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ADDIS ABABA INSTITUTE OF TECHNOLOGY

CENTER FOR ETHIO-MINES DEVELOPMENT

MASTER OF ENGINEERING IN MINERAL ENGINEERING

Beneficiation of Lithium Ore Using Flotation Technique, In case of Erar Area, Harar Region, Ethiopia.

By

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Approval sheet

This is to certify that the project report prepared by Taju Mohammed "Beneficiation of lithium ore through flotation technique from Harar region" submitted in the partial fulfillment of the requirements for the degree of masters of engineering in mineral process engineering compiles with the regulation of the university and meets the accepted standard with respect to originality and quality.

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Abstract

Enhancing the recovery of lithium from its ores is vital for supporting the growing demand for lithium-ion batteries used in electric vehicles and energy storage systems. This research investigates the beneficiation of lithium ore from Ethiopia's Harar region through the froth flotation method, focusing on how varying reagent dosages affect flotation performance. Flotation tests were carried out by adjusting the amounts of collectors, frothers, and activators to study their effects on both the yield (concentration weight) and the purity (grade) of the lithium concentrate. The findings indicate that the amount of reagents used significantly influences flotation efficiency. The optimal result was obtained in experiment number 3, which used 5 mL of frother, 7 mL of collector, and 10 mL of activator, achieving the highest concentration weight. A steady increase in concentrate yield was observed from the first to the third experiment, followed by a decline through the ninth experiment. These results highlight the importance of precise reagent dosage control to maximize both the quantity and quality of lithium recovery. The study offers practical insights into improving the effectiveness and sustainability of lithium ore processing in the Harar region.

Key words; Beneficiation, Frothers, Lithium, Harar

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Acronyms

DMS- Dense medium separation

FF- Froth flotation

AAS- Atomic Absorption Spectroscopy.

LRPM- lithium-rich pegmatite minerals

SCS- Solution of copper sulphate

Chapter One

1. Introduction

1.1 Background

Lithium, a vital resource for energy storage that uses for the electric vehicle batteries, has become increasingly important as global demand for renewable energy solutions rises. Efficient extraction and beneficiation of lithium from ore are critical to meeting this demand. Among various beneficiation techniques, flotation is one of the most widely employed methods for concentrating valuable minerals, including lithium. Flotation works by exploiting differences in the surface properties of minerals, allowing for the separation of lithium-bearing minerals from gangue materials.

The Harar region of Ethiopia holds significant potential for lithium mining, with lithium-bearing minerals found in its deposits. However, the beneficiation of lithium ore from Harar presents unique challenges due to the presence of various impurities that can complicate the flotation process. While flotation has been proven effective for lithium ore processing in other regions, there is limited research on its application to ores from Harar, particularly concerning the effect of reagent dosage.

Flotation relies heavily on the type and number of reagents used, such as collectors, frothers, and modifiers, which influence the concentrate weight and grade of the concentrate. The optimal reagent dosage can significantly improve the efficiency of the flotation process by enhancing the separation of lithium minerals from unwanted materials. However, excessive or insufficient reagent usage can lead to poor concentration weight, low concentrate purity, or increase valuable minerals in tailing. Therefore, understanding the relationship between reagent dosage and flotation efficiency is critical for the successful beneficiation of lithium ore from Harar.

This study aims to investigate the effect of reagent dosage on the flotation performance of lithium ore from the Harar region, with the goal of picking up flotation reagents dosage for improved lithium concentration weight and concentrate quality. By focusing on reagent dosage, this research will contribute to the development of more efficient and sustainable flotation practices, offering valuable insights for the lithium industry in Ethiopia and other regions with similar ore characteristics.

1.2 Regional Geology

The Harar area is underlain by Precambrian basement rocks, predominantly composed of granitic gneisses and gabbros. These rocks have experienced extensive deformation, resulting in complex folding and shear structures. Additionally, pegmatitic intrusions indicate episodes of magmatic activity during the Precambrian era (Abdelsalam 1996; Chernet & Abebe 2010).

The foundational rocks in this area, known as Precambrian basement rocks, are some of the oldest geological formations and have experienced significant deformation. This deformation occurred in two main forms: ductile and brittle. Ductile deformation refers to the bending, folding, and flowing of rocks under high temperature and pressure conditions deep within the Earth, without fracturing. In contrast, brittle deformation occurs when rocks break or fracture due to stress, typically at shallower depths where temperatures and pressures are lower. Overlying this basement are Mesozoic sedimentary formations, notably within the Dire Dawa and Harar provinces. These include:

- **Adigrat Sandstone**: a lower fluviatile sandstone unit.
- **Antalo Limestone**: an intermediate carbonate-marly unit, previously referred to as Antalo Limestone.
- **Amba Aradam Formation**: an upper fluviatile sandstone unit.

These formations represent sedimentary sequences deposited during the Middle to Late Jurassic period and correlate with similar sequences found across East Africa and parts of Yemen (Bosellini et al., 2001). In the Cenozoic era, the region features intercalated volcanic and sedimentary rocks in varying proportions. These include marine and continental sediments dating from the Paleocene to Middle Eocene, with thicknesses reaching up to 1000 meters in areas such as eastern Ogaden (Johnson, & Woldehaimanot 2003; McDougall, & Brown, 2006)

