

ORE GENESIS OF HYDROTHERMAL GOLD DEPOSITS IN WABO DISTRICT, CENTRAL MYANMAR

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**ORE GENESIS OF HYDROTHERMAL GOLD DEPOSITS IN
WABO DISTRICT, CENTRAL MYANMAR**

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for the degree of

Doctor of Engineering

By

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Ore genesis of hydrothermal gold deposits in the Wabo district, Central Myanmar

ABSTRACT

The Wabo district in Central Myanmar is located along the Mogok Metamorphic Belt and the district is known for fertile gold production. The deposits are composed of two ore types: graphite associated mineralized gold-bearing quartz veins at the Myo Lwin, Zaw Min and Kyarpazat Prospects and mineralized gold-bearing quartz vein at the Kyaw Soe Thu Prospect. The host rocks are composed of garnet-biotite gneiss, marble, diopside calc-silicate rock and biotite granite. This study focuses on the characteristics of gold mineralization, and sources of hydrothermal ore fluids. In addition, fluid inclusion microthermometry were conducted to understand the temperature condition of the mineralizing fluids. This dissertation consists of six chapters and the order in which contents are presented in specific chapters are as follows:

Chapter I describes the location of the investigated area, scope of the study, problem statement, aims and objectives, methodology and procedure of analysis. The expected outcome is also presented in this chapter.

Chapter II describes the geological setting and regional geology of the Wabo district. It reviews the geology and stratigraphic succession around the Mogok Metamorphic Belt and major gold mineralizations in Myanmar. Geology, and petrography of the host rocks in the Wabo district are also demonstrated in this section.

Chapter III presents the graphite associated quartz vein hosted gold mineralization in the research area at three prospects (Myo Lwin, Zaw Min and Kyarpazat) in the Wabo district. Graphite with auriferous quartz veins is the first occurrence in Myanmar. Quartz is mostly milky, drusy and white within the veins. The quartz texture of the mineralized veins varies in each prospect from fine to medium grained with sub-grains. Some are randomly oriented with a hydrothermal graphite matrix and display an elongated form. Minor sericite occurs in the mineralized veins. Ore mineral assemblage is composed of pyrite, chalcopyrite, galena, sphalerite, hessite and electrum in the Zaw Min and Kyarpazat prospects, with pyrite, sphalerite, galena, chalcopyrite and electrum in the Myo Lwin Prospect. Pyrite is dominant in the ore zones. Mineralization is described in three stages for three prospects. Electrum is often observed as free grains. Chemical composition of electrum reveals an Ag at.% content of 25 to 35 at Myo Lwin, 35 to 45 at.% at Zaw Min, and 40 to 45 at.% for Kyarpazat prospects. Notably, the Ag content on electrum grains from the Myo Lwin Prospect is lower than that of the other two prospects.

Chapter IV describes the gold mineralization styles of the Kyaw Soe Thu Prospect in the Wabo district. Gold bearing veins are hosted by garnet-biotite gneiss at the Kyaw Soe Thu Prospect. In this prospect, the mineralization occurs in chalcedonic quartz veins and ankerite-quartz-sericite veins. The veins are dominantly composed of various types of quartz (smoky, milky, green, and sporadic blue quartz). Mineralized chalcedonic quartz veins range from 1 cm to 3 cm in width. The vein is composed of fine quartz grains and some fragments of

earlier quartz. Gold occurs as visible to the naked eye on the quartz vein wall and hand specimens. The quartz textures within the veins include feathery and plumose texture. The ankerite-quartz-sericite vein is a late mineralized vein at the Kyaw Soe Thu Prospect. The boundary is distinctly sharp between the chalcedonic quartz veins and the ankerite-quartz-sericite veins. The late vein crosscuts the early chalcedonic quartz veins. The ankerite observed at the Kyaw Soe Thu Prospect in hand specimen is light pink, milky, and pale brown in color. The ankerite-quartz-sericite veins range in width from a centimeter to two centimeters. The late hydrothermal mineralized vein or ankerite-quartz-sericite veins are dominantly composed of ankerite, quartz and small quantities of sericite with some calcite. Prismatic quartz crystals within ankerite-quartz-sericite veins are aligned parallel to ankerite crystals. Calcite occurs as cross-cutting to radiating feathery quartz crystals. Ore minerals include pyrite, sphalerite, chalcopryite and electrum at the Kyaw Soe Thu Prospect. Electrum is common in chalcedonic quartz veins and ankerite-quartz-sericite veins. Based on the ore mineral assemblages, and quartz textures, the Kyaw Soe Thu Prospect maybe categorized as a low-sulfidation epithermal deposit.

Chapter V describes fluid inclusion microthermometry of the mineralized quartz vein from the Zaw Min Prospect in the Wabo district. Two types of fluid inclusions were classified from mineralized quartz veins: Type I-three phase; liquid (H_2O) + liquid (CO_2) + vapor (CO_2), and type II-two phase; liquid (H_2O) + vapor (H_2O) inclusions. These two types of fluid inclusions are hosted in gold-bearing quartz vein within garnet-biotite gneiss. The melting temperature of CO_2 (T_{m-CO_2}) for type I varies from -57.9 to -57.0 °C, which probably indicates the presence of others gaseous species (CH_4 , N_2 , etc.) in the inclusion. The homogenization temperature of carbonic phases is between 28.8 to 32.3 °C. The total homogenization temperatures of type I inclusions is 320 and 361°C, with corresponding salinities from 0.2 wt.% to 2.6 wt.% NaCl equivalent. The homogenization temperature of type II inclusions ranges from 220 to 360 °C, with corresponding salinities from 0.88 to 2.9 wt.% NaCl equivalent. Consequently, the inclusions associated with gold mineralization exhibit a low salinity with moderate temperature, suggestive of a metamorphic hydrothermal ore fluid source.

Chapter VI discusses on ore genesis of gold mineralization in Wabo district and summarizes the results of the research and provides a general conclusion, with further recommendations for future research works. The gold and graphite are closely associated within the mineralized ore zone at Zaw Min, Myo Lwin, and Kyarpazat prospects. The graphite bearing auriferous ore zone are formed in the faults and structures that are major controlling factors for fluid flow. A presence of carbon dioxide inclusions and aqueous constituents within the mineralized quartz veins suggests that the fluid responsible for gold mineralization is comprised of a H_2O -NaCl- $CO_2 \pm CH_4$ system. The moderate temperature and very low salinity are likely the metamorphic hydrothermal ore forming fluid source. Therefore, the close relationship of graphite and gold indicates a likely reducing condition at the Zaw Min, Myo Lwin, and Kyarpazat Prospects.

Gold mineralization is closely associated with carbonate veining at Kyaw Soe Thu Prospect. The carbonate deposition, silicification and gold deposition is likely related to carbonate

oversaturation at higher temperature than gold and silica. The colloform-crustiform structure in the quartz-carbonate veins has interpreted as an epithermal mineralization environment in contrast to the other prospects. Therefore, the gold mineralization at the Kyaw Soe Thu Prospect is likely formed after the post regional metamorphism in a shallow crustal environment. Thus, the research results suggest multiple stages of gold mineralization occurred in the Wabo district.

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CHAPTER I

INTRODUCTION

1.1 Location, size and accessibility

The Wabo area is situated 70 km North of Mandalay and South southwest of Mogok. It is bounded by the 96° 8' 47" E - 22° 37' 30" N and 96° 12' 34" E - 22° 37' 33" N, and 96° 8' 53" E and 22° 33' 43" N - 96° 12' 38" E - 22° 33' 48". It covers approximately 5 km² of rugged terrain and moderate relief. The location map of the investigated area is shown in (Fig 1-1).

1.2 Physiography

The investigated area lies within the mountainous region forming the western border of the Eastern Highland and is covered by highly rugged terrain and dense forest. It forms a hilly tract. Generally, the area is located on the dextral strike-slip Sagaing Fault to the West and Shan scarp fault to the East.

The northern part of the area is, in general, dense forest and mountainous. Most of the ridges are a north-south alignment. In the area, the highest mountain is U Pein (Fig 1-2). Mount U Pein hosts gold mineralizations with various quartz veins. It is also the first gold occurrence in the area in terms of both placer and quartz vein type. The topography gradually slopes down from the central to southern part of the area.

The Eastern part of the area is generally low relief and covered with granitoid rocks. The streams flow from northwest to southeast, passing through to granite rock units. According to the climatic conditions, chemical weathering is prevalent in this area. Differential weathering and physical weathering of the granitic rock in the Eastern part of the area is noted.

1.2.1 Nature of exposure

The whole area is covered by thick vegetation, with dense forest and rugged roads. However, stream sections, road sections, cart tracts, foot paths, and occasional mountain ridges yield good exposures of the rocks for regional field work. The mining work site is situated at the top of the mountain. Overview of the streams displays the coarse patterns, streams starting from the watershed of the highest mountain around Wabo village. Mount U Pein is a well-known landmark of the area

which was the first gold occurrence in the area from 1990-1995. Wabo is covered with dense vegetation rather than sparse parts of the entire of the area. In the South part of the

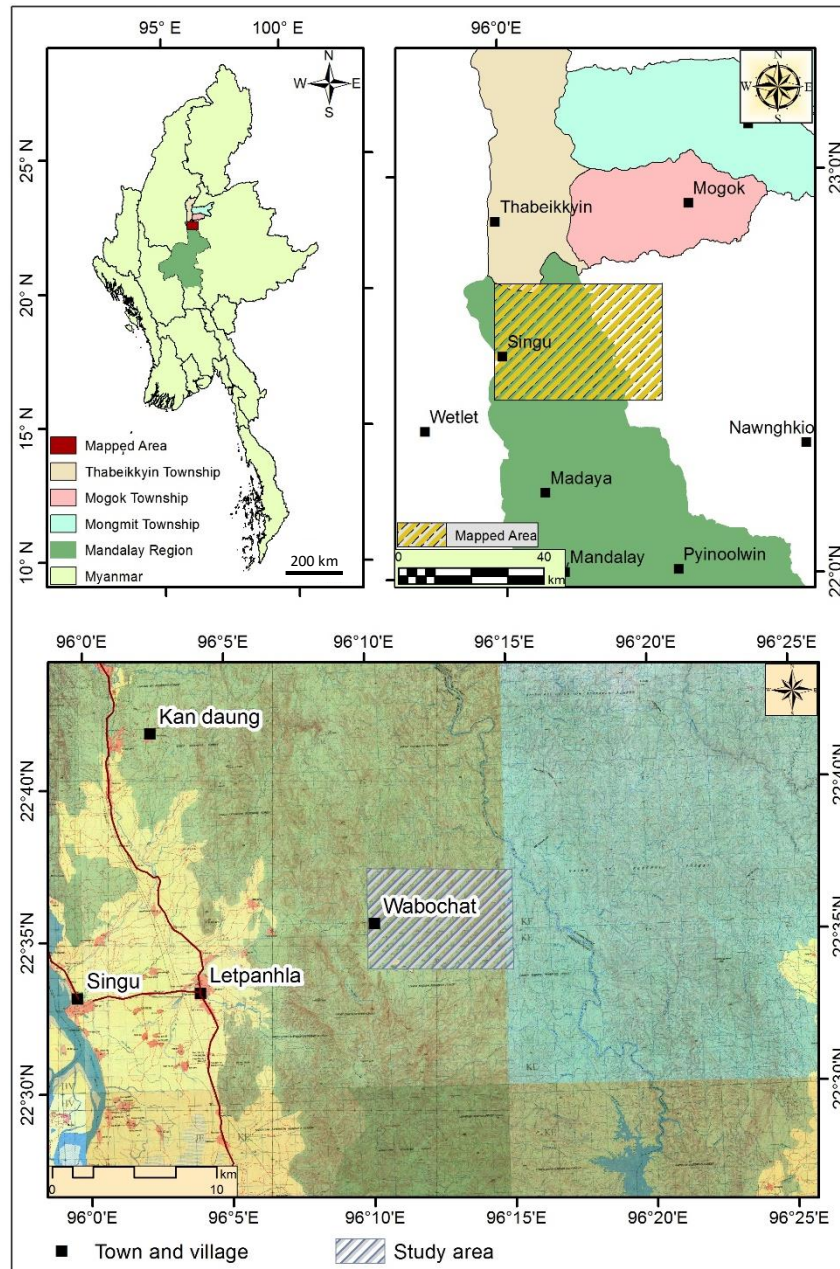
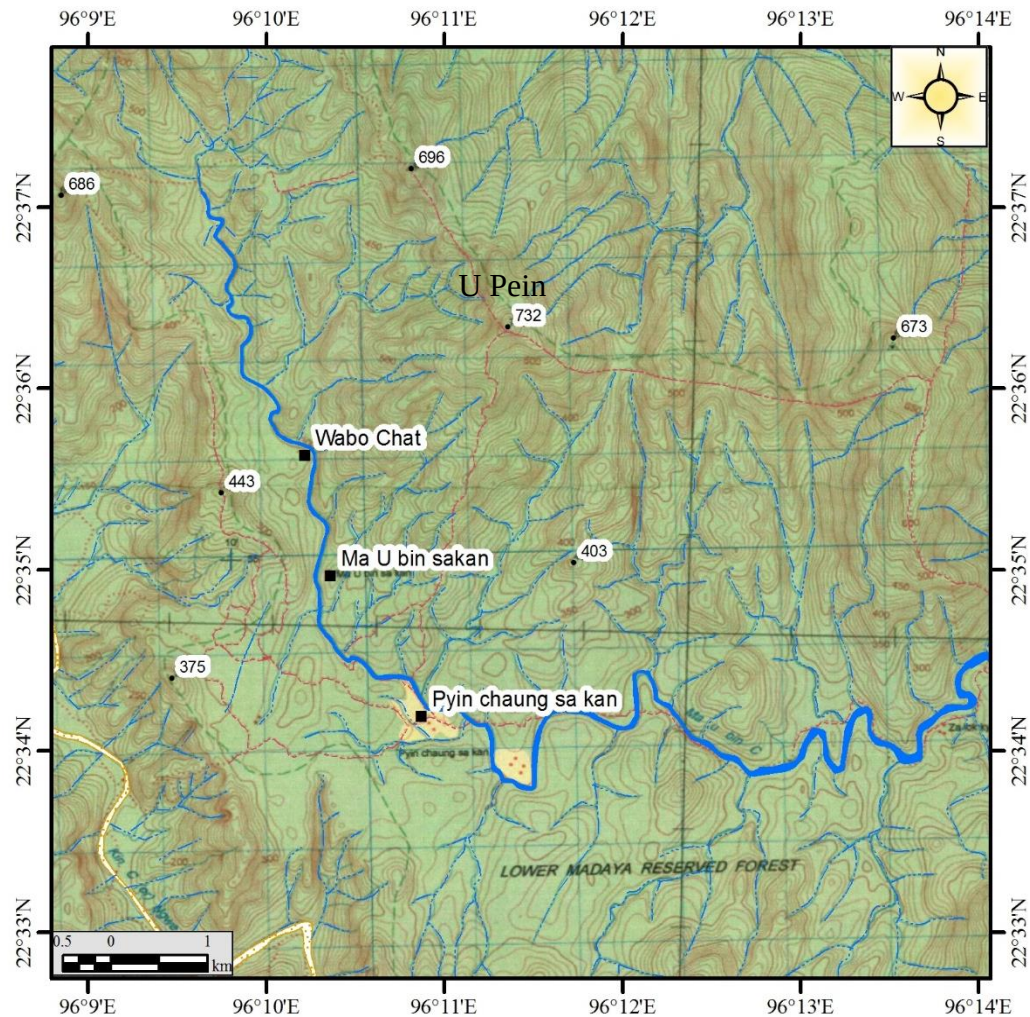


Figure 1-1 Location map of the research area (Source: UTM)

1.3 Problem statement

There has been no scientific research regarding general geology, as well as mineralization. For regional geology, there is still lack of research on the basis of petrography of meta-sediments and plutonic rocks, understanding the ore- forming fluids, ore-forming fluids emplacement in terms of depth and timing of mineralization.

There are several local small-scale working prospects within the Wabo gold district. Among them, the main theme of this research is to emphasize genetic variables, mineralogical, petrological and geochemical study for host-rocks, to examine the nature of gold mineralization and to explore the type of ore deposits.



Index

- Elevation in meter
- Stream
- Annual Stream
- Village
- FoothPath

Figure 1-2 Topographic map of the study area (source: part of UTM Map)

1.4 Thesis aim

- To create a simplified geological map of the Wabo area.
- Distinguish the petrology of host rocks.

- Elucidate gold mineralization and evolution of hydrothermal fluids and to provide the genesis of mineralization and estimate trapping pressure of ore-formation.
- To establish a genetic model for gold mineralization styles and comparing the results with other gold deposits.

1.5 Field work and sampling

During 2017-2018, field studies were carried out for three consecutive field seasons, for a month consecutively. All of the data involved in the research was collected from the area while going field work. Field research was conducted for geological mapping and sampling in the study area. During the field trip, basic geological data was collected to draw a general geological map, to investigate a genetic relationship of the host rocks and characteristics of mineralization. Sixty host rock samples were collected from both underground and surface of the area for petrological and mineralogical analysis. Twenty-four plutonic rock samples were collected for geochemical analysis.

1.6 Research methodology

Detailed geochemical analysis has been conducted to evaluate alteration, mineralization and origin of ore-forming fluids. The methodology includes literature reviews, field working, laboratory analysis, and interpretation based on the laboratory results. The laboratory analysis of petrological, mineralogical and geochemical analysis has been carried out and submitted to fulfill the purpose of the research. More than fifty thin sections were analyzed for the petrographic studies. All the samples were examined under standard reflected and refracted light by using petrographic microscope. Petrographic studies involve the study of minerals for recognition, textural features and their associations to interpret mineral composition and rock types. Mineralized quartz veins are collected from each part and place of the area. Generally, the Wabo is mainly composed of metamorphic and intrusive igneous rocks.

1.6.1 Mineralogical analysis

Mineralogical analyses were analyzed by microscopic for petrographic analysis, (XRD) X-ray Diffraction and (XRF) X-ray fluorescence analysis for petrochemistry.

1.6.2 Petrography

Petrographic analyses was undertaken on thin sections and polished sections using transmitted and reflected light microscopy and uncertain minerals are also detected by X-ray diffraction analysis. Polished-sections and thin-sections were made and investigated under the petrographic microscope (transmitted and reflected light). This analysis was necessary in order to identify both altered and ore minerals as well as their textural relationships. Moreover, diagnostic hydrothermal minerals are recognized which typically occur in the alteration zone.

1.6.3 X-ray diffraction (XRD)

Samples were crushed manually in an agate mortar for some altered host rock and altered samples. To examine a mineral identification, have to make a thins section for petrography analysis. Powder was hardened on an aluminum plate which had a square hole. The samples were then scanned using an XRD RIGAKURINT 2000 machine. The intensity of the diffracted x-ray is measured as a function of the diffraction angle (2θ). These diffraction patterns are used to identify the mineral species. An approximate sample size of 1 cm³ (powder, 10 μ m) is required. XRD was conducted by applying X-ray diffractometer of under an operating condition of 40kV and 40 mA.

1.6.4 X-ray fluorescence (XRF)

Twenty-four samples for geochemical analyses were prepared by crushing with a hammer and then by powdering within 200-mesh using an agate ball mill. Concentration of major and trace elements were determined by X-Ray Fluorescence (XRF) using a RIGAKU RIX-3100 under operating conditions of 30 kV and 70 mA. Loss of ignition (LOI) at 1000 °C was measured for each sample, and elemental concentrations were calculated from the results of both analyses. The standard JA-S was repeatedly analyzed to monitor precision, yielding an error of less than $\pm 5\%$.

1.6.5 SEM-EDS analysis

Elemental analysis for the determination of chemical composition of ore minerals was performed with a scanning electron microscope with an energy-dispersive X-ray analyzer (SEM-EDS) SU3500 by Hitachi High-Technologies Corporation, at the Center of Advanced Instrumental Analysis, Kyushu University.

1.6.6 Fluid inclusion microthermometry

This analysis allowed the estimation of the temperature of homogenization and salinity and trapping pressure of ore-formation. A detailed study of fluid analysis was conducted from quartz samples from gold-bearing quartz veins at Zaw Min Prospect, Wabo District. Samples were collected from quartz veins associated ore minerals. The quartz chips were double-polished by hand in order to avoid overheating and decrepitating of low temperature fluid inclusions during sample preparation. Thickness of quartz chips varies from 50 to 200 μm .

Fluid inclusions of the samples were analyzed on double polished sections in order to measure the final ice melting temperature for salinity and the homogenization temperature using a Linkam-THMS600 heating-freezing stage equipped on a Nikon ECLIPSE LV100N POL as a polarizing microscope. During analysis, freezing rates of $\leq 1^\circ\text{C}/\text{min}$ whereas heating rates were $0.1^\circ\text{C}/\text{min}$. The homogenization temperature was measured in fluid inclusions with minimum size of 5 μm while for freezing temperature; the size of fluid inclusion was measured in 10 μm . The fluid inclusion classification is based on Roedder (1984). Total salinities of $\text{H}_2\text{O} - \text{NaCl}$ inclusions were calculated by the equation of $1.7 T - 0.0442 T^2 + 0.000557 T^3$, where T is depression temperature in $^\circ\text{C}$ (Bodnar, 1993). The salinities of CO_2 -bearing fluid inclusions were calculated using the melting temperature of clathrate and had standard errors of $\pm 0.5^\circ\text{C}$ and $\pm 0.2^\circ\text{C}$, (in the presence of liquid CO_2 and vapor CO_2) is a function of salinity according to the following mathematical expression (Diamond, 2001; Collins, 1979): $\text{wt\% NaCl} = 15.52022 - 1.02342 * t - 0.05286 * t^2$, where t is the clathrate melting temperature expressed in $^\circ\text{C}$.

CHAPTER II

2.1 Regional geologic setting

Myanmar is positioned at the junction of the Alpine-Himalayan Orogenic Belt and the Indonesian Island Arc System. In northern Myanmar, the orogenic belt is bent around the Eastern Himalayan Syntaxis into a north-south orientation and passes southwards through the resource-rich Indo-Myanmar Ranges into the Andaman and Nicobar Islands, Sumatra and the Sunda-Banda arcs of Indonesia (Barber et al., 2017). The Himalayas and the mountain ranges of northern Myanmar mark the collision between the Indian subcontinent and the southern margin of the Eurasian continent. It is a tectonically complex region and composed of microplates such as Sibumasu, West Myanmar, and India. The tectonic history of the region built up by repeated subduction, accretion and collision has resulted in the metallogenic provinces of Myanmar. Myanmar lies at a crucial geologic junction where the main Tethys related suture zones, swing south around the Eastern Himalayan Syntaxis into Southeast Asia, with the consequence that the region has experienced an increasingly oblique collisional geometry over its Mesozoic – Cenozoic orogenic history (Gardiner et al., 2016). Myanmar has experienced Late Mesozoic - Cenozoic orogenic event that operated over a reasonably short period of time with little overprinting complexity, yet an orogenic system that was potentially responsible for the genesis of a significant range of mineral deposits. The preservation potential of Myanmar's near surface, epizonal mineral deposits is relatively high due to its recent geological evolution (Gardiner et al., 2016).

Myanmar is divided into two geological provinces, Eastern province and Western province by the 1200 km long, N-S trending dextral Sagaing Fault (Fig 2-1 and 2.4). The Eastern province belongs to the Shan-Thai block (Bunopas, 1982), also known as the Sibumasu Block, together with western Malaysia and eastern Sumatra (Metcalf, 1988), whereas the western part, which belongs to the west Burma terrane comprises the Indo-Myanmar Ranges and the Wuntho-Popa magmatic Arc (Fig 2-1 and 2-2) system overlying Cretaceous-Pliocene strata (Mitchell et al., 2012; Searle et al., 2007).

The Western Myanmar province originated from Gondwana, and later drifted, accreted and collided with Eurasia in either the latest Triassic (Metcalf, 1988) or earliest Triassic (Metcalf, 2000). In the western part of Southeast Asia, the MMB occurs as a narrow (30-40 km wide) and elongated (1500 km long) belt of metamorphic rocks

(Searle et al., 2007), including kyanite and sillimanite schists and granites lying along the Western margin of the Shan Plateau in central Myanmar and extends northwards from the Mogok region to the Himalayan syntaxis, continuing southwards through the Kyaukse region (Fig 2-2). It lies parallel to the western margin of the Sibumasu Block, where it is juxtaposed with the West Myanmar Block. The formation of the MMB is considered to be related to the Indian-Asian continental collision events (Barley et al., 2003).

The MMB (Searle and Haq, 1964) is a north-south trending alignment of metamorphic rocks and granites that extends from the Andaman Sea through Mandalay northwards in an arcuate trend towards the Eastern Himalayan Syntaxis. It comprises a sequence of high-grade meta-sedimentary and meta-intrusive rocks, representing a regionally metamorphosed amphibolite-grade belt (Mitchell et al., 2007), suggesting that the Mogok Belt is a metamorphic core complex, tectonically unroofed during crustal extension on low-angle detachment faults (Mitchell, 1993).

The entire length of the topographic configuration between the central basin and the Shan Plateau borders the MMB along which numerous metamorphic and foliated intrusive rocks crop out (Bertrand and Rangin, 2003). The Mogok area comprises a sequence of undifferentiated high-grade metamorphic rocks. The dominant unit is banded gneiss with biotite, garnet, sillimanite and oligoclase. Marble consists of calcite, white dolomitic marbles are limited. Some marbles contain ruby, whereas others have spinel, forsterite or diopside, phlogopite-graphite marbles. Rutile, graphite, calcite, paragonite, zircon, titanite, apatite, scapolite, spinel and zircon also form inclusions in Mogok rubies (Kyaw Thu and Khin Zaw, 2017). Biotite granites are widely exposed at Kabaing and Thabeikkyin, near Mogok and some syenite pegmatites contain sapphires (Khin Zaw, 1990; Khin Zaw et al., 2014).

Most U-Pb, Th-Pb, and U-Th-Pb ages display recrystallization from the Middle Eocene to Early Oligocene (43.8 ± 1.0 to 27 ± 0.8 Ma), which might be derived from detrital and/or inherited grains. On the other hand, Ar-Ar ages, which probably represent the cooling stage after peak metamorphism, indicated Late Oligocene-Early Miocene ages of 24.0 ± 0.8 to 16.0 ± 1.0 Ma. So, metamorphic ages gained by CHIME (Maw Maw Win et al., 2016) reported the high temperature-type Mogok metamorphism in central Myanmar, which was caused by Indian-Asia continental collision during the Paleogene, probably reaching peak temperature conditions in the Late Eocene, then subsequently

shifted to the exhumation and /or cooling stage. Barley et al. (2003) stated SHRIMP U-Pb zircon ages of 30.9 ± 0.7 Ma and 22.4 ± 0.4 Ma from hornblende syenite (Mandalay Hill) and biotite syenogranite (Yesin Dam area).

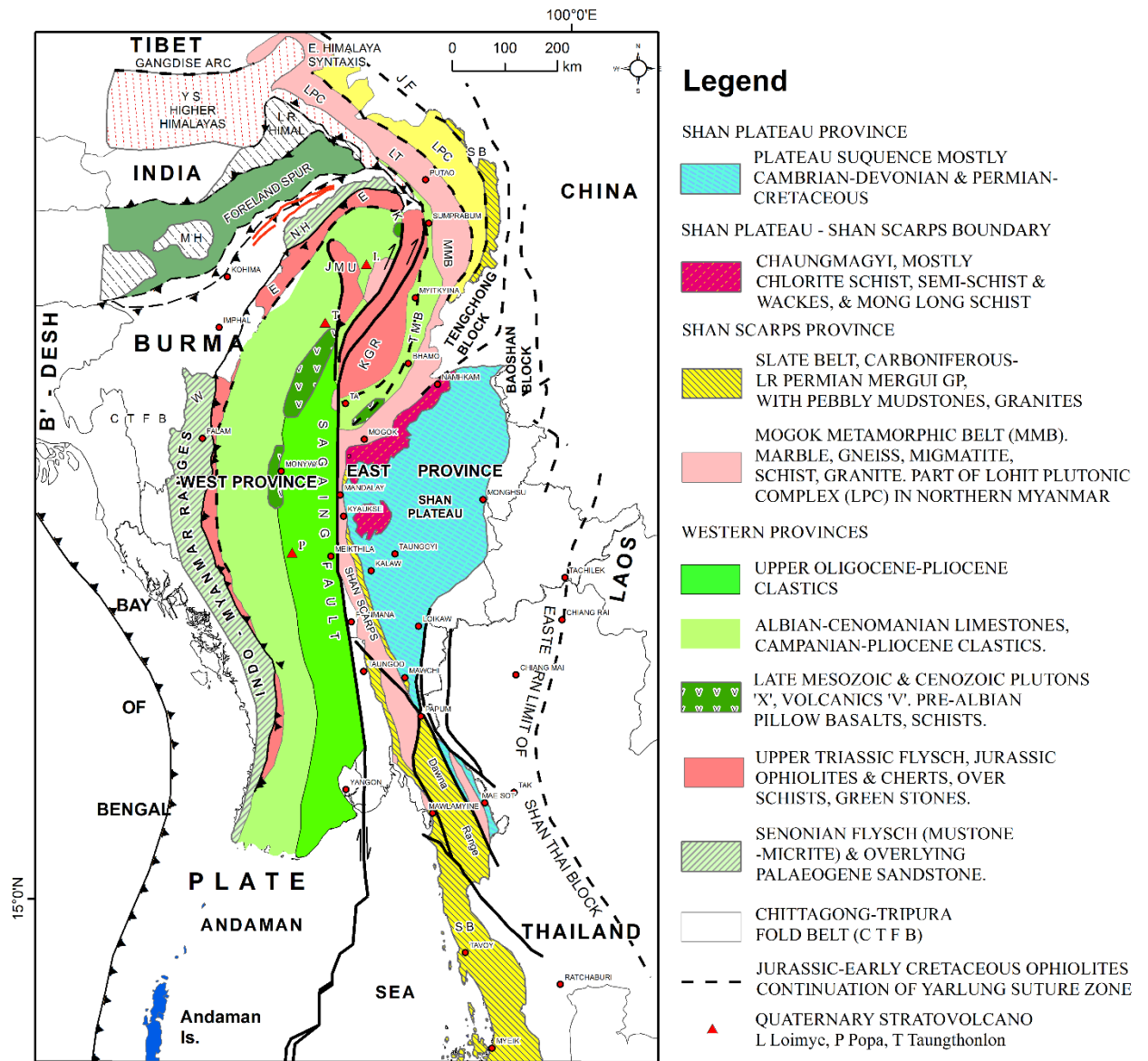


Figure 2-1 Regional geologic setting of Shan Scarps zone in Myanmar and adjacent areas showing locations of Fig 2 and 3. Indo-Myanmar Ranges: E Eastern, W Western belts, JF jiali Fault, JMU jade mines uplift, K Kaw-Ta-Bum volcanics, KGR Katha-Gangaw Range, LPC Lohit Plutonic Complex, LT Lohit Thrust, M Monywa, MH Mikir Hills, NH Naga Hill, SB slate belt, SBa Shwebo basin, TMB Tagaung-Myitkyina belt, W Wuntho segment of Wuntho-Popa magmatic arc, Ta Tagaung, YS Tarlung suture . Modified after Mitchell et al. (2012). Black rectangular denotes a research area.

