UNIVERSITI SAINS MALAYSIA

Mineral Characterization Study of Gold Deposit in Tawau, Sabah Focusing on Mineralogy and Geochemistry

by

Richell Maijin

Supervisor: Dr. Zakaria Endut

Dissertation submitted in partial fulfillment
of the requirements for the degree of Bachelor of Engineering with Honours
(Mineral Resources Engineering)

Universiti Sains Malaysia

August 2022

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SCHOOL OF MATERIALS AND MINERAL RESOURCES ENGINEERING

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled 'Mineral Characterization Study of Gold Deposit in Tawau, Sabah Focusing on Mineralogy and Geochemistry'. I also declare that it has not been previously submitted for the award of any degree and diploma or other similar title of this for any other examining body or University.

Name of Student:	Richell Maijin	Signature:	
Date:	19 August 2022		

Witness by

Supervisor:	Dr. Zakaria Endut	Signature:	
Date:			

ACKNOWLEDGEMENTS

First and foremost, I would like to offer my sincerest gratitude to my supervisor, Dr. Zakaria Endut, who has given me guidance and support from the initial to the completion of my final year project which helped me to understand more and run my project. Without the guidance and support from Dr. Zakaria, this project will be difficult to execute and complete.

Special thanks to all the technicians and staff of PPKBSM, especially En. Junaidi and En Mior for the assistance in helping me to run the machinery and guiding me to get a better end product of my samples.

I also thank Mr. Sharol, chief operating officer of Wullersdorf Resources Sdn. Bhd. for providing samples from Tawau gold mine, Sabah for the use of my project. I also would like to thank all the staff in the company that has given me a helping hand to provide guidance on some of my questions.

Last but not least, I owe my loving thank to my lectures at PPKBSM and my family and friends who consistently give me support and encouragement throughout the period of doing the project.

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SYMBOLS AND ABBREVIATION

SYMBOLS

wt%	Weight percent
g	Gram
km	Kilometer
oz	Ounce
µm	Micrometer
ppm	Part per million
^{o}C	Degree Celsius

ABBREVIATIONS

IRGS	Intrusion Related Gold Systems
XRF	X-ray Fluorescence
XRD	X-ray Diffraction
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
SEM	Scanning Electron Microscopy

KAJIAN KLASIFIKASI MINERAL DI LOMBONG EMAS TAWAU, SABAH YANG MEMFOKUSKAN MINERALOGI DAN GEOKIMIA

ABSTRAK

Lombong emas Tawau adalah termasuk dalam system emas deposit '*low sulfidation'*. Emas deposit ini termasuk dalam peninsular Tawau. Peninsular Tawau adalah tergolong dibawah Oligocence ke Miocene Tengah sedimen pembentukan Kalumpang dan terdiri pra-dominant daripada mudstone dan shale dengan *inter-bedded* sandstone, conglomerate, limestone, dan rare chert. Kajian ini bertujuan untuk menganalisis mineralogi dan geokimia jalur emas deposit dan mengenal pasti sistem pembentukan deposit emas tersebut. Mineral klasifikasi amat penting untuk membangun dan mengoperasi perlombongan aktiviti dan sistem pemprosesan mineral. Komposisi kimia mineral, saiz, morphologi, dan interaksi mineral adalah semua factor yang mempengaruhi kualiti deposit itu dan produk yang dapat dihasilkan dari deposit itu dan juga dalam bidang komersial. Cara yang digunakan untuk mengkaji kajian ini ialah X-Ray Fluorescent (XRF), Micro X-ray Fluorescence (µXRF), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), Scanning Electron Microscopy (SEM), dan X-Ray Diffractometry (XRD). Analisis Mineralogi menunjukkan kehadiran pyrite, chalcopyrite, bornite, sphalerite, galena, dan quartz sebagai gangue mineral yang utama. Ini dapat dilihat daripada kandungan kimia deposit itu. Berdasarkan daripada kajian mineralogi dan geokimia, analisis data menunjukkan emas deposit daripada lombong tersebut adalah *low sulfidation epithermal* sistem dan merupakan refraktori ore dengan kandungan base metal yang tinggi.

MINERAL CHARACTERIZATION STUDY OF GOLD DEPOSIT IN TAWAU, SABAH FOCUSING ON MINERALOGY AND GEOCHEMISTRY

ABSTRACT

Tawau gold mine is included in the low sulfidation epithermal gold deposit system. The gold deposit is within the Tawau Peninsular. The Tawau Peninsular is underlain by the Oligocene to Middle Miocene sediments of the Kalumpang formation that consist predominantly of mudstone and shale with inter-bedded sandstone, conglomerate, limestone, and rare chert. The research purpose is to analyze the mineralogy and geochemistry of gold vein deposits and determine the system of the ore deposits. The mineral characterization study is an important stage in the development and operation of mining and mineral processing systems. The minerals' chemical composition, size, morphology, and association are all factors influencing the attraction of the deposit or products produced from it, and therefore their success as a commercial venture. The method employed in this study is a combination of X-Ray Fluorescent (XRF), Micro X-ray Fluorescence (µXRF), Inductively Coupled Plasma-Mass Spectrometry (ICP-MS), Scanning Electron Microscopy (SEM) and X-Ray Diffractometry (XRD). The study of the sample revealed the presence of pyrite, chalcopyrite, bornite, sphalerite, galena, and quartz as the main gangue mineral. Gold is not observed as free gold and possibly occurs as a sub-micron scale or solid solution. Based on those characteristics of the mineralogy and geochemistry this study showed that low sulfidation epithermal gold ore deposit in this area is refractory ore with high base metals.

