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CHEMICAL AND MINERALOGICAL PROPERTIES OF LEJJA NSUKKA IRON ORE DEPOSITS

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Abstract

The ore deposits obtained from Dunoka, Amankwo and Umuakpo in Lejja Nsukka were found to be iron silicate in nature. They were analysedby XRD, XRF, AAS and the ores were found to contain 60.59% Fe, 64.81%Fe and 64.67%Fe respectively. These ores when compared to those iron ore producing nations, they were classified as medium-grade iron ore. Other elements like titanium, magnesium and manganese were present and could be mined for commercial use. Chemical analysis of the ore samples showed that traces of phosphorous of ≤ 0.0079% and were free from the deleterious elements, sulphur and arsenic.

1.0 INTRODUCTION

Iron and steel industrialisation is crucial in the technological and infrastructural development of a country. Nigeria has vast raw materials of iron ore needed for development of steel such as coal, iron ore, limestone and natural gas [7]. Nigeria has high potentials of becoming West Africa's regional economy. But the economy of the country cannot be vibrant and strong without the development of its iron and steel which is the bedrock of the manufacturing sector [5].

The Government of Nigeria and her mineral sector has been searching for additional and supplementary iron ore deposits to sustain its iron and steel industries. These ores occur extensively in different parts of the country as metamorphic and sedimentary deposits with the large concentration in Kogi state [9]. The Lejja ore is one of the many ores in the South-Eastern Nigeria that belong to the metamorphic types, which occur in bands, popularly referred to as "ferruginous quartzite".

The iron ore, a mineral from the iron ore rocks, can be economically mined to produce metallic iron and steel. They are rich in iron oxides, ranging from bright yellow, dark-grey, rusty red to deep purple [11]. The oxides possess iron-bearing minerals that are readily available, and consist mainly of haematite (reddish), magnetite (blackish), limonite (brownish) and siderite (pale brown) [5]. The Fe content determines the quality of the iron ore. Ores with more than 65% are considered as high-grade ores; a range between 62–64% are classified as medium grade ores and below 58% Fe are regarded as low-grade ores [1]. Nigeria is searching for ways to effectively utilise the solid minerals to improve the economy by providing job opportunities.

Several iron ore deposits have been characterised using different analytical techniques. Some of the techniques include the use of scanning electron microscopy (SEM) and optical image analysis, diffuse reflection spectroscopy, Mossbauer spectroscopy and x-ray diffraction (XRD). Characterisation of some Nigeria solid mineral deposits were reported. The characterisation of these ores were analysed by SEM-EDS, XRD and ICP [12].

Characterisation of iron ore is an important step required to establish the potential benefits of the ore for production. The quality, quantity, shape, density and physical characteristics are determined to effectively utilise the economic and technical parameters required to support planning, production and evaluation of the economic viability of deposits [10]. [2] carried out the determination of chemical, mineralogical and liberation size of Ochokochoko iron ore. It was reported that the ore contained 50.60% Fe, 17.70% SiO_2, 0.05% P_2O_5, and 0.03% S which is mostly hematite, magnetite, calcite, alumina, and silica. Raw Materials Research and Development Centre (RMRDC) and Geological Survey of Nigeria (GSN) concluded on mineralogical study that reports that the ore is a replacement of amphibolites and basement gneisses by iron rich solution emanating from granites bodies of older-granite suite of Pan-Africa. An update of mineral reserves of 111,400,000 tonnes has been outlined, with a grade level of about 35% Fe which could be easily upgraded. It is currently being utilised in open pit mining and provides feed for the Delta and Ajoakuta Steel Companies [13; 15].

KotonKarfe iron ore deposit has also been studied by [16] and was reported to have an iron composition of 43.34% with a low silica amount (10.14%). According to them, the content is mainly magnetite, siderite and goethite and some haematite. The work index determined was 11.33kWh/tonne and 17.00kwh/tonne for the calcined and uncalcined samples. [15] reported that Gujeni iron ore deposit ore contains 48.6% Fe, 12.01% Ti, 0.2% Mn, 0.2% S, 2.06% P, 4.4% Al and 6.0% Si. Mineralogically, the ore contained hematite, rutile and goethite in large quantities with, manganese oxide, zirconium, silicate and zincite minerals present in small quantities. The work index was recorded at13.96kwh/tonne.

