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# CHARACTERIZATION OF WASAGU MANGANESE DEPOSIT

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## ABSTRACT
*In this work, characterization of low grade manganese ore was attempted. The low grade ore deposit is located in Wasagu/Danko Local Government Area of Kebbi State, North Western Nigeria. The work involved chemical and mineralogical characterization of the ore. Results of chemical analysis using X-ray fluorescence spectrometer (XRF) revealed that the manganese ore contains 38.67% Mn on the average. Mineralogical characteristics of the ore determined using the X-ray diffraction (XRD) and Scanning Electron Microscope (SEM) revealed that the ore is predominantly spessartite with quartz and hematite as minor minerals while others are in trace amounts. Additionally, manganese, oxygen and iron are found to be the most abundant element in the ore from the EDS result.*
***Keywords:*** *Characterization, manganese ore, spessartine, quartz, hematite.*

## INTRODUCTION
Most of the Nigeria's manganese bearing minerals deposits are found in the schist belts in the basement complex. The schist belts include: Birin Gwari in Kaduna State, Kushaka in Niger state, Igarra in Edo State, Maru in Zamfara State, and Maska in Funtua, Katsina State. Available results of geological studies show that in Nigeria, most of the manganese deposits are of metamorphic origin. These include Tudun Kudu and Unguwar Mallam Ayuba in the Maska belt, Ruwan Dorawa and Maraba Hill in the Maru belt of North Western Nigeria. Others are the supergene enrichment deposit of Igarra formation within the schist belt of South-Western Nigeria (Mucke and Okujeni, 1984). Manganese is never found free in nature, but generally occurs as a mineral in the form of oxides, silicates or carbonates. The genesis of these manganese minerals depends on so many factors; some of the factors include environment of deposition, tectonic setting, climate and biogenic conditions, conditions of temperature and pH and etc. Basically, there are three main environments of manganese deposition; these include the igneous, sedimentary and metamorphic environment (Yaro, 1998).

Wasagu town is located in Wasagu/Danko Local Government Area of Kebbi state, (North Western, Nigeria). The town lies on latitude 6$^o$E and longitude 11$^o$N (Buhari and Bello, 2019) and falls within the Sokoto basin. The deposit from where a sample for this research work was obtained is about 10 km from Wasagu town. The manganese deposit in Wasagu and its environs covers an area of approximately 40,000 km$^2$; this is estimated figure from artisanal mined out areas (NSRMEA, 2010).

Metallurgical grade manganese ores are located in only four countries: Gabon, South Africa, Australia and Brazil and usually concentrates of up to 52.50% Mn can be accommodated for the production of ferromanganese alloys for iron and steel companies (Yaro, 1998). Hence, the low grade deposits of the world need to be beneficiated to metallurgical grade before utilization in iron and steel industries.

## MATERIALS AND METHODS
A composite sample of the manganese ore weighing 50 kg was collected from four (4) pits spaced at a distance of 5 m and a depth of 6 m respectively. The pits were dug by local artisanal miners. The average size of a sample is about 8 cm. After the composite sample was collected, it was dried, crushed, using the cone crushers to sizes ranging from 0.5 cm to 0.2 cm and was finally pulverized by grinding to 1400 µm + 63 µm.

### *Determination of Specific Gravity*
The test was carried out at the National Metallurgical Development Centre Jos, Nigeria. The specific gravity of the manganese ore was determined using a dried 50ml density bottle (pycnometer). Density of the ore was first determined after which the specific gravity was obtained by dividing the density with that of water.

### *X-Ray Diffraction (XRD) Analysis*
The XRD was done at the Faculty of Natural and Agricultural Science, Geology Department, University of Pretoria, Pretoria South Africa. The samples were prepared for XRD analysis using a back loading preparation method.