CHAPTER 1
INTRODUCTION

1.1 Research Background

This study aims to analyze the mineral characterization of the gold deposit at the Tawau gold mine, Sabah, which focuses mainly on mineralogy and geochemistry. The gold deposit is within the Tawau Peninsular. The Tawau Peninsular is underlain by the Oligocene to Middle Miocene sediments of the Kalumpang formation that consist predominantly of mudstone and shale with inter-bedded sandstone, conglomerate, limestone, and rare chert. Tawau gold mine has been operated from 2018 until now, 2022 which still can be considered a mining company that still growing to reach its full potential in mining and processing. The gold mine at Tawau is a low-sulfidation epithermal vein-style gold deposit with associated copper and silver mineralization hosted in altered andesite rocks. The mineralization is contained within a narrow northeast-southwest and north-south quartz-sulphide veins in a tension vein array network of fractures bounded by regional fault structures. The advanced exploration stage on drilling is still taking place at Bukit Tundong to open a new mine area. (Cervoj et al., 2016)

The Bukit Mantri project is located within the forest reserves of Mount Wullersdorf and Ulu Kalumpang on the Tawau Peninsula in eastern Sabah, Malaysia (figure 1.1). The deposits contain epithermal gold, copper, and silver mineralization hosted in a sequence of volcanic andesite flows and breccia units.

Figure 1.1 The red box is the general location plan of the Bukit Mantri project area in the Tawau area, Sabah.

Being a newly operated gold mine company, it still left a big room to understand more about the mineral characterization of the gold deposit at Tawau, Sabah. The study of mineralogy will involve identifying and characterizing minerals occurring in pure form or a solid-state mixture in rocks. Whereas the study of geochemistry is fundamentally concerned with the occurrence and distribution of the chemical elements, with a stronger emphasis on processes occurring in the upper continental crust.

1.2 Problem Statement

Comprehensive data on all minerals present and their respective proportions in the ore are important to exploit any mineral deposit. The chemical composition of the minerals, morphology, and association with other minerals are all factors influencing the attractiveness of the deposit or products produced from it, and therefore determine if the deposit can be economically mine. Other factors, such as the mineralogical distribution of harmful trace elements, can affect the processing flow to be employed and thus the profitability.

Mineral characterization study of gold deposits in Tawau, Sabah focusing on mineralogy and geochemistry will provide more knowledge of minerals contained in terms of their occurrence, chemical composition, morphology, texture, association with other minerals, and other physical attributes that can help in optimizing mineral processing. To sum, a comprehensive study of mineral characterization of the gold deposit in Tawau, Sabah is an indispensable advantage, which can guide the exploitation of the deposit for maximum profit.

1.3 Significant of Research

The significance of studying the mineralogy and geochemistry of the ore deposit in the Tawau gold mine, Sabah is to give information about the mineralogical composition of the deposit and continued the need to achieve optimization of mineral processing and motivation to achieve maximum economic benefit from resource exploration. The associated mineral such as copper are also important in adding value to the ore deposit as well as the complexity of mineral processing.

1.4 Scope of Research

The sample used in this research was obtained from the Tawau gold mine, Sabah. The early stage of this research involves polished section preparation using selected rock samples. Comminution using crushing and grinding was conducted for the preparation of ground gold ore samples. Mineralogical characterization analysis conducted included X-ray Diffraction (XRD), X-ray Fluorescence (XRF), Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-WDZ), and Inductively Coupled Plasma -Mass Spectrometry (ICP-MS) analysis.

1.5 Objective of Research

Rock samples from the mine site and exploration site at Tawau gold mine, Sabah are taken and several laboratory tests are conducted for the following studies:

1. To study the mineralogy of the samples taken from the Tawau gold mine, Sabah.
2. To analyze the geochemistry of the samples taken from the Tawau gold mine, Sabah.

1.6 Structure of Thesis

The chapter structure of this thesis is:

Chapter 1 presents the introduction and aims of this project as well as an overview of the selected study site which is the Tawau gold mine, Sabah.

Chapter 2 is an overview of what is minerals and a review of the literature relevant to Mineralogy and geochemistry study for mineral characterization.

Chapter 3 describes the systems and techniques that have been used for the analysis of mineralogy and geochemistry.

Chapter 4 presents the findings and results of the systems and techniques used for the analysis of mineralogy and geochemistry.

Chapter 5 presents the discussion and conclusions for this research as well as recommendations for further work in this field.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The earth's crust is composed of many different types of rocks, that was made of more than one or more mineral. A mineral can be defined as a naturally occurring solid substance with specific crystal structures and chemical composition. The mineral composition is referred to the elements that built up the mineral. The structures of the mineral are determined by the way that the elements bonded together. There are 12 major elements that occur in the earth's crust which is oxygen, silicon, aluminum, iron, calcium, sodium, potassium, magnesium, titanium, hydrogen, manganese, and phosphorus. Economic valuable minerals (metallic and nonmetallic) are rare and harder to find. These valuable minerals are used as important raw materials for the industry. Thus, considerable effort and skill are necessary to find the occurrences and extract them in economically. Table 2.1 shows the elemental chemical composition of the Earth's crust in order of their significant abundance.

Table 2.1 The elements in the Earth's crust

Element name	Symbol	% by weight of the Earth's crust
Oxygen	O	46.6
Silicon	Si	27.7
Aluminum	Al	8.1
Iron	Fe	5.0
Calcium	Ca	3.6
Sodium	Na	2.8
Potassium	K	2.6
Magnesium	Mg	2.1
All other elements		1.5

The physical properties of a mineral are determined by its crystalline structures and its chemical composition. Within the limits of the permissible variation in the chemical composition of a single mineral, different samples are expected to display the same set of physical properties. These characteristic physical properties are useful in the field of geology in describing and identifying a specimen.

The accurate identification of minerals is important in the mining industry. Primarily, exploration geologists will undertake the mineral identification at the beginning stages of discovering deposits and then routinely by mining geologists during operational stages of mining. Data of misclassified minerals will remain in databases until a comprehensive and accurate mineral analysis is undertaken to correct the existing data of minerals. In worst cases, misclassified minerals or unidentified minerals that remain will affect the processing stages resulting in low recovery of the desired minerals thus resulting in significant financial loss for the company. (Natalee & Bonnici, 2012)

The study of mineralogy and geochemistry of gold deposits in Tawau, Sabah will provide an essential understanding of minerals characterization of the gold deposit thus giving an idea to optimize the mineral processing and maximizing profit and also an overview of the geological formation of the gold deposit. The study of ore at different locations would allow an assessment of the most optimum and economic processing route for its constituent minerals or metals through the knowledge of mineralogical or chemical composition, association with other minerals, size, and morphology. This information will provide information and insight into the type, nature, characteristics, and amount of minerals and elements present within the ore. A deeper understanding of the ore characteristics and its behavior in the process can be obtained from optimum exploration of the mineral resource.

