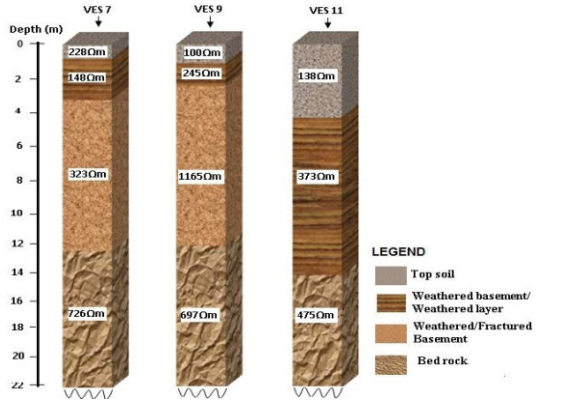


Figure 5 (c): Geoelectric section along VES 7, 9, and 11

Hence, the depth to the weathered layer (overburden) is between 3.3 and 6.7m. Based on the geoelectric parameter established in this area, the points most suitable for groundwater abstraction are VES 2 and VES 5, which are high yield potential zones and possibly VES 7 but with less yield as compared with the aforementioned VES points. Other surveyed points are not recommended for borehole drilling because the weathered layers, even though with appreciable thickness are composed of shale/clay. This is because shale/clay is an aquitard (porous but not permeable) which makes groundwater exploration difficult. Hand-dug well will be the preferred source of potable water in those points.

Conclusion and Recommendation

The study was carried out using a combination of VLF- Electromagnetic and Electrical resistivity methods (Schlumberger array). The VLF–Electromagnetic method was used to delineate the geologic structures (sheared or fractured zones) where Vertical Electrical Soundings were carried out to determine subsurface geoelectric sequence of the earth in terms of layer resistivity and thickness. The geoelectric parameters obtained were used to explain the hydrologic system of the area. The study therefore concluded that groundwater potential of Oke-Isimi Layout is of low to medium yield of groundwater potential

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Oyeladun O. A. W., Thomas D. G. & Yaro S. A..(2015) Nigerian Mining Journal, 13(1) 9 - 17

Determination of Work Index of Azara Copper Ore

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Abstract

The work Index of Azara Copper ore was determined using the modified Bond method (Berry and Bruce method). The test sample was obtained from Azara, Nasarawa State and the reference sample (granite) obtained from Kujama, Kaduna State. The reference sample of known weight (200g) and known work index (15.44KWh/tonne) was ground for about one hour period using laboratory ball mill. An equal weight of test sample was also ground for one hour and its power consumption was compared with that of the reference sample (granite). Size analyses of the ball mill feed and discharge for both the reference and test samples were carried out and the result was used to determine the 80% passing 100 µm. The work index of Azara copper ore was found to be 12.989kWh/tonne. Using the Denver grindability test curves, the copper ore can be classified as a medium soft texture type (B).

Keywords: work index, grindability test, reference sample, test ore

Introduction

The mineral processing industry utilizes two fundamental operations which are the liberation of the valuable minerals from waste gangue minerals and concentration involving separation of the liberated product. Comminution is the cause, and liberation is its effect. Optimum system operation is dependent upon a large number of critical factors, of which the knowledge of work index is of utmost importance.

Work index is the comminution parameter which expresses the resistance of material to crushing and grinding; numerically it is the kilowatt hours per tonne required to reduce the material from theoretically infinite feed size to 80% passing 100µm. The determination of work index of an ore will help in calculating the energy requirement for comminution of the ore and selection of appropriate comminution equipment. The Bond work index of material is determined by ball mill grindability test (Bond, 1961) in Wills and Napier-Munn (2006).

Berry and Bruce (1966) developed a comparative method of determining the work index of an ore known as Modified Bond's Method. The method requires the use of a reference ore of known work index. Oyeladun et al (2012) adopted the comparative grindability test for the determination of work index of Rafin Gabas (Nigeria) chalcopyrite ore. A reference ore is ground for a certain time period and the power consumption recorded. An identical weight of the test ore is then ground for a length of time such that the power consumed is identical with that of the reference ore. Equation 1 gives the work index of the test ore;

$$W_r = W_t = W_{ir}\left[\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right] = W_{it}\left[\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}\right] \quad \text{... Equation 1}$$

hence,

$$W_{it} = W_{ir}\left[\frac{10}{\sqrt{P_r}} - \frac{10}{\sqrt{F_r}}\right] \Big/ \left[\frac{10}{\sqrt{P_t}} - \frac{10}{\sqrt{F_t}}\right] \quad \text{... Equation 2}$$

Where W_r = Work input of reference ore,

W_t = Work input of test ore

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W_{ir} = Work index of reference;

W_{it} = Work index of test

P_r = 80% of Product(reference ore)passes;

P_t = 80% of Product(test ore)passes;

F_r = 80% of feed (reference ore)passes;

F_t = 80% of feed (test ore)passes

Materials and Methods

The Modified Bond's method, also called Berry and Bruce method of determining the work index of an ore, was used in this research work because of its simplicity, and speed. It is called the comparative method of determining grindability parameter. This method requires the use of a reference ore of known work index (Granite of work index 15.13kwh/ton). The procedure used in the determination of work index of Azara copper ore included: grinding 200grams each of the test and reference ores in a laboratory ball mill for one hour and sieving for 20 minutes using the automatic sieve shaker. Each sieve size fraction was weighed and the value recorded as "discharge or product". The ball mill used for this test was 305mm in length by 305mm in diameter, run at a mill speed of 70rpm; hence its length/diameter ratio is 1:1

i. The ore under test and the reference ore were crushed and pulverized.
ii. An identical weight of the test and reference ores were taken and sized by sieving for 20 minutes into a number of size fractions in the automated sieve shaker.
iii. Each sieved fraction of the test and reference ores was weighed and the value recorded as the "Feed".
iv. The "Feeds" of test and reference ores were gathered together and fed into the laboratory ball mill and ground for one hour respectively.
v. The test and reference ores from the laboratory ball mill were sieved and each sieved fraction was weighed and the value noted as the product or discharge".

Result and Discussion

Tables 1 to 4 and Figures 1 to 4 present the results of particle size analyses of both reference ore (granite) and the test sample (copper ore). The values of 80% passing for feeds and products for both reference and test samples were obtained using the semi log plots and calculated using Gaudin-Schuhman logarithm equation to verify if the values obtained from the plots are the same. The value of the work index of the reference ore (15.44kWh/tonne) and 80% passing 100µm of the reference ore were used to determine the work index of the copper ore.

Table 1: Particle Size Analysis of Feed Sample (Copper Ore)

S/No	Size Fraction (µm)	Sieves, (µm)	Mass (g)	Mass (%)	Cum. Mass % Retained	Cum. Mass % Passing
1	– 355 + 250	355	38.386	19.193	0.00	100.00
2	– 250 + 180	250	29.998	14.999	19.19	80.81
3	– 180 + 125	180	35.601	17.8005	34.19	65.81
4	– 125 + 90	125	17.283	8.6415	51.99	48.01
5	– 90 + 50	90	7.72	3.86	60.63	39.37
6	– 50	50	71.012	35.506	64.49	35.51
Total			200		100.00	0.00

Table 2: Particle Size Analysis of Ball Mill Discharge for the Test Ore (Copper ore)

S/No	Size Fraction, μm	Sieves, μm	Mass (g)	Mass (%)	Cum. Mass % Retained	Cum. Mass % Passing
1	– 355 + 250	355	14.424	7.212	0.00	100.00
2	– 250 + 180	250	18.312	9.156	7.21	92.79
3	– 180 + 125	180	18.753	9.3765	16.37	83.63
4	– 125 + 90	125	17.075	8.5375	25.74	74.26
5	– 90 + 50	90	32.448	16.22	34.28	65.72
6	– 50	50	98.989	49.4945	50.51	49.49
Total			200		100.00	0.00

Table 3: Particle Size Analysis of Feed (reference ore - granite)

S/No	Size Fraction (μm)	Sieves, (μm)	Mass (g)	Mass (%)	Cum. Mass % Retained	Cum. Mass % Passing
1	– 355 + 250	355	40.099	20.0495	0.00	100.00
2	– 250 + 180	250	36.959	18.4795	20.05	79.95
3	– 180 + 125	180	36.007	18.0035	38.53	61.47
4	– 125 + 90	125	18.098	9.0490	56.53	43.47
5	– 90 + 50	90	18.567	9.2800	65.58	34.42
6	– 50	50	50.27	25.135	74.87	25.14
Total			200		100.00	0.00

Table 4: Particle Size Analysis of Ball Mill Discharge for the reference ore (granite)

S/No	Size Fraction (μm)	Sieves, (μm)	Mass (g)	Mass (%)	Cum. Mass % Retained	Cum. Mass % Passing
1	– 355 + 250	355	15.772	7.886	0.00	100.00
2	– 250 + 180	250	17.95	8.975	7.89	92.11
3	– 180 + 125	180	23.075	11.5375	16.86	83.14
4	– 125 + 90	125	16.519	8.2595	28.40	71.60
5	– 90 + 50	90	35.542	17.77	36.66	63.34
6	– 50	50	91.142	45.571	54.43	45.57
Total			200		100.00	0.00

From the Gaudin-Schuhman distribution given as

$$y = 100\left(\frac{x}{k}\right)^a$$

Where y = cumulative mass % passing size
x = screen aperture size
k = size parameter
a = distribution parameter
From fig.2,

$$\text{Slope} = \frac{\log 90 - \log 9}{\log 300 - \log 8} = 0.6353$$

Using point (8, 9) in Gaudin-Schuhman logarithm equation, we have

$Y = 0.6353X + 0.3805$

$Where\ Y = \log y\ and\ X = \log x$

Calculating 80% passing, gives log 80 = 0.6353 log x + 0.6353

$x = 249.3\ \mu m$

From fig. 4

$$\text{Slope} = \frac{\log 90 - \log 20}{\log 200 - \log 9} = 0.485$$

Using point (9, 20) in Gaudin-Schuhman logarithm equation, we have

$Y = 0.485X + 0.8382$

$Where\ Y = \log y\ and\ X = \log x$

Calculating 80% passing, gives log

80 = 0.485 log x + 0.8382

$x = 156.9\ \mu m$

From fig.6,

$$\text{Slope} = \frac{\log 90 - \log 40}{\log 300 - \log 100} = 0.738$$

Using point (100, 40) in Gaudin-Schuhman logarithm equation, we have

$Y = 0.738X + 0.1261$

$Where\ Y = \log y\ and\ X = \log x$

Calculating 80% passing, gives log 80 = 0.738 log x + 0.1261

$x = 255.8\ \mu m$

From fig.8,

$$\text{Slope} = \frac{\log 100 - \log 40}{\log 300 - \log 30} = 0.3979$$

Using point (100, 40) in Gaudin-Schuhman logarithm equation, we have

$Y = 0.3979X + 1.0143$

$Where\ Y = \log y\ and\ X = \log x$

Calculating 80% passing, gives

log 80 = 0.3979 log x + 1.0143

$x = 171.3\mu m$

Calculating the Work Index using Modified Berry and Bruce Method;

$$\text{Work index, } W_t = W_r\left(\frac{\frac{1}{\sqrt{P_r}} - \frac{1}{\sqrt{F_r}}}{\frac{1}{\sqrt{P_t}} - \frac{1}{\sqrt{F_t}}}\right)$$

$$\text{Work Index} = 15.14\left(\frac{\frac{1}{\sqrt{171.3}} - \frac{1}{\sqrt{255.8}}}{\frac{1}{\sqrt{156.9}} - \frac{1}{\sqrt{249.3}}}\right)$$

$$= 12.989 KWh/ton$$

Tables 1 to 4 show the results of particle size analyses of both reference sample and test ores passing for the feed and product sieve size fractions. The 80% passing particle size fraction for both feed and product of Azara copper ore was used in computing the work index. Hence, using the modified Bond's method of work index determination for Azara copper ore was found to be 12.989kWh/tonne and this implies that about 12.989 kilowatts hour of energy is required to grind the ore from infinite size to 80 per cent passing 100microns in line with Bonds work index. The work index obtained applies to particle sizes in the range -355µm to -50µm. The result obtained when compared with other copper ores lies favourably within the work indices of copper minerals cited in the literatures. Using the Denver grindability test curves, Azara copper ore can be classified as a medium soft texture type ore (B) because the work index of the Azara copper ore samples ground for one hour cuts through the curve line of the ore type **B** of Denver grindability curves (Mathur, 1985)

Conclusion

The Bond's work index of Azara copper ore was determined in this study. It is expected that this energy requirement (12.989kWh/tonne) will aid the design of the grinding plant for beneficiation of the ore.

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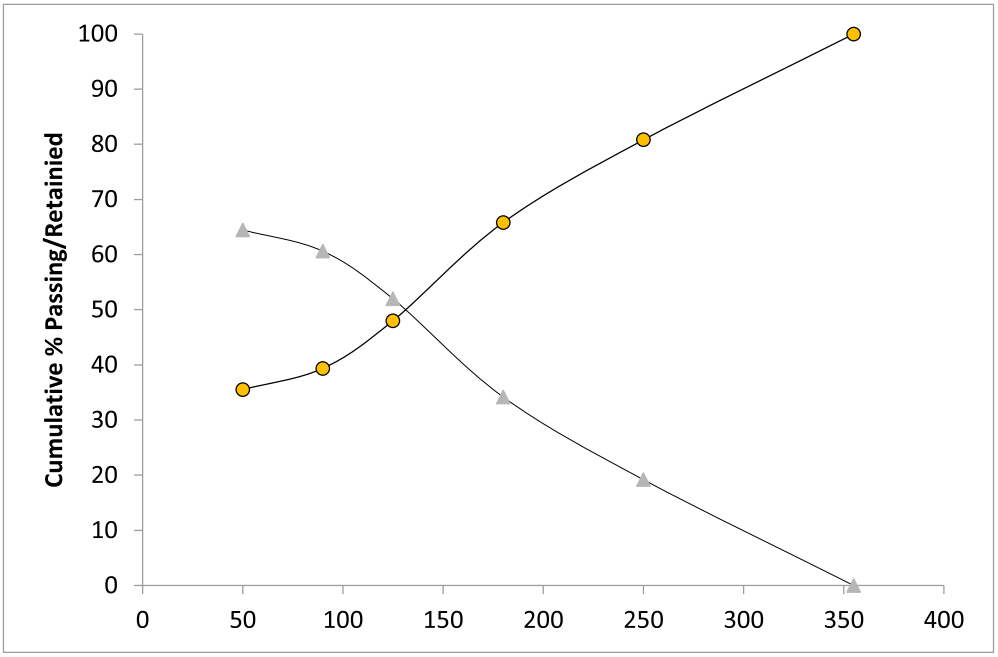

Fig.1: Plot of cumulative % undersize (passing) and oversize (retained).

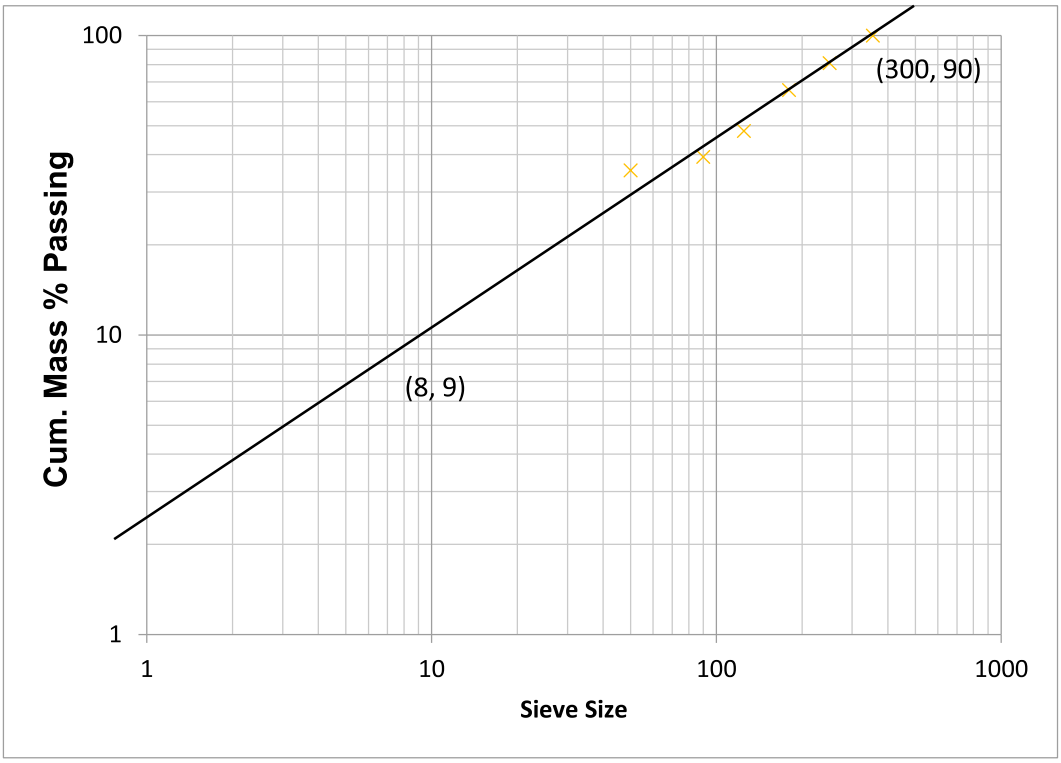

Fig. 2: Log-log plot of cumulative % passing (undersize) vs size, (Gaudin-Schuhman plot)

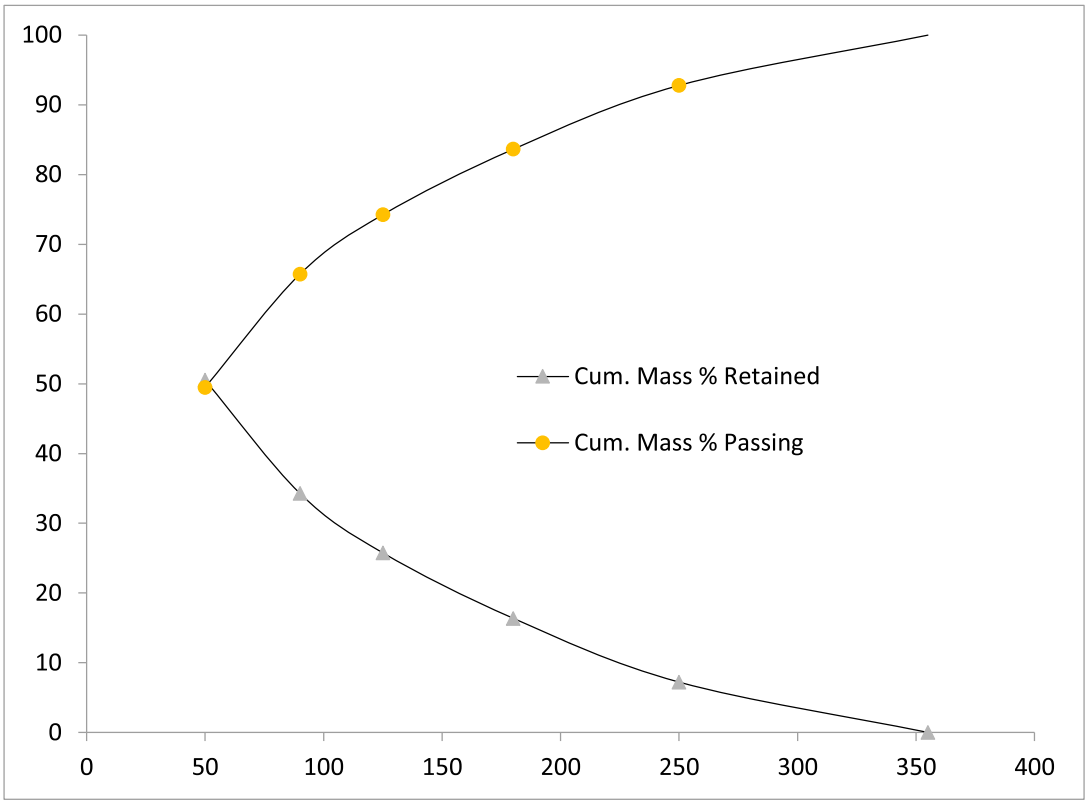

Fig.3: Plot of cumulative % undersize (passing) and oversize (retained).

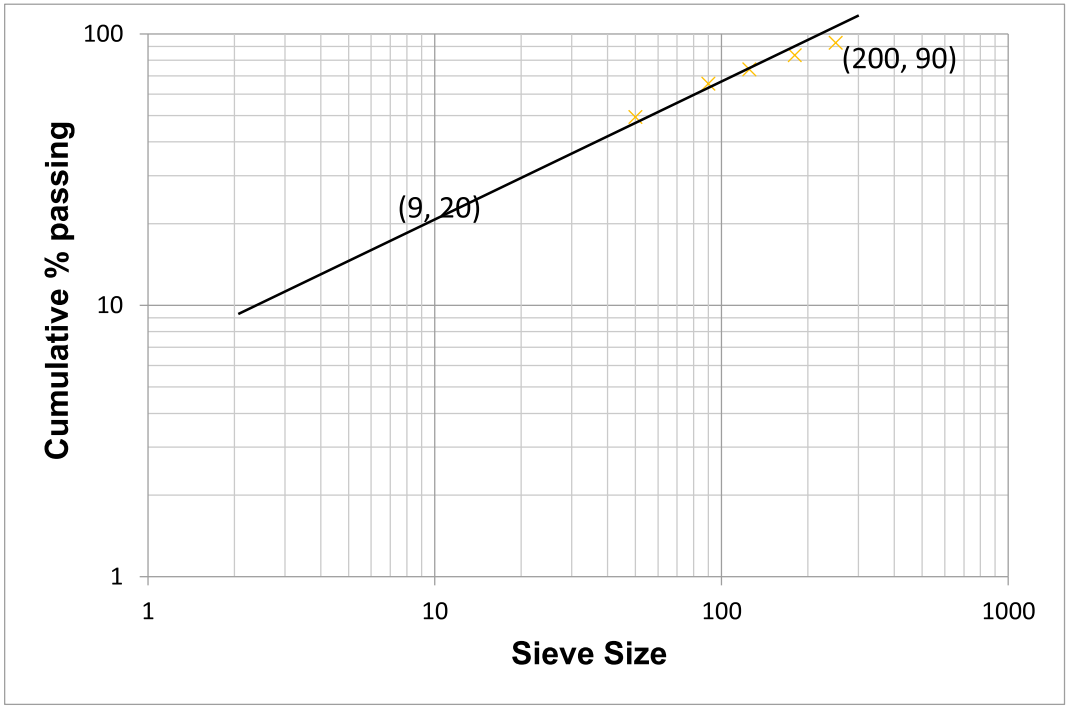

Fig. 4: Log-log plot of cumulative % passing (undersize) vs size, (Gaudin-Schuhman plot)

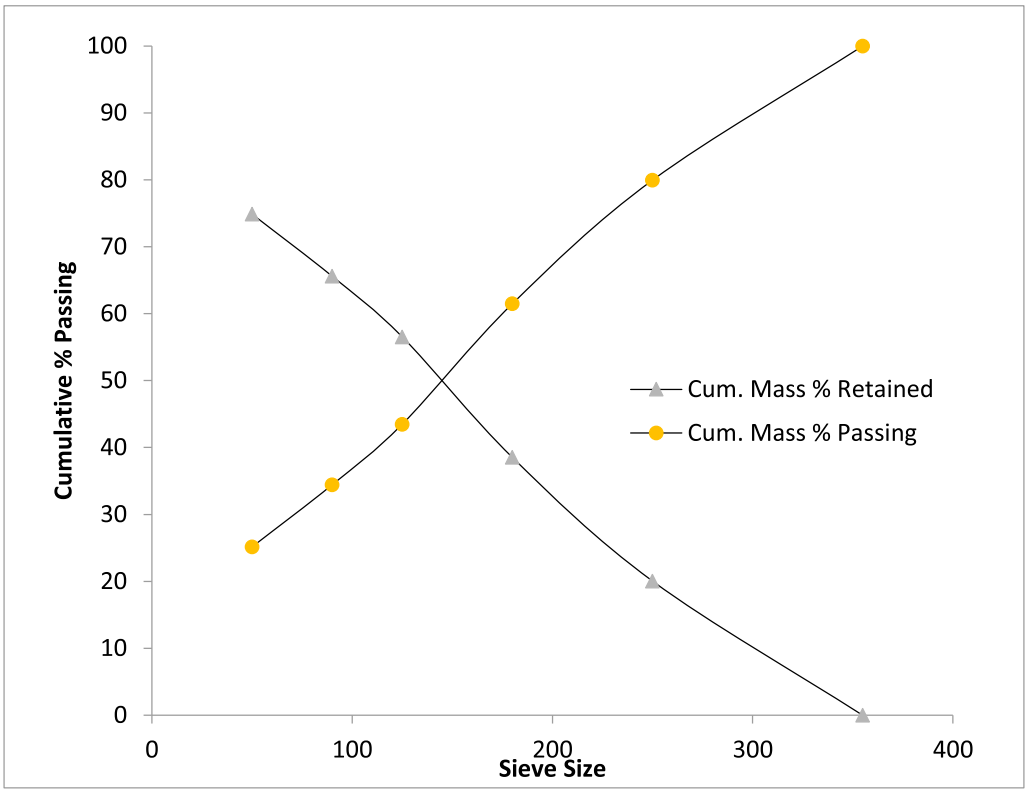

Fig.5: Plot of cumulative % undersize (passing) and oversize (retained).