The samples were analyzed using a PAN analytical X'pert pro powder diffractometer with X'celerator detector and a variable divergence slit with Fe filtered Co-Kα radiation. The phases were identified using the X'pert Highscore plus software. The relative phase amounts (weights %) were estimated using the Rietveld method (Autoquan program).

### *Scanning Electron Microscopy (SEM)*
The analysis was conducted at the center for Scientific and Industrial Research (CSIR) building in Pretoria, South Africa, using the Field Emission Scanning Electron Microscope equipped with Energy Dispersion Spectrometer (FESEM-EDS) and a sparter coating machine.

### *X- ray Florescent (XRF) Analysis*

The XRF analysis was carried out at the National Metallurgical Centre Jos. Before the analysis, the ore was first milled to -63 µm each. Each sample was placed in the machine for one hour thirty minutes.

## RESULTS AND DISCUSSION

### *Specific Gravity Determination*

The specific gravity of the ore was found to be 4.0 which is below the specific gravity of most of the well-known manganese minerals of 4.7 (Farhat *et al.*, 2015). This low specific gravity can be due to inclusion of silica and others. The manganese bearing mineral is spessartite/almadine, a complex compound of $SiO_2$, $A1_2O_3$ and $MnO_2$.

### *Chemical and Mineralogical Analysis of the Head Sample*

The chemical analysis of the head sample (Tables 1) shows that the average manganese content is 50.14% MnO (38.67% Mn) with FeO content of 14.30% and a silica content of 7.50%. The result compared favorably with the 35% Mn sighted in the literature (Mucke, 2005) and makes the Wasagu manganese ore another potential deposit. The silica and iron contents can easily be processed out during beneficiation and slag formation (Wills and Finch, 2015). The proportions of other elemental components such as $TiO_2$ and CaO in the manganese ore are within acceptable limits (Kudrin, 1999).

Table 1: Chemical analysis of the head sample using XRF

| SAMPLE | $Al_2O_3$ | $SiO_2$ | $SO_3$ | $K_2O$ | CaO | $TiO_2$ | Cr $O_3$ | MnO | FeO | NiO | CuO | ZnO | SrO | $ZrO_2$ | $MoO_3$ | BaO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| % | 6.6 | 7.5 | ND | 0.36 | 0.73 | 0.36 | 0.09 | 50.14 | 14.3 | 0.1 | 0.06 | 0.07 | 0.07 | ND | 0.12 | 0.19 |

