Nigerian Journal of Engineering
Faculty of Engineering
Ahmadu Bello University
Samaru - Zaria, Nigeria

Vol. 26, No. 3, December 2019
ISSN: 0794 - 4756

DETERMINATION OF CHEMICAL, MINERALOGICAL AND PETROLOGICAL COMPOSITIONS OF YALMATU-DEBA IRON ORE DEPOSIT

D. G. Thomas*[1], S. A. Yaro[2] and E. G. Kefas[3]

[1,2]Department of Metallurgical and Material Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria
[3]Department of Chemical Engineering, College of Engineering, Kaduna Polytechnic, Kaduna State, Nigeria
***Corresponding Author's Email: dungkathomas@gmail.com**

ABSTRACT
Determination of chemical, mineralogical and petrological compositions of Yalmatu-Daba iron ore deposit, Gombe State, Nigeria was carried out in the course of this research work. The iron ore deposit is located in Kwadon - Yamaltu village of Deba Local Government Area of Gombe State. The samples were sourced from three different Pits 1, 2 and 3 at 50 m apart and 1 m depth with their respective coordinates respectively. The samples were harmonized crushed, pulverized and characterized using X-ray Fluorescence Spectrometer (XRF), X-ray Diffraction (XRD) and Optical microscope techniques respectively. The XRF result of the chemical analysis of the homogenized sample revealed that the ore contained 46.34% Fe_2O_3, 50.7% SiO_2, 0.43% CaO, 0.196% K_2O, 0.546% V_2O_5, 0.029% Cr_2O_3, 1.07% MnO, 0.029% CuO, 0.0453% ZnO, 0.016% Rb_2O, 0.34% ZrO_2, 0.029% SrO, 0.47% Ln_2O_3, 0.11% BaO, 0.47% Eu_2O_3, 0.036% Re_2O_7 on the average. XRD result of the mineralogical analysis revealed that the ore contained Quartz, Goethite, Magnetite and Kaolinite as the major mineral phases while Silica as the minor mineral phase in the matrix of the ore. The petrological result revealed that the ore matrix is an assemblage of interlayered of different minerals crystals with different shapes and sizes at different angles of orientation and separated by grain boundaries. The results of chemical and mineralogical compositions of the ore compare favourably with other results of some Nigerian iron ore deposits cited in the literatures. Thus, making the Yalmatu-Deba iron ore deposit another potential source of iron ore that can be beneficiated and utilize in the nation's iron and steel industries.
***Keywords**: Iron ore, mineralogical, magnetite, spectrometer, techniques.*

INTRODUCTION
The ability of a nation to exploitsits minerals lies fully in characterization of its minerals deposits in a manner that will expose the minerals potentials and hence attracting the much-needed investors. The identification and characterization of a mineral is one of the fundamental parameters necessary in the development of the process route of that mineral ore (Hope *et al*., 2001; Thomas and Yaro, 2009). And also, a very importance indicator in choosing a suitable unit process for recovering the valuable constituents of the ore. Cook, (2000) and Salawu, *et al*. (2015). Stated that the growing needs for detailed information about the chemical, mineralogical and petrological compositions of a mineral deposit is an integral part of investigations. Knowledge of chemical, mineralogical and petrological compositions, size, morphology and degree of association with other minerals is therefore expected to provide insights and information on the characteristics, type, nature and amount of minerals and elements present in the matrix of the ore at different locations. This will enhance an assessment and determination of the optimal processing route for its constituent minerals and metals.

Nigeria is blessed with vast iron ores deposits which are located across the country and Itakpe is believed to have the largest concentration of iron ores deposits. Other States where iron ores can be found in the country includes: Abia Anambra, Bauchi, Benue, Kwara, Kaduna, Katsina, Sokoto, Niger, Enugu, Gombe, Plateau, and Nasarawa (Agava, 2006).

It is on record that Nigeria has a proven deposit of over three billion (3,000,000,000) tonnes of iron ore cutting across the above aforementioned States and those yet to be discovered. At present most of our steel demands are been met from the recycling of metals scraps and the demand has been estimated at two million (2,000,000) tonnes annually.