2.2 Mineralogy study

The mineral processing technology evolved to recover and separate ore minerals from gangue in a commercially viable method and is mainly based on the process of mineral separation and the process of mineral liberation. Even though ore is mined using the most efficient technology, the excavated ore during mining gets partly contaminated by the geological material closely associated with the ore during mining and its surrounding host rock. Both the materials are unwanted and hence will form the gangue. Thus, from the point of view of mineral processing, it is important to identify the ore and gangue minerals through mineralogical study and textural relationship (grain boundary relationship, grain size, etc.). Modal distribution of ore and gangue minerals which decides the grade of ore also can be obtained from the mineralogical study. The textural relationship of the minerals and their grain size will help in deciding the liberation and the size reduction of minerals in mineral processing. An effective liberation of valuable ore minerals and gangue minerals will influence the optimum separation efficiency.

2.3 Geochemistry Study

Geochemistry is a branch of science that deals with the distribution and contents of chemical elements in the atmosphere, waters, soils, rocks, ores, and minerals. It also studies the circulation of these chemical elements in nature based on the properties of their ions and atoms. From the early stage of exploration to mine closure, applied geochemistry plays a crucial role in the mineral resources value chain. Mineral deposits and metal are geochemical anomalies. The fundamentals of element mobility (i.e. fixation and transport) in the near-surface environment are used by geochemists to refine effective and benign extraction and waste disposal techniques. It also helps geochemists to reveal element distributions in and around deposits, detect mineral deposits at depth, and assess the total geochemical environment. Both applied and pure research ventures play fundamental roles in providing the techniques that benefit society and most importantly to manage metal resources.

The field of geochemistry is important in the study of mineral deposits because mineralization involves several processes, of which chemical processes are the ones that resulting in the formation of minerals and the precipitation of metals. Understanding the geochemical characteristics of mineral deposits is important in gaining knowledge of mineral deposit classification, ore genesis, mineral exploration, geo-environmental studies and mineral processing or extractive metallurgy. Geo-environmental models for mineral deposits can be developed from the knowledge of ore genesis that can guide the flow of mineral processing and metal extraction. Thus, understanding ore genesis is the most important of the different fields of application of geochemical characterization of mineral deposits, because it provides data that is essential to other applications.

2.4 Epithermal gold deposit

Epithermal gold (± Cu & Ag) deposits form at more shallow crustal levels than porphyry Cu-Au systems and are primarily distinguished as high and low sulphidation using varying criteria of ore mineralogy and gangue minerals, deposited by the interaction of different ore fluids with groundwaters and host rocks. Low sulphidation deposits are further divided according to mineralogy related to the environment and depth of formation, while high sulphidation systems vary with permeability control and depth, and are distinguished from several styles of barren alteration. Figure 2.1 and figure 2.2 show generalized sketches showing the relation of fluid types to alteration zoning in the two styles of epithermal deposits.

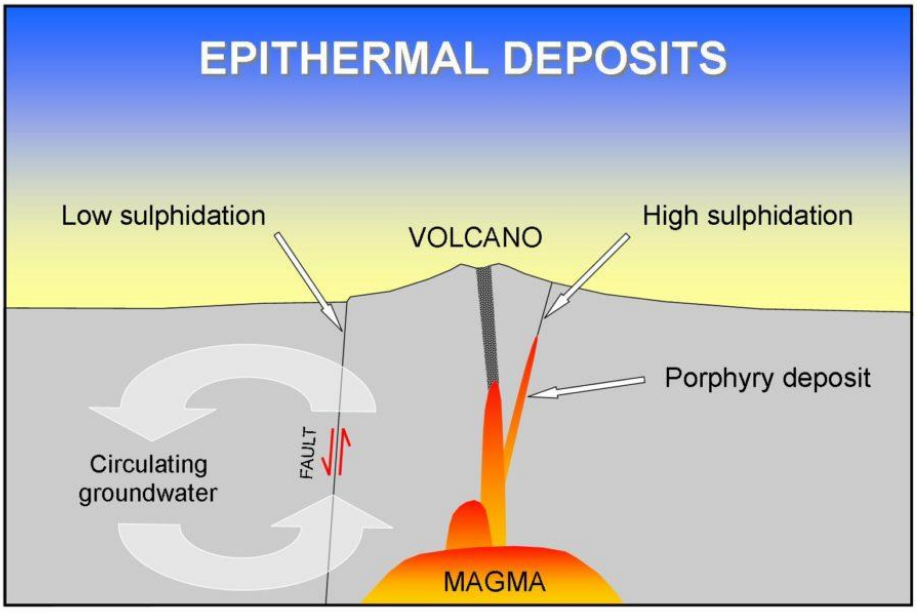

Figure 2.1 Epithermal Gold Deposit

Epithermal ore deposits form at shallow depths. This conclusion was initially based on related textures, geologic reconstructions and ore mineralogy. This has subsequently been solidified with fluid inclusion data to indicate that epithermal ores form over the range of 150^0C to ~ 300^0C, from the surface to as deep as 1 to 2 km. Epithermal mineralization has two principles styles in which gold is the dominant economic metal. Generalizations are made based on observations of many prospects and deposits in the circum-Pacific region. Differentiating between the two styles is important for effective exploration and although they show similar alteration mineralogy, the economic mineralization is associated with different parts of the system and the distribution of the alteration zones is different. When the style has been correctly recognized, the alteration zone can be used as a pointer towards the most prospective part of the system. Additionally, the geochemical associations of the two styles of mineralization is different. (White & Hedenquist, 1995)