**XRD Result**

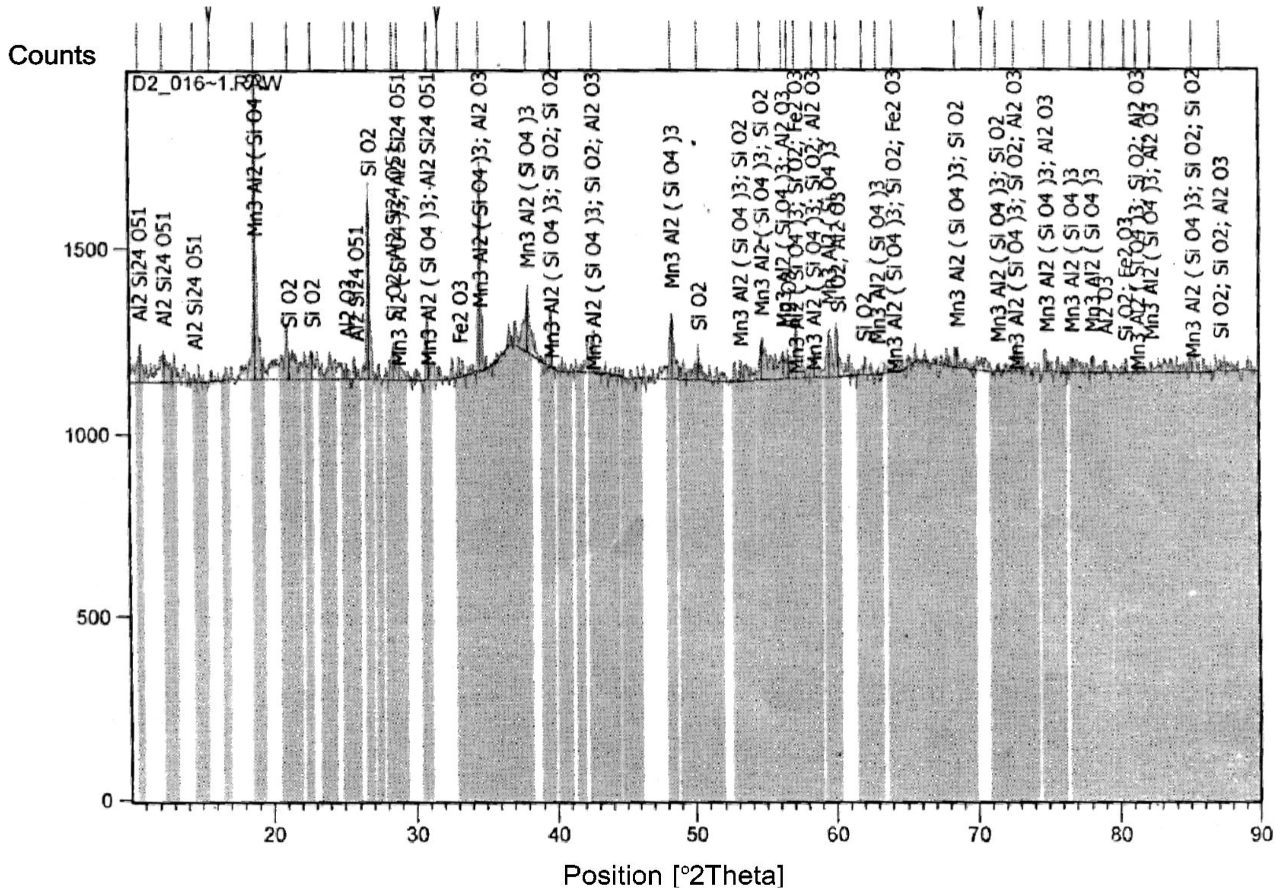



Figure 1: XRD result, indicating the major diffraction peaks of the minerals in the ore

Table 2: XRD result, revealing the major compounds found in the ore

| Ref. Code | Score | Compound name | Displacement [°2Th.] | Scale factor | Chemical formula |
|---|---|---|---|---|---|
| 01-087-1717 | 58 | Spessartine, Syn | 0.140 | 0.802 | $Mn_3Al_2(SiO_4)_3$ |
| 01-083-0539 | 46 | Quartz | 0.156 | 0.732 | $SiO_2$ |
| 01-079-1914 | 29 | Quartz | 0.205 | 0.112 | $SiO_2$ |
| 01-071-1684 | 31 | Aluminum Oxide | 0.086 | 0.225 | $Al_2O_3$ |
| 00-024-0072 | 14 | Hematite | 0.011 | 0.079 | $Fe_2O_3$ |
| 00-046-0748 | 19 | Aluminum Silicate | -0.359 | 0.076 | $Al_2Si_{24}O_{51}$ |

