DETERMINATION OF ECONOMIC POTENTIALS OF MANGANESE MINERALIZATION IN TUDUN KUDU, GIWA, KADUNA, FOR STEEL MAKING INDUSTRY IN NIGERIA.

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Abstract:
Nigeria is home to valuable manganese deposit that hold immense potential as raw materials for industrial applications like steel production, and other electrical appliances. However, the current level of manganese exploitation in the country is significantly underutilized, necessitating appropriate processing to attain desired qualities for optimal utilization. This study presents a comprehensive characterization of manganese ore from the Tudun kudu area of Giwa local government, Kaduna state, Nigeria, focusing on its petrological, chemical, and mineralogical properties. The ore samples were taken from the field and prepared in the laboratory by cutting chips from lumps, grinding and polishing the surfaces, and mounting them on slides for microscopic analysis. The chemical composition was determined using X-ray Fluorescence (XRF), while the mineral phases were identified using X-ray Diffraction (XRD). The results revealed the presence of heavy minerals and a segregated distribution of minerals in the samples. The XRF analysis indicated a manganese content of 74.81% MnO and 62.16% Mn, along with significant amounts of Fe_2O_3 9.56% and Al_2O_3 4.1%, The major mineral phases identified included Pyrolusite (MnO, 1.098) spessartine (Gondite) ($3MnO,Al_2O_3$), Silicon oxide (SiO_2,0.98), Almandine ($Fe3Al_2SiO_2$) and Quartz (SiO_4,1.056). These findings highlight the potential of the Tudun kudu manganese ore as a raw material for various industrial applications, including steel, batteries, and electrical appliances. However, further processing is required to attain desirable qualities for effective utilization. The study provides valuable insights for the development of suitable beneficiation processes to enhance the quality and economic viability of the manganese ore in the region.

Keywords: Manganese deposits, Steel production, Tudun kudu, Petrological properties, Mineralogical analysis.

INTRODUCTION

The word manganese comes from the Latin word *manganese* which means magnet. Manganese is a metallic element and one of the transition elements of the first long period of the Periodic Table with chemical symbol Mn, lying between chromium and iron, it is the twelfth most abundant element in the Earth's crust, approximately 0.1%. Manganese is the most important of the ferroalloy metals. It does not occur as a native metal in nature but in combination with other elements forming oxides and silicates often referred to as ferromanganese nodules or Manganese nodules.

Manganese mineralization in Nigeria has great potential for the steel-making industry. Nigeria is one of the countries in Africa with significant manganese mineralization, estimated at over 5 million metric tons, which is mainly found in the Northern states of Zamfara, Kaduna, Katsina, and Kebbi. (Kehinde, et al, 2020)

Steel-making is a significant economic activity in Nigeria and is vital for the country's industrialization and infrastructure development. Steel is an essential material for various construction projects, including bridges, buildings, and roads, as well as for machinery and equipment in various industries.

Manganese is a critical component in the production of steel, acting as a deoxidizer, desulfurizer, and alloying element. Manganese enhances the strength, toughness, and hardenability of steel, making it suitable for use in construction, machinery, and transportation. With Nigeria's significant manganese mineralization, the country has the potential to become a major supplier of manganese to the steel-making industry in Africa and Globally.

The utilization of Nigeria's manganese mineralization can provide significant economic benefits to the country. The exploration and exploitation of manganese deposits in Nigeria can create employment opportunities and generate revenue for the government through taxes and royalties. The development of the steel-making industry in Nigeria can also lead to the growth of downstream industries, such as construction and manufacturing, creating a multiplier effect on the economy.

However, the full potential of manganese mineralization for the steel-making industry in Nigeria is yet to be realized. The exploration and exploitation of manganese deposits in Nigeria face several challenges, including inadequate infrastructure, inadequate funding, and inadequate mining technologies. There is a need for the government and private sector to invest in the exploration and exploitation of manganese deposits, as well as in the development of the necessary infrastructure, to unlock the full potential of manganese mineralization for the steel-making industry in Nigeria.

Most of the manganese found in Nigeria, so far are in the form of manganiferous ores and occur as small bodies and discontinues bands. Manganese occurs in various forms and grades in many localities in Nigeria. These include Tudun Kudu (our case study), Malam Ayuba, Gayan, Tsofon Birnin Gwari and Ungwan Nachibi in Kaduna state: Ruwan Dorowa and Mariri in Zamfara State; Gunni, Ayaba and Budwi in Niger state and Oban Hills in Cross River State, (Ogundele *et al,* 2019).

Known Manganese occurrences in Nigeria appear to be concentrated in the western Metasedimentary belt of Northern Nigeria, mainly in Kaduna, Niger and Sokoto states. Small quantities of manganese have been reported from basement rocks in south eastern parts of Nigeria and adjacent Cameroun (Geol. Surv. Nigeria, Ann. Rept. 1942, 1955-6), and manganese oxides are a ubiquitous minor constituent in Peneplain laterites, which are widespread throughout the country. The Tudun Kudu, deposits occur within metamorphosed rocks; phyllites, schists and quartzite. Other manganiferous deposits in Niger and Sokoto states also occur in the same geological setting. The manganiferous deposits are low grade ores ranging from 9.4 -35% MnO. The manganese content is contributed by manganese-bearing and manganese oxide minerals, viz; spessartite, other minerals such as garnet, quartz, iron oxide and tourmaline were present in appreciable amounts.

