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Characterization of Birnin Gwari Gold Sand for its Appraisal for Gold Recovery

Olanrewaju C. Alaba[1]*, Oladunni O. Alabi[2], Mbuyi M. Melodi[3] and Bamidele M. Oseni[4]

[1,3]Department of Mining Engineering, Federal University of Technology, Akure; Ondo State, Nigeria

[2]Department of Metallurgical and Materials Engineering, Federal University of Technology, Akure, Ondo State, Nigeria

[4]Department of Statistics, Federal University of Technology, Akure, Ondo State, Nigeria

Corresponding Author: ocalaba@futa.edu.ng

ABSTRACT

Characterization is a vital step in material analysis, bridging the gap between material structure, processing methods and real-world applications. Crude gold samples were carefully sourced from Birnin Gwari pits in Kaduna State. Then proceeded to crush and homogenize them to sizes ranging between 3 to 5 mm using both manual and laboratory equipment. The samples were meticulously prepared for chemical and mineralogical analysis using the atomic absorption spectrophotometer (AAS), the energy X-ray fluorescence spectrometer (ED-XRFS), the X-ray diffractometer (XRD) the scanning electron microscope paired with the energy dispersive X-ray spectrometer (SEM-EDS) and the Leica petrographic microscope. The AAS assessment indicated a concentration of 118 ppm, in the ore sample validating its mining potential. However, the gold content in the ore is extremely low and cannot be detected easily; it is not found in its natural form based on ED-XRFS analysis results. The sample displayed diffraction patterns corresponding to a variety of minerals present based on XRD analysis. In addition, the SEM-EDS examination validates the presence of alumina, silica, and potassium oxide in the ore. The petrological study revealed that the mineral compositions, in the ore are closely interlocked with grain boundaries with quartz being identified as the gangue mineral.

Keywords: Birnin Gwari, gold sand, gold recovery, gold minerology, gold characterization

INTRODUCTION

It is important to consider the relationships among the structures of the materials, the properties and performance before processing. This is achieved by investigating the composition and structure of materials to understand their properties, their processing methods, and the possibilities of their use in practice. In the same way, the arts of the extraction of minerals, their natural characteristics and their constitution should be known as they determine the conduct of their treatment. In the same way, the properties of the minerals often determine the profitability of the mining operations (Gbadamosi *et al*., 2021).

Reserves of gold exist in Nigeria from the northern part of the country to a few regions in the south. Large deposits can be found in Zamfara State (Anka, Malele and Maru), Kebbi State (Bin Yauri), Kogi State (Okolom-Dogondaji), Kaduna State (Tshohon Birnin Gwari and Kwaga), Osun State (Ipenrindo), and Niger State (Gurmana). There are also signs of gold in other states like Abia, Abuja, Bauchi, Edo, Cross-River, Ogun, Sokoto, and Oyo (Kankara and Darma, 2016; Bwala *et al*., 2021). Gold is a precious metal and rather uncommon one which has numerous worth-using applications gold. It is not only actively used as an electric lead for connecting a wide variety of electronic devices, but it is also important as a neutron reflector in nuclear

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arms. In most cultures, gold has been used for the production of coins, ornamental articles and different forms of art. Furthermore, it is used for its infrared reflecting ability (Duckenfield, 2016; Alabi and Gbadamosi, 2021).

In the mining sector, gold extraction and processes are paramount due to the high value associated with the metal. Of the different methods of recovering gold, it appears that gravity separation techniques including sluice box and tabling methods are applicable in the case of alluvial and vein deposits. The sluice box, one of the earliest forms of mining, uses gravity to separate gold from other mineral particles in an ore because gold is relatively heavier than most other minerals. Water acts as a washing medium which moves the ore along a series of inclined riffles or rectangular troughs where the heavier particles of gold settle down while lighter waste material is washed away (Alabi and Gbadamosi, 2021). The tabling processing method is a gravity concentration technique, and it can process grains of various densities distributed and segregated in water through shaking along an inclined plane (Falconer, 2003; Falconer and Hischier, 2020). The table creates movement, with the larger particles tending to settle to the center and top while lighter minerals and waste are carried.

