CHARACTERIZATION OF GUJENI IRON ORE DEPOSIT, KADUNA STATE, NIGERIA.

BY

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF METALLURGICAL AND MATERIALS ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF DEGREE OF MASTER OF SCIENCE IN METALLURGICAL AND MATERIALS ENGINEERING.

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DECLARATION

I hereby declare that this dissertation entitled “characterization of Gujeni iron ore deposit”was carried out by me in the Department of Metallurgical and Materials Engineering. The information used from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation has been presented for purpose of award of degree or diploma in any other institution.

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APPROVAL

This dissertation entitled "Characterization of Gujeni iron ore deposit" by AishatOmetereSalawu meets the requirements for the award of the degree of Masters in Metallurgical and Materials Engineering of Ahmadu Bello University, and is approved for its contributions to knowledge and literary presentation.

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ABBREVIATIONS, DEFINITIONS, GLOSSARY AND SYMBOLS

XRF	X-Ray Fluorescence
XRD	X-Ray Diffractometer
SEM	Scanning Electron Microscope
EDS	Energy Dispersive Spectrum
µm	Micrometer
%	Percentage
GSN	Geological Survey of Nigeria
RMRDC	Raw Material Research Development Centre
Fe	Iron
GPS	Global Position System

ABSTRACT

The characterization of Gujeni iron ore was carried out in the course of this research work. The iron ore deposit is located in Gujeni village, Kagarko Local Government Area, 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, analysed and characterized using XRF, XRD and SEM/EDS techniques. The result of the chemical analysis revealed that the composite sample contained 48.6%Fe, 0.2%Mn, 12.01%Ti, 2.06%P, 0.2%S, 6.0%Si, 4.4%Al on the average. Physical properties of the ore such as specific gravity, density and electrical conductivity were determined and the values are within the standard values specified for iron ores. Mineralogical analysis showed that the ore contained the following minerals in major quantity; haematite, goethite, rutile while, manganese oxide, zincite, zirconium and silicate minerals are present in minor quantities. The SEM/EDS analysis results revealed that the iron bearing minerals are separated from other minerals contained in the ore by smooth boundaries hence, they can be liberated from other associated minerals simply by crushing and grinding. Petrological results revealed that the structure of the iron bearing minerals are in the form of plates and river line which are the characteristic of haematite and goethite. Particle size/mineral assay analyses revealed that the various mineral phases are evenly distributed in all the various sieve size fractions(+355µm to -50µm). 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 work index of the ore was found to be 13.96kWh/t and classified as a type B ore with soft medium texture. The results obtained are compared with that of the literatures cited. Gujeni iron ore may be another potential source of iron ore deposit that can be beneficiated and supplied to iron and steel making industries in the country.

CHAPTER ONE

1.0 INTRODUCTION

1.1. Preamble

Iron and steel industries are some of the basic foundation for the technological development of any country. A country that neglects 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. Although, the establishment of these project was laudable, inadequate attention was given to the development of the raw materials to feed the plants even though Nigeria is endowed with large reserves of proven and unproven iron-ore, coal and other raw materials scattered all over the country, which are required for the production of iron and steel. As a result, on commissioning the Aladja and Ajaokuta in early eighties Nigeria had to depend on foreign sources of iron concentrates and coke. Not until, the 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).

Individuals and other research institutions have also worked on other locally available iron ore deposits for example Agbaja iron ore deposit. This is the largest iron ore deposit in the country estimated at over 1 billion tonnes and has been established to possess extremely fine grained texture and hence has to be ground to less than -5µm in order to achieve substantial degree of liberation of the individual minerals in the ore. In addition, it has a

very high phosphorus content, which has discouraged its utilization to date. Some researches have been carried out with the aim of getting rid of the phosphorous. Attempt has also been made on the beneficiation of AgbodoOkudu iron ore deposit. The investigation revealed that the ore could be upgraded to a standard concentrate using combination of gravity and magnetic separation techniques (Thomas *et al.*, 2014).

However, mineral deposits can be considered as naturally occurring substances existing in association with other substances formed as a result of geochemical processes. This nature of occurrence of most minerals as co-associates with other material necessitated the characterization of their composition for the purpose of establishing an insight into the status of valuable and the unwanted associates. It has been established that Nigeria is endowed with mineral resources (Abubakre*et al*., 2014).

The upgrading of valuable mineral from their naturally occurring ores is variously termed as "ore dressing" "mineral dressing" and "mineral beneficiation". Beneficiation is an important intermediate step in the transformation of natural ore to pure metal (Abubakre*et al*., 2014) hence, it is imperative that the key to successful beneficiation of an ore is greatly attached to the amount of information available on the nature and properties of the various components making up the ore. Cognizant of the fact that achieving the aforementioned step is usually related to the chemical and mineralogical characterization of an ore; this research work will be conducted to carry out the characterization of Gujeni iron ore deposit in order to select a suitable concentration method for beneficiation of Gujeni iron ore in case that of Itakpe is exhausted after 25 years of operation.

1.2. Statement of Problems of the Research

- The total iron ore requirement of Ajaokuta for the production of 1.3 million tonnes of steel per annum is about 2.135 million tonnes of iron concentrate of which at this

rate the Itakpe iron project is conservatively estimated to last for about 25 years which is negligible for a life of a nation.

- There are no available data on the characterization of Gujeni iron ore deposit, without data on the characterization of the iron ore deposit the process route for the beneficiation of the Gujeni iron ore cannot be developed and there by hampering its iexploitation.

1.3. Justifications of the Research

(i) The characterization of the Gujeniiron ore will provide the basic data required for its development (processing).

(ii) Through this research the appropriate technology for beneficiation of Gujeniiron ore deposit would be developed.

iii Additional source of iron ore would be added to the existing data base

1.4. Aim and Objectives

The aim of this research work is to characterize Gujeni iron ore deposit and the specific objectives are

- Determination of the chemical composition of the iron ore using X-ray Florescence (XRF),
- Determination of the physical properties of the iron ore,
- Carrying out the mineralogical and petrological analyses of the iron ore using XRD, SEM/EDS,
- Conducting the size/ mineral assay analyses of the iron ore, determination of the liberation size and the work index of the iron ore.

1.5. Scope of the Research

This research work involved sourcing of the ore sample from the deposit, analysing the ore sample to determine its physical, chemical and mineralogical compositions using XRF, XRD and SEM/EDS. Furthermore, to also conduct the size/assay analyses in order to determine the distribution of the minerals in various sieves fractions; liberation size of the various minerals and the work index of the ore.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. The Nigerian Iron Ore Deposits

The most important economically iron oxides are those occurring within the Okene magnetite complex in North Central Nigeria which described the Itakpe Hill deposit. The largest of several similar deposits in the district is haematite-magnetite quartz body, which is a ferruginous quartz of the Itapenite types. Recently Geological Survey of Nigeria (GSN) and Raw Material Research Development Centre (RMRDC) concluded on mineralogical ground that it represent a replacement of basement gneisses and amphibolites by iron rich solution emanating from nearby granites bodies of the Pan-African older-granite suite. Work to date has outline miner-able reserves of 111,400,000 tonnes grading about 35% Fe which is easily upgraded and is now being developed for open pit mining to provide feed for the Ajoakuta and Delta Steel Companies (Udadiale, 1989).

The most extensive occurrence of the iron ore as Banded Iron Formation (BIF) in the matrix (GSN, 1987; Uwadiale, 1989 and RMRDC, 2000) of the mineral ore are fine grained peitic sediment which are finely layered of sedimentary rocks of probable chemogenic origin, often spatially associated with amphibolites unit. The layering is 1-5 mm thick, quartz is cleanly cryptocrystalline and the iron oxides phases also occurred, especially at the Southern part of the Kushaka belt. Structurally, these units occur as linear ridges aligned North-south but internally reliefs of complex fold pertain found reflecting several phases of deformation. These deposits were investigated by the Geological Survey and National Steel council in 1960s and 1970s as potential iron ore sources but they were found to be low graded (30% Fe_T) and the work was stopped (Thomas and Yaro, 2007).

2.2 Previous Work Done on Some Nigerian Iron Ores

Muro hill (Toto local Government Area of Nasarawa State) has been worked on and reported that within a litherto is schist belt, a banded iron oxide quartz rock which is associated with dolomite rock (Oloche*et al*., 2001).

AgbadoOkudu iron ore deposit has also been worked on by Agava, (2006), who reported that the iron ore contained on the average total iron content of 38.82% and mineralogical analysis revealed that the iron bearing minerals are predominantly magnetite and haematite.

KotonKarfe iron ore deposit also has been investigated by Thomas and Yaro (2007) and concluded that it has iron content of 43.34% with low amount of silica (10.14%) from their findings, they reported that the ore contained magnetite, siderite, goethite as the major constituents while haematite as the minor mineral.The work index of Kotonkarfe iron deposit was determined to be 11.33kwh/tonne and 17.00kwh/ton for both calcined and uncalcined samples.

Asuke (2014) has also worked on the dephosphorization of KotonKarfe iron ore by acidic leaching and concluded that the phosphorous content of KotonKarfe iron ore can be reduced by acidic leaching technique.

The techniques used by the aforementioned individual researchers were reviewed and the suitable ones were adopted for the purpose of this research work.

2.3. Types of Iron Ores

The most widely available iron-bearing minerals are oxides and consist mainly of hematite (Fe_2O_3), which is red; magnetite (Fe_3O_4), which is black; limonite or bog-iron ore ($2Fe_2O_3{\cdot}3H_2O$), which is brown; and siderite ($FeCO_3$), which is pale brown. Hematite and magnetite are by far the most common types of ore. Pure magnetite contains 72.4 % Fe, hematite 69.9% Fe, limonite 59.8% Fe and siderite 48.2% Fe but, since these minerals

never occur alone, the metal contents of real ores are lower. Deposits with less than 30 % Fe are commercially unattractive, although some ores contain as much as 66% Fe, there are many in the 50–60% range. The quality of iron ore is also influenced by the presence of other constituent which are collectively known as gangue. Silica (SiO_2) and phosphorus-bearing compounds (usually reported as P_2O_5) which caused cold embrittlement in steel and can notnot be removed during the iron making except in steel making process which make the production of steel more expensive. The quality of iron ore is mainly judged based on the Fe content. More specifically, ores with Fe contents above 65% are regarded as high-grade ores; 62–64% as medium- (or average) grade ores and those below 58% Fe are considered as low-grade ores (Thomas and Yaro, 2007). Table 2.1 is a collection of some of Nigerian iron ores deposits.

Table 2.1: 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 (Egenji Ate)	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	Rishi	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)

Table 2.2: Chemical Composition of Some Nigerian iron Ore Deposits

Deposit	K_2O	CaO	TiO_2	MnO	Fe_T	MgO	Al_2O_3	SiO_2	P_2O_5	S
Chokochoko	0.53	0.15	0.16	0.08	34.45	0.18	9.67	51.07	0.02	0.007
Agbado-Okudu	0.04	0.72	0.37	0.14	47.80	0.38	9.60	10.89	2.08	0.12
Ajagbaoko	0.26	0.21	Trace	0.01	37.22	0.15	3.39	46.50	0.01	0.03
Bassa-Nge	0.02	0.17	0.17	0.13	46.90	0.40	8.28	8.28	1.45	0.05

Source: RMRDC (2000)

Table 2.3: Standard Density for Ore Materials

Ores in powder and solid form	Kg/m^3
Alumina	3400
Gypsum, broken	1290-1600
Gypsum, crushed	1602
Gypsum, pulverized	1121
Halite (salt), solid	2323
Halite (salt), broken	1506
Hematite (iron ore)	5095 – 5205
Hemimorphite (zinc ore)	3395 – 3490
Ice, solid	919
Ice, crushed	593

Ilmenite	2307
Iridium	22154
Iron ore – crushed	2100-2900
Iron oxide pigment	400
Iron Pyrites	2400
Iron sulphate - pickling tank – dry	1200
Iron sulphate - pickling tank – wet	1290
Ivory	1842
Kaolin, green crushed	1025
Kaolin, pulverized	352
Lead, rolled	11389
Lead, red	3684
Manganese oxide	3700
Silica	2700
Titanium oxide	3770

Source: Wikipedia, 2015.

2.4. Mineral Processing Conceptual Parameters

Ores are usually subjected to some concentration processes in order to separate the various minerals in the ore into two or more products. This is done for the purpose of beneficiating the ore for its desired mineral or metallic value (Sirajo 2008). Beneficiation of minerals is a

physical, chemical and physico-chemical process of using the inherent properties of the minerals in order to maximize its quality (Olokesusi, 2010). Separation is achieved by utilizing some specific difference in physical or chemical properties between the valuable and the gangue minerals in the ore. After the geological survey has been carried out, the standard procedure usually followed in the development of the conceptual flow sheet for the beneficiation of a newly discovered ore deposit and are as follows (Thomas and Yaro, 2007).

a) **Determination of Chemical Composition of a Representative Sample of the ore**: This is to establish the chemical composition of the ore and also to confirm the result of the geological investigation and probably Mining Engineers who had already worked on the ore deposit. Chemical analysis is used to detect and estimate quantities of elements or compounds present in the ores. The present of the dominant element or compound determined the name of the mineral ore.

b) **Mineralogical Analysis: -**evaluation of the ore in order to reveal the major and minor compounds making up the ore under characterization process, grain size of each mineral in the ore, allocation of each element to each mineral present in the ore and the degree of association of valuable minerals to the gangue minerals.

Generally the study of these properties can be achieved by chemical, mineralogy, physical and crystallography analyses and studies. These involved uses of petrography microscope, XRD, XRF and SEM/EDS machines.

Petrography analysis is the study of rocks using a microscope. In this study, cross section is useful for the identification of rocks minerals of the ores, their characteristics, and properties such as cleavage, twining, reflectance and shape. The thin section is observed with a transmitted polarized Microscope (Beuler, 2009).

The petrography microscope is a type of microscope used in the study of thin section of minerals and rocks by examining the mineral fragment, grained crystal or aggregate and in the interpretation of texture, structure, growth pattern and various relationship of natural or artificial substance (Arogundade, 1999).

c) **Carrying out Size Analysis:** this is use to establish the distribution of both the valuable and gangue minerals in the various size fractions. Particle size analysis is of great importance in determining the quality of grinding and in establishing the degree of liberation of the valuable mineral from the gangue mineral at various particle size in the separation stage.

d) **Conducting of Liberation studies:** this is used to establish the liberation size of the individual mineral in the ore; here emphasis is placed on the grain size of the valuable minerals and probably the gangue which may likely affect the subsequent separation process. Liberation size of an ore is very significant component in any process design as it gives the operators a clear view of the sieve size. It avoid over grinding and hence save a cost.

e) **Determination of the Work Index:** this is used in calculating the energy requirement for the comminution process. Work index is the comminution parameter which expresses the resistance of the material to crushing and grinding; numerically it is the kilowatt hour per short ton required to reduce the material from theoretically infinite feed size to 80% passing 100μm (Will and Napier-Munn, 2006).

f) **Concentration test**: the method of concentration to be used in the beneficiation of the ore will depend on the information obtained in a-d above.

2.5. Comminution Process

Comminution is a process in which the 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. (Gupty, 2003).

2.5.1. Purposes of Comminution

The major purposes of comminution are:

1) Liberation of one or more economically 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.

2.5.2. Theory of Comminution

Comminution theory is concerned with the relationship between energy input and the particle size produced from a given feed size. The greatest problem is that the machine itself absorbs most of the energy input to a crushing or grinding machine, and only a small fraction of the total energy is available for breaking the material (Gupty, 2003).

The oldest theory is that of Von Rittinger, which states that the energy consumed in the size reduction is proportional to the area of new surface produced.

$$E = K\,(1/D2 - 1/D1) \quad \text{..... 2.1}$$

Where E is the energy input, D_1 is the initial particle size, D_2 is the final particle size, and K is a constant (Will, 2006). While Kick stated that the work required is proportional to the reduction in volume of the particles concerned. Where f is the diameter of the feed particles and p the diameter of the product particles, the reduction ratio R is f/p. According to Kick's law, the energy required for comminution is proportional to log R/log 2 (Will, 2006).

Bond (1952) developed an equation which is based on the theory that the work input is proportional to the new crack tip length produced in particle breakage, and equals the work represented by the product minus that represented by the feed. In particles of similar shape, the surface area of unit volume of material is inversely proportional to the diameter. The crack length in unit volume is considered to be proportional to one side of that area and therefore inversely proportional to the square root of the diameter.

For practical calculations the size in microns which 80% passes is selected as the criterion of particle size. The diameter in microns which 80% of the product passes is designated as

P, the size which 80% of the feed passes is designated as F, and the work input in kilowatt hours per short ton is W. Bond's third theory equation is

$$W = \left(\frac{10Wi}{\sqrt{P}} - \frac{10Wi}{\sqrt{F}}\right) \quad \text{.....2.2}$$

Where W_I is the work index; work index is the comminution parameter, which expresses the resistance of the material to crushing and grinding; numerically it is the kilowatt-hours per short ton required to reduce the material from theoretically infinite feed size to 80% passing 100 microns.

2.5.3. Grindability

Ore grindability refers to the ease with which materials can be comminuted, and data from grindability tests are used to evaluate crushing and grinding efficiency. Most widely used parameter to measure ore grindability is the Bond work index wi. Berry and Bruce known as modified bond energy equation (1966) developed a comparative method of determining the grindability of an ore. The method requires the use of a reference ore of known grindability. The reference ore is ground for certain time 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. If r is the reference ore and t the ore under test, then from Bond's Equation,

$$\left(\frac{10Wir}{\sqrt{Pr}} - \frac{10Wir}{\sqrt{Fr}}\right) = \left(\frac{10Wit}{\sqrt{Pt}} - \frac{10Wit}{\sqrt{Ft}}\right) \quad \text{.....2.3}$$

While Bond energy equation is the best-known grindability test for rod and ball mills

2.5.4. Determination of work index using Modified Bond's Method.

Bond developed an equation which is based on the theory that the work input into either a crushing or grinding mill is proportional to the new crack tip length produced during the particle breakage which also equals to the work represented by the product minus that represented by the feed. Bond equation is given by

$$W = \frac{10Wi}{\sqrt{P}} - \frac{10Wi}{\sqrt{F}} \quad \text{.....2.4}$$

Where WI = work index of the material being broken

P = the diameter in micrometer which is 80% of the product passes

F = the diameter in micron meter which is 80% of the feed passes

W = work input in kilowatt hour per short ton.

A reference ore of known grindability is used.

The reference sample is ground and power consumed during the grinding is measured. An identical weight of the ore whose grindability is to be determined is ground for a length of time such that the power consumed is the same as that consumed in grinding the reference sample. If r stands for reference ore and t stands for ore whose grindability is to be determined called the test ore.

Power consumed in grinding reference sample

$$W_r = w_{ir}\left(\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}\right) \quad \text{.....2.5}$$

Power consumed in grinding the test sample

$$W_t = w_{it}\left(\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Fr}}\right) \quad \text{.....2.6}$$

Equating (2) and (3) since energy consumed is the same

$W_r = w_t = W_{ir}\left(\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}\right) = wit\left(\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}\right)$ ……2.7

Where,

W_r = energy input in grinding the reference ore

W_t= energy input in grinding the ore under test

W_{ir} = work index of the reference ore

W_{it} = work index of the ore under test

F_r = 80% passing feed of the reference ore

F_t = 80% passing feed of the ore under test

P_r= 80% passing product of the reference ore

P_t = 80% passing product of the ore under test

Therefore, the work index of unknown ore is

$$W_{it} = Wir\frac{\left[\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}\right]}{\left[\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}\right]} \quad \text{.....2.8}$$

This method is relatively simple and is called comparative method of determining the grindability parameter i.e. work index (Wills, 2006).

Table 2.4: Selected Bond Work Index

Solid ores	Work index (kWh/ton)
Andesite	18.25
Granite	15.13
Silica sand	14.10
Taconite	14.61
Hematite	12.84
Graphite	43.56
Gypsum rock	6.73
Glass	12.31
Gravel	16.06
Magnetite	9.97
Quartz	13.57
Titanium ore	12.33
Zinc ore	11.56
Magnesite	11.13
Manganese ore	12.20
Bauxite	8.78
Pyrrhotite	9.57
Ferro manganese	8.30
Silicon carbide	25.87
Lead ore	11.90

Source: Weiss, (1985).

2.6. Analytical Methods Used in Metallurgical Analyses

Metallurgical analysis involves the qualitative as well as the quantitative analyses of various metallurgical raw materials like ores and products like metals, alloys and slag (Yaro, 1997). Analytical methods employed in metallurgical analysis can be classified into classical and instrumental methods.

The classical method is slow and is for practical purpose, the instrumental methods are faster and accurate (Gilchrist, 1989).

In the instrumental methods of analyses, measurement is made upon the system as a whole. A particular physical and chemical property of the system is measured in order to get the desired analytical results. Comparison of the results of the samples to be analysed with standard samples of known composition is necessary in this method (Yaro, 1997).

The common instrumental analytical techniques used are Atomic Absorption Spectrophotometer (AAS), X-ray Fluorescence (XRF), X-ray Diffractometer (XRD), Scanning Electron Microscopy (SEM) etc.

2.6.1. 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 analysed by XRF (Huang, 1992). The x-rays have a precisely defined energy and the wavelength (velocity of electron) which are related by the plank's energy equation:

$E_1 - E_2 = hc$

Where, E_1 = former energy level of the electron before filling the vacancy

E_2 = new energy level of the electron after filling the vacancy

h = plank's constant, c = velocity of light

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 non destructive, rapid, precise and potentially very accurate.

2.6.2. Scanning Electron Microscopy (SEM)

SEM is often the first analytical instrument used when a "quick look" at a material characteristic is required and the light microscope no longer provides adequate resolution. The method is used to study the properties of material at microscopic level. The most important applications are the investigation of the micro-structure and analysis of in-homogeneity such as defects, dislocations, submicroscopic precipitates, inclusions, domains, etc. it is used for determining the composition of individual grains of particles and surface properties like topography.

In SEM, a small area of the specimen of a material is irradiated with direct electron beam and characteristic x-ray are produced which are used for the qualitative analysis. As the beam interacts with the sample it creates various signals (secondary electrons, internal currents, photon emission, etc), all of which can be appropriately detected (Bindell, 1992). The most important of the produced electrons (x-rays), called backscattered or primary reflected electrons are detected and amplified. The output from this is a function of the composition of the area irradiated by electron beam (Thomas and Yaro, 2007). The

intensity of the backscattered electron signal is dependent on the atomic number of the specimen and specimen surface of different chemical composition will produce different signal intensities and appear different on the SEM screen. The signal intensities are used for quantitative analysis.

2.6.3. X-ray Diffraction (XRD)

XRD analysis is a non-destructive method of analysis. It is used for both qualitative and quantitative analysis of materials. This method can be used to determine the actual compounds present in a material and can also distinguish the different crystal forms of the compounds. XRD can also be used to measure the structural properties (strain state, grain size, epitaxial, phase composition, preferred orientation and defect structure) of these phases and to determine the thickness of thin films and multilayer's, and atomic arrangement in amorphous materials including polymers and at interfaces (Toney, 1992).