Iron is regarded as the building block of economic activity, and per capita iron consumption is a well recognized predictor of a nation's degree of development. Although, there are local deposits of iron ore identified at various places in the country, the Nigerian iron industry is dependent on imported raw materials [3]. By establishing the development of commercial amounts of iron ore mineral in the Lejja area, the economic benefits will significantly enhance the local economy there and open up technical job opportunities in the transportation, mining, and manufacturing sectors, guiding the nation towards the achievement of key millennium development goals.

Understanding the essential properties and composition of ores determines how it could be processed. It is an important factor for the exploitation of any mineral. The economics of commercial ore exploitation are frequently determined by the characteristics of minerals [1]. This study's primary goal is to assess the chemical and mineralogical makeup of raw iron ore from the Lejja deposits in Nsukka, Nigeria. The chemical composition of the ore will be compared to those of other ore deposits in Nigeria and major iron ore producing nations to evaluate its quality and determine whether it can be used for commercial purposes (market standards).

The research work will contribute a new and detailed information on the chemical and mineral makeup of the Lejja iron ore deposits. This will guide the ore processing and assist to determine the grade and utilisation of the iron ore in production. This will also create a platform for researchers to understand the behaviour of Lejja iron ore deposits during its utilization.

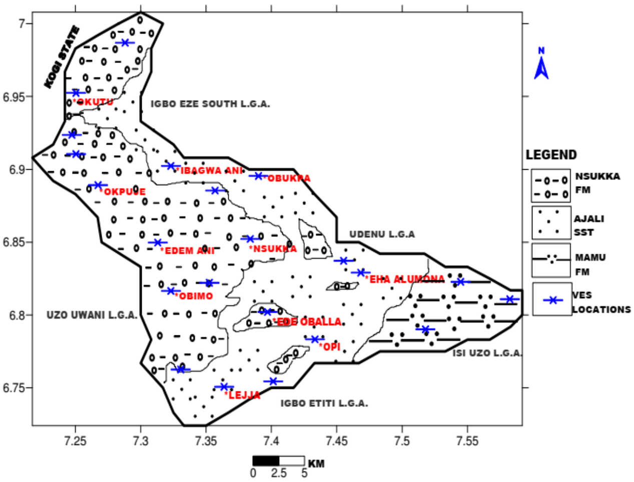


Figure 1: Geologic map of the study area [12].

1.1 Study Area and its Geology

Lejja is a small community about 14km south of Nsukka town in Nsukka Local Government Area of Enugu State, Nigeria. It lies at latitude 6°45ᴵN and longitude 7°22'E. The hill sites under investigation are Dunoka, Amankwo and Umuakpo villages respectively, in Lejja [16]. It covers roughly 480 km^2 of area. (Figure 1).

The area under investigation has two distinct types of landforms: a high relief zone with residual undulating hills and valleys, and lowland sections (Figure 1); with the residual hills being a remnant of the Nsukka formation constituting the surface layers. The AjaliSandstone is overlying the strata, which are severely weathered and degraded [12]. There are three main geologic formations in this region: the Mamu, Ajali, and Nsukka formations (Figure 1), which are the characteristic of the Eastern Nigeria sedimentary basin in the southern portion of the Benue Trough of Nigeria [8].

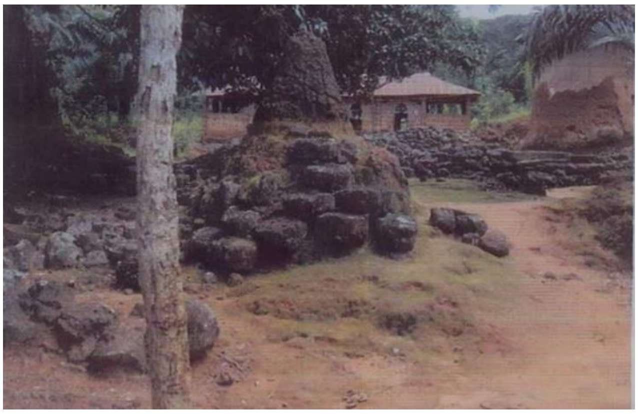


Figure 2: Iron slag visibly scattered at Otobo-Dunoka village square [8].