Two (2) types of Iron ore occur prominently in Nigeria, namely:
(i) Banded iron formation: It occurs in folded bands and lenses associated with the Precambrian metasedimentary schist belts prominently outcropping in the western half of the country. Prominent locations include Tajimi, Itakpe, Ajabanoko, Ochokochoko Toto-Muro, Farin Ruwa, Birnin Gwari, Maru, Jamare, Kaura Namoda, Kakun, Isanlu, Roni and Ogbomoso areas (Thomas and Yaro, 2009).

(ii) The Cretaceous sedimentary (Oolitic) iron deposits: This type of deposit is found around Agbaja, Koton-Karfi, Nsudde areas in the North central and south eastern zones of the country respectively.

The banded iron formation of Nigeria generally occurs in metamorphosed folded bands, associated with Precambrian basement complex rocks which include low grade meta-sediments, high grade schist, gneisses and migmatites. In these groups are the well-known Lokoja-Okene occurrences notably at Itakpe, Ajabanoko, Kakun, Chokochoko, Toto Muro and Tajimi (Thomas and Yaro, 2009).

In the north western parts of Nigeria, the banded iron formation occurs sporadically in narrow bands and lenses interbedded with pelitic and semi pelitic phyllites and schists.

In some cases, especially around Tsofon Birinin Gwari they are inter-banded with garnet-quartz mica schist, lenticular bodies of orthoquartzites and carbonaceous schist. While in Maru area, they are inter-bedded with massive green phlyllites, feebly developed slaty rocks, flaggy tuffaceous materials and amphibolites. The iron formation bands which vary in thickness from about 3 centimeters to 5 meters are found commonly in groups intercalated within surrounding country rocks or as isolated thin units. The bands have variable strike extent with some stretching though discontinuously for several kilometers (Thomas and 2009).Three main phases have been identified: they are the oxide, silicate and sulphide. The oxide phases which is represented by the silica iron oxide assemblage, is the most predominantly phase usually consists of a thinly banded but occasionally slaty rock having a rhythmic alternation of light coloured (light gray) silica rich bands of variable thickness. The silicate phase is quartz-garnet- grunerite assemblage (Thomas and Yaro, 2009).

The sulphide phases occur as the pyrite bearing members of the pelitic meta-sediments which consists of carbonaceous schist and phyllite, green phyllite and slaty rock. These rocks are invariably inter-banded with the oxide iron formation (Thomas and Yaro, 2009).

As Nigeria strives to achieve her economic development objectives, it is important that Government pay attention to the development of the various iron ores fields in the country. Hence, through their utilization the nation will greatly be seen as it is on the right path to economic diversification and industrialization as indices usually use to measure national prosperity. In fact, it can be said that the more a nation mining industry grows, the more they prosper economically and examples can be seen across the world from Canada, Australia, India, S/Africa Ghana, etc., they all have a vibrant mining economic lead sector and industries. On the basis of the above-mentioned predicaments prompted this research work on “determination of chemical, mineralogical and petrological compositions of Yamaltu-Deba iron ore deposit” with the view of developing the nation’s mineral industries and diversifying the economy. The iron ore deposit is estimated to be over 60 million tonnes, but the estimated reserve of the ore deposit is stilled on an inferred stage (MMSD, 2012).

Some of the iron ores deposits found in the country with their proven reserve and chemical compositions presented in Tables 1.0 and 1.1 respectively.

Table 1.0: Some Nigerian iron ores deposits and their locations

S/No.	Deposits	Locations	Iron content (%)	Estimated reserve in tonnes
	Itakpe	Kogi	36-88	200-300 million
	Ochokochoko	Kogi		12-14 million
	Ajabanoko	Kogi	40	60 million
	Agbadookudu	Kogi	38-48	60 million
	Akoina	Kogi		Under investigation
	Tajimi	Kogi		200 million
	Ero	Kogi		-
	Ebiya	Kogi		-
	Obajana	Kogi		-
	Koton Karfe	Kogi	43-53	850 million
	BassaNge (Egenji Ate)	Kogi	43-49	400 million
	Kakun (Kabba)	Kogi		-
	Ubo-Toso	Kogi/Edo		-
	Akunu (Ikare)	Ondo		-
	Gujeni	Kaduna		-
	Kagara (Kubacha)	Kaduna		-
	BirniGwari	Kaduna		-
	Toto Muro	Nasarawa		3.8 million
	Rishi	Bauchi	10-19	-
	Ayi Wawa	Bauchi		-
	Karfe	Borno		-
	Gamawa	Bauchi		-

