eISSN 2500-0632
https://mst.misis.ru/

BENEFICIATION AND PROCESSING OF NATURAL AND TECHNOGENIC RAW MATERIALS

Research paper

https://doi.org/10.17073/2500-0632-2023-07-130
UDC 622.7.1

Investigation of old waste dump composition of lean gold-bearing ores from the Golden Pride Project (GPP) mining operation in Nzega district, Tanzania

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Abstract
The search for alternative sources of useful minerals is a pressing issue. One such possible source is the processing of lean gold-bearing ores, which previously did not seem feasible to exploit for subsoil users, leading to their disposal in off-balance ore dumps. Processing these resources becomes economically viable as gold prices rise and processing technologies improve over time. This paper presents the elemental and mineralogical composition of lean gold-bearing ore dumps from the Golden Pride Project (GPP) mining operation in Tanzania's Lihendo district. This area contains an old dump of lean gold-bearing ores, weighing approximately 1.4 million tons. Extracting valuable components from lean mineral raw materials is a current priority. Sampling was conducted to study the dumps. Boreholes were drilled to a depth of 1 m, covering a total sampling area of 20 ha; 18 samples, each averaging 3 kg in weight, were collected. The results of X-ray fluorescence analysis (XRF) indicated the presence of Fe, S, Si, Ca, Ca, Mn, Cu, Al, Cr, Ti, As, and Ag in the collected samples. X-ray diffraction (XRD) analysis revealed that the main minerals in the dumps are muscovite, kaolinite, quartz, montimorillonite, and goethite. The average gold grade in the selected samples is 0.72 g/t. Studies of the grain-size distribution and gold distribution by grain-size classes after ore grinding demonstrated that the majority of gold (74%) is in the −75 μm class. In the initial mineral material of the dumps, the share of the +30-50 mm grain-size class is 81%. The paper proposes potential methods for processing lean dumps of gold-bearing ores. One such methods involves crushing the dump material, separating the −75 μm class, and subjecting it to direct leaching or leaching using "carbon-in-pulp" technique. Heap leaching appears to be the most promising method for extracting gold from such dumps in terms of technical and economic feasibility. Positive experience has been reported in applying this process to ores of similar mineralogical type.

Keywords
Golden Pride Project (GPP), X-ray phase analysis, X-ray fluorescence analysis, lean gold-bearing ore, ore characterization, processing methods

For citation
Shirima J., Wikedzi A., Rasskazova A.V. Investigation of old waste dump composition of lean gold-bearing ores from the Golden Pride Project (GPP) mining operation in Nzega district, Tanzania. *Mining Science and Technology* (*Russia*). 2024;9(1):5–11. https://doi.org/10.17073/2500-0632-2023-07-130

ОБОГАЩЕНИЕ, ПЕРЕРАБОТКА МИНЕРАЛЬНОГО И ТЕХНОГЕННОГО СЫРЬЯ

Научная статья

Исследование лежалых отвалов бедной золотосодержащей руды горнодобывающего предприятия Golden Pride Project (GPP) в районе Нзега, Танзания

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Аннотация
Поиск альтернативных источников полезных минералов является достаточно актуальной проблемой. Одним из таких возможных источников является переработка бедных золотосодержащих руд, переработка которых ранее не представлялась привлекательной для недропользователей, вследствие чего