2.2 Mogok metamorphic belt

Gold is by far the most important mineral product after gemstones in the Mogok Metamorphic Belt. Almost all the mines are in the Shante gold district between Mandalay and Mogok, the most productive and perhaps least well-known gold district in Myanmar (Mitchell, 2017). The Mogok Metamorphic Belt of (Searle and Haq, 1964), the Medial Metamorphic Belt of (Mitchell et al., 1999, 2004, 2007) follows the entire length of the country along the western edge of the Shan scarp and bends northeastwards along the eastern margin of the Kachin-China Border (Ye Myint Swe et al., 2017). Metamorphic rocks along the MMB are highly foliated and strongly deformed. The MMB has also suffered strong extensional deformation, as indicated by the numerous brittle-ductile structures. Gold mineralization in the MMB occurs as skarn-type and orogenic gold-quartz veins in marbles, calc-silicates and gneisses. The skarn-gold mineralization appears to be related to the intrusion of diorites, and developed at the contact between the granitic intrusions and marble (Ye Myint Swe et al., 2017).

Along the entire length of the topographic transition between the Central Basin and the Shan Plateau border lies a belt along which numerous metamorphic and foliated intrusive rocks crop out (Bertrand and Rangin, 2003). This belt has first been described by (Chhibber, 1934), who named the MMB. The metamorphic rocks found along the belt are micaschist, gneisses, marble, granulite and rare quartzites, with grades ranging from greenschist to granulite facies (Bender, 1983; Bertrand and Rangin, 2003).

In the western part of Southeast Asia, the Mogok Metamorphic Belt (MMB) occurs as a narrow (~40 km wide) and elongated (~1500 km long) belt of metamorphic rocks (Searle et al., 2007), lying parallel to the western margin of the Sibumasu Block, where it is juxtaposed with the West Burma Block (Searle and Haq, 1964). The formation of the MMB is considered to be related to the Indian-Asian continental collision event (Barley et al., 2003). Nevertheless, it has been also proposed that the MMB is linked to the Inthanon Zone (Searle et al., 2007), which was formed by the continental collision between the Sibumasu and Inthanon blocks during the Late Triassic (Sone and Metcalfe, 2008). In Southeast Asia, it is considered that several granulites were generated by continental collision (e.g., Trans Vietnam Orogenic belt; Osanai et al., 2008; Yonemura et al., 2013). Therefore, it is also possible that the granulites from the MMB were formed by such a collisional event.

The Mogok Metamorphic Belt (MMB) extends for over 1500 km along the western margin of the Shan-Thai Block, from the Andaman Sea north to the eastern Himalayan syntaxis. The Belt (MMB) is located at central Myanmar and contains an assemblage of medium- to high-grade metamorphic rocks believed to have been formed during a

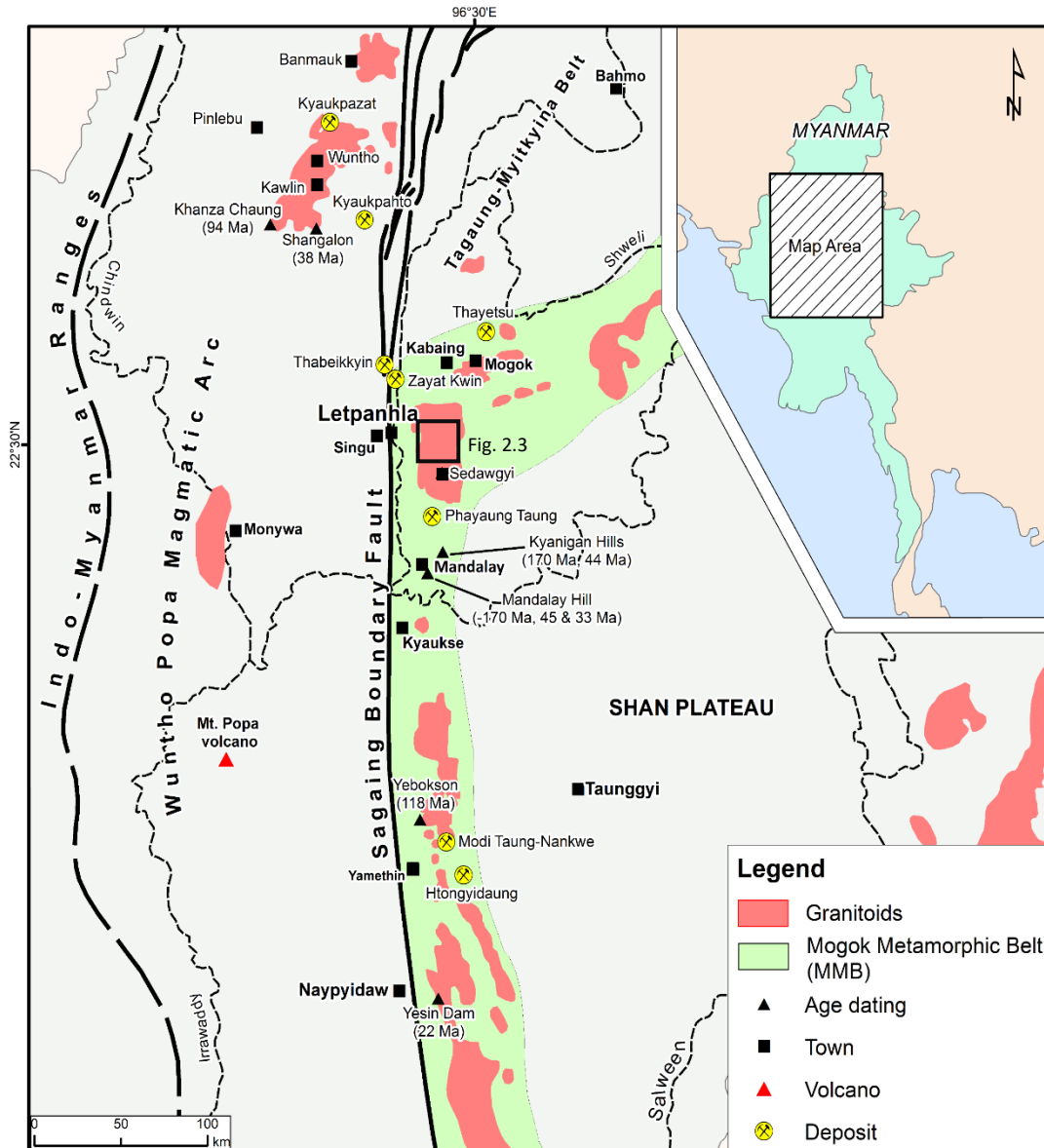


Figure 2-2 Map of Upper Myanmar showing outline of the Mogok Metamorphic Belt (MMB, major granitoid outcrops (Modified from Cobbing et al., 1993; Barley et al., 2003; Mitchell et al., 2012) black rectangular denotes Fig 2-3.

regional Early Eocene-Oligocene metamorphic event. The MMB lies within the Sagaing Fault and the Shan scarp as a belt of metamorphic rocks (Chhibber, 1934). The age of the metamorphism along this belt has been the source of numerous discussions: some authors have considered it to be Precambrian to Paleozoic (e.g. Bender, 1983),

while others have suggested that it could be as young as Cenozoic (e.g. Searl and Haq, 1964; Mitchell, 1993). Bertrand et al., (2001) described the ages of the Mogok Metamorphic Belt ranging from Oligocene to Middle Miocene and a slight diachroism with ages decreasing from the south to the north within the belt. Bertrand et al. (2001) clearly mentioned that the MMB that is not only to confirm the Oligo-Miocene to Middle-Miocene ages for the metamorphism, but also to better constrain the diachronous cooling along the Mogok Metamorphic Belt. Bertrand et al. (2001) also described on the high-grade metamorphic and foliated intrusive rocks from the Tnatkon (southern Shan scarp), Mandalay (northern Shan scarp) and Mogok (northwesternmost border of the Shan Plateau) areas. The upper amphibolite to granulite facies metamorphic rocks are widely distributed in the middle segment of the Mogok Metamorphic Belt by (Maw Maw Win et al., 2016; Ye Kyaw Thu et al., 2018; Yonemura et al., 2013).

The Mogok Series, mainly meta-sediments, is placed in the Tertiary Period, whereas formerly it has always been considered as Pre-Cambrian. The sediments, prior to their metamorphism, are considered to have ranged in age from the Pre-Cambrian to Permo-Carboniferous and may even have included sediments of Jurassic and Cretaceous age (Searle and Haq, 1964).

The MMB is considered to have been emplaced by several granulites and tectonically exhumed in the late Miocene following uplift related to the India-Asia (Mitchell, 1993) which were generated by continental collision (Yonemura et al., 2013). Maw Maw Win et al. (2016) obtained monazite CHIME ages from three segments; 49.9 ± 7.9 Ma, 38.1 ± 1.7 Ma and 28.8 ± 1.6 Ma for segment I, 49.3 ± 2.6 Ma, 37.8 ± 1.0 and 28.0 ± 0.8 Ma for segment II, and 30.7 ± 0.9 Ma and 23.7 ± 1.3 Ma for segment III, respectively. The suggested age of Maw Maw Win et al. (2016) are similar to Ar-Ar biotite of Mogok Metamorphic rocks by Bertrand et al. (2001).

2.3 Mineralization along MMB

The Mogok-Mandalay-Margui Belt (MMMB) hosts numerous gold mineralization and S-type granites which display significant Sn-W mineralization. The MMB can be divided in to two belts (the Mogok Metamorphic Belt and Slate Belt). In the southern Mergui Archipelago of Myanmar, and extending north to Mandalay, the Slate Belt (Mitchell et al., 2004; Gardiner et al., 2015) is a predominantly Late Paleozoic

succession of pebbly mudstones and wackes, collectively defined as the Mergui Group. To the east and north of Mandalay outcrop high-temperature marbles of the Mogok Metamorphic Belt, which are also intruded by these granites, in places causing skarn-type gold and base metal mineralization. The local contact between the Mogok Metamorphic Belt and the Slate Belt remains unclear (Mitchell et al., 2012; Gardiner et al., 2015).

The Slate Belt (Mitchell et al., 2004), running broadly north-south from Mandalay towards Myeik and Phuket, is predominantly a late Palaeozoic succession of pebbly mudstones and wackes with occasional limestones – collectively defined as the Mergui Group (Mitchell, 1999). The Mogok Metamorphic Belt from the sequences of the Shan Plateau, with which it is bounded to the east by the Panlaung Fault (Gardiner et al., 2015). Bertrand and Rangin (2003) interpreted Panlaung Fault as being active after transtensional exhumation of the Shan Scarp as a brittle, dextral transpressional overprint on Oligocene-Early Miocene ductile structures. Mitchell et al. (2012) suggested that the Chaung Magyi Formation, which comprises Cambrian units of the Shan Plateau sequences, is thrust over Slate Belt Mesozoic sedimentary rocks along the Panlaung Fault during the Mesozoic.

Gold mineralization has been recognized from numerous localities throughout the Slate Belt (Mitchell et al., 1999; Gardiner et al., 2015), and usually occurs within quartz-pyrite stringers and veinlets. Au is not spatially related to the granites, being considered on the basis of cross-cutting evidence to be before their emplacement (Mitchell et al., 2004). In general, the gold mineralization found widely within the Slate Belt is inferred to be of Orogenic type, likely the result of ascent of metamorphic fluids within schists and phyllites, as evidenced in the Modi Taung-Nankwe gold district of central Myanmar (Mitchell et al., 2004). The veins form well-defined tabular ore bodies in the mudstone, oblique to bedding, becoming more dispersed where hosted by adjacent sandstone, forming stockworks or sheeted veinlets (Mitchell et al., 2004).

The Mogok Metamorphic Belt around Sagaing Fault zone forms the most gold occurrence zone (Fig 2-3) than other places. The gold mineralization associated with granite intrusions is found in several localities. Metamorphic rocks along the MMB are highly foliated. The MMB has also suffered strong extensional deformation, as indicated by the numerous brittle-ductile structures within it (Ye Myint Swe et al., 2017). The Shante gold belt is located in the Mabein district, south of Mogok. Quartz-

veins occur in the marbles and host both base metal (Zn-Pb) sulfides and gold mineralization. The Kwinthonze Au-Ag mine, near Thabeikkyin, is a marble-hosted Au-base metal sulfide deposit interpreted to be of skarn type and related to local peraluminous magmatism (Khin Zaw et al., 2014; Gardiner et al., 2015).

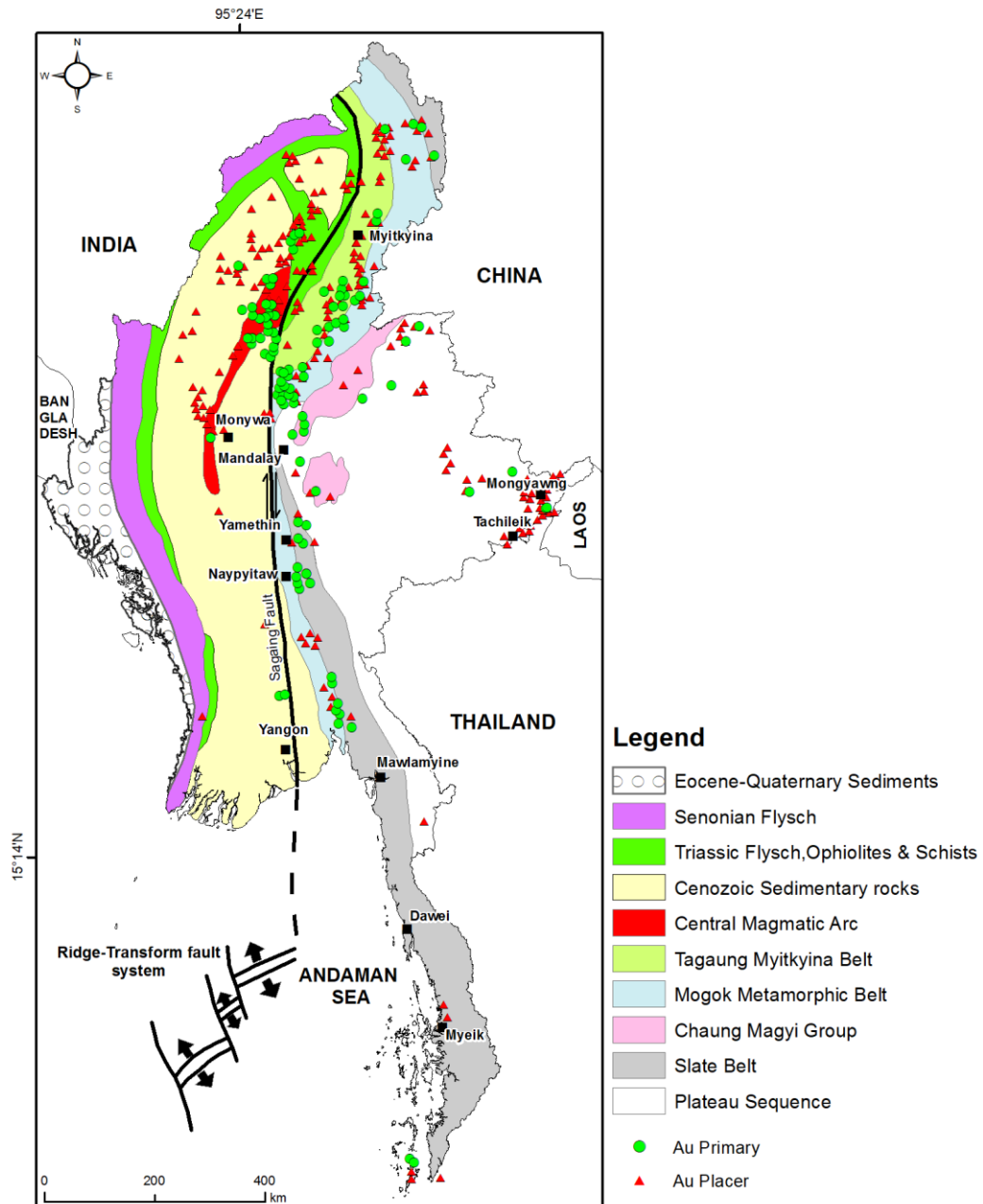


Figure 2-3 Primary and placer gold occurrences in Myanmar (Modified from Ye Myint Swe et al., 2017)

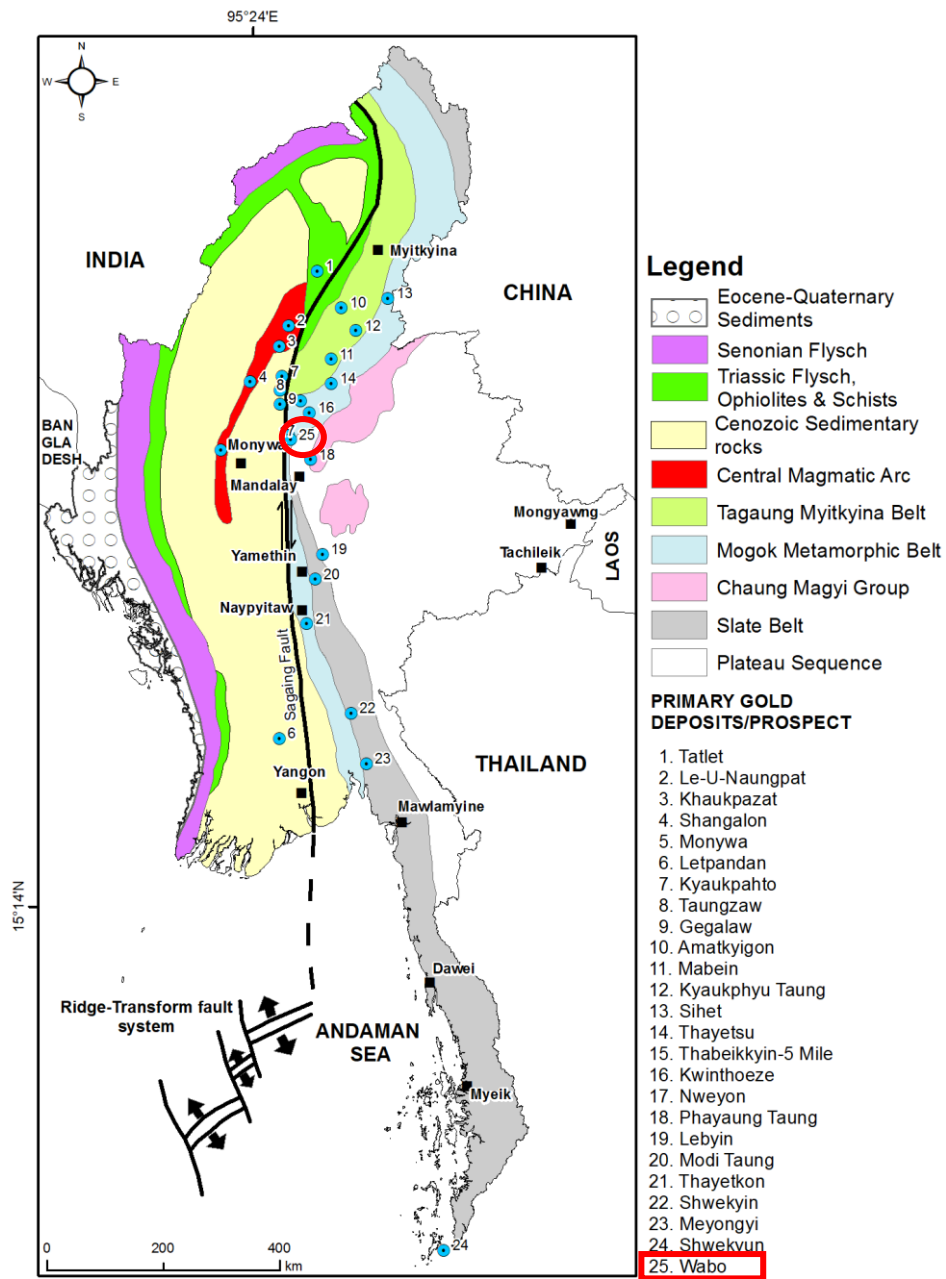


Figure 2-4 Major tectonic belts and locations of major gold deposits and prospects in Myanmar (Modified from Ye Myint Swe et al., 2017), and red circle denotes a research area.

2.4 Structural setting

The Sagaing Fault is the longest and most active strike-slip fault in Myanmar. It accommodates more than half for the right-lateral motion between Sibumasu and India within the diffuse plate boundary along the eastern margin of India (Soe Thura Tun et al., 2017), which occupies much of Myanmar. The fault was first documented and suggested a major strike-slip fault by Win Swe (1970), who also introduced the name Sagaing Fault. The Sagaing Fault is located the western margin of Sibumasu and the eastern margin of the Neogene Burma Plate, a forearc sliver which occupies much of western Myanmar (Soe Thura Tun et al., 2017). The Western margin of the Sibumasu block is marked at the Shan Scarp by the Mogok Metamorphic Belt (Searl and Haq, 1964; Mitchell et al., 2007; Soe Thura Tun et al., 2017) and the Slate Belt. Lying between the Sagaing Fault and the Shan Scarp Fault Zone, the Mogok Metamorphic Belt comprises a narrow strip of gneisses and schists which in the north curves around the Bhamo, and may be continuous with northern Thailand metamorphic core complexes such as Doi Suthep and Doi Inthanon, and the Lhasa Terrane in South Tibet (Mitchell et al., 2007, 2012; Soe Thura Tun et al., 2017).

East of the Shan Scarp Fault Zone is the north-south-trending dextral Kyaukkyan Fault, which passes through the Inle Lake pull-apart system and curves into the NW-SE-trending Mae Ping Fault in the SE (Soe Min et al., 2017; Soe Thura Tun et al., 2017). Near the northern termination of the Kyaukkyan Fault east of Mogok, a series of apparently left-lateral faults, including the Kuaukme and Momeik faults, trend ENE-WSW and terminate adjacent to the Sagaing Fault near Thabeikkyin (Fig 2-5).

Regionally, the Shan Scarp is characterized by the major active fault zone of the Sagaing Fault, Momeik Fault, and Kyaukkyan Fault. The Shan Scarp extends southwards from Mandalay along the Shan State and Mandalay region boundary, adjacent to the Shan Plateau to the east. It is steep-slopes and rugged relief of the belt occurred. The Shan scarp is also known as the boundary of the Shan Plateau to the east and Sagaing fault to the west. The Shan scarp includes three narrow north-south aligned zones (from west to east): the Mogok Metamorphic belt; the Slate Belt; and Paunglaung Mawchi Belt (Barber et al., 2017), the Shan Scarp is interpreted as a fold and thrust belt (Barley et al., 2003; Bertrand and Rangin, 2003). The structural setting (Fig 2-5) along Sagaing Fault zone also plays a role for metal and non-metals deposits in Myanmar.

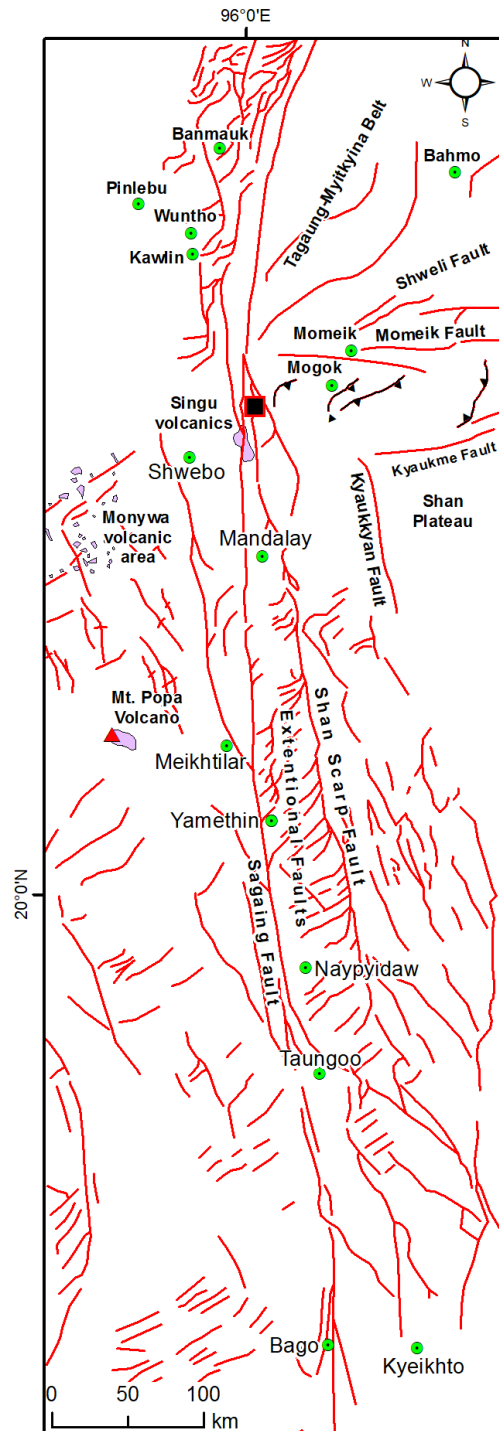


Figure 2-5 Landsat TM and SPOT image interpretation of the Sagaing Fault and Shan Scarp Fault zone (Source: Vigny et al., 2003; Soe Thura Tun et al., 2017) and black square indicates research area.

2.5 Deposit geology

The Wabo area is mainly composed of metamorphic and igneous rocks. Metamorphic rocks are minor marble along stream section, and diopside calc-silicate rock and gneiss which is widely distributed at the northern part and around the center of the area (Fig. 2-6). The age of the protolith of the metasedimentary was originally interpreted as Precambrian (Bender, 1983). However, Permian fossils in marble near Kyaukse (Maung Thein and Soe Win, 1969) suggested to be Carboniferous to Triassic age. The igneous rock units are generally exposed at the eastern part and around the central part of the research area. Most of the igneous rocks in the research area are biotite granite intruding the metamorphic rocks. Radiometric dating of magmatic and metamorphic rocks along the Mogok Belt includes an Ar–Ar biotite age of 15.8 Ma for the Kabaing granitoid and Ar–Ar biotite ages of three nearby metamorphic rocks ranging from 16.5 to 19.5 Ma (Bertrand et al., 2001). Khin Zaw et al. (2014) dated leucocratic granite intrusions at Mogok using the LA-ICP-MS U-Pb zircon method and obtained ages of 45 and 25 Ma. These ages suggest that the MMB has experienced multiple tectonic magmatic and metamorphic, uplift and exhumation processes, most likely accompanied by a metamorphic core complex formation from as early as the Jurassic to recent times. The metamorphic rocks in the belt are mica schists, gneisses, marbles, granulites and rare quartzites, with metamorphic grades ranging from greenschist to granulite facies (Bender, 1983; Bertrand and Rangin, 2003).

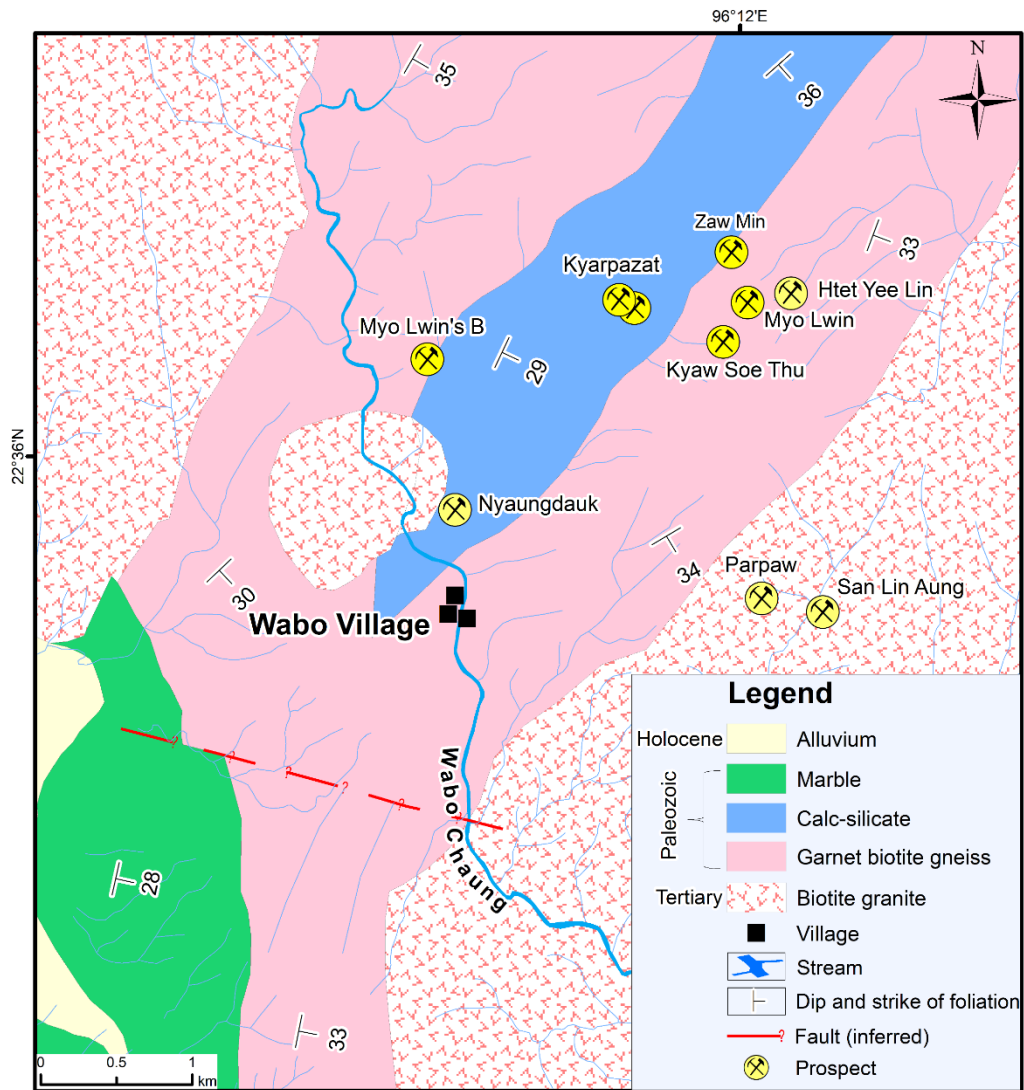


Figure 2-6 Simplified geological map of the Wabo gold deposits with local artisanal working sites in the area.