	Dakin Gari	Kebbi		-
	Nsude	Enugu		-
	Ameki/Ohafia	Abia		-
	Veketuwo	Plateau		-
	Agbaja	Kogi		Over one billion
	Nsuge Hill	Anambra	43-50	3.8 million
	Bakingari	Sokoto	37	

Source: (Thomas and Yaro, 2009)

Table 1.1: Chemical compositions of some Nigerian iron ores deposits

Deposits	K_2O	CaO	TiO_2	MnO	Fe_T	MgO	H_2O_3	SiO_2	P_2O_5	S
Itakpe	0.42	0.30	0.10	0.05	36.88	0.20	1.00	44.80	0.18	Trace
Chokochoko	0.53	0.15	0.16	0.08	34.45	0.18	9.67	51.07	0.02	Trace
Ajabanako	0.26	0.21	Trace	0.01	37.22	0.15	3.39	46.50	0.01	0.03
Agbado-Okudu	0.04	0.72	0.37	0.14	47.80	0.38	9.60	10.89	2.08	0.12
Koton-Karfe	0.02	0.45	0.25	0.56	48.18	0.07	6.70	5.13	2.14	0.04
Bassa-Nge	0.02	0.17	0.17	0.13	46.90	0.40	0.87	8.28	1.45	0.05

Sources: RMRDC (2000); GNS, (1987); Thomas and Yaro, (2009)

Previous Work Done on some Nigerian Iron Ores

Bashir (2017) worked on the characterization of Gyaza iron ore deposit, Katsina State, Nigeria and reported that, the XRF result revealed that the ore contained 0.17%P, 0.02% K, 0.23% Ca, 0.11% Mn, 36.17% Fe, 0.08% Ba, 0.18% Mg, 1.10% Al and 17.21% Si. XRD result revealed that the major mineral phases are goethite, hematite and silica. Also, the SEM and petrological results revealed that the ore matrix is an assemblage of inter-layered different minerals crystals with different shapes, sizes and angles of orientations and separated by grains boundaries.

Salawu *et al*. (2015) characterized the Gujeni iron ore and reported that the ore contained 48.6%Fe, 0.2%Mn, 12.01%Ti, 2.06%P, 0.2%S, 6.0%Si, 4.4% Al. The major mineral phases are predominantly hematite, goethite, rutile, aluminite and minor minerals are silica, phosphorus, sulphur, zincite and zirconite. The SEM results revealed that the minerals are separated by smooth boundaries that can facilitate their easy liberation. The petrological results revealed that the structures of the iron bearing minerals are in form of plates and river lines, which are the characteristics of hematite and goethite.

Ahmad *et al*. (2017) worked on Jaruwa iron deposit and reported that the ore is rich in hematite ore intercalated with kaolinitic clays covered by lateritic overburden and hosted mainly by amphibolites and meta-sediments. He asserted that based on analysis of the Fe content, gangue (SiO_2 + Al_2O_3), contaminants (P and S) and other impurities. The iron ore from Jaruwa met the requirements for profitable exploitation and exportation, and can serve well as a good raw material for iron production.

Michael (2008) reported that Mozambique Belt, Ikutha area in Kenya's iron ore deposits has characteristics as follows: the ore deposits are fairly rich in magnetite and apatite, although other minerals such as amphiboles and pyroxenes are found associated with them. Some of the rocks have high iron values, some as high as over 90%. This iron can therefore be mined economically. Apatite varies between 4% and 20%. Many of the magnetite rich rocks were found to have more than 70% iron oxide. These include disseminated iron ore, thin ore veins and 3.5 m of weathered hornblende/pyroxene gneisses. He noted that samples with more than 40% Fe_2O_3, phosphate values range between 1.9% –6 %, with averages of 4.4%. These samples have little or no water at all, i.e. no loss on ignition.

