

Geochemistry, Ore Characteristics and Origin of Gold and Base Metal Mineralization in Skarn Zone at Shwe Min Bon, Southern Shan State, Myanmar

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and Base Metal Mineralization in Skarn Zone at Shwe
Min Bon, Southern Shan State, Myanmar**

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July 2018

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By

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Abstracts

Skarn deposits are primarily associated with intrusive rocks emplaced into or near carbonate rocks formed in magmatic arcs related to subduction. Skarn-type Cu-Au deposit at Shwe Min Bon is one of the primary gold deposits among around 300 gold occurrences in Myanmar. It is necessary to understand the formation environments and type of skarn deposit at Shwe Min Bon in order to establish a genetic model that can be applied to further exploration of skarn deposit in the similar geologic setting of other areas in Myanmar. At Shwe Min Bon, the Cu-Au mineralization occurred along the contact between the Nwabangyi Dolomite and Shweminbon Formation and the Cretaceous dioritic rocks. This study focused on the genetic characterization of skarn and ores at Shwe Min Bon. In addition to the skarn and ore mineral assemblages, fluid inclusion microthermometry was carried out to understand the evolution of hydrothermal system in both space and time. The whole-rock geochemistry of intrusive rocks which were related to the skarn deposits were analyzed in order to understand the formation environment of skarn deposit. This dissertation consists of seven chapters and the main contents in each chapter are as follows:

Chapter I introduced the research background, description of the study area, problem statement and objectives of this study. The methodology and procedure of analyses are described. The backgrounds on skarn deposit are also described.

Chapter II described the geologic setting, stratigraphy and lithologies of the Shwe Min Bon area. This literature review focused on the stratigraphy and geological structure of the research area.

Chapter III demonstrated on the geology, petrography and geochemistry of the host rocks in Shwe Min Bon. The host rock consists of diorite, granodiorite and siltstone, sandstone and marble of Shweminbon Formation. The dioritic rocks belong to the calc-alkaline series and indicate meta-aluminous characters.

Chapter IV described the occurrence of skarn at the contact between intrusive rocks and marble suggesting that both exoskarn and endoskarn were developed in the Shwe Min Bon area. In the Shwe Min Bon deposit, seven orebodies are mined. Among them, Bwet Taung, Tiger Mouth, Shwe Taung Gyar and Lun Htoe orebodies are the main mineralized zones. Based on field observation, the Bwet Taung, Zin Yaw, Tiger Mouth and Shwe Gu Lay orebodies are classified as proximal skarns. The Shwe Taung Gyar and Lun Htoe orebodies are identified as distal skarns. Moreover, a hydrothermally altered zone occurs in the Bwet Taung and Tiger Mouth orebodies

where igneous rocks intruded into the clastic rock of the Shweminbon Formation. From north to south, skarn is zoned from intrusive rocks in the sequence: garnet, pyroxenoid to marble. Three skarn stages were recognized: prograde skarn (pre-ore stage), retrograde skarn and Cu-Fe-As-Bi sulfides mineralization (retrograde I) and Bi-Te mineralization associated with calcite (retrograde II) in brecciated marble. In addition, supergene stage marked by secondary Cu mineralization (malachite and azurite) is closely associated with oxidized zone. The prograde and retrograde alteration extensively occurred in exoskarn zone. Silicification also occurred on the Shweminbon Formation in the shear zone.

Chapter V characterized the condition of ore mineralization and skarn formation in the Shwe Min Bon deposit. The ore minerals include native gold, chalcopryite, bornite, chalcocite, tennantite, sphalerite, galena, magnetite, hematite with minor enargite and cosalite. In the present study, Bi-bearing minerals such as tellurobismuthite, bismuthinite, emplectite, wittichenite, hedleyite and cosalite were identified. Gold mineralization was mainly associated with chalcopryite and tennantite in the retrograde stage I and with tellurobismuthinite in the retrograde stage II. The temperature and salinity of fluid associated with the prograde skarn formation were high temperature (314-492°C) and hypersaline (up to 46.4 wt. % NaCl equiv.). The Cu-Au mineralization mainly occurred in the retrograde stage I, characterized by moderate temperatures (260-320°C) with a moderate salinity 5.0-6.0 % NaCl equiv. Retrograde stage II was formed at low temperature (180-200°C) and a low salinity 2.0-3.0% NaCl equiv. The gold mineralization at Shwe Min Bon appears to have occurred at lower temperatures later than the prograde skarn minerals and mostly confined to the retrograde stage.

Chapter VI discussed the classification of the type of the Shwe Min Bon skarn deposit and the geologic setting where the Shwe Min Bon deposit was formed. The skarn deposit at Shwe Min Bon was classified as oxidized Cu skarn based on the occurrence of hematite and magnetite, in addition to the andradite-rich compositions of the garnet. Meta-aluminous composition of dioritic rocks of I-type affinity suggests that those dioritic magmas were formed by partial melting of igneous protoliths. The dioritic rocks of calc-alkaline character were generated in a volcanic arc setting.

Chapter VII summarized the results of the research and concluded that the skarn deposit at Shwe Min Bon is characterized by the oxidized skarn-type Bi-bearing Cu-Au deposit formed at a magmatic arc in subduction setting.

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Abbreviations: Cal=calcite, Grt=garnet, Opx= orthopyroxene, Wol=wollastonite, Qtz=quartz, Epd=epidote, Act=actinolite-tremolite, Chl=chlorite, ccp= chalcopyrite.....47

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CHAPTER I. Introduction

1.1 Background and history of the research area

Shwe Min Bon skarn copper-gold mineralization is among around 300 gold occurrences in Myanmar. Since Myanmar is rich in natural resources with processing of a variety of minerals, among them, precious and base metal are of important as well as future exploration. Nowadays, gold exploration becomes very famous, not only from secondary (placer), but also from primary fields (Fig. 1.1). Although the different types of gold mineralization in Myanmar, the role of exploration is needed to develop to be a systematic one. In the primary prospect one of the challenging mineralization styles is skarn mineralization.

The Shwe Min Bon gold deposit lies on the Shan scarp zone which is located between the Slate belt and Shan plateau. There are seven prospect in the deposit which are trending nearly north-south. The host rocks comprise brecciated marble, skarn, siliceous and calcareous siltstone and mudstone. Shwe Min Bon deposit has been investigated by many researcher and recorded as the gold mineralization occurs skarn ore zone, hornfels zone, hydrothermal breccias- skarn zone, gossanous zone and late stage tectonic breccias. However, the origin of the mineralization is still remained unclear.

In the Shwe Min Bon area, the ancient tunnels were investigated by German geologists over the period 1914 to 1942. Numerous tunnels were excavated for mining activities by the Department of Geological Survey and Mineral Exploration as well as by Ivanhoe Myanmar Holding Ltd from 1996 to 2004. Since 2011, the mining operations by Geo Asia Co. Ltd are focused entirely on the silicified zone. Local people are also exploiting part of the small scale mining in the skarn zone, which had been mined out by Geo Asia Co. Ltd. The estimated ore reserved were calculated by

the Department of Geological Survey and Exploration (DGSE, 2015) as 238,900 metric ton @ 1.07- 5.94 ppm Au.

The Shwe Min Bon area is in a steep west- facing slope most of which show karst topography. The emplacement of diorite is associated with regional deformation of the area and is implicit in the formation of contact metamorphism, skarn and metasomatic mineralization. There is no record for the timing of intrusion and mineralization. Late stage tectonic breccia of calcite and a limonitic clay matrix occurs along the NW-N-NE fault. The Au contents of tectonic breccia zone is low. But the breccia zone is relatively wide, and has now been utilized for open cut mining.

Chhibber (1934) first suggested that the gold mineralization in southern Shan state including the Shwe Min Bon area is related to dioritic and granitic intrusions. Thacpaw (1966) carried out the preliminary investigations on the alteration and mineralization in the Shwe Min Bon area and suggested that two phases of mineralization are revealed by two stages of pyrite formation. Naing et al. (2013) suggested that the gold mineralization was of the calcic skarn type.

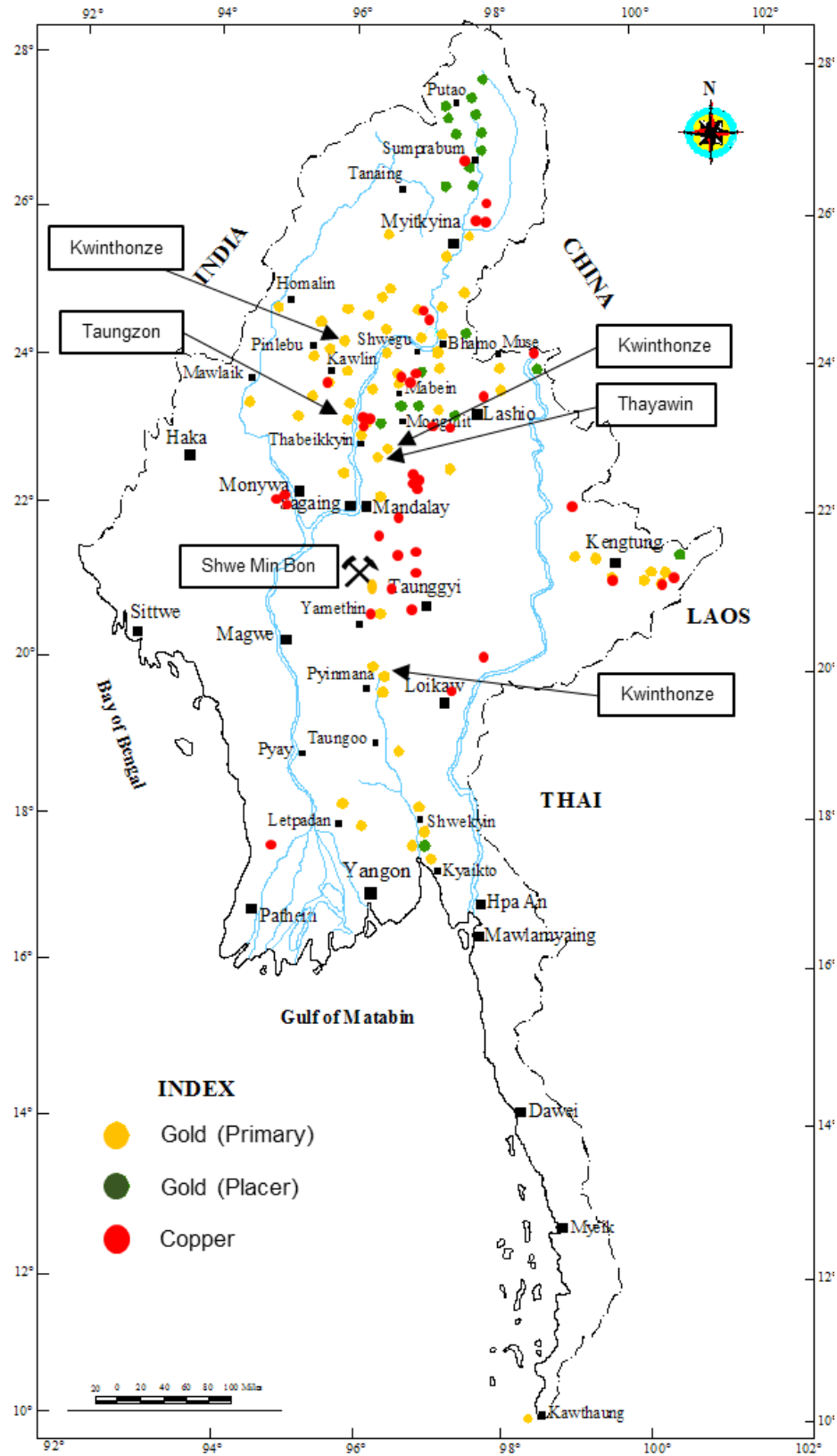


Fig. 1.1 Distribution of gold and copper deposit in Myanmar.

1.2 Location of the study area

The Shwe Min Bon (also spelled as Shweminbon) Cu-Au skarn deposit is located between latitudes 20° 39' 15" N to 20° 40' 15" N and Longitudes 96° 27' 30" E to 96° 28' 30" E, near Kalaw township, southern Shan state, Myanmar. The Shwe Min Bon deposit is an important Cu deposit in Myanmar within the Shan scarp zone of the Mogok metamorphic belt (MMB) (Fig. 1.2). The MMB occurs as a highly deformed zone between the Central Basin to the west and the Shan plateau to the east, divided by the major Shan scarp and Sagaing faults respectively. The MMB is one of the most important mineral belts in Myanmar. Many different types of ore deposits occur within the MMB and the Shan scarp fault zone. Mesothermal, orogenic gold deposits are hosted by the Slate belt, located in the southern part of the MMB (e.g., Modi Taung, Swe et al., 2017). The Slate belt in central Myanmar consists of argillaceous rocks correlated with the Mergui group trending N-S. Consequently, the Shan scarp zone which lies between the Mergui group and plateau limestone are the host the gold mineralization in Shwe Min Bon area. Au-Cu mineralization appears to be located in a narrow, elongated belt along the Shan Scarp fault zone.

Topographically, the research area is located in mountainous area. Although the elevation is about 1400m, most of prospects have a karstic surface and steep slope. (Fig. 1.3). As it is in tropical region, the area is covered by thick vegetation during the rainy season and less vegetation in dry season.

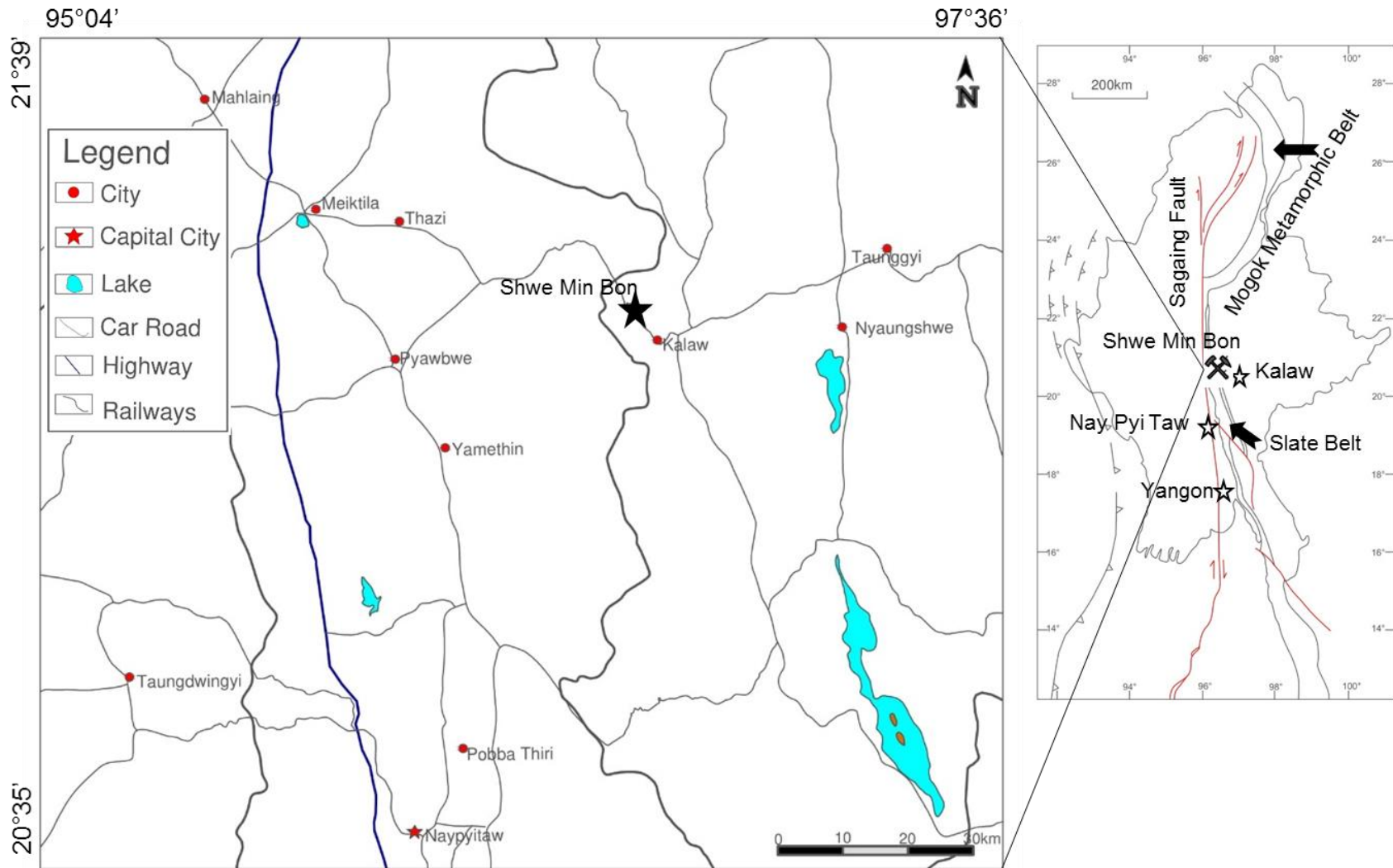


Fig. 1.2 Location map of the Shwe Min Bon area.

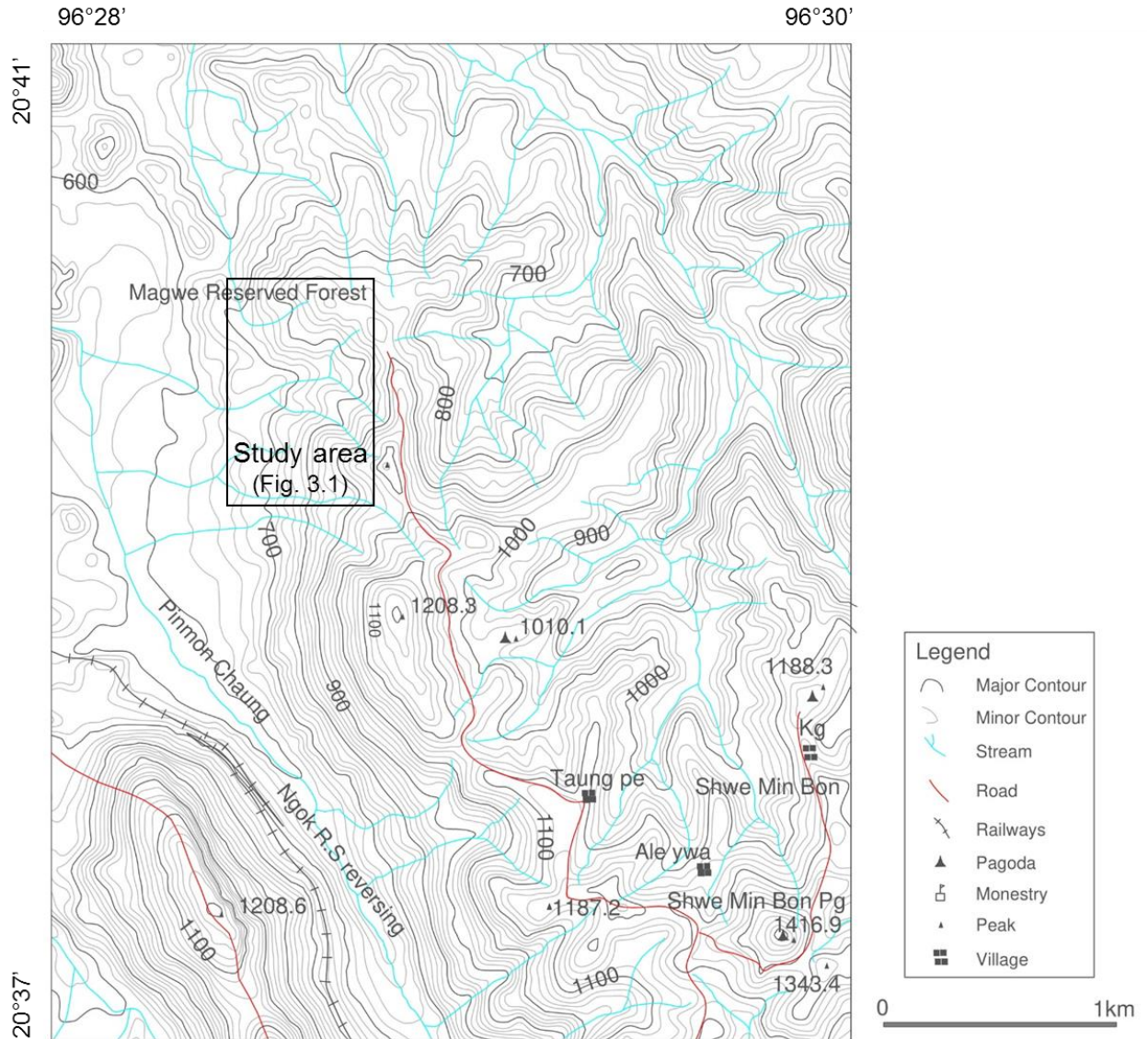


Fig. 1.3 Topographic map of the research area. (UTM, 2096-06)

1.3 Statement of the problem and objectives

Thacpaw (1966) and Naing et al. (2013) have investigated the aspects of the gold and copper mineralization but little work has been done to understand the formation of the skarn assemblages and associated copper-gold mineralization. There are seven prospects within the gold district, with exploration and production of gold carried out over 3 years by the Geo Asia Industries and Mining

Co., Ltd. The Department of Geological Survey and Mineral Exploration (D.G.S.E) has been providing a technical team to Geo Asia Industries and Mining Co., Ltd for gold exploration at the Shwe Min Bon gold district since 2011. The geological team has been carrying out regional geological mapping, detailed geological mapping for 2 years and also the drilling at the gold district. Although the company explore for gold production, the research area have favorable for copper mineralization.

In this zone, although both of Ngayant Chaung Formation and Shweminbon Formation are turbidite units, they have different mineralization as Sb and Au-Cu deposits respectively. The main tectonic line in this area, namely Shan scarp zone is oriented in a nearly NS direction. Nwabangyi Dolomite is recognized in thrust fault contact along the west margin of the research area. The presence of numerous cross-cutting veinlets and micro-veinlets of quartz, calcite and sulfides were developed principally during thrusting, suggesting that gold mineralization is related with formation of metamorphic rock or deformation of the structural zone.

Among two or more phases of intrusions, gold mineralization can be occurred in syn- and post-skarnization process by hydrothermal process. It can lead to assist on the exploration aspect and to assay the potential of mineralization. The oxidation products of copper minerals include malachite and azurite. However, the formation of these sulfide minerals and gold mineralization processes remains completely unresolved. To ensure better understanding on the different stages and timing of mineralization, detailed mapping, and fluid inclusion microthermometry need to be conducted in order to understand the physicothermal conditions and nature of sulfide and gold mineralization.

The purpose of this study is to systematically document the skarns deposition based on skarn mineralogy and its related mineralization in the Shwe Min Bon area. In addition, this study

identifies the bismuth-, telluride-bearing minerals which are associated with the gold mineralization.

1.4 Methodology

A total of about 200 samples of intrusive rocks, host rocks, skarn rocks and ores samples were collected. About petrographic thin sections and thirty polished sections were prepared in order to identify the texture and mineralogy of the host rocks, skarns and ore minerals. These were analyzed by a Nikon Eclipse E600 POL microscope, equipped with a AdvanCam-U3II camera at Department of Earth Resources Engineering, Kyushu University. Scanning Electron Microscopy (SEM) using a SUPERSKAN SS-550, equipped with standardless, Energy Disperse X-ray analyzer (EDAX) at the Center of Advanced Instrumental Analysis, Kyushu University was used for the determination of chemical composition of different ore minerals. Major and minor elements of fifteen fresh and non-mineralized samples were analyzed in order to determine whole rock geochemistry by X-ray fluorescence (XRF) analysis using a RIGAKU RIX-3100. Loss on ignition (LOI) was determined by heating the samples at 1000°C for 2 hours to determine relative loss of weight. The sample pellets for XRF analysis were prepared by pressing at (20t) for about 2 minutes in a vinyl chloride ring. The measurement conditions of analysis were 30kV and 70mA and JA-3 andesite was used as a standard sample.

Different types of minerals (quartz, calcite, garnet) in prograde, retrograde (I) and (II) of the skarn deposition were also prepared for fluid inclusion analysis. The measurements were conducted using a Linkam LK600 cooling/heating unit with a Nikon Y-IM microscope at the Department of Earth Resources Engineering, Kyushu University. The homogenization and the final ice melting temperature were measured at the rate of 1°C/mins. Thermocouples were calibrated at -53.2°, 0.0°, and +313.5°C using boiling point of hydrocarbon. The salinity of two-

phase fluid inclusions were calculated using the fluid inclusion freezing temperature through the equation provided in Bodnar (1993), based on the freezing-point depression of H₂O-NaCl solutions, ranging from pure water to the eutectic composition (23.2 wt.% NaCl). The salinity of three-phase inclusions was calculated using the halite dissolution temperature through equations by Sterner et al. (1988).

The two garnet samples were used for oxygen and hydrogen isotope analysis. Mineral separation was carried out at the economic geology laboratory in Kyushu University, Japan. All mineral separates were examined using a binocular microscope prior to isotopic analysis to ensure 99% purity. Oxygen isotopic analyses were performed by Laser fluorination, involving total sample re-action with excess ClF₃ using a CO₂ laser as a heat source (in excess of 1500°C; following Sharp, 1990) at the Scottish Universities Environmental Research Centre (Glasgow, UK). Samples are ablated by laser and the resulting liberated gases were analysed. The CO₂ converted from O₂ by reaction with hot graphite and the isotopic composition determined by an on-line VG Optima mass spectrometer. The results are in standards notation ($\delta^{18}\text{O}$) as per mil (‰) reported with respect to Standard Mean Ocean Water (SMOW).

Hydrogen isotope analysis involved the release of water from fluid inclusions by crushing. The pure garnet samples were heated at 100°C overnight under high vacuum to release labile volatiles after loading into thoroughly outgassed Pt crucibles. Radiofrequency induction in an evacuated quartz tube at 1200°C was used to heat the samples and release water, then reduced to H₂ in a chromium furnace at 800°C (Donnelly et al. 2001). The yield measured by Hg manometer, with the evolved gas measured standard corrections applied to raw $\delta^{18}\text{D}$ values to produce true $\delta^{18}\text{D}$.

1.5 Background on skarn deposit

Since skarn deposits are becoming more and more important for the sources of metals and now the subject of extensive scientific investigation in recent literature. Skarn deposits are widely distributed around the world, containing an array of useful metals, such as iron, tungsten, copper, lead, zinc, molybdenum, silver, gold, uranium, rare-earth elements, fluorine, boron, and tin (Meinert et al., 2005). Skarn deposits are one of the most abundant ore types in the earth's crust, and form in rocks of almost all ages (Meinert et al., 2005). Skarn-type copper deposits are considered to be the most significant skarn-deposit type in the world (Calagari and Hosseinzadeh, 2006). Skarn-type copper deposits mined out high grade ore than the porphyry type deposit in Ertsberg-Grasberg district, Indonesia (2.8 g/t Au with 1.12 % Cu in the skarn and 2.3g/t Au with 1.14 % Cu in the porphyry respectively).

Skarn (or skarn-type) gold deposits can be divided into gold only, copper–(gold), copper–iron–(gold) and lead–zinc–(gold), with gold only skarn as the most attractive exploration target (Meinert, 1989). The gold mineralization was formed in skarn systems during retrograde alteration, concurrent with or later the main stage of sulfide mineralization. The ore shoots in most deposits are commonly highly irregular and the limits are generally determined by assay methods. Characteristically, relatively high temperature Ca-Mg-Fe-silicates such as garnet, vesuvianite, diopside, scapolite, wollastonite and axinite are usually present in skarn deposits, in addition to lower temperature mineral assemblage of actinolite-tremolite, epidote, serpentine, phlogopite, muscovite, quartz, calcite, dolomite and various sulfides, mainly chalcopyrite, bornite, chalcocite, pyrite, pyrrhotite, arsenopyrite, galena, sphalerite, molybdenite and locally various Ni-Co sulfides and arsenides. Magnetite and hematite occur in many deposits.

Calcic copper skarn deposits are the most abundant skarn type in the world and mainly associated with I-type, magnetite-series, calc-alkaline, porphyritic plutons (Einaudi et al., 1981, Meinert et al., 2005). They are commonly associated with both oceanic and continental subduction settings. Copper skarns are formed in proximity to stock contacts with relatively oxidized skarn mineralogy characterized by andraditic garnet. Reduced gold skarns are associated with reduced diorite-granodiorite plutons and dike/sill complexes. Gold in these deposits is deposited in relatively late stages as native gold associated with Bi-minerals (Douglas et al., 2000). Skarn deposit characterized by low garnet/pyroxene ratios presence of hedenbergitic pyroxene and abundant sulfide minerals dominated by pyrrhotite and arsenopyrite, which are related with gold skarn deposits classified as reduced skarn (Brooks et al., 1991).

1.6 Skarn deposits in Myanmar

Most of the skarn deposits in Myanmar occur along the Mogok metamorphic belt as shown in Fig. (1.1). The Kwinthonze deposit thought to be linked to the intrusion of the Kabaing Granite near Thabeikkyin, is a marble-hosted Au base metal sulfide deposit with accessory garnet and wollastonite, interpreted as a skarn-type deposit, dated through zircon U-Pb geochronology to ca. 17Ma and related to the late stages of Mogok belt metamorphism (Myint et al., 2014). Nearby Thayawin, a marble-hosted Au skarn is characterized by native Au and Pb-Zn sulfides.

Kyaukpazat deposit is also known as an intrusion related copper-gold skarn deposit. It occurs as Au and sulfide bearing quartz vein in andesitic tuff, schist and phyllite of the Shwedaung Formation. Thayetkhone deposit is also characterized by the skarn gold ore and related gold-quartz veins which are hosted in calc-silicate and gneiss of Mogok metamorphic rocks intruded by syenite and granitic rocks. The Taungzon deposit located near Bilin Township is copper skarn deposit which is genetically related with I-type granitic rocks of Early Oligocene (Phyu Phyu Lwin, 2009).

The Baladokhta copper skarn deposit is characterized by the quartz-sulfide veinlets and disseminated sulfides in limestones. The Chaunggyi Cu-Au skarn deposits occur as gold-sulfide vein in the gneiss and marble of Mogok metamorphic belt (Khin Zaw et al., 2017). Moreover, there are some skarn type Pb-Zn-Ag and Sb deposits in Myanmar.

CHAPTER II. Regional geologic setting

2.1 Regional geologic setting

Much of Myanmar has been subjected to both of the Triassic-Early Jurassic Indosinian and Cenozoic Himalayan orogenies, two major plate collisions related to the closure of the Palaeo-Tethys and the Neo-Tethys oceans, respectively. Myanmar lies at a geologic juncture where the main Tethys Ocean suture zone swing southward around the Eastern Himalayan Syntaxis into Southeast Asia, colliding during the Mesozoic-Cenozoic orogenies (Gardinar *et al.*, 2016; Barber *et al.*, 2017). As a result, several major Tethyan-related metamorphic belts extend from the Eastern Syntaxis southwards across Myanmar, which may be correlated with those lying further west along the main India-Asia collision zone (Searle *et al.*, 2007). The sigmoidal Mogok metamorphic belt (MMB) is exposed at the margin of the Shan-Thai (Sibumasu) terrane (Barley *et al.*, 2003), along the northwestern margin of the Shan Plateau and southwards between the north-south trending Sagaing fault and Shan Scarp (Searle and Haq, 1964; Mitchell, 1993). The tectonic framework of Myanmar can also be sub-divided into seven province; 1. The Rakhine (Arakan) Coastal Strip which is an ensimatic fore-deep, 2. The Indo-Myanmar Ranges which represent an outer-arc or fore-arc, 3. The Western Inner-Myanmar Tertiary Basin or inter-arc basin, 4. The Central Volcanic Belt representing a magmatic-volcanic arc, 5. The Eastern Inner-Myanmar Tertiary Basin forming a back-arc basin, 6. The Mogok-Mandalay-Mergui Metamorphic Belt, 7. The Eastern Shan Highlands or Sino-Myanmar Ranges which host the Bawdwin deposit. The Mogok metamorphic belt and Slate belt which together lie to the west of the Paung Laung-Mawchi Zone (Fig. 2.1). The Panung Laung-Mawchi Zone is interpreted by Mitchell *et al.* (2012) as a possible pre-Permian suture, consisting of folded late Jurassic to mid-Cretaceous marine clastic sedimentary rocks and limestones. The Panlaung Fault, recognized by arial photography and satellite images as a deep,

rectilinear, series of valleys trending NNW–SSE (Fig. 2.2). The Panlaung Fault marks the western boundary of the Shan Plateau (Grason et al., 1976; Mitchell et al., 2004, 2007, 2012). The Eastern Shan Highlands or Sino-Myanmar Ranges hosts the Bawdwin deposit. The Sagaing Fault is the tectonically significant boundary between the Eastern Inner-Myanmar Tertiary Basin (back-arc basin) and the Mogok-Mandalay-Mergui Metamorphic Belt (Thein, 1973; Zaw, 2017). The Eastern Highland is covered with Plateau Limestone and older Palaeozoic rocks, which were concealed beneath the Lower Palaeozoic Mergui Group. These are possibly the protoliths of the Mogok Metamorphic Complex. The Mergui Group was deformed and acquired schistosity (Mitchell et al., 2007, 2012). The Mogok Metamorphic Belt lying between the Eastern Highland and Central Cenozoic Belt, trending north-south (Maung Thein, 1973). It exists within the 10–25 km wide zone of the western Shan Scarp, west of the Slate Belt and continues to beyond the Sagaing Fault which trends north-south. Consequently, the Shan scarp zone, which sits between the Mergui Group and Plateau Limestone, is the regional structurally deformed zone. The Shan scarp zone results from the NNW-SSE ductile stretching and associated normal faults striking N70E, cross-cut by younger right-lateral faults (Bertrand et al., 2003). The probable age of the first deformation has been suggested as Middle or Upper Miocene (Bertrand et al., 2003). The younger cross-cutting event during the Neogene was also indicated by age dating on the metamorphic rocks (Bertrand et al., 1999).

