ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CHEMICAL AND BIO ENGINEERING

DEPARTMENT OF ETHIO-MINES DEVELOPMENT CENTER

Process Mineralogy of Laga Dambi Gold Ore, Oromiya, Southern Ethiopia

By Walkite Alemayehu

This Project Work is presented for Degree of Masters in Mineral Engineering

September, 2023

Addis Ababa, Ethiopia

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"The Project is submitted to the School of Chemical and Bio Engineering, ETHIO-MINES DEVELOPMENT CENTER in Partial Fulfillment of the Requirements for the Degree of Master in Mineral Engineering."

Name of the Student- Walkite Alemayehu

Name of Advisor- Bogale Tadesse (PhD)

APPROVAL SHEET FOR SUBMITTING FINAL PROJECT

"Process Mineralogy of Laga Dambi Gold Ore, Oromiya, Southern Ethiopia" Submitted in partial fulfillment of the requirement for the degree of masters of engineering in mineral engineering, complies with regulations of university and meets the accepted standards with respect to originality and quality.

Approved by board of examiners;

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Advisor	**Signature**	**Date**

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STATEMENT OF THE AUTHOR

I declare and confirm that this project entitled **"Process Mineralogy of Laga Dambi Gold Ore, Oromiya, Southern Ethiopia"** is my own work conducted under the supervision of Bogale Tadesse (PhD). I have followed all the ethical principles of Project preparation, data collection, data analysis and completion of the Project. All the literature review that is included in the project has been given recognition through citation. I have adequately cited and referenced all the original sources. This project is submitted in partial fulfillment of the requirement for a degree of Masters in **Mineral Engineering from School of Chemical and Bio Engineering, ETHIO-MINES DEVELOPMENT CENTER** at **Addis Ababa University AAiT**. I further declare that this project has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

School**:** Chemical and Bio Engineering

Department**:** Mineral Engineering

Student's Name: Walkite Alemayehu

Signature:- ___________________

Date:- _______________________

Advisor's Name:- Bogale Tadesse (PhD)

Signature:- ___________________

Date:- _______________________

Acknowledgment

Firstly I would like to thanks my God for he gives me peace and success to complete this project starting from the beginning to end. A lot of people have been contributed in many ways to the success of this project and as part of my appreciation to the contribution of these people I would want to express my profound gratitude to each of them:

Firstly, I would like to give heartfelt thanks to my Advisor Bogale Tadese (PhD) for he gave me his precious time and advised me. I always remember your valuable contribution and constructive ideas for this project success.

Next, I am extremely grateful and pay my gratitude to Ato Dula Mekonin Deputy CEO of Midroc Mining Cluster who gave me permission to have an access to the processing plant and relevant data. I don’t have word to express his great contribution towards my succes; may God bless him. My special thanks goes to Ato Dabere Sidelil, General manager of Midrock Gold Mine PLC, Tesfaye Ersedo Metallurgy Operation Division Head, Sileshi Demissie Devision Head Quality control Service and Ato mulugeta Ayalew Metallurgy lab Technician of Laga Dambi for their valuable support on completion of this project.

Finally, I sincerely thank to my family, friends and Relative for their unreserved encouragement and supportive ideas during project work.

ABSTRACT

To understand gold ore processing, the important mineralogical properties of Laga Dambi gold ore was described qualitatively and quantitatively. This is required to determine the parameters of gold ore grade, ore composition (elemental and mineralogical), and concentration of any valuable minerals, nature and concentration of minerals detrimental to the processing. One 75mm x50mm size polished thin section was supplied from each sample and was examined by conventional transmitted and reflected light polarizing microscope to determine the distribution of gold in the samples. Sub samples (500g) of each ore type were ground to 1mm and the heavy minerals concentrated using gold pan. The concentrates were submitted for mineralogical analysis to determine the distribution and particle size of gold in the samples. XRD, XRF and Geochemical analysis was carried out for gold mineralogical characterization and its concentration determination. From the data obtained it can be concluded that, gold is the most valuable element in the ore. The samples are all well graded and show excellent liberation. Sulphide mineralization is coarse within all the samples The pyrrhotite is the most abundant sulphide in all the samples, with the exception of Mse T5 where it is second in abundance to pyrite.Samples OP T1 and MSe T5 containing the highest concentrations of sulphide minerals. The gangue in the samples is dominated by crystalline quartz and mica (muscovite, biotite and phlogopite). Gold was identified in all but the Op T1 head sample. Pyrroyite, pyrite, and chalcopyrite are the most frequent interfering minerals that either consume cyanide or oxygen, or both, and adversely affect the rate or extent of gold leaching. From mineralogical point of view liberation size of gold can be determined to be120µm. from XRD and XRF techniques quartz was predominant gangue minerals in all types. Ankerite, dolomite and plagioclase feldspar were also present in minor constituent. All samples contained low levels of base metals, with the possible exception of OP T3, which are not likely to hinder processing mechanism.

Keywords: Gold ore, gangue minerals and sulphide minerals

1. Introduction

1.1. Back ground

Process mineralogy is an inter discipline which integrates quantitative and qualitative of mineralogical techniques with other metallurgical activities. From a metallurgical perspective, free-milling and refractory ores are the two categories of gold ores. As free-milling gold ore types are being mined and other more complex refractory ores are being explored and processed, process mineralogy takes more consideration from both the mineralogists and metallurgists for it is more useful to solve many challenges that may encounter while gold ore extraction. Gold's extractive metallurgy are mainly depends on mineralogical properties such as: particle size, gold's association with gangue minerals, coatings and rimmings, presence of cyanide consumers, oxygen consumers and carbonaceous materials, interlocking of submicroscopic gold in structure sulfide minerals.

Process mineralogist is necessary to provide clue for chief metallurgist on ore mineralogical aspects and mill products for optimization of product and metallurgical flow-sheets development. So, process mineralogy is always applied to grades and recovery optimization within active mine site and has been applied to many deposit types including gold (Zhou, 2008) Platinum Group Metals (PGMs) (Cabri, 2005) Phosphates and Uranium. This paper is intended to discuss the Laga Dambi gold ore mineralogy and common mineralogical factors affecting its extractive metallurgy.

1.1.1. Statement of problem

Mineralogy is extremely important in understanding the ore body, and to address the problematic minerals that affect grinding, flotation and leaching. Mitigation of hazardous mineral species during the correction stage is not only applied to risk and cost minimization , for the truth of ore bodies complexity and lower-grade gold ore are being increased daily. Detailed mineralogical properties like texture, is the most valuable idea to understand how difficult it would be to separate valuable minerals from gangue and evaluate the feasibility of the project. Effective plant design is based on known mineralogical properties of an ore feed. Textural relationship of the valuable with gangue minerals leads to the recommendations on grinding mechanism selection.

Additional in-depth quantitative analysis of interested mineral can shows the existence of elements which could be problematic effect to the processing route as hazardous components. In a case of Laga Dambi Gold Mine the most recent problematic effect in the process is gradual increment of energy and cyanide consumption. The increasing demand for the production of yellow gold metal, along with the progressive increase in gold prices, also creates a need for gold process mineralogy.

1.1.2. Questions to be answered in The Project Study

What is mineralogical information of Laga Dambi gold ore?

What are its associated gangue minerals?

What is the precious minerals' textural relationship (size, grain boundaries) with gangue?

What are hazardous mineral species of the ore?

What is liberation size of valuable mineral and gangue minerals?

1.2. Objective of Study

1.2.1. General Objective

The general objective of the project is to study process mineralogy of Laga Dambi Gold ore of Shakiso area, Southern Oromiya.

1.2.2. Specific Objectives

The project is aimed specifically to;

- Characterize mineralogical information of Laga dambi gold ore ,
- Study associated gangue minerals of Laga dambi gold ore,
- Identify the textural relationship (size, grain boundaries) of gold with the gangue minerals,
- Identify deleterious mineral species of an ore and
- Determine liberation size of valuable mineral(gold) and gangue minerals,

2. Literature Review

2.1. Gold ores and minerals

2.1.1. Gold ore types

Metallurgist classified Gold ores commonly into two main classifications; free milling and refractory gold ores. Those are more than 90% of gold that can be recovered by well known cyanide leaching process is defined as free-milling ores. Refractory ores are defined as those that require more complicated pre-treatment procedures, yield low gold recoveries, or only produce expected gold recoveries when much more reagent is used. Gold ores can be divided into numerous categories according to the necessary mineral processing techniques and mineralogical characteristics. Below is a summary of some metallurgical considerations for these types of gold ore.

- **Placers, quartz vein gold ores, and oxidized ores:** In most instances, these resources are free-milling, and gold can be extracted using either a direct cyanidation process or a physical separation method using gravity. Refractory gold ore is another term for the oxidized portions of epithermal deposits that are still free-milling, although they generally contain large amounts of sulfide minerals in which gold may appear as minute inclusions or submicroscopic gold.

- **Silver-rich ores and copper sulfide ores**: Minerals with copper sulfide and silver (Ag) rich ores are classified as free-milling; nevertheless, gold exists as electrum when the silver grade exceeds 10 g/t, and the processing technique may then need to be modified. The higher reactivity of silver can affect how gold behaves during flotation, leaching, and other recovery procedures. Due to the silver's tarnishing, A high-silver electrum concentration could yield poor gold extraction (Fleming, 1998). In the event that the concentration of copper in the ore exceeds ±0.3%, the viability of direct cyanidation may be compromised unless the Cu (CN) 2 produced during leaching is treated again..

- **Iron sulfide ores and arsenic sulfide ores:** The amounts of free milling and refractory gold in this ore vary. Ore cyanidation or a combination of flotation and cyanidation can be used to recover gold from non-refractory sulfide ores. The only way to recover gold from refractory materials that is acceptable is to use a pre-treatment method like oxidation before cyanidation.

- **Bismuth sulfide, telluride and antimony gold ores**: Because slow-dissolving gold minerals like maldonite, aurostibite, and gold tellurides are present, bismuth sulfide, antimony, and telluride gold ores are frequently fairly refractory.