XRD is based on the diffraction of x-rays by polycrystalline solids and the reflections are called powder diffractometry. X-rays are deflected by crystals when the condition satisfying the Bragg's equation is fulfilled. The Bragg's equation is given as Bragg's law ($2d\sin\theta = n\lambda$, where d is the spacing between atomic planes in the crystalline phase and n is an integer called order of reflection). The intensity of the diffracted x-rays is measured as a function of the diffraction angle 2θ and the specimen's orientation (Brundle, 1992).

These characteristic x-rays which are deflected by the crystal are detected by a detector and registered and displayed on paper chart recorder as series of peaks (x-rays patterns). Each has a unique x-ray powder pattern (fingerprints) because the line position depends on the unit cell size and the type of atoms present and their intensities of powder lines are used for qualitative phase analysis, while quantitative phase analysis depends on the accurate

determination of the line intensity (Markowiez, 2002, in Thomas and Yaro, 2007). XRD offers unparalleled strain states in thin films. XRD is non-contact and nondestructive, which makes it ideal for in situ studies. The limitation of XRD is that, compounds to be measured must be in a crystalline form to give rise to measurable signals.

2.7. Concentration Processes

There are a number of ways of increasing the concentration of the valuable minerals: in any particular case the method chosen will depend on the relative physical and surface chemical properties of the mineral and the gangue. Concentration means the increase of the percentage of the valuable mineral in the concentrate in relation to the feed.

2.7.1. Gravity Concentration Technique

Gravity concentration is the process for the separation of minerals of different specific gravity by inducing variable movement in response to gravitational force and one or more natural or applied force with the aid of a flowing film. It is used, sometime along with other processes in particle flotation, magnetic separation and chemical treatment (Gupty, 2003).

Gravity separation process is effective, practical and efficient in the treatment of many ores. But their applicability to the treatment of any specific ore or in combination with other processes must be determined through the mineralogical composition and characteristic of representative samples of the ore and from careful and comprehensive testing (Yaro, 1997).

The major demerit of gravity separation process is the recovery of fines and it is inherent in the process itself, even with advance slime gravity concentrators, the practical lower limit of particle size which can be handle is still about 100μm (Yaro, 1997).

2.7.2. Froth FlotationTechnique

Froth flotation is an important concentration process. This process can be used to separate any two different particles and operated by the surface chemistry of the particles. In flotation, bubbles are introduced into a pulp and the bubbles rise through the pulp. In the process, hydrophobic particles become bound to the surface of the bubbles. The driving force for this attachment is the change in the surface free energy when the attachment occurs. These bubbles rise through the slurry and are collected from the surface. To enable these particles to attach, careful consideration of the chemistry of the pulp needs to be made. These considerations include the pH and the presence of flotation reagents. This process involves treatment with suitable reagent of an ore pulp to create conditions favorable for the attachment of certain hydrophobic or aerophilic mineral particle to air bubbles and render the other solids hydrophilic or water loving, submerged in the solution (Thomas and Yaro, 2007).

2.7.3. Magnetic Concentration Technique

The principle of magnetic separation involves the action of several external forces with a dominant magnetic force. The separation of mineral from another depend upon their motion in response to the dominant force and other competing forces namely gravitational frictional, inertia and centrifugal. In the case of separation involving ferromagnetic minerals in the magnetic field of a separator, the magnetic force acting on the particle must be greater than sum of all other competing forces. As a result of which the mineral will be attracted to the magnet. For non-magnetic minerals the magnetic force will be smaller than

the sum of all the competing forces and the minerals will then be repelled away from the magnetic field (Dwight, 1976 in Agava, 2006).

2.7.4. Electrostatic Concentration Technique

There are two main types of electrostatic separators. They work in similar ways, but the forces applied to the particles are different and these forces are gravity and electrostatic attraction. The two types are electrodynamics separators (or high tension rollers) or electrostatic separators. In high tension rollers, particles are charged by a corona discharge. This charges the particles that subsequently travel on a drum. The conducting particles lose their charge to the drum and are removed from the drum with centripetal acceleration. Electrostatic plate separators work by passing a stream of particles past a charged anode. The conductors lose electrons to the plate and are pulled away from the other particles due to the induced attraction to the anode. These separators are used for particles between 75 and 250 microns and for efficient separation to occur, the particles need to be dry, have a close size distribution and uniform in shape. Of these considerations, one of the most important is the water content of the particles. This is important as a layer of moisture on the particles will render the non-conductors as conductors as the layer of the water is conductive. Electrostatic plate separators are usually used for streams that have small conductors and coarse non-conductors. The high tension rollers are usually used for streams that have coarse conductors and fine non-conductors (Wikipedia, 2014).

CHAPTER THREE

This chapter explained the methodology of the tests conducted during the course of this research work.

3.0. MATERIALS AND METHODS

3.1. Materials and Equipment

(i)Iron ore sample (ii) Reference ore sample (granite) (iii) Sledge hammer (iv) Jaw crusher (v) Cone crusher (vi) Ball mill (vii) Set of sieves (viii) Laboratory sieve shaking machine (ix) Weighing machine (x) X-ray florescence (XRF) Machine (xi) X-ray diffractometer (XRD) Machine (xii) Petrological microscope (xiii) Scanning electron microscope (SEM)/ Energy Dispersive Spectrum(EDS)

3.2. 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.

3.3. Methodology

3.3.1. Sample Collection

Samples of the iron ore were collected from various points of deposit site located at Gujeni village, in Kagarko Local Government Area of Kaduna State. 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. The reference ore sample (granite) was sourced from Kujama area of Kaduna State. Table 3.1 shows the GPS coordinates of where the iron ore samples were sourced.

Table 3.1: Coordinates of the Area of the Deposit

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

3.3.2. 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.

3.3.3. 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.

3.3.4. Chemical Composition Analysis

After communication processes and proper sampling, a composite sample was taken and analysed using X ray Florescence machine to determine the elemental composition of the ore. The results of the analyses are presented in Tables 4.1 and 4.2.

(a) Procedure for Determination of percentage Elemental Composition of Rock Sample Using XRF(X-ray Fluorescence) ThermoscientificAdvant'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

3.3.5. Determination of the Physical Properties of Iron Ore

Specific gravity, density and electrical conductivity of the iron ore were determined as follows;

(a) Determination of Specific Gravity of the Iron Ore

The specific gravity was carried out in Applied Science Department, Kaduna Polytechnic. Relative density bottle and chemical balance method was used in carrying out the specific gravity of the iron ore.

The specific gravity bottle was weighed and recorded as $W_{0,}$ then partly filled with iron ore sample and recorded as W_1 and water added to the sample to fill the bottle and recorded as W_2. W_3 is the weight of the water in the bottle.

Weight of water filling space above sample = $W_2 - W_1$, and weight of water completely filling bottle

$= W_3 - W_0$

Therefore, weight of water equal in volume to sample = $(W_3 - W_0) - (W_2 - W_1)$

Specific gravity = $\frac{weigth\ of\ sample}{weigth\ of\ equal\ volume\ of\ water}$ 3.1

(b) Determination of Density of the Iron Ore:

Specific gravity is the same thing with relative density

Relative density = $\frac{\text{density of substance}}{\text{density of water}}$ 3.2

Density of substance = relative density x density of water

(c) Determination of Electrical Conductivity of the Iron Ore

The electrical conductivity was carried out in Physic Department, A. B. U. Zaria.

The iron ore sample was crushed and pelletized into circular shape that could be measured. Inductance Capacitance and Resistance meter(ICR) was used to measure the resistance of the pelletized sample which was used to calculate the resistivity and then the conductivity. The diameter and the thickness of the sample were taken. Resistance of a material is directly proportional to the length and inversely proportional to the area of that sample. The result is presented in Table 4.2a.

Mathematically: R L/A= R = L/A = RA =L, RA/L..... 3.3

3.3.6. Mineralogical and Petrological Analyses

Mineralogical analysis was carried out using X-ray diffraction and Scanning Electron Microscope/EDS. Polished section was prepared for each sample from pit 1, pit 2, pit 3, and pit 4 for petrological analysis. The samples were viewed under reflected microscope for identification of mineral phases present and determination of grain size of the various minerals.

(a) Procedure for the Preparation of Polished Section

The petrological analysis was carried out in the Department of Geological Science, A. B. U. , Zaria.

The iron ore sample was cut to size using cutting machine. The sample was ground and polished using grinding and polishing machine until mirror like surface was obtained. Silicon carbide and polishing paste were used for the grinding and polishing. The polished

samples were used for petrological analysis. The photomicrography obtained for the polished samples viewed under microscope are shown in plate Ia to Id2.

(b) Procedure for the Determination of Mineralogical Composition of Rock Sample Using XRD(X-ray Diffractometer) Schimadzu 6000 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 sample was smeared evenly on the sample made of aluminium material. The setting of machine was done between angle of 2^{o} to 60^{o}degree theta as the sample scanning range. The running rate (scanning speed) was set at 6 degree per minutes. The holder is carefully placed on the loading point of the movable **GONIMETER** arm that contain a clamp capable of gripping the sample firmly. The window indicating readiness after properly closed. The pronounced PEAKS OR DIFFRACTOGRAMMS displayed, express the minerals composition at the various angle of the degree theta.

(c) procedure for the determination of morphology of grain size of the iron ore sample using (SEM/EDS) Aspex 3020 Model

The analysis was carried out in the Department of Materials Science at Kwara State University, Ilorin. using the field emission Scanning Electron Microscopy equipped with Energy Dispersive Spectrometer. In SEM, a small amount of powder sample was taken and placed on the sample holder which was then placed inside the machine and waited for the machine to be ready. A vacuum was built in the sample chamber, the sample was irradiated to generate emission from which micrography of the sample was produced. During the process the EDS was also carried out to establish the spectra of the major elements.

3.3.7. Particle Size / Mineral Assay Analyses of the Iron Ore

Particle size and mineral assay analyses were carried out to establish the distribution and determination of minerals phases present in the various sieve size fractions. 600g of the pulverized sample was placed on the set of sieves arranged on the basis of √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. The result of the test is presented in Table 4.10

3.3.8. Liberation Size Analysis

Liberation study was conducted to determine the liberation size of the valuable mineral. The minerals in each sieve size fractions was analysed, the sieve size fractions that contains the highest percentage assay of Fe content was acknowledged as the liberation size of the iron ore . The result of the test is presented in Table 4.18.

3.3.9. Determination of Work Index for the Composite Sample

Work Index expresses the resistance of a material to crushing and grinding. Modified Bond's method that involves the uses of reference and test ores was used to determine the work index.

The sample under test and the reference samples were crushed and pulverized.

The same quantity of test and reference ores was measured and sieved into a number of sieve size fractions using automatic sieve shaking machine for 30minutes. The selection of sieves was based on scale of root two and arranged from the coarsest on top and the finest sieve at the bottom. The sample was placed at the topmost sieve and a pan was placed at the bottom. The sieve size fraction ranges from +425µm,-425+355µm, -355+250µm, -250+180µm, -180+125µm, -125+90µm, -90+50µm and-50µm (pan) were used.

Each sieve fractions for both reference and test samples were weighed and the values obtained were recorded as "feed". The "feed" of the test and reference samples were introduced into the ball mill and ground for 1 hour. The discharge of test and reference samples from the ball mill was sieved into different sieve size fractions, they were weighed and the values were recorded as the "product". 80% passing was calculated and the work index was determined. The results of the test are presented in Tables 4.19 to 4.22.

Modified Bond energy relationship (Berry and Bruce) shown as equation 3.4 was used to calculate the work index of the iron ore.

$$W_{it}=Wir\frac{\left[\frac{10}{\sqrt{Pr}}-\frac{10}{\sqrt{Fr}}\right]}{\left[\frac{10}{\sqrt{Pt}}-\frac{10}{\sqrt{Ft}}\right]} \quad \text{.....3.4}$$

Where,

W_{it} = work index of the ore under test

Wir = work index of the reference ore

F_r = 80% passing feed of the reference ore

F_t = 80% passing feed of the ore under test

P_r= 80% passing product of the reference ore

P_t = 80% passing product of the ore under test

CHAPTER FOUR

4.0 RESULTS AND DISCUSSIONS

4.1 Chemical Analysis Result of Gujeni Iron Ore Sample

The chemical analysis results of Gujeni iron ore composite sample and the various samples from different pits are presented in table 4.1 and 4.2 below

Table 4.1: 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

Table 4.2: Chemical Analysis Result of the 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

From Table 4.1, it is observed that the composite sample composition is comparable with other chemical compositions of the major iron ore deposits in the country cited in Table 2.2 (RMRDC, 2000).

Table 4.2 presents the results of the iron ore samples from different Pits

From the results of the analysis, pit 1 contains the highest iron content when compared 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).

4.2. Results of Physical Properties of the Composite Sample

Physical properties such as specific gravity, density and electrical conductivity of iron ore were determined as follows:

4.2.1 Specific Gravity of the Composite Sample

Specific gravity = weight of sample/ weight of equal volume of water

Weight of empty bottle = W_0 = 29.9g

Weight of bottle with sand = W_1 = 93.4g

Weight of bottle with sand and water = W_2 = 128.2g

Weight of bottle filled with water = W_3 = 79.9g

Weight of sample = $W_1 - W_0$

Weight of equal volume of water = $(W_3 - W_0) - (W_2 - W_1)$

Specific gravity = $\frac{W1 - W0}{(W3 - W0) - (W2 - W1)}$ $= \frac{93.4 - 29.9}{(79.9 - 29.9) - (128.2 - 93.4)}$ $= \frac{63.5}{50 - 34.8} = \frac{63.5}{15.2} =$

4.2

4.2.2 Density of the Composite Sample

Specific gravity is the same thing with relative density

Relative density = $\frac{\text{density of substance}}{density\ of\ water}$

Density of substance = relative density x density of water =4.2 x $1x10^3 kg/m^3$

Density = 4.2 x 10^3kg/m^3

4.2.3 Electrical Conductivity of the Composite Sample

Diameter of the sample = d = 40mm= 0.04m

r =d/2 =0.04/2= 0.02, Area= $A = \pi r^2$, 3.142 $(0.02)^2$= 3.142 x 0.0004= A =0.001257m^2

Thickness of the sample = 3.5mm = 0.0035m

R =33.9 ×10^6

Resistance of a sample is directly proportional to the thickness of the sample and inversely proportional to the area

R L/A, R = L/A, RA =L

ρ = RA/L= $\frac{33.9 \times 106 \times 0.001257}{0.0035}$ = 121.7m

Conductivity, τ = 1/ resistivity

τ= 1/ρ, $\tau = \frac{1}{121.7}$

τ = 8.216 x $10^{-3}\Omega^{-1}$ m^{-1}

τ = conductivity, ρ =resistivity, R = resistance, A = area, L = length or thickness of the sample

r = radius, d = diameter

Table 4.2a: Summary of the Results of Physical properties of the Composite Sample

Property	Value
Specific gravity	4.2
Electric conductivity	8.216 10^{-3} $\Omega^{-1}m^{-1}$
Density	4.2 x 10^3kg/m^3

Table 4.2a presents the summary of the results of physical properties of the composite sample. From the results the specific gravity of the ore was found to be 4.2 and the density to be 4.2 x 10^3kg/m^3, the value is below the acceptable standard for haematite when compared with 5.2 x10^3kg/m^3 in table 2.3 for haematite. The difference in the results is due to the fact that, the other impurities associated with the iron bearing minerals are having low specific gravity and density as presented in table 2.3. The electrical conductivity of the ore was found to be 8.216 x $10^{-3}\Omega^{-1}m^{-1}$.

4.3 Mineralogical Analysis Results of Iron Ore Sample

4.3.1 XRD Analysis Results

Table 4.3: XRD Analysis Result for the Composite Sample

Card no	Mineral name	Chemical name	Chemical formula
21-1276	Rutile	Titanium oxide	TiO_2
33-0664	Hematite	Iron oxide	Fe_2O_3
21-1272	Anatase	Titanium oxide	TiO_2
4-0831	Zincite	Zinc oxide	ZnO
44-0992		Manganese oxide	MnO_2
37-0031		Zirconium oxide	ZrO_2
10-0492		Potassium Magnesium Aluminum Silicate hydrate	$KMg_3(Al\ SiO_3)(OH)_2$

Table 4.4: XRD Analysis Result for Sample from Pit 1

Card no	Mineral name	Chemical name	Chemical formula
36-1451	Zincite	Zinc oxide	ZnO
34-1084		Zirconium oxide	ZrO_2
21-1276	Rutile	Titanium	TiO_2
33-0664	Hematite	Iron oxide	Fe_2O_3
44-0141		Manganese oxide	MnO_2
13-0092	Goethite	Iron oxide hydrate	$Fe_2O_3.\ H_2O$
10-0492		Potassium Magnesium Aluminum Silicate	$KMg_3(Al\ SiO_3)(OH)_2$

Table 4.5: XRD Analysis Result for Sample from Pit 2

Card no	Mineral name	Chemical name	Chemical formula
10-0492		Potassium Magnesium Aluminum Silicate Hydrate	$KMg_3(Al\ SiO_3)(OH)_2$
37-0031		Zirconium oxide	ZrO_2
44-1472	Rhodochrosite	Manganese Carbonate	$MnCO_3$
33-0664	Hematite	Iron oxide	Fe_2O_3
21-1272	Anatase	Titanium oxide	TiO_2
44-0141	Manganesite	Manganese oxide	MnO_2

Table 4.6: XRD Analysis Result for Sample from Pit 3

Card no	Mineral name	Chemical name	Chemical formula
36-1451	Zincite ,	Zinc oxide	ZnO
36-0383	Magnesite	Iron Magnesium Carbonate	(Mg, Fe) CO_3
44-1472	Rhodochrosite	Manganese Carbonate	$MnCO_3$
13-0092	Goethite	Iron oxide hydrate	$Fe_2O_3 .H_2O$
21-1272	Anatase ,	Titanium oxide	TiO_2
44-0141	Manganesite	Manganese oxide	MnO_2

Table 4.7: XRD Analysis Result of Sample from Pit 4

Card no	Mineral name	Chemical name	Chemical formula
21-1276	Rutile	Titanium oxide	TiO_2
44-0141	Mangnesite	Manganese oxide	MnO_2
34-1084		Zirconium oxide	ZrO_2
13-0092	Goethite	Iron oxide hydrate	$Fe_2O_3. H_2O$
36-0383	Magnesite	Iron Magnesium Carbonate	$(Mg,Fe) CO_3$
33-0664	Hematite	Iron oxide	Fe_2O_3
36-1451	Zincite	Zinc oxide	ZnO
44-1472	Rhodochrosite	Manganese Carbonate	$MnCO_3$

4.3.2: Results of the SEM/EDS Analysis of the Composite Sample and Sample from Pit 1

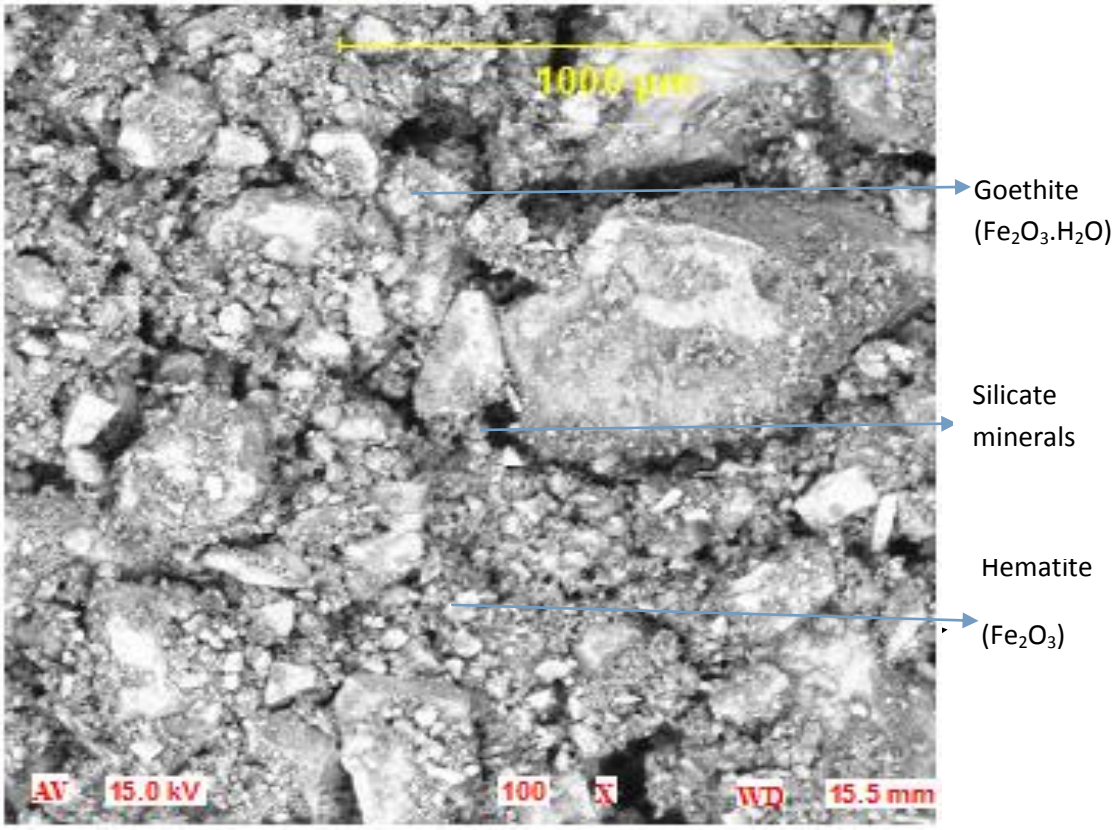


Plate I : Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 1000 Microns and 100 Magnification

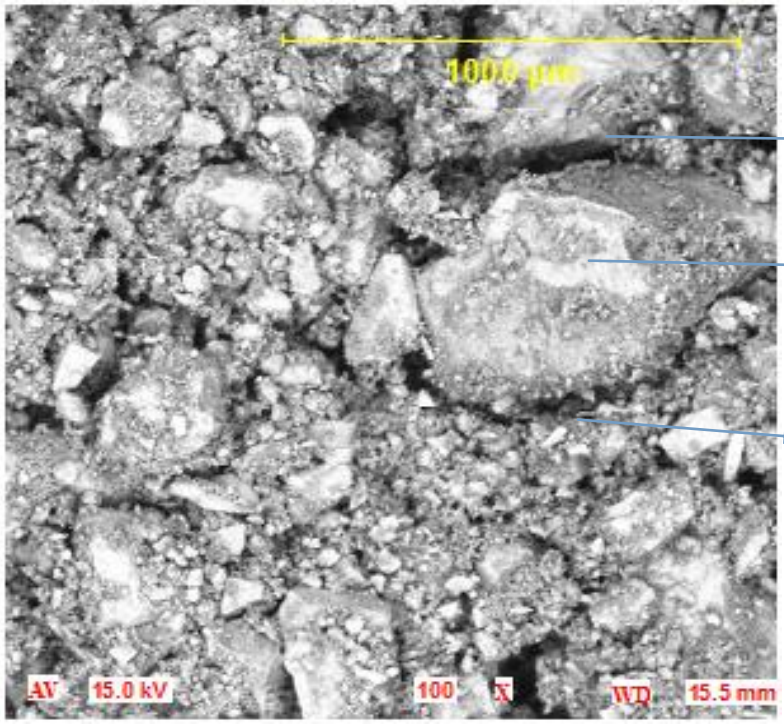


Plate II: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 1000 Microns and 100 Magnification

