ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY, AAIT

CENTERFOR ETHIO- MINES DEVELOPMENT

APPLICABILITY OF GRAVITY SEPARATION METHOD ON THE ASHASHIRE GOLD ORE DEPOSIT FROM BENISHANGUL GUMUZ REGION, ETHIOPIA

A PROJECT WORK SUBMITTED IN THE PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER IN MINERAL PROCESS ENGINEERING, TO CENTER FOR ETHIO-MINES DEVELOPMENT, ADDIS ABABA INSTITUTE OF TECHNOLOGY, ADDIS ABABA UNIVERSITY

BY MISGANU KABETA

JUNE, 2023

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JUNE, 2023

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This is to certify that the project report prepared by Misganu Kabeta, entitled: "*Applicability of gravity separation method on the ashashire gold ore deposit from Benishangul gumuz region, Ethiopia*" and submitted in partial fulfillment of the requirements for the degree of Master of Engineering in Mineral process Engineering complies with the regulations of the university and meets the accepted standards for originality and quality.

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DECLARATION OF ORIGINALITY

I hereby affirm that the project is my original work and has not previously been submitted for credit at another university or for any other honour, and that all sources of material used in the project work have been properly acknowledged.

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We confirm that the work reported in this project was carried out by the student under our supervision.

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ABBREVIATIONS

ppm = parts per million

g/cm^3 = gram per cubic centimeter

g/t = gram per tone

Wt. % = Weight percent

pH = potential of hydrogen

µm = micro meter

XRD = Diffraction X-ray

SEM = Scanning electron microscope

ICP = Inductively coupled plasma

AAS = Atomic Absorption Spectroscopy

CIP = carbon in pulp

GSR = Golden Star Resources Limited

GSE = Geological Survey of Ethiopia

GSB = greenstone belt

EIGS =Ethiopian Institute of Geological Survey

UNDP = United Nation Development Program

BLEG = Bulk Leach Extraction of Gold

PLC = Private limited company

MMAJ = Metal Mining Agency of Japan

EMRDC = Ethiopian mineral resource development committee

GSE = Geological Survey of Ethiopia

BGME = Benzu gold mining Ethiopia Ltd

KC-MD-3 = Knelson concentrator

ACS = Ashashire composite sample

AD = Ashashire deposit

psi = Pounds per inch

QEMSCAN) = Qualitative evaluation of minerals by Scanning electron microscope

BSE = Back scattered electron

NOTES

This part describes detail work of calculation system used throughout the laboratory analysis.

1. For raw ore come from some interval for Au grade assaying

Mass of ore = $(Volume * SG)/100$

Gold assay = Fire assay with AAS

Gold mass = mass of ore *gold assay

2. For gravity concentrates come for mineralogical analyses

Tail = feed –concentrate

Gold head assay = Fire assay with AAS

Calculated gold head = $\frac{\text{Mass of gold in concentrate and tail}}{\text{Mass of feed}}$

Mass of gold in concentrate = mass of concentrate * concentrate assay

Mass of gold in tail = mass of tail * tail assay

Gold Mass percentage (mass %) = = $\frac{\text{Concentrate mass}}{\text{Feed mass}} * 100$

Gold distribution = mass of gold in concentrate / total mass of gold (in concentrate + tail) *100

$$\frac{\text{Mass of gold in concentrate}}{\text{Total mass of gold (in concentrate and tail)}} * 100$$

ABSTRACT

The current Project of applicability of gravity separation method for gold ore deposit was conducted in Ashashire locality of Benishangul gumuz region, North western Ethiopia. The purpose of this project is beneficiating the Ashashire gold ore deposit by applying the gravity separation. The Ashashire composites were produced to provide sufficient mass for this study and experiment includes sample preparation, head assay analysis of gold and multi-element, gravity concentration and mineralogical analysis. The study conducted to determine the applicability of gravity separation method by using KC on the Ashashire gold ore deposit. The samples were moderately ground to the standard grind size of P_{80} - passing 106, 75, 53 µm and this nominal size was selected for the preliminary assessment for Concentration optimization. During the study, a grind optimization was conducted on the composites sample with varying grind size to evaluate the effect of grind size on gold recovery. The gravity testing comprised three-stage concentration by centrifugal knelson concentrator to produce gravity concentrate. High recovery of gold from the gravity concentrates was achieved from the second gravity concentration. Based on the results from laboratory experiments, a grind size of P_{80} 75 µm is selected as optimal size for the ashashire deposit using KC gravity methods. Increasing the grind size from P_{80} of 75 µm to106 µm decrease recovery rate from 75 % to 54 % or decreasing the grind size from P_{80} of 75 to 53 µm decrease gold recovery rate to 37%. It was observed that repeat gold head assays varied, indicating the presence of coarse gold particles and uneven gold particle distribution. The native gold grain in the ores is mostly associated with quartz and Fine gold is closely associated with pyrite, forming inclusions and dispersed within pyrite. According to the fire assay, chemical, and mineralogical analyzes data, only gold and telluride is commercially valuable component in the ores. Presence of 2.13 ppm Te was detected in the composite sample during head assay analysis. The differences between assayed head grades and calculated head grades would indicate that the gold is not evenly distributed within the ore and occurs as localised spots. Gold was identified to occur predominantly in the native form and as Au-Te. The sample subjected to gravity separation assayed about 2.6 g/t Au.

Key Words: Ore, Gangue, Ashashire, Gravity, Gold, Telluride, Concentration, Knelson concentrator

CHAPTER –I INTRODUCTION

1.1 Background Information

Gravity separation, flotation, cyanidation, or combinations of these processes is typically used in the beneficiation and processing of gold bearing ores. The physical, chemical, and mineralogical characteristics of the gold and associated gangue minerals often determine which of these processing techniques is best in gold ore processing (A. Gül et.al, 2010).

Gravity separation is one type of gold ore beneficiation method which depends on the size, shape and density characteristics of gold and associated minerals (Gerardo et.al, 2001).

Gravity concentration method remained the dominant mineral processing methods and does not lost its importance with development of the flotation and cyanidation methods. Improvement is made to gravity concentration methods due to relative ease and low cost of gravity operations, as well as the increasing flotation costs, the environmental and health hazards associated with cyanide Zhixian Xiao (2001). To concentrate different types of ores which has variable particle size distribution, varieties of effective gravity separators have recently been developed. This has leads to a substantial advancement in gold gravity recovery to treat fine particles with newly developed methods Zhixian Xiao (2001). Due to the difference in specific gravities between gold and its gangue minerals, free gold particles can be extracted effectively using gravity separation methods Zhixian Xiao (2001). Jigs, pinched sluices, shaking tables, spirals, Knelson, Falcon, and Multi-Gravity separator are among some of gravity concentrating tools that have been developed and utilized in the processing of minerals Zhixian Xiao (2001).

Advanced gravity concentrators such as Knelson, Falcon and Multi-Gravity have ability to economically separate fine particles based on their density variations and this bridge technological gap that exist in mineral processing (Emre. et.al, 2022; A. Gül et.al, 2010; Avimanyu et.al, 2018).

Naturally gold particles which found in alluvial (placer) gold deposits can be recovered with traditional methods if placer gold deposits have liberated gold particles. However, unliberated gold particles found in the hosting minerals require appropriate comminution to remove by gravity separation methods (Gerardo et.al, 2021). This project study focus on the applicability of gravity separation method using KC-MD-3 to treat Ashashire gold ore deposit, from Benishangul gumuz Region, Ethiopia.

1.2 Location and Accessibility of the Study Area

The Ashashire gold deposit area is located in the Kumruk Woreda, Benishangul Gumuz Regional State, in western Ethiopia. The area is far away from Addis Ababa an approximately 750 km asphalt road and100 km far from Asosa city to Kumruk Woreda through all weathered graveled road. The study area is situated in geographically bounded between 34° 24' 55" to 34° 25' 22" Longitude E and 10° 32' 41" to 10° 33' 27" Latitude N. The accessibility of the study area is through two ways of routes. The first way of accessibility is using an asphalted from Addis Ababa-Ambo-Nekemte-Gimbi-Mandi-Asosa-Komosha- Kumruk. The second way of accessibility is by flying from Addis Ababa to Asosa and then, via paved road that passes through Agubela-Kutaworke villages to Kumruk.