The tailings do not only contain waste materials but also some other valuable minerals like magnetite, ilmenite and hematite which are of various degrees of magnetism (Jones *et al.*, 2021) found in several gold deposits. These minerals are often ignored in gravity methods of separation and are left in the tailings; however, the use of a magnetic separator proves to be very efficient in further processing the tailings and retrieving these accompanying minerals. These trace minerals have magnetic properties which can be used, together with a high magnetic field intensity to facilitate their separation from non-magnetic materials (Wills and Napier-Munn, 2006). This in turn greatly enhances the efficiency in the recovery of gold as well as the other valuable minerals hosted in the ores. This research aims to combine the sluice box, tabling, and magnetic separation processes for the processing of gold, especially in locations where gold and magnetic trace minerals coexist. The focus is on recovering gold and separating magnetic minerals from the resulting products by utilizing their magnetic properties.

MATERIAL AND METHODS

Sample Collection

The raw sample of gold ore from Birnin Gwari were procured from ten (10) distinct pits, each measuring 1 m x 1 m x 2 m, with geological coordinates detailed in Table 1 pertaining to the Birnin Gwari deposit in Kaduna State. The acquired samples underwent a homogenization process, and the boulders were subjected to mechanical crushing utilizing a sledgehammer to achieve a particle size distribution within the range of 3-5 mm, and subsequently further reduced to 1 mm employing a laboratory jaw crusher.

Table 1: Details of the Ten (10) Pits from Birnin Gwari Gold Ore Deposit.

Pit No.	Sample ID	Lat. (N)	Long. (E)
1	BGS/001	10°36'0''	6°11'30''
2	BGS/002	10°35'0''	6°13'30''
3	BGS/003	10°35'0''	6°12'30''
4	BGS/004	10°34'0''	6°11'30''
5	BGS/005	10°36'0''	6°14'30''
6	BGS/006	10°35'0''	6°14'30''

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7	BGS/007	10°35'0''	6°13'30''
8	BGS/008	10°34'0''	6°13'30''
9	BGS/009	10°34'0''	6°14'30''
10	BGS/010	10°33'0''	6°15'30''

Chemical Characterization of Birnin Gwari Gold Ore

The Atomic Absorption Spectroscopy (AAS) and Energy Dispersive X-ray Fluorescence (ED-XRF) techniques were employed to analyze the elemental and chemical compositions.

Atomic Absorption Spectrometer (AAS)

One (1) gram of the milled specimen was accurately weighed and placed into a 100-millilitre conical flask, subsequently moistened with distilled water. A total of 10 mm of aqua regia, comprising a mixture of HNO_3 and HCl in a ratio of 3:1, was introduced and subjected to control boiling until the solution approached dryness. Following this, the mixture was allowed to cool and was leached with 5 mm of 6M H_2SO_4. An additional 5 mm of distilled water was incorporated and permitted to simmer for 10 minutes. The solution was then cooled and subjected to filtration. The resultant filtrate was diluted to a final volume of 100 mm and prepared for subsequent mineral and metal analysis. The analytical method employed, or the investigation of metal concentration was spectrometry, utilizing an Atomic Absorption Spectrophotometer (AAS) of the Buck Scientific model 230 ATS for measurements.

Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRF)

Approximately 20 grams of the ore specimen were meticulously pulverized to achieve passage through a 125 µm sieve, subsequently undergoing thorough amalgamation with cellulose flakes as a binding agent in a proportion of 10 grams of sample to 5 grams of binder, followed by palletization at a pressure of 20 tons per square inch utilizing a pelletizing apparatus. The resultant pelletized specimens were then positioned within the sample turret of the Genius-IF XRF apparatus. The outcomes obtained were expressed as percentage (%) compositions for both trace and prominent compounds.

Mineralogical Characterization of Birnin Gwari Gold Ore

XRD, SEM/EDX, and petrological methods were used to examine the ore's mineralogical properties.

XRD Analysis of Birnin Gwari gold ore

The mineralogical constituents and their spatial distribution within the ore matrix were ascertained utilizing a PANalytical Empyrean Diffractometer Scatter - X78 equipped with a PIXcel detector, complemented by fixed slits and employing Fe-filtered Co-Kα radiation. The specimen was meticulously prepared for X-ray diffraction (XRD) examination through backloading procedures. The mineral phases were characterized utilizing X'PertHighscore plus software, and the relative proportions of each phase (expressed as % weight) were systematically assessed through the Rietveld refinement methodology.

SEM/EDX Analysis of Birnin Gwari gold ore

In a Denton vacuum, DV-502A, five (5) grams of the ore were painstakingly processed, securely mounted in epoxy resin, polished to a high sheen, and made conductive by a carbon coating. The SEM was used to definitively study the gold ore's morphology at a 20 KVA accelerating voltage with a 30-second real-time and a 60-second lifespan. The device was properly set up with three WDS spectrometers, an ultra-thin window energy dispersive X-ray

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spectrometry, and a Geller dSpec automation system that perfectly regulated the motorized stage and the spectrometers. The EDX conclusively identified the chemical components of the samples, and the backscattering electron detectors successfully acquired the images.

