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Research Article

Characterization of Chemical Composition and Microstructure of Natural Iron Ore from Muko Deposits

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The study aimed at investigating the chemical composition and microstructure of raw iron ore from the deposits in Muko area (south-western Uganda). The quality of this iron ore was evaluated to establish its suitability to serve as a raw material for iron production. Samples were taken from the six hills of Muko ore deposits and tests carried out to establish their composition and properties. X-ray diffraction and scanning electron microscopy were employed in the investigation and chemical analysis performed to determine the compounds constituting the ore. The quality of this ore was compared to generalized world market standards and ores from other nations. It was found that Muko ore is a rich hematite grade with Fe content above 65%. It has little gangue (<6% SiO_2 and 3-4% Al_2O_3) and low contents of the deleterious elements ($P \sim 0.02\%$ and $S < 0.006\%$), which correspond to acceptable levels for commercial iron ores.

1. Introduction

The most commonly used iron-bearing minerals contain iron compounds as follows: hematite, Fe_2O_3 (70% Fe); magnetite, Fe_3O_4 (72.4% Fe) and of much less importance are: limonite, $2Fe_2O_3 \cdot 3H_2O$ (60% Fe); siderite, $FeCO_3$ (48.3% Fe); pyrite, FeS_2 (46.6% Fe) [1]. These iron percentages are in their pure states. In ores, the Fe content is lowered according to the amount of impurities present. Overall, 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% medium- (or average) grade ores and those below 58% Fe are considered as low-grade ores [2–5].

Iron ore consumption for steelmaking was standing at 850 million tonnes at the end of the twentieth century and was estimated to reach more than 1.3 billion tonnes over the first quarter of the century [6]. The known world resources of crude iron ores are approximately 800 billion tonnes containing about 230 billion tonnes of Fe [7]. It is apparent that most of the known deposits contain low-grade ores with iron contents less than 30%. By contemporary growth of the world consumption of iron ores (about 10% per year), the known resources of iron ores could run out within the next 64 years [8]. It is thus imperative to find new sources of iron ore to supplement the existing sources, in order to meet the growing demand. Therefore, revealing and exploiting new deposits of iron ores, particularly of high-grade, is very important.

Iron ore deposits have been known to occur in the Muko area in south-western Uganda (430 km from the capital city Kampala) since the 1920s. However, they still lay unexploited and little study has been done on them. The deposits, located on six hills in Kabale/Kisoro district, occur as hematite of high Fe content. Specific quantification for the exact tonnage has not been carried out yet but estimates put the ore reserves at 50 million tonnes of raw ore.

In exploitation of any mineral, it is important to understand the main inherent properties and composition which determine their behaviour during processing. Moreover, the characteristics of minerals also often determine the economical aspect of commercial exploitation of deposits. Therefore, the main purpose of this study is to evaluate the chemical composition and microstructure of raw iron ore from Muko deposits in Uganda. The analysed chemical compositions of this ore are compared to those of major iron ore producing nations. Furthermore, it is compared with market standards in order to assess its quality and determine the viability for commercial exploitation.

2. Experimental

Representative iron ore samples were collected from the six hills of Muko: Rushekye, Kamena, Kyanyamuzinda, Nyamiyaga, Butare, and Kashenyi. The samples were randomly collected from each hill within a radius of about 10 metres. In this study, the ores from these hills are designated with letters (a), (b), (c), (d), (e), and (f), respectively.

2 kg of each hill-sample was crushed and sieved. The necessary amount of sieve passage below 100 μm was used for mineralogical and chemical analysis. The FeO and the total Fe contents were determined titrimetrically. Thereafter, the Fe_2O_3 content was calculated from those results. The contents of C and S in iron ore samples were determined using combustion and IR absorption. The Si and Al contents were determined using XRF after fusion in $Na_2B_4O_7$. The contents of the other elements in iron ore such as Ti, P, Pb, Mg, Mn, Zn, and Cu were determined using ICP-OES.

Mineralogical analysis was carried out by X-ray diffraction using a Phillips X-ray diffractometer, PW 1130/90 with Ni-filtered K_α Cu-radiation operated at 40 kV and 30 mA. It was operated at a scan speed of 0.5 with increments of 0.02° from 20° to 80° 2θ range.

Small pieces from each hill-sample were put in bakelite and silica polished for micro structural analysis. The microstructure was observed using a Field Emission Gun Scanning Electron Microscope (FEG-SEM), LEO 1530 with a GEMINI column.

3. Results and Discussion

3.1. Chemical Composition of Muko Iron Ores. The quality of raw iron ores and its viability for commercial exploitation is mainly determined by its chemical composition. In this study, this was analysed together with the micro structure and mineralogy of Muko iron ore and compared with other exploited and exported iron ores in the world.