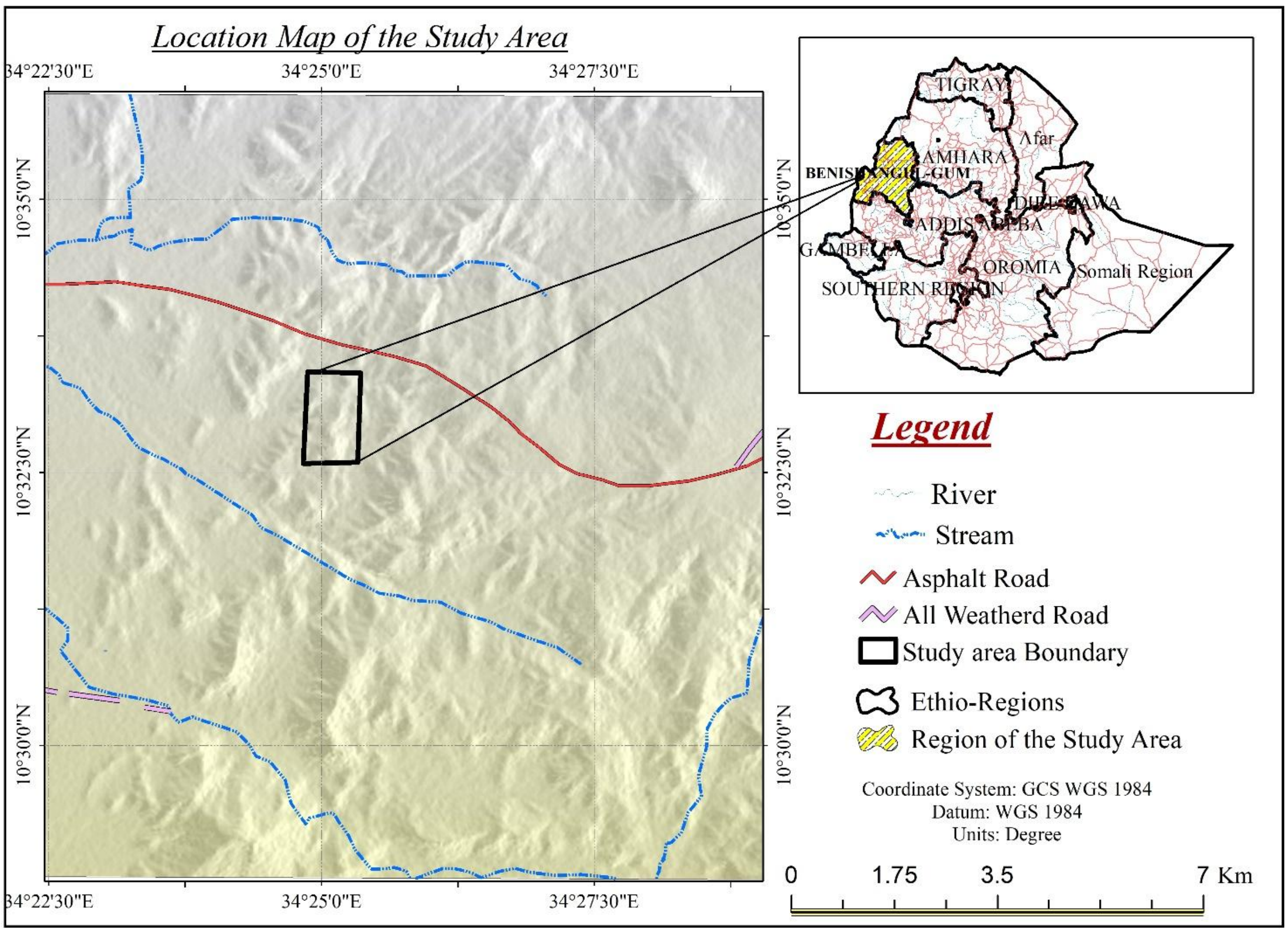

Figure 1. Location and Accessibility Map of the Study Area

1.3 Physiography and Climatic Condition of the Study Area

The Physiography of the study area is characterized by steep slope to flat lands, rugged topography, parallel undulating mountainous ridges and elevated area varies from 701 to 1438m above sea level, and reaches 1250 m at the top of the deposit. West portion is mostly low lands while the eastern part forms hills and mountain ridges (Refer 3D physiographical setting Fig). Most of the streams flow westwards and they are intermittent. The stream flows E-W crosses the northern part of the deposit area is a tributary of kota worke, in which artisanal miners are active (Refer 2D physiographical setting Fig). It is sparsely vegetated by small bushes, savanna grass lands, shrubs, acacia, incense trees and bamboo, reflecting the arid and semi-arid climate conditions in the region. Thick tree growth is mainly confined to river valleys. The climate of the study area is arid to semi-arid type of climate with long dry season ranges from end of October to mid-May with a temperature ranging between 25°C to 45°C, and a rainy period extends from June to mid of October(Refer rainfall and temperature Fig). The area is populated by indigenous Benishangul people of Berta tribes living in groups in scattered villages, normally near streams. The local inhabitants are mostly dependent on the surrounding natural resources such as agriculture, artisanal mining, livestock farming, gum collection as well as honey production and bamboo harvesting). There are many wild life habitats in the area including several varieties of antelope, monkey and others.

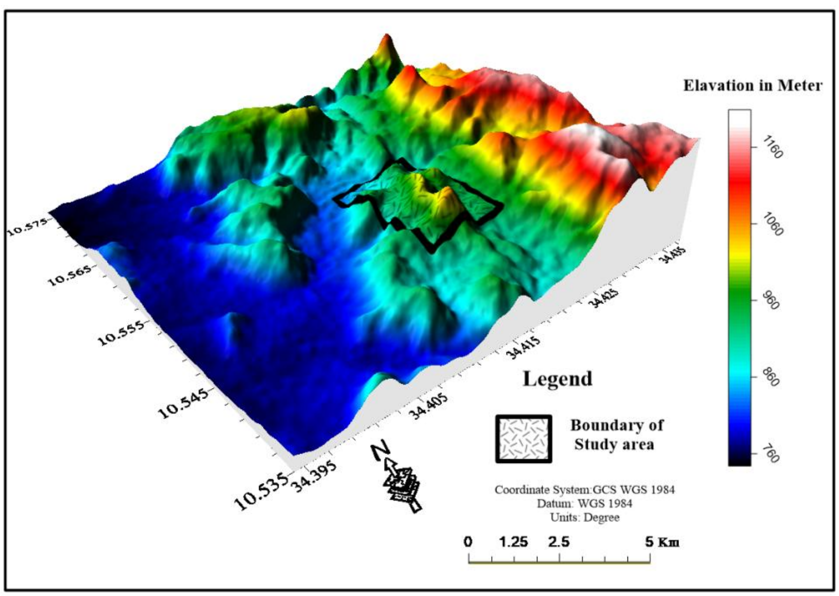

Figure 2. 3D Physiographic Map of the Study Area

Figure 3. Physiographic Map showing the Study Area

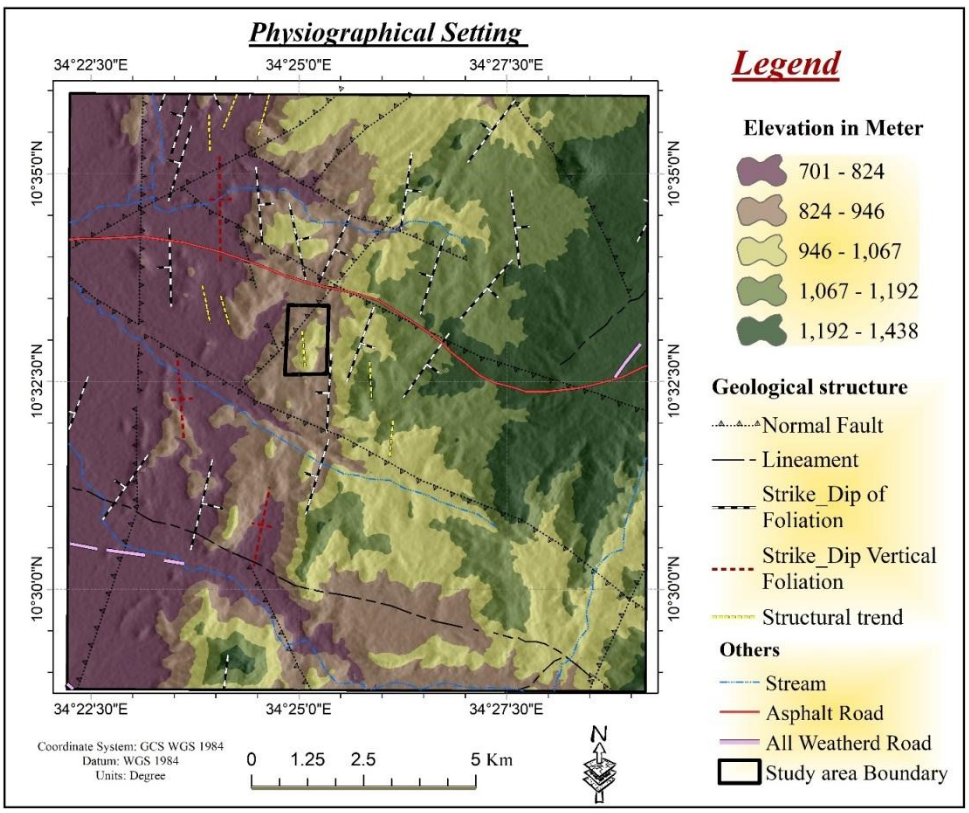

Figure 4. 2D Physiographic Map of the Study Area

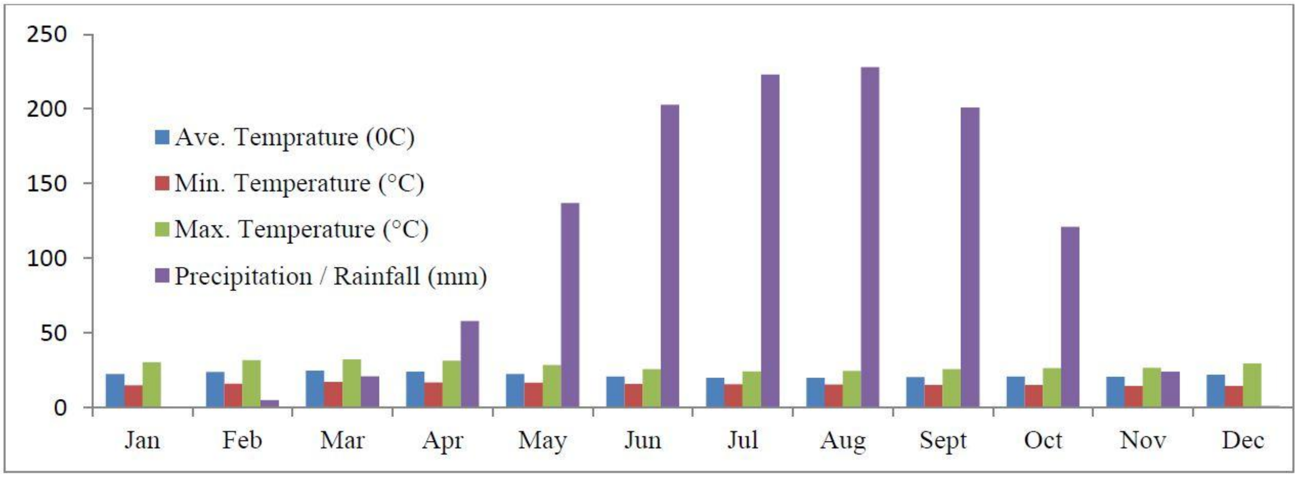

Figure 5. The Histograph showing rainfall and temperature of the study Area, https://en.climate-data.org/africa/ethiopia/benishangul-gumz-1688/*)*

1.4 Previous Study

The presence of gold in Ethiopia has been known for centuries and recorded by historians through evidence that early Egyptian Pharaohns conducted commercial expeditions to the region trading of gold with Ethiopia (GSR, 1996). Since that time, artisanal mining of placer gold at river beds has continued in many regions (Golden Star Resources Limited, 1996).