из них формировались отвалы забалансовой руды. Переработка этих ресурсов становится востребованной на фоне роста цен и уровня технологий с течением времени. В данной статье представлен элементный и минералогический состав бедных золотосодержащих отвалов горного предприятия Golden Pride Project (GPP) в Танзании, в районе «Лихендо». В данном районе находится старый отвал бедной золотосодержащей руды (масса составляет примерно 1,4 млн т). Извлечение ценных компонентов из бедного минерального сырья является актуальным направлением в настоящее время. Для опробования отвалов был произведён отбор проб. Глубина бурения скважин составила 1 м, общая площадь опробования – 20 га; было отобрано 18 проб средней массой 3 кг. Результаты рентгенофлуоресцентного анализа (РФА/XRF) показали, что в отобранных пробах присутствуют такие элементы, как Fe, S, Si, Ca, Mn, Cu, Al, Cr, Ti, As, Ag. Результаты рентгенофазового анализа (XRD) показали, что основными минералами в отвалах являются мусковит, каолинит, кварц, монтимориллонит и гетит. Среднее содержание золота в отобранных пробах составляет 0,72 г/т. Исследования гранулометрического состава и распределения золота по классам крупности после измельчения руды показали, что большая часть золота (74 %) находится в классе –75 мкм. В исходной минеральной массе отвалов доля класса крупности +30–50 мм составляет 81 %. В статье предложены возможные методы переработки бедных отвалов золотосодержащих руд. Одним из возможных методов переработки отвалов является измельчение минерального сырья, отделение класса –75 мкм и его прямое выщелачивание либо выщелачивание по технологии «уголь в пульпе». Наиболее перспективным с точки зрения технико-экономических показателей представляется метод кучного выщелачивания. Имеется положительный опыт применения данной технологии в отношении руд аналогичного минерального типа.

Ключевые слова
Golden Pride Project (GPP), рентгенофазовый анализ, рентгенофлуоресцентный анализ, бедная золотосодержащая руда, характеристика руды, методы переработки

Для цитирования
Shirima J., Wikedzi A., Rasskazova A.V. Investigation of old waste dump composition of lean gold-bearing ores from the Golden Pride Project (GPP) mining operation in Nzega district, Tanzania. *Mining Science and Technology* (*Russia*). 2024;9(1):5–11. https://doi.org/10.17073/2500-0632-2023-07-130

Introduction

In today's world, the industrial revolution has led to an increased demand for minerals such as gold, cobalt, nickel, rare earth elements, and platinum group elements like rhodium, osmium, palladium, ruthenium, and iridium [1, 2]. However, primary reserves of these minerals worldwide are limited. The search for alternative sources of minerals is a pertinent issue [3]. One such potential source is the processing of lean gold-bearing ores, which were previously deemed unprofitable by subsoil users and consequently sent to off-balance ore dumps. The relevance of processing these resources becomes more pronounced as gold prices rise and processing technologies improve over time. Currently, the costs of processing lean ores are justified [1]. It is imperative to employ methods for assessing the cut-off grade of valuable components and the economic feasibility of projects to make informed operational and economic decisions [4].

The extraction of gold from lean mineral raw materials is relevant in many regions worldwide, driven by a decline in the gold grade of currently extracted ores due to the preferential extraction of richer and more easily processable ores [5]. Examples include the Ridgway mine in the United States, as well as Simmergo, Ergo, and Crown Sand in South Africa [6].

Despite the utilization of low-grade ore in processing at various plants globally, each deposit presents its unique challenges necessitating specific feasibility studies [7]. Key to such studies is understanding the properties of the ore itself, as they dictate the selection of a processing method, thereby directly influencing the economics of mineral mining, such as gold [8, 9].

This paper aims to investigate elemental and mineralogical composition and grain-size distribution of the lean gold-bearing ore dumps from the Golden Pride Project (GPP). Additionally, recommendations on possible methods of processing lean mineral raw materials from the dumps are provided.

The Golden Pride Project (GPP) was a gold mining project in the Nzega district of Tanzania, 25 km from the town of Nzega. The open pit operated from 1998 until its closure in 2013[1], extracting 2.589 million tons of ore and produced 169 thousand ounces of gold. The deposit reserves are estimated at 5.79 million tons of ore (2.04 million tons in category A and 3.75 million tons in category B, with an average grade of 2 g/t). The deposit was developed using an open-pit method, with the primary method of gold extraction being sorption leaching via activated carbon (carbon-in-pulp (CIP) process).

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[1] Report of the Presidential Mining Review Committee to Advise the Government on Oversight of the Mining Sector. 2008. URL: https://www.policyforum-tz.org/sites/default/files/BomaniReport-English_0.pdf [Accessed: January 2023].