Petrological analysis of Birnin Gwari gold ore

The Birnin Gwari gold ore run-of-mines were sampled according to standard sizes, and then their surfaces were ground using emery paper with grit sizes of 500 µm and 1000 µm in turn. The samples were put on a slide and examined under a Leica Petrographic Microscope (model DM 2700 P) at a magnification of X1000 to identify the various minerals and assess the microstructure of the ore.

RESULTS AND DISCUSSION

The elemental components of the Birnin Gwari gold ore were analyzed using Atomic Absorption Spectroscopy (AAS) to determine their concentrations in parts per million (ppm). The results, presented in Table 2, indicate that the ore contains significant amounts of key elements such as iron (Fe), gold (Au), copper (Cu), platinum (Pt), manganese (Mn), silver (Ag), and sulfur (S) across 10 different pits. After homogenizing the samples from these pits, it was found that the composite sample contains the following elements with the corresponding concentration values in ppm: Au (gold) - 118, Ag (silver) - 0.152, Pt (platinum) - 0.149, Mn (manganese) - 24.57, Fe (iron) - 2692.15, Cu (copper) - 2.671, and S (sulfur) - 0.317. The notably high concentration of gold, as detected from the AAS analysis, confirms the potential for mining the gold deposit in Birnin Gwari once the reserve estimate is determined.

Table 2: Atomic Absorption Spectroscopy Analysis of Birnin Gwari Gold Ore for 10 Pit Sample and Homogenized

Sample ID	Au (ppm)	Ag (ppm)	Pt (ppm)	Mn(ppm)	Fe(ppm)	Cu(ppm)	S(ppm)
BGS/001	115	0.164	0.161	26.23	4021.03	3.624	0.138
BGS/002	104	0.142	0.093	24.12	3989.03	2.912	0.126
BGS/003	112	0.109	0.132	21.09	3107.12	3.001	0.346
BGS/004	117	0.170	0.121	25.10	2936.01	2.926	0.412
BGS/005	110	0.108	0.181	20.90	2635.71	3.003	0.241
BGS/006	125	0.123	0.313	26.23	4005.01	3.620	0.143
BGS/007	109	0.151	0.175	25.91	2867.91	2.981	0.135
BGS/008	127	0.139	0.096	20.04	2734.27	2.023	0.214
BGS/009	123	0.147	0.069	24.81	2732.24	2.823	0.302
BGS/010	116	0.099	0.120	22.41	2803.16	2.905	0.212
Homogenized	118	0.152	0.149	24.57	2692.15	2.671	0.317

The chemical analysis results for 10 pit samples and the homogenized Birnin Gwari gold ore using Energy Dispersive X-ray Fluorescence Spectrometer (ED-XRFS) are detailed in Table 3. The analysis revealed the presence of various compounds in the ore, including SiO_2, V_2O_5, Cr_2O_3, MnO, Fe_2O_3, CuO, NiO, MoO_3, WO_3, CaO, K_2O, and Al_2O_3, along with other trace compounds. Specifically, the homogenized sample contains 80.71% SiO_2, 0.033% V_2O_5, 0.103% Cr_2O_3, 0.247% MnO, 2.694% Fe_2O_3, 0.026% CuO, 0.023% NiO, 0.032% MoO_3, 0.003% WO_3, 0.0341% CaO, 0.048% K_2O, and 3.581% Al_2O_3. The ED-XRFS analysis indicates that the gold in the Birnin Gwari deposit is below

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the detectable level and does not occur in a free state. Also, silica, iron oxide, and aluminum oxide are the main associated gangue minerals in ore. These minerals have different specific gravities and magnetic properties about the desired value, which is gold. The recovery of gold concentrate from the ore is therefore being investigated in light of the differences in the physical characteristics of the main gangue minerals. This exploration includes the consideration of sluice box, tabling, and magnetic separation processes.