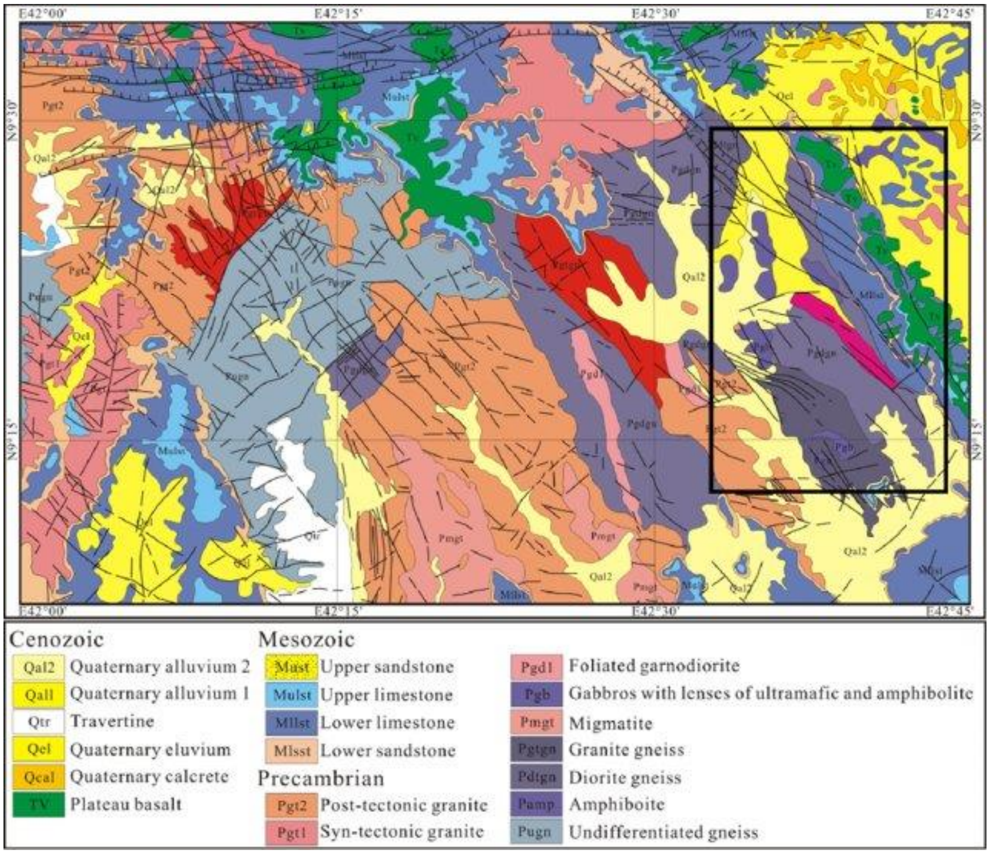

Figure 1 Regional geological map of Harar (Chung et al 2015; Tefera et al., 1996).

These structural features collectively have a profound impact on the landscape and geology of the Harar region. They influence the region's topography by controlling the elevation, slope, and orientation of landforms. Moreover, they play a critical role in the geological evolution of the area by affecting rock distribution, mineralization patterns, groundwater flow, and seismic activity. Understanding these structures is essential for geological mapping, resource exploration, and assessing geohazards in the region.

The Harar region hosts a variety of mineral resources, including:

- **Granitoid Rocks:** Located in areas such as Anger Gute, these rocks date from the Proterozoic to Early Paleozoic era and are commonly quarried for dimension stone.
- **Pegmatites:** Found within the Precambrian basement, these formations often contain economically important minerals like feldspar and mica.

1.3 Statement of problem

The complex mineralogy of Harar's lithium ores, combined with limited research on flotation parameters with reagent dosages, and particle size hinders the establishment of beneficiation process. Without addressing these problems, the country risks underutilizing its lithium reserves and missing out on the economic benefits of a burgeoning global lithium market. This study aims to overcome these challenges by investigating flotation as a viable beneficiation method tailored to the Harar deposits, thereby laying the groundwork for sustainable and profitable lithium beneficiation in Ethiopia

1.4 Objective of the Project

General Objective

The main objective of this project is beneficiation of lithium using flotation technique in case of Erar area, Harer, Ethiopia

Specific Objectives

- To evaluate the effect of collector and frother dosage on concentration weight
- To study how different flotation reagents dosage affect the grade of lithium mineral
- To identify the optimum reagents dosage for concentration and for grade.

1.5 Location and accessibility

The study is located in the Harar region of eastern Ethiopia, approximately 525 kilometers from the capital, Addis Ababa. The area lies within the geographic coordinates of 9°15' N to 9°25'N latitude and 42°05'E to 42°20'E longitude (Fig.1)

Part of the Ethiopian Highlands, Harar features moderately elevated, rugged terrain, which holds geological significance due to the presence of pegmatite formations known sources of lithium-bearing minerals.

- Accessibility to the region is relatively convenient, with both road and air transportation available:

- A paved highway connects Addis Ababa to Harar through Dire Dawa, ensuring smooth transportation of equipment and personnel.
- Dire Dawa International Airport, situated around 52 kilometers from Harar, provides regular flights to Addis Ababa, making travel for research and exploration teams more manageable.
- Inside the region, gravel and rural roads lead to key geological sites and outcrops, although accessing some remote locations may require off-road vehicles or brief trekking.

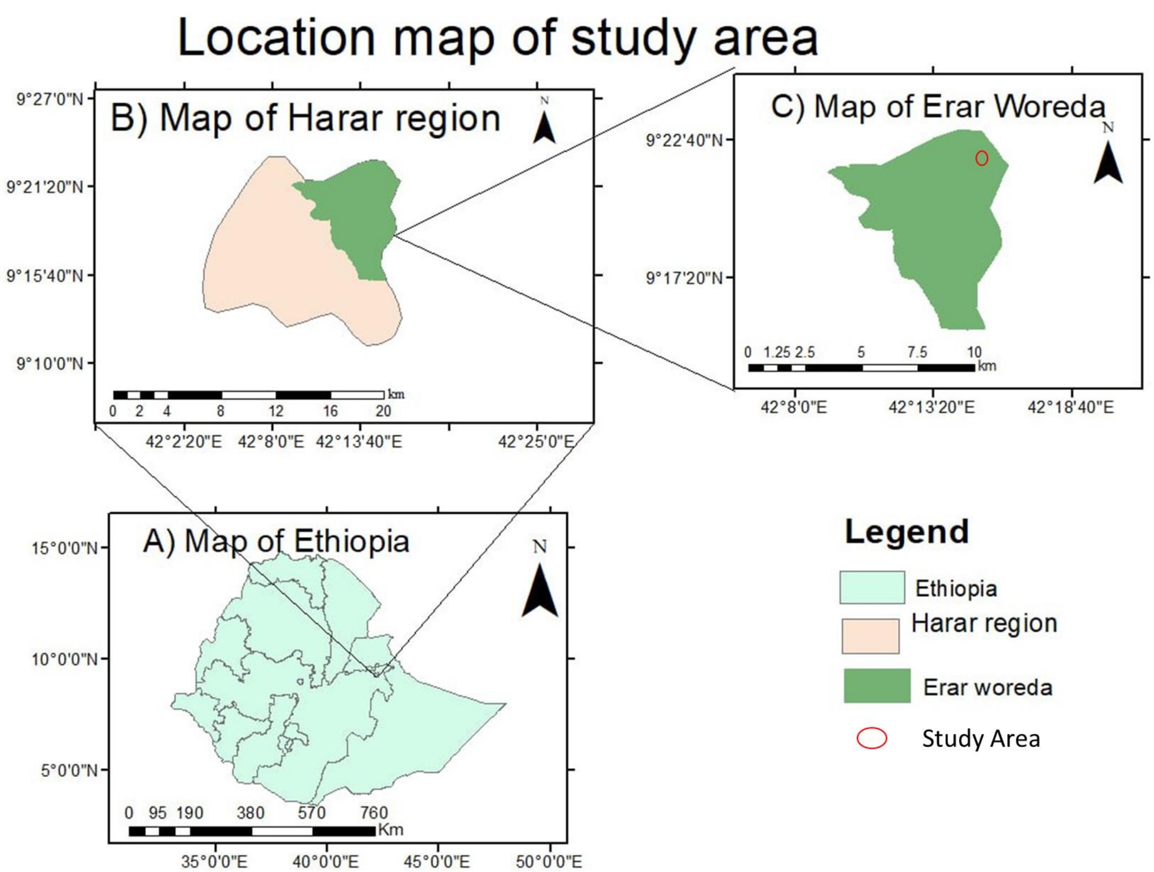

Figure 2 Geological map of study area

1.6 Scope of the study

The scope of the study aims to assess the use of flotation for beneficiating lithium-rich ores from Ethiopia's Harar region. It involves analyzing the ore's composition, optimizing reagent dosage, and measuring lithium grade to establish an effective local extraction method.