2.6 Geology of the rock units

2.6.1 Garnet-biotite gneiss

The main outcrops of the gneiss unit in the area are associated with numerous boudinages (Fig 2-7a) and augens (Fig 2-7b) with varying sizes of garnet minerals. Compact biotite flakes show shiny luster and are well observed on the surface of the foliation planes. The segregation layers become prominent in this rock unit. Most of biotite crystals are larger than 0.5 mm in length. Curved biotite flakes observed around garnet grains seem to be caused by the development of garnet porphyroblasts (Fig 2-7a and b). Banded gneiss is also exposed along the road and vertical and horizontal adits in the mining work-sites. Garnet grains in the rock unit are euhedral to anhedral grains

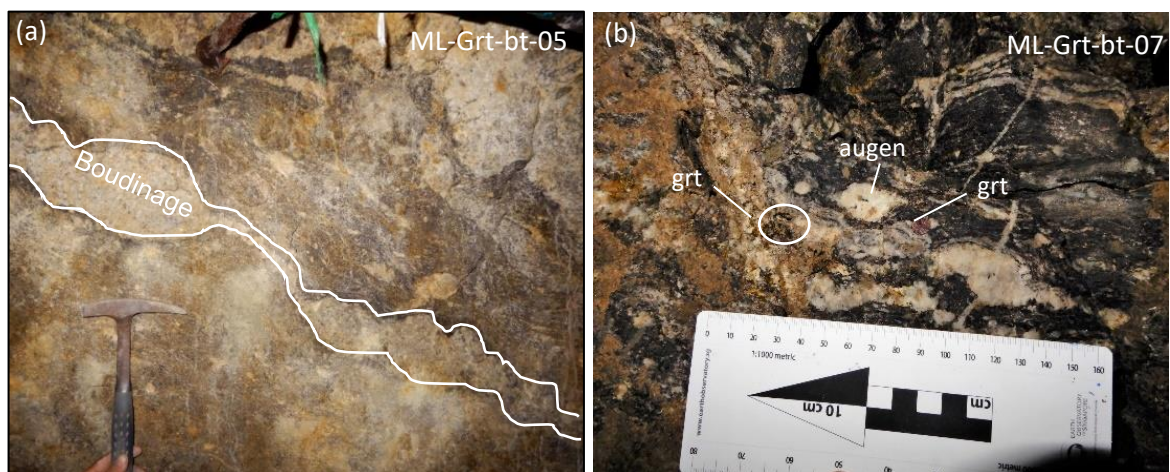


Figure 2-7 Outcrops of garnet biotite gneiss unit within Myo Lwin horizontal adit. (a) Boudinage structure in garnet biotite gneiss body within inclined underground mine. Note that structure showing as fabric of sense of shear. (b) In-situ of garnet biotite gneiss with len-shaped or augen structure of quartz and feldspar. Abbreviation: grt=garnet.

ranging in size from mm to cm. The rock unit is a medium- to coarse-grained rock with a poorly developed schistosity, and consists of feldspar and quartz, biotite, garnet as distinctive components and cordierite. This unit commonly has a banded structure reflecting compositional and/or structural variations. Gneiss is also generally presumed to be the product of medium- to high-grade metamorphism. Augen textures are prominent in this unit both in foliation plane and within the band. Augens are large, lenticular eye-shaped mineral grains or mineral aggregates visible in some foliated

metamorphic rocks (especially garnet-biotite gneiss and biotite gneiss) in the study area. Rotation of augen during growth, due to shearing, leads to sigmoidal inclusion trails and augen tails at different levels in the external foliation. Drag foldings are often observed in garnet-cordierite gneiss rock units. On the foliation margin, they form as aggregated grains with various sizes.

2.6.2 Marble and calc-silicate rocks

The marble unit is well exposed in the eastern part of the area and along the creek section. It is locally exposed as a small outcrop and mainly occurs along the stream section (Fig 2-8a). According to field observation, it is a massive rock unit with phlogopite and graphite. This unit is medium- to coarse-grained, hard and compact and generally bears a criss-crossed structure. The weathered surface is dark grey in color. It also exhibits granulose texture. The diopside calc-silicate rock is well characterized as a bedded unit and consists of diopside which can be easily observed with naked eyes (Fig 2-8b). Most of the diopside are rounded grains in crystal habit. Minor drag folds



Figure 2-8 Outcrops of (a) calc-silicate rock unit at Kyarpazat Prospect and (b) phlogopite graphite marble along stream section.

and associated fractures of competent bands are common on the weathered surfaces. This unit can be easily recognized by its characteristic features such as plastic deformation, drag folds, and tight folds. It is fine- to medium-grained, hard and compact, and shows remarkable foliation bandings. The foliation bands range from 0.7 cm to 1 m in thickness. On the fresh surface, they show pale green and greenish grey and dark grey on the weathered surfaces and are highly deformed.

2.6.3 Biotite granite

This unit is equivalent to the Kabaing Granite which is widely exposed at the well-known Mogok Gemstone Tract to the north. The unit was named by Brown (1896) after extensive exposure of the rock around the Kabaing village and the Kabaing Hill on Thabeikkyin-Mogok road situated about 16 kilometers west of Kyatpyin. They show varying degrees of foliation and in places display sheeted jointing and spheroidal weathering. The biotite granite unit is the largest intrusive body in the study area. It mainly occupies the eastern part of the area. Generally, they intrude all metamorphic rocks in the area. Biotite granite is younger than the surrounding metamorphic rocks. It shows a light grey color on fresh surfaces and yellowish or brownish grey on weathered surface (Fig 2-9). It has a uniform texture and is dominantly composed of feldspar, quartz, and biotite. Exfoliation also occurs in the central part of the area and near the Parpaw Prospect. The exfoliated medium-grained texture is the significant feature of



Figure 2-9 Outcrop of biotite granite unit along the stream with light to pinkish color.

Kabaing Granite. Some pegmatite and aplite dikes are intruded into biotite granite, both along foliation plane and diagonally. The main exposures are found in the stream section and within the mining work sites. Leucogranite is also exposed in the area. On the weathered surface, they show buff to pinkish color. It may have intruded as a late-stage magmatic phase. Pegmatites occur as dykes and veins and are observed along stream at the middle part of the area near the Wabo Village.

2.7 Petrography of the host rocks

2.7.1 Garnet-biotite gneiss

Under the microscope, it is mainly composed of biotite, quartz and garnet. They sometimes produce a prefer orientation and parallelism of small biotite flakes. Some quartz grains marked very tightly in garnet porphyroblasts and foliation plane. Garnet crystals in this rock unit are mostly subhedral and anhedral. They show red color, and

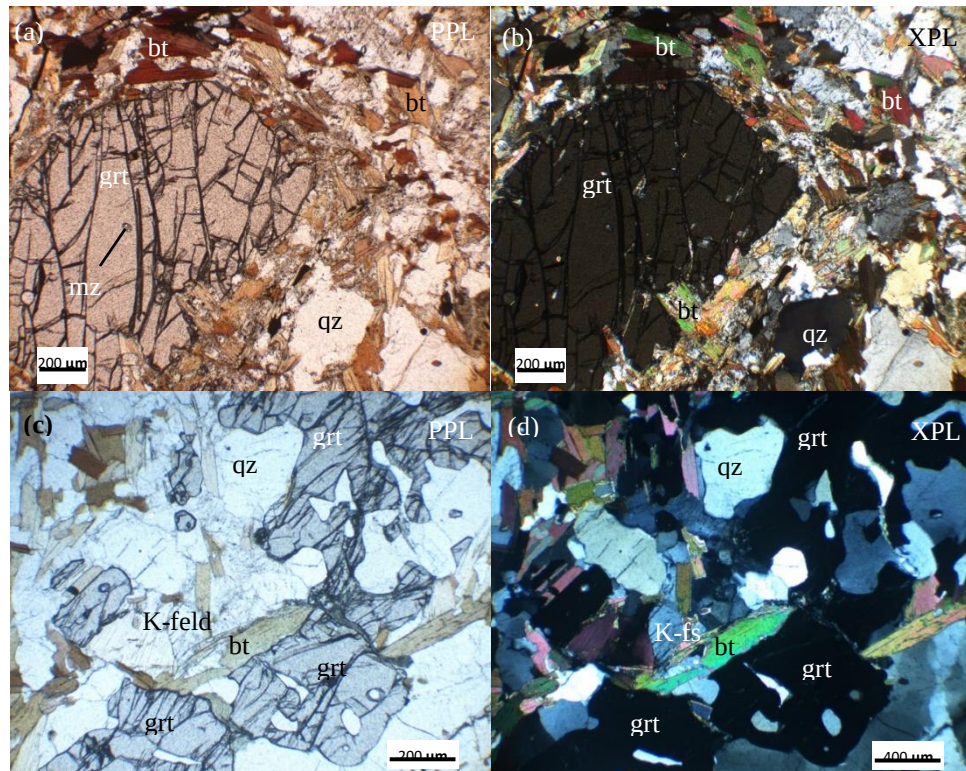


Figure 2-10 Photomicrographs of garnet-biotite gneiss at Myo Lwin Prospect (ML-Grt-bt-07). (a) and (b) Garnet porphyroblasts are generally deformed displaying patchy or highly fractured and curved biotite flake in garnet biotite gneiss. (c) and (d) Anhedral garnet grain with biotite alignment adjacent to K-feldspar and biotite indicating a wide range of regional metamorphism. Abbreviations: grt = garnet, K-fs = K-feldspar, bt = biotite, qz = quartz, mn = monazite.

nearly all are transparent. Most of them are about 2 mm and some are over 1 cm in diameter. Even though a few garnet crystals include some inclusions, they are too small to identify even under microscope. Highly deformed garnet crystals are common in the rock unit. The garnet crystals can easily be seen along the foliation plane. In some places, there might be intense rotation in the rock because the area is highly deformed

and tectonized. Quartz crystals are usually medium- to coarse-grained and slightly subhedral. Some of them are preserved within the garnet crystal. In rare cases, minute quartz grains are frequently seen in the porphyroblasts of garnets. Apatite, monazite, and xenotime are accessory minerals in this rock type. Monazite is frequently found under microscope.

2.7.2 Marble and diopside calc-silicate

Under the microscope, it is mainly composed of quartz, calcite, and calc-silicate minerals, sphene or titanite, and apatite. The rock shows greenish to dark grey color. This color variation is due to the presence of different varieties of calc-silicate minerals. It shows fine- to medium-grained, granoblastic texture with distinct banding characters probably due to metamorphic differentiation. Most mineral grains are too small to identify by naked eye. Quartz occurs as xenoblastic grains, and their grain sizes rarely exceed 0.5 mm in diameter. Calcite appears as medium-grained, anhedral to subhedral crystals with clear cut twin lamellae. Polysynthetic twin is common in calcite. It also shows xenoblastic to idioblastic texture. Most calcite grains range from 0.5 to 1.5 mm

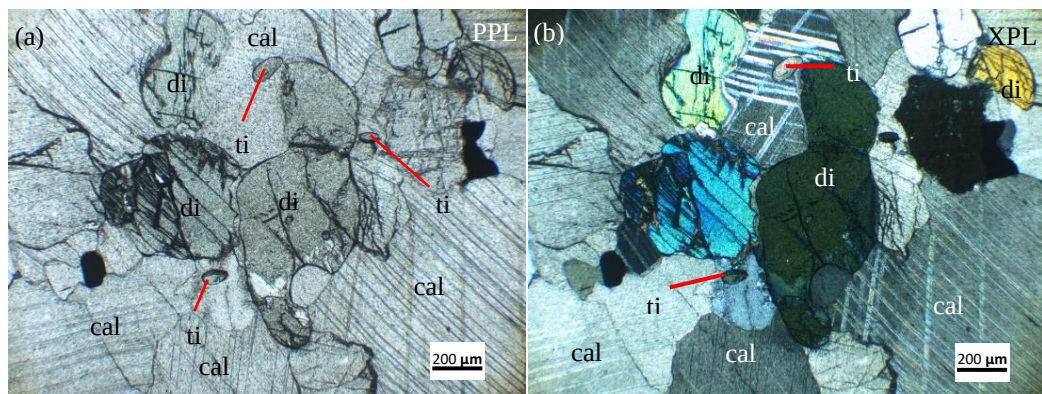


Figure 2-11 Photomicrographs of diopside calc-silicate rock at Kyarpazat Prospect (KPZ-CSR-04). (a) and (b) Diopside surrounded by medium-grained calcite mineral. Note titanite formed in calcite. Abbreviations: cal=calcite, di=diopside, ti=titanite

in diameter. The grains boundary calcite is clear white and formed as sutured contact each other. They can be easily recognizable under the microscope. Diopside is medium-grained and anhedral to subhedral and their grain size reaches up to 0.5 mm in diameter. It displays high relief, pale green and sometimes greenish pink in color, depending upon the cutting of thin section. They are disorderly oriented and show porphyroblastic

texture. The sphene is mostly subrounded and anhedral. Some sphenes exhibit wedge-shaped grains.

2.7.3 Biotite granite

It is commonly medium-grained, and sometimes coarse-grained with granular texture. Grain size of clear quartz varies from 0.1 cm to 0.4 cm and biotite flakes range up to 0.5 cm in diameter. Texturally it is medium- to coarse-grained, biotite is surrounded by the quartz grains. Sometimes, the feldspar phenocrysts are surrounded by smaller

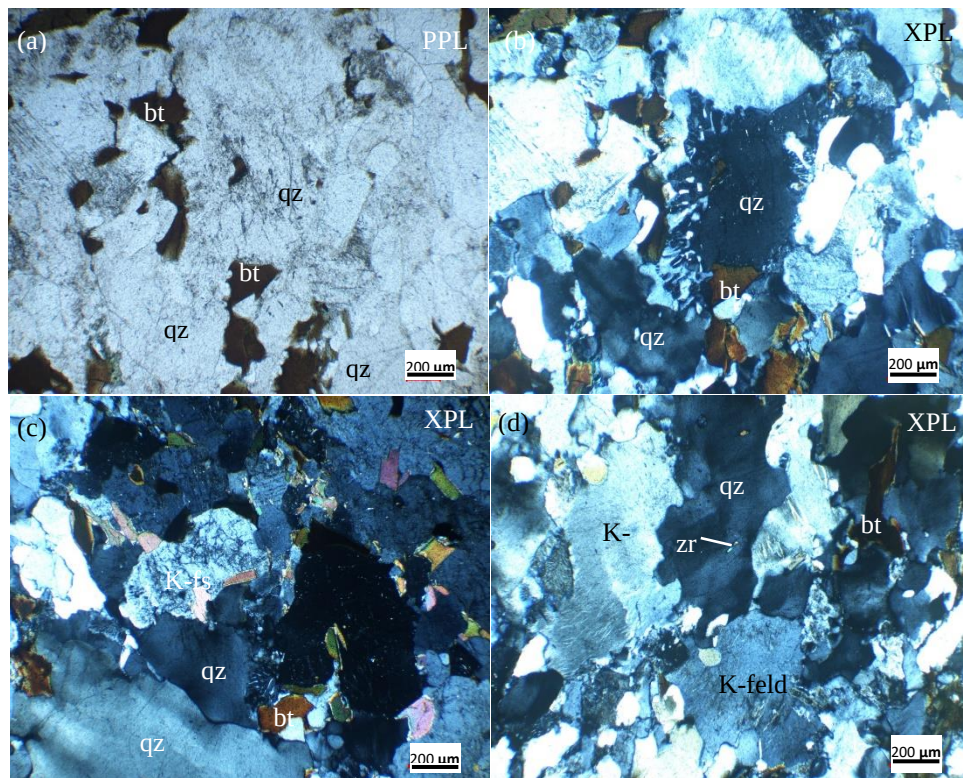


Figure 2-12 Photomicrographs of Biotite granite (WB-Bt granite-11) (a) and (b) Myrmekitic or vermicular intergrowth of quartz and sodic plagioclase. Note biotite are intercalated within quartz. (c) and (d) Pale green to brown biotite within K-feldspar and some quartz displays a undulose texture. Abbreviations: bt=biotite, K-fs=K-feldspar, qz =quartz, and zr=zircon.

anhedral quartz crystals. Under the microscope, the rock unit is mainly composed of quartz, plagioclase, and biotite as mafic minerals with other minor accessory minerals such as zircon, apatite, and tourmaline. Orthoclase feldspar is the most abundant and tends to occur as subhedral to anhedral crystals. Most orthoclase is cloudy in color.

Graphite intergrown with orthoclase and quartz is occasionally present. Both untwinned and simple contact twinning of the orthoclase is common. Microcline is also observed, and quartz occurs as anhedral irregular aggregates to lensoid elongated crystals. Some quartz shows undulatory extinction due to strain effect. Myrmekitic texture is commonly found showing vermicular intergrowth of quartz and sodic plagioclase adjacent to K-feldspar. Subhedral prismatic plagioclase is present in small quantities. Closely spaced lamellae-polysynthetic twinning of plagioclase is also present. Biotite as a major mafic mineral usually occurs as subhedral prismatic and also as small flakes arranged in subhedral alignment. It is dark brown to dark green in color. Zircon inclusions are present in quartz.

2.8 Summary

The investigated area is located in central Myanmar. It is also famous a gold province in Thabeikkyin-Singu area. The host rocks are commonly in greenschist to granulite metamorphic facies grade that intruded by granitoid rock. The formation of MMB is related to Indian-Asian continental collision events. The MMB is a north-south trending alignment of metamorphic belt to Andaman Sea. It is a tectonically very complex and metamorphic rocks are highly foliated and strongly deformed. The Wabo district is composed of metamorphic and igneous rock. The stratigraphic age ranges from Pre-Cambrian to Oligocene-Miocene. Numerous gold mineralization is hosted in MMB including the research area. The gold mineralization associated with granite intrusions is found in several area, and orogenic gold mineralization also formed in the area.

CHAPTER III

QUARTZ-GRAPHITE VEINS AT THE MYO LWIN, ZAW MIN AND KYARPAZAT PROSPECTS

3.1 Quartz graphite veins

The thickness of the sulfide-graphite ore zones varies considerably and is a critical point to the interpretation of the formation of ore zones. The thickness of the ore zone varies from centimeter to meters. In Myo Lwin Prospect, the type of veins range over a meter wide (Fig 3-1). Visible gold is frequently observed in this zone associated with graphite-sulfide assemblages. Probably the graphitization is a common alteration product adjacent to the quartz veins in the area. An appearance of cross cutting is also displayed by calcite veinlets in both hand-specimen and under microscopic observation. It exhibits millimeter scale width. Zaw Min Prospect is indicated by the auriferous sulfide graphite ore zones. The vein is wider (Fig 3-2a and b) than other prospects (Fig 3-1 and Fig 3-4) around the area. In general, sulfide rich graphite ore zone is the most recognizable, with a thickness of the adjacent ore zone of the other prospects. Similar graphite associated ore zones are present elsewhere in the Kyarpazat Prospect (Fig 3-4) at the lower depth. But the veins are quite thin (approximately 5 to 10 cm) in width compared with other two prospects.

3.2 Structural control on the formation of mineralization

Gold mineralization is mainly associated with the quartz vein and quartz carbonate veins in the study area. The mineralized quartz veins run parallel to the regional foliation trend, and fracture and fault zones displaying the structural controls. Quartz vein displacement, and ribbon structure in the area suggest the structural deformation controlling the mineralization in the research area. So, the research area can be implied that the host rock experience the metamorphism which is more or less related with the mineralization in the research area. Although no data about specific deformation in the MMB, gold and sulfide mineralization is normally associated with the deformation events in the study area. The area is within the active tectonic terrain with at places the shearing or striation plane features on the mineralized quartz veins surface. It is the one indicator of tectonic features in the area. Primary gold exploration has been produced from the green, blue, smoky, white quartz veins in the study area. Underground exploration has been mined by the local company at numerous auriferous quartz veins

at different working level. In the Wabo district underground mines, all working levels develop at vertical to subvertical. Hence, the metamorphism indirect triggered the formation of mineralization and intense deformation may also favor preferred for gold precipitation along fractures and fault zones in the Wabo district.

3.3 Myo Lwin Prospect

The Myo Lwin Prospect is located at the top of mount Arkartha Taun, that was the first gold occurrence in the Wabo area. Exploration has been undertaken of subsurface to underground mining systems. This prospect is hosted in garnet-biotite gneiss. The veining structure are dominant from surface mining to subsurface underground exploration. The subsurface adit or tunnel is over 1000 meters in horizontally. Underground is over 150 meters in depth but first occurrence (top of mountain) to lowest level is over 300 meters. The lode type veining network is complicated and connected to each veining system. As field observation, the mineralization style dominantly displays a stock work, network, sheet vein, a book and ribbon, and breccia in which sulfide minerals are concentrated within dark and white lenses of quartz-graphite veins.

The underground veining system has interconnected each other. These are variety color quartz veins: milky, smoky, white, blue and green entire of the area. The gold can be seen on the massive quartz vein wall in underground. On the wall of adit, some are developed a vein where saddle reefs (displacement or vein offset) within the host rock body (Fig 3-1a). In the horizontal tunnel, some mineralized display splays veins along foliation plane with over a meter in length and around 5 cm in width. The indicator of moment also can be observed on the displacement of quartz vein in the horizontal adit of Myo Lwin Prospect. The mineralized graphite rich black quartz vein is observed at the lowest level of the vertical shaft. The mineralized veins comprise black and white colored ribbon quartz (Fig 3-1b) within garnet-biotite gneiss. Vein within this zone pinch and swell (Fig 3-1b) and vary in width from millimeter to about 15 centimeters. It is a representing character of ductile veins structure. That book and ribbon texture provides an evidence for syn-mineralization shearing. As well as book and ribbon (pinching and swelling) texture vein also displays, particularly in exposures situated within the gneiss. The pinch and swell vein texture or boudinage, is a common characteristic of quartz-graphite vein system. This is due to a combination of evidences.

Firstly, original hydrothermal fluids have flowed through spaces of weakness and concentrated in the area that may not be uniform. Secondly these veins have stretched/elongated through extension to form the pinch and swell, boudinage characteristics which are a typical feature of sheared veins and shear zone planes. Stretching along the shear foliation and perpendicular shortening is due to the late fault or intense reactivation of the shear zones.

It is composed of pyrite and crystalline graphite. Sometimes free gold grains and microscopic grains (Fig 3-1c and d) can be seen. The forming of black color might be due to the graphitization or carbon. The width of quartz graphite vein ranges over a meter with vertically. Around quartz graphite vein zone, the breccia body also observed. It is a characteristic feature of open-space breccia zone. That breccia in the area shows multiple clast shape as spheroidal, angular and sub-rounded, whereas some breccia clasts are of a more equant size. The diameter of the host-rock breccia fragment

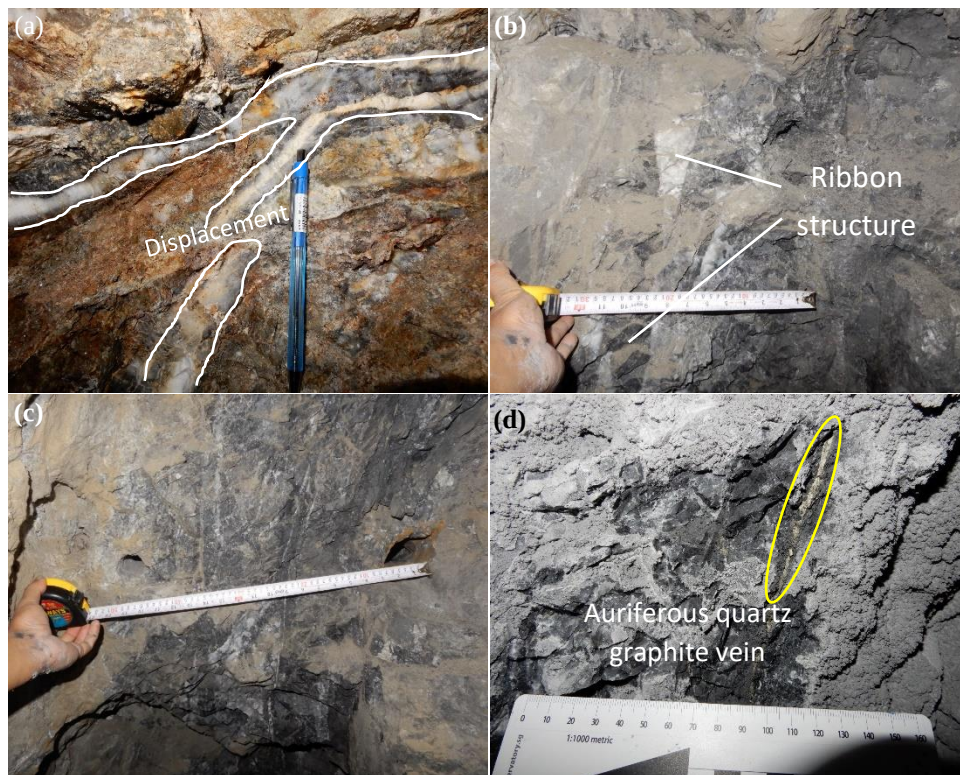


Figure 3-1 Out crop nature of quartz vein structure at the Myo Lwin Prospect. (a) thin saddle reef quartz vein with displacement vein structure within garnet biotite gneiss, (b) typical white and black lenticular or ribbon structure in graphite bearing mineralized quartz vein, (c) quartz-graphite vein with thin quartz stringer veinlet with over a meter width by absolutely vertically dipping , (d) close-up view of quartz-graphite vein with sulfide ore zone (within yellow circle).

clasts varies from 5 centimeter to over 15 centimeters. The matrix in the breccia is mainly quartz being the dominant matrix. It is an outer of mineralized zone though has some sulfide minerals.

3.4 Zaw Min Prospect

Gold mineralization at the Zaw Min Prospect is characterized by a shear zone quartz sulfide veining system. This prospect is also hosted by garnet-biotite gneiss. In some parts of the adit wall, boudinage structure is formed. Garnet crystals range from fine to medium-grained in the host rock along the foliation plane. Minor fold or drag fold also occurs on the host-rock wall. Quartz veins are multiphase mineralization styles within shear zone. This prospect has two types of mineralization. It consists of breccia and vein types. The mineralized breccia system is composed of sulfide and crystalline graphite, and some carbonate materials. It also shows a section of brecciated vein. The breccia consists of rounded, sub angular mineralized quartz graphite clasts around 1 to 5 cm in length. The mineralized quartz-graphite clasts are supported by a silica cements with fine breccia matrix. Brecciated clasts are often on the quartz vein and comprise fragments of the mineralized quartz-graphite mixed in the quartz vein.

It is an invisible gold mineralization associated with quartz graphite ore zone (Fig 3-2a and b). Adjacent to the quartz graphite zone frequently are graphite seams on both sides of vein or breccia wall. That kind of graphite seam often occurs adjacent to the mineralized veins and breccias in the Wabo district. The quartz graphite ore zone is relatively fractured and structurally controlled zones. The auriferous quartz graphite ranges over two meters in width. And opposite side of the quartz graphite vein is narrow, thinner than the breccia zones. The breccia ore zone at the Zaw Min Prospect is also composed of mainly graphite with sulfide rich.

At the Zaw Min Prospect also occurs crystalline white quartz vein (Fig 3-3a) also occurs within the main ore zone that was at the deep of the inclined adit. On the vein surface, slickenline or fault striations (Fig 3-3b) have been commonly found. Some quartz veins display a green color with coarse gold grain that is diagonal to the quartz veins (Fig 3-3c). It indicates continuous deformation. It is a significant feature on the vein zone in this prospect. In this prospect also characterized with graphite seam both side of mineralized quartz veins.



Figure 3-2. Quartz-graphite vein (breccia) at the Zaw Min Prospect. (a) Mineralized breccia with graphite bearing quartz sulfide ore zones (quartz vein formation in the center of the figure (a) in the Zaw Min Prospect of right down-going inclined adit. (a), and (b) Mineralized graphite bearing breccia ore zone.

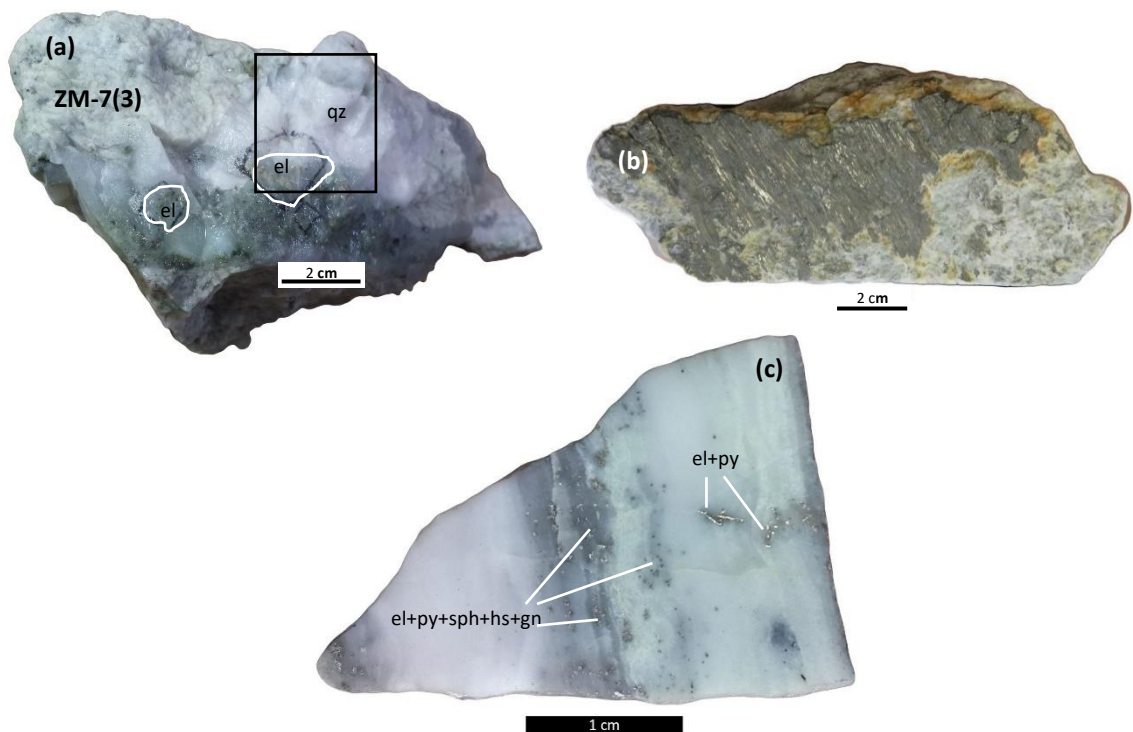


Figure 3-3 Handspecimen of quartz vein at Zaw Min Prospect. (a) clearly white crystal quartz vein with quartz stringer and visible gold (black rectangular denotes Fig 3-6 (b) striation lines with sulfide minerals on the vein surface, (c) sulfide layer associated with mineralization and coarse-grained gold is diagonally to quartz vein.

