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## แร่วิทยาและธรณีเคมีของสายแร่และหินทิ้ง
## ของแหล่งแร่ทองคำแบบอีพิเทอร์มอล
## พื้นที่สำรวจโชคดี จังหวัดพิษณุโลก

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# MINERALOGY AND GEOCHEMISTRY OF MINERALIZED VEINS AND WAST ROCKS OF CHOKDEE EPITHERMAL GOLD PROSPECT, PHITSANULOK PROVINCE

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A PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF THE
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# แร่วิทยาและธรณีเคมีของสายแร่และหินทิ้งของแหล่งแร่ทองคำ แบบอีพิเทอร์มอล พื้นที่สำรวจโชคดี จังหวัดพิษณุโลก

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# ABSTRACT

The Chokdee prospect is located about 20 km northeast of Chatree gold mine, Phitsanulok province. The mineralization occurs as quartz veins, stockworks and minor breccia hosted in volcaniclastic rocks. Base on stratigraphic study, the host volcanic sequence can be grouped into 3 units namely, 1) Tuffaceous sandstone unit, 2) Polymictic volcanic breccia unit and 3) Siltstone unit. Base on cross-cutting relationship, mineral assemblages and textures, mineralization consists of 3 stages namely, 1) quartz-sulfide veins, 2) quartz ± carbonate-sulfide-gold veins and 3) quartz ± carbonate veins. Quartz ± carbonate-sulfide-gold veins (Stage 2) is the main gold mineralization stage which occurs as quartz veins with or without carbonate. Pyrite and chalcopyrite are major sulfide minerals with minor sphalerite. For environmental study, a Synthetic Precipitation Leaching Procedure (SPLP) was used to leach out heavy metals from host rock and veins samples. This procedure was performed at pH level of 4. The following elements were selected for analysis: copper, zinc, arsenic, lead, manganese, mercury, cadmium and chromium. The results reveal that the mineralized veins samples have leached out arsenic and mercury exceeding the Surface Water Quality Standard (SWQS) whereas, waste rocks has leached out cadmium exceeding SWQS. Copper, zinc, lead, manganese, and chromium leach out below SWQS and Industrial Effluent Standard (IES) for both types of samples. Although, arsenic and mercury are elevated in in mineralized veins and cadmium in waste rocks when used pH level 4. However, petrographic studied suggested that the amount of sulfides present in both types of samples are very low in comparison to some other mineral deposits. Therefore, there is less chance that these types of material will cause acid mine drainage even exposed to the surface. Furthermore, pH level in natural area in this region is far higher than 4. It is further suggested that there is very low chance that both types of materials from Chokdee prospect will pollute the environment if it were mined. The results of this study will also help in managing waste rocks during the mine operation if it became a mine in future.

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คำสำคัญ: พื้นที่สำรวจ ระยะการเกิดแร่ การชะละลาย โลหะหนัก

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**บทคัดย่อ**

พื้นที่สำรวจโชคดีตั้งอยู่ในตำบลวังโพรง อำเภอเนินมะปราง จังหวัดพิษณุโลก โดยอยู่ห่างจากเหมืองแร่ทองคำชาตรีไปทางเหนือประมาณ 20 กิโลเมตร สายแร่ในพื้นที่ศึกษาเกิดในลักษณะของสายแร่ควอตซ์ สายแร่ร่างแห และมีลักษณะของหินกรวดเหลี่ยมเล็กน้อย อยู่ในหินตะกอนภูเขาไฟ โดยจากการศึกษาศิลาวรรณาสามารถแบ่งหน่วยหินในพื้นที่ศึกษาออกได้เป็น 3 หน่วยหิน คือ 1) หน่วยหินทรายเนื้อทัฟฟ์ (Tuffaceous sandstone unit) 2) หน่วยหินกรวดเหลี่ยมหลากชนิด (Polymictic breccia unit) และ 3) หน่วยหินทรายแป้ง (Siltstone unit) และจากการศึกษาแร่วิทยาของสายแร่พบว่าการเกิดแร่สามารถแบ่งได้เป็น 3 ระยะการเกิดแร่คือ 1) สายแร่ควอตซ์-แร่ซัลไฟด์ 2) สายแร่ควอตซ์ ± คาร์บอนเนต – แร่ซัลไฟด์ - ทองคำ และ 3) สายแร่ควอตซ์-คาร์บอนเนต โดยสายแร่ระยะที่ 2 เป็นสายแร่ที่ให้ทองซึ่งเกิดในลักษณะของสายแร่ควอซต์ที่ไม่พบคาร์บอนเนต และแร่กลุ่มซัลไฟด์ที่พบประกอบไปด้วย 3 ชนิดคือ 1. ไพไรต์ ($FeS_2$), 2. คาลโคไพไรต์ (CuFeS) และ 3. สฟาเลอไรต์ (ZnS) ซึ่งพบเป็นจำนวนน้อย สำหรับการศึกษาด้านสิ่งแวดล้อม การทดสอบการชะละลายของโลหะหนักด้วยวิธี Synthetic Precipitation Leaching Procedure (SPLP) ถูกนำมาใช้ในการหาปริมาณของโลหะหนักที่ชะละลายออกมาจากสายแร่และหินท้องที่ในสภาวะความเป็นกรดที่พีเอช 4 โดยโลหะหนักที่สนใจนำมาศึกษาประกอบไปด้วย ทองแดง, สังกะสี, สารหนู, ตะกั่ว, แมงกานีส, ปรอท, นิกเกิล, แคทเมีย และโครเมียม จากผลการศึกษาสามารถสรุปได้ว่ามีการชะละลายของสารหนูและปรอทออกมาจากสายแร่เกิดกว่าเกณฑ์มาตรฐานคุณภาพน้ำในแหล่งน้ำผิวดิน และมีการชะละลายของโครเมียมออกมาจากหินท้องที่เกิดกว่าเกณฑ์มาตรฐานคุณภาพน้ำในแหล่งน้ำผิวดินเช่นกัน และจากการศึกษาศิลาวรรณาพบว่าปริมาณแร่กลุ่มซัลไฟด์ในสายแร่และหินท้องที่ของพื้นที่สำรวจโชคดีมีน้อยเมื่อเทียบกับแหล่งแร่อื่นๆ ซึ่งสามารถอนุมานได้ว่าพื้นที่สำรวจโชคดีมีโอกาสที่จะก่อให้เกิดความเป็นกรดขึ้นในเหมืองน้อยกว่า และในบริเวณพื้นที่สำรวจโชคดีค่าความเป็นกรดที่เกิดขึ้นโอกาสสูงที่พีเอชจะมากกว่า 4 ทำให้ในกรณีที่มีการเปิดทำเหมืองในพื้นที่สำรวจโชคดี สายแร่และหินมีโอกาสน้อยที่จะก่อให้เกิดมลภาวะต่อสิ่งแวดล้อม ซึ่งผลลัพธ์ที่ได้สามารถนำไปวางแผนในการจัดการกับหินทิ้งเมื่อมีการเปิดทำเหมืองอย่างเป็นระบบในอนาคต

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# Chapter 1
# Introduction

## 1.1 Introduction

A number of mineral deposits have been found in Thailand. Among them, tin, tungsten, niobium, tantalum, lead, zinc, gold, iron and stibnite are the most important metallic minerals that play an important role in country economic, industry and energy. Metallic minerals especially golds are mainly found in Loei Fold. Gold is important to metal for world's economy. Thailand has been known as a gold producing country for more than a century and there are no an official reports of ancient gold production.

In 1987, when foreigners were allowed for a gold exploration in the country, Australian Thai Gold Fields Limited chose Thailand as an exploration target. When the geology of Thailand was studied, the selected areas which are epithermal gold deposits in volcanic rocks were stared at the mining operation. In 1988, Gold was first found by a Thai Gold Fields Limited exploration team at Khao Mo in central Thailand which is resistant to isolated hills due to pervasive silicification. In 1994, There is an exploration at the Chatree area by Akara Mining Ltd which within a few years of the commencement of the drilling program economic orebodies were identified and the mining operation had remained until temporary closing in 2017. The Chatree deposit is located approximately 280 km from Bangkok in the north direction, Thailand, and lies within the Loei Fold Belt. The deposit is the large-scale gold mine which was well known as one of the lowest production cost of gold mines in the world.

In Thailand, these deposits mostly found in western flank in Khorat plateau or Loei Fold Belt, for example, Pu Thab Fah gold mine, Chatree gold mine and Khao Phanom Pha gold mine (Salam et al. 2014). In general, metal deposits always occur with sulfide minerals eg. pyrite, chalcopyrite or pyrrhotite.

Sometimes, the environmental problem occurs occurred which affects the wildlife living within the affected body of water. Aquatic macroinvertebrates living in streams or parts of streams affected by acid mine drainage show fewer individuals, less diversity, and less biomass. Consequently, it may affect the human health somehow.

Almost sulfide minerals have heavy metals in their molecular infrastructure including copper, iron, silver, zinc, mercury, arsenic, lead, manganese or cadmium. However, amount of sulfide minerals and heavy metals are different in each deposit and also depend on the type of deposits (Changul et al. 2009). Whenever topsoils and rocks are disturbed by the unsystematic mining operation, sulfide minerals that contain in soils and rocks can be oxidized by oxygen and water. The disintegration of sulfide minerals by the oxidizing reaction will mix up with water and become sulfuric acid that would increase the acid concentration that occurring before and leaching potential of heavy metals. Consequently, it would be a cause of environmental pollution if there has no a systematic waste management or mining operation. Anyway, some deposits which mining operation doesn't exist yet may cause the environmental pollution.

Chokdee prospect is located at Wang Phrong sub-district, Noen Maprang district, Phitsanulok province which is approximately 20 km from the Chatree gold mine in a northeast direction. According to the drilling result of Kingsgate Consolidated Ltd, they found a geochemical anomaly which implies there is a gold in this area, approximately 30 $km^2$, surrounds the area of the discovery, which is larger than the 23 $km^2$ anomaly that covers the existing Chatree mine.

Chatree deposit which is the largest gold mines in SE Asia. Gold deposit is hosted by volcaniclastic and volcanogenic sediment (Salam et al. 2014). According to Changul et al. (2010), silicified lapilli tuff and shear tuff are potentially acid-forming materials which could be a cause of acid mine drainage. As a geochemical test, the concentration of some heavy metals leaching out from waste rocks exceeds the Industrial Effluent Standard and the Surface Water Standard.