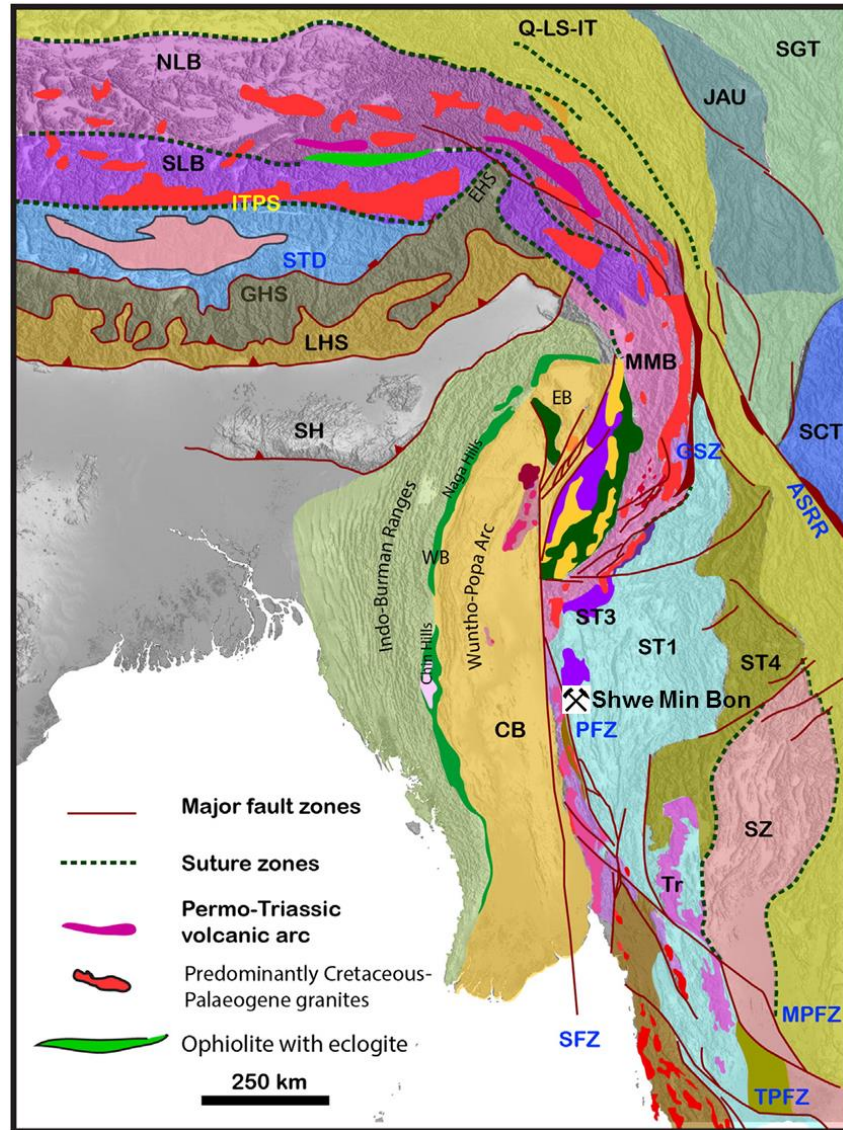


Fig. 2.1 Regional tectonic setting of Myanmar and its environment, MMB Mogok Metamorphic, EB Eastern Ophiolite Belt, CB Central Basin, WB Western Ophiolite Belt, ST3 Sibumasu Terrane (3) Chaunggyi Schist, ST1 (Sibumasu Terrane1) including Baoshan Block, ST2 (Sibumasu Terrane2) Slate Belt, ST4 (Sibumasu Terrane1) Shan Thai Block (overthrust remnants of Palaeo-Tethys sediments on Sibumasu), PFZ Pan Laung Fault Zone, SFZ Sagaing Fault Zone, SH Shillong Plateau, LHS Lesser Himalayan Series, GHS Greater Himalayan Series, ITPS Indus-Tsangpo Suture Zone, SLB South Lhasa Block, NLB North Lhasa Block, Q-LS-IT Qiangtan+ Lanping Simao+ Indochina Terranes, JAU Jinsha accretionary unit+Yidun unit, SGT Songpan Ganze Terrane +Transitional Unit, EHS Eastern Himalayanm, Syntaxis, GSZ Graze Litang Suture Zone, SCT South China Terrane, ASRR Ailao Shan- red river shear zone, SZ Sukhothai Island Arc Zone, Tr Triassic-Early Jurassic granite and gneiss belt, MPFZ Mae Ping Fault Zone, TPFZ Three Pagodas Fault Zone (modified after Gardiner et al., 2016).

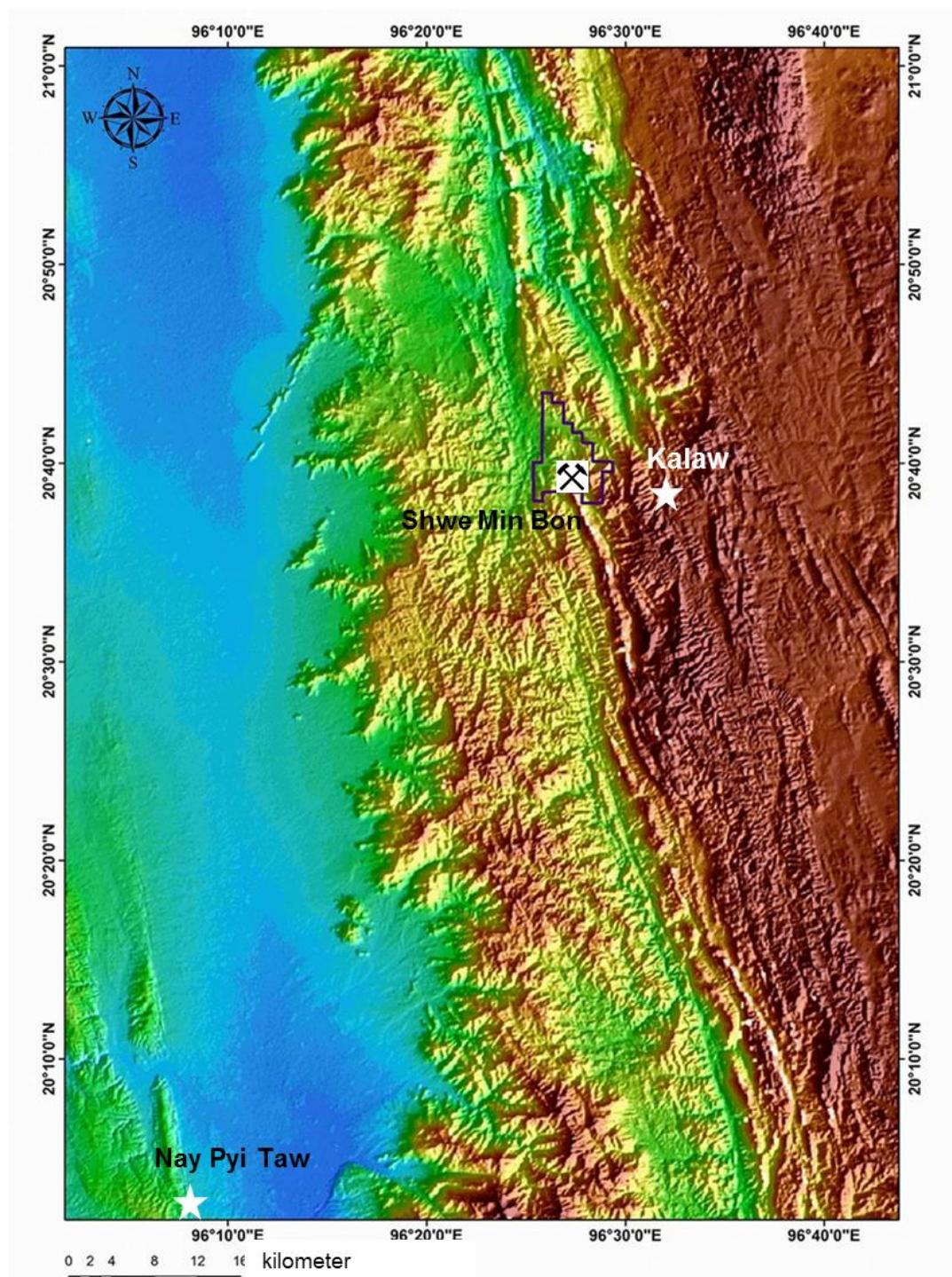


Fig. 2.2 Satellite image showing the physiography of the Shwe Min Bon and surrounding area.

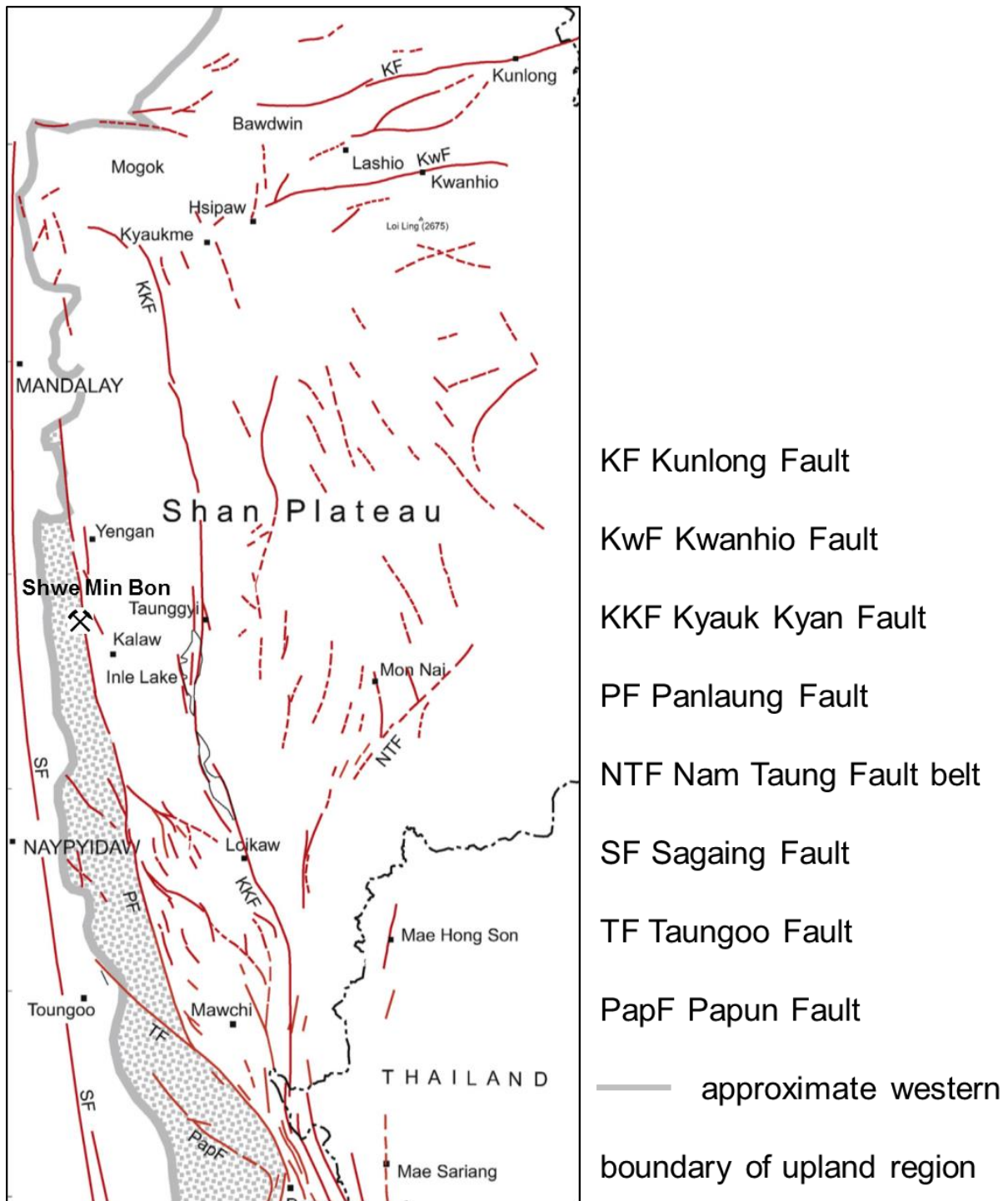


Fig. 2.3 Regional structural map of the Shwe Min Bon area (modified after Ridd et al., 2013).

2.1.1 Shan scarp zone

The Shan scarp zone is of significantly high relief, due to different erosion levels between resistant Shan Dolomite (Thisipin Limestone and Nwabangyi Dolomite) and adjacent mostly clastic sedimentary rocks (Mergui Slate Belt, Kalaw Red Bed and Pan Laung Groups-Kyauksu Taung Formation). The turbidite units of Ma-u-bin Formation (Ngayant Chaung and Shweminbon Formations) are preserved in the thrusts and high-angle fault-bounded slices (UNDP, 1978) as shown in Fig. 2.3. The Nwabangyi Dolomite (Upper Permian and Lower Triassic: Garson et al., 1976) consists of grey to dark grey color dolomite, trending NW-SE, and dipping to the east. The Triassic to Jurassic Shweminbon Formation consists of grey, buff, yellowish brown color mudstone, siltstone and white calcitic marble with limonitic fractures and light grey colored limestone (Ivanhole Myanmar Holding Ltd, 2000) (Fig. 2.4).

The angular unconformity of Kalaw Conglomerate on the older rocks units (Fig. 2.4) suggests that the latest thrusting may have occurred during the post-Cretaceous or Early Paleogene. The Permian Thitsipin Limestone and Permo-Triassic Nwabangyi Dolomite were thrust by Triassic- Jurassic Ngayant Chaung Formation and Shweminbon Formation probably during post-Cretaceous or Early Paleogene. A thrust fault contact between the Nwabangyi Dolomite and the turbidite unit of Ngayant Chaung Formation and Shweminbon Formation occurs along the west margin of the area (Fig. 2.4).

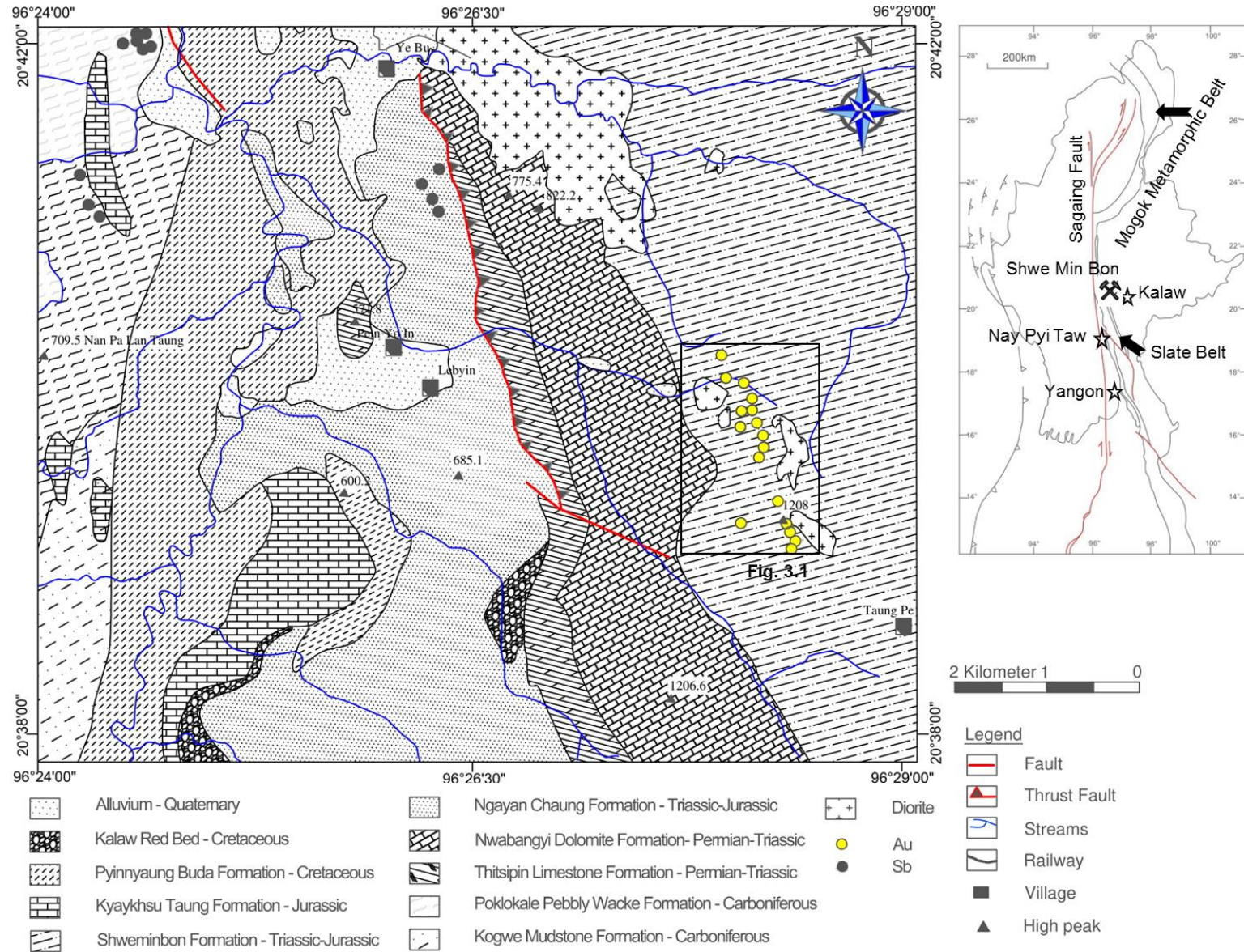
2.1.2 Structural setting

Regionally, Sharn scarp is characterized by the major active fault zone such as Pan Laung Fault. The Shan scarp extend southwards from Mandalay along the Shan State and Mandalay region boundary, adjacent to the Shan plateau to the east. The Pan laung Fault in Eastern Myanmar separates the Shan Plateau and Slate belt of the Shan scarp fault zone (Figs. 2.2 and 2.3). Within

the Shan scarp, the steep slopes and rugged relief of the belt occurred. The Shan scarp is also known as the boundary between Shan Plateau to the east and Sagaing fault to the west. The Shan scarp include three narrow north–south-aligned zones (from west to east): the Mogok Metamorphic Belt; the Slate Belt; and the Paunglaung–Mawchi Belt (Barber et al., 2017). The Shan Scarps area is interpreted as a fold-and-thrust belt (Barley et al., 2003; Bertrand and Rangin 2003) (Fig. 2.2). Folding and uplift resulted in erosion of the Shan Dolomite Group and Ma-u-bin Formation from the west of the area. Fractures trending northeast-southwest, and north-south are observed within the area. Thrust faults expose trending approximately NNW-SSE along the mineralized area. Gold mineralization is mainly confined to the NE-SW and E-W trending faults probably related to the movement of Shan Scarp Fault system.

2.1.3 Intrusives

The emplacement of granites, granodiorites and diorites with local Au mineralization and Sb mineralization in turbidite units, preceded deposition of the Kalaw Conglomerate (UNDP, 1978). Dioritic and small microdioritic dykes intruded the Ngayant Chaung Formation and small dioritic stocks intruded the Shweminbon Formation. Laser ablation inductively coupled plasma mass spectrometry U-Pb dating on zircon of the diorite intrusion yielded a late- early Cretaceous age (119 ± 1.1 Ma) (Wai Phyo, 2016; Wai Phyo et al., 2017). Gold-copper mineralization occurred in a narrow, elongated belt along the Shan scarp zone. The presence of numerous cross-cutting veinlets of quartz, calcite and sulfides were developed and appeared to be associated with thrusting, suggesting that gold mineralization was related to the formation of metasomatic rocks when igneous rocks intruded, and/or during deformation.



2.2 Stratigraphy and lithology of the Shwe Min Bon deposit

Shan scarp zone is the boundary zone between Shan Plateau of the Eastern highlands and Slate Belt. The Eastern Highland is covered with Plateau Limestone and older Palaeozoic rocks, which were concealed beneath the Mergui Group (the Lower Palaeozoic) as shown in the simplified stratigraphic column (Fig. 2). These are possibly the protoliths of the Mogok Metamorphic Complex. The Mergui Group (Slate Belt) was deformed and acquired schistosity (Mitchell et al., 2007, 2012). The Mogok Metamorphic Belt which is formed by the highly suggestive of the syntectonic or late-tectonic mode of emplacement of intrusives into the Eastern Highland and Central Cenozoic Belt with regional structural trend (Maung Thein, 1973). The region is composed of Mesozoic and Tertiary sediments, intermediate igneous rocks and Upper Paleozoic limestones (Fig. 2.5). It consists largely of argillaceous rocks correlated with the informally named Mergui Group which continue to southern Myanmar. These rocks are thought to have been deposited in a glacio-marine rift setting as the Sibumasu block parted from Gondwana (Metcalf, 1999).

A late Triassic-early Jurassic succession of tightly folded beds including turbidites has been mapped as the Shweminbon Formation and Ngayant Chaung Formation overlying the Permo-Triassic Plateau Limestone by Mitchell et al. (2002, 2004, 2007, 2012). Mitchell et al. (2004, 2007, and 2012) interpreted these rocks are as Neo-Tethys sediments which was deposited in ocean and probably located between the Shan Plateau and the Slate Belt. Shweminbon Formation turbidites were deposited on the western margin of the Sundaland block (if there was no magmatic arc west of the Shan Plateau at that time), or if separated from the Mesotethys by a magmatic arc that would later form the strike-slip fault boundary of the Slate belt (Ridd, 2013). An Andean-type margin developed intrusion of I-type granites, possibly as early as the Late Triassic, which continued at least to the Cretaceous and probably into the Palaeogene. The back-arc basin was conjectural, but

might have accounted for the deep marine Shweminbon Formation in Myanmar (Ridd, 2013). In the western part of the research area, the Triassic and Jurassic rocks of Ngayant Chaung Formation were overlain by Cretaceous conglomerate and contact with Permian Limestone and Nwabangyi dolomite by thrusting. In the research area, the Nwabangyi Dolomite (Upper Permian to Lower Triassic) and Shweminbon Formation of siltstones and impure limestone were intruded by the dioritic rocks Fig 2.4.

2.2.1 Nwabangyi Formation

The Nwabangyi Formation (or) Nwabangyi Dolomite (Upper Permian and Lower Triassic: Garson et al 1976) consists of grey, dark grey dolomite. It trends NW-SE dipping to the east. Thitsipin Permian Limestone transitionally in contacts in the west and Shweminbon Formation thrusts in eastern part.

2.2.2 Shweminbon Formation

Shweminbon Formation was named after IMHL (E) (2000) and it consists of Triassic to Jurassic grey, buff, yellowish brown mudstone, siltstone (Fig.2.4) and white calcite marble with limonitic fractures interbedded layers of silts and sands, micritic limestone and light grey limestone. The thrust fault contact with the Nwabangyi Dolomite along the west margin.

2.2.3 Dioritic rocks

The diorite intrusions occur as stock and dikes (Fig.2.4). The stocks are weathered and the dikes are fresh and compact.

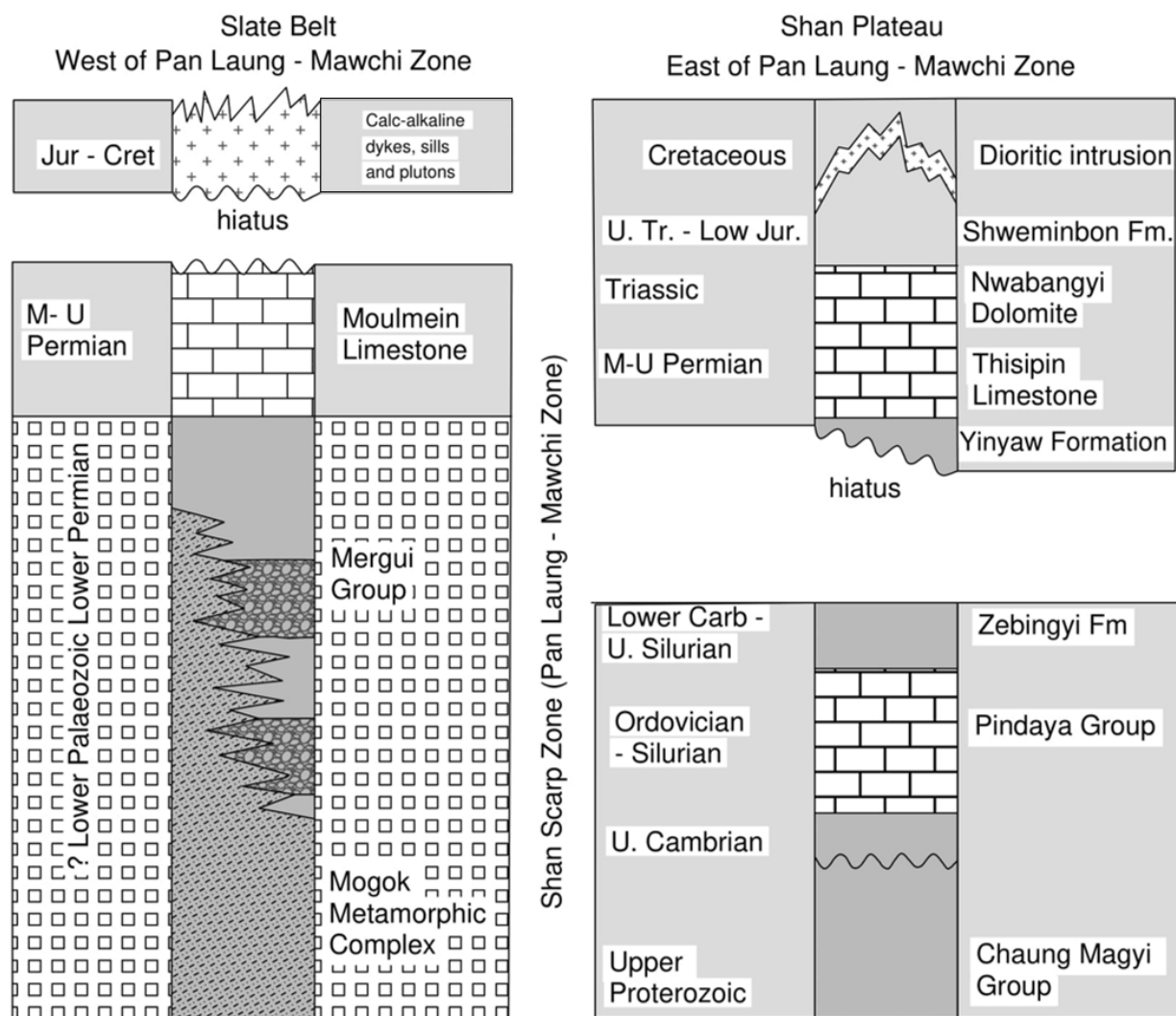


Fig. 2.5 Simplified stratigraphy of the Shan Scarps region of Myanmar (modified after Ridd and Watkinson, 2013), dark grey tone is mudstone, siltstone and sandstone; brick pattern referring to the limestone.

CHAPTER III. Geology, lithology and host rock geochemistry

3.1 Geology of rock units

The Shwe Min Bon deposit comprises skarn-type metasomatic alteration, with mineralization occurring along the contact between Nwabangyi Dolomite, Shweminbon Formation and Cretaceous dioritic rocks (Fig. 3.1). Limestone and turbidities units of Shweminbon Formation were metamorphosed into marble, quartzite, lime-silicate and hornfelsic rocks. The emplacement of dioritic rocks associated with regional deformation of the area and was implicit in the formation of contact metamorphism, skarn and copper-gold mineralization. Shweminbon Formation is mainly exposed in the eastern part of the research area and it is recognized as yellowish brown siltstone extending NW-SE along the east margin, and white calcite marble and limestone are exposed at the central part of the deposit.

In the Shwe Min Bon deposit, seven orebodies have been mined out (Fig. 3.1). Among them, the Bwet Taung, Tiger Mouth, Shwe Taung Gyar and Lun Htoe orebodies are the main mineralized zones. The Zin Yaw, Shwe Gu Lay and Shwe Taung Gyi prospects are currently not operational. This study will focus on the Bwet Taung, Zin Yaw, Tiger Mouth, Shwe Taung Gyar, Shwe Gu Lay and Lun Htoe orebodies. Based on field observation, the Bwet Taung, Zin Yaw, Tiger Mouth and Shwe Gu Lay orebodies are classified as proximal skarns. The Shwe Taung Gyar and Lun Htoe orebodies are identified as distal skarns. Moreover, the silicified zone occurs in the Bwet Taung and Tiger Mouth orebodies where igneous rocks intruded into the clastic rock of the Shweminbon Formation.