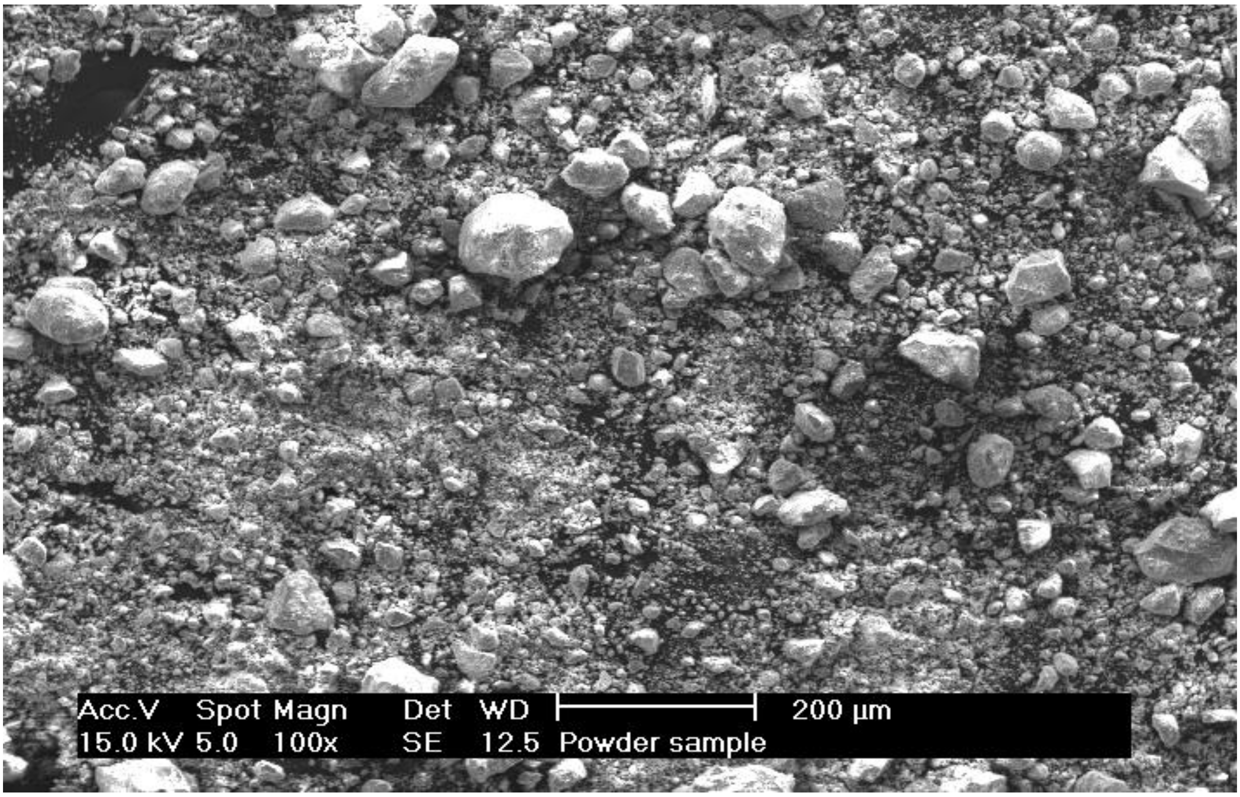
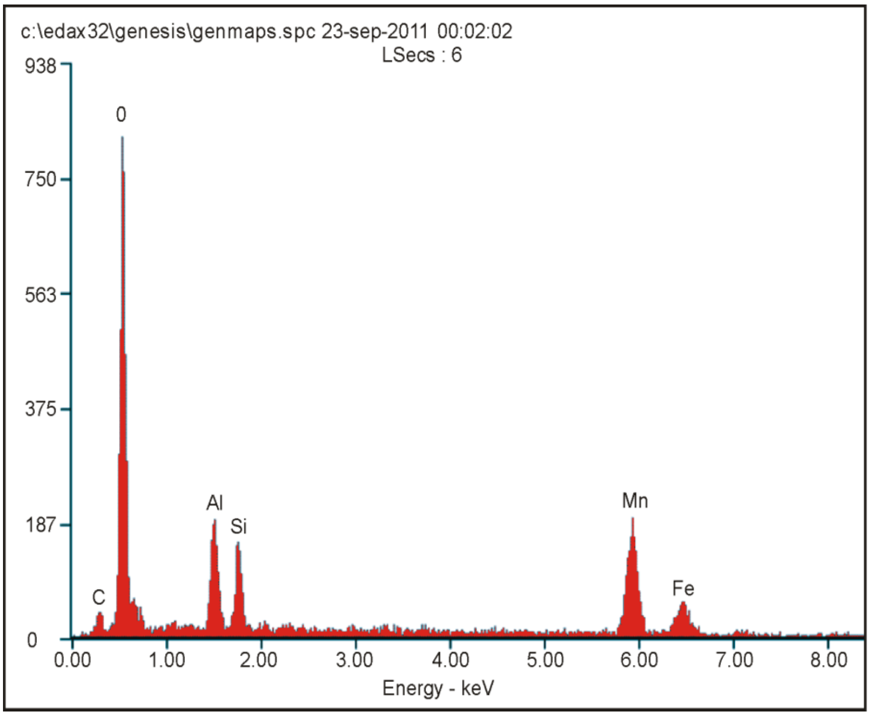