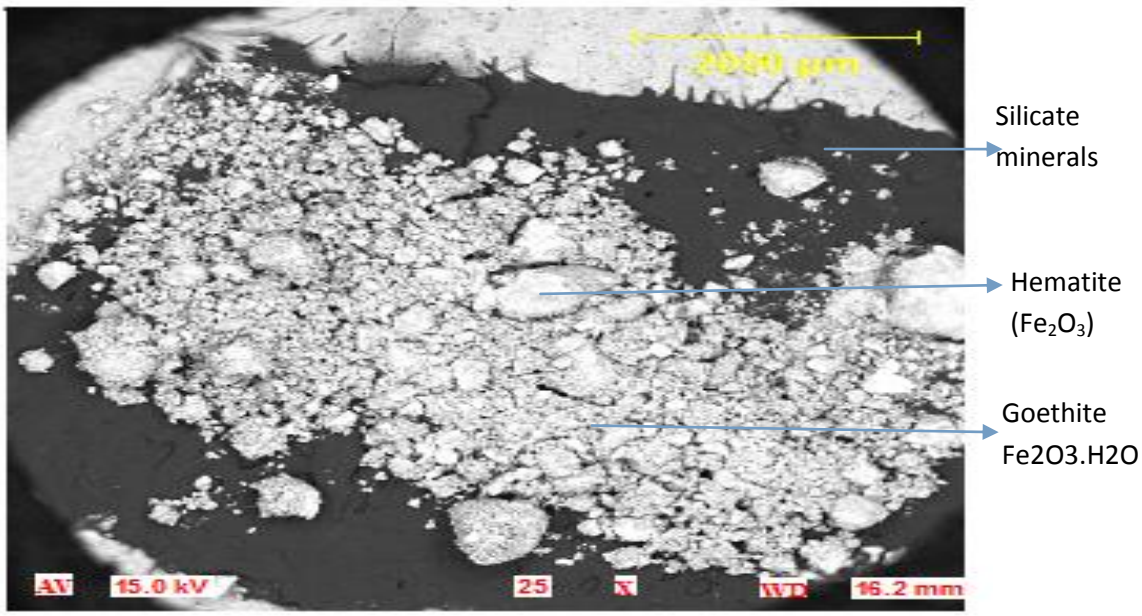


Plate III Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 2000 Microns and 25 magnification

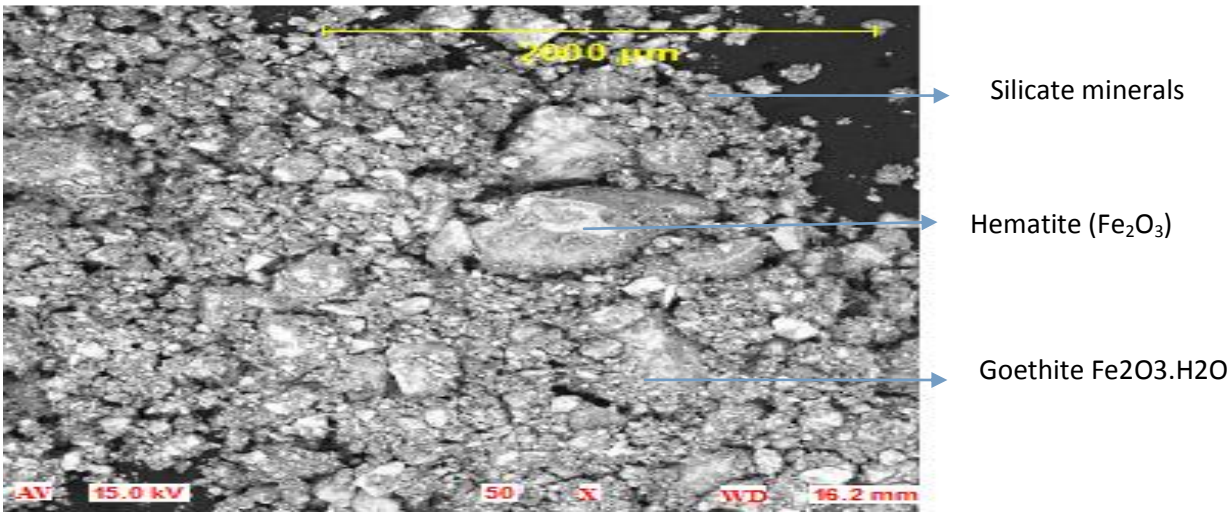


Plate IV: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 2000 Microns and 50 Magnification.

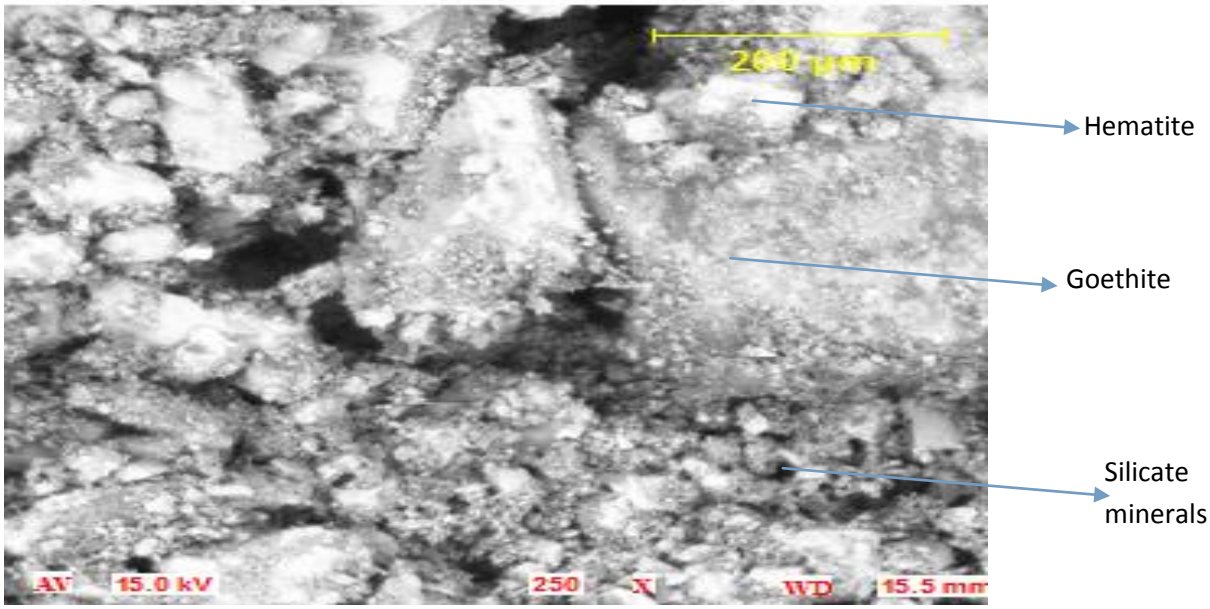


Plate V: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 200 Microns and 250 Magnification

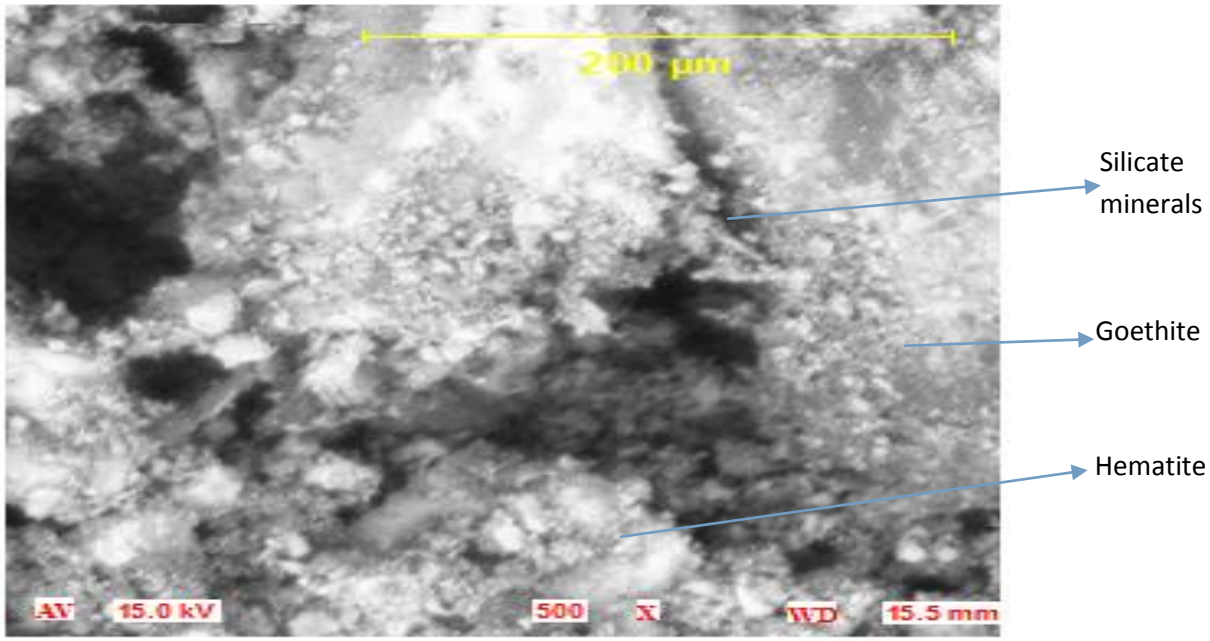


Plate VI: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 200 Microns and 500 Magnification

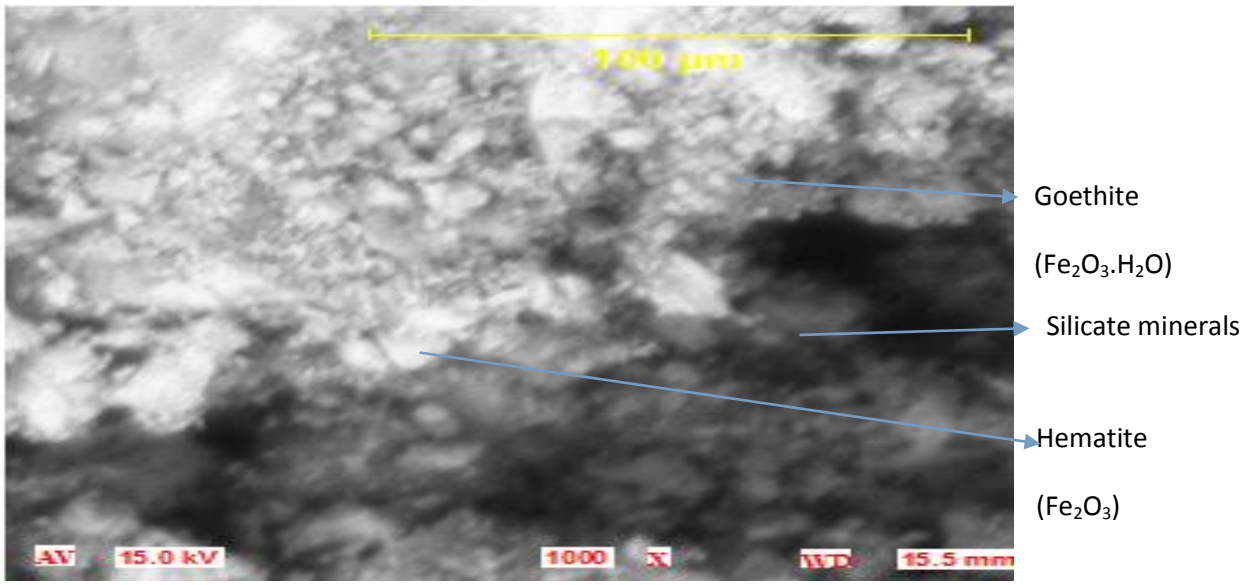


Plate VII: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 100 Microns and 1000 Magnification

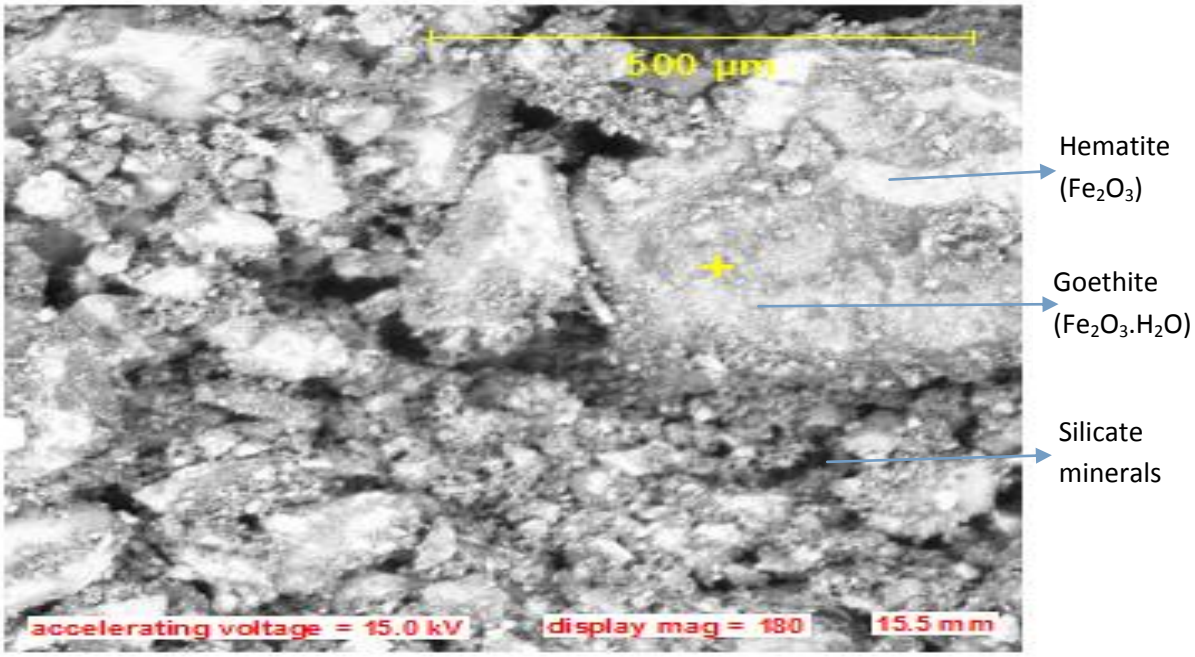


Plate VIII: Photomicrograph of SEM Analysis Result of Sample from Pit 1 at 500 Microns and 180 Magnification

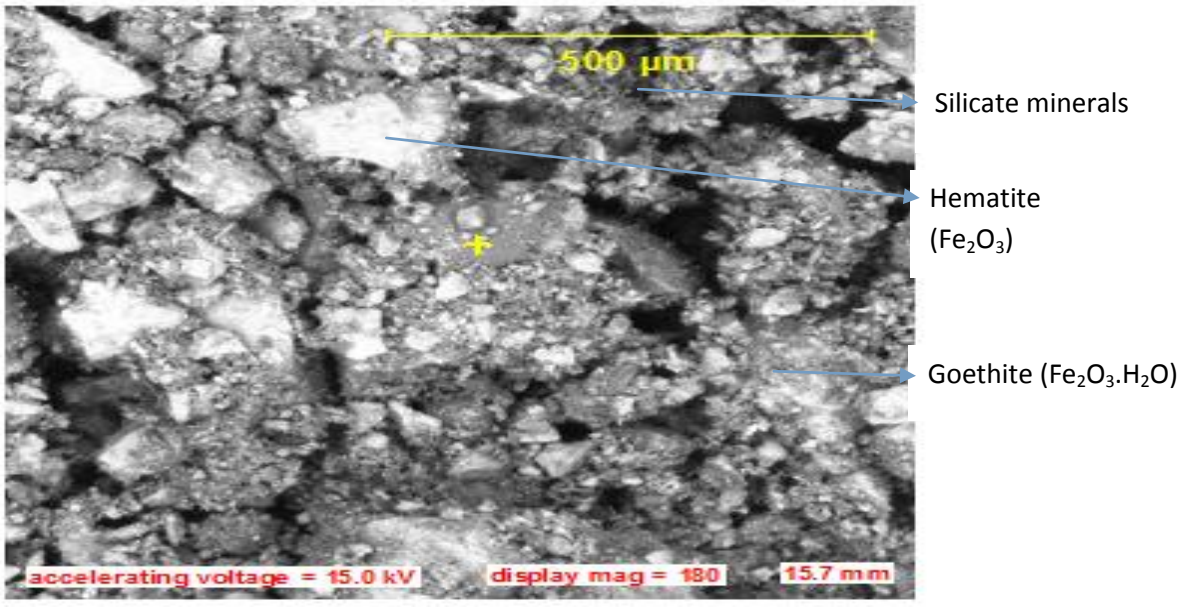


Plate IX: Photomicrograph of SEM Analysis Result of Composite Sampleat 500 Microns and 180 Magnification

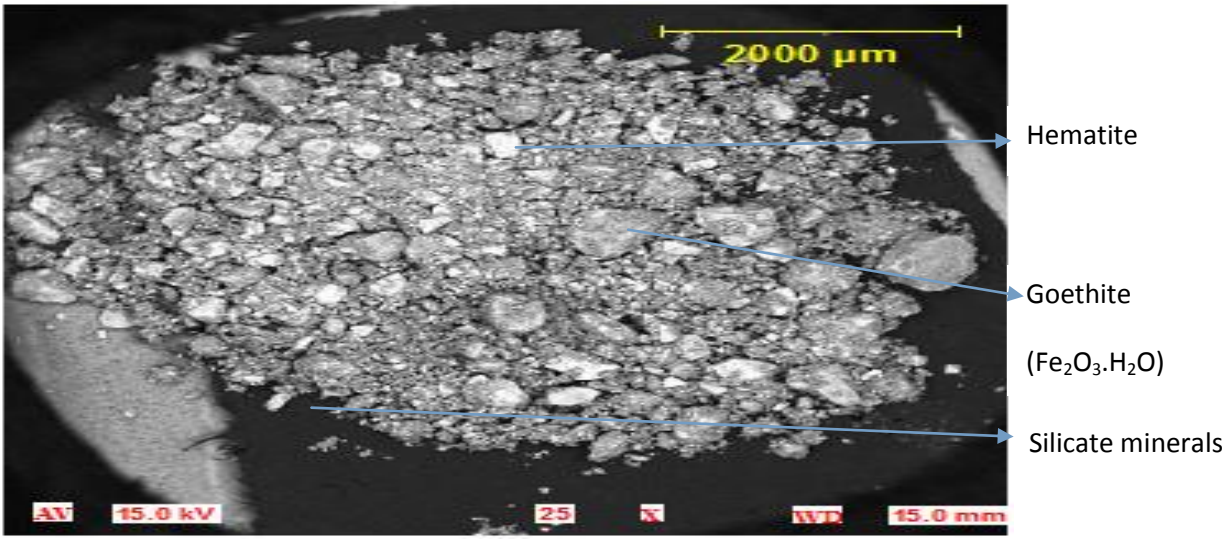


Plate X: Photomicrograph of SEM Analysis Result of Composite Sample at 2000 Microns and 25 Magnification

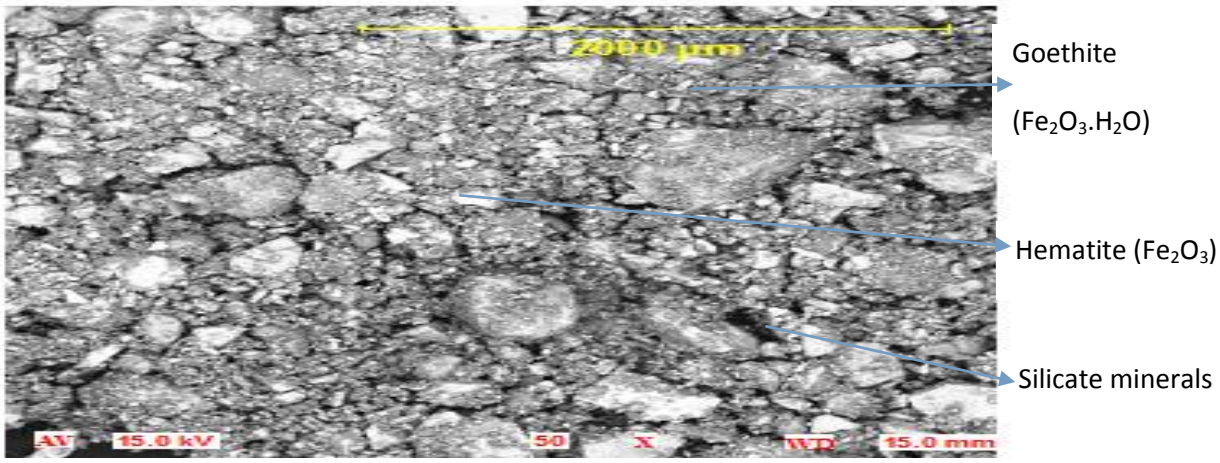


Plate XI: Photomicrograph of SEM Analysis Result of Composite Sample at 2000 Microns and 50 Magnification

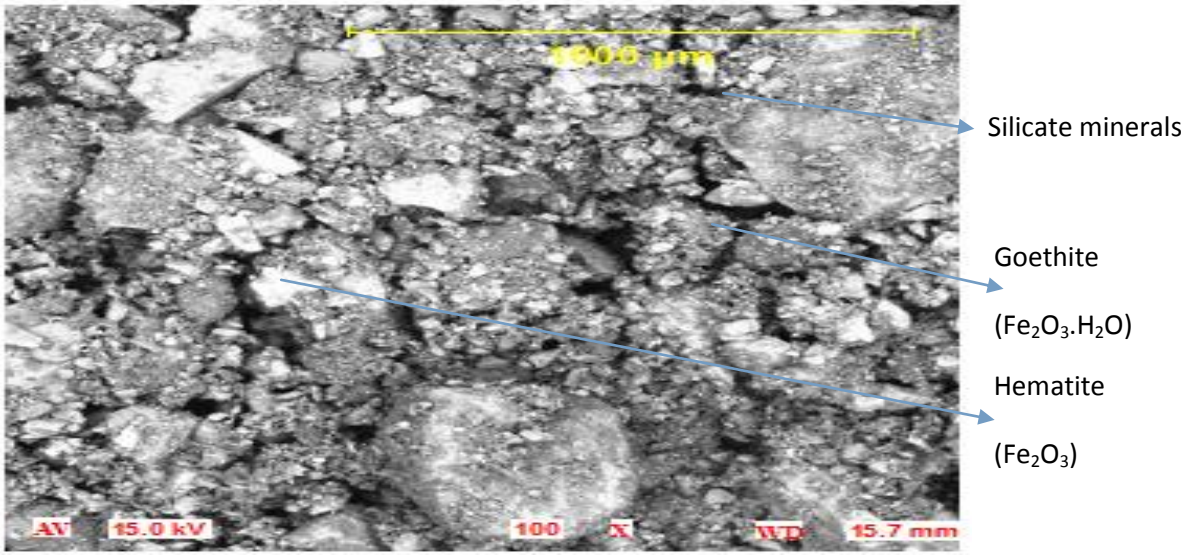


Plate XII: Photomicrograph of SEM Analysis Result of Composite Sample at 1000 Microns and 100 Magnification.