Table 1 shows the results of the total chemical analysis of Muko iron ore in weight percentages. The most important elements and components of consideration in iron ores are the content of Fe, gangue (SiO_2 and Al_2O_3) and contaminations such as P and S. It can be observed that in its raw form, Muko ore occurs as hematite (Fe_2O_3) with low gangue content. Samples from five hills (a, b, c, e, and f) exhibit very high hematite content, 96–98%, with correspondingly low levels of silica and alumina, 0.41–1.20% and 0.35–1.00%, respectively. In addition, sample (d) from Kashenyi hill has a lower hematite content (86.7%) and higher silica and alumina contents (5.1 and 6.0%, resp.). In addition, the ores contain other impurities such as MnO, ZnO, PbO and others, which exist in considerably negligible amounts. Alumina, sulphur, and phosphorous represent contaminations in the steel making process and are specific targets during iron ore beneficiation [9].

3.1.1. Fe Content in Iron Ores. For commercial viability, iron ores should preferably have high Fe contents and low impurity element contents, in order to justify the investment during exploitation. In the world practice, no minimum standards have been set for iron, silica, alumina, calcium, and magnesium percentages in commercial iron ores, although certain generalizations can be made [10]. However, for classification and evaluation of quality, the raw iron ores can be divided into three basic classes depending on the total Fe content: (i) high-grade iron ores with a total Fe content above 65%, (ii) medium- or average-grade ores with varied Fe contents in the range between 62–64%, and (iii) low-grade ores with Fe contents below 58% [2–5]. The generalized contents of the most important elements in raw iron ores are given in Table 2.

To understand and assess the quality of Muko ore, the contents of the major elements in this ore were compared with the composition of extracted ores from other nations. Among the biggest iron ore producing nations are China, Brazil, Australia, India, Russia, and the USA. The chemical composition of some ores from these nations is given in Table 3 [1, 11–15].

Figure 1 shows the Fe and gangue contents in the iron ores from different deposits of the major iron ore producing nations and from Muko deposit of Uganda. In this figure, the total gangue content was determined as the sum of SiO_2 and Al_2O_3 contents in iron ores. All the iron ores were divided into three groups according to the total Fe and gangue content. The ores in Group I have lower contents of gangue materials (<4%) and higher Fe contents (>65%). These correspond to the high-grade ores. Group II includes the iron ores containing 4–7% of gangue materials and 60–65% of Fe. These correlate to the medium-grade ores. Finally, Group III has higher contents of gangue materials (>7%) and between 50–63% of Fe. Most of these ores correspond to low-grade ores.

It can be observed that most of the iron ores from Uganda (Ug1-5) fall in Group I and have a 67.5–69.0% Fe content and a 0.8–2.2% gangue material content. It should be pointed out that the total iron content of most exported hematite iron ores in the world is in the range of 62–64%. Therefore, the quality of iron ores from the five hills of Muko deposit (Ug1-5) is comparable with the best iron ores from Brazil (B1-3). Thus, they are among the world high-grade ores, which can be exported.

The ore from Kashenyi hill (Ug6) contains 60.6% Fe and correlates to the medium-grade ores although it has a relatively high content of gangue materials (about 11.7%). It can be seen in Figure 1 that the quality of this iron ore is comparable to the other iron ores of Group III from United States of America (U1 and U3) and from India (I1).

Table 1: Complete chemical composition of Muko iron ore.

Ore	Ug 1	Ug 2	Ug 3	Ug 4	Ug 5	Ug 6
Mine	Rushekye	Kamena	Kyanyanuzinda	Nyamiyaga	Butare	Kashenyi
Marking	a	b	c	e	f	d
			Chemical composition (mass %)			
FeO	0.26	0.82	0.26	0.10	0.33	0.46
Fe_2O_3	97.8	97.2	98.3	98.7	96.6	86.7
SiO_2	0.96	0.80	0.41	0.62	1.20	5.10
Al_2O_3	0.58	0.65	0.35	0.43	1.00	6.00
S	<0.001	0.002	0.006	0.001	<0.001	0.003
P_2O_5	<0.02	0.02	0.02	<0.02	0.05	0.02
MnO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
ZnO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
PbO	<0.01	0.02	<0.01	<0.01	<0.01	<0.01
CuO	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
MgO	<0.01	<0.01	<0.01	<0.01	0.02	0.02
TiO_2	<0.02	<0.02	<0.02	<0.02	0.03	0.17
C	0.013	0.020	0.020	0.010	0.019	0.083

Table 2: Generalized percentages of elements of major interest in assessing iron ore quality.

Components	Total Fe			SiO_2	Al_2O_3	P	S
	Low (L)	Medium (M)	High (H)				
Content (mass %)	<58	62–64	>65	<6	3-4	0.05–0.07	0.1
Reference		[7, 8, 10]		[8]	[10]	[8–10]	[8]

Table 3: Complete chemical composition of iron ores from different nations.