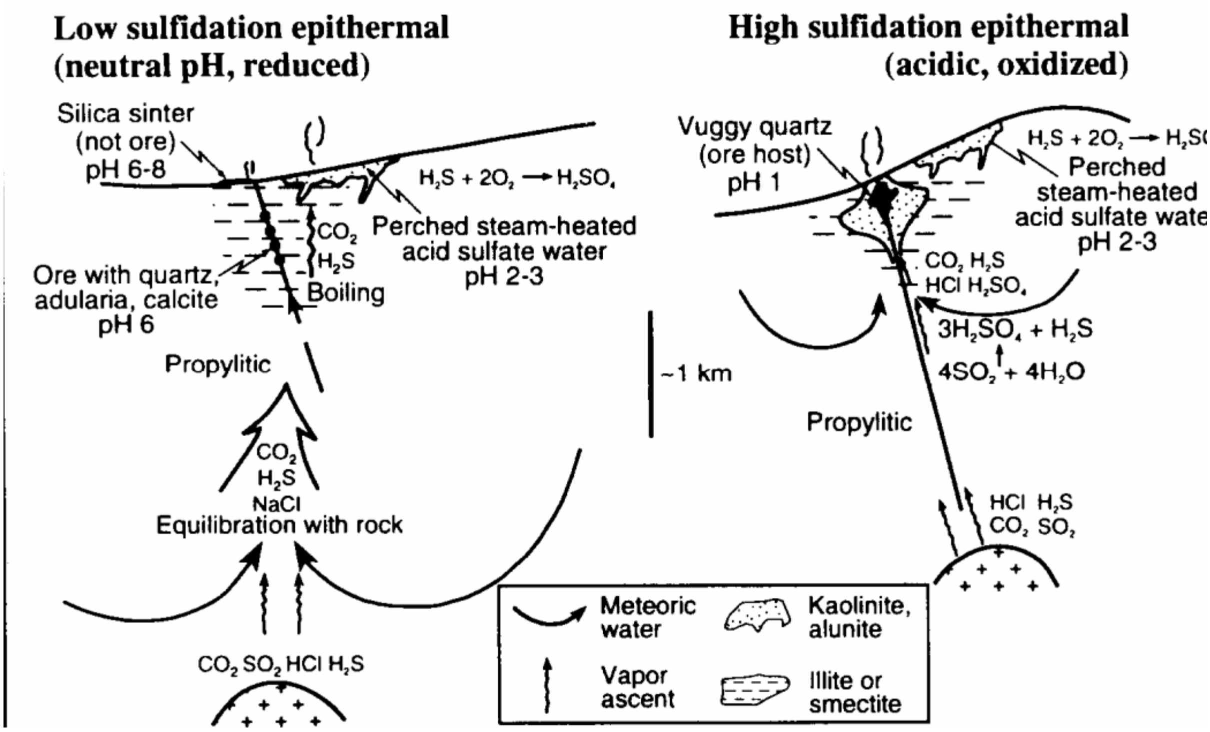

Figure 2.2 Generalized sketches showing the relation of fluid types to alteration zoning in the two styles of epithermal deposits. (a) In low-sulphidation systems, the fluids at 1-2 km depth is near-neutral pH and reduced, and in equilibrium with the host rocks at greater depths. The boiling fluid rises along permeable zones, depositing ore and gangue minerals, and may discharge from near-neutral pH hot springs. The separated vapor with CO_2 and H_2S condenses in the vadose zone to form a steam-heated water, acidic from oxidation of H_2S. (b) In high-sulfidation systems, magmatic volatiles ascend to the epithermal environment where they are absorbed by meteoric water, and HCl and SO_2 form a highly acidic solution that leaches the rock outward from the fluid conduit. Ore metals may be introduced into this leached rock by later magmatic fluids.

Fluids of contrasting chemistry formed the two deposit styles. The mineralizing fluids are usually tapped by drilling into active geothermal systems, in the low sulphidation environment. The reduces fluids and near-neutral Ph form low-sulfidation state sulphide minerals. In contrast, high-sulfidation systems and their relatively high-sulfidation state minerals are associated with oxidized and acidic fluids formed in the magmatic-hydrothermal environment adjacent to young volcanoes. These two types of epithermal mineralization systems are also known as adularia-sericite and acid-sulfate types, respectively.

The hydrothermal fluid in the low-sulfidation environment is dominated by meteoric water, but some systems may contain water and reactive gases of magmatic origin. The fluids that rise from great depth have equilibrated with their host rocks, so are reduced and have a near-neutral pH. This reaction results in H_2S, CO_2, and NaCl being the principal species in the fluid. Boiling at shallow depth generates a H_2S and CO_2 rich vapor that may condense near the surface in the vandose zone, forming steam-heated acid-sulfate waters from oxidation of H_2S (pH 2-3 waters with a temperature close to 100^oC).

By contrast, in a high-sulfidation environment, reactive components derived from an oxidized magmatic source ascend to the near-surface with little water-rock interaction at depth. The SO_2 and HCl rich vapor may become absorbed by groundwater, resulting in highly acidic (pH 0-2), a hot (200^oC – 300^oC), and oxidized fluid that reacts extensively with and leaches the host rock at shallow depth. Thus, one major difference between these two styles of fluids is the degree to which they have equilibrated with their host rocks below the level of ore deposition. Table 2.2 show the examples of epithermal gold deposits around the world.

Table 2.2 Examples of Epithermal Gold Deposits

Low sulfidation	High sulfidation
Tawau Gold Mine, Sabah, Malaysia	Goldfield, Nevada, USA
Round Mountain, Nevada, USA	Lepanto, Philippines
Hishikari, Japan	La Coipa, Chile
Emperor, Fiji	El Indio, Chile
Lebong Tandai, Indonesia	Chinkuashih, Taiwan
Pajingo, Australia	Summitville, Colorado, USA

The most basic characteristics of any ore deposit are its alteration zoning, textures, mineralogy, and form. There is considerable overlap in characteristics of high-sulfidation deposits and low-sulfidation and other distinctive features. (White & Hedenquist, 1995). Most low-sulfidation deposits consist of stockworks of small veins or cavity-filling veins with sharp boundaries. Veins may be important in high-sulfidation deposits, but the majority consist of disseminated ores that replace or impregnate leached country rock. Table 2.3 show the form of deposits for low sulfidation and high sulfidation.