Plate 1: SEM image of Wasagu Manganese ore sample x100 showing white particles of free silica embedded in the matrix of spessartite indicated by the dark patches




| Element | wt % | At % |
|---|---|---|
| CK | 07.10 | 15.32 |
| OK | 30.52 | 49.43 |
| AlK | 07.12 | 06.84 |
| SiK | 05.39 | 04.97 |
| MnK | 38.57 | 18.19 |
| FeK | 11.30 | 05.24 |
| Matrix | Correction | ZAF |

Figure 2: SEM/EDX pattern and the major elements present in the Wasagu manganese ore

**X-ray Diffraction Spectrometer Results**

The XRD pattern in Figure 1 reveals that, the major diffraction peaks are spessartite, quartz, Aluminum oxide, Hematite, and Aluminum silicate while others are in traces. Each of these phases has a score of 58, 46, 31, 14 and 19 (see Table 2). The XRD pattern (see Figure 1) reveals that the major diffraction peaks are 74.857, 72.744, 71.462, 70.440 and 68.563 degrees and their inter-planar distances are 1.268, 1.300, 1.320, 1.336 and 1.368Å.

The XRD result shows that there is no free $MnO_2$ mineral in the ore, the manganese is in complex combination with $Al_2O_3$ and $SiO_2$. Only little free silica and $Al_2O_3$ are present in the ore. The major manganese bearing mineral is spessartine/Almandine as indicated ($Mn_3Al_2$ $(SiO_4)_3$.) This manganese bearing mineral is similar to the manganese ore found in Mallam Ayuba in Kaduna State (Yaro, 1998). In this mineral it is very difficult to isolate the manganese using any known mineral processing technique except by thermal decomposition. For instance, gravity separation cannot be employed because there are no sufficient differences between the specific gravity of the valuable (MnO) and gangue minerals ($Al_2O_3$ and $SiO_2$).

**SEM/EDS Results**

Surface morphology of the manganese ore shows manganese containing quartz, as obtained from SEM results Indicates silver colour characteristics crystals and pure black patches (matrix) which is a characteristic feature of quartz mineral ($SiO_2$) (Kerr, 2008). The SEM/EDS microstructure of Wasagu manganese is presented in Figure 2. The understanding of the mineralogy of an ore provides an insight into the liberation size of the ore and the separation technique likely to be employed in the concentration of the valuable minerals. The results obtained from SEM and XRD confirms that the manganese ore is intimately associated with other minerals and cannot be separated by any physical means, hence other complex techniques need to be employed.

**CONCLUSIONS**

Wasagu manganese ore has been successfully characterized. In the process, the chemical analysis of the ore revealed that the head sample of the ore assays 38.76% Mn. In other words, the ore contains 50.14% MnO on the average. The mineralogical characteristics of the ore revealed that it predominantly consists of spessartine, while quartz and hematite are in minor amount and other minerals associated with the ore are in traces. The study further revealed that Wasagu manganese ore have specific gravity of 4. Nevertheless, the results confirm that the manganese ore is intimately associated with other minerals and cannot be separated by any physical means, hence other complex techniques need to be employed such as thermal decomposition and froth floatation techniques.

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