The greenstone belts (GSB) of western Ethiopia has been well known for its gold occurrences since 1930's (Chewaka S, and de Wit, 1981; Jelenc, 1966). The greenstone belts of western Ethiopia has been regionally mapped and evaluated by Hess (1932) and Fontana (1954). Geological Survey of Ethiopia (GSE) has been conducted a regional scale mineral exploration and mapping projects, including Ashashire, in different parts of Ethiopia.

Therefore Gold occurrences in greenstone belts (GSB) of western Ethiopia have been reported by different agencies and institutions. Among these is the joint work of EIGS-UNDP, 1972; Metal Mining Agency of Japan (MMAJ, 1974), Ethiopian mineral resource development committee (EMRDC, 1982), Geological Survey of Ethiopia (GSE, 1991, 1995), Golden star resources Ltd, (GSR, 1996), Benzu gold mining Ethiopia Ltd (BGME, 2013) and currently ASCOM Gold Mine PLC is engaged. They have conducted geological and geochemical mapping, sampling stream sediment, soil, grab, pit, trench samples, surface and borehole samples and pan concentrate to delineate gold deposit and their work confirmed the presence of good grade of gold. The joint work of Gold Fields Ltd and Benzu Gold Mining Ethiopia PLC Ashashire area gold exploration mostly focuses on the grade and tonnage deposit. This work delineated a number of anomalies within Dul Mountain, Azale and Ashashire targets Jembere M, (1984).

Golden Star Resources Ltd (1996) undertook a systematic Bulk Leach Extraction of Gold (BLEG) by Geological mapping, collecting soil and rock samples and dug seven trenches to analyze gold using BLEG analysis method at Ashashire GSR, (1996). Accordingly, Ashashire gold accounts an average gold grade approximately 2.58g/t from assay results that analyzed by GSR from seven trenches GSR, (1997). While the fire assay results from Benzu Gold mining Ethiopia, (2013) recorded up to 64 ppm. Similarly, the fire assay geochemical result of Sewagegn, (2020) study record shows gold concentration ranging <0.02 ppm to 10.3 ppm and on average approximately reaches to 4.17 ppm for 10 selected samples. The main objective of the previous work in the areas was to locate economic gold deposit however; they did not mention processing option for this deposit, rather they study location of economic gold deposit and the grade and tonnage of deposit.

1. 5. Statement of the Problem

Gold (Au) is a significant element, economically used as a symbol of wealth and prosperity. Because of gold's low concentration and dispersed distribution in gold bearing ores, gold processing is difficult and requires critical processing steps. The grade of concentrate is inversely correlated with gold recovery, and it is critical to figure out how to get a high-grade concentrate using the right recovery techniques which is environmentally benign. Conventional gold processing method with aid of chemicals poses a risk on human health and environment. This has sparked substantial research to find and create environmentally friendly gold processing method. Different minerals have been separated via gravity separation according to their densities for millennia. Despite widespread use of flotation and cyanidation beneficiation methods, as well as hydrometallurgical processes, gravity separation methods do not lose their relevance. All methods of gravity separation are implemented at relatively low capital and operating costs, being highly productive and environmentally friendly and gained popularity in gold industry to concentrate and recover effectively free coarse and fine gold. Gravity separation is always the first consideration in any flow sheet development program because of its high efficiency and low cost when there are substantial variances in the specific gravities of the valuable and gangue minerals. Gravity separation is typically an effective technique to remove gold particles from the other gangue minerals. The density, size, and shape of the mineral particles in the ore are factors that affect how gravity separation methods are effective. Newly developed modern gravity separation methods have been effectively treat fine particles size despite their density, size and shape.

Enhanced gravity separators such as Knelson concentrator, Falcon concentrator, and Multi-gravity separator have been created to close the gaps in performance between conventional processes to treat fine particles.

The main objective of the previous work in the areas was to locate economic gold deposit and the grade and tonnage of deposit however; they did not mention processing option for this deposit. Therefore by considering this as one gap and problem, the main goal of this project aims to study the applicability of gravity separation methods to treat Ashashire gold ore deposit which is ecologically benign. This would close the gaps that exist between international done work and that of our country’s context. Also this would close the gaps between gravity separation techniques and widely used conventional methods for recovering fine gold particles, such as flotation and cyanidation for similar type of deposit. For this, the laboratory Knelson concentrator (KC-MD-3) was used and gold ore sample was obtained from the kurmuk gold company.

1. 6. Objectives of the Study

1. 6.1. General Objective

The main objective of this project study is to investigate the applicability of the gravity separation methods on the Ashashire gold ore deposit, from Benishangul Gumuz Region, Ethiopia.

1. 6.2. Specific Objectives

- To concentrate gold and investigate optimum size to achieve high recovery
- To optimize separation condition using gravity separation methods
- To investigate and analysis ore sample and concentrate for gold and associated elements content

1. 7. Scope of the Study

The scope of project study was more confined on the concentrating gold from Ashashire gold deposit using laboratory Knelson concentrator (KC-MD-3). Due to financial and time constraint, it does not cover more than one type of gravity method and three grinding size during investigation and further tailings treatment was not attempted. The study is more confined on the activities such as sampling, comminution and laboratory analysis and separation test. However, primary data is collected based on the laboratory experiments outcomes. During this project study, the best optimum grinding size of good gold recovery were determined for the ashashire gold deposit and this can be used by any gold industry in the future for similar gold deposit in the country. After investigation, improve the yield and grade of ore by grinding to the best size fraction suitable for best recovery.

1.8. Significance of the Project

As discussed above, the use of chemical based methods in gold processing has effects on the environment. But, the gold can be efficiently recovered by using gravity separations techniques with different degree of liberation sizes. And this project study was having considerable significance in solving problem associated with use of chemicals in gold extraction. This was having a great contribution to the mineral industry on how to recover gold from its deposit without affecting environment with right mineral separation techniques. So, this project was attempted to show how gravity separation method used to recover gold efficiently without any environmental problem which will used by any offered body. This paper was systematically study the application of gravity separation method on Ashashire gold which will provide an important reference for the efficient development of similar gold mine resources.

1.9. Project Structure

Chapter 1 introduces the project by providing the background on the subject matter. The location and accessibility of the study area, physiography and climatic condition of the study area, geology of Ethiopia and study area, previous study, and objectives of the study, Scope of the Study, the problem statement and project significance are presented. Chapter 2 contains a comprehensive review on gravity separation methods. This chapter provides methods that were used in gold processing industry previously. The gold ore property and occurrence, a few selected beneficiation techniques are reviewed and discussed. Chapter 3 outlines the methodology used to conduct the project study, which includes the sample selection and preparation methods, instruments used, the approach taken for experimental procedure beneficiation test and sample analysis methods. Chapter 4 presents analysed data collected and discusses the findings of the study. Chapter 5 summarizes the final conclusion of the project and recommendation on possible further work.

1.10 General Overview of Geology of Ethiopia

Different geological studies have confirmed presence of different rocks and mineral deposits of different origin, age and evolution in Ethiopia. Ethiopia has a varied geological history characterized by Precambrian basement to Quaternary sediments. The Precambrian geology of Ethiopia consists of variety of sedimentary, volcanic and intrusive rocks which are subjected to low to high degree of metamorphism and deformation. The Precambrian rocks of Ethiopia are exposed in eastern, western, northern, and southern parts of the country (Asrat.et.al, 2001). The Precambrian terrain of Western Ethiopia consist high-grade gneissic terrain and low-grade metavolcano-sedimentary terrain sequences (Braathen et.al, 2001). The greenstone belt of Western Ethiopian has formed through different processes beginning early rifting and associated sedimentation (Kazmin et.al, 1979).

Western Ethiopia covers the largest green stone belt of the country that consists of various Precambrian rocks. Occurrences of different Economic minerals are identified in these belts Tadesse, (2009). The belt is known for hosting different types of mineralization that are associated to different lithologies and styles of mineralization Golden Star Resources, (1996). The primary gold deposits associated with these belts are observed in the different parts of the area. The economic gold deposit is discovered by different companies in the Western Ethiopia. Tulu Kapi gold deposit by Nyota Minerals Limited, Dish Mountain and Ashashire gold deposit by ASCOM precious metal mining, Egambo gold deposit by Midroc – Gold Company. Some economic minerals other than gold such as platinum, copper, iron zinc, silver and arsenic also found in the basement rocks of western Ethiopia Tadesse, (2009). Benzu Gold mining Ethiopia, (2013) recorded different gold mineralization style in metasediments of the area. A Potential economic graphite-bearing schist deposit is discovered in the Asosa region, which is hosted predominantly by quartz-graphitic schist, quartz-feldspar-mica schist and quartzite Bullock and Morgan, (2015).