Table 2.3 Form of Deposits

Low sulfidation (Adularia-sericite)	High sulfidation (Acid sulfate)
• Open-space veins dominant • Disseminated ore mostly minor • Replacement ore minor • Stockwork ore common	• Veins subordinate, locally dominant • Disseminated ore dominant • Replacement ore common • Stockwork ore minor

The mineralogy of ores shows considerable overlap for high-sulfidation and low-sulfidation, but there are several significance differences, based on a compilation of mineral data for more than 130 epithermal deposits (table 2.4 & table 2.5); these differences are mainly in the sulphide mineralogy, which reflects the different redox conditions of the hydrothermal fluid. One distinction is the common occurrence of sphalerite and arsenopyrite in low-sulfidation deposits, whereas sphalerite is scarce and arsenopyrite rare in high-sulfidation deposits. The high-sulfidation state sulfosalts eargite-luzonite, commonly contain copper minerals. Such sulphides, including the relatively high-sulfidation state minerals tennantite-tetrahedrite, are typically absent or rare in low-sulfidation deposits. The total abundance of sulfide minerals (dominantly pyrite) is not significant, as it can be high or low in either style. (White & Hedenquist, 1995)

The gangue minerals in epithermal mineralization that associated with high-sulfidation and low-sulfidation deposits also show significance overlap, but there are clear differences as well, differences that reflect the reactivity (pH) of the altering fluid. Quartz is commonly found in both styles of mineralization. Calcite and adularia, both indicating near-neutral pH conditions that are common minerals found in low-sulfidation deposits but are absent from high-sulfidation deposits. Minerals that is formed under acidic conditions, such as alunite and kaolinite (plus REE-bearing phosphate-sulfate minerals, pyrophyllite, diaspore, P-, Sr-, and Pb-), are common but minor in high-sulfidation deposits. In low-sulfidation deposits, alunite and kaolinite do not occur as gangue minerals, except as an overprint.

Table 2.4 Ore Minerals in Au-rich Ores

Deposit / Mineral	Low sulfidation	High sulfidation
Pyrite	Ubiquitous (abundant)	Ubiquitous (abundant)
Sphalerite	Common (variable)	Common (very minor)
Galena	Common (variable)	Common (very minor)
Chalcopyrite	Common (very minor)	Common (minor)
Energite-luzonite	Rare (very minor)	Ubiquitous (variable)
Tennantite-tetrahedrite	Common (very minor)	Common (variable)
Covellite	Uncommon (very minor)	Common (minor)
Stibnite	Uncommon (very minor)	Rare (very minor)
Orpiment	Rare (very minor)	Rare (very minor)
Realgar	Rare (very minor)	Rare (very minor)
Arsenopyrite	Common (minor)	Rare (very minor)
Cinnabar	Uncommon (minor)	Rare (very minor)
Electrum	Uncommon (variable)	Common (minor)
Native gold	Common (very minor)	Common (minor)
Tellurides-selenides	Common (very minor)	Uncommon (variable)

The textures that classify the two types of deposits are very different. Low sulfidation shows a variety of textures, including multiple-episode vein breccias, druse-lined cavities, chalcedony veins, banded and crustiform quartz.

High sulfidation shows multiple hydraulic fracturing and mineral deposition, followed by explosive pressure release which may be associated with hydrothermal eruptions at the surface. Lattice-bladed calcite is common, formed as a result of boiling, though it may be replaced by quartz as the system cools. Areas that have little erosion, distinctive silica sinters deposited at the paleosurface by neutral-pH hot-spring waters may still be present. The sinters are rhythmically banded, with vertical growth structures, easily distinguished from the siliceous replacement of bedded sediments, and may contain plant fragments.

Table 2.5 Mineralogy of Gangue

Deposit / Minerals	Low sulfidation	High sulfidation
Quartz	Ubiquitous (abundant)	Ubiquitous (abundant)
Chalcedony	Common (variable)	Uncommon (minor)
Calcite	Common (variable)	Absent (except as overprint)
Adularia	Common (variable)	Absent
Illite	Common (abundant)	Uncommon (minor)
Kaolinite	Rare (except as overprint)	Common (minor)
Pyrophyllite-diaspore	Absent (except as overprint)	Common (variable)
Alunite	Absent (except as overprint)	Common (minor)
Barite	Common (very minor)	Common (minor)

The common textures of high-sulfidation deposits show relatively little variation, with the major characteristic texture being massive bodies of vuggy quartz typical of Nansatsu-type deposits, though locally breccias and veins may be important hosts to ore. The vuggy quartz is caused by acid leaching at pH <2, which leaves mainly silica behind and open spaces. This residue then recrystallizes to quartz, with additional quartz and pyrite deposited from the solution. Massive to banded sulfide veins consisting of enargite and pyrite may also cut the vuggy quartz bodies.

The zonation and mineralogy hydrothermal alteration assemblages is another distinguishing characteristic of the two types of deposits. Many alteration minerals are stable over limited temperature and/or pH ranges, and thus provide important information to reconstruct the geothermal and thermal structures of the hydrothermal system. (White & Hedenquist, 1995). Table 2.6 show the hydrothermal alteration of low sulfidation and high sulfidation deposit.

Table 2.6 Hydrothermal Alteration

Deposit / Aspect	Low sulfidation	High sulfidation
Deep, mineralizing fluid mineral assemblage	• Near-neutral pH • Illite (sericite) Interstratified clays	• Acid (pH <1 to 3>) • Alunite, kaolinite, pyrophyllite, diaspore, zoned out to illite

Other types of gold deposit include Orogenic gold deposit, Intrusion-related gold deposit, and porphyry gold deposit. Orogenic gold deposits are hosted by shear zones in orogenic belts, specifically in metamorphosed fore-arc and back-arc regions and were formed during syn- to late metamorphic stages of orogeny (figure 2.3). Formation of orogenic gold deposits is related to structural evolution and structural geometry of lithospheric crust, as hydrothermal fluids migrate through pre-existing and active discontinuities (faults, shear zones, lithological boundaries) generated by tectonic processes. These discontinuities provide pathways and channel fluid flow, not only of ore-bearing fluids, but also of fluids transporting metallic elements such as silver, arsenic, mercury and antimony and gases, as well as melts. Gold-bearing fluids precipitate at an upper-crustal level between 3 and 15 km depth (possibly up to 20 km depth), forming vertically extensive quartz veins, typically below the transition of greenschist- to amphibolite metamorphic facies.