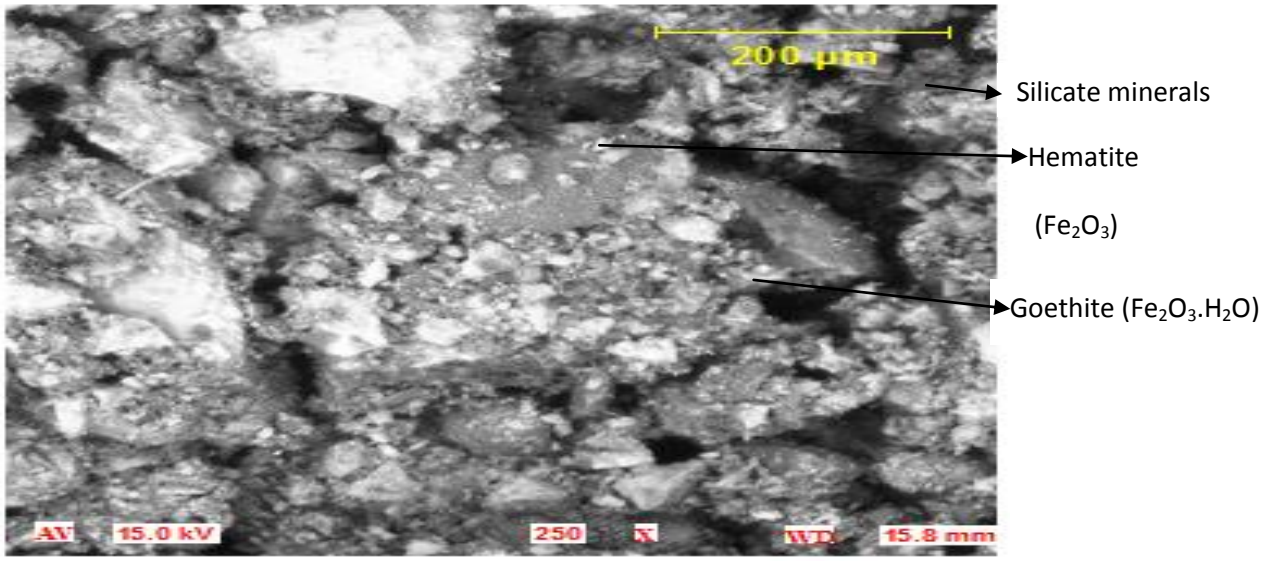


Plate1 XIII: Photomicrograph of SEM Analysis Result of Composite Sample at 200 Microns and 250 Magnification

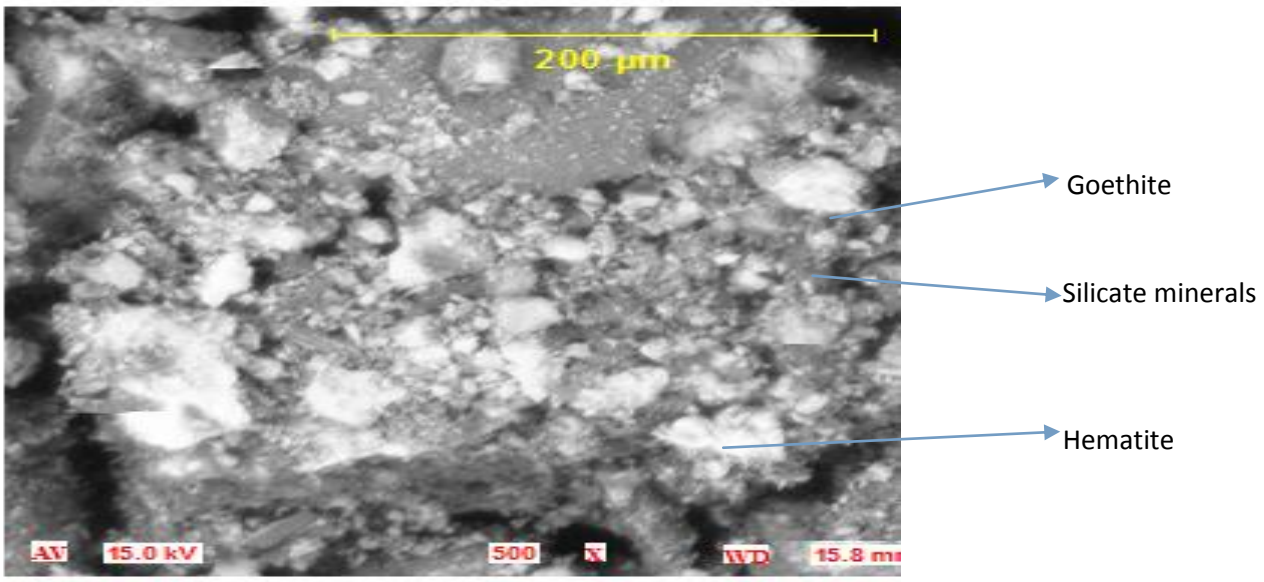


Plate XIV:Photomicrograph of SEM Analysis Result of Composite Sample at 200 Microns and 500 Magnification

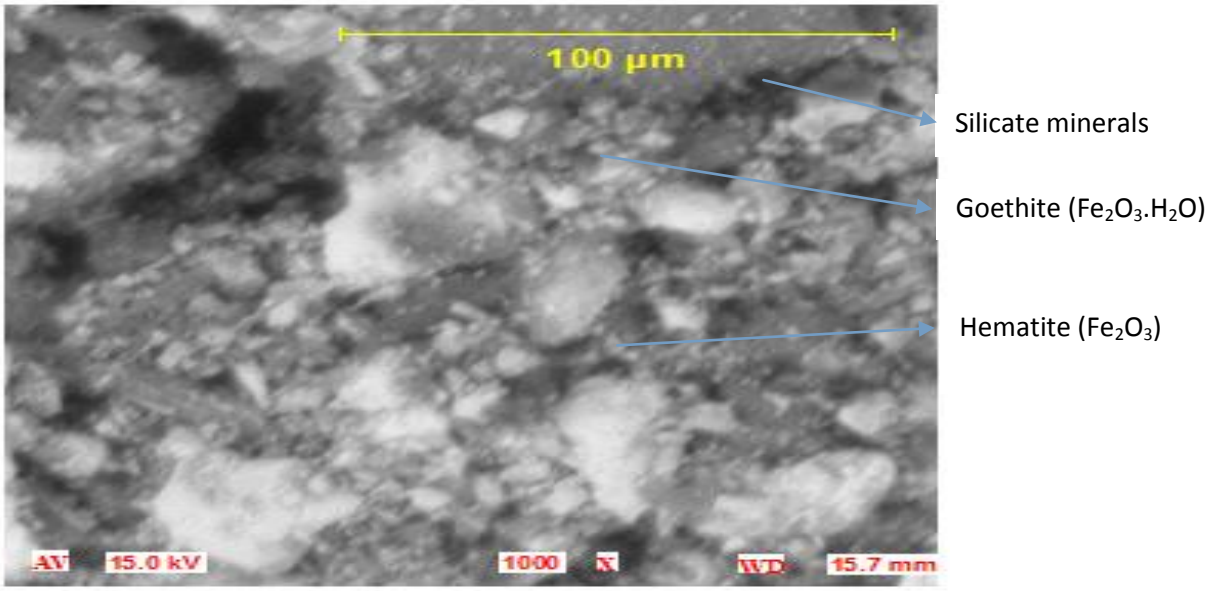


Plate XV:Photomicrograph of SEM Analysis Result of Composite Sample at 100 Microns and 1000 Magnification

Plates I to XV are the SEM micrographs of Gujeni iron sample showing grain size of the minerals contained in the ore at different magnifications.

White – Hematite (Fe_2O_3)

Grey – Goethite ($Fe_2O_3.H_2O$)

Black – Silica (SiO_2)

Table 4.8: EDS Result of Sample from Pit 1

Element	Percentage
Fe	52.8
Si	3.1
Ti	12.1
Al	1.7
Br	12.6
Ba	12.3
La	1.4
W	2.9
U	1.1

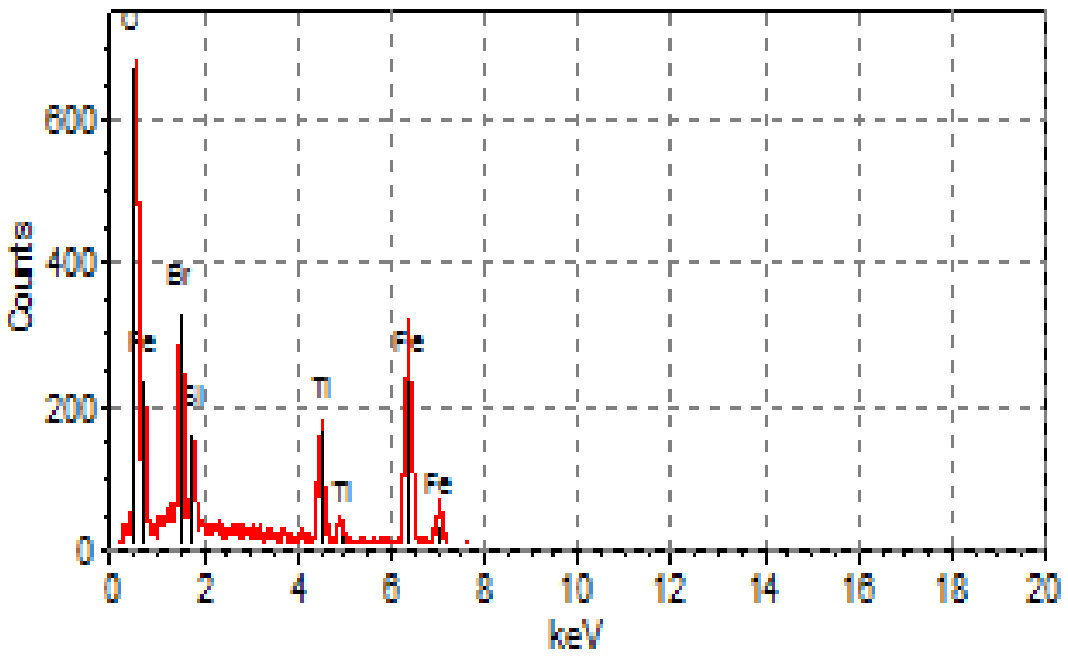


Figure4.1: EDS Analysis Result Showing the Spectra of Major Elements for Sample from Pit 1

Table 4.9: EDS Result of the Composite sample

Element	Percentage
Al	3.8
Si	6.2
Ti	4.9
Fe	62.3
Br	17.2
Sr	1.6
Ba	3.9

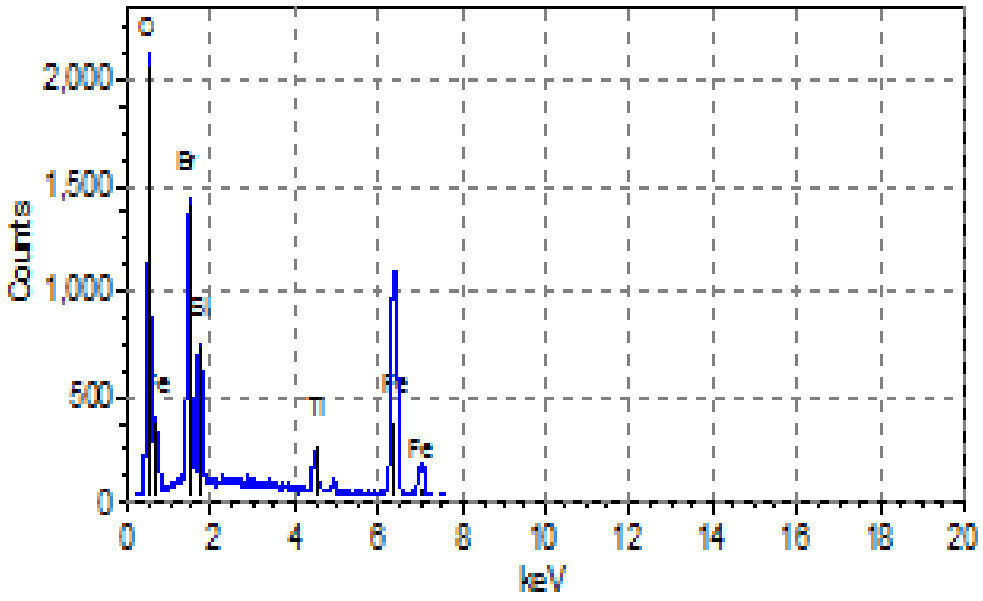


Figure 4.2: EDS Analysis Result Showing the Spectra of Major Elements for Composite Sample

4.3.3 Photomicrograph Obtained by Petrological Analysis for Iron Ore Samples from Each Pit

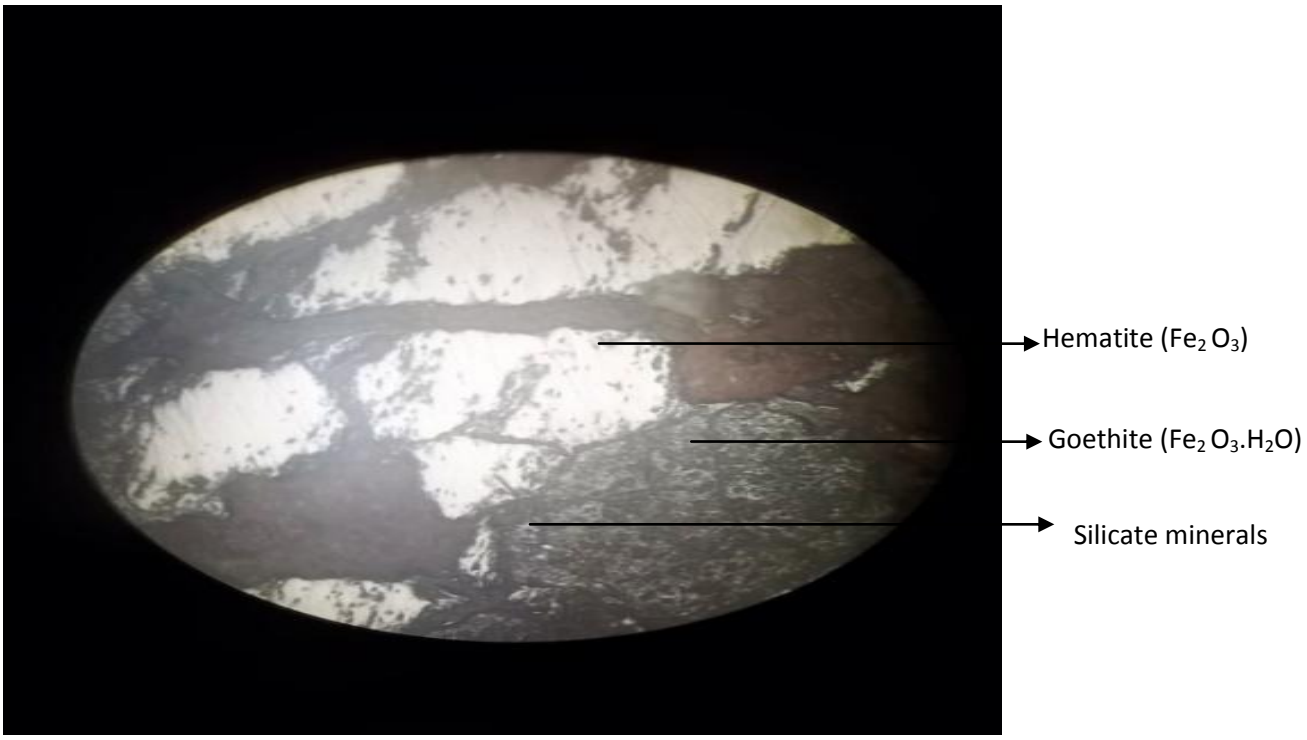


Plate Ia: Photomicrograph Obtained by Petrological Analysis for Sample from Pit 1

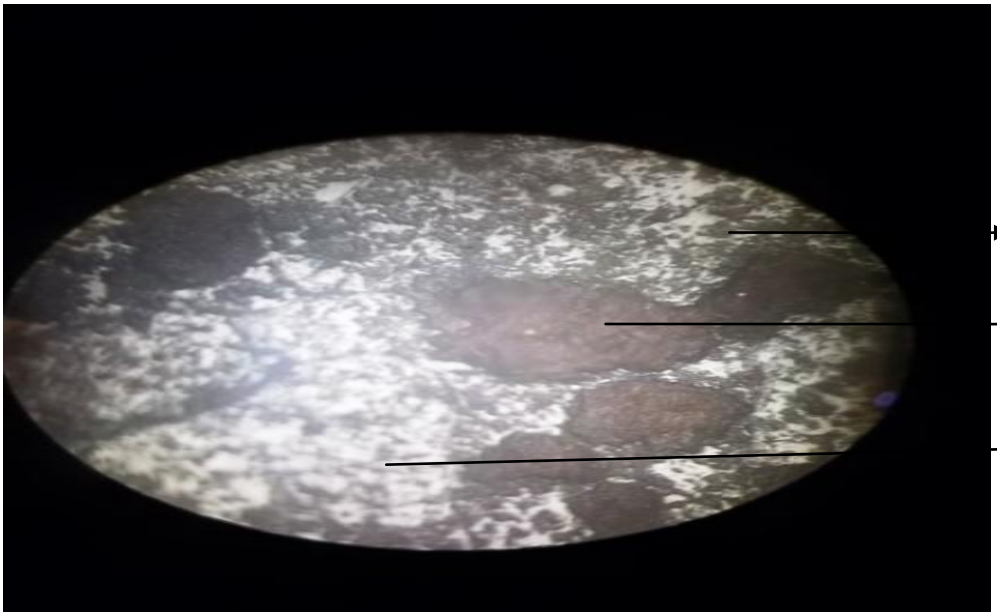


Plate Ib1: Photomicrograph Obtained by Petrological Analysis for Sample from Pit 2 with crossed polarized light

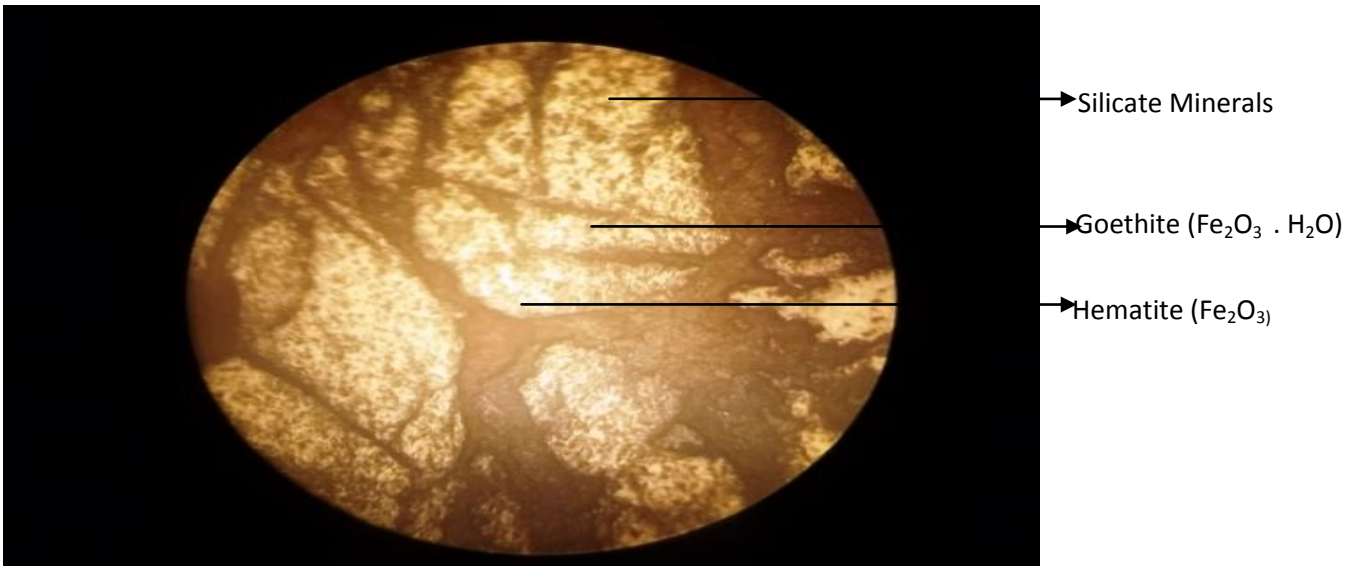


Plate Ib2: Photomicrograph Obtained by Petrological Analysis for Sample Pit 2 with Polarized Light

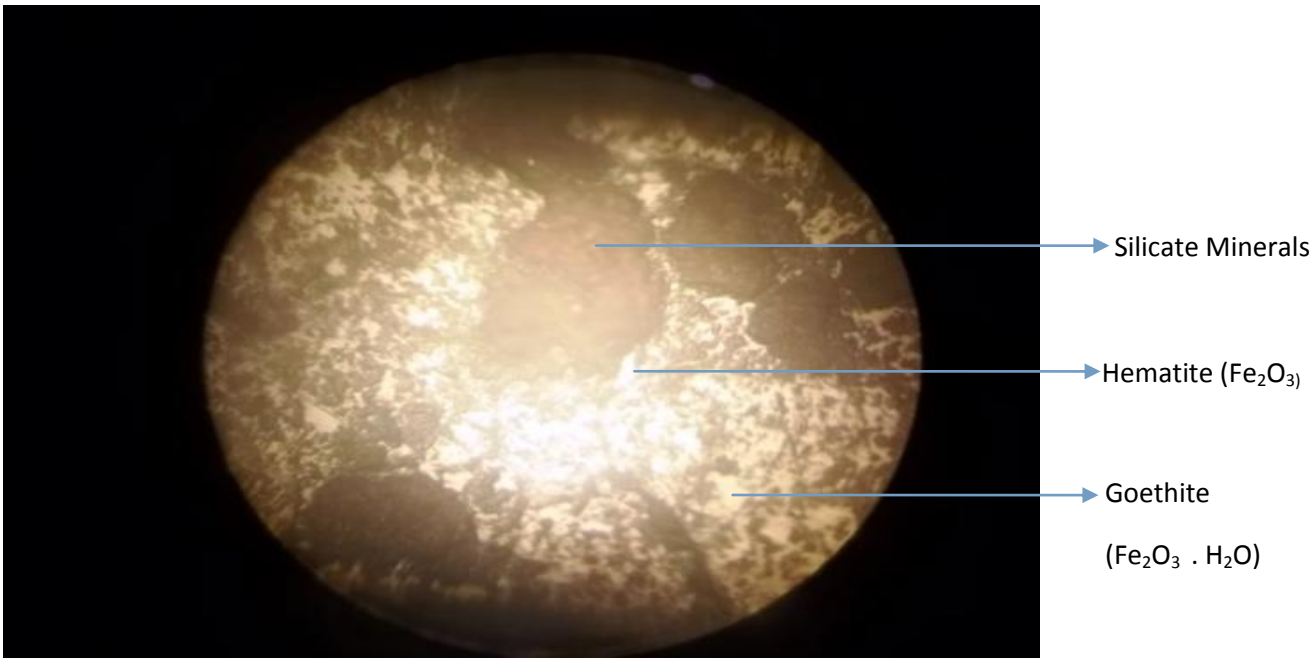


Plate Ic1: Photomicrograph Obtained by Petrological Analysis for Sample from Pit 3 with polarized light