White to grey, fine to medium-grained sandstones, shaly sandstones, sandy shales, grey mudstones, shales, and coal seams make up the Mamu formation (lower coal measures). The Ajali formation is conformably underlain by this layer, which is around 450 meters thick. The Ajali formation, often referred to as false bedded sandstone, is composed of thick, friable, irregularly sorted, iron-stained, white sandstones. It has a typical thickness of 300 m and is frequently covered in a thick layer of red earth, which is made up of red, earthy sands created by the formation's weathering and ferruginization. The Ajali sandstone conformably rests on the Nsukka formation, which is the upper coal measure. The lithology is extremely reminiscent of the Mamu formation and is composed of a succession of alternating sandstone, black shale, and sandy shale, with thin coal seams at various layers [6]. Eroded remnants of this formation compose of outliers and its thickness averages 250m. At Otobo-Dunoka village (which spans an area of about 500m^2) and environs [8], slag blocks of various sizes and shapes are clearly visible (Figure 2), describing the size of the area's historical iron smelting operations. The abundance of the iron slag has turned the area into an archeological site which confirms the area as a previous iron smelting area [8].

2.0 MATERIALS AND METHODS

The samples of the ores were collected from three hills;Donoka, Amankwo and Umuakpo in Lejjacommunity of Enugu state. Within a 10-meter radius surrounding each hill, samples were taken at random. The initials A, B, and C, respectively, were assigned to the ores from these hills.

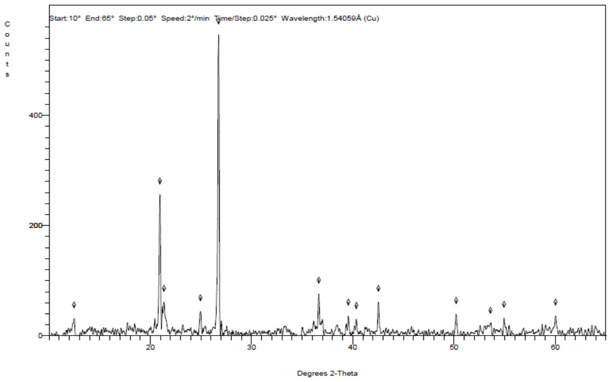
2 kg of each sample was crushed and sieved with a Ro-Tap shaker to 38, 53, 75, 106, 125, 150, 212, 300, 600, and 850$^+$ microns. Samples A, B and C of the ores were crushed with a jaw, cone and roll crushers respectively. The ore fines of sieve size below 100μm were used for mineralogical and elemental analysis. The FeO and other oxides were determined using Perkin-Elmer Model 3100 Atomic Absorption Spectrophotometer (λ = 253.7nm, I = 11mA, bandwidth = 0.7nm) at PRODA Enugu. The elemental composition of element such as Fe, Si, Al, P, Ti, Mg, Mn, Pb, Zn, and Cu were determined using XRF (Philips 2400 XRF) after fusion in $Na_2B_4O_7$. Mineralogical analysis was carried out using an X-ray diffractometer (Bruker D8 X-ray diffractometer) with Ni-filtered Kα Cu-radiation, at 40 kV and 30 mA. It operated at a scan speed of 0.5 with steps of 0.02^0 from 200 to 80^0 2θ range.

3.0 RESULTS AND DISCUSSION

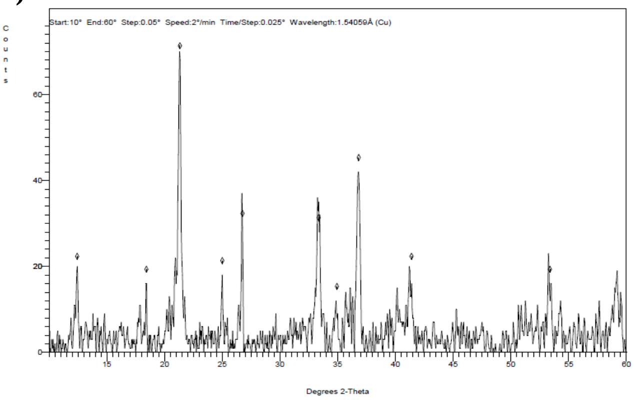
3.1 Mineralogical Analysis Results

The results of X-ray diffraction analysis of iron ores from various ore deposits in Lejja community/town are as shown in Figure 3. The chemical compound observed in Dunoka sample was iron silicate, a common mineral known as isocrite or heptairon silicate hexaoxide {$Fe_7O_{10}Si$ or $Fe_7(SiO_4)O_6$}. Amankwo and Umuakpo samples were analysed to be iron silicate of a common mineral called Fayalite {Fe_2O_4Si or $Fe_2(SiO_4)$}. The major compound observed in the XRD scans of all ore specimens is iron silicate. The main peak appearing at 2θ of 26.85° for Dunoka iron ore, 21.38° for Amankwo and 26.87° for Umuakpo iron ore samples. According to the results obtained, it suggests that all the ores from Lejja community were observed to be iron silicate in nature. Iron ore with high iron composition (65–70% Fe), can be used directly in the blast furnace for production of iron without beneficiation, agglomeration and in direct reduction of iron ore (DRI) process. The ore samples from Dunoka are a compact, bonded crystalline ore varying in colour from grey to black.