Adedeji and Sale (1984) also reported the characteristics of Itakpe, Agbaja and Corby (Nigerian) iron ores as: Itakpe ore is a rich hematite ore in which some hematite forms an intergrowth with magnetite. The main impurity is silica. Liberation by crushing and physical separation of the quartz, the Itakpe ore is suitable as a feedstock to one of the direct reduction methods of iron making. The ore is typical of one formed by magmatic segregation. The Agbaja ore is an acidic pisolitic ore consisting of goethite, magnetite and major amounts of aluminous and siliceous minerals. It cannot be used directly in a blast furnace or other reduction process without further treatment. Corby ore is confirmed as a basic pisolitic carbonate ore with a basicity of 0.9, both Agbaja and Corby ores are lean and of sedimentary origin.

Oloche *et al*. (2001) reported that Toto-Muro iron ore is within a litherto schist belt and is a banded iron oxide quartz rock which is associated with dolomite rock.

Agava (2006) worked on Agbado Okudu iron ore deposit, he reported that the iron ore contained on the average iron content of 38.82% and the major minerals phases are magnetite and hematite.

Thomas and Yaro (2009) worked on Koton-Karfi iron ore and concluded that it has iron content of 43.34% Fe with low amount of silica (10.14%SiO_2). Their findings also revealed that the ore contained magnetite, siderite, goethite as the major constituents while hematite as the minor mineral. The work index of Koton-Karfe iron deposit was determined to be 11.33 kWh/tonne and 17.00 kWh/tonne for both calcined and uncalcined samples.

MATERIALS AND METHODS

Materials

The iron ore head samples were sourced from various points of the deposit site located at Kwadon-Yamaltu village, in Deba Local Government Area of Gombe State. GPS was used to measure the exact location of the sourced sample as follow: Pit 1(10◦ 16' 36.548832" N; 11◦ 18' 12.009564" E), Pit 2 (10◦ 16' 35.653908" N; 11◦ 18' 9.62928" E) and Pit 3: (10◦ 16'36.418332" N; 11◦18' 6.729588" E). Grab technique of sampling was used in sourcing the sample and fifty (50) kg of the sample in total was collected from three (3) points at interval of 50 m apart at 1m depth respectively.

Methods

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 are accepted by the crusher using sledge hammer. The sample was crushed using Denver Laboratory jaw crusher and pulverized using ball milling machine respectively. Coning and quartering sampling method was used to divide the pulverized sample into smaller portions that were used for analyses. The pulverized sample was analyzed for its chemical and mineralogy compositions using EX-7000 X-ray Spectrometer and Schimadzu 6000 XRDmachines respectively.

Determination of Chemical Composition using XRF

EX-7000 X-ray Spectrometer was used for the analysis. The analysis was carried in National Steel Raw Material Development Agency (NSRMDA) Laboratory, Malali, Kaduna State. EX-7000 X-ray Spectrometer is a compact Energy Dispersive X- ray Spectrometer analytical instrument designed for the detection and measurement of elements in a (solids, powders and liquids) from Beryllium (Be) to Uranium (U). The pellet was charged into the sample chamber of the spectrometer and voltage (30 kV maximum) and a current (1 mA maximum) was applied to produce the x-rays to excite the sample for a precise time. The spectrum from the sample was analyzed to determine the concentration of the element in the sample. The result is as presented in Table 4.1.

Determination of Mineralogical Composition using XRD

Schimadzu 6000 XRD was used to analyze the sample. The analysis was carried out in National Steel Raw Material Research Council (NSRMRC) Laboratory, Malali, Kaduna State. The same procedure for the preparation of the sample for XRF analysis was repeated for the preparation of XRD sample. The prepared sample was analyzed for its mineralogical composition. The result is presented in Table 4.2.

Petrological Analysis

Petrological analysis of the ore sample was carried using NJF-120Amodel optical microscope with inbuilt camera at NSRMRC, Malali, Kaduna State. Polished section was prepared from samples of Pits 1, 2 and 3 for petrological analysis. The iron ore sample was cut to size using cutting machine. The sample's surface was prepared for petrological viewing using grinding and polishing machines respectively until mirror like surface was obtained. Silicon carbide and polishing paste of aluminum oxide powder were used for the grinding and polishing. The samples were viewed using the optical microscope for identification of the mineral phases present and determination of grain size of the various minerals. The photomicrograph of the observed polished sample is shown in Plate 4.1.