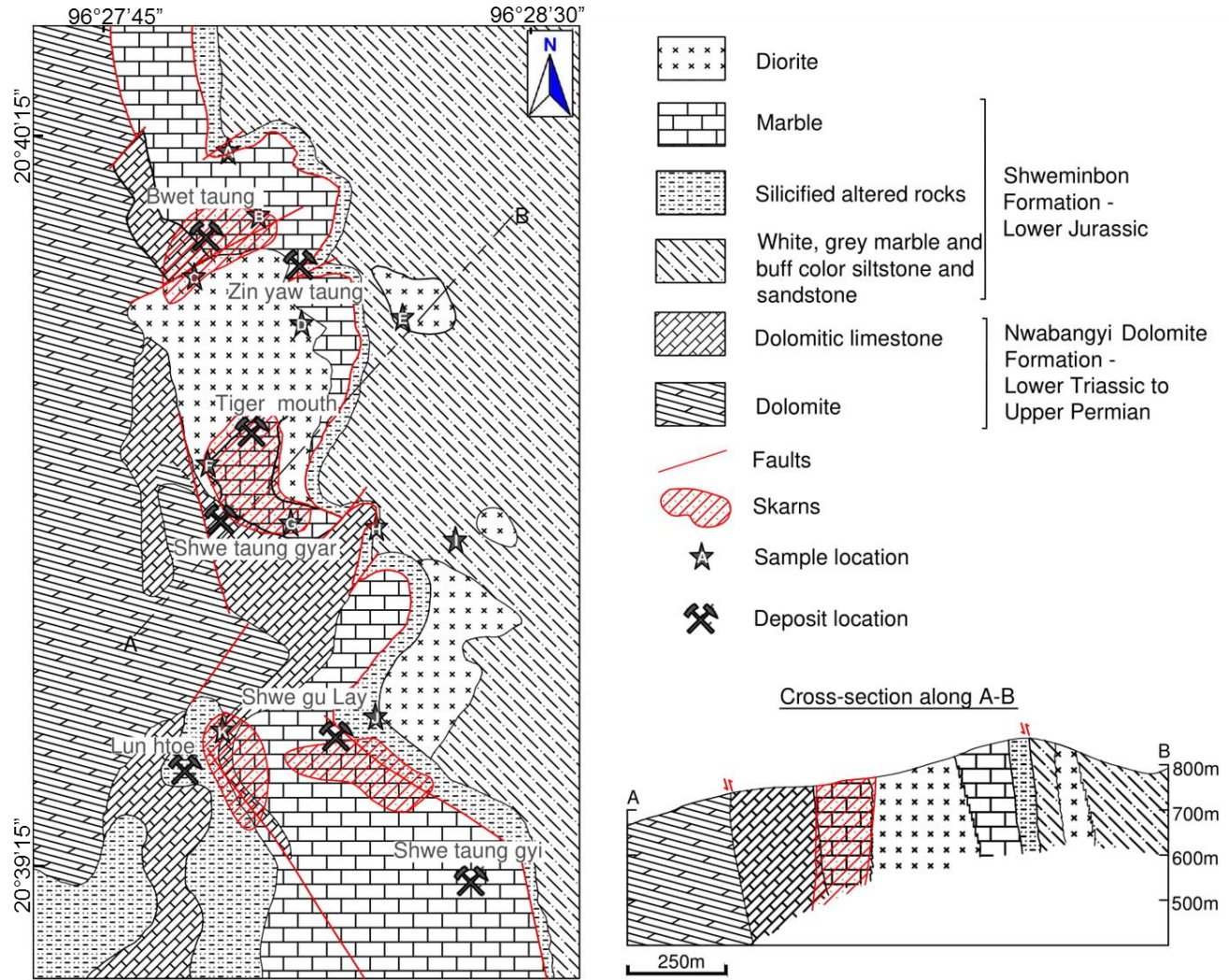


Fig. 3.1 Geological map of the Shwe Min Bon area (modified after Ivanhoe Myanmar Holding Ltd., 2000). Location of the collected samples are shown by star; (A) BT009, (B) BT1, BT6, BT7, (C) BT9, BT003, BT006, ZY5A, ZY7, TGM8, (D) TGM1, TGM5, TGM18, TGM15, TGM20, TGM-X1, TGM-X2, TGM-X3, (E) TGM22, (F) TGM9, TGM19, TGM25, TGM35, (G) STG1, STG2, STG3, STG4, TGM28, (H) TGM29, TGM008, (I) TGM014, TGM33, (J) SGL1, STG1, STG003, (K) LH9-star. Abbreviation; BT=Bwet Taung, ZY=Zin Yaw, TGM= Tiger Mouth, STG=Shwe Taung Gyar, SGL= Shwe Gu Lay, LH= Lun Htoe.



Fig. 3.2 Outcrop of the contact between diorite and Shweminbon Formation at Tiger Mouth orebody.

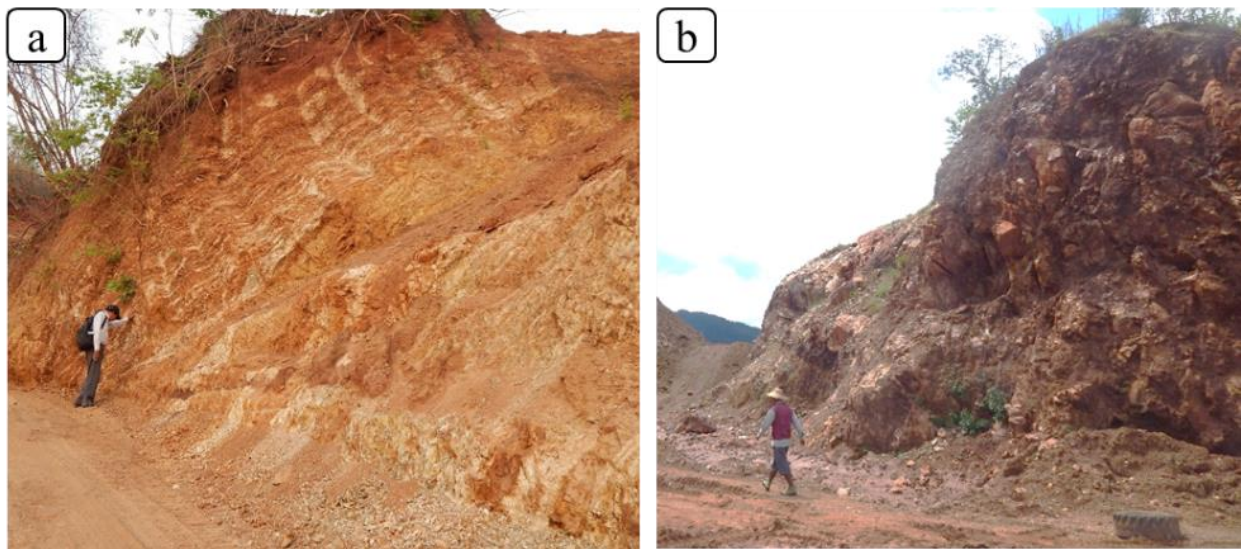


Fig. 3.3 Outcrops of (a) Shweminbon Formation and (b) breccia zone in Shweminbon Formation occurred in Shwe Min Bon deposit.



Fig. 3.4 Outcrop of intrusive rocks in the Shwe Min Bon deposit. (a) surface weathering of dioritic rock, (b) highly jointed dioritic rock, (c) exfoliation appearance of dioritic rock.

3.1.1 Shweminbon Formation

Siltstone and sandstone of the Shweminbon Formation were intruded by diorite and occurred as silicified zone along the contact (Figs. 3.2 & 3.3a). The dioritic rocks intruded into the Shweminbon Formation of calcareous rock in center and clastics rock in eastern part of the research area which are mostly occurred as dykes and a stock. The brecciated occurred in Shweminbon Formation (Fig. 3.3b).

3.1.2 Dioritic rocks

The dioritic rocks are exposed spread the Shwe Min Bon deposit except the Lun Htoe orebody. It is exposed as stock in the center of the deposit area near Bwet Taung orebody and Tiger Mouth orebody whereas the dyke occurs in Shwe Gu Lay, Shwe Taung Gyar orebody and eastern part of Tiger Mouth orebody (Fig. 3.1). Dioritic rocks intruded into limestone, siltstone and mudstone of Shweminbon Formation (Fig. 3.2). They are yellowish brown color where weathered, and exhibits greenish grey color. It showed porphyritic granular texture and is mainly composed of medium to coarse-grained plagioclase feldspar, hornblende, biotite and fine-grained quartz. These rocks were highly altered (Fig. 3.4 a, b) near the contact zone. Fresh diorite was observed along the tunnel wall and drill samples. The exfoliation were observed in diorite as a

physical weathering (Fig. 3.4c). However, these exfoliation rocks are very hard and compact probably due to the silicification.

3.2 Petrography of rock units

3.2.1 Shweminbon Formation

Siltstone and sandstone occur as interbedded, exhibiting fine to medium grained quartz, plagioclase with minor pyrite. These rocks are silicified when they occur near the dioritic intrusion. Marble occurred as both fine grained massive and crystalline coarse-grained (Figs. 3.5a, b).

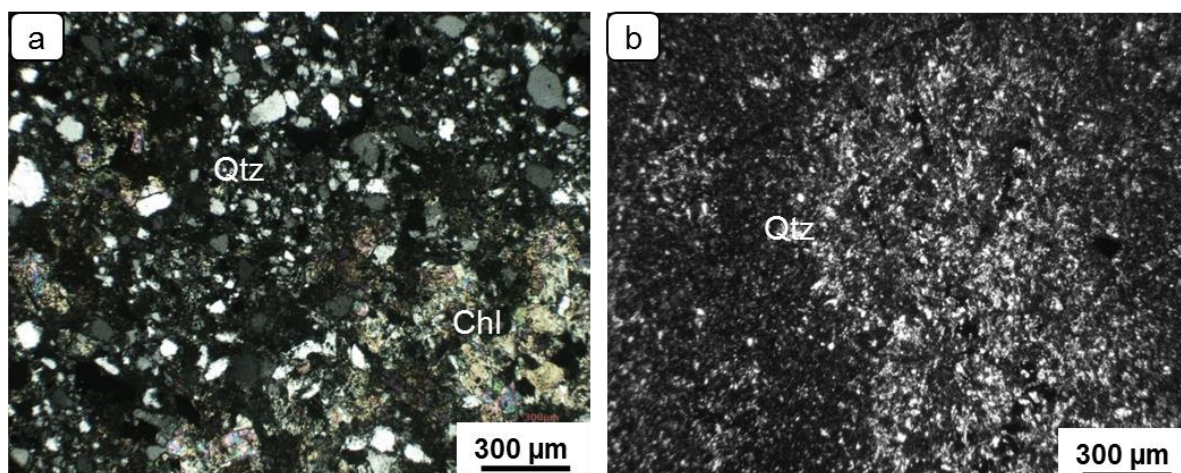


Fig. 3.5 Photomicrographs showing (a, b) quartz and chlorite in sedimentary rock of Shweminbon Formation.

3.2.2 Dioritic rocks

Based on the microscopic observation, dioritic rocks are composed mainly of plagioclase, pyroxene (diopside and augite), amphibole (hornblende and actinolite) with a minor amount of alkali-feldspar, biotite, quartz. These dioritic rocks exhibit a medium-grained porphyritic granular texture (Fig. 3.6a). Hornblende occurs as medium to coarse-grained euhedral phenocryst. Chlorite is present in dioritic rocks by the hydrothermal alteration of primary biotite (Figs. 3.6b, c). The

diorites are mainly composed of plagioclase, hornblende, and minor biotite and quartz. Pyrite and chalcopyrite occur as ore minerals in altered dioritic rocks (Fig. 3.6d). The granodiorite consists phenocryst of plagioclase, hornblende, with minor groundmass of quartz and alkali-feldspar (Fig. 3.6e). Saussuritization occurs in calcic plagioclase, which is altered to a assemblage of chlorite, amphibole, and carbonates (Fig. 3.6f).

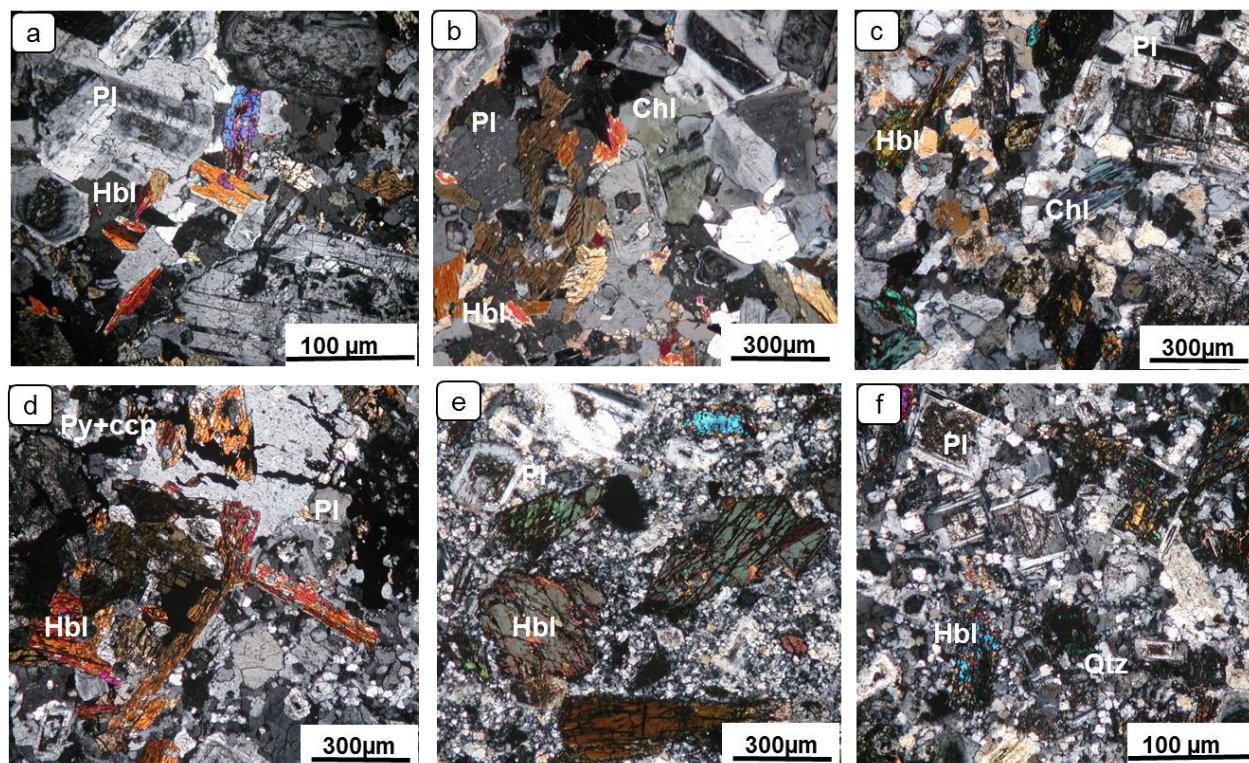


Fig. 3.6 Photomicrographs showing (a) coarse-grained hornblende & biotite (b) replacement of biotite by chlorite (c) hornblende, plagioclase and chlorite in dioritic rock (d) altered dioritic rock (saussuritization, chloritization) associated with opaque mineral (e) phenocrysts of hornblende occurring in a fine-grained groundmass (f) zoned plagioclase showing saussuritization in diorite. Abbreviations: Hbl=hornblende, Pl=plagioclase, Qtz=quartz, Chl=chlorite, ccp=chalcopyrite, py=pyrite.

3.3 Geochemistry of the host rock

3.3.1 Intrusive rocks

The spatial distribution of the dioritic rocks in the study area were shown in Figure 3.1. The fresh or least altered rocks were selected for chemical analysis of major and minor elements. The results are listed in Tables 3.1 and 3.2. The intrusive rocks from Shwe Min Bon were also classified as diorite and granodiorite (Fig. 3.7) in order to the whole-rock composition in terms of $\text{Na}_2\text{O} + \text{K}_2\text{O}$, total FeO and MgO contents (Middlemost, 1994). The intrusive rocks from Tiger Mouth are classified as diorite and granodiorite, while the intrusive rocks from Shwe Gu Lay and Zin Yaw are classified as granodiorite. The intrusive rocks of Shwe Taung Gyar are diorite in composition. The SiO_2 , Na_2O , K_2O and Al_2O_3 contents of diorites range from 55.9 wt. % to 62.2 wt. %, 1.7 wt. % to 2.1 wt. %, 2.7 wt. % to 5.6 wt. %, and 14.4 wt. % to 15.7 wt. % respectively, with $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios ranging from 0.45 to 0.68 (Table 3.1). The SiO_2 , Na_2O , K_2O and Al_2O_3 contents of granodiorites in the study area range from 63.2 to 65.3 wt. %, 2.1 to 2.8 wt. %, 1.7 to 5.9 wt. % and 9.1 to 15.8 wt. % respectively and the $\text{Na}_2\text{O} + \text{K}_2\text{O}$ values range from 5.0 to 8.1 wt. %, and $\text{K}_2\text{O}/\text{Na}_2\text{O}$ ratios from 0.36 to 1.35 (Table 3.2). These rocks belong to calc alkaline series in AFM diagram (Fig. 3.8). The A/NK versus A/CNK values indicate metaluminous characters (Fig. 3.9).

Trace elements normalized to MORB (Pearce and Parkinson, 1993) (Fig. 3.10) show the enrichment of LILE or mobile elements, especially K, Rb, and Ba. On the other hand, the HFSE or immobile elements show moderate enrichment to slight depletion. The depletion of the high field strength elements (HFSE; Nb, Zr, and Ti) with respect to the large ion lithophile elements (LILE) is a characteristic feature of subduction-related magmatism. It is importance as a tectonic tracer for the continental crust with strong depletion in Nb and Ta, formed subduction-related

processes (Taylor and McLennan, 1985; Rudnick and Fountain, 1995). The titanium is depleted probably due to the alteration of amphibole. The geochemical results show that the major oxide (Fig. 3.11) compositions are negatively correlated with SiO_2 while K_2O and Na_2O are positively correlated. The minor elements such as Pb, Cu, Y, Sr and V are also negatively correlated with SiO_2 of dioritic rocks (Fig. 3.12). While Ba is positively correlated, Cr, Ni and Zr are steadily correlated.

The geochemical result also suggest the crystallization differentiation process played an important role in the formation of the dioritic rocks. For example, Fe–Ti oxide crystallization differentiation is suggested by the decreasing of Fe_2O_3 , MgO and TiO_2 with increasing SiO_2 (Fig. 3.11). K feldspar and alkaline feldspar fractionation crystallization is indicated by the negative correlation between SiO_2 and K_2O (Fig. 3.11). The trace elements show positive correlation with SiO_2 (Fig. 3.12).

3.3.2 Sedimentary rocks

Geochemically, the concentration of copper and gold are positively correlated with arsenic and bismuth in various types of host rocks such as skarn, brecciated marble and silicified rocks of Shweminbon Formation are listed in Table 3.3.

Table 3.1. Chemical composition of the granodiorite: major (wt. %), minor (ppm) (n.d=not determined).

Localities	Zin Yaw	Shwe Gu Lay	Tiger Mouth					
Samples	ZY-7	SGL-X1	TGM-X1	TGM-X2	TGM-5	TGM-18	TGM-X3	TMG-20
SiO ₂ (wt %)	63.23	64.69	64.79	63.67	65.32	63.99	63.95	64.57
TiO ₂	0.56	0.44	0.48	0.45	0.47	0.48	1.16	0.42
Al ₂ O ₃	15.22	15.80	14.54	15.03	14.80	15.37	9.07	15.38
FeO	4.83	2.16	4.61	3.21	4.36	3.36	6.29	2.52
MnO	0.11	0.06	0.12	0.07	0.09	0.09	0.06	0.03
MgO	2.99	1.64	2.68	2.11	2.28	2.48	3.19	1.85
CaO	6.22	5.60	4.69	5.48	5.06	7.61	6.38	5.12
Na ₂ O	2.09	2.44	2.82	2.32	2.12	2.34	2.33	2.16
K ₂ O	2.91	5.07	3.43	4.15	3.55	3.05	1.72	5.98
P ₂ O ₅	0.09	0.10	0.09	0.09	0.08	0.09	0.18	0.09
S	0.02	0.03	0.06	1.00	0.27	0.02	1.39	0.31
LOI	1.58	1.76	1.52	2.23	1.42	0.97	3.50	1.37
Cu (ppm)	13	34	19	62	31	18	126	18
Zn	39	32	50	36	58	34	26	10
Pb	12	23	22	30	24	15	29	14
V	160	106	122	115	129	110	148	94
Cr	46	7	35	n.d.	34	31	248	n.d.
Co	51	36	39	44	40	n.d.	58	n.d.
Ni	18	n.d.	14	n.d.	20	n.d.	123	n.d.
Rb	151	282	180	190	191	151	123	292
Sr	333	579	400	370	346	395	206	381
Ba	601	951	770	900	791	677	171	890
Y	26	26	24	24	23	23	31	26
Zr	133	160	146	164	141	138	323	161
Nb	9	9	9	9	10	10	17	9
Na ₂ O+K ₂ O	5.00	7.50	6.25	6.47	5.67	5.39	4.05	8.14
K ₂ O/Na ₂ O	0.72	0.48	0.82	0.56	0.60	0.77	1.35	0.36

Abbreviation of the orebody names are listed in Figure 3.1.

Table 3.2. Chemical composition of the diorite: major (wt. %), minor (ppm) (n.d=not determined).

Localities	Tiger Mouth		Shwe Taung Gyar			
Samples	TGM15	TGM35	STG1	STG2	STG3	STG4
SiO ₂ (wt %)	61.81	58.36	57.10	55.92	57.63	62.19
TiO ₂	0.45	0.47	0.46	0.46	0.42	0.55
Al ₂ O ₃	14.37	14.36	15.21	15.09	15.73	14.86
FeO	4.41	4.55	5.10	5.03	4.59	5.60
MnO	0.08	0.09	0.08	0.08	0.07	0.13
MgO	2.55	3.00	3.28	3.03	3.57	2.54
CaO	6.35	8.02	8.22	9.48	7.82	6.34
Na ₂ O	2.20	1.71	1.79	1.88	1.64	2.22
K ₂ O	3.45	5.65	3.38	2.75	3.11	3.83
P ₂ O ₅	0.08	0.10	0.10	0.09	0.08	0.10
S	0.22	0.12	0.31	0.64	0.05	0.75
LOI	3.55	3.34	4.83	5.69	4.49	1.38
Cu (ppm)	26	56	52	47	84	51
Zn	21	28	27	31	7	56
Pb	17	27	7	5	8	28
V	123	150	148	141	151	150
Cr	32	47	45	59	47	38
Co	31	45	61	57	48	70
Ni	n.d.	15	n.d.	14	n.d.	15
Rb	198	384	238	200	237	201
Sr	350	448	412	453	431	384
Ba	824	965	936	692	891	866
Y	24	31	28	27	27	28
Zr	127	153	151	160	147	160
Nb	8	12	10	12	11	11
Na ₂ O+K ₂ O	5.65	5.39	5.17	4.63	4.75	6.05
K ₂ O/Na ₂ O	0.64	0.45	0.53	0.68	0.53	0.58

Abbreviation of the orebody names are listed in Figure 3.1.

Table 3.3. Chemical composition of host rock from skarn and silicified zone.

Sample	BT004	BT006	BT7	BT(gh1)	TGM28	TGM014	TGM008	TGM(cse1)	ZY5(A)	STG003
SiO ₂ (wt. %)	49.78	42.24	46.12	75.23	1.06	68.54	69.39	49.31	63.92	16.01
TiO ₂	0.01	0.60	0.01	0.97	0.01	0.22	0.17	0.02	0.24	0.02
Al ₂ O ₃	0.30	2.89	0.31	8.69	0.27	7.27	1.92	1.01	14.87	0.39
FeO	3.37	20.55	5.18	2.99	0.09	2.93	2.79	39.88	2.48	3.05
MnO	0.14	0.00	0.16	0.01	0.02	0.10	0.53	0.01	0.03	0.14
MgO	0.18	0.50	0.43	1.68	0.00	1.40	0.22	0.09	1.74	1.39
CaO	39.13	0.18	40.73	3.12	54.23	6.49	14.34	0.21	2.80	54.74
Na ₂ O	0.01	0.04	0.01	0.22	n.d	0.02	0.01	0.01	0.21	0.01
K ₂ O	0.01	1.31	n.d	5.21	n.d	2.20	0.40	0.02	10.17	0.01
P ₂ O ₅	n.d	0.08	n.d	0.20	0.01	0.03	0.02	0.02	0.04	0.00
S	0.32	2.26	1.06	0.02	0.01	1.08	1.82	1.38	0.04	0.37
Cu	0.64	0.05	1.93	0.04	0.01	0.11	0.04	0.18	1.26	0.34
Zn	0.02	0.02	0.12	0.003	0.002	0.31	0.04	0.01	0.01	0.37
Pb	0.003	0.49	0.03	n.d	0.01	0.53	0.01	0.01	0.002	0.001
LOI	5.64	14.58	2.68	1.46	43.33	6.16	5.92	7.58	1.85	23.34
V (ppm)	n.d	79	2	89	13	60	25	7	74	18
Cr	51	166	128	250	233	59	68	35	54	67
Co	30	n.d.	n.d	n.d	n.d.	n.d	88	231	n.d	45
Ni	31	44	37	78	20	54	146	238	38	40
Au	n.d.	n.d.	n.d.	n.d.	1726	n.d.	n.d.	n.d.	n.d.	n.d.
As	2793	*****	5633	n.d.	n.d	24930	10293	1908	n.d.	n.d.
Sb	376	300	1470	n.d.	n.d	n.d.	170	n.d.	n.d.	n.d.
Mo	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	265	n.d.	n.d.	n.d.
W	252	37	246	22	n.d	99	n.d	49	n.d	23
Rb	5	67	33	333	83	234	43	n.d.	730	6
Sr	97	791	16	173	196	48	48	5	280	267
Ba	n.d.	141	51	401	n.d.	281	57	n.d.	1620	n.d.
Y	n.d.	27	n.d	72	n.d	66	21	n.d.	135	n.d.
Zr	n.d	179	n.d	306	n.d	n.d.	n.d.	n.d.	106	n.d.
Th	267	124	1600	7	2712	54	208	50	138	391
U	n.d	n.d.	n.d	n.d	n.d	20	n.d.	n.d.	n.d.	n.d.
Bi	460	180	2750	n.d	4570	n.d.	340	n.d.	190	630

Major (wt. %), minor (ppm) (n.d=not determined) (*****=above detection limit). Abbreviation of the orebody names are listed in Figure 3.1.

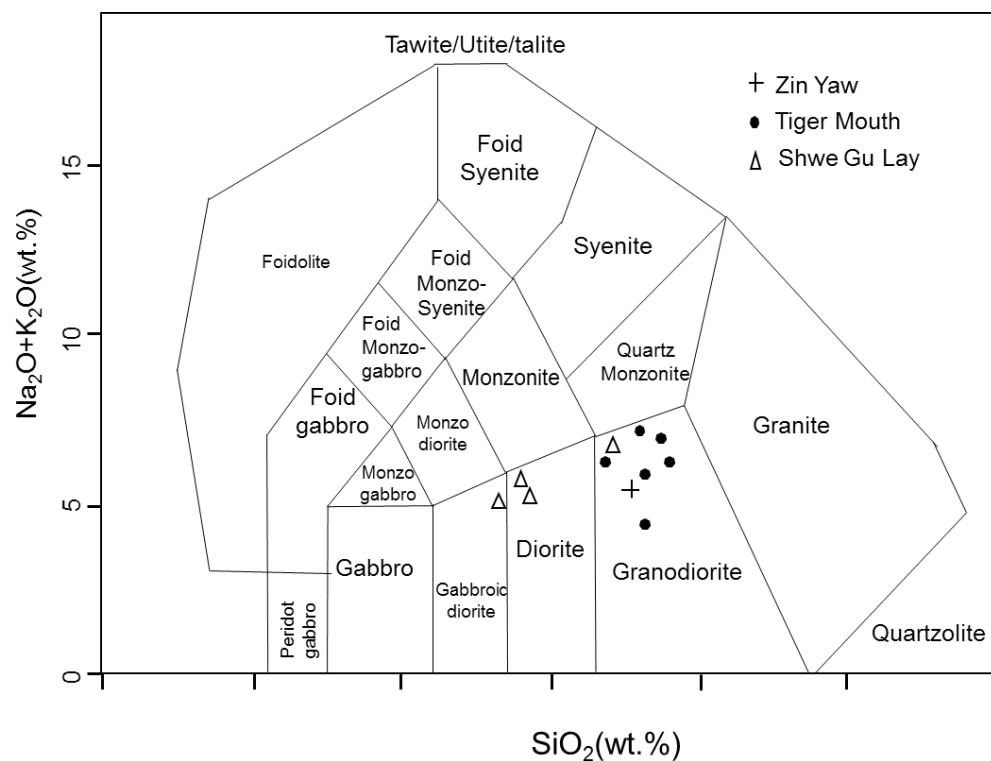


Fig. 3.7 Geochemistry of the intrusive rocks on the classification of intrusive rock according to the combined alkali content and silica content (Middlemost, 1994).

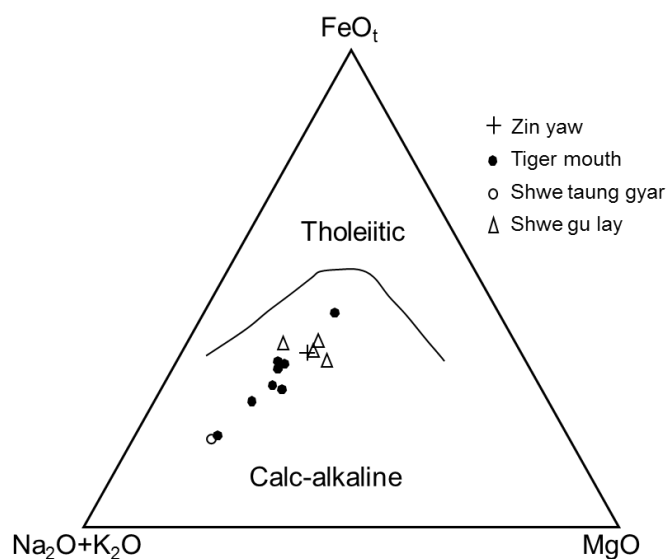


Fig. 3.8 Geochemistry of the intrusive rocks on the AFM diagram showing whole-rock composition in terms of $\text{Na}_2\text{O} + \text{K}_2\text{O}$, total iron as FeO and MgO (Irvine & Baragar (1971)).

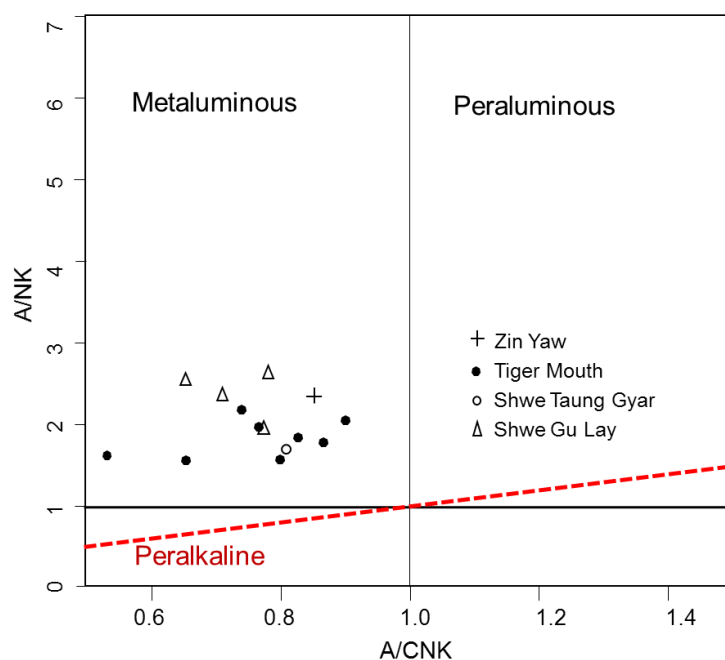


Fig. 3.9 Geochemistry of the intrusive rocks on the total alkali versus SiO_2 diagram; A/NK ($\text{Al}_2\text{O}_3/\text{Na}_2\text{O}+\text{K}_2\text{O}$) versus A/CNK ($\text{Al}_2\text{O}_3/(\text{CaO}+\text{Na}_2\text{O}+\text{K}_2\text{O})$) (Shand, 1943).

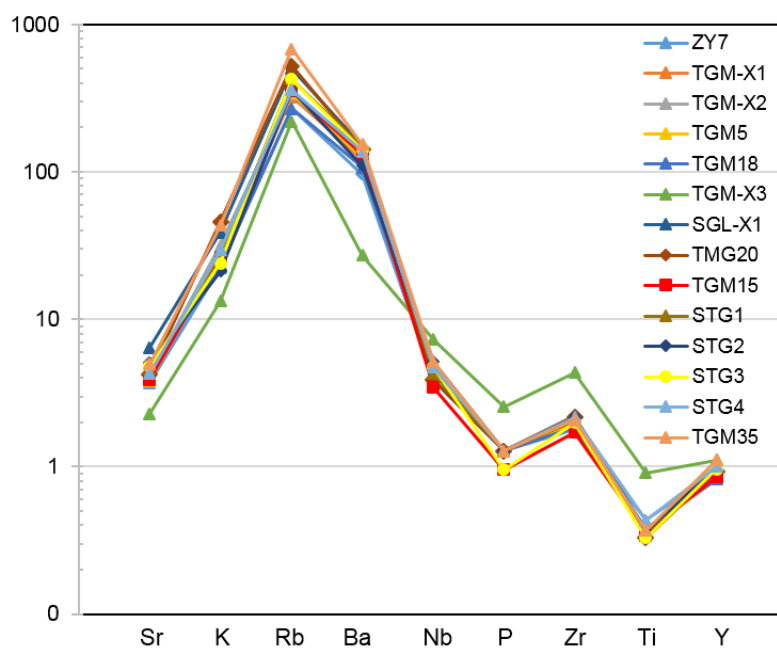


Fig. 3.10 A spider diagram of selected major and trace elements of the dioritic rocks, normalized to the composition of MORB (Pearce & Parkinson, 1993).