The ore district comprises layers of basic volcanites, volcanoclastic rocks, banded ferruginous formations, and intrusive porphyries intruded by late granites. The complex structure includes thick north-striking structures emphasized by late dolerite dykes and thinner structures of northwestern and northeastern strike. Exploration identified two main types of mineralization: gold-quartz vein mineralization with high gold grade and extensive carbonate-siliceous alteration and pyrite veinlets, and extensive low-grade impregnated gold mineralization located in the northeastern Kanegele shear system.

The Golden Pride Project (GPP) ores belong to the latter type of mineralization.

Throughout the mine's operational life, the cut-off grade was approximately 2 g/t gold[2]. Materials with a gold grade below this threshold were either stockpiled for blending or transported to the waste rock dump, as their processing was deemed unprofitable [10–12]. However, with rising gold prices and advancements in processing techniques, this material may become expedient for processing. Of particular interest are the dumps in Lihendo County, where an earlier estimation indicated approximately 1.4 million tons of gold-bearing ore at a grade of 1.37 g/t gold, necessitating further evaluation of the ore processing potential.

[2] Developing the golden opportunity, GPP Annual Report. 2004. URL: https://www.annualreports.com/HostedData/AnnualReportArchive/R/ASX_RSG_2004.pdf [Accessed: January 2023].

Materials and Methods

1. Materials

At the first stage of sampling preparation, the whole Lihendo district in Tanzania (130 ha) was subdivided using Expert GPS Pro version 7. Samples were then collected at the intersections of the vertical and horizontal grid lines within an area of 20 ha (inside the area circled by the line in Figure 1 using a Germin GPS, Montana 680t navigator).

A total of 18 samples were procured from boreholes drilled to a depth of 1 m, amounting to approximately 54 kg of samples (Table 1). The coordinates of the sampling points (longitude and latitude in Arc1960 format) are provided in Table 1.

2. Techniques

2.1. Sample Preparation

Initially, the samples underwent drying in a desiccator at 105 °C for 1 h to eliminate moisture. Three samples were combined into a single metallurgical sample, ground to a fineness of −2 µm, and then divided into 6 samples using a rotary splitter (Sepor 040J-001 24), each weighing approximately 9 kg each. The rotary splitter operated at a rotation speed of 0.5 rps. From each of the these 9-kg samples, a 0.5-kg subsample was extracted for X-ray diffraction analysis. Additionally, 1-kilogram samples were set aside for X-ray diffraction and X-ray fluorescence analyses.

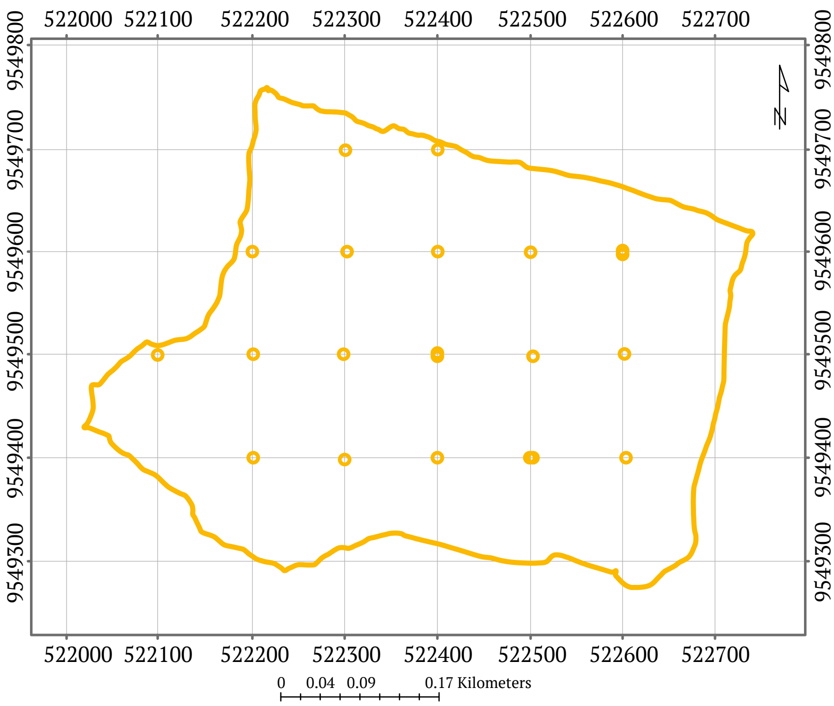

Fig. 1. Diagram of sampling points in the Lihendo district (UTM)