Ore	Mine	Nation	Chemical composition (mass %)					Ore grade[a]	Reference
			Total Fe	SiO_2	Al_2O_3	S	P		
B1	Itabira	Brazil	68.9	0.35	0.60	0.010	0.030	H	[1]
B2	MBR	Brazil	67.3	0.79	0.72	0.005	0.037	H	[11]
B3	Carajas	Brazil	65.4	1.00	1.05	0.010	0.038	H	[12]
C1	Nanfen	China	63.4	6.28	1.17	0.110		M	[15]
A1	Goldsworthy	Australia	63.2	4.90	1.60		0.035	M	[1]
A2	Hammersley	Australia	62.7	4.20	2.73	0.016	0.059	M	[11]
A3	Irvine Island	Australia	54.4	21.3	0.23	0.040	0.010	L	[14]
I1	Goa	India	57.8	2.50	6.50	0.020	0.040	L	[1]
I2	Donimalai	India	63.5	3.00	3.00	0.050	0.080	M	[13]
I3	Bailadila	India	64.0	2.50	2.50	0.050	0.100	M	[13]
R1	Bakal	Russia	60.7	2.40	2.00	0.030	0.004	M	[1]
R2	Tula	Russia	52.2	10.10	1.25	0.100	0.600	L	[1]
U1	Mesabi	USA	57.5	10.10	0.70	0.010	0.060	L	[1]
U2	Minnesota	USA	54.3	6.80	0.40		0.230	L	[1]
U3	Reserve Pellet	USA	63.0	8.10	0.40	0.003	0.025	M	[1]
Ug 1	Rushekye	Uganda	68.4	0.96	0.58	<0.001	<0.02	H	Present study
Ug 2	Kamena	Uganda	67.9	0.80	0.65	0.002	0.02	H	Present study
Ug 3	Kyanyamuzinda	Uganda	68.7	0.41	0.35	0.006	0.02	H	Present study
Ug 4	Nyamiyaga	Uganda	69.0	0.62	0.43	0.001	<0.02	H	Present study
Ug 5	Butare	Uganda	67.5	1.20	1.00	<0.001	0.05	H	Present study
Ug 6	Kashenyi	Uganda	60.6	5.10	6.00	0.003	0.02	M	Present study

[a] H: High, M: Medium, L: Low.

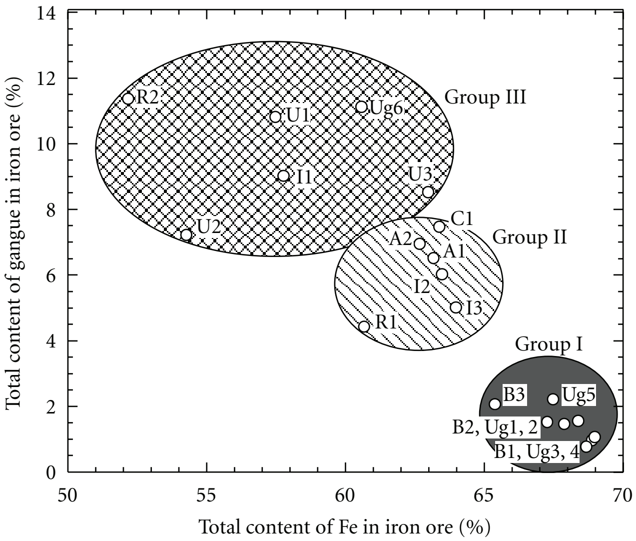


Figure 1: Fe and gangue contents ($SiO_2 + Al_2O_3$) in iron ores from different nations; A: Australia, B: Brazil, C: China, I: India, R: Russia, U: USA, and Ug: Uganda.

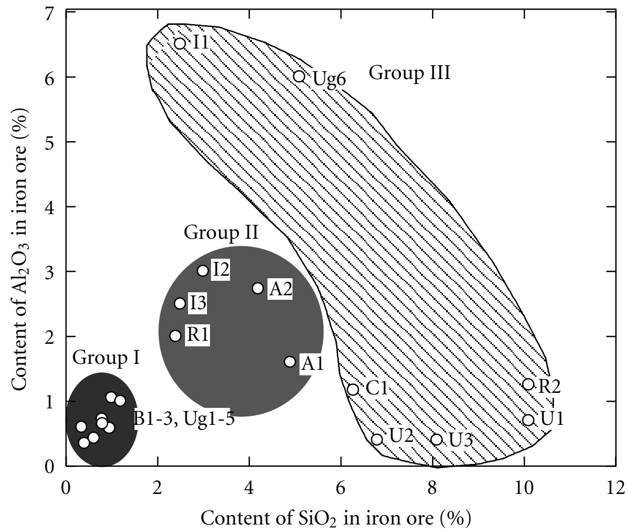


Figure 2: Contents of SiO_2 and Al_2O_3 in iron ores from different nations. A: Australia, B: Brazil, C: China, I: India, R: Russia, U: USA, and Ug: Uganda.