- **Carbonaceous ores**: Fine-grained gold is invariably linked to sulfide minerals such as pyrite or arsenopyrite, which can be found in carbonaceous ores. In order to recover gold from this kind of ore, pre-oxidation is typically used to dissolve the sulphide minerals. This is followed by cyanidation, either with or without flotation to concentrate the gold first. Some appear as microcrystalline quartz particles or colloidal size grains (-0.1µm) in carbonates (Fleming, 1998). Because the carbonaceous debris "robs" the gold from the cyanide solution, recovering gold from the carbonaceous sulfidic ore is more challenging. (Wan, 2001)

Gold can be found in pyrite in refractory sulfide ore and double-refractory sulfidic/carbonaceous ore at Barrick's Goldstrike Mine, which is a noteworthy example of a double refractory carbonaceous sulfide ore. Before cyanide leaching, these ores undergo pretreatment in an autoclave and roaster (Thomas, 2000). Gold is extracted by roasting a flotation concentrate and then cyanidating it. Gold occurs mostly as submicroscopic gold in arsenopyrite and pyrite in the Jinya Carlin-type gold deposit in China.

Gold is separated into three types based on how it occurs: surface-bound gold, submicroscopic gold, and microscopic gold. The valuable mineral gold is present as a primary ingredient in the gold minerals that are discussed here, including native gold and electrum. The terms "gold carrier" refer to both the mineral that contains gold and the mineral in which it is present in trace amounts (pyrite and arsenopyrite, for example).

- **Microscopic Gold**

Visible gold, occasionally referred to as microscopic gold, includes gold alloys, tellurides, sulfides, selenides, sulfotellurides, and sulfoselenides, among several types of gold. Electrum (Au, Ag) and native gold (Au) are the two most prevalent and significant gold minerals; they can be found in many kinds of gold deposits. Auricupride (Cu_3Au), Kustelite (AgAu), calaverite

(AuTe2), tetraauricupride (CuAu), krennerite ((Au, Ag)Te2), aurostibite (AuSb2), and maldonite (Au2Bi) are additional gold minerals of economic relevance in certain gold deposits. In primary ores, microscopic gold can be found as inclusions with other minerals or as pure grains of various sizes and shapes attached to fractures and micro fractures. A few typical instances of gold occurrences found in product of mill and ore are shown in Figure 1.

- **Submicroscopic Gold**

Invisible gold or submicroscopic gold is defined as gold that is undetectable under an optical or scanning electron microscope. This invisible gold is the major form of gold deposit in some epithermal gold deposits of South America. Carlin-type gold deposits (such as Jerritt, Carlin, Getchelland Goldstrike in the USA. . Also china has epithermal gold deposits like Gaolong, Lannigou, Donbeizhai and Jinya.

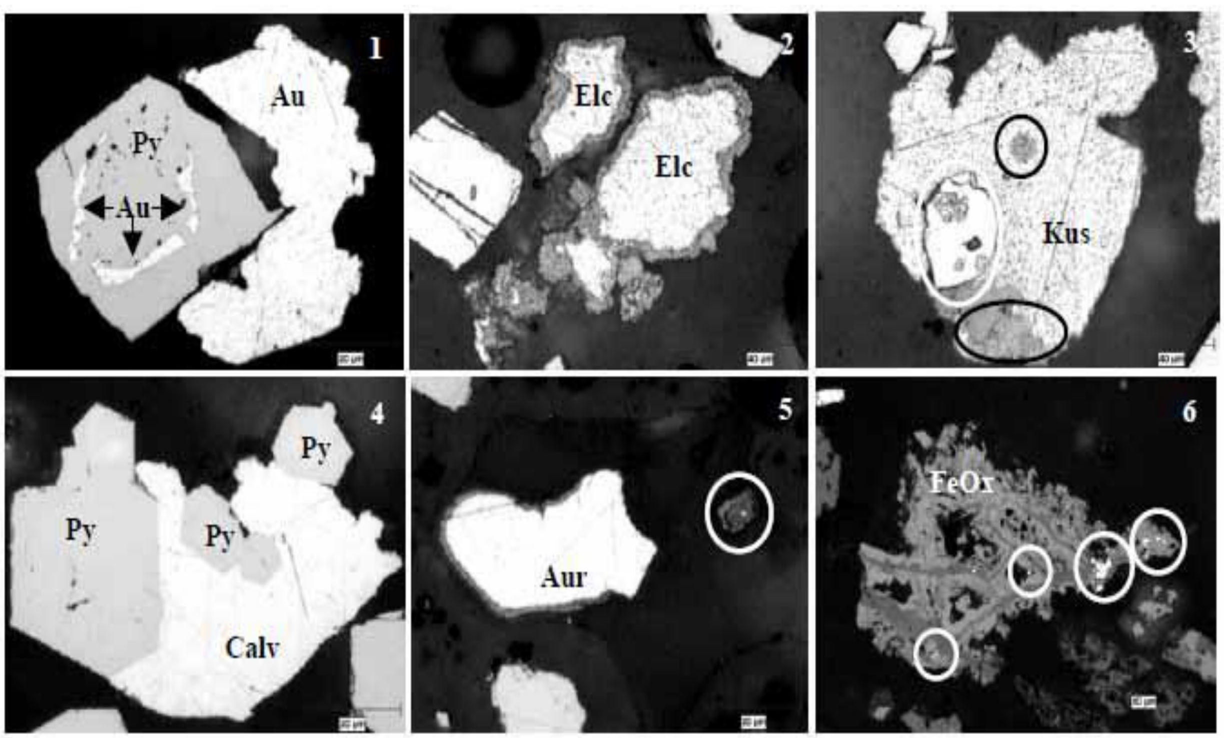


Figure 1.Some examples of gold occurrence;

1 - Gold (Au) that is visible and locked in pyrite; 2 - Acanthite-rimmed electrum (Elc) (gray); 3 - kustelite attached to and including acanthite (gray particle within black circle).; 4 -pyrite and calaverite (Calv) together; 5 - unleached aurostibite (Aur) from a cyanide leach residue with a modified aurostibite (within white circle) and a secondary rim (deep brown).; 6 - native gold from a flotation tail that is bound in FeOx within white circles

Pyrite and arsenopyrite are frequently found in three morphological forms in gold ores: coarse, porous (blastic), and fine-grained. In general, pyrite and arsenopyrite have higher concentrations of gold in the following order: fine-grained, porous, coarse-grained. Zoned pyrite has a high concentration of gold in certain gold deposits, and the outside accretion zone frequently has a higher gold content than the center. Pyrite and arsenopyrite can contain anything from a few hundred to less than one part per million of gold. There have been reports of up to 15,400 ppm of gold concentration in arsenopyrite (Chryssoulis, 1990). Chalcopyrite (Cook, 1990), marcasite, Fe Ox (in calcines or oxidized ores), realgar, and clay minerals are other submicroscopic gold transporters. The two main types of submicroscopic gold are colloidal and gold solid solution.

Surface Gold

Surface-bound gold is gold that has adsorbed onto the surface of other minerals as a result of metallurgical processing, oxidation, or mineralization. Additionally undetectable with optical and electron microscopes, surface gold is only detectable by LIMS. The main transporters of surface gold in the ore are clay minerals, wood chips, carbonaceous debris, stained quartz, and Fe Ox

2.2. Factors Influencing Extractive Metallurgy of Gold

The primary mineralogical factors influencing gold extractive metallurgy are discussed briefly below.

- ***Grain Size of Gold***: The effectiveness of gold methods for recovery can be greatly affected by the size of the grains within the gold mineral. It is possible for coarse gold to be neither carried by flotation bubbles nor fully leached, or it could get trapped upstream of the cyanidation circuit. Flotation or gravity approaches aren't very effective in recovering ultrafine gold. Poor cyanidation performance can also occur when gold is extremely fine ($<10\mu m$) and paired with sulfide minerals (Marsden, 1992). One prominent reason for gold losses is the entrapment of visible gold within silicate and sulfide minerals.

- ***Submicroscopic gold:*** One important source of lost gold from several cyanidation processes is submicroscopic gold, which was first described. Solid-solution gold concentrations are typically highest in the finest-grained sulphides. As such, inadequate liberation of the ultra-fine, gold-hosted sulphides frequently makes the issue worse (Hausen, 1985).

- **Coatings and rimming:** Mainly influence the cyanidation and flotation methods of gold extraction. Iron oxides or hydroxides (limonite or goethite), which are created by oxidation, dissolution, and precipitation reactions, may be used for these coatings and rimming. Furthermore, gold and sulfide ions combine to generate insoluble coatings of aurous sulfide.

- **Silver in gold minerals:** Silver is exists in gold ores not only as silver minerals but also frequently as electrum and sporadically in kustelite. In the existence of sulfide ions, silver-rich electrum and kustelite tarnish quickly and produce a silver sulfide layer that is 1-2 μm thick. This layer can restrict the passage of cyanide solution. These coatings have certain hydrophilic properties, especially when they oxidize further to become silver sulfate or oxide. This could make flotation recovery more difficult (Jilin Institute, 1978).

- **Gold aurostibite, maldonite and tellurides:** Because gold tellurides, aurostibite, and maldonite dissolve slowly in cyanide solutions, they are typically regarded as refractory materials.

- **Existence oxygen and consumers of cyanide**: Numerous gold ores have minerals in them that react in cyanide solution, consuming either cyanide or oxygen, or both, and adversely affecting how quickly or how much gold leaches. The most prevalent minerals that cause interference include iron, arsenic, antimony, copper, zinc, and tellurium sulfides (Fleming, 1998).

- **Gangue mineralogy:** Thiscan be described in many forms;

Although silicate rocks like quartz and many others are virtually harmless, they can dissolve to some degree in very acidic environments, as those seen in bio-oxidation, to produce a gelatinous silicate that can coat exposed gold surfaces and is difficult to filter. Sulfuric acid dissolves chlorite, forming compounds that are usually hard to filter. Sulfuric acid and carbonates react easily to produce the corresponding sulfates, such as magnesium sulfate and gypsum. Significant amounts of acid are frequently consumed in these processes. For instance, 10 kg H2SO4/t of ore is needed for every 1% limestone present. In addition, increased slurry viscosity, coatings on exposed gold surfaces, and scale formation in pipes and reactors are potential downstream issues caused by the reaction products of carbonate breakdown. (Marsden, 1992).

Through the adsorption of dissolved gold from the pregnant solution, carbonaceous matter and other contaminants can decrease the extraction of gold during cyanide leaching. The shale found in Witwatersrand ores and pyrophyllite, which absorbs gold, have also been identified as preg-robbers. Potential preg-robbers include wood support systems, wood chips from subsurface blasting (Petersen et al.,1997), and FeO+MgO+Al2O3 in shale from the Beatrix gold mine in South Africa (Vuuren, 2000).Solid-solution gold analysis should not always be restricted to the sulphides, an example of this being cited in the 1989 Cyanamid Minerals Handbook (Cyanamid:, 1989).