1.7 Significance of the project work

The significance of this project lies in conducting the beneficiation of lithium ore samples and evaluating the effect of reagent dosage on the performance of the flotation process. Utilizing the flotation method a proven and effective technique for lithium mineral beneficiation—the research seeks to enhance purity efficiency and evaluate the effect of reagent dosage on lithium minerals. It will also provide important information for future processing plant of the lithium ore deposit and the result of this study is good input for the mining sector investor, for academic researchers as well as for the ministry of mines.

The beneficiation of lithium ore using flotation techniques in the Erar area, Harar region, Ethiopia, holds significant importance due to the growing demand for lithium in various high-tech industries. Lithium is a critical element for rechargeable batteries used in electric vehicles, portable electronics, and energy storage systems. The project focuses on improving lithium extraction efficiency from local pegmatite ores, which contain valuable lithium minerals such as spodumene and associated gangue minerals.

Effective beneficiation through flotation enhances lithium concentration by separating valuable minerals from waste, thereby increasing the ore's economic value and supporting sustainable mining practices. This process also helps optimize downstream processing, reducing environmental impact and operational costs. Given Ethiopia's potential lithium deposits, particularly in pegmatite formations, this study contributes to the development of local lithium resources, fostering economic growth and supporting the global transition to renewable energy technologies.

In summary, the project's significance lies in:

- Unlocking the lithium potential of the Erar area through efficient mineral processing.
- Providing data to design sustainable and cost-effective beneficiation methods tailored to local ore characteristics.
- Supporting Ethiopia's strategic position in the global lithium supply chain.
- Contributing to cleaner energy solutions by enabling the production of lithium for batteries and other applications.

1.7 Limitation of the project

This study was limited by both laboratory equipment and budget constraints. Key equipment, such as sieves and the cross beater mill, were not in standard working condition, which prevented us from achieving the desired feed amount for the flotation cell experiments on the mineral sample. The sieve shaker, especially the 63-micrometer sieve, was damaged and could not accommodate multiple sieves simultaneously. Additionally, the existing screen was unable to process samples to a size smaller than 0.5 millimeters. These equipment limitations were carefully noted and considered in the analysis of the results.

A major constraint of this study was the limited budget, which restricted the ability to perform repeated measurements and cover laboratory analysis fees necessary to ensure optimal results. Given these limitations, the outcomes achieved in this study were not as robust as desired.

Chapter Two

2. Literature Review

2.1 Lithium extraction from pegmatites

Lithium extraction from pegmatite involves mining hard-rock pegmatite deposits, which are igneous rocks formed from magma and characterized by large crystal sizes. These rocks are widespread globally, with some containing high concentrations of lithium minerals such as spodumene, lepidolite, and petalite. Typically, lithium is extracted through open-pit mining, which includes drilling and blasting to access the ore.

The mining process generally includes the following steps:

1. **Prospecting and Exploration:** Identifying and assessing pegmatite deposits with significant lithium content.
2. **Mining and Processing:** Extracting lithium-bearing pegmatite through drilling and blasting, followed by transporting the ore to a processing plant where it is crushed and ground into fine particles.
3. **Separation and Concentration:** Using techniques like flotation or gravity separation to isolate lithium minerals from other materials and impurities, depending on the deposit's mineralogy.
4. **Refining and Purification:** Further processing the lithium concentrate to remove impurities and produce high-purity lithium compounds such as lithium carbonate or lithium hydroxide, essential for lithium-ion battery manufacturing.

Compared to lithium extraction from brine deposits, pegmatite mining can be more environmentally friendly due to lower water usage and reduced risk of water contamination. However, it tends to be more costly because hard-rock mining and processing are often more complex and energy-intensive.

2.2 Beneficiation of lithium ores

The major techniques used in the beneficiation of lithium minerals include dense medium separation (DMS), magnetic separation, and froth flotation. Dense media separation is usually employed for coarse gangue rejection, but can also be used to produce lithium concentrates from high grade ores. Flotation is used for processing fine particle size feed, and where high grade concentrates are required. Magnetic separation is used to remove large quantities of iron-bearing gangue minerals to make the concentrate suitable for use in ceramics and glass manufacturing. These separation flotation techniques and gravity and dense medium separation will be reviewed in the following section.

2.2.1 Gravity and dense media separation

Beneficiating pegmatite ore with other valuable minerals like tin and tantalum increases processing complexity, often requiring additional steps for byproduct removal. Spiral circuits and gravity separation are used to remove tantalum minerals and heavy minerals like SnO_2, Ta_2O_5, and Fe_2O_3. Dense Media Separation (DMS), which exploits specific gravity differences between spodumene (3.1-3.2) and gangue minerals (quartz, albite, muscovite), is used for pre-concentration. An early DMS plant used ferrosilicon and magnetite, achieving a 5.36% Li_2O spodumene concentrate. However, issues with feed size have led to DMS being replaced by flotation in some operations, while bromoform has been used to achieve higher spodumene grades with smaller feed sizes. Advanced DMS setups have achieved concentrate grades up to 6.4% Li_2O.

2.2.2 Flotation of lithium ore

Lithium ore is commonly associated with gangue silicate minerals like calcite, muscovite, feldspar, and quartz. While the flotation behavior of these gangue minerals is well understood, few studies focus on separating lithium from them by flotation. Typically, cationic collectors such as dodecyl amines are used, but Choi et al. (2012) investigated oleic acid as a collector for lithium flotation from ore containing feldspar, quartz, calcite, and muscovite. The flotation was conducted in three stages based on the isoelectric points (IEP) of the minerals: lepidolite (<2), quartz (2.5), albite (2.3), and calcite (9.7).

First, the pulp was floated at pH 9 using 50–200 g/t oleic acid and 40 g/t kerosene frother to separate calcite by depressing its flotation. Second, the concentrate was cleaned at pH 6–8 with

50 g/t oleic acid and 20 g/t frother to further remove calcite. Finally, lepidolite was selectively floated at pH 2, where it showed stronger electrostatic interaction with oleic acid compared to quartz and albite. This process resulted in a lepidolite concentrate with a lithium grade 3.8 times higher than the feed (Choi et al., 2012).