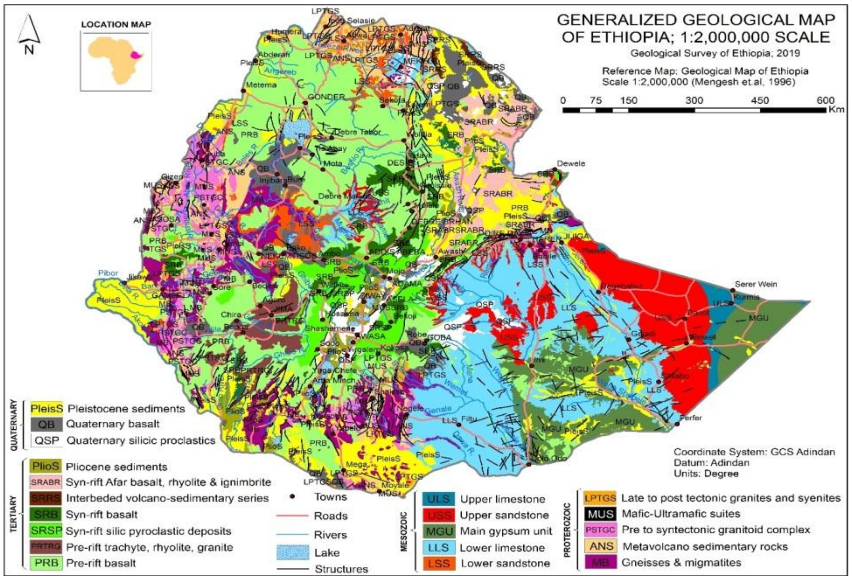

Figure 6. Geological setting of Ethiopia

1.11 Geology of the Study Area (Ashashire)

The Asosa Concession lies in greenstone belts (GSB) of western Ethiopia, north of Asosa, within the Neoproterozoic volcano-sedimentary Tulu Dimtu Belt where it is mapped as a succession of phyllite, green schist, minor graphite and talc schists, quartzite and marble on the Geological Survey of Ethiopia GSE, (1997). The Tulu Dimtu Belt is a Pan-African orogenic belt, comprising generally low metamorphic grade rocks, produced by the collision between the Nile and Somali cratons during the Neoproterozoic assembly of West Gondwana. The Ashashire deposit is located in the portion of the Asosa Concession of volcano-sedimentary succession within western green stone belt within Tulu Dimtu shear belt in Sirkole Domain and topographically rugged in the form of parallel undulating ridges, mountainous ranges and elevated areas trending northeast southwest. Ashashire study area is geologically situated in western Green Stone Belt of Precambrian rocks of Ethiopia. It is mainly comprises various rocks units metamorphosed to low grade Metavolcano-sedimentary sequences and intruded by felsic to mafic plutonic complexes with different extent. The Ashashire area is generally covered by metavolcanic to meta-volcaniclastic, metasediment and syn-post orogenic felsic to mafic intrusive rocks. There are numerous visible old mining pits in Ashashire area and surroundings. In the Western Ethiopia, at Kurmuk area, local communities are participating in artisanal gold mining activities following the river channels. This shows presence of placer and primary gold deposits in the area.

The Ashashire gold mineralization is dominated by Precambrian metasediments and metavolcanics of green schist facies as reported by (GSR, 1996 and GSE, 1995). The morphology of minerals in Ashashire gold mineralization indicates that the deposit is structurally controlled. The gold in the calcite-quartz veins occurs within quartz or within, or marginal to pyrite minerals. Gold occurs as native form in the form of inclusions and disseminations in pyrite and calcite-quartz veins.

The gold mineralization in the area is related with quartz veins resulted from hydrothermal processes and the type of gold deposit in the study area is categorized as low-sulphide gold–quartz vein. Low-sulphide gold-quartz veins are also known as orogenic gold, ("shear zone hosted", "Mesothermal", "greenstone-hosted quartz-carbonate vein" deposit) consisting gold in massive wispy nature along with multiple persistent quartz veins that are hosted mainly in regionally metamorphosed rocks Drew, (2003). Gold is hosted in quartz, dolomite, chlorite, and pyrite veins and adjacent dolomite-muscovite-pyrite altered selvages within broad dolomite-muscovite alteration.

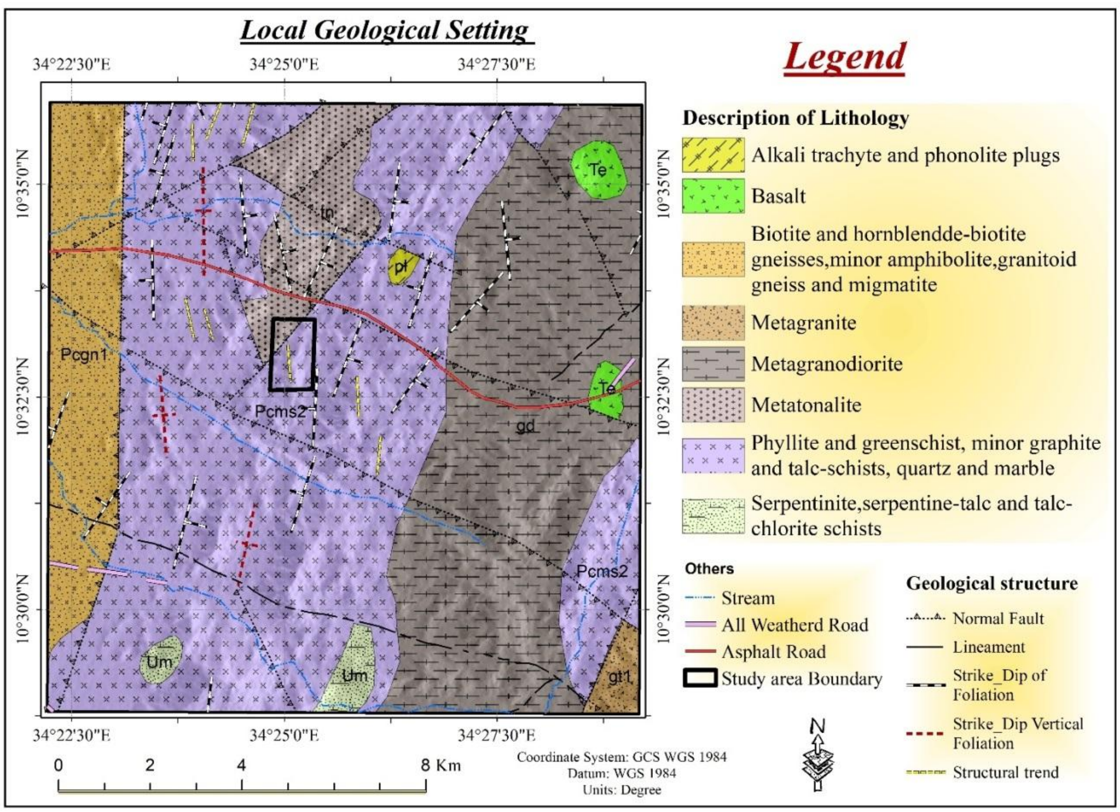

Figure 7. Local Geological setting of the Study area

CHAPTER –II LITERATURE REVIEW

2.1 Mineral Beneficiation

Mineral Beneficiation is any process that improves the economic value of the ore by physicals and chemicals methods by removing the gangue minerals to increase the concentrate enrichment. There are many different types of mineral processing methods developed to separate and improve the ores into the concentrates, by-products and waste or tail. The most common mineral beneficiation processes such as sample preparation, comminution, classification, etc are used in the separation of valuable minerals from the gangue minerals for the purposes of concentration. The ore composition, chemical and physical characteristics, ore grain-size distribution, etc. determine the most appropriate methods to distinguish the valuable minerals from the gangue and host material. Generally, industrial scale mineral beneficiation involves stages of mining and comminution process through crushing and grinding to reduce particles size of large lumps with help of Sizer and classifier to produce concentrate and converting it into intermediate product and purification and/or refining of these intermediates to final useable product.

2.2 Gold Ores Properties and Occurrence

Gold is a very precious and uncommon element that can be discovered in nature both as pure nuggets of native gold and as compounds with other elements. Gold is a heavy metal with a relative density of 19.3 g/cm3. Gold has a variety of applications because of these features, uses in jewelry, dentistry, ornamentation, coins, and electronics Norgate and Haque, (2012). The most typical natural process for gold concentration relies on the oldest action of heated fluid within the Earth's crust and can be concentrated to levels in the parts per thousand, parts per million, or parts per billion if the fluids travel over an area large enough and dissolve the gold for a long enough length of time (Geoscience Australia).

Gold occurs in many forms in ore deposits as free particles or nuggets and compound in other minerals, like fine inclusions or solid solution in sulphides (Mineral Processing and Extractive Metallurgy (Trans. Inst. Min. Metall. C) 2012 Vol. 121 No. 4). Based on its mode of occurrence, gold is classified as microscopic gold, which commonly referred to as visible gold, submicroscopic gold, also called refractory gold and surface-bound gold which adsorbed onto the surface of other minerals (Wang et.al, 2003). Gold-bearing ores can generally be classified into placers, free-milling, oxidized, silver-rich, gold antimonides, gold bismuthites, gold sulfides, gold selenides, copper-sulphides, gold tellurides, and carbonaceous ores based on their mineralogical characteristics (A. Gül et.al, 2010). However, no matter in which form gold found, some is liberated in grinding circuits where it accumulates due of its density and malleability (Basini et.al, 1991). Mineralogical factors associated with ores, including the degree of liberation, mineral association, and gangue mineral composition, play key roles in determining the most appropriate processing method in gold recovery (Zhixian Xiao, 2001; Zhao et.al, 2014).

2.3 Selected Gold Ores Processing Method

The gold ore process is usually depends on the physical, chemical and mineralogical properties of ore. Nowadays gold has economic worth in numerous industries and its extraction from gold bearing ores becomes a topic of issue to recover gold by appropriate methods (Ogundare et.al, 2014). Recovering gold from its ores using simple method is difficult, due to finely dispersions of gold in gold bearing rocks and the way it interacts with the surrounding minerals. Depending on the gold properties and particle size, numerous types of beneficiation and processing techniques have been successfully developed and used to extract gold from its ores. As stated by Liipo, (2003) Size reduction, size classification, gravity separation, roasting, cyanidation, oxidation, chemical and/or bacterial leaching, ion exchange and/or solvent extraction, and froth flotation were only a few of the methods that were tried to overcome this issue and used to extract gold from its ores. However, mineralogy and particle size distribution of the deposit is ultimately determines the optimum gold processing techniques for that deposit also by Liipo, (2003). Various scholars have been conducted to improve the enhancement of gold collecting from its ores using different techniques. Those are gravity separation, flotation, cyanidation, and mercury amalgamation were widely used methods to recover gold from its ores (Gerardo et.al, 2021). The development of the flotation and cyanidation process methods has reduced the relevance of gravity separation, one of the frequently employed ways in the gold ore beneficiation. However, the relative ease and low cost of gravity operations, as well as the rising flotation costs, and related environmental and health risks with cyanide, have improved gravity concentration technologies (Zhixian Xiao, 2001). The assessment work done by C.J. Mitchell et.al. (1997), assessment based on the environmental effect of each method used to recover gold, ranked flotation, mercury amalgamation, and cyanidation as high impact methods.