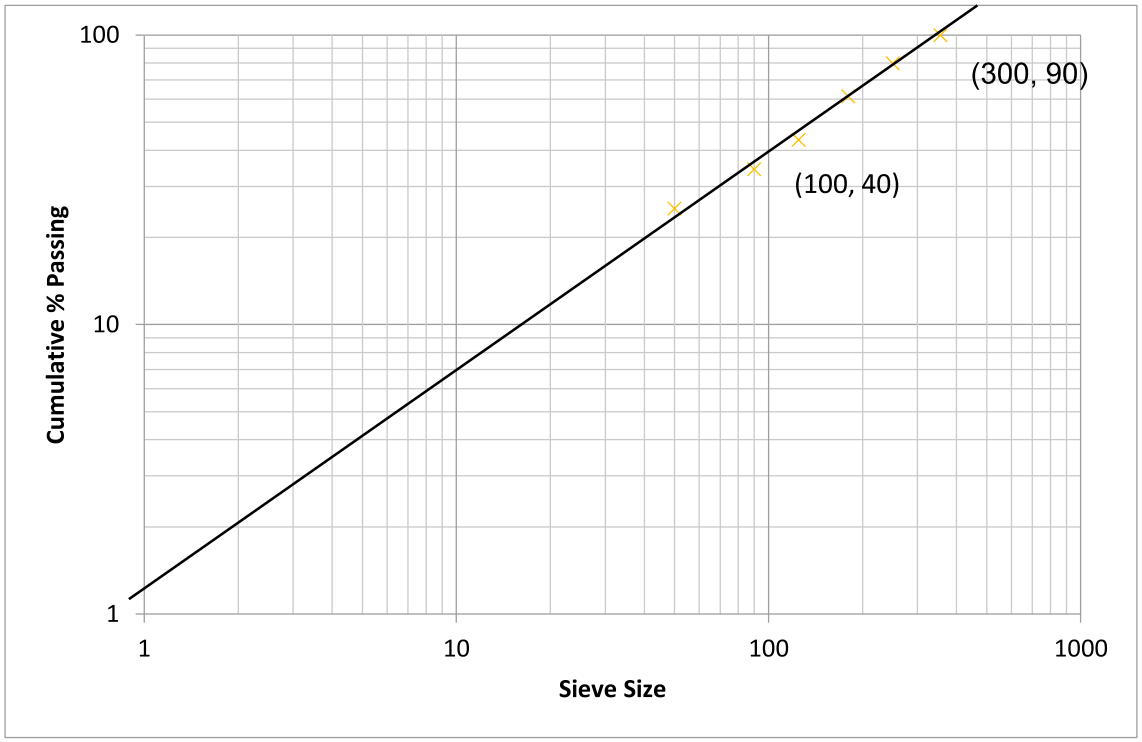

Fig. 6: Log-log plot of cumulative % passing (undersize) vs size, (Gaudin-Schuhman plot for reference ore feed)

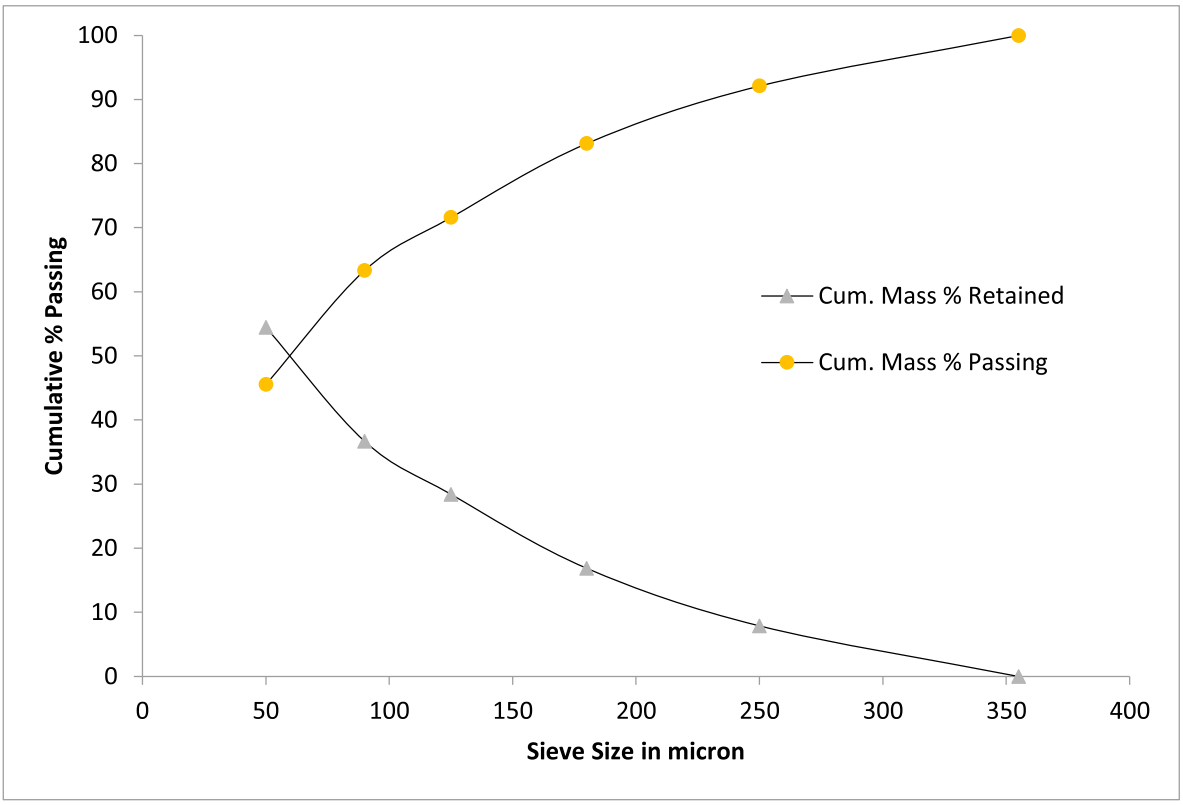

Fig.7: Plot of cumulative % undersize (passing) and oversize (retained).

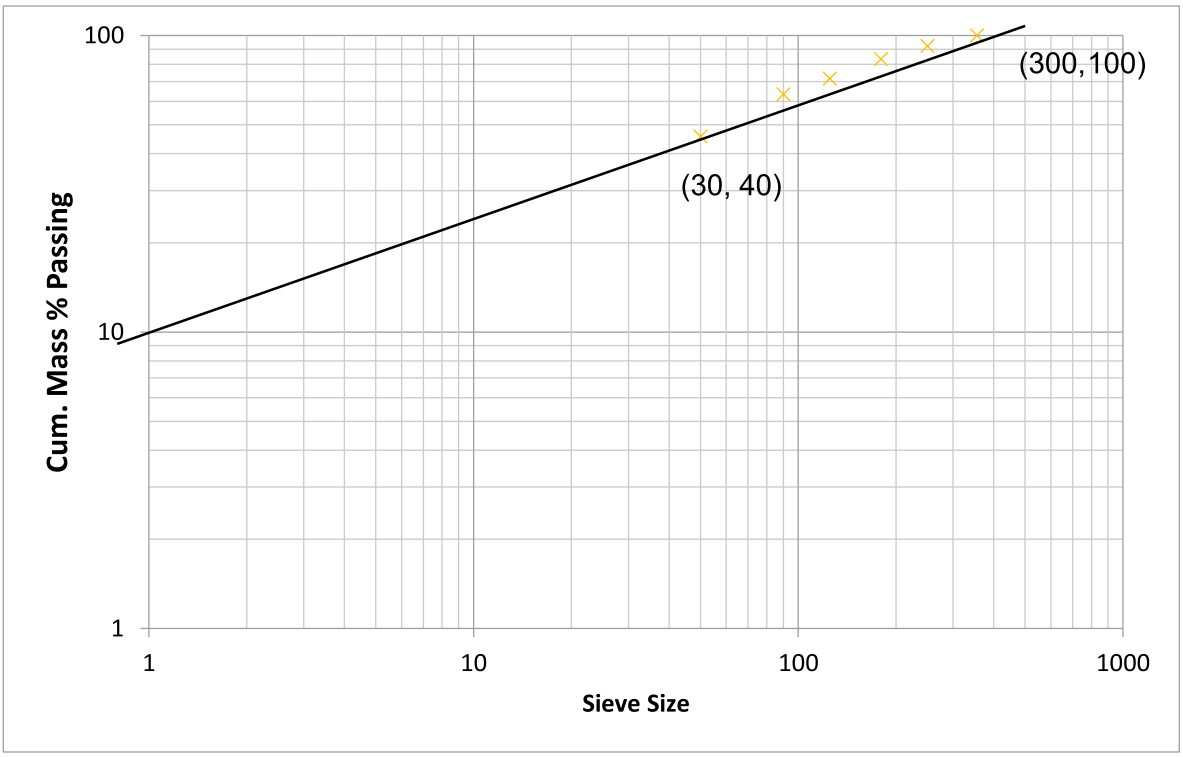

Fig. 8: Log-log plot of cumulative % passing (undersize) vs size, (Gaudin-Schuhman plot for reference ore product)

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Design and Development of Impact Apparatus for Determination of Crushability of Selected Rocks

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Abstract

The size reduction of brittle materials is the most essential mechanical operation within the raw materials processing and mining industry (reduction of large rocks into smaller rocks, gravel, or rock dust). Different types of mineral (rock) have different resistance to crushing force. In view of this, an impact apparatus was developed to enhance the availability of the equipment needed for determination of the required force to crush the rock material and selection of appropriate crusher. The apparatus was tested and it was found that the energy required to crush a dry sample was determined by the impact of two swinging hammers. Five (5) samples of the same thickness (50 mm) and geological formation were tested to determine the input energy required to crush each of the samples. The average input energy (1.28 Joules/mm) was used to determine the Bond Crushing Index of 19.23kWh/t.

Keywords: Aggregate, Construction, Comminution, Crushability Index and Impact Crushing Energy

Introduction

Size reduction of brittle materials is the most essential mechanical operation within the raw material processing, and mining industry. It is also an inefficient, energy intensive process that consumes billions of kilowatt-hours of electricity per year (approximately 3 - 5% of all electricity consumed on the national level (Hofler, 1990; Duthoit, 2000). In a large part because the scientific research required to lay down the theoretical foundations of particle size reduction has lagged behind the actual achievements of technology, resulting in the design and operation of crushing equipment based on standards that fail to adequately describe the entire particle breakage process (Noaparast, 2001). Since the technology is already in place, improvements in comminution are dependent upon optimizing the application and operation of that technology.

The failure to optimize the selection and operation of large, costly crushing equipment affects the entire mining industry. However, the aggregate industry is particularly burdened by the utilization of inefficient crushers due to the absolute dependence on the crushing plant to provide a finished product that provides all the revenue for the mining operation (Svensson and Steer, 1990). Aggregate producers are reliant on crushers to produce low value materials at high-throughputs that also must meet stringent quality standards (particle size and shape for Supersaver mix design). Furthermore, the design of aggregate crushing processing plants requires rugged, massive, and expensive equipment, and misjudgements in design are difficult, if not impossible, and expensive to correct (Duthoit, 2000).

In today's crushing environment, the need for the optimization of primary crusher selection and operation to meet the economics of quarrying requirements has become imperative (Dediemar, 1990). The benefits of optimization include reduced capital costs, reduced unit operation costs, increased throughput and improved performance of downstream processes as a result of improved feed size specification

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(Napier-Munn *et al.*, 1999).

Crushing is the process of transferring a force amplified by mechanical advantage through a material made of molecules that bond together more strongly, and resist deformation more, than those in the material being crushed. Crushing is one of the steps involved in preparing and processing of minerals. This operation is carried out using equipment called crusher.

A crusher is a machine design to reduce large rocks into the smaller rocks, gravel, or rock dust. However different types of mineral (rock) have different resistance to crushing force, Therefore an apparatus for determining the energy required or force required to crush the rock material was designed and developed locally to enhance the availability of the equipment needed for mineral processing.

The Table 1 shows bond work index by minerals.

Materials and Methods

Material Selection

In order to achieve an intelligent and durable design, to produce a machine that could be easily maintained, materials were sourced for locally. The factors considered in selecting the materials used for this machine were the chemical and mechanical properties: the strength, fatigue, impact, cutting, service life, loading shock, wear, corrosion, service cost, and environmental.

Design Considerations

The following were some of the important factors considered in the design of the machine.

Strength

The stress acting on various part of any machine should be known to avoid failure.

Rigidity

The machine should be firm in operation. The parts are properly bolted, the frame well brazen and part needed to be welded to give adequate rigidity.

Vibration Stability

The machine was constructed to have stability and less vibration.

Durability

The machine should have long life span and low maintenance cost. Basically, the selected materials should be corrosion resistant.

Transportability

This is one of the essential reasons for fabricating such machine, simple and portable machine that could be transported easily in the quarry site and easy to operate by the quarry operators.

Machine Description

The design adopted is shown in Fig.1. It consists of two hammers, two wheels and belt for swinging the hammers and a pedestal table that carries the pedestal on which the rock sample is placed. It also has a frame supported by a pillar which serves as stand for the apparatus and a hanger that carries the hammers.

Design Parameters

The design of an impact crushing for processing depends on the following parameters:

i. Nature of deposit to be crushed;
ii. Feed size; and
iii. The desired product size.

The Nature of Material to be crushed

The material to be crushed is of metamorphic origin. The nature of the ore or material can be based on the following criteria:

Hardness

This is the resistance a material imposed to abrasion or scratching and is commonly designated approximately by number. This is done according to the scale of hardness.

Specific Gravity

This is the weight of substance compared with that of an equal volume of water.

Feed Size

The feed size for the impact crusher is determined by the space provided for the feed bin on the impact crusher between the two hammers. In this work, the feed bin is designed to handle about 2 inch (50 mm) height of feed size material to crushing chamber.

The Desired Product Size

The output or the final product size which is to be obtained by crushing the feed material depends on the purpose the material is to be

Table 1: Work Bond index by Minerals

	Source 1	Source 2	Source 3	Source 3	Source 4	Source 5	Source 6	Source 6 KWh/t	Source 6
Average Bond Work Index	kWh/t	kWh/t	kWh/sh.t	kWh/t	kWh/t	kWh/t	kWh/t	Range	No of Tests
Alumina							17.9	7-34	6
Andesite	20.1		18.3	20.1	19.5				
Barite	6.3		4.7	5.2	5.0		5.8	4-9	7
Basalt	18.9		17.1	18.8	19.0	19.0			
Bauxite	9.7	9.5	8.8	9.7	10.0	10.0	14.5	1-31	29
Cement clinker	15.0	13.1	13.5	14.8	15.0	15.0	13.6	7-77	180
Cement (raw)	11.6				12.0	10.6	10.0	3-27	284
Chrome ore							13.4	7-17	5
Clay			6.3	6.9	7.0	7.1	10.8	4-23	11
Clay calcined						11.4	19.6	15-26	7
Coal		11.3	13.0	14.3	14.5	11.4	15.4	13-18	6
Coke	16.7	21.0	15.1	16.8	16.5	17.0	33.5	29-40	4
Coke Petroleum		74.5							
Copper - nickel ore							15.5	13-18	6
Copper ore	14.0	13.0	12.7	14.0	14.0		12.8	4-30	769
Copper - zinc ore							9.8	5-14	9
Corundum						30.4			
Diorite	23.0		20.9	23.0	23.0		11.6	10-13	2

Source 1: Table of Materials Reported by Fred Bond (1960); Source 2: Out-Okumpu, The Science of Comminution; Source 3: Equipment and Pipelines; Source 4: Tenova Bateman Mills (AG/SAG, Rod, Ball Mills); and Source 5: Doering International GmbH www.cylpebs.com

used for. In this design, the end product size is collected from the table housing the crushing plant (Kogbe, 1989).

Description of Various Units and Components

Frame

The frame of the impact apparatus was designed with 710 mm x 70 mm x 50 mm U-channel bar, supported by a pillar designed with a square pipe of 92 mm x 92 mm mild steel which serves as the stand for the apparatus (Fig 1).

Pedestal Table

The pedestal table was designed with 70 mm x 5 mm U-channel bar of length 1020 mm. The table is to carry the pedestal on which the rock sample is placed (Fig. 1).

Hammer Mill

The hammer mill which operates by striking rock or ore piece placed on the pedestal was designed with a rectangular bar of 980 mm x 50 mm x 25 mm (Fig. 1).

Wheel and Protractor

Bicycle wheel of diameter 434 mm was used in the design. The protractor made with ply wood was calibrated in degrees for measuring the striking angle (Fig. 2).

Fabrication of Various Components and Units

Frame

U-channel bars of 710 mm x 70 mm x 50 mm was welded together using electric arc welding to form the frame which served as the stand for the apparatus. This is to enable it withstand the weight and swinging effect of the hammer mill. A square pipe of 92 mm x 92 mm was also welded to the frame to provide support for the frame and hanger to carry the hammer (Fig. 3).

Pedestal Table

The pedestal table was fabricated using U-channel (1020 mm x 70 mm) bar of thickness 5mm, welded to the frame. The pedestal 200 mm x 60 mm x 8 mm U-channel bar was also welded to the frame.

Hammer Mill

Two rectangular bars of 980 mm x 50 mm x 25mm (mild steel) was welded together to fabricate the hammer mill. The hammer mill was joined to the wheel using a 240 mm x 50 mm x 25 mm rectangular bar.

Wheel and Bearing

Two bicycle wheel of diameter 434 mm were used as the wheel of the apparatus through which the hammer swing. Two 80 mm x 30 mm shaft was machined to form the bearing house. 12 mm rods were then used to connect the bearing house to the wheel (Fig. 4).

Table 2 is the specification for the Design and Fabrication of Impact Apparatus for Determination of Crushability of Selected

Results and Discussion

Results

After the apparatus has been assembled, it is necessary to test the equipment to determine its efficiency and adjust where necessary. A sample of dolomitic marble from Oreke dolomite deposit in Ifelodun Local Government Area of Kwara State was used to test the machine. Five specimens each of 50 mm thickness were used and the result tabulated as in Table 3.

Discussion

The result obtained from the crushability test (Table 3) shows that each specimen breaks at different angle of the hammer mill. The different in the breaking angle results in different work index for the specimens as the angle is used in calculating the height of the hammer. Table 3 also indicate the weight of each specimen and their corresponding relative density.

The difference in the work index for each specimen is as a result of difference in the mineralogical compositions of the sample. Dolomitic marble with high content of magnesium are said to be brittle and require less energy.

The impact crushing energy (I) is calculated for each of the specimen from the expression:

$$I = \frac{2 \text{ x } M \text{ x } H}{d} \qquad (1)$$

Where M = mass of one Hammer is16.3 kg

d = the thickness of the specimen (mm)

Height of the Hammer (H) is given by

$$H = L\,(1 - \cos\theta)\,(m) \qquad (2)$$

Where, L is the vertical length (m) of the hammer from the bearing and θ is the breaking angle (°) of each of the specimen.

The average impact energy (I) was calculated as 1.28 Joules/mm. The value of I was averaged over the five tests and the below expression is used to calculate the Bond Work Index (W_i).

$$W_i = \frac{C\,X\,I}{Relative\ Density\ of\ Specimen} \quad \ldots(3)$$

Where C, is a constant which converts the crushing strength, numerically and dimensionally to the work index, C = 53.49 for I in Joules/mm and W_i in kWh/t (Bond, 1960).

Therefore,

$$W_i = \frac{53.49 \times 1.28}{3.573}$$

$$W_i = 19.23\text{kWh/t}$$

Conclusions and Recommendation

Conclusions

The Impact Apparatus designed and constructed can be used to determine the required force to crush the rock material and selection of appropriate crusher. From the result obtained, it shows that the average impact energy required to crush dolomitic marble of about 50 mm thickness from Oreke marble deposit is 1.28 Joules/mm and the work index is 19.23kWh/t. The point at which rocks shattered varies, and this depends on the weight of the rock. The materials used in fabricating the impact apparatus were locally sourced. This is an indication that equipment like this could be fabricated and utilized in the processing of minerals, reducing the amount of imported ones.

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Table 2: Design Specification

S/N	Description	Dimension
1.	Frame	710 mm x 710 mm x 50 mm
2.	Pedestal Table	70 mm x 5 mm x 1020 mm
3.	Hammer Mill	980 mm x 50 mm x 25 mm
4.	Wheel and Protractor	o 434 ????
5.	Square Pipe	92 mm x 92 mm
6.	Bearing	o 12 ????
7.	Rectangular Bar	240 mm x 50 mm x 25 mm
8.	Feed Size Height	50 mm

Table 3: Results of the Crushability Test

SPECIMEN	WEIGHT (grams)	NUMBER OF FRAGMENTS (n)	BREAKING ANGLE(θ) (°)	Relative Density (g/cm^3)
1	1510	5	140^0	3.113
2	880	4	120^0	3.485
3	710	3	100^0	3.944
4	650	4	90^0	3.333
5	560	2	80^0	4.000

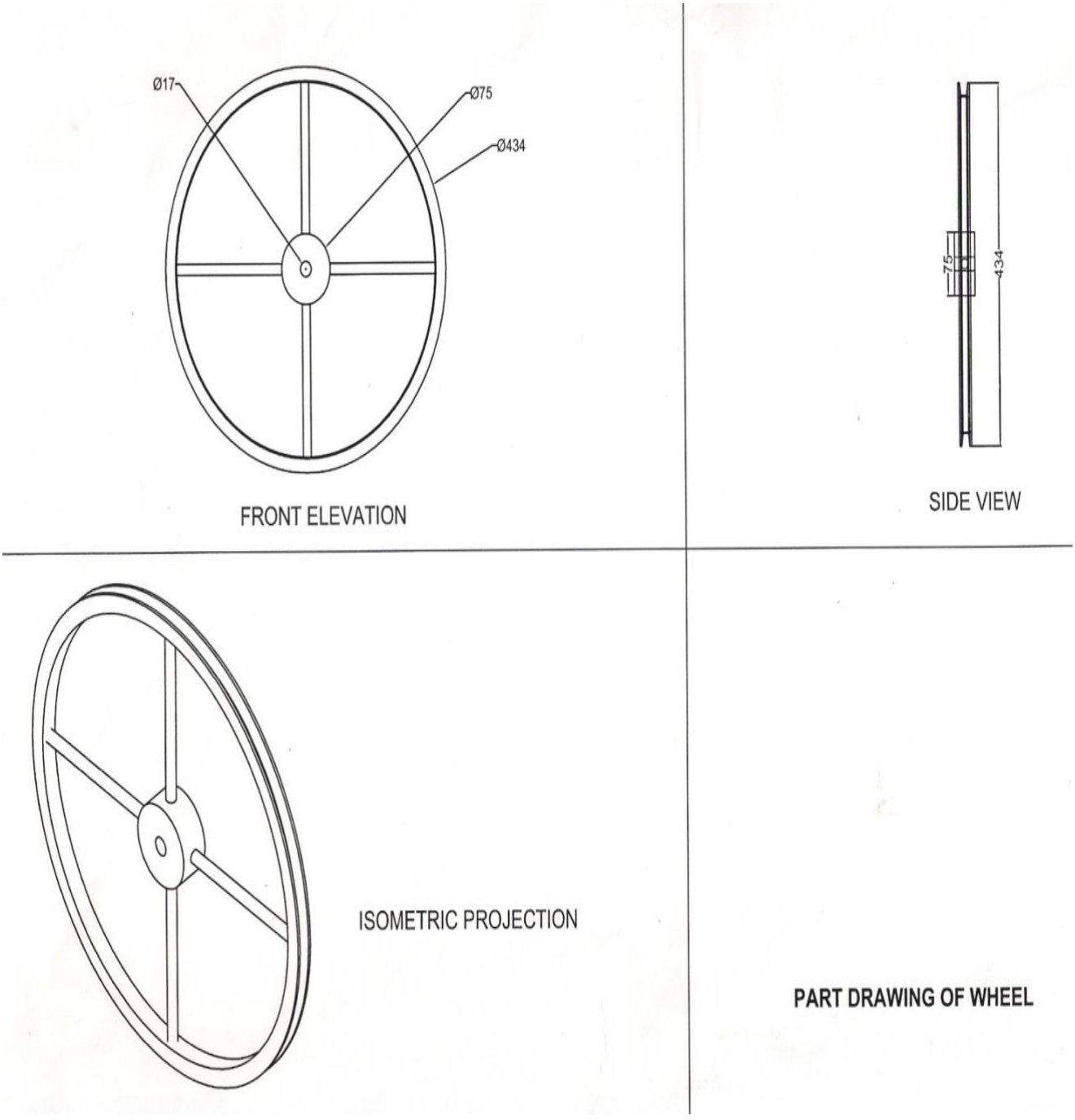

Fig. 4: Diagram Showing the Wheel and Bearing

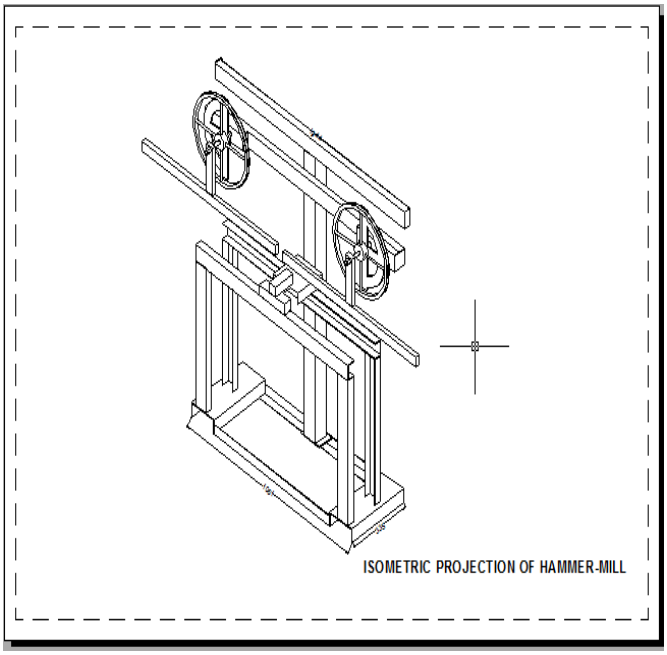

Fig. 1: Diagram showing the isometric projection of the apparatus

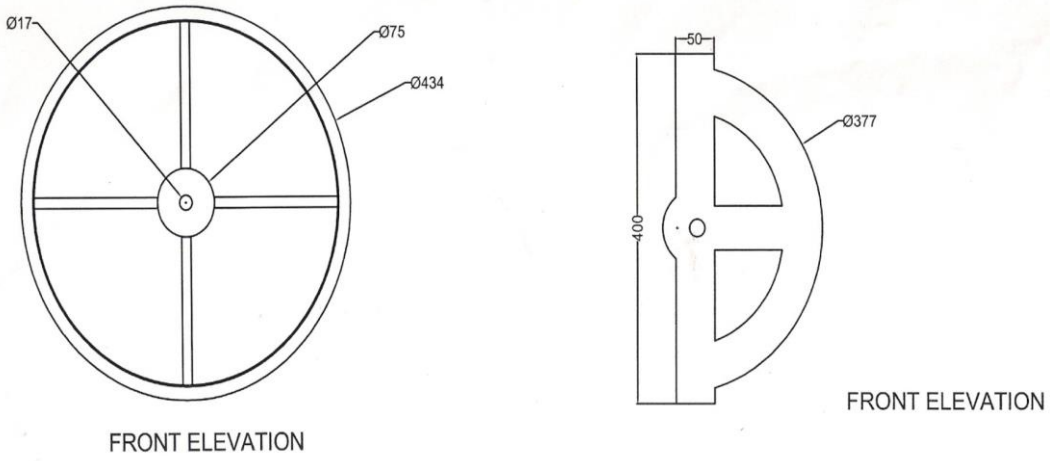

Fig 2: Diagram showing the Wheel and Protractor

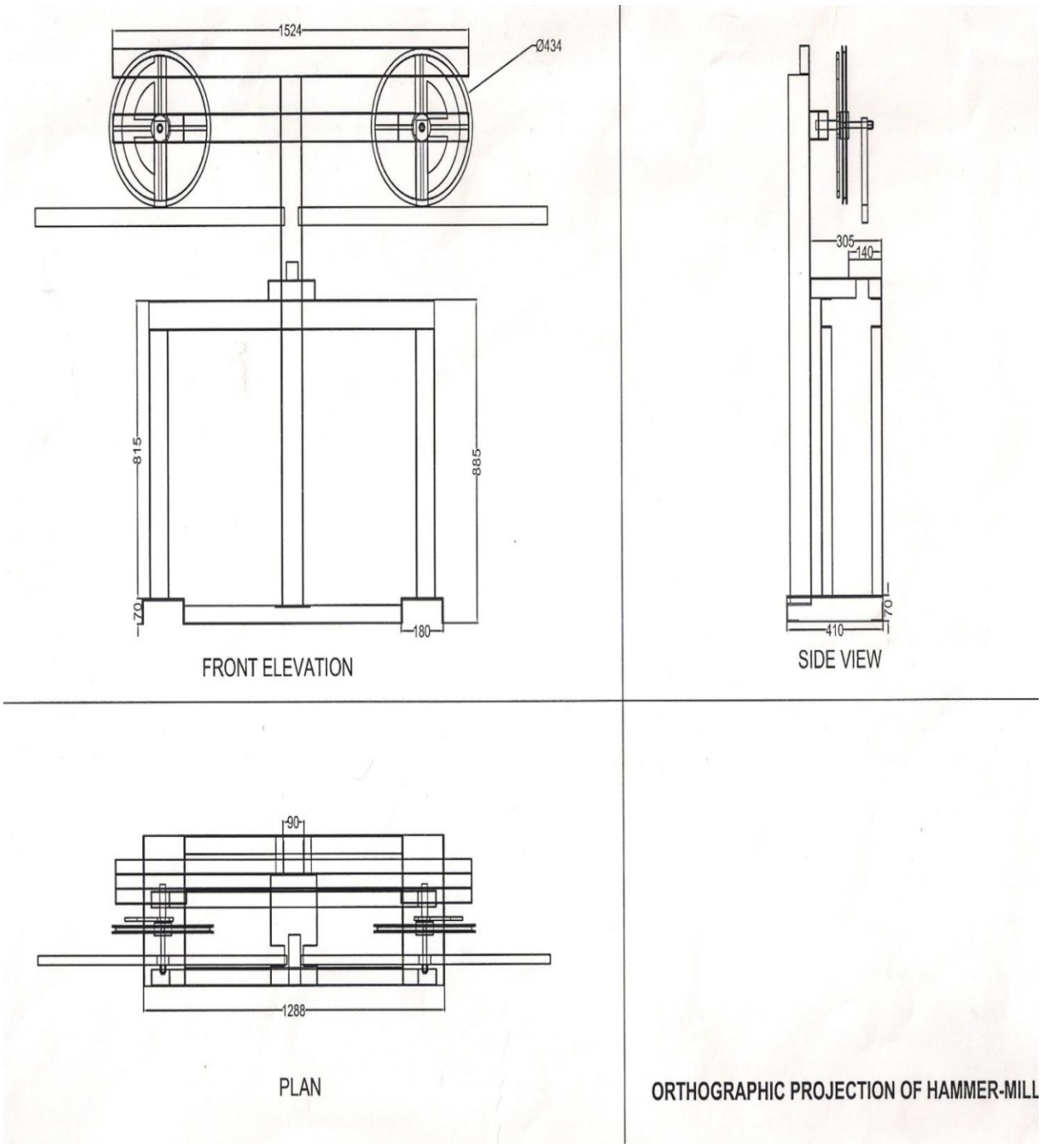

Fig. 3: Orthographic Projection of the Apparatus

Chemical, Mineralogical Characterization and Determination of Liberation Size of Gyel Columbite Mineral Ore, Plateau State, Nigeria

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Abstract
The chemical, mineralogical characterisation and determination of the liberation size of Gyel columbite ore sample were carried out. The sample was sourced from different pits within the vicinity of Gyel village, a community in Plateau state of Nigeria. The samples were homogenized, pulverized and analysed using ED-XRF, XRD and SEM to ascertain the chemical and mineralogical compositions of the Gyel columbite mineral ore. The XRD result of the analysed mineral ore sample revealed that, the ore consists of anastase, cassiterite, columbite, ilmenite, muscovite, quartz, rutile and zircon as the predominant mineral constituents. The chemical composition of the Gyel columbite mineral ore was determined using Energy Dispersive X-ray Fluorescence Spectrometry and the ore contains the following: Nb_2O_5 (6.71%), Al_2O_3(4.2%), SiO_2(27.0%), Fe_2O_3(23.1%), TiO_2(22.2%), Ta_2O_5(0.79%), SnO_2(6.47%), ZrO_2(14.7%), and MnO(1.01%) as the major chemical compounds, while CaO, V_2O_5, NiO, HfO, Rb_2O, Ag_2O, Au, PbO, Bi_2O_3,U_3O_5, and ThO_2 were found in traces as the minor chemical compounds of the ore sample.