Table 1

Coordinates of sampling points (in Arc1960 format)

Point No.	Latitude	Longitude	Point No.	Latitude	Longitude
1	4°4‘31”	33°12‘0”	10	4°4 ‘24”	33°11‘57”
2	4°4‘28”	33°12‘0”	11	4°4‘21”	33°11‘57”
3	4°4‘24”	33°12‘0”	12	4°4‘41”	33°11‘54”
4	4°4‘21”	33°12‘0”	13	4°4‘38”	33°11‘54”
5	4°4‘41”	33°11‘57”	14	4°4‘34”	33°11‘54”
6	4°4‘38”	33°11‘57”	15	4°4‘31”	33°11‘54”
7	4°4‘34”	33°11‘57”	16	4°4‘28”	33°11‘54”
8	4°4‘31”	33°11‘57”	17	4°4‘24”	33°11‘54”
9	4°4‘28”	33°11‘57”	18	4°4‘21”	33°11‘54”

2.2. Chemical and Mineralogical Analysis

It is important to conduct elemental and mineralogical analysis prior to selecting any mineral processing method, as these analyses directly influence the economics of a project. In this study, the elemental composition was determined using X-ray fluorescence analysis (XRF, HITACHI-X MET 8000 instrument). The MINING LE mode was employed to measure Si, P, Al and Mg, while the MINING MODE was used for determining the other elements. Each analysis had a duration of 120 s per sample.

Mineral phases were identified using a Bruker AXS D2 PHASER XRD instrument manufactured in Germany (model A26-X1-A2B0D2C). To identify these phases, the XRD generator operated at 30 kV and 10 mA current using a copper anode.

2.3. Grain-Size Analysis

Researchers have discovered that the majority of gold particles are liberated when an ore is milled to approximately 50–80% of −75 µm size class [13, 14]. In this study a similar methodology was adopted. A sample weighing approximately 1 kg was pulverized to 50% of −75 µm class [14]. The dry sample was screened for approximately 15 min, after which the gold content of each mesh-screen size (oversize) was analyzed using an atomic absorption spectrometer (AAS).

Findings

The XRF analysis results of six samples revealed a relatively uniform elemental composition of the dumps (Fig. 2). The elemental composition observed in the studied samples is statistically representative, with a confidence level of 95%. The results of the elemental composition of the dumps are: Fe – 7.61, S – 0.22, Si – 10.74, Ca – 0.61, Mn – 0.04, Cu – 0.01, Al – 2.69, Cr – 0.025, Ti – 0.49, As – 0.04% (wt), Au – 0.72 g/t, Ag – 0.06 g/t. Among the valuable metals identified, Ag and Au are notable, while Si predominates as the major nonmetal. The samples exhibit low concentrations of sulfur and arsenic, as well as calcium, manganese, copper, chromium, and titanium.

X-ray diffraction (phase) analysis revealed the presence of the following mineral phases in the samples: quartz, biotite, kaolinite, montimorillonite, goethite, cuprite, and muscovite (Fig. 2).

The primary minerals, each constituting more than 10% of the composition, include muscovite, kaolinite, and quartz. Biotite, montimorillonite, and goethite are categorized as minor phases, with their respective weight share amounting to less than 10% (Table 2).

Gold distribution was investigated through mesh-screen analysis using mesh sizes of 75 µm, 106 µm, 125 µm, and 150 µm. The results of this analysis revealed a unimodal distribution of gold in the ore, with the majority of gold present in the −75 µm fine fraction, as outlined in Table 3.