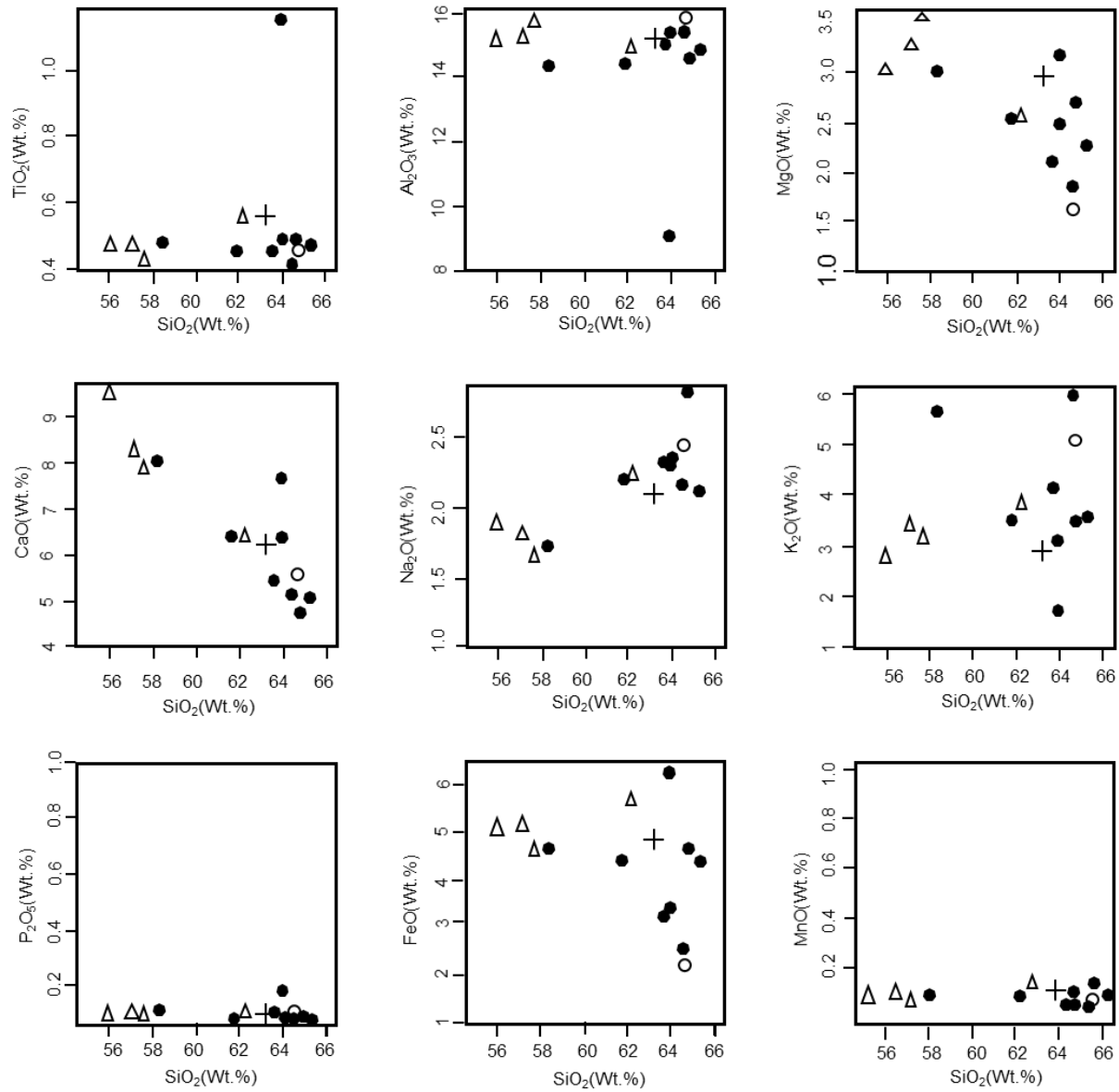


Fig. 3.11 Plot of SiO_2 vs. TiO_2 , Al_2O_3 , MgO , CaO , Na_2O , K_2O , P_2O_5 , FeO weight percent of intrusive rocks. Abbreviation of the orebody samples are as in Figure 3.9.

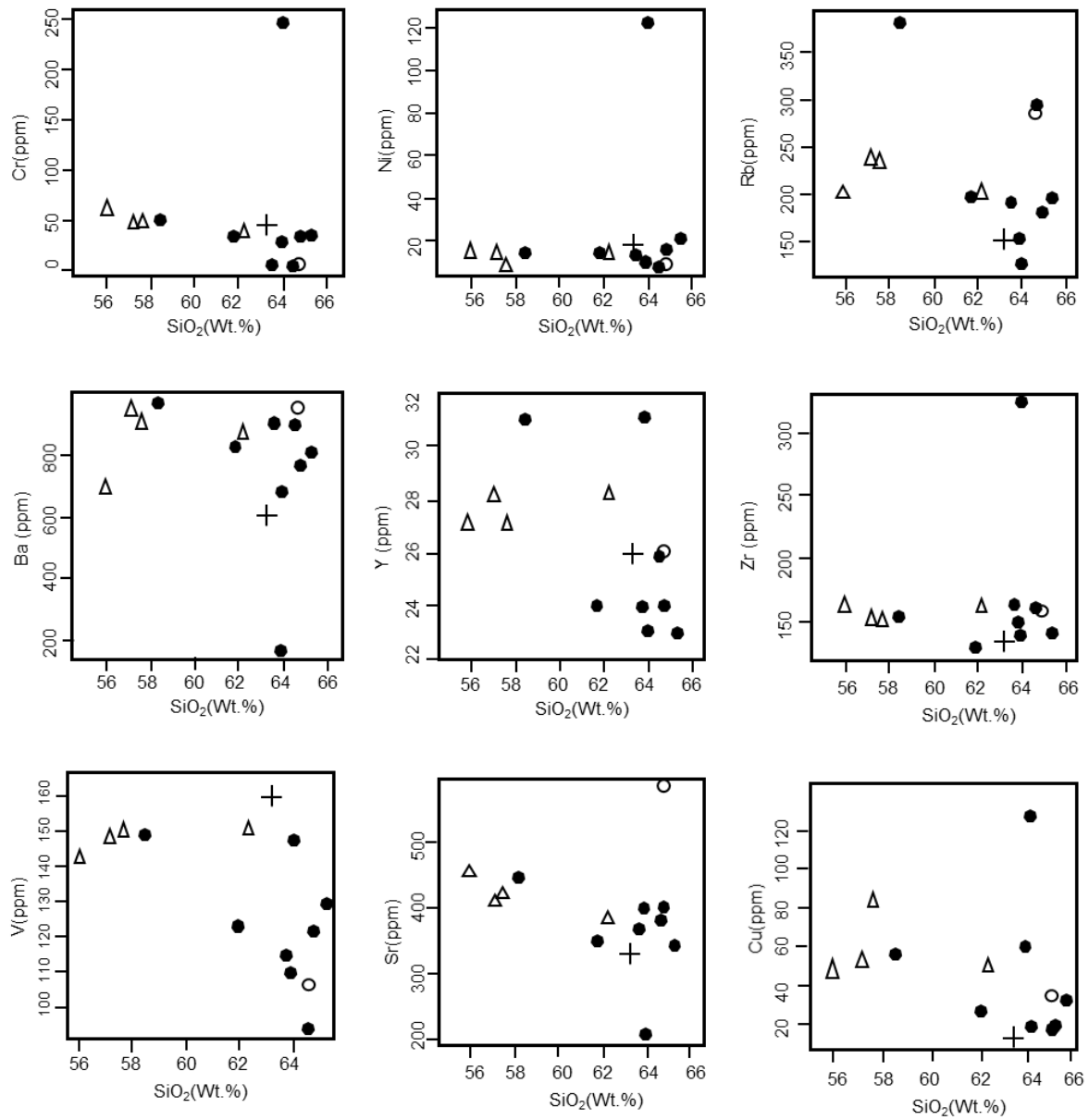


Fig. 3.12 Selected trace element contents (ppm) vs. SiO₂ of dioritic intrusive rocks from.

Abbreviation of the orebody samples are as in Figure 3.9.

CHAPTER IV. Occurrence of skarn

4.1 Occurrences of skarn

The distribution of skarn and mineralogy reflect both structural and lithologic controls. Exoskarn occurs as the principle skarn zone which is in contact with diorite and contains copper and gold mineralization (Fig. 4.1). The thickness of this zone varies up to 300m. Exoskarn extensively occurred in the Shwe Min Bon deposit as three proximal garnet-rich skarns and one distal pyroxene-rich skarn. Endoskarn was developed as a narrow band (1-2m) along the contact in the granodiorite (Fig. 4.2). It is characterized by the alteration zone composed of epidote and chlorite. The endoskarn is associated with epidotization and chloritization, whereas exoskarn is characterized by garnet and wollastonite (Figs. 4.3, b and c). The skarn is zoned from the intrusive rock outwards in the sequence: from garnet skarn (Tiger Mouth, Zin Yaw and Bwet Taung), pyroxenoid (Shwe Taung Gyar and Lun Htoe) to marble (Shwe Taung Gyi). Three skarn stages were observed mainly in exoskarn as: prograde skarn (pre-ore stage), retrograde skarn stage I and Cu-Fe-As-Bi sulfides (main ore stage) and retrograde stage II; Bi-Te minerals associated with calcite (late ore stage) in brecciated marble. In addition, another supergene stage marked by secondary Cu mineralization (malachite and azurite) is closely associated with the oxidized zone. Metal zoning also can be identified in the Shwe Min Bon deposit. Proximal skarn is rich in Fe and distal skarn is rich in Cu, Au, Bi, Pb, Zn and Sb. Arsenic and bismuth are strongly associated with gold mineralization.



Fig. 4.1 Field photograph of the contact between exoskarn and diorite in Bwet Taung orebody.



Fig. 4.2 Field photograph of the contact between marble, endoskarn and granodiorite in Zin Yaw orebody.

Skarn-type metasomatic alteration and mineralization occurs along the contact between Shwe Min Bon Formation and the post Mesozoic dioritic intrusive rocks. There are four main skarn zones; three proximal (1) the Bwet Taung orebody (outcrop showing in Fig. 4.1), (2) Tiger Mouth orebody and (3) Shwe Taunggyar orebody, and one distal of Shwe Gu Lay and Lun Htoe orebody.

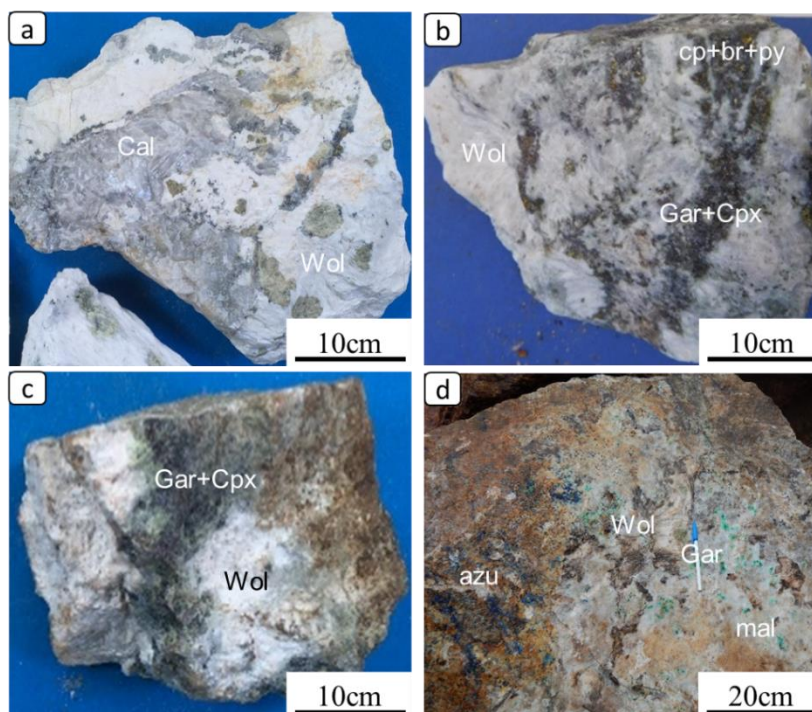


Fig. 4.3 Photographs of skarn and sulfide vein from the Bwet Taung orebody. (a) wollastonite garnet-calcite-chalcopyrite in exoskarn, (b) massive chalcopyrite, bornite, pyrite, calcite, quartz, actinolite in retrograde alteration of garnet-wollastonite skarn, and from Tiger Mouth orebody, (c) garnet- pyroxene-wollastonite skarn at Bwet Taung orebody, (d) copper oxide ores (malachite and azurite) occurred in skarn rock at Tiger Mouth orebody. Abbreviations: Cal=calcite, Grt=garnet, Opx= orthopyroxene, Qtz=quartz, Wol=wollastonite, cp=chalcopyrite, br=bornite, py=pyrite, sph=sphalerite.

Skarn is characterized by the development of garnet with pyroxene in proximal zone, and wollastonite-bearing assemblages in distal zone. Retrograde skarn develops with the formation of chlorite, epidote (Figs. 4.4a & b) and tremolite-actinolite in the later stage (Figs. 4.4c & d). The most intense retrograde skarn overprints the prograde skarn and are mainly composed of epidote, quartz, and chlorite.

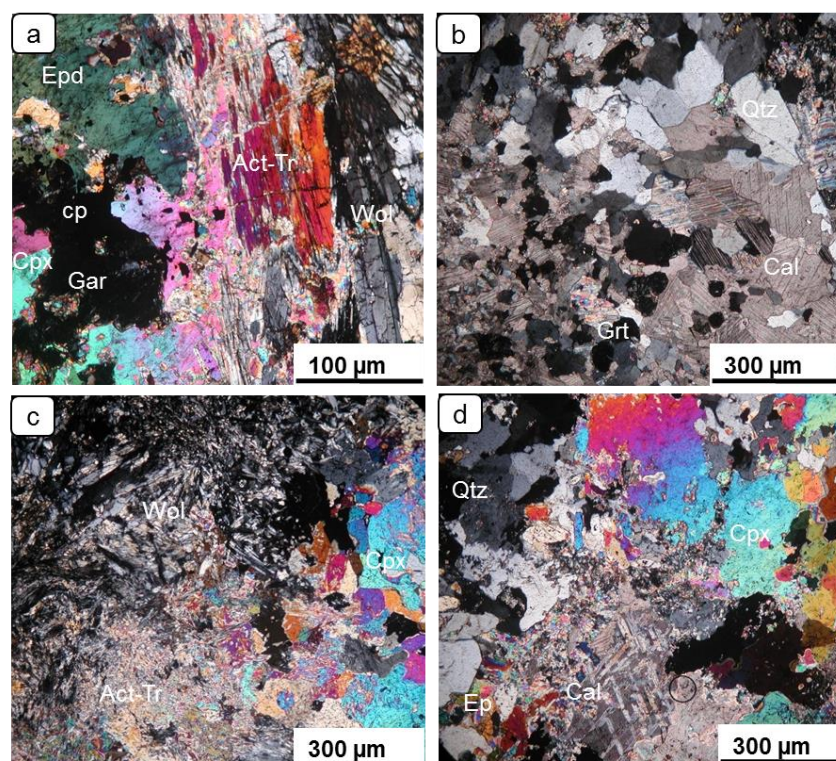


Fig. 4.4 Photomicrographs showing (a) the prograde mineral assemblages of garnet, wollastonite and clinopyroxene partially altered to retrograde mineral assemblages of epidote and actinolite with minor chalcopyrite in skarn at Tiger Mouth orebody (b) anhedral garnet, quartz and calcite in skarn Tiger Mouth orebody (c) wollastonite and tremolite in wollastonite skarn at Bwet Taung orebody (d) quartz, epidote, diopside and calcite occurring in diopside skarn at Bwet Taung orebody. Abbreviations: Grt=garnet, Cal=calcite, Cpx= clinopyroxene, Wol=wollastonite, Qtz=quartz, Epd=epidote, Act=actinolite-tremolite, Chl=chlorite, cp= chalcopyrite.

4.2 Skarnization

4.2.1 Skarn petrography

The occurrence of skarn at the contacts between intrusive rocks and marble suggest that both exoskarn and endoskarn were developed in the Shwe Min Bon area. The formation of endoskarn began with the replacement of garnet, which is coarse-grained and associated with sulfide mineralization including plagioclase and hornblende relict (Fig.4.5). Endoskarn is developed as a narrow band (1-2m) along the contact with the diorite and is characterized by epidotization. Exoskarn is the main skarn zone in the area, and contains ore-grade copper and gold. The thickness of this zone varies along the intrusive contact but locally reaches up to 30m. Exoskarn is enclosed by marble and mainly composed of garnet, wollastonite, epidote, actinolite, quartz and calcite (Fig. 4.6). Prograde and retrograde alteration extensively occurs in the exoskarn zone. As most skarn ore deposits are characterized by two distinctly different alteration styles, Shwe Min Bon skarn deposits also exhibit two types of skarn alteration; (1) an early prograde stage with anhydrous minerals, garnet, pyroxene and pyroxenoid, (2) a later retrograde stage with hydrous minerals, epidote, actinolite-tremolite, and chlorite plus sulfide ore minerals. Metasomatism developed both prograde and retrograde mineral assemblages in both endo- and exoskarn contemporaneous with or following recrystallization of limestone to marble. However, exoskarn extensive occurs and associated with copper and gold bearing minerals. Skarn zoning normally define by mineral assemblages according to their proximal and distal occurrences. Prograde skarn is characterized by the development of garnet with pyroxene proximal to the dioritic rocks and wollastonite bearing assemblages distal to the dioritic rocks. The most intense retrograde skarn are mainly composed of epidote, quartz, and chlorite, overprinted the prograde skarn garnet (Fig. 4.5). Retrograde skarn develops chlorite, epidote and tremolite-actinolite in the

later stage (Fig. 4.6). Later activity occurred as pyrite-bearing quartz veins and sulfide veins. The prograde and retrograde mineral assemblages were formed mainly in the exoskarn contemporaneous with or after the recrystallization of limestone to marble.

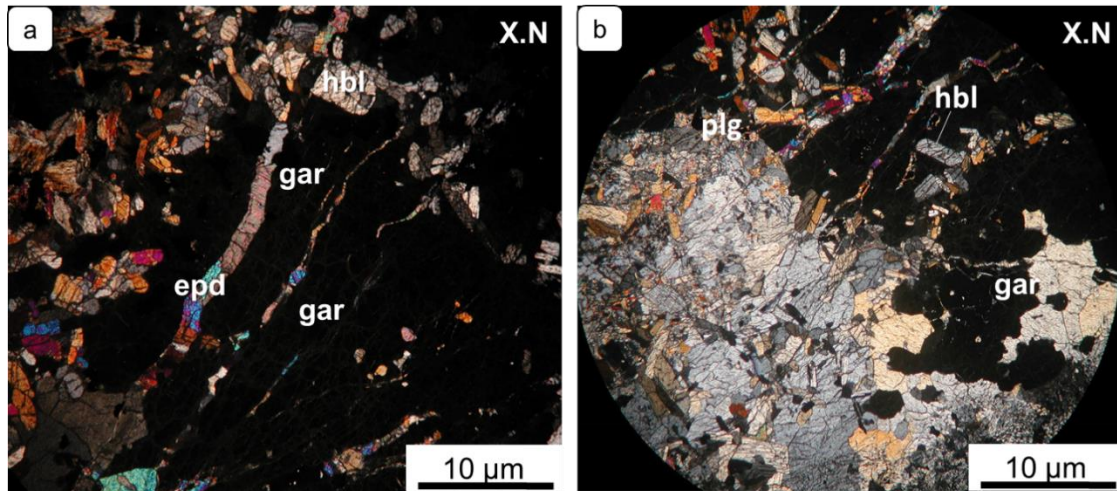


Fig. 4.5 Epidote minerals replace earlier formed garnet in skarn at Bwet Taung orebody.

Abbreviations: X.N=*crossed Nicols*, grt=garnet, epd=epidote, hbl=hornblende.

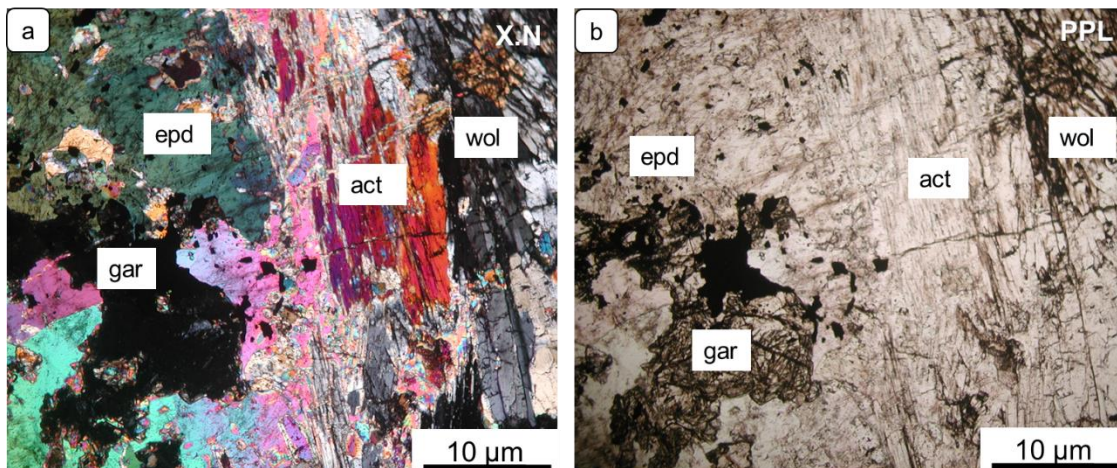


Fig.4.6 Exoskarn mineral assemblages (a) under crossed nicols (X.N) and (b) plane polarized light (PPL) of wollastonite (wol), garnet (gar), epidote (epd) and actinolite (act) at Bwet Taung orebody.

4.1.1.1 **Bwet Taung orebody**

The Bwet Taung orebody is located in the exoskarn zone which is located northern part of the deposit. In this skarn zone exoskarn occurs as the principal skarn zone and it occurs as a proximal skarn. It is enclosed by marble and hornfelsic sandstone and siltstone. Chalcopyrite is the most abundant ore mineral in the Bwet Taung orebody, and it coexists with bornite, tennantite, enargite, pyrite, and cosalite. Ore deposits are present not only in the skarn zone but also associated with the silicified zone. Silicified rock mainly occurs in the Shweminbon Formation of this orebody.

The prograde skarn is characterized by garnet with minor clinopyroxene and wollastonite-bearing assemblages. The retrograde skarn consists of wollastonite, epidote, chlorite and actinolite (Fig. 4.7a &b). Wollastonite and garnet is the gangue minerals of sulfide minerals (Fig. 4.7c &d). Gold mineralization is mainly associated with chalcopyrite in this orebody.

4.1.1.2 **Zin Yaw**

In this orebody, endoskarn is associated with epidotization and chloritization, between the marble and granodiorite. Skarn minerals consist of Fe-rich garnet with clinopyroxene and minor chlorite, calcite, and quartz. Fe-oxide mineralization is dominated by magnetite and mainly occurs as secondary ore minerals such as hematite, azurite and malachite.

4.1.1.3 **Tiger Mouth**

Exoskarn is the principal skarn zone in the Tiger Mouth orebody which is hosted by marble and hornfelsic sandstone and siltstone. The formation of endoskarn began with the formation of garnet, which occurs as coarse-grained assemblages associated with sulfide mineralization, as well as relict plagioclase and hornblende of diorite or granodiorite. The skarn minerals consist mainly

of andradite garnet, which is partly replaced by retrograde skarn minerals such as chlorite, calcite, quartz (Fig. 4.7e). The prograde skarn minerals of garnet and wollastonite were overprinted by retrograde minerals such as epidote and chlorite (Fig. 4.7f). Telluobismuthinite is remarkably associated with chalcopyrite and tennantite in Cu-sulfide mineralization in this zone.

In this orebody, sulfide-bearing quartz veins, sulfide veins and vuggy quartz are found in the silicified zone. Sphalerite and chalcopyrite were also formed after pyrite, galena and arsenopyrite in the silicified zone. In addition, malachite and azurite were formed as secondary minerals.

4.1.1.4 *Shwe Taung Gyar*

Skarn minerals present in this orebody are wollastonite, vesuvianite, actinolite, chlorite, quartz, and calcite (Fig. 4.7g). The ore minerals are bismuthinite, tellurobismuthite, chalcopyrite (being the most abundant in Cu-sulfide mineralization), pyrite, bornite and tennantite. Native gold grains are typically up to 50 μm in diameter. Gold mineralization is mainly associated with tennantite and chalcopyrite in the wollastonite-rich skarn, Bi-Te minerals in the brecciated marble mainly tellurobismuthinite, and hedleyite and some are enclosed by bismuthinite. Wittichenite is associated with tennantite in the exoskarn.

4.1.1.5 *Shwe Gu Lay and Lun Htoe*

The Shwe Gu Lay orebody was developed in the contact aureole of the marble and granodiorite. Skarn minerals are mainly vesuvianite, garnet and minor quartz. Chalcopyrite is the main copper mineral and covellite and malachite occur as secondary minerals. Based on mineralogy and geochemical studies, Shwe Gu Lay belongs to Cu and Fe mineralization. The Lun Htoe orebody is the main distal skarn zone in the Shwe Min Bon deposit. Wollastonite, actinolite,

fluorite and chlorite are common skarn minerals (Fig. h& i). Chalcopyrite, sphalerite, bornite, chalcocite and tennantite are mainly associated with wollastonite and calcite. Gold in this orebody is associated with sphalerite and chalcopyrite.

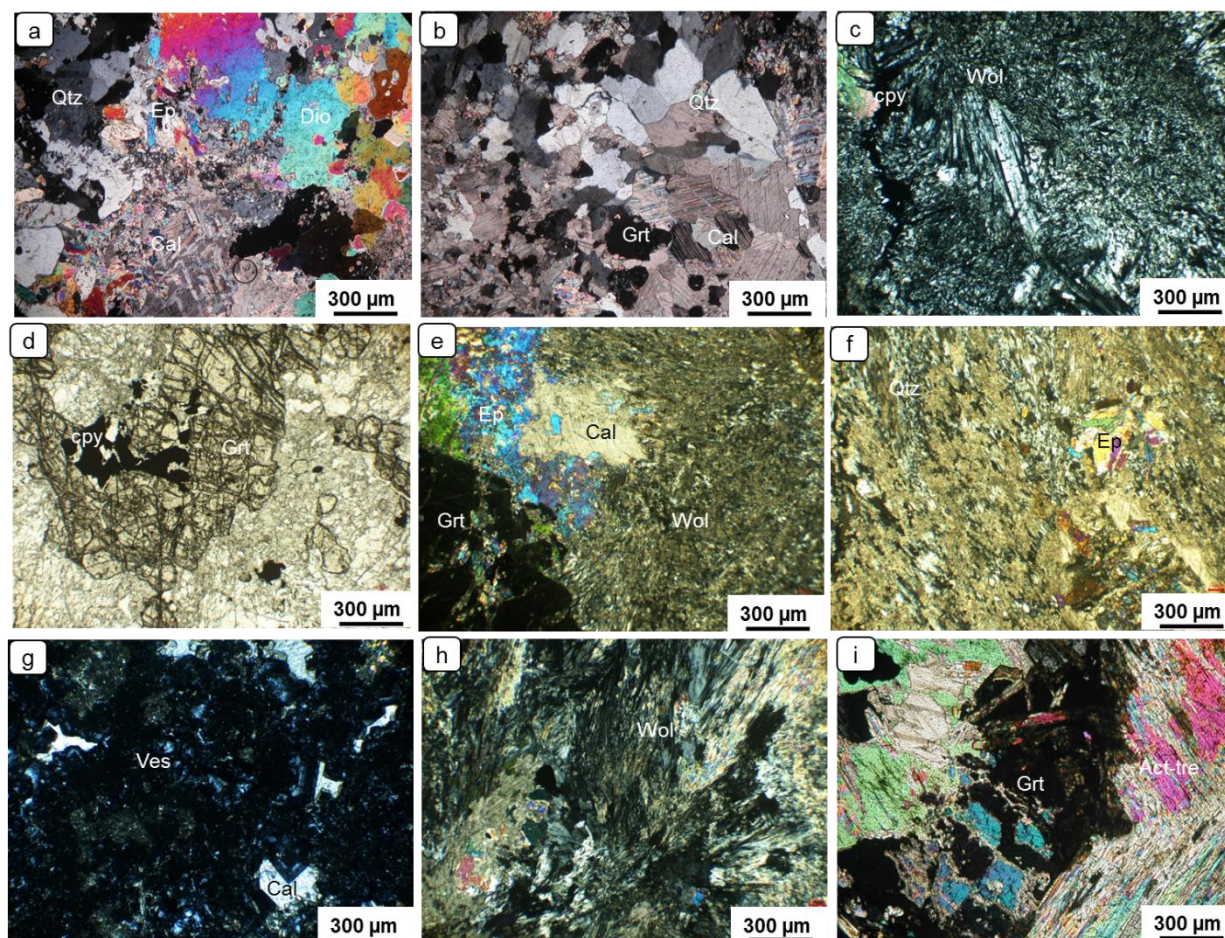


Fig. 4.7 Photomicrographs showing the skarn mineral assemblages (a) garnet+ diopside+ epidote+ quartz+ calcite in Bwet Taung orebody, (b) garnet+ quartz + calcite, (c) wollastonite+ epidote with chalcopyrite in Bwet Taung orebody, (d) garnet with chalcopyrite in Bwet Taung orebody, (e) garnet+ wollastonite+ epidote+ quartz+ calcite in the Tiger Mouth orebody (f) wollastonite+ quartz+ epidote in Tiger Mouth orebody, (g) vesuvianite+ calcite+ orthopyroxene in Shwe Taung Gyar orebody, (h) wollastonite partially replace by epidote with ore minerals in Lun Htoe orebody, (i) garnet granually replaced by epidote with actinolite-tremolite at Bwet Taung orebody. Abbreviations: Cal=calcite, Grt=garnet, Opx= orthopyroxene, Wol=wollastonite, Qtz=quartz, Epd=epidote, Act=actinolite-tremolite, Chl=chlorite, ccp= chalcopyrite.

4.2.2 Skarn mineralogy

Various types of anhydrous and hydrous calc-silicates (garnet, clinopyroxene, epidote, wollastonite, actinolite), silicates (chlorite, plagioclase, clay minerals), and quartz, sulfides (pyrite, chalcopyrite, tennantite, bornite, enargite, galena), oxides (magnetite, hematite) and carbonates (calcite) were developed during sequential stages of skarnification in the skarn zones through the contact between intrusions and impure carbonate rocks.

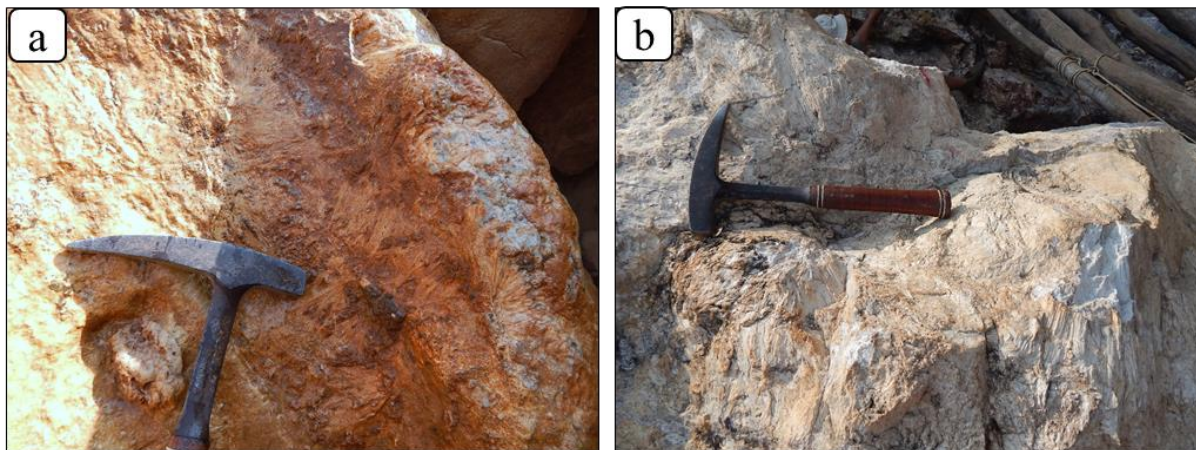


Fig. 4.8 Photographs showing the characteristics of the garnet-wollastonite skarn outcrop in Shwe Min Bon deposit (a) Tiger Mouth orebody and (b) Lun Htoe orebody.