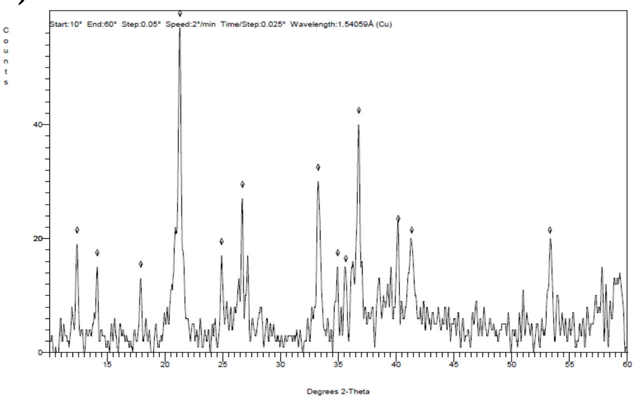
The Amankwo samples consist of aggregates of brown compact and fine-grained particles as compared to report by [14]. That of Umuakpo ore samples are brownish-yellow in colour and fine-grained particles as seen physically.



a) Dunoka ore



b) Amankwo ore



c) Umuakpo ore

Figure 3: XRD Spectra of the iron ores (a, b, and c)

3.2 Elemental and Oxide Analysis Results

The chemical characteristics (AAS and XRF data) of iron ores under investigation are presented in the Tables 1 and 2 respectively. The phosphorous content in all the ores were found to be below the acceptable contents of 0.07% (Table 2), as it follows iron during downstream reduction process, transforming into iron phosphides that makes steel brittle and hence increase the cost of making steel. Therefore, the ores can thus serve as raw materials for iron production. These ores have Fe contents of 60–65% which correlate to the medium-grade ores. Iron ores with high iron content (65–70% Fe) similar to those obtained by [2] and [12] and can be utilised in the direct reduction of iron ore (DRI) process and without beneficiation or agglomeration in the blast furnace for manufacturing iron.

The impurity elements in Dunoka iron ore mainly consist of 1.12% Ti, 0.81% Co, 0.14% Mn and 0.12% Pb. Other elements present in less than 0.1% include Al, Cr, Zn, Ni, V, Mg, K, Ca, and Cu. Phosphorous has 0.0079%. The ore was found to be free from deleterious elements such as sulphur and arsenic. The results from the AAS analysis show that the iron ores obtained from Dunoka hill was rich in iron content (60.59%).

Data from the composition indicated that the impurity elements in Amankwo iron ore mainly consist of 1.58% Ti, 0.64% Co and 0.18% Pb. Other elements present in the ore include Al, Mn, Cr, Zn, Ni, V, Mg, K, Ca, Cu, but are present in less than 0.1%. Phosphorous has 0.0059%. The ore was found to be free from deleterious elements such as: S, As and hence comparable to those of Muko deposits as studied by [1] and GidanJaja in Zamfara state (Nigeria) by [5]. The result shows that the iron ores obtained from Amankwo hill has the richest iron content of 64.81%.

Within the composition of Umuakpo iron ore, the impurity elements mainly consist of 1.37% Ti, 0.55% Co and 0.15% Pb. Other elements such as Al, Mn, Cr, Zn, Ni, V, Mg, Ca, Cu, Ag, are also present in less than 0.1% and 0.0079% P. The ore was also found to be free from deleterious elements such as sulphurand arsenic. The result (as in Table 2) established that the iron ores obtained from Umuakpo hill was also rich in iron content (64.67%). The AAS test results also show the presence of all the above elements as in XRF analysis data (Table 2). Elements such as Titanium, Lead and Cobalt are found to be largely present among the impurities which can be extracted for commercial use. The Lejja iron ore deposits having an iron content of 60-65%, can serve as direct-shippable ore (DSO) and will only need minimal beneficiation.