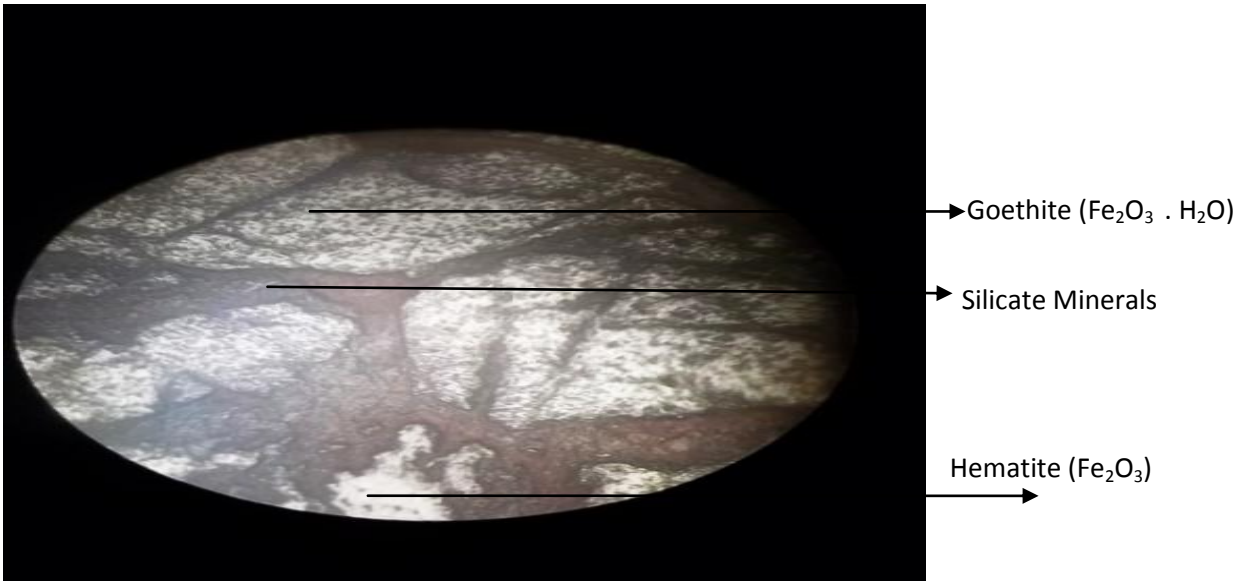


Plate Ic2: Photomicrograph Obtained by Petrological Analysis for Sample from Pit3 with Crossed Polarized Light

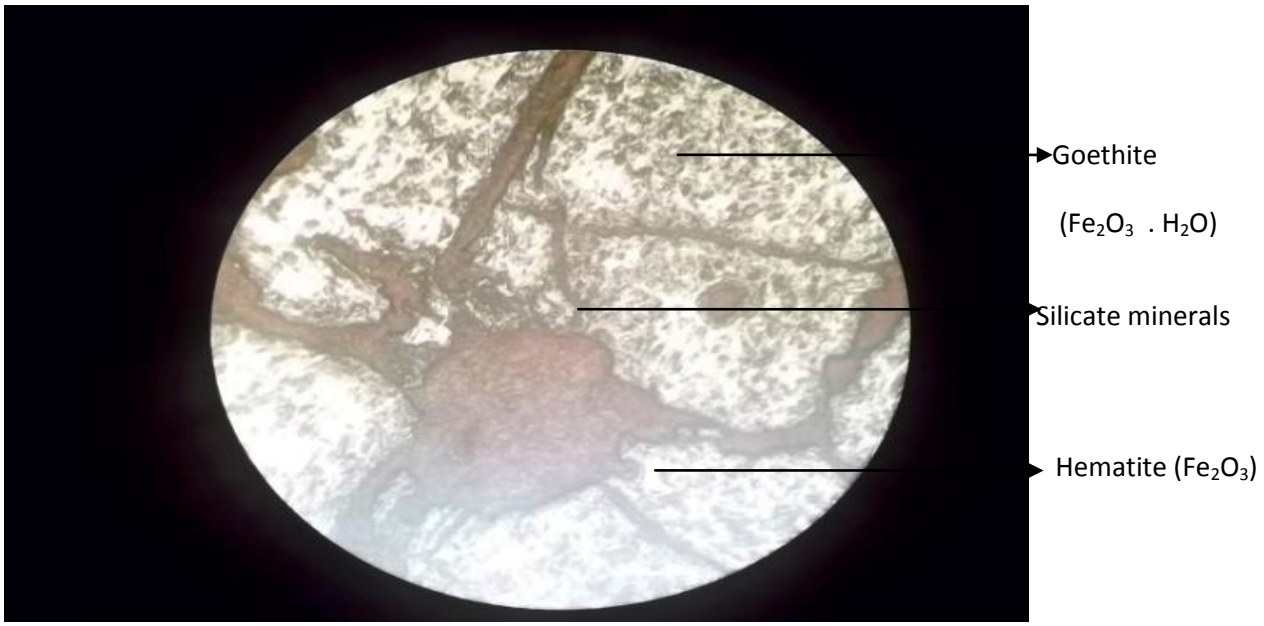


Plate Id1: Photomicrograph Obtained by Petrological Analysis for Sample from pit 4 with Crossed Polarized Light.

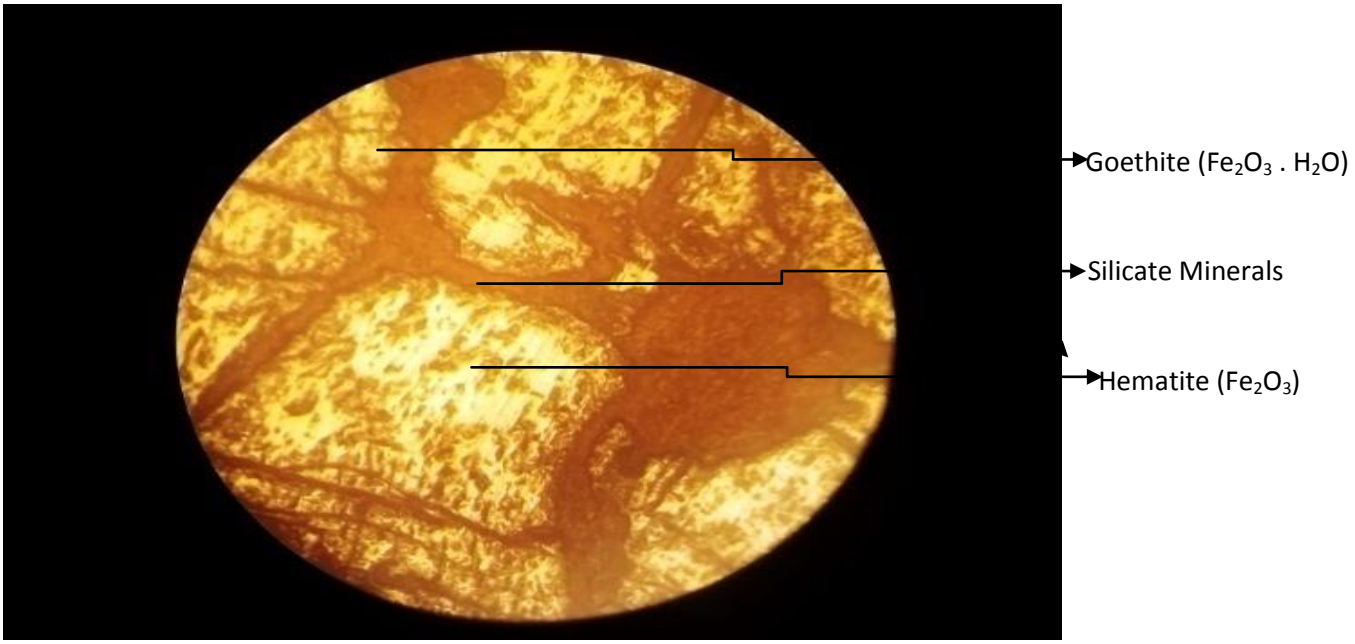


Plate Id2: Photomicrograph Obtained by Petrological Analysis for Sample from Pit 4 with polarized light

Tables 4.3, 4.4, 4.5, 4.6 and 4.7 are the results of XRD analyses of Gujeni iron ore samples. Table 4.3 (Figure A18) present the result of the major and the minor mineral phases present in the composite sample (homogenous mixture of the samples from various pits) while Tables 4.4, 4.5, 4.6 and 4.7 present the results of the major and the minor mineral phases contain in the samples of pit 1, pit 2, pit 3 and pit 4.

From the result in Table 4.3 the minerals present in the composite sample are rutile (TiO_2), hematite (Fe_2O_3), manganese oxide (MnO_2), zirconium oxide (ZrO_2) and potassium magnesium aluminum silicate (KMg_3AlSiO_3). Table 4.4 (Figure A14)present the result of the mineral compositions of the sample from pit 1 which contains hematite (Fe_2O_3), rutile (TiO_2), goethite ($Fe_2O_3.H_2O$), zincite (ZnO), manganese oxide (MnO_2) and potassium magnesium aluminum silicate (KMg_3AlSiO_3). Table 4.5 (Figure A15) present the mineral phases presents in the sample from pit 2 and these minerals are hematite (Fe_2O_3), zirconium oxide (ZrO_2), rhodochrosite($MnCO_3$) rutile (TiO_2) and manganese oxide (MnO_2). Table 4.6(Figure A16) present the mineral phases in the sample from pit 3: zincite (ZnO), ferro-magnesite($Fe,MgCO_3$), rhodochrosite($MnCO_3$), goethite ($Fe_2O_3.H_2O$), rutile (TiO_2) and manganese oxide (MnO_2). Table 4.7(Figure A17) present the mineral phases present in the sample from pit 4 and they are rutile (TiO_2), manganese oxide (MnO_2), zirconium oxide (ZrO_2), goethite ($Fe_2O_3.H_2O$), ferro- magnesite($Fe,MgCO_3$), hematite (Fe_2O_3), zincite (ZnO) and rhodochrosite($MnCO_3$). From the analyses the ore could be said to be predominantly hematite (Fe_2O_3), goethite ($Fe_2O_3.H_2O$) and rutile (TiO_2) as the major minerals while rhodochrosite($MnCO_3$), zirconium oxide (ZrO_2), manganese oxide (MnO_2)and silicate minerals as the minor minerals present in the ore. The mineralogical composition of the ore is similar and comparable with some major iron ore deposits earlier worked upon and cited in the literature (Thomas and Yaro, 2007).

The SEM results are presented in Plates I to XV. The analysis was carried out on the composite sample and pit 1 that contained the highest iron content among the pits to determine the morphology of the grain sizes of the ore. The plates revealed the grain size at the different magnifications and at the different microns. It can be observed that in both the composite and pit 1 samples iron minerals have smooth boundaries which create segregation between the iron and other minerals contained in the ore. This phenomenon enhances easy liberation of the valuable mineral from the gangue. The iron minerals are not occluded with the other minerals contained in the ore, also not in vein or in shell with other minerals within the ore.

Tables 4.8 and 4.9 present the EDS results of the SEM analysis of pit1 and the composite samples. It can be observed from the EDS results that the Fe contents of the ore samples are generally high and indication that the Gujeni iron ore deposit is rich in iron. Figures 4.1 and 4.2 are showing the spectra of the major elements contained in the ore that is, iron, barium and titanium for pit 1 and the composite samples respectively. The results of the EDS tally with those values obtained using the XRF analysis for the same sample presented in Tables 4.1 and 4.2.

Plates Ia to Id2 show the petrological analysis of iron ore samples from different pits. It can be observed from the photomicrograph that the dark area is the silicate mineral. The goethite is mixed with silicate minerals in form of river line but the side that is mostly goethite is reflecting iron, the brighter area is hematite which is in form of plates. Further oxidation, more iron oxide will form and brighter the darker area becomes. The river line and plates form are the characteristic of hematite and goethite. This confirmed the results of XRD analysis, that the major iron oxide minerals present are hematite and goethite. The

petrological analysis also reveals that the iron minerals are coarse in nature with a grain size less than 3mm .

4.4. Particle Size/ Mineral Assay Analysis Results of the Iron Ore Sample

Table 4.10: Result of Particle Size Analysis of the Composite 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 4.11: Mineral Assay Analysis Result of the Composite Sample (-50μm)

Card no	Mineral name	chemical name	chemical formula
21-1276	Rutile, syn	Titanium oxide	TiO_2
34-1084		Zirconium oxide	ZrO_2
36-1451	Zincite	Zinc oxide	ZnO
21-1272	Anatase, syn	Titanium oxide	TiO_2
36-0383	Magnesite, ferr	Iron Magnesium carbonate	(Mg, Fe) CO_3
33-0664	Hematite, syn	Iron oxide	Fe_2O_3
44-0141		Maganese oxide	MnO_2
44-1472	Rhodchrosite	Manganese Carbonate	$MnCO_3$
10-0492		Potassium Magnesium Aluminum Silicate Hydrate	$KMg_3(Al SiO_3)(OH)_2$
10-0495		Potassium Magnesium Aluminum Silicate Hydrate	$KMg_3(Al SiO_3)(OH)_2$

Table 4.12: Mineral Assay Analysis Result of the Composite Sample (-90+50μm)

Card No	Mineral Name	Chemical Name	Chemical Formula
20-0684		Zirconium oxide	ZrO
26-1136	Magnetite	Iron oxide	Fe_3O_4
24-0735	Pyrolusite	Manganese oxide	MnO_2
19-0629	Magnetite	Iron oxide	Fe_3O_4
6-0395	Romarchite	Tin oxide	SnO
34-0842		Calcium Aluminum Iron Silicate Hydroxide	Ca,Al, $FeSiO_3$,).$4H_2O$
21-1276	Rutile	Titanium oxide	TiO_2

Table 4.13: Mineral Assay Analysis Result of the Composite Sample (-125+90 µm)

Card No	Mineral Name	Chemical Name	Chemical Formula
13-0092	Goethite	Iron oxide hydrate	$Fe_2O_3 .H_2O$
36-1451	Zincite	Zinc oxide	ZnO
46-1045	Quartz,	Silicon oxide	SiO_2
44-0141		Manganese oxide	MnO_2
10-0492		Potassium Magnesium Aluminum Silicate Hydrate	KMg_3 (Al SiO_3) $(OH)_2$
10-0495		Potassium Magnesium Aluminum Silicate Hydrate	KMg_3 (Al SiO_3) $(OH)_2$
21-1276	Rutile	Titanium oxide	TiO_2
33-0664	Hematite	Iron oxide	Fe_2O_3

Table 4.14: Mineral Assay Analysis Result of Composite Sample (-180+125µm)

Card no	Mineral name	Chemical name	Chemical formula
27-0997		Zirconium oxide	ZrO_2
44-0103		Sodium Aluminum silicate hydrate	$NaAlSiO_3.H_2O$
19-0629	Magnetite	Iron oxide	Fe_3O_4
19-0629	Magnetite	Iron oxide	Fe_3O_4
8-0454		Barium sulfide	BaS
34-0140	Chromate	Iron chromium oxide	$FeCrO_2O_4$
34-0977		Tantalum oxide	TaO
12-0104		Manganese oxide	MnO_2
4-0712		Calcium carbide	CaC_2
18-1304		Tantalum oxide	Ta_2O_5
30-1836		Nickel iodide Triethylamine oxide	Ni_2IO_3
33-0285		Calcium Iron Titanium Silicate	Ca,Fe, $TiSiO_3$
6-0408		Neodymium oxide	Nd_2O_3
5-0390		Cassiterite	SnO
5-0592	Galena	Lead sulphate	Pbs
4-0326		Manganese oxide	MnO
19-1297		Tantalum oxide	TaO_2
26-1399		Zirconium oxide	ZrO
6-0399		Barium Zironium oxide	$BaZrO_3$
6-0695		Aluminum Iron	Fe_3Al

Table 4.15: Mineral Assay Analysis Result of the Composite Sample (-250+180µm)

Card no	Mineral name	Chemical name	Chemical formula
21-1276	Rutile	Titanium oxide	TiO_2
36-0383	Magnesite	Iron Magnesium Carbonate	(Mg, Fe) CO_3
36-1451	Zincite	Zinc oxide	ZnO
21-1272	Anatase	Titanium oxide	TiO_2
13-0092	Goethite	Iron oxide hydrate	$Fe_2O_3 . H_2O$
44-0141		Manganese oxide	MnO_2
10-0492		Potassium Magnesium Aluminum Silicate hydrate	$KMg_3(Al SiO_3)(OH)_2$
44-1472	Rhodochrosite , syn	Manganese Carbonate	$MnCO_3$

Table 4.16: Mineral Assay Analysis Result of the composite Sample (-355+250µm)

Card no	Mineral name	Chemical name	Chemical formula
36-1451	Zincite	Zinc oxide	ZnO
33-0664	Hematite	Iron oxide	Fe_2O_3
21-1276	Rutile	Titanium oxide	TiO_2
44-0142	Ramsdellite	manganese oxide	MnO_2
44-1472	Rhodochrosite	Manganese carbonate	$MnCO_3$
21-1272	Anatase	Titanium oxide	TiO_2
46-1045	Quartz	Silicon oxide	SiO_2
10-0492		Potassium Magnesium Aluminum Silicate hydrate	$KMg_3(Al\ SiO_3)(OH)_2$

Table 4.17: Mineral Assay Analysis Result of the Composite Sample (+355µm)

Card no	Mineral name	Chemical name	Chemical formula
22-1025		Zirconium oxide	ZrO
33-0285		Calcium Iron Titanium Silicate	Ca, Fe, $TiSiO_3$
12-0141		Manganese oxide	MnO_2
39-0238	Hematite	Iron oxide	Fe_2O_3
5-0390		Cassiterite	SnO
27-1402		Silica	SiO_2

The particle size and minerals assay analysis are presented in Tables 4.10, 4.11, 4.12, 4.13, 4.14, 4.15, 4.16 and 4.17. Table 4.10 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. This trend shows that the minerals in the ore sample are uniformly distributed and

the particle size of the minerals in the ore can enhance the degree of liberation of the various minerals as the particle size reduces (Wills, 2006; Weiss, 1985).

Table 4.11(Figure A7) presents the mineral phases contained in -50µm size fraction. The mineral phases are rutile (TiO_2), zirconium oxide (ZrO), zincite (ZnO), rhodochrosite ($MnCO_3$), ferro-magnesite($Fe,MgCO_3$), hematite (Fe_2O_3) and potassium-magnesium-aluminum-silicate (KMg_3AlSiO_3). With 47.9%Fe, 0.02%Zn, 0.2%Mn, 0.8%Zr, 9.7 % (Al and Si), 12.0%Ti, 12.1%Ba, 11.26%Br as its assay.

Table 4.12 presents (Figure A8) the mineral phases contained in -90+50µm size fractions. The minerals phases are zirconium oxide (ZrO_2), rutile (TiO_2), magnetite (Fe_3O_4), manganese oxide (MnO_2), calcium- aluminum-iron-silicate (Ca, Al, $FeSiO_3$).With assay content of 42.6%Fe, 0.07%Zn, 10.21 % (Al and Si), 12.1%Ti, 12.15%Ba and 11.33%Br.

Table 4.13(Figure A9) presents the mineral phases contained in -125+90µm size fractions. The mineral phases are goethite ($Fe_2O_3.H_2O$), zincite (ZnO), potassium-magnesium-aluminum-silicate (KMg_3AlSiO_3), rutile (TiO_2) and hematite (Fe_2O_3).With assay contents of 46.0%Fe, 0.8%Zn, 9.73% (Al and Si), 12.01%Ti, 12.0%Ba, and 11.44%Br.

Table 4.14 (Figure A10) presents the mineral phases contained in -180+125µm size fractions. The mineral phases are hematite (Fe_2O_3), sodium-aluminum-silicate ($NaAlSiO_3$), magnetite (Fe_3O_4), lead sulphate ($PbSO_4$), calcium carbide (CaC_2), hematite (Fe_2O_3), iron chromate ($FeCrO_4$) and manganese oxide (MnO_2) with assay contents of 45.9%Fe, 9.65%(Al and Si), 12.0%Ti, 12.0%Ba and 11.55%Br.

Table 4.15 (Figure A11)presents the mineral phases contained in -250+180µm size fractions. The mineral phases are ferro-magnesite ($Fe,MgCO_3$), potassium-magnesium-aluminum-silicate (KMg_3AlSiO_3), goethite($Fe_2O_3.H_2O$), rhodochrosite ($MnCO_3$), hematite

(Fe_2O_3), zincite (ZnO), rutile (TiO_2) and manganese oxide (MnO_2) with assay contents of 48.80%Fe, 0.2%Mn, 9.15%(Al and Si), 12.01%TiO, 0.9%Zn, 12.0%Ba and 10.85%Br.

Table 4.16 (Figure A12)presents the mineral phases contained in -355+250µm size fractions. The predominant mineral phases are zincite (ZnO), rhodochrosite($MnCO_3$), hematite (Fe_2O_3), rutile (TiO_2), potassium-magnesium-aluminum-silicate (KMg_3AlSiO_3) with assay contents of 45.80%Fe, 0.9%Zn, 0.1%Mn, 12.0%Ti, 9.9% (Al and Si), 12.02%Ba and 11.45%Br.µm

Table 4.17 (Figure A13) presents the mineral phases contained in +355µm size faction. The mineral phases are hematite (Fe_2O_3), manganese oxide (MnO_2), Calcium-Iron-Titanium - Silicate (Ca, Fe, Ti, and SiO3) and zirconium oxide (ZrO_2) with assay contents of 43.3%Fe, 0.1%Mn, 12.1 % Ti , 12.1%Ba, 11.5%Br and 9.5% (Al and Si).

From the results of the analyses, majority of the mineral phases contained in the ore sample are distributed in all the sieve size fractions and this could be attributed to the allocation of the mineral constituent to the particle size that formed the mineral grain of the ore. This phenomenon has also been observed and reported by Thomas and Yaro, (2007), Weiss, (1985) and Wills(2006).

4.5 Liberation Size Analysis Results of the Composite Sample

Table 4.18 Chemical Composition of the Various Size fractions Determined by XRF Analysis

Elements	+355µm	-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

The minerals distributed in each sieve size were analysed 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 4.18 presents the result of chemical analysis of various sieve size fractions of the iron ore sample. Sieve size fraction of +355µm contains 43.3%Fe, 0.1%Mn, 1.89%SiO_2, 6.66% Al_2O_3 12.1%Ti, 0.3%Zr, 0.3%V, 0.1%Pb, 0.9%Zn, 1.23%P. -355+250µm contains 45.80%Fe, 0.1%Mn, 2.00%SiO_2,7.12% Al_2O_3, 12.0%Ti, 0.4%Zr, 0.3%V, 0.2%Pb, 0.9%Zn, 0.89%P and 0.1%S. -250+180µm contains 48.80%Fe, 0.2%Mn, 2.65%SiO_2, 8.05% Al_2O_3, 12.01%Ti, 0.4%Zr, 0.3%V, 0.3%Pb, 0.9%Zn, 1.45%P. -180+125µm contains 45.9%Fe, 0.2%Mn, 1.98% SiO_2, 7.4% Al_2O_3, 12.0%Ti, 0.4%Zr, 0.2%V, 0.2%Pb, 0.02%Cd, 0.9Zn, 1.02%P, 0.1%S. -125+90µm contains 46.00%Fe, 0.1%Mn, 2.03% SiO_2, 6.93% Al_2O_3, 12.1%Ti, 0.4%Zr, 0.3%V, 0.2%Pb, 0.8%Zn, 1.345P. -90+50µm contains 42.60%Fe, 0.2%Mn, 3.01% SiO_2, 8.01%Al_2O_3, 12.1%Ti, 0.5%Zr, 0.3%V, 0.2%Pb, 0.7%Zn, 0.67%P. -50µm (pan) contains 47.9%Fe, 0.2%Mn, 2.01% SiO_2, 7.05%Al_2O_3, 12.0%Ti, 0.8%Zr, 0.3%V, 0.2%Pb, 0.2%Cd, 0.2%Zn and 1.90%P. 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.