Key Words: Columbite, Chemical, Mineralogical, Liberation Size, Characterization.

Introduction
Niobium occurs in Nigeria in the form of columbite with varying associated minerals such as tin, Iron (Ofor, 1992 and Martins et al, 2011). The major sources of ore bearing columbite in Nigeria are the alluvial and lode deposits from the biotite granites within the Jurassic alkaline ring complex of the Jos Plateau. Pastor,(1986) and Martins Ogwuegbu et al, (2011) stated in their work on mineralogical characterization of Kuru cassiterite ore by SEM-EDS, XRD and ICP Techniques that are less than 5% of the total production of these minerals have been recovered from the pegmatites within the largely Precambrian basement complex consisting of magnesites, gneisses, but with rapidly depleting reserves. Large deposits of columbite mineral have so far been discovered in the country, making Nigeria one of the potential countries in the world as far as the mineral is concerned; with a workable columbite reserve estimated at over 114,000 million tons (Nnamdi, 2010). Nigeria was a major exporter of columbite, cassiterite and tantalite in the past to the tune of about 11,000 tons per annum in the 60s to mid-70s; since then there has been a drastic decline to about 2000 tons per annum in recent years (Mallo, 2007). Among the factors accounting for the collapse of columbite industry in the country are the inaccessibility of placer deposits due to outdated machineries in use and the prohibitive cost of mining the ores beneath the basalt flow of Jos, Plateau (LME, 2014 and Metallic mineral, 2010).

In the nineties, the available technique used for analysis in Nigeria is the solution or wet methods of either fusion or acid digestion which were believed to report low data due to incomplete solubilisation of the minerals in aqueous medium (Funtua et al, 1997, Evans and Jackson, 1989, Martins et al, 2011). This has resulted in production of large quantity of tailings which when further processed, could yield more minerals such as columbite, tin ore, zircon sand e.t.c (Funtua, et al, 1997 and Abubakar, et al,

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2009. Presently, several attempts have been made to correct the analytical deficiency, (Funtua, et al, 1997, Abubakar, et al, 2009 and Xiaohui et al, 2009). In each of these, either the elemental analysis is carried out or just the phase analysis, this provides incomplete information about the ore and delude the proper development of the process route for the beneficiation and extraction of the metallic content of the ore.
Dungka, et al, (2014) worked on some Nigerian columbite mineral deposits with special focus on the newly discovered Soba-Wanka columbite ore deposit. In their findings they concluded that most of the columbite mineral deposits in Nigeria have high percentages of titanium and tantalum than the niobium mineral which prospective buyers do claim to buy and the purchased columbite mineral ore samples are mostly pyrochlore-coltan minerals in nature rather than columbite mineral. See Tables 1 and 2.

Table 1: Chemical Analysis (conversion of oxide to element) of Soba-Wanka Pyrochlore- coltan Mineral Ore Deposit using XRF.

Compound	**% composition**	**Element**	**Multiplier**	**% composition**
Ta_2O_5	16.0	Ta	0.4095	6.55
Fe_2O_3	34.28	Fe	0.8993	30.83
Nb_2O_5	5.0	Nb	0.3495	1.75
Sc_2O_3	0.19	Sc	0.6519	0.12
TiO_2	29.6	Ti	0.5992	17.74
V_2O_5	0.63	V	0.5599	0.35
MnO	4.46	Mn	0.7740	3.45
Al_2O_3	0.9	Al	0.5291	0.48
SiO_2	7.9	Si	0.4671	3.69
CaO	0.49	Ca	0.7148	0.35
Au	0.57	Au	-	0.57

Source: (Dungka, et al, 2014)

Table 2: Petrological/mineralogical Composition of Soba-Wakan Pyrochlore -coltan Mineral Ore

S/No	Mineral Composition(compound)	Natural/Colour	Estimated Population(counts)
1	(Fe,Mg)$_3$Mn,Nb,Ta}Al_2SiO_{12}) Pyrochlore(Sphene/Rutile) ($FeCr_2O_4$) ((Na,Ca)2(Ti, Nb)$_2O_6$	-Light Brown - Pale Yellow	45 35
2	Quartz (SiO_2)(silica)	-Green/Blue	8
3	Others (associated minerals)	Unstable various colours in traces	12

Source: (Dungka, et al)

This work is aimed at characterizing a typical Nigerian ore named Gyel columbite with different modern instruments for the purpose of compositional elucidation and documentation of the comprehensive data produced on the chemical, mineralogical composition and liberation size of the Gyel columbite ore

Materials and Method

Materials and method used in carrying out this research work successfully are as follows:

Materials

Columbite sample weighing 200kg was collected from Gyel mining site pits. The ore sample was dried in the sun; out of which

only 5kg was taken using random sampling method for the entire analyses. The sample was pulverized using Denver roll crusher and sieved using sieve sizes of ASTM 1400µm, 1000µm, 710µm, 500µm, 355µm, 250µm, 180µm, 125µm, 90µm and 63µm.

Chemical Composition Characterization of the head sample Using XRF

The chemical composition of the head sample was determined using XRF. The XRF analysis was done in the Faculty of Natural and Agricultural Science, Geology Department, University of Pretoria. Pretoria, South Africa. Thermo Fisher ARL9400 XP + Sequential XRF and aliquant software were used for the XRF analysis. Before the analysis of the ore was milled to -75 µm, pressed into powder briquettes standard as required by the machine for proper mineral count and analysis. Each sample was placed in the machine for one hour thirty minutes (thirty minutes for major elements and one hour for the trace elements). The software used analysed all elements in the periodic Table between Sodium (Na) and Uranium (U) but only elements found above the detection limits were reported. All major elements were expressed as oxides and analysed in percentage (%) composition.

However, for trace elements analyses, the samples were mixed with polyvinyl alcohol (PVA) binder and pressed into a pellet using a 10 ton press. The sequential XRF with WinXRF software was used for analysis. A blank and certified reference material was always analysed alongside with the samples. The result of this analysis in parts per million (ppm) is presented in Table 3.

Mineralogical Characterization Using X-Ray diffractometer (XRD)

The XRD analysis of the sample was carried out at the Faculty of Natural and Agricultural Science, Geology Department, University of Pretoria, Pretoria South Africa. The samples were prepared for XRD analysis using a back loading preparation method. The back loading sample preparation method involved cleaning the holder ring and back piece with acetone, placing the ring in the spring-loaded holder, transferring enough sample material to fill the ring just above level, using the blade to tap the powder into place, making sure no gaps were left near the edge of the ring. Pressing the pug down and clearing away of powder that fell on the outer ring, while holding the die in place, the pug was then removed and the back piece was placed over the ring, the ring was then released from the spring loader holder. Care was taken to avoid crack or collapse of material. The rings were marked with a permanent marker and then put in the machine sample holder and then placed in the machine. The sample was analysed using a PANalytical X'Pert Pro powder diffractometer with X'Celerator detector and variable divergence and receiving slits each set at 10mm with Nb filtered Co-Kα radiation. The sample was scanned at the required 2θ angle. The phases were identified using X'Pert High score plus software. The relative phase amounts (weight %) were estimated using the Rietveld method (Autoquan Program). Errors encountered during this process are on the 3 sigma. The results of the analyses are presented in Figure 1 and Table 4.

Scanning Electron Microscopy/Energy Dispersive Spectrometer (SEM/EDS).

The SEM-EDS was carried out at the Centre for Scientific and Industrial Research (CSIR), Pretoria Republic of South Africa. Using the Field Emission Scanning Electron Microscope equipped with Energy Dispersive Spectrometer (FESEM-EDS) model JEOL JSM-7500F and a sparter coating machine (Emiteck K950X) for gold plating of particles. During the observation EDS mapping and EDS point analysis were also carried out and back scatter images generated. In SEM analysis a small amount of powder sample was taken and placed on the sample holder which was then placed inside the machine. A vacuum was then built in the sample chamber, then the sample was irradiated to generate emission from

which micrographs of the sample were generated after which back images of the sample were captured and readings taken. The elements of the sample were determined by the EDS. The images were shown with point analysis at the positions of the ore particles. The results are presented in Plate 1 and figure 2.

Liberation Study

100g of the crushed ore was introduced into a set of sieve arranged in descending order using root two formula from 1400µm to 63µm and shaken for 15 minutes. The weight retained in each sieve was taken and expressed as percentage of the total sample weight. Liberation studies were carried out with optical microscope calibrated with a stage micrometer used in viewing the mounted sample. With this calibration, accurate average sizes of the various minerals associated with the ore were measured. This measurement is not only important scientifically but also permits the estimation of the crushing size necessary to free the mineral grains of the ore. The result of this study is presented in Table 5.

Results and Discussion

Chemical Compounds Characterization of Gyel Columbite Ore Sample Using Energy Dispersive X-ray Spectrometer(ED-XRF)

The result of the chemical compounds composition analysis of Gyel columbite using ED-XRF on Table 3 revealed that, the ore contained Nb_2O_5(6.71%), Al_2O_3(4.2%), SiO_2(27.0%), Fe_2O_3(23.1%), TiO_2(22.2%), Ta_2O_5(0.79%), SnO_2(6.47%), ZrO_2(14.7%) and MnO(1.01%). Others found in their traces are CaO,V_2O_5,NiO,HfO,Rb_2O,Ag_2O,Au,PbO,Bi_2O_3,U_3O_5, and ThO_2. This result compared favourably with that of the literature sighted in Table 1 and portrays Gyel columbite as another potential source of niobium, titanium manganese and zircon minerals.

Table 3: ED-XRFS Analysis of Gyel Columbite Ore

Parameters	% Composition
Al_2O_3	4.2
SiO_2	27.0
TiO_2	22.20
Fe_2O_3	23.1
ZrO_2	14.7
Nb_2O_5	6.71
SnO_2	6.47
Ag_2O	1.0
Ta_2O_5	0.79
ThO_2	0.15
U_3O_8	1.26

Mineralogical Characterization of Gyel Columbite Ore Sample Using X- ray Diffraction (XRD) and SEM
Using X- Ray Diffraction (XRD)

The mineralogical composition analysis of the crushed columbite bearing ore was carried out using X- ray diffraction technique. The main mineral found in the sample and their standard deviation in 3ơ error were Anastase (0.51), Cassiterite (0.28), Columbite(0.63), Ilmenite(1.14), Muscovite(1.68), Quartz(1.05), Rutile(0.63) and Zircon(0.66). Table 4 shows the relative phase amount (weight %) using the Rietveld method and Figure 1 shows the XRD phase diffraction pattern (diffractogram). From the diffractogram ilmenite minerals are predominant when compared to zirconite and other minerals in the matrix of the Gyel columbite mineral ore sample. Hence, the Gyel columbite is more of titanite than niobium base columbite and could be another pyrochlore-coltan mineral ore rather than columbite. The mineral phases present in the Gyel presumed columbite mineral ore compared favourably with the literature result sighted in Table 2.

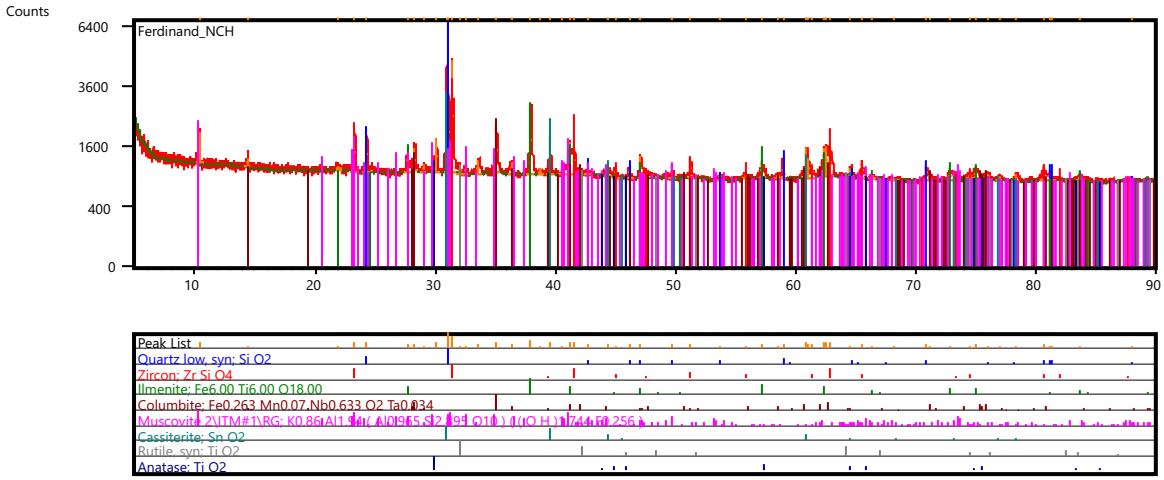

Figure 1: XRD Pattern of Gyel columbite ore showing the signature lines for Nb_2O_5

Table 4: **XRD Peak Analysis by PANanalytical X'pert Pro Powder Diffractometer in θ - θ Configuration Identified using X'pert High Score plus Software**

NCH		
	weight%	3 σ error
Anatase	3.97	0.51
Cassiterite	5.08	0.28
Columbite	8.19	0.63
Ilmenite	33.54	1.14
Muscovite	8.66	1.68
Quartz	20.35	1.05
Rutile	3.99	0.63
Zircon	16.22	0.66

Using Scanning Electron Microscopy (SEM)

The elemental morphological characteristics of the crushed particles of Gyel columbite were analysed in order to determine liberation size of each particle using EDS-SEM techniques. The sizes of the particles varied from 300 µm to 63µm. The SEM image shows interlocking of some minerals within some crystal aggregates. The EDS %weight elemental composition analysis presented in a tabular form below revealed the presence of Zn, Al, Ta, P, Nb, Ag, Ti, V, Fe and O. with tantalum, titanium and niobium elements as the predominant constituents in the matrix of the Gyel columbite bearing minerals. Plate 1 shows the SEM images of the various mineral particles and Figure 2 shows the details of the EDS analysis data. This result compares favourably with the results of literatures sighted in Table 2.

Liberation Studies

Table 5. gives the percent degree of liberation of the major constituents minerals in the Gyel columbite sample at various sieve size fractions. Significant liberation of 29%Nb_2O_5 was obtained at the sieve size fractions of -63µm. This indicates that reasonable quantities of Nb_2O_5 can be obtained if the ore is ground to -63µm when compared to other sieve size fractions. Hence, -63µm is the liberation size of niobium bearing mineral of the Gyel columbite ore sample.

Conclusion

The chemical, mineralogical characterization and determination of the

liberation size of Gyel columbite ore sample in Plateau state of Nigeria has been investigated and the following conclusions could be drawn:

(i) the chemical composition characterization revealed that the ore contained Nb_2O_5(6.71%), Al_2O_3(4.2%), SiO_2(27.0%), Fe_2O_3(23.1%), TiO_2(22.2%), Ta_2O_5(0.79%), SnO_2(6.47%), ZrO_2(14.7%) and MnO(1.01%) and others traces found in the ore sample are CaO, V_2O_5, NiO, HfO, Rb_2O, Ag_2O, Au, PbO, Bi_2O_3, U_3O_5, and ThO_2,

(ii) the mineralogical composition characterization of the ore revealed that ore consists of anatase (TiO_2), cassiterite (SnO_2), columbite (Nb_2O_5), ilmenite ($FeO.TiO_2$), muscovite, quartz (SiO_2), rutile (TiO_2), zircon ($ZrSiO_4$) as the major minerals with different proportions of weight percent.

(iii) the liberation study of the ore revealed that the niobium bearing minerals in the ore matrix can be liberated at particle size fractions of -63µm.

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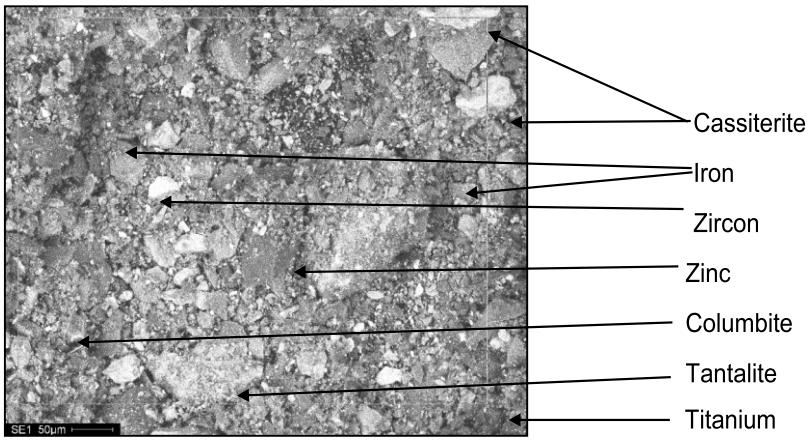

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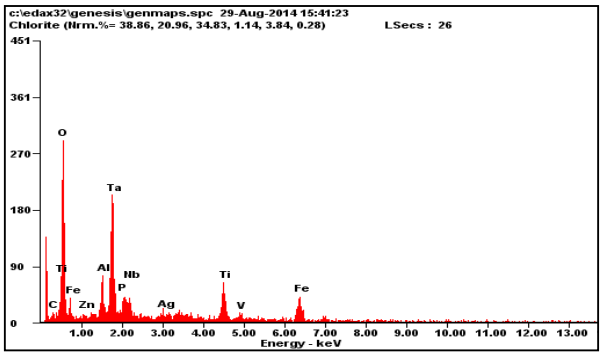
Plate 1. Scanning Electron Microscopy image of representative crushed Gyel columbite mineral sample.



Element	Wt%	At%
CK	01.96	05.82
OK	28.09	62.61
ZnL	00.49	00.27
AlK	03.07	04.06
TaM	34.33	06.77
PK	01.87	02.16
NbL	04.87	01.87
AgL	02.27	00.75
TiK	08.97	06.68
VK	00.65	00.46
FeK	13.43	08.57
CK	01.96	05.82
OK	28.09	62.61
ZnL	00.49	00.27
AlK	03.07	04.06
TaM	34.33	06.77
PK	01.87	02.16
NbL	04.87	01.87
AgL	02.27	00.75
TiK	08.97	06.68
VK	00.65	00.46
FeK	13.43	08.57
Matrix	Correction	ZAF

Figure 2: EDS peaks for the various minerals in the Gyel columbite ore deposit showing different elemental composition.

Table 5: Degree of Liberation at Various Sieve Sizes

SIEVE SIZE (µm)	Weight (g)	Weight (%)	% Cumulative Retained	% Cumulative passing	% Nb_2O_5 in Gyel Columbite
+1400	1.31	1.312	1.312	98.688	2.12
-1400 +1000	1.62	1.622	2.934	97.066	1.24
-1000 + 710	4.20	4.205	7.139	92.861	1.77
-710 + 500	9.13	9.142	16.281	83.719	3.24
-500 + 355	16.20	16.221	32.502	67.498	4.52
-355+ 250	19.81	19.836	52.338	47.662	5.68
-250 +180	19.60	19.626	71.964	28.036	7.55
-180+ 125	14.31	14.329	86.293	13.707	10.60
-125+ 90	8.01	8.020	94.313	5.687	17.10
-90 + 63	3.86	3.865	98.178	1.822	22.80
-63	1.82	1.822	100.00	0.00	29.00
	99.87				

Alaba O.C. and Ifelola E. O.(2015) Nigerian Mining Journal, 13(1) 35 - 40

Effect of Oil Spillage on the Economy of Local Residents of Oil Producing Areas of Ondo State, Nigeria

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Abstract
The study evaluates the economic effect of oil spillage on the local residents of Ilaje community in Ondo State. This was achieved by administered a well-structured questionnaire to the selected farmers, fishermen and traders who has experienced oil spillage in their environment in recent time. The data collected were tabulated in frequency table and analyzed by using Multiple Linear Regression. Two hypotheses were tested by using analysis of variance (ANOVA) statistical test. The result obtained from Multiple Linear Regression analysis shows that oil spillage has significant effect on the income of the people of Ilaje community as confirmed by the negative values obtained in socio-economic and environmental characteristics of the people. It was deduced that most of the income of the people were spent on daily needs of large jobless family size and treatment of various diseases caused by oil spillage in the area. The incomes of the people were also drained by rapid reduction in aquatic animals and farm products over the years due to oil spillage. The result of ANOVA test shows that differences in income of the farmers in the area represent the monetary values of their agricultural output destroyed during the oil spillage.
Keywords: Oil spillage, income, socio-economic characteristics, environmental characteristics.

Introduction
Oil production plays significant role in Ilaje community. It generates revenue for the people in the study area and the entire country. It consists about 98% of hydrocarbon which is the raw materials for the chemicals used in pharmaceutical, fertilizer and textile industries and thousands of other valuable products that essential for sustainability of human being. In spite of this, oil spillage which is the most common associated problem with oil production is a potential threatening to the economy and standard of living of the people of Ilaje community. Oil spillage is unavoidable in exploitation of crude oil. It involves releasing of drilling mud or oil into water (surface or underground) and farmland making them unfit for either domestic or industrial used (Atubi and Onokala, 2006) According to Alaba and Ifelola (2011) Ilaje community has witness series of oil spillage from Chevron's company, which is the major oil operator in the area. First on the list is the Ewan Oil Well blowout of July 1998 located in Ewan Oil Field near Ubale-Nla community where thousands of gallons of oil were spilled. In May 2002, over 300,000 gallons of oil were spilled with five days blowout at Chevron's well A and B located between Ojumole and Ikorigho communities. These were followed by Ikorigho and Otumara pipelines leakages of May 2006 where more than 200,000 gallons of oil were spilled and so on. Felix (1998) classified the main causes of oil spillage in this area as sabotage, corrosion of pipes and inability of effective control of oil drilling and wells.

The people of Ilaje community mainly generates their income from farming, fishing and harvesting of natural resources

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from near shores which are the areas particularly fouled by oil spillage. Opafunso and Apera, (2011) enumerated some fishing sites and farmlands that have been abandoned as a result of oil spillage without evaluating their effect on the income of the people. Also, Alaba and Ifeola (2011 identified some social evils associated with oil spillage in the study area such as frequent kidnappings, killings, depression and domestic violence, conflicts among friends and within families without considering its adverse effect on income and standard of living of the people. Therefore, this study was carried out to assess the effect of oil spillage on the economy of local residents of oil producing areas of Ondo state, Nigeria.

Research Questions

(a) What are the socio-economic and environmental problems confronting your community due to Oil Spillage?

(b) Enumerate the types of ailments you observed in your community as a result of oil spillage?

(c) Do you witness death of animals and reduction of agricultural products as a result of oil spillage?

(d) What are your incomes before and after oil spillage?

Research Hypothesis

Two research hypotheses were formulated as stated below:

(a) There is no significant difference in the income of respondents before and after oil spillage.

(b) There is no significant difference between farmer's income and the values of agricultural output destroyed during oil spillage.

Research model

In order to estimate the economic effect of oil spillage on respondents' income, the following models relating socio-economic and environmental characteristics with under listed descriptive variables were specified and consequently estimated in equation (1) and (2).

$$I = a_0 + a_1 s_1 + a_2 s_2 + a_3 s_3 + a_4 s_4 \quad \ldots(1)$$

$$I = a_0 + a_1 e_1 + a_2 e_2 + a_3 e_3 + a_4 e_4 \quad \ldots(2)$$

Where,

I is the dependent variable of annual income of the respondents; $s_1, s_2, s_3 \text{and} s_4$ are independent variables of socio-economic characteristics (age, Household size, education and occupation) while e_1, e_2, e_3, and $e_4$are independent variables of environmental characteristics (prevalence diseases, crop and plant, domestic animal, and aquatic animal) respectively; $a_0$is the intercept; and a_1, a_2, a_3 and $a_4$are the slopes of independent variables.

Materials and Methods

The study area is Ilaje community with population of 289,615and is located in the southern part of Ondo State (NPC, 2011). The area is blessed with natural resources, which include oil and gas reservoirs, extensive forest, good agricultural land and aquatic culture (Odjuvwuederhie *et al,* 2006). In the course of this study, ten (10) communities were selected based on their past experienced on the effect of oil spillage and that they would be able to recollect their input and output levels before and after oil spillage. The primary data for the study were obtained with the aid of a well-structured questionnaire that was randomly distributed to one hundred and forty (140) selected farmers, fishermen and traders within these communities while only one hundred (100) questionnaires were retrieved as shown in Table 1. The data collected were the socio-economic characteristics, environmental characteristics and income before and after oil spillage and values of agricultural output destroyed during the oil spillage as shown in Table 2 and 3. The data were analyzed using Multiple Linear Regression Model to estimate the effect of oil spillage on respondents' income. Two hypotheses were tested using analysis of variance (ANOVA) statistical test.