Problem Statement / Justification

In 1970, Wright and McCurry discovered manganese in the Tudun Kudu area. The presence of manganese oxides in the region was a result of supergene alteration of a spessartite-quartzite lens within the metasedimentary belts. However, little research has been conducted on the manganese mineralization in Tudun Kudu.

To determine the economic viability of these mineral deposits, a geochemical and mineralization study is needed. This study would assess the Tudun Kudu - Giwa manganese deposit, which could be a valuable source of alloy material for African Natural Resource and Mines Ltd, a major company involved in iron ore mining in Kaduna. Additionally, the manganese deposit could benefit other steel industries in Nigeria and Africa as a whole.

Aim and Objectives

Aim:

The aim of this research is to study the petrographic and geochemical peculiarities of manganese occurrences in the Tudun Kudu area, Giwa, with a view to establishing their genesis and economic potentials.

Objectives:

1. To determine the petrological and mineralogical characteristics of the manganese associated rocks.
2. To determine the geochemistry of the rocks in order to infer the genesis of the Manganese with the aid of major and trace elements concentrations
3. To determine the extent, nature, geochemical composition as well as quality of the manganese mineralization.

LITERATURE REVIEW

Wright and McCurry (1970) recorded the first occurrence of Manganese in the area. According to their description, supergene alteration of a spessartite-quartzite (gondite) lens within the metasedimentary belts has resulted in concentrations of manganese oxides in the area mapped. They described the metasediments as characterized by generally steep isoclinal folding with predominantly north-south trending axial plane. The previous geological work carried out by them is largely restricted to reconnaissance techniques of aerial photograph interpretation supplemented by selected field traverses by McCurry (1970b).

Through the geological mapping of the Zaria area (Sheet No.102 SW) they reported tourmaline to be widespread in or near the Young metasedimentary beds and in some cases occur in association with quartz. McCurry and Wright (1970a) reported the occurrence of the manganese mineralization at Ugogo near Tudun Kudu. The interest of subsequent workers in the area is centred on the described manganese mineralization. And the National Steel Council dug a trench across the mineralization (Manganese), in apparent attempt to the line its extent and attitude and to enable sample material to be collected. Mucke and Baer (1982) reported that Manganese deposits in northern Nigeria are confined to the metasedimentary belts which mainly or exclusively are composed of phyllites. They described the rocks formerly mapped around Tudun Kudu as "barren quartzite" highly sheared vein-quartz which occur along cleavage planes of phyllites and occasionally are rich in tourmaline. Dada (1982) and Ogundele (1982) also worked immediately south of the study area, where they studied the geology and geochemical secondary dispersion patterns of the occurrence of manganese in the southern part of Tudun Kudu area. Dada (1982) reported that the geology of the area is characterized by basement gneiss, metasediments (phyllites), and Pan-African granite including late intrusive and the presence of manganese mineralization in the area. The ore microscopic evidence he documented showed that in addition to the primary manganese minerals (spessartite), other minerals such as garnet, quartz, iron oxide and tourmaline were present in appreciable amounts.

The metasediment in the area was mainly phyllites, which is intercalated with quartz veins. The Pan-African granites are mainly grannodiorites (part of which was highly weathered and jointed) and diorite with a boundary exposure. Dada, (1982) also noted that the quartz veins (late Intrusives) are of two varieties, the greyish-white, variety forming prominent ridges with regular fractures while the yellow-white variety which intercalate with phyllites and are foliated. However, Ogundele (1982) reported that the portion of Tudun Kudu area he mapped is underlain by basement rocks composed of meta-sediments, predominantly phyllites and the manganese mineralization is hydrothermal vein type.

He also noted that the area was devoid of major structures, except the prevalent N-S regional trend. Polish section examination by Ogundele (1982) revealed that the Manganese ore body has quartz, iron oxide and hydroxides, tourmaline in addition to primary manganese minerals like spessartite, pyrophanite, manganese oxide hydroxide. The high percentage of aluminium couple with the low concentration of manganese makes the ore body to be of low economic value.

Location and Accessibility

Giwa Local Government is located in Kaduna State, Nigeria. It is situated in the north-western part of the country. The local government area shares boundaries with other local government areas in Kaduna State, including Igabi, Chukun, and Kaduna North. Figure 1.

Accessibility to Giwa Local Government is primarily through road transportation. The major roads connecting Giwa to other parts of Kaduna State and neighbouring states are the Kaduna-Zaria Expressway and the Kaduna-Kano Road. These roads provide convenient access to the local government area and facilitate the movement of people, goods, and services.

The Kaduna-Zaria Expressway is a major highway that links Giwa Local Government to the city of Kaduna, the state capital. This road is well-maintained and offers a smooth journey for commuters. The Kaduna-Kano Road, on the other hand, connects Giwa to the neighbouring state of Kano, offering access to various destinations along the route.

Within Giwa Local Government, there are also several internal roads and routes that connect the various towns and communities within the area. These roads enable residents to travel within the local government and access different facilities and services.