As mention previously, the leaching of heavy metals from waste rocks and mineralized veins in acid conditions are the important thing that must be concerned whenever there is a mining operation. Hence, this study focuses on the leaching of heavy metals from waste rock and mineralized veins in Chokdee gold prospect which is a gold potential area and find the way protect and reduce the environmental impact if the mining occurs.

## 1.2 Objectives

1) Geological characteristics of rocks in the study area

2) Amount of heavy metals leaching from waste rocks and mineralized veins in acidic condition

## 1.3 Study area

This study focuses on mineralogy and geochemistry of rocks and mineralized veins in Chokdee area which is a prospect area that hasn't ever appear the mining operation. The study area is in a topographic map, sheet 5141IV series NO. L7018, the series name "Baan Wang Sai Phun" scale 1:50000 (Thai Royal Survey Department, 1997) between latitude 16°23'33" N to 16°23'42" N and longitude 100°39'50" to 100°39'56".

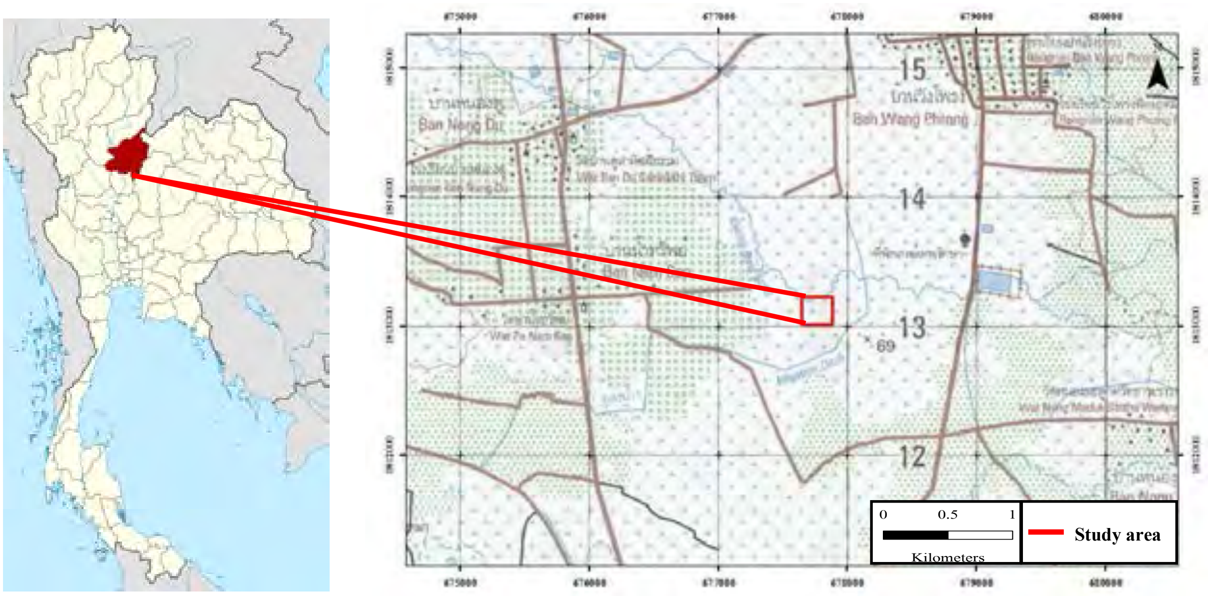



Fig 1.1 Topographic map, sheet 5141IV series NO. L7018, series name "Baan Wang Sai Phun" scale 1:50000 (Thai Royal Survey Department, 1997)


Fig 1.2 Satellite image of the study area which is located at Wang Phrong sub-district, Noen Maprang district, Phitsanulok province

## 1.4 Expected results

1) Amount of heavy metals leaching from a different type of waste rocks and mineralized veins
2) The results can be used in mining operation plan and appropriate waste rocks or soils management.

## 1.5 Literature review

1.5.1 Phu Thap Fah gold skarn deposit

Khin Zaw et al. (2013) studied Phu Thap Fah gold deposit (northeastern Thailand). The Phu Thap Fah deposit is hosted in a Permian sedimentary that intruded by Early Triassic granodiorite and Late Triassic andesitic dikes (Khin Zaw, 2011). The mineralized skarn zone had crosscut by Late Triassic andesitic dikes, suggesting skarn formation and gold mineralization probably occurred during the Middle Triassic. Gold occurs as electrum, gold–bismuth and gold–bismuth–telluride associations and the gold is confined mainly to the massive pyrrhotite and pyrite with chalcopyrite (Khin Zaw, 2011). According to Klongsamran et al. (2014), the research study on the effect of pH on heavy metal leaching from the waste rock in Phu Thap Fah gold mining consists of Cr, Mn, Ni, Cu, Zn, As, Cd, Hg, and Pb. At pH 2, there is the highest heavy metals leaching inferior to pH 4 and pH 6 respectively. It shows that the solubility constant of heavy metals will increase if pH decreases.

1.5.2 Chatree epithermal gold-silver deposit

In 2014 Salam et al. stated that the Chatree deposits is the largest low sulfidation epithermal gold-silver deposit in mainland Southeast Asia which located in Loei Fold Belt or between Phichit and Phetchabun provinces, central Thailand. The mineralization host by volcaniclastic and volcanogenic sedimentary rocks which occur as veins, stockworks, and minor breccias. The main gold-silver mineralization is characterized by colloform-crustiform banded quartz ± carbonate ± chlorite ± adularia–sulfide–electrum veins. Gold mainly occurs as electrum, both as free grains associated with quartz, carbonate minerals and chlorite, and as inclusions in sulfides, mostly pyrite.

Changul et al. (2010) have studied the environmental aspect of the Chatree deposit using the Synthetic Precipitation Leaching Procedure (SPLP) for detecting the amount of the heavy metals which could be leached out from tailings of Akara gold mine. The study was focused on various acid conditions (e.g., pH 2, 4 and 6.5). The study revealed that Mn is exceeding the Thailand Surface Water Quality Standard for Agricultural and the Thailand Industrial Effluent Standard at pH 2. Although leachate at pH 4 contains lower Mn than the Industrial Effluent Standard it still exceeds the surface water quality standard. Interestingly, the leachate of Pb has exceeded both standards. At all pH conditions, Ni concentration is lower than the Industrial Effluent

Standard but still exceeds the Surface Water Standard at pH 2 and 4. They concluded that pH plays the most important role in the leaching process because concentrations of all elements in leachates decreased from pH 2 to 4 and 6.5, respectively. Moreover, they estimate heavy metal concentrations in mine tailing samples based on EPA 3052 method and ICP-OES analysis comprises Cd, Co, Cr, Cu, Pb, Mn, Ni, and Zn. The result shows that there is no relationship between the total heavy metal concentration in solid waste and its leaching ability.

1.5.3 Khao Phanom Pha gold skarn deposit

Vicheanteab (2015) stated that the paragenesis of the Khao Phanom Pha mineralization has at least three sessions, the first session is Pre-mineralization which microdiorite intrudes through the country rocks cause the occurrence of contact metamorphism. The second one is major gold mineralization which there is a metasomatism that makes skarn and quartz-chlorite-sulfide-gold vein. Sulfide mineral is founded in this vein including pyrite, pyrrhotite, and chalcopyrite. The third session is post-mineralization that found mainly quartz vein without gold which is a cause of silicification. Petrography and mineralogy study can be concluded that Khao Phanom Pha gold mine is skarn deposit which the main gold deposits are related to quartz-chlorite-sulfide-gold vein host by a volcanic and pyroclastic rock. Sulfide mineral is mostly pyrrhotite, subordinate pyrite and a bit of chalcopyrite.

According to Panaj-Ampol (2015) that the study focuses on petrography and the leachate of heavy metals from waste rocks on Khap Phanom Pha gold mine, Waste rocks from this area contain mainly 3 type of sulfide minerals: pyrite ($FeS_2$), Pyrrhotite ($Fe_{1-x}S$) and Chalcopyrite ($CuFeS_2$). As a leaching test at pH 4, Cr, Mn, Ni, Zn, As, Cd and Pb has a lower concentration than the Industrial Effluent Standard and the Thailand Surface Water Quality Standard whereas Cu and Hg are higher than both standard.

# Chapter 2
# Geological Background

## 2.1 Geology of Phitsanulok province

Phitsanulok is located upper central Thailand which covers some 10,815 square kilometers, 2.1 % of area in Thailand. The north is adjacent to Uttaradit and Lao. The south is adjacent to Phichit. The east is adjacent to Loei and Phetchabun. The west is adjacent to Kamphangphet and Sukhothai. Phitsanulok is a flatland in central with some hills and mountain ranges in the north and northeast of the province. In the south, there is a plain along Yom River and Nan River which are the most important agricultural district of Phitsanulok.

### 2.1.1 Sedimentary Rocks

1) Carboniferous rocks consist of grey to dark grey limestone which show lamination to thick bed and fossils including coral, foraminifera, algae, brachiopod, bivalve, ostracod, bryozoan and echinoderm are also found. This rock unit distributes on eastern Phitsanulok in Noen Maprang district.

2) Permian rocks consist of sandstone mudstone and limestone which coral, brachiopod and crinoid fossil are found. The rocks of this unit is distributed along the southeast area of Noen Maprang district and this unit lies under Khorat group with a unconformable contact.

3) Triassic to Cretaceous rocks consist of Khorat group which mostly consists of sandstone that form in the continental area in Mesozoic era and lies on the Paleozoic rock with a unconformable contact. Khorat group which found in Phitsanulok distributes in central to eastern part of the province and can be described from older to younger as follows:

4) Quaternary sediments are distributed in the western and central plain of Phisanulok which deposit in Phitsanulok basin or Upper Chao Phraya basin.

### 2.1.2 Igneous Rocks

Distribution of igneous rocks in Phitsanulok is very small. These are found in the southern part of Noen Maprang district and southeast of Bang Krathum district. They can be described as follow:

1) Extrusive rocks mostly consist of basalt with few rhyolite. Their age is Permian to Triassic.