RESULTS AND DISCUSSION

Determination of Chemical Composition of the Ore Sample using XRF

Table 4.1 presents result of the chemical analysis of the head samples obtained from the various pits using XRF.

Table 4.1: Chemical compositions of the various pits of the ore head samples

Chemical Compound	Pit1 Assay (%)	Pit2 Assay (%)	Pit3 Assay (%)	Average Assay (%)
Fe_2O_3	28.94	57.83	52.26	46.34
SiO_2	66.9	39.9	45.5	50.76
CaO	0.45	0.29	0.55	0.43
K_2O	0.46	0.13	0.0	0.196
TiO_2	0.760	0.478	0.400	0.546
V_2O_5	0.02	0.00	0.00	0.006
Cr_2O_3	0.014	0.040	0.033	0.029
MnO	0.750	0.19	0.13	1.07
CuO	0.043	0.040	0.035	0.029
ZnO	0.060	0.034	0.042	0.0453
Rb_2O	0.018	0.01	0.02	0.016
ZrO_2	0.11	0.92	0.00	0.343
SrO	0.088	0.0	0.00	0.029
Ln_2O_3	0.2	0.44	0.77	0.47
BaO	0.33	0.00	0.00	0.11
Eu_2O_3	0.69	0.43	0.30	0.47
Re_2O_7	0.03	0.04	0.04	0.036

Table 4.1 present the chemical composition of the various pits. From the result, it can be observed that the amount of iron content in Pit 2 (57.83% Fe_2O_3) is higher than that of Pit 1 (28.94% Fe_2O_3) and Pit 3 (52.26% Fe_2O_3). This could be attributed to the differences in the geochemical mineralization processes of the ore deposit that favoured the formation of more iron mineral in pit 2 when compared to pits 1 and 3. The major gangue mineral is silica (SiO_2) with an average of 50.76% which can be easily removed during beneficiation. Furthermore, Pit 1 contained 66.9% SiO_2, 0.46% K_2O, 0.4% CaO, 0.760% TiO_2, 0.02% V_2O_5, 0.014% Cr_2O_3, 0.75% MnO, 28.94%Fe_2O_3, 0.043% CuO,0.060% ZnO, 0.018% Rb_2O, 0.088 % SrO, 0.11% ZrO_2, 0.2.0% In_2O_3, 0.33% BaO, 0.69% Eu_2O_3,0.03% Re_2O_7,0.16% PbO; Pit 2 contained 39.9% SiO_2, 0.13% K_2O, 0.29% CaO, 0.478% TiO_2, 0.040% Cr_2O_3, 0.19% MnO, 57.83% Fe_2O_3, 0.040% CuO, 0.034% ZnO, 0.01% Rb_2O, 0.091wt% ZrO_2, 0.44%In_2O_3, 0.02%La_2O_3, 0.43% Eu_2O_3, 0.04% Re_2O_7 while Pit3 contained 45.50 %SiO_2, 0.552% CaO, 0.40%TiO_2, 0.033%Cr_2O_3, 0.13% MnO, 52.26% Fe_2O_3, 0.035% CuO, 0.042% ZnO, 0.02% Rb_2O, 0.77%In_2O_3, 0.03% La_2O_3, 0.30%Eu_2O_3, 0.04% Re_2O_7. The reason for variations in the ore samples percent compositions of the various samples agreed with similar observations advanced by Salawu, *et al*. (2015). However, the presence of silica and other associated impurities minerals in the ore matrix cannot hinder its utilization. Since, today there are advanced technologies than can be used for the beneficiation of the ore. However, the result of the chemical analysis of the ore compare favourably with other major iron ore deposits in the country cited in Table1.1.

Determination of Mineralogical Composition of the Ore Sample

Tables 4.2 and 4.2.1 present the results of the mineralogical composition of the ore sample while Figure 4.1 shows the XRD diffractogram of the ore sample.