4.6 Results of the Determination of work Index for the Composite Sample

Table 4.19: Particle Size Analysis of the Feed to the Ball Mill for Test Sample (Iron Ore)

Sieve size(µm)	Weight(g) retained	Weight(%) retained	Nominal aperture	Cumulative (%)	
				Weight (%) retained	Weight (%) passing
+425	0.00	0.00	425	0.00	100
-425+355	270.00	54.00	355	54.00	46
-355+250	73.07	14.61	250	68.61	31.39
-250+180	13.37	02.67	180	71.28	28.72
-180+125	51.5	10.30	125	81.58	18.42
-125+90	14.17	02.83	90	84.41	15.59
-90+50	17.47	03.49	50	87.9	12.10
-50	60.37	12.07	Pan	100	0.00
Total	500				

Table 4.20: Particle Size Analysis of the Feed to the Ball Mill for Reference ore Sample (Granite)

Sieve size(µm)	Weight(g) retained	Weight(%) retained	Nominal aperture	Cumulative (%)	
				Weight(%) retained	Weight (%) passing
+425	0.00	0.00	425	0.00	100
-425+355	250.60	50.12	355	50.12	49.88
-355+250	64.20	12.84	250	62.96	37.04
-250+180	20.20	04.04	180	67.00	33.00
-180+125	64.90	12.98	125	79.98	20.02
-125+90	28.50	05.70	90	85.68	14.32
-90+50	26.10	05.22	50	90.90	09.10
-50	45.50	09.10	Pan	100	0.00
Total	500				

Table 4.21: Particle Size Analysis of the Product of the Ball Mill Discharge for Test ore Sample (Iron Ore)

Sieve size(µm)	Weight(g) retained	Weight(%) retained	Nominal aperture	Cumulative (%)	
				Weight (%) retained	Weight (%) passing
+425	0.00	0.00	425	0.00	100
-425+355	102.4	20.48	355	20.48	79.52
-355+250	49.48	09.90	250	30.38	69.62
-250+180	44.48	08.90	180	39.28	60.72
-180+125	66.58	13.31	125	52.59	47.41
-125+90	37.96	7.60	90	60.19	39.81
-90+50	56.08	11.21	50	71.40	28.60
-50	143.00	28.60	Pan	100	0.00
Total	500				

Table 4.22 Particle Size Analysis of the Product of Ball Mill Discharge for Reference ore Sample (Granite)

Sieve size(µm)	Weight(g) retained	Weight(%) retained	Nominal aperture	Cumulative (%)	
				Weight (%) retained	Weight (%) passing
+425	0.00	0.00	425	0.00	100
-425+355	89.75	17.95	355	17.95	82.05
-355+250	48.12	09.62	250	27.57	72.43
-250+180	38.91	07.78	180	35.35	64.65
-180+125	61.76	12.35	125	47.70	52.30
-125+90	34.43	06.89	90	54.59	45.41
-90+50	64.12	12.82	50	67.41	32.59
-50	162.91	32.58	Pan	100	0.00
Total	500				

4.6.1 Calculation for Determination of Work Index

To calculate the 80% passing for feed under test

If 355 ----------46

x ----------80

$x = \frac{355 \times 80}{46} = x = \frac{28400}{46} = x$ = 617.39µm

To calculate the 80% passing feed of reference sample

If 355 ----------49.88

x ----------80

$x = \frac{355 \times 80}{49.88} = x = \frac{28400}{49.88} = x$ = 569.37µm

To calculate the 80% passing for product under test

If 355 ----------79.52

x ----------80

$x = \frac{355 \times 80}{79.52} = x = \frac{28400}{79.52} = x$ = 357.14µm

To calculate the 80% passing for product of reference sample

If 355 ----------82.05

x ----------80

$x = \frac{355 \times 80}{82.05} = x = \frac{28400}{82.05} = x$ = 346.13µm

The values obtained from the cumulative weight percentage passing, sieve size of test and reference sample were used to calculate the 80% passing

$$W_{it} = Wir \frac{\left[\frac{10}{\sqrt{Pr}} - \frac{10}{\sqrt{Fr}}\right]}{\left[\frac{10}{\sqrt{Pt}} - \frac{10}{\sqrt{Ft}}\right]}$$

Wir = work index of reference sample (granite) is 15.13kwh/t, Pr = reference sample product (granite) is 346.13µm

F_r = reference sample feed (granite) is 569.37µm, P_t = test sample product (iron ore) is 357.14µm

F_t = test sample feed (iron ore) is 617.39µm

$$W_{it}=Wir\frac{\left[\frac{10}{\sqrt{Pr}}-\frac{10}{\sqrt{Fr}}\right]}{\left[\frac{10}{\sqrt{Pt}}-\frac{10}{\sqrt{Ft}}\right]}= W_{it}=15.13\frac{\left[\frac{10}{\sqrt{346.13}}-\frac{10}{\sqrt{569.37}}\right]}{\left[\frac{10}{\sqrt{357.14}}-\frac{10}{\sqrt{617.39}}\right]}= Wit = 15.13\frac{\left[\frac{10}{18.6}-\frac{10}{23.86}\right]}{\left[\frac{10}{18.90}-\frac{10}{24.85}\right]}$$

$$W_{it}=15.13\frac{[0.54-0.42]}{[0.53-0.40]}= W_{it}=15.13\frac{[0.12]}{[0.13]}= W_{it}=15.13x0.923= Wit = 13.96kwh/t$$

Tables 4.19, 4.20, 4.21, 4.22 (Figures 3 to 6 in the appendix) present the results of particle size analysis of the reference sample (granite) and the test sample (iron ore). The values of 80% passing for feed and product for both samples were obtained from the tables using simple proportion method. The values of 80% passing and the reference ore work index of 15.13kwh/t was used to determine the work index of Gujeni iron ore which was found to be 13.96kWh/t. The value of the work index 13.96kWh/t indicate that the ore can be classified as a type B ore with medium soft texture using grand-abilities test curves (Mathur, 1985). Furthermore, the value obtained means that approximately 13.96kWh/t of energy is required to reduce 1tonne of the Gujeni ore from 80% passing particle size 617.39µm to 80% passing particle size 357.14µm.This is very significant because energy is very expensive and grinding is the most energy intensive operation in mineral processing (Wills, 2006). The value obtained was compared with the standard work index of a pure haematite (12.87kWh/t) in Table 2.4

CHAPTER FIVE

5.0. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The characterization of the Gujeni iron ore was carried out. The chemical analysis revealed that the iron ore contains mainly 48.6%Fe, 0.2%Mn, 12.01%Ti, , 2.06%P, 0.2%S, 6.0%Si, 4.4%Al etc. The analyses results was comparable with the six other major iron ore deposits within the country. The mineralogical analysis of the ore revealed that the iron ore is predominantly haematite, goethite, rutile, aluminite and other associated minerals like silica, phosphorus, sulphur, zincite and zirconite which can be separated during mineral processing. The physical properties of the iron ore indicate that the iron ore can be separated using gravity and magnetic methods of concentration. The SEM analysis results revealed that the iron minerals are separated from other minerals contained in the ore by smooth boundaries that may make it easy to liberate from other associated minerals. The petrological analysis results revealed that the structures of the iron bearing minerals are in form of plates and river lines, which are the characteristics of haematite and goethite . The dark areas are mixture of goethite and silicate minerals while the white area is haematite. The liberation size of the ore was found to be -250+180µm, being the particle size with highest percent assay of iron. The work index ore was found to be 13.96kWh/t indicating that the ore is a type B with soft medium texture. All the results obtained compared with those cited in the literature. Thus, Gujeni iron ore is another potential iron ore deposit that can be explored and exploited for its usage in the local iron and steel plants.

5.2. Recommendations

(1)Tests for the amenability to different concentration techniques of the iron ore should be carried out

(2) Actual separation test should be carried out.

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APPENDIX A

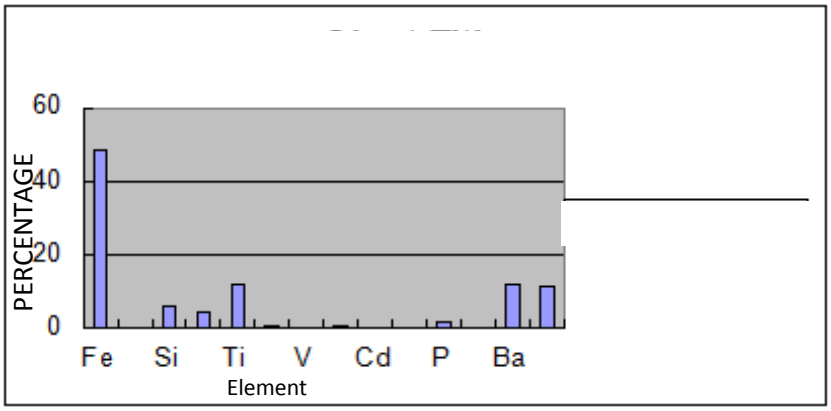


Figure A1: **Bar Chart of the XRF Analysis Result 0f the Composite Sample**

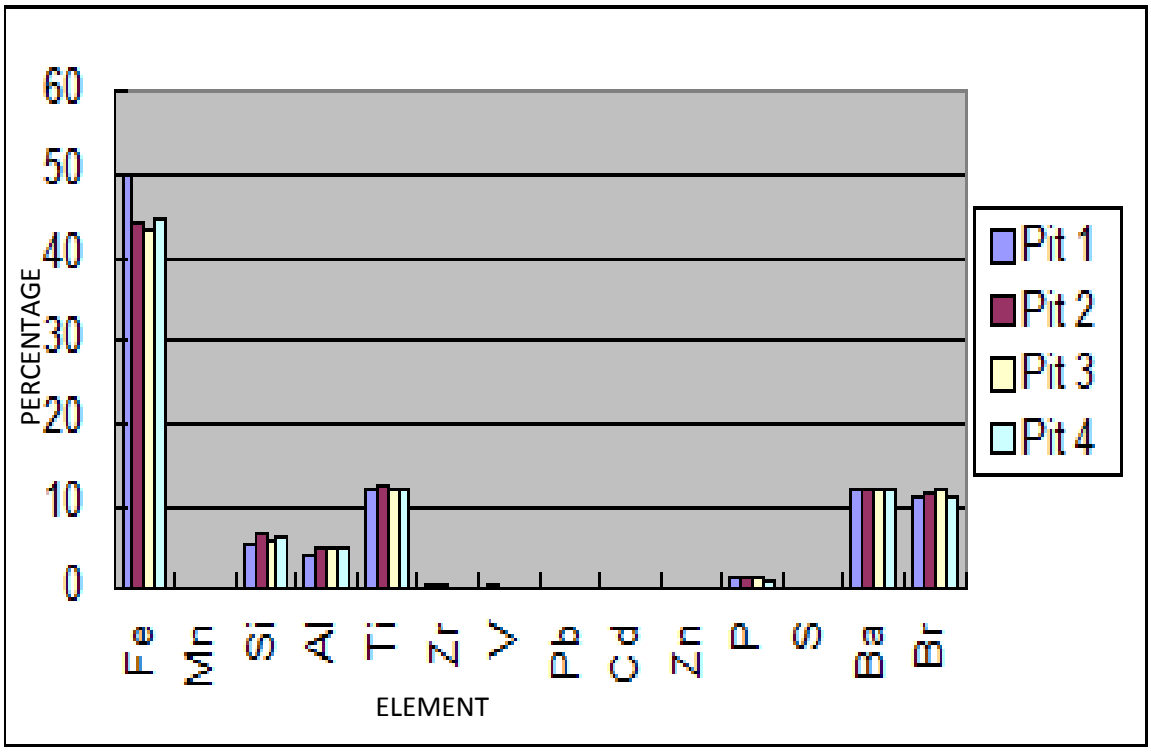


Figure A2: Bar Chart of the XRF Analysis Results of the Samples From Various Pits

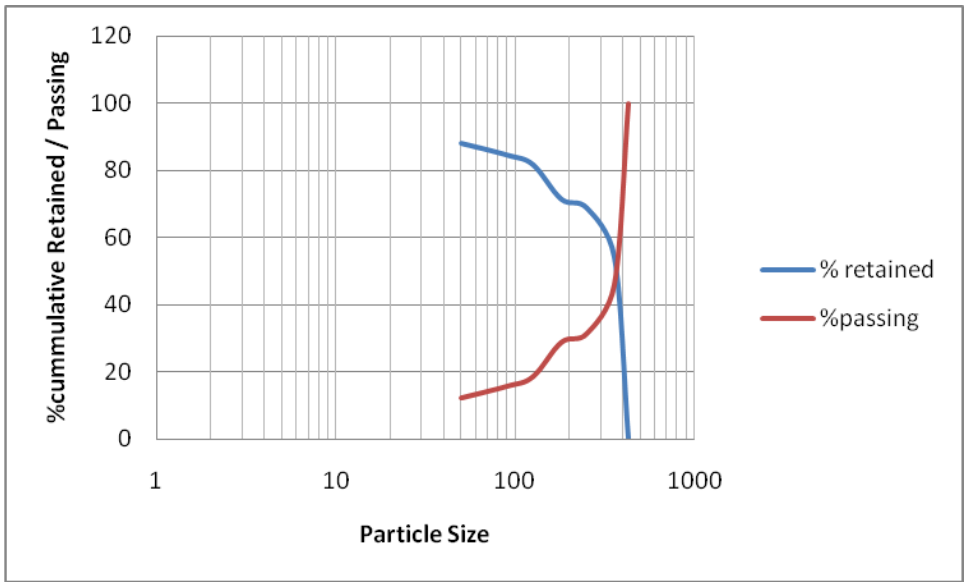


Figure A3: **A graph of Cumulative % passing and % Retained Versus Particle Size for Iron Ore Feed**

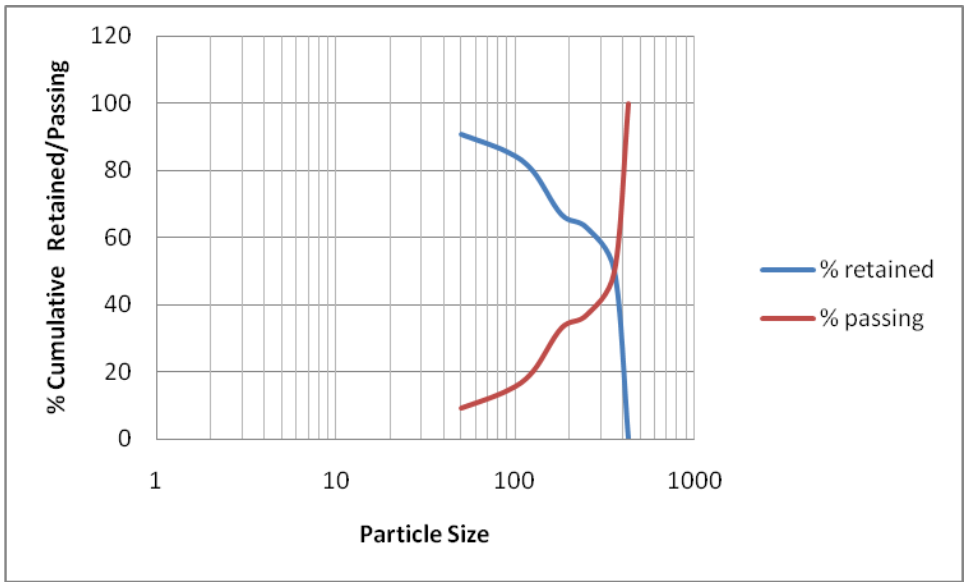


Figure A4: **A graph of Cumulative % passing and % Retained Versus Particle Size for Granite Feed**

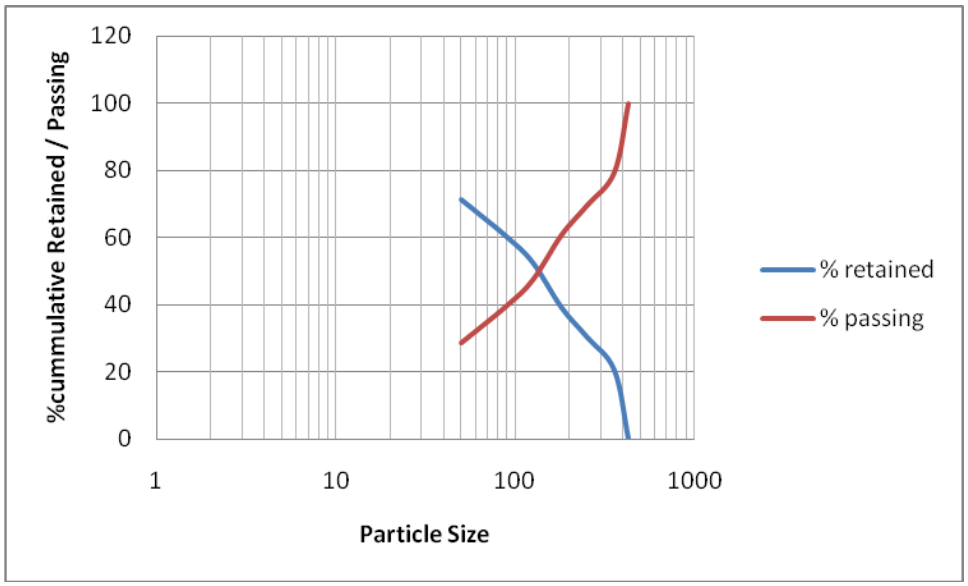


Figure A5: A Graph of Cumulative % Passing and % Retained Versus Particle Size for Iron Ore Product

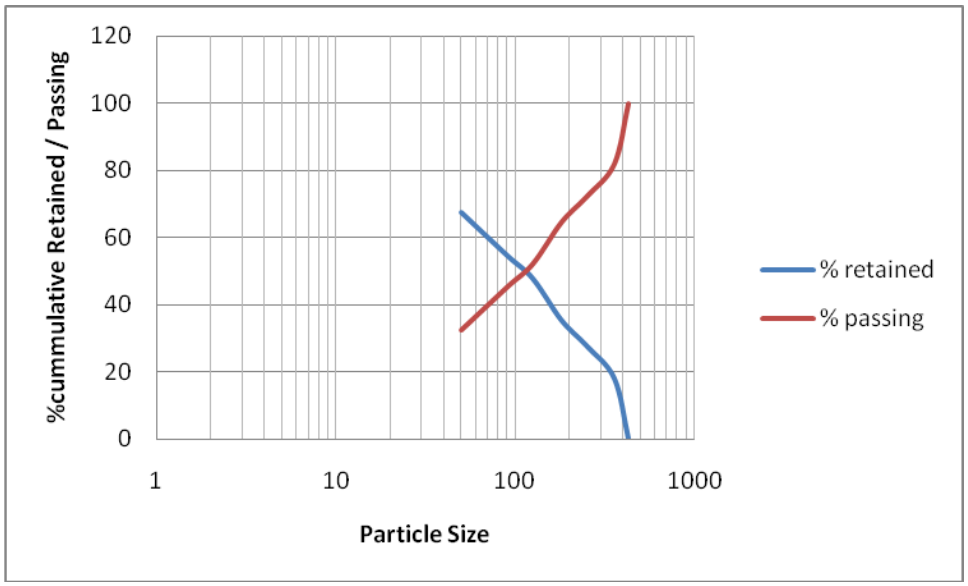


Figure A6: A Graph of Cumulative % Passing and % Retained Versus Particle Size for Reference Ore Product

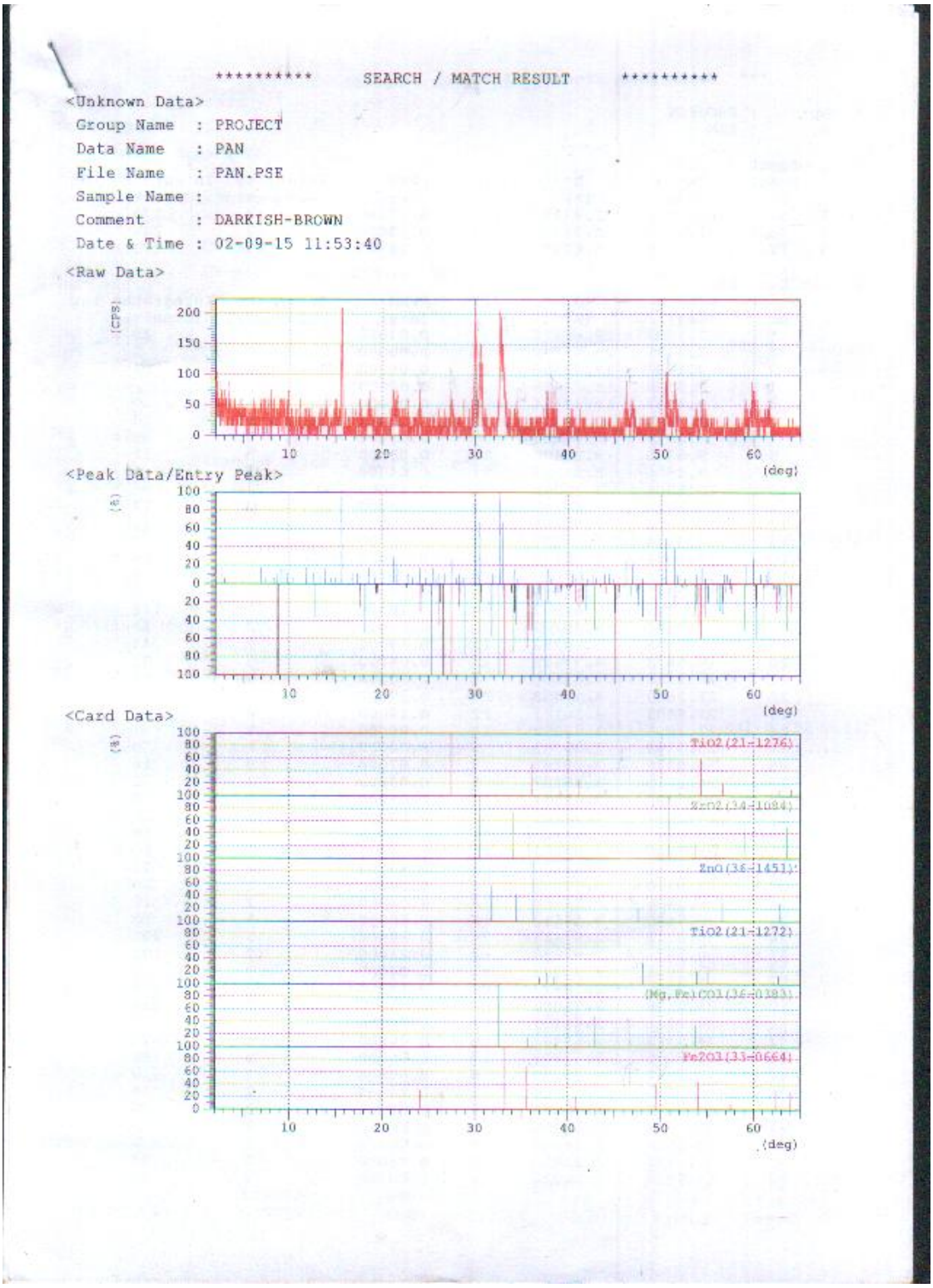


Figure A7: Defractogram of the Minerals Present in the -50µm Size Fraction for the Composite Sample