By concentrating free gold and gold-bearing pyrite (gold exists as fine inclusions), a flotation unit had been recovering gold. But the recovery of gold was relatively poor. A mineralogical analysis of the head and tailing samples revealed that some of the pyrite had been replaced by limonite, which also contained gold that was quite finely locked in. Together with its inherited gold inclusions, the limonite was being rejected to the tailing.

3. Materials and Methods

3.1. Materials

Optical microscopy, XRD, XRF, AAS, Jaw Crusher, Boyd Crusher, riffles and Ring Mill are the main equipment s for the project work.

3.2. Methods

3.2.1. Sampling and Sample Preparation

Sampling and sample preparation is a crucial procedure in any gold processing mineralogy study, particularly when dealing with the ore or concentrate containing a high content of gold bearing sulfides. Eight representative samples were taken from mine site and other five polished section was supplied from the sample. One 75mmx50mm polished sections was examined by conventional transmitted and reflected light polarizing microscopy using a Nikon Labophot-2 research polarizing microscope. Digital photomicrographs were taken using a Nikon DMC1200F 13.5 mega pixel camera attached to trinocular head of the microscope and the target is to determine gold concentrate, its mineralogical characteristics, describe and distinguish its associated gangue minerals. XRD and XRF were used to describe ores mineral composition qualitatively and quantitatively. Three to Five kilogram per eight representative samples was taken from mining area for geochemical analysis and fire assay.

Most samples of naturally occurring materials and process plant samples require some kind of physical preparation prior to chemical analysis. Samples are required for preparation to affect one or more of the following.

I. Reduce the sample to a size that is more conveniently transported.

II. Increase the surface area to enhance the efficiency of subsequent chemical attack.

III. Homogenize the sample to ensure that a sub sample is representative of the entire sample.

IV. Separate the sample into components based on mineralogy, grain size, or physical and morphological criteria.

Sample preparation is an important step in the analytical process. The value of the ensuing analyses is considerably reduced in the absence of meticulous preparation and attention to inter-sample contamination. So, care is taken to clean all equipment before crushing/grinding each sample. To determine the elemental content (in terms of ppm, ppb) in the analytic, the finely pulverized, weighed and roasted sample is dissolved using conventional analytical methods (such as WA, FA, Geochemical, etc.). After the standard atomic absorption condition was well stabilized and optimized for the element required, a diluted solution was then aspirated and atomized in to the flame (air-acetylene) of an atomic absorption spectroscopy for single element analysis. The sample details are given and summarized in the following table 1.

Table 1Summary of Sample submitted to Laga Dambi Laboratory

Sample Id.	**Origin**	**Form**	**Weight(Kg)**
OP T1	Open Pit mine	Run of Mine	3.5
OP T2	Open Pit mine	Run of Mine	4.5
OP T3	Open Pit mine	Run of Mine	4
OP T4	Open Pit mine	Run of Mine	3.5
Mse T5	Sakaro Underground	Blast mine	4
MSe T6	Sakaro Underground	Blast Mine	3
MSe T7	Sakaro Underground	Blast Mine	3.5
MSe T8	Sakaro Underground	Blast Mine	4

Fire assay is a conventional method of gold process mineralogy, which can measure gold concentrations down from about 0.1 g/t to 50 g/t.

3.2.2. Investigative procedure

A routine process mineralogical study of gold ore normally includes the following activities;

- Determination of Au and Ag by fire assay and multi-elemental analysis
- Identification of Gold minerals, their size distribution, composition, liberation characteristics and associated minerals,

- Determination of liberated gold fraction, total visible gold, gold associated with sulfides, gold associated with oxides/silicates, and gold associated with carbonaceous material,
- Quantification of microscopic gold in sulfide and other minerals,
- Determination of any other valuable minerals (such as silver and copper) and deleterious minerals (e.g talc, serpentine, graphite, cyanicides, oxygen consumers, and water soluble minerals) in terms of amount, type and distribution and
- Evaluation of preg-robbing potential of carbonaceous matter and gangue minerals.

The pre-dried sample is reduced to <20mm sizes in a Jaw crusher and <5mm in Boyd crusher. The crushed sample is milled (<1mm) and homogenized by using continuous-flow-ring mill, and split into a representative analytical sample (approximately 350 to 550 grams). The analytical sample (split) is then pulverized to approximately minus 200 mesh (<75micron).

In some methods where the quality of pulverization (due to nature of grinding media) is critical in obtaining accurate results, hand grinding sample is required. The sample is placed in a ceramic mortar with pestle and ground until 100 percent passes a 100-mesh (<159micron) screen, that is ready for analysis.

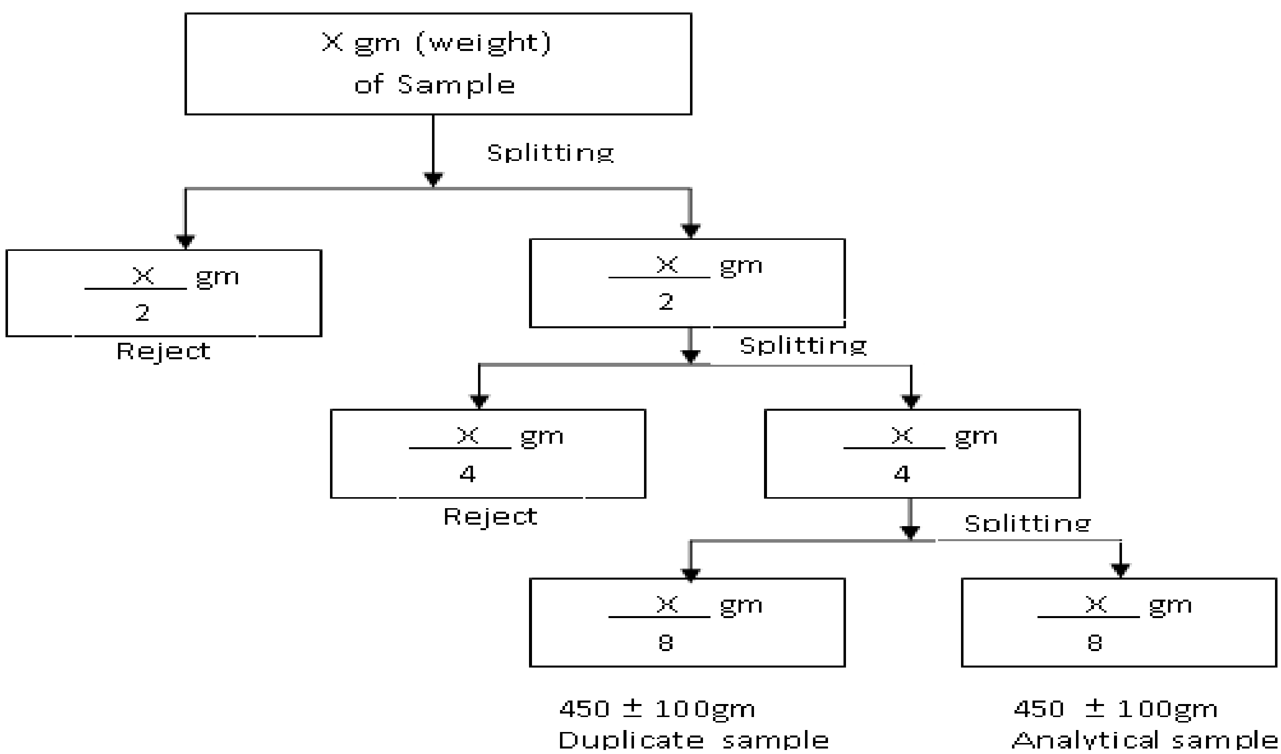


Figure 2 Sample preparations in analytical process (adopted from Laga Dambi Lab.)

4. Results and Discussion

4.1. Results

4.1.1. Mineralogical Investigations

To understand gold ore processing, the important mineralogical properties of ore must be described usually in quantitative terms. This is required to determine the parameters of gold ore grade, ore composition (elemental and mineralogical), concentration of any valuable minerals and nature &concentration of minerals detrimental to the processing (e.g., cyanide consuming mineral, cays, etc.). One 75mm x50mm polished thin section was supplied from each sample and was examined by conventional transmitted and reflected light polarizing microscope to determine the distribution of gold in the samples. Sub samples (500g) of each ore type were ground to 1mm and the heavy minerals concentrated using gold pan. The concentrates were submitted for mineralogical analysis to determine the distribution and particle size of gold in the samples.

OP T1:- According mineralogical study of open pit metallurgical test sample, grain size distribution ranges from 200µm to 2mm with moderate abundance of sulphide minerals. Pyrrhotite, pyrite and galena occur as coarse liberated grains, between 100 µm and 1 mm with an average size of approximately 400 µm. Chalcopyrite occurs as liberated grains, simple locked grains with pyrrhotite and complex intergrowths with pyrite. Pyrrhotite, pyrite & galena and chalcopyrite is main, minor and trace sulphide minerals respectively. Scheelite is the major non sulphide minerals which can be described as coarse liberated grains between 200µm -2mm and rare composite grains with quartz and mica. Quartz is the main gangue mineral and biotite, phlogopite and musvite are the minor gangue minerals. No gold grain was identified under the investigation (*Fig.1*). Aggregates of microcrystalline quartz +/- mica < 1 mm, liberated single crystal fragments < 1 mm and as liberated aggregates of crystals < 2 mm. Mica typically occurs as aggregates in composite grains with quartz < 1 mm and liberated books < 400 µm. The sample also contains traces of liberated magnetite.