2.3 Mineralogy of lithium-bearing minerals

Lithium ores often occur as hard rock complex aluminium silicate deposits known as pegmatites (Bale & May, 1989; Colton and D. M, 1957). Pegmatites are intrusive igneous rocks mainly composed of interlocking mineral grains of quartz, feldspar, spodumene, mica (Colton and D. M, 1957). The lithium pegmatite ores contain lithium minerals such as spodumene, petalite, lepidolite and amblygonite (Bulatovic, 2015). Other lithium minerals such as zinnwaldite, triphylite and eucryptite are also reported in the literature (Colton and D. M, 1957; Grosjean et al; 2012). Among the lithium-rich pegmatite minerals, spodumene is one of primary economic importance. The typical lithium grade in exploitable pegmatite deposits ranges from about 1.25–4% Li2O (Bale & May, 1989).

2.4 Flotation of lithium

Anionic collectors such as oleic acid, sodium oleate, and various fatty acids have been widely used for lithium flotation from pegmatite ores, achieving concentrate grades around 6.4–6.52% Li2O in both laboratory and pilot plant studies. Historically, anionic collectors dominated industrial-scale lithium flotation, while cationic collectors like amine acetate were mainly used for reverse flotation to remove gangue minerals such as quartz and feldspar. However, due to their lower flotation performance, cationic collectors have largely been replaced by more selective anionic collectors.

Recent research highlights the benefits of combining anionic and cationic collectors to improve flotation selectivity and purity. Mixed collector systems, such as sodium oleate (NaOL) and dodecyl ammonium chloride (DTAC), have demonstrated synergistic effects, enhancing lithium purity from 50% with NaOL alone to over 82% in the mixed system. This improvement is attributed to better surface activity and molecular arrangement, with FTIR analyses showing complex interactions between collectors and lithium surfaces that promote co-adsorption and stronger binding.

In addition to collectors, conditioning reagents including gangue minerals and lithium depressants are used to enhance selectivity during flotation. The flotation efficiency depends on optimizing collector types, concentrations, and pH conditions, with studies indicating maximum lithium flotation at pH 8–9 due to optimal adsorption and surface tension properties of oleic acid. Overall, mixed collector systems and proper conditioning reagents offer promising routes to improve lithium concentrate quality from pegmatite ores.

Chapter Three

3. Materials and Methods

3.1 Materials

3.1.1 Sample Collection

In this study, a total of 4 kilograms of lithium-bearing ore was obtained from the Erar area, Harar region, which is recognized for its promising pegmatite deposits. The sampling procedure was carefully planned to guarantee that the raw material used in the beneficiation experiments was representative and dependable. To minimize sampling bias and ensure the sample accurately represents the ore body, a random sampling method was used. First, the sampling area was visually inspected and divided into different zones according to geological features such as mineral distribution, rock type, and surface exposure. Then, samples were randomly collected from each zone using a geological hammer and chisel. Each sub-sample ranged between 200 and 500 grams. These sub-samples were then combined and thoroughly mixed to form a uniform composite sample weighing 4 kilograms. The composite was stored in sealed and properly labeled containers to avoid contamination or moisture changes before laboratory analysis. By using random sampling, the collected ore sample captured the natural variability within the deposit and minimized the impact of localized irregularities. This approach enhances the accuracy and reproducibility of the flotation tests performed in the beneficiation process.

3.1.2Sample Preparation

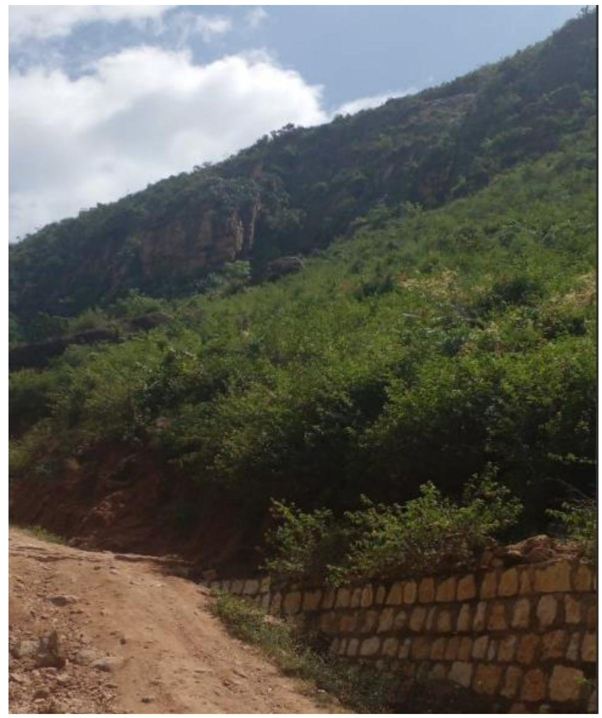

Figure 3 Site sample Collection

The initially collected lump-sized ore samples were too large to be processed directly in the laboratory, so they needed to be reduced to laboratory standar. This size reduction began manually, where a sledgehammer was used to break the large lumps into smaller fragments suitable for the laboratory jaw crusher.

The manual breaking was performed carefully to prevent significant loss of material or contamination. Using a sledgehammer allowed for controlled fracturing of the ore, ensuring that the fragments were small enough to be efficiently processed by the crusher. This preliminary step was necessary because the jaw crusher has specific feed size limits and cannot handle oversized or irregular lumps.

After the ore pieces were properly sized, they were introduced into the laboratory jaw crusher. The crusher operated by applying compressive force between two jaws—one stationary and one moving—which further reduced the fragments into smaller particles within a target size range appropriate for beneficiation tests.

Following crushing, the ore was pulverized to produce even finer particles. Pulverization involved grinding the crushed material into powder or fine grains, thereby increasing the surface area exposed. This finer particle size is crucial for the flotation process, as it improves the separation efficiency by exposing more mineral surfaces.

Overall, the size reduction—from manual breaking with a sledgehammer through jaw crushing and pulverization—was carefully managed to maintain sample integrity and prepare the ore adequately for flotation testing. This preparation stage is essential to obtaining consistent and reliable results in the beneficiation study.

Figure 4 Samples preparation to feed into laboratory jaw crusher

Proper preparation of the ore sample before feeding it into the laboratory jaw crusher—including breaking down large pieces, controlling moisture, mixing the sample evenly, and feeding it carefully—ensures the sample remains consistent and intact. This results in a uniform particle size that is suitable for further grinding and flotation tests.