Well-formed wollastonite crystals are found in the Tiger Mouth (Fig. 4.8a) and the Lun Htoe orebodies (Fig. 4.8b). Crystals of wollastonite are bladed or fibrous, occurring as fine to coarse-grained masses and massive aggregates.

Wollastonite is the main skarn minerals (Figs. 4.9a). Wollastonite as a gangue mineral of sulfide minerals and gold in the Tiger Mouth, Shwe Taung Gyar and Lun Htoe orebodies. Wollastonite is partly replaced by actinolite and tremolite (Fig. 4.9a).

Clinopyroxene occur as medium to coarse-grained anhedral crystals in the Bwet Taung orebody (Figs. 4.9b). Crystals are prismatic and nearly square in section. They are partially to entirely altered to epidote.

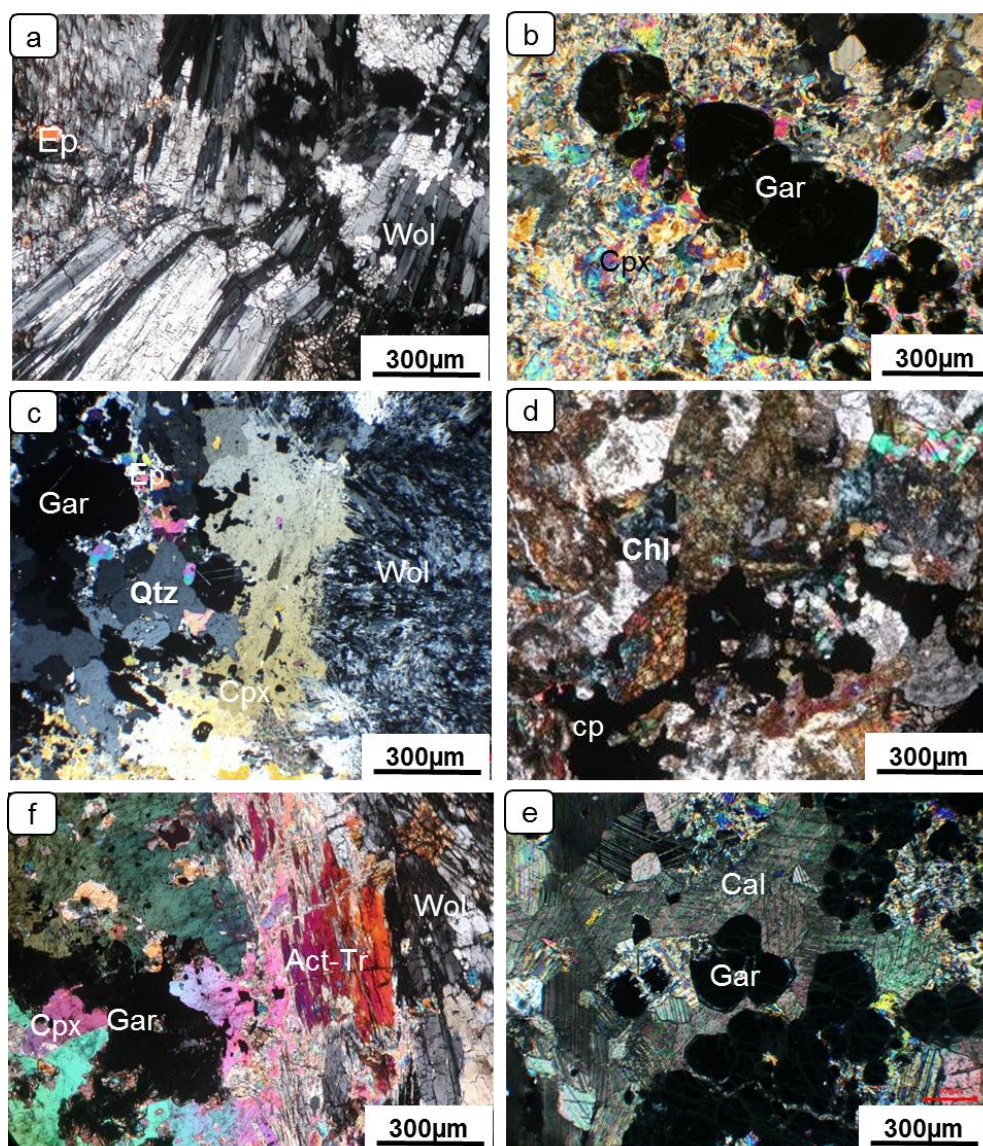


Fig. 4.9 Photomicrographs showing the mineralogy of exoskarn. (a) epidote together with chlorite replacing andradite in the retrograde skarn alteration at Lun Htoe orebody, (b) garnet from Au-rich ore exhibits oscillatory zonation in Bwet Taung orebody, (c) retrograde mineral assemblage of epidote, quartz and calcite and exoskarn of Tiger Mouth orebody, (d) chalcopyrite associated with chlorite in skarn at Bwet Taung orebody, (e) fine to medium-grained garent in skarn associated with epidote and calcite in Bwet Taung orebody, (f) garnet, clinopyroxene and wollastonite partially altered to actinolite in retrograde skarn at Bwet Taung orebody. Abbreviations: Cal=calcite, Grt=garnet, Opx= orthopyroxene, Wol=wollastonite, Qtz=quartz, Epd=epidote, Act=actinolite-tremolite, Chl=chlorite, cp= chalcopyrite.

Vesuvianite occurred as granular crystals and massive aggregates mainly found in Shwe Gu Lay orebody. They are euhedral grains mainly associated with garnet and calcite.

Garnets occur ubiquitously in the skarn zone are fine to coarse-grained with anhedral to euhedral crystals in Bwet Taung orebody. Textural examination shows that two types of garnet are distinguishable. (1) medium- to coarse-grained, anhedral to euhedral anisotropic garnet which are mainly present in the outer parts of the skarn zone, near the marble zone at Bwet Taung orebody (Fig. 4.9b), (2) fine- to coarse-grained anhedral, colorless to pale green, isotropic garnet which are mainly common in marble at Tiger Mouth orebody. Garnet (samples listed in Table 5.1), which is generally isotropic, has no specific zoning along the growth lines and falls within a compositional range ($\text{Adr}_{88.78.27-60.13}$ $\text{Grs}_{29.05-0.74}$ $\text{Alm}_{11.81-5.58}$). This garnet type exhibits weak diffusion and irregular zoning with andradite-rich. Andradite exhibits oscillatory zonation in Bwet Taung orebody (Fig. 4.9b).

Epidote occurs as fine to medium anhedral crystal aggregates showing granoblastic texture (Fig. 4.9 c) and is mainly associated with garnet at Bwet Taung orebody. The majority of epidote is the product of retrograde alteration. It occurred as the product of hydrothermal alteration of various minerals clinopyroxene, garnets of prograde skarn.

Chlorite is present as fine flakes within the anhydrous and hydrous calc-silicates in Bwet Taung orebody (Fig. 4.9d). It appears to be a late-alteration product.

Actinolite occurs as medium- to coarse-grained aggregates (Fig. 4.9e) associated with pyroxene and wollastonite at Bwet Taung orebody. Textural relationships suggest that they are the product of retrograde alteration of pyroxenes.

Calcite occurs as fine to coarse-grained anhedral to subhedral crystals within the skarn zone and marble. Calcite is also associated with prograde minerals (Fig. 4.9f). Quartz occurs as fine-grained groundmass in intrusive and fine- to medium-grained crystals in skarn zone.

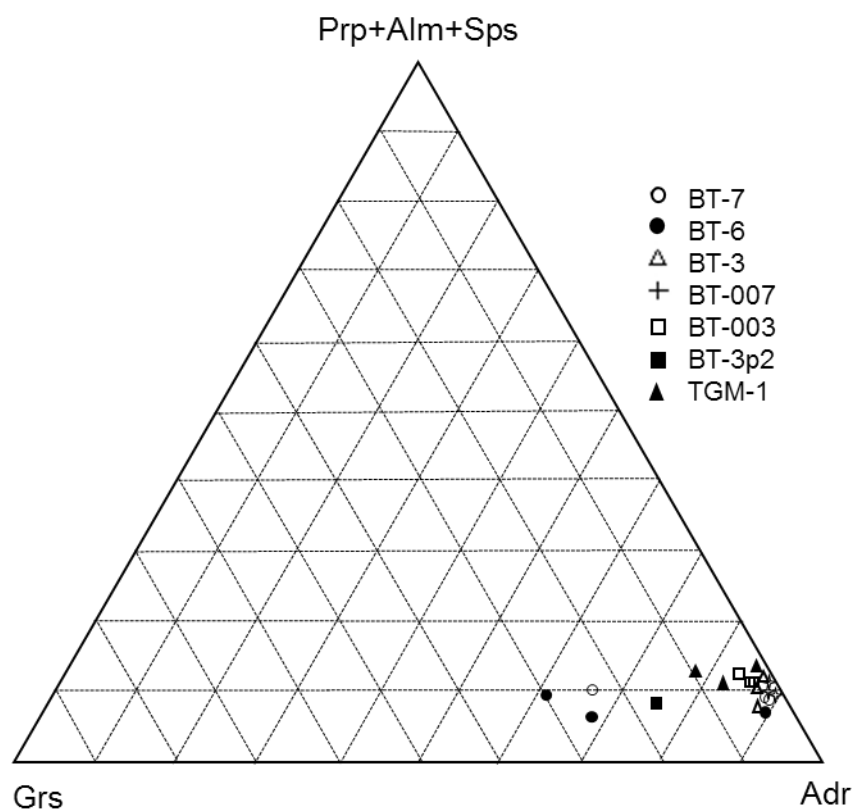


Fig. 4.10 Composition of the skarn garnets in the andradite-grossular-pyralspite ternary diagram. Pyralspite includes pyrope, almandine and spessartine. SEM data are given in Table 4.1. Abbreviations: Adr = andradite, Alm = almandine, Grs = grossular, Grt = garnet, Prp = pyrope, and Sps = spessartine.

Table 4.1 SEM data for garnets of Bwet Taung and Tiger Mouth orebody, Shwe Min Bon skarn deposit.

	BT7	BT7	BT7	BT3	BT3	BT3	BT3	BT003	BT003	BT003
SiO ₂ (wt. %)	39.0	38.0	38.8	38.2	38.0	38.6	38.9	39.0	38.5	38.9
TiO ₂	0.1	0.2	0.1	0.2	0.4	0.4	0.1	0.2	0.3	0.2
Al ₂ O ₃	4.6	0.4	0.1	0.8	3.4	0.3	0.3	0.4	0.5	0.7
FeO	23.0	28.5	28.3	27.5	24.8	28.3	28.0	27.8	28.2	27.9
MnO	0.4	0.4	0.2	0.5	0.4	0.4	0.3	0.4	0.3	0.3
MgO	0.2	0.1	0.1	0.1	0.4	0.2	0.1	0.2	0.2	0.2
CaO	33.7	32.4	32.3	32.9	32.7	32.0	32.3	31.9	32.0	31.8
Total	100	100	100	100	100	100	100	100	100	100
Si (at. %)	3.14	3.12	3.18	3.12	3.08	3.17	3.19	3.20	1.15	3.18
Ti	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.02	0.01
Al	0.44	0.04	0.01	0.07	0.32	0.02	0.03	0.04	0.05	0.07
Fe ₃	1.27	1.71	1.61	1.66	1.48	1.60	1.59	1.55	1.61	1.55
Fe ₂	0.28	0.25	0.33	0.22	0.19	0.34	0.32	0.36	0.32	0.36
Mn	0.03	0.03	0.02	0.03	0.03	0.03	0.02	0.03	0.02	0.02
Mg	0.03	0.02	0.01	0.01	0.04	0.02	0.01	0.02	0.02	0.02
Ca	2.82	2.84	2.84	2.88	2.84	2.81	2.83	2.80	2.81	2.78
Almandine	8.87	7.86	10.25	6.96	6.22	10.55	10.14	11.21	10.13	11.34
Pyrope	0.84	0.51	0.27	0.23	1.36	0.57	0.42	0.68	0.69	0.76
Grossular	22.79	1.80	0.74	3.65	16.15	1.29	1.74	2.16	2.60	3.77
Spessartine	0.82	0.86	0.50	0.99	0.86	0.83	0.63	0.82	0.68	0.69
Andradite	66.40	88.30	87.77	87.48	74.33	85.57	86.83	84.36	84.86	82.91
Ca-Ti Gt	0.28	0.67	0.47	0.68	1.07	1.19	0.24	0.77	1.04	0.53
Total	100	100	100	99.99	99.99	100	100	100	100	100

Formula is on the basis of 8 cations and 12 oxygens. Fe₂O₃ calculation after Droop (1987).

4.3 Host rock alteration

The host rock alteration with primary or syn-skarn deposit is well developed next to altered diorite. The different vein textures are observed in different host rocks. The stock work veinlets occurred in dolomite (Figs. 4.11a). The sulfide bearing calcite veins occurred in dioritic rocks (Figs. 4.11 b, e). Calcite veinlets occurs crosscutting the garnet grains in skarn rock (Figs. 4.11 c, d).

The altered diorite could be subjected to latter intense hydrothermal alteration such as argillic, advanced argillic, propylitic, silicification and kaolinization. Argillic alteration and propylitic alteration extensively occur in Shwe Min Bon deposit. Propylitic alteration is related with skarn zone. The chloritization and epidotization are common in skarn rock. Kaolinization mainly occur in intrusive rock. Significant silicified alteration is more extensive than other alteration types in Shwe Min Bon area.

Silicified and metamorphosed limestone are exposed eastern part of the research area. Silicified rock mainly develops in Shweminbon Formation. The Shweminbon Formation which is contact with dioritic rocks were highly silicified (Fig. 4.11f). Silicification also occurred on Shweminbon Formation in the shear zone that could have been favorable for latter retrograde skarn mineralization linked with latter hydrothermal activity. Although extensive overlapping of wall rock alteration occurs, they can be zoned into the formation of alteration zones at Shwe Min Bon.

The endoskarn is associated with epidotization and chloritization, whereas exoskarn is characterized by garnet and wollastonite. The prograde and retrograde skarn assemblages are overprinted by pervasive supergene alteration causing extensive replacement of sulfides by limonite. Limonite alteration seems to have been important by redistributing gold on a local scale.

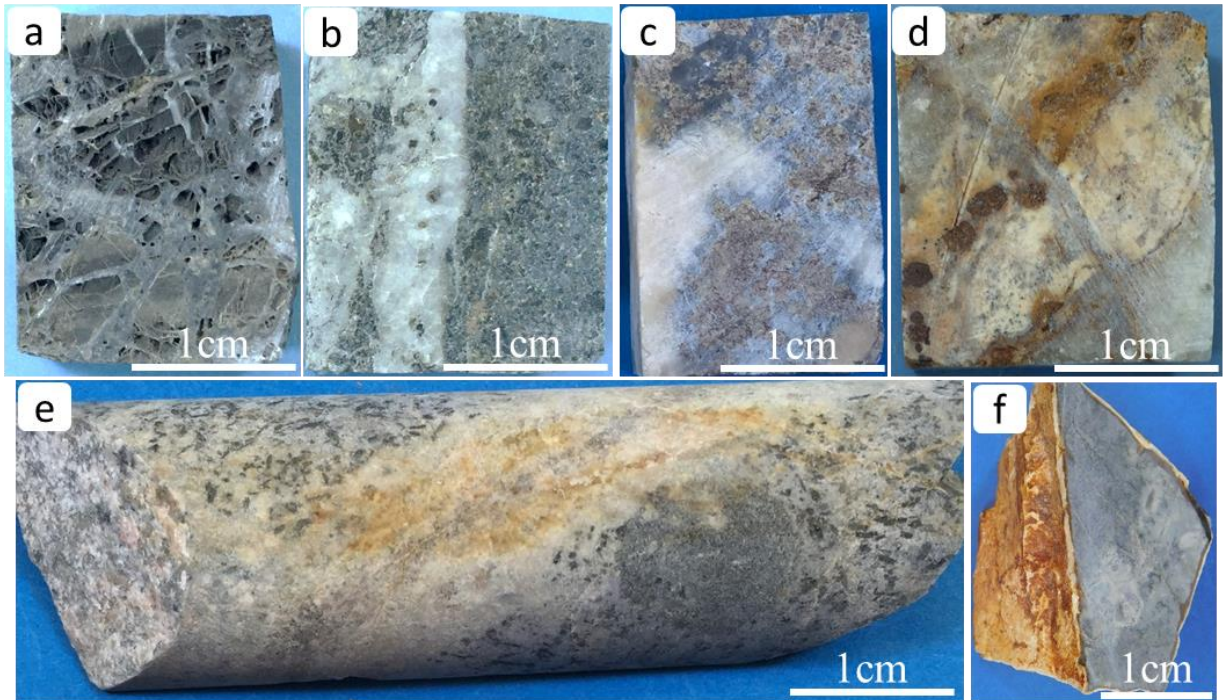


Fig. 4.11 Photographs showing textures and alteration of host rock at Shwe Min Bon; (a) the stockwork vein occurred in dolomite at Tiger Mouth orebody, (b) sulfide bearing calcite vein in dioritic rocks at Tiger Mouth orebody, (c) garnet skarn with calcite veinlets in Bwet Taung orebody, (d) oxidized garnet crossed cut by calcite veinltes in garnet skarn at Tiger Mouth orebody, (e) dioritic rocks with calcite veinlets and fine-grained xenolith at Tiger Mouth orebody, (f) silicified rocks in Shweminbon Formation at Tiger Mouth orebody.

Open cut mining is being carried out in the breccia zone along the NW-SE 200m in length and about 60m in width. The breccia zone expose near the Tiger Mouth orebody and comprise dioritic rocks, marble and siltstone. The occurrences of these zoning from altered diorite to garnet-bearing diorite, garnet-pyroxene bearing skarn, and finally to a marble indicate the formation by hydrothermal fluids. These indicate that formation of the hydrothermal fluid in a proximal part of the intrusion to the distal part of the Shweminbon Formation. The alteration mineral assemblages are listed in Table 4.1.

Table 4.2 (a) The alteration mineral assemblages and type of alteration in the Bwet Taung orebody.

No.	Sample Name	Alteration Mineral Assemblages	Type of Alteration
1	BT02	Chlorite/Smectite	Propylitic
2	BT04	Smectite+Illite+Kaolinite	Argillic
3	BT06	Illite+Chlorite/Smectite	Propylitic
4	BT08	Smectite+Chlorite/Smectite	Propylitic
5	BT09	Smectite	Argillic
6	BT014	Smectite	Argillic
7	BT015	Smectite+Kaolinite	Argillic
8	BT016	Illite/Smectite+Smectite+Illite	Argillic
9	BT2	Chlorite/Smectite+Kaolinite	Propylitic
10	BT9	Illite+Illite/Smectite+Kaolinite	Argillic
11	BT8	Smectite	Argillic
12	BT001	Illite/Chlorite+Kaolinite	Argillic

Table 4.2 (b) The alteration mineral assemblages and type of alteration in the Tiger Mouth orebody.

No.	Sample Name	Alteration Mineral Assemblages	Type of Alteration
1	TGM011	Smectite	Argillic
2	TGM012	Illite/Smectite+Kaolinite	Argillic
3	TGM013	Chlorite/Smectite	Propylitic
4	TGM002	Smectite	Argillic
5	TGM004	Illite+Illite/Smectite+Kaolinite	Argillic
6	TGM16	Chlorite/Smectite+Halloysite	Propylitic
7	TGM20	Smectite	Argillic
8	TGM22	Chlorite	Propylitic
9	TGM23	Chlorite/Smectite	Propylitic
10	TGM31	Illite+Chlorite/Smectite+Kaolinite	Argillic

Table 4.2 (c) The alteration mineral assemblages and type of alteration in the Zin Yaw orebody.

No.	Sample Name	Alteration Mineral Assemblages	Type of Alteration
1	ZY01	Smectite	Argillic
2	ZY1	Chlorite/Smectite	Propylitic
3	ZY5	Smectite+Kaolinite	Argillic
4	ZY5(B)	Chlorite/Smectite	Propylitic

Table 4.2 (d) The alteration mineral assemblages and type of alteration in the Shwe Taunggyar and Shwegulay orebody.

No.	Sample Name	Alteration Mineral Assemblages	Type of Alteration
1	STG05	Illite+Kaolinite	Argillic
2	STG07	Kaolinite	Argillic
3	SGL03	Smectite+Illite/Smectite+Kaolinite	Argillic
4	SGL010	Smectite	Argillic
5	SGL017	Smectite+Halloysite	Advanced argillic

4.3.1 Silicified and brecciated zone

The silicified rocks exposed eastern part of the research area along the fault. The Au-Cu mineralization is widely associated in the silicified zone and is now utilized in open cut mining (Fig. 4.12a& b). The mineralization is associated with vuggy quartz, quartz veins and sulfide veins (Fig. 4.12c, d& e). The brecciated zone occurred in Tiger Mouth orebody. The brecciated zone recognized as clast of marble, intrusive rocks and skarn. Moreover, surface weathering produced rusty-stained bleached zone (Fig. 4.13) from which the metals have been leached, and then redeposited near the water table to form an enriched zone.

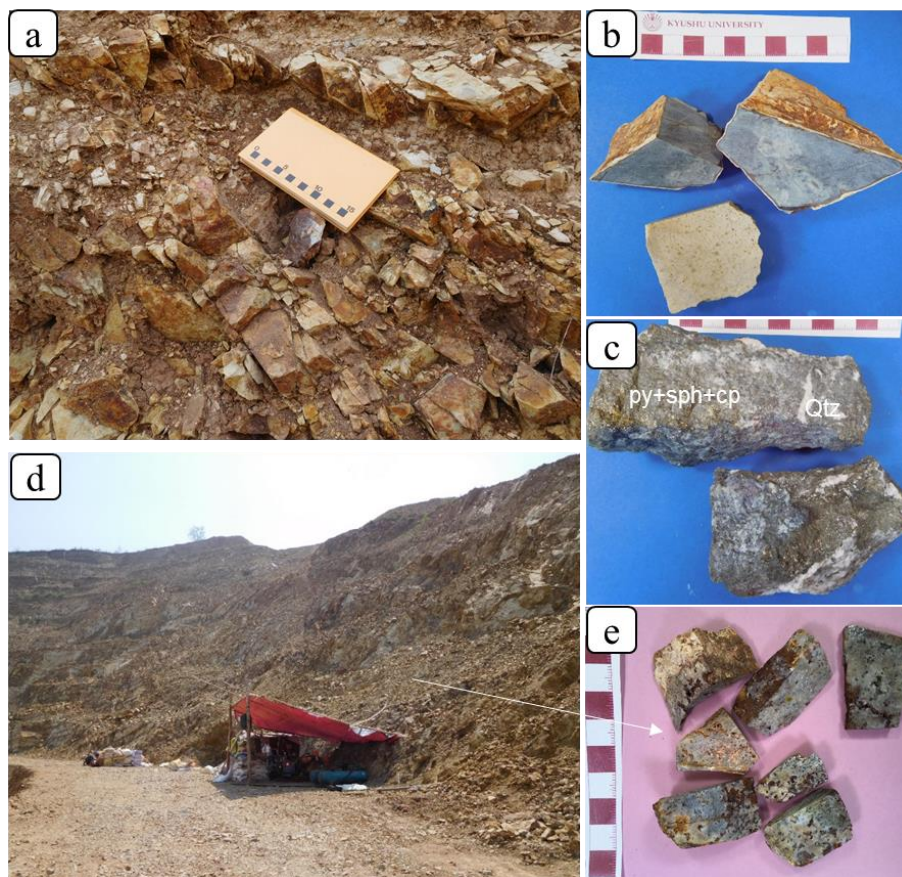


Fig. 4.12 (a) the silicified rocks of Shwe Min Bon Formation at Bwet Taung orebody, (b) a hand specimen of silicified rocks from Bwet Taung orebody, (c) sulfide vein associated with calcite and quartz from Tiger Mouth orebody, (d) Shweminbon Formation at Tiger Mouth orebody and (e) vuggy quartz in silicified rocks.



Fig. 4.13 Outcrops of the bleached zone occurring in the silicified zone at Tiger Mouth orebody.

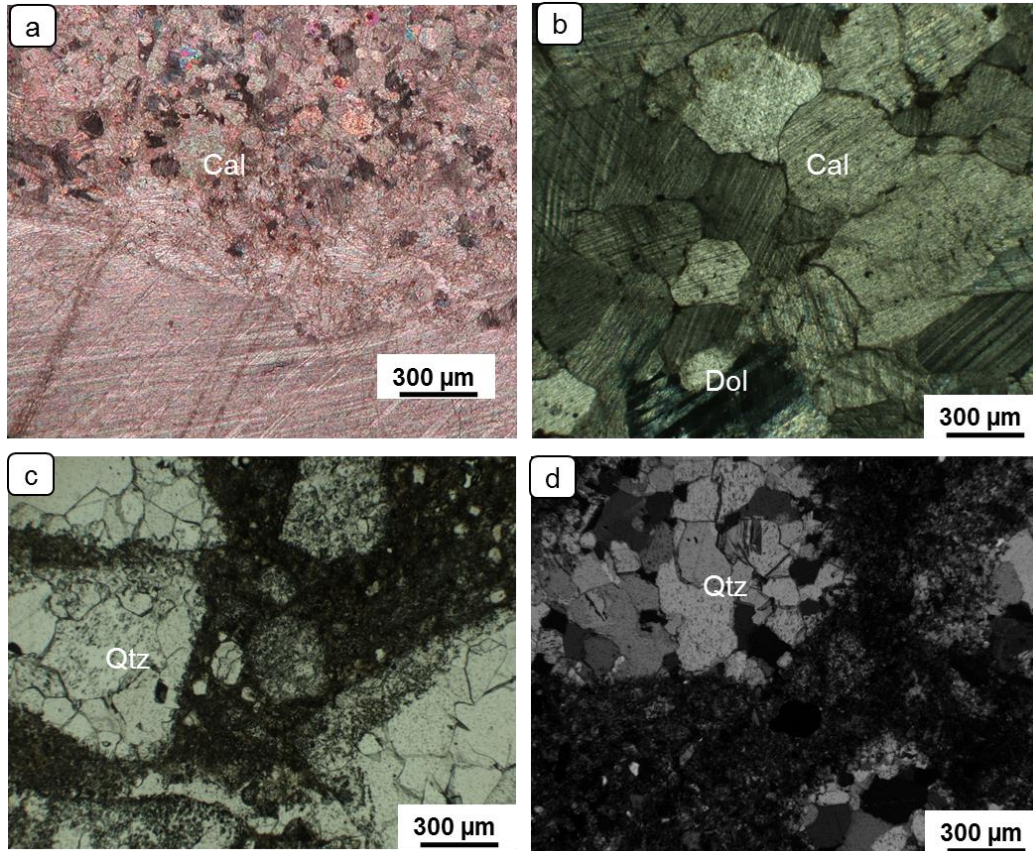


Fig. 4.14 Photomicrographs showing (a, b) calcite and dolomite in marble of Shweminbon Formation (c, d) hydrothermal breccia occurred in breccia zone. Abbreviations: Cal=calcite, Dol=dolomite, Qtz=quartz, Chl=chlorite.

Silicified rocks are composed of fine grained quartz and minor chlorite. The calcite and dolomite occurred in the marble (Fig. 4.14a &b). The hydrothermal breccia is composed of fine to medium grained quartz with siliceous and carbonate cement (Figs, 4.14 c &d).

CHAPTER V. Mineralization and characteristics of skarn deposit

5.1 Mineralization

5.1.1 Ore mineralogy

Skarn deposits in this study area are mainly related with copper and gold mineralization. The gold and copper deposits were likely be associated with the dioritic intrusions into marble, siltstone and sandstone of the Shweminbon Formation. Predominantly limestone and dolomitic limestones were intruded by diorite intrusions. The isochemical metamorphism formed as pure marble and later followed by skarn formation and copper-gold mineralization.

The mineralization formed native gold and copper-bearing minerals mainly chalcopyrite, bornite, chalcocite, tennantite, sphalerite, galena and minor enargite and cosalite (Figs. 5.1a, b &c). Copper and gold mineralization is mainly deposited in retrograde skarn stage. Native gold is mainly associated with chalcopyrite and tennantite in retrograde skarn stage ore (Figs. 5.1d& e). The native gold associated with bismuthite and tellurobisumuthinite occurred along the cleavage boundary of calcite in marble (Figs. 5.1 f). Gold mineralization occurred as dissemination throughout the skarn and high grade ore is related with oxidized zone. In the oxidized zone, malachite and azurite occur associated with other copper minerals. Mineralization occurs not only in skarn zone but also in silicified altered zone which is characterized by the pyrite, chalcopyrite, sphalerite and arsenopyrite (Figs. 5.1g, h& i).

Ore minerals consist mainly of magnetite in the Fe-oxide mineralization type, chalcopyrite, bornite, tennantite and minor pyrite in the Cu-sulfide mineralization type, and native gold, bismuthinite, and emplectite in the gold mineralization. Fe-oxide mineralization is characterized by presence of a significant amount of magnetite, which is particularly common in the garnet-rich skarn.