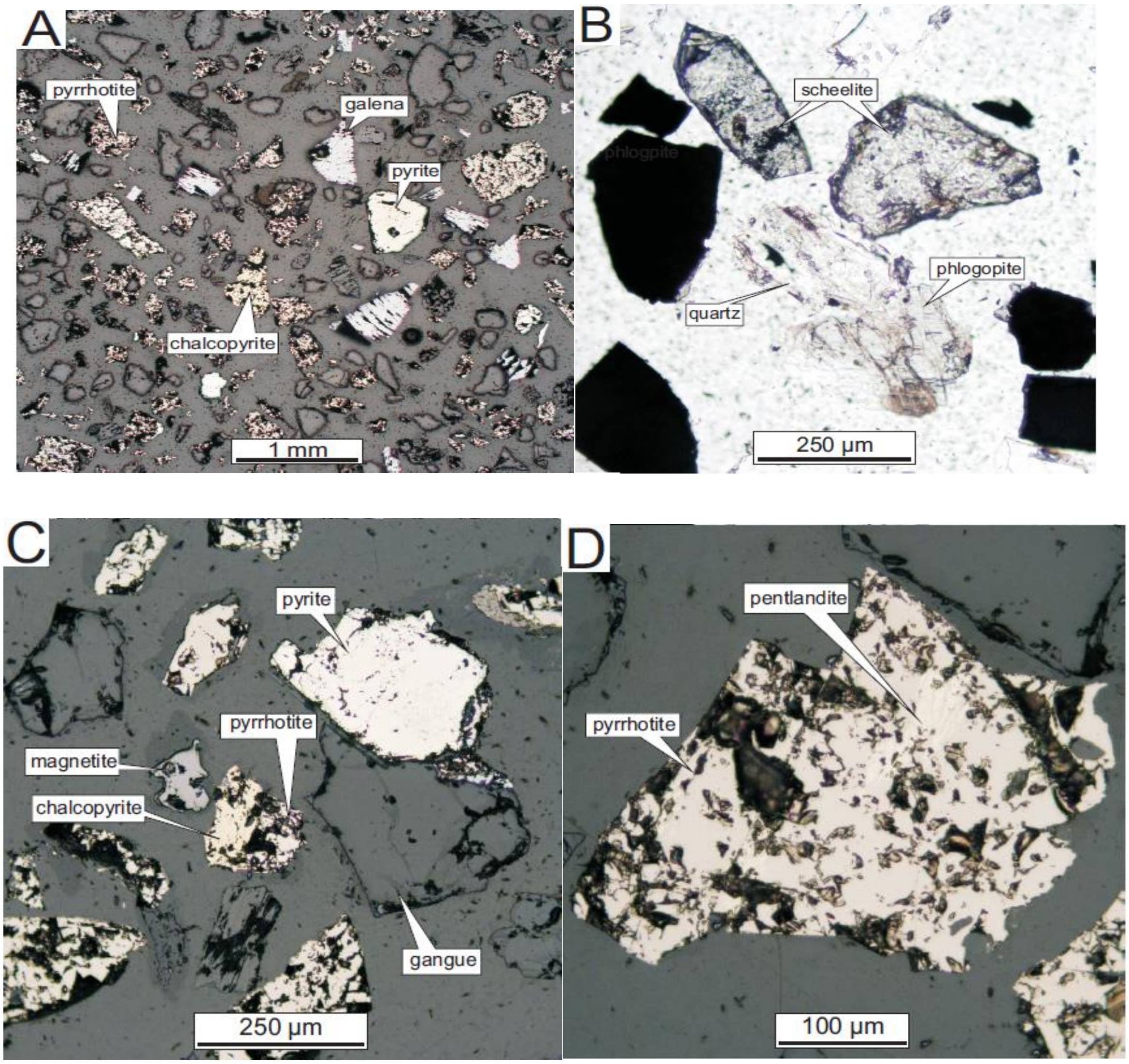


Figure 3 *Midroc- Op T1*

A) View showing the high sulphide content of concentrate, B) Two coarse liberate grains of scheelite C) view showing principle sulphide phases D) Pyrrotite containing rare exsolution pentlandite.
(A, C&D- Plane polarized reflected light B- Plane polarized transmitted light)

Op T2: its minerals grain size ranges from 200μm to 2mm Pyrrhotite, pyrite & galena and chalcopyrite are main, minor and trace sulphides minerals respectively. One grain of gold was identified in the sample *see fig 2C*. The grain was 260 μm in size and had a minor 40 μm attachment of galena. Pyrrhotite, pyrite and galena occur as coarse liberated grains, between 100 μm and 2 mm with an average size of approximately 400 μm. Chalcopyrite occurs as liberated grains and as simple locked grains with pyrrhotite. Quartz, mica (biotite, phlogopite & muscovite) and magnetite is major, minor and trace amount of gangue minerals. Quartz occurs as liberated single crystal fragments < 1 mm and as liberated aggregates of crystals < 2 mm. The sample also contains a minor amount of mica typically occurring as aggregates in composite grains with quartz < 1 mm and liberated books < 400 µm. The sample also contains traces of liberated magnetite.

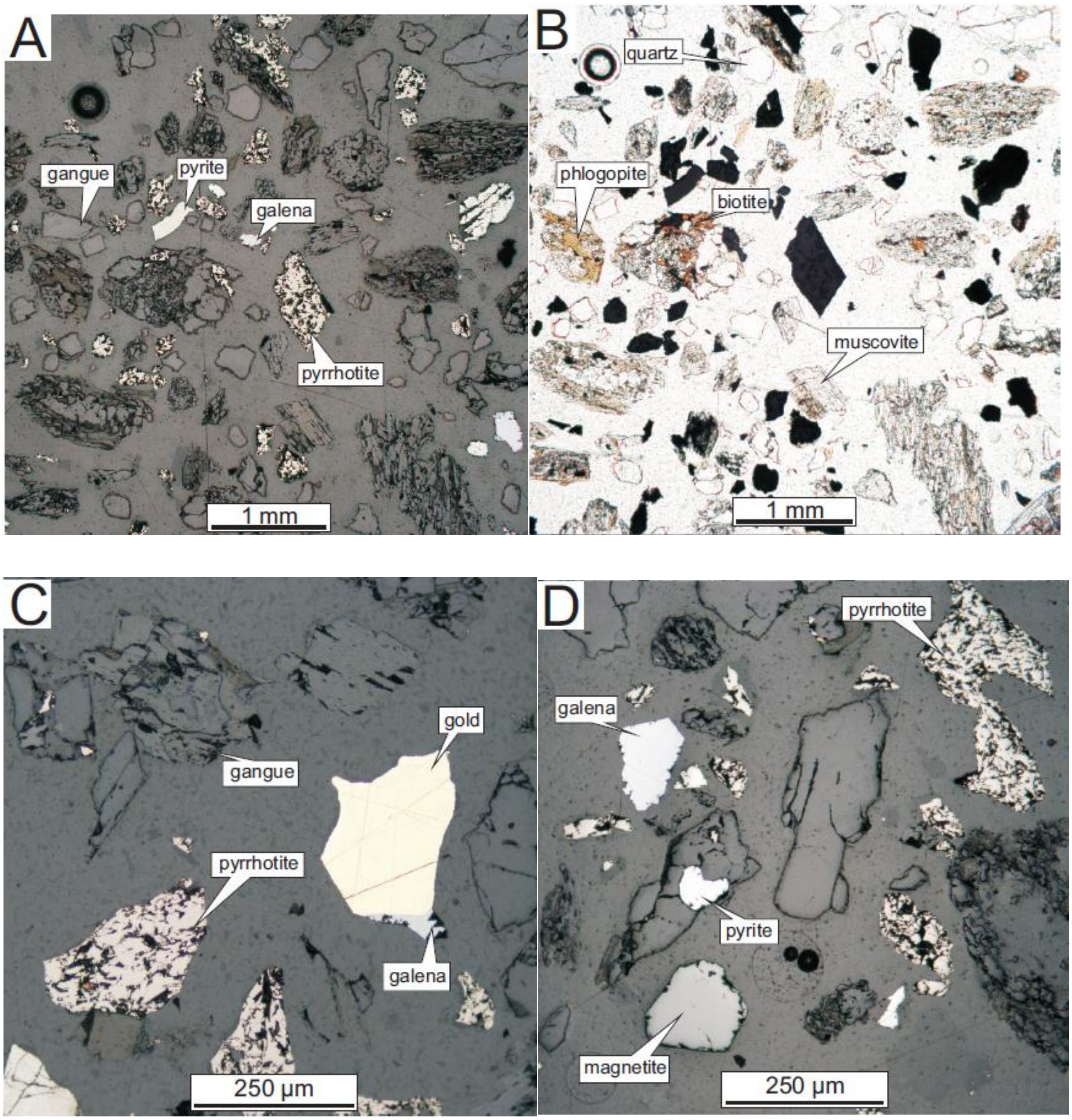
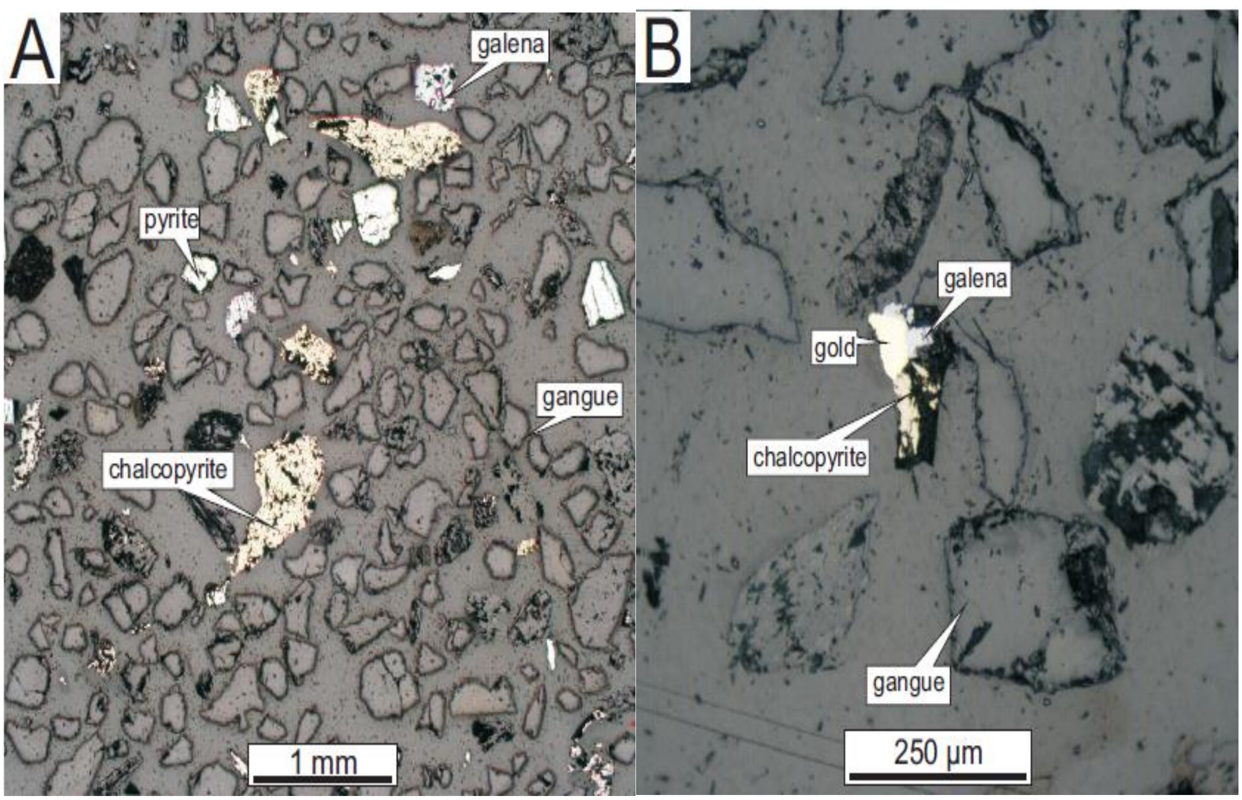


Figure 4 Midroc Op T2

A) View showing the high pyrrhotite content of concentrate B) Transmitted light view of A C) Gold with a minor attachment of galena D) Main sulphide phases with pyrrhotite, galena, pyrite, galena, pyrite, gangue silicates and rare grain of magnetite (A, C&D-Plane polarized reflected light B-Plane polarized transmitted light)

Op T3: Three grains of gold were identified in the sample *see fig. 5B, 5C & 5D*. All the grains were locked with sulphides, one 50 µm grain with galena and chalcopyrite (*fig. 5B*), another 50 µm grain with pyrrhotite and quartz (*fig.5C*) and one as a < 20 µm inclusion in pyrrhotite (*fig. 5D*). Mineralogically its grain size distribution ranges from 200µm -1mm. coarse liberated grains between 100 µm and 1 mm with an average size of approximately 300 µm. Where locked the most common locks are between pyrrhotite and chalcopyrite, rare simple locks observed between all the sulphide phases. Pyrrhotite, pyrite, chalcopyrite and galena (approx. equal) are abundant sulphide minerals of concentrate. Scheelites are minor non sulphide minerals and its liberation grain size is less than1mm.