From the result in Table 4.2, it can be observed that Goethite, Quartz, Magnetite and Kaolinite are the predominant single-phase minerals while others are presences in combined phases. Also, Table 4.2.1 presents the frequency of appearance of the compositions of the various mineral's phases in the ore matrix. The reason for the above phenomenon could be attributed to the mineralization process of the ore deposit resulting from the tectonic activity of the basement complex. The present of magnetite, goethite, quartz as single phases and also in the combined form indicate the susceptibility of the minerals to magnetic and gravity separation techniques. The absent of sulphur and phosphorus indicates less penalty for the ore and good suitability for iron and steel making. Figure 4.1 revealed the XRD characteristics of the mineral peaks contained in the ore matrix. The different peaks exhibited by the various minerals contained in the ore matrix indicates that the minerals are crystalline in nature and separated by planes (slip lines or boundaries) that can enhance their fragmentations. The result obtained for the ore agreed with that of Salawu, *et al*. (2015) and Bashir, (2017).

Table 4.2: XRD mineralogical composition of the ore sample

Mineral name	Chemical name	Chemical formula
Quartz	Silicon oxide	SiO_2
Goethite	Iron hydroxide	FeO(OH)
Magnetite	Ferrous-ferric oxide	Fe_3O_4
Kaolinite	Aluminum silicate oxide	$Al_2Si_2O_5(OH)_4$

Table 4.2.1: Mineral phases distribution frequency of the ore sample (XRD)

Mineral	Frequency
Quartz	2
Goethite	3
Magnetite	1
Kaolinite	2
Goethite, Kaolinite	3
Goethite, Magnetite, Kaolinite	1
Quartz, Goethite, Magnetite	1
Quartz, Kaolinite	4
Quartz, Goethite, Kaolinite	4
Quartz, Magnetite, Kaolinite	1