2.3.1 Mercury Amalgamation

In order to extract gold from its ores, amalgamation with mercury is the most used technique (Hylander.et.al, 2006) Gold miners continue to use the amalgamation method to separate gold from ore. In the amalgamation process, gold ore and mercury are combined to create an alloy, Hg-Au. The amalgam is heated to vaporize the mercury and release the gold. This procedure carries a high potential risk and can result in severe environmental mercury exposure as well as health issues. In order to decrease mercury pollution and health dangers, mercury use in gold mining and processing outlawed internationally (Pulungan et.al, 2019; Gerardo et.al, 2021; Peter W.U. Appel and Leoncio Na-Oy, 2013)

2.3.2 Cyanidation

The processes of cyanidation are the most widely employed process in the gold industry. Nowadays, cyanide has been employed on large scale to extract gold from gold bearing ores. The concentration of gold from its ores has a better result because cyanide gold complexes are more stable than other lixiviants products rather than to substitute it. Cyanide combines with gold to form water-soluble complexes from which gold will extracted from a solution after reduction and treatment with the carbon activation. However, cyanidation has its limitations due to the environmental hazard of the reagents and the decrease in efficiency of gold recovery from carbonaceous and organic raw materials as well as from raw materials high in copper, zinc, nickel, antimony and arsenic (Sergei et.al, 2018).The cyanidation gold recovery process release cyanide solution which contain toxic chemicals and heavy metals into the environment (Youlton.et.al, 2021; Friedhelm.et.al, 2000; Ogundar et.al, 2014; La Brooy et.al, 1994). Havening in mind this, it has a risk on the environment, marine and terrestrial life with respect to on human health and cause skin rashes, headaches, a weak and rapid heartbeat, nausea, vomiting, burns, and intense pain. However, prolonged of skin exposure and inhalation on cyanide gas is at high amounts can be fatal Lesley (2019). This has sparked substantial research to find environmentally friendly gold processing method Hilson and Monhemius, (2006).

2.3.3 Flotation

The flotation method is widely used for recovering gold from its ores where alternative processing methods are inapplicable. Floatation also used to upgrade low grade and refractory ores for further treatment and used to remove interfering impurities before send to hydrometallurgical process. For

gold ores containing the easily floatable minerals, flotation offers a number of alternative processing methods such as flotation of free gold and gold-bearing sulphides to produce a gold-rich concentrate followed by cyanidation, oxidative pretreatment and cyanidation or direct smelting and the flotation of carbonaceous material, or other material that may interfere with processing; the differential flotation. Flotation is the most economical method for concentrating gold with reagents from appropriate particle size ranges. However, it is well known that flotation is not very effective for recovering the particles at relatively coarse or ultrafine particle size ranges (Klein.et.al, 2010).
For many years, flotation has been used on native and free gold particles; however modifiers and collectors affect how gold particles are floatable (A. Gül et.al., 2010).

When native gold is naturally floatable, collectorless flotation employed only using frothers. Heyes and Trahar (1977) investigated the gold flotation from chalcopyrite without a collector and carried out another work on selective gold separation. They looked at the various collector types for separating gold tellurides from pyrites and discovered that tellurides floated readily at pH levels prevalent in nature.

The gold content and flotation recovery were enhanced by the addition of xanthate and mercaptoben zothiazole. Similar to how dithiophosphate attaches to gold surfaces during flotation, also xanthate can as well, Yan and Hariyasa, (1997). Auriferous ore from the Barry Region in Northwestern Quebec, Canada, was examined by Yalcin and Kelebek, (2011). In the grinding circuit, soda ash was used as the pH regulator with a single dosage. In flotation studies, a combination of sodium isopropyl xanthate and potassium amyl xanthate was used as the collector. At the conclusion of flotation studies, it was discovered that when the particle size fell from 205 µm to 53 µm, the gold recoveries increased from 91.8 wt % to 95.8 wt %. To enhance the gold recovery from such ores, a strong collector should be utilized. Oxides and silicates are the main gangue minerals linked with gold.

2.3.4 Gravity Separation

Gravity separation is the most tried-and-proven method for concentrating minerals, which has been employed as the main method of mineral concentration for millennia. Due to its low cost and ecologically favorable operations, the recovery of gold using gravity method has gain interest. Gravity based equipment such as medium separators, jigs, shaking tables, spirals, Knelson and

Falcon concentrators are typically employed in gold processing Murphy et.al, (2012). Numerous investigations in utilizing gravity separators have been conducted by a large number of researchers and business sectors on various types of ores Surimbayev.et.al, (2021). Egbe.et.al, (2013) studied effectiveness of gravity separation methods for the beneficiation of Lead-Gold ore from Baban Tsauni (Nigeria) with Jigging, shaking table and Multi-gravity separation. According to all of the data, lead is the most valuable mineral in the concentrates, with lead grades of 61% for jigged samples with particle sizes of -1400 µm + 1000 µm, 59% for multi-gravity with particle sizes of -355 µm + 250 µm, and 57% for shaking table with particle sizes of -710 µm + 500 µm. Shaking table beneficiation produced lead enrichment of 2.051 and a gold enrichment of 3.744 at a particle size of -710 µm + 500 µm with a gold grade of 0.11%. Gold is the most valuable mineral reported in the tailings, according to the study's findings. This happened as a result of the gold's fine dispersion within the quartz. Since liberated gold (free gold) is heavier than galena, it would not have floated preferentially in a lead and gold jigging process.

According to (Meza et. al, 2004), Knelson concentrator was used to study the alluvial gold-containing sands from Bajo Cauca and El Bagre, Colombia and after three stages of testing, yielded more than 98 wt % of the gold. Knelson concentrators were used to process carbon in pulp (CIP) tailings at the Golden Giant Mine in Canada. From CIP tailings grading 0.4-0.5 Au g/t, Au concentrates grading 3 wt. %–8 wt. % were produced. Knelson concentrate was subsequently processed on a Gemini shaking table to provide a final concentrate that measured between 75 to 80 percent gold Hendriks and Chevalier, (2004). As stated by Wotruba and Müller (2001), the treated the tailings of Nicaraguan gold ore that assayed 31.2 g/t Au with particle size less than 20 µm using a Falcon concentrator and Falcon concentration led to produce a gold concentrate with a recovery of 59.4 wt. % and a concentration of 509.5g/t Au.

Even though, all the above discussed, tried and practiced internationally, in context of Ethiopia, there is no gravity method studied. Therefore, taking this as a gap and according to the Ashashire gold ore deposit mineralogy characteristics gravity separation method applicability is investigation is necessary to determine gold recovery.

CHAPTER - III PROJECT METHODOLOGY

The mentioned objectives of this project were achieved through a variety of ways, methods, techniques and instruments used to accomplish. The literature review conducted is related to gravity separation method and gold mineral. Previous work data including published and unpublished articles, scientific journals from different websites, relevant books and published and unpublished reports from Geological Survey of Ethiopia, Golden Star Resources GSR, (1996) and Ascom PLC were reviewed. These data includes geological maps, geochemical assay results from stream sediment, soil, and trench, channel and core samples. The representative samples have been collected and laboratory analysis and beneficiation test work was performed. General sketch of flow chart procedure of this project study was described below.

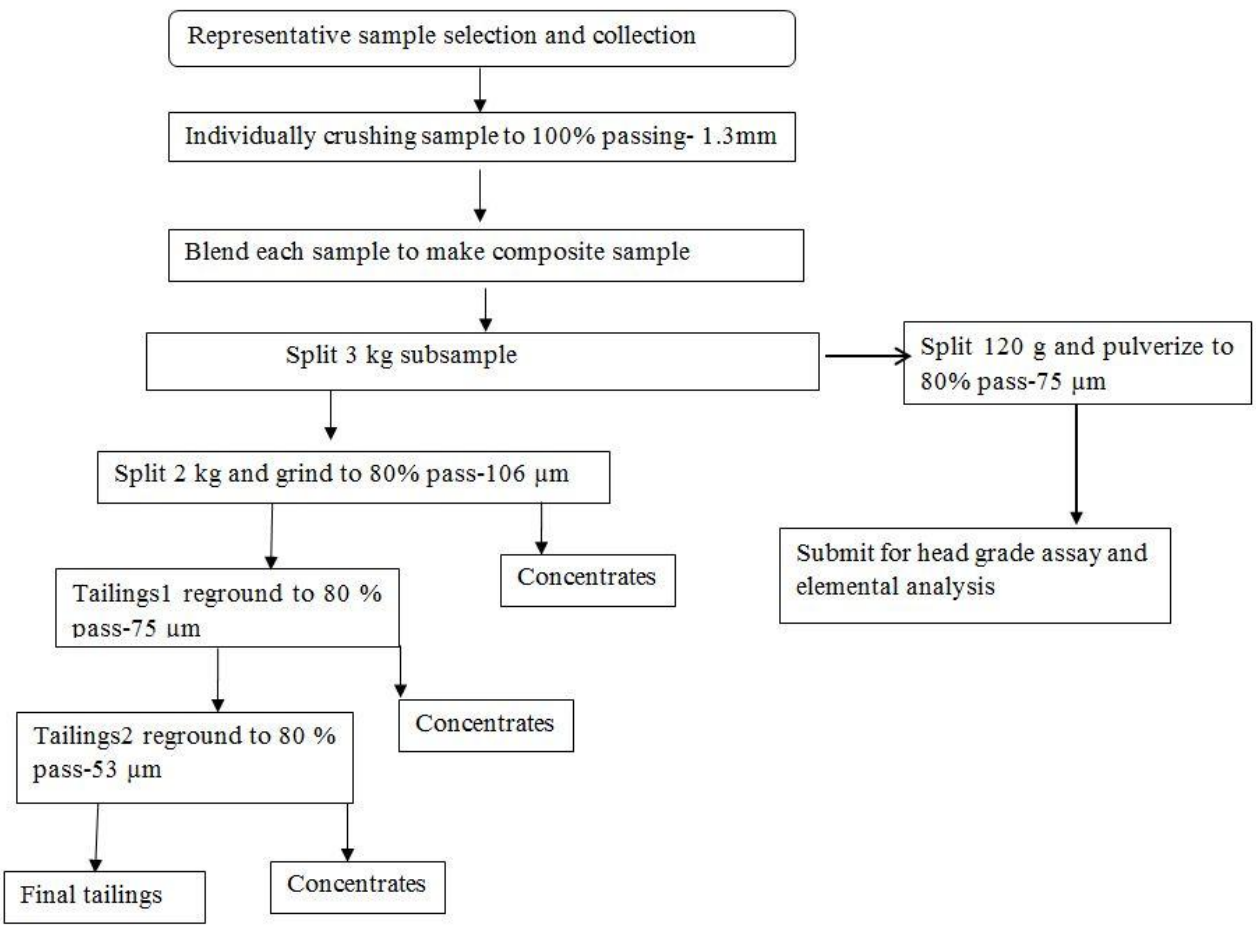

Figure 8: Experimental Procedure of gravity separation test by Knelson concentrator flow chart

3. Materials and Methods

3.1Materials

Materials required to perform this project work were ore sample, comminution equipment, gravity concentrator and mineralogical analysis instruments.