It can thus be noted that in comparison to the world standards and ores from other nations, most of the raw iron ores from Muko deposit are high-grade iron ores.

3.1.2. SiO_2 and Al_2O_3 Contents in Iron Ores. The alumina to silica ratio that is typically greater than one possesses serious operational problems during sintering and subsequent smelting in the blast furnace [16, 17]. More specifically, high alumina content in iron ore and sinter leads to a viscous slag during smelting in a blast furnace. This in turn requires a high coke rate [17] and results in some troubles during tapping of the viscous slag. Generalised contents for SiO_2 and Al_2O_3requirements in commercial iron ores are given in Table 2. It can thus be observed that the contents of SiO_2 and Al_2O_3 in commercial ores should be less than 6 and 4%, respectively.

Figure 2 highlights the percentages of SiO_2 and Al_2O_3 in iron ores of Muko deposit and ores from other nations. It can be observed that the silica and alumina contents in iron ores of Group I (<2% SiO_2 and ≤1% Al_2O_3) and Group II (2–5% SiO_2 and 1.5–3% Al_2O_3) are within the acceptable limits for commercial ores. However, the ores in Group III have either silica or alumina contents, which are above the acceptable levels. The three ores from USA (U1-3) and one from Russia (R2) have high silica contents, but low alumina contents. Furthermore, one ore grade from India (I1) has high alumina content, but low silica content. The ores from the five hills of Muko deposit (Ug1-5) have silica and alumina contents of 0.4–1.2% SiO_2 and 0.3–1.0% Al_2O_3, respectively. This corresponds to the ores in Group I. The iron ore from Kashenyi hill (Ug6) has high alumina content (6% Al_2O_3). However, the silica content (5.1% SiO_2) in this ore is just below the acceptable level. Overall, based on the analysis of SiO_2 and Al_2O_3 contents, it may be concluded that the iron ores of Muko deposit can serve well as a good raw material for iron production.

3.1.3. S and P Contents in Iron Ores. Phosphorus (P) and sulphur (S) are considered to be contaminants in iron ores. More specifically, phosphorus lowers the solidification temperature, increases fluidity, and renders the metal very fluid indirectly through the production of a low melting constituent in iron and steel making [18]. Moreover, phosphorus increases the cold shortness of steel. Unfortunately, phosphorus cannot be effectively removed from iron ores by fluxing and smelting during preparation of raw materials for the blast furnace process. Small amounts of sulphur in iron also have significant deleterious effects on the final properties of products (such as red and hot shortness). Here, sulphur can exist as either iron sulfide (FeS), which tends to promote cementite producing a harder iron, or as manganese sulfide (MnS), which hardens the iron [18]. The content of S in ores can be decreased by roasting and washing during preparation of raw materials to be used in the blast furnace process.

There are minimum specifications for trace elements, including sulphur, phosphorus, and most of the transition metals. These specifications though are not usually applied to the ore only, but to the general blast furnace burden. The generalized iron ore specifications for P and S in commercial iron ores are given in Table 2. It can be observed that the acceptable contents of phosphorus and sulphur in commercial ores should be lower than 0.07% P and 0.1% S, respectively.

Figure 3 illustrates the contents of P and S in iron ores from six of the major iron ore producing nations. It can be observed that most of the ores have S contents that are within the acceptable levels for the commercial ores. In addition, some ores from India (I2, I3) and Russia (R2) have P contents above the acceptable average. According to the obtained

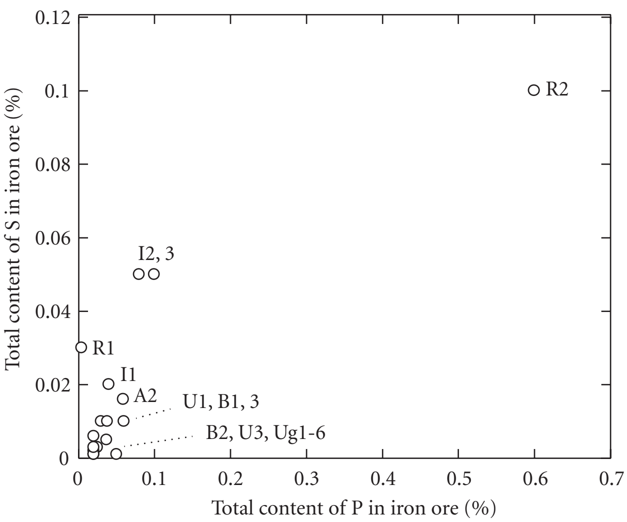


Figure 3: P and S contents in iron ores from different nations. A: Australia, B: Brazil, I: India, R: Russia, U: USA, and Ug: Uganda.

results of chemical analysis, it should be pointed out that the S and P contents in iron ores from the Muko deposit are significantly lower compared to those of the other ores. This includes the high-grade iron ores from Brazil. Thus, Muko ores are within the general acceptable levels for commercial iron ores.