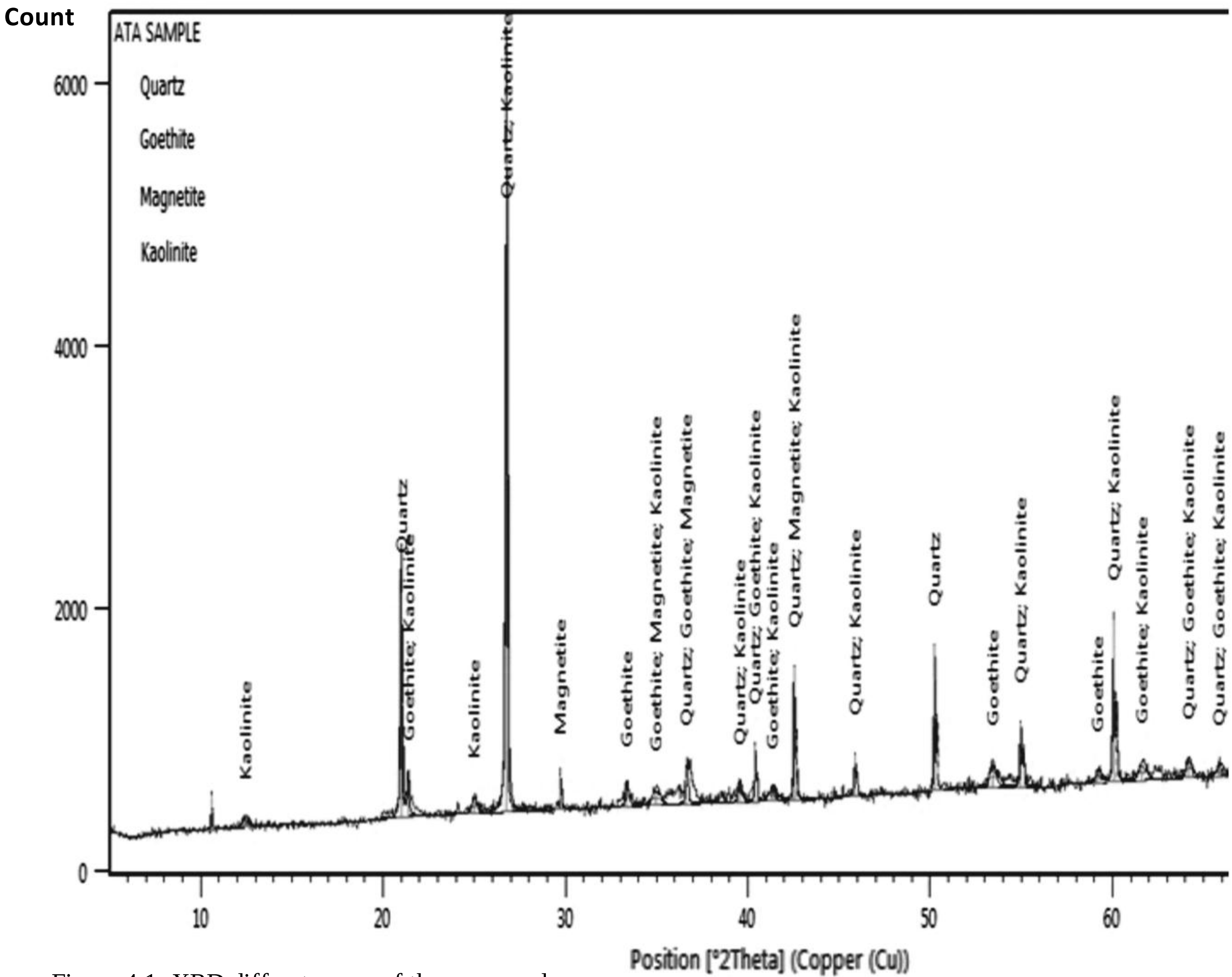

Figure 4.1: XRD diffractogram of the ore sample

Petrological Analysis of the Iron Ore Sample

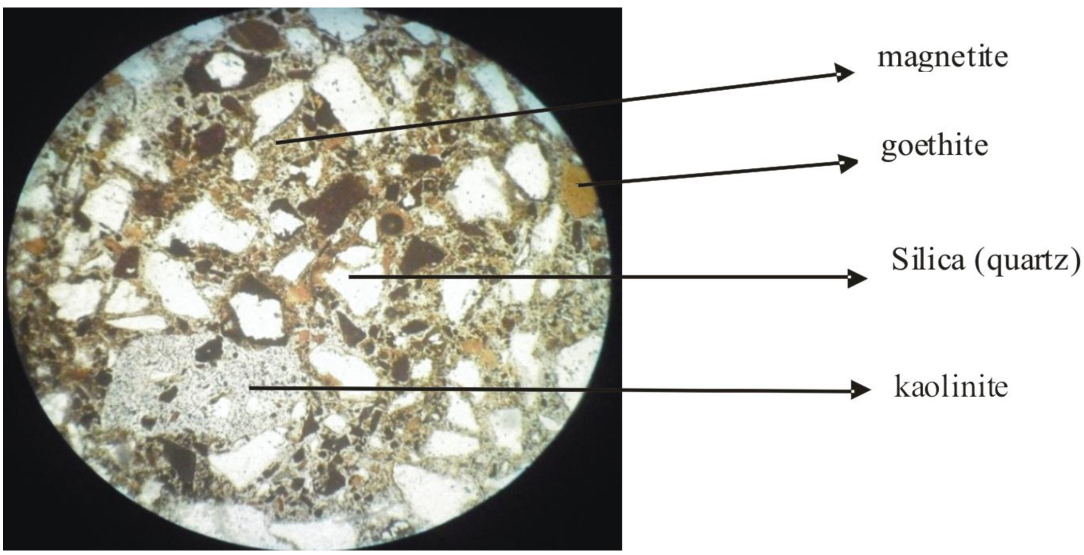

Plate 4.1: petrological composition of the ore sample

From Plate 4.1 it can be observed that quartz is colorless, angular to sub-rounded in shape, no cleavage, not pleochroic, not fractured nor altered, does not have inclusions in the grains, the grains do not have contact with each other, impregnated and has low relief. While the opaque minerals grains have high relief that appears reddish-brown to dark colours under plane and cross polarize light. These colours revealed the present of goethite and magnetite and other associated minerals respectively but clearly separated by grain boundaries that can enhance their comminution and separation. The various mineral colours observed from the ore matrix matched and agreed with that cited in MacKenzie and Adams, (1995).