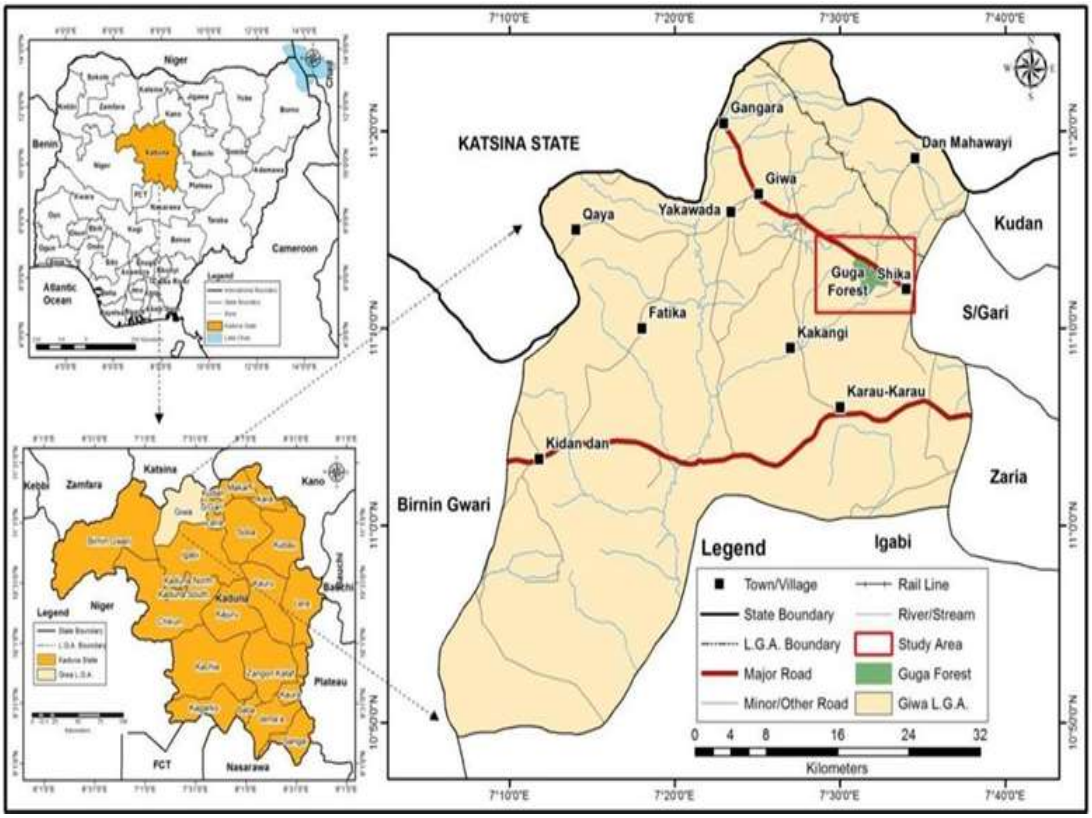

Figure 1. Map of Giwa local government (Source: NGSA, 2019)

Petrology

The basement complex is one of the three major lithological components that make up the geology of North-western Nigeria. The Nigerian basement complex forms a part of the Pan-African mobile belt and lies between the West African and Congo Craton and south of the Tuareg Shield which was affected by the c. 600Ma Pan-African. The Pan-African deformation was accompanied by a regional metamorphism, Magmatisation and extensive. Late tectonic emplacement of granites and grannodiorites and associated contact metamorphism accompanied the end stages of this last deformation (Obaje, 2009). The end of the orogeny was marked by faulting and fracturing which have a consistent NE-SW and NW-SE trends, within the Basement complex of Nigeria, three major rock groups are distinguishable (Figure 2), namely:

a) The Migmatite-Gneiss Complex
b) The Schist Belts (metasedimentary and Metavolcanic rocks)
c) The Older Granites (Pan African Granitoids)