To determine the grain-size distribution of the initial material from the lean gold-bearing ore dumps, mesh-screen analysis of the materials was performed. Screens with mesh sizes ranging from 15 to 50 mm were employed for this analysis. The resultant grain-size distribution (Fig. 3) indicated that only 0.4% of the material exhibited a grain size smaller than 20 mm, while the predominant portion (81%) possessed a grain size falling within the range of +30–50 mm.

Discussion

Based on the results of X-ray phase analysis, the lean gold-bearing dumps predominantly consist of oxides and silicates. Mineralogical analysis suggests that the dump material corresponds to the gold-quartz type, with indication of metasomatism in-

eISSN 2500-0632
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ferred from the muscovite content. Minor sulfide minerals present have negligible influence on potential leaching processes [15, 16]. The XRF results indicate copper and sulfur contents below 0.05% and 0.5%, respectively. Copper acts as a cyanicide, interfering with cyanide during gold leaching processes, leading to increased consumption. However, adverse effects from cupper are not anticipated in the examined minerals. The material contains approximately 28% kaolinite, which may exhibit sorption properties toward gold-cyanide complexes formed during leaching. The high kaolinite content may also adversely affect filtration properties, which are crucial in heap and in-situ leaching processes.

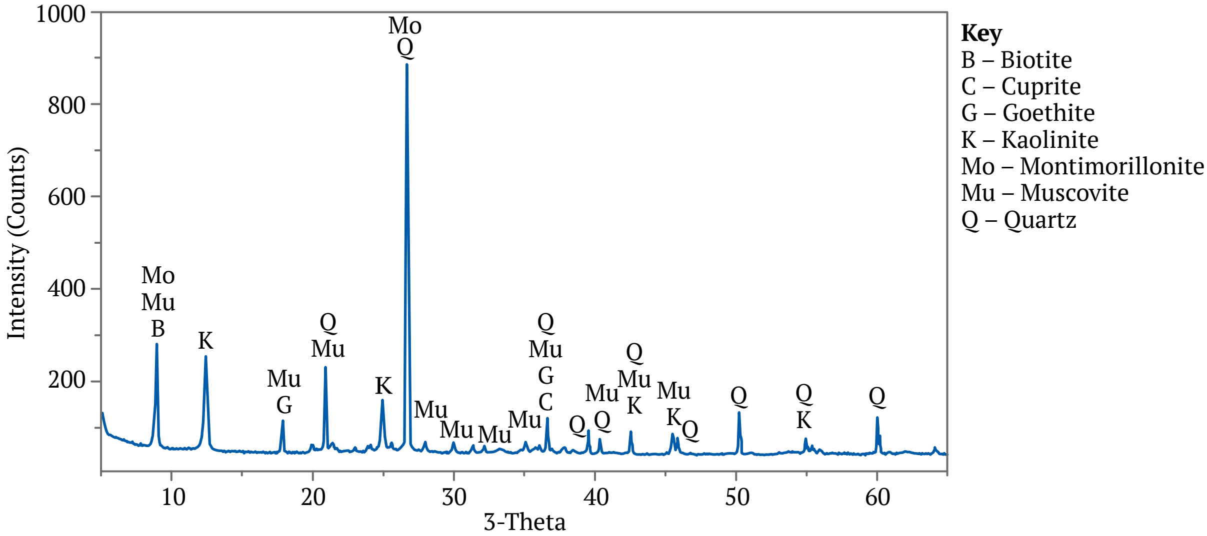

Fig. 2. X-ray phase analysis (XRD) and major mineral phases

Table 2

Basic mineralogical composition of the sample

Mineral	Weight fraction, %
Muscovite	37.66
Quartz	28.03
Kaolinite	27.77
Biotite	3.89
Goethite	1.44
Montmorillonite	0.89
Other minerals	0.32
Total	**100**

Table 3

Gold grain size distribution

Grain-size class, μm	Grain-size class yield, %	Gold grade in grain-size class, g/t	Gold distribution, %
+150	11.49	0.07	3.39
+125–150	23.41	0.05	4.93
+106–125	44.21	0.08	14.91
+75–106	6.61	0.10	2.79
–75	14.27	1.23	73.99
Total	**100.00**	**0.24**	**100.00**