Table 3: XRF Analysis result of Birnin Gwari Gold Ore for 10 Pit Sample and Homogenized

Sample ID	SiO_2	V_2O_5	Cr_2O_3	MnO	Fe_2O_3	CuO	NiO	MoO_3	WO_3	CaO	K_2O	Al_2O_3
BGS001	83.21	0.039	0.106	0. 262	4.022	0.036	0.039	0.049	0.005	0.460	0.081	5.389
BGS/002	78.12	0.024	0.093	0.241	3.984	0.026	0.027	0.021	0.001	0.113	0.073	4.005
BGS/003	76.34	0.029	0.096	0.211	3.106	0.037	0.028	0.027	0.003	0.521	0.083	3.821
BGS/004	79.23	0.032	0.102	0.253	2.930	0.022	0.041	0.019	0.003	0.246	0.067	2.972
BGS/005	79.04	0.037	0.108	0.206	2.637	0.039	0.026	0.015	0.004	0.391	0.058	4.112
BGS/006	81.09	0.028	0.098	0.263	4.005	0.036	0.015	0.024	0.002	0.198	0.064	4.222
BGS/007	78.23	0.041	0.107	0.257	2.867	0.025	0.012	0.053	0.004	0.196	0.067	3.254
BGS/008	82.09	0.035	0.101	0.201	2.733	0.023	0.041	0.068	0.003	0.178	0.056	3.921
BGS/009	79.31	0.036	0.132	0.247	2.730	0.029	0.035	0.046	0.003	0.167	0.049	2.965
BGS/010	75.54	0.026	0.078	0.222	2.804	0.025	0.016	0.036	0.002	0.216	0.052	3.210
Homogenized	80.71	0.033	0.103	0.247	2.694	0.026	0.023	0.032	0.003	0.341	0.048	3.581

In Figure 1, the XRD Pattern of the homogenized sample of Birnin Gwari Gold Ore is presented. The XRD analysis of the Birnin Gwari gold ore indicated the presence of diffraction peaks corresponding to various minerals in the ore body. These minerals include Quartz, syn (SiO_2), Albite ($NaAl\,Si_3O_8$), Orthoclase ($Al_2O_3{\cdot}K_2O{\cdot}6SiO_2$), Muscovite ($H_2KAl_3\,(SiO_4)_3$) with weight fractions of 53(4) %, 24(2)%, 18(6)%, and 5.5(8)%, respectively. Additionally, figures of merit of 1.358, 3.036, 2.882, and 1.834 were observed. The diffractogram findings are consistent with the ED-XRFS result, which suggests that the gold in the ore body is not present in its free state. This data is valuable as it provides insights into the appropriate techniques for recovering gold concentrate from the Birnin Gwari gold ore.

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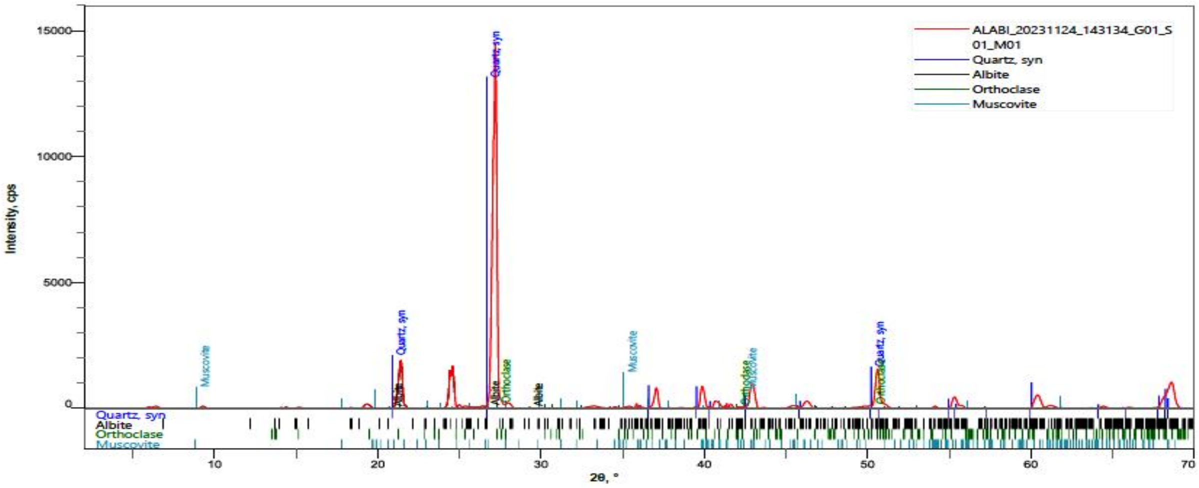

Figure 1: XRD Pattern of Birnin Gwari Gold Ore for Homogenized Sample.