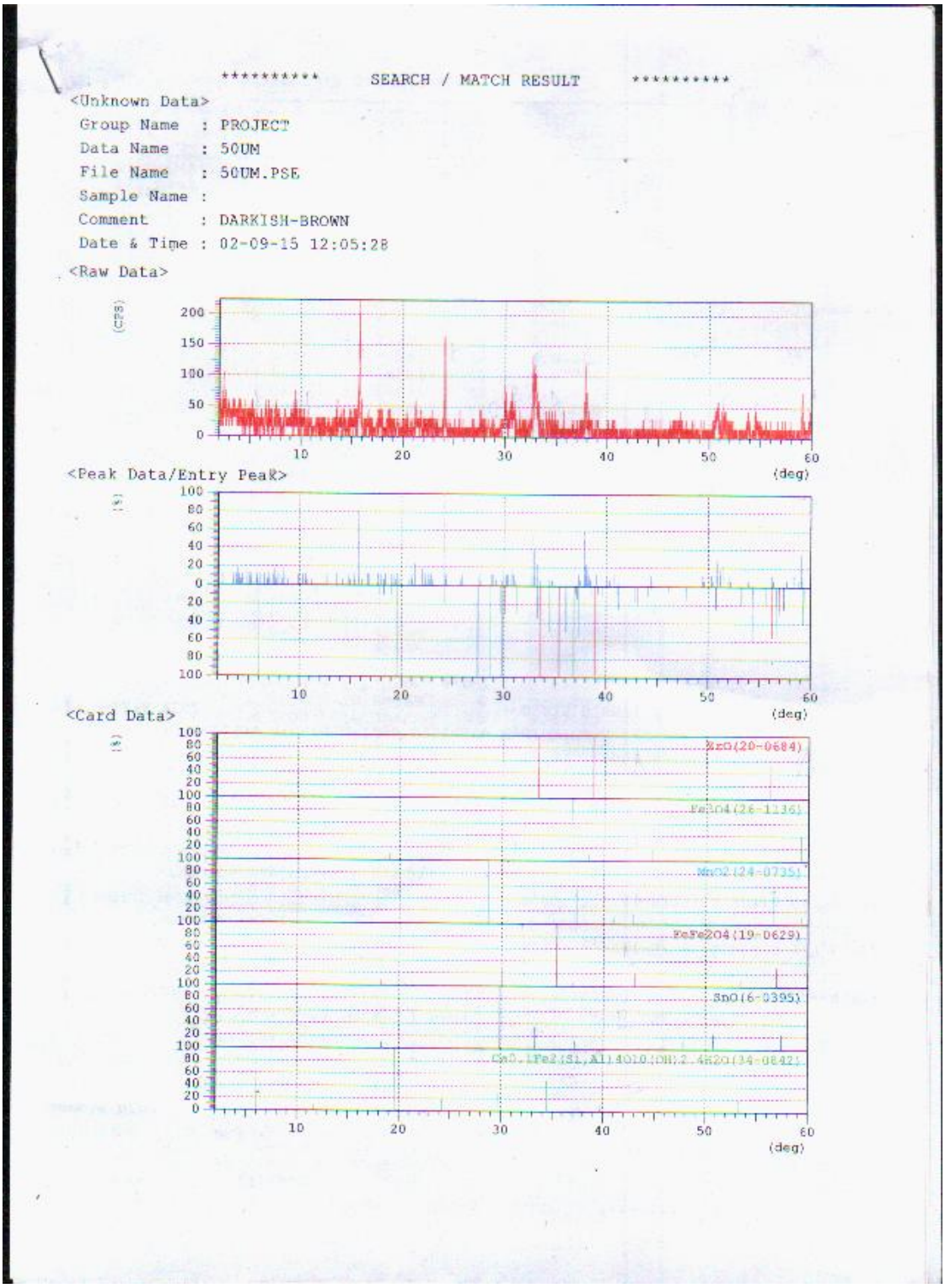


Figure A8: Defractogram of the Minerals Present in -90+50µm Size Fractions for the Composite Sample

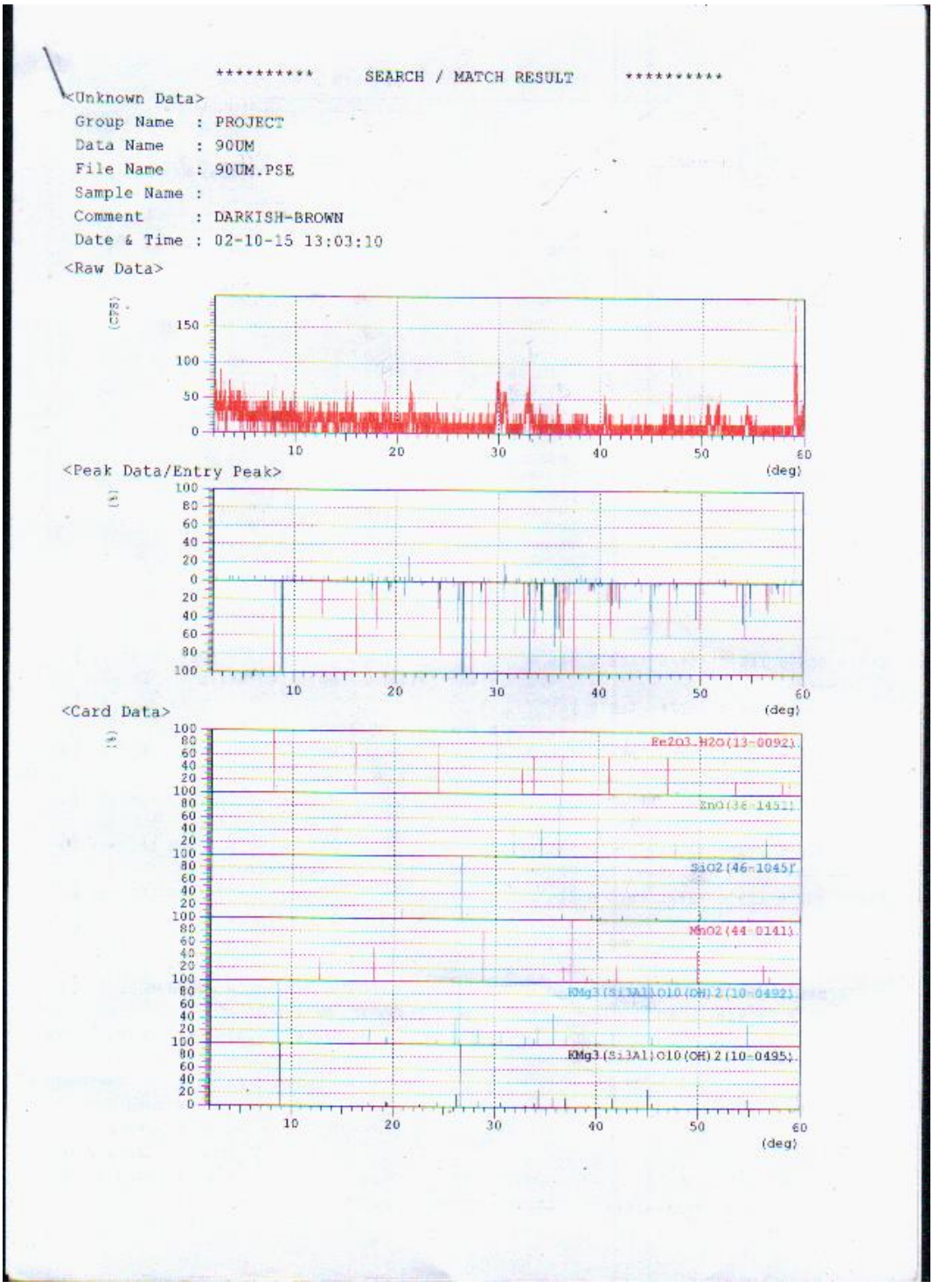


Figure A9:**Defractogram of the Minerals Present in -125+90µmSize Fractions for the Composite Sample**

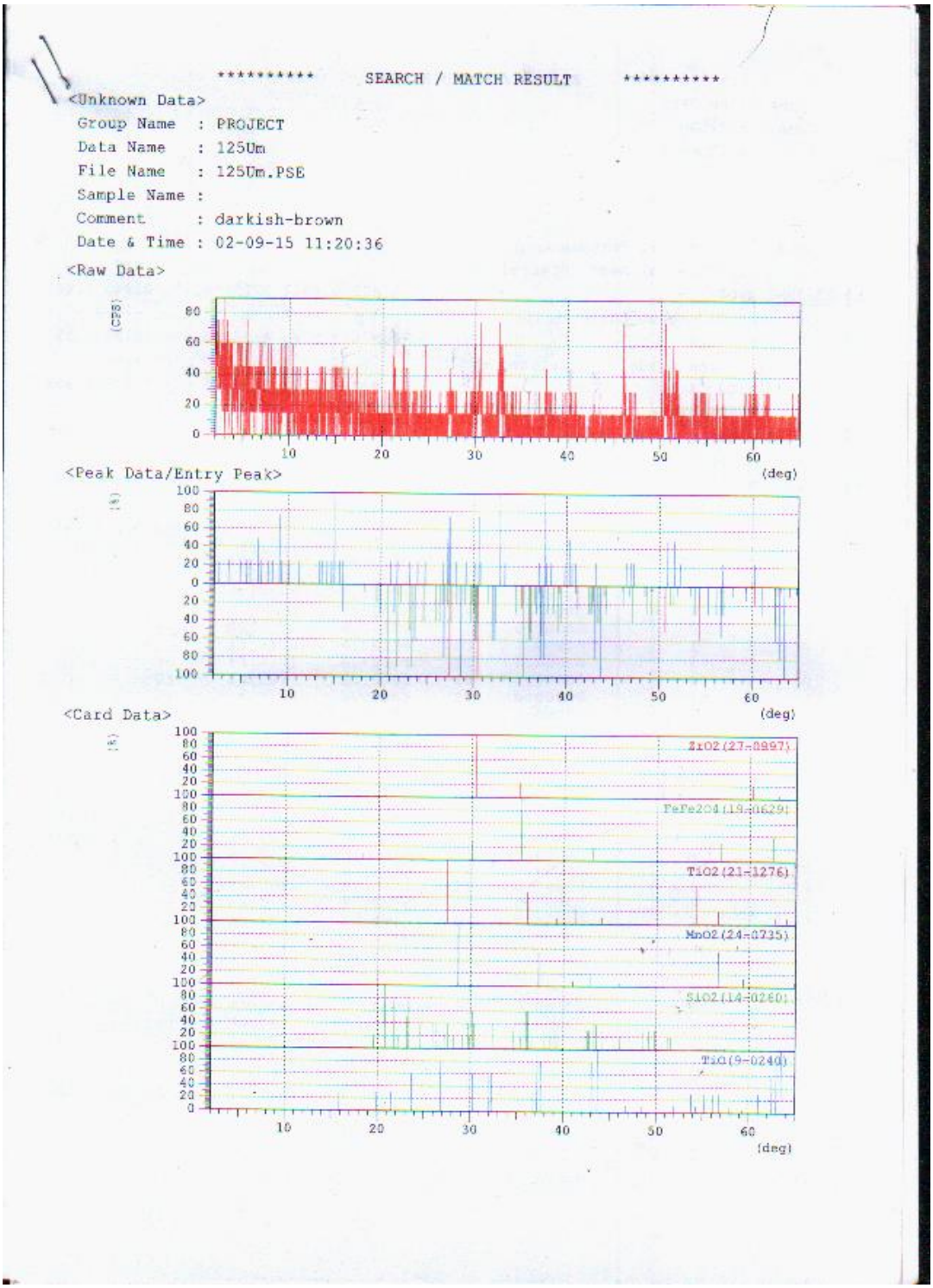


Figure A10:**Defractogram of the Minerals Present in -180+125µm Size Fractions for the Composite Sample**

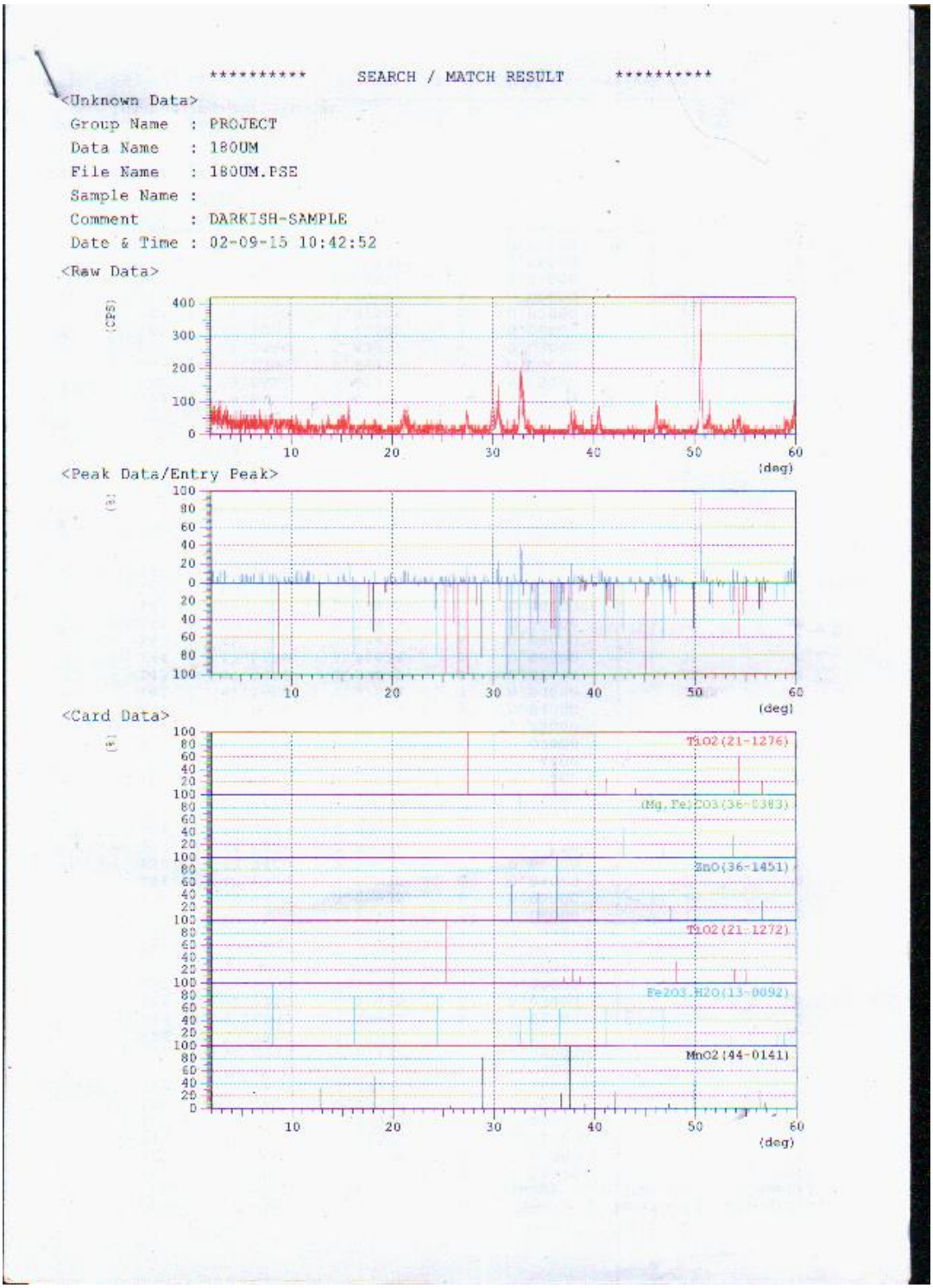


Figure A11:**Defractogram of the Minerals Present in -250+180µm Size Fractions for the Composite Sample**

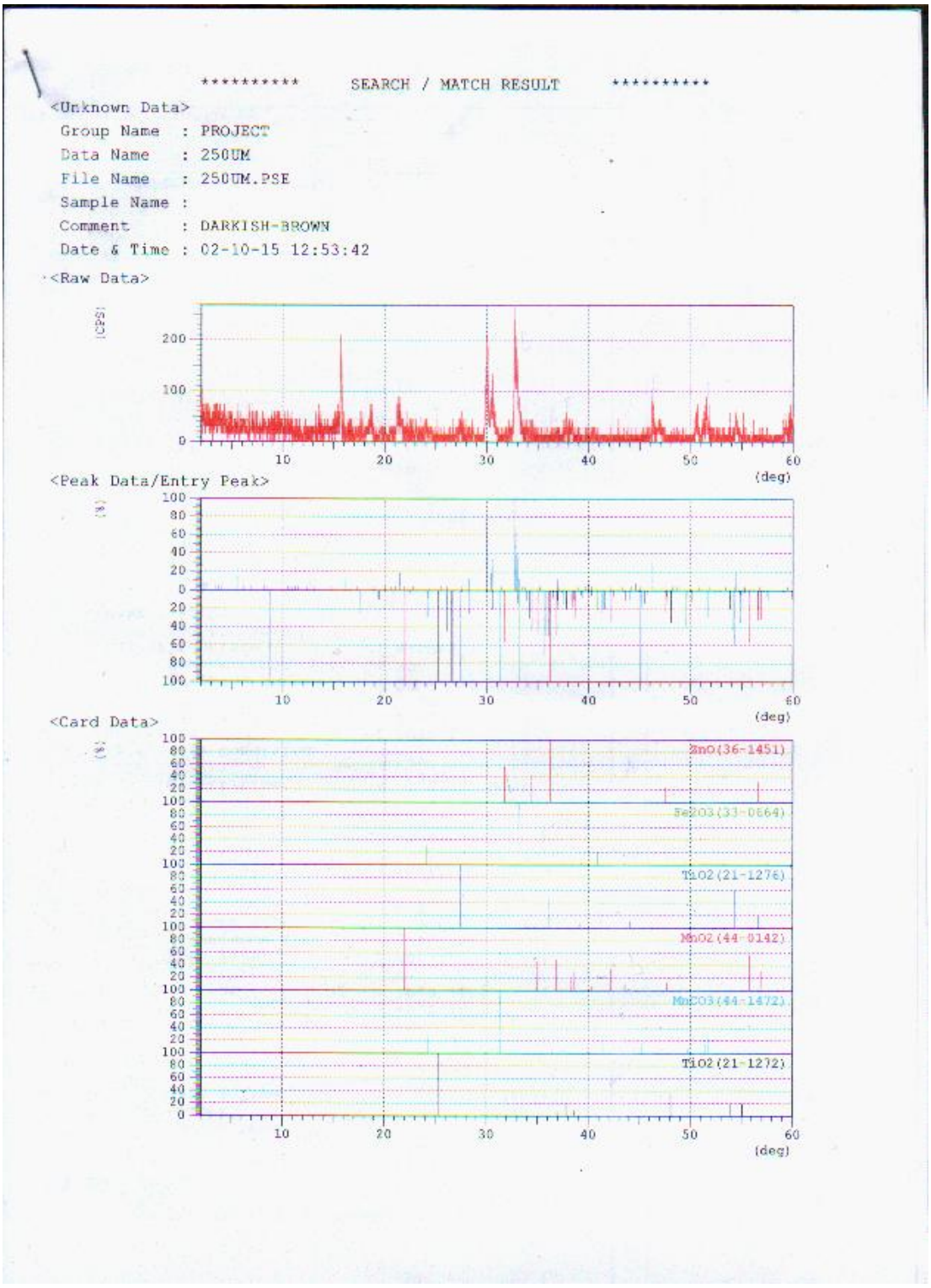


Figure A12:**Defractogram of the Minerals Present in -355+250µm Size Fraction for the Composite Sample**

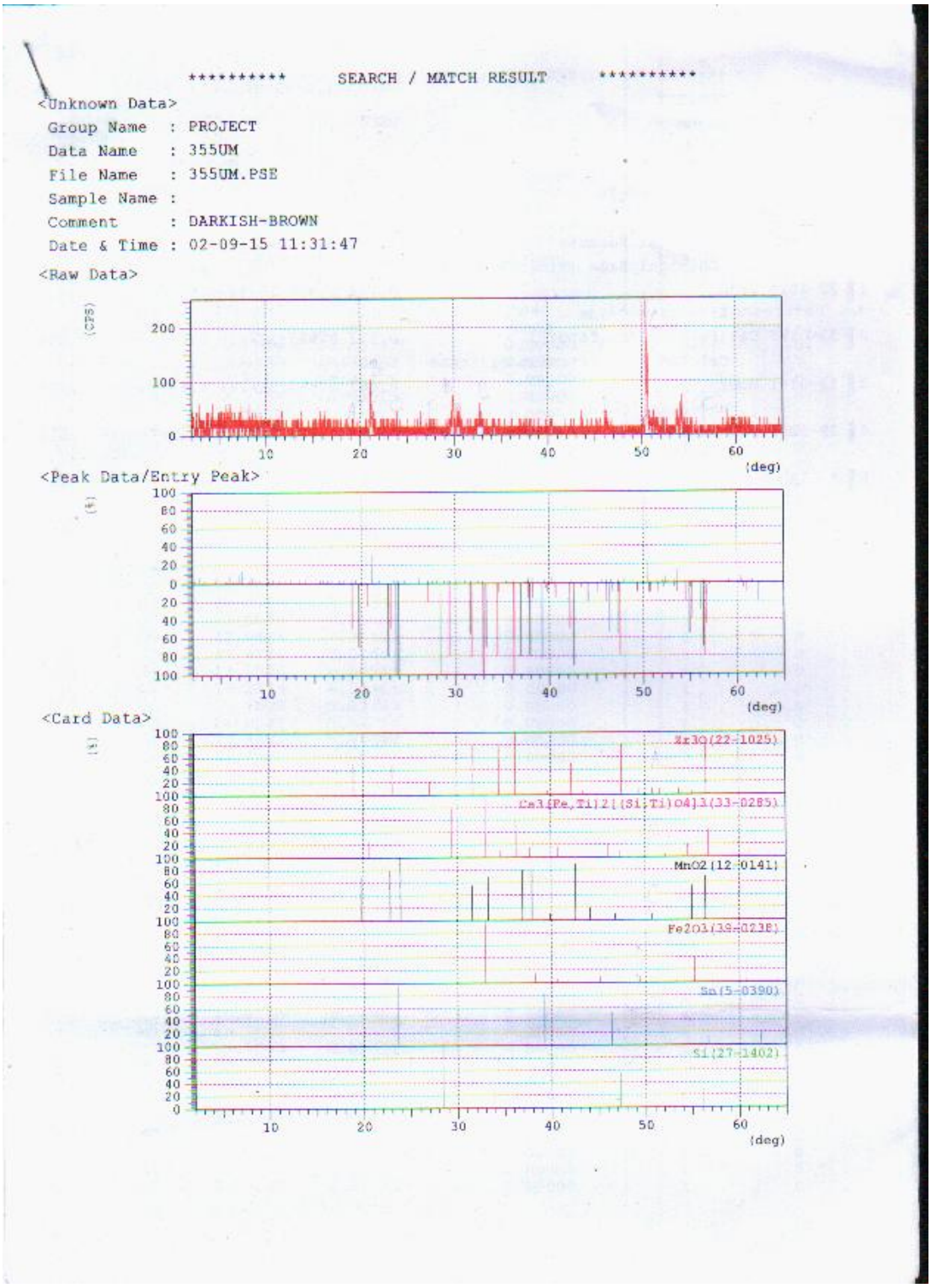


Figure A13: Defractogram of the Minerals Present in +355µm Size Fraction for the Composite Sample