Figure 5 Samples preparation to feed into flotation cell

3.1.3 Laboratory tools

The AAiT laboratory is equipped with various instruments including a jaw crusher, electronic weight balance, cutting mill, cross beater mill, flotation cell, sieve shaker, and a range of sieves of different sizes. These tools are utilized for sample preparation, size reduction, weighing, and mineral processing experiments.

Figure 6 Materials used for laboratory works

Instruments and Their Functions in Flotation

Instrument	Function	Application in Flotation
Cylinder	Accurately measures liquid volumes	- Prepares chemical reagents (collectors, frothers, pH modifiers) - Determines pulp density (solid-liquid ratio) influencing flotation performance
Digital Weight Balance	Precisely measures the weight of solid materials	- Measures mass of feed, concentrate, and tailings - Used for recovery rate calculation and assessing flotation efficiency
Sieve Stack with Shaker	Conducts particle size analysis via mechanical sieving	- Determines particle size distribution (PSD) - Identifies optimal grinding size (typically 75–150 µm) - Evaluates need for regrinding - Analyzes post-flotation tailings for particle loss

Crushing and Grinding Equipment Used in Flotation Sample Preparation

Equipment	Function	Working Principle	Application in Flotation
Cross Beater Mill	Provides fine grinding for hard and brittle materials	Rotating beater impacts and shears material against a metal screen or chamber	- Produces fine, uniform particles (<150 µm) - Ensures effective mineral liberation prior to flotation
Jaw Crusher	Performs primary crushing of large samples	Fixed jaw and moving jaw compress material until it breaks	- Reduces sample size (<5 mm) for further grinding - Promotes consistent particle sizing for enhanced flotation efficiency
Cutting Mill	Medium to fine size reduction for soft/heterogeneous materials	High-speed rotating blades cut and shear sample; output passes through a screen	- Processes fibrous or moist samples - Prepares uniform feed for flotation.

3.1.4 Reagents Used in Flotation

The Reagents used in flotation such as, Oleic acid, kerosene, and copper sulfate were chosen as the collector, frother, and activator, respectively, due to their accessibility and demonstrated effectiveness in lithium ore flotation. Oleic acid is an affordable and widely available fatty acid collector that effectively adsorbs onto lithium minerals such as spodumene and lepidolite, particularly in oxide and silicate ores, enhancing their hydrophobic properties. Kerosene, a petroleum-based product commonly accessible even in areas with limited resources, functions as an efficient frother by stabilizing the froth layer without disrupting the collector-mineral interaction, thereby improving flotation recovery and concentrate quality. Copper sulfate, an inexpensive and frequently used chemical, acts as an activator by increasing the surface reactivity of silicate-associated lithium minerals, promoting better collector attachment. The use of these reagents collectively supports a flotation process that is both technically effective and cost-efficient, suitable for processing lithium ores from the Harar region.

1) Oleic Acid as Collector

Oleic acid is a commonly used collector reagent in mineral flotation, known for its ability to selectively adsorb onto the surfaces of target minerals. As a collector, oleic acid plays a vital role in increasing the hydrophobicity of valuable mineral particles. It does this by chemically attaching to the mineral surfaces via its polar carboxyl (-COOH) group, while its long hydrocarbon chain imparts hydrophobic properties.

In lithium ore flotation, oleic acid selectively binds to lithium-bearing minerals, enhancing their adhesion to air bubbles during the flotation process. This selective adsorption helps separate valuable minerals from the gangue by making them repel water and attach to rising bubbles, which facilitates their recovery in the froth layer.

Oleic acid is preferred because of its strong collecting ability, widespread availability, cost-effectiveness, and being environmentally friendly compared to synthetic collectors. Its efficiency depends on factors such as pH, dosage, and conditioning time, which must be optimized to achieve the best purity.

2) Copper Sulfate as Activator

Copper sulfate ($CuSO_4$) is frequently used as an activator in flotation to improve the response of certain minerals, particularly sulfide and oxide minerals that are otherwise difficult to float. As an activator, copper sulfate alters the surface characteristics of mineral particles by depositing copper ions onto their surfaces.

In the flotation of lithium ore, copper sulfate increases the floatability of lithium-bearing minerals that might not naturally respond well to collectors. Copper ions adsorb onto the mineral surfaces, creating active sites that enhance the effectiveness of the collector (oleic acid). This activation improves both the selectivity and recovery of valuable minerals, making them more responsive to flotation reagents.

However, careful control of copper sulfate dosage is necessary, as excessive amounts may activate unwanted gangue minerals, thereby reducing flotation selectivity.

3) Kerosene as Frother

Kerosene is employed as a frother in flotation, playing a key role in generating and stabilizing the froth layer at the flotation cell's surface. The main function of the frother is to produce fine, stable bubbles that effectively carry hydrophobic mineral particles to the surface.

By lowering the surface tension of water, kerosene aids in forming small air bubbles and maintaining froth stability throughout the flotation process. Stable froth is essential to keep floated particles suspended long enough for collection as concentrate.

In lithium ore flotation, kerosene helps maintain a consistent froth texture and thickness, which supports the efficient separation of lithium minerals from the gangue. The amount of kerosene must be carefully regulated, as too much can cause overly stable froth that is difficult to manage, while too little may lead to poor bubble formation and reduced recovery.

Together, oleic acid as a collector, copper sulfate as an activator, and kerosene as a frother create a synergistic reagent system that significantly enhances the flotation performance of lithium ores. Their combined use improves mineral selectivity, flotation kinetics, and concentrate quality—key factors for the successful beneficiation of lithium ore.

Figure 7 Reagents used for laboratory works

3.2 Methods and flotation procedure

An initial 4-kilogram sample of lithium ore was subjected to size reduction, beginning with a jaw crusher. This primary crushing stage broke the large ore lumps into smaller, more manageable pieces suitable for further processing. The crushed material from the jaw crusher was then passed through a cutting mill for secondary size reduction. The cutting mill used shearing and cutting actions to produce a finer and more uniform particle size distribution necessary for the next steps. Subsequently, the material from the cutting mill was further ground using a cross beater mill, which applies high-speed impact forces to pulverize the ore into even finer particles. This step was essential to reach the particle size required for the flotation beneficiation process. After milling with the cross beater, the sample was sieved for 10 minutes to separate particles according to size. Sieving allowed for classification of the ore into distinct size fractions, ensuring consistent particle sizes for flotation testing. Oversized particles that remained on the sieve were subjected to additional crushing in the cross beater mill, followed by a second sieving cycle. This iterative process guaranteed that the entire sample met the desired size specifications. The particle size fractions were identified using standard sieve designations, where a negative sign (-) indicates particles that pass through the sieve (finer than the sieve size), and a positive sign (+) denotes particles retained on the sieve (coarser than the sieve size). This system enabled clear categorization and selection of appropriate size fractions for flotation. For flotation testing, the sample was prepared by isolating particles sized at 63 micrometers (µm), which is considered optimal for efficient recovery of lithium minerals. Selecting the correct particle size is crucial since flotation performance depends heavily on particle size, surface area, and mineral liberation. The flotation experiments were conducted using 120 grams of the prepared feed material. The flotation cell operated at a speed of 1850 revolutions per minute (rpm), and the test was repeated 27 times to ensure consistent and reliable results. These operational parameters were chosen to maximize the separation of valuable lithium minerals from the gangue. This detailed sample preparation procedure—from initial crushing to sieving and flotation—ensured a homogeneous sample and reproducible test conditions, which are vital for accurately assessing the effectiveness of the flotation beneficiation method for lithium ore sourced from Harar.