2) Intrusive rocks is found in dike and sill shape which intrude along fault and fracture underneath Earth’s crust cut through Permian to Triassic rocks. Hence, their age must between Early to Late Triassic. These rocks comprise mainly diorite.

### 2.1.3 Structural Geology

There is a little complexity in rock structure in Phitsanulok province. All rocks had been deformed their shape due to continent collision in the past especially in Late Permian to Early Triassic which the collision between Shan-Thai and Indochina had occurred. Consequently, there are deformation present on rocks including fold, fault, fracture. Moreover, the metamorphism are occurred in rocks and unconformities are clearly observed between recent sedimentary rocks and older rocks.

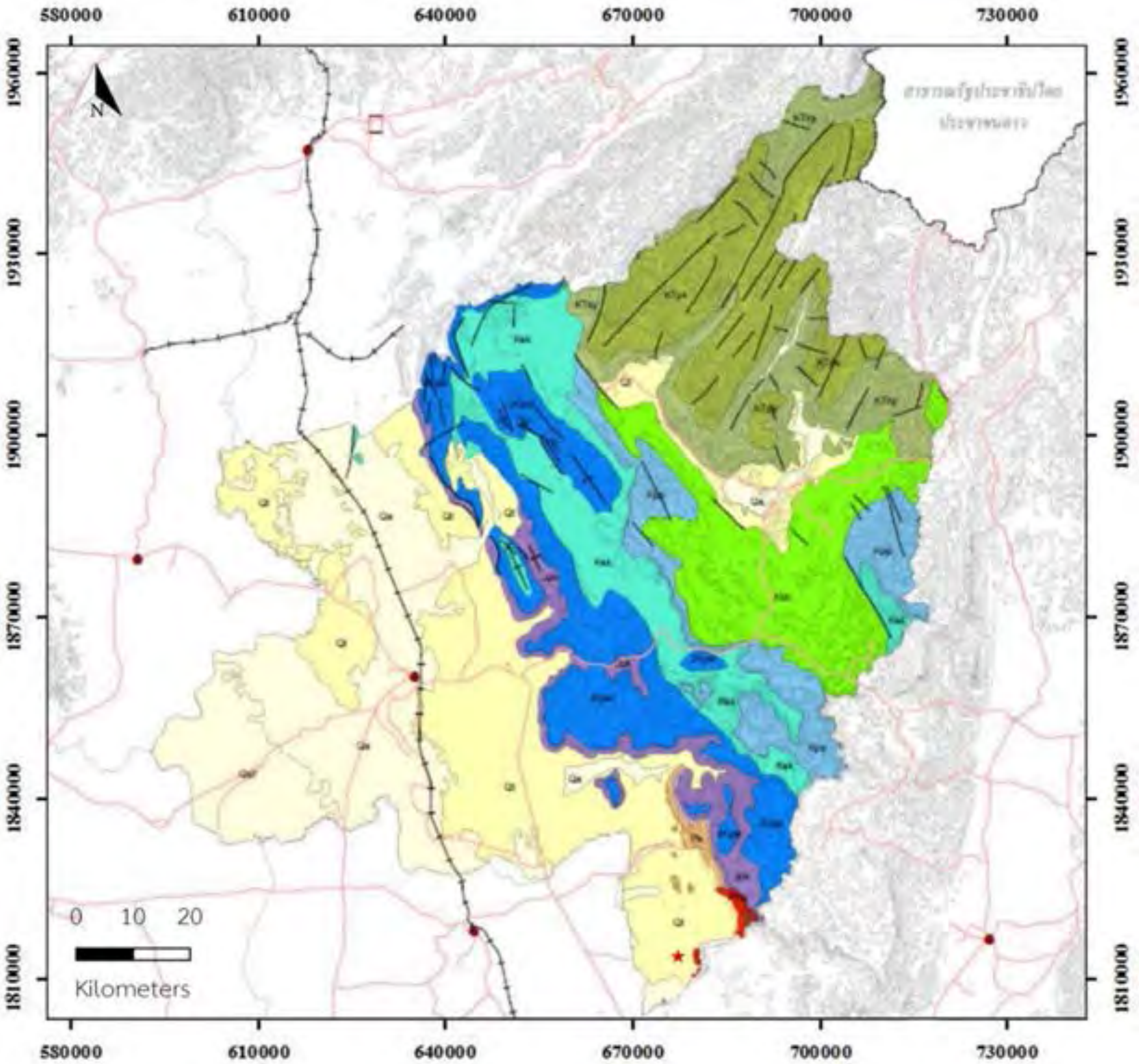



Fig 2.1 Geological map of Phitsanulok province and explanation (Thai Royal Survey Department, 2007)

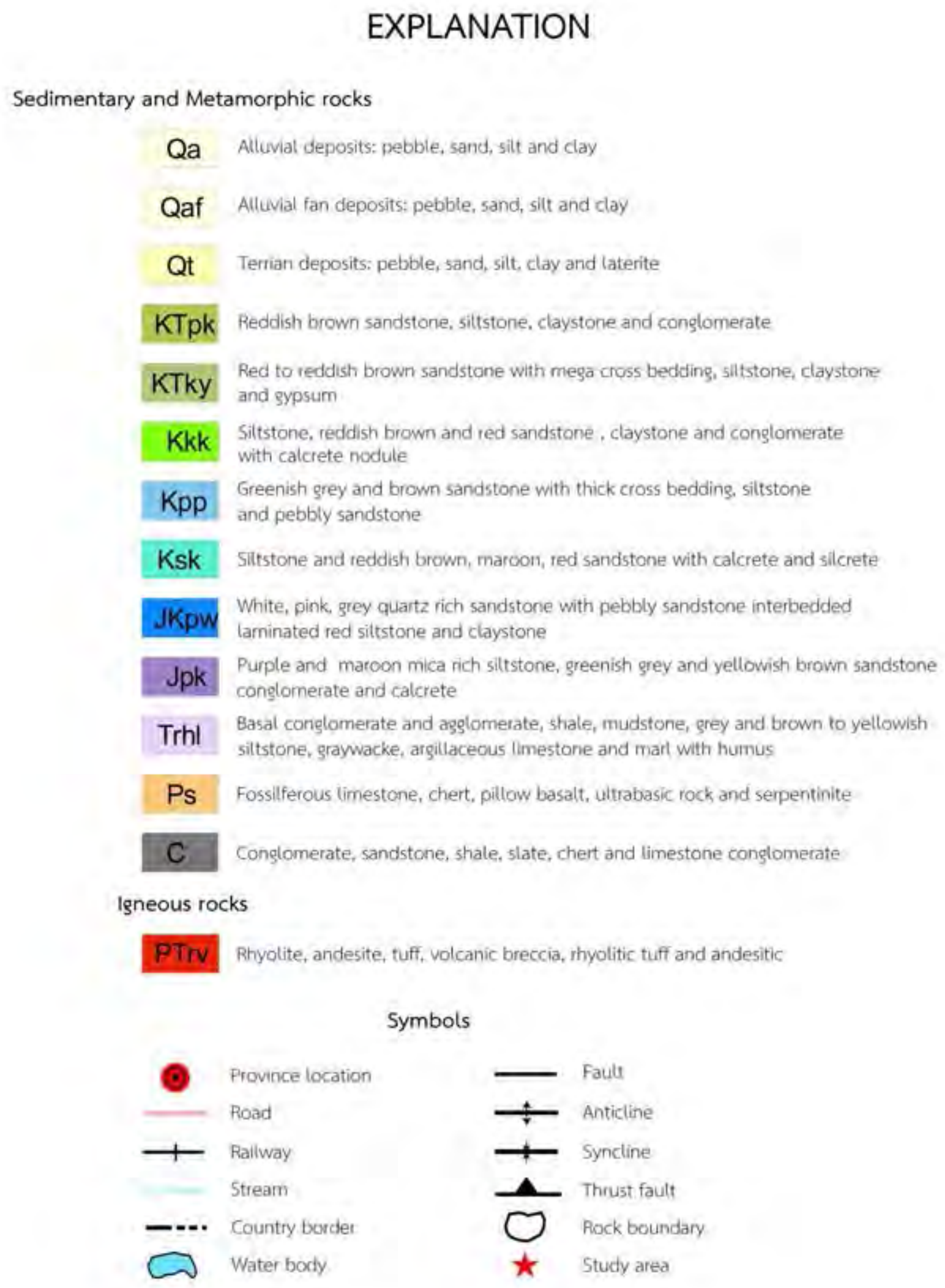



Fig 2.1 Geological map of Phitsanulok province and explanation (Thai Royal Survey Department, 2007)

## 2.2 Tectonic setting of Loei Fold Belt

Thailand and adjacent countries of mainland SE Asia comprise two major tectonic terranes: Indochina in the east and Sibumasu in the west. In Precambrian, Sibumasu is a part of Gondwanaland and Indochina is a part of Pan-Cathaysia which used to contact with Gondwanaland. There was a spreading of Paleo-Tethys ocean between Sibumasu terrane and Indochina terrane started from the late Middle Devonian (Metcalfe, 1996; Sone and Metcalfe, 2008). During the Carboniferous, its oceanic width was probably greatest. Then, the Paleo-Tethys oceanic floor subducted beneath Indochina terrane during the Late Carboniferous or Early Permian which caused the development of Sukhothai Fold Belt and Loei Fold Belt along the margin of the Indochina terrane due to its subduction (Bunopas, 1981; Kamvong et al., 2014). The Palaeo-Tethys subducted continuously beneath the volcanic arc because of the prolonged subduction. In Middle to Upper Triassic, the Sibumasu collided with the Sukhothai arc of the western Indochina terrane due to the spreading of Meso-Tethys which also was a cause of the complete closure of the Paleo-Tethys in this region (Sone and Metcalfe, 2008; Arboit et al., 2017). Arc magmatism in both the Loei Fold Belt and Sukhothai Fold Belt consists of Devonian to Cenozoic volcano-sedimentary and plutonic rocks belt were produced from multiple volcanic events during arc formation (Khin Zaw et al., 2014). In the Loei Fold Belt, the oldest is the Devonian to Triassic volcanic rocks which are confined to the Loei area at the north. The younger one is volcanic rocks which lie to the south through Phetchabun (central part) to Nakhon Nayok with predominant post-collisional Cenozoic volcanic rocks in Lopburi and Saraburi area south of Phetchabun Province (Intasopa, 1993).