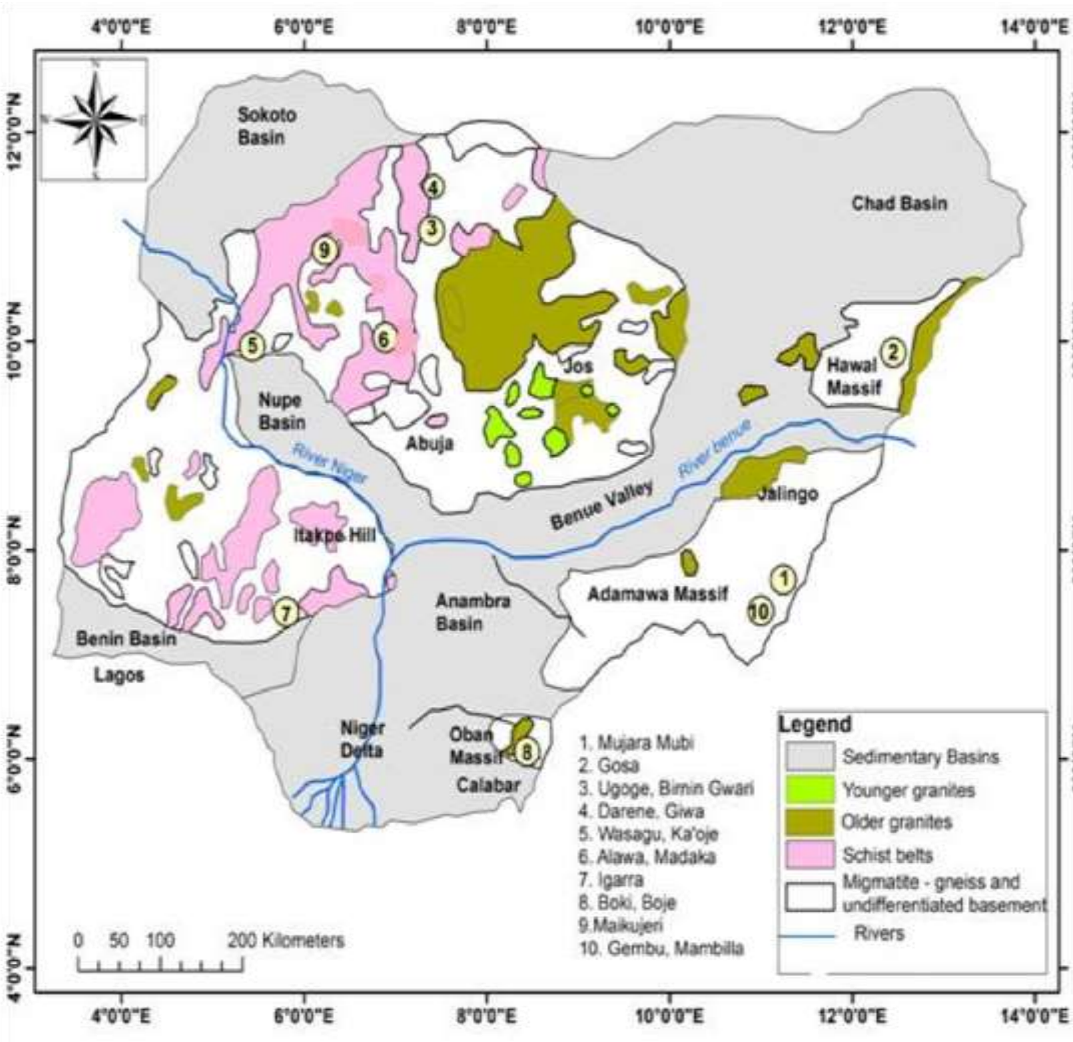

Figure 2: Simplified geological map of Nigeria Basement Complex showing the occurrence of manganese deposits (Modified after Woake et al., 1987, Mucke, 2005 and Akintola, 2019).

The Migmatite-Gneiss Complex

This is a polymetamorphic trigmatite-gneiss complex composed largely of migmatites and gneisses. The migmatite-gneiss complex is considered to be the basement ***sensu stricto***, and most radiometric ages lies in the range 600 +/- 50 Ma, dating the imprints of the Pan-African orogeny, but with relict Eburnean (c. 2000 Ma) and Liberian (c. 2700Ma) ages obtained in many localities. Metamorphism is generally in the amphibolite facies grade.

The Schist Belt (Metasedimentary and Metavolcanic rocks)

The supracrustal schist belts consist dominantly of schists, phyllites and quartzites with minor volcanic rocks, banded iron formations and conglomerates. Metamorphic grades are variable from amphibolite facies in the southern belts to predominantly green schist facies in the northern belts. The dominant tectonic fabric is a steeply dipping N-S phyllites to slaty cleavage arising from isoclinal folding. Radiometric ages of the schist belts range between c. 1100 Ma (Kibaran) and c. 600 Ma (Pan-African).

The Older Granites (Pan-African Granitoids)

These are syntectonic to late tectonic granitic rocks, which cut both the migmatite-gneiss complex and the schist belts. The Granitoids include rocks varying in composition from granite to tonalites, with smaller bodies of syenite, charnockite and gabbro. They have generally yielded radiometric ages in the range of 750-500 Ma, corresponding to the Pan-African age.

World Manganese Resources and Production

Manganese is a widely distributed element with global resources estimated to be around 690 million metric tonnes (MMT). The largest manganese deposits are found in South Africa, Australia, Brazil, Gabon, and China.

According to the United States Geological Survey (USGS), the world production of manganese ore in 2021 was estimated to be approximately 20.4 MMT. South Africa was the leading producer, accounting for about 34% of global production, followed by Australia (16%), China (11%), and Gabon (10%). Other significant producers include Brazil, Ghana, India, and Ukraine.

The demand for manganese is expected to continue to grow, particularly in developing countries where infrastructure development and industrialization are driving steel production.

Mining and Processing

Depending on their size, grade and morphology, manganese deposits are mined by either underground or open pit methods, or a combination of both.

Where an ore body is close to the surface (normally less than 100 m depth), open pit mining is favoured as it is more cost effective than underground mining. This method typically involves removing the overburden, digging the ore or blasting with explosives, then removing the ore by truck or conveyor belt for stockpiling prior to further processing. Typical example is the Voisey's Bay deposit, Canada. Here sulphide deposits are drilled on 5 m benches. After mining, pure manganese is produced by hydrometallurgical and electrolytic processes. The higher oxides, MnO_2, Mn_2O_3, and Mn_3O_4 can all be reduced to Manganese Oxides MnO by carbon monoxide.

Environmental Impact of Manganese

Manganese is an essential nutrient, but it can also be toxic at high levels. Exposure to high levels of manganese can cause neurological symptoms, including tremors, difficulty walking, and cognitive impairments. Manganese pollution can also have a negative impact on the environment, particularly on aquatic ecosystems. High levels of manganese in water can harm fish and other aquatic organisms, causing reproductive and developmental problems.