Table 1: Questionnaire Distribution

Distribution (Community)	Number Administered	Number Retrieved	Number Not Retrieved	% Retrieved	% Not Retrieved
Ayetoro	20	15	5	15.0	12.5
ObeRowoye	15	12	3	12.0	7.5
Otumara	10	8	2	8.0	5.0
Ikorogho	15	12	3	12.0	7.5
Ilu Abo	15	8	7	8.0	17.5
Odufado	10	9	1	9.0	2.5
Awoye	15	10	5	10.0	12.5
UbaNla	15	8	7	8.0	17.5
OdunOyinbo	15	10	5	10.0	12.5
Jinrinwo	10	8	2	8.0	5.0
Total	140	100	40	100.0	100.0

Table 2: Socio – economic and Environmental Characteristics

Socio-economic Characteristics	Frequency	Percentage
Age		
Below 20	18	18.0
21 – 60	65	65.0
Above 60	17	17.0
Household size		
1 – 4	6	6.0
Above 4	94	94.0
Education		
Tertiary edu.	10	10.0
Sec/Tech. Sch.	11	11.0
Edu.	30	30.0
Pry. Sch. Edu.	49	49.0
No Formal edu		
Occupation		
Farming	30	30.0
Fishing	45	45.0
Trading/Business	15	15.0
Others	10	10.0

Environmental Characteristics	Frequency	Percentage
Prevalence diseases		
Typhoid	47	47.0
Fever/Malarial	30	30.0
Skin diseases	23	23.0
Diarrhea		
Effect on crop or		
plant	70	70.0
Seriously reduced	22	22.0
fairly reduced	8	8.0
No reduction		
Effect on Domestic		
Animal	80	80.0
Seriously reduced	14	14.0
fairly reduced	6	6.0
No reduction		
Effect on Aquatic		
Animal	90	90.0
Seriously reduced	7	7.0
fairly reduced	3	3
No reduction		

Table 3: Income before and after Oil Spillage and Value of Agricultural Output Destroyed

Income Before (₦)	Income After (₦)	Income Difference (₦)	Output Destroyed (₦)
6500	7000	500	300
9000	5500	3500	800
12000	10400	1600	1000
7500	4600	2900	1200
8000	6000	2000	2000
4000	2500	1500	1000
5500	4500	1000	800
14500	11600	2900	2600
7500	6000	1500	1500
4500	4000	500	400
16000	14500	1500	1000
3000	2000	1000	400
6500	4200	2300	1600
11300	8500	2800	1400
6000	5500	500	200
6000	4700	1300	300
9500	9500	0	0
14400	13800	600	300
20000	17400	2600	900
12800	8900	3900	1500
4200	3400	800	200
6400	5200	1200	1000
2000	1800	200	100
3400	2200	1200	800
17800	15300	2500	1000
18000	14000	4000	2500
15500	10200	5300	3200
8000	4500	3500	1500
9400	4200	5200	3000
10300	8400	1900	900
11600	7200	4400	2000
19600	14300	5300	4500
6400	4800	1600	1400
5000	300	2000	1000
7600	5500	2100	1500
12000	10200	1800	13000

Results and Discussion

Multiple Linear Regressions Analysis

Equation (3) and Table 4 show the effect of oil spillage on socio-economic characteristics (age, household size, educational level and occupation) while Equation (4) and Table 5 show the effect of oil spillage on environmental characteristics (prevalence disease, crop and plant, domestic animal and aquatic animal)

$$I = 1.345 + 0.025s_1 - 0.143s_2 + 0.082s_3 - 0.042s_4 \quad (3)$$

$$I = 1.724 - 0.067e_1 - 0.270e_2 - 0.295e_3 - 0.020e_4 \quad (4)$$

Table 4: Income Model of Socio-economic Characteristics

Variable	Estimated Coefficient	t - Statistics	Significance.
Constant	1.345	4.271	0.000
Age	0.025	0.383	0.702
Household size	- 0.143	-1.801	0.075
Education	0.082	0.958	0.340
Occupation	- 0.042	-1.220	0.226
F – Statistics= 1.531			
Sig. – Statistics= 0.99			
R – Squared= 0.66			
N= 100			

Significant at 5% level

Table 5: Income Model of Environmental Characteristics

Variable	Estimated Coefficient	t - Statistics	Significance.
Constant	1.724	3.201	0.002
Prevalence disease	-0.067	-0.262	0.794
Farmland pollution	-0.270	-0.940	0.349
Aquatic pollution	-0.020	-0.929	0.089
Water pollution	-0.295	-1.303	0.196
F – Statistics	= 0.739		
Sig. – Statistics	= 0.503		
R – Squared	= 0.42		
N= 100			

Significant at 5% level

Significant at 5% level

The negative values obtained in socio-economic characteristics and environmental characteristics show that oil spillage has adverse effects on the income and standard of living of the people of Ilaje community. Negative values obtained in household size and occupation of socio-economic characteristics implied that most of the respondents incomes were used to cater for large jobless family size which put them into economic hardship while the negative values obtained in prevalence diseases, crop and plant, domestic animal and aquatic animal implied that the income of the people were reduced due to treatment of various diseases, reduction in crop/plant, domestic animal and aquatic animals as a result of frequent oil spillage in the area.

Hypotheses

The analysis of variance (ANOVA) statistical test was adopted to ascertain the validity of these formulated hypotheses:

(a) There is no significant difference in the income of respondents before and after oil spillage.

(b) There is no significant difference between farmer's income and the values of agricultural output destroyed during oil spillage.

Table 6 shows that there was significant difference in the income of respondents before and after oil spillage while Table 7 shows that there was no significant difference between farmer's income and the valve of agricultural output destroyed during oil spillage. Since there was a significant effect on the economic status of the people, the negative impact of oil spillage on income of the people was established.

Table 6: ANOVA Data of Income before and after Oil Spillage

Source of Variation	Sum of Square	Degree of Freedom	Mean of Square	F	Sig.
Regression	4.548	2	2.274	0.875	0.482
Residual	122.14	47	2.600		
Total	126.69	49			

Table 7: ANOVA Data of Income difference Plus Agricultural Output Destroyed

Source of Variation	Sum of Square	Degree of Freedom	Mean of Square	F	Sig.
Regression	1.270	2	0.635	0.587	0.5867
Residual	50.89	47	1.083		
Total	52.16	49			

Significant at 5% level

Conclusion

The analysis has proved that oil spillage has negative effect on the economy of the local resident of Ilaje community. These were proved by the negative values obtained in the socio-economic and environmental characteristics of the respondents. The proved was validated by the hypotheses that there was significant difference in the income of respondents before and after oil spillage. Since the production of oil in the study area is indispensable and cannot be stopped. The study therefore concluded that good precautions and adequate measures should be adopted by the government, oil operators and the community in controlling oil spillage so that the people of Ilaje can be liberated from economic hardship.

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Review of Perilous Effect of Water Pollution by Mining and Mineral Processing Operations: A Lesson for Nigeria

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Abstract

The purpose of this paper is to provide an overview of the environmental impacts of mining and mineral processing activities as a basis for assessing the negative consequences of water pollution, its prevention and control. Further discusses environmental effects of mining and/or mineral processing which include: alteration of the landscape with pits and waste rock; subsidence of the land over underground mine workings; pollution of surface water with acid drainage and metals from waste rock and tailings and chemicals from mineral beneficiation; damage to sensitive ecosystems; and human health risks from contaminated water sources. This paper observes some of the consequential impacts of water pollution within and outside Nigeria soil and summarizes some of the environmental control technologies and regulatory approaches on Water Pollution Prevention and Control Diversion Systems. It concluded that, preventing these hazards, policy-makers are to take more steps to strongly encourage pollution prevention options as stipulated in Nigerian Minerals and Mining Regulations 2011. The paper recommends better dissemination of the existing information via education, training, technical advisory, consulting services, research and development programmes at all levels couple with the establishment of National Pollution Prevention and Control (NPPC) monitoring outfit with sole aim of developing a database of all pollution incidences and devise possible enforcement strategies to forestall future occurrences, also to minimize if not eradicating the harmful environmental impacts of mining and mineral processing operations, most especially now that the attention of Nigeria government tending towards mining and processing of solid minerals for foreign exchange.

Keywords: Water pollution, Mining, Mineral Processing, Environmental Impacts**.**

Introduction

The introduction of harmful substances into the environment has been shown to have many adverse effects on human health, agricultural productivity and natural ecosystem (Gabriella and Anton, 2005). Water pollution is mostly artificial occurring phenomenon commonly referred to as hazardous waste which contaminate the water bodies such as lakes, rivers, oceans, aquifers and groundwater thereby leading to environmental degradation that affects the entire biosphere – plants and organisms living in these bodies of water and the effect is damaging not only to individual species and population, but also to the natural biological communities (Anon, 2010).

Hazardous waste center on wastes or combination of waste that pose a potential hazard to human or the environment, in part because they are not degradable, persistent in the environment and are deleterious to human health or natural resources. Most hazardous waste are produced in the manufacturing of products for domestic consumption or further industrial application (EPA, 1976).

According to Ogezi (1998), mining is achieved through several activities from exploration through exploitation to processing and finally to the consumer. However, inefficient mineral processing techniques and poor metal recovery has generated mine tailings with high metal concentrations. The problem is compounded by the presence of sulphide minerals, which, upon exposure to the

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atmosphere or oxygenated water, oxidize to produce acid water with high amounts of sulphate, heavy metals and metalloids. An understanding of the complex chemical reactions within sulphidic wastes is essential, as the reactions can cause and influence Acid Mine Drainage (AMD) (Lottermoser 2003). Soils and sediments represent the major sinks for anthropogenic metals released to the environment with regards to their interface between the geosphere, the atmosphere, the biosphere and the hydrosphere. While some organic contaminants can undergo biodegradation, heavy metals remain in the environment. Fortunately, the toxicity of metals largely depends on their speciation; the less soluble form is usually less toxic (Manceau et al. 2011). A particular mine waste may be changed into a valuable commodity at changing circumstances to recover metals of interest. The current situation does not make mine tailings and mine wastes chemically safe at the dams. To a large extent, they inevitably pose the greatest potential source of environmental pollution, if inadequate management and monitoring are conducted on regular basis.

Since the minerals exploited are commonly associated with a variety of others, which are not needed, they were simply thrown away or heaped within the tin shed as tailings. Among the waste are minerals like magnetite, zircon, ilmenite, monazite, silica sand, thorite, amethyst, etc. (Ngyang, 2007). The abundant mine ponds, heaps of overburden and mine tailings are believed to have negative impact on the environment in the sense that the mine ponds and Lotto pits are considered to be death traps (Adiuku- Brown 1999), while the once flat land have been defaced by heaps of over burden with gully erosion taken over in many places. The tailings could be a silent and unnoticeable time bomb, as they are replete with radioactive materials excessively enhanced through the mineral processing. The mine ponds left by these mining activities are today used for irrigation, domestic, and industrial purposes. The quality of these waters, and indeed that of the underground water with which they may possibly interact, are not known.

Leachates from mine waste can pollute the water in the mine ponds, which in turn can infiltrate the ground and pollute the ground water if it gets at it (Lindslay, 1975), while the rains could also wash off heavy metals and radioactive materials in mine tailings, which as surface run off could pollute the water.

In addition to water contamination resulting from acids and dissolved metals, mining operations have other effects on water sources in the vicinity of mine sites. Changes to the natural topography of the land surrounding the mine site can reduce the amount of precipitation that seeps into aquifers and can increase runoff to streams and rivers, causing erosion problems

The main aim of the study was to acquire and document all the background information that is necessary for an understanding of dangerous effects associated with mining and mineral-processing activities. This involves descriptions of unit mining processes and beneficiation steps, operational parameters, identification of sources of hazardous waste. An overview of negative impacts of mining and mineral processing operations in Nigeria and beyond, a framework for mitigation, prevention and control of hazardous waste. This information will also go a long way bring to the limelight the perilous effects, appropriate prevention and control involve in water pollution, thereby facilitate any necessary measures to arrest the menace.

Figure 1(a and b): Showing Unlicensed Miner Washing Tailings Direct Into The River

Causes of Water Pollution

The causes of water pollution are numerous among which are: sewage and wastewater, pollution from farms, oil pollution, mining, chemical and industrial wastes. All these polluting factors change the physical, biological and chemical conditions of the water source, harmfully disturbing the ecological balance previously achieved in the water body leading to grater dangers (Anon, 2015). Below, centered on how mining and mineral processing operations contaminate water;

Mining is another of the major causes of water pollution. Mining activities consumes large amounts of water in processing the ores from the mines. In addition, mining also results in large amounts of chemicals, heavy metals soil and other waste rock materials contaminating and polluting the water bodies.

During mining, large quantities of ore (rocks containing valued substances like metals or coal) are excavated from the mines. The ore comprises a large proportion of waste rock (rocks not containing the desired substance) and only a very small proportion of the desired substance.

These mining wastes are often left in piles above ground. Exposed to (oxides), harmful materials from the mining waste are readily leeched out and these materials drain freely into water bodies nearby. (Anon, 2015).

Once the mineral ore is exploited, it is then processed. The science of mineral processing (or mineral dressing) is a specialized area that studies the mechanical means of crushing, grinding, and washing that enable the separation (extractive metallurgy) of valuable metals or minerals from their gangue (waste material). Processing of placer ore material consists of gravity-dependent methods of separation, such as sluice boxes, air floats, fluidization among others. Only minor shaking or washing may be necessary to disaggregate lump of sands or gravels before processing. Processing of ore from a lode mine, whether it is a surface or subsurface mine, requires that the rock ore be crushed and pulverized before extraction of the valuable minerals begins. After lode ore is crushed, recovery of the valuable minerals is done by one, or a combination of several, mechanical and chemical techniques. Since most metals are present in ores as oxides or sulfides, the metal needs to be reduced to its metallic form. This can be accomplished through chemical means such as smelting or through electrolytic reduction (Anon, 2015).

Environmental Effect

In many respects, water pollution represents the most common and most serious environmental problem caused by mining. Metal-bearing rock that interacts with rainwater or with process chemicals such as cyanide and mercury can lead to water pollution impacts at all stages of the mining/beneficiation/disposal process.

Principal sources of water contamination include:

- Runoff from excavated mine pits and changes in surrounding terrain;
- Milling and leaching operations, especially when cyanide, mercury, or other process chemicals are used in beneficiation;
- Runoff from waste and tailings dumps; and
- Leakage of process or runoff waters from pipes or holding ponds;

When acid drainage occurs, acidic and metals-laden water may be carried out of the mine site into groundwater or nearby streams and rivers.

Acid drainage lowers the pH of the surrounding water, making it corrosive and unable to support many forms of aquatic life. Vegetation growing along streams is also affected as plant species that can survive in acidic water replace native species. The flow of acidic mine water can also carry toxic, metal-bearing sediment into streams. These toxic sediments may kill waterborne plant and animal species. In the most extreme cases, acid drainage may kill all living organisms in nearby streams. If humans are exposed to water or fish contaminated with heavy metal, serious health effects may occur. Acid drainage can continue to be a problem long after a mine closes. Abandoned mines and refuse piles can produce acid damage for over 50 years. The U.S. Forest Service estimates that 5,000 - 10,000 miles of streams in the U.S. are currently affected by acid drainage from active and inactive mines and waste rock piles (see United States Department of Agriculture, Acid Drainage From Mines on the National Forests: A Management Challenge. Program Aid 1505, March 1993.) Because of the difficulty and cost of acid damage cleanup, environmental agencies often focus their efforts on prevention.

Beneficiation Leach sites have the potential to introduce highly concentrated levels of acids and heavy metals into surrounding water sources. The leaching process mimics acid drainage although it is conducted under much more aggressive conditions, using high concentrations of acid, base, or cyanide to extract metals from ore. Since leaching produces large volumes of contaminated water, it is crucial that leach dumps and associated holding/extraction areas be designed to limit contamination. Most of the environmental problems associated with leaching are caused by leakage, spillage, or seepage of the leaching solution at various stages of the process. Potential problems include: Seepage of solutions through soils and liners beneath leach piles; Leakage from solution-holding ponds and transfer channels; Spills from ruptured pipes and recovery equipment; Pond overflow caused by excessive runoff; and Ruptures of dams or liners in solution holding ponds (EPA, 1985).

Hydrologic Impact and Erosion of Sediment in addition to water contamination resulting from acids and dissolved metals, mining operations have other effects on water sources in the vicinity of mine sites. Changes to the natural topography of the land surrounding the mine site can reduce the amount of precipitation that seeps into aquifers and can increase runoff to streams and rivers, causing erosion problems. This addresses the effects of mining on groundwater levels as well as the impacts of surface mining on the erosion of sediments (Sengupta, 1993).

Figure 2: Stream Channel Interrupted Due to Active Mining

Consequences of Environmental Pollution

Pollution has Consequences, which is heavily in terms of deaths followed by environmental damages, financial losses e.t.c. but the following are some of the highlighted/documented consequences in Nigeria, Africa and other part of the World.

According to Olusegun (2009), reported in an Annual Memorial Lecture, on the threats to Nigerian Environment that many parts of the country mining wastelands have now become very hazardous for people in neighbourhoods where open cast activities have taken place. When mining pits are filled with water from tailings, they become stagnant pools and thus constitute a significant environmental threat as they become breeding grounds for mosquitoes and other pests. Supporting the findings was example of Plateau State where thousands of heaps of mine wastes which are now found to be radioactive were abandoned

after the decline of tin mining many years back was identified. According to him, health officials of the state have reported that laboratory analyses of the 1,100 abandoned mines scattered over five districts showed the presence of radioactive materials at concentrations that are harmful to human health and that the inhabitants here stand the risks of skin, lung and liver cancer as well as eye impairments from prolonged exposure to these radioactive wastes. Yet, these piles of the dangerous wastes remain unattended to. He also noted that mine pits by artisanal and small scale miners of gemstones in Ijero-Ekiti, Nassarawa, Olode, Shaki, Jos, Keffi, Akwanga and other parts of Nigeria also create huge environmental hazards to farmers as many of them have been accidentally buried in abandoned pits and shafts.

Ojo and Adeyemi (2003) conducted a research on environmental impacts of aggregate mining and stone quarrying in Ondo State using field survey. They found out that mining pollute water resources; generate

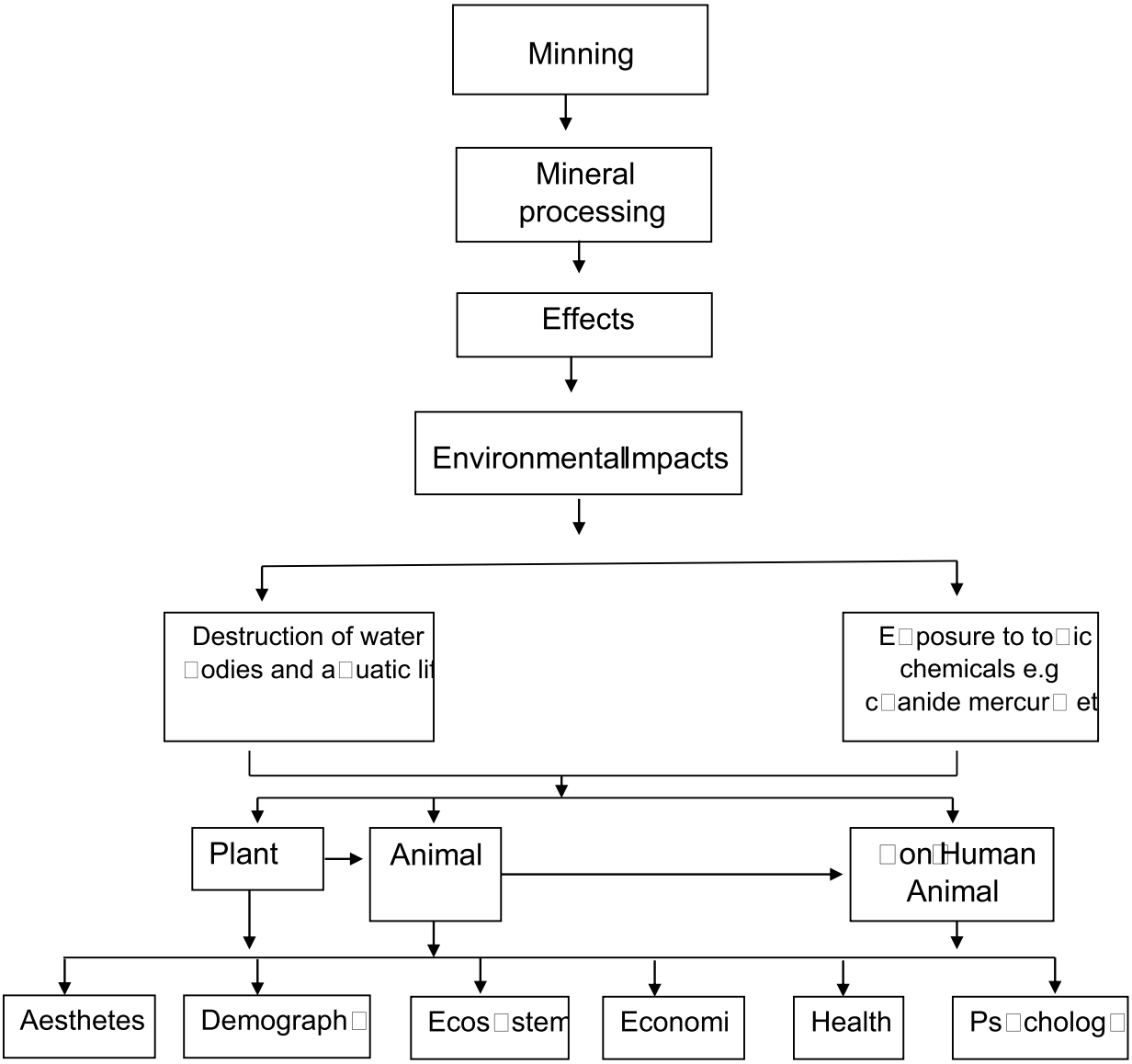

Figure 3: Flowchart of Environmental and Health Impacts of Mining Mineral Processing Operations. (Source: Author's Compilation)

hazardous dust, causes deforestation, flooding, erosion and damage to vegetation.
Morris (1986) carried out study on Ghana Gold Mining using a field survey and laboratory technique. He discovered that small-scale mining activities carried out in the area by illegal miners contributes to environmental hazards. The environmental effects include diversion of rivers within the area without reclamation of the rivers after mining has ceased. The resultant effects of this activity are water pollution, increased soil erosion, leaching of effluents, desertification and damage to fauna and flora environment. He also noted through laboratory procedure that the miners use mercury in the mining operation which resulted to the pollution of water resources and adversely affected aquatic life and man.
Worldwatch (2000) observed a tailings dam split open at the Baia Mare mine in Romania using Geographical Information System (GIS) and field survey. The result showed that the accident sent some 10,000 tons of wastewater and 20,000 tons of sludge contaminated with cyanide, copper, and heavy metals into the Tiszra River and eventually into the Danube-destroying 1,240 tons of fish and polluting the drinking water supplies of 2.5 million people.
International Development Research Centre (IDRC) (2009) reported the incident that occurred as result of discharging mine tailings of abourt 1.6 million cubic meters into the Makulapnit-Boac River along the 27-km span and the coastal areas near the river mouth west of the island province. The impact on the river ecosystem was extensive. The devastating effects of the pollution on the river and coastal ecosystems were of such magnitude that a UN assessment mission declared the accident an environmental disaster, UNDP (1996). Boac River was left virtually dead. The onrush of tailings downstream displaced the river water, which in turn flooded low-lying areas, destroying crop farms and vegetable gardens along the banks and clogging the irrigation waterways to rice fields. Road sections straddling the river were damaged, temporarily isolating some barangays (villages) and affecting trade and access to services. All these impacts adversely affected the local residents in Boac whose livelihood activities were river-dependent.

Hence, to view pollution in its proper perspective, it is necessary to remember the tragedy that occurred in Zamfara State, Nigeria where more than 400 children died from acute lead poisoning caused by unsafe mining and mineral processing of ore and little attention is being paid to the extent of this kind problem in other areas of Nigeria (OK international, 2012).

Mitigation, Prevention and Control Of Water Pollution

Environmental hazards posed by mining activities can be reduced by adapting best mining practice such as mine reclamation after mining (Alford and Tulay, 1974), while mine waste should be properly disposed. Furthermore, current mines should be properly planned to minimize the amount of hazardous waste they produce (Sawyer and McCarthy, 1967), while on historical mines where waste already exist, remedial action maybe required, such as suitable land use planning, so as to restrict the use of contaminated sites.
Mining laws enacted by the Government (i.e Nigerian Minerals and Mining Regulations) should be strictly enforced to ensure compliance and prevent future unwholesome practices.

The following **summarizes** some of the environmental control technologies and regulatory approaches on Water Pollution Prevention and Control Diversion Systems. (Sengupta, 1993).

- Reducing the amount of contaminated water produced by channeling runoff away from exposed mine pits and waste dumps.
- Drainage Ditches; Channeling contaminated water into containment ponds for treatment or recycling.

- Containment Ponds; Constructing ponds to hold contaminated water for treatment which prevent contamination of ground or surface water e.g. synthetic or clay liners.
- Recycling Systems; Reusing contaminated water, after appropriate filtering or treatment, in the extraction process for dust elimination or drilling.
- Subsurface drainage systems and barriers; Collecting or deflecting groundwater prior to contact with exposed mine pits, preventing groundwater contamination.
- Liners; Underlining for leach units or tailings ponds to prevent or minimize leakage of contaminated water to ground or surface waters.
- Runoff Controls; Providing means for stabilizing, filtering, and/or settling out soil materials which can be picked up during storm runoff for the purpose of controlling erosion of disturbed areas and limiting stream sedimentation.
- Wastewater Treatment; Including the use of lime to reduce acidity and settle out metals and other solid contaminants.
- Wetlands; An experimental and unproven technology, constructed wetlands rely on natural processes of wetlands to remove water contaminants before discharge (Sengupta, 1993).
- Better dissemination of the existing information via education and training, technical advisory and consulting services, and research and development programmes at all levels

In fact, the use of pollution prevention technologies and environmental controls also can substantially reduce the volume of contaminants released and the concentration of the contaminants discharged into the surrounding environment. In some cases, these pollution prevention approaches may also be economically beneficial to mine operators because they may decrease the process chemicals needed, and therefore the cost of producing a given amount of mineral.

Conclusions

The fact that water pollution is causing negative environmental impacts; wasting of natural resources, financial loss, inconvenience to humans, sometimes leading to loss of life, cannot be overemphasized. There is thus, needs to inform the government and anyone concerned about this menace. Potential way out and recommendations in terms of ways to realize prevention and control from water pollution damage could be achieved through better dissemination of the existing information via education and training, technical advisory and consulting services, and research and development programmes at all levels. It is therefore concluded that, preventing these hazards, policy-makers are to take more steps to strongly encourage and enforce the strict compliance of pollution prevention options as stipulated in Nigerian Minerals and Mining Regulations 2011. Hence, as a matter of urgency, Nigeria has to establish a National Pollution Prevention and Control (NPPC) monitoring outfit with sole aim of developing a database of all pollution incidences and devise possible enforcement strategies to forestall future occurrences, now that government wants to venture in full force into solid minerals as a means of diversifying the economy.

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Determination of Chemical, Mineralogical and Bomb Calorific Parameters of Owukpa Coal Deposit, Benue State, Nigeria

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Abstract
The determination of chemical, mineralogical and bomb calorific parameters of Owukpa coal deposit, Benue State, Nigeria has been investigated. The sample of the coal was sourced from Owukpa village in Ogbadibo Local Government Area of Benue State. The coal sample was pulverized using laboratory Denver pulverizing machine and the pulverized sample was analysed for its chemical and mineralogical compositions using XRF, XRD, and SEM/EDS respectively. Mineralogical analysis of the coal sample revealed that the coal contained carbonaceous compound, fluorites, alumina, strontiumites as major mineral compounds while other minerals are minor in the matrix of the coal. Further chemical analysis of the coal sample using SEM/EDS revealed that the coal contained 25.83%C, 13.96%Sr, 35.17%F, 7.0%Y, 3.43%Al, 5.21%Rr on the average for all the spots analysed. The XRF revealed that most of the elements are in small amounts with titanium having 1.17%. Ultimate analysis revealed that the coal sample contained 60.36% C, 0.14%P, 0.89%S, 15.89%O, 6.50%H and 1.90%N while the proximate analysis revealed that the coal sample contained 47.40% fixed carbon, 11.86% ash, 26.0% volatile matter and 14.74% moisture. The bomb calorimetric value for the coal was found to be 18,543.2kJ/kg. The results obtained compared favourably with those cited in literatures and the deposit poses as another potential source of coal that can be utilized in the nation's metallurgical industries.
Keywords: bomb calorific parameter, pulverize,

Introduction

Nigeria is blessed with various solid fuels such as coal, charcoal, wood and other mineral fuels like uranium and sulphur deposits which ought to be practically explored and converted to different quality materials consumable to its citizens. With regard to the operation of Iron and steel industries in Nigeria, the quality of coal that will be used for the production of the required heat or energy needs to be analysed (Thomas and Yaro, 2007).

For the purpose of obtaining good quality coal, a lot of researches on the use of Nigerian coals for example the Benue, Enugu, and Kogi coal deposits for coke production are still under investigations. In previous researches it has been concluded that Nigerian local coals do not meet the requirement for metallurgical coke and therefore coals are imported for use in Nigerian iron and steel industries. Today there are high possibilities that newly discovered coal deposits and new technology developed could revise such statement. This is what has prompted this research work on ``*Determination of Chemical, Mineralogical and Bomb Calorific Parameters of Owukpa Coal Deposit, Benue State, Nigeria" w*ith the aim of classifying the coal for metallurgical and other related engineering applications.

Coal consists largely of carbon, hydrogen and oxygen, with oxygen having important influence on their most distinctive characteristics. Relatively small amounts of oxygen and nitrogen are organically associated with the coal substance (Gupta, 2008).

In case of iron production, the rate and quantity of the production mainly depend upon the quality of coke which in turn depends on the quality of the coal. The suitability of coal for a particular purpose is generally a function of its composition. The main parameters describing the qualities of coals are the moisture, ash, fixed carbon contents and calorific value (Agada, 2014).