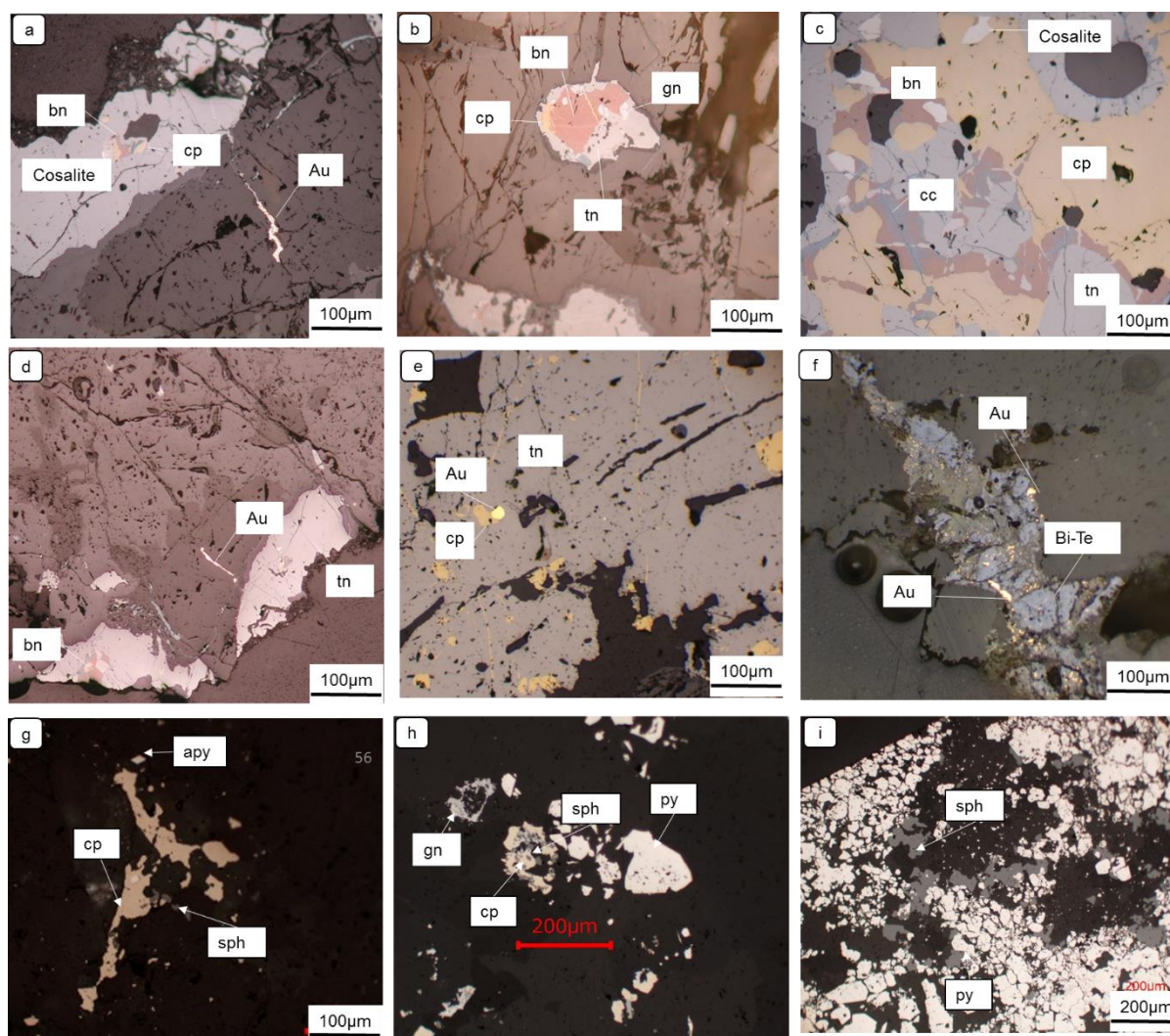


Fig. 5.1 Photomicrographs showing (a) native gold occurred along the fracture of garnet in the retrograde skarn at Bwet Taung orebody, (b) intergrowth of bornite and chalcopyrite with tennantite and galena in the retrograde skarn Bwet Taung orebody, (c) replacement of chalcopyrite by tennantite and bornite in the retrograde skarn at Bwet Taung orebody, (d) the relation of tennantite, bornite and native gold in the retrograde skarn Bwet Taung orebody, (e) native gold and chalcopyrite with tennantite in retrograde skarn at Bwet Taung orebody, (f) native gold associated with bismuth-tellurite mineral in brecciated marble Tiger Mouth orebody, (g) arsenopyrite, chalcopyrite and sphalerite in vuggy quartz vein at Tiger Mouth orebody, (h) chalcopyrite, pyrite and galena in quartz vein at Tiger Mouth orebody and (i) sphalerite and pyrite associated with vuggy quartz in Tiger Mouth orebody. Abbreviations: tn=tennantite gn=galena, cc=chalcocite, cp=chalcopyrite, bn=bornite, py=pyrite, sph=sphalerite, apy=arsenopyrite, Au=native gold, Bi-Te= Tellurobismuthinite.

Galena occurred as fine grains and mostly associated with bornite and chalcopyrite at the Bwet Taung orebody. Galena with chalcopyrite, bornite and tennantite are rimmed by pyrite (Fig. 5.1b). Occasionally it has been replaced partially by bornite and chalcocite.

Cosalite ($\text{Pb}_2\text{Bi}_2\text{S}_5$) is associated with chalcopyrite in the skarn zone at the Bwet Taung orebody (Fig. 5.1c). It occurred as accessory ore minerals and 50 to 100 μm in grain size.

Tennantite is observed as massive aggregates within the calc-silicates in retrograde skarn and are commonly replaced to chalcopyrite and bornite (Fig. 5.1c). Tennantite is commonly associated with native gold (Fig. 5.1d & e). Wittichenite is associated with tennantite in Shwe Min Bon area. These Au-Bi-Te mineral assemblages occupy cavities and fracture in the tellurobismuthinite or in the calcite (Figs. 5.1f).

Arsenopyrite occurred in the silicified zone, associated with sphalerite and pyrite in vuggy quartz vein. Fine euhedral grains arsenopyrite is mainly found in Tiger Mouth orebody (Fig. 5.1g). The mineral assemblages of sphalerite, pyrite and chalcopyrite occurred with minor arsenopyrite (Fig. 5.1 h& i).

Pyrite occurs as isolated grains in propylitic altered diorite showing anhedral to subhedral grains throughout the deposit (Fig. 5.2a). It is mainly associated with chalcopyrite and sphalerite in skarn. In the silicified zone, pyrite associated with sphalerite, chalcopyrite and arsenopyrite in sulfide veins and vuggy quartz veins in the Tiger Mouth orebody. First generation pyrite was associated with the garnet skarn and propylitic altered diorite but first generation pyrite appears to be largely unrelated to mineralization. Second generation pyrite appears to have formed during the retrograde evolution of the exoskarn and is spatially associated with epidote that occurs as disseminations and along fractures in skarn zone in the Shwe Taung Gyar orebody. The pyrite has been entirely replaced by supergene limonite.

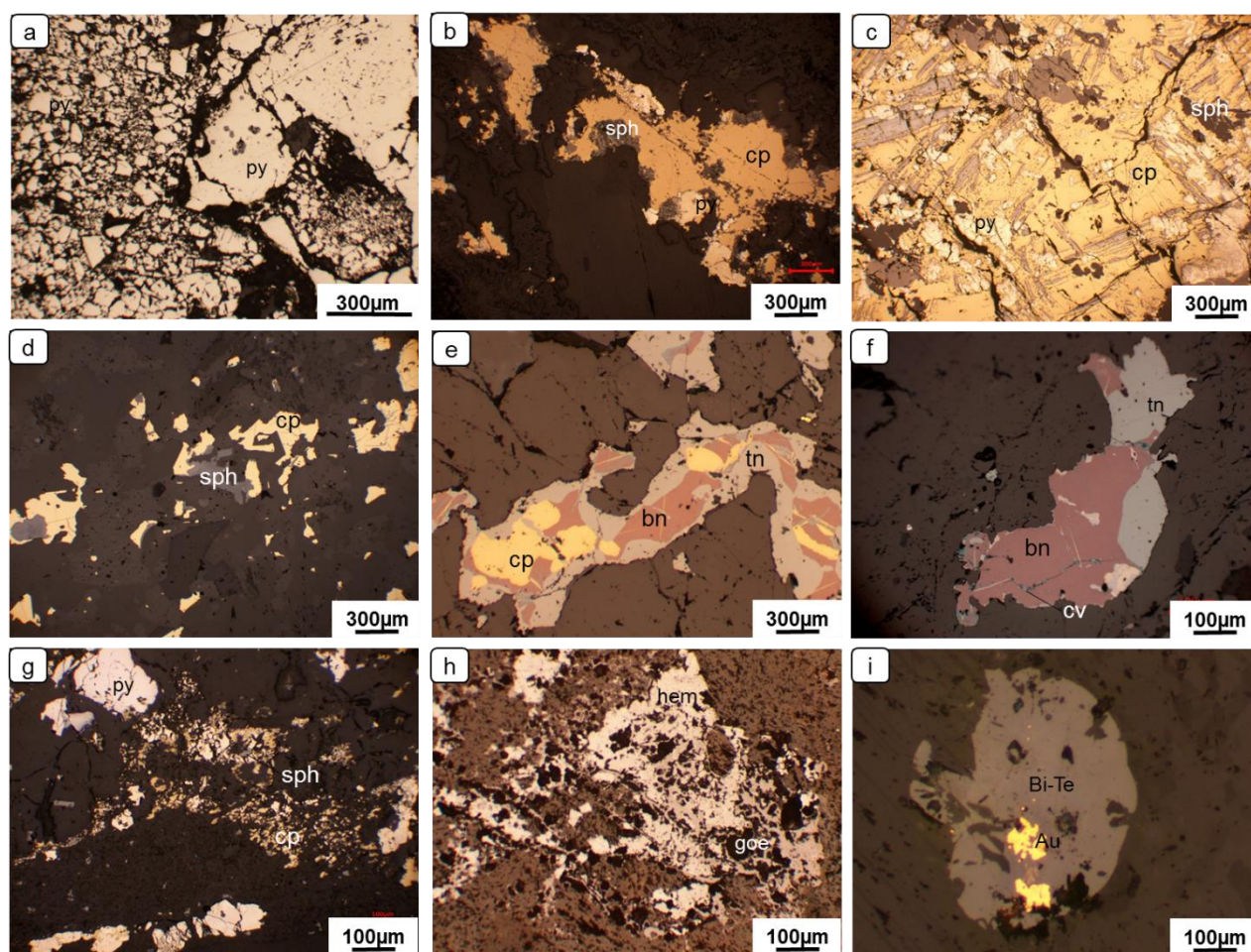


Fig. 5.2 Photomicrographs showing nature of ore minerals (a) pyrite and (b) chalcopyrite with sphalerite and pyrite in sulfide vein at Tiger Mouth orebody, (c) chalcopyrite, pyrite and sphalerite in skarn at Shwe Taung Gyar orebody, (d) chalcopyrite together with sphalerite at Shwe Taung Gyar orebody, (e) chalcopyrite and bornite replaced by tennantite at Bwet Taung orebody, (f) bornite replaced by tennantite and along the fracture with secondary covellite at Tiger Mouth orebody, (g) sphalerite associated with chalcopyrite after pyrite coarse grained at Tiger Mouth orebody, (h) hematite with goethite at Tiger Mouth orebody, (i) Au associated with tellurobismuthite at Shwe Taung Gyar orebody. Abbreviations: tn=tennantite gn=galena, cp=chalcopyrite, bn=bornite, py=pyrite, sph=sphalerite, cv=covellite, Au=native gold, Bi-Te= Tellurobismuthinite.

Chalcopyrite is mainly associated with bornite and tennantite. Chalcopyrite contains exsolution blebs and lamellae of bornite. Occasionally, chalcopyrite has been replaced partially by bornite, tennantite, chalcocite and covellite (Figs. 5.2b & c). Chalcopyrite is the main skarn mineral occurring in all skarn ore bodies. In the exoskarn zone of Bwet Taung orebody, chalcopyrite is associated with gold. Chalcopyrite occurred as minor constituent in silicified zone.

Sphalerite occurred as fine grains in all skarn orebodies and silicified zone (Fig. 5.2d). In silicified zone, it is mutually interpenetrating with pyrite.

Bornite is commonly related with chalcopyrite in retrograde skarn mainly at the Bwet Taung and Lun Htoe orebody. It occurred as massive aggregates. Bornite is partly replaced by tennantite, which is partially replaced by chalcocite (Figs. 5.2e & f).

Chalcocite is mainly associated with bornite, chalcopyrite and tennantite in retrograde skarn. It occurs mostly in Bwet Taung and Shwe Gu Lay orebodies.

Covellite occurs as both primary and secondary minerals. Primary covellite occurs in the Shwe Taung Gyar orebody mainly associated with sphalerite and chalcopyrite. Secondary covellite occurs in the Shwe Gu Lay and Lun Htoe orebodies.

Magnetite and hematite mainly found in skarn zone at Tiger Mouth orebody and associated with oxidized garnet. Magnetite occurs as polycrystalline massive aggregates, sometimes with a lesser amount of chalcopyrite, pyrite, or hematite (Fig. 5.2h).

Native gold grains are typically up to 100 μm in diameter associated with brecciated marble (Fig. 5.2i). The gold occurs as native gold and is accompanied by hedleyite, bismuthinite, chalcopyrite and tennantite (Fig. 5.3a). The gold contents are 46-65ppm (Geo Asia Co.Ltd) in breccia-skarn zone along fault breccia.

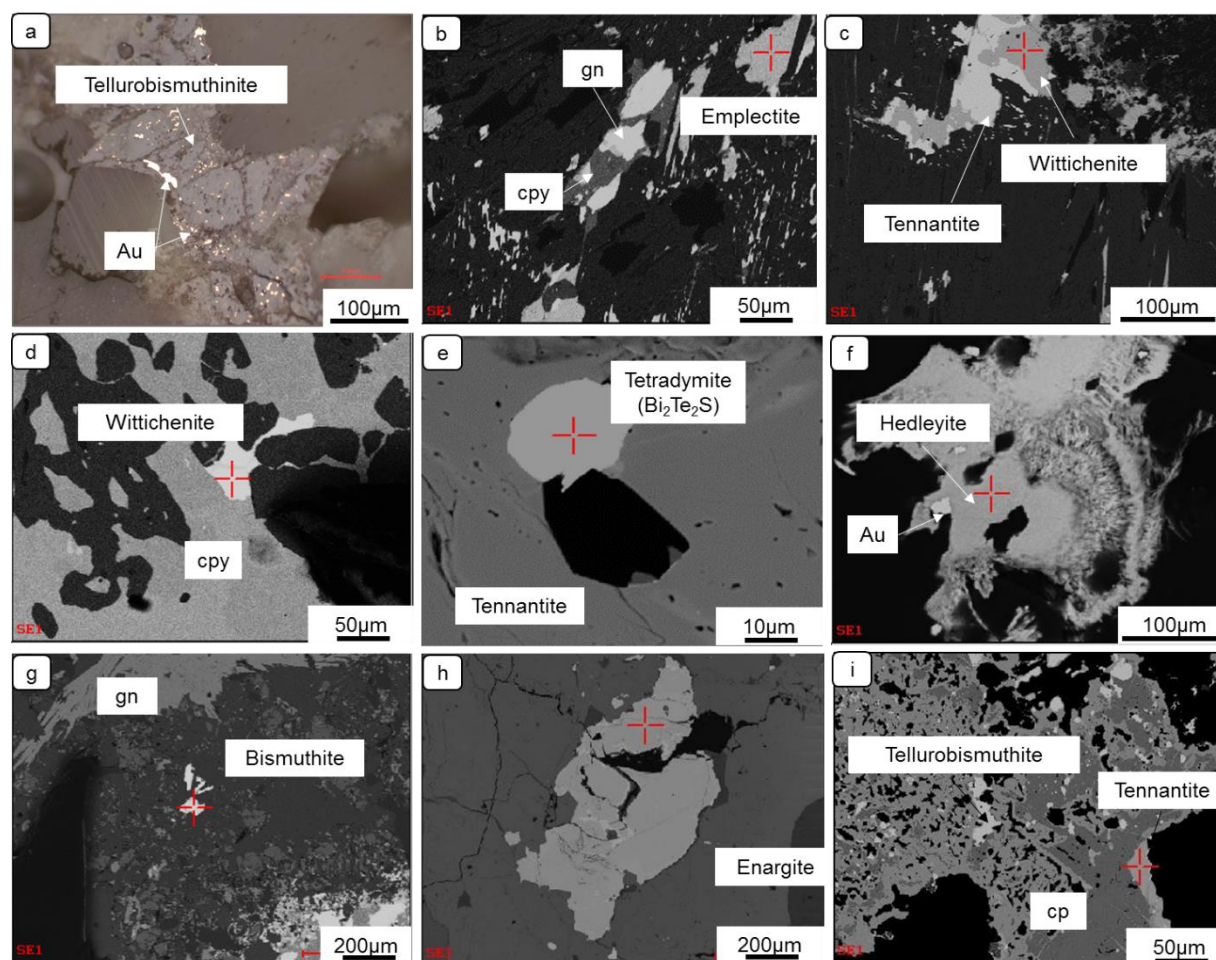


Fig. 5.3 Backscattered electron images showing (a) native gold associated with tellurobismuthinite in brecciated marble of Tiger Mouth orebody, (b) chalcopyrite, emplectite and galena in retrograde skarn at Tiger Mouth orebody, (c) the mutual intergrowth of tennantite and wittichenite in retrograde skarn at Bwet Taung orebody, (d) chalcopyrite associated with wittichenite at retrograde skarn at Bwet Taung orebody, (e) tetradymite associated with tennantite in retrograde skarn at Bwet Taung orebody, (f) native gold grain in hedleyite in brecciated marble of Tiger Mouth orebody, (g) galena and bismuthate occurred in retrograde at Bwet Taung orebody, (h) enargite occurred in retrograde skarn at Bwet Taung orebody, and (i) tellurobismuthinite, tennantite and chalcopyrite in retrograde skarn at Tiger Mouth orebody.

Emplectite (CuBiS_2) is associated with chalcopyrite and galena in the retrograde skarn zone at the Bwet Taung orebody (Fig. 5.3b).

Wittichenite (Cu_3BiS_3) occurs with tennantite in skarn zone at the Bwet Taung orebody (Figs. 5.3c and d). Wittichenite normally formed in hydrothermal veins with other Bi minerals. Tetradymite occurred as inclusion in tennantite (Fig. 5.3e).

Hedleyite (Bi_7Te_3) is mainly found with gold in brecciated marble at the Tiger Mouth orebody (Fig. 5.3f). Hedleyite is mainly associated with chalcopyrite, tennantite and bornite in retrograde skarn at the Bwet Taung and Tiger Mouth orebody.

Bismuthinite (Bi_2S_3) is isolate occurring in the retrograde skarn zone at the Bwet Taung orebody (Fig. 5.3g). Bismuthinite occurred with galena in retrograde skarn stage.

Enargite (Cu_3AsS_4) occurs in the retrograde skarn zone at Bwet Taung orebody. It is mainly associated with chalcopyrite (Fig. 5.3h).

Tellurobismuthite (Bi_2Te_3) is mainly associated with native gold in Shwe Min Bon deposit. It is also associated with chalcopyrite, emplectite and tennantite in retrograde skarn zone at the Bwet Taung orebody (Fig. 5.3i). It is mainly associated with gold in brecciated marble at the Tiger Mouth orebody.

Malachite abundantly occurs in Shwe Gu Lay orebody. It can be found as crystallize and less associated with azurite in Shwe Gu Lay orebody. Malachite occurs as secondary minerals in oxidized zone at Bwet Taung orebody.

Azurite mainly occurs in Bwet Taung and Zin Yaw orebodies. It is found at endoskarn zone in Bwet Taung orebody. In Zin Yaw orebody, azurite is associated with malachite.

5.1.2 Mineral paragenesis

The skarn and ore minerals are listed and grouped by the type; sample locations are shown in Chapter III. Textures of ore minerals such as exsolution, replacement, and zone have been interpreted to correspond to the order of deposition (Fig. 5.4). The occurrences of skarn minerals and ore minerals in different orebodies show in table 5.1. Based on the thin sections and polished section studies, garnet-skarn, clinopyroxene-garnet skarn and wollastonite skarn occur in the prograde stage. Other silicate minerals such as tremolite, epidote, chlorite and fluorite are formed during retrograde stages. In these retrograde stages, sulfide mineral assemblages were crystallized in the interstices between silicate minerals. The silicified zone may have been formed by hydrothermal alteration during or after skarn formation. In this zone, sulfide-bearing quartz veins, sulfide veins and vuggy quartz are found. Based on the skarn and ore mineralogical studies, the mineral paragenesis were established as Fig. 5.5.

Table. 5.1 Summary of the occurrence of orebodies in the Shwe Min Bon deposit.

Orebody	Bwet Taung	Zin Yaw	Tiger Mouth	Shwe Taung Gyar	Shwe Gu Lay	Lun Htoe
Host rock	Prograde and retrograde Skarn and silicified zone	Retrograde Skarn	Prograde and retrograde Skarn, brecciated marble, silicified zone	Retrograde Skarn	Retrograde Skarn	Prograde Skarn and retrograde skarn
Intrusion	Diorite	Granodiorite	Granodiorite and diorite	Diorite	Granodiorite	Granodiorite
Zone of skarn development	Contact aureole	Contact aureole	Contact aureole, distal(200m)	Contact aureole, distal (200m)	Contact aureole	Distal (300m)
Skarn minerals	Garnet, wollastonite, vesuvianite epidote, fluorite, chlorite	Garnet, wollastonite, tremolite	Garnet, wollastonite, vuggy quartz	Vesuvianite, wollastonite, epidote, chlorite	Vesuvianite, garnet, quartz	Wollastonite, actinolite, fluorite, chlorite
Ore minerals	Tennantite, chalcopyrite, bornite, galena, bismuthinitete chalcocite, azurite	Magnetite, hematite, malachite, azurite	Tellurobism u-thite, pyrite, sphalerite, chalcopyrite, arsenopyrite	Chalcopyrite , pyrite, covellite, tennantite, sphalerite	Chalcopyrite , covellite, malachite	Chalcopyrite, sphalerite, tennantite, bornite, chalcocite
Commodity	Cu	Fe	Au, Cu and Fe	Au	Cu and Fe	Au

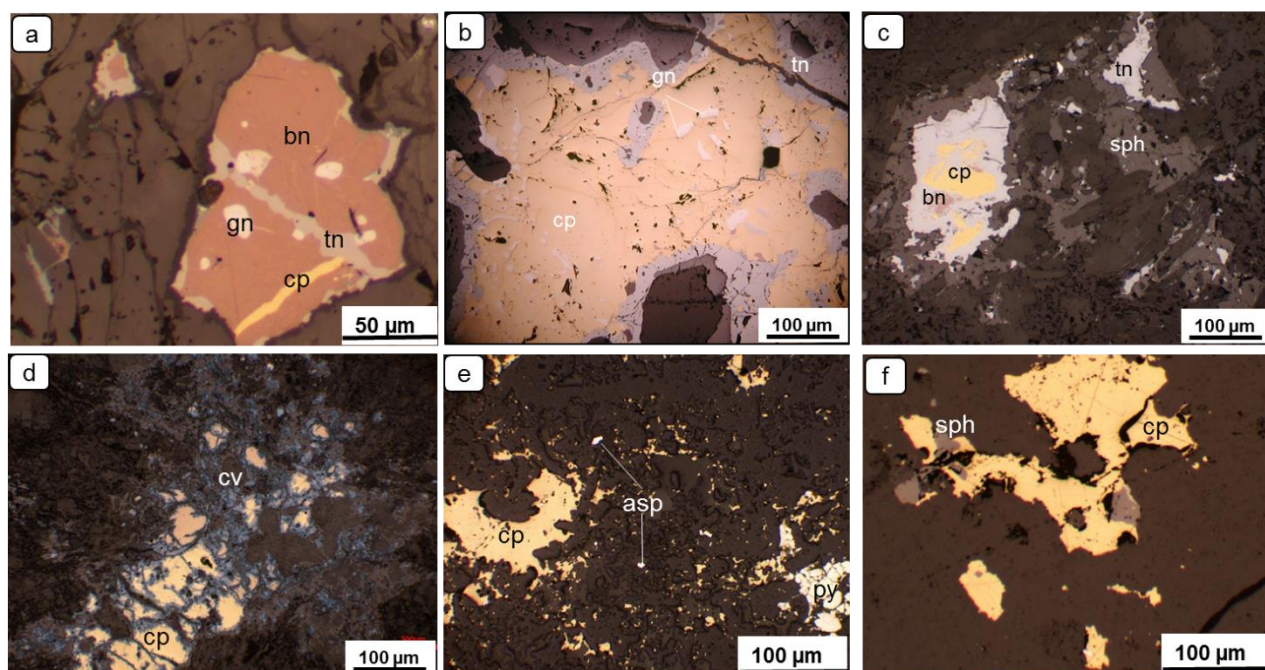


Fig. 5.4 Photomicrographs showing (a) bornite cross cut by tennantite and chalcopyrite with galena inclusion in retrograde skarn at Bwet Taung orebody (b) chalcopyrite with galena inclusion and peripheral replacement by tennantite in retrograde skarn at Bwet Taung orebody (c) bornite sequentially replace by chalcopyrite, tennantite and sphalerite (d) chalpyrite replace by covellite in retrograde skarn at Shwe Gu Lay orebody (e) pyrite, chalcopyrite and arsenopyrite in vuggy quartz vein at Tiger Mouth orebody and (f) mutual intergrowth of chalcopyrite and sphalerite in quartz vein at Tiger Mouth orebody. Abbreviations: tn=tennantite gn=galena, cp=chalcopyrite, bn=bornite, sph=sphalerite, cv=covellite.

Minerals		Prograde Skarn	Retrograde Skarn		Supergene
			I	II	
Skarn and gangue minerals	Chlorite				
	Epidote				
	Fluorite				
	Andradite				
	Clinopyroxene				
	Tremolite				
	Vesuvianite				
	Wollastonite				
	Quartz				
	Calcite				
Ore minerals	Galena				
	Pyrite				
	Arsenopyrite				
	Bornite				
	Chalcocite				
	Chalcopyrite				
	Cosalite($Pb_2Bi_2S_5$)				
	Enargite (Cu_3AsS_4)				
	Bismuthinite(Bi_2S_3)				
	Wittichenite(Cu_3BiS_3)				
	Emplectite ($CuBiS_2$)				
	Hedleyite (Bi_7Te_3)				
	Tellurobismuthite (Bi_2Te_3)				
	Sphalerite				
	Tennantite				
	Covellite				
	Magnetite				
	Hematite				
Secondary minerals	Goethite				
	Malachite				
	Azurite				

Fig. 5.5 Schematic diagram showing paragenetic relationships of skarn and ore assemblages in orebodies of the Shwe Min Bon skarn deposit

5.2 Fluid inclusion microthermometry

5.2.1 Petrography of fluid inclusions

Fluid inclusions in the prograde garnet and retrograde quartz in samples collected from the Bwet Taung and Tiger Mouth ore bodies were examined. Brecciated marble associated with gold mineralization at the Tiger Mouth orebodies were also studied. Inclusions are classified as primary and secondary, principally based on their spatial relationship to other fluid inclusions and growth zones in crystals (Roedder, 1984; Baker and Lang, 2003). The fluid inclusions studies were focused to track the fluid pathways in the ore-forming stages from the prograde skarn to the retrograde skarn stage. Among the primary and secondary fluid inclusions, primary fluid inclusions were identified and measured in this study.

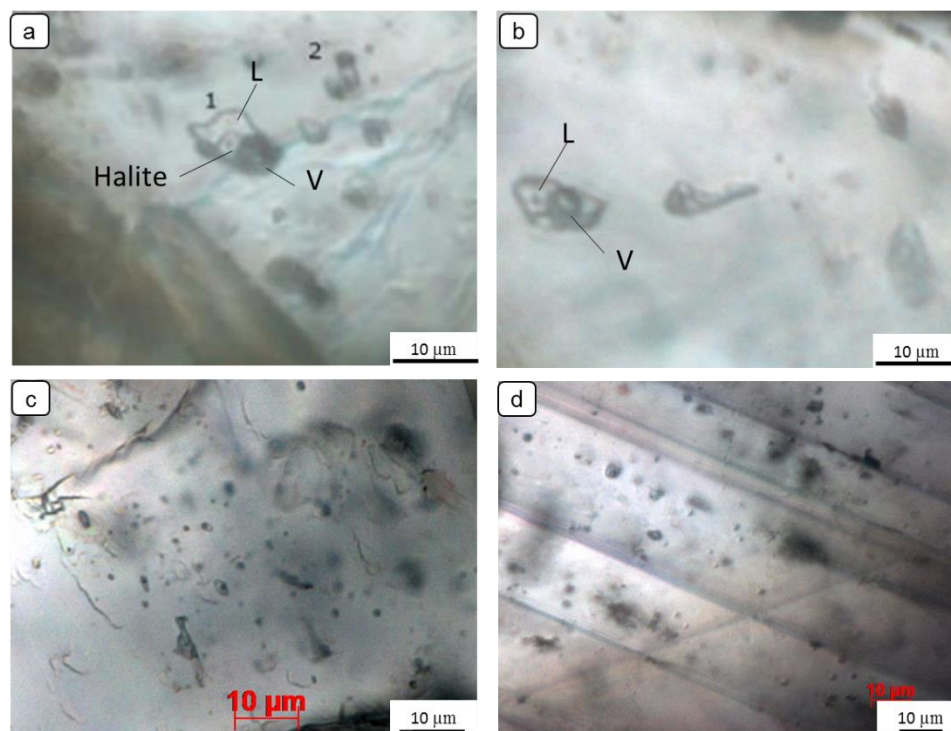


Fig. 5.6 Photomicrographs of fluid inclusions from the Shwe Min Bon skarn deposit (a) fluid inclusions containing aqueous liquid, halite and liquid phase in garnet of prograde skarn, (b) two phase fluid inclusions in quartz, associated with chalcopyrite in retrograde skarn, (c) two phase fluid inclusions in quartz, (d) two phase fluid inclusions in calcite. V-gas; L-liquid; H-halite.

The fluid inclusions in the Bwet Taung orebody can be divided into two types: three phase fluid inclusions in garnet of the prograde stage (Figs. 5.6a, b) and two phase fluid inclusions in calcite and quartz of the retrograde stage (Fig. 5.6c, d). Fluid inclusions in garnet are found as both solitary and cluster in each crystal. They are scattered throughout the crystal and are interpreted as primary (Bodnar et al., 1994). They exhibit various morphologies such as negative crystal, oval, rhombic, rectangular, and irregular. Their sizes vary from 3 to 20 μm . Vapor/liquid ratio of liquid-vapour two phase inclusions in garnet range from 0.2 to 0.4. Three phase inclusions consist of vapor, liquid, and daughter minerals such as halite. Vapor/liquid ratios of primary inclusions in quartz and calcite tend to be less than 0.5. Size of inclusions varies from 3 to 10 μm in calcite and 5 to 10 μm in quartz in the Bwet Taung orebody.

Fluid inclusions are identified as two phase in quartz of skarn and calcite of brecciated marble in the Tiger Mouth orebody. The volume percentage of vapor range from 0.1 to 0.4 and the sizes vary from 3 to 10 μm in the quartz of the Tiger Mouth orebody. Fluid inclusions in the calcite of the Tiger Mouth orebody range from 2 to 8 μm with 0.1 to 0.2 of vapor phase.

5.2.2 Homogenization temperature and salinity

Table 5.3 summarizes the data from the fluid inclusion study. Three phase fluid inclusions in garnet of the Bwet Taung orebody record high-temperature and high-salinity fluid. The daughter salt minerals are dissolved between 206 and 355°C. These are primary polyphase fluid inclusions with vapor-liquid homogenization in the range from 377 to 493°C (Fig. 5.7a). Two phase fluid inclusions in quartz recorded a salinity in the range of 2.4 to 12.5 wt. % NaCl equiv. and homogenization temperature ranges from 157 to 380 °C. Salinity of fluid inclusions in calcite

ranges from 1.7 to 14.6 wt. % NaCl equiv. and a homogenization temperature ranges from 179 to 358°C.

Fluid inclusions in quartz and calcite from Au-rich ore from the Tiger Mouth orebody formed during retrograde stage I and stage II. Primary liquid-rich fluid inclusions with moderate salinities ranging from 1.7 to 13.3 wt % NaCl equiv recorded in the quartz, whereas 0.5 to 6.9 wt % NaCl equiv in calcite, with homogenization temperatures ranging from 132-355°C in quartz and 101 to 363°C in calcite in retrograde stage I and II (Fig. 5.7b &c).

Table 5.2 Summary of microthermometric and salinity data of fluid inclusion in the Shwe Min Bon deposit.

Mineral	Prospect	Type	Vol % of vapor	Size µm	T _h (°C)	Salinity (wt. % NaCl (equiv.))	Number of fluid inclusion
Garnet	Bwet Taung	L+V+H	15-35	5-20	377-493	32.2-46.4	10
Garnet	Bwet Taung	L+V	15-35	5-20	314-493	-	35
Quartz	Bwet Taung	L+V	20	5-10	157-380	2.4-12.5	9
Calcite	Bwet Taung	L+V	10-40	3-10	179-358	1.7-14.6	34
Quartz	Tiger mouth	L+V	10-35	3-10	132-355	1.7-13.3	53
Calcite	Tiger mouth	L+V	10-20	2-8	101-363	0.5-6.9	21

Garnet and quartz from skarn zone of Bwet Taung orebody and calcite from skarn zone of Tiger Mouth orebody. Abbreviation: L=liquid, V=vapor, H=halite. Salinity estimated by fluid ice melting temperature (Bodnar and Vityk, 1994) and halite dissolution temperature Sterner et al. (1988).