Manganese Prices

Manganese prices globally are expected remain around 4.5 US dollars per metric ton unit CIF between 2020 and 2022. (Figure 3) Low grade manganese price may fall further.

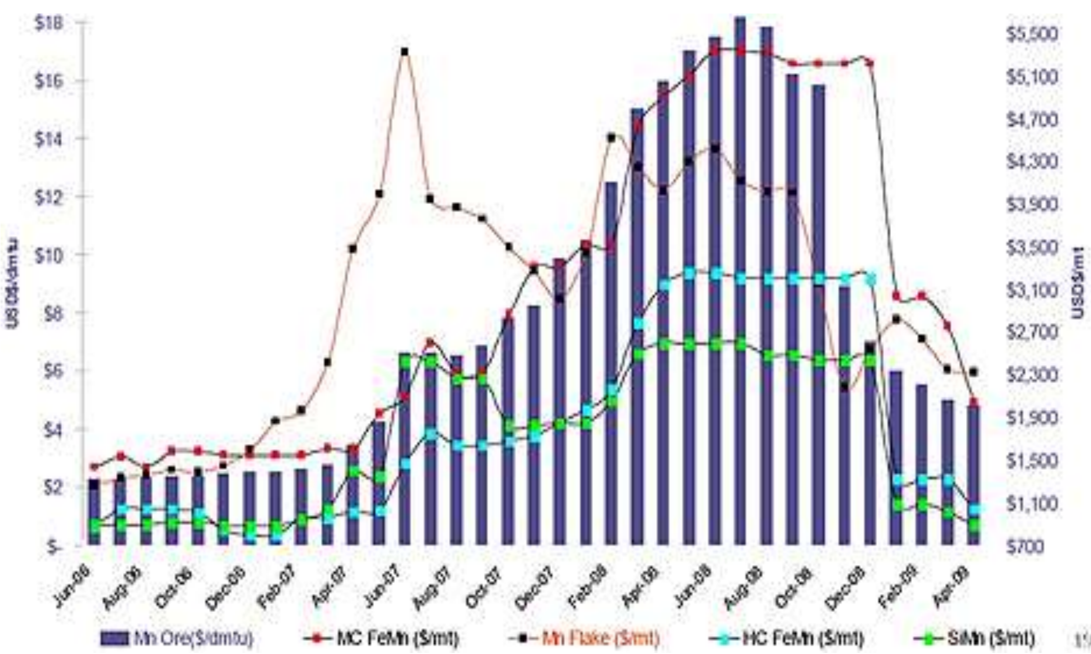

Figure 3: Manganese Commodity Prices chart (Source: from USGS Mineral Commodity Summaries, 2020)

METHODOLOGY

The methodology used in the execution of this work consists of remote sensing and desk studies, followed by field mapping (petrographic studies), sampling and laboratory analysis, which includes: Scanning Electron Microscopic Analysis (SEM) and differential thermal analysis. A detailed study of surface sample preparation and ore microscopy was carried out following Fuerstenau and Hau (1977). The principle of X-ray diffraction (XRD) and Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRFS) was applied in accordance with the Warsaw Convention (1996) at Geoplate Discovery Nigeria limited in Kaduna, Nigeria.

Remote Sensing Study and desk study

Desk studies was carried out using Google Earth pro software and Arc GIS Pro 2021 version, the satellite imageries were captured to determine the accessibility, geological lithologies and structures using Google Earth pro while the Arc GIS Pro, was used to produce the satellite imagery figure 4 below. And the samples location were identified during filed survey.

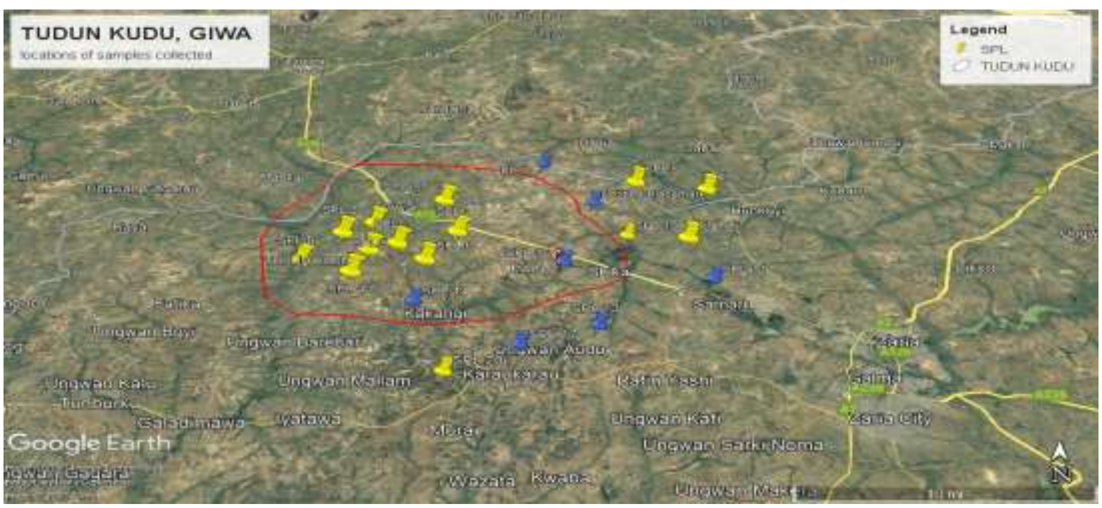

Figure 4: satellite imagery showing the locations of sample collected for analysis.