In summary, Muko ore is a high-grade hematite ore with Fe content above 65%. It has low gangue content which is within the acceptable commercial level (<6% SiO_2 and ≤4% Al_2O_3) and low content of deleterious elements (<0.07% P and <0.1% S). It can thus serve well as a raw material for iron production. According to the comparison analysis, the quality of most iron ores from Muko deposit is comparable with the best iron ores from Brazil and corresponds to the world high-grade ores which can be profitably exported.

3.2. Microstructural Analysis of Iron Ores from Muko Deposit. The microstructures and the distribution of the impurities within the matrix of iron ores from the six hills of Muko deposit were investigated and analysed by using light optical microscopy (LOM) and scanning electron microscopy (SEM). Optical examination of microstructures of iron ores show generally crystalline platy structure with fibres and granular structure. The grey hematite matrix structure contains dark inclusions which are believed to be concentrations of the impurities in the ore.

Although the chemical composition of iron ores from most hills is similar, the observed microstructures of these ore samples have significant differences. Typical micrographs of the samples and qualitative evaluation of the structure in the different Muko iron ores are given in Table 4. The various shapes of microstructure were classified into six categories. It can be observed in Table 4 that the Type 1 microstructure is almost pure grey hematite matrix with small amounts of small size dark inclusions. Type 2 has mainly a grey crystalline platy structure with some area of fibrous texture. The dark impurity inclusions are located between crystalline plates and have a chaotic arrangement in the ore matrix. The microstructure of Type 3 also contains the grey crystalline platy structure. However, the length of plates on average is significantly smaller in comparison with those found in the Type 2 microstructure. Moreover, the neighbouring crystalline plates have approximately the same direction in the matrix. Some grains are also granular shaped and of small size (mostly from 10 to 40 μm). In this case, Type 3 looks as a very fine structure. In addition, Types 4 and 5 microstructures contain mainly the granular structure. The size of grains varies in the ranges from 10 to 90 μm and from 30 to 350 μm, respectively. The dark impurity inclusions are located at the grain boundaries and within grains. The size of some irregular impurity inclusions in these samples is larger than 200 μm. The Type 6 microstructure has the characteristic large size layers (with length > 500 μm) and larger areas of dark impurity inclusions.

It should be pointed out that the Muko iron ores contain different microstructure types in varying amounts. The iron ores from the different hills have differing shapes of microstructure. As follows from Table 4, the ore samples Ug3 (c) and Ug4 (e) exhibit generally the Types 1 and 2 microstructure, respectively, with a relatively low number of impurity inclusions. It is interesting to note that these samples have the highest content of total Fe (68.7 and 69.0%, resp.) and the lowest content of gangue materials (0.76 and 1.05%, resp.), as given in Tables 1 and 3. The microstructure of Ug 1 sample (a) consists mostly of a fine structure (Types 3 and 4). The sample Ug2 (b) has various shapes of structures, which includes mainly the larger grains of hematite with dark inclusions (Type 5) and fine crystalline platy structures (Type 3). The ore samples Ug5 (f) and Ug6 (d) have a relatively large area with large irregular (Type 5) and layer-shaped (Type 6) dark inclusions within the structure. These samples, particularly Ug6 sample from Kashenyi hill, have the highest gangue content as observed from the chemical analysis. The differences in the microstructure of the ore samples from the different hills of Muko deposit may be explained by the different natural conditions that prevailed during the formation of the ore [19].

To determine the composition of the main observed phases, a quantitative point analysis of the different zones in various types of microstructures was made in samples Ug2 (b), Ug5 (f), and Ug6 (d). The different phases that appear in these samples were identified in all the six iron ores. The location of the analysed zones and determined content of basic elements are shown in Table 5. The discovered impuritiy elements were Si, Al, and K. Although the structure of Zones 1 to 3 are different, the point analysis of these grain zones shows practically a pure Fe matrix with a very low content of Si (0.2–0.5%) and Al (0–0.5%). The contents of Si and Al increase in the boundary between the matrix grains (Zone 5) up to 2.8% and 2.5%, respectively. Zones 4, 6, and 7 correlate with the largest dark impurity inclusions observed in Types 6 and 5 microstructures, respectively. In these lump inclusions within the Fe matrix, Si (46–49%), and Al (29–34%) together with some amount of potassium (15–17% K) are found. Small contents of Fe (1–6%) are also found

Table 4: Typical microstructures of Muko iron ores[a].