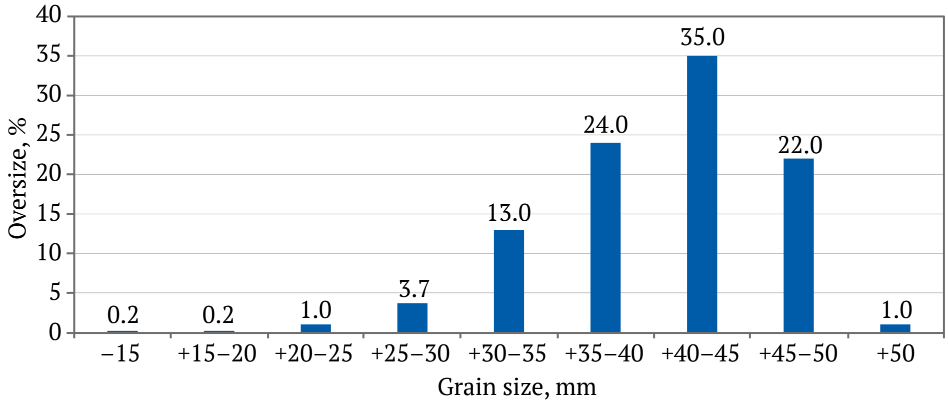

Fig. 3. Grain-size distribution of lean gold-bearing ore dump material

Moreover, the average gold grade was determined to be 0.72 g/t, contrasting with a higher grade of 1.37 g/t[3] reported in a historical study. The disparity could be attributed to the limited sampling points (7) in the historical study, alongside potential variations in a sampling depths, which can influence gold grades[4].

The heap leaching process emerges as a promising method for processing this mineralized material, given the low gold grades (0.72 g/t) necessitating lower capital and operating costs for extracting valuable components [17]. The profitability from gold sales generated by heap leaching may significantly surpass that of processing plant methods. The grain size of the dump material (+25 mm) meets heap leaching requirements, although additional pelletizing operations may be necessary, necessitating further metallurgical studies.

Positive experience from heap leaching of gold-quartz ores at the Mayskoe deposit (Khakassia, Russian Federation) is are documented, achieving recoveries of 73–86%. The process involved crushing the ores to −10 mm, pelletized, heaped, and cyanide solution spraying, followed by gold precipitation from the pregnant solutions through electrolit precipitation on zinc chips. Subsequent acid treatment of the precipitates and roasting led to the production of base billion [18].

[3] Developing the golden opportunity, GPP Annual Report. 2004. URL: https://www.annualreports.com/HostedData/AnnualReportArchive/R/ASX_RSG_2004.pdf [Accessed: January 2023].

[4] Ibid.

Conclusion

This study examined lean gold-bearing dumps from the Lihendo area in the Nzega District, Tanzania. The presence of clay minerals, such as kaolinite, poses challenges to filtration processes in heap leaching method and may also exhibit sorption activity towards extracted gold cyanide complexes resulting from leaching.

The minimum required grain size for mineral raw material in agitation leaching processes is typically 80% of the −75 µm size class. However, various design solutions exist where the grain size of leachable material is smaller [19]. Based on the mineralogical and elemental analysis findings, agitation leaching, including the carbon-in-pulp mode, appears to be the likely hydrometallurgical treatment method. It was established that in the minerals from the dump, where the grain size was reduced to meet the requirements agitation leaching, 74 % of the gold was found in the −75 µm fraction. Therefore, crushing, pulverization, and separation of fine fraction using hydrocyclones could be a viable approach for material processing. The −75 µm fraction could be processed via direct leaching or in the coal-in-pulp mode, reducing the portion of ore subjected to leaching. This approach is practical as 74% of the gold is contained in the −75 µm fraction, yielding approximately 14.27%. Despite the technical feasibility of agitation leaching, heap leaching of the studied material emerges as a practically applicable method in terms of economic indicators. Similar gold-quartz ores have demonstrated gold recovery rates of about 70–80%.

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Received 05.07.2023
Revised 17.11.2023
Accepted 20.11.2023