3.5 Kyarpazat Prospect

Gold mineralization at the Kyarpazat Prospect is characterized by structurally controlled mineralized quartz vein (Fig 3-4). The gold quartz vein is hosted in quartz sulfide and quartz sulfide with graphite (Fig 3-4). The sulfide rich with mineralized quartz graphite vein is dominant in the area. Gold in quartz graphite is often associated within pyrite. Mineralogy consists of quartz, sericite, graphite and sulfides minerals. It associates with graphite flake. Two types of graphite are exhibited as well-crystalline and very fine-grained particles. The graphite flake is together with semi-breccia stage. Within that breccia, well-flaky graphite is well order coexisted with sulfide minerals (pyrite is common sulfide). There, the graphitic seam is also recognized alongside of

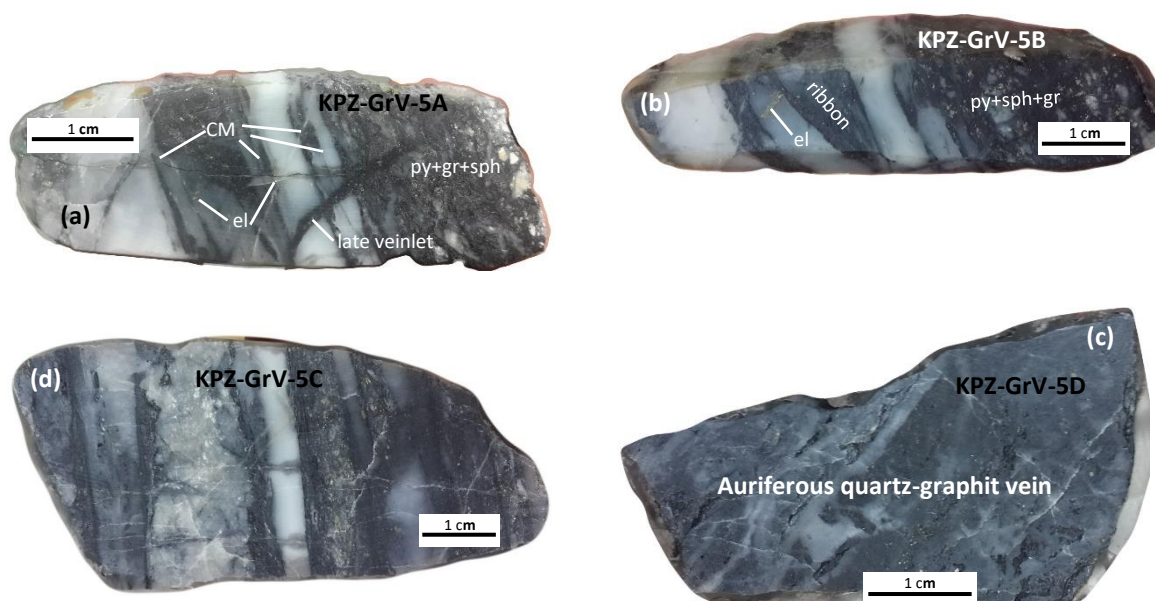


Figure 3-4 Hand specimen of black quartz vein at the Kyarpazat Prospect: (a) pyrite and graphite rich vein and cross-cutting with late veinlets, (b) small ribbon structure and auriferous graphite with sulfide rich vein, (c) quartz gold veins with late stringer veinlets, (d) graphite with sulfide vein cross cut into quartz-graphite vein.

mineralized quartz veins. The another one is observed in the late mineralization of within quartz layered band. It is very fine-grained in band and sometimes its in very small relic mineralized breccia clasts. A thin cross-cutting quartz vein is observed in the veins (Fig 3-4a and d). Micro-ribbons structures also display within the lode vein (Fig 3-4b). Graphite with sulfide vein ranges from 0.5 mm up to 3 cm in width. Between graphite veins and late stage vein are clear contact with thin layered boundaries. Late veining is composed of very thin layered quartz sulfide veins. Depending on

morphology and quartz precipitation stage, two types of graphite are recognized in this prospect. Some cross-cutting late stock work veins are also found in the samples (Fig 3-4d).

3.6 Petrography of gold-bearing quartz veins

3.6.1 Quartz texture at the Myo Lwin Prospect

The quartz texture of the quartz veins varies with each prospect in the Wabo deposit. Quartz is mostly milky and drusy and totally black in some part of quartz vein (Fig 3-5a). The quartz texture exhibits fine to medium grained with sub-rounding grain (Fig 3-5b). Calcite vein crosses to the graphite quartz vein. Calcite veinlet and quartz veinlets (Fig 3-5c) are sub parallel. Some quartz random orients with fine grained

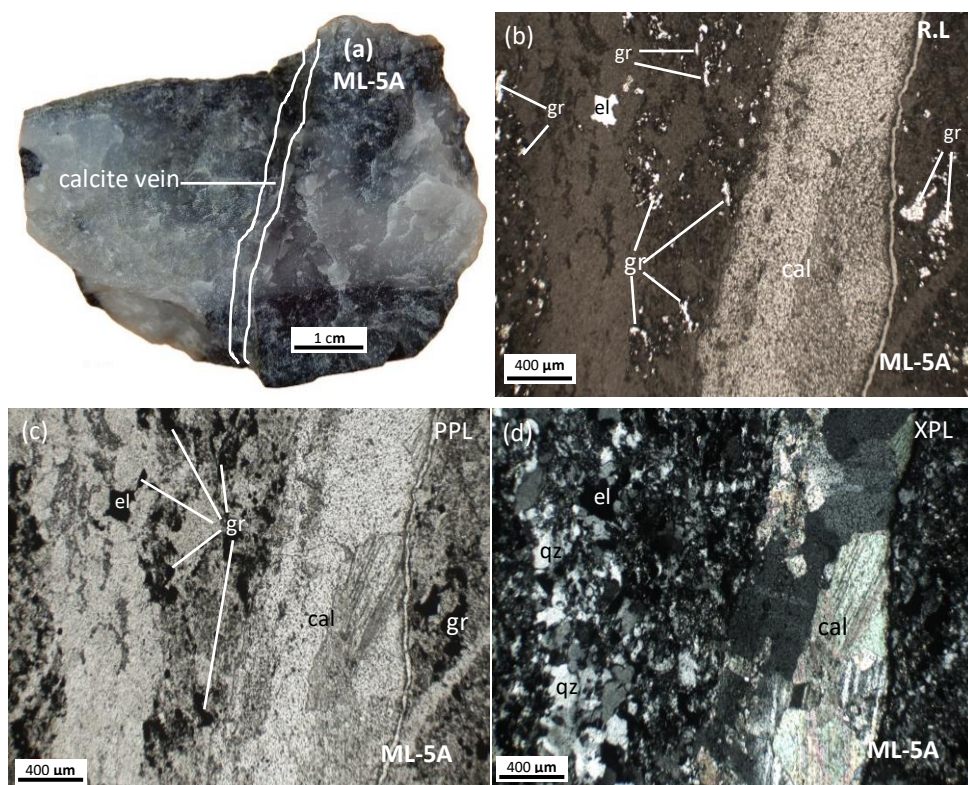


Figure 3-5 Hand specimen and photomicrographs of graphite with gold mineralization at the Myo Lwin Prospect. (a) Hand specimen of graphite bearing quartz vein with cross cut calcite vein-let, (b) reflected light of electrum closely associated with graphite flakes and sulfide minerals, cross cutting calcite veinlet, (c) observed clearly calcite-veinlets outline on the right side of photo, (d) fine-grained graphite around electrum.

graphite matrix (Fig 3-5b and d). Calcites give medium to coarse grained texture (Fig 3-5d). Between calcite and quartz vein remarked by sharp boundaries (Fig 3-5b, c and d). To compare the grain size with quartz and electrum (Fig 3-5 b), electrum is relatively coarse than majority of quartz grains.

3.6.2 Quartz texture at the Zaw Min Prospect

It is relatively quartz dominant veining system. Early quartz veining stages with mineralization are typically coarse-grained (Fig 3-6) and display only low strain (undulose extinction) and it is due to tectonic stress. The alignment of quartz grains indicates the deformation within a shear zone or deformation period during mineralization. The quartz grains in photomicrographs show the truncated texture or elongated quartz texture. The grains also display an evidence of shadow-preferred orientation. The quartz texture displays an elongated texture and polygonal grains with grain boundaries. Some quartz crystals form a sub-grain formation and split-out a grain resulting from the regional metamorphism and deformation. It also hosted rich fluid inclusions with aqueous, and aqueous carbonic rich fluid inclusions.

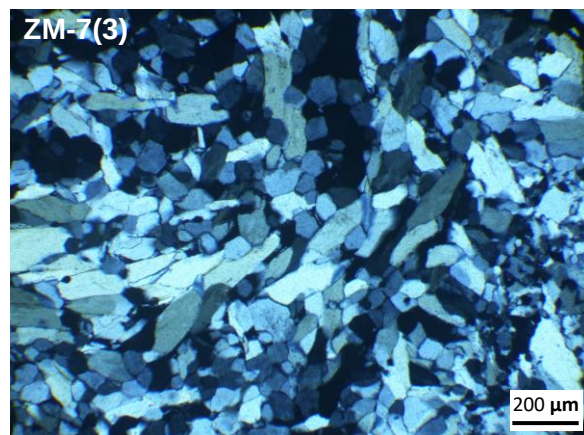


Figure 3-6 Photomicrographs of quartz texture. The undulose quartz texture, prefer orientation during mineralization at the Zaw Min Prospect (Sample-ZM-7(3)).

3.6.3 Quartz texture at Kyarpazat Prospect

The quartz texture in the Kyarpazat is also recognized under microscope. The quartz grain is fine to medium grained. Quartz grains are of rounded, elongated and sub rounded shape (Fig 3-5a, b, and c). Some sulfides are intercalated within quartz grain boundaries (Fig 3-5a, and c). Graphite flakes are dominant in the quartz vein of the Kyarpazat Prospect. The graphite and some quartz grains are nearly equant shape (Fig 3-7b). Sericite in graphite and quartz grains (Fig 3-7c) also displays. In some parts of

quartz vein, the quartz texture displays fine grained quartz with very thin layered vein (Fig 3-7c).

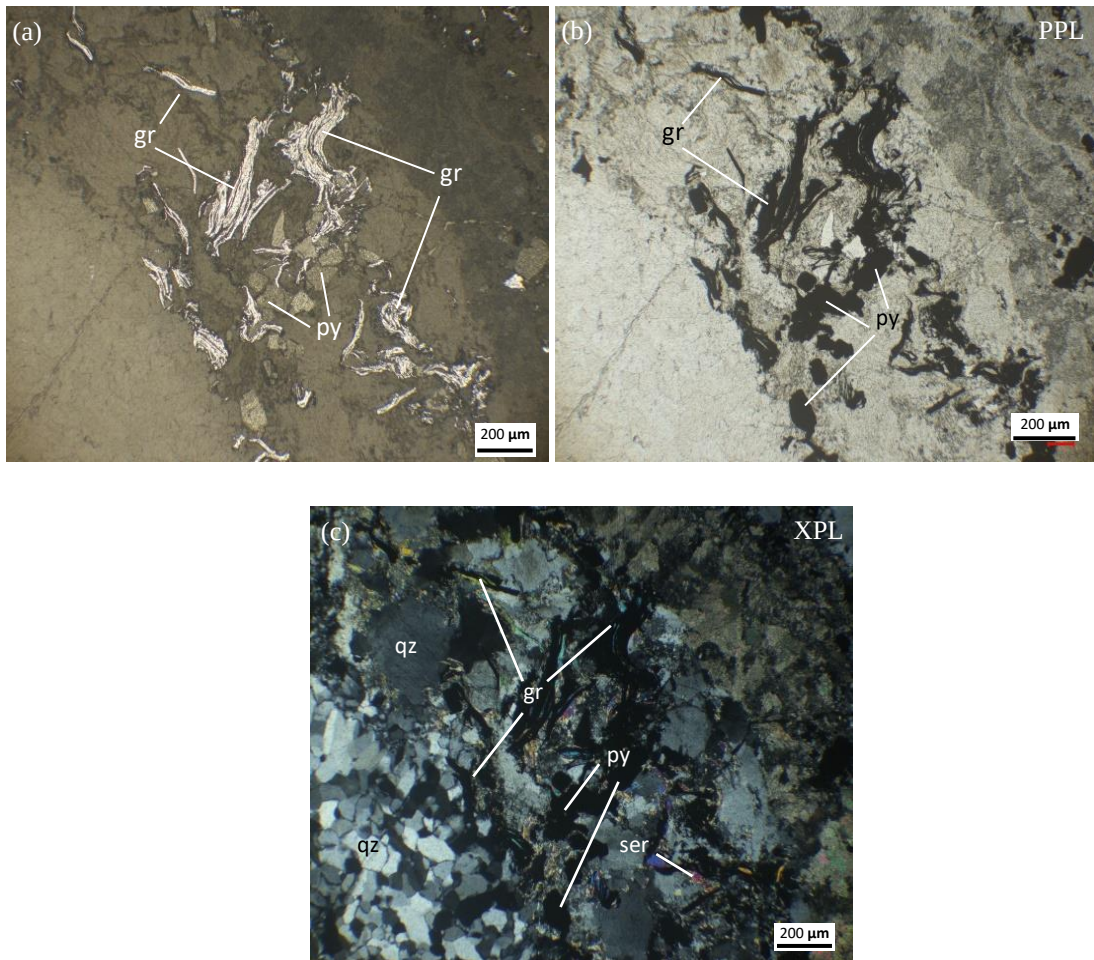


Figure 3-7 Photomicrographs of graphite minerals associated with gold mineralization (sample KPZ-GrV-5A): (a), (b), prismatic, elongated, flaky graphite closely relationship with auriferous quartz vein with dominant sulfide minerals (especially pyrite). (c) graphite and alteration mineral assemblage (sericite) formed together within the subhedral quartz, and very fine-grained or recrystallize quartz crystal at Kyarpazat Prospect. Abbreviation: gr=graphite, py=pyrite, qz=quartz, ser=sericite. R.L=Reflected light, PPL=plane polarized light, and XPL=cross polarized light.

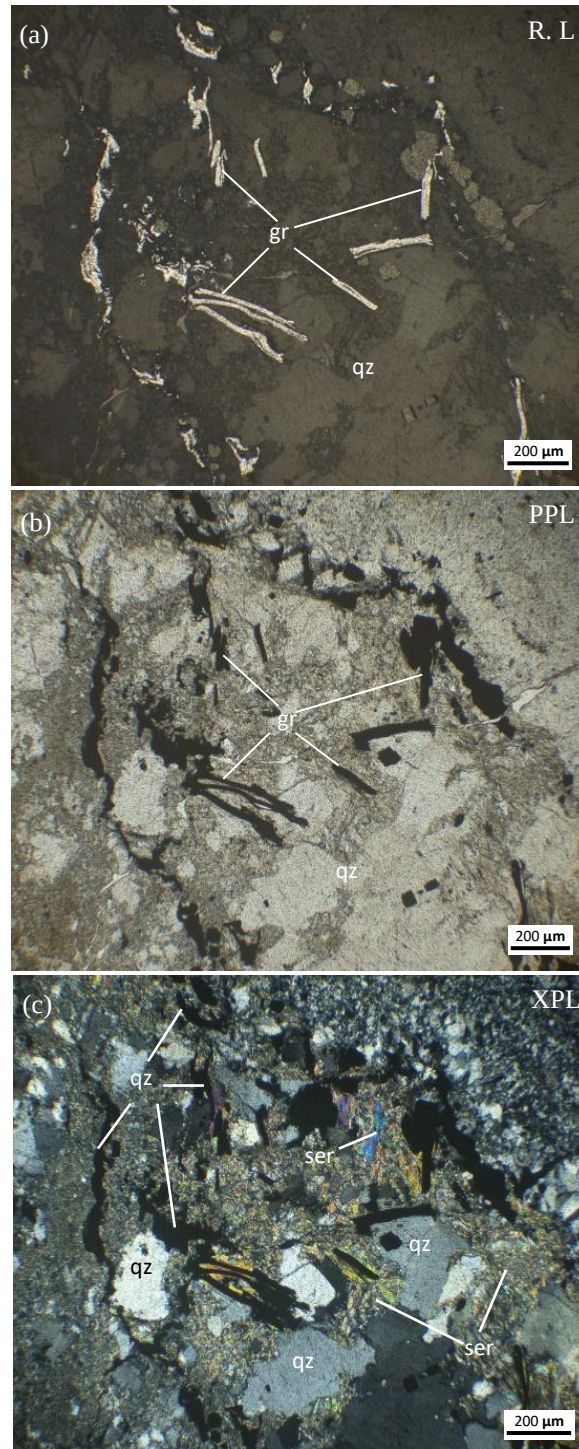


Figure 3-8 Photomicrographs of graphite minerals associated with gold mineralization (sample KPZ-GrV-5A): (a), (b), prismatic, elongated, flaky graphite is closely related with auriferous quartz vein with dominant sulfide mineral (especially pyrite). (c) graphite and alteration mineral assemblage (sericite) formed together within the subhedral quartz, and fine-grained quartz crystal at the Kyarpazat Prospect. Abbreviation: gr=graphite, py=pyrite, ser=sericite, R.L=Reflected light, PPL=plane polarized light, and XPL=cross polarized light.

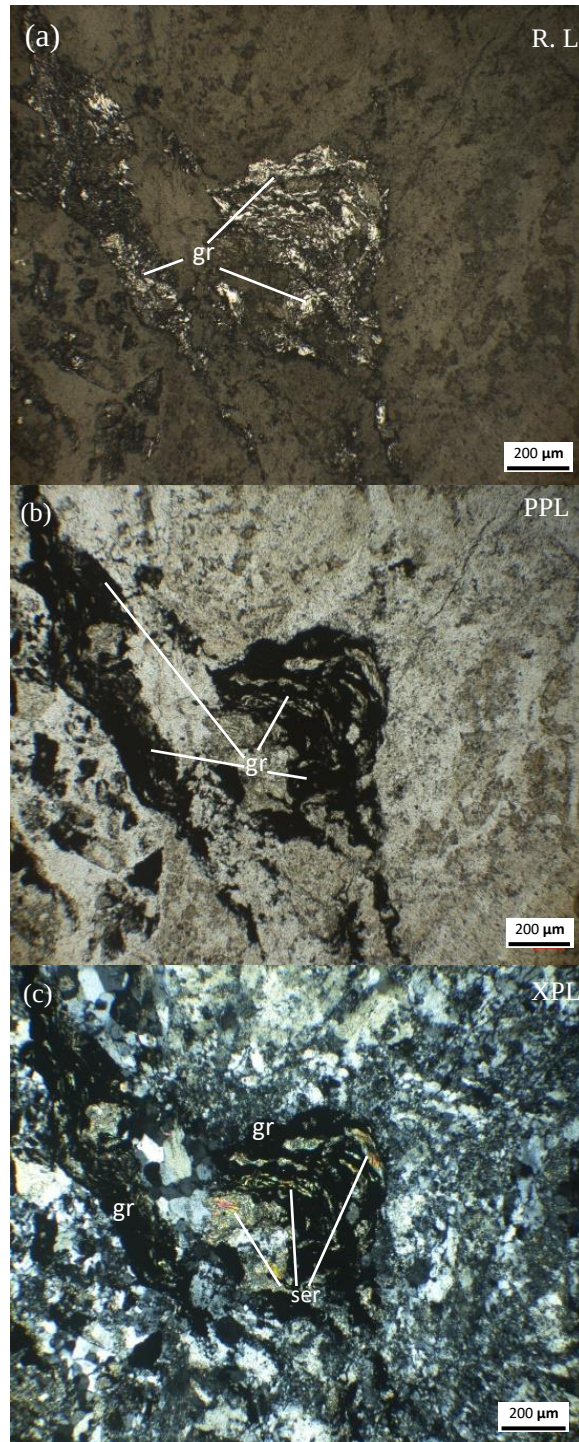


Figure 3-9 Photomicrographs of graphite (Sample KPZ-GrV-5C) (a), (b) and (c) the crenulation or spherulites and irregular clumps of graphite with sericite. The main sulfide is pyrite. The quartz grain is fine at the Kyarpazat Prospect. Abbreviation: gr=graphite, py=pyrite, qz=quartz, ser=sericite, R. L=Reflected Light, PPL=plane polarized light, and XPL=cross polarized light.

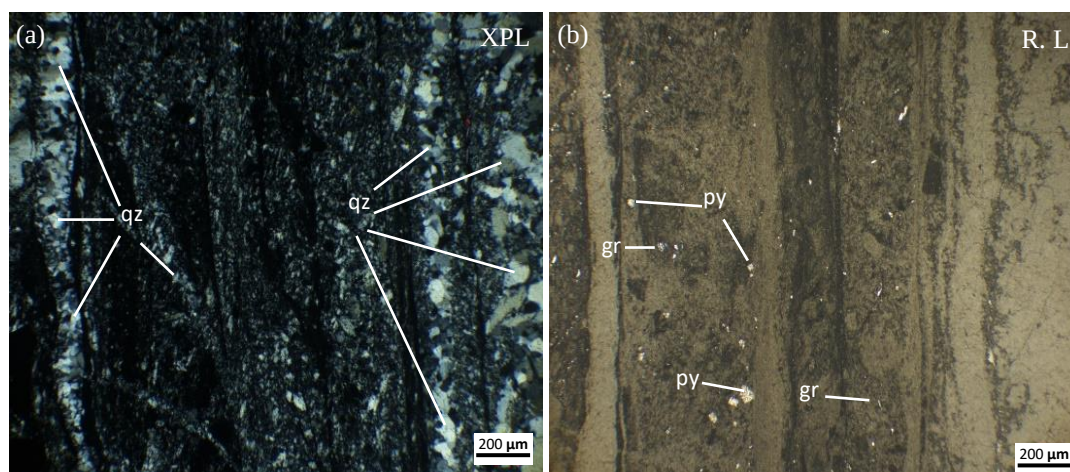


Figure 3-10 Photomicrographs of graphite bearing quartz vein that is banding with fine grained graphite flake at the Kyarpazat Prospect. Abbreviation: gr=graphite, py=pyrite, qz=quartz, ser=sericite, R.L=Reflected light, PPL=plane polarized light, and XPL=cross polarized light.

3.7 Mineralogical characterization of graphite in the Wabo district

The precipitation of graphite is identified within the gold-bearing quartz graphite veins (Myo Lwin, Zaw Min and Kyarpazat Prospects) in the Wabo district. The graphite is crystalline or flaked and fine-grained in quartz graphite veins. Some auriferous quartz veins are composed of the crystalline graphite (fine grained graphite). Microscopic studies reveal the occurrence of common graphite crystals within the mineralized quartz-graphite vein zone. Morphologically two distinct graphite types have been observed based on the mineralogy: lath shaped and crenulated form in the veins. Gold is associated with this two phased graphite, some of them show a preferred alignment intercalated with sericite and occur in both quartz graphite veins and breccia.

Two characteristic types of graphite have been observed from the Wabo gold deposit and consist of the flaky to irregularly shaped graphite and another variety indicates lath-shaped crystals of graphite. Lath shaped graphite crystals are randomly oriented within black lode quartz veins. In many places graphite appears as two distinct types (flakes or prismatic and slumps and very fine grains) that differ in crystal size and shape forming at variable graphite forming processes.

Graphite precipitated from hydrothermal fluids occurs throughout the gold quartz vein in the Wabo district. That graphite might be syngenetic or epigenetic hydrothermal products closely related with gold forming fluids in a reduced carbon system.

3.8 X-ray diffraction analysis on graphite

The characteristic features of graphite from the Wabo deposits have been carried out by means of X-ray diffraction (XRD). XRD of the graphite is normally detected to obtain bulk information the order of structural state arrangement the direction of c-axis of the carbon crystal or flake. The XRD pattern of the samples displays sharp and symmetrical peaks. The morphology of graphite exhibits a crystalline or flake graphite to spherulitic varieties.

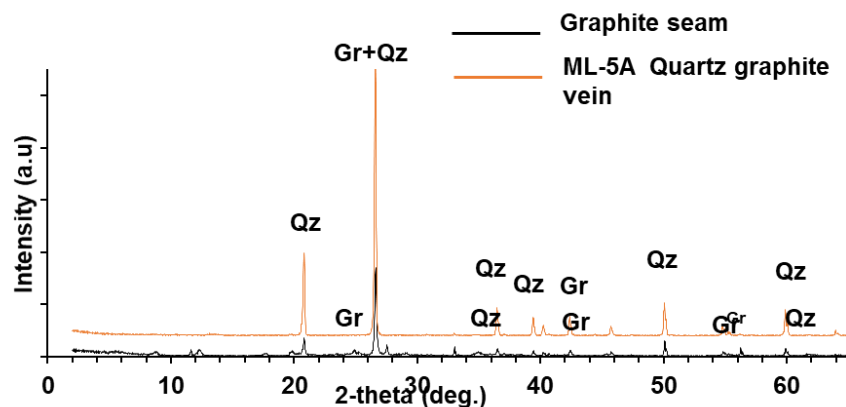


Figure 3-11 XRD pattern of quartz and graphite. Showing the 2-theta peak of quartz-graphite vein of the Myo Lwin Prospect (ML-5A) and graphite seam.

3.9 Mineralization styles

Field relationships and petrographic analysis suggest that the gold mineralization is controlled by structural features. Gold mineralization in the Wabo district occurs within the high-grade metamorphic rock as well as the auriferous quartz veins placed along the fracture zones. It is a multi-connected veining system with variable widths. The mineralized zone is the highly deformed of brittle-ductile in nature an indication of brecciation of mineralized quartz veins, as evidence of ribbon structures. Textural features of veins in the Wabo district exhibit a black and white colored book and ribbon, quartz veinlets, displacement or mineralized offset in saddle reef veins, indicate multiple episodes of mineralization quartz vein and ore deposition in the working area. The vein morphology varies between the vein systems of the Wabo gold district. This

work would be expected to impact on the mineralization style between the veins: this notion will be explored of observation of gold and sulfide mineralization within the veins systems. Although each prospect features economically important gold mineralization, there are huge in gold grade within the veins. Discontinuous zone of gold enrichment can be traced down to quartz-graphite vein of the Myo Lwin Prospect and may correlate with areas where the main shear zone shows a pinch and swell texture. This zone shows a zone of particularly high gold enrichment in the associate quartz-graphite vein in the area. It is also loosely associated with zones of brecciated quartz graphite vein observed downside of veining systems of the Zaw Min Prospect.

The Wabo gold district suggests that the gold only occurs as free gold cluster and fine grains (microscopic grains) within the veins. The highest gold is found associated with common pyrite in quartz veins. Highest gold are found as free gold usually within the quartz veins.

Most of the veins are gold-bearing and sometimes intensely sericitized within the quartz veins. The geometry of quartz gold veins and pinch- and -swell are characterized by pyrite dominant sulfides. Most quartz veins are sub-horizontal along foliation and sub-vertical within the host rock and shear plane. Shears indicator are often observed on the quartz vein with parallel or sub-parallel lines and sometimes those shearing lines give small grooves on the quartz vein walls. Boudinage (shoots and lensoidal bodies) of the quartz and feldspar veins are spread out on the host-rocks around the area. It especially reflects the shear zone and forming the significant fabric in the host rocks (garnet-biotite gneiss).

3.10 Ore mineralogy, gangue minerals and paragenesis

3.10.1 Ore mineralogy

Pyrite is the most abundant sulfide mineral within the deposits through the Wabo district. It is also present in all mineralized quartz veins, mineralized breccia and also in veinlets. The pyrite are various morphological types, euhedral to anhedral, fine to coarse grained and some aggregates. Some are well-formed crystals small and round crystal. The pyrite commonly ranges in size from 500 μm to 20 μm . Pyrite is closely related with gold mineralization. Pyrite also occurs though the pre-mineralization.

Sphalerite is not abundant in the auriferous quartz vein and breccia. It is mostly darkgrey color which may be attributed to high iron content. Most sphalerite is fine grained but rare coarse. It sometimes found in isolated grain and fill in porous pyrite grains. It is also related with hydrothermal graphite. Sometimes it coexists with other minerals: galena, and chalcopyrite. Moreover, it still needs to do more detailed sulfide geochemistry in order to better understanding.

Chalcopyrite is also not a common sulfide in both mineralized quartz vein and breccia. It is associated with pyrite, galena, sphalerite and hessite. It is also related with electrum but seldom in mineralized quartz vein. Most chalcopyrite is anhedral and the size ranges from 20 to 200 μm . Galena is the less often sulfide mineral in the auriferous quartz vein and breccia in the Wabo district. Galena is an isolated with fine grain. Most of galena occurs as irregular shape with fine grains. It is mostly associated with pyrite. Galena is generally found together with electrum but in rare. Hessite is a fine grained and associated with chalcopyrite and pyrite.

3.10.2 Gangue minerals

Quartz

Quartz is the dominant gangue mineral in the Wabo district and responsible for all the other gangue minerals combined. The quartz is generally milky, green, white and drusy. Quartz is fine to medium grained in the auriferous quartz vein. It displays an elongate texture in some mineralized quartz vein. This type of quartz is fluid inclusion rich in the quartz veins. It is closely associated with graphite and minor sericite alteration in the veins.

Calcite

Calcite generally forms in cross cutting veinlets within the quartz graphite vein. These veins are interpreted to post-date mineralization in a mineralized quartz veins. It is a fine to medium grained with clear sharp boundary between calcite veinlets and quartz graphite veins. It is not common in the auriferous quartz vein in the area.

Sericite

Sericite generally occurs with graphite in the dark colored auriferous quartz graphite veins of the book and ribbon zones, breccia and vein systems. The sericite is distinctive because of its semi lustrous sheen. As the vein has occurred within the shear compressional deformation shear zones, sericite is interpreted to be a product of shear related metamorphism and hydrothermal alteration of the wall rock components. Although the sericite and graphite are gangue minerals, they occur only in the high-grade zone of gold mineralization. It also represents a visible indication of a free gold grains and invisible mineralization.

3.10.3 Mineral paragenesis

Mineralization associated with graphite at the Myo Lwin prospect can be divided into three stages based on the occurrence of mineral assemblages. In stage I, quartz is the dominant gangue mineral with pyrite. Pyrite is common sulfide minerals than others. In accordantly with mineral assemblage, pyrite and sphalerite are associated with electrum in stage II. Graphite is also gangue mineral together with electrum.

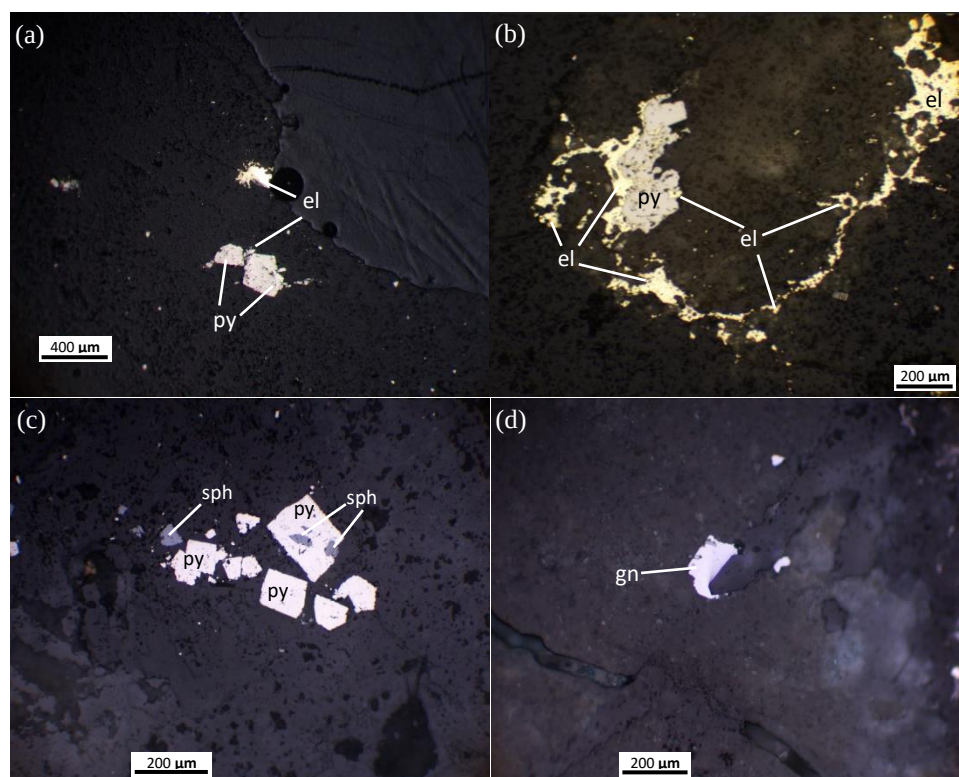


Figure 3-12 Photomicrographs of graphite bearing quartz vein (ML-5A) at Myo Lwin Prospect (a) bright yellow electrum and pyrite, (b) electrum on margin of pyrite, (c) Some pyrite generate into another grain size, sphalerite fills in euhedral pyrite, (d) isolated galena.