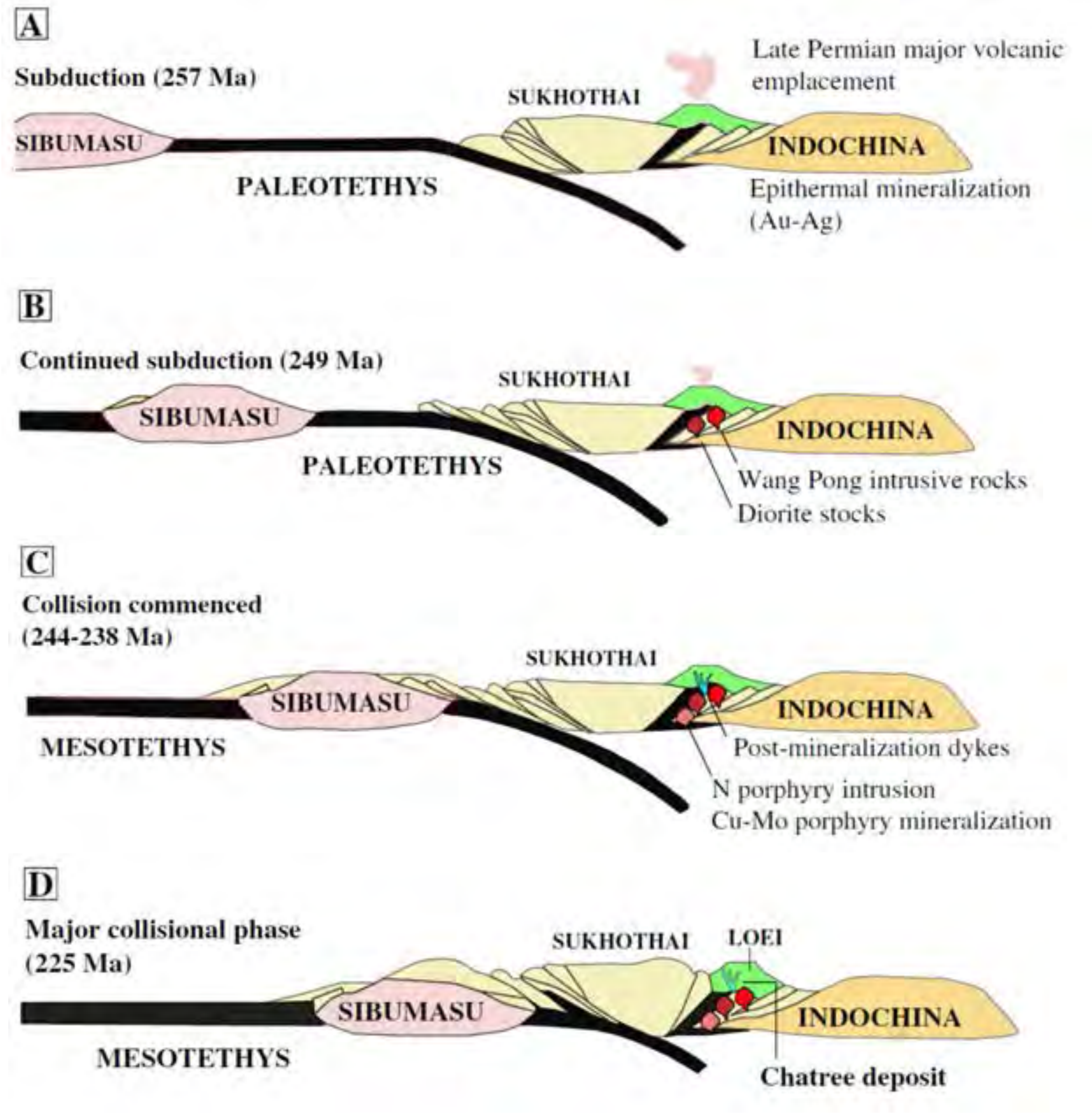



Fig 2.2 Schematic diagram showing tectonic development of Loei Fold Belt after Salam et al. (2014)

## 2.3 Mineral deposits in Loei Fold Belt

A number of mineral deposits associated with igneous rocks occur along the Loei Fold Belt (Fig 2.3). This region has undergone a complex geological history that dominated by the development of the Indosinian tectonic event during Late Permian to Early Triassic (Sone and Metcalfe, 2008; Arboit et al., 2017). The Loei Fold Belt is located on the western flank of the Korat Plateau which comprises various type of volcanic and plutonic rocks that had been generated and deformed during paleotethys closure and collision between Sibumasu and Indochina. As result of collision and paleotethys closure, there are volcanic activities occurred in this region which make Loei Fold Belt is a host of several important mineral deposits (e.g. the Chatree epithermal Au-Ag deposits). According to Kromkhun K. et al. (2013), igneous activity is commonly a consequence of plate tectonics to which closely related epithermal, skarn and porphyry. The Loei Fold Belt igneous rocks are mainly andesitic or intermediate in composition and are chemically similar. Their study results show that the volcanic and plutonic suited from Loei are classified as a calc-alkaline which is restricted to subduction zone magmas. Hence, these igneous rocks are generated as result of the subduction between Indochina and Sibumasu blocks. According to of Khin Zaw et al., (2007), Salam (2013) and Salam et al., (2014), geochemical studies show that most of the granitoids within Loei Fold belt are I-type which relates to copper–gold mineralization in the belt.

### 2.3.1 Skarn deposits

Skarn deposits in the Loei Fold Belt are mainly Cu/Au exoskarn which is hosted by calcareous rocks that are in contact with dioritic intrusion. The host rocks in the northern part of the Loei Fold Belt were mineralized by Early Triassic intrusions. Hence, Cu/Au skarn deposits mainly are confined to this region, whereas the southern part of the Loei Fold Belt is weakly-mineralized as a Cu-Au skarn deposits by Late Triassic to Early Jurassic intrusive rocks (e.g., French Mine and Khao Pra Ngam) (Khin Zaw et al., 2007, 2009). Phu Thap Fah is a one of the reduced Au skarn deposit located in Loei Fold Belt has a unique style of skarn which still has a mining operation until present day. (Khin Zaw et al., 2007, 2009).

### 2.3.2 Epithermal deposits

The middle part of the belt where is dominated by Late Permian to Early Triassic volcanic and volcaniclastic rocks is related to epithermal Au-Ag deposits which occur along this region. Several epithermal Au-Ag deposits can be found in the Chatree District (i.e., Chatree and Wang- Yai). Gold-bearing mineralization typically forms as veins and stockworks of quartz-sulphide that are hosted by volcanogenic sequence.

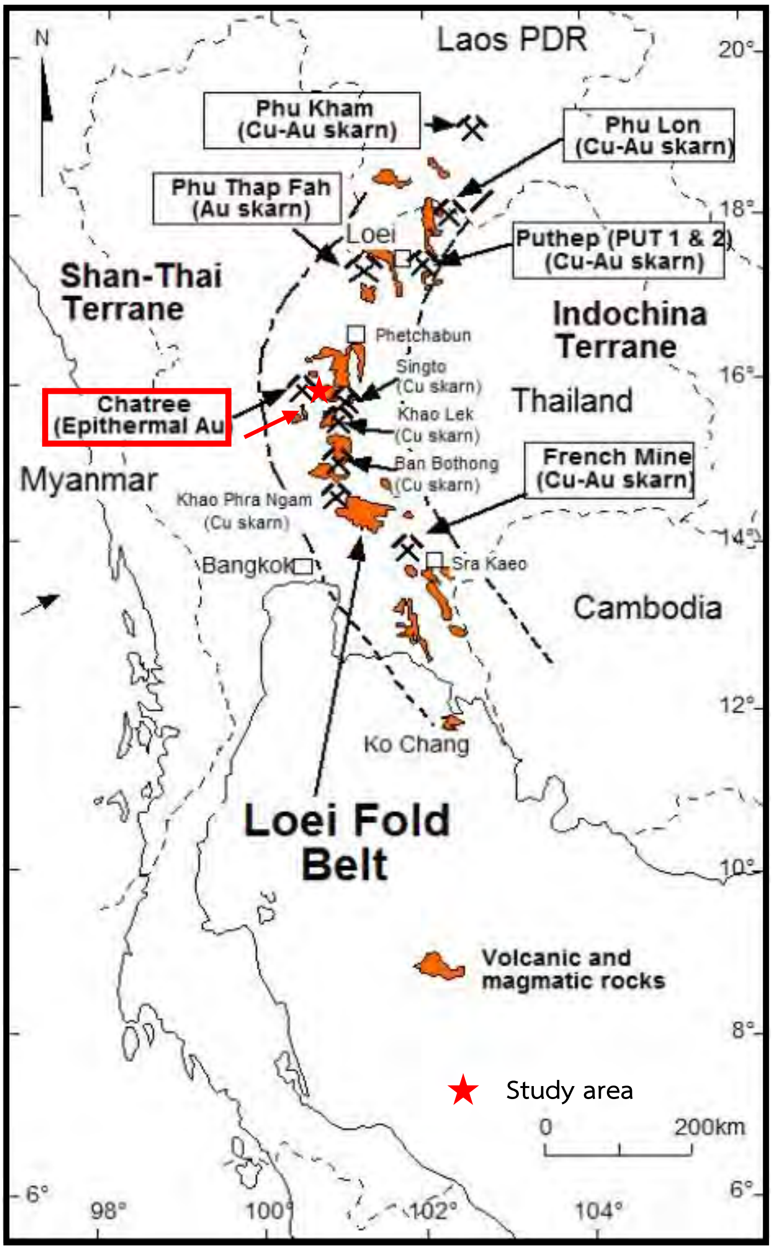



Fig 2.3 Mineral deposits in Loei Fold Belt (Khin Zaw et al., 2009)

# Chapter 3
# Methodology

Research methodology consists of mainly 5 parts: 1) pre-work study and literature review 2) field data collecting and rocks sampling 3) laboratory works 4) discussion and conclusion and 5) report writing and presentation. This chapter comprises two parts. The first part is a methodology for field data collecting and rocks sampling in the study area. The second one is a methodology for laboratory works.