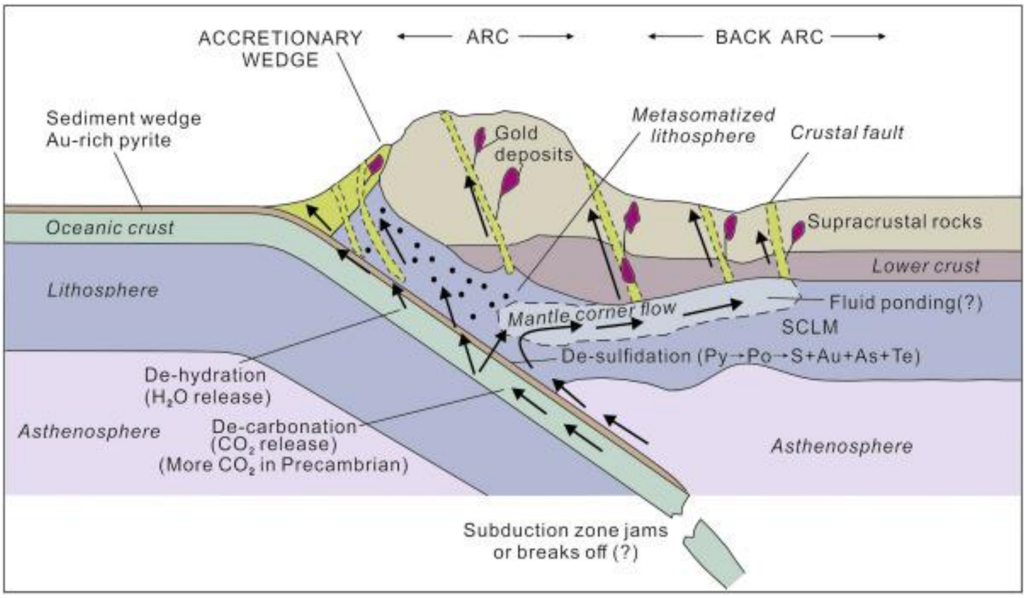

Figure 2.3 Orogenic gold deposit.

Intrusion-related gold deposits refer to an incoherent group of deposits with wide ranging characteristics produced by local-scale fluids derived from a cooling pluton (figure 2.4). Intrusion related gold systems or IRGSs are intrusive, major deposits that mostly occur in a continental setting. IRGS are a significant source of gold, however, they also can contain a significant amount of antimony, arsenic, copper, lead, tin, tungsten, tellurium, and bismuth. Intrusive deposits are not the same as orogenic deposits. When parts of the earth's mantle that are heated cool, intrusive deposits are formed whereas when parts of the earth's crust plates collide, and/or separate, orogenic deposits are formed. In general, when magma moves toward the earth's surface and thereby encounters lower temperature and pressure, this results in cooling of the magma. This phenomenon is crucial as it makes big impact in the business of gold exploration and mining.

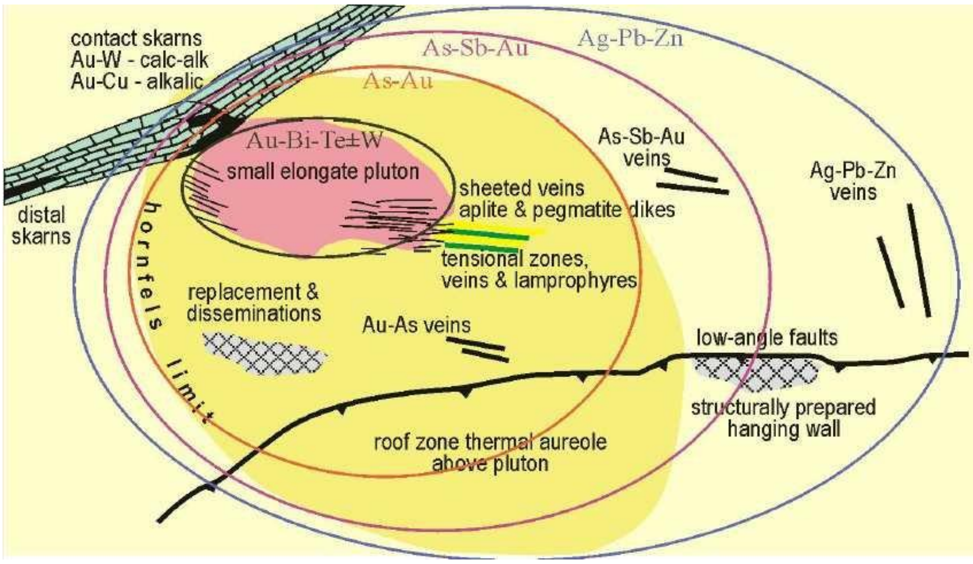

Figure 2.4 Intrusion Related Gold Deposit

Porphyry deposits are large, low to medium-grade deposits in which primary (hypogene) ore minerals are dominantly structurally controlled and which are genetically and spatially related to felsic to intermediate porphyritic intrusions (figure 2.5). The large size and structural control (e.g., breccia pipes, veins, vein sets, fractures, 'crackled zones' and stockworks) serve to distinguish porphyry deposits from a variety of deposits that may be peripherally associated, including skarns, high-temperature mantos, breccia pipes, peripheral mesothermal veins, and epithermal precious-metal deposits. Secondary minerals may be developed in supergene-enriched zones in porphyry Cu deposits by weathering of primary sulphides. Such zones normally have significance high Cu grades, thereby enhancing the potential for economic exploitation. In porphyry gold deposit the ore and gangue mineralogy are electrum and native gold in a quartz stockwork. Magnetite is commonly present. In sulphide ore; pyrite is up to 8%, with minor chalcopyrite and molybdenite. Anhydrite is common in and adjacent to ore. Specular hematite is locally abundant (Caseli). Marcasite is the most abundant sulphide mineral at Lihir. Gold is finely disseminated along subparallel veinlets and locally in stockworks and breccia.