Chalcopyrite forms in stage III together with some pyrite generation. Hydrothermal graphite is closely associated with gold forming stage. But fine-grained graphite is in stage III. Calcite is after mineralization stage in the vein as cross-cutting to early quartz sulfide rich (graphite) quartz vein stage. The carbonate ankerite is late hydrothermal alteration product.

Mineral \ Stage		Stage I	Stage II	Stage III
Ore mineral	Pyrite	Abundant	Common	Trace
	Chalcopyrite		Minor	
	Sphalerite		Common	
	Galena		Minor	
	Electrum		Common	
Gangue mineral	Quartz	Abundant	Abundant	Abundant
	Calcite			Common
	Graphite (flake)		Common	
	Graphite (fine)			Trace

Abundant Common Minor Trace

Figure 3-13 Simplified paragenetic sequence at the Myo Lwin Prospect

The mineralization at the Zaw Min Prospect, in the early stage I, quartz is an ubiquitous gangue mineral in the main zones. The quartz texture in the mineralized quartz vein is a good indicator with undulose texture. Quartz is coarse to fine grained. In some places, they show a preferred orientation along the grain boundaries. In this stage, pyrite is also common in the veins. Electrum grains are locked within subhedral pyrite crystals. A few chalcopyrite is in this stage (Fig 3-14a) and electrum are locked in pyrite (Fig 3-14b). In stage II, most of electrum grains are encapsulated (Fig 3-14c and Fig 3-15c) in euhedral pyrite grain. These pyrites might be later than electrum as morphology of ore minerals. In the same time, galena also occurs isolate beside of small pyrite grain. In stage III, chalcopyrite filled within the fracture of or grain boundaries of pyrite. Sphalerite also fills in pyrite grains. Hessite coexists with chalcopyrite in pyrite grains (Fig 3-14d). The gangue minerals are quartz, and graphite in mineralized quartz vein.

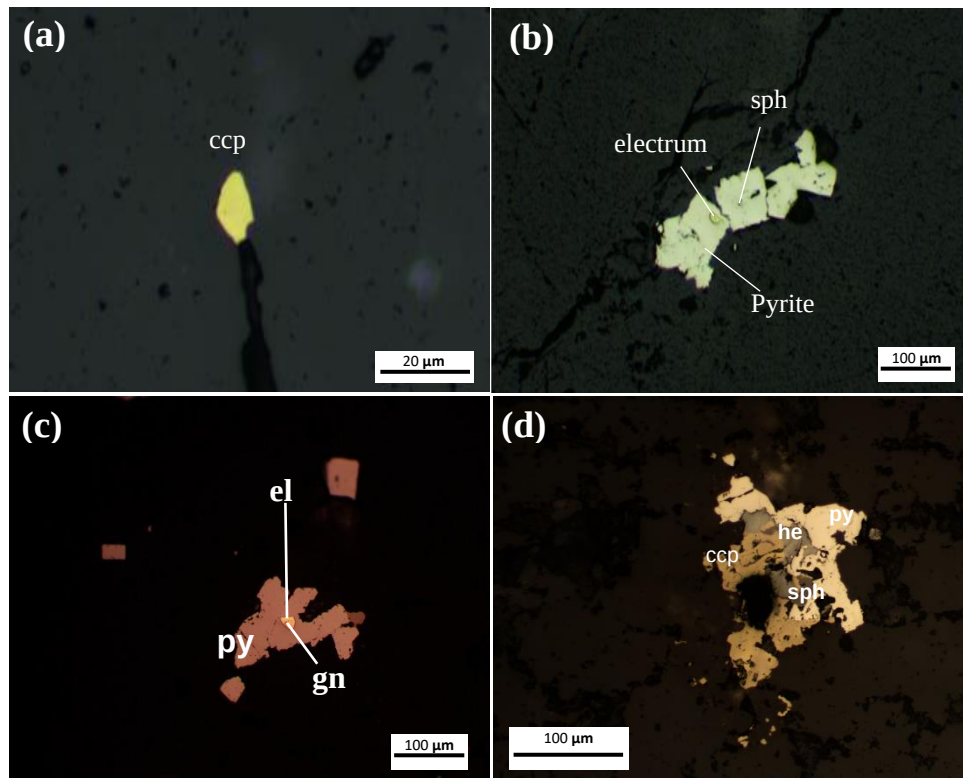


Figure 3-14 Photomicrographs of (a) isolated chalcopyrite, (b) electrum grain and sphalerite within the anhedral pyrite, (c) galena on the electrum grain, (d) hessite and sphalerite fill around pyrite and chalcopyrite.

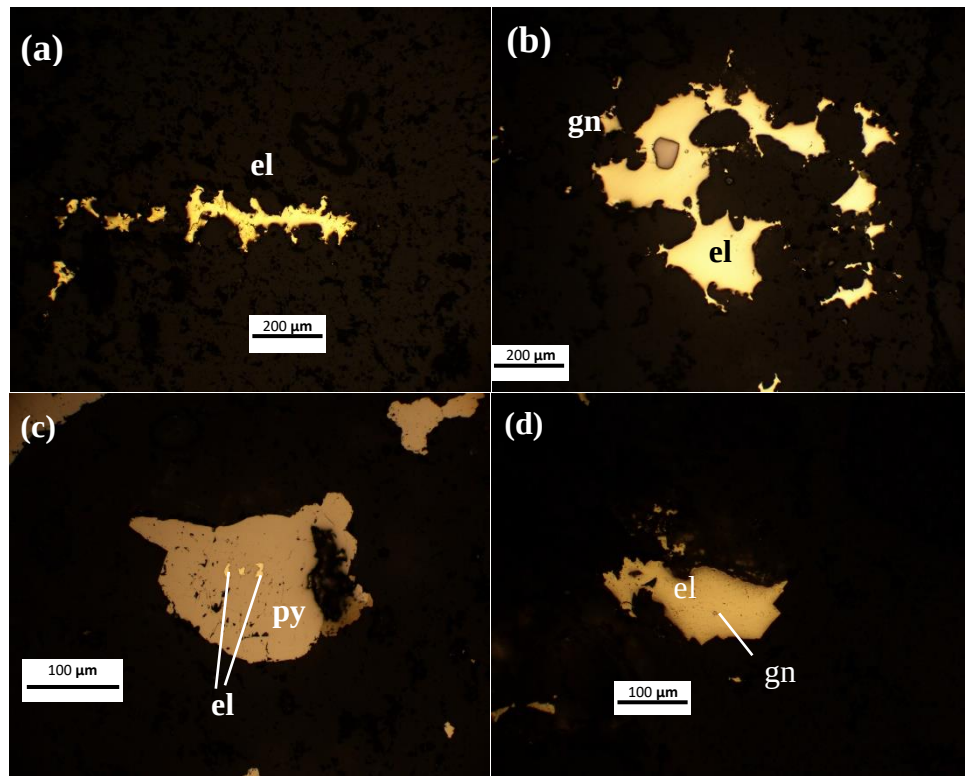


Figure 3-15 Photomicrographs of (a) coarse-grained electrum, (b) galena on the electrum, (c) encapsulate electrum within pyrite, (d) galena on electrum.

Graphite is the dominant gangue mineral and associated with gold mineralization. The flaky graphite ranges at least 100 μm in length (Fig 3-16a) and abundance in ore zones. Sulfides is the common in quartz graphite vein. Pyrite is abundant as sulfide in the vein materials. Pyrite is anhedral with fine and medium grains. Fine chalcopyrite fills outer of anhedral pyrite grained (Fig 3-16b). Medium grained sphalerite is richer than chalcopyrite in the quartz graphite vein. Fine grained pyrite fills within the sphalerite boundaries. That fine grained pyrite coexists with auriferous graphite in the quartz graphite zone (Fig 3-16c). Within this gold bearing quartz graphite ore zones.

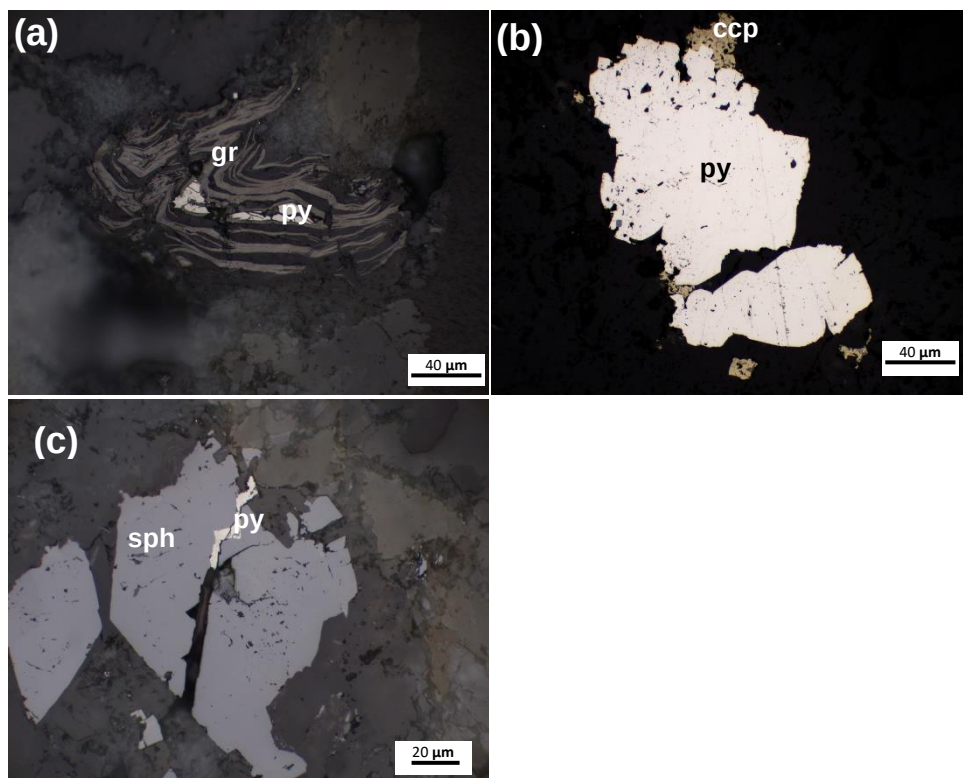


Figure 3-16 Photomicrographs of (a) pyrite coexists with graphite flakes, (b) chalcopyrite fills outline of anhedronal pyrite. (c) fine pyrite infills within sphalerite. Abbreviation: py=pyrite, ccp=chalcopyrite, sph=sphalerite, gr=graphite, qz=quartz, and REE=rare earth element.

Mineral \ Stage		Stage I	Stage II	Stage III
Ore mineral	Pyrite	abundant	Common	Minor
	Chalcopyrite	Common	Minor	Trace
	Sphalerite	Common	Minor	Trace
	Galena	Common	Minor	Trace
	Hessite	Common	Minor	Trace
	Electrum	Common	Minor	Trace
Gangue	Quartz	abundant	Common	Minor
	Graphite	Common	Minor	Trace

abundant Common Minor Trace

Figure 3-17 Paragenetic sequence at the Zaw Min Prospect

The mineralization at the Kyarpazat Prospect can be divided three paragenetic stages according to mineral assemblages. In stage 1, pyrite (1) and quartz form in the vein stages. In this stage, pyrite is very common with euhedral to subhedral form. In Stage 2, it is still pyrite (2) rich in the veins. In addition, crystalline graphite (Fig 3-8 and Fig 3-8) is very common in this stage associated with sulfide minerals. Some graphite flakes are distributed within the vein associated with pyrite (Fig 3-18b). Some pyrite crystal was deformed their morphology and corroded out-side of the crystal or pyrite 2 rims (Fig 3-18e). Among them some pyrite is gradually decrease their morphology or it might be a pyrite segregation of their generation on this stage (Fig 3-18g and h). In late mineralization stage, euhedral pyrite is formed with override to pyrite 1 (Fig 3-18d). Chalcopyrite associated with sphalerite and hessite (Fig 3-19a, b, c). Some electrum grains are scattered on the chalcopyrite. Galena formed around chalcopyrite. Fine grained graphite exhibits in late stage. Minor sericite alteration (Fig 3-9) occurs together with crystalline graphite in stage II.

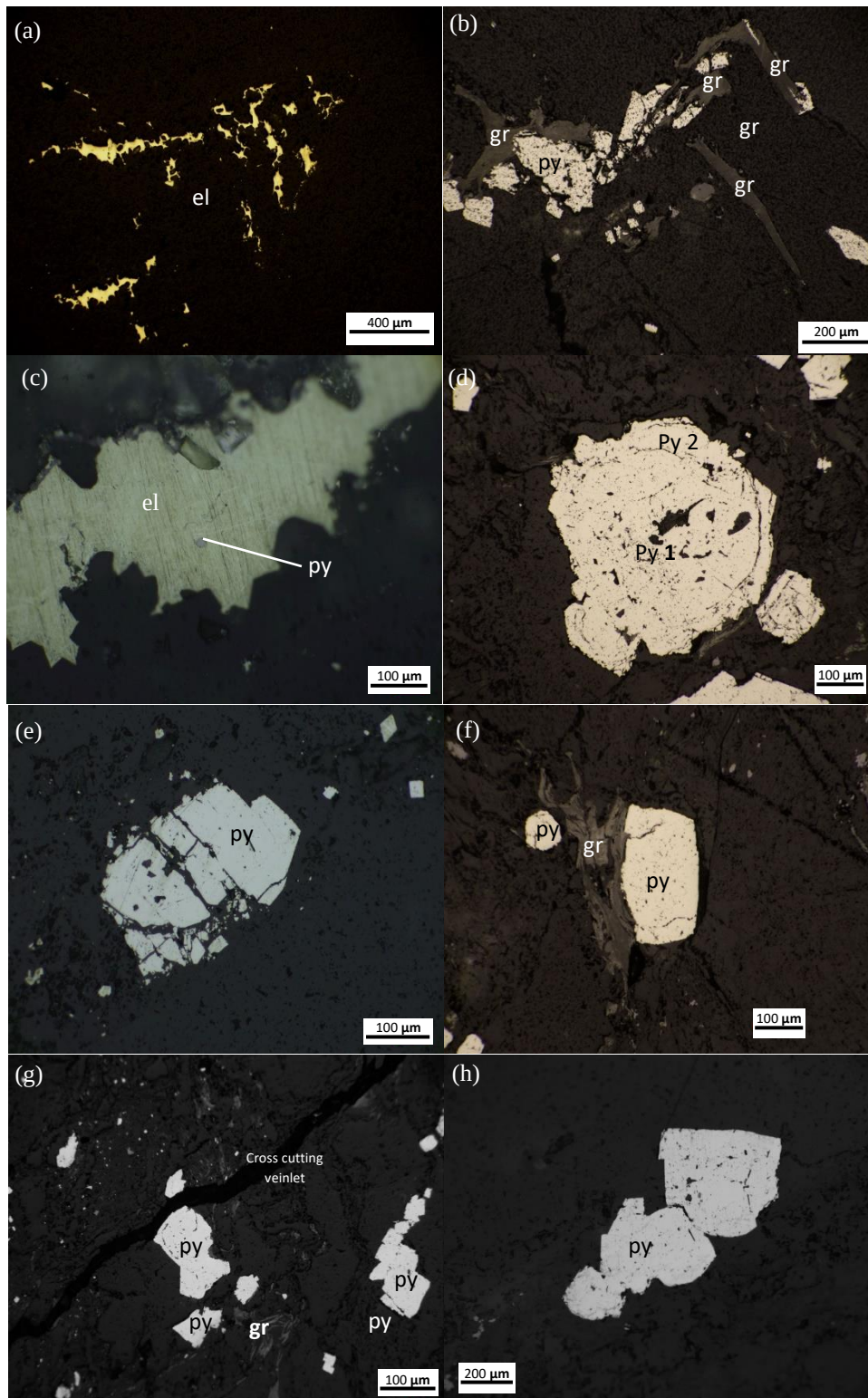


Figure 3-18 Photomicrographs of crystalline graphite rich with mineralization (a) free electrum grain, (b) coarse-grained graphite flake with pyrite, (c) pyrite disease in electrum, (d) rounded zoned pyrite in quartz graphite vein, (e) anhedral pyrite deformed and broken edge, (f) crystalline graphite places between pyrite.

Figure 3-18 (g) and (h) late hydrothermal veinlet cross-cuts to anhedral pyrite and right-side pyrite gradually changes the form into a fine grain size. It occurs in auriferous mineralized graphite bearing black quartz vein. Abbreviation: py=pyrite, gr=graphite, qz=quartz, el=electrum and gr=graphite.

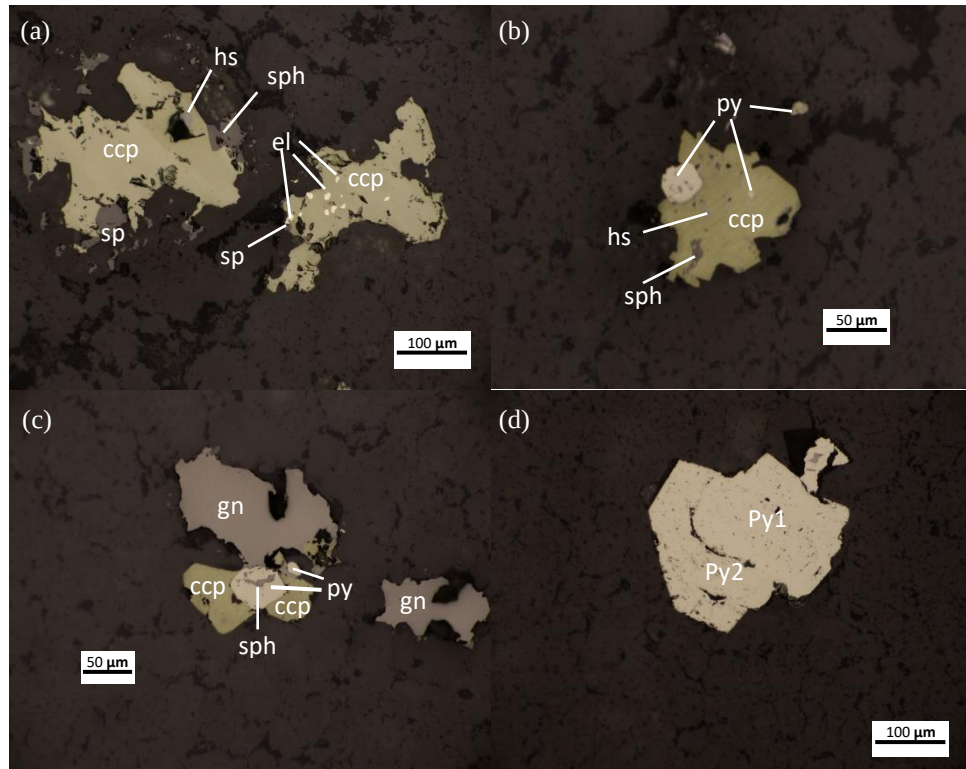


Figure 3-19 Photomicrographs show (a) Electrums locked within chalcopyrite and hessite is later forming in chalcopyrite, sphalerite also later stage forming mineral (b) Hessite is within chalcopyrite and sphalerite, pyrite formed in early stage, (c) pyrite is coexisted with chalcopyrite and galena and sphalerite is replace in the pyrite and hessite diseases is in chalcopyrite. (d) Anhedral pyrite 1 is overgrowth with pyrite 2 and sphalerite formed in late stage mineralization. Abbreviation: py=pyrite, ccp=chalcopyrite, sph=sphalerite, gr=graphite, qz=quartz, hs=hessite, gn=galena and el=electrum.

Mineral \ Stage		Stage I	Stage II	Stage III
Ore mineral	Pyrite 1	Abundant		
	Pyrite 2			
	Chalcopyrite			
	Sphalerite			
	Galena			
	Hessite			
	Electrum			
Gangue mineral	Quartz			
	Graphite (Flake)			
	Graphite (fine)			
	Sericite			

Abundant Common Minor Trace

Figure 3-20 Simplified paragenetic sequence in the Kyarpazat prospect

3.11 SEM-EDS analysis on electrum grains

Electrum often observes as free grains. Some electrums are frequently associated with pyrite and occurs as encapsulate grain in pyrite. In quartz vein, electrum ranges nearly 1 cm in length. The grain size of the electrum generally ranges from over 400 μm to 5 μm . Some electrum grains from three prospects (Myo Lwin, Kyarpazat and Zaw Min) were analyzed by SEM-EDS (see Appendix A, B, and C). The Ag content at the Myo Lwin Prospect ranges from 25 to 40 at.%. The average of the Ag at.% ranges 25 to 35 at.%. The Ag content at the Zaw Min Prospect ranges from 35 to 45 at.%. The average on the Ag at.% is 40 to 45 at.%. The Ag content of Kyarpazat Prospect from graphite associated quartz vein ranges from 35 to 45 at% and the average on the Ag at.% is 35 to 40 at.%. Therefore, The Ag content on the electrum grains from the Myo Lwin Prospect is lower than that of other two prospects, and to compare with Zaw Min Prospect and Kyarpazat, the Ag content on the electrum of the Zaw Min Prospect is slightly higher than the Kyarpazat Prospect. Hence, high gold concentration suggests the high temperature. As compared geochemical data by SEM-EDS, the graphite associated gold quartz vein of the Myo Lwin and Kyarpazat Prospects are higher temperature than those of the Zaw Min Prospect.

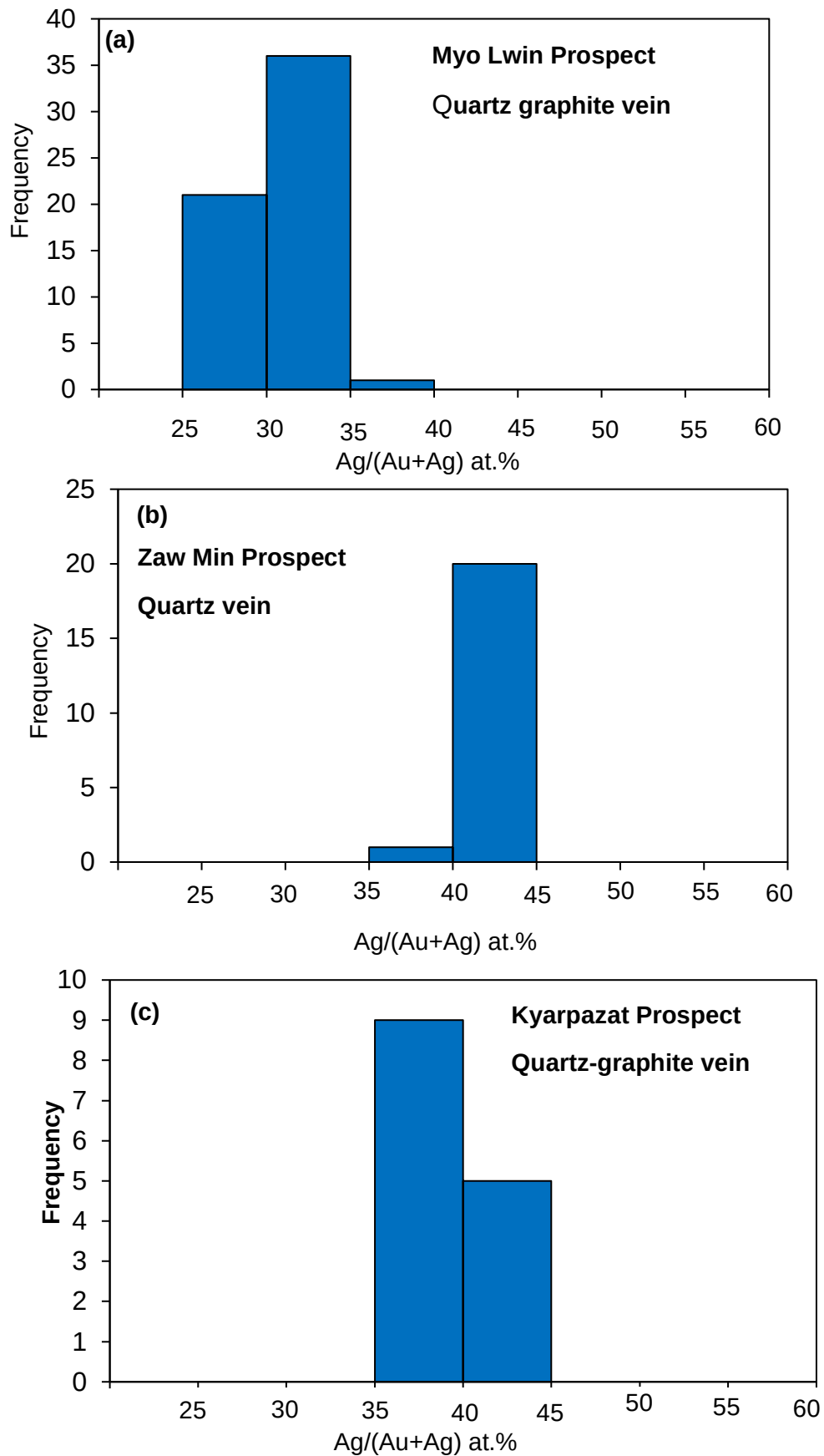


Fig 3.21 Histogram (a, b, c) for Ag/(Au+Ag) at.% from graphite associated gold-sulfide vein (quartz graphite veins) at the Myo Lwin Prospect and Kyarpazat, and quartz veins at the Zaw Min Prospect.

3.12 Summary

The gold mineralization hosted in quartz graphite vein is a unique feature in the Wabo district. Structural feature of the dark quartz veins (mineralized quartz graphite vein) varies in centimeter to meter in width. The signature of vein structure is recognized as displacement vein, ribbon quartz in auriferous quartz graphite veins, mineralized breccia and vein types. Quartz texture displays sub-rounding, elongate, undulose extinction, and preferred orientation. It is a distinctive character to estimate the ore forming temperature from gold concentration of electrum under the reducing environment. Higher gold concentration indicates in quartz graphite vein at Myo Lwin Prospect. So, graphite coexists with gold mineralized veins plays an important role in the chemical evolution of the ore fluids and tracer for economic exploration. Other ore minerals are galena, sphalerite, hessite, with minor chalcopyrite. To compare the gold enrichment among mineralized quartz veins, the graphite associated quartz veins are more gold rich than graphite free quartz veins in the Wabo district.

CHAPTER IV

QUARTZ-CARBONATE VEINS AT THE KYAW SOE THU PROSPECT

4.1 Textural features of the veins

Gold bearing veins are hosted by garnet-biotite gneiss at the Kyaw Soe Thu Prospect. The Kyaw Soe Thu Prospect lies at the top of mountain (Arkartha Taung) in the Wabo area. The host rocks are strongly altered adjacent to the mineralized quartz veins. Sometimes, remarkable striations are recorded on the surface of quartz veins. The veins range from 4 cm to 7 cm in thickness along metamorphic foliation planes of the host

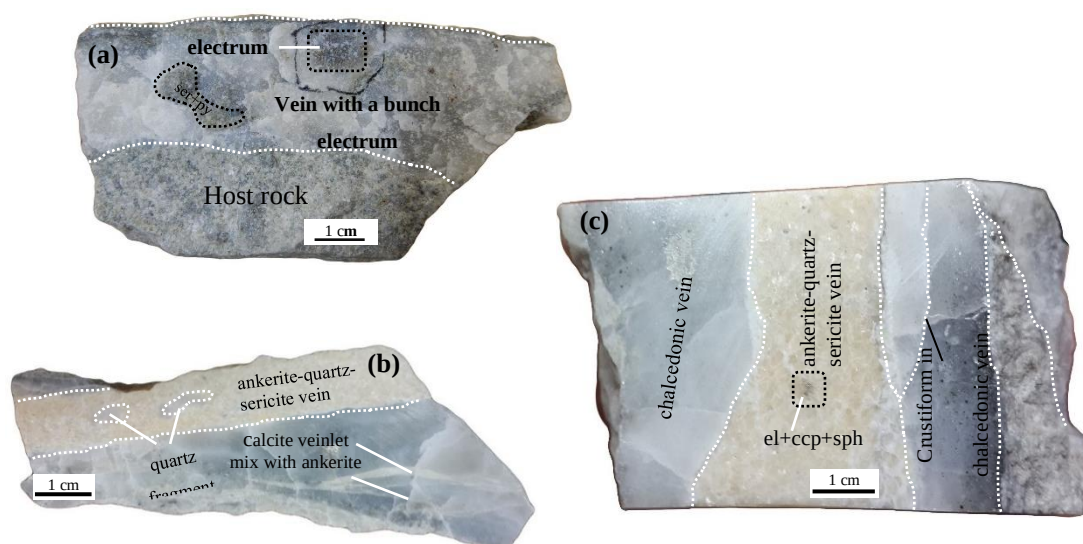


Figure 4-1 Photographs of stage I thin crustiform layer between host rock and chalcadonic quartz vein, stage II quartz vein samples and stage III ankerite-quartz-sericite vein samples. (a) KST-01 Host-rock fragment within the stage II quartz vein adjacent to host rock with clear and sharp contact that is stage I thin crustiform layer (white dotted line). (b) KST-02 stage III ankerite-quartz-sericite vein with stage III calcite cross-cutting the stage II chalcadonic quartz vein. (c) KST-02 stage III ankerite-quartz-sericite vein with sharp boundary with stage I chalcadonic quartz vein and altered rock fragments with sericite. The square by dotted in the central part of stage II

rocks as well as along fractures in the fault zones. The quartz veins in the Wabo deposit are dominantly composed of milky, green, sometimes blue, and white quartz. Among them, smoky and milky quartz are the most common in the Wabo deposit. White quartz is not dominant in the veins at the Kyaw Soe Thu Prospect. Mineralized chalcadonic

quartz vein ranges from 1 cm to 3 cm in width (Fig 4-1a). The vein is composed of fine quartz grains and some fragments of earlier quartz. The band of ankerite-quartz-sericite vein at the Kyaw Soe Thu Prospect ranges from 1 cm to 2 cm. (Fig 4-1b and 4-1c) in width. The boundary is distinctly sharp between the chalcedonic quartz veins and the ankerite-quartz-sericite veins. Ankerite and electrum are observed in the stage III veins cross-cutting the stage II chalcedonic quartz veins.