3.2 Methods

The method of study includes ore sampling, sample preparation, comminution, head assay analysis, mineralogical analysis and ore separation with Knelson concentrator, data documentation, interpretation, analyzing and final report presentation.

3.2. 1.Sample Selection

The sample selection was focused on the producing representative of different ore types from the Ashashire gold deposit. For this project study six core samples were taken from different location to make ore representatives of the deposit. Therefore, samples weighing 6 kg were randomly selected to produce mixed and homogeneous composites samples which denoted as ACS. During sampling process, the selected and collected samples labeled as AD35 & AD36 to denote meta-granite sampled from two locations, AD37 & AD38 to denote meta-Pelite sampled from two locations and AD39 & AD40 to denote Meta-mafic sampled from two locations. Accordingly, from these composites samples, representative samples were generated for this project study and weight of each sample and representative composite sample was present in Table 1 and Table 2 respectively.

Sample code	rock type	Mass, kg
AD35	Meta-Granite	2
AD36		
AD37	Meta-Pelite	2
AD38		
AD39	Meta-Mafic	2
AD40		

Table 1: Mass of representative sample collected from different location and rock types

Composite code	description	Mass, kg
ACS	composites	2

Table 2: Mass of representative composite sample generated for study

3.2. 2.Sample Preparation and Experimental Procedure

The selected samples were dispatched to ALS for sample preparation and analysis activities. Therefore, the ALS facilities in Addis Ababa prepare the sample and forward the prepared sample to ALS laboratory Johannesburg, South Africa for testing and analysis.

The preparation of collected representative ore samples was comprised a typical volume reduction by crushing and grinding. The ore sample was individually crushed to 100% less than 1.3mm through a Boyd jaw crusher and thoroughly blends to ensure homogeneity after crushing. From the mixed ore sample, representative composite 3kg subsample was produced and 120g were split for head grade analysis and 2kg used for separation test with 80% passing grinding size of 106 µm, 75 µm and 53 µm. The gold content of sample was determined by fire assay with an AAS finish to 0.01 ppm detection limit and a chemical element analysis was done using full Inductively Coupled Plasma (“ICP”) scan. The 2kg representative composite sample was used for the applicability of gravity separation test on the Ashashire gold deposit. First the sample was ground in the rod mill to provide a product grading nominally 80% passing 106 microns. The mill product was fed as slurry to a laboratory Knelson Concentrator KC-MD-3 at a cone rotational speed suitable to provide 60g centrifugal force and fixed fluidizing water flowrate of +/-2.5 liters/minute under the following operating conditions: Gravitational acceleration - 60g, grinding size- 80 % -106, 75, 53 µm, fluidizing water volume +/-2.5 L/min, fluidizing water pressure – 1.5 psi, feed pulp density- 38-25% solids as presented in table 3.

The primary gravity concentrate was removed from the KC-MD-3 cone and the entire KC-MD-3 tails from the first separation was filtered, re-pulped to required slurry density and further reground with help of rod mill to an 80 % passing 75 microns and fed through the KC-MD-3 as above and Concentrate products were removed. At last, the entire KC-MD-3 tails from the second process was filtered, re-pulped to required density and further reground to 80% passing 53 microns and fed to KC-MD-3 as above. Concentrate products were collected. During testing procedure, representative concentrate and final tailings was split for mineralogical analysis.

Knelson KC-MD-3 laboratory test unit	
Grind	80 % -106, 75,53 µm
Gravitational acceleration	60g
fluidizing water volume	+/-2.5 L/min
fluidizing water pressure	1.5 psi
feed pulp density	38-25 % solids by weight
rotation speed	2000

Table 3: Gravity concentration operating parameters

3.2.3 Beneficiation Test and Sample Analysis

Separation process was performed using knelson concentrator KC-MD3 at ALS laboratory. All required procedure test conditions were described above in table 3. Applicability of knelson concentrator on the ashashire deposit to separate gold from gangue was tested. Concentration optimization was investigated. Sample and concentration head assay and mineralogical analysis were conducted. The analysis was performed for gold content via fire-assay, chemical analysis using Inductively Coupled Plasma ("ICP"), mineralogical analysis by quantitative evaluation of minerals by scanning electron microscopy (QEMSCAN) and X-ray diffraction (XRD), morphology and grain size distribution by Scanning Electron Microscope (SEM) and X-ray spectrum spot analyses (energy dispersive detector), back scattered electron (BSE). The representative ore sample subjected to experimental studies was assayed about 2.55 g/t Au.

CHAPTER - IV RESULT AND DISCUSSION

4.1 RESULT

The study was conducted to determine applicability of gravity separation method using KC on the Ashashire gold ore deposit. Concentration optimization was done with variable grind size. Mineralogical and head assay analysis was conducted. The mineralogical characteristics of the deposit such as the gold and associated element concentration, the gold grain sizes, the gold distribution and composition, mineral association and liberation characteristics, gangue minerals, etc. were determined by using the above mentioned techniques and the results are discussed as follows.

4.1.1 Mineralogy of Head Assay Sample Analysis

Sample for head assay was obtained by rotary splitter and analytical tests were carried out on the head samples. The triplicate gold head grade assay via fire assay analysis with AAS to determine the amount of gold present in mineral sample and elemental head assay analysis including C-total, S-total via full ICP Scan, were accomplished to determine the amount of elements associated with gold in the ore sample. The results of gold head grade assay analysis and the other key elements related with gold in the composite sample are presented in table 4 and table 5 respectively.

Assay	Au1	Au2	Au3	Au (Average)
Value	2.398 ppm	2.43 ppm	2.808 ppm	2.55 ppm

Table 4: Gold head grade assay analysis

Chemical element	Te	Ag	As	Cu	Bi	C	C-org	S	$S_{-sulphide}$	Ti	Fe
Abundances	2.13 ppm	0.75 ppm	0.75 ppm	163 ppm	0.88 ppm	2.5 ppm	0.02 ppm	1.68 ppm	1.65 ppm	0.75 ppm	6.59 ppm

Table 5: Chemical analysis of head assay sample

4.1.2 Mineralogical Analysis of Sample

Mineralogical analysis was performed by quantitative evaluation of minerals by scanning electron microscope (QEMSCAN) and X-ray diffraction (XRD) and using scanning electron microscope (SEM), and X-ray spectrum spot analyses (energy dispersive detector), back scattered electron (BSE) to validate individual gold grains. The purpose of the mineralogy testing was to identify the nature and mode of occurrence of the gold bearing minerals, to determine and identify chemical and mineralogical components of the ore, to identify the type of gold ore and associated element in the ore, for identifying and quantifying gangue minerals present in an ore and the results of this sample analysis are described under subsection below.

4.1.2.1 Chemical Compositions

The chemical composition of sample was determined by ICP at the ALS. The ICP analysis also applied on the ore sample to determine chemical composition of the Ashashire deposit. This chemical composition analysis applied to all particle size fractions of the ore to evaluate valuable chemical element content of the ore sample and the results of chemical composition and chemical elements of ore analysis are tabulated in table 6 and table 7.

Chemical compound	Weight %
SiO_2	50.7
AlO_2	16.03
TiO_2	0.95
FeO_2	9.4
NaO_2	3.5
CaO	9.1
MgO	8.3
K_2O	1.76
MnO	0.327
Total	100.067

Table 6: Results of chemical composition analysis of ore sample

Elements	Si	Al	Ca	Na	K	Mg	Fe	Ti	Cu	As	Te
Weight	15.7 %	5.93 %	4.9 %	1.73 %	0.89 %	2.127 %	6.59 %	0.75 %	160 ppm	0.5 ppm	2 ppm

Table 7: Results of chemical element analysis of ore sample

4.1.2.2 Mineralogical Compositions

Mineralogical analysis of Ashashire gold ore deposit was studied to identify native size of gold for liberation process. This was shows the mineral that associated with gold. In order to identify the type of mineral constituents and to determine abundance of mineral present in the ore sample, comprehensive mineralogical analysis was carried out using QEMSCAN and XRD. From the

QEMSCAN and XRD mineralogical analysis the ore sample has a main gangue mineral composition dominated by quartz, Ankerite-dolomite, Albite, Chlorite, Muscovite, calcite, Paragonite and group of metal minerals mainly pyrite and trace amount of rutile, ilmenite and chalcopyrite. Table 8, shows the Mineralogical composition and relative abundances of ore minerals.

Metal minerals	Abundance (wt. %)	Gangue minerals	Abundance (wt. %)
Pyrite	4.4	Quartz	29.1
ilmenite	2.3	Ankerite-dolomite	18.4
Magnetite	1.6	Albite	14.4
Chalcopyrite	Trace	Chlorite	13.3
		Muscovite	12.2
		Calcite	2.3
		Paragonite	2.1

Table 8 Results of mineralogical composition analysis of ore sample

4.1.3 Results of Gravity Separation Test Using Knelson Concentrator

The composite sample was moderately ground to the standard grind size of P_{80} - passing 106, 75 and 53 µm. results of applicability test on the Ashashire deposit is present below by table 9 and figure 9 and 10. Detail results of applicability test on the Ashashire deposit is shown in the appendices.