Quartz occurs as liberated single crystal fragments < 1 mm and as rare aggregates of crystals +/- mica < 1 mm. The sample also contains a minor amount of mica typically occurring as liberated books <400 µm of mica and rare aggregates with quartz. The most common forms are muscovite and phlogopite.



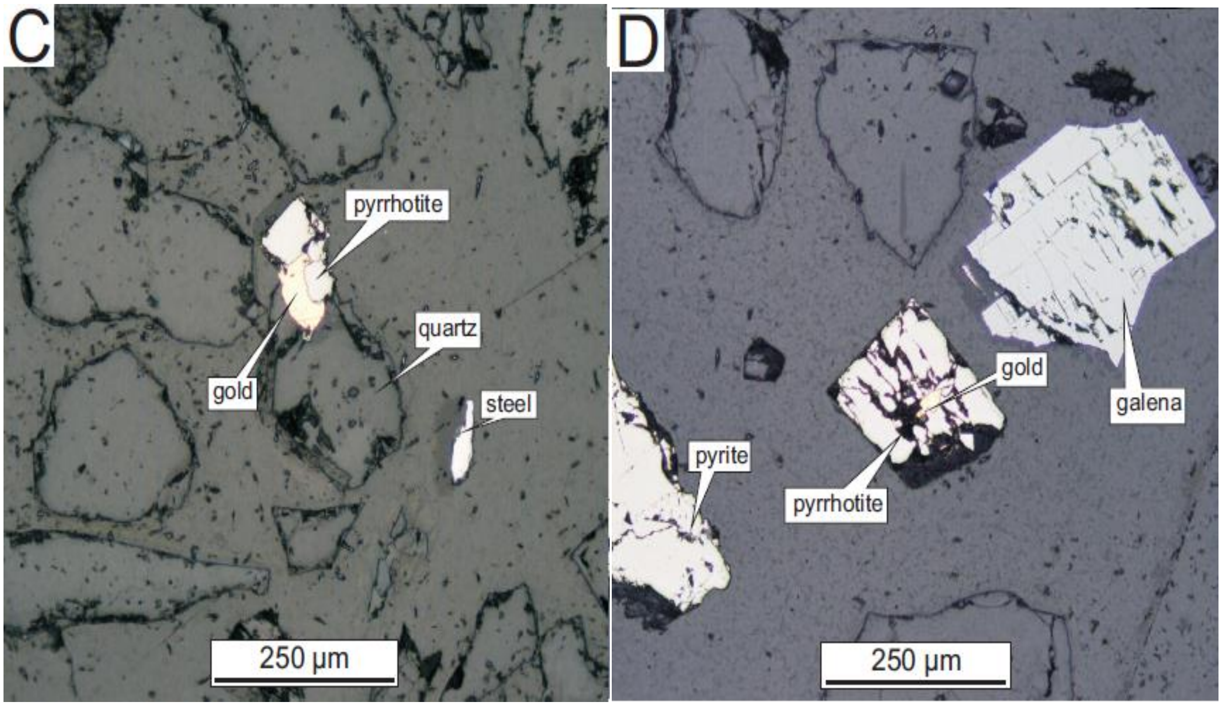


Figure 5MidrocOp T3

A) View showing the high chalcopyrite content of the concentrate, B)Gold locked with galena and chalcopyrite, C)Gold locked with pyrrhotite and quartz, D) Fine gold inclusion in pyrrhotite (A,B,C &D-Plane polarized reflected light)

MSe T4: Two grains of liberated gold were identified in the sample *see fig. 6B & 6C*. The first grain was 100 µm in size and the second 120 µm. The sample also contains two fine < 20 µm grains of gold locked in pyrite. Sulphides occur as coarse liberated grains, between 100 µm and 1 mm with an average size of approximately 500 µm. Pyrrhotite, Galena & Pyrite, Chalcopyrite and Sphalerite are major, minor and trace sulphide minerals observed in the concentrate. Scheelite is trace non sulphide mineral with liberationgrain size is <1mm. Quartz occurs as liberated single crystal fragments <1 mm and as rare aggregates of crystals +/- mica <1 mm. The sample also contains a minor amount of mica typically occurring as liberated books <400 µm of mica and rare aggregates with quartz. The most common forms are muscovite and biotite.

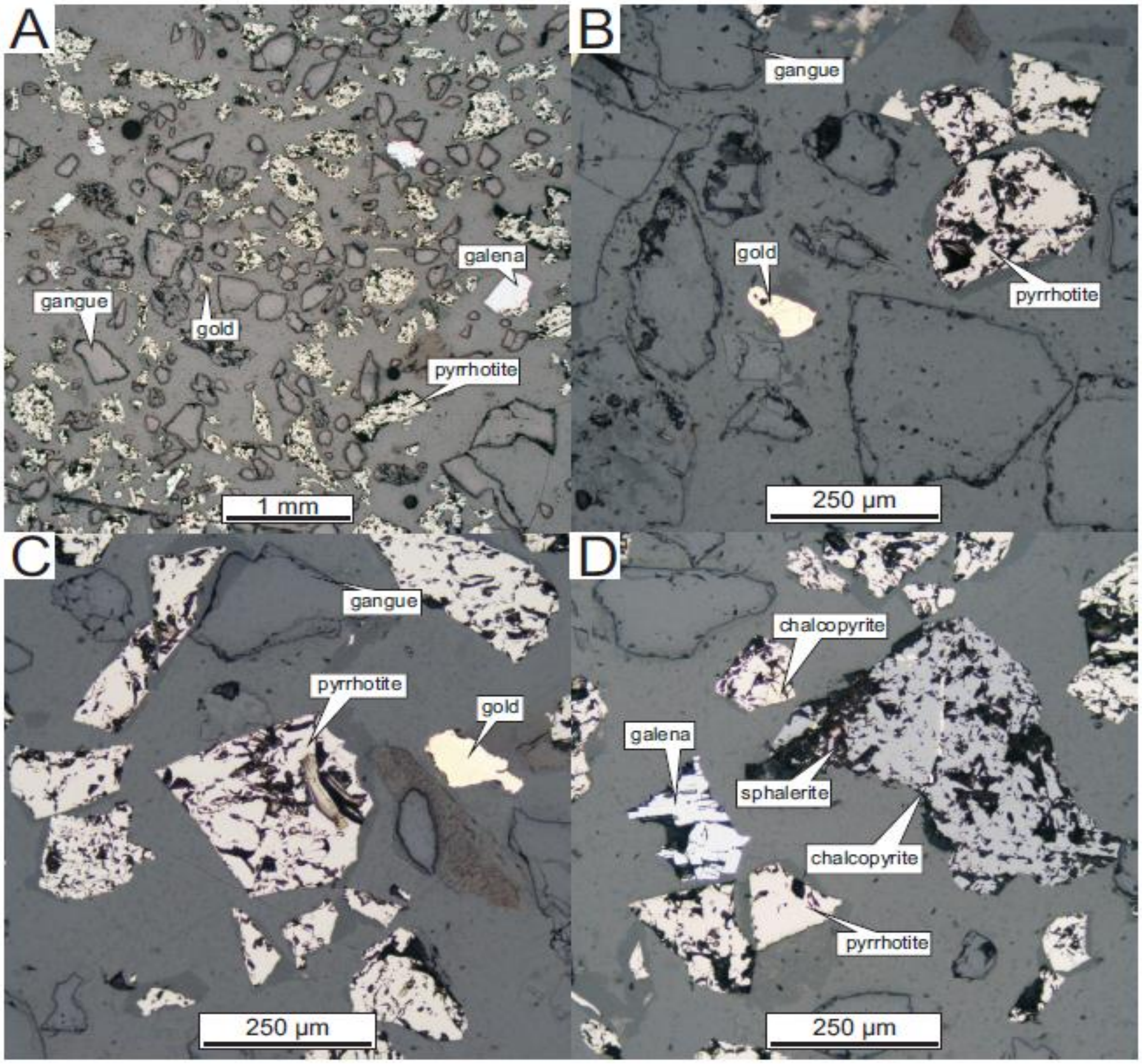


Figure 6 Mse T4

A) View showing the high pyrrhotite content of the concentrate. The view also contains a grain of liberated gold, B) High magnification view of view A, C)Liberated grain of gold, D)View showing main sulphides; liberated pyrrhotite and galena, pyrrhotite locked with chalcopyrite and a grain of coarse crystalline sphalerite containing a veinlet of chalcopyrite. (A, B, C&D- Plane polarized reflected light)

MeS T5: Two grains of gold and one possible grain of electrum were identified in the sample *see fig 7B, 7C & 7D.* The first grains fig.7B is apparently liberated and 320 µm in size. The second grain occurred as a < 20 µm attachment on galena. The sample also contained a grain of galena containing a high reflectively phase provisionally identified as electrum. Quartz occurs as liberated single crystal fragments < 1 mm and as rare aggregates of crystals +/- mica < 1 mm.

The sample also contains a minor amount of mica typically occurring as liberated books <400 µm of mica and rare aggregates with quartz.