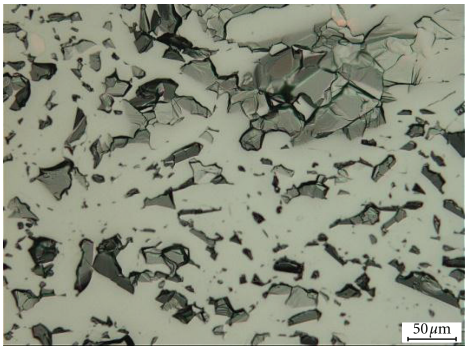
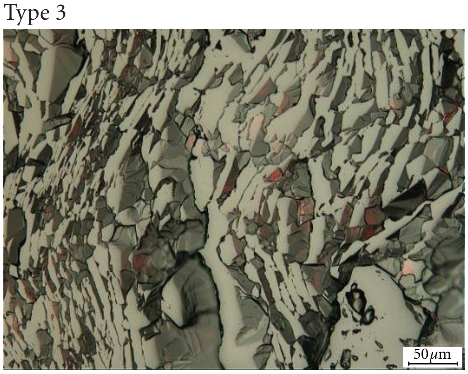
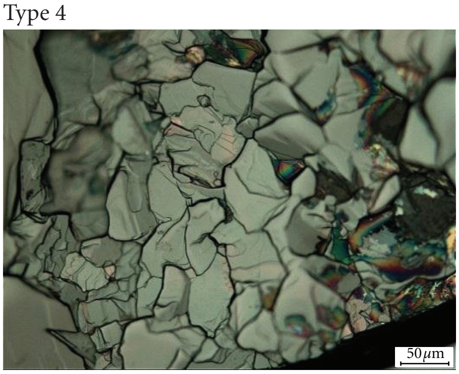
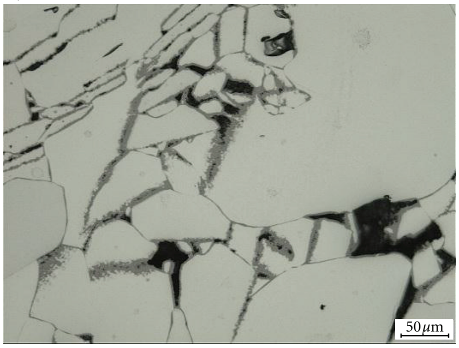
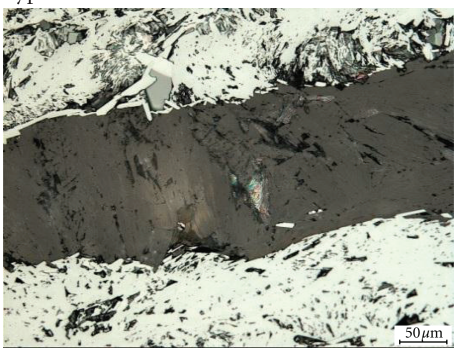
Ore sample	Ug 4 (e)	Ug 3 (c)	Ug 1 (a)	Ug 2 (b)	Ug 5 (f)	Ug 6 (d)
Total Fe content (mass %)	69.0	68.7	68.4	67.9	67.5	60.6
Microstructure: Type 1 	many	many		few		
Type 2 	many	many	some		few	
Type 3 	few	few	many	some	some	
Type 4 			many	few	some	

Table 4: Continued.

Ore sample	Ug 4 (e)	Ug 3 (c)	Ug 1 (a)	Ug 2 (b)	Ug 5 (f)	Ug 6 (d)
Total Fe content (mass %)	69.0	68.7	68.4	67.9	67.5	60.6
Type 5 				some		many
Type 6 					many	many

[a] Few: <10%, some: 10–25%, many: 25–50% of observed area.

in these lumps. These spots appear darker than the other phases.

Finally, it can be concluded that the results obtained from investigation of different microstructures and composition analysis of the various phases in iron ores of Muko deposit agree very well with the data of chemical compositions of these ores.

3.3. Mineralogical Analysis of Muko Iron Ores. The typical results of X-ray diffraction analysis of iron ores from the different hills of Muko deposit are shown in Figure 4. The chemical species observed in their decreasing order were α-Fe_2O_3, γ-Fe_2O_3, and Fe_3O_4. The major phase observed in all XRD scans of all ore specimens is α-Fe_2O_3 (the main peaks appearing at 2θ of 33°; 36° and 56° as shown in Figure 4).