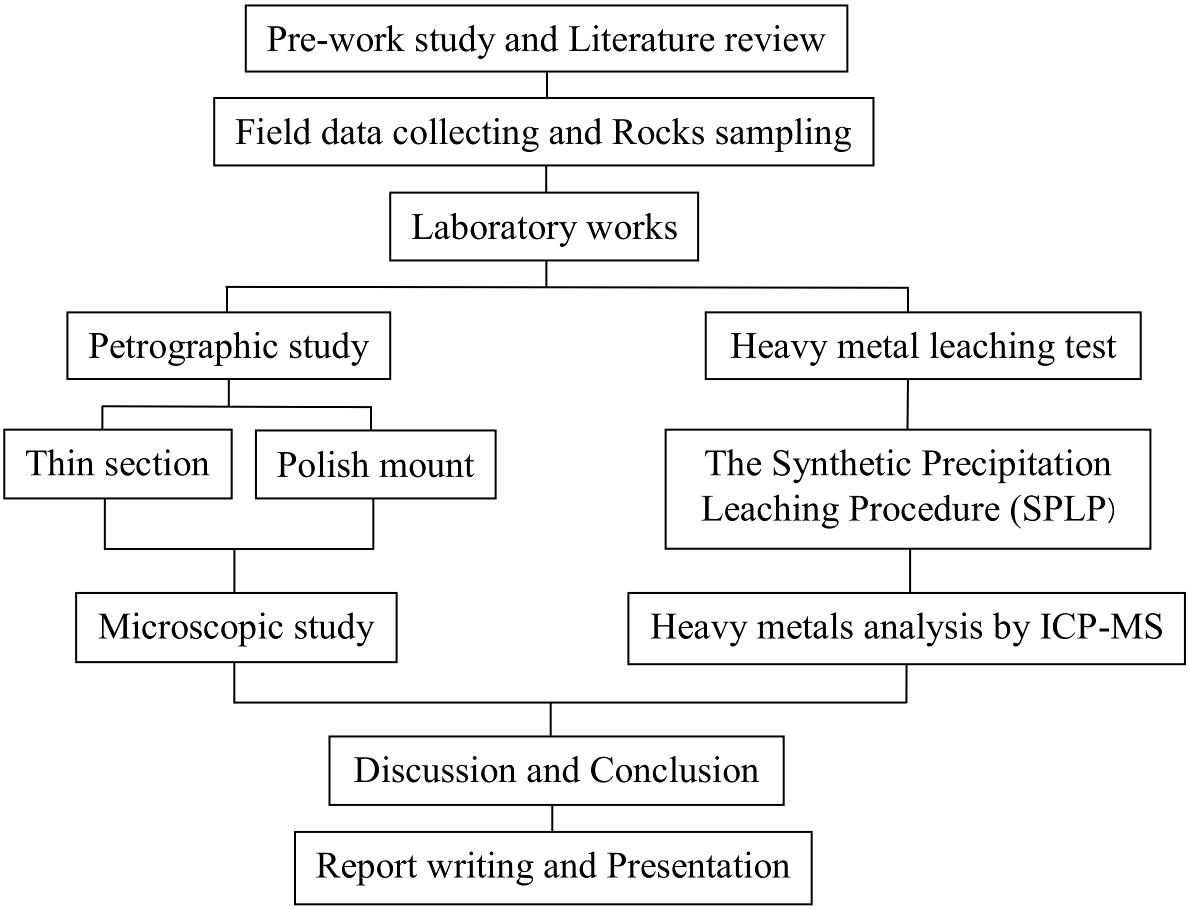



Fig 3.1 Research methodology flowchart

**3.1 Field Data collecting and Rocks sampling**

According to the study is a gold prospect area, it had already explored and drilled by Kingsgate Consolidated Ltd. Data collecting is done by note stratigraphic data of 3 boreholes in the same section (Fig. 3.2) on graph paper and then sampling drilling cores which represent all rock units and mineralized veins in study area. All data and samples (table 3.1 and Fig 3.3) would be interpreted for making stratigraphy of the study area. Some of the samples would be analyzed by SPLP leaching test for detect the amount of heavy metals leaching from rocks and mineralized veins in acid condition. Sampling points and rock samples are described as follow:

1) Mineralized veins which is contain mostly quartz with sulfide minerals dissemination

2) Altered wall rocks which contact to the mineralized veins, contain more sulfide minerals compared to the country rock

3) Volcanic rocks (non to slightly altered country rocks)


Fig 3.2 Satellite image of study area and sampling point which is located at Wang Phrong sub-district, Noen Maprang district, Phitsanulok province

Table 3.1 Rock samples and analytical method

| NO. | Sample ID. | Latitude | Longitude | Depth from top (m) | Thin section | Polish mount | ICP-MS |
|---|---|---|---|---|---|---|---|
| 1 | SM-1 | 16° 23' 33.66" N | 100° 39' 50.43" E | 0.00-5.00 | | | ✓ |
| 2 | SM-2 | 16° 23' 33.66" N | 100° 39' 50.43" E | 27.43-27.57 | ✓ | | |
| 3 | SM-3 | 16° 23' 33.66" N | 100° 39' 50.43" E | 50.90-51.00 | ✓ | | |
| 4 | SM-4 | 16° 23' 33.66" N | 100° 39' 50.43" E | 52.10-52.20 | ✓ | | |
| 5 | SM-5 | 16° 23' 33.66" N | 100° 39' 50.43" E | 59.73-59.86 | ✓ | | |
| 6 | SM-6 | 16° 23' 33.66" N | 100° 39' 50.43" E | 63.35-63.70 | | | ✓ |
| 7 | SM-7 | 16° 23' 33.66" N | 100° 39' 50.43" E | 70.80-70.90 | ✓ | | |
| 8 | SM-8 | 16° 23' 33.66" N | 100° 39' 50.43" E | 80.10-80.30 | ✓ | | |
| 9 | SM-9 | 16° 23' 33.66" N | 100° 39' 50.43" E | 88.90-88.98 | ✓ | | |
| 10 | SM-10 | 16° 23' 33.66" N | 100° 39' 50.43" E | 98.08-98.24 | ✓ | | |
| 11 | SM-11 | 16° 23' 33.66" N | 100° 39' 50.43" E | 110.95-110.05 | ✓ | | |
| 12 | SM-12 | 16° 23' 33.66" N | 100° 39' 50.43" E | 128.37-128.50 | ✓ | | ✓ |
| 13 | SM-13 | 16° 23' 33.66" N | 100° 39' 50.43" E | 138.54-138.70 | ✓ | | |
| 14 | SM-14 | 16° 23' 33.66" N | 100° 39' 50.43" E | 149.85-150.00 | ✓ | | |
| 15 | SM-15 | 16° 23' 34.16" N | 100° 39' 52.45" E | 4.75-4.89 | ✓ | | |
| 16 | SM-16 | 16° 23' 34.16" N | 100° 39' 52.45" E | 18.80-18.90 | | | |
| 17 | SM-17 | 16° 23' 34.16" N | 100° 39' 52.45" E | 21.30-21.45 | | ✓ | |
| 18 | SM-18 | 16° 23' 34.16" N | 100° 39' 52.45" E | 21.80-21.92 | | ✓ | ✓ |
| 19 | SM-19 | 16° 23' 34.16" N | 100° 39' 52.45" E | 25.15-25.35 | | ✓ | |
| 20 | SM-20 | 16° 23' 34.16" N | 100° 39' 52.45" E | 57.69-57.92 | | | ✓ |
| 21 | SM-21 | 16° 23' 34.16" N | 100° 39' 52.45" E | 73.59-73.77 | ✓ | | |
| 22 | SM-22 | 16° 23' 34.16" N | 100° 39' 52.45" E | 100.48-100.64 | ✓ | | |
| 23 | SM-23 | 16° 23' 34.16" N | 100° 39' 52.45" E | 106.24-106.43 | ✓ | | |
| 24 | SM-24 | 16° 23' 34.16" N | 100° 39' 52.45" E | 112.17-112.32 | ✓ | | |
| 25 | SM-25 | 16° 23' 34.16" N | 100° 39' 52.45" E | 115.81-115.90 | ✓ | | ✓ |
| 26 | SM-26 | 16° 23' 35.22" N | 100° 39' 54.68" E | 114.43-114.55 | ✓ | | |
| 27 | SM-27 | 16° 23' 35.22" N | 100° 39' 54.68" E | 119.70-119.87 | ✓ | | |
| 28 | SM-28 | 16° 23' 35.22" N | 100° 39' 54.68" E | 131.80-131.94 | | ✓ | ✓ |
| 29 | SM-29 | 16° 23' 35.22" N | 100° 39' 54.68" E | 165.70-165.83 | ✓ | | |