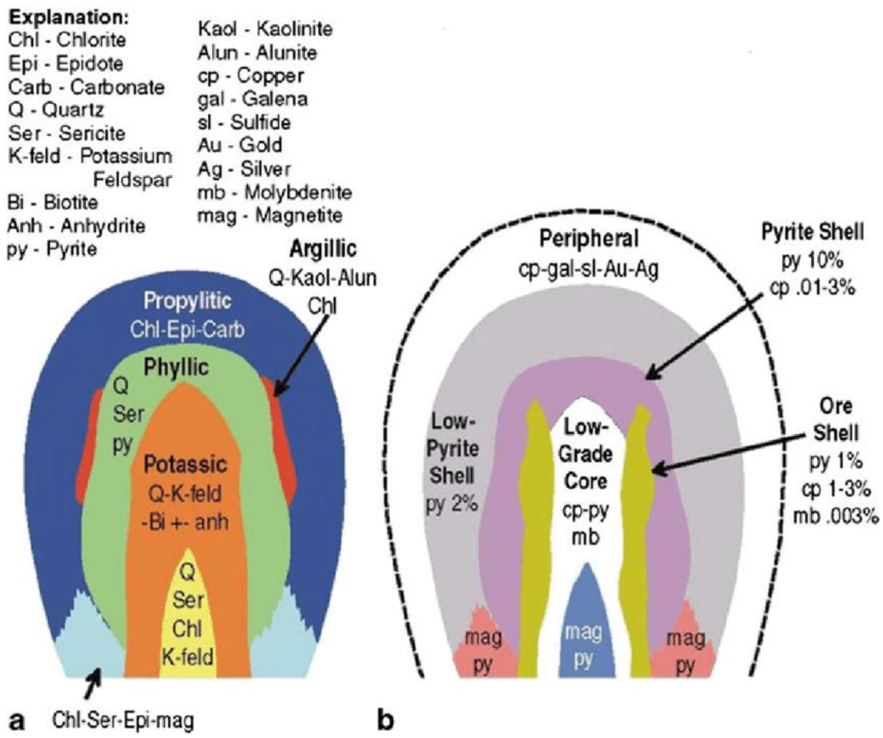

Figure 2.5 Porphyry Gold Deposit

2.5 Mineral Processing

There are two types of ore mine at the Tawau gold mine which are oxide ore and sulphide ore and both have respective stockpiles due to different methods applied for communition. Roasting is applied for sulphide ore to convert them into metal oxides, as to minimize the usage of oxygen during the leaching process. It is easier to obtain metal from its oxide, as compared to its sulphide. Roasting is the process of heating a sulphide ore to a high temperature in the presence of air. Figure 2.6 show the flowchart of mineral processing apply in the Tawau gold mine, Sabah.

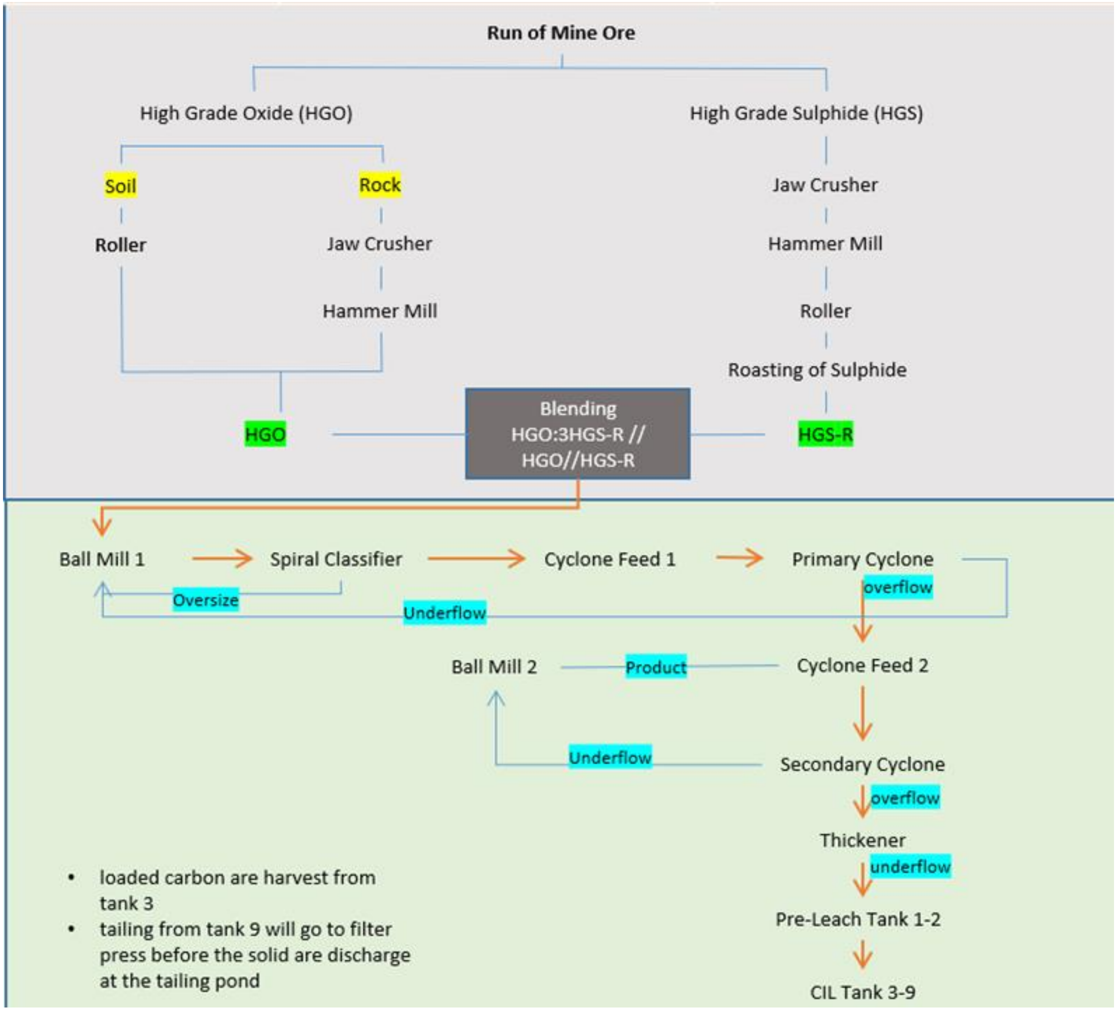

Figure 2.6 Mineral Processing Flow Chart of Tawau Gold Mine, Sabah.