Chapter Four

4. Results and Discussion

4.1 Results

4.1.1Chemicals analysis of results

The chemical analysis result of the Harar lithium ore in pegmatite are presented on Table 1 according to analytical method AAS (Atomic Absorption Spectroscopy) done on sample. From these results, Harar lithium ore contains on the average 74.98% SiO2 (silicon oxide), 15.86 % Al2O3 (Aluminium oxide), 1.04CaO % (Calcium oxide), <0.01% MgO (Magnesium oxide), 3.28% Na2O (Sodium oxide), 3.8 % K2O (Potassium oxide), 0.36% Fe2O3 (Iron oxide) and <0.01% Li2O (Lithium oxide).

Table 1. Chemical analysis result

Sample's code	SiO2	Al2O3	CaO	MgO	Na2O	K2O	Fe2O3	Li2O	MnO
Taju-01	74.98	15.86	1.04	<0.01	3.28	3.8	0.36	0.01	0.02

4.1.2 Lithium Oxide Content and Concentration Analysis

In the context of the beneficiation study on lithium ore using flotation methods, a set of samples labeled C-01 to C-09 were examined to assess their lithium oxide (Li_2O) content. The concentration of Li_2O serves as a key measure of lithium mineralization and overall ore grade. Elevated Li_2O percentages typically indicate a higher abundance of lithium-rich minerals such as spodumene, petalite, and lepidolite, which are the main sources of lithium in hard rock deposits.

4.1.3 Interpretation and Observations

Trend Analysis:

The data reveals a general upward trend between the lithium oxide (Li_2O) content and the corresponding concentrate weight. This implies that samples with higher Li_2O levels tended to produce larger quantities of concentrate following the flotation process.

For instance, sample C-09, which recorded the highest Li_2O content at 1.62%, also yielded the heaviest concentrate at 58 grams. In contrast, C-01, with the lowest Li_2O concentration of 1.20%, produced the smallest concentrate weight of 30 grams.

Grade Distribution:

The majority of the samples exhibit Li_2O concentrations within the 1.3% to 1.6% range. This range falls within the classification of moderate-grade lithium ore, which is typically considered suitable for beneficiation.

These consistent values point to a steady distribution of lithium-bearing minerals within the ore, indicating its potential for further processing and possible commercial-scale extraction.

Sample Variability:

Although the differences in Li_2O content across samples are relatively modest, even slight variations can have a significant impact on economic feasibility and processing decisions at a commercial scale. Small increases in lithium grade can lead to notable improvements in yield and profitability in large-scale operations.

Table 2. Results of laboratory after flotation

Sample's code	Percent of lithium oxide (Li_2O)	Concentration weight in gram	Grade of lithium oxide (Li_2O)
C-01	1.2	30	1.2
C-02	1.43	33	1.43
C-03	1.39	36	1.39
C-04	1.46	39	1.46
C-05	1.5	44	1.5
C-06	1.58	47	1.58
C-07	1.47	52	1.47
C-08	1.36	56	1.36
C-09	1.62	58	1.62

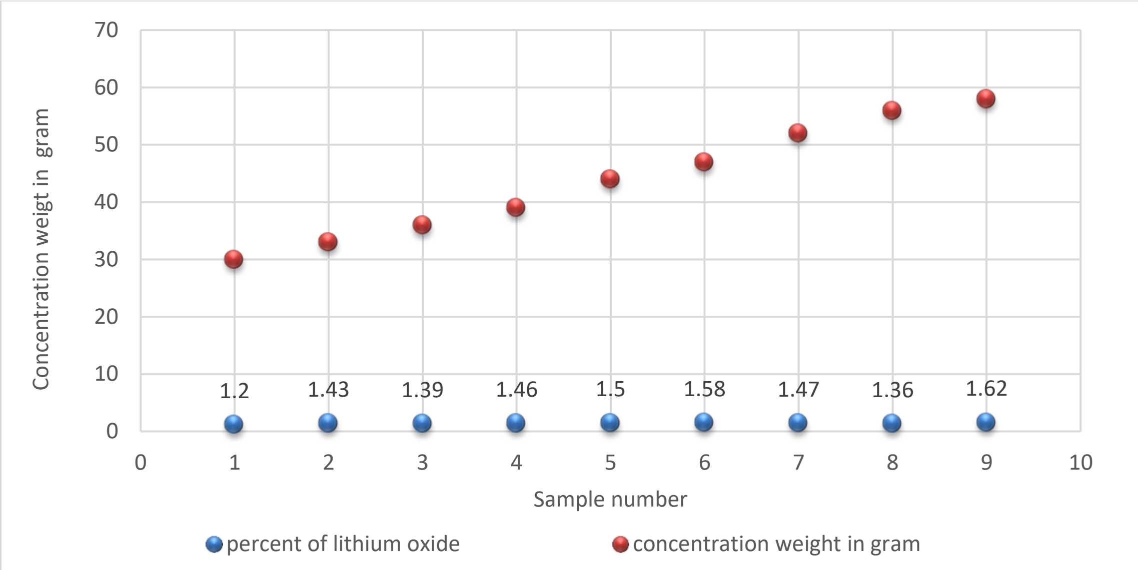

Figure 8 Graphical representation of Lithium ore after flotation

The flotation graph indicate a steady increase in Li_2O content from 1.20% at 30 g to 1.58% at 47 g, reflecting efficient separation and concentration of lithium minerals in the early stages. After this point, the Li_2O grade becomes inconsistent, dropping to 1.47% at 52 g and further to 1.36% at 56 g, before unexpectedly rising to a peak of 1.62% at 58 g. This pattern suggests a general improvement in grade initially, followed by a temporary decline and then a sudden spike. Such variations may result from factors like entrainment of unwanted gangue materials, mechanical inefficiencies, or suboptimal froth cleaning. These irregularities at later stages could also stem from the flotation of middling particles or dilution effects, indicating that while the process is effective early on, adjustments may be needed to maintain selectivity and enhance the overall quality and weight of the concentration.