Fig 3.3 Rock samples SM-1 to SM-29

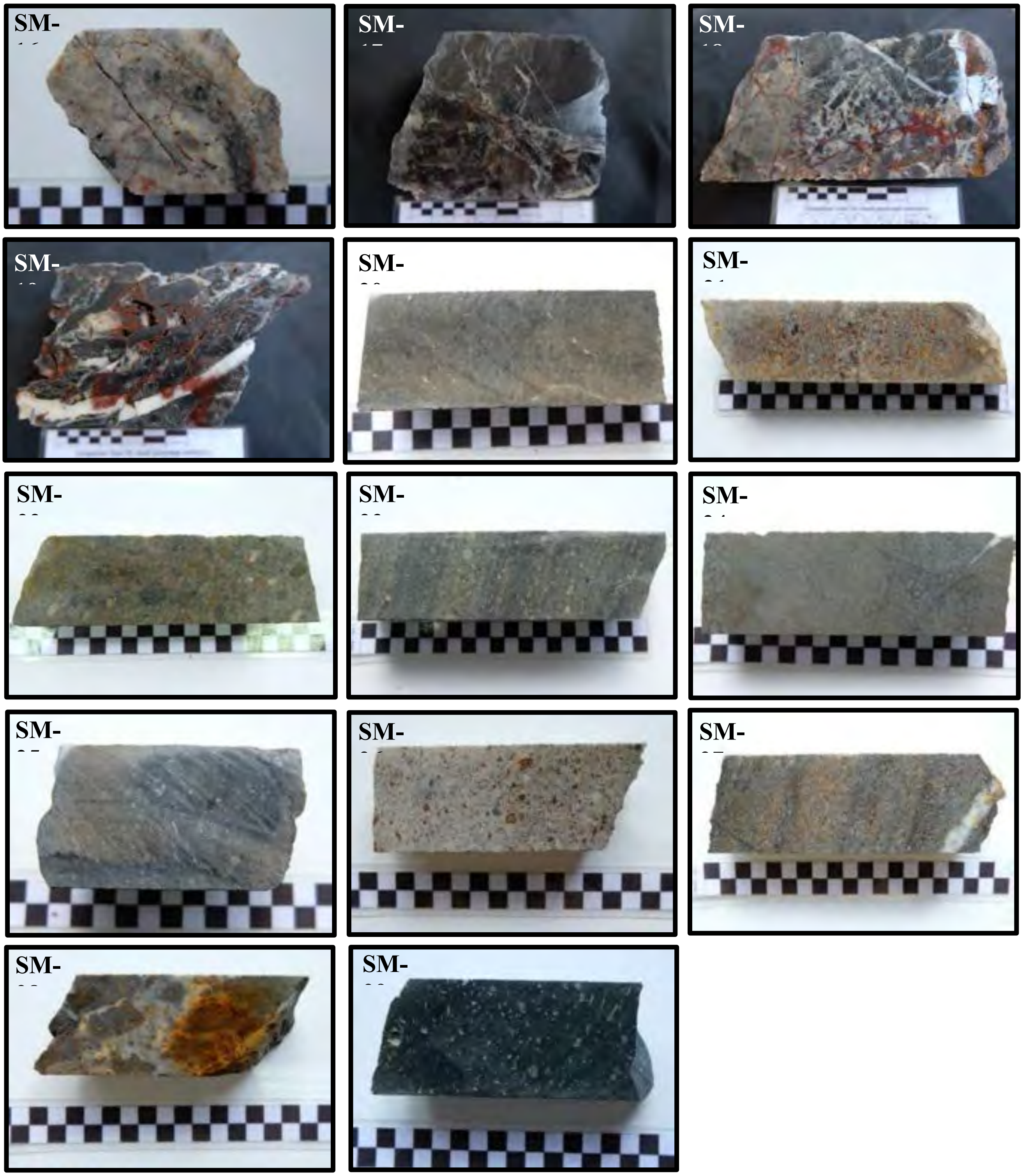



Fig 3.3 Rock samples SM-1 to SM-29 (continued)

## 3.2 Laboratory work

Laboratory work consists of 2 major steps: petrography study and heavy metal leaching test. Petrographic study is a part which would be done before starting heavy metal leaching test because stratigraphy and cross-section of the study area are needed for sample choosing that use in heavy metal leaching test.

### 3.2.1 Petrographic study

Rock samples are brought to make thin section (Fig 3.4) for geological characteristic identification using polarized light microscope which is important for stratigraphy and cross section. The second one is polished mount (Fig 3.5) which is use for paragenesis study and sulfide minerals identification using reflected light microscope.

#### 3.2.1.1 Thin section

Rock samples are cut by cut-off saw to be a slab. The slab would be glued with the slide by balsam epoxy. Next is grind the chip of the slide using grinder unit the slab thickness is nearly 30 µm. Then cover slip is added on the slide to protect the section from damage, and increase the clarity observed in the microscope.

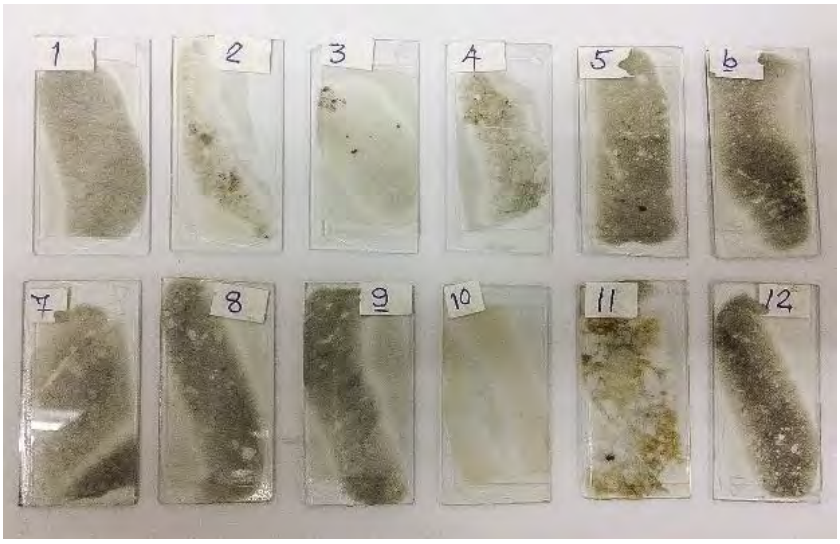



Fig 3.4 Thin section

#### 3.2.1.2 Polished mount

Rock samples are cut into a proper size piece using cut-off saw. The specimen would be place into a mold and add it epoxy resin to make them weld. The mounting resin and the specimen are placed into the exsiccator under vacuum condition for several minutes, this draws air from the voids, and the subsequent release of the vacuum tends to drive the mounting resin into the voids. After that the samples are brought out and place it in room temperature until there is a hardening of the epoxy.

Fig 3.5 Polished mount

Next step, the sample would be grinded using 600 and 1000 µm (Fig 3.6A) silicon carbide respectively for removing surface irregularities, casting resin that covers the sample, toreduce thickness, to prepare a smooth surface and to remove any zone of major deformation resulting from initial sample cutting. Finally, the samples are polished and grinded using abrasives of 6 (Fig 3.6B), 3 (Fig 3.6C) and 1 µm respectively to removes only a very small amount of the specimen surface and should produce a relatively scratch-free surface. Then we will get polished and smooth samples which is appropriate for sample analysis.

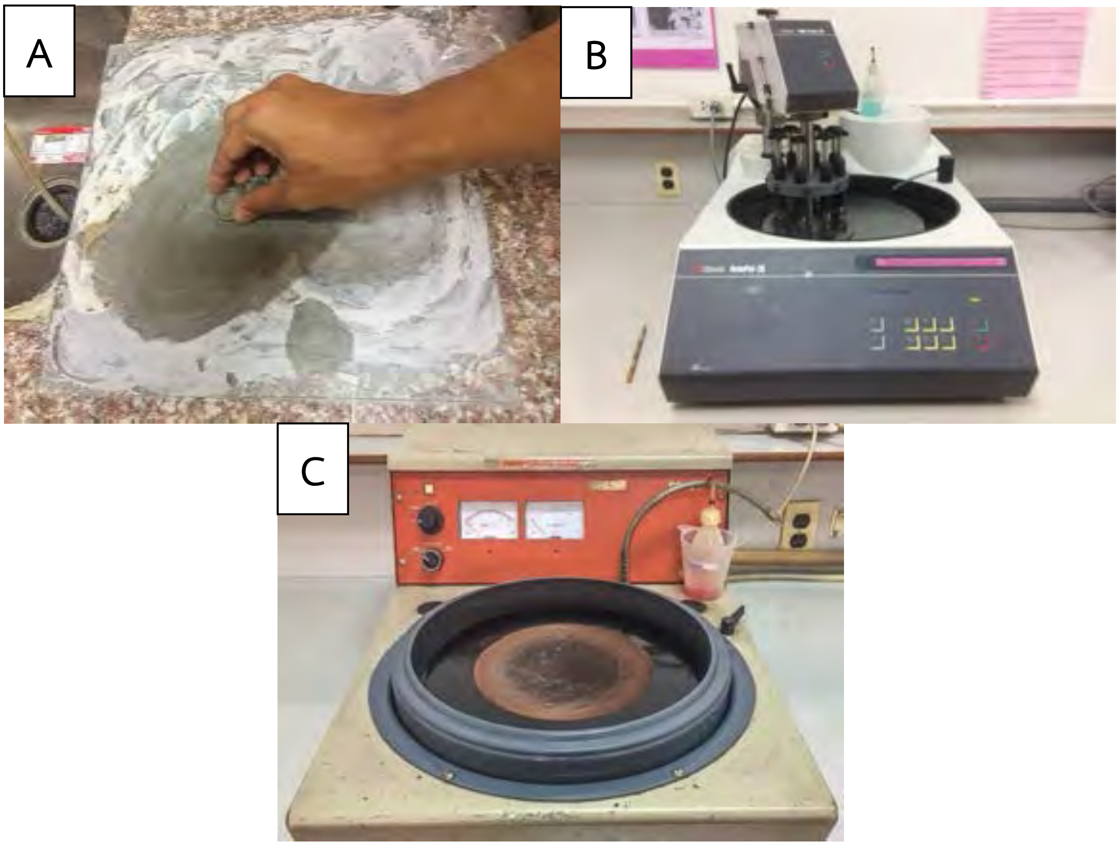



Fig 3.6 **A)** Grinding sample by 600 and 1000 µm silicon carbide
**B)** 6 µm Grinding-polishing instrument
**C)** 3 µm Grinding-polishing instrument

### 3.2.2 Heavy metals leaching test

#### 3.2.2.1 Sample preparation

Rock samples are needed for particle size reduction using jaw crusher and then samples are dried at 60 °C for 24 hrs. Dried samples (Fig 3.7) are crushed by dish mill for less than 9.5-millimeter particle size (U.S. EPA, 1994)

Fig 3.7 Dried sample powder

#### 3.2.2.2 Synthetic Precipitation Leaching Procedure

**1) Solution preparation**

Sulfuric acid ($H_2SO_4$) and nitric acid ($HNO_3$) are mixed in a ratio of 60:40 by weight and following by pH adjustment using distilled water. pH is adjusted until it reaches 4 which represent the acid condition that can be occurred in mine (sulfuric acid and nitric acid mixing is a solution which simulate acid rain due to oxidizing reaction of sulfide mineral when exposed to air and water.)

**2) Sample preparation for leaching test**

Sample power is added into the prepared acid solutions in a ratio of 1:20 (Fig 3.8) before shaking for 18 under 30 rpm (Fig 3.9). The slurry is then filtered through the funnel before taking to heavy metals analysis.