The SEM micrographs coupled with EDS data provide the characterization of a homogenized sample from Birnin Gwari gold ore. The recorded images and analyses of these can be seen in Plate 1, Table 4 and Figure 2. Figure 2 demonstrates when the mineral grains in ore reach their peak; Plate 1 is a backscatter image that shows non-equiaxial (light grey) silicate minerals disseminated throughout the dark grey color of massive iron-rich phases. Table 4 provides details of major elements discovered within the ore, with Si, Al, Fe, K, P, S, Ti, Cl, Na, and Mg exhibiting atomic and weight concentrations of 82.89 (79.77), 6.09 (5.63), 2.90 (5.54), 1.62 (2.17), 1.36 (1.44), 1.11 (1.22), 0.72 (1.18), 0.90 (1.10), 1.38 (1.09), and 1.02 (0.85) respectively. The result indicates the predominance of alumina, silica, and potassium oxide within the ore, this is consistent with the findings from energy-dispersive X-ray fluorescence (ED-XRF) analysis. The mineral grains are consolidated, which likely accounts for the non-detection of elemental gold within the ore (Harmon *et al*., 2019). Therefore, it is essential to comminute the ore to a size range that decisively allows for the effective liberation of elemental gold or gold compounds from associated minerals, thus facilitating their separation.

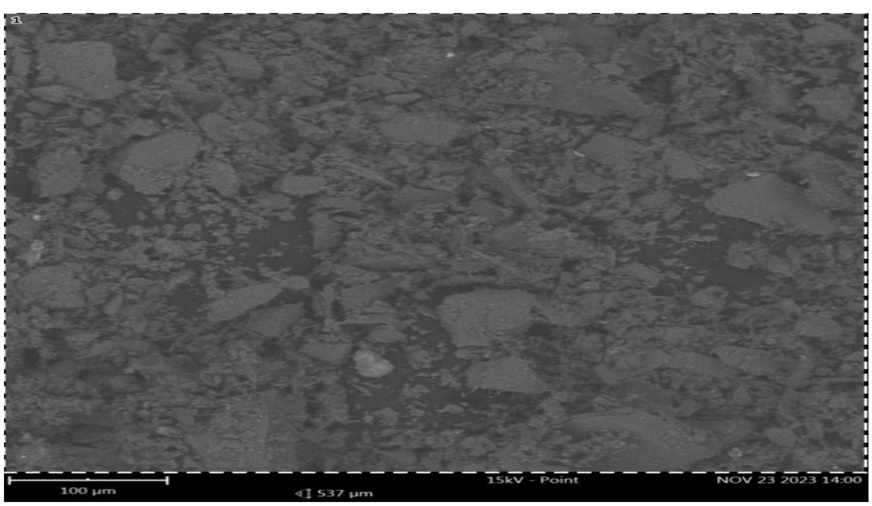

Plate 1: SEM Images of Birnin Gwari Gold Ore for Homogenized Sample at 537 µm Mode: 15kV - Point using the backscattered electron.

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Table 4: EDS Analysis of the Birnin Gwari Gold Ore for Homogenized Sample

Element Number	Element Symbol	Element Name	Atomic Conc.	Weight Conc.
14	Si	Silicon	82.89	79.77
13	Al	Aluminum	6.09	5.63
26	Fe	Iron	2.90	5.54
19	K	Potassium	1.62	2.17
15	P	Phosphorus	1.36	1.44
16	S	Sulfur	1.11	1.22
22	Ti	Titanium	0.72	1.18
17	Cl	Chlorine	0.90	1.10
11	Na	Sodium	1.38	1.09
12	Mg	Magnesium	1.02	0.85