Pyrite & pyrrhotite, Galena and Sphalerite & chalcopyrite are the main, minor and trace are Sulphide minerals. It occurs as coarse liberated grains, between 100 µm and 1 mm, with an average size of approximately 500 µm.

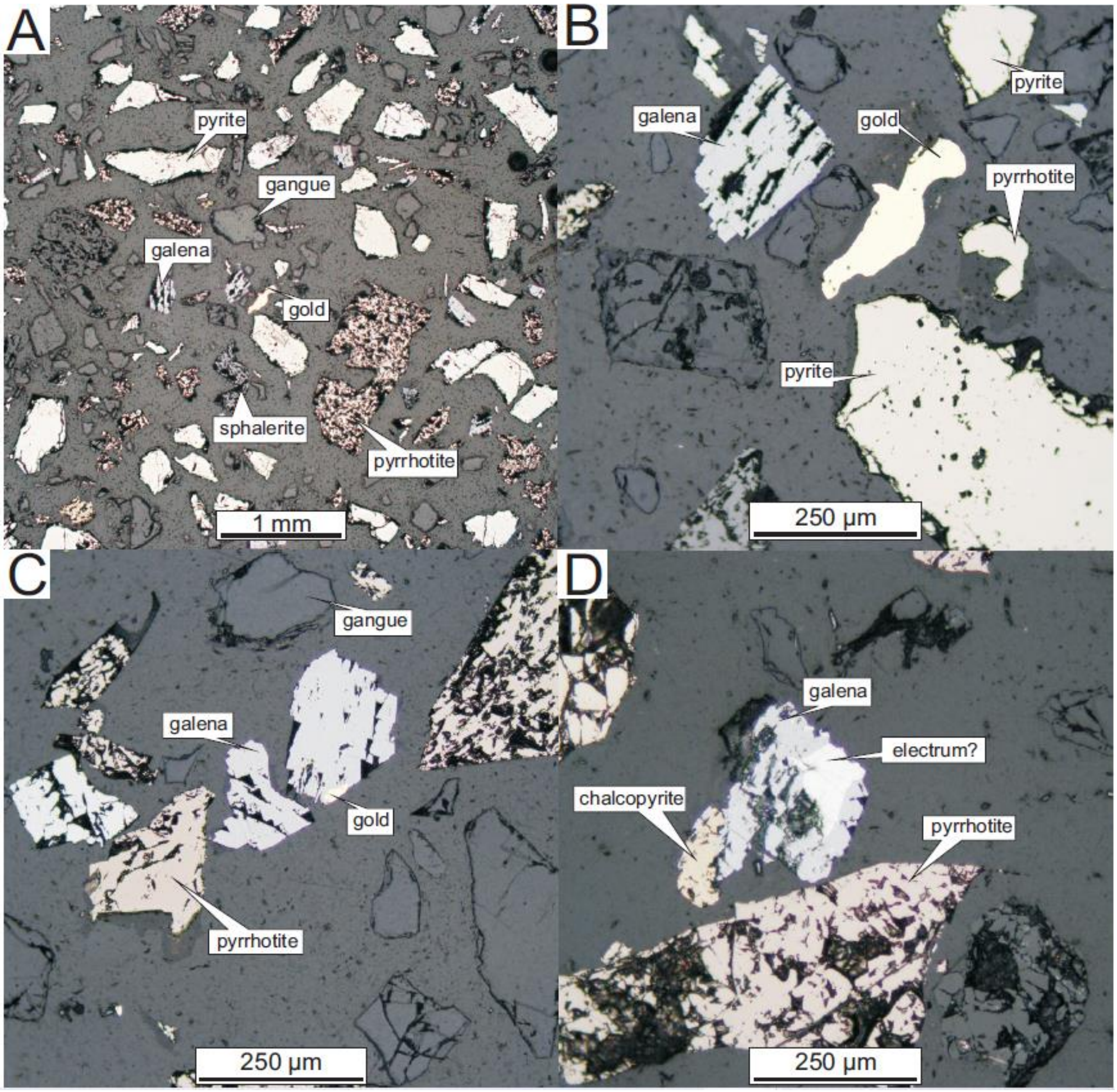


Figure 7 Midroc Mse T5

A) View showing major sulphide phases and grain of liberated gold, B)High magnification view of view A, C) Attachment of fine gold on galena, D) Composite grain of chalcopyrite galena and a high reflectivity phase (electrum or silver?)
(A,B,C&D- Plane polarized reflected light)

4.1.2. XRD and XRF analysis

X-Ray Fluorescence (XRF) analysis was undertaken on each ore type; the results are shown in table 2. Quartz was abundant in all samples and ranged from 64.9% in OP T2 to 82% in Op T3. The sample all contained appreciable amounts of aluminium oxide and iron oxide. The samples contained low levels of base metals, with the possible exception of OP T3.

Table 2 XRD results

Element	OP T1	MseT4	MseT5	OP T2	OP T3
	%				
LOI	2.27	1.82	2.66	2.23	1.41
Na_2O	1.19	1.17	0.94	1.07	0.94
MgO	3.8	1.38	2.13	5.40	3.70
Al_2O_3	13.42	8.40	7.64	13.31	4.72
SiO_2	66.73	77.95	76.23	64.91	82.30
P_2O_5	0.14	0.12	0.16	0.17	0.09
S	0.59	1.06	1.53	0.61	0.31
K_2O	3.78	1.94	1.82	3.89	1.06
CaO	2.74	1.77	1.81	2.62	2.52
TiO_2	0.46	0.31	0.38	0.48	0.13
Cr_2O_3	0.05	0.04	0.05	0.08	0.06
MnO	0.08	0.07	0.06	0.09	0.05
Fe_2O_3	4.54	3.76	4.00	4.96	2.49

X-Ray Diffraction (XRD) was also undertaken on each samples and the results are detailed in *fig 8 -11*. Quartz was predominant in all types. Ankerite, dolomite and plagioclase feldspar were also present.

From the following XRD diffractogram OPT1 head sample red color represents crystalline quartz (SiO_2) with hexagonal crystal lattice. Muscovite, phylogopite, anorthite and albite are other crystal minerals detected with variable intensity from this sample.

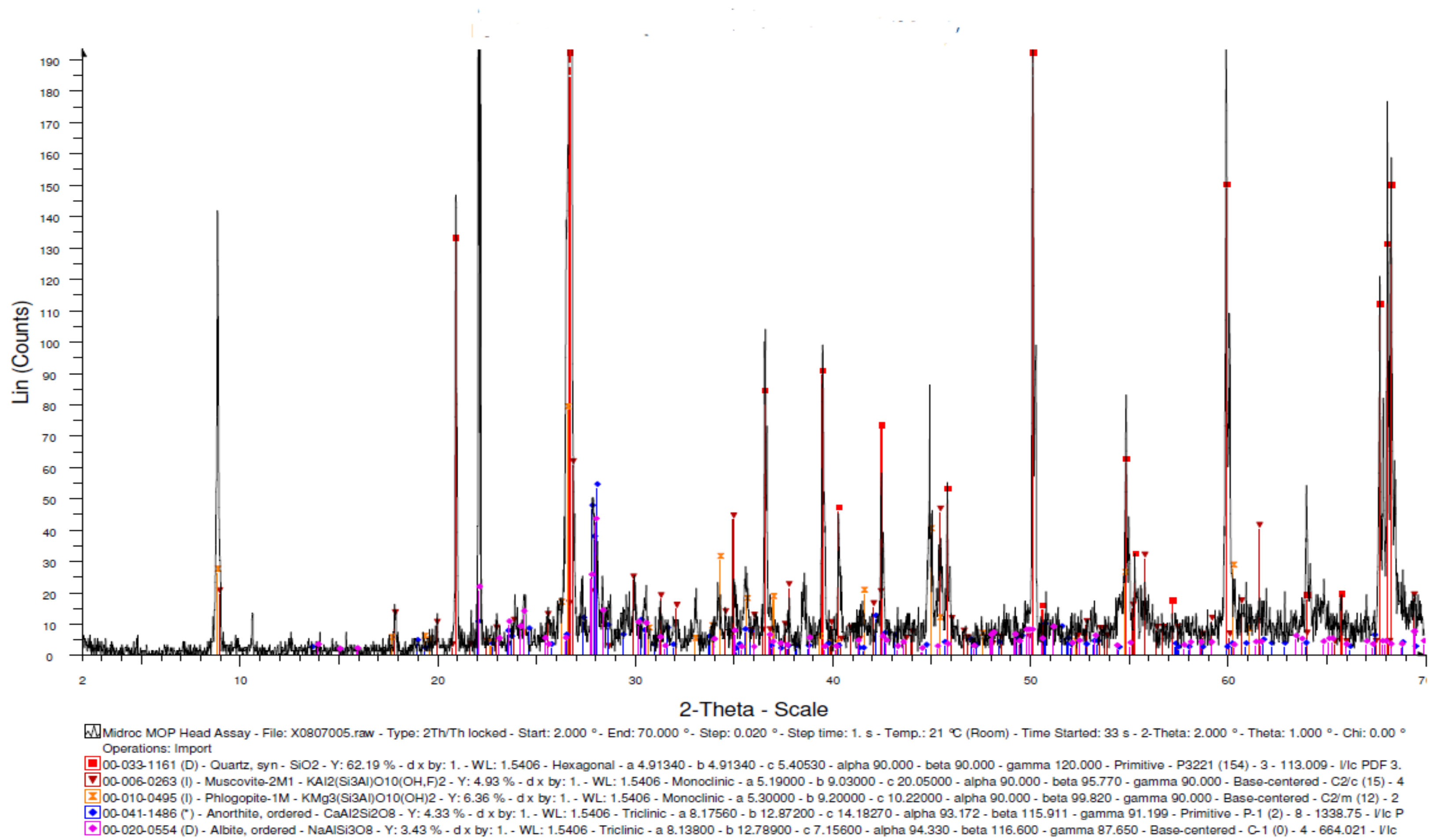


Figure 8 Op T1 head XRD assay

From the following XRD diffractogram OPT2 head sample red color represents crystalline quartz (SiO2) with hexagonal crystal lattice. As per color legend muscovite, phylogopite, anorthite, biotite and albite are other crystal minerals detected with variable intensity from this sample.