CONCLUSIONS

(i) The characterization of Kwadon-Yamaltu iron ore was carried out. The chemical analysis revealed that the iron ore contains averagely 46.34% Fe_2O_3, 50.76% SiO_2, 0.43% CaO, 0.196% K_2O, 0.546% TiO_2, 0.006% V_2O_5, 0.029% Cr_2O_3, 1.07% MnO, 0.029% CuO, 0.0453% ZnO, 0.016% Rb_2O, 0.343% ZrO_2, 0.029% SrO, 0.47% In_2O_3, 0.11% BaO, 0.47% Eu_2O_3, 0.036% Re_2O_7.

(ii) The mineralogical analysis of the ore revealed that the iron ore is predominantly goethite, magnetite, quartz, kaolinite which are in single phases while other associated minerals are in complex phases and are minor which can be separated during mineral processing. The present of magnetite, goethite and silica phases indicate that the iron ore can be separated using gravity and magnetic methods of concentration respectively or in combination of the methods.

(iii) The petrological analysis revealed that the structures of the iron bearing minerals are in form of plates and river lines, which are the characteristics of magnetite and goethite. The dark and reddish-brown areas are mixture of goethite and silicate minerals while the white area is quartz.

All the results obtained compared favourably with those cited in the literatures. Thus, Kwadon-Yamaltu iron ore can be said to be another potential iron ore deposit that can be explored and exploited for its usage in the nation's iron and steel industries.

REFERENCES

Adedeji, F. A. and Sale F. R. (1984). Characterization and reducibility of Itakpe and Agbaja (Nigeria) iron ore. *Journal of Minerals. 19*, 843-856.

Agava, A. A. (2006). Beneficiation of Agbado-Okudu iron ore deposit, Department of Metallurgical Engineering, A.B.U. Zaria. Unpublished.

Ahmad, I. H., Umar, S. U., Abdullahi, A. M. and Maude, K. A. (2017). Geochemistry and economic potential of Jaruwa Iron ore, NW- Nigeria. *Imperial journal of Interdisciplinary research. 3*(3), 1067.

Bashir, H. (2017). Characterization of Gyaza Iron Ore Deposit, Katsina State, Nigeria. Undergraduate Project, Dept. of Metallurgical and Materials Engineering, Faculty of Engineering, Ahmadu Bello University, Zaria. Pp 20-22, Unpublished.

Cook, N. J. (2000). Mineral characterization of industrial minerals deposits at the Geological Survey Norway: A Short Introduction. *Norges geologiske undersekelse Bulletin*, 436, 189-192.

GSN (1987). Annual Report of the Geological Survey of Nigeria. Pp 26-27.

Hope, G. A., Woodsy, R., Munce, C. G. (2001). Raman microprobe mineral identification. Miner. Eng. 14 (12), 1565–1577.

MacKenzie, W. S. and Adams, A. E. (1995). A Colour Atlas of Rocks and Minerals. Manson Publishing, Barcelona, Spain.

Michael, K. M. (2008). Geochemical Characterization of Iron Ore Deposits of the Mozambique Belt, Ikutha area in Kenya, Project in Geology Kang'utu University, Kenya.

Ministry of Mines and Steel Development (MMSD), (2012). Nigeria Mineral Projects. Annual Report of the Ministry of Mines and Steel Development, Abuja. Pp. 12.

Oloche, O. B., Yaro, S. A. and Thomas, D. G. (2001). Up-Grading of Muro Iron Ore by Wet Shaking Table Separation Method. Nigerian Mining Journal, a Publication of Nigerian Society of Mining EngineersNo1, Vol.5. Pp17-21.

RMRDC, (2000). Industrial Raw materials, Journal of the Raw Material Research and Development Council. Abuja, pp. 3 - 4.

Salawu, A. O., Yaro, S. A. and Thomas, D. G. (2015). Determination of Chemical Composition and Liberation Size of Gujeni Iron Ore Deposit, Kaduna State, Nigeria. Nigerian Mining Journal, a Publication of Nigerian Society of Mining Engineers. Vol.13, No.1, Pp62-67.

Thomas, D.G. and Yaro, S. A. (2009). Chemical and Mineralogical Characteristics of Koton-Karfe Iron Ore. Journal of Engineering and Technology (Jet) Bayero University, Kano. Vol. 4, No.1, Pp 65-71.