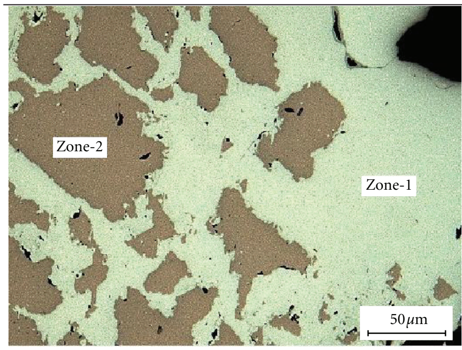
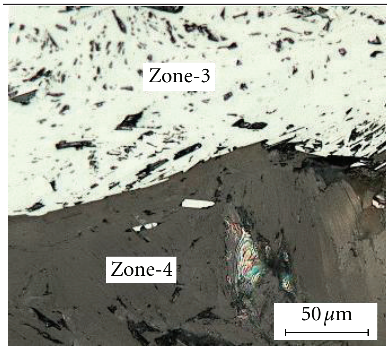
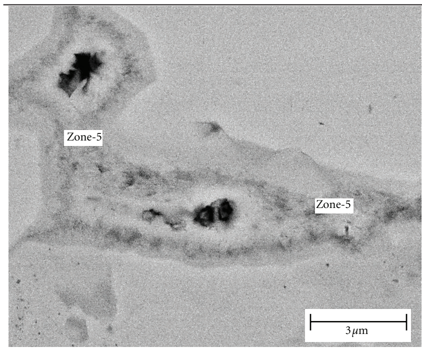
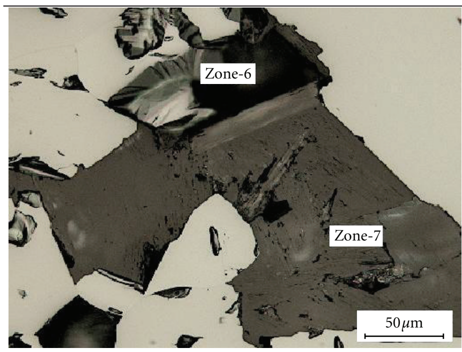
The peaks of γ-Fe_2O_3 and Fe_3O_4 were overlapping with those of α-Fe_2O_3 at 2θ of about 26°, 36° and 57°–63°. This may be due to the fact that, according to the Fe-O phase diagram, Fe_3O_4 coexists with α-Fe_2O_3 below 570°C on its Fe-rich side and is in equilibrium with α-Fe_2O_3 at low temperatures on its O-rich side [20–22]. Also, γ-Fe_2O_3 is a common constituent of tropical soils and may be dispersed in the matrix or concentrated in concretions, and it structurally appears more as a modification of Fe_3O_4.

According to obtained results of X-ray diffraction analysis, it can be safely suggested that all ore samples from Muko deposit were observed to be mainly of a hematitic nature. Certain hematite ores with high iron content (65–70% Fe), including most of Muko ores, can be used directly in blast furnace for iron making without beneficiation and agglomeration and in direct reduction of iron ore (DRI) process. Moreover, most hematite deposits require little beneficiation and can be direct-shippable ore (DSO).

4. Conclusions

The chemical composition and microstructure of raw iron ore from the six hills of Muko deposit (Uganda) were investigated. According to the obtained results of X-ray diffraction analysis, it can be concluded that all ore samples from Muko deposit were found to be mainly of a hematitic nature. It was also found that although the chemical composition of these ores is almost the same, the microstructures have significant differences. More specifically, they depend on the various natural conditions that prevailed during the formation of these ores. The results obtained from the investigations of area fractions of different microstructures and from composition analysis of various phases in iron

Table 5: Quantitative point analysis of typical phases in Muko iron ores.

Typical zones of microstructure	Analysed zone	Fe (%)	Si (%)	Al (%)	K (%)
	Zone-1 Zone-2	99.8 99.0	0.2 0.5	— 0.5	— —
	Zone-3 Zone-4	99.6 6.4	0.2 48.8	0.2 28.5	— 16.3
	Zone-5	94.7	2.8	2.5	—
	Zone-6 Zone-7	5.8 1.3	45.7 49.5	31.8 33.8	16.7 15.4

ores of Muko deposit agree well with the data of chemical compositions of these ores.

Iron ore from five hills contains more than 67.0% Fe. This is regarded as high-grade iron ore and compares well with other iron ores from the main iron ore producing nations. The silica and alumina contents of these ores are also below 1.2% and 1.0%, respectively, with correspondingly low levels of S (<0.006%) and P (<0.05%).

However, the iron ore from Kashenyi hill has lower iron content (about 6l% Fe) and higher gangue content (5% SiO_2 and 6% Al_2O_3) at low concentration of the deleterious elements (0.02% P and 0.003% S). According to commercial

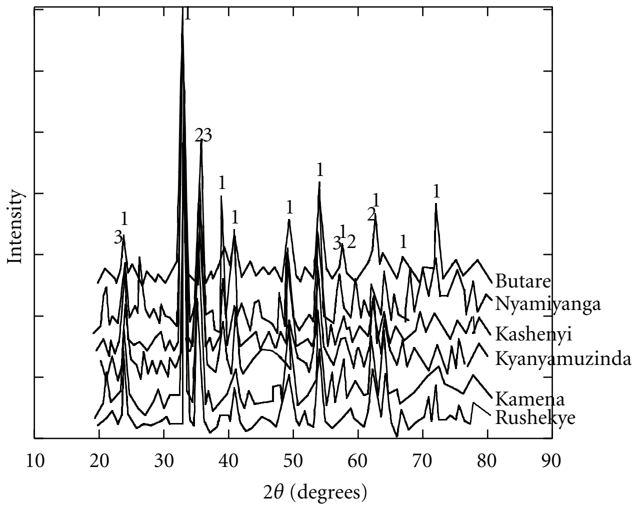


FIGURE 4: XRD pattern for Muko iron ore samples. The mineralogical composition of the ore is represented by numbers as: 1:α-Fe_2O_3, 2:Fe_3O_4, and 3:γ-Fe_2O_3.

standards for crude iron ores, this ore can be defined as medium-grade ore. Generally, the impurities in Muko ore are found concentrated as lumps within the grain boundaries and in the Fe matrix. Mineralogically, the ore is of a hematitic nature.