4.2 Mineralization at the Kyaw Soe Thu Prospect

Stage I mineralization: the earliest stage I consists of quartz, pyrite, and minor chalcopyrite. It occurs as chalcedonic quartz veins. Quartz crystals are fine-grained. The sulfide minerals appear to have formed as cementing the rock fragments in the veins. Sericite alteration occurred in this stage.

Stage II mineralization: stage II represents the formation of quartz with sulfide and electrum. Quartz in the stage II veins is smoky and milky associated with pyrite, chalcopyrite and sphalerite. The quartz veins are composed of fine-grained randomly distributed quartz crystals. The cluster of electrums ranges up to 1 cm in size and mostly coarse grained (Fig 4-3a). The electrum grains are closely associated with pyrite (Fig 4-3b). Traces of sphalerite and chalcopyrite (Fig 4-3c) are also formed in stage II. Sometimes electrum grains are found on the margin of the pyrite grains (Fig 4-3d).

Stage III mineralization: stage III consists of ankerite-quartz-sericite veins. These veins crosscut the stage II mineralization veins. The stage III veins are composed of mainly ankerite, quartz, sericite, electrum, sphalerite and chalcopyrite. Electrum occurs as fine and anhedral grains in euhedral ankerite crystals (Fig 4-4a and 4-4b). The electrum grain ranges from 20 μm up to 200 μm in length. Sphalerite (Fig 4-4b) is fine-grained and anhedral and closely associated with fine-grained anhedral electrum. Chalcopyrite is also fine-grained. Calcite veins cross-cut the stage II quartz veins. The margins of calcite veinlets with the stage II quartz veins are irregular. Some stage II quartz grains were intersected sharply by late calcite and ankerite-quartz-sericite veins.

In some places fine- to coarse-grained ankerite-quartz-sericite veins cross-cut the chalcedonic quartz vein. These ankerite-quartz-sericite veins are milky, pale brown in color and ankerite crystals are also visible with naked-eyes. Sometimes ankerite crystals are noticeably observed as a milky spot in the chalcedonic quartz vein. Some host rocks

are found as breccia fragments preserved within the ankerite-quartz-sericite veins. These ankerite-quartz-sericite veins are closely related with the gold mineralization. The irregular thin layers of calcite and ankerite-quartz-sericite veinlets are also cross-cutting each other. It appears to be stage III mineralization events as calcite and ankerite-quartz-sericite veins are cross-cutting the early chalcedonic quartz veins.

4.3 Ankerite-quartz-sericite veins

The late hydrothermal mineralized veins or stage III ankerite-quartz-sericite veins are dominantly composed of carbonate mineral (ankerite), quartz and small amount of sericite with a few calcites. The principal ore minerals in the stage III ankerite-quartz-sericite veins are electrum with minor sphalerite and chalcopryrite.

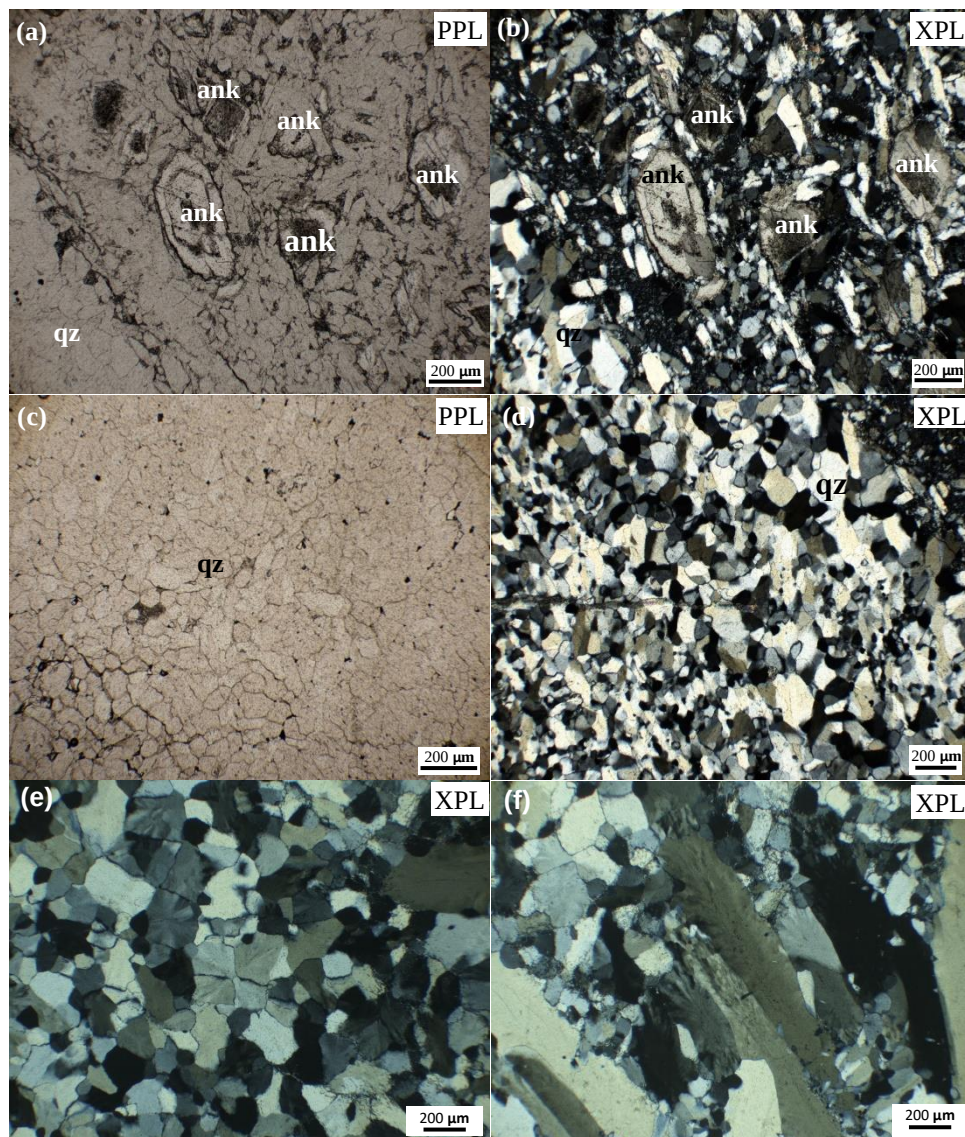
This study is the first-time documentation of the electrum-bearing ankerite-quartz-sericite veins in the Wabo deposit area. Ankerite-quartz-sericite veins are found mainly as later veins. The ankerite observed at the Kyaw Soe Thu Prospect in hand specimen is light pink, milky, and pale brown in color. The ankerite-quartz-sericite veins range in width from a centimeter to two centimeters.

All ankerite grains at the Kyaw Soe Thu Prospect are rhombohedral (Fig 4.2 a and 4.2 b). These crystals reach over 400 μm in size at most. They occur together with the very thin calcite veinlets or cross-cutting veinlets. Zonings of the ankerite are observed in well-crystallized euhedral ankerite grains.

4.4 Quartz texture

Quartz is a generally ubiquitous gangue mineral in the Kyaw Soe Thu Prospect. The hydrothermal quartz in the stage I thin crustiform quartz layer, in the stage II chalcedonic quartz vein, and stage III ankerite-quartz-sericite veins displays distinctive textures associated with gold mineralization. Quartz commonly exhibits chalcedonic texture as well as saccharoidal and granular textures (Fig 4-2c and 4-2d). Some of quartz crystals are elongated with subhedral to anhedral habit. Micro-plumose texture (Fig 4-2e) exhibits a feathery (Fig 4-2f) appearance in some parts of the stage I thin layered crustiform, stage II chalcedonic quartz vein and a few quartz crystals in the stage III ankerite-quartz-sericite vein. Within stage III ankerite-quartz-sericite veins, prismatic quartz crystals are aligned parallel to ankerite crystals. Calcite is cross-cutting

radiating feathery quartz crystals. Crustiform thin layers are recognizable in stage I quartz. Electrum occurs in the stage II chalcedonic quartz veins and in the stage III ankerite-quartz-sericite veins. An alteration mineral is sericite on the margin of quartz crystals of stage II chalcedonic veins and in the stage III ankerite-quartz-sericite veins (Fig 4-2g and 4-2h). Calcite occurs as the latest veinlets and cross-cut in the stage II chalcedonic quartz vein (Fig 4-2i and 4-2j).



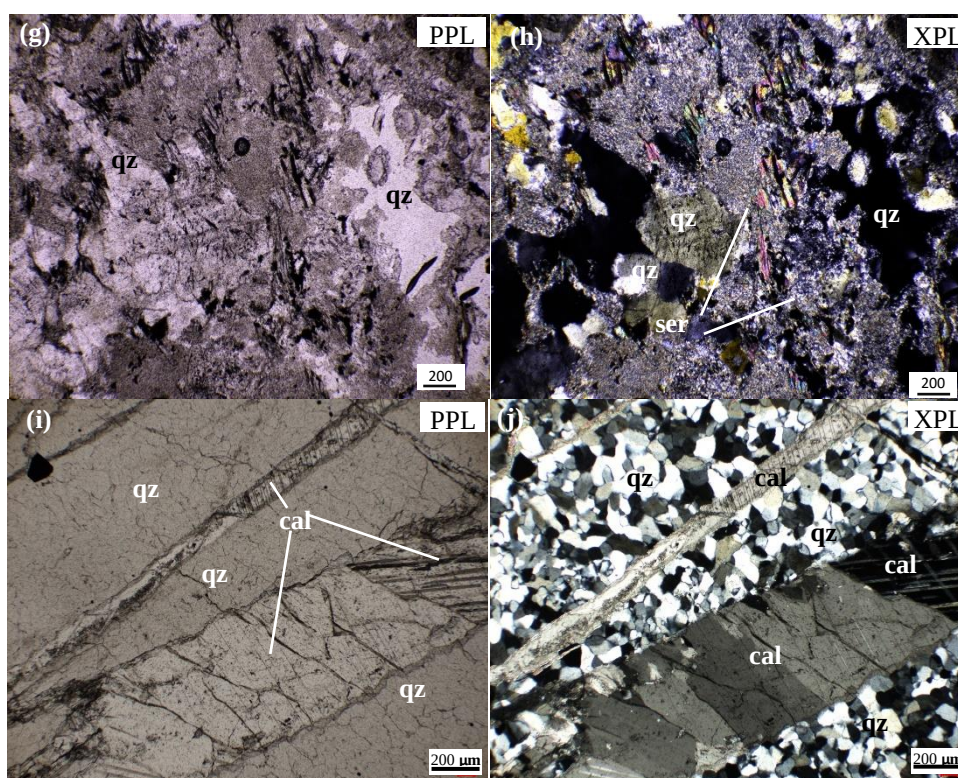


Figure 4-2 Photomicrographs of stage III ankerite-quartz-sericite vein crosscutting stage II chalcedonic quartz vein (KST-02). (a), (b) Rhombohedral ankerite with rhythmic overgrowth in stage III ankerite-quartz-sericite vein. (c), (d) Massive quartz consisting of fine-grained granular quartz showing mosaic texture in stage II chalcedonic quartz vein. (e) Plumose quartz texture with feathery appearance in chalcedonic quartz vein. (f) Feathery quartz texture in stage II chalcedonic quartz vein. (g), (h) Sericite alteration of host rock fragments with quartz cement. Sericite also forms within the vein. (i), (j) Stage III calcite veinlet crosscutting stage II chalcedonic quartz vein. Abbreviations: qz= quartz, cal=calcite, ser=sericite, ank=ankerite. XPL=crossed polarized light, PPL=plane polarized light.

4.5 Ore mineralogy and paragenesis

The gold mineralization stages are classified into three stages. Stage I recognizes a thin crustiform quartz layers. It displays a smoky colored thin crustiform quartz layers. It is mostly pyrite and a few fine-grained chalcopyrites. The pyrite crystals are mostly subhedral to anhedral. Stage II displays a massive chalcedonic quartz vein and exhibits a milky and white color. In stage II, the ore minerals are pyrite, electrum, chalcopyrite and a very few sphalerites. Pyrite commonly occurs as subhedral to anhedral form with a diameter of 100 µm to 200 µm. In some places, it is closely associated with electrum.

Chalcopyrite is fine-grained. Stage III indicates ankerite-quartz-sericite vein phase. It is mainly composed of ankerite with calcite and sericite. The ore minerals are electrum, pyrite, chalcopyrite and sphalerite. The principal gangue minerals are ankerite, quartz, and calcite. Sphalerite forms as small particles with electrum grains in the stage III ankerite-quartz-sericite veins and also in the Stage II chalcedonic quartz veins. Chalcopyrite occurs as tiny particles at the edge of electrum grains in the stage III ankerite-quartz-sericite veins. Chalcopyrite is not common in the Kyaw Soe Thu Prospect. Electrum dominantly occurs in not only stage II chalcedonic quartz veins but also in the stage III ankerite-quartz-sericite veins in the Kyaw Soe Thu Prospect. The morphology of electrum in quartz veins appears as a bunch of grains that are nearly 1 cm wide in the stage II chalcedonic quartz veins.

Samples from stage II chalcedonic quartz vein and from stage III ankerite-quartz-sericite vein at the Kyaw Soe Thu Prospect were selected for SEM-EDX (Fig 4-5a and 4.5b) (see Appendix D and E) to identify Au - Ag ratio by semiquantitative analysis (see Appendix D and E). The $\text{Ag}/(\text{Au}+\text{Ag})$ of electrum in the stage II chalcedonic quartz veins of the Kyaw Soe Thu Prospect ranges from 35 to 50 at.% (Fig 4-6). The $\text{Ag}/(\text{Au}+\text{Ag})$ of electrum from the stage III ankerite-quartz-sericite vein ranges from 30 to 50 at.% (Fig 4-6).

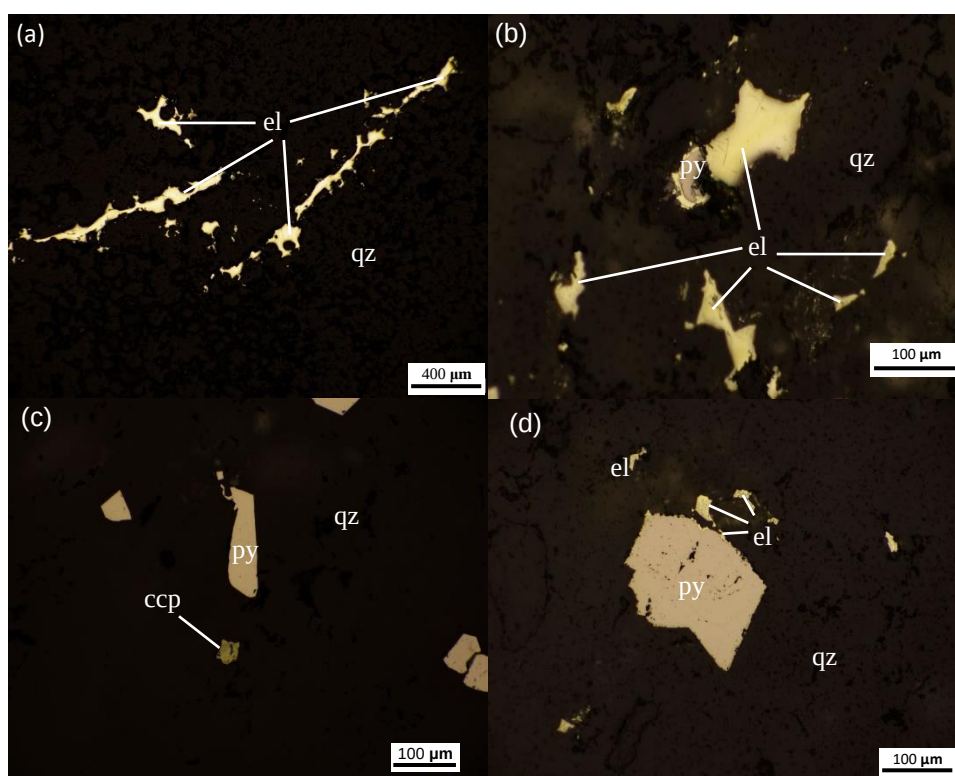


Figure 4-3 Photomicrographs of ore minerals in stage II quartz vein (KST-01) from Kyaw Soe Thu Prospect. (a) Coarse-grained electrum. (b) Pyrite associated with electrum. (c) Anhydrous pyrite formed fine-grained chalcopyrite. (d) Fine-grained electrum on the margin of pyrite. Abbreviations: py=pyrite, ccp=chalcopyrite, el=electrum, qz =quartz.

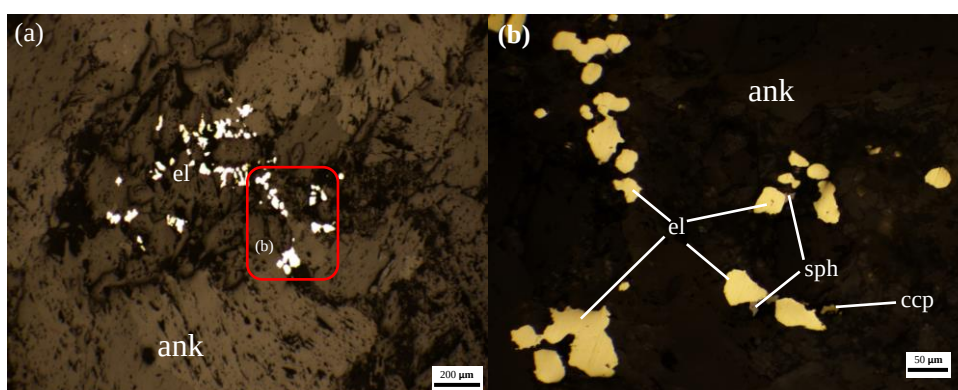


Figure 4-4 Photomicrographs of stage III ore minerals in the rectangle by dotted lines in the central part of the stage III ankerite-quartz-sericite vein crosscutting the stage II stage chalcedonic quartz vein shown in Fig 4-1 (c) (KST-02) from the Kyaw Soe Thu Prospect. (a) Irregular electrum grains in stage III ankerite-quartz-sericite vein. Red rectangle is enlarged in (b). (b) Electrum grains associated with fine-grained sphalerite and chalcopyrite. Abbreviations: ccp=chalcopyrite, sph=sphalerite, el=electrum, ank=ankerite, qz=quartz.

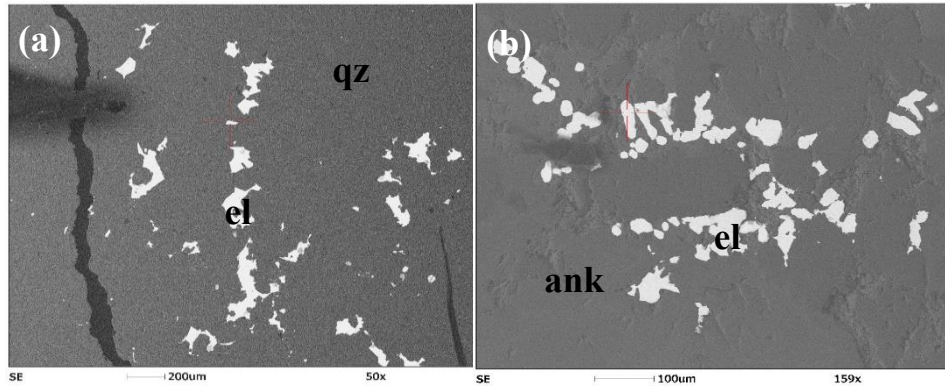


Figure 4-5 Backscattered image of the electron grain for (a) chalcedonic quartz vein and (b) ankerite-quartz-sericite vein at the Kyaw Soe Thu Prospect. Abbreviation: el=electrum, qz=quartz, ank=ankerite.

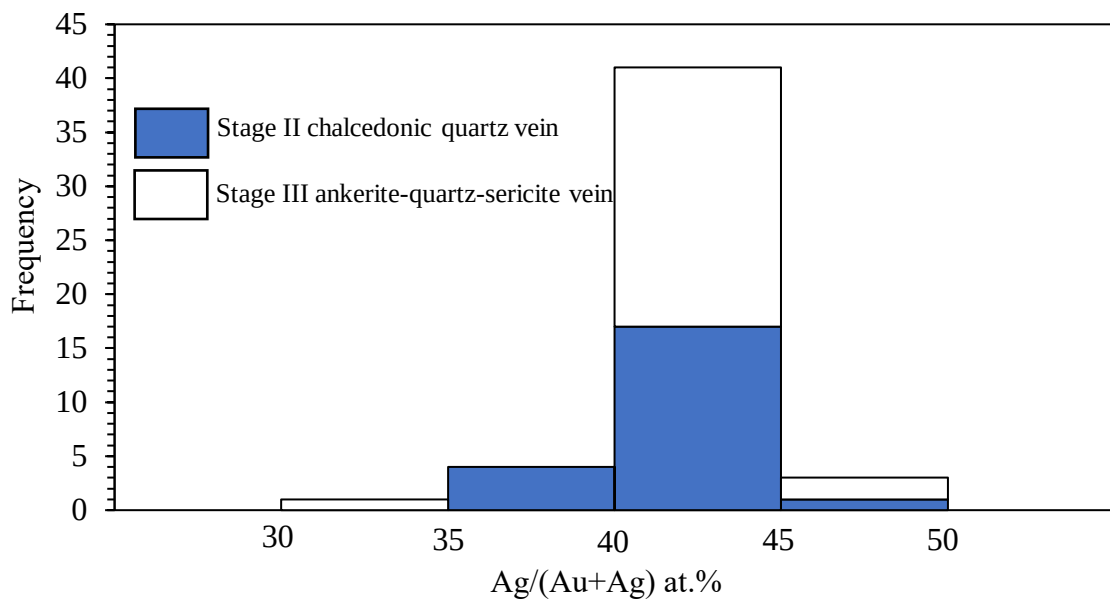


Figure 4-6 Frequency diagram of Ag/(Au+Ag) at.% of electrum from stage II chalcedonic quartz vein (KST-01) and stage III ankerite-quartz-sericite vein (KST-02) from the Kyaw Soe Thu Prospect in the Wabo deposit.

Mineral \ Stage		Stage I	Stage II	Stage III
ore mineral	Pyrite			
	Chalcopyrite			
	Sphalerite			
	Electrum			
gangue mineral	Quartz			
	Ankerite			
	Calcite			
	Sericite			

Major
 Common
 Minor
 Trace

Figure 4-7 Paragenetic sequence of thin crustiform layer, chalcedonic quartz vein and ankerite-quartz-sericite vein in the Kyaw Soe Thu Prospect.

4.6 Geochemistry of quartz-carbonate vein at the Kyaw Soe Thu Prospect

The carbonate veins, it is the most abundant minerals in the mineralized vein at Kyaw Soe Thu Prospect. During mineralization stage, carbonate is quite significant together with mineralizing fluids, quartz and minor clay minerals (sericite). The elemental composition of the carbonate is used from the XRF data (Appendix F) of mineralized quartz-carbonate vein. The quartz-carbonate veins are more abundant associated with gold mineralization in the Kyaw Soe Thu Prospect. The XRF analysis on bulk chemical composition of quartz-carbonate vein at the Kyaw Soe Thu Prospect shows that the sample (KST 02-0) is SiO₂-21.4%; FeO-14.8%; MnO-0.6%; MgO-19.1%; CaO-42.4%, and (KST-02-1) is SiO₂-29.4 %: FeO-13.4%; MnO- 0.6%; MgO-16.8%; CaO-38.3% and respectively. The bulk chemical composition of quartz-carbonate vein is composed of SiO₂, FeO, MnO, MgO and CaO with relatively large amount of CO₂. The carbonate

minerals are predominantly composed of FeO, MgO, CaO and minor amount of MnO. Therefore, it needs to recalculate a bulk composition to know an actual carbonate chemical composition by removing SiO₂ weight percent from XRF analysis of both samples. The calculation is based on stoichiometry of carbonate mineral. The indication of FeO amount, minor MnO, MgO and CaO, the carbonate mineral is ankerite (Fig 4-8). So, the CO₂ rich carbonate vein with iron oxide mineral is closely associated with the high-grade gold content at the Kyaw Soe Thu Prospect, Wabo District.

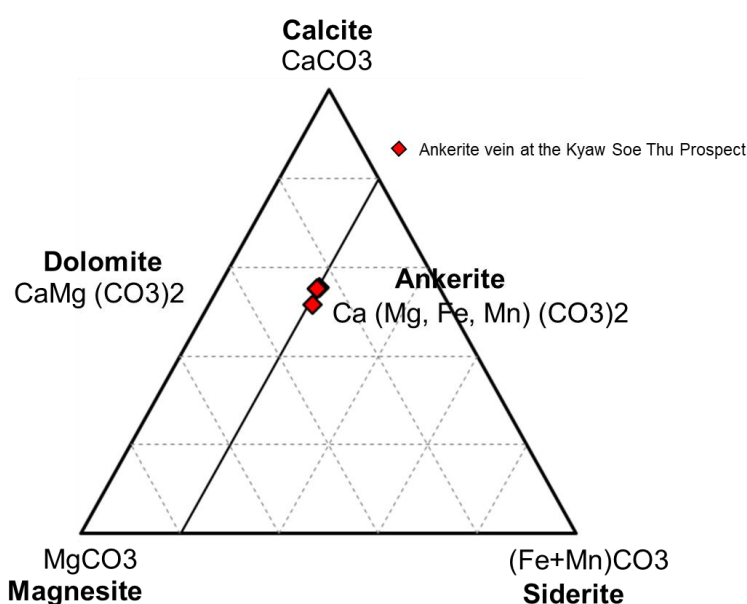


Figure 4-8 Chemical composition of representative carbonate mineral (ankerite) of the Kyaw Soe Thu Prospect, Wabo District

4.7 Discussion

The Wabo deposits is located in the Southern Himalayan Orogenic syntaxis and MMB (Khin Zaw et al., 2017). The mineralization is hosted by amphibolite to granulite facies metamorphic rocks. It is formed in a structural deformed zone. Quartz veins with gold mineralization are widespread in the Wuntho area and on the western margins of the MMB and the Shan Plateau in the Slate Belt in Myanmar by Searle and Haq (1964) (Fig 2-1). Mining of primary gold deposits has been conducted at Kyaukpazat to the North of Wuntho. In the Wuntho area and several areas along the western margin of the Shan Plateau, including Modi Taung, east of Tatkon and Phayaung Taung, NE of Mandalay are the significant gold occurrences. Although most of the primary mesothermal orogenic lode gold mineralization is commonly widespread (Chapman et al., 2016), the Kyaukpahto deposits in the Wuntho area is a Carlin-like sediment-hosted

deposits in Eocene turbiditic sandstones (Ye Myint Swe et al., 2017; Khin Zaw et al., 2017). The gold mineralization in the Wabo deposit in the MMB is hosted by the garnet-biotite gneiss, calc-silicate, marble and biotite granite. The veins are in some place massive veins, sheeted, networking each other, and exhibit saddle-reef and ribbon structures. The vein-type quartz gold mineralization at the Kyaw Soe Thu Prospect is formed in a fault system.

Chalcedony at the Kyaw Soe Thu Prospect is considered to have formed either by direct precipitation from hydrothermal solution or by transformation of amorphous silica to crystalline materials as suggested by (Dong et al., 1995). Quartz with radiating texture shows a plumose texture. Some plumose textures are interpreted to reflect the crystallization of amorphous silica to quartz by Sandar and Black (1988). Textures formed by recrystallization of amorphous silica to chalcedony, such as the plumose (radiating) texture, are restricted to near-surface hydrothermal condition by Vearncombe, (1993). Dong et al. (1995) indicated that these textures are loosely packed vitreous to milky fine-grained quartz cluster having the appearance of saccharoidal in hand specimens. Morrison (1990) indicated that intermediate silica supersaturation with respect to quartz is needed for chalcedony to precipitate directly from solution. Morrison (1990) also showed that chalcedony forms persistently only at temperature below about 180 °C. The hydrothermal chalcedony quartz associated with gold mineralization may be formed the temperature around 180 °C as formation of chalcedony with recrystallized quartz texture. After mineralized quartz formation, temperature and pressure may have dropped within the mineralized quartz vein fracture. Then, the carbonate veining associated gold mineralization has followed as the late hydrothermal gold mineralization under the low temperature condition. Ankerite associated gold mineralization might be indicated the hydrothermal system that perhaps a iron sulfides associated with gold formation at the Kyaw Soe Thu Prospect.

4.8 Summary

Gold-bearing quartz veins are hosted by the metasedimentary rocks in the Wabo area. Structurally, mineralization at the Kyaw Soe Thu Prospect in Wabo district is probably considered a related with the deformation of MMB. Kyaw Soe Thu Prospect related to those structure control of faults. The structure control will provide a weakness zone in the host rocks for channel way of hydrothermal fluids responsible for mineralization at

the Kyaw Soe Thu Prospect. The nature of vein margins is generally sharp, and the veins are mostly steeply dipping. In the Kyaw Soe Thu Prospect, slickenside and striation are also observed along the mineralized quartz vein on the vein surfaces. The abundance carbonate veining systems are indicating that the type of gold deposits. The hydrothermal process may be formed within near surface during igneous activity in the Miocene. The hydrothermal fluids may migrate upwards along fracture or fault into near the surface. Therefore, it is assumed that the lithology of host rocks and structure are the main control the formation of gold mineralization. The carbonate vein is indicated ankerite that based on stoichiometry calculation. Consequently, the multiple stage of gold mineralization may likely relate the Kabaing Granite intrusion along MMB during Miocene age. Based on the texture of the chalcedonic quartz veins, the mineralization at the Kyaw Soe Thu Prospect in the Wabo gold deposit can be classified as a low-sulfidation epithermal deposit.

CHAPTER V

FLUID INCLUSION STUDIES

5.1 Sample materials and analytical methods

Representative mineralized vein hosted quartz samples from the Zaw Min Prospect were collected for fluid inclusions study. Fluid inclusions were analysed in doubly polished 100-300 μm thick wafers. The quartz samples were cut to observe fluid inclusions. On polished thick sections of quartz samples were examined under the microscope. Of these five polished thick sections were selected to carry out microthermometric analysis and to investigate fluid trap temperature in the mineralized quartz vein. After fluid inclusion observation petrography under microscope, the microthermometric study was conducted only on primary fluid inclusions (Roedder, 1984). Microthermometric measurements were performed on a Linkam THM 600 heating-freezing stage at the Economic Geology Laboratory, Department of Earth Resources Engineering, Kyushu University, Japan. The precision of measurements below 0 °C was ± 0.1 °C and of homogenization temperature was ± 0.5 °C. Salinity of fluid inclusions was calculated in weight percent NaCl equivalent using the system H_2O -NaCl (Bodnar, 1993) and on clathrate melting temperature (Diamond, 2001; Collins, 1979) for liquid CO_2 -bearing inclusion. While the microthermometric analysis is undertaken down to the lowest limit of temperature of the heating-freezing stage, in order to detect the presence of CO_2 . For CO_2 fluid inclusions were freeze at temperature ranging from -100 °C to -105 °C. The morphology of the CO_2 at that time formed as a compound of solid CO_2 and the CO_2 gas, clathrate and gas. During heating from cooled temperature was around -100 °C, the ice melting temperature mostly close to the triple point of pure CO_2 is -56.6 °C and the pure water of melting point is 0.1 °C (Roedder, 1984).