Most coal classifications are based on the results of chemical, mineralogical analyses and physical tests, but some are more empirical in nature. Coal classifications are important because they provide valuable information to commercial users (for example for power generation and coke production) and to researchers studying the origin of coal (Agada, 2014). The most common classification is based on rank, referring to the degree of coalification that has occurred. The rank

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of a coal is determined primarily by the depth of burial and temperature to which the coal was subjected over time. With increasing temperature, peat is converted to lignite, a very soft, low rank coal. With further increase in temperature, lignite is transformed into sub-bituminous coal and then into bituminous coal. At even higher temperature usually accompanied by intense deformation generated by the folding and faulting of the earth's crust, anthracites, the highest rank of coal, are produced. The increase in the coal rank is accompanied by decrease in the amount of moisture and other volatile materials in the coal. In general, the calorific (heat) value of coal increases with rank from lignite through bituminous coal to anthracite (Damisa, 2001).

Table 1: Distinctive Features of Various Ranks of Coal

Ranks of coal	Physical appearance	Characteristics
Peat	Brown	Soft; fibrous, high moisture content
Lignite	Brown to brownish black	Poorly to moderately consolidated; weathers rapidly, plant residue apparent.
Sub-bituminous	Black, dull or waxy luster	Weather easily; plant residue faintly shown, ignites easily.
Bituminous	Black; dense, brittle	Does not weather easily; plant structure visible with microscope, ignites easily with short blue flame.
Anthracite	Black; hard usually with glassy luster	Very hard and brittle; burns with almost no smoke.

Source: (Eugene, 2008)

Coal Series

The gradual transformation from rotten woody matter to coal can be represented by peat, lignite (brown to brownish black coal), sub-bituminous (black, dull or waxy luster), bituminous (black; dense coal) and anthracite (black; hard coal). This sequence is called Coal series.

Peat

It is the first stage product in the formation of coal from wood under the action of temperature, pressure and bacteria. Freshly dug peat contains large amount of water (up to 90%). It is a brown fibrous mass of partially decayed material that has accumulated under water-logged conditions. Its calorific value is (around 4500 kcal/kg) slightly higher than that of wood and it is mainly used as a domestic fuel as well as for power generation. It is the lowest rank. It is a non-commercial fuel and has no metallurgical importance. In most cases, it is not considered as a variety of coal. Peat is extracted either by hand – cutting or by the mechanized excavation method. It is easy to ignite and burns freely with long flame (Eugene, 2008).

Lignite

It is the second stage product in the formation of coal from wood. It is friable and occurs in thick seams (up to 30 meters thickness) near the earth's surface. Its moisture content is up to 60% and calorific value around 5000 kcal/kg (on 10% moisture basis).

On exposure to atmosphere, the brown colour of lignite darkens and the moisture content reduces to an equilibrium value of 10 to 20%. On drying, lignite shrinks and breaks up in an irregular manner. Compositions and properties of lignite vary widely, the carbon content is 70-75% and the oxygen content is 21-26%. The volatile matter is often over 50% (d.m.m.f.) and in a large number of cases the ratios of volatile matter to fixed carbon is 1:1. The high oxygen content is responsible for relatively low calorific value (6500-70000 kcal/kg) even on d.m.m.f. basis. On air-dried basis the value may be as low as 3800 kcal/kg due to high moisture content. The ash of lignite is generally low (Eugene, 2008).

Sub-Bituminous

It is a black, homogeneous and smooth mass having high moisture and volatile matter content which breaks into smaller pieces on exposure to air. Its carbon content is around 70-80% and oxygen content is 10-20%. It is a non-coking coal having a calorific value about 7000 kcal/kg.

It is a variety of mature lignite resembling true coal in colour and appearance. It is black in colour with a dull, waxy luster. It is denser and harder than lignite and has lower moisture content (12-25%). Most sub-bituminous coals appear banded like bituminous coal. Like lignite, sub-bituminous coal disintegrates on exposure to atmosphere and is therefore difficult to transport. It ignites easily and is used in raising steam and for manufacture of gaseous fuels (Eugene, 2008).

Bituminous

It is the most common variety of coal. It is black

and brittle and burns and ignites readily with yellow smoky flame. It has a low moisture content (<10%) and the carbon content varies from 75-90% whereas volatile matter content is 20-45%. Depending upon the volatile matter content, it is termed as low volatile, medium volatile and high volatile coal. Its calorific value on mineral – free basis goes up to 9000 kcal/kg. Most of the coking coals are essentially bituminous coal. It is used for power generation, coke making, gasification, domestic heating etc. Non-coking bituminous coals are generally used for purposes other than coke making which requires coking coal.

The name bituminous is perhaps due to the fact that it burns with a smoky yellow flame similar to that of bitumen and that pitch obtained from coal tar is of a bituminous nature. The term coal alone ordinarily refers to bituminous coal. Bituminous coal is black and usually banded, the bands being parallel to the bedding plane. The coal breaks along vertical joints (cleats) into rectangular, columnar or cubical pieces. Bituminous coal is denser and harder than lignite and sub-bituminous coal and does not disintegrate into slacks on exposure to the atmosphere (Eugene, 2008).

Anthracite

This is the most mature coal; hence it is of the highest rank. This high carbon content (80 – 85%) and low volatile matter (<10) coal is hard, non-coking and burns without smoke with a short luminous flame thereby imparting intense localized heating. It ignites with difficulty due to low volatile matter content. The calorific value may be up to 8000-8500 kcal/kg which is slightly lower than that of bituminous coal due to its low hydrogen content.

It has sub-metallic luster, sometimes even a graphite appearance. It does not soil the hand. Although there is banded structure which is not always obvious. Anthracites are characterized by their low volatile matter [3-10% dry mineral matter free (d.m.m.f.)] and high carbon content (over 92% d.m.m.f.). The air dried moisture is 2-4%, hydrogen content is 2.8-3.9% on d.m.m.f. basis, and anthracites are non-coking (Eugene, 2008).

Standard Specification of Coking Coals

There are various factors which are considered before the utilization of coal for coke making. Some of these are: the coal must be strong and hard; have low ash, sulphur and phosphorus contents; be consistent that is of uniform quality.

As the ranks of coking coal decrease, its coking properties also diminish. Highly swelling coals when used alone produce weak coke whose reactivity is very high hence it must be blended with weakly coking coal, anthracite, steam coal, coke breeze (about 3%) or non-swelling, non-coking coals so as to get moderately reactive coke with optimum hardness and strength (Thomas et al, 2014).

Ideally, the coking coal should have 8-10% of ash so that coke produced from it will have around 11-14% ash. Sulphur content in metallurgical coal should be less than 1% in the coke and volatile matter should be within 22-30%. Table 2 gives the summary of the properties required of a good coking coal.

Characterization Parameters of Coal

The characterization parameters used to evaluate the chemical, mineralogical and other tests have been devised to determine the major and minor constituents of the coal sample. Some of these "model" tests are empirical in nature, others demand more analytical skill. They are proximate and ultimate tests, X-ray fluorescence, Scanning Electron Microscope/Energy Dispersive Spectrometry (SEM/EDS), X-ray diffraction and bomb calorific analyses. These analyses give insights to the coal quality, phase compositions and energy content in the coal and through these tests the liberation size and suitable adoptable concentration technique will be established and utilized in the development of a process route for the coal (Agada, 2014).

Bomb Calorimetry Test

Bomb calorimetry is used for determining the calorific value of solid fuels. A bomb calorimeter consists of a strong stainless steel vessel, called bomb, capable of withstanding high pressure. The bomb is placed in a copper calorimeter having a known weight of water. The copper calorimeter, in turn, is surrounded by an air jacket to prevent loss of heat due to radiation. The calorimeter is provided with an electrical stirrer for stirring water and Bechmann thermometer. The calorific value of the fuel can be calculated as

Gross calorific value,

$$C = \frac{(y+z)(t_2 - t_1)kcal/kg}{x} \qquad \ldots 1$$

Table 2: Summary of Characteristics of Good Coking Coal

Parameter	Desire	Typical limit	Comments
Total moisture %	5 – 10	12	Limited for easy handling and grinding
Volatile matter various dmmf (%)	Various	16 – 21 21 – 26 26 – 31	Low volatile coals Medium volatile coals High volatile coals
Total sulphur (air dry)	Low %	0.6 – 0.8	Sulphur content of coke should be low to limit take- Zip of sulphur by pig iron in blast furnace.
Free swelling index	7.9	Min. 6	
Roga index	60 – 90	Min. 50	
Gray king coke	G6 – G14	Min. G4 – G5	
Dilatometry	25 – 70 80 – 140 150 – 350	Min. 20 Min. 60 Min. 100	Low volatile coals Medium volatile coals High volatile coals
Plastometry Fluidity range	Min. 80 Min. 100 Min. 130	Min. 70 Min 80 Min. 100	Low volatile coals Medium volatile coals High volatile coals

Source: (Damisa, 2001); Eugene, (2008).

C = gross calorific value, y = weight of water in the calorimeter (kg), z = water value of the calorimeter, stirrer, thermometer and bomb (kg), x= weight+ fuel taken in crucible, t_1 and t_2 = initial and final temperature of water in calorimeter

Metallurgical Properties of Coal

Some coal when heated in the absence of air produce a porous carbon residue called coke. Coking coals possess unique properties of softening, fusing and re-solidifying to form a porous carbon structure when carbonized. When coking coals are heated, the complex organic molecules break down into simpler primary volatile gaseous and liquid compounds. Some of the primary products react to form secondary product. The solid residue is coke (Thomas et al, 2014).

The properties and qualities of coal is of great importance when it is put to use for metallurgical purposes, that is when used to produce fuel (coke, coke-oven gas, blast furnace gas) in foundry, iron and steel making plants and for chemical and electrical purposes. The principal industrial use of coke is in the blast furnace. The main constituents of coke which influence furnace performance and detract it from its value as a source of carbon are moisture and ash. The former must be controlled to the lowest possible value since excess moisture requires additional heat for evaporation and results in higher fuel consumption. The amount of ash present affects slag volume and slag chemistry influences coke consumption and has a marked effect on both the technology and economics of iron production (Agada, 2014).

Coke is the only solid material present in the regions of higher temperature within the blast furnace and in lump form. It confers the required degree of permeability to the burden in the melting zone. It must have sufficient physical strength not only to support the weight of the burden but also to be capable of withstanding severe degradation during its descent in the furnace shaft (Agada, 2014).

For a particular type of coal to be used for metallurgical purpose it must possess some properties summarized in Table 3.

Nigerian Coal Deposits

Nigeria has numerous mineral resources including coal. It has been discovered that there are many coal deposits in the country including the Enugu (Ezimo, Enugu city Afikpo, Inyi),

Table 3: Specifications for Blast Furnace Coke

Volatile matter	0.75 – 2% by weight
Ash	7.0 – 9.0% by weight
Sulphur	0.65 – 1% by weight
Shatter test (on 5cm)	70 – 78% by weight
Drop number	4
Drop resistance	4
Porosity	7-10%
Size	7 – 12cm
Fixed carbon	48.91 – 90%
Moisture content	Below 5%
Calorific value kcal/kg	7,652
Phosphorus	0.007
Total Reactive	97.6%

Source: (Weiss, 1985; Eugene, 2008)

Kogi (Okaba, Ogboyoga), Benue (Owukpa), Delta (Asaba), Lafia amongst other minor coal deposits located in different parts of the country. Unfortunately, the characteristics of these coal deposits have not been fully investigated to verify their suitability for metallurgical coke production except for Lafia coal which has been reported in some forum as having similar characteristics to coking coals but with high sulphur content which is detrimental to its utilization in iron and steel production since sulphur causes hot shortness in steel, that is, cracking of steel surface during hot rolling. The Lafia coal is mostly of the lignite and sub-bituminous class. However Nigerian coal seams could be of great value to the nation's power sector/industry as it could be used for power generation. In the three major districts of coal deposits studied previously, the entire currently defined coal resource for the areas is 1,487 million tonnes. The coal seam thickness averages 2.2 meters throughout Enugu north to Ogboyoga and Owukpa. The remaining districts are essentially unexplored and unexploited. Coal in the areas studied is considered to be an excellent thermal coal for fueling coal-fired electrical generating plants or for other industrial uses except in the metallurgical industry, where they can only be used after beneficiation (Damisa, 2001).

Considerable additional work must be done to fully explore and exploit the coal resources in Kogi, Benue and Enugu states for there is enough information already to indicate that there is a high probability that each of these deposits can support a significant coal firing generating , iron and steel plants (Thomas, 2009).

Several analyses carried out on Nigerian coals confirm that their poor coking properties can be improved by blending the coals with high grades ones (Damisa, 2001; Mathias, 2008; Eugene, 2008). The Enugu, Benue and Kogi coals have similarities in low sulphur and ash contents, high moisture and reaction to weathering. Although Lafia coal seem to have some properties which liken it to coke producing coal, it is composed of high sulphur and ash which limits its uses for metallurgical blast furnace coke unless if beneficiated (Agada, 2014). Tables 4 and 6 give the quality, ultimate and proximate analyses of some Nigerian coal deposits.

Table 4: Some Nigerian Coal Deposits and Approximations of Coal Quality

	Moisture	Ash	Sulphur	Heating value	
Area	(%)	(%)	(%)	Btu/ lb	Kcal/kg
Ogboyoga	13.50	8.00	0.58	9.930	5,520
Okaba	10.30	9.30	0.65	10,280	5,710
Orukpa	11.80	11.20	0.40	9,990	5,550
Ezimo	10.90	6.40	0.50	10,900	6,050
Enugu	7.60	6.70	0.93	11,900	6,610

Source: (Agada,2014)

Table 5: Proximate Analyses of some Nigerian Coal Deposits

Content Deposit	Proximate Analysis(dmmf) %			
	Moisture	Volatile	Fixed Carbon	Ash
Enugu	5.0 – 6.6	40 – 45	51.4 – 55.3	7.5 – 14.5
Okaba	13.5 – 16.2	41 – 47	49.5 – 50.6	7.9 – 11.9
Orukpa	4.0 – 10.8	13 – 49	49.1 – 52.2	7.0 – 10.3
Lafia	1.2 - 1.5	26.4 – 31.0	46.9 – 58.3	18.0 – 30.0
Coking coal	1.5 – 2.0	19.6 – 40.0	55.0 – 60.0	4.0 – 7.0

Source: (Agada,2014)

Table 6: Ultimate Analyses of some Nigerian Coals

Content Deposit	Ultimate Analysis, %				
	C	H	N	S	O
Enugu	78-82	4.6-5.8	1.8-2.1	0.6-1.2	9.8-12.2
Okaba	72-80	3.7-51	1.5-1.9	0.7-1.3	15.0-21.2
Orukpa	75-81	3.6-5.0	1.5-2.0	0.4-0.5	11.6-15.4
Lafia	82-90	5.5-6.2	1.0-1.8	1.5-2.6	5.1-7.6
Coking coal	95	1.0	0.8-1.5	0.6-1.0	1.5-2.0

Source: (Agada,2014)

Materials and Methods

Equipment/Reagents

(i) Mini Pal4 version XRF machine (ii) Shimadzu X-ray diffractometer
(iii) Phenom Pro X Scanning electron machine (iv) Crucibles (v) Muffle furnace and Oven (vi) Stop watch (vii) Dessiccators (viii)Silica plates; flat about 5mm thick (ix) conical flask and beakers (x)Laboratory slake hammer (xi) Ball milling machine (xii) Sieves (xiii) Sieves shaker (xiv)Digital weighing balance (xv) Bomb calorimeters

Reagents

(i) Barium chloride solution – 100g $BaCl_2.2H_2O/dm^3$ (ii) saturated bromine water (iii) Eschka Mixture (iv) Hydrochloric acid (v) Benzene solution

Sample Collection and Preparation

The coal sample used in this research work was sourced from Owukpa village of Ogbadibo Local Government Area of Benue state. The selection of samples was based on random method. 10kg of the sample was collected, some on top of the outcrop and some 1m deep beneath the earth's crust to enhance true representation of the coal sample.

Experimental Methods

The experimental steps taken in the course of this research work are as follows:
(i) determination of chemical and mineralogical compositions of the coal samples using X-ray fluorescence, X-ray diffraction analysis and scanning electron microscopy. (ii) determination of fixed carbon using proximate and ultimate analyses (iii) determination of calorific value of the coal using bomb calorimeter.

Chemical Analysis of Owukpa Coal using X-Ray Fluorescence Spectroscopy

The required parameters were set to standard. Such parameters are pressure values, set at 16 Pa (Pascal), chamber for the opening and lifting of the cassette (a holder that houses the pellet sample) the voltage recommended level is 45v and the current recommended level is 40A. The equipment was allowed to run for at least 4 to 5hrs to enable the standards and other mechanical parts responsible for analysis to stabilize and initialized.
The sample was loaded into the cassette by placing the surface side facing downward, with the help of spring attached to the cassette, the cassette was locked manually by turning it clockwise, to keep the pellet from falling off or scattered on the goniometer when analysis was going on. The loading and the cassette points were positioned directly facing the goniometer position for easy analysis. The analysis started immediately the cassette was lifted down with command L2 and this resulted in the closure of the opening valve. The result is given in Table 8.

Mineralogical Analysis of Owukpa Coal using X-Ray Diffraction

This was run between 0° and 120° theta Bragg angle depending on the type of the minerals in question. The running rate (scan speed) was within 2 to 10 degrees per minute. The voltage recommended is 40V and current recommended level of 30A was used. The auto-silts (divergence, scatter and receiving) used for the various aperture controls were of sizes 1.0, 1.0 and 0.3 (degree). After twenty minutes, the analysis was completed and the data generated was collected automatically followed by the manual Results Drag-Dropping Techniques onto the save where the result can be produced in either ionic, carbonic, elemental, oxides or non-ionic forms. The result was produced, once the concentration of the parameters involved are equal or greater than the already calibrated and installed standards. The result of this analysis is given in Figure 1.

Bomb Calorimetric Test of Owukpa Coal

0.89g of the coal was placed in the silica crucible and the crucible was supported over ring. A fine magnesium wire touching the coal sample was stretched across the electrodes. Oxygen supply was forced into the bomb till a pressure of 25 – 30atmosphere was reached. Initial temperature of the water in the calorimeter was noted after thorough stirring. The current was switched on and the fuel in the crucible and burned with evolution of heat. The heat produced was transferred to water which was stirred thoroughly throughout the experiment by the electric stirrer. Maximum temperature shown by thermometer was recorded and the calorific value of the coal was calculated using the expression $C = \frac{(y+z)(t_z - t_1)}{x}\ kcal/kg$. The result of this test is given Table 9

Scanning Electron Microscopy/EDS Analysis of Owukpa Coal

Here the surface of the sample to be analyzed was observed with an optical microscope to view and mark the position or area of interest on the specimen. The specimen was then introduced into the machine (SEM) where electron beam was focused into the specimen by a system of electromagnetic lenses and by means of deflection coils. The electron beam was made across several lines to cover a rectangular area enclosing the marked area of interest. The quantitative analysis of that particular point of interest on the specimen was then carried out using crystal spectrometer which collected all the signals from that point and recorded them. The recorded signals were used for identification and quantitative analysis of the sample. The results of the SEM micrographs are given in Plates 1-7 and the EDS summary result in Table 7.

Ultimate (Chemical) Analysis of Owukpa Coal

The percentage of some elemental compositions of the coal sample was determined in the ultimate analysis. These are hydrogen, nitrogen, sulphur, phosphorous, oxygen and total carbon contents. In determining the percentage of carbon and hydrogen, 100g of the coal sample was burnt in a current of dry oxygen thereby converting C and H of the coal into CO_2(CO_2 and H_2O) and ($H_2 + \frac{1}{2} O_2 = H_2O$) respectively.

The products of combustion of (CO_2 and H_2O) were passed over weighed tubes of anhydrous calcium chloride and potassium hydroxide which absorb H_2O and CO_2 respectively. The increase in the weight of $CaCl_2$ tube represent the weight of water (H_2O) formed while increase in the weight of KOH tube represent the weight of CO_2 formed.

In determining the sulphur content of the coal, 100g of coal was heated with Eschka mixture (consist of 2 parts of MgO and 1 part of anhydrous Na_2CO_3) at 800^{0}C. The sulphate formed is precipitated as $BaSO_4$ (by treating with $BaCl_2$) and it is filtered, washed, dried and weighed from which the sulphur content was computed as follows:

$$\% \text{ of sulphur in coal} = \frac{0.1374y}{x} \text{ x } 100$$

where x = weight of coal sample taken, y = weight of $BaSO_4$ precipitate formed.

Also in Nitrogen estimation, same weight of coal was heated with concentrated sulphuric acid in the presence of potassium sulphate in a long necked flask called Kjeldahal's flask, thereby converting nitrogen of coal to ammonium sulphate. When a clear solution was obtained, it was treated with 50% NaOH solution. The ammonia thus formed was distilled over and absorbed in a standard sulphuric acid solution. The volume of sulphuric acid solution was then determined by titrating against standard NaOH solution. Thus the amount of acid neutralized by liberated ammonia (from coal) was determined. Therefore, the oxygen percent of the coal was estimated by deducting the result of carbon, hydrogen, nitrogen, sulphur and ash from 100. The result is given in Table 10.

Proximate Analysis of Owukpa Coal

The proximate analysis was done by determining the moisture, volatile matter, ash and fixed carbon contents of the sample. The moisture content was measured by heating 75g of the sample in a crucible in a muffle furnace at 105-110^{0}C for an hour. Thereafter, the crucible was taken out, cooled in desiccators and weighed. The process was repeated four times and a constant weight of coal (anhydrous) was achieved and the moisture content was calculated. Similarly, the volatile matter was calculated after achieving a loss in weight of moisture free powdered coal on heating for seven minutes at 950^{0}C. Thereafter, another quantity of coal was burnt in air at 750 ^{0}C to obtain a weight of the residue after burning in an open crucible. The fixed carbon was then calculated by deducting the moisture, volatile matter and ash values from 100. The result is given in Table 11.

Discussion of Results, Conclusion and Recommendation

Discussion of Results

(a) Chemical Analysis of Owukpa Coal Sample using XRF

Table 8 gives the chemical analysis of the Owukpa coal head sample and the various sieve sizes fractions using XRF analytical instrument. From the result, the head sample of the coal contained 1.17%Ti, 0.76% Fe and

0.09%Zr as the major elements while other elements are in traces. This indicates that the Owukpa coal sample has low percentages of metallic elements present in it and this could be attributed to the nature of the vegetation that formed the coal deposit. The sieve size analysis revealed that as the particle size reduces more of the metallic minerals present in the coal sample are liberated and retained in the lowest sieve size fraction. This indicates that the Owukpa coal sample can be sized for beneficiation. The result obtained compared favourably with those cited in Tables 1 to 3.

(b)Mineralogical Analysis of Owukpa Coal Sample using XRD, SEM/EDS

Figures 4.2(A-E) give the X-ray diffraction analysis diffractograms result, Plates 1-7 show the micrographs of spots 1- 7 and Tables 4.1(a-h) give EDS result summary of the elemental compositions of the various SEM spots of the Owukpa coal head sample. The result revealed that the coal sample contained 25.83%C, 13.96% Sr, 35.17%F, 22.7%O, 3.0% Al, 7.0%Y, 5.21%Rb and 3.74%N on the average. The SEM/EDS results indicate that the Owukpa coal sample contained low ash forming substance as reflected by the percentage of aluminium present in it and also contained carbon- a major constituent required of a coal material. The result obtained compared favourably with other results cited in this work.

(c)Bomb Calorific Test Analysis

Table 4.3 gives the result of the Bomb calorific value of the Owukpa coal sample. The calorific value of the coal was found to be 18.5432 mJ/kg or 18,543.2 kJ/kg. This indicates that 18.5432 mJ is released when 1kg of the Owukpa coal sample is combusted and the value obtained for the Owukpa coal sample is higher compared to the heating values of some Nigerian coal deposits cited in Tables 3 and 4 of this work.

(d)Ultimate and Proximate Analyses

(i) Ultimate Analysis

Table 10 gives the ultimate analysis result of Owukpa coal sample. The result revealed that the Owukpa coal sample contained 60.36%C, 6.5%H, 1.9N, 15.89%O, 0.14%P and 0.89%S. The result of the elemental composition of the ultimate analysis of the coal sample shows that the Owukpa coal has less percentage of carbon (60.36%) compared to that of Enugu (78-82%C), Okaba (72-80%C), Orukpa (75-81%C), Lafia (82-90%C) and coking coal (95%C). The hydrogen content of the Owukpa coal is higher compared to other five Nigerian coal deposits. The nitrogen content of the Owukpa coal compared favourably with that of Enugu coal. The sulphur content of the Owukpa coal is less than that of Enugu, Okaba, and Lafia but higher than that of Orukpa coal deposit. The result of the ultimate analysis of the Owukpa coal falls short of that of coking coal but compared favourably with those of some Nigerian coal deposits cited in Table 5. Thus making Owukpa coal deposit another potential source of coal supply for the nation.

(ii) Proximate Analysis

Table 11 gives the proximate analysis result of the Owukpa coal sample. The result revealed that Owukpa coal contained 47.40% fixed carbon(C), 11.86% ash, 26.0% volatile matter and 14.74% moisture contents. The fixed carbon of the coal is less than that of coking (60.0%C), Enugu (55.3%C), Okaba(50.6%C), Orukpa(52.2%C) and Lafia (58.3%C) coal. This could be attributed to the biochemical and chemical compositions of the vegetation that formed the Owukpa coal deposit. The ash content of Owukpa coal is higher than that of the coking (7.0%) and Orukpa(10.3%) coals but less than that of Enugu(14.5%), Okaba(11.9%) and Lafia(30%) coal deposits. This phenomenon could also be attributed to the biochemical and chemical compositions of the vegetation that formed the coal deposit. The moisture content of the Owukpa coal is higher compared to those of all the deposits cited in Table 6. The volatile matter of the Owukpa coal compared favourably with that of the coal cited in Table 6. The variations in the compositions of Owukpa coal compared to those cited in Table 6 could be attributed to the type of vegetation that formed the Owukpa coal deposit and its transformation over time due to biochemical processes.

(e) Sieve Size Analysis

Table 8 gives the chemical analysis of the sieve size fractions using XRF analytical instrument.

The result revealed that -90 + 50µm sieve fraction contained the highest percentages of the liberated mineral elements of the Owukpa coal compared to sieves sizes of -355 +180µm and -180+90µm. This phenomenon indicates that the coal can respond to size reduction operation in order to achieve meaningful liberation and beneficiation.

Conclusion

The determination of chemical, mineralogical and bomb calorific parameters of Owukpa coal has been investigated and the following conclusions are drawn:

1. the chemical analysis of the Owukpa coal revealed that the coal contained1.17%Ti, 0.76% Fe and 0.09%Zr as the major elements while other elements are in traces.
2. the mineralogical analysis of the SEM/EDS of Owukpa coal revealed that it contained 25.83%C, 13.96% Sr, 35.17%F, 22.7%O, 3.43% Al, 7.0%Y, 5.21%Rb and 3.74%N on the average. The Owukpa coal sample contains low ash forming substance as reflected by the percentage of aluminium present in it and contains carbon a major constituent required of a coal material.
3. the calorific value of the coal was found to be 18.5432 mJ/kg or 18,543.2 kJ/kg.
4. the result of the ultimate analysis revealed that the Owukpa coal sample contained 60.36%C, 6.5%H, 1.9N, 15.89%O, 0.14%P and 0.89%S. The result of the proximate analysis revealed that Owukpa coal contains 47.40% fixed carbon(C), 11.86% ash content, 26.0% volatile matter and 14.74% moisture content. Thus the Owukpa coal deposit can be classified as a lignite type coal deposit that can respond to beneficiation process to improve its quality.
5. the sieve size analysis result revealed that -90+50µm sieve fraction contained the highest percentages of the mineral elements of the Owukpa coal.