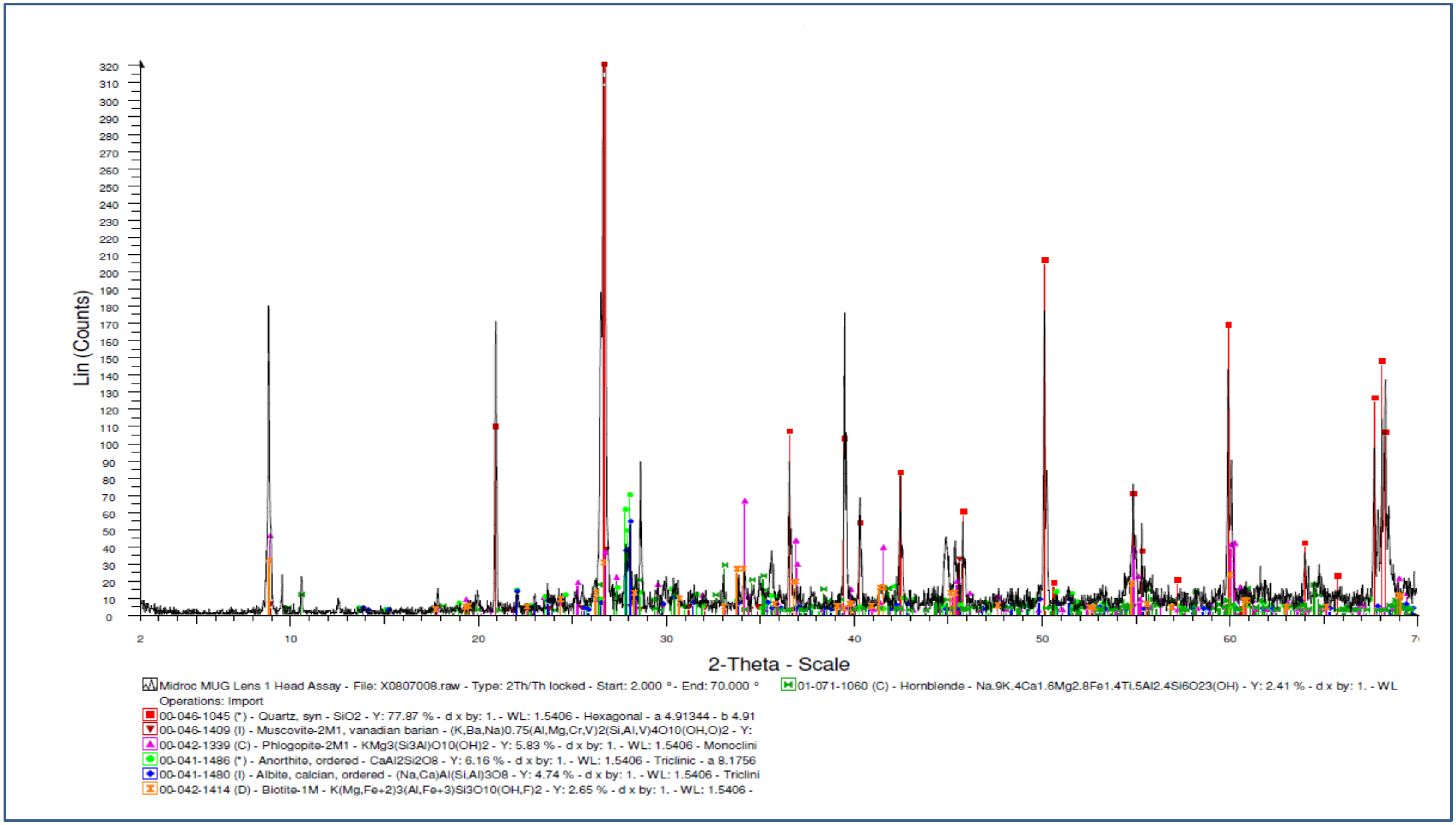


Figure 9 Op T2 XRD Head assay

From the following XRD assay diffractogram OPT3 head sample red color represents crystalline quartz (SiO2) with hexagonal crystal lattice. Muscovite, phylogopite, anorthite, albite and hornblend are other crystal minerals detected with variable intensity from this sample.

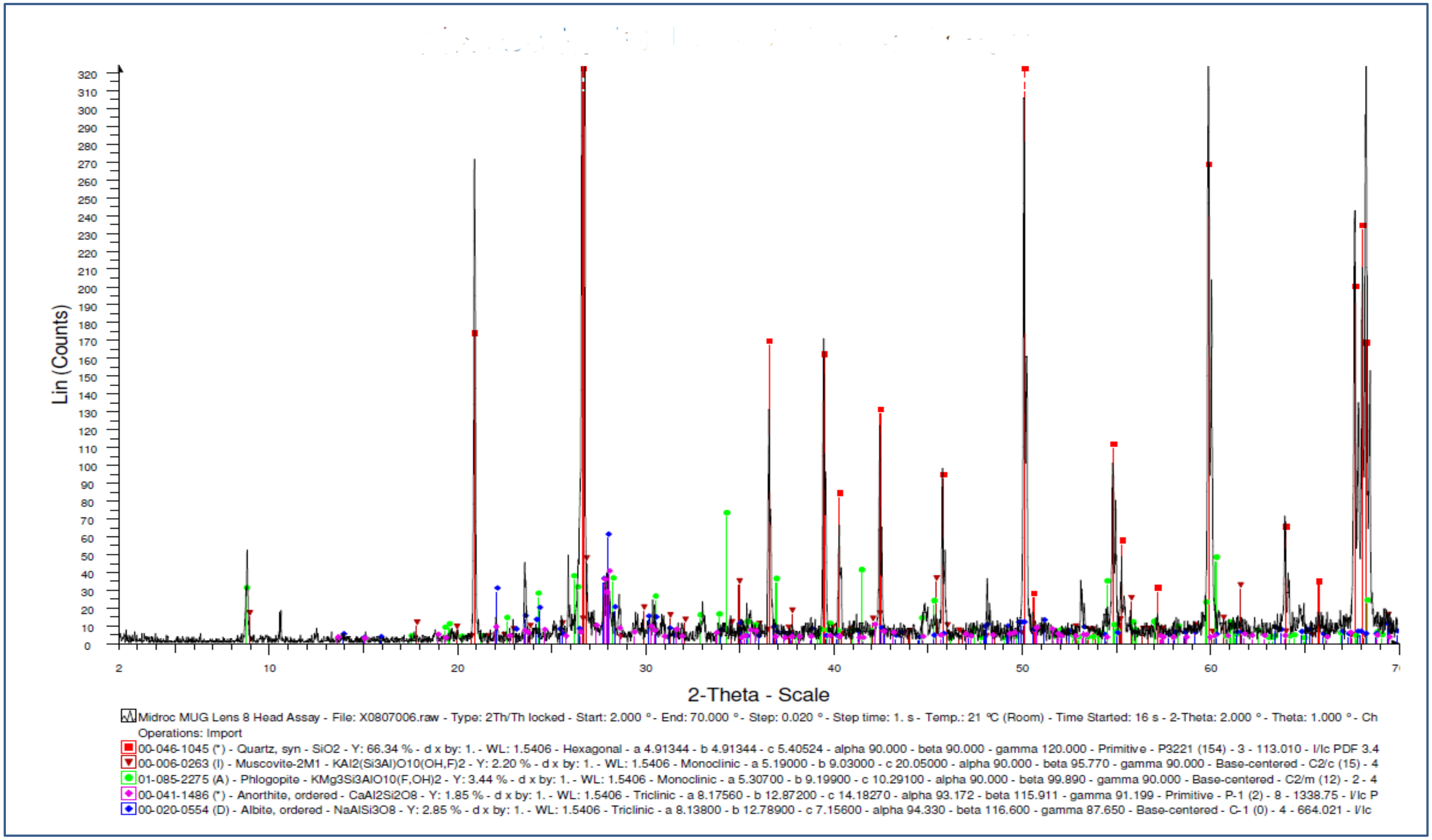


Figure 10 OP T3 XRD assay

From the following XRD assay diffractogram Mse T5 head sample contains crystalline quartz (SiO_2) with hexagonal crystal lattice by large percentages. Muscovite, phylogopite, anorthite and albite are other crystal minerals detected with variable intensity from this sample.

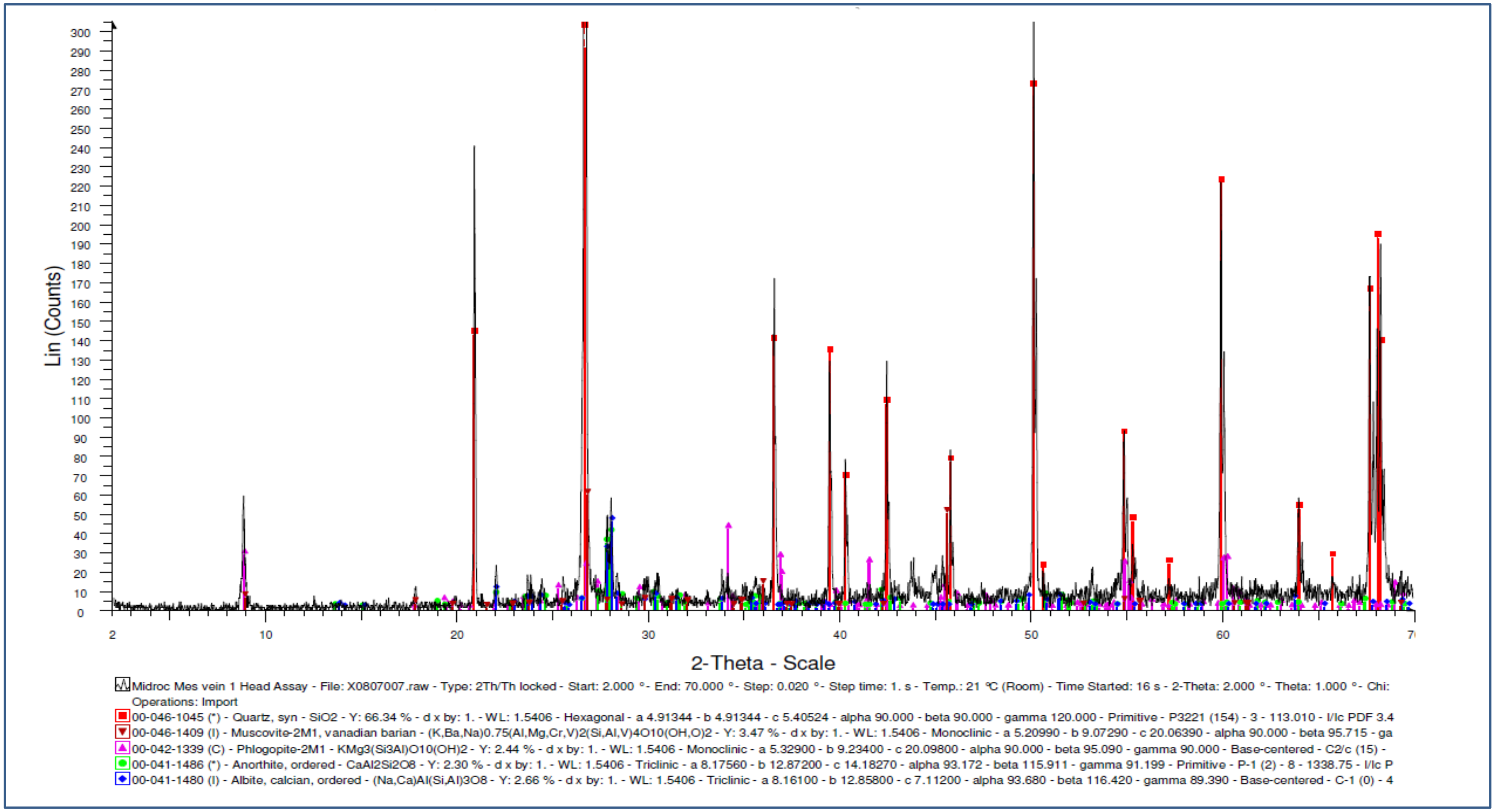


Figure 11 Mse T4 XRD Head assay

From the following XRD diffractogram Mse T5 head sample contains crystalline quartz (SiO_2) with hexagonal crystal lattice by large percentages. Muscovite, phylogopite, anorthite and albite are other crystal minerals detected with variable intensity from this sample.