Based on the obtained results, it may be concluded that most of Muko iron ores are a high-grade hematite ore that can be profitably exploited for the production of iron.

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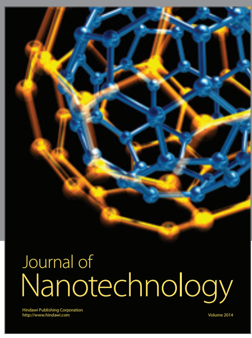
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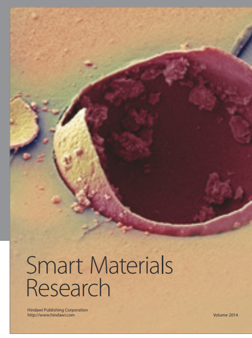
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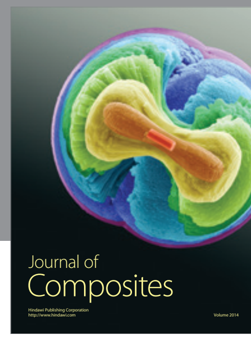
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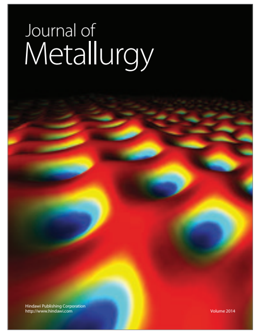
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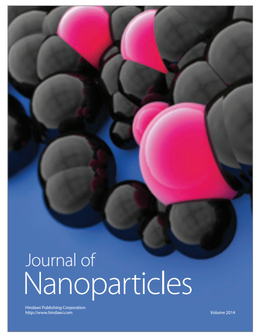
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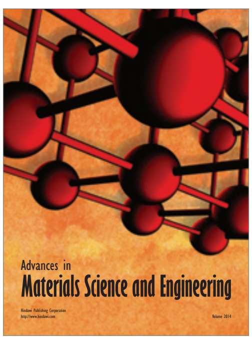
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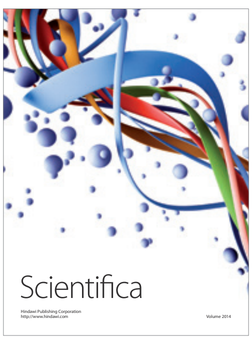
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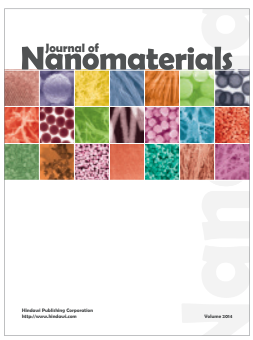
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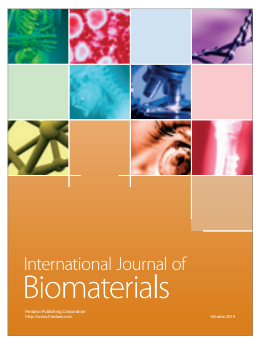
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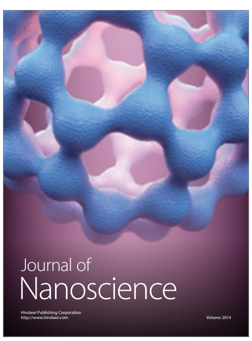
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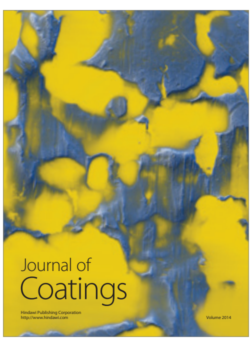
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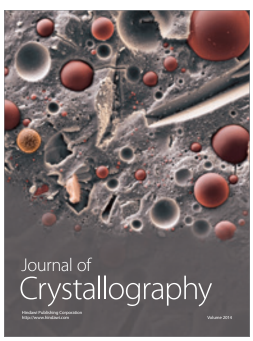
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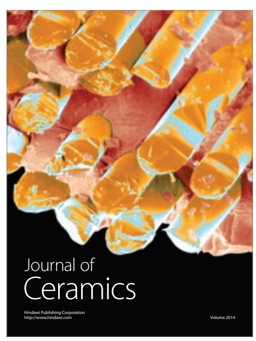
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