Size p80 (µm)	Product	Mass		Gold	
		Gram	%	Grade, g/t	Recovery rate,%
106	Gravity concentrate	15.7	0.79	296	53.938
75	Gravity concentrate	21.1	1.06	352	75.165
53	Gravity concentrate	11.8	0.60	285	37.275
	Final tails	1951.4	99.39	2.9	
Total	concentrates	48.6	101.84		
	feed	2000			

Table 9: Gravity Concentration Test Result

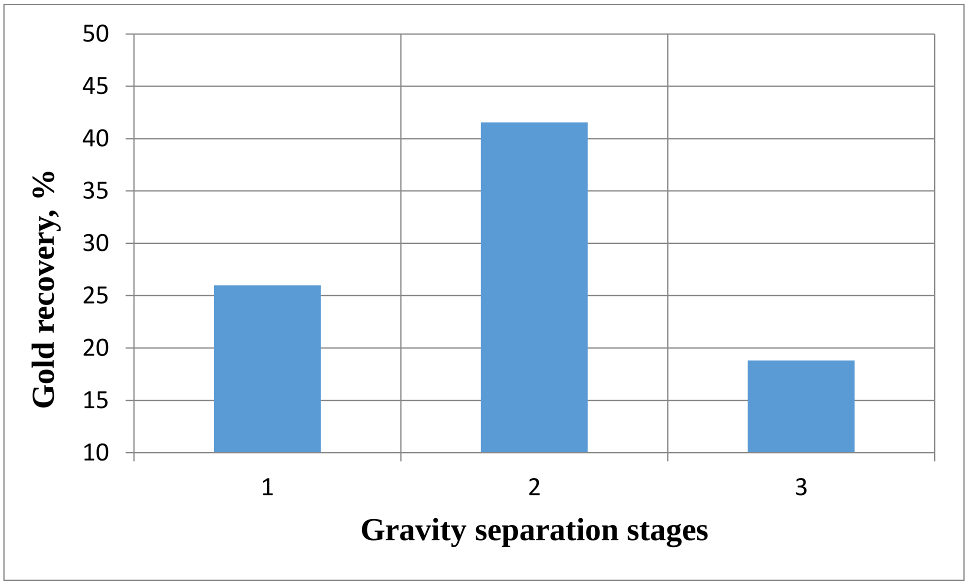

Figure 9: Recovery of gold by concentration stages

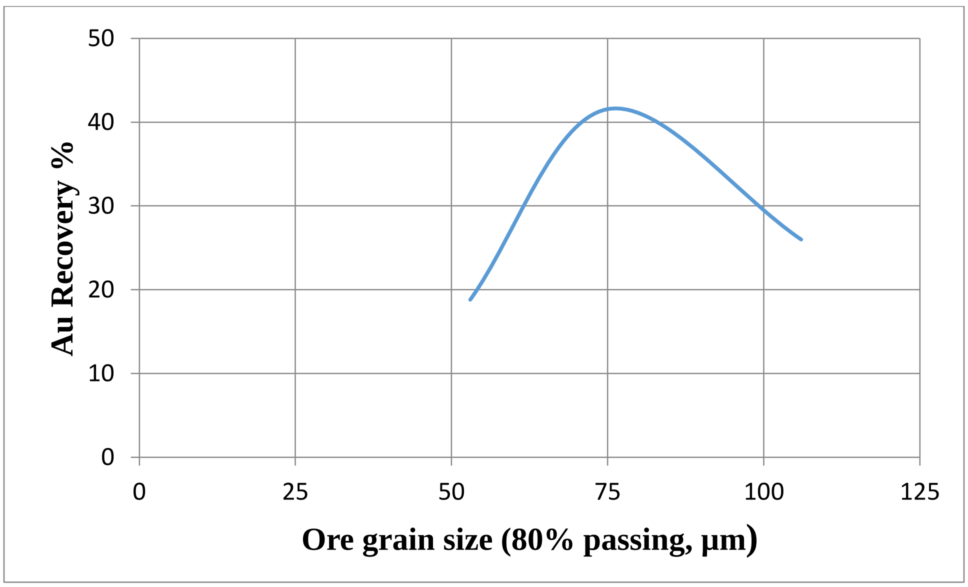

Figure 10: Total percentage of gold recovered by gravity depending on the ore grain size

4.2 DISCUSSION

4.2.1 Mineralogical and Particle Size Distribution Analysis

The sample has been analyzed with QEMSCAN and XRD instrument for quantitative mineralogy examination and Scanning electron microscope (SEM) particle scanner for gold-telluride minerals grains search. The Quantitative Automated Mineralogy QEMSCAN mode of measurement used to analyze Particle Mineralogical Analysis (PMA) and all particles larger than one pixel were analysed. Gold-rich mineral phases search was undertaken with a SEM Particle Scan. All selected grains were individually validated using X-ray spectrum spot analyses (energy dispersive detector) quantification. Scanning electron microscopy with scattered X-ray energy (back scattered electron), (SEM- BSE) was used to determine particle morphology.

As it is seen from table 4, the repeated gold head grade assay analyses carried out on the composite sample yielded an average gold grade of 2.55 g/t Au. Mineralogical analysis reveals the presence of Te in the ore which detected during head assay analysis and has a value of 2.13 ppm Te. The telluride to gold ratio is high and this will have impact on the further processing, (e.g. refining by cyanidation). The composite sample tested contained low silver, arsenic, bismuth and organic carbon levels. Presence of Arsenic indicates minerals that may host refractory gold and arsenic grade is negligible (< 10 ppm). A Mercury grade is very low (< 0.1 ppm) and confirms this is not a possible health and safety threat. Organic carbon grades (possible preg-robbing) are low (< 0.1 ppm) and are not considered significant for further concentrate treating.

The QEMSCAN and XRD analysis results show that quartz minerals had the largest portion and were dominant in the ore, whereas pyrite have been less distributed in the deposit and chalcopyrite, ilmenite and Magnetite have nearly equal distribution as trace minerals. A significant proportion of concentrates mass is made up of comparatively large particles composed of common quartz, carbonates (Ankerite-dolomite), Albite, Chlorite and muscovite.

Pyrite is the dominant sulphide mineral detected and makes up approximately 4.4% by mass in the ore.

The non-sulphide gangue species and their abundance are variable and the main gangue minerals were quartz and Ankerite-dolomite, Albite chlorite, muscovite with lower levels of calcite and Paragonite present (table 8). Only trace amounts of chalcopyrite were detected in composite sample.

The sample exhibited some level of variation between assayed and calculated gold head grade. This variation would indicate that the gold is not evenly distributed within the ore and occurs as localised a coarse 'spotty' gold component locked in particles. A number of coarse gold grains were detected in the gravity concentrates analysed (figure 11). Primarily native gold grains occur from medium to coarse are equant and liberated. The analysis outcome shows that the main gold minerals detected are native gold and gold-telluride. Gold-telluride phase (probably calaverite, $AuTe_2$) is the dominant gold-bearing phase detected with some petzite (Ag_3AuTe_2) and muthmannite ($AuAgTe_2$). Gold in the ore occurs in the form of free native and small grains. Fine gold is closely associated with pyrite, forming inclusions and enclosed by pyrite and dispersed within pyrite as invisible gold (i.e. sub 0.1 µm colloidal and solid solution type) that deport to tail. Gold grain high finesse and occasional association with pyrite indicates secondary and remobilized character of the gold mineralization.

Gold is finely disseminated and/or encapsulated in quartz and gangue rock, or associated with and/or locked in sulphides. This shows that these occurrences of gold are more difficult to recover by gravity method as these particles tend towards gravity tails. Gold that is not amenable to gravity separation could occur as small gold grains in low density minerals, or as liberated flaky gold grains that are smaller than the gravity efficiency cut-off. Consequently the small or flaky gold particles and hidden gold within pyrite as solid solution may have deported to tails, because pyrite may host proportion of undetected very fine gold minerals.

The some gold grains were not well-liberated but native gold grain was the dominant gold-bearing phase detected and grains ranged in size between <2 µm to 27 µm while Au-Te grain size reaches 75 µm. All non-liberated gold grains are hosted by pyrite, except for a calaverite ($AuTe_2$) grain hosted by chlorite in the gravity tail. Some gold grains are associated with chalcopyrite and melanite ($NiTe_2$) inside the hosting pyrite. Images of select gold grains are presented below.

The main oxide minerals are iron oxides and oxyhydroxides found as finer grained. Unliberated gold grains are mainly associated with iron oxides. Iron bearing gold particles was also observed in this sample. Other minerals typically form fine to medium grains indicating some intergrowths. Gangue minerals are mutually moderately intergrown. Muscovite shows some intergrowths with major mineral phases. The majority of the iron elements are contained in the pyrite. The majority of the Aluminium is contained in the dominant muscovite while impure iron oxides and other aluminosilicates contain most of the remaining Aluminium. The majority of abundant calcium is confined in carbonates. Trace of calcium is from locked in minor silicates, titanite and apatite.