Refractory ores at the Tawau gold mine do not provide economic gold recovery with the conventional cyanidation method. The high base metals contained in the ore, especially copper, consume the leach reagents in side reactions and there may be insufficient cyanide and/or oxygen in the pulp to leach gold.

During cyanidation, alkaline cyanide solutions will form a complex with gold, silver and other metals which are stable in the solution. Cyanide ions can form complex with various precious metals. The gold dissolution process occurs at the solid’s surface. The reactions involved in gold dissolution occur in three different phases which are: solid (metallic gold), liquid (water, cyanide ions), and gas (oxygen) (figure 2.7).

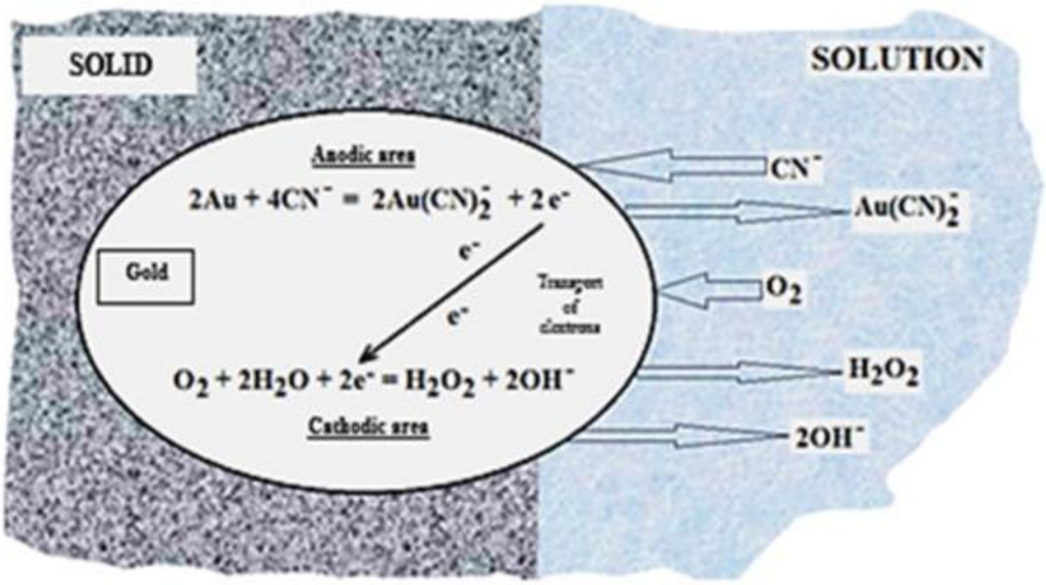

Figure 2.7 Diffusion of cyanide ions and gaseous oxygen from the solution to the metallic gold.

The chemical reaction for the dissolution of gold, the 'Elsner Equation', follows;

$4Au + 8NaCN + O_2 + H_2O \rightarrow 4Na\,[Au\,(CN)_2] + 4NaOH$

In this redox process, oxygen removes via a two-step reaction, one electron from each gold atom to form the complex $Au\,(CN)_2^-$

CHAPTER 3
METHODOLOGY

3.1 Introduction

Mineral characterization study of deposits of industrial mineral is important to ensure optimization of mineral processing, thus maximizing profit and further understanding the geological formation of the deposit. Different approaches laboratory test is conducted to analyze the samples taken from Tawau gold mine for the study of mineralogy and geochemistry in terms of their size, habit, chemical composition, morphology, texture, association with other mineral, and other physical attributes. The research method employed is; XRF, XRD, micro XRF, SEM, and ICP-MS analysis.

3.2 Polished Section

A piece of chip rock is taken from each sample focusing on sulphide mineral observe on the rock sample for polish section that will be used for SEM-EDX and micro XRF analysis. As different minerals have different optical properties, most rock forming minerals can be easily identified.

At the beginning of sample preparation each sample are manually smash to get representative chip rock focusing on observe sulfide mineral, the chip rock is then polish using sand paper to get a nice flat surface. The resin and hardener ratio use are 1:1 (1 gram: 1 gram) and mix slowly until homogenous, the mixture is used as medium for mounting the samples (figure 3.1). Each sample is mounted by placing it in a mold and filling it with the prepare medium of resin and hardener, the medium will embed the sample and holds it firmly during the grinding and polishing operations that ensue (figure 3.2). The samples are polish until a nice flat surface is achieved as in figure 3.3.

Figure 3.1 Resin and hardener use as a medium

Figure 3.2 Grinding Sample

Figure 3.3 Polish rock sample

3.3 Pulverize sample (<75µm) preparation for XRD, XRF, and ICP analysis

All samples are pulverized (Table 3.1) as a dry representative portion of the rock samples before sending the test sample for analysis. The rock sample is first crushed with small jaw crusher (figure 3.4) follow by cone crusher and lastly the ring mill (figure 3.5). One scoop of spoon of each sample from cone crusher product are added to ring mill as to maximize fine grind of <75µm sample.

Table 3.1 Pulverize sample

Number	Sample ID
1	VN16
2	VN04
3	BT09
4	BT08
5	BT10
6	VN01
7	VN13
8	VN11
9	VN12
10	VN14
11	VN07
12	VN15

After all samples is pulverized the samples are then sieved using 75µm sieve size to get a particles size of -75µm for XRF and XRD analysis.

Figure 3.4 Small jaw crusher

Figure 6.5 Ring Mill

3.4 X-ray Fluorescence (XRF) Analysis

XRF analysis can be performed qualitatively as well as quantitatively to analyze major, minor, and trace elements in various kinds of samples. The working principle is based on the excitation of the sample atoms by high energy X-rays, followed by the emission of