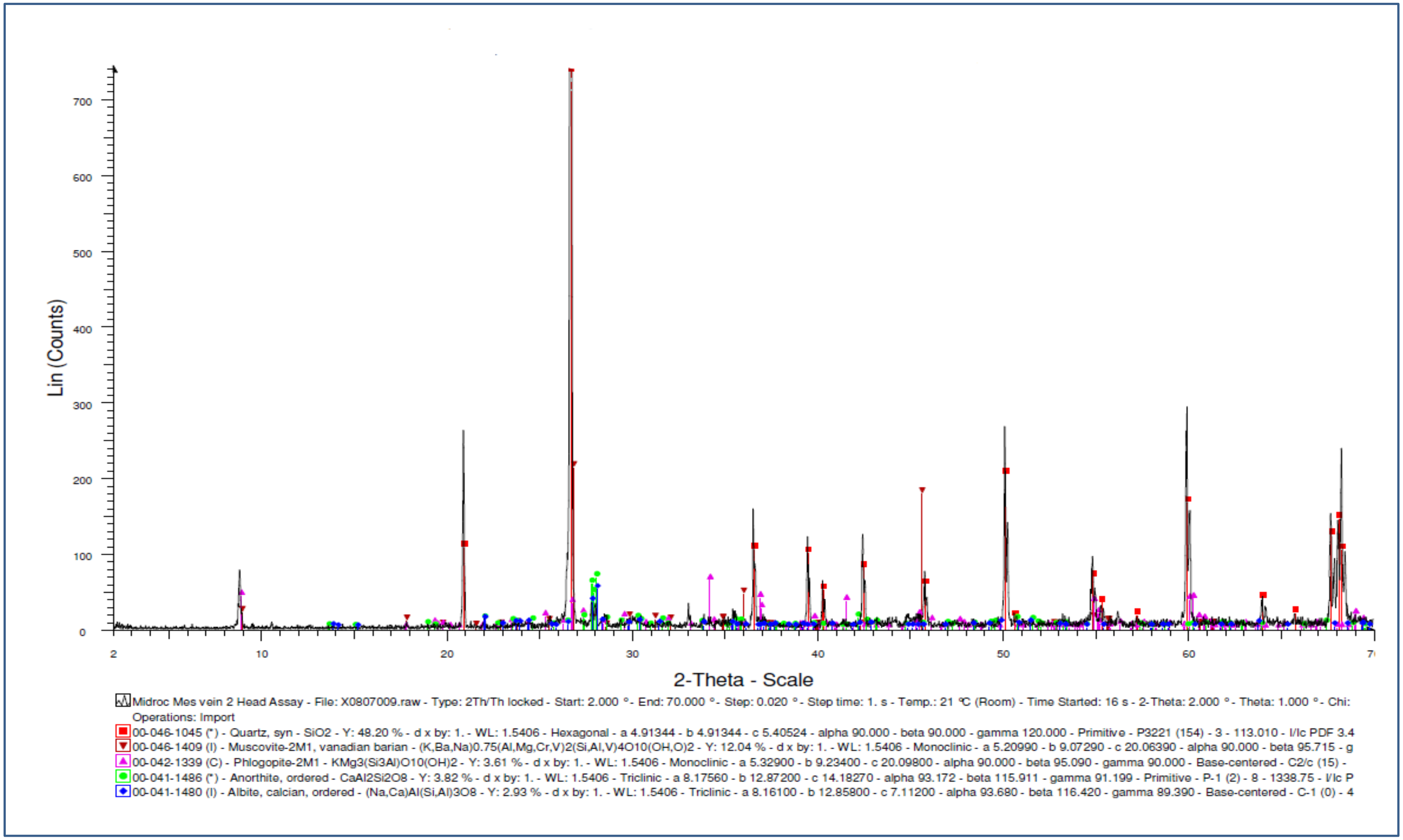


Figure 12 Mse T5 XRD Head assay

4.1.3. Chemical analysis

Through the coarse crushing, fine crushing and dry grinding, measured quantity of finely pulverized samples subjected for various chemical distraction process to expose sought characteristics for chemical measurement system. For all samples fire assay and geochemical analysis was carried out at Laga Dambi quality control laboratory and the results are indicated in table 3 and table 4 respectively.

Table 3 Fire assay sample results

S/N	Sample Code	Lab. No.	Au (g/t)
1	OP T1	E-005-01	0.36
2	OP T2	E-005-02	2.25
3	OP T3	E-005-03	2.43
4	OP T4	E-005-04	5.75
5	Mse T5	E-005-05	3.31
6	MSe T6	E-005-06	2.22
7	MSe T7	E-005-07	5.1
8	MSe T8	E-005-08	7.1

Table 4 Geochemical results

S/N	Sample code	Lab.No.	Ag gm/t	Cu gm/t	Pb gm/t	Zn g/t
1	OP T1	E-005-01	<0.1	69	43.99	55.16
2	OP T2	E-005-02	<0.1	105.14	153.09	164.36
3	OP T3	E-005-03	0.57	66.33	633	461.95
4	OP T4	E-005-04	1.43	141.3	129.75	69.44
5	Mse T5	E-005-05	<0.1	33.21	<0.1	22.75
6	MSe T6	E-005-06	1.48	21.49	80.26	31.20
7	MSe T7	E-005-07	<0.1	28.34	2.76	22.06
8	MSe T8	E-005-08	0.27	18.88	11.54	29.80

4.2. Discussion

Optical microscopy in reflected light allows the sulfide minerals to be identified by reflectivity, hardness (Figure 3-7)), cleavage, and other mineralogical characteristics, and is useful in identifying relatively coarse textural associations (e.g., common sulfide mineral relationships and liberation sizes for sulfides). Transmitted light microscopy is a significant analytical tool to determine and quantify gangue mineralogy. The pyrrhotite is the most abundant sulphide in all the samples, with the exception of Mse T5 where it is the second in abundance to pyrite. In addition to the iron sulphides, all the samples contain variable amounts of galena, sphalerite and chalcopyrite. The samples also contain variable amounts of coarse liberated scheelite (tungsten oxide see fig. 3B).

The detection and quantification of gold was performed by fire assaying analytical technique. Gold concentration by fire assay analysis reveals that it ranges from 7.1 ppm (Mse T8) to 0.36ppm (Op T1). From multi elemental analysis Ag with highest concentration (1.48ppm) was found in head sample Mse T6. From Op T1, Opt2, Mse T5 and MseT7 samples Ag concentration is >0.1ppm. Cu concentration ranges from 18.88ppm to 141.3ppm at Mse T8 to Op T2 respectively. Pb concentration is <0.1 at Mse T7 and 153.09ppm at OpT2. Op T3 contains highest concentration 461.95ppm) of Zn and Mse T7 contains lowest (22.06ppm). The samples contained low levels of base metals, with the possible exception of OP T3, which are not likely to hinder processing.

The chemical analysis of gangue minerals is generally easier than gold due to their higher concentrations and achieved using XRD and XRF techniques (fig 8-11). Quartz was predominant in all types. Ankerite, dolomite and plagioclase feldspar were also present.

5. Conclusion and Recommendation

5.1. Conclusion

From laboratory results obtained, it can be concluded that gold is the most valuable element in the ore. The samples are all well graded and show excellent liberation. Sulphide mineralization is coarse within all the samples The pyrrhotite is the most abundant sulphide in all the samples, with the exception of Mse T5 where it is second in abundance to pyrite. In addition to the iron sulphides, all the samples contain variable amounts of galena, sphalerite and chalcopyrite. The samples also contain variable amounts of coarse liberated scheelite (tungsten oxide see fig. 3B). Samples OP T1 and MSe T5 containing the highest concentrations of sulphide minerals. The gangues in the samples are dominated by crystalline quartz and mica (muscovite, biotite and phlogopite). Gold was identified in all but the Op T1 head sample. The most common interfering minerals which consume oxygen or cyanide or both, and negatively influence the rate or extent of gold leaching are pyrroyite, pyrite and chalcopyrite. In three of the samples (Op T2, Mse T4 and Mse T5) gold occurs as > 200 µm liberated grains. In OP T3 gold is finer < 100 µm and locked in sulphides and gangue silicates.. And from mineralogical point of view liberation size of gold can be determined to be120µm. from XRD and XRF techniques quartz was predominant gangue minerals in all types. Ankerite, dolomite and plagioclase feldspar were also present in minor constituent. All samples contained low levels of base metals, with the possible exception of OP T3, which are not likely to hinder processing mechanism.

5.2. Recommendation

To determine liberated gold fraction, it is better to use SEM. The application of these advanced SEM techniques may provide the user with accurate and quantitative mineralogical information on a timely basis. It helps to identify the type and quantity of minerals present, distribution of mineral grains by size fraction and the size distribution of each mineral type and extent of mineral associations, such as locking, degree of encapsulation, and galvanic connection

Leaching procedures was recommended as additional metallurgical test for gold ores to determine the association of gold with gangue minerals. These methods involve sequentially leaching gold and ore components with progressively stronger leaching reagents to liberate gold in different mineralogical associations.

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