5.2 Fluid inclusions petrography

Fluid inclusions were studied from gold bearing quartz vein at the deep of the Zaw Min Prospect. The fluid inclusions hosted quartz are clearly white or crystalline white quartz. The distinguishing features of fluid inclusions were examined to determine the inclusion types. Most fluid inclusions contained the fluid size that are to be enough for microthermometric work. The focus on this study are the fluid inclusions trapped in the

quartz. In this study, the secondary fluid inclusions in the healed fracture were avoided conducting microthermometry. Most of fluid inclusion within the quartz are good rounding, spheroidal shape, and the daughter have not noticed. Some fluids are a grouping, a cluster, and isolated. In this study secondary, pseudo secondary fluid inclusions were avoided.

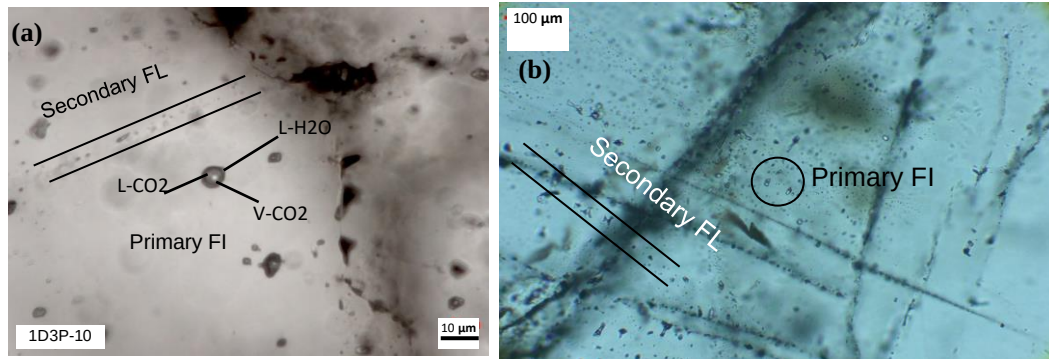


Figure 5-1 Photomicrographs of fluid inclusions (Sample (ZM-7(3))): (a) primary three-phase (aqueous carbonic) fluid inclusion in quartz vein with shape of rounded and secondary fluid inclusion parallel alignment in the quartz grain boundary. (b) secondary fluid inclusions trail crosscut to the grain boundary of quartz crystals.

5.3 Fluid inclusion types

Two types of fluid inclusion were observed on the basis of fluid inclusions in the quartz vein at the Zaw Min Prospect. The fluid inclusions were identified with three-phase (liquid H₂O+ liquid CO₂+vapor CO₂) (Fig 5-1a and 5-2a and b)) and two-phase (liquid H₂O+vapor H₂O) fluid inclusions (Fig 5-1b and 5-3a and b) in ore stage. Type I fluid is a characteristic of three phase consisting of liquid-aqueous, liquid-carbon dioxide, and vapor carbon dioxide, with the volume of the CO₂ phase (liquid) relatively high from 60 vol% to 80 vol% which is observed in gold bearing quartz vein. The whole range of CO₂ volume is obviously observed in a single fluid inclusion. The fluid inclusions size ranges from less than 5 μm up to approximately 50 μm at their long axis. The shape of fluid inclusion from these samples are spheroidal, and tube shape. Most of type I (liquid carbonic rich) were (about 75% liquid and 25% vapor) in the inclusion. Majority of type I fluid inclusions are liquid carbonic rich than vapor. Type I fluid inclusions include a clear liquid phase and gaseous bubble. During heating, most

carbonic inclusions decrepitated before to total homogenization. Hence, this time could take only a few numbers of Th-tot data from carbonic rich inclusions.

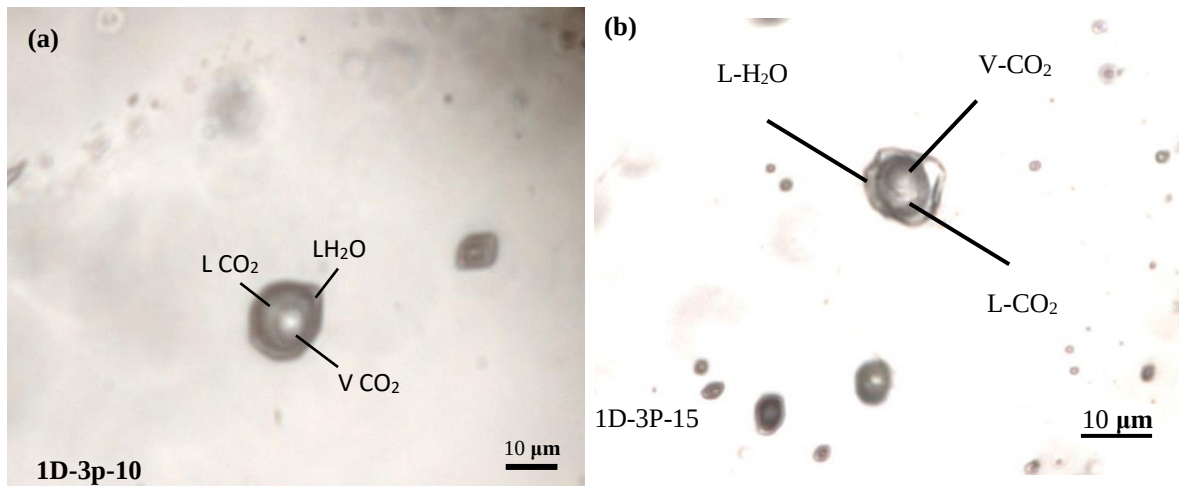


Figure 5-2 Photomicrographs of fluid inclusions of (ZM=7(3)): (a) fluid inclusion in quartz vein with shape of rounded and aqueous carbonic rich fluids. (b) fluid inclusion in the same sample with primary aqueous carbonic fluid inclusion and small inclusion also carbon dioxide rich fluid inclusions

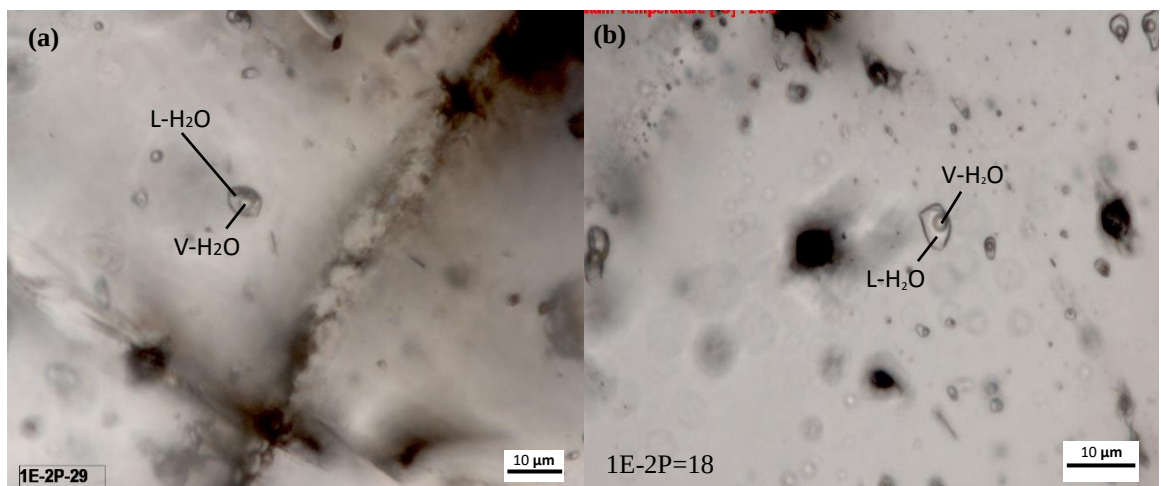


Figure 5-3 Photomicrographs of fluid inclusions: (a) primary two-phase fluid inclusion in quartz vein with shape of sub-rounded at the edge of three or four quartz grain or near the grain margin, (b) aqueous two phase primary fluid inclusion on the edge of quartz grain boundary.

Type II fluids are two-phase, they consist of combination of liquid and vapor phases (L +V) at room temperature (Fig 5-5 a) that fluid inclusions range from 5 μm to 20 μm in diameter. Most of two-phase inclusions are ellipsoidal and sub-rounding and relatively small than three-phase fluid inclusions. They are dominant fluid inclusion types in the mineralized quartz vein. These differing properties of liquids and vapor phase present in the inclusion are recorded at room temperature.

5.4 Microthermometric analysis of fluid inclusions

The microthermometry of the fluid inclusions was analyzed by conducting heating freezing experiments on the inclusions in mineralized quartz samples from the study area. Histogram showing frequency distribution of homogenization temperature (T_h) for two phase and three phase fluid inclusions. These distribution patterns could represent a population of inclusions trapped wide range of P-T conditions implying an evolution of fluid entrapment.

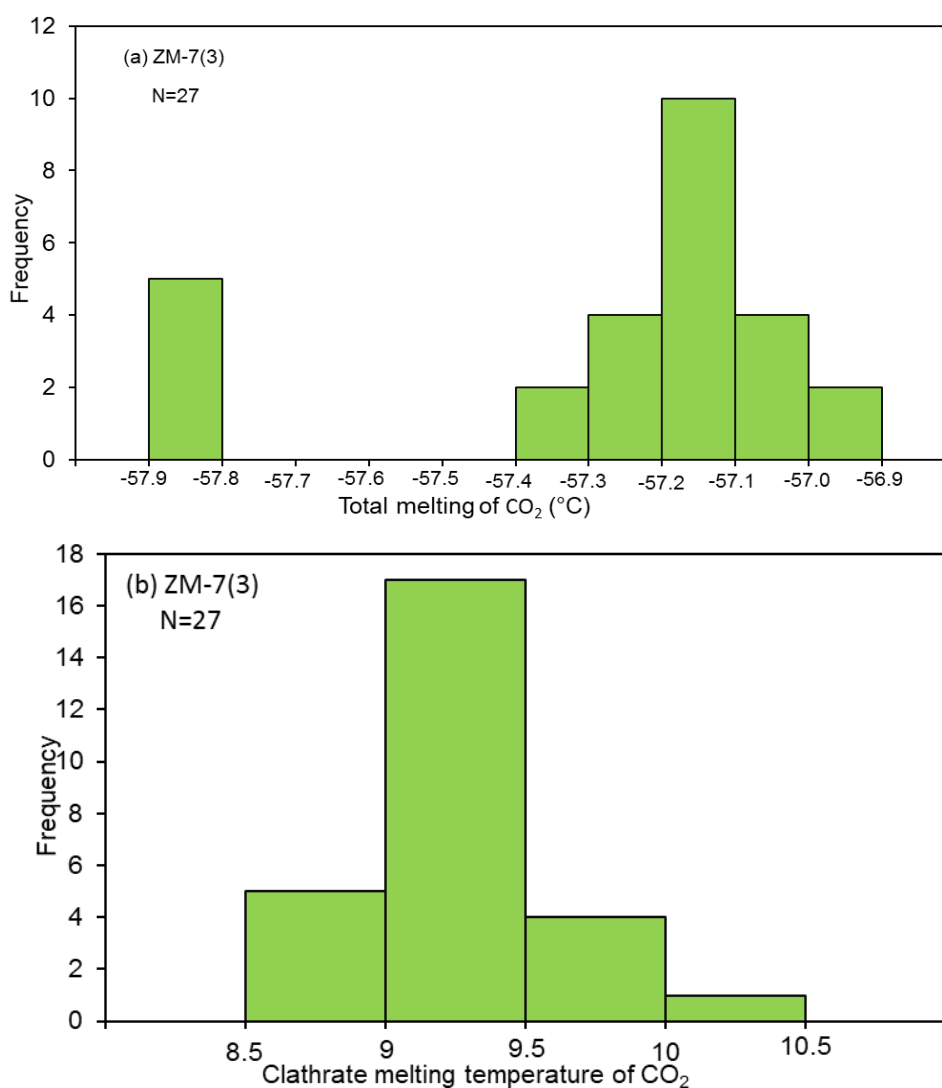
5.4.1 Type I

After heating from the low temperature, the melting temperature of the CO_2 bearing phase ($T_{m-\text{CO}_2}$) appeared in a closely space interval from the quartz vein samples, on heating slowly the first liquid CO_2 appeared between -57.4°C and -56.9°C , and a fluid was -57.8°C to -57.9°C (Fig 5-4a). The vapor bubble is disordered by an invisible solid phase which may be the clathrate. The formation of clathrates recorded on the type I inclusions, which range from 8.7°C to 10.2°C (Fig 5-4b). The clathrate disassociation is accompanied by rapid appearance of liquid CO_2 around a perfectly rounded gas bubble rich in CO_2 . The salinities of carbonic rich fluid inclusion are very low salinities ranging with 0.2 wt% to 2.6 wt%NaCl equivalent (Fig 5-4c). The salinity calculated from the clathrate melting temperature. Measurement of T_m and T_h were conducted on primary fluid inclusions. There is no characteristic of necking-down. The homogenization temperature of CO_2 is ranging 29°C to 32.5°C (Fig 5-4d). Except of a fluid inclusion which is 23.5°C . Most of carbon-dioxide fluid inclusion were homogenized into liquid CO_2 . It means while increasing temperature, the vapor of aqueous carbon fluid inclusion is getting disappear by shrinkage into liquid carbon dioxide. Decrepitated fluid inclusion of type I are frequent disappeared before the reaching of final total homogenization temperature (between 310°C to 330°C). The

measurement of total homogenization temperature of type I fluid inclusions ranges from 323°C and 361°C.

5.4.2 Type II

The salinities of type II inclusions are also low salinity. It ranges from 0.88 to 2.9 wt%NaCl equivalent (Fig 5-5a). The total homogenization temperature of type II fluid inclusions is 228°C to 373.1°C. Histograms (Fig 5-7b) show temperature of homogenization against frequency (for mineralized quartz). The summarized details have been presented in (Table 5.1). Two-phase in the salinity-total homogenization temperature diagrams, aqueous inclusions are characterized by relatively low salinities and medium temperature, whereas CO₂ bearing inclusions have relatively low salinities and high temperature. The temperature and salinity of ore fluid can be estimated according to the plot of homogenization temperature versus salinity (Fig 5-6).



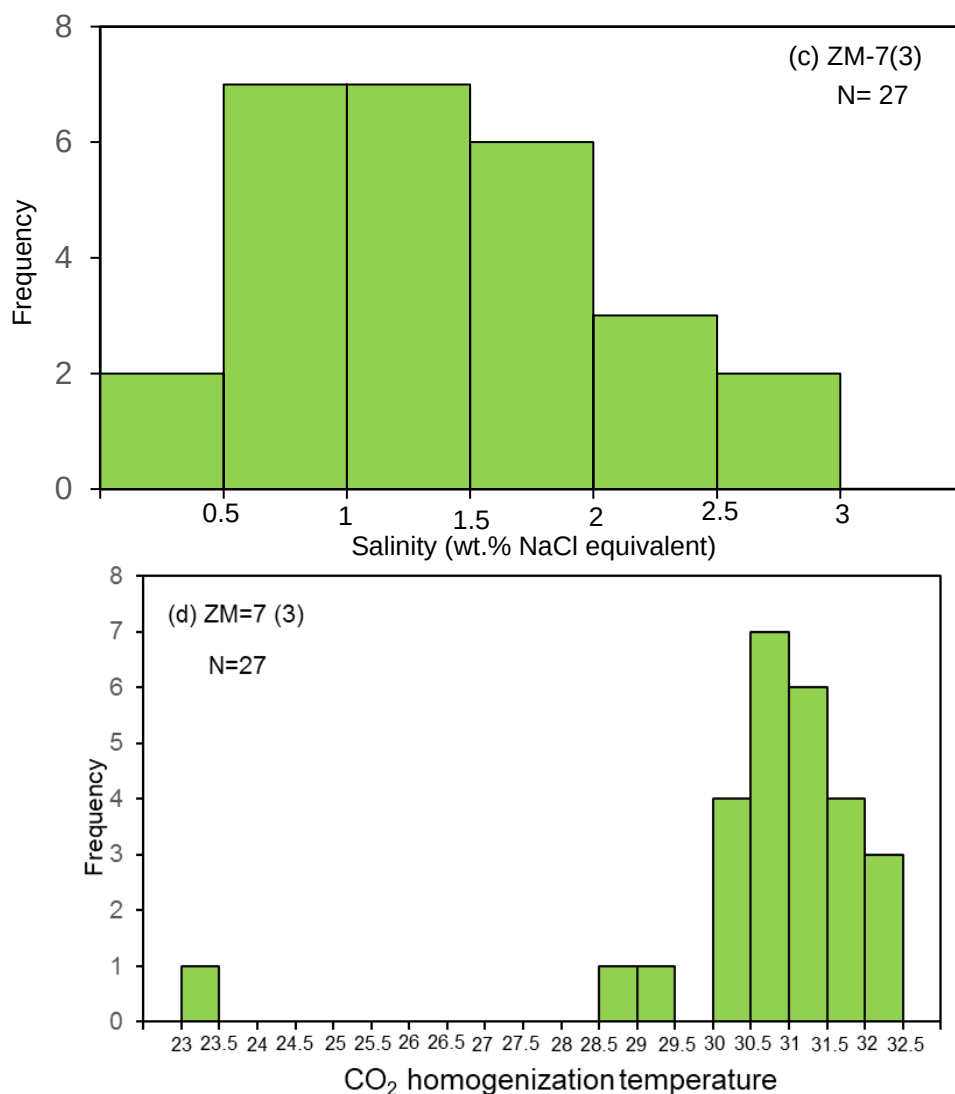


Figure 5-4 (a) Histogram of CO₂ melting temperature, and (b) Histogram of clathrate melting temperature of CO₂ fluid inclusions. (c) Histogram of salinity of CO₂, (d) Histogram of CO₂ homogenization temperature. Note: N= total number of fluid inclusions.

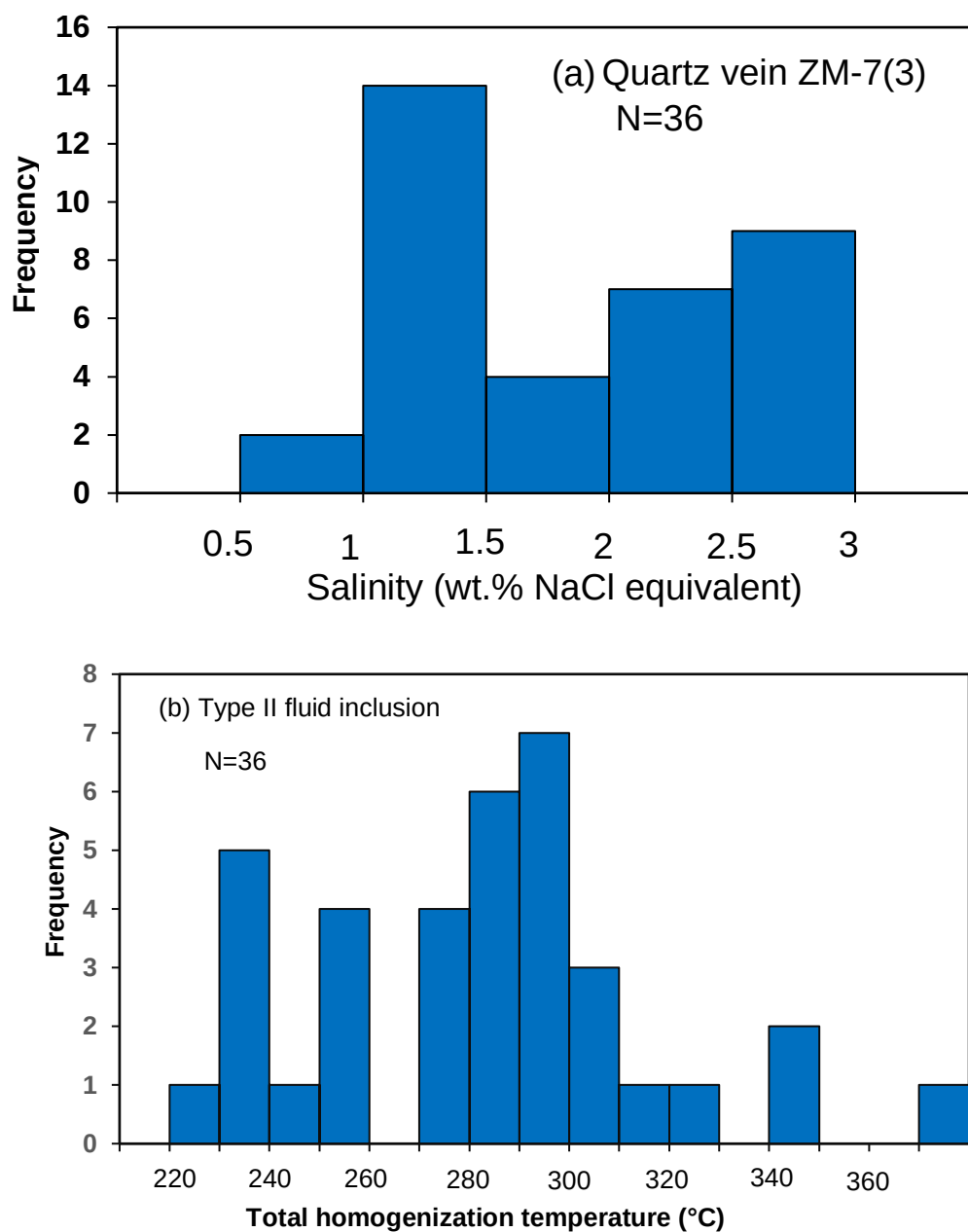


Figure 5-5 Histogram of salinities from aqueous two-phase fluid inclusions and (b) Histogram of T_h of primary aqueous fluid inclusions in quartz vein from the Zaw Min Prospect. Note: N= total number of fluid inclusions.

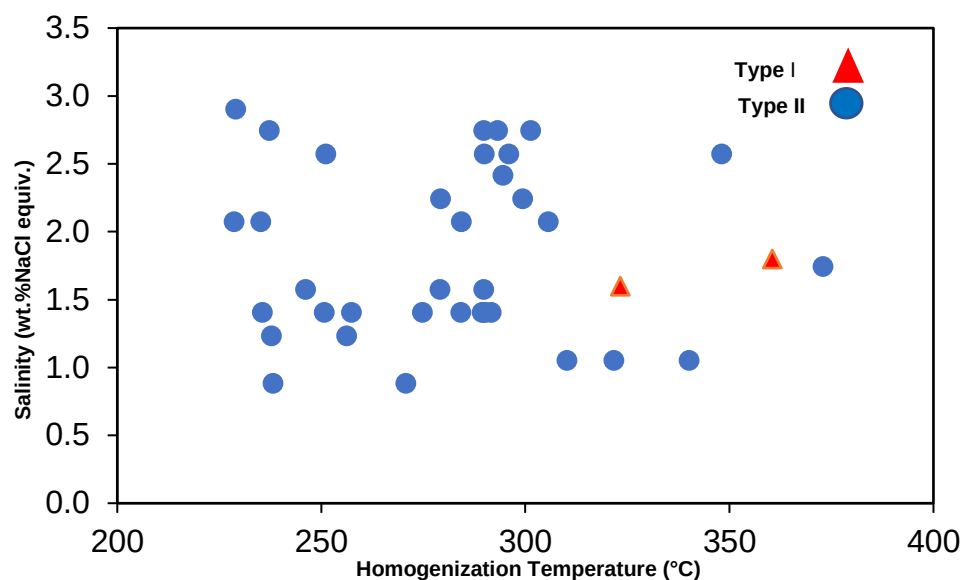


Figure 5-6 Bivariate plot showing the relationship between homogenization temperature versus salinity (wt.% NaCl equivalent) plot diagram for type I and type II fluid inclusions from the quartz vein of the Zaw Min Prospect.

Table 5.1 Summary of fluid inclusion types and microthermometric data for fluid inclusions of the quartz vein at the Zaw Min Prospect.

Deposit Name	Sample	Type (FIs)	T _{mCO2} (°C)	T _{mClath} (°C)	Th _{CO2} (°C)	T _{mice} (°C)	Th-tot (°C)	Salinity (wt.%NaCl eq.)
Zaw Min	Quartz	Type I	(-57.9 to -57.0) (N=27)	(8.8 to 10.2) (N=27)	(28.8 to 32.3) (N=27)		323, 361 (N=2)	(0.2 to 2.6)
Zaw Min	Quartz	Type II				(-0.9 to -1.7)	220-360 (N=36)	(0.24 to 2.9)

Notes: T_{mCO2}-melting temperature of CO₂; T_{m-Clath}- melting temperature of CO₂ clathrate; Th- total homogenization temperature of fluid inclusions; T_{m-ice}- final ice melting temperature; wt.% NaCl eq., weight percent NaCl equivalent, N=total number of fluid inclusions.

CHAPTER VI

DISCUSSION AND CONCLUSION

6.1 Discussion

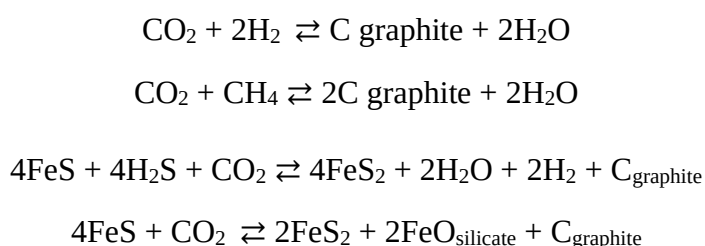
6.1.1 Graphite implications on gold mineralization

With burial, heating and deformation, organic matter deposited in sedimentary rocks matures and becomes increasingly well-structured and carbon rich through the release of hydrogen, nitrogen, and oxygen, eventually becoming crystalline graphite (Pitcairn et al., 2005). Graphite dominantly occurs in mid-crustal deformation zones, closely associated with gold and sulfide (Craw et al., 2014). Most graphite occurs in host rocks such as graphitic pelites, and a direct chemical link between the presence of graphite and deposition of gold from solution during mineralization processes has been inferred (Cox et al., 1995). Craw et al. (2014) mentioned that graphite was deposited after reaction, during fluid mixing of a CO₂-rich and a CH₄-rich fluid.

Graphite and gold are commonly associated in many orogenic gold deposits, and imply a genetic relationship (Henne and Craw, 2012; Cox et al., 1995). This type of relationship is particular in orogenic gold deposits observed in metasediments, and metaturbidite terrains where host rock are particularly graphitic units (Henne and Craw, 2012; Zoheir, 2008). The graphite in both host rock and quartz vein is commonly derived from organic materials deposited with the sediments, and metamorphosed with the host rocks (Bierlein and Crowe, 2000). There is widespread evidence for these processes in many gold-bearing metasedimentary terranes (Craw and Upton, 2014). Henne and Craw (2012) has suggested that low concentration of metals, including gold, are deposited with the organic material on the sea floor. Organic matter present in high carbon sedimentary rocks associated gold mineralization in central Victoria gold deposit is dominated by a distinctive poorly ordered and not crystalline graphite (Bierlein and Crowe, 2000). The graphitic carbon is principally distributed in the Otago Schist, and the Hyde-Macraes Shear Zone. The primary organic matter and hydrothermal graphite in both types of graphite have been strongly formed in formation of the gold deposit (Craw and Mackenzie, 2016). The carbonaceous matter undergoes a series of reactions which ultimately destroy the organic compounds to eventually form graphite or are completely transferred to the vapor phase as CO₂ or CH₄ under oxidized and reducing conditions respectively (Bucher, 2011). The graphite in granulite terrains reveals that CO₂ plays a major role in their petrogenesis and an important source of

carbon for graphite formation (Dissanayake and Rupasinghe, 1992). The CO₂ rich fluids are ultimately derived from reservoirs fixed near the Earth's surface (carbonate sediments, organic carbon and seawater-derived hydrothermal carbonates), from the mantle, or represent recycled mixtures of both, an important issue arising from this problem is the role played by CO₂ and organic carbon in the geochemistry of gold (Dissanayake and Rupasinghe, 1992). The organic matter (OM) in mineral deposits is the very useful information for understanding the hydrothermal systems (Glikson, and Mastalerz, 2000).

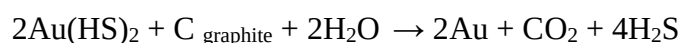
Three principal chemical reactions responsible for a graphite remobilization and formation of hydrothermal graphite by (Craw et al., 2016, Henne and Craw 2012, Hahn-Weinheimer et al., 1981, and Mukherjee et al., 2017):



The precipitation of hydrothermal graphite could result from the mixing of carbon dioxide and methane fluids during repeated metamorphism events and repeated intense tectonism in the Wabo district. Gold mineralization may follow probable pathways of metamorphic fluids trapped from escaping, resulting in precipitation gold and associated sulfides along favorable sites such as faults and fractures under high-grade metamorphism and strong tectonism.

Graphite deposition from a C-O-H system bearing fluid is unavoidable below 400°C, because carbon dioxide and methane at these temperatures can coexist only in very small amounts (Kirilova et al., 2017). And also, hydrothermal graphite can precipitate under the fluid mixing of carbon dioxide and methane (Craw et al., 2016). Carbon dioxide and methane can coexist in higher concentration under amphibolite-facies conditions, rather than greenschist facies fluid (Kirilova et al., 2017). These gases are produced by decomposition of carbonates (CO₂, CO), by reactions between silicates and carbonates and between carbonates or metaloxides and hydrogen (CO₂, CH₄). The release of gases and deposition of carbon provide a mechanism for the formation of graphite deposition. The sedimentary rock plays a role in orogenic gold mineralization, the formation of carbonate or graphite is subjected to repeating events of metamorphism

and intense tectonic events (tectonism). As a consequence, organic matter together with carbonate are transformed into graphite. Under greenschist-amphibolite facies conditions, gold is potentially carried as $\text{Au}(\text{HS})_2$ and also suggests gold complexes are generally carried under low pH condition (Mukherjee et al., 2017). The presence of graphite in a mineralized quartz vein can react as a chemical reductant to cause precipitation of gold.



Oxidation reactions also result in gold precipitation. The gold precipitation was closely associated with sulfide minerals and graphite in the Wabo district. The solubility of gold as reduced sulfur complex is strongly affected by the amount of dissolved sulfur, as well as redox conditions, and little affected by temperature (Craw et al., 2016).

Fluid-deposited graphite in volumetrically large occurrences is known to be restricted to high-temperature environments and universally displays high crystallinity (Luque et al., 2009). Genesis of graphite in a low temperature environment can be presumed predominantly two ways (1) graphitization process through progressive transformation of carbonaceous matter via prograde metamorphism and (2) the activity and reaction-front generated by C-O-H fluids (Luque et al., 2009). In the evolution of graphitization process, resulting wide range of structural ordering that may be revealed to the grade of metamorphism (Landis, 1971; Wada et al., 1994) while poorly crystalline fluid deposited graphite is commonly associated with hydrothermal gold-sulfide carbonate quartz veins in the shear zone (Mastalerz et al., 1995). Carbon-rich substances occur in veins and as disseminated aggregates, varying widely in C, O, H, and S contents, rich in rare elements, degree of maturation-crystallinity, and other chemical and physical properties. Variations in the properties of carbon-rich materials are mainly the result of source materials, interactions with the host rock during the migration from the source to the depositional site, and the geothermal regime during and after entrapment (Mastalerz et al., 1995). Graphite can be associated with high grade metamorphism, but it can also precipitate from carbon-bearing fluids during cooling (Luque et al., 2009). The compressional deformation and folding within the organic-rich and structurally weak host rock creates high permeability zones which focus silica-saturated metamorphic hydrothermal fluids to produce bedding parallel laminated quartz veins at the Bendigo orogenic gold deposits in Victoria gold fields by (Thomas et al., 2011).