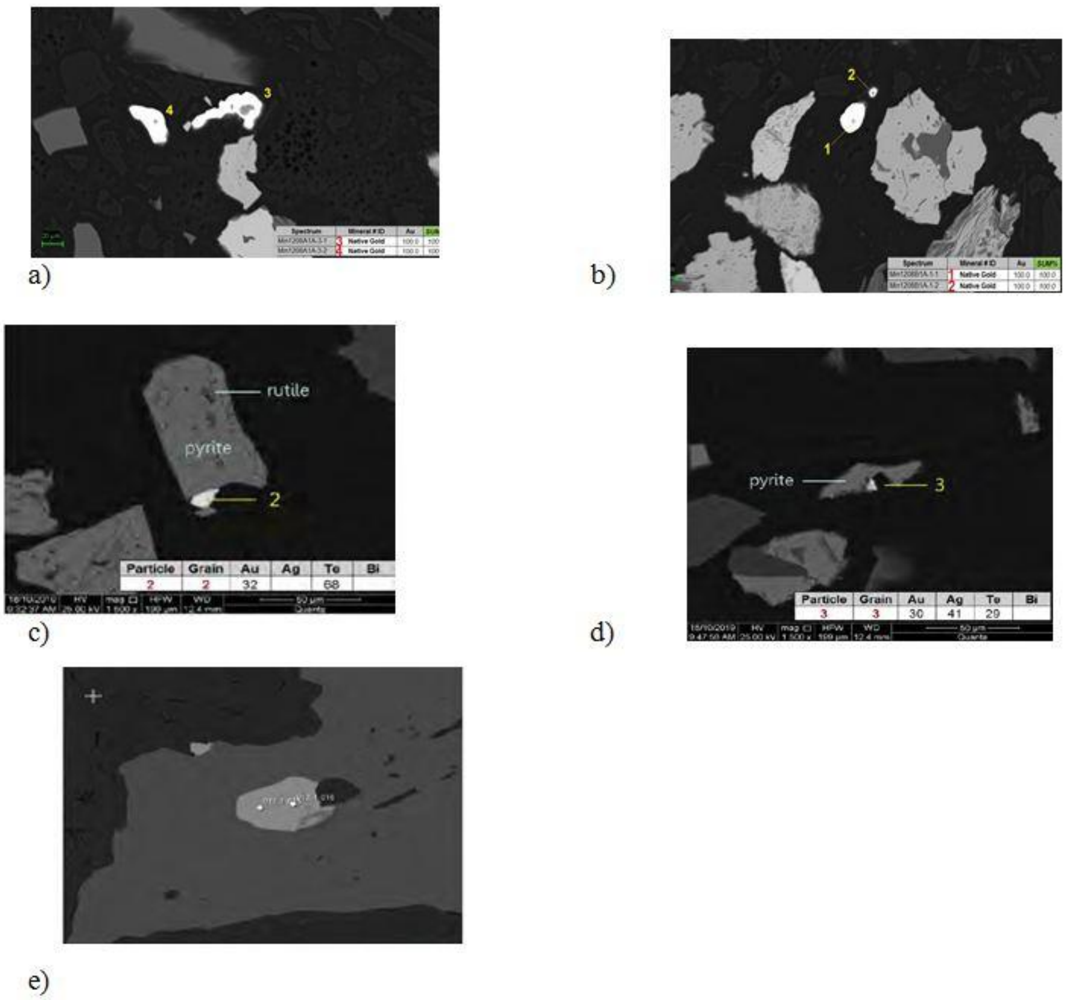

Figure 11: SEM-BSE images of select gold grains. (a) (b) Liberated native gold (free-milling ore); (c)native gold (Au) in association with pyrite along grain boundaries; (d) Native gold (Au) in association with pyrite and quartz; (e) pyrite contains small inclusions of gold-telluride, possibly calaverite ($AuTe_2$) (refractory ore)

4.2.2 Concentration and Recovery Analysis

The main objective of this project study was to assess applicability of gravity methods on the Ashashire gold deposit related to gold recovery. Sufficient mass of Ashashire composites were produced from selected sample for this study and the experiment includes sample preparation, head assay analysis of gold and multi-element, gravity concentration and mineralogical analysis.

The gravity testing comprised three-stage concentration by centrifugal knelson concentrator to produce gravity concentrate. A nominal grind size of 80 % passing 106, 75 and 53µm was selected for this test to produce gravity concentrates and tails.

From studying this composites sample (as seen from figure 10) gravity recoverable gold was ranges from 37% to 75 %. However, mass distribution to the gravity concentrates ranged between 0.6% and 1.06 % (table 10).

Table 10 shows the first gravity concentration testwork on composite sample yielded a concentrate containing 54% of the gold, assaying 296 ppm Au, collected in 0.79% of the feed mass and the second gravity concentration testwork on composite sample achieved the gold recovery containing 75% of the gold, assaying 352 ppm Au, collected in 1.06% of the feed mass while the last gravity concentration testwork on composite sample yielded a concentrate containing 37% of the gold, assaying 285 ppm Au, collected in 0.60% of the feed mass.

Table 10 data show that the total gold recovery is more than 75%. The gravity concentration recovery efficiency of each stage during gravity method applicability test is shown in figure 9. The highest gold recoveries were achieved at the second stage ore particles 80% passing 75 µm and moderate gold recovery is attained at first stage with 80% passing 106 µm with some gold grains lost to tail, table 10. This indicates that presence of relatively coarse gold grains and fine free gold grains in the ore. This is also confirmed by scanning electron microscope (SEM) and back scattered electron detection and quantification of gold grain size from the mineralogical analysis (Figure. 11). Total percentage of gravity recoverable gold depending on the ore grain size is present in figure. 10. This figure. 10 show that the highest percentage of gold recovery is achieved at grinding ore to the 80% passing 75 µm.

All selected grains were individually validated using X-ray spectrum spot analyses (energy dispersive detector) quantification. Scanning electron microscopy with scattered X-ray energy (back scattered electron), (SEM- BSE) was used to determine particle morphology.

4.2.3 Adequate Liberation Size Optimization

This experiment was conducted on the composite sample to assess the optimal grind size with varying grind size to evaluate the effect of grind size on gold recovery. To liberate gold particle from associated minerals and determine optimal, the ore sample is subjected to comminution stages through crushing and grinding. This comminution liberates the gold minerals from the rest of gangue minerals. The crushing was done to reach a size of –1.3mm while grinding was to reach grinding size of 106 µm, 75 µm and 53 µm to get optimum particle size for separation optimization. Based on the results from these tests in this study (table 10), a grind size of P_{80} 75 µm is selected as optimal size for the ashashire deposit using gravity methods. Increasing the grind size from P_{80} of 75 µm to106 µm decrease recovery rate from 75 % to 54% or decreasing the grind size from P_{80} of 75 to 53 µm decrease gold recovery rate to 37 % (figure 10).

CHAPTER –V CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

This study has shown that Ashashire gold deposit is amenable to the gravity separation to recover gold using a centrifugal separator appropriately as a pretreatment method ahead of cyanidation.

This ore is amenable to gravity methods and the gold that reports to gravity concentrate indicates the presence of significant gravity recoverable gold by Knelson Concentrator.

According to the fire assay, chemical, and mineralogical analyzes data, only gold and telluride is commercially valuable component in the ores.

As indicated in table 10, gravity recoverable gold was ranges up to 75 %; however, mass distribution to the gravity concentrates was above 0.6 %. This experiment was conducted on the composite sample to assess the optimal grind size by varying grind size and based on the experimental results of these tests, a grind size of P_{80} 75 µm is selected as optimal. As we can see from figure 10, increasing the grind size from P_{80} of 75 µm to106 µm decrease recovery rate from 75 % to 54 % or decreasing the grind size from P_{80} of 75 µm to 53 µm further decrease gold recovery rate to 37 %. This study shows that high gravity gold recoveries from the Ashashire deposit which contain some tellurides can be achieved using gravity separation method, Knelson concentrator. The mineralogical characteristics of the deposit such as the gold and associated element concentration, the gold grain sizes, the gold distribution and composition, mineral association and liberation characteristics, gangue minerals, etc. were determined. Pyrite is the dominant sulphide mineral detected in the ore. The non-sulphide gangue species and their abundance are variable and the main gangue minerals were quartz and ankerite-dolomite, with lower levels of muscovite and chlorite present. Only trace amounts of chalcopyrite were detected in composite samples.

5.2 RECOMMENDATION

After evaluating of all those techniques depending on their findings of this project the following recommendations are given: -

Gravity recovery is recommended to recover coarse gold grains. Gravity recoverable gold was 75% at 80% passing 75 µm. From sub-sample selected for mineralogical analysis (table 5) Elements in the head assays provide indicators to processing characteristics and detail mineralogical characterization recommendable. Since, high recovery of gold to the gravity concentrates was achieved from this gravity tests, gravity circuit flowsheet inclusion would advise for plant that treats this ore.

Pyrite may host some proportion of very fine “invisible or hidden” gold minerals and pyrite is amenable for further upgrading with a possible gold-rich concentrate for additional processing.

Further assessment is recommended to recover gold grains lost to tailings due to encapsulated in pyrite. The presence of tellurides in the Ashashire deposit will may affect further processing in the recovery and purification (leaching), this will increase cost of gold extraction, because tellurides require high pH for extraction.

The telluride to gold ratio is high and this might have impact on the further processing and requires further investigation.

APPENDICES

Appendix 1: Gravity Concentration Test Result

Grind Size p80 (µm)	Product	Mass		Gold			Cumulative
		Gram	%	Grade, g/t	Total mass, mg	Recovery rate,%	mass%
106	Gravity concentrate	15.7	0.785	296	4647.2	53.938	0.785
75	Gravity concentrate	21.1	1.063	352	7427.2	75.165	1.848
53	Gravity concentrate	11.8	0.6011	285	3363	37.275	2.4491
	Final tails	1951.4	99.3989	2.9	5659.06		101.848
Total	concentrates	48.6			15437.4		
	feed	2000					

Appendix 2: Gravity Gold Distribution Calculations

	Gravity Concentration						
Operating Conditions							
Grind size	80% passing -106 µm						
Water pressure	1.5psi						
% solids	38-25						
KC unit	KC-MD-3 lab unit						
Product	Mass		Gold			Cumulative	
	gram	%	Grade, g/t	Total (mg)	Distribution %	Mass, %	Distribution %
Gravity Concentrate	15.7	0.785	296	4647.2	53.938	0.785	53.938
Gravity Tailings	1984.3	99.215	2	3968.6	46.062	100	100

Total	2000	100		8615.8	100		
Calculated Head			4.3079				
Feed Assayed Head			8.75				

Gravity Concentration

Operating Conditions

Grind size	80% passing -75 µm
Water pressure	1.5psi
% solids	38-25
KC unit	KC-MD-3 lab unit

Product	Mass		Gold			Cumulative	
	gram	%	Grade, g/t	Total (mg)	Distribution %	Mass, %	Distribution %
Gravity Concentrate	21.1	1.063	352	7427.2	75.165	1.063	75.165
Gravity Tailings	1963.2	98.937	1.25	2454	24.835	100	100
Total	1984.3	100		9881.2	100		
Calculated Head			4.9797				
Feed Assayed Head			8.75				

Gravity Concentration

Operating Conditions

Grind size	80% passing -53µm
Water pressure	1.5psi
% solids	38-25
KC unit	KC-MD-3 lab unit

Product	Mass		Gold			Cumulative	
	gram	%	Grade, g/t	Total (mg)	Distribution %	Mass, %	Distribution %
Gravity Concentrate	11.6	0.6011	285	3363	37.275	0.6011	37.275
Gravity Tailings	1951.4	99.3989	2.9	5659.06	62.725	100	100
Total	1963.2	100		9022.06	100		
Calculated Head			4.59559				
Feed Assayed Head			8.75				

Appendix 3: Gravity Concentrate Assays

Grind size (µm)	Assay Au1	Assay Au2	Average
106	292	300	296
75	313	390	352
53	260	310	285

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