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Experimental Results of Owukpa Coal Deposit

Table 7: EDS Result Summary of the Elemental Compositions of the Various SEM Spots of the Owukpa Coal Head sample

Element Symbol	Element Name	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6	Spot 7	Total	Average
C	Carbon	22.90	17.30	19.30	29.00	23.10	35.70	34.90	180.79	25.83
Sr	Strontium	19.10	14.00	15.30	15.40	15.00	13.70	15.20	97.70	13.96
F	Fluorine	27.70	40.00	40.10	27.90	39.30	37.90	37.30	250.60	35.17
Y	Yhrium	4.70	7.10	7.50	7.90	7.40	6.90	7.50	49.00	7.00
O	Oxygen	21.90	23.40	23.60	19.80	23.50	23.50	23.20	158.90	22.7
Rb	Rubidium	3.70	5.60	5.60	5.60	5.70	5.10	5.20	36.50	5.21
Al	Aluminum	2.50	3.70	3.70	3.50	3.90	3.40	3.30	24.00	3.43
N	Nitrogen	7.50	2.40	2.00	5.00	2.10	3.70	3.70	26.20	3.74

Table 8: Chemical Analysis of the Head Sample and Sieve Size Fractions using XRF Analytical Instrument

Element	Head sample	Sieve size fraction		
		-355 +180µm	-180 +90µm	-90 +50µm
	%	%	%	%
Ti	1.1742	1.0630	0.3295	1.1546
Fe	0.7672	0.8432	0.3440	0.9027
Zr	0.0959	0.0930	0.0653	0.1183
Ag	0.0220	-	0.0226	-
Sn	0.0139	0.0135	-	-
Nb	0.0114	0.0096	0.0054	0.0090
Sr	0.0090	0.0095	0.0052	0.0084
Zn	0.0085	0.0047	0.0012	0.0045
Pb	0.0045	0.0041	-	0.0040
Mo	0.0038	0.0043	0.0038	0.0047
Cu	0.0020	0.0026	-	0.0031
Sb	-	-	0.0214	0.0183
Co	-	-	-	-
Ni	-	-	-	-
Mn	-	0.0098	-	0.0139

Table 9: Bomb Calorific Value of the Owukpa Coal Sample

Sample	Sample weight (G)	Temperature rise (°C)	GCV (MJ/Kg)	GCV (KJ/Kg)
Coal	0.89	0.2464	18.5432	18,543.2

Where
GCV = Gross Calorific Value

Table 10: The Ultimate Analysis Result of Owukpa Coal Sample

Elements	%
Carbon	60.36
Hydrogen	6.50
Nitrogen	1.90
Oxygen	15.89
Phosphorous	0.14
Sulphur	0.89

Table 11: The Proximate Analysis Result of the Owukpa Coal Sample

Analysis	%
Moisture content	14.74
Ash content	11.86
Volatile matter	26.00
Fixed carbon	47.40

Spot 1

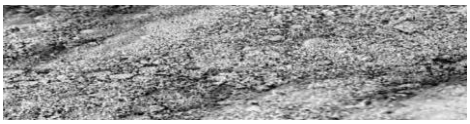
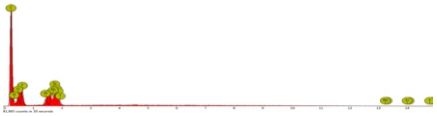


Plate 1:Micrograph ofSpot 1 of Owukpacoal sample



Figurea: Spot1 Diffractogram of Owukpa coal sample

Spot 2

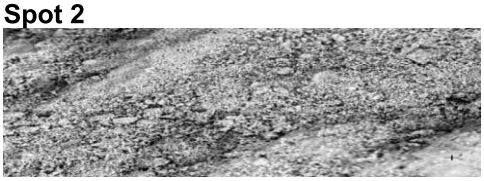
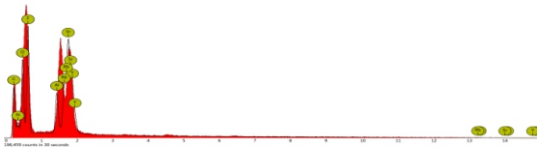


Plate 2:Micrograph ofSpot 2 of Owukpacoal sample



Figureb: Spot2 Diffractogram of Owukpa coal sample

Spot 3

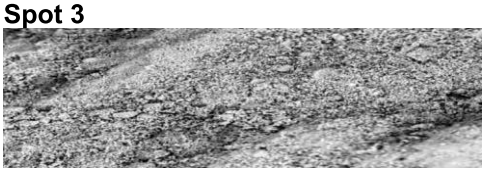
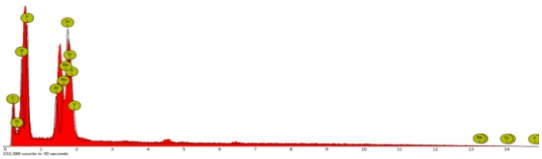


Plate 3:Micrograph ofSpot 3 of Owukpa coal sample



Figurec: Spot3Diffractogram of Owukpa coal sample

Spot4

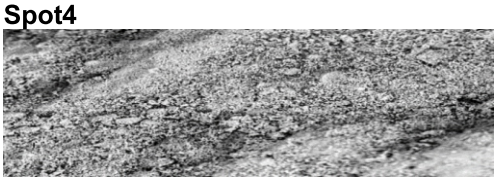
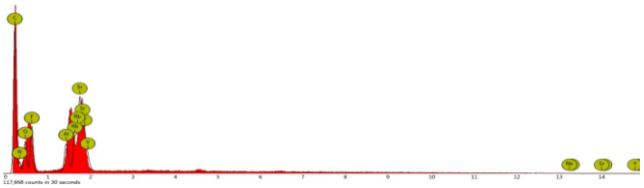


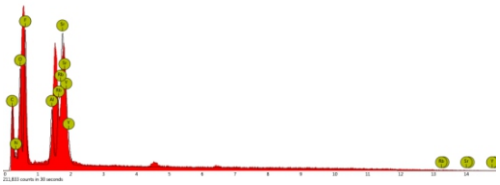
Plate 4:Micrograph ofSpot 4 of Owukpacoal sample



Figured: Spot4 Diffractogram of Owukpa coal sample

Spot 5

Plate 5:Micrograph ofSpot 5 ofOwukpa coal sample



Figuree: Spot5 Diffractogram of Owukpa coal sample

Spot 6

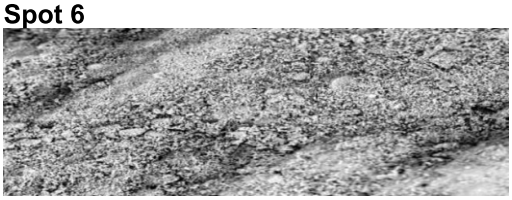
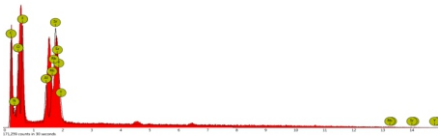
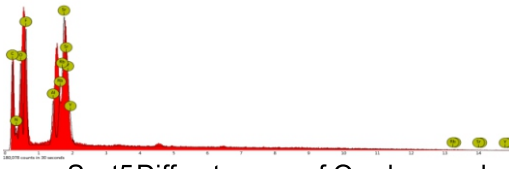


Plate 6 Micrograph of spb6 of Owukpacoal sample



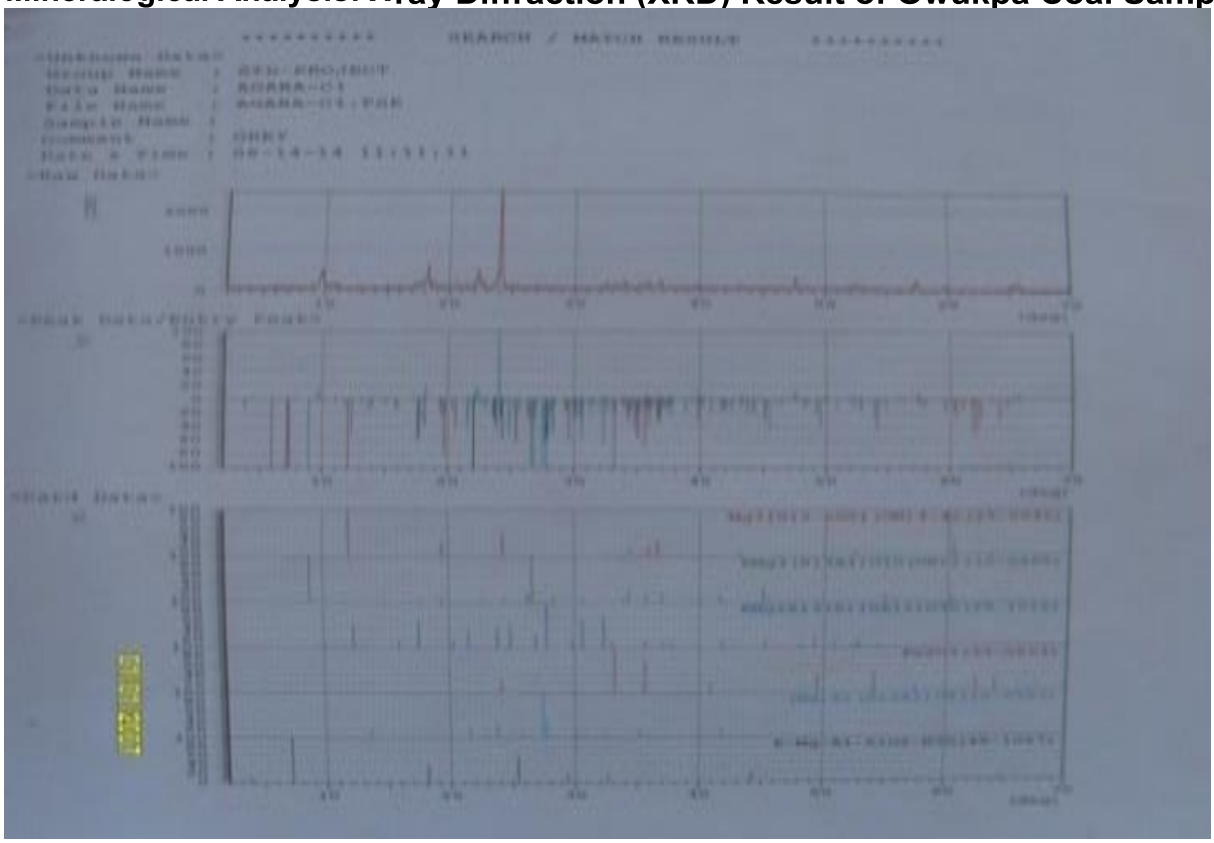
Figureg: Spot5 Diffractogram of Owukpa coal sample

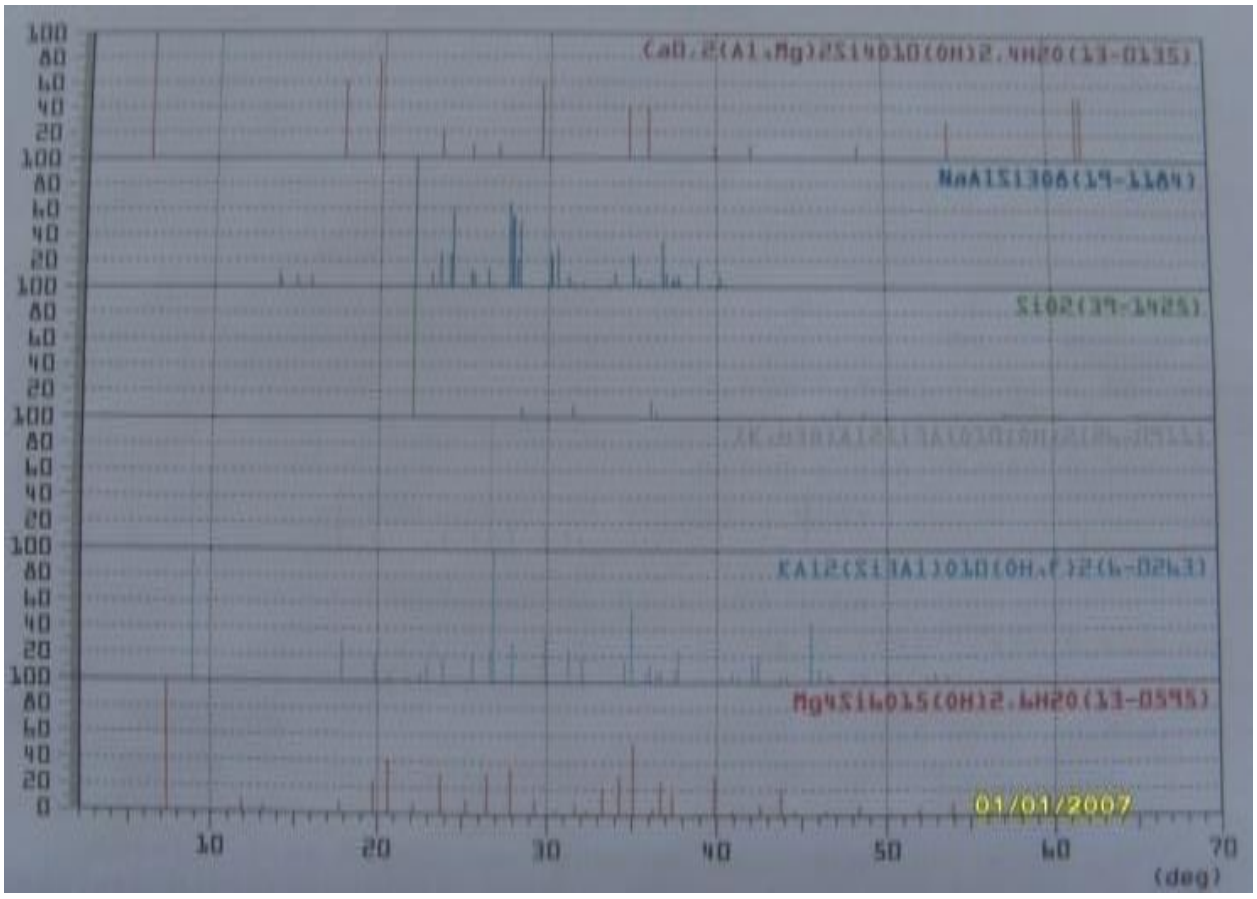
Plate 7:Micrograph of spb7 of Owukpacoal sample



Figureg: Spot5 Diffractogram of Owukpa coal sample

Mineralogical Analysis:-Xray Diffraction (XRD) Result of Owukpa Coal Sample





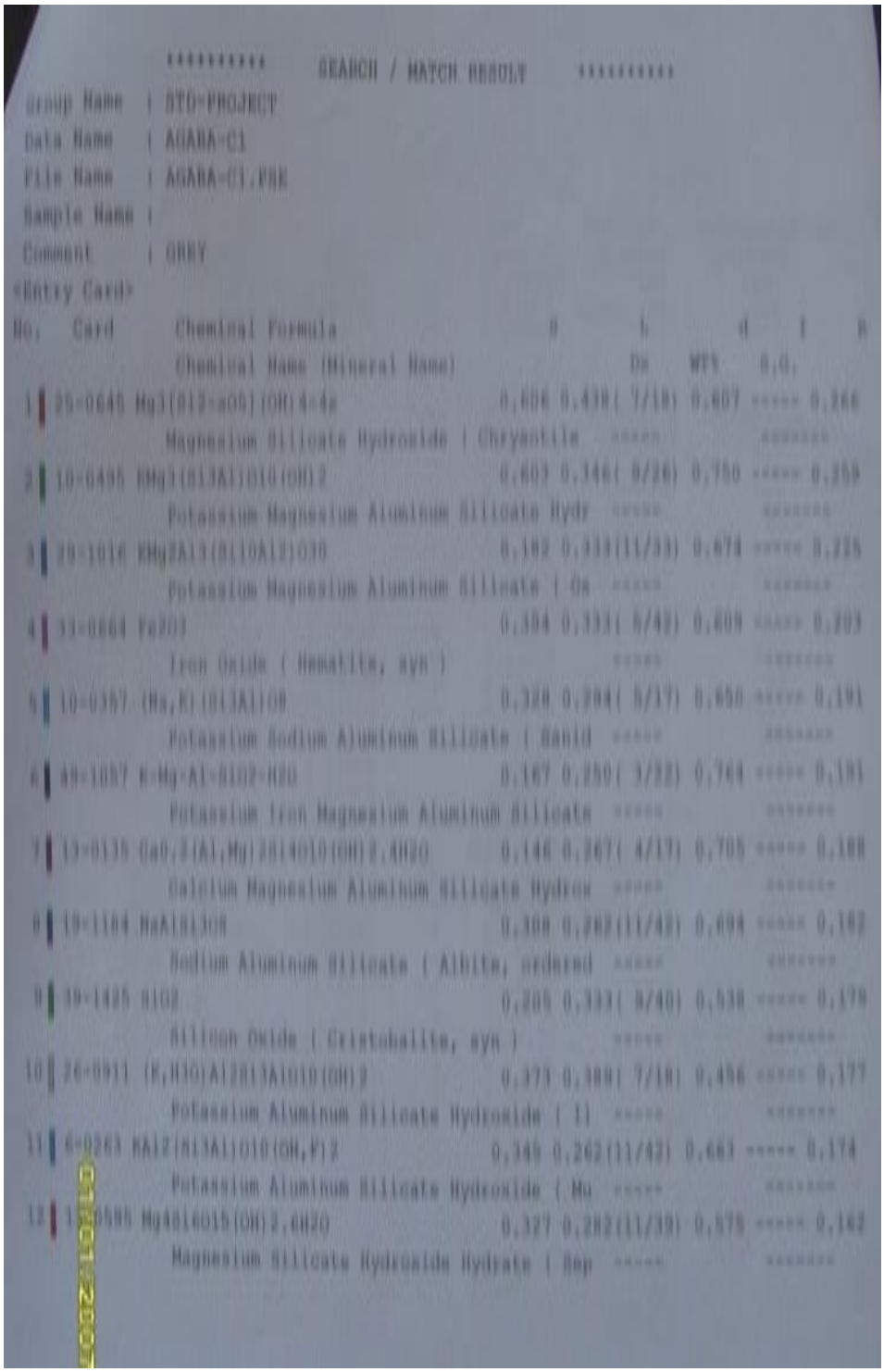


Figure 1 X-ray diffraction analysis diffractograms results of Owukpa coal sample.

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Determination of Chemical Composition and Liberation Size of Gujeni Iron Ore Deposit, Kaduna State, Nigeria.

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Abstract

Determination of chemical composition and liberation size of Gujeni iron ore was carried out in the course of this research work. The iron ore deposit is located in Gujeni village, Kagarako Local Government Area, of Kaduna State. The Samples were taken from four different pits 1, 2, 3 and 4 at 100m apart and at 3m depth. The four samples were mixed together to form composite sample. The composite sample was crushed, pulverized and analyzed using XRF techniques. The result of the chemical analysis reveals that the composite sample contained 48.6%Fe, 0.2%Mn, 12.01%Ti, 2.06%P, 0.2%S, 6.0%Si, and 4.4% Al on the average. The liberation size of the iron bearing minerals was found to be -250+180µm, containing the highest percentage assay of iron (48.80%Fe). The results obtained as the chemical composition of the iron ore shows that Gujeni iron ore may be another potential source of iron ore deposit that can be beneficiated and supply to iron and steel making industries in the country.

Keywords: liberation, chemical composition, composite, sieve size, beneficiation and iron ore.

Introduction

Iron and steel industries are some of the basic foundation for the technological development of any country. A country that neglect iron and steel will remain undeveloped and technological backward in its national development plan. As a result of the realization of the importance of the iron and steel industries and with the intention of laying a formidable foundation for technological take-off of the country, the Government of the Federation in 1971 established the Aladja and Ajaokuta iron and steel projects. As a result, on commissioning the Aladja and Ajaokuta in early eighties had to depend on foreign sources of iron concentrates and coke. Not until, with efforts of the National Ore Mining Project Itakpe, National Metallurgical Development Centre, Jos and individuals researchers that a process flow sheet has been developed for the beneficiation of the Itakpe iron ore deposit, estimated over 200 million tonnes to be upgraded and used as feedstock in Ajaokuta and Aladja iron and steel plants (Thomas *et al.,* 2014).

Some of the iron ore deposits in Nigeria and their location are shown below in Table 1.

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Comminution Process

Comminution is a process in which particle size of the ore is progressively reduced until the clean particles or valuable minerals are liberated from the gangue and can be separated by such methods are available. Crushing and grinding are the two primary comminution processes. Crushing is normally carried out on "run-of-mine" ore, while grinding normally carried out after crushing. In comminution, the size reduction of particles is done by three types of forces: compression, impact and attrition. Compression and impact forces are extensively used in crushing operations while attrition is the dominant force in grinding. The primarily used equipment in crushing are:-jaw crushers, gyratory crushers and cone crushers. Crushing is a dry process whereas grinding is generally performed wet. (Gupta, 2003).

The major purposes of comminution are

1) Liberation of one or more economically

Table 1: Some Iron Ore Deposits in Nigeria and their Locations

S/no	Deposits	Locations	Iron Content	Estimated Reserve in tonnes
1	Itakpe	Kogi	36-88%	200-300 million
2	Oshokoshoko	Kogi		12-14 million
3	Ajabanoko	Kogi	40%	60 million
4	Agbadookudu	Kogi	38-48%	60 million
5	Akoina	Kogi		Under investigation
6	Tajimi	Kogi		200 million
7	Ero	Kogi		-
8	Ebiya	Kogi		-
9	Obanaja	Kogi		-
10	KotonKarfe	Kogi	43-53%	428 million
11	BassaNge (EgenjiAte)	Kogi	43-49%	400 million
12	Kakun (kabba)	Kogi		-
13	Ubo-Toso	Kogi/Edo		-
14	Akunu (Ikare)	Ondo		-
15	Gujeni	Kaduna		-
16	Kagara (kubacha)	Kaduna		-
17	BirniGwari	Kaduna		-
18	Toto Muro	Nasarawa		3.8 million
19	Reshi	Bauchi	10-19%	-
20	Ayi Wawa	Bauchi		-
21	Karfe	Borno		-
22	Gamawa	Bauchi		-
23	DarkinGari	Kebbi		-
24	Nsude	Enugu		40.6 million
25	Ameki /Ohafia	Abia		-
26	Veketuwo	Plateau		-
27	Agbaja	Kogi		Over one billion
28	Nsuge Hill	Anambra	43-50%	3.8 million
29	Bakingari	Sokoto	37%	

Source: (Thomas and Yaro, 2007)

important minerals from the gangue components in an ore matrix.

2) Exposure of a large surface area per unit mass of material to facilitate some specific chemical reaction, such as leaching.

3) Reduction of raw material to the desired size for subsequent processing or handling.

4) Satisfaction of market requirement concerning particle size specification.

X-ray Fluorescence (XRF)

An x-ray source is used to irradiate the specimen and to cause the elements in the specimen to emit their characteristic of x-rays, when electrons are ejected from the atom making up the material. A detector system is used to measure the positions of the fluorescent x-ray peaks for qualitative identification of the elements present, and to measure the intensities of the peaks for quantitative determination of the composition. All elements but, low atomic number elements e.g. H, He and Li can be routinely analyzed by XRF (Huang, 1992).

As the energies and wavelengths are characteristic of the atoms of the elements emitting the x-rays. They are used for qualitative analysis while the intensity of these characteristic x-rays is related to the concentration of the particular element in the

material, and is used for qualitative elemental analysis (Thomas and Yaro, 2007).
XRF can be used extensively for the analysis of solids, powders and liquid. The technique is nondestructive, rapid, precise and potentially very accurate.

Liberation

Liberation is the main objective of comminution, or release of the valuable minerals from the associated gangue mineral at the coarsest possible size. The degree of liberation refers to the percentage of the mineral occurring as free particles in the ore in relation to the total content. This can be high if there are weak boundaries between the minerals and the gangue particles.

Equipment and Methods

Equipment

(i) Sledge hammer (iii) Jaw crusher (iv) Cone crusher (v) Ball mill (vi) Set of sieves (vii) Laboratory sieve shaking machine (viii) Weighing machine (ix) X-ray florescence (XRF) Machine

Location and Accessibility of Gujeni Iron Ore Deposit

The Gujeni iron ore deposit is located in a village called Gujeni. The Gujeni village is along Kaduna/Abuja express way. It is about 20 km away from Jere village towards Abuja and about 50 km to Zuba town. The Gujeni village can be accessed through Zuba or Kaduna town. The deposit covers a distance of about 2.3 kilometres square and its reserve has not yet been quantified by any of the agencies responsible for mineral resources development in the country.

Methods

Sample Collection

Samples of the iron ore werecollected from various points of deposit site located at Gujeni village, in Kagarko Local Government Area of Kaduna State. Global Position System (GPS) was used to measure the exact location at which sample was taken. Grab method of sampling was adopted in collecting the sample. 60kg of the sample was collected from (4) four points at interval of 100m apart at 3m depth.
Table 2 shows the GPS coordinates of where the iron ore samples were sourced.

Table 2: Coordinates of the Area of the Deposit

S/no	Coordinates
Pit 1	N 09° 27' 03.3", E 007° 22' 36.3"
Pit 2	N 09° 27' 05.4", E 007° 22' 38.4"
Pit 3	N 09° 27' 06.6", E 007° 22' 31.3"
Pit 4	N 09° 27' 05.5", E 007° 22' 28.5"

Sample Preparation

Sample preparation involves comminution which consists of crushing and grinding process. The lump sizes of the ore sample were reduced to the sizes that could be accepted by the crusher using sledge hammer. The sample was crushed using jaw crusher and pulverized using ball mill.

Sampling for the Purpose of Tests and Analyses

Coning and quartering sampling method was used to divide the pulverized sample into smaller portions that were used for other tests and analyses conducted.

Chemical Composition Analysis

After Comminution processes and proper sampling, the sample was thoroughly mixed and analyzed using X ray Florescence machine to determine the elemental composition of the ore. The results of the analyses are presented in Tables 3 and 4.

(a) Procedure for Determination of percentage Elemental Composition of Rock Sample Using XRF(X-ray Fluorescence) Thermo – scientific – Advant'x 1500 Model

The iron ore sample was pulverized using jaw crushing machine, disc miller and finally cup miller to fine particle size of 100mesh (0.15 microns). The powder sample was mixed with borax in ratio of 4: 1 to form a pellet using pelletizing machine. The pellet sample was used to carry out the XRF analysis

Particle Size Analysis of the Iron Ore

Particle size analysis was carried out to establish the distribution of minerals present in the various sieve size fractions. 600g of the pulverized sample was placed on the set of sieves arranged on the basis of $\sqrt{2}$ and placed

on the sieve shaking machine. The sieves were vibrated for 30 minutes to enhance proper sieving. The minerals on each sieve was weighed, packed in cellophane leather and properly labelling for analyses.

Liberation Size Analysis

Liberation study was conducted to determine the liberation size of the valuable mineral. The minerals in each sieve size fractions was analyzed, the sieve size fractions that contains the highest percentage assay of Fe content was acknowledged as the liberation size of the iron ore .

Results and Discussions

Tables 3 and 4 are the results of chemical analysis of Gujeni iron ore composite sample and the various samples from the different pits.

Table 2: Chemical Analysis Result of the Composite Sample

Elements	Percentage
Fe	48.6
Mn	0.2
Si	6.0
Al	4.4
Ti	12.01
Zr	0.7
V	0.3
Pb	0.6
Cd	0.2
Zn	0.1
P	2.06
S	0.2
Ba	12.1
Br	11.3

From Table 3 the composite sample contains 48.6%Fe, 0.2%Mn, 12.01%Ti, 0.7%Zr, 0.1%Zn, 0.3%V, 0.6%Pb, 0.2%Cd, 0.1%Cu, 2.06%P, 0.2%S, 6.0%Si, 4.4%Al, etc. which are comparable with other chemical compositions of the major iron ore deposit.

From the results in Table 4, pit 1 contains the highest iron content when compared

Table 3: Chemical Analysis Result of th Samples from each Pit

Elements	Pit 1	Pit 2	Pit 3	Pit 4
Fe	49.9	44.2	43.3	44.60
Mn	0.2	0.2	0.2	0.2
Si	5.5	6.5	6.00	6.3
Al	3.9	4.9	4.8	5.0
Ti	12.1	12.4	12.0	12.01
Zr	0.7	0.6	0.05	-
V	0.4	0.3	0.3	0.3
Pb	0.3	0.3	0.2	0.2
Cd	-	-	0.17	-
Zn	0.3	0.2	0.3	0.1
P	1.6	1.20	1.21	0.98
S	-	0.1	0.1	-
Ba	12.0	12.01	12.0	12.01
Br	11.0	11.5	11.8	11.0

with the other samples from other pits. This could be attributed to the different in mineralization process of the deposit, which may have favoured pit1 to other pits. The silica content of the ore deposit is about 12% which is still comparable to other major iron ore deposits in the country (GSN, 1980; RMRDC, 2000; Thomas and Yaro, 2007). The Gujeni iron ore sample also contained about12%Ti which can be used as an alloying element during the iron and steel making process (Kudrin, 1985).