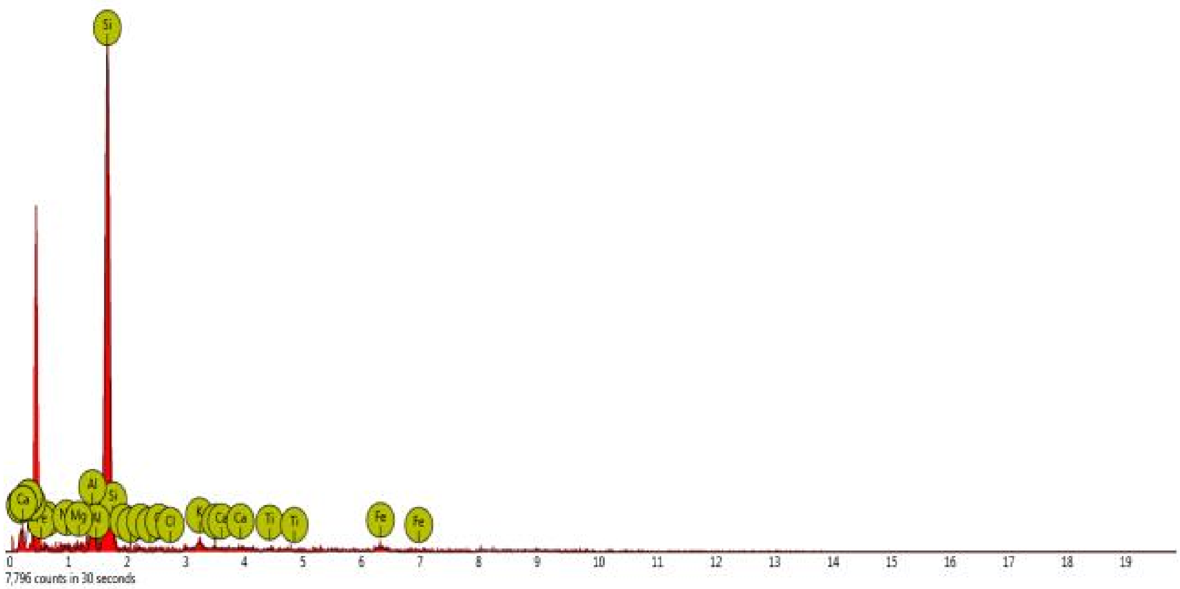

Figure 2: EDS Analysis of Identified Minerals in the Homogenized Sample of Birnin Gwari Gold Ore.

Plate 2 presents the photomicrographs from the petrological analysis of the homogenized sample from Birnin Gwari gold ore. This analysis was carried out to ascertain the occurrence of different minerals and their relative distribution within the ore body. It can be deduced that the mineral phases in the ore are closely packed with well-defined grain boundaries. The mineral phases were well-defined under plane-polarized light, which makes it evident that quartz is predominant and probably houses a more significant percentage of the gold (Gold locked in veins of Quartz, with the filling micro-fractures in the pyrite and arsenopyrite).

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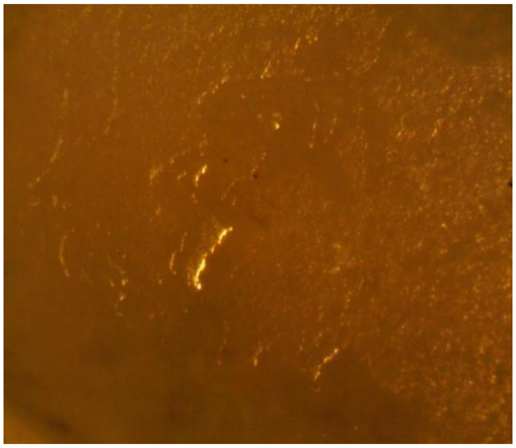

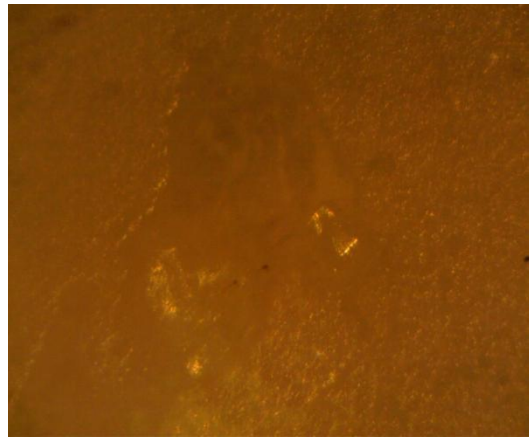

Plate 2: Photomicrographs of Homogenized Sample of Birnin Gwari Gold Ore under Plane-Polarized Light

CONCLUSION

The research thoroughly investigates the chemical and mineralogical characterization of Birnin Gwari Gold Sand to appraise gold recovery potential. The analysis using Atomic Absorption Spectroscopy (AAS) revealed a gold content of 118 ppm in the ore, confirming its potential for mining. However, the ED-XRFS analysis indicated that the gold in the ore is present below detectable levels and does not occur in a free state. The XRD pattern of the sample revealed diffraction peaks corresponding to various minerals, including quartz syn, albite, orthoclase, and muscovite. Additionally, the SEM and EDS analysis suggest the likely predominance of alumina, silica, and potassium oxide within the ore. The petrological analysis showed that the mineral phases in the ore are closely packed with well-defined grain boundaries, with quartz being the predominant mineral. Consequently, a suitable processing route for gold recovery is imperative.

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