Sampling

A total of twenty samples of Tudun kudu manganese were collected, using use a hammer and chisel to chip off a small piece of rock at different locations as shown on the satellite imagery figure 3, which were then placed in a sample bag container and numbered SPL1 to SPL 20. The samples (Figure 6 A and B) were homogenized using quartering and cone method and it was taken to laboratory for analysis.

Filed Geology/ Petrographic

The field studies revealed that the area is underlain by metasedimentary schist belt and the manganese mineralization in Tudun kudu is characterized by spessartite-quartzite vein, apart from the hill at centre of Tudun kudu, the general morphology of the area is devoid of structures except the prevalent N-S regional trend observed. The photomicrograph (Figure 5 A and B) shows a non-evenly, sparingly, and segregated distributed manganese ore and it reveals that there are associated minerals like tourmaline.

Chemical analysis of the manganese ore sample

A sample of manganese ore weighing 20 grams was finely processed and mixed with a binder. The mixture was then pelletized under pressure and kept in a desiccator for analysis. After a two-hour warm-up period, an Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRFS) was used to chemically analyse the sample. Finally, suitable programs for the various elements of interest were used to detect the presence or absence of the sample material(s). For minor and major element concentrations, the analysis result was reported in percentage (%) or parts per million (ppm).

X-Ray Diffractometric Analysis

XRD analysis was conducted on the prepared sample using a back-loading method. Analytical Empyrean Diffractometer with a Pixel detector and fixed slits, along with Fe-filtered Co-K radiation, was utilized for the analysis. The X'PertHighscore Plus software was employed to identify the phases present in the sample and calculate their relative weights using the Rietveld method. The SEM (JEOL 840) provided high-resolution images to study the physical properties and morphology of the minerals, while the EDX spectroscopy revealed information about their elemental composition. The samples underwent a preparation process involving cutting, polishing, embedding in epoxy resin, and carbon coating before analysis. The resulting data enabled the generation of backscattered images (BSI) and facilitated a comprehensive understanding of the minerals' characteristics and chemistry.

RESULT AND DISCUSSIONS

Result

Table: 1 Chemical Composition of Tudun Kudu Giwa-Kaduna) Manganese Ore

SiO_2	Al_2O_3	CaO	TiO_2	K_2O	MnO	Fe_2O_2	V_2O5	CuO
3.9	**4.1**	**0.87**	**0.23**	**0.22**	**74.81**	**9.56**	**0.21**	**0.068**
ZnO	**NiO**	**SrO**	**ZrO_2**	**RuO_2**	**MnO_3**	**ReO_7**	**Mn**	**TiO_2**
0.23	**0.11**	**0.08**	**0.035**	**0.43**	**0.31**	**0.12**	**62.1**	**0.004**

Note: The chemical composition are in percentage (%) the major mineral phases identified included Pyrolusite (MnO, 1.098) spessartine (Gondite-) (3MnO, Al2O3), Silicon oxide (SiO_2, 0.98), and Almandine ($Fe3Al_2SiO_2$) and Quartz (SiO_4, 1.056) and they are part per million. (PPT)

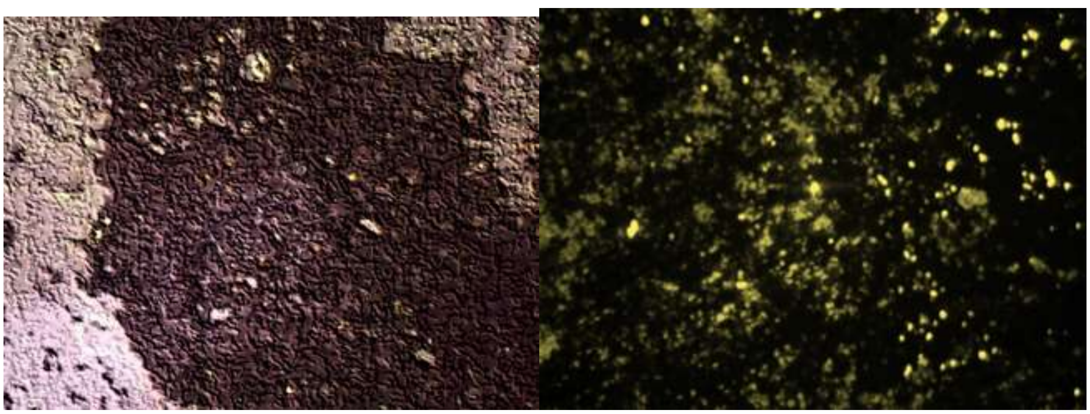

Figure: 5 a and b, Photomicrographs of Tudun kudu manganese ore (Giwa-Kaduna)

Figure: 6 a and b, Hand specimen of Tudun kudu manganese ore (Giwa-Kaduna) N-S trending observed.