The progressive transformation of carbonaceous matter through prograde metamorphism (graphitization) and the deposition from C-O-H fluids are the two major processes responsible for the formation of graphite in rocks. Transformation induced by metamorphism of carbonaceous matter include both structural and chemical modifications that eventually lead to the formation of graphite (Luque et al., 2009). Thus, the metamorphic graphite clearly shows a wide range of structural ordering that can be correlated with metamorphic grade, mainly with temperature (Landis, 1971), (Wada et al., 1994; Luque et al., 2009). Graphitic carbon can be precipitated from the source through reduction of carbonates, sedimentary organic matter, or a magmatic source.

The previous two sources might be considered significant in the formation of graphite deposits. In case of origin, carbon is considered to be mobilized as various (CO , CO_2 or as CH_4 resulting from reactions of carbonate minerals with hydrogen at elevated pressure-temperature conditions (Mastalerz et al., 1995). Formation of graphite from the precursor organic carbon enhanced by further hydrothermal influx led to gold precipitation (Mukherjee et al., 2017). Disordered crystalline fluid-deposited graphite has been designated associated with hydrothermal gold quartz vein or along shear zones (Mastalerz et al., 1995). The graphite bearing bands in the laminated quartz veins in the Bendigo orogenic gold deposit are enriched in gold that characterize the diagenetic pyrite (Thomas et al., 2011).

Fluid percolation during metamorphism may be meteoric, magmatic, or metamorphic (released by devolatilization reactions at greater depth) and increasing carbon concentration eventually stabilized graphite which it buffers the carbon content of the fluids (Winter, 2014). The common assumption that metamorphic fluids are prevailing CO_2 - H_2O mixtures is proper for graphite-bearing assemblages at very high temperature, but CH_4 is dominant below 700°C and that devolatilization has a composition reaching pure carbon (graphite) (Robb, 2004).

The graphite associated gold deposition could be characterized due to the opening of a reducing environment discovered by the carbonic fluid composition from which flaky graphite were presumed to be crystallized in the investigated area. Graphite precipitated from hydrothermal fluids occurs throughout the lode-gold quartz vein in the Wabo district. That graphite might be syngenetic hydrothermal product closely related with

gold forming fluids in a reduced carbon system. Each hydrothermal system might be applicable to the formation of metals and graphite. The graphite is closely associated with gold and sulfur in the mineralized quartz veins in Wabo district. It is a critical metal precipitation stage as graphite coexists with the gold or hydrothermal fluids in the Wabo district. So, the formation of graphite mechanism is important to understand the origin of mineralization and relationship with gold forming ore-fluids in both petrogenetic and the tracer from an exploration perspective in the Wabo district. It is not yet clear the source of ore forming fluids a relationship between gold and graphite. It is a significant feature between mineralized quartz graphite veins and graphite free host rocks (garnet-biotite gneiss). Hence, the graphite might formed from the original composition of organic material or carbonaceous matter within the host rocks during medium to high-grade metamorphism (Late Jurassic to Early Tertiary of events metamorphism) of Mogok Metamorphic Belt.

6.1.2 Carbonate on gold mineralization at the Kyaw Soe Thu Prospect

1. To understand the crustal thickening under regional metamorphism and deformation periods during mineralization in the Wabo district, the history of hydrothermal systems conditions in the past, more ore body structural mapping, tectonic structural analysis, isotopic studies are required. The ankerite veins in the Dome mine are commonly the gold rich mineralization zone with coarse grained carbonate (Stromberg et al., 2019). The ankerite vein in Dome mine is an overprint or late mineralization vein at the margin of quartz veins. The quartz veins at Dome mine are often accompanied by sericite alteration, visible gold and pyrite (Stromberg et al., 2019). Epithermal gold deposits are hydrothermal deposits that formed at shallow depths (usually <1 km) and moderate to low temperature (150 –350°C) as veins and disseminations in and around volcanic centers, and in clastic and carbonate-rich sedimentary rocks (Paterson, 1990).
2. Gold mineralization is closely associated with carbonate veining, it has been shown that gold deposition is closely associated with silica and sulfides. It is likely that deposited gold, silica and sulfides are part of the same evolving hydrothermal system responsible for precipitation the carbonate and quartz veins. The reason that the bulk of the carbonate deposition, silicification and gold deposition is probably due to carbonate becoming oversaturated at higher temperature than gold and silica. As temperatures continue to decrease

following carbonate deposition, gold and silica were deposited, whereas carbonates were locally dissolved due to their increased solubility caused by decreased temperature. The well interpreted colloform-crustiform structure in the carbonate-quartz veins have been reported as indicating epithermal mineralization environments (Chi et al., 2009; Dong et al., 1995).

3. After repeated erosion, post regional metamorphism probably follows the quartz veins together with carbonate veining of low sulfidation (epithermal) gold mineralization type at the Kyaw Soe Thu Prospect in Wabo district.

6.1.3 Source of ore forming fluids

The Wabo deposit is located in a high-grade metamorphic terrain where a wide range of both metapelitic and metacarbonate are present. Granite bodies are also present in the vicinity of the area. Magmatic intrusion would provide formation of some shallow precious metal rich deposits. The formation of metamorphic fluid is a critical point for understanding all crustal processes, including mineralization that is in both contact and regional metamorphism (Cartwright and Oliver, 2000). Orogenic gold deposits are structurally hosted ores, which typically formed at relatively great depth and were uplifted to the surface over tens of millions of years (Goldfarb and Groves, 2015). The gold deposits that are present in deformed metamorphic terranes all of ages, from Paleoproterozoic to Tertiary (Groves et al., 1998 and Goldfarb and Groves, 2015) into metamorphic fluids which are ascended from metamorphic devolatilization, and fluids derived from other sources (e.g., synmetamorphic igneous rocks, the mantle, or the surface) that infiltrate the terrane during metamorphism (Cartwright and Oliver, 2000) and deformational processes at convergent plate margins (Groves et al., 1998). Some metamorphic terranes show little evidence for the majority of rocks interacting with fluid pressure during regional metamorphism (Cartwright and Oliver, 2000) that (have caused some devolatilization or) metamorphic fluids would have been produced during the regional events. All orogenic gold ores formed from metamorphic fluids released from progressively devolatilizing supracrustal successions (Goldfarb et al., 2015). Gold and other ore compositions have been released into metamorphic fluids during greenschist- to amphibolite-facies metamorphism, most orogenic gold deposits are located in medium-grade metamorphic rocks (Goldfarb et al., 2015). The Victorian gold province north of the Bendigo goldfield that has especially deep seismic traverse provides some of the crustal architecture to depth being suggested for metamorphic

devolatilization (Phillips and Powell, 2010). The Bendigo gold deposit in the metasedimentary rocks derived from the precipitation of deeply sourced metamorphic fluids in fold- and fault related vein networks during regional deformation (Wilson, et al., (2013). The quartz is commonly in veins at Bendigo and has a variety of grain size and deformation stages (Wilson et al., 2013). Fractured quartz ribbon and coarse quartz-graphite breccias were observed in quartz veins and faulted vein in Bendigo gold deposit where graphite commonly along and adjacent to the marginal faults by (Wilson et al., 2013). The quartz textures from the Um Egat and Dungash orogenic gold deposit, Egyptian Eastern Desert have shown the subparallel to the direction of elongation of quartz but oriented at a high angle to the subgrain boundaries, and also characterized by deformational textures (Zoheir et al., 2008). Fluid inclusions in vein quartz from the Egyptian orogenic gold deposits all suggest as important role for low-salinity, $\text{CO}_2\pm\text{CH}_4$ -bearing fluids in the transport and /or precipitation of gold (Zoheir et al., 2008). Commonly in orogenic deposits, phase separation is important to explain the coexistence of aqueous and carbonic inclusions and sometimes inferred to have played a role in the precipitation of gold (Zoheir et al., 2008). The recent study of the quartz vein from the Zaw Min Prospect displays a moderate to high angle to subgrain boundaries of the mineralized quartz vein. That structural evidence could be supported the metamorphism and a brittle-ductile shear zone that indicate the placement of metamorphism and most common deformational events showing undulating texture.

The important quartz texture of gold bearing quartz vein in the Bendigo gold deposit are also composed of elongate blocky quartz or euhedral quartz crystals, and the only sign of crystal plastic deformation is slightly undulose extinction (Wilson et al., 2013). As fluid evidence shows, similar commonly orogenic fluids source have low salinity and moderate temperature. Salinity is typically low. The salinity is a primary control on the ability of fluids to transport many ore-forming elements (Yardley and Graham, 2002). While the major component characteristics of the ore-forming fluids in orogenic gold deposits are well established and broadly similar for all deposits, the ultimate source of the ore fluids (Fusswinkel et al., 2017). The Bendigo orogenic gold deposit hosted gold-bearing metamorphic fluids originated at the greenschist-amphibolite boundary at depths of 12 to 15 km (Phillips and Powell, 2010). Many studies on orogenic ore formation suggest that the metamorphic fluids are the important ingredients for mesothermal ore formation, and that fluid production and precious

metals are the consequence of devolatilization reactions in metasedimentary rocks (Phillips and Powell, 2010). (Goldfarb and Groves, 2015 and Fusswinkel, 2017) also suggested that most evidence of devolatilization versus magmatic hydrothermal fluid sources is based on equivocal mineralogical, isotopic, and fluid inclusions. Orogenic gold deposits are commonly associated with metamorphic rocks in the mid to shallow crustal level (5 to 15 km), and form above the brittle ductile transition in a compressional regime which facilitates transfer of hot gold-bearing fluids from depth (Goldfarb et al, 2001; Phillips and Powell, 2010).

It is more likely that diagenetic and metamorphic waters derived from passive margin type sediments could play a role in the migration of metals and in the formation of base metal ores (Yardley and Graham, 2002). Fluids produced in low to medium grade metamorphic terranes are dominated compositionally by H₂O, CO₂, and CH₄ in approximately that order of abundance (Robb, 2004). High grade rocks tend to be dominated by dense CO₂ with lesser amounts of associated water and methane (Robb, 2004). The characteristics of orogenic gold deposits around the world are genetically linked to the formation of metamorphic fluids that are typically characterized by low salinity, near neutral pH, a mixed H₂O-CO₂±CH₄ compositions (Robb, 2004 and Groves et al., 1998).

These gold deposits are associated with regionally metamorphosed terranes resulting from compression at convergent plate margins and have been termed orogenic gold deposits (Groves et al., 1998). The widespread occurrence of H₂O and CO₂ bearing fluid inclusions in the rock or quartz vein record attests to the ubiquity of aqueous-carbonic fluids especially in the deep crust (Robb, 2004). Most metamorphic fluids have low salinities and low concentrations of reduced sulfur. The characteristic of the metamorphic fluids is globally implicated in the formation of orogenic gold deposits, which represent a very important gold deposit type (Phillips, 1993; Robb, 2004). The CO₂ might be an importance role of hydrothermal solutions in the originating metamorphic devolatilization (Robb, 2004). Phillips and Evans (2004) suggested the effect of H₂O-CO₂ immiscibility, may be important in gold deposition and CO₂ is essential in the formation of gold-only provinces. (Phillips, 1993) also suggested the fluids derived from metamorphic devolatilization can adequately account for the nature of the gold-only fluids. Both H₂O and CO₂ as well as volatiles such as CH₄, CO, O₂, H₂, H₂S, SO₂ and CO₂, are produced as metamorphic fluids during prograde reactions

(Robb, 2004). In fluid inclusions, CO₂ is not only the volatile compound (e.g., CH₄, H₂S, SO₂, C₃H₈ may also be present), mixed hydrates of CO₂ and the other gases will be formed under cooling and the most common of these other gases occurring in the fluid inclusion is CH₄ (Collin, 1979). As a result of two types of fluid data, corresponding to a metamorphic fluid source at the Zaw Min Prospect in Wabo district. The temperature versus salinities (Fig 5.6) represents the ore formation source. The Zaw Min Prospect in the Wabo district is also located within the accretionary terrain under amphibolite and granulite metamorphic facies grade. The gold mineralization at the Zaw Min Prospect might be formed under the control as a result of multiple tectonic movement with multiple stage mineralization. The structurally controlled gold mineralization in orogenic deposits is favors the ore fluid deposition by the channel way along the fault or fracture. Regional metamorphism and tectonic setting constrained to form gold deposits in the Wabo district. The source of the fluids is likely to be metamorphic devolatilization or metamorphic hydrothermal ore-forming fluid, which points to a metamorphic origin of the ore fluids.

6.2 Conclusions

Wabo gold deposit is the most prominent gold deposit in the Proterozoic to Tertiary age of the Mogok Metamorphic Belt. It is located not only in the central part of Myanmar but also in the central Mogok Metamorphic Belt. The area is structurally very complex and has been under a repetitive tectonic deformation regime. There are often imprints of minor folds in the area. Exhibiting major boudinage within the host rocks, evidenced within both horizontal tunnels and vertical mining shaft in the research area. Remarkable structural features with striations on the mineralized quartz veins. Some quartz veins are steeply vertical to subvertical, and along foliation planes of the host rocks.

The mineralization is dominantly hosted in quartz-graphite veins, gold bearing quartz veins and quartz-carbonate veins. It is a notable mineralization within the MMB that hosted these multiple types of mineralization events. The gold rich quartz veins in the orogenic deposits worldwide are characterized by structurally deformed zones. Consequently, fault movement typically formed in both brittle and ductile deformation of the veins after their formation, with extensive recrystallization of the vein minerals, typically the hydrothermal quartz. The mineralized quartz veins formation is complex

with multi-mineralization events. Veins appeared with unroofing from the deep crustal level by tectonic activity, regional metamorphism and deformation/uplifting periods.

Fluid inclusion studies of the mineralized quartz veins from the Zaw Min Prospect suggests the presence of common carbonic rich fluid and homogenization temperatures varying from 220 to 360 °C with contrasting salinity of 0.2 to 2.9 wt.% NaCl equivalent. Based on the field occurrences and laboratory results, vein morphology, controls on mineralization with graphite, enrichment of carbon dioxide fluid inclusions in mineralized quartz vein and moderate temperature with very low salinity, quartz texture of fluid inclusion quartz wafer, gold rich carbonate vein, recrystallized quartz texture show their correlative with other orogenic (mesothermal) to epithermal deposit. Sulfides, carbon dioxide rich fluids in the quartz vein and carbonate vein may be traced as petrogenetic of source of ore forming fluid and indicator for future exploration. This research shows that the gold deposits in the Wabo district is associated with multiple hydrothermal gold mineralization events within the accretionary tectonic regimes in the Mogok Metamorphic Belt.

The new dataset constrains the mineralization styles, type of mineralization, the paragenetic sequence of gold mineralization, and the fluid inclusions data. The Wabo gold district is a newly investigated research area, and the most productive gold producer in the Thabeikkyin-Singu gold fields. The following statements are concluding remarks on the current research:

1. The host rock is an amphibolite to granulite metamorphic facies intruded by granitoids into host rocks.
2. The preservation of elongate quartz texture is interpreted as the orogenic quartz within deformation regime. Quartz is an ubiquitous gangue mineral within the veins and breccia during multiple generations of growth.
3. The structural setting plays a role for the gold mineralization during the Carboniferous to Miocene.
4. Fluid inclusions petrography and microthermometric data indicate moderate temperature, CO₂ rich and aqueous fluid inclusions with very low salinities.
5. The mineralization process was followed by later mineralization events with the formation of ankerite-quartz-sericite veins.

6. The petrographic and structural phenomena constrained the mineralized quartz vein and ankerite-quartz-sericite vein and indicates the late mineralization with the formation of quartz and carbonate veins. The ore fluid could be derived from devolatilization reactions during regional metamorphism and deformation in Jurassic to Early Tertiary related to granitic intrusion.

6.3 Future investigation

Due to the time limited study on the gold mineralization at the Wabo district, further investigation is needed to better understand the genesis of gold mineralization. Any future studies involving the quartz graphite veins and quartz carbonate veins system should include detailed comparisons with other prospects in the Wabo district and epithermal to orogenic gold mineralization systems worldwide regardless of any rock units. Future research should include the detailed regional sampling from the auriferous quartz veins and barren areas of the surround Thabeikkyin gold fields outside of the Wabo district including Phayaung Taung, Modi-Moemi Taung (southern gold districts), and other gold deposits in Myanmar. This comparison would give a regional outline of the understanding on mineral deposits in the central part of Myanmar to regional wide conditions. Trace element geochemistry on pyrite analysis and S, H, O isotope studies are very applicable to the source of ore fluids and an evolution of hydrothermal fluid conditions of ore formation, but also for future exploration guidance. Geochronology on a REE minerals of the auriferous quartz graphite vein will provide the mineralization age in the Wabo district, with a lack on the mineralization age along Thabeikkyin gold fields. New research on quartz graphite, carbonate associated gold mineralization still requires more understanding of the relationship on fluid chemistry and organic carbon content in the gold rich quartz graphite vein and should be studied for future comparative investigation.

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Appendix A Chemical compositions of electrum determined with SEM-EDX
at the Myo Lwin Prospect (quartz-graphite vein)

Point no	Au (wt%)	Ag (wt%)	Total (wt%)	Au (at%)	Ag (at%)	Total (at%)
ML-BV-1	80.64	19.36	100	69.53	30.47	100
ML-BV-2	80.69	19.31	100	69.59	30.1	99.69
ML-BV-3	81.4	18.6	100	70.57	29.43	100
ML-BV-4	81.85	18.15	100	71.19	28.81	100
ML-BV-5	82.26	17.74	100	71.74	28.26	100
ML-BV-6	82.75	17.25	100	72.43	27.57	100
ML-BV-7	81.76	18.24	100	71.06	28.64	99.7
ML-BV-8	81.89	18.11	100	71.24	28.76	100
ML-BV-9	81.44	18.56	100	70.61	29.39	100
ML-BV-10	81.07	18.93	100	70.1	29.9	100
ML-BV-11	80.73	19.27	100	69.64	30.36	100
ML-BV-12	81.37	18.63	100	70.52	29.84	100.36
ML-BV-13	81.13	18.87	100	70.19	29.81	100
ML-BV-14	82.23	17.77	100	71.71	28.29	100
ML-BV-15	81.79	18.21	100	71.09	28.91	100
ML-BV-16	78.91	21.09	100	67.2	32.8	100
ML-BV-17	81.43	18.57	100	70.6	29.4	100
ML-BV-18	81.43	18.57	100	70.6	29.4	100
ML-BV-19	82.44	17.56	100	72	28	100
ML-BV-20	81.29	18.71	100	70.42	29.58	100
ML-BV-21	81.46	18.54	100	70.64	29.36	100
ML-BV-22	81.35	18.65	100	70.49	29.51	100
ML-BV-23	80.55	19.45	100	69.4	30.6	100
ML-BV-24	80.09	19.91	100	68.78	31.22	100
ML-BV-25	80.52	19.48	100	69.36	30.64	100
ML-BV-26	80.02	19.98	100	68.69	31.31	100
ML-BV-27	81.66	18.34	100	70.91	29.09	100
ML-BV-28	80.19	19.81	100	68.92	31.08	100
ML-BV-29	79.01	20.99	100	67.34	32.66	100
ML-BV-30	80.25	19.75	100	68.99	31.01	100
ML-BV-31	80.26	17.74	98	69.01	30.99	100
ML-BV-32	78.22	21.78	100	66.29	33.71	100
ML-BV-33	75.78	24.22	100	63.15	36.85	100
ML-BV-34	78.89	21.11	100	67.18	32.82	100
ML-BV-35	80.35	19.65	100	69.13	30.87	100
ML-BV-36	79.95	20.05	100	68.59	31.41	100
ML-BV-37	79.51	20.49	100	68	32	100
ML-BV-38	79.9	20.1	100	68.52	31.48	100
ML-BV-39	79.61	20.39	100	68.14	31.86	100
ML-BV-40	79.88	20.12	100	68.5	31.5	100
ML-BV-41	81.5	18.5	100	70.69	29.31	100
ML-BV-42	79.02	20.98	100	67.35	32.65	100
ML-BV-43	78.55	21.45	100	66.72	33.28	100
ML-BV-44	78.54	21.46	100	66.72	33.28	100
ML-BV-45	80.14	19.86	100	68.85	31.15	100
ML-BV-46	78.36	21.64	100	66.48	33.52	100
ML-BV-47	78.54	21.46	100	66.72	33.28	100
ML-BV-48	78.24	21.76	100	66.32	33.68	100
ML-BV-49	79.72	20.28	100	68.28	31.72	100
ML-BV-50	78.71	21.29	100	66.93	33.07	100
ML-BV-51	77.91	22.09	100	65.89	34.11	100
ML-BV-52	80.18	19.82	100	68.9	31.1	100
ML-BV-53	80.46	19.54	100	69.27	30.73	100
ML-BV-54	81.51	18.49	100	70.72	29.28	100
ML-BV-55	79.94	20.06	100	68.58	31.42	100
ML-BV-56	80.71	19.29	100	69.61	30.39	100
ML-BV-57	78.09	21.91	100	66.12	33.88	100
ML-BV-58	79.61	20.39	100	68.14	31.86	100
ML-BV-59	80.64	19.36	100	69.52	30.48	100

Appendix B Chemical compositions of electrum determined with SEM-EDX
at the Kyarpazat Prospect (quartz-graphite vein)

Point no	Au (wt%)	Ag (wt%)	Total (wt%)	Au (At%)	Ag (At%)	Total (At%)
KPZ-01	73.47	26.53	100.00	60.26	39.74	100.00
KPZ-02	74.54	25.46	100.00	61.59	38.41	100.00
KPZ-03	72.85	27.15	100.00	59.50	40.50	100.00
KPZ-04	70.63	29.37	100.00	56.84	43.16	100.00
KPZ-06	73.36	26.64	100.00	60.13	39.87	100.00
KPZ-07	74.10	25.90	100.00	61.04	38.96	100.00
KPZ-08	73.71	26.29	100.00	60.56	39.44	100.00
KPZ-09	73.49	26.51	100.00	60.29	39.71	100.00
KPZ-10	72.13	27.87	100.00	58.63	41.37	100.00
KPZ-11	72.82	27.18	100.00	59.47	40.53	100.00
KPZ-12	71.78	28.22	100.00	58.21	41.79	100.00
KPZ-13	73.41	26.59	100.00	60.20	39.80	100.00
KPZ-14	70.20	29.80	100.00	56.34	43.66	100.00
KPZ-15	71.86	28.14	100.00	58.31	41.69	100.00

Appendix C Chemical compositions of electrum determined with SEM-EDX
at the Zaw Min Prospect (quartz vein)

Point no	Au (wt%)	Ag (wt%)	Total (wt%)	Au (At%)	Ag (At%)	Total (At%)
ZM-FHQV-1	73.06	26.94	100.00	59.76	40.24	100.00
ZM-FHQV-2	71.52	28.48	100.00	57.90	42.10	100.00
ZM-FHQV-3	70.56	29.44	100.00	56.76	43.24	100.00
ZM-FHQV-4	69.27	30.73	100.00	56.73	43.27	100.00
ZM-FHQV-5	74.07	25.93	100.00	59.25	40.75	100.00
ZM-FHQV-6	71.33	28.67	100.00	57.25	42.75	100.00
ZM-FHQV-7	70.43	29.57	100.00	56.45	43.55	100.00
ZM-FHQV-8	72.03	27.97	100.00	58.25	41.75	100.00
ZM-FHQV-9	71.95	28.05	100.00	58.22	41.78	100.00
ZM-FHQV-10	73.11	26.89	100.00	59.82	40.18	100.00
ZM-FHQV-11	71.59	28.41	100.00	57.28	42.72	100.00
ZM-FHQV-12	71.51	28.49	100.00	57.89	42.11	100.00
ZM-FHQV-13	69.98	30.02	100.00	56.25	44.75	100.00
ZM-FHQV-14	73.56	26.44	100.00	60.28	39.72	100.00
ZM-FHQV-15	70.87	29.13	100.00	57.23	42.77	100.00
ZM-FHQV-16	72.17	27.83	100.00	58.68	41.32	100.00
ZM-FHQV-17	71.55	28.45	100.00	57.94	42.06	100.00
ZM-FHQV-18	70.49	29.51	100.00	56.68	43.32	100.00
ZM-FHQV-19	72.02	27.98	100.00	58.25	41.75	100.00
ZM-FHQV-20	70.85	29.15	100.00	57.10	42.90	100.00
ZM-FHQV-21	70.00	30.00	100.00	56.25	43.75	100.00

Appendix D Chemical compositions of electrum determined
with SEM-EDX of Kyaw Soe Thu Prospect (chalcedonic quartz vein)

Point no	Au (wt%)	Ag (wt%)	Total (wt%)	Au (At%)	Ag (At%)	Total (At%)
KST-01-QV0-1	72.51	27.49	100.00	59.09	40.91	100.00
KST-01-QV0-2	73.94	26.06	100.00	60.84	39.16	100.00
KST-01-QV0-3	72.40	27.60	100.00	58.95	41.05	100.00
KST-01-QV0-4	70.66	29.34	100.00	56.88	43.12	100.00
KST-01-QV0-5	69.86	30.14	100.00	55.93	44.07	100.00
KST-01-QV0-6	74.10	25.90	100.00	61.04	38.96	100.00
KST-01-QV0-7	72.54	27.46	100.00	59.13	40.87	100.00
KST-01-QV0-8	69.73	30.27	100.00	55.79	44.21	100.00
KST-01-QV0-9	70.25	29.75	100.00	56.40	43.60	100.00
KST-01-QV0-10	71.84	28.16	100.00	58.28	41.72	100.00
KST-01-QV0-11	69.29	30.71	100.00	55.27	44.73	100.00
KST-01-QV0-12	71.42	28.58	100.00	57.78	42.22	100.00
KST-01-QV0-13	68.50	31.50	100.00	54.36	45.64	100.00
KST-01-QV0-14	73.70	26.30	100.00	60.54	39.46	100.00
KST-01-QV0-15	69.43	30.57	100.00	55.43	44.57	100.00
KST-01-QV0-16	70.84	29.16	100.00	57.09	42.91	100.00
KST-01-QV0-17	71.26	28.74	100.00	57.59	42.41	100.00
KST-01-QV0-18	74.15	25.85	100.00	61.08	38.92	100.00
KST-01-QV0-19	72.72	27.28	100.00	59.35	40.65	100.00
KST-01-QV0-20	71.38	28.62	100.00	57.73	42.27	100.00
KST-01-QV0-21	72.50	27.50	100.00	59.08	40.92	100.00
KST-01-QV0-22	69.82	30.18	100.00	55.88	44.12	100.00

Appendix E Chemical compositions of electrum determined with SEM-EDX at the
Kyaw Soe Thu Prospect (ankerite-quartz-sericite vein)

Point no	Au (wt%)	Ag (wt%)	Total (wt%)	Au (At%)	Ag (At%)	Total (At%)
KST-02-CV-1	70.63	29.37	100.00	56.84	43.16	100.00
KST-02-CV-2	72.37	27.63	100.00	58.92	41.08	100.00
KST-02-CV-3	73.24	26.76	100.00	59.98	40.02	100.00
KST-02-CV-4	72.47	27.53	100.00	59.05	40.95	100.00
KST-02-CV-5	67.86	32.14	100.00	53.63	46.37	100.00
KST-02-CV-6	72.45	27.55	100.00	59.03	40.97	100.00
KST-02-CV-7	72.20	27.80	100.00	58.72	41.28	100.00
KST-02-CV-8	69.07	30.93	100.00	55.02	44.98	100.00
KST-02-CV-9	68.04	31.96	100.00	53.83	46.17	100.00
KST-02-CV-10	74.51	25.49	100.00	61.55	38.45	100.00
KST-02-CV-11	71.30	28.70	100.00	57.64	42.36	100.00
KST-02-CV-12	70.56	29.44	100.00	56.76	43.24	100.00
KST-02-CV-13	69.87	30.13	100.00	55.94	44.06	100.00
KST-02-CV-14	70.24	29.76	100.00	56.78	43.22	100.00
KST-02-CV-15	72.64	27.38	100.00	59.23	40.77	100.00
KST-02-CV-16	69.58	30.42	100.00	55.61	44.39	100.00
KST-02-CV-17	70.64	29.36	100.00	56.86	43.14	100.00
KST-02-CV-18	68.15	31.85	100.00	53.96	46.04	100.00
KST-02-CV-19	72.05	27.95	100.00	58.54	41.46	100.00
KST-02-CV-20	70.09	29.91	100.00	56.20	43.80	100.00
KST-02-CV-21	70.12	29.88	100.00	56.24	43.76	100.00
KST-02-CV-22	73.06	26.94	100.00	59.76	40.24	100.00
KST-02-CV-23	72.89	27.11	100.00	59.55	40.45	100.00
KST-02-CV-24	73.18	26.82	100.00	59.91	40.09	100.00
KST-02-CV-25	72.69	27.31	100.00	59.31	40.69	100.00
KST-02-CV-26	71.22	28.78	100.00	57.54	42.46	100.00
KST-02-CV-27	68.79	31.21	100.00	54.69	45.31	100.00
KST-02-CV-28	72.73	27.27	100.00	59.35	40.65	100.00
KST-02-CV-29	69.25	30.75	100.00	55.22	44.78	100.00

Appendix F Chemical compositions of carbonate mineral determined with XRF at the
Kyaw Soe Thu Prospect (ankerite-quartz-sericite vein)

Sample No	SiO ₂	FeO	MnO	MgO	CaO	CO ₂	Total
	Wt%						
KST-02-0	21.4	14.8	0.6	19.1	42.4	?	98.3
KST-02-1	29.4	13.4	0.6	16.8	38.3	?	98.5

XRF data excluding CO₂ of quartz-carbonate vein at Kyaw Soe Thu Prospect,
Wabo district

Sample No	SiO ₂	FeO	MnO	MgO	CaO	CO ₂	Total
	Wt%						
KST-02-0	13.22	9.14	0.37	11.80	26.19	39.27	100
KST-02-1	18.91	8.62	0.39	10.81	24.63	36.69	100

Actual chemical composition including CO₂ in quartz carbonate vein
at Kyaw Soe Thu Prospect

Sample No	FeO	MnO	MgO	CaO	CO ₂	Total	FeO	MnO	MgO	CaO	CO ₂	Total
	Wt%						Mol%					
KST-02-0	10.53	0.43	13.60	30.18	45.26	100	7.13	0.29	16.40	26.17	50.00	100
KST-02-1	10.36	0.48	13.32	30.38	45.19	100	7.20	0.33	16.10	26.38	50.00	100

The classification of carbonate mineral (ankerite) excluding SiO₂ using stoichiometry
calculation in quartz-carbonate vein at Kyaw Soe Thu Prospect