4.2 Calculations of lithium ore grade before/after flotation

Grade = (Weight of Desired Mineral / Total Weight of sample) * 100% (Wills & Finch, 2016 ; Wills & Napier-Munn, 2006).

Desired mineral = lithium oxide

From table 1

Step 1. Calculate the weight of the desired mineral

0.01% of 400 g=0.01/100×400=0.04 g

So, the sample contains 0.04 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.01/400*100= 0.0025

Therefore, grade of lithium oxide before flotation is 0.0025

After flotation

For experiment 1

Step 1. Calculate the weight of the desired mineral

1.2% of 30 g=1.2/100×30=0.36 g

So, the sample contains 0.36 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.36/30*100= 1.2

Therefore, grade of lithium oxide after flotation is 1.2

For experiment 2

Step 1. Calculate the weight of the desired mineral

1.43% of 33 g=1.43/100×33=0.4719g

So, the sample contains 0.4719 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.4719/33*100= 1.43

Therefore, grade of lithium oxide after flotation is 1.43

For experiment 3

Step 1. Calculate the weight of the desired mineral

1.39% of 36 g=1.39/100×36=0.5 g

So, the sample contains 0.5 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.5/36*100= 1.3888

Therefore, grade of lithium oxide after flotation is 1.3888

For experiment 4

Step 1. Calculate the weight of the desired mineral

1.46% of 39 g=1.46/100×39=0.5694 g

So, the sample contains 0.5694 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.5694/39*100= 1.46

Therefore, grade of lithium oxide after flotation is 1.46

For experiment 5

Step 1. Calculate the weight of the desired mineral

1.5% of 44 g=1.5/100×44=0.66 g

So, the sample contains 0.66 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.66/44*100= 1.5

Therefore, grade of lithium oxide before flotation is 1.5

For experiment 6

Step 1. Calculate the weight of the desired mineral

1.58% of 47 g=1.58/100×47=0.7426 g

So, the sample contains 0.7426 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.7426/47*100= 1.58

Therefore, grade of lithium oxide after flotation is 1.58

For experiment 7

Step 1. Calculate the weight of the desired mineral

1.47% of 52 g=1.47/100×52=0.7644 g

So, the sample contains 0.7644 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.7644/52*100= 1.47

Therefore, grade of lithium oxide after flotation is 1.47

For experiment 8

Step 1. Calculate the weight of the desired mineral

1.36% of 400 g=1.36/100×56=0.7616 g

So, the sample contains 0.7616 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.7616/56*100= 1.36

Therefore, grade of lithium oxide after flotation is 1.36

For experiment 9

Step 1. Calculate the weight of the desired mineral

1.62% of 58 g=1.62/100×58=0.9396 g

So, the sample contains 0.9396 grams of the desired mineral.

Step 2. Calculate grade of desired mineral

By using above formula

Grade of lithium oxide = 0.9396/58*100= 1.62

Therefore, grade of lithium oxide after flotation is 1.62

From calculation the grade lithium oxide is equal to its percent.

Table 3. Experiment runs with different reagent dosage

No of experiment	Frother in ml	Collector in ml	Activator in ml	Weight of concentration in g
1	5	3	10	52
2	5	5	10	56
3	5	7	10	58
4	8	3	10	47
5	8	5	10	44
6	8	7	10	39
7	10	3	10	36
8	10	5	10	33
9	10	7	10	30

4.3 Discussion

According to these result the average composition of Harar lithium ore is 74.98% SiO_2 (silicon oxide), 15.86 % Al_2O_3 (Aluminium oxide), 1.04CaO % (Calcium oxide), <0.01% MgO (Magnesium oxide), 3.28% Na_2O (Sodium oxide), 3.8 % K_2O (Potasium oxide), 0.36% Fe_2O_3 (Iron oxide) and <0.01% Li_2O (Lithium oxide). From table 2 the grade of lithium ores are (1.2, 1.43, 1.39, 1.46, 1.5, 1.58, 1.47, 1.36, and 1.62) respectively with 1.62 is largest of all. From table 3 different experiment runs with different reagent dosage were done and among them experiment number 3 gives high concentration weight at frother 5 milliliter, collector 7 milliliter and activator 10 milliliter. From first to the third the experiment the weight of concentration became increasing. On third experiment the weight of concentration became maximum and then decreasing to the ninth experiment number.

Chapter Five

5. Conclusions & Recommendations

5.1 Conclusions

The beneficiation of lithium ore sourced from the Harar region was effectively carried out at laboratory scale using the flotation method. This technique was employed to selectively separate lithium-rich minerals from unwanted gangue materials. The results provided valuable insight into both the grade of lithium oxide and the yield of concentrate obtained through flotation. The flotation process produced nine distinct concentrate samples with lithium oxide (Li_2O) grades as follows: 1.47%, 1.36%, 1.62%, 1.58%, 1.50%, 1.46%, 1.39%, 1.43%, and 1.20%. The average Li_2O grade across all samples was calculated to be 1.4455%, indicating that the lithium ore from Harar is of moderate grade, making it a viable candidate for further beneficiation and possible industrial use. The corresponding concentrate weights for these samples were: 52 g, 56 g, 58 g, 47 g, 44 g, 39 g, 36 g, 33 g, and 30 g, respectively. These values reflect the variability in flotation performance, which appears closely linked to the differences in reagent dosages applied during each test. The highest Li_2O grade of 1.62% and the largest concentrate weight of 58 grams were achieved under the frother (5 ml), collector (7 ml), and activator (10 ml) reagent condition. This particular reagent combination demonstrated the most effective flotation results, emphasizing the importance of optimizing reagent dosage. Proper control and selection of flotation reagents can significantly enhance lithium concentration and product quality, while also helping to minimize chemical waste and reduce operational costs, particularly at industrial scales. The parameters used in this experimental study—such as rotational speed, reagent type, and dosage levels—were well chosen and relevant to the characterization and beneficiation of Harar's lithium ore. The data obtained were consistent and reliable, offering a clearer understanding of how flotation conditions affect mineral separation and concentration efficiency.

5.2 Recommendations

In light of the results obtained from the flotation-based beneficiation of lithium ore sourced from the Erar area, Harar region, the following suggestions are made to further enhance lithium concentration in terms of both grade and efficiency:

➢ Investigate Alternative Beneficiation Technique although flotation has shown promise, it is recommended that additional beneficiation methods—such as gravity separation, magnetic separation, or hydrometallurgical processing—be considered in future research. These alternative techniques may offer improved lithium concentration or concentrate quality, particularly in cases where flotation does not achieve the desired performance. A comparative study of these methods could help determine the most suitable and economically viable option for upgrading lithium ore from Harar.