Fig 3.8 Solution for leaching test

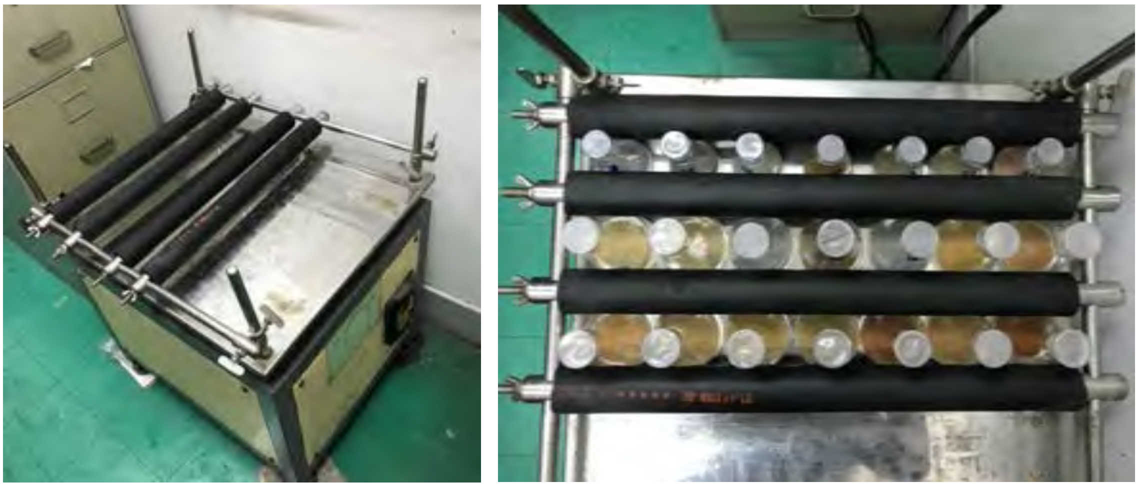


Fig 3.9 Shaker for leaching test

**3.2.2.3 Heavy metals concentration analysis**

The slurry is analyzed for amount of heavy metals by Inductively Coupled Plasma Mass Spectrometry (ICP-MS) (Fig3.10) at Central Instrument Facility (CIF), Faculty of Science, Mahidol University. Element which is detected including lead (Pb), mercury (Hg), arsenic (As), nickel (Ni), manganese (Mn), zinc (Zn), copper (Cu), cadmium (Cd) and chromium (Cr). Limits of detection is Pb 0.001 ppm, As 0.001 ppm, Ni 0.005 ppm, Mn 0.005 ppm, Zn 0.005 ppm, Cu 0.005 ppm, Cd 0.005 ppm and Cr 0.005 ppm. The result would be compared to Industrial Effluent Standard and Surface Water Quality Standard.

Fig 3.10 Inductively Coupled Plasma Optical Emission Spectrometry (ICP-MS)

# Chapter 4
# Results

## 4.1 Introduction

This Chapter describes the geology, mineralogy and geochemistry of the host volcanic succession and mineralized veins of the Chokdee prospect. Results from this study include 1) stratigraphy of the Chockdee prospect, 2) Mineralization, 3) Geochemistry of host sequences and ore materials (veins materials).

## 4.2 Geology

Based on diamond drill cores logging of selected cross-section consisting 3 droll holes (4240DD, 4239DD and 4305DD) and accompanied by petrographic investigation of representative samples, stratigraphic column of 3 drill holes are established (Fig 3.2). There is no study of formal stratigraphic division of the Chokdee prospect volcanics prior to this study. Observation of diamond drilling core during this study has allowed us to establish stratigraphy of volcanics in Chokdee prospect area.

### 4.2.1 Volcanic stratigraphy

Terms and classification in this study is based on McPhie et al. (1993) and follows details study of Chatree volcanics by Salam (2013). Bases on detailed logging and petrographic study, the rock at Chockdee can be grouped into three units and cross section represent prospect area is shown in Figure 4.3. The Chokdee prospect has a well-defined volcanic stratigraphic sequence (Fig 4.1 and 4.2) comprising at least three main units including tuffaceous sandstone (Unit 1), polymictic volcanic breccia unit (Unit 2) and siltstone unit (Unit 3). Based on the available information (diamond drill cores), at least the succession is 116 meters thick. Siltstone unit (Unit 3) mainly consists of siltstone and tuffaceous sandstone with minor polymictic breccia. Polymictic volcanic breccia unit (Unit 3) consists of polymictic volcanic breccia and polymictic breccia interbedded with the equal quantity of tuffaceous sandstone and siltstone. Unit 2 and 3 show gradational contact. The las one is tuffaceous sandstone unit (Unit 1), this unit consists of tuffaceous sandstone and siltstone with minor polymictic breccia. Boundary between unit 1 and 2 show gradational contact. Moreover, at middle and bottom of the hole has rhyolite dike, andesite dike and hornblende phyric andesite dike which was considered as a coherent rock. Cross section in the study area was created after correlating three stratigraphic columns which is based on their rock units and lithology. The cross section (Fig 4.3) shows overall bedding of all units are slightly dipping into east direction. The coherent rocks which were considered as dike had sub vertically intruded through all rock units.

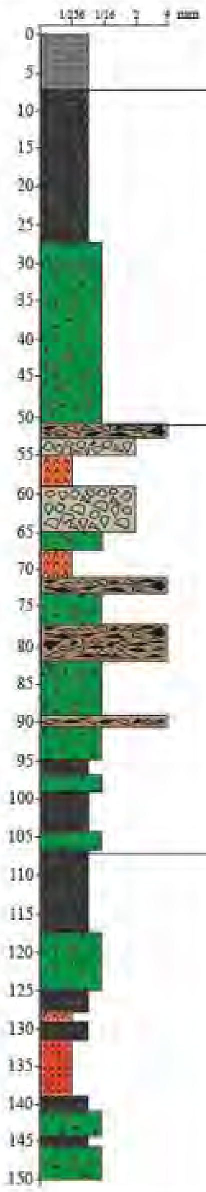
| Stratigraphic column | Unit name | Rock assemblages | Unit NO. |
|---|---|---|---|
|   | | | |
| | Tuffaceous sandstone unit | Tuffaceous sandstone and siltstone | Unit 1 |
| | Polymictic volcanic breccia unit | Polymictic breccia, polymictic volcanic breccia, tuffaceous and siltstone<br>Coherent rhyolite | Unit 2 |
| | Siltstone unit | Siltstone and tuffaceous sandstone<br>Coherent rhyolite and andesite | Unit 3 |

Fig 4.1 Stratigraphy of the Chokdee prospect

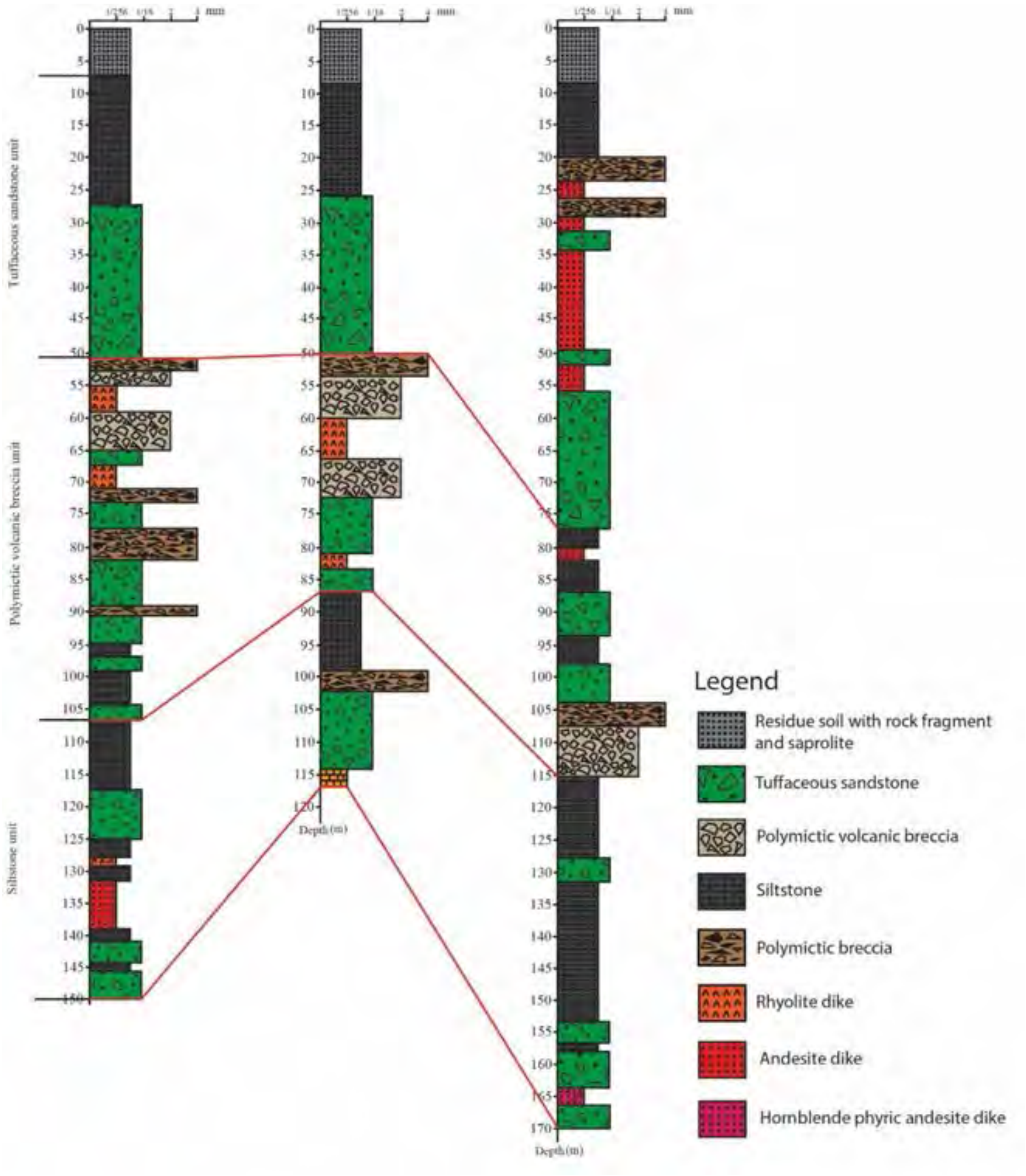



Fig 4.2 Stratigraphic column of drilling hold 4240DD 4239DD and 4305DD (from left to right)