Table 5: Result of Particle Size Analysis of the Sample

Sieve size(µm)	Weight(g) retained	Weight(%) retained	Nominal aperture	Cumulative (%)	
				Weight (%) retained	Weight(%) passing
+355	195.00	32.50	355	32.50	67.50
-355+250	81.4	13.57	250	46.07	53.93
-250+180	34.8	05.80	180	51.87	48.13
-180+125	54.5	09.08	125	60.95	39.05
-125+90	47.10	07.85	90	68.80	31.20
-90+50	49.00	08.17	50	76.97	23.03
-50	138.00	23.00	Pan	100	0.00
Total	600				

Table 5 presents the result of particle size analysis and reveals that +355µm retains 195g,-355+250µm (81.4g), -259+180µm (34.8g), -180+125µm (54.5g), -125+90µm (47.1g), -90+50µm (49.0g) and -50µm (138g) of the minerals.

Liberation Size Analysis Results of the Composite Sample

The minerals distributed in each sieve size were analyzed to determine the percent assays. The sieve size that contained the highest percentage assay of iron is the liberation size of the iron ore.

Table 6 presents the result of chemical analysis of various sieve size fractions of the iron ore sample.

Table 6: Chemical Composition of the Various Size fractions Determined by XRF Analysis

Elements	+355 µm	-355+250µm.	-250+180µm	-180+125µm	-125+90µm	-90+50µm.	-50µm
Fe	43.30	45.80	48.80	45.9	46.00	42.60	47.9
Mn	0.1	0.1	0.2	0.2	0.1	0.2	0.2
Si	5.5	6.0	5.65	5.8	6.03	6.01	6.01
Al	4.0	3.9	3.5	3.85	3.7	4.2	3.6
Ti	12.1	12.0	12.01	12.00	12.01	12.1	12.0
Zr	0.3	0.4	0.4	0.4	0.4	0.5	0.8
V	0.3	0.3	0.3	0.2	0.3	0.3	0.3
Pb	0.1	0.2	0.3	0.2	0.2	0.2	0.2
Cd	-	-	-	0.2	-	-	0.2
Zn	0.9	0.9	0.9	0.9	0.8	0.7	0.2
P	1.23	0.89	1.45	1.02	1.34	0.67	1.90
S	-	0.1	-	0.1	-	-	-
Ba	12.1	12.02	12.0	12.0	12.00	12.15	121
Br	11.5	11.45	10.85	11.55	11.44	11.33	11.26

From the results -250+180µm contains the highest percent assay of iron when compared to other sieve size fractions; hence -250+180µm size fractions is the liberation size of Gujeni iron ore deposit.

Conclusions and Recommendations

Conclusions

The determination of chemical composition and liberation size of the Gujeni iron ore was carried out. The chemical analysis reveals that the iron contains 48.6%Fe, 0.2%Mn, 12.01%Ti, 0.7%Zr, 0.1%Zn, 0.3%V, 0.6%Pb, 0.2%Cd, 0.1%Cu, 2.06%P, 0.2%S, 6.0%Si, 4.4%Al etc and the result is comparable with the six other major iron deposits within the country. The liberation size of the ore was found to be -250+180µm, being the particle size with highest percent assay of iron.

Recommendation

- Based on this research work, it is recommended that Gujeni iron ore deposit can be upgraded to the blast furnace requirement, because it contained high iron content of 48.6%.
- It is also recommended that -250+180µm size fraction should be used for the concentration process of Gujeni iron ore

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Rock Breakage Using Explosive: A Review and Consideration for Expansive Mortar Chemical.

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Abstract
The concept of rock breakage using explosive is one of the several methods of rock fragmentation. Though the method has posed a lot of challenges on the environment such as ground vibration and air blast, still its efficiency cannot be overemphasized. There are several other methods of achieving rock breakage discovered in the recent past that are capable of toppling the conventional method of using explosive. These new methods are effective when applied, while others are still evolving. This report reviewed the conventional method and existing challenges with a view to proffering a possible solution through the use of non-explosive means of achieving rock fragmentation. In this research, expansive chemical method that is one of the alternative methods was discussed and tested. The method cracks rock and concrete mortar without fly rock, characteristics fumes and gases that are common with conventional method. Though the cost comparative of alternative method exceed that of conventional method but with time and increase in the patronage this may be taken care of. Recommendations are made on how to properly carryout and improve the method.
Keywords: *rock breakage, explosive, environment, non-explosive and expansive chemical*

Introduction

Rock breakage using explosive has been a crucial technological challenge to mankind since ancient periods. The primary application of this innovation or technology has remained essentially unchanged during last 10,000 years, in the production of fragmented boulders, minerals and concrete. In the recent pasts, improved innovations have been found in the breakup of artificial materials such as concrete, rubber, plastics, etc (Viktorov and Kuznetsov, 1998).

Nowadays, same as in the past years, the major standard for measuring the success of a particular technology or another in the rock breakage is the economic competitiveness of the innovation in question. The recent past of this decade has brought forth yet another yardstick for evaluating one rock breakage method or another and the ecological effects. Operations related to rock breakage are usually conducted on large scale. The amount of energy consumption required in such operations constitutes a significant fraction of the entire energy consumption of mankind. The resultant effects on the ecosystem as a result of the large scale and energy-consuming activities are becoming unbearable (Viktorov and Kuznetsov, 1998).

The author emphasized that the most efficient method for rock breakage and materials in general is blasting, which is also most hazardous of all breaking technologies. Blasting operations are hazardous not only because of the production of harmful gases and dust formed by the action of detonation wave on the rock, but also because of poorly controllable action of the explosion on the rock mass, as evidenced by the integrity of the

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mass, changes in the filtration properties of the mass, and a cumulative effect of change in its mechanical properties and those of nearby facilities such as dams, structures, etc (Viktorov and Kuznetsov, 1998).

However, up to the present time, the use of explosive in rock breakage remains the most widely used method, since the specific energy consumption in realizing this is minimal, comparative-cost analysis as well as output of the operations is relatively high. The negative consequences of large scale rock breakage using explosive cannot over emphasized despite the aforementioned merits.

Careful examination of the merits and demerits of rock breakage using explosive has led the engineering and scientific community in working toward improvements of the production and economic indexes of the traditionally used methods of rock breakage, both mechanical and hydraulic. Though new cutting materials were being used, as well as new operating modes, design and engineering solutions are becoming more sophisticated and efficient. Rock breakage using explosive has been strategically and substantially improved upon in areas of compositions, engineering and safety, and consequential harmful effects on the ecosystem (Viktorov and Kuznetsov, 1998).

Viktorov and Kuznetsov, (1998), expressed that serious efforts were being geared toward the development of new methods for rock breakage and materials at large using fluxes of thermal, electrical, or electromagnetic energy. Also, in commercial application is thermal drilling and break up of materials through an electrical discharge in a static electric field or a pulsed electromagnetic field. Another possibility under investigation is the use of microwave-frequency vibrations of an electromagnetic field for purposes of break up, still under investigation is the application of lasers in the optical or infrared range.

In view of all these developments, this work reviewed the environmental effects of rock breakage using explosive and possibly exposing an alternative technology using an expansive chemical, which has found some acceptance in part of Asia and U.S.A.

Rock breakage using explosives

According to Persson *et a*l., 1994, the use of explosives in mining goes back to the year 1627, when gunpowder was first used in place of mechanical tools in the Hungarian (now Slovakian) town of Banska Stiavnica. The innovation spread quickly throughout Europe and the Americas.

Rock blasting currently utilizes many different varieties of explosives with different compositions and performance properties. Higher velocity explosives are used for relatively hard rock in order to shatter and break the rock, while low velocity explosives are used in soft rocks to generate more gas pressure and a greater heaving effect. For instance, an early 20th-century blasting manual compared the effects of black powder to that of a wedge, and dynamite to that of a hammer. The most commonly used explosives in mining today are ammonium nitrate and fuel oil (ANFO) based blends due to lower cost compare dynamite.

In 1990, 2.1 million tonnes of commercial explosives were consumed in the USA, representing an estimated expenditure of 3.5 to 4 billion dollars on blasting in 1993. Australia had the highest explosives consumption that year at 500 million tonnes, with Scandinavian countries another leader in rock blasting (Persson *et al.*, 1994).

The potential of nuclear explosives for rock blasting and earth-moving was tested by the United States and Soviet Union in the 1960s and 70s as the focus of two research projects, Operation Plowshare and Nuclear Explosions for the National Economy respectively. Their potential was never used beyond mere experimentation, due to ensuing issues of radioactivity and public opposition, and was ended alongside the general end of atmospheric testing of nuclear explosives (Persson *et al.*, 1994).

Non-explosive techniques of rock breakage

Efforts to develop alternatives to conventional explosive blasting have included water jets, firing high-velocity slugs of water into pre-

drilled holes, rapidly pressurizing pre-drilled holes with water or propellant generated gases, mechanically loading pre-drilled holes with specialized splitters, various mechanical impact devices, and a broad range of improvements on mechanical cutters. (Source?) Each of these methods may be evaluated in terms of specific energy (the energy required to excavate or demolish a unit volume of material), their working environment, their complexity, their compatibility with other excavation operations, and their suitability for automation (Chapman and Charles, 1999).

Controlled fracture methods, in various forms, have been proposed for several years as means to excavate rock more efficiently. Many of these methods, including hydraulic, mechanical and propellant loading methods are reviewed in the subsequent section. This review of the efficiency and limitations of many of the controlled fracture rock breakage and an excavation method has led to the development of a new method. This method is centered on the use of expansive chemicals. However, the earlier methods of controlled or preferred fractures have proven to be the most efficient way to break rock. The propellant techniques have the advantage of providing a high-pressure gas for this controlled pressurization but are hindered by the fact that the low viscosity of these gases require that the breakage process be completed in a very short period of time (before the gases can escape). This requires that the initial gas pressures be quite high, on the order of 300 MPa or higher. These high pressures result in significant air blast and fly rock, which detract from the utility of the process.

The propellant gas methods have the advantage over the water/steam pressurization methods in that the gases can expand as they flow into a developing fracture system and will thus maintain their ability to adequately pressurize fractures. The propellant gases are comprised primarily of carbon monoxide, however, which requires special ventilation considerations in restricted or underground situations (Chapman and Charles, 1999).

Non-explosive technology is currently experiencing a boom in the west and developing nations as Malaysia, China e.t.c The use of silent expansive chemical with an amazing expansive strength of 18,000 psi which is easy to use by mixing with water, poured into the drilled holes, then it expands, crack reinforced concrete and rocks safely and quietly. This is a credible alternative to blasting, diamond blade saw and hydraulic breaker to mention few. The advantages of this are that no special permit is required, insurance, training or equipment needed. Depending on the rock or concrete temperature it is designed in three categories as follows: category I: 25 to 40 ^{0}C; category II: 10 to 25 ^{0}C; category III: -5 to 10 ^{0}C. The required time for result is maximum of 24 hours or less depending on the material in question (www.dexpan.com).

Increasing pressure on mining and related industries has led to the investigation into methods of excavation that will reduce the impacts on the surrounding environment. This may be because of environmental concerns, the proximity of residential areas, areas of cultural heritage or particular sensitivity, such as schools or hospitals. This has led to an escalating number of products on the market claiming to reduce the affects noise, vibration, dust and fly rock, as well as other advantages (Caldwell, 2005).

These recent innovations competing and earnestly striving to upstage the use of explosive, some are discussed below as follows:

Nonex

The Nonex system has undergone extensive research and development in the UK and Spain. In the UK it has a niche market for particular use in slate mines where it is necessary to keep large slabs of the rock intact, and also for the breaking and removal of slate from within the mine shaft. The Nonex system consists of a cartridge which contains a propellant which when ignited produces high volumes of harmless gases such as nitrogen and carbon dioxide are released, providing a pressure increase when the cartridge is sealed in a drill hole. Nonex is particularly suited in situations

where the rock is not required to be fractured, but rather, split as it does not cause the rock to shatter. Nonex is classified as a 1.4S pyrotechnic rather than as an explosive. This has a major impact on insurance premiums and they are much lower for sites which use Nonex exclusively over conventional explosives. The product is electrically initiated, and the ignition system is built in to the cartridge. The product is water resistant, which is another advantage over many conventional explosives (Caldwell, 2005).

Penetrating cone fracture (PCF)

The PCF tube is a hollow plastic tube, open at one end which can then be filled with the powdered smokeless propellant and then closed with a small cap. The other end is machined into a wedge to lock into the stemming, and to seal the hole when inserted for ignition. In the cap there is an entry port for insertion of an electric match, which is the means of detonation. This heat ignites the propellant. As there are not the crushing effects of compressive breakage as with explosives, dust and fines are significantly reduced. As the rock requires less energy to break in tension than compression, a much smaller energy input is required. A 200g charge of PCF blasts the same volume of rock as does 1.2 kg of explosive charge, whilst releasing one tenth of the energy.

Some gas is produced from the combustion of the cartridge, for PCF, the majority of the gases produced are carbondioxide, water, nitrogen, carbon monoxide and hydrogen. The main problem gases which are detectable are carbon monoxide, and nitrous oxide which also occurs at low levels. The addition of a very small amount of ANFO pill does increase the toxic fumes from the product, but still below minimal levels in modern ventilation systems. This gives the product a little extra power to fragment the rock. The product also has the ability to enable users to have more control over the accuracy of the excavation profile and drive perimeters. Figure 4 shows resultant effect of PCF on concrete (Caldwell, 2005).

PCF has also been used in floor stripping, back stripping and side wall stripping in a number of mines in Australia, particularly when a larger equipment size is required and minimal disruption to underground operations is essential. By altering the position of the charges in the holes the products flexibility allows for the rock to be fractured or split. PCF can also be used for the clearing of block grizzlies, crushers or chutes, or anywhere else where oversize is a problem. The classification for PCF is 1.4S pyrotechnic, as an added safety precaution, the electric match used for detonation is inserted right before firing (Caldwell, 2005).

Non-explosive expansive chemical

It is a powder with amazing 18,000 psi expansive strength when mixed with water, poured into the holes, breaks reinforced concrete and rock safely and quietly, while providing silent cracking. It provides controlled demolition according to drilling patterns, chosen spacing and burden and desired degree of fragmentation. It is very easy to break reinforced concrete and all kinds of stone into desired sizes and shapes, without noise, vibration or dust. Expansion forces more than 30 N/mm^2 are typically achieved in a period of 18 - 24 hours. This acts against the tensile strength of the material to be fragmented.

In mining and quarrying industry, expansive chemical helps to achieve perfect slabs and blocks from limestone, onyx, marble, granite or any other type of stone you are working with. Compares to blasting, expansive chemical avoids waste of valuable stone, high insurance, costly storage and labour. The holes should preferably be greater than 25mm diameter and 500mm length, of great importance it should not be used in holes greater than 50mm diameter, if it has to be used a technical consult should be made to the manufacturer.

This chemical can also be applied along with traditional methods like primer cord, hydraulic breaker, diamond blade saw and jackhammer to help cut cost, work time and increase safety, plus silent operation, this is perfect for residential, school and airport area. It helps

your work to become more efficient and cost effective.

Application

The recommended water powder ratio is 0.25 to 0.30 for all grades that is 1.5 liters for 5kg packet, the quantity of powder needed can be calculated based on diameter, length and total number of holes. A measured quantity of water should be placed in a mixing drum. Water should not exceed 1.5litres per 5kg of expansive Chemical breaker.

The powder should be added to the water, being continuously stirred with a hand mixer or drill and paddle until a lump free, even consistency is obtained.

The mixed material will become a light gel within a maximum of 15 minutes from mixing. For ease of placing, the grout should be poured into the holes before this time has elapsed.

Care must be taken to ensure that the grout level is flush with the mouth of the hole. Cover the mouth of the hole sacking or sheeting directly after filling, then retire immediately. After placing, expansive chemical should be left undisturbed until cracking has taken place up to 24 hours after placing. It is recommended that the work area is cordoned off with warning signs.

Principle of working

The principles applied in using "Expansive Mortar" are very much similar to those ones followed in traditional blasting techniques. As like for explosives, holes must be drilled to contain Expansive chemical which must thoroughly be mixed with a measured quantity of water and poured into the holes. Few minutes after filling, a reaction of hydration is taking place generating heat and crystallizing and expanding while hardening. If hydration takes place under confinement, significant expansive pressure will result. Cracks will develop along the line of holes. A person who can deeply understand hydration reaction, Starvation and Expansion process become an expert in this product application. No need for detonator, ignition and certified explosive operators.

Cracking Mechanism

After the chemical has been filled into holes drilled on rock or concrete, the expansive stress gradually increases with time, the material to be cracked undergoes a process of:

a) Crack initiation.
b) Crack propagation.
c) The increase of crack width.

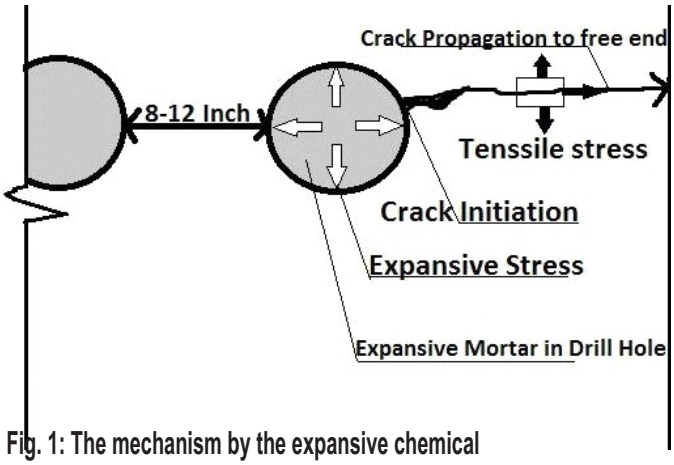

Fig. 1: The mechanism by the expansive chemical (http://www.pmsindia.co.in/non-explosive-rock-demolition-agents.htm)

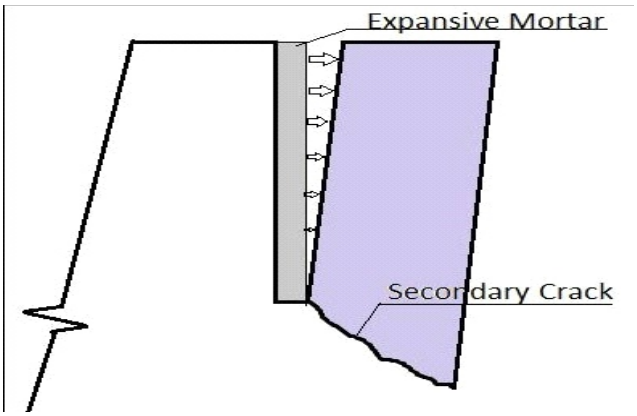

Fig. 2: The crack as it occurred through shear stress (http://www.pmsindia.co.in/non-explosive-rock-demolition-agents.htm)

The mechanism by the expansive stress of expansive chemical is shown in Figure 5 Cracks initiate from an inner surface of the hole, being caused by tensile stress at a right angle with the compressive stress which occurs by the expansive stress of being developed while hardening. The expansive stress continues even after the appearance of cracks, the cracks propagate and also new cracks initiate during the process. Usually, for a single hole, 2-4 cracks initiate and propagate either towards nearest free surface or nearest hole. When a free surface exists, the crack, as shown in Figure 6, is pushed apart mainly by

the shear stress, and a secondary crack also arises from the bottom of the hole, running toward the free surface. Please note during the initial reaction process there are chances for blow-shot releasing gases evolved in the hydration reaction. So, during initial reaction period (i.e., 30-60mins) we insist workers to stay away at least 10 meters from Job place. Do not peep into hole from top view.

Table 1: Composition/Information on Ingredients (www.dexpan.com).

NAME	PERCENTAGE (%)
Calcium Hydroxide	60-100
Silica, Vitreous	5-10
Diiron Trioxide	1-5
Aluminum Oxide	1-5

The chemical composition or ingredients used in the production of this chemical is seen in Table 1, it helps to suggest that the content is safe to a very large extent. It also forms the basis for necessary precautions to be taken when using it or mistakenly ingested.

Materials and Methods

The sources of materials used in the research work were Jack hammer, In-situ rock, expansive chemical bucket, long turning stick and water.

The method used in this research work was absolutely quantitative whereby the direct field results were obtained practically, which gives actual events that happened on the field. The means employed are: experiment and observation.

Some blast holes were drilled for the purpose of this research to experiment the expansive chemical by pouring the mixed chemicals into them for reaction at setraco nigeria limited, abuja quarry.

The reaction was carefully observed after the chemical was poured into the holes. Intermittently the site was visited to see the result.

Results and Discussions

Results

Figs. 3-7 show the results of rock breakage using the alternative method “expansive chemical”.

Table 2: Details of the experiment and results

Number of holes drilled	
Depth of hole (m)	1.22
Total length of hole drilled (m)	9.76
Depth of each column charged (m)	1.02
length of hole charged (m)	8.16
Total quantity of chemical used (Kg)	8.16
Quantity of water used (Litres)	3.50
Quantity of blocks produced after use	3
Dimension of the block (m)	1.5 by 1.5

Fig 3 : Drilling process going on using jack hammer drilling machine

Fig. 4: Expansive chemical and the drilled holes in preparation for mixing

Fig. 5: Protected holes after drilling preventing dirts from gaining entrance

Fig. 6: Result of the reaction with the rock splitting the rock

Fig. 7: Blowout in the case it's not properly done

Discussions

The total number of holes drilled were eight (8), using jack hammer. The details of the experiment and chemical mixing ratio are shown in Table 2. The drilling pattern was square pattern with a spacing and burden of 1.5m by 1.5m.

The expansive chemical or mortar provides a better and credible alternative with a good strength which reacted leaving cracked blocks with the dimension of 1.5m by 1.5m as seen in Fig. 6 after being measured. The chemical reaction is without noise, flying rocks, vibration and air pollution as seen Fig. 6. It does not also alter the rock or changes the physical composition of the rock before and after the reaction which was examined by visual inspection.

The comparative cost analysis of explosive and expansive chemical is shown in Table 3. A total number of 50 holes with a depth of 5 metres each and diameter of 76.2mm (3 inches) showing comparative analysis of both. A careful analysis shows that it costs 247050 naira to crack 50 holes using expansive chemical while it cost a total sum of 108120 naira to blast the number of holes. The expansive chemical is higher but it elimination of noise, fly rock, dust etc with a better advantage over explosive usage which has posed a lot threat to fauna and flaura for decades.

Conclusions and Recommendations

Conclusions

The non-explosive expansive chemical if properly developed and improved upon would serve as possible alternative to explosive usage in the rock breakage mechanism. Considering its numerous advantages it offer over older means of rock breakage, such as non-emission of poisonous gases, no ground vibration, noise to mention few, it would not only be credible but a better way of achieving rock fragmentation.

Recommendations

It is therefore recommended that expansive chemical be used for the following:

a. Rock breaking and Excavating. These kinds of activities could be achieved under this

Table 3: Comparative cost analysis of expansive chemical and explosive usage

Explosive				Expansive chemical	
Materials	Quantity	Unit price (Naira)	Cost (Naira)		
DTH	50 pieces	500	25000	Total depth of the holes(m)	225
Gelatin	128 kg	450	57600	Depth of Each Column filled (m)	4.5
Trunk line connectors	50 pieces	500	25000	Quantity needed (kg)	450
Eletric detonators	2 pieces	260	520	Cost of 20kg	10980 naira
Total cost			108120	Total cost	247050 naira

category such as excavation of rock, splitting of boulders, rock and slab breaking for road expansion, resident development, excavation associated with tunneling, trenching shaft sinking and other various types of construction work;

b. It is better applied for best results at dimension stone quarry where dimensional blocks are the end target, such as marble, granite quarrying and controlled expansive cracking to avoid waste of valuable stone; and
c. For demolitions and concrete cutting. Demolition of mass reinforced concrete, foundations for machinery, piers, pillars, beams, bridges and retaining walls could be done.

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Effect of Artisanal and Small Scale Gold Mining and Granite Quarrying on Women Miners and Ground Water in Parts of Chanchaga and Maitumbi areas of Minna, North Central Nigeria.

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Abstract
Environmental effect of Artisanal and Small Scale Gold mining and Granite quarrying in parts of Chanchaga and Maitumbi areas of Minna, North Central Nigeria was studied with the aim of determining its impact on women, children and water resources. Geological mapping was conducted on a scale of 1:10,000 to determine the geology of the area using the geological traverse method. Thin section of rock sample was prepared and analyzed using a polarizing petrological microscope. Water samples were obtained from the quarry sites and analysed for both physical and chemical parameters using standard analytical procedures. Questionnaires were also administered to the miners. The area is basically underlain by granite and schist, dominant minerals in the thin sections are quartz, biotite, feldspar, epidote and opaque mineral. Water samples from the study area contain Fe, Cr, Cu and Zn. The concentration of Zn and Cu were below detectable limit. Fe concentration was above Nigerian Standard for Drinking Water Quality (NSDWQ) limit. Both water **is classified** as Normal Earth Alkaline freshwater with a high calcium sulfate pollution index. Results of the questionnaire indicate that the age of most of the miners fall between 36 – 50 and most of them are divorced or widowed women accompanied by their children with no formal schooling. Effect of artisanal mining is mostly on the devastation of the environment, disruption of schooling in children; and ground and surface water contamination.
Keywords: artisanal, small scale, thin section

Introduction

Mining is as old as humankind, it enabled civilization by providing materials like flint stone, copper, bronze and precious metals such as gold and silver, which were sacred to many ancient cultures (Hentschel, *et al;* 2003). The high value bestowed upon minerals and precious metals gave way to them being used as a universal currency for almost three millenniums, spurring the growth of global trade. Mining has always required hard, manual labour and it wasn't until the 19th century that ancient manual techniques became substituted by mechanization. "Industrial" mining took over the landscape and altered the face of mining forever. Following the first sharp rise in gold prices in the 1980s, artisanal gold mining again became a mainstream economic opportunity in developing countries. But, because modern mining and mineral processing technology required considerable investment that could not be made by the "new generation" of poor miners, artisanal mining reverted to the same technology used before mechanization in the 20th century (Hruschka, 2009). Generally, artisanal and small-scale mining is considered as mining by individuals, groups, families or cooperatives with minimal or no mechanization, and is largely of the informal sector (IIED, 2003). Artisanal and small scale mining (ASM) is largely a poverty driven activity practiced in some of the world's poorest regions, most often in remote and impoverished regions of developing countries. It is a practice that involves rudimentary techniques of mineral extraction, highly manual process, hazardous working conditions, and frequently negative human and environmental health impacts (Hilson, 2011). In many parts of the world, artisanal and small-scale mining (ASM) activities are at least as important as large-scale mining activities, particularly in terms of the numbers of people employed (Hentschel,.*et al;* 2003). But in recent times, an estimated 80-100million people worldwide are currently engaged in this industry and directly or indirectly depend on it for their

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livelihoods (Hentschel*et al;* 2002; Veiga and Baker, 2004 , Barreto, 2008 and Vera, *et al.,* 2012).

Artisanal mining communities around the world are diverse, dynamic and distinct – they vary from culture-to-culture, region-to-region and mine-to-mine, and change over the course of time. The women within these communities are also heterogeneous and unique; however, they tend to be engaged in specific roles, typically, they are laborers (e.g. panners, ore carriers and processors), providers of goods and services (e.g. cooks, shopkeepers) and are often solely responsible for domestic chores. Women's responsibilities in mineral processing activities range from crushing, grinding, sieving, washing and panning, to amalgamation and amalgam decomposition in the case of gold mining. Less commonly, women are concession owners, mine operators, dealers and buying agents, and equipment owners. In many locales, women function in multiple capacities. For instance, a woman working as a panner may also obtain income as a sex trade worker and a cook.