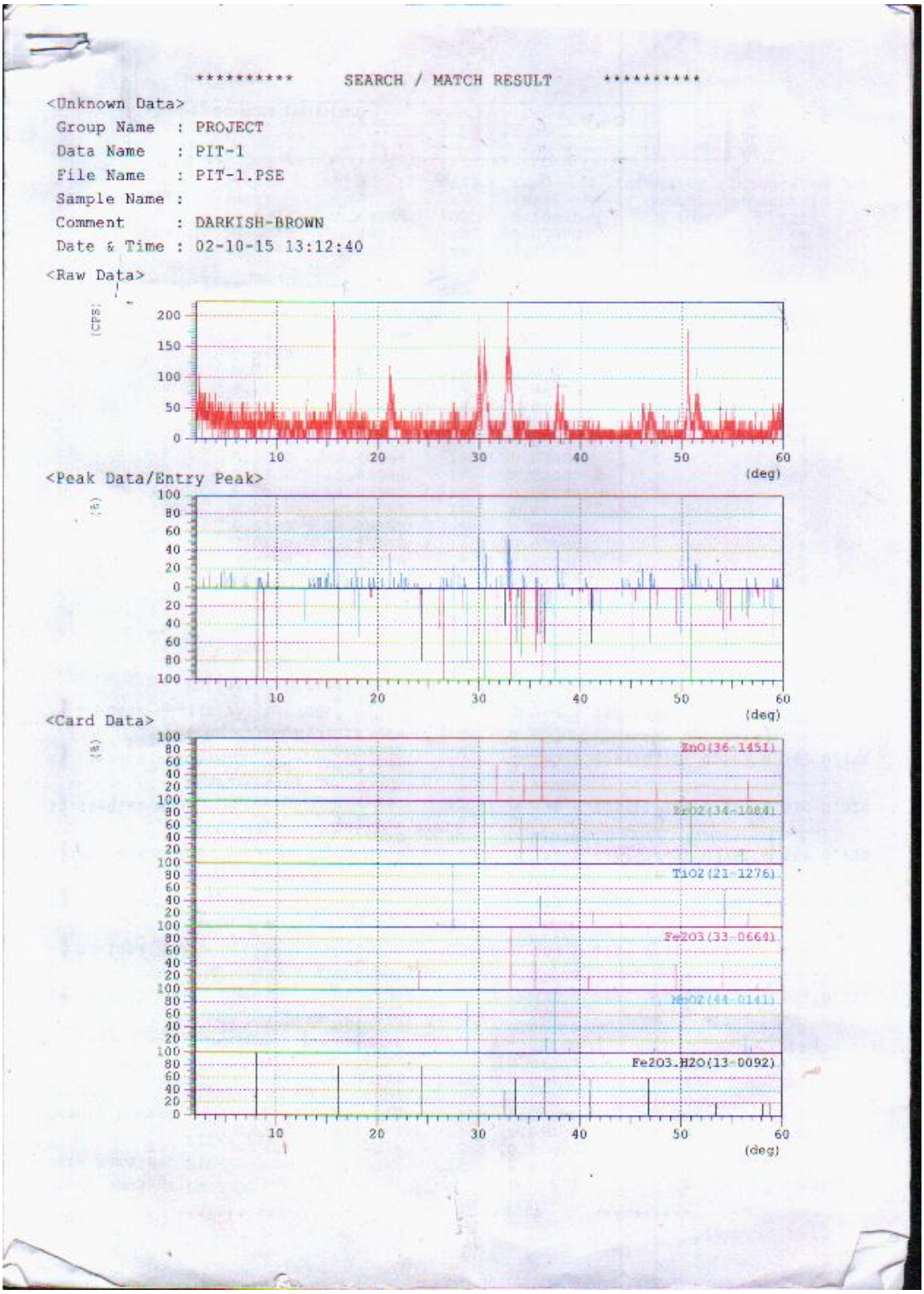


Figure A14: Defractogram of the Minerals Present In Sample from Pit 1

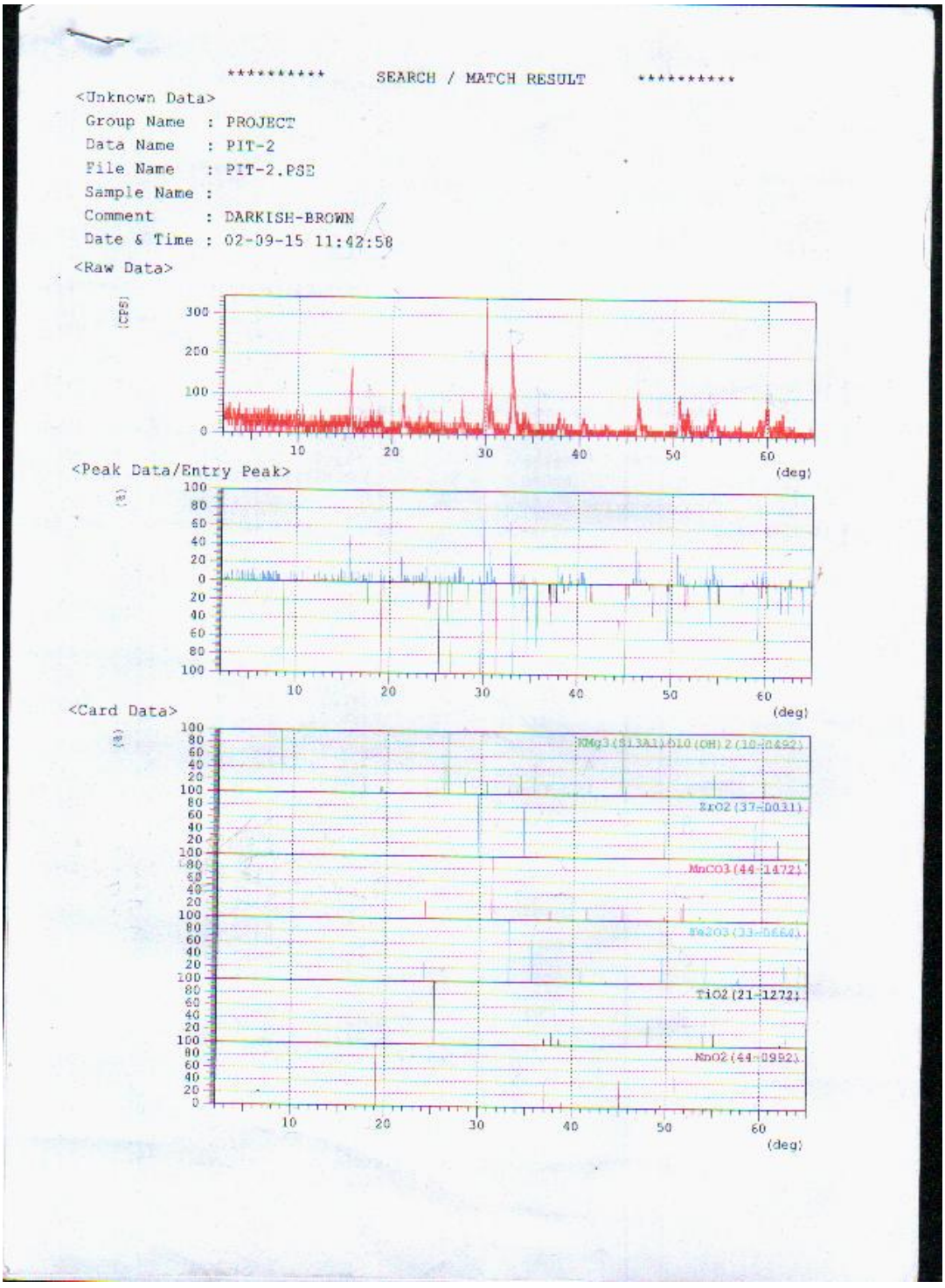


Figure A15: Defractogram of the Minerals Present in the Sample from Pit 2

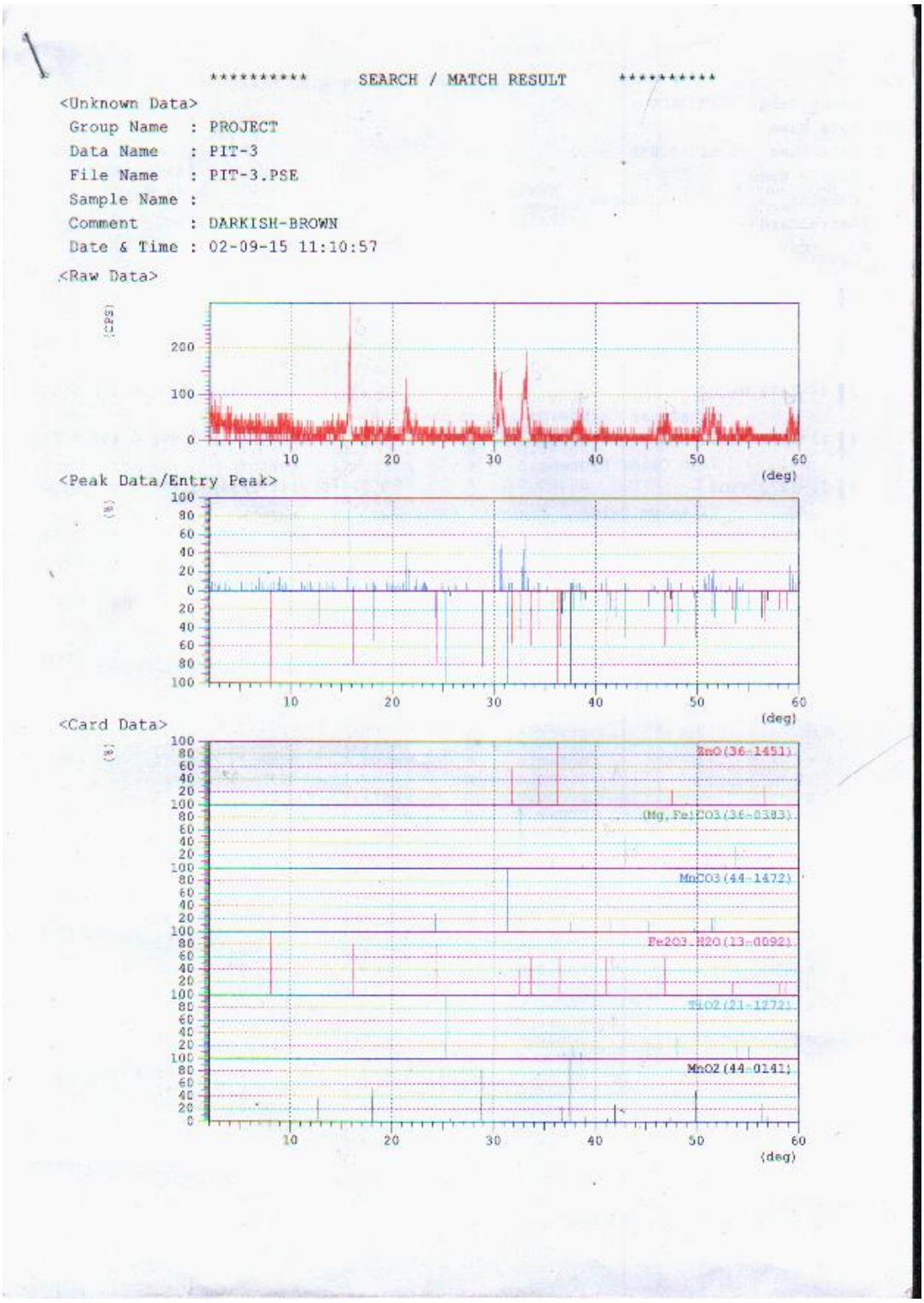


Figure A16:**Defractogram of the Minerals Present in Sample From Pit 3**

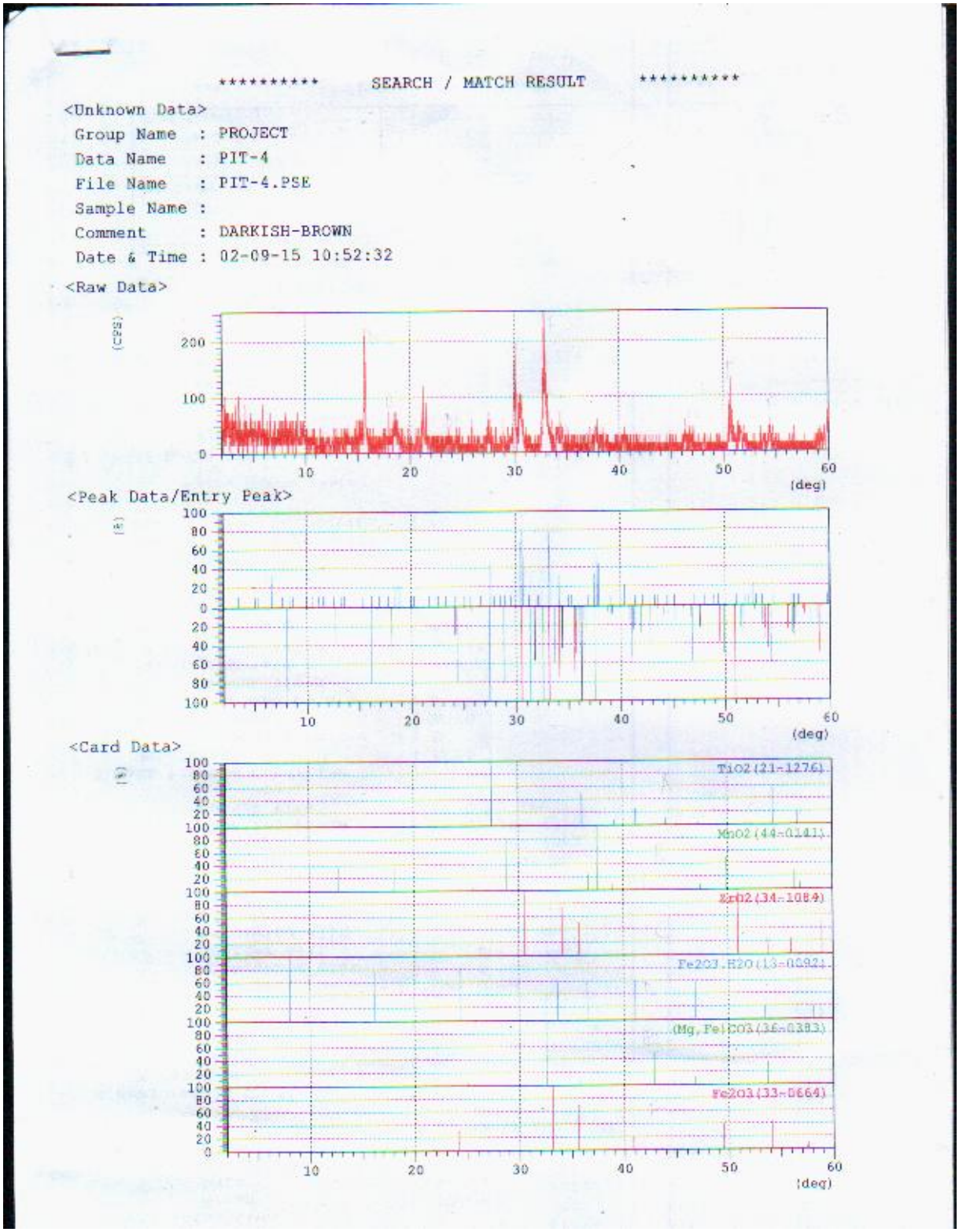


Figure A17: Defractogram of the Minerals Present in Sample from pit 4

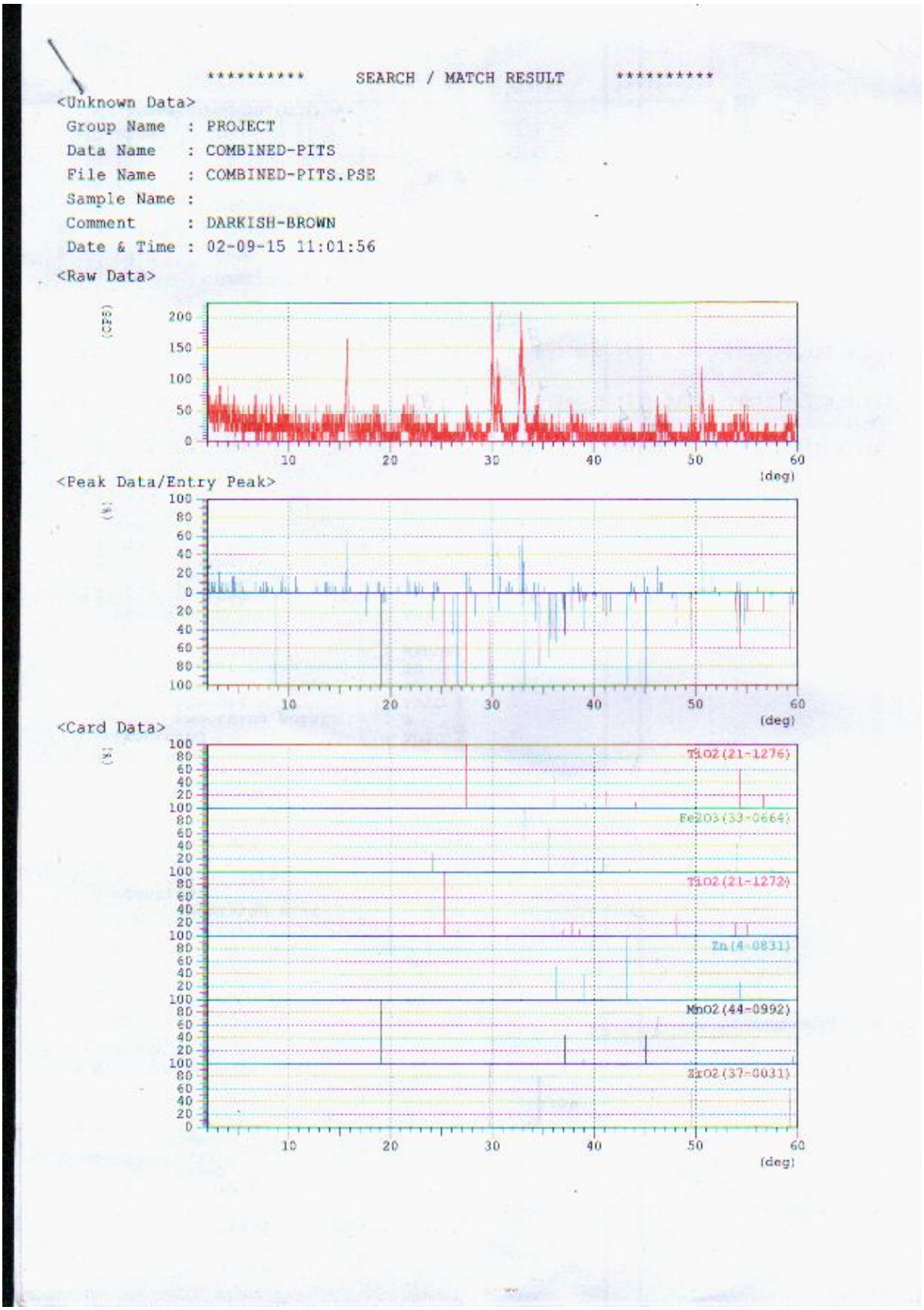


Figure A18: Defractogram of the Minerals Present in the Composite Sample



Figure A19: Satellite Image of KagarkoTown(Source: Google Earth, 2015)



Figure A20: Map of Kaduna State showing all the Local Government Areas (Wikipedia, 2015)

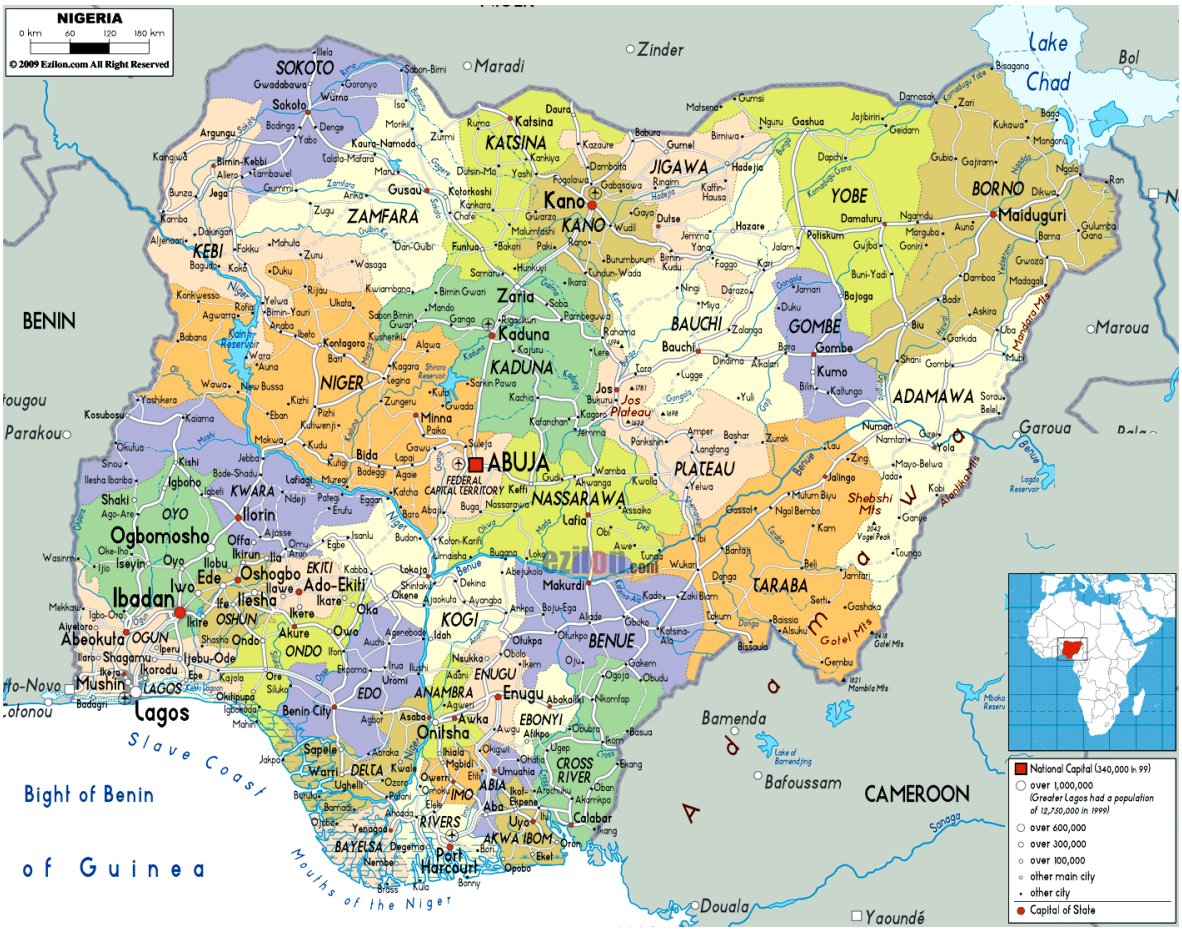


Figure A21: Map of Nigeria (Source: Google Map)



Plate A1: site of the iron deposit in Gujeni village