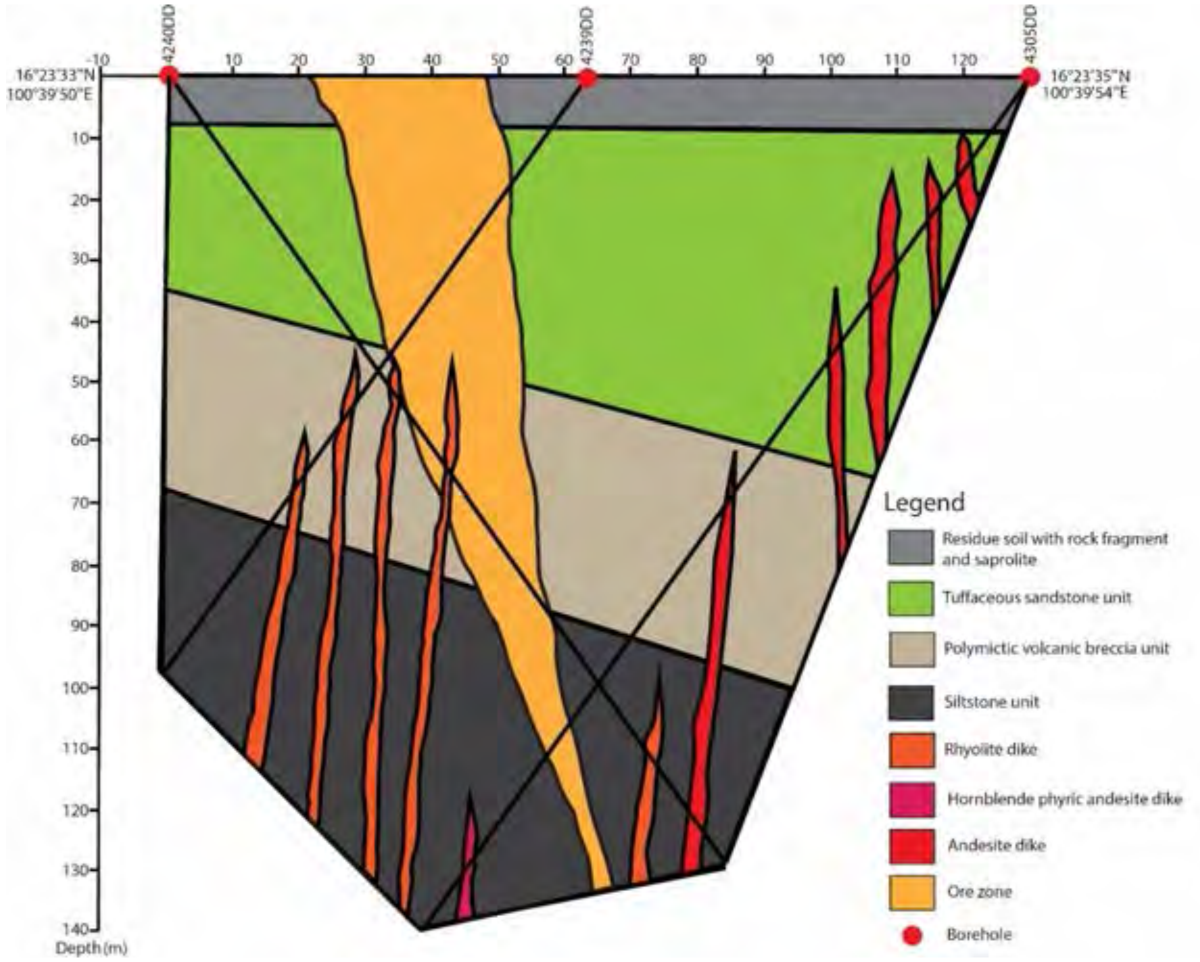



Fig 4.3 Cross section of study area

The stratigraphic units are described from the top to the bottom as a following:

**Unit 1 (top): Tuffaceous sandstone unit**

Tuffaceous sandstone is identified in tuffaceous unit (Unit 1) that forms at the top of stratigraphy. It is associated with tuffaceous siltstone, and minor polymictic breccia. Hornblende phyric andesite dyke are common and cross-cut through the succession. Tuffaceous sandstone is simply described as sandstone in this session for the convenient. It is grey to black in color and contains small amount of gravels (Fig. 4.4A) in some part of stratigraphy. This sandstone comprises of quartz, feldspar and rock fragment in fine-grained matrix of similar composition (Figs. 4.4B and C). Sand size particle ranging from 1/8 to 1/16 mm. Crystals consist mainly quartz and k-feldspar. Quartz is sub angular to sub rounded and has size of approximately 0.1-1 mm. Other clasts are mudstone which had well sorted, roundness is sub round.

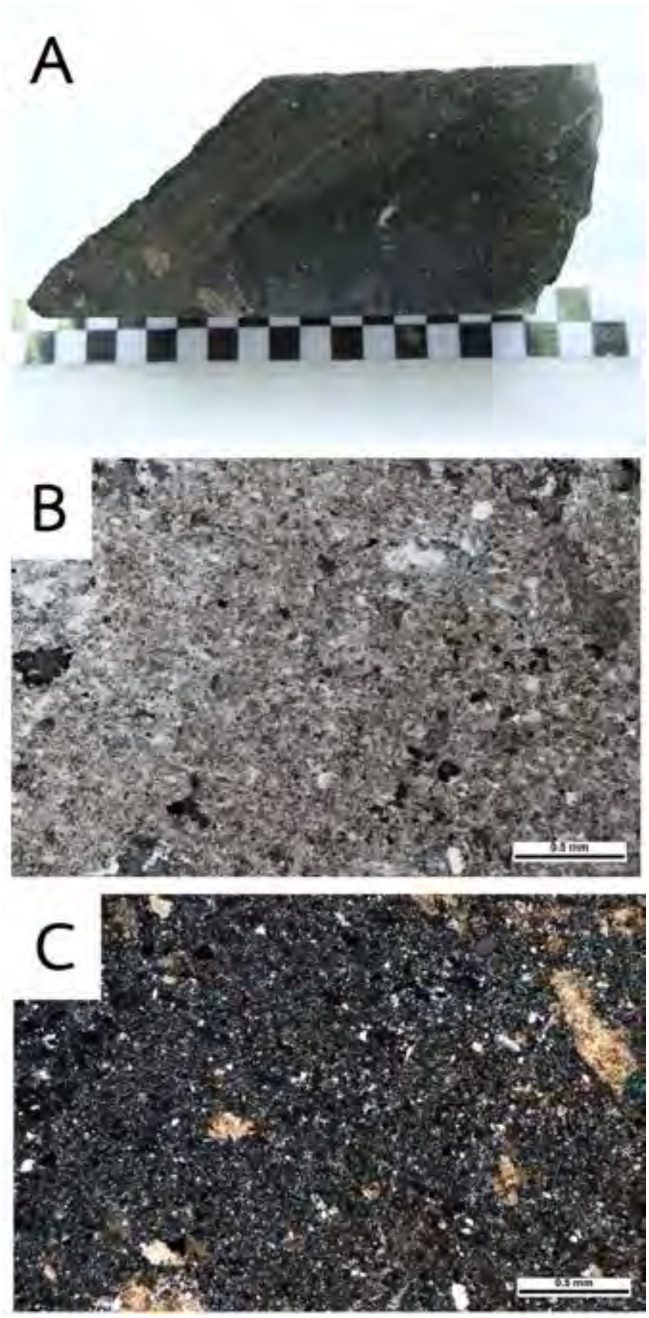



Fig 4.4 Characteristics of tuffaceous sandstone, **A)** Photograph of tuffaceous sandstone showing small amount of gravel, **B)** Photomicrograph showing tuffaceous sandstone in PPL, **C)** Same as Fig. 4.4B in XPL.

**Unit 2: Polymictic volcanic breccia unit**

Polymictic breccia mainly identified in polymictic volcanic breccia unit (Unit 2) and it is also associated with tuffaceous siltstone, tuffaceous sandstone. Rhyolite dikes are common and cross-cut through the succession. The polymictic breccia is commonly intersected in drill hole no. 4240. Polymictic volcanic breccia is commonly interbedded with polymictic breccia The polymictic volcanic breccia in diamond drill core is light grey to grey and the light color probably due to alteration (silicification). Majority of clasts are andesite clast (Figs. 4.5D and E) with minor rhyolite clast. The rhyolite clasts are sub-rounded to round and overall clast size ranging from 1-2 mm and some clasts show their shape like lens. Crystal component includes quartz and k-feldspar which had been altered to sericite and carbonate minerals. The last one is andesite clasts which show aphanitic texture and plagioclase porphyritic texture (Figs. 4.5D and E). Overall clast size ranging from 0.5-1.5 mm and almost clasts show circular shape. Other clasts are quartz and k-feldspar clasts distribute in the rock. Matrix compose of very fine sand to silt size particles (less than 1/8 mm). Almost clasts and some matrix had been replaced by carbonate.

Second one is polymictic sedimentary breccia which color is grey to greenish grey and clast could be obviously seen on the hand specimen (Fig. 4.6A). Poorly sorted and sub angular clast roundness could be observed too. Polymictic breccia is clast support breccia comprises mainly 3 types of clast (Figs. 4.6B and C). The first one is very fine sandstone clasts which mineral assemblages compose of quartz and k-feldspar that had been altered to sericite. Their sorted is moderate to well, moderate sphericity roundness is sub angular to sub-rounded and overall clast size is approximately 0.5-1 mm. The second one is mudstone clasts which overall clasts size is approximately 0.1-1 cm. The last one is siltstone clasts which had moderately sorted and sub angular clasts. Other clasts are quartz which clast size is 0.4-2 mm and felsic volcanic clasts which consist of small grains of quartz and k-feldspar that had been altered to sericite. Matrix are considered as very fine sand size (between 1/8 mm and 1/16 mm) and mainly compose of quartz and feldspar. This sand-matrix polymictic breccia facies is characterized by poorly sorted, angular to subangular clasts. Almost matrix had been replaced by carbonate as same as some clasts.