Table 3 shows the chemical composition of iron ore deposits from Lejja Nsukka communities (Dunoka, Amankwo and Umuakpo) as compared to other deposits in Nigeria. These deposits have much higher iron contents than other deposits as observed in the XRF chemical analysis results.

Table 1: Result of Lejja iron ore in oxide form from AAS Analysis

Deposit	S	FeT	TiO_2	CaO	MnO	MgO	SiO_2	P_2O	Cr_2O_3	CO	Al_2O_3	K_2O	ZnO
Dunoka	UN	60.65	1.12	0.45	1.00	0.98	4.85	Trace	Trace	Trace	0.86	Trace	0.062
Amankwo	UN	65.40	1.62	Trace	0.57	8.81	3.78	Trace	0.035	0.32	0.30	UN	0.060
Umuakpo	UN	64.69	1.45	0.432	0.14	8.20	3.41	Trace	0.006	0.57	0.24	UN	Trace

Where UN= Undetected

Table 2: Elemental analysis results of Lejja iron ore (XRF analysis)

Element	Dunoka	Amankwo	Umuakpo
Mg	0.0100	0.0092	0.0348
Al	0.0858	0.0312	0.0238
Si	0.1995	0.1703	0.1515
P	0.0079	0.0059	0.0063
S	0.0000	0.0000	0.0000
K	0.0154	0.0000	0.0000
Ca	0.0313	0.0201	0.0229
Ti	1.1198	1.5764	1.3650
V	0.0373	0.0485	0.0354
Cr	0.0611	0.0609	0.0613
Mn	0.1378	0.0894	0.0967
Co	0.8063	0.6389	0.5457
Fe	60.5927	64.8108	64.6735
Ni	0.0529	0.0549	0.0560
Cu	0.0232	0.0198	0.0190
Zn	0.0619	0.0523	0.0536
As	0.0000	0.0000	0.0000
Pb	0.1161	0.1759	0.1544
W	0. 0000	0.0000	0.0115
Au	0. 0000	0.0000	0.0000
Ag	0. 0000	0.0000	0.0006
Rb	0.0028	0.0049	0.0050

Table 3: Composition of some Nigerian iron ores as compared to Lejja deposits (AAS analysis).

Deposit	S	P_2O_3	K_2O	CaO	TiO_2	FeT	MgO	Al_2O_3	SiO_2	Cr_2O_3	ZnO
Chocochoko	UN	0.02	0.53	0.15	0.61	34.45	0.18	9.67	44.8	UN	UN
Agbajanoko	0.03	0.01	0.03	0.21	Trace	37.22	0.15	3.39	46.5	UN	UN
Agbaja	0.12	2.08	0.04	0.72	0.37	47.8	0.38	9.60	10.89	UN	UN
Kotun-karfi	0.04	2.14	0.02	0.45	0.25	48.18	0.07	6.70	5.13	UN	UN
Bassange	0.05	2.14	0.02	0.17	0.17	46.9	0.46	10.87	8.28	UN	UN
Itakpe	UN	0.18	0.42	0.3	0.1	36.88	0.2	1.0	44.8	UN	UN
Dunoka	UN	Trace	Trace	0.45	1.12	60.65	0.98	0.86	4.85	Trace	Trace
Amankwo	UN	Trace	UN	Trace	1.62	65.40	8.81	0.30	3.78	0.035	Trace
Umuakpo	UN	Trace	UN	0.432	1.45	64.69	8.20	0.24	3.41	0.006	Trace

Where UN= Undetected, Modified after [4].

4.0 CONCLUSION

The mineralogical and chemical composition characterisation of raw iron ore from the three deposits, Dunoka, Amankwo and Umuakpo in Lejja community, Nsukka Local Government Area of Enugu State were studied. The results show that the ore samples were found to be mainly composed of iron silicate in nature. The results obtained from the analysis of iron ores using XRD analysis well-aligned with chemical composition data (XRF and AAS) of these ores. Iron ore from Dunoka contains 60.59% Fe, Amankwo ore contains 64.81% Fe as the highest and Umuakpo contains 64.67%Fe. When compared to other iron ores from the countries that produce iron, these are considered to be of medium grade. The iron ores can be efficiently exploited to produce steel and iron. There are also other elements like titanium, magnesium and manganese that can be mined for commercial use. Chemical analyses established that all the samples of iron ore under investigated contain trace of phosphorous of < 0.0079 and were free from the deleterious elements, sulphur and arsenic.

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