➢ Test Different Reagent Combinations Further flotation experiments should be carried out using varied reagents and reagent formulations. Since the effectiveness of flotation largely depends on the nature and concentration of reagents (collectors, frothers, and activators), altering the reagent types could lead to different outcomes in terms of lithium grade and concentrate mass. Exploring different chemical schemes may reveal more selective or more efficient reagents that better match the mineralogical characteristics of the Harar deposit.

Adopting these recommendations will not only improve the understanding of Harar's lithium ore properties but also support the development of a more robust and optimized beneficiation process tailored to the region’s unique geological context.

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Appendix

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Taju Mohemmed

Sample type ; Rock

Sample Preparation:-200 Mesh

Date Submitted :18/12/2024

Issue Date:-02/01/2025

Request No:- GLD/RQ/707/24

Report No:- GLD/RN/4229/24

Number of Sample One(01)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

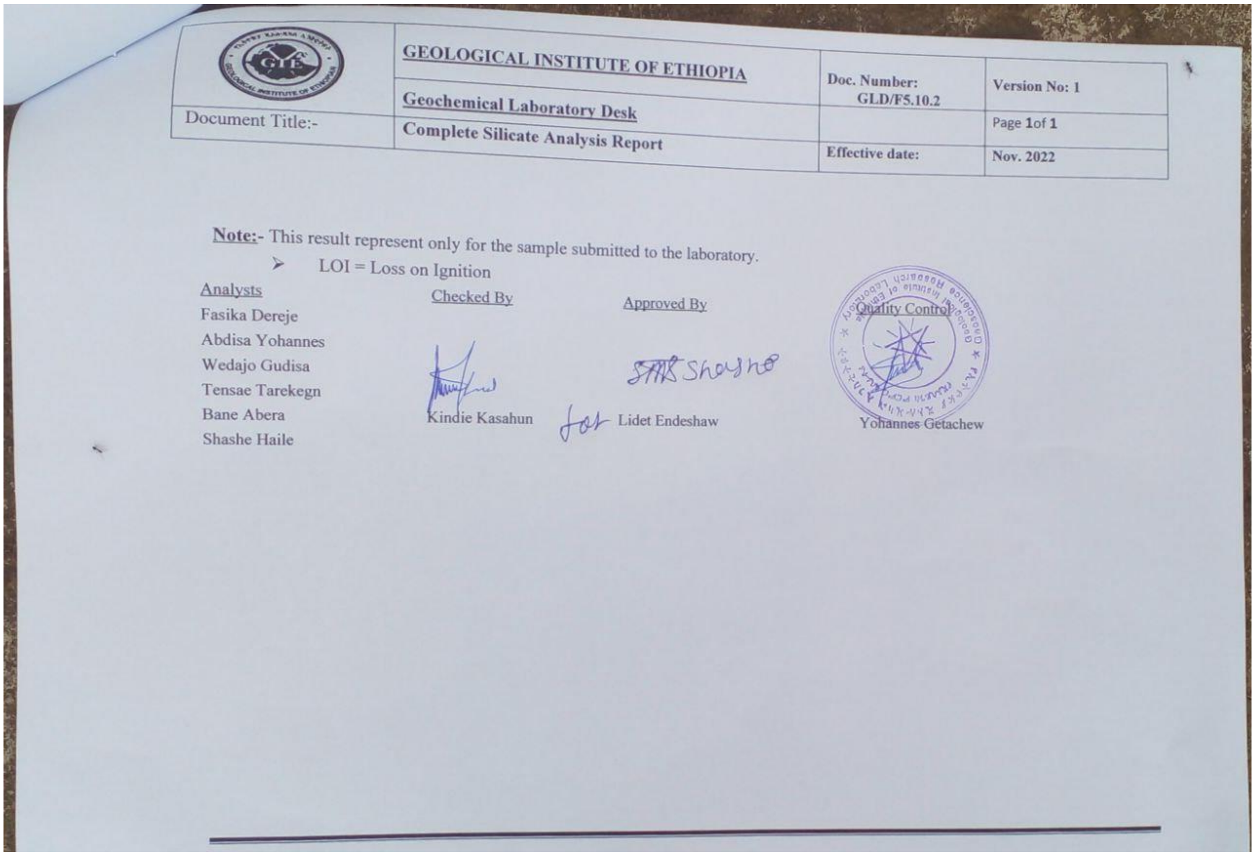
Collector'scode	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	P_2O_5	TiO_2	H_2o	LOI	Li_2O	weight of sample
Taju-01	74.98	15.86	0.36	1.04	<0.01	3.28	3.80	0.02	0.06	0.18	0.12	0.75	<0.01	400gm

Note:- This result represent only for the sample submitted to the laboratory.

- LOI = Loss on Ignition

Analysts	Checked By	Approved By	Quality Control
Fasika Dereje Abdisa Yohannes Wedajo Gudisa Tensae Tarekegn Bane Abera Shashe Haile	Kindie Kasahun	Lidet Endeshaw	Yohannes Getachew

Page 1



	GEOLOGICAL INSTITUTE OF ETHIOPIA	**Doc. Number: GLD/F5.10.2**	**Version No: 1**
	Geochemical Laboratory Desk		Page **1** of **1**
Document Title:-	**Complete Silicate Analysis Report**	**Effective date:**	**Nov. 2022**

Note:- This result represent only for the sample submitted to the laboratory.

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Analysts	Checked By	Approved By	Quality Control
Fasika Dereje	Kindie Kasahun	Lidet Endeshaw	Yohannes Getachew
Abdisa Yohannes			
Wedajo Gudisa			
Tensae Tarekegn			
Bane Abera			
Shashe Haile			

	GEOLOGICAL INSTITUTE OF ETHIOPIA	Doc. Number: GLD/F5.10.2	Version No: 1
	Geochemical Laboratory Desk		Page 1of 1
Document Title:-	Complete Silicate Analysis Report	Effective date:	Nov. 2022

Customer Name;- Taju Mohammed

Sample type ;- Powder

Sample Preparation:-200 Mesh

Date Submitted ;- 25/03/2025

Issue Date:- 31/03/2025

Request No:- GLD/RQ/1136/25

Report No:- GLD/RN/4596/25

Number of Sample: Nine(09)

Analytical Result: In percent (%) Element to be determined Major Oxides & Minor Oxides.

Analytical Method: $LiBO_2$ FUSION, HF attack, GRAVIMETERIC, COLORIMETRIC and AAS

Collector'scode	Li_2O	weight Of sample
C--01	1.20	30gm
C--02	1.43	33gm
C--03	1.39	36gm
C--04	1.46	39gm
C--05	1.50	44gm
C--06	1.58	47gm
C--07	1.47	52gm
C--08	1.36	56gm
C--09	1.62	58gm