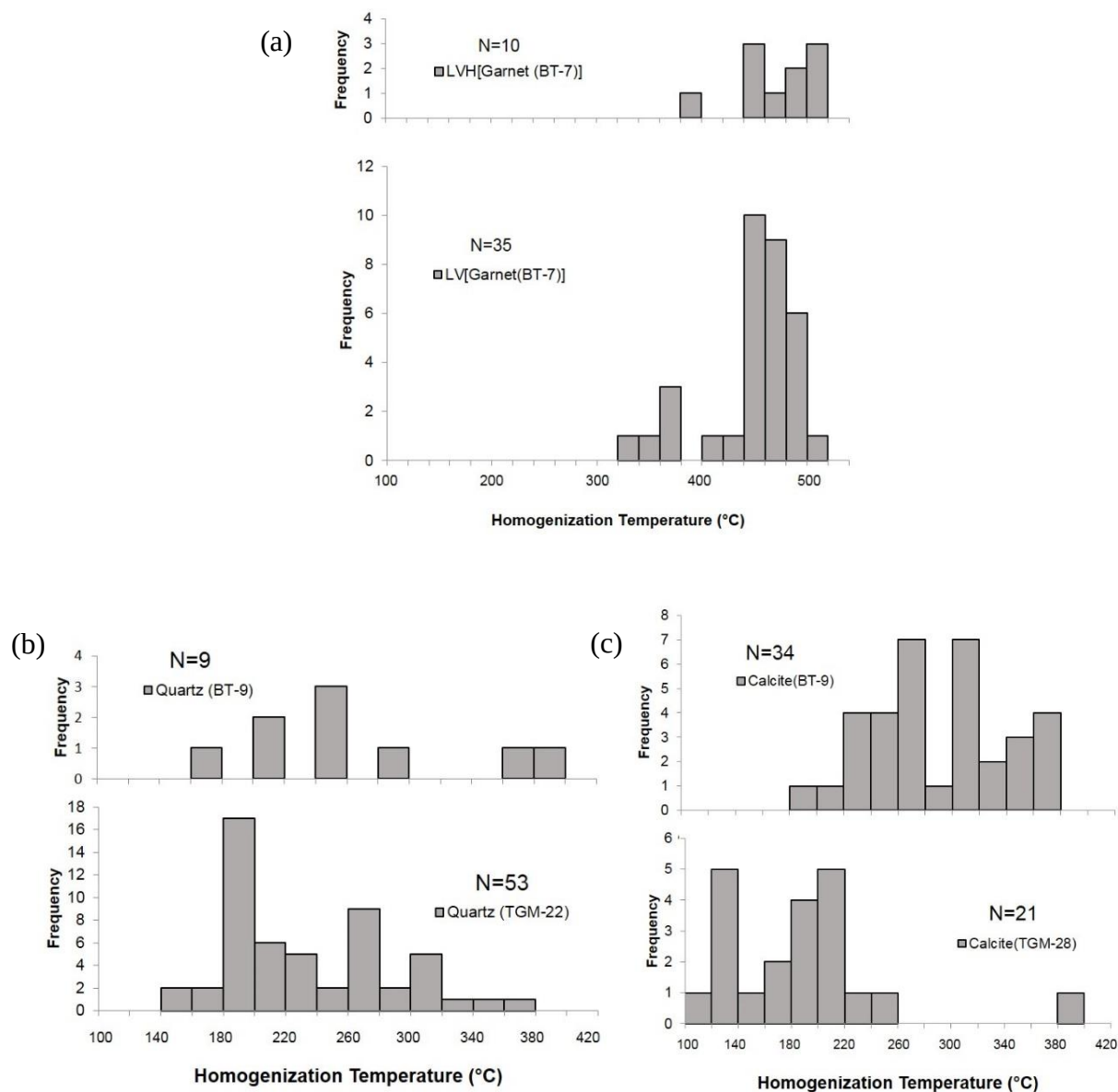


Fig. 5.7 Histogram of fluid inclusion homogenization temperatures from (a) garnet of prograde skarn from Bwet Taung orebody. (b) quartz and (c) calcite of retrograde skarn of Bwet Taung and Tiger Mouth orebodies. Abbreviation; LV= liquid+vapor, LVH=liquid+vapor+halite.

5.3 Stable isotope composition

The two oxygen and hydrogen analyses were performed on the prograde stage. Garnet was measured based on being directly related to sulfide mineralization. The calculated oxygen and hydrogen isotopic compositions of fluids in equilibrium with garnets from the Shwe Min Bon deposit are listed in Table 5.3. The garnet in the prograde skarn exhibit $\delta^{18}\text{O}$ values of 6.3‰ and 7.7‰. The isotopic fields for common geological waters from Taylor (1992) and results from Shwe Min Bon are respectively shown in Fig. 5.8. Skarn minerals proximal to the intrusion provide evidence of the composition of the hydrothermal fluid. The $\delta^{18}\text{O}$ values of garnet were calculated for oxygen isotope fractionations in anhydrous silicate minerals equation for mineral-water system by Zheng (1993). The calculated $\delta^{18}\text{O}$ value of the fluid in equilibrium with garnets within the Shwe Min Bon deposit is range of values for degassing of magmatic fluids. These garnets have lighter than typical of most magmatic systems, compositions exhibiting δD fluid compositions of -92.2‰ and 106‰. Residual fluids within skarn systems related to intrusions containing between 0.5 and 1 wt. % water, are fixed by primary hydrous minerals and can have δD values of less than -100‰ as a result of late-stage open-system degassing (Taylor, 1986, 1988; Hedenquist and Richards, 1998). The δD values of garnets in the Shwe Min Bon deposit may record the degassing of the parental magma chamber, as this process causes fractionation that generates melts containing residual fluids with lighter δD values (Suzuoki and Epstein, 1976). These observations suggest that garnets formed as a result of the evolution of the magmatic hydrothermal system.

Table 5.3 Stable isotope composition of garnet from the Shwe Min Bon skarn deposit.

Sample	Mineral	T _h (°C)	$\delta^{18}\text{O}_{\text{fluid}}(\text{‰})$	$\delta^{18}\text{O}_{\text{garnet}}(\text{‰})$	$\delta\text{D}_{\text{V-SMOW}}(\text{‰})$
Bt-6	garnet	440	+4.9	+7.7	-106.0
Bwt-7	garnet	440	+3.5	+6.3	-92.2

Calculated fluid compositions for garnet are based on fractionation factors of Zheng (1993).

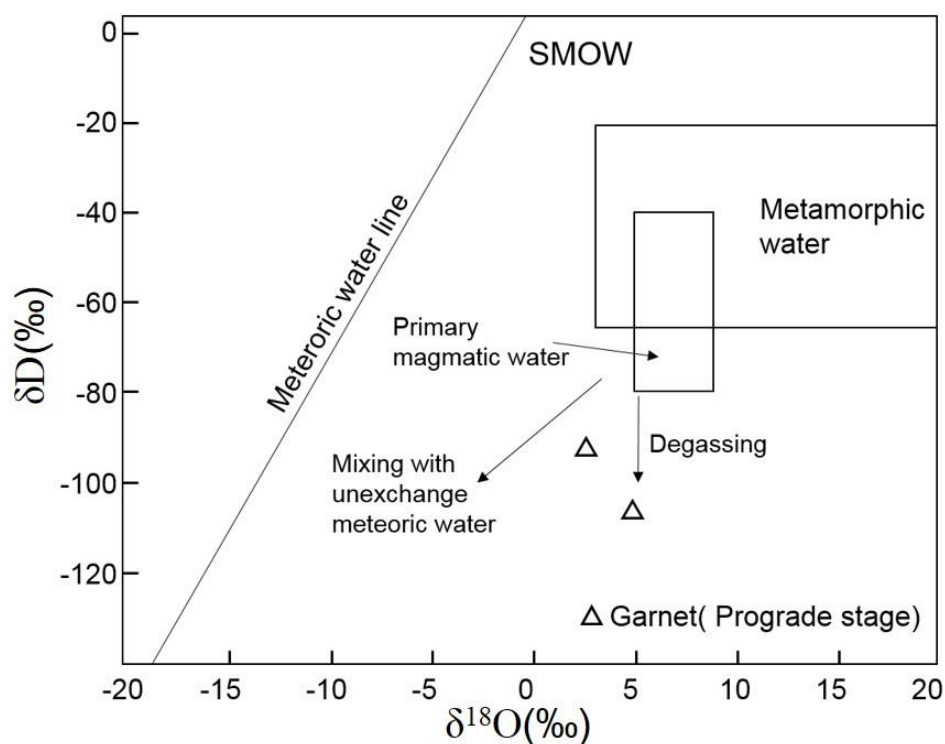


Fig. 5.8 Plot of $\delta^{18}\text{O}$ vs. δD values for prograde skarn related garnet calculated from minerals or measured directly on inclusion fluids. Temperatures used for fluid calculations are from fluid inclusion. Sources of the mineral–fluid fractionation equation are noted in the text. Meteoric Water lines and Primary Magmatic Water boxes plotted for reference. Shaded arrows indicate mixing or water–rock exchange processes that affect isotopic composition of fluids. Black arrows indicate the depletion of residual magmatic waters during open-system degassing (Taylor, 1992; Hedenquist et al., 1998).

5.4 Type of skarn deposit

There are some skarn deposit without define by porphyry such as the Geodo Mine, South Korea. Many researcher studied the direct relation between magmatic activity and most skarn deposits which has a correlations between the composition of causative plutons and contents of the related skarns (Meinert, 2005).

The skarn in the Shwe Min Bon deposit is characterized by a combination of garnet, wollastonite, epidote, amphibole (tremolite-actinolite), pyrite, magnetite and hematite. Gold and copper mineralization occur in the retrograde stage I, mainly with tennantite and chalcopyrite in the Bwet Taung, Tiger Mouth and Lun Htoe orebody. On the other hand, the gold mineralization also occurred during the retrograde stage II in the Tiger Mouth and Shwe Taung Gyar orebodies. The ore minerals in these orebodies are represented by a group of bismuth and bismuth-bearing minerals including sulfide (bismuthinite), Cu–Bi sulfosalts (emphletite, wittichenite) and Pb-Bi sulfosalts (cosalite). The association of gold and bismuth in the deposit is spatially and genetically related with dykes of diorite intruded into the Triassic to Jurassic carbonate and clastic rock of Shweminbon Formation.

The Shwe Min Bon skarn deposit can be classified as oxidized copper skarn based on the occurrence of hematite and magnetite (Meinert et al., 2005). The andradite-rich compositions of the garnet together with abundant magnetite (with no pyrrhotite) also indicate that the skarn belongs to the oxidized type (Meinert et al., 2005). Bismuth-tellurite associations are often seen in skarns and orogenic gold deposits (Ciobanu et al., 2003, Cook et al., 2004; Mudrovskaya et al., 2004). The type of association reveals an oxidizing character during the retrograde skarn stages (Ciobanu et al., 2005).

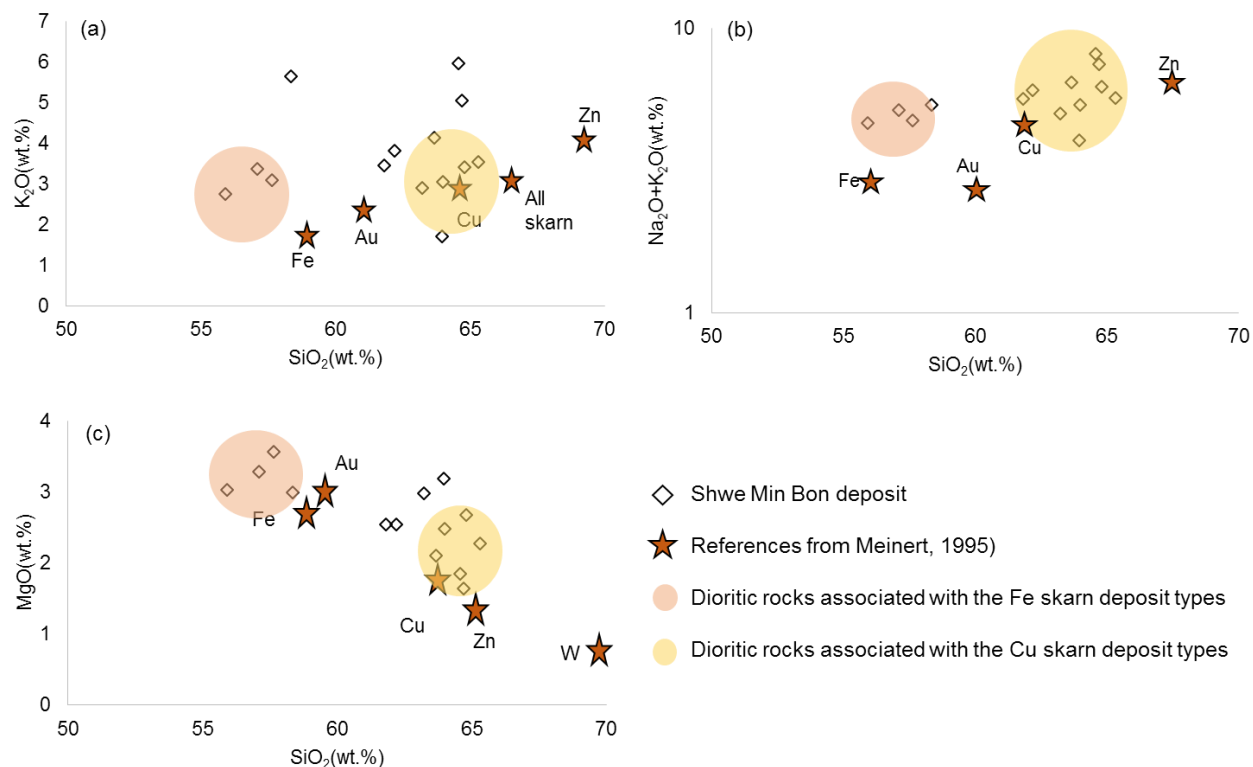


Fig. 5.9 Harker-type (a) total alkalis vs SiO_2 , (b) MgO vs SiO_2 (c) K_2O vs SiO_2 diagrams of the intrusive rocks in Shwe Min Bon deposits compared with those of granitoids associated with skarn deposit in world (the averages for skarn granitoids shown by star mark are taken from Meinert, 1995).

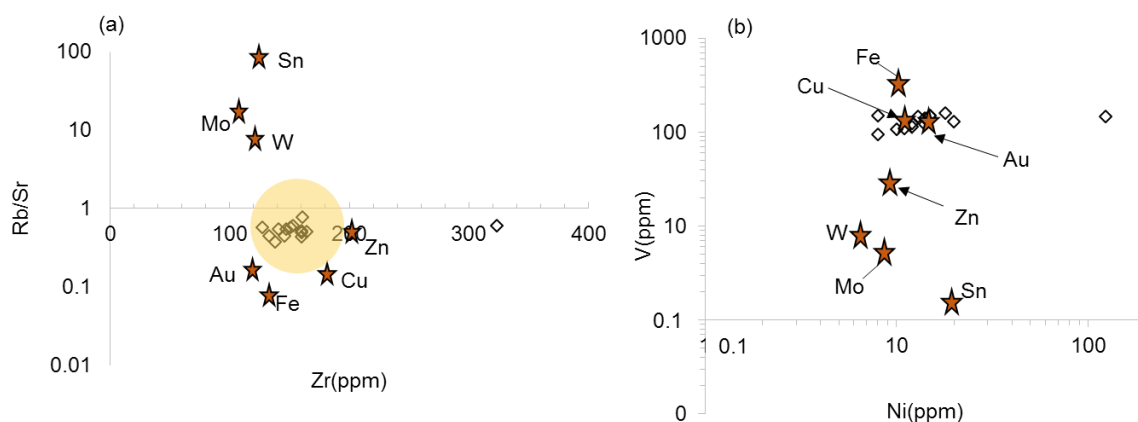


Fig. 5.10 (a) Rb/Sr vs Zr and (b) V vs Ni contents of the intrusive rocks from Shwe Min Bon deposit compared with those of granitoids associated with skarn deposit in world (the averages for skarn granitoids shown by star mark are taken from Meinert, 1995). Abbreviations are as shown in Fig. 5.9.

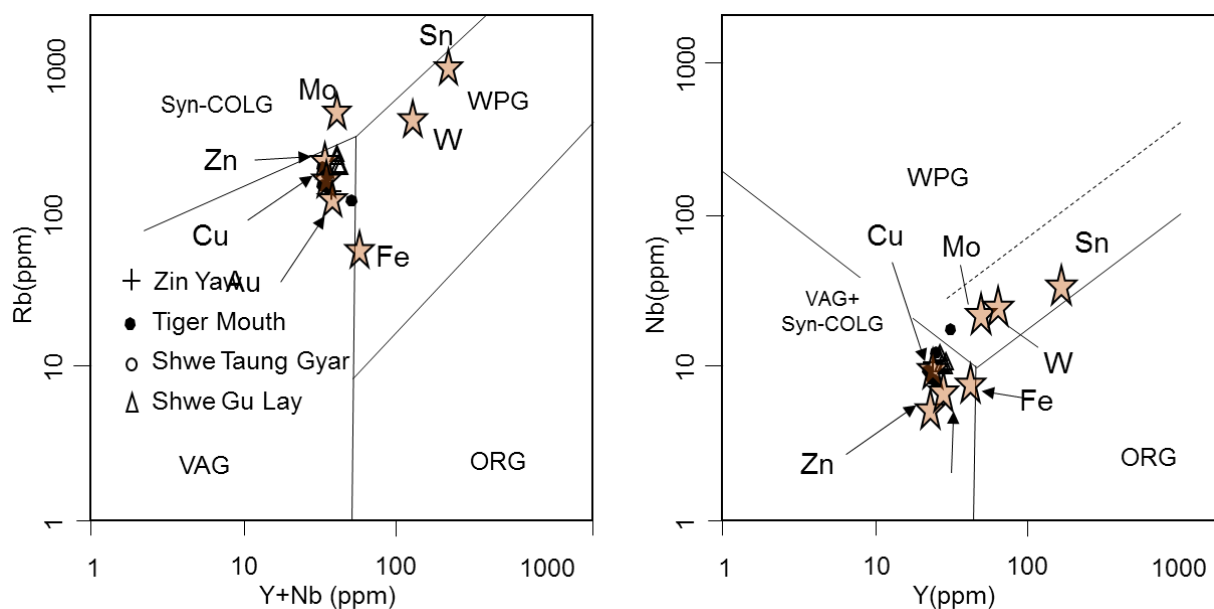


Fig. 5.11 (a) Rb vs Y+Nb contents and (b) Nb vs Y contents of the dioritic rocks of Shwe Min Bon skarn deposit compared with intrusive rocks associated with skarn deposits in the world (the averages for skarn granitoids shown by star mark are taken from Meinert, 1995). ORG, oceanic ridge granite; VAG, volcanic arc granite; syn-COLG, syn-collision granite; WPG, within plate granites. Abbreviations are as shown in Fig. 5.9.

Examination of the distribution of various trace elements allows some generalizations about melt behavior and distinctions among skarn-associated plutons (Meinert, et. al 2005). Figure 5.9 illustrates the relationship for intrusive rocks associated with Shwe Min Bon skarn deposits and world skarn granitoids. Figure 5.10 for the elements V and Ni, Zr and Rb/Sr of intrusive rocks associated with Shwe Min Bon skarn deposits and world skarn granitoids. These Harker type diagrams suggest the type of skarn deposit based on major and minor elements of intrusive rocks associated with skarn deposit.

Most skarn-associated intrusive rocks occur in volcanic arcs and within continental plates (Meinert et al, 2005). Iron, Au, Cu, and Zn skarns are exclusively associated with volcanic-arc

pluton, whereas Sn, W, and most Mo skarns are associated with within-plate pluton the intrusive rocks at the Shwe Min Bon. Shwe Min Bon skarn deposit mostly plot in syn collision field as illustrated in Figure 5.11.

CHAPTER VI. Genetic implication

6.1 Evolution of ore fluids

Fluid evolution can be recorded as two stages; those are skarn formation stage and mineralization stage. Fluid inclusion microthermometry was conducted in garnet, quartz and calcite. In the prograde skarn stage, fluid inclusions are composed of three-phase (liquid-vapor-halite) with an average liquid-vapor homogenization temperature of 440 °C. The main ore stage fluid inclusions in quartz formed under two-phase (fluid-vapor) and liquid-rich fluid inclusions gives a homogenization temperature between 240° and 320°C.

The temperature and salinity of fluid associated with the prograde skarn formation trapped in garnet were high temperature (314-492°C) and hypersaline (up to 46.4 wt. % NaCl equiv.). The temperature and salinity of fluid associated with the retrograde skarn I were low to moderate temperature (260-320°C) and low to moderate salinity (5 to 6 wt. % NaCl equiv.). Fluid associated with the retrograde skarn II was lower temperature (180-200°C) and low to moderate salinity (2 to 3 wt % NaCl equiv.).

These homogenization temperatures and salinities likely indicate a mixing of hotter saline fluids with cooler dilute water of meteoric origin. Hence, during the retrograde skarn stage, the formation of epidote and other retrograde minerals may have resulted from the mixing of magmatic fluids with meteoric water (e.g., Einaudi et al., 1981; Haynes & Kesler, 1988). Cu and Au appear to have been deposited with the retrograde mineral assemblages, such as actinolite, epidote, chlorite, quartz, and calcite. The skarn in the Shwe Min Bon deposit is characterized by a combination of garnet, wollastonite, epidote, amphibole (tremolite-actinolite), pyrite, magnetite, and hematite. The pro- and retrograde stages mainly occurred in exoskarn, which is extensively

exposed in Shwe Min Bon deposit. Cu–Au mineralization occurred chiefly in the retrograde stage I, mainly with tennantite and chalcopyrite in the Bwet Taung, Tiger Mouth, and Lun Htoe orebodies. However, Au mineralization also occurred during the retrograde stage II in the Tiger Mouth and Shwe Taung Gyar orebodies.

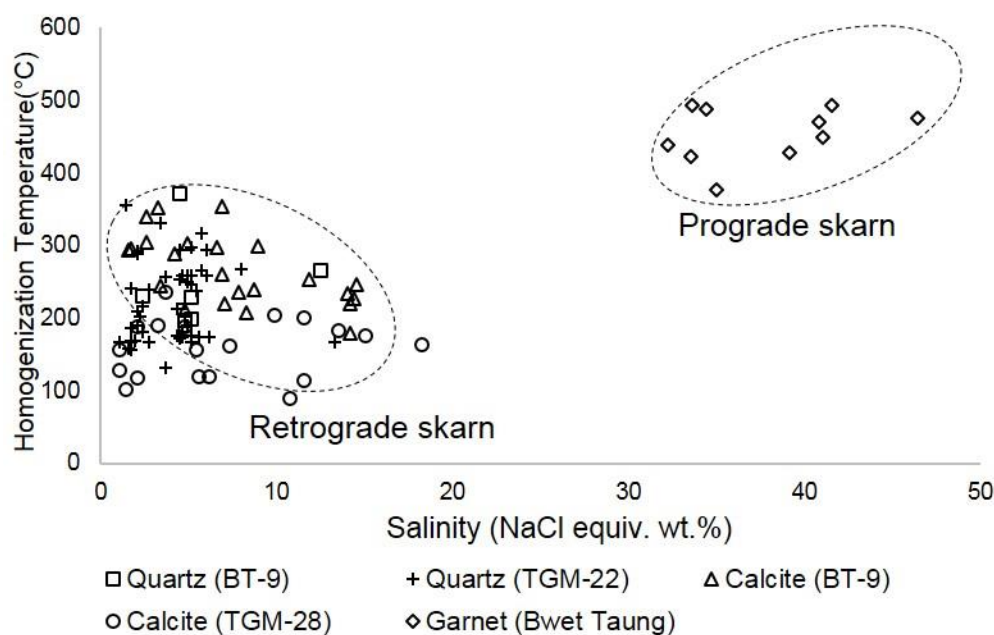


Fig. 6.1 Homogenization temperature and salinity of fluid inclusions for prograde skarn and retrograde skarn. Garnet, quartz and calcite from skarn of the Bwet Taung orebody and quartz from skarn and calcite from brecciated marble of the Tiger Mouth orebody.

6.1.1 Boiling evidence

The fluid inclusion results show that boiling was widespread during the mineralizing events at Shwe Min Bon (Fig. 6.1). Coexisting of primary LV, L and LVH populations with different vapor to liquid ratios are indicators of boiling in the hydrothermal system (eg. Ronacher et al., 2000; Simmons et al., 2005; White and Hedenquist, 1995; Thiersch et al., 1997).

6.1.2 P-T conditions

The trapping pressure can be calculated based on microthermometric measurements if the phase separation can be confirmed (Willkinson 2001). The homogenization temperatures and pressures of liquid-vapor inclusions can be used directly as deposition and trapping temperature and pressures. (Roedder and Bodnar, 1980). The prograde mineral assemblages dominated by denser and more saline magmatic hydrothermal fluids at hydrostatic pressure range from 200 to 500bar. The retrograde mineral assemblages are formed by late hydrothermal fluids at hydrostatic pressure of ~ 200 bars (Fig. 6.2). These homogenization temperatures and salinities permissively indicate a mixing of hotter, saline fluids with a cooler dilute water of meteoric origin. Hence, during the retrograde skarn stage, the formation of epidote and other retrograde minerals may have resulted from mixing of magmatic fluids with meteoric water (e.g., Einaudi et al., 1981; Haynes and Kesler, 1988). Based on the fluid inclusion studies of calcite and quartz in the retrograde stage, which are related to sulfide minerals, Cu–Au mineralization was deposited at lower temperatures than prograde silicate minerals (Fig. 6.2).

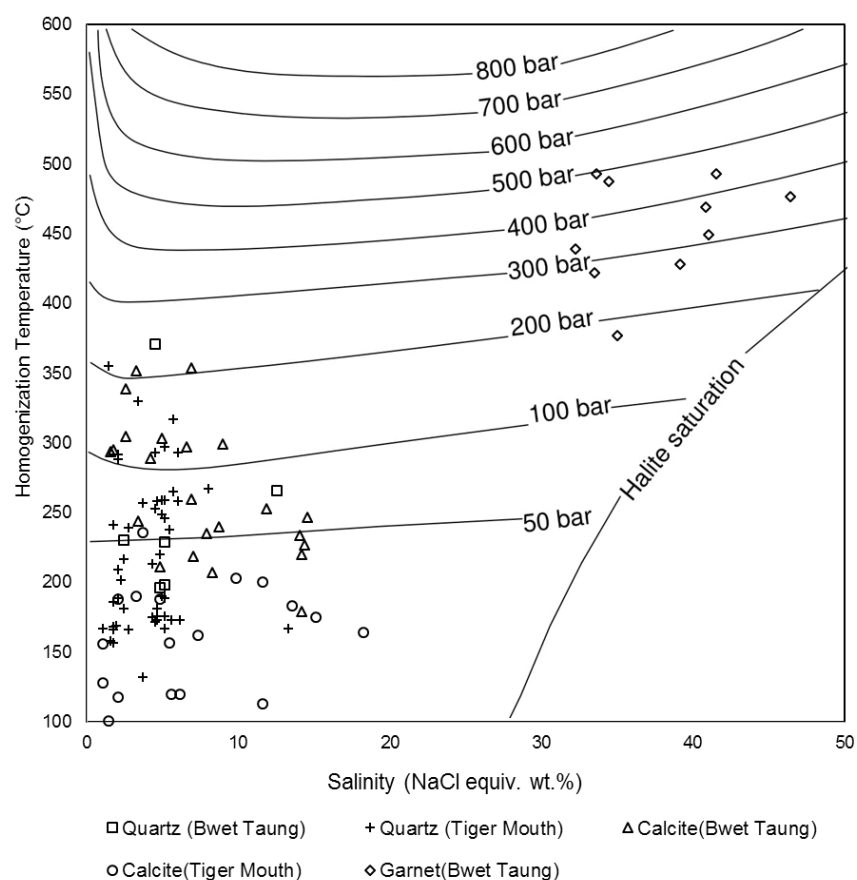


Fig. 6.2 Pressure estimation for fluid inclusions of the Shwe Min Bon Cu-Au skarn deposit. Note that the H-type and V-type inclusions of the quartz+chalcopryrite± Au stage were trapped under immiscible conditions, and L-type and V-type inclusions of the quartz–polymetallic sulfide ±Au stage and calcite+bismuthinite+Au stage were trapped under boiling conditions, thus the estimated pressures indicate the actual trapping pressures. Isobars were calculated from the equations of Driesner and Heinrich (2007).

Based on the fluid inclusion results, hydrothermal fluids developed from a prograde skarn to an early retrograde skarn stage I, followed by retrograde skarn stage II (Fig. 6.3). The prograde stage formed under ductile condition while retrograde I and II formed under brittle condition. The

brittle condition is characterized by the occurrence of breccia zone and brittle mineral grain's texture.

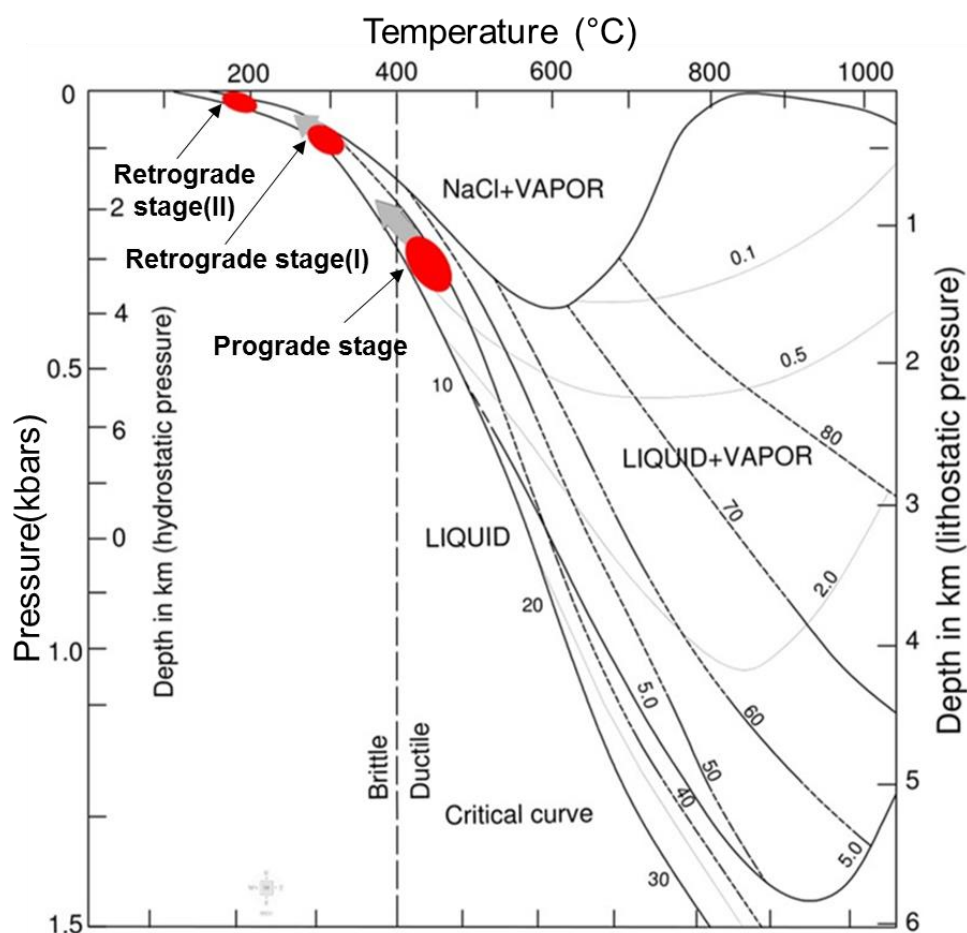


Fig. 6.3 Pressure-temperature diagram for the H₂O-NaCl system (Hedenquist et al., 1998; Fournier, 1999; Redmond et al., 2004), showing the magmatic hydrothermal fluids leading to ore formation at the Shwe Min Bon deposit.

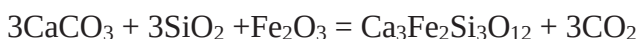
6.2 Metasomatism

Based upon field evidence, along with mineralogic and petrographic data from intrusive rocks, the impure carbonate rocks (as protolith), the skarn zone and the metamorphic-metasomatic alteration zones in Shwe Min Bon area, the process of skarnification can be categorized into two

stages: (1) prograde and (2) retrograde. These two alteration stages commonly have been thought to reflect a dominance of magmatic and meteoric water, respectively, with relevance to the source of ore metals (Meinert, et al., 2005). Garnet and wollastonite are the important anhydrous calc-silicates that is ubiquitously present within this zone.