Artisanal and small scale mining is a mining that operate with an annual production of processed material of 50,000 tons or less. It is usually characterized as informal, illegal and unregulated by government, undercapitalized, utilizing simple tools and lacking in technology and hazardous under labour intensive conditions. However, it is a source of income for those living in remote, rural and poor area of the country (Shoko, 2011). Small Scale miners are described, as poor dependent on mining for sustenance (Yakovleva, 2007). Although women play significant roles in small scale mining activities, they are rarely recognized as "miners" consequently, the roles of women in small scale mining have been largely over looked by policy makers (Yakovleva, 2007).

This study was conducted to look into the occupational health and safety issues of women engaged in small scale mining in the hope of increasing awareness on their plight gender issues associated with mining were put to light for consideration in the regulatory and policy frame works of both local and national government. Small scale mining has been a traditional livelihood and a family based activity. The women perform precious work such as processing of ores and hand picking mineral processing which is mostly performed by women requires a lot of dexterity. It also requires patience which is why some aspect of the work is given to women (Hayes, 2008). Small scale mining is an economic activity that contributes to the rural economy and is very common in all mining communities. Associated with these concerns are other cross cutting issues such as violence, prostitution, HIV/AIDS, gender equality, child labour, family breakdown and law and order problems. In area where large scale mining activity take place, illegal small scale mining activities co-exit leading to land disputes and violence. Illegal mining activities, wide unsafe use of mercury, gold smuggling and severe environmental impacts are increasing rapidly because of the fact that small scale mining is not regulated in the country. The legally recognized mining outfits are mostly dependent on these artisanal miners for their mineral supply. The artisanal miners mostly operate without legal cover and appropriate mining and processing method (Hayes, 2008).

Description of the study area

The area is part of Minna sheet 164, Nigeria and is located along latitude 9°40'00''N and longitude 6°37'00''E. It covers approximately 6km^2 in extent. Fig 1 is the map of part of Minna, central Nigeria showing the study areas.

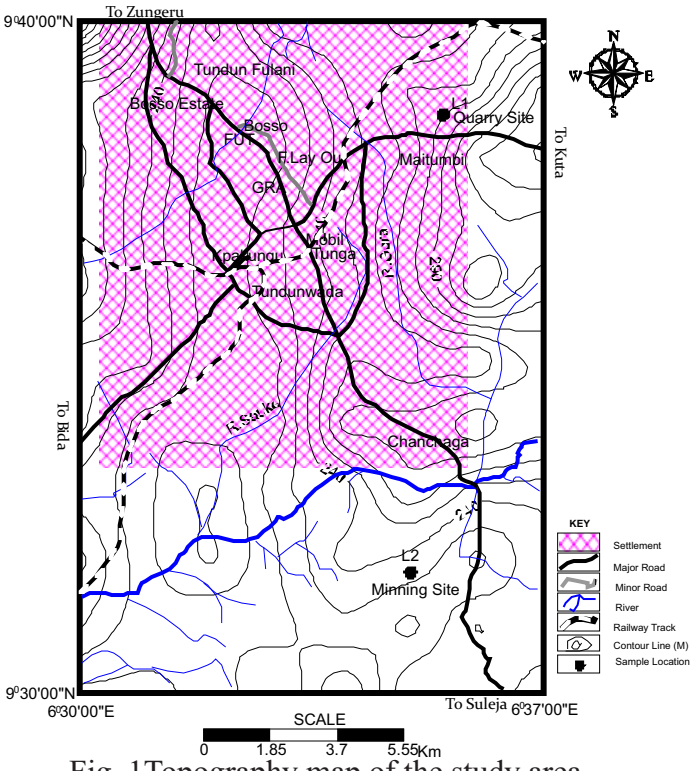

Fig. 1Topography map of the study area

Geology

Minna is located on the central portion of the Nigerian Basement complex, comprises of meta sedimentary and meta-igneous rocks which have undergone polyphase deformation and metamorphism. These rocks have been intruded by granitic rocks of Pan-African age, the basic rocks include granite, gneisses and schist occurring in various proportions in the area. In Nigeria, gold occurs both as placers and primary vein deposits within the schist belts of northwest and southwestern Nigeria. Garba (2003) identified some of the most important occurrences at Maru, Anka, Kwaga, Gurmana, Birnin-yauri, Okolum, Dogon-Daji and Iperindo areas all associated with the schist belts. Personal field observations within the Kushaka schist belt showed that there are several new artisanal workings in places like Gusoro, Zumba, Maitumbi-Minna, Pago and Maiwayo villages which is almost at the contact between the sedimentary Bida basin and the basement complex rocks.

Materials and Methods

The methodology adopted for the study involved the geographical coordinate of the sites were determined using Global Positioning System (G.P.S) instrument. Geological hammer was used to take sample of the rock for thin section preparation. Samples of water were collected from the two (2) sites for analysis at Regional water quality laboratory Minna, Niger state. Rock samples for thin section in geology department at federal university of technology Minna. Digital Camera was used to take pictures of the activities at the sites. Questionnaires were designed for the study and copies were distributed to the ASM women workers in the studied sites. The questionnaire cover personal information, research questions like health, productivity and family. Oral interview was used to obtain information from those that questionnaires could not be administered on. Interviews chosen include a semi structured type using open ended format of questions to allow the interviewee to give as much information as possible. Thin section preparation was aimed at producing a very thin rock section that was transparent under transmitted light microscope, the petrographic microscope. The standard thickness of thin section is 0.03mm, (30 microns). A thin section slide was basically made up of a glass slide, rock section and a cover glass slip. A thin section of the host rocks was done with the aim of determining the mineralogical composition of the rocks.

Results and Discussion

Geology

Minna is positioned in the central part of Nigeria basement complex, bounded by rugged terrain of granitic rocks. Minna area comprises of metasedimentary and meta-igneous rocks which have experienced polyphase deformation and metamorphism. The schist, which hosts the gold, occur as a flat lying narrow southwest-northeast belt at the central part of Minna with small quartzite ridge parallel to it, the gneiss occur as a small suite at the northern and southern part of the area forming a contact with the granite. Feldspathic rich pegmatite occurs to the east, with average width of 65meters and 100 meters long, the pegmatite hosts tourmaline. The Granitic rocks dominate the rock types in Minna and vary in texture and composition.

Thin sections of the granite was studied using a polarizing petrological microscope under both crossed polarized light and plane polarized light to evaluate the mineral constituent.

Under Plane Polarized Light the mineral constituent of the rock are; Quartz, Plagioclase Feldspar, orthoclase, Biotite Mica. Biotite and Quartz has a very high relief.

Photomicrograph under cross polarized light in the plate showing Quartz, Biotite Mica, Orthoclase Feldspar, Accessory mineral like Epidote, Microcline, Opaque mineral. There is also the presence of twinning which characterizes the plagioclase feldspars.

Economic and Environmental aspects of artisanal mining and quarrying.

This aspect involved the use of questionnaires and oral interviews to determine the economic, social and environmental aspects of women and children involvement in mining and quarrying at artisanal level.

Figure 2 shows the age distribution of ASM women workers in the studied site, this range from below 18 to 50 with higher range falling between

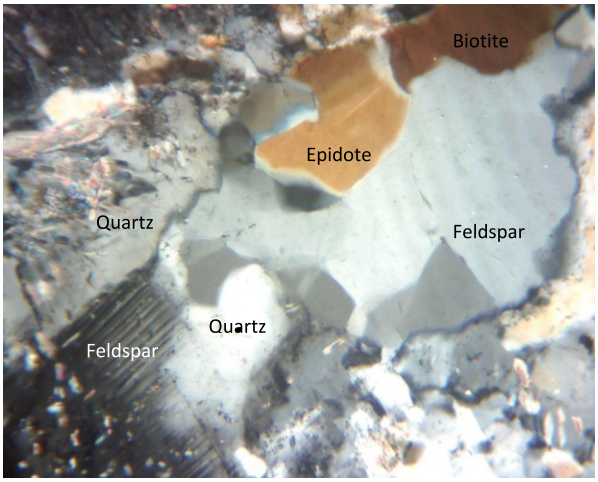

Plate 1 Photomicrograph of granite (Magnification ×10)

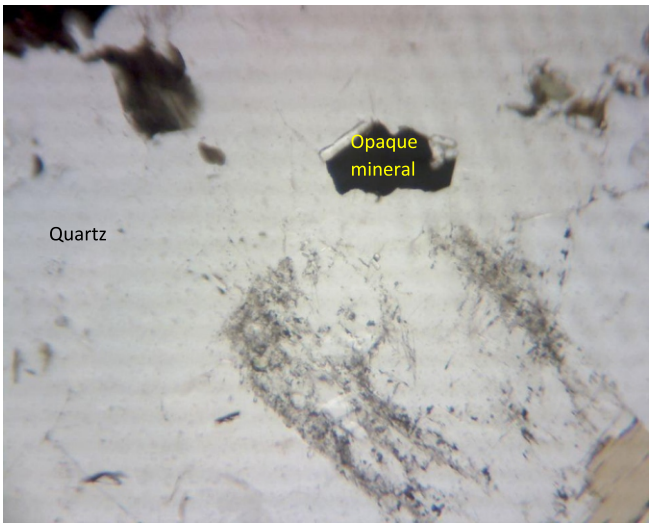

Plate 2 Photomicrograph of granite studied under plane polarized light (Magnification ×10)

36 and 50. Figure 3 shows the educational level of women involved in mining in the site, the highest percentage did not have any formal education while some attained up to secondary school level but had to drop out as a result of financial difficulties. Figure 4 shows the Marital Status of ASM Women Workers in the studied area, it shows that divorcee's accounts for the highest percentage of women involved in artisanal mining. Majority of the women have been working as artisanal miners for six years and above with no formal training whatsoever in mining. Figure 5 shows the Production Rate of ASM Women Workers in the mining site, the highest production rates for washing for gold is 6 – 10 head pans per day, a few older women that work extended hours wash 11-20 head pans per day. For granite chippings production the highest production rate is 6-10 kilograms per day, while a few others produce up to 20 kilograms per day (figure 6). Figure 7 shows the Health Facilities Available for ASM women workers in the studied site, which are herbal, Clinic and home, majority of them depend on local herbal medicine and the local clinical facilities for persistent ailments. Figure 8 shows the commonest ailment among ASM women workers in the studied area, these include body pain, malaria, back pain, catarrh and headache. The commonest are constant body pain and back pain. Most of the workers do not really see any occupational risk associated with the work and hardly link the constant headache and body pains to the strenuous work they do. Majority of the workers resume by 8-9am and close between 4 and 6pm depending on demand, they work six days a week with only Sunday being the off day, some however work all week. On cases of sexual harassment only fifteen percent claimed to have suffered some form of sexual harassment from male miners and casual laborers, majority of the women said the mine sites are quite safe and relatively free from sexual harassment. School attendance among children of ASM women workers, 73.7% of the women workers in the site did not allow their children to accompany them to site, instead they send them to school, but just 26.3% of them allow their children to follow them to site. For those employed as workers in the mine sites they claimed disparity in wages between them and their male counterparts is quite high even though the level of work remains the same. Some however said the disparity is not that much since they are treated almost equally.

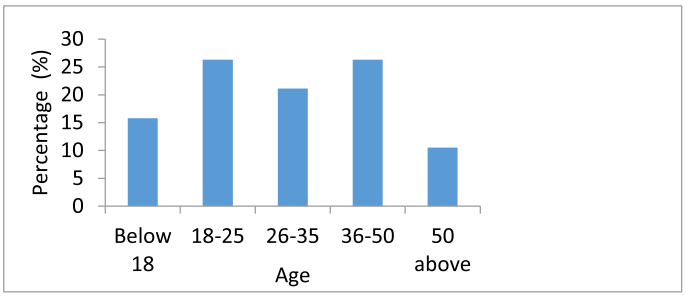

Fig 2 Age distribution of ASM women workers in the site

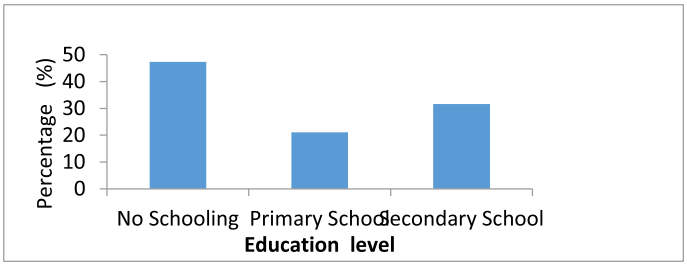

Fig 3 Educational level of ASM women workers

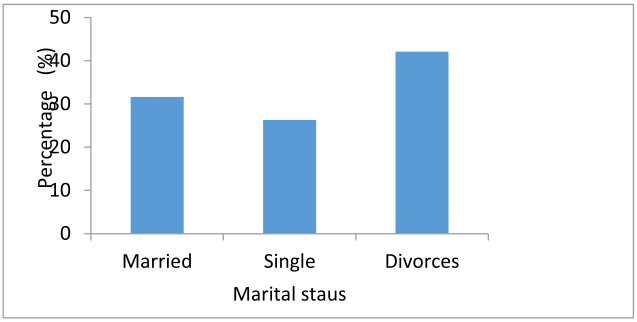

Fig 4. Marital status of ASM women workers

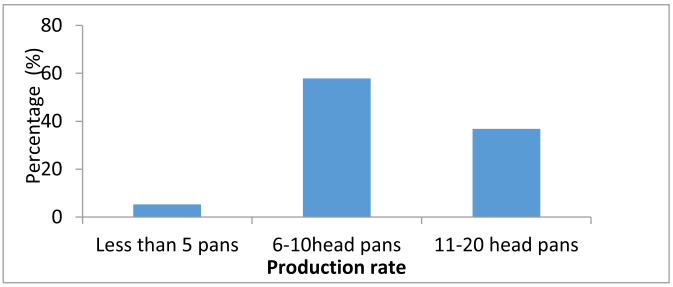

Fig 6 Production rate of ASM women workers

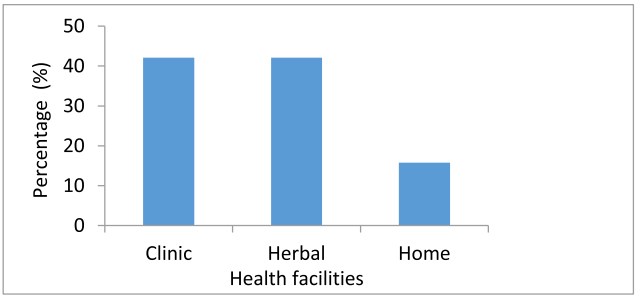

Fig 7 Health facilities available for ASM women workers

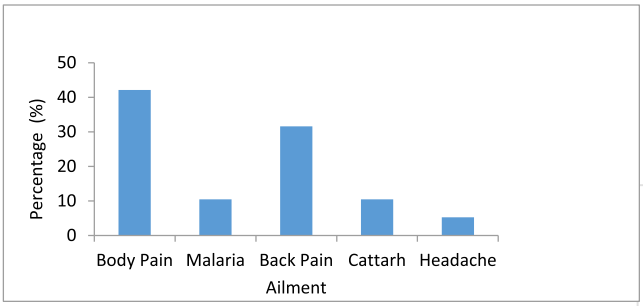

Fig 8 Ailment among ASM women workers

Table 1 Water analysis results for Chanchaga and Maitumbi areas

Parameters	Method	Chanchaga	Maitumbi	NSDWQ 2007
TDS (mg/l)	APHA 2510 B	218	170	500
Conductivity (µS/cm)	APHA 2510 B	326	255	1000
Dissolved Oxygen (mg/l)	DO_2 Meter	1.96	4.83	>4
Temperature ^{O}C	APHA 2550 B	26.9	26.9	Ambient
$_{P}H$	APHA 4500 $H^{+}B$	7.2	7.17	6.5-8.5
Turbidity (NTU)	Turbidity Meter	712	21.3	5
Colour (TCU)	Colorimetric	1,750	350	15
Suspended Solid (mg/l)	Colorimetric	816	98	75
Total Hardness (mg/l)	APHA 2340 C	118	112	150
Calcium Hardness (mg/l)	APHA 2340 C	34	56	-
Magnesium Hardness (mg/l)	APHA 2340 C	84	56	-
Chloride (mg/l)	APHA 500 $Cl^{-}B$	25	13	250
Total alkalinity (mg/l)	APHA 2320 B	43.4	35	-
Carbonate (mg/l)	APHA 2320 B	0	0	-
Sulphate (mg/l)	APHA 4500 $SO_4^{2-}E$	0	9	100
Zinc (mg/l)	APHA	0.53	0.27	5
Bicarbonate (mg/l)	APHA 2320 B	43.4	35	-
Chromium (mg/l)	APHA 3500 $-Cr^{+6}$ D	0	0	0.05
Fluoride (mg/l)	APHA	0	0.29	1.5
Iron (mg/l)	APHA 3500 – Fe D	2.62	0.32	0.3
Sodium (mg/l)	APHA 3500 Na – D	35	12	200
Potassium (mg/l)	APHA 3500 K-D	1	9	50
Calcium (mg/l)	APHA 3500 – Ca D	13.6	22.4	180
Magnesium (mg/l)	APHA 3500 – Mg D	20.5	13.66	20
Nitrate (mg/l)	APHA 4500 NO_3^{-} B	0	0	50
Nitrite (mg/l)	APHA 4500 $NO_2^{-}B$	0	0	0.2
Copper (mg/l)	APHA 9222	0	0	1
Total Coliforms (cfu/100 ml)	APHA 9222	280	180	10
E. coli (cfu/100 ml)	APHA 9222	49	7	NIL
Faecal Coliforms (cfu/100 ml)	APHA 9222	48	8	NIL

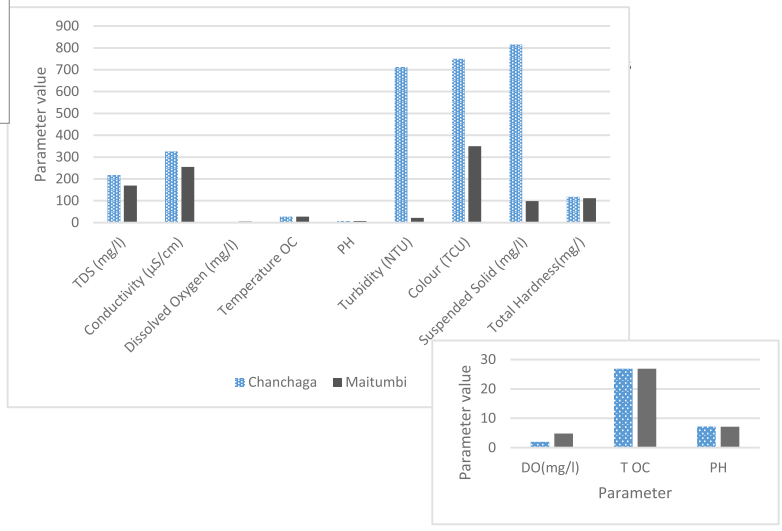

Fig 9Physical parameter for Chanchaga and Maitumbi mine pits

Table 1 is the results of the analysis carried out on water samples from the gold mine pit in Chanchaga and quarry pit in Maitumbi area, while figure 9 is the bar graph of the analysed physical parameters. Total Dissolved Solids (TDS) in the water is relatively low (108 – 218mg/l) compared to the acceptable standards (500mg/l), it is however higher in water from gold mining sites than in the quarry pits, the same aplies to Electrical Conductivity, colour, turbidity and suspended solids. This may be attributed to the mining methods adopted in the area which loosens materials thereby freeing elements and other compounds which easily becomes dissolved in the water while others are carried into the atmosphere as dust. The pH and dissolved oxygen are the same and seem not to be affected by the method adopted. Figure 10 is the bar graph of the analysed chemical parameters. Parameters with the highest concentration are bicarbonates, sodium, chloride, magnesium and calcium. The highest concentrations are found in water from the gold mine pits than in the granite quarry, except for calcium and potassium that are highest in the quarry water.

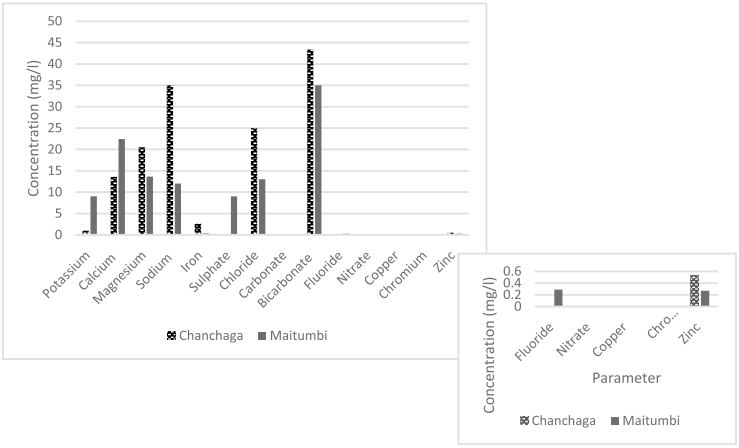

Fig 10Chemical parameter for Chanchaga and Maitumbi mine pits

Sodium concentration in this study ranged 35mg/l and 12mg/l. This concentration is below the limit of 200mg/l based on guidelines set out for drinking water purposes by the Nigeria standard for drinking water (NSDWQ, 2007). Going by the study conducted here, the presence of sodium has no negative effect on plant and Human health. Concentration of potassium in the water samples from the study area range from 1mg/l to 9mg/l. And this is below the NSDWQ 2007. Going by the study conducted here, the presence of potassium has no negative effect on plant and Human health. Chlorides are salts resulting from the combination of the gas chlorine with a metal. Chlorine can usually be found in the ground as rock salts or halite and is usually bond with sodium concentration of Cl in this study range from 25mg/l to 13mg/l and values in all locations falls below the maximum limit of 250mg/l (NSDWQ, 2007). Since high chloride in groundwater indicates pollution by sewage or industrial waste, the possibility of ground water in the study area being polluted by sewages is therefore ruled out. Iron is among the earth's most abundant elements. Rainwater dissolves it mainly because it infiltrates the soil to the underlying geological formations. Although iron is not hazardous to health, it is considered a secondary or aesthetic contaminant. It is essential for good health as it helps transport oxygen in the blood. Iron causes taste and odour problem in water and may result in red water colouration when it exceed the maximum permissible limit of 0.3mg/l Nigerian standard. Iron concentration in all the water samples analyzed is generally high. The explanation for the anomalous concentration of iron in all the water samples could be attributed to the geology of the underlying rocks in the study area which are mostly schistose in nature, highly weathered and rich in iron bearing minerals.

The concentration of zinc in the area is 0.53mg for the mine pit and 0.27mg/l for the quarry pit. These values falls below the Nigerian Standard for drinking Water quality limit of 3.00mg/l (NSDWQ, 2007).

The Piper trilinear diagram illustrate the relative concentrations of Cations (left diagram) and Anions (right diagram) in each sample. For the purposes of a piper diagram, the Cations are grouped into three major division. Sodium (Na^+) plus Potassium (K^+) plus Calcium (Ca^{2+}) plus Magnesium (Mg^{2+}). The Anions are similarly grouped into three (3) major categories: Bicarbonate (HCO_3) plus Carbonate (CO_3^-), Sulfate (SO_4^-) and Chloride (Cl^-). Each sample will be represented by a point in each trilinear diagram. Figure 11 represents the Piper diagram (Piper, 1944) which was plotted from the concentration of Cations and Anions contained in the water. It is

used to characterize the water and also to compare water of different origin, effects of mixing is also clearly shown in the plot, based on the interpretation of the diagram both waters plot on the 50% mark for Calcium Magnesium Sulphate Chloride water and Calcium/Magnesium Bicarbonate water. This implies that the water is predominantly a Calcium Magnesium water with intermixing from Chloride and Bicarbonate. Based on interpretation both water classify as Normal Earth Alkaline freshwater while based on interpretation of pollution index it classifies as water that has suffered from calcium sulfate pollution. These may be indications of water quality degradation as a result of mining activities and other anthropogenic factors associated with artisanal mining such as open defecation.

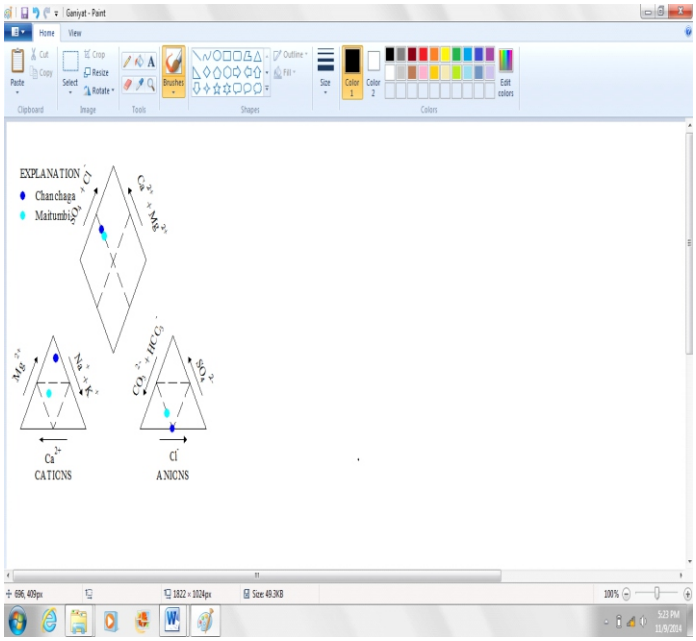

Figure 11 Piper diagram for water characterization in the study area (modified after Piper, 1944)

Conclusions and Recommendations

Conclusions

The area falls within the basement complex system of Nigeria, the major rocks in the study area are Granites and Schists. The mineral present in granite includes Quartz, Plagioclase Feldspar, Opaque mineral, Biotite, Epidote. The average age of women involved in artisanal and small scale mining is between 36 to 50 years without any formal education, though some attained some secondary school education, most of them are either widowed or divorced and have working as artisanal miners without any basic tarining in the operation. They work extended hours (sometimes up to 10 hours) to produce 10 - 20 kg of crushed rock in a day, while those involved in washing and panning for gold also do so for a minimum of 8 hours. Major health challenges they face are body pain, backache and constant headache, with very poor access to health facilities they mostly tend to the use of herbal remedies for treatment. Majority of the workers however seldom come to work with children that are of school going age, the children attend school and only come to the mines when there is no school. While some suffer some form of sexual assault from their male counterparts, most are not subjected to such abuse, even though prostitution is high among the female workers to augment the meagre resources they generate from the work. Analysed water samples show that Electrical Conductivity, Turbidity, Colour and suspended solids are generally higher in the water in the mines than that of the quarries, the pH and temperatures are relatively the same. Other chemical compounds with high concentration include bicarbonates, sulphate, chloride and calcium and flouride while the heavy metal with the highest concentration is zinc. All the analytes, except for calcium, are higher in the mine waters than in the quarry. The water from both sites generally plots as a calcium Magnesium water with intermixing from chloride and bicarbonates which has suffered from calcium sulphate pollution.

Devaluation, misrecognition and criminalization of artisanal and illegal miners hamper their participation not only in the environmental and political decision-making process but also in negotiating potential alternative livelihoods for the rural dwellers. Artisanal gold mining is dangerous and has very serious negative effects on surface and groundwater. It is important to note that water is key to daily human activities hence, without clean and potable water, there cannot be life. Other negative impacts on the environment include air and soil pollution, loss of biodiversity, scaring of the environment, loss of arable land for farming, health and disease. However most of these challenges can be mitigated if adequate attention is given to the

activities of the miners and enabling laws put in place, or implemented if already in place, to ensure maximum contribution to the growth of the economy.

Recommendations

In order to reduce the negative impacts on the environment, it is recommended that government should accord due recognition to artisanal and illegal mining as a legitimate organization that can contribute legitimately and meaningfully to sustainable development. This will nurture them into being able to provide an alternative viable livelihood for the rural dwellers. In addition, it will give them the opportunity to be part of decision-making process and eventually part of efforts to minimize the negative impact of their activities on the environment.

From the results of this study, it is recommended that all the rock chip tailings should be removed from the site and buried in a safe land fill to prevent further water contamination.

A follow-up research work is recommended to measure the level of heavy metals and other toxic elements at regular interval in water bodies in the study area. This is necessary to further substantiate the findings from this study.

Copper, mercury, manganese, iron, lead and zinc dusts are carried in the air; therefore it is recommended that a study to determine levels of these metals in the air in the study area be carried out with a view to ascertain their content in the atmosphere.

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