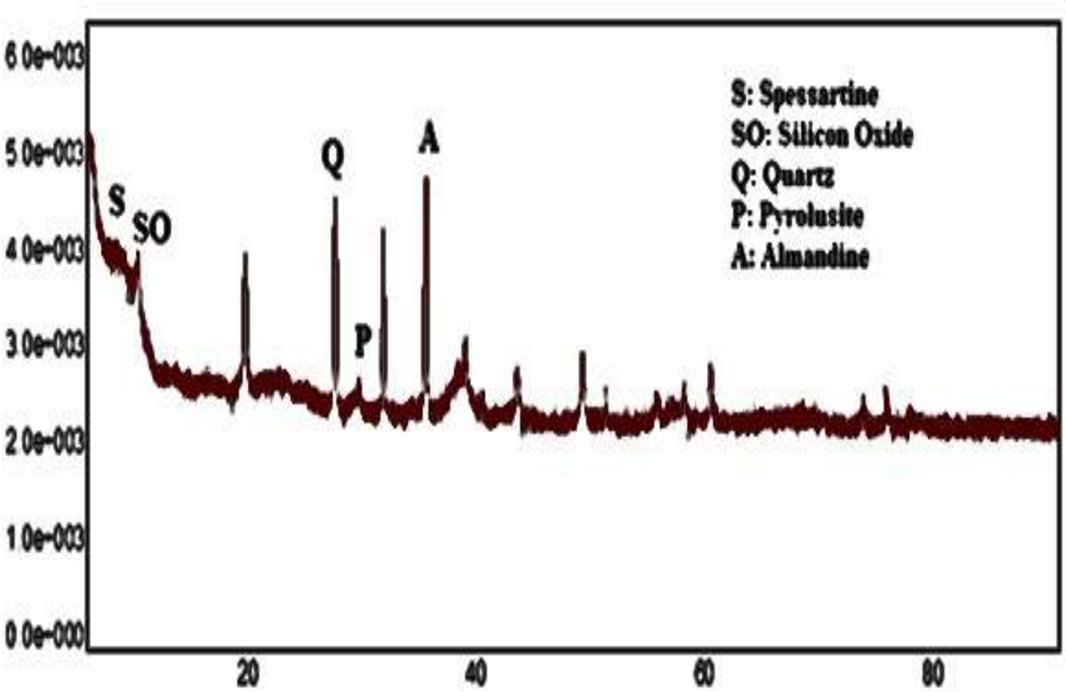

Figure: 7 X-rays Diffractometer (XRD) of Tudun kudu manganese ore (Giwa-Kaduna)