6.2.1 Prograde stage

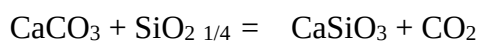
Early, high-temperature prograde anhydrous minerals are dominated by garnet and pyroxene. Einaudi (1982a) proposed the following chemical reactions;



calcite

andradite

A large volumes of wollastonite have been formed in the calcitic marble by the reaction:



calcite fluid

wollastonite fluid

where an H₂O-rich fluid is supplied from an external source (e.g., Greenwood, 1967; Tanner et al., 1985; Dipple and Gerdes, 1998; Fernandez-Caliani and Galan, 1998). Therefore fluid composition was controlled by the fluid reservoir outside the metasomatized marble.

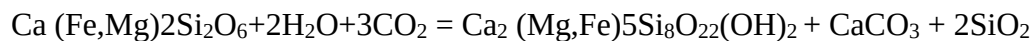
6.2.2 Retrograde stage

Intense retrograde alteration is common in Cu skarns. It was formerly assumed (e.g., Einaudi et al., 1981) that the gradual cooling of the system following the solidification of associated plutons. The geochemical association of prograde silicate minerals (garnet, clinopyroxene) and retrograde silicate minerals (epidote, tremolite-actinolite) were likely formed by the following equations.



garnet

epidote



clionpyroxene

tremolite–actinolite

calcite

quartz



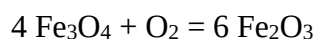
clinopyroxene

epidote

tremolite–actinolite

epidote

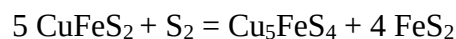
The difference between the oxygen or sulfur fugacity implied by a natural mineral assemblage compared with that of a buffer reaction forms the basis for assigning relative oxidation or sulfidation states. For ease of comparing the sulfidation state between different fluids and between fluids and mineral assemblages, (Einaudi et al., 2003) suggest an informal terminology based on sulfidation reactions among minerals in the system “Cu-Fe-As-S”.



magnetite

hematite,

The boundary between intermediate and high sulfidation states,

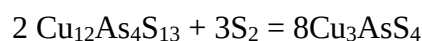


chalcopyrite

bornite

pyrite

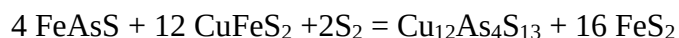
which approximately coincides with the sulfidation reaction,



tennantite

enargite

The sulfidation reaction,



arsenopyrite chalcopyrite tennantite pyrite

Inter element correlation trends confirm the paragenetic stage from early base metal (Cu-Fe) stage to the late precious-metal (Au, Bi-Te) stage. The sulfur fugacity of the hydrothermal fluids for gold mineralization can be estimated from the plot of the log f_{S_2} (ranges from -7 to -11) based on FeS content of sphalerite and temperature by the formation temperature of sulfide minerals based on the associated with retrograde skarn stage, 260-320°C. This result suggest for the intermediate to high sulfidation state in the Shwe Min Bon skarn deposit (Fig. 6.4). Although the occurrence of arsenopyrite in vuggy quartz vein of retrograde stage II, arsenopyrite is largely unrelated with retrograde skarn mineral assemblages.

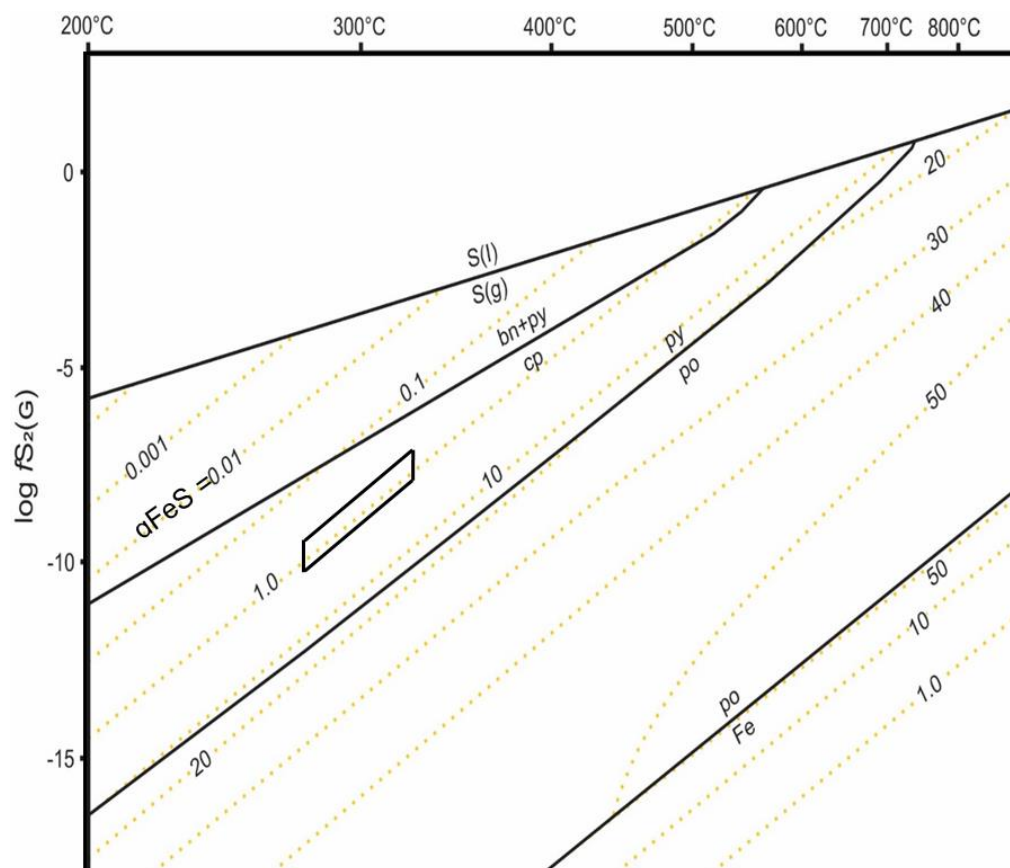


Fig. 6.4 Activity of S_2 vs T diagram from Toulmin and Barton (1964), sulfidation curves are from Barton and Skinner (1979).

The Shwe Min Bon skarn deposit can be classified as an oxidized Cu skarn based on the occurrence of hematite and magnetite (Meinert et al., 2005). The andradite-rich compositions of the garnet together with abundant magnetite (with no pyrrhotite) also indicate that the skarn belongs to the oxidized type (Meinert et al., 2005). The possible formation of skarn and alteration shown in Fig. 6.5. The formation of skarn deposit could be formed from the metal bearing saline and hypersaline liquid fluids to high sulfidation and high to very high sulfidation and oxidation state. The prograde stage is characterized by potassic alteration and anhydrous skarn with disseminated/veinlet chalcopyrite-bornite-(magnetite) at 400-600°C, lithostatic pressure, and intermediate sulfidation states. Late fluids are dominantly meteoric, boiling at 350-250°C under

hydrostatic pressures, and are characterized by moderate acidity, low-salinity, and high sulfidation-oxidation states (Einaudi, 1994). The formation temperature of retrograde stage II represents late fluids formed in temperature range 320-260°C in Shwe Min Bon. Acid-sulfate fluids of meteoric water and/or magmatic-vapor plume origin, are formed at 350-200°C, near-hydrostatic pressure, and high to very high sulfidation-oxidation states (Einaudi, 1994). In skarn or carbonate wall-rocks, these fluids generate silica-pyrite Cu- (Au) fissures and replacement bodies (e.g., Bisbee, Arizona; Yauricocha, Peru).

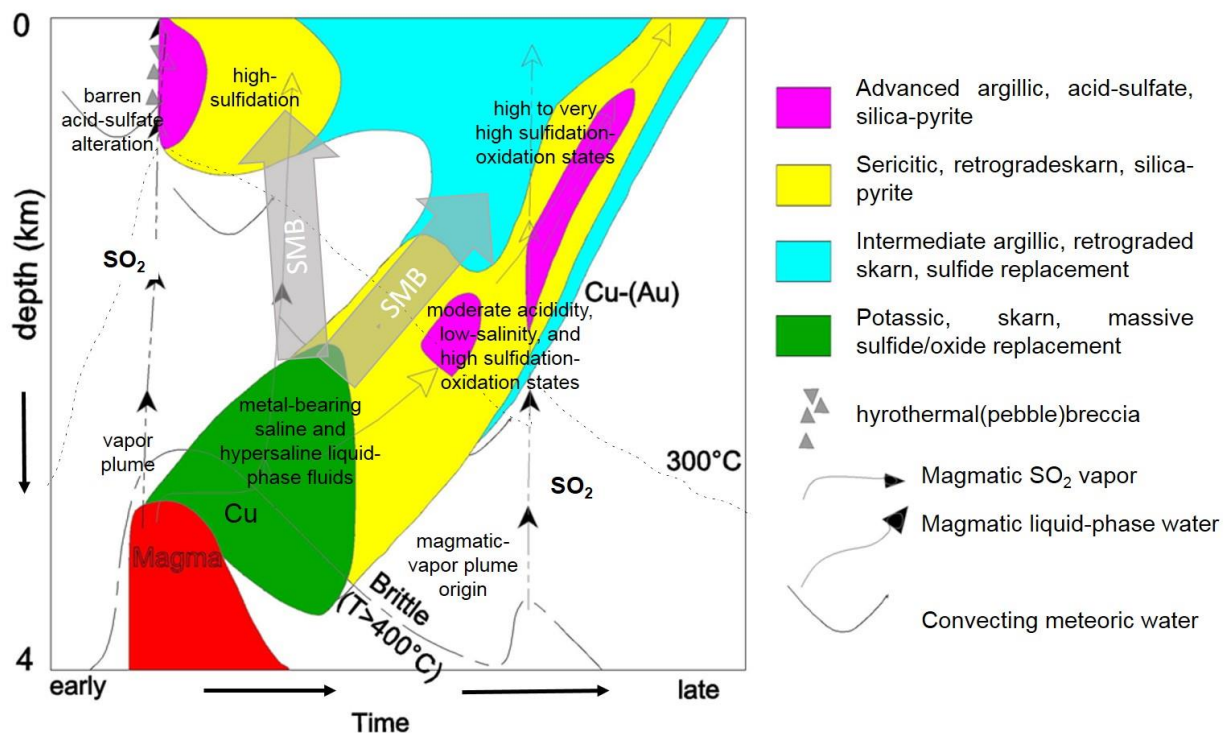


Fig. 6.5 Schematic diagram of skarn and hydrothermal breccia suggesting the formation of Shwe Min Bon skarn deposit (modified after Einaudi, 1994). The two shaded arrows represent the formation of Shwe Min Bon deposit.

6.3 Genesis of skarn deposit

6.3.1 Relation to intrusive rocks

The oxidation state of the magma provides a metallogenic classification for skarn deposits and has an important role in controlling the compatible or incompatible nature of many elements in magma (Blevin, 2004). The composition of calc-alkaline magma can be suggested for the formation of oxidized magma. Geochemical analysis suggests that the compositions of intrusive rocks in the Shwe Min Bon area are diorite and granodiorite. Based on the geochemical classification of granitic rocks (Maniar & Piccoli, 1989), the intrusive rocks in the Shwe Min Bon area are metaluminous and calc-alkaline. The magma composition suggests that the study area belonged to a convergent plate margin. Metaluminous composition suggests an I-type affinity, considered to have formed by partial melting of igneous protoliths. An I-type affinity and calc-alkaline series can be associated with Cu skarn (Meinert et al., 2005). In the tectonic setting discrimination diagram of Pearce et al. (1984), these dioritic rocks plot mainly in the field of arc granites. The geochemical results of the intrusive rocks suggest subduction signature, having formed possibly in a continental arc.

6.3.2 Association of Bi-Te minerals

The Au+Bi-tellurides association will reflect the oxidation characteristic of sulphidation reactions (Ciobanu et al. 2003, 2004, Mudrovskaya et al., 2004). The high content (375 – 1000 ppm) of Bi in the associated intrusive rock is the major source of Bi (Zhang, 1998). The content of Bi in dioritic rocks in Shwe Min Bon deposit show 275ppm. The significant presence of Bi suggested by the paragenetic association of the gold with Bi-Te-S-bearing minerals (Fig. 6.6).

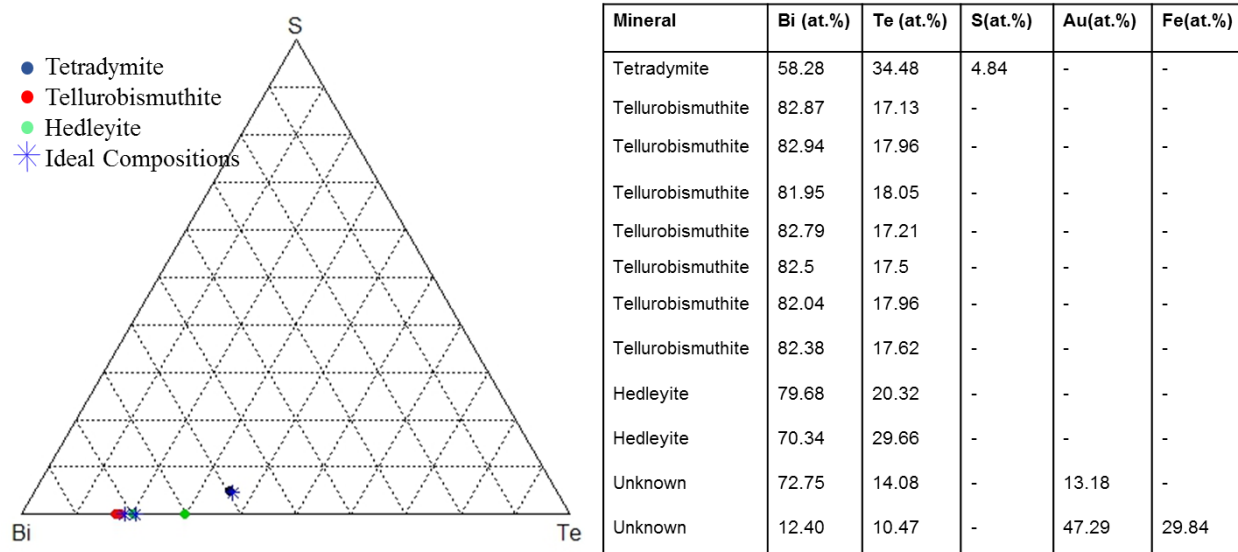


Fig. 6.6 Diagram showing (a) the composition of tetradyomite, tellurobismuthinite and hedleyite (b) representative values of Bi-Te-S-bearing minerals from SEM-EDX.

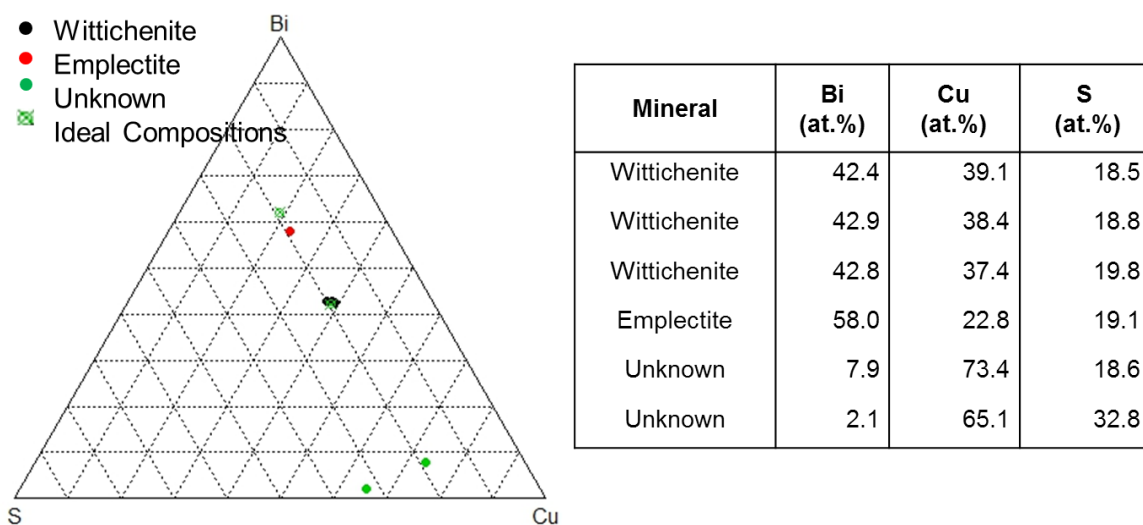


Fig. 6.7 (a) the composition of wittichenite and emplectite (b) representative values of Bi-Cu-S-bearing minerals obtained from SEM-EDX.

The ore minerals in the Shwe Min Bon area are represented by a group of bismuth and bismuth-bearing minerals including sulfide (bismuthinite), Cu–Bi sulfosalts (emplectite, wittichenite), and Pb–Bi sulfosalts (cosalite). The compositions of bismuth-tellurium bearing minerals and bismuth-

copper sulfide minerals are plotted in Fig. 6.6 and Fig. 6.7. The association of Au and bismuth in the deposit is spatially and genetically related to the dykes of diorite intruded into the Triassic-to-Jurassic carbonate and the clastic rocks of the Shweminbon Formation. The Au mineralization, which is mainly associated with bismuth minerals in the retrograde stage II, suggests that it was deposited later than the Cu mineralization. The skarn deposit in Shwe Min Bon is related to Bi–Te. Bismuth–tellurium associations are often seen in skarns and orogenic Au deposits (Ciobanu et al., 2003, Cook et al., 2004; Mudrovskaya et al., 2004). This type of association reveals an oxidizing character during the retrograde skarn stages (Ciobanu et al., 2003).

6.4 Formation environment of skarn deposit

The genetic model for the skarn mineralization was constructed base on field and laboratory results (Fig. 6.8). The possible deposit model for the skarn deposit show the intrusive rocks are trigger for the Cu-Au skarn mineralization formed by the hydrothermal alteration and mineralization process in Shwe Min Bon.

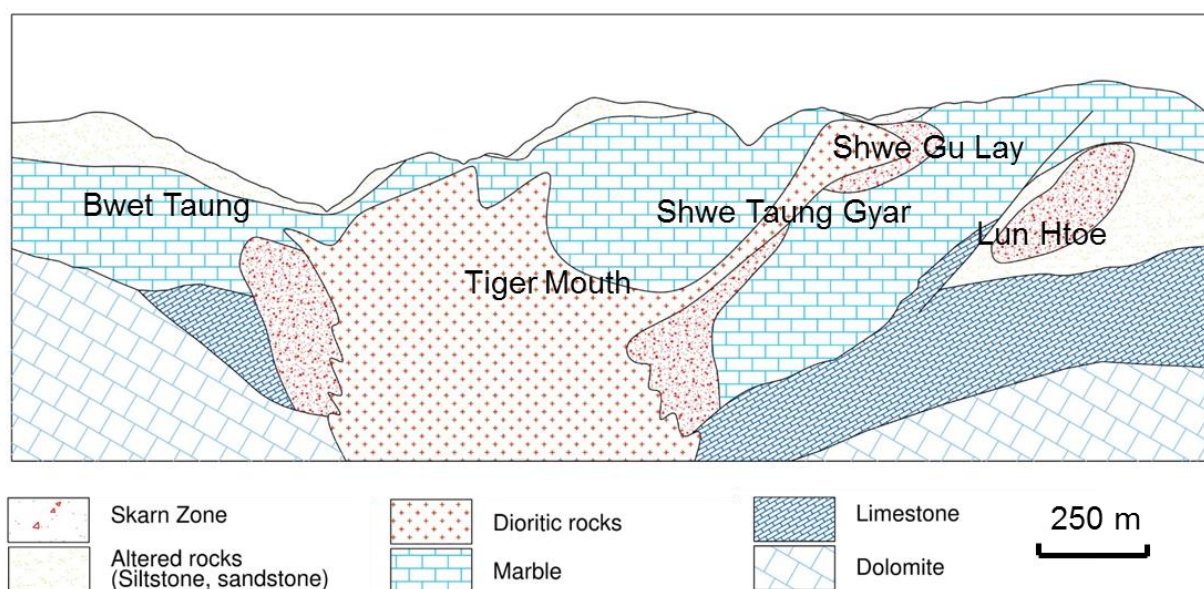


Fig. 6.8 Schematic model of Cu-Au skarn deposit in Shwe Min Bon showing relation of host rock, associated skarn and replacement deposits.

Much of Myanmar has been subjected to both Triassic-Early Jurassic Indosinian and Cenozoic Himalayan orogenies, which are related to the closure of the Palaeo-Tethys and the Neo-Tethys oceans. A late Triassic-Early Jurassic succession of tightly folded beds including turbidites has been mapped as the Shweminbon Formation and Ngayant Chaung Formation overlying the Permo-Triassic plateau limestone by Mitchell et al. (2002, 2004, 2007, and 2012). Mitchell et al. (2004, 2007, 2012) interpret these rocks as Neo-Tethys sediments which were deposited in a marine environment and likely located between the Shan plateau and the Slate belt. Both magmatic belts (Wuntho Popa Arc and MMB) formed adjacent parallel belts on a continental margin, overlying the subducting Neo-Tethys ocean.

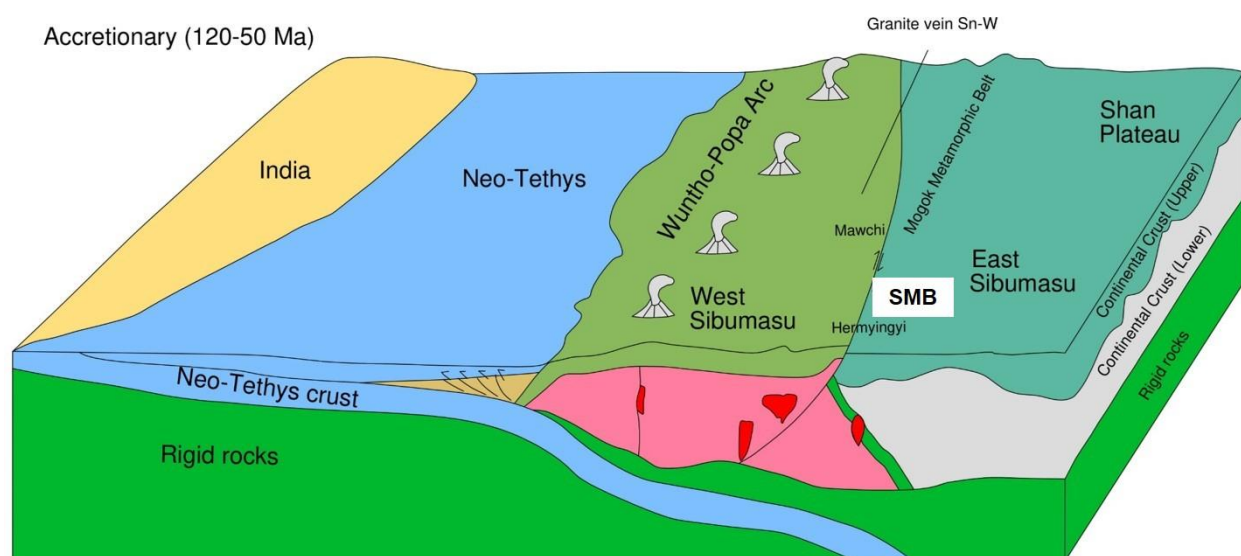


Fig. 6.9 Schematic tectonic evolution of Shwe Min Bon deposit (SMB) with metallogenesis related to major stage and location of major mines (modified after Gardiner et. al, 2016).

According to regional tectonic setting of Myanmar, the Tethyan collision zone, resulting in the Alpine- Himalayan Orogeny, has, in places, proved a highly fertile zone for metallogenesis.

The West Burma Block may be an artifact of movement on the Sagaing Fault, and that the continental crust underlying western Myanmar is either Sibumasu crust, or a separate block accreted possibly by the mid-Cretaceous times at the latest. Both magmatic belts (the WPA and the MMM Belt) to have formed as adjacent parallel belts on a common continental margin, overlying the subducting Neo-Tethys. Mineralization processes associated with Central Granite Belt magmatic responsible for the skarn deposit in Shwe Min Bon (Fig. 6.9).

CHAPTER VII. Summary and conclusions

The Shwe Min Bon deposit is an important Cu deposit in Myanmar within the Shan scarp zone of the Mogok Metamorphic Belt (MMB). The MMB is one of the most important mineral belts in Myanmar. Many different types of ore deposits occur within the MMB and the Shan scarp fault zone. Most of the skarn deposits in Myanmar are mainly occurred along the Mogok Metamorphic Belt. However, the Shwe Min Bon skarn deposit mostly found within Shan scarp fault zone. The Shwe Min Bon skarn deposit was mainly formed in contact zone between dioritic rocks and marble, siltstone and sandstone of Shweminbon Formation. The mineralization is associated with the Cretaceous magmatic activity within the Shan scarp zone in the Mogok Metamorphic Belt.

At Shwe Min Bon, skarn deposit is mainly related with copper mineralization. Ore deposits are not only primary skarn zone but also associated with silicified altered rock and oxidized zone. In the Shwe Min Bon deposit, seven orebodies have been mining out. Among them, Bwet Taung, Tiger Mouth, Shwe Taung Gyar and Lun Htoe orebodies are the main mineralized zones. This study will focus on the Bwet Taung, Zin Yaw, Tiger Mouth, Shwe Taung Gyar, Shwe Gu Lay and Lun Htoe orebodies. Based on field observation, the Bwet Taung, Zin Yaw, Tiger Mouth and Shwe Gu Lay orebodies are classified as proximal skarns. The Shwe Taung Gyar and Lun Htoe orebodies are identified as distal skarns. Moreover, the silicified zone occurs in the Bwet Taung and Tiger Mouth orebodies where igneous rocks intruded into the clastic rock of the Shwminbon Formation. The intrusive rocks from Tiger Mouth are classified as diorite and granodiorite, while the intrusive rocks from Shwe Gu Lay and Zin Yaw are classified as granodiorite. The intrusive rocks of Shwe Taung Gyar are diorite in composition.

The occurrence of skarn contact between intrusive rocks and marble suggesting that both exoskarn and endoskarn were developed in the Shwe Min Bon area. Skarn-type metasomatic alteration occurred in both the intrusion and limestone and marble. The prograde and retrograde alteration extensively occurred in exoskarn zone. As most skarn ore deposits are characterized by two distinctly different alteration styles, Shwe Min Bon skarn deposits also exhibit two skarn alteration; (1) an early prograde stage with anhydrous minerals, garnet, pyroxene and pyroxenoid, forms from relatively high-temperature, hypersaline liquid, (2) a later retrograde stage with hydrous minerals, epidote, actinolite-tremolite, and chlorite plus sulfide ore minerals. Primary or syn-skarn deposition is well developed next to altered diorite. The altered diorite could be subject to later strong hydrothermal alteration such as prophylic alteration, silicification, and kaolinization. Silicification is also associated with Shweminbon Formation in the shear zone that can be favorable to latter retrograde skarn mineralization linked with later hydrothermal activity. Gold mineralization mainly associated with chalcopryrite in first stage and bismuth-tellurite in late stage.

The mineralization includes native gold and copper-bearing minerals mainly chalcopryrite, bornite, chalcocite, tennantite, sphalerite, galena and minor enargite, cosalite, magnetite and hematite. Native gold is mainly associated with chalcopryrite and tennantite in retrograde skarn stage ore. The native gold associated with bismuthinite and tellurobisumuthinite occurred along the cleavage boundary of calcite in marble. In the present study, Bi-bearing minerals such as bismuthinite, emplectite, wittichenite, cosalite were identified. The results of the present study characterized the Shwe Min Bon deposit as an oxidized Cu-Au type Bi-bearing skarn. Gold mineralization is mainly associated with wollastonite, epidote and chlorite in exoskarn with

chalcopyrite, bornite, tennantite and cosalite in retrograde skarn stage I and tellurobismuthinite in retrograde skarn stage II.

Based on the thin section and polished sections studies, garnet-skarn, clinopyroxene-garnet skarn and wollastonite skarn occurred as prograde stage. Other silicate minerals such as tremolite, epidote, chlorite and fluorite are formed during retrograde stages. In these retrograde stages, sulfide mineral assemblages are crystallized in the interstices of silicate minerals. Pyrite is mainly common in altered diorite and is showed anhedral to euhedral. Chalcopyrite is associated with tennantite. Island of galena, chalcopyrite, bornite and pyrite rimmed by tennantite are also present. Occasionally it has been replaced partially by bornite, chalcocite and covellite. Tennantite is observed as massive aggregates within the calc-silicate and are commonly accompanied by pyrite. Tennantite partially to completely replace pyrite and chalcopyrite. Chalcopyrite contains exsolution blebs and lamellae of bornite.

From north to south, skarn is zoned away from intrusive rock in the sequence: from garnet, pyroxenoid to marble. Three skarn stages were observed as: prograde skarn (pre-ore stage), retrograde skarn and Cu-Fe-As-Bi sulfides (main ore stage) and Bi-Te minerals associated with calcite (late ore stage) in brecciated marble. In addition, a supergene stage marked by secondary Cu mineralization (malachite and azurite) is closely associated with oxidized zone.

The Shwe Min Bon skarn deposit was mainly formed in the contact faces between dioritic rocks and the marble, siltstone, and sandstone of the Shweminbon Formation. The mineralization is associated with the Cretaceous intrusive rocks within the Shan scarp zone in the MMB. In the present study, Bi-bearing minerals such as bismuthinite, emplectite, wittichenite, hedleyite, and cosalite were identified. The results of the present study characterized the Shwe Min Bon deposit as an oxidized Cu–Au-type Bi-bearing skarn. Au mineralization is mainly associated with

wollastonite, epidote, and chlorite in exoskarn with chalcopyrite, bornite, tennantite, and cosalite in the retrograde skarn stage I and tellurobismuthinite in the retrograde skarn stage II. The Shwe Min Bon skarn deposit can be classified as oxidized copper skarn (Meinert et al., 2005) based on the occurrence of hematite and magnetite. The andradite-rich compositions of the garnet together with abundant magnetite (with no pyrrhotite) also indicate that the skarn belongs to the oxidized type (Meinert et al., 2005). Copper skarn gold-rich mineralization in the Shwe Min Bon skarn deposit is related with Bi-Te.

The temperature and salinity of fluid associated with the prograde skarn formation were high temperature (314–492°C) and hypersaline (up to 46.4 wt % NaCl equiv.). Cu–Au mineralization mainly occurs in the retrograde stage I, characterized by moderate temperatures (260–320°C) with a moderate salinity (5.0–6.0% NaCl equiv) fluid. The retrograde stage II was formed at low temperature (180–200°C) and a low salinity of 2.0–3.0% NaCl equiv. Au mineralization is mainly associated with chalcopyrite and tennantite in the retrograde stage I and with tellurobismuthinite in the retrograde stage II. The mechanism for the Au deposition is a fluid mixing of up-welling metal-bearing hydrothermal solutions with relatively near-surface meteoric fluids. Au mineralization at Shwe Min Bon appears to have been deposited at lower temperatures later than the prograde silicate minerals and was mostly confined to the retrograde stage.

Garnet and wollastonite are the important anhydrous calc-silicates that is ubiquitously present. These homogenization temperatures and salinities permissively indicate a mixing of hotter, saline fluids with a cooler dilute water of meteoric origin. Hence, during the retrograde skarn stage, the formation of epidote and other retrograde minerals may have resulted from mixing of magmatic fluids with meteoric water. Based on the fluid inclusion studies of calcite and quartz in the retrograde stage which are related with sulfide minerals, the temperature and salinity of the fluid

associated with gold mineralization appears to have been deposited at lower temperatures than the prograde silicate minerals.

The magma composition suggests the study area belongs to a convergent plate margin. Metaluminous composition suggests an I-type affinity, considered to have formed by partial melting of igneous protoliths. An I-type affinity and calc-alkaline series can be associated with copper skarn (Minert, 2005). In the tectonic setting discrimination diagram of Pearce et al. (1984), these dioritic rocks plot in the field of arc granites and in the syn-collision field. The geochemical results of the intrusive rocks point towards a subduction signature, having formed possibly in a continental arc.

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