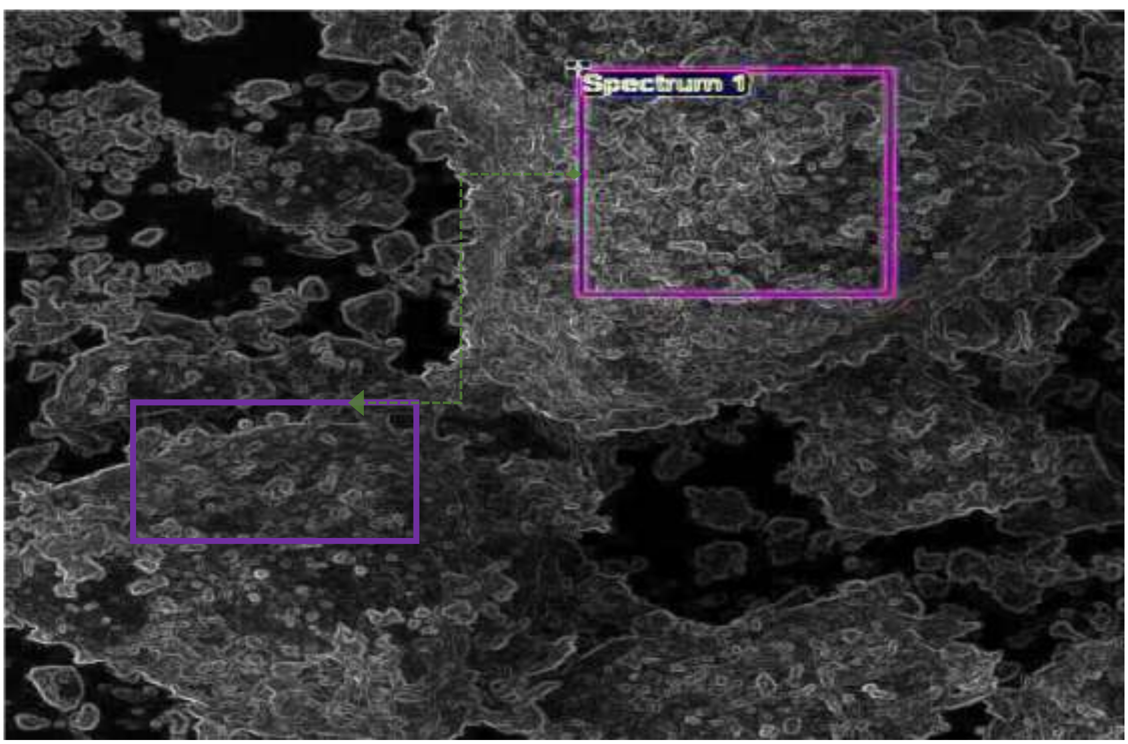

Figure: 8 SEM Image showing the Ore Microstructure at 90 µm

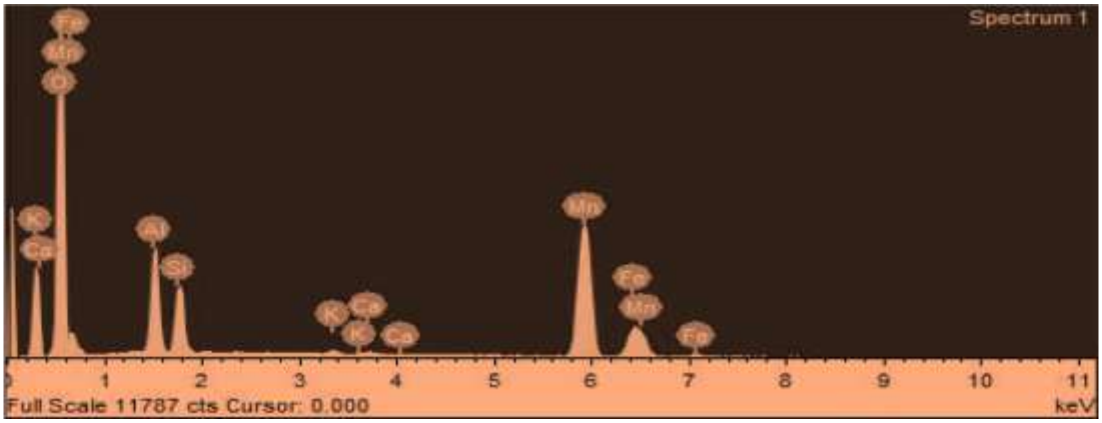

Figure: 9 EDS analysis of spectrum

Discussion

Table: 1 presents the findings of the chemical compositional analysis of the crude Tudun Kudu (Giwa, Kaduna state) manganese ore. The analysis reveals a significant manganese content, with 74.81% MnO and 62.1% Mn. additionally, the ore contains 9.56% Fe2O3, 4.1% Al2O3, and various other constituent compounds.

According to Yaro and Dodo (2016), a manganese content of 52.50% Mn is deemed suitable for the production of ferromanganese alloys in iron and steel companies. Considering this criterion, the manganese ore from Tudun Kudu (Giwa) has great potential for beneficiation to attain metallurgical grade. By doing so, the dependence on imported sources of manganese can be reduced, benefiting the iron and steel industry.

Hence, there is an opportunity to enhance the quality of the Tudun Kudu (Giwa) manganese ore through beneficiation, making it suitable for utilization in local iron and steel companies. This would contribute to self-sufficiency in manganese supply, thereby fostering a more sustainable and independent production process.

Figure 7 showcases the mineralogical composition of the Tudun Kudu (Giwa, Kaduna state) manganese ore, as determined by XRD analysis. The diffractogram exhibits distinct peaks corresponding to different minerals present in the ore matrix, providing insights into their relative abundance. The minerals identified and their respective figures of merit are as follows: spessartine (3 MnO.Al2O3, 0.830), Silicon oxide (SiO2, 1.122), Quartz (SiO4, 0.728), Pyrolusite (MnO, 1.543), and Almandine (Fe3Al2SiO12, 1.583).

Based on the diffractogram, it is evident that the Tudun Kudu (Giwa) manganese ore exhibits a complex mineralogical composition. The predominant minerals detected are spessartine, quartz, and Pyrolusite. This mineral assemblage suggests that the ore possesses metallurgical properties, indicating its potential suitability for utilization in metallurgical processes related to manganese.

The SEM/EDS analysis of the crude Tudun Kudu (Giwa, Kaduna state) manganese ore yielded significant findings, as illustrated in Figure 8 and figure 9 displays SEM micrographs at a magnification of 90 µm, revealing the morphology of the ore minerals. The SEM images provide visual insights into the structural characteristics and surface features of the ore minerals, offering a glimpse into their intricate formations and textures.

Furthermore, the EDX analysis, depicted in Figure 9, delved into the elemental composition of the ore. By analysing the spectra and detecting characteristic peaks, the composition of different elements within the sample was established. Notably, manganese emerged as one of the prominent elements, ranking among the top 2% based on the analysis.

These findings from the SEM/EDS analysis shed light on both the physical morphology of the ore minerals and the elemental compositions present within the sample. Such information is crucial for understanding the nature of the manganese ore and its potential applications in various industries.

Conclusion

The characterization of Tudun Kudu Manganese ore has uncovered the presence of valuable minerals that hold great potential for economic benefit. However, the extraction of these minerals requires a beneficiation process to separate them effectively from the surrounding tailings. It is imperative to prioritize the development of suitable beneficiation techniques to ensure the efficient utilization of these mineral resources

By implementing an appropriate beneficiation process, the valuable minerals can be extracted, purified, and transformed into marketable products. This not only maximizes the economic benefits derived from the ore but also reduces waste generation and minimizes the environmental impacts associated with mining operations. A judicious beneficiation approach will involve a series of processes such as crushing, grinding, screening, and various separation techniques like gravity separation, magnetic separation, and flotation. These techniques aim to selectively concentrate the valuable minerals while discarding or minimizing the content of impurities or unwanted gangue minerals.

In addition to the economic advantages, prioritizing the development of a suitable beneficiation process for Tudun Kudu Manganese ore has wider implications for the mining industry's growth and sustainability. It promotes efficient resource utilization, reduces reliance on imported minerals, and contributes to local economic development. Moreover, implementing environmentally friendly beneficiation practices ensures the responsible and sustainable exploitation of mineral resources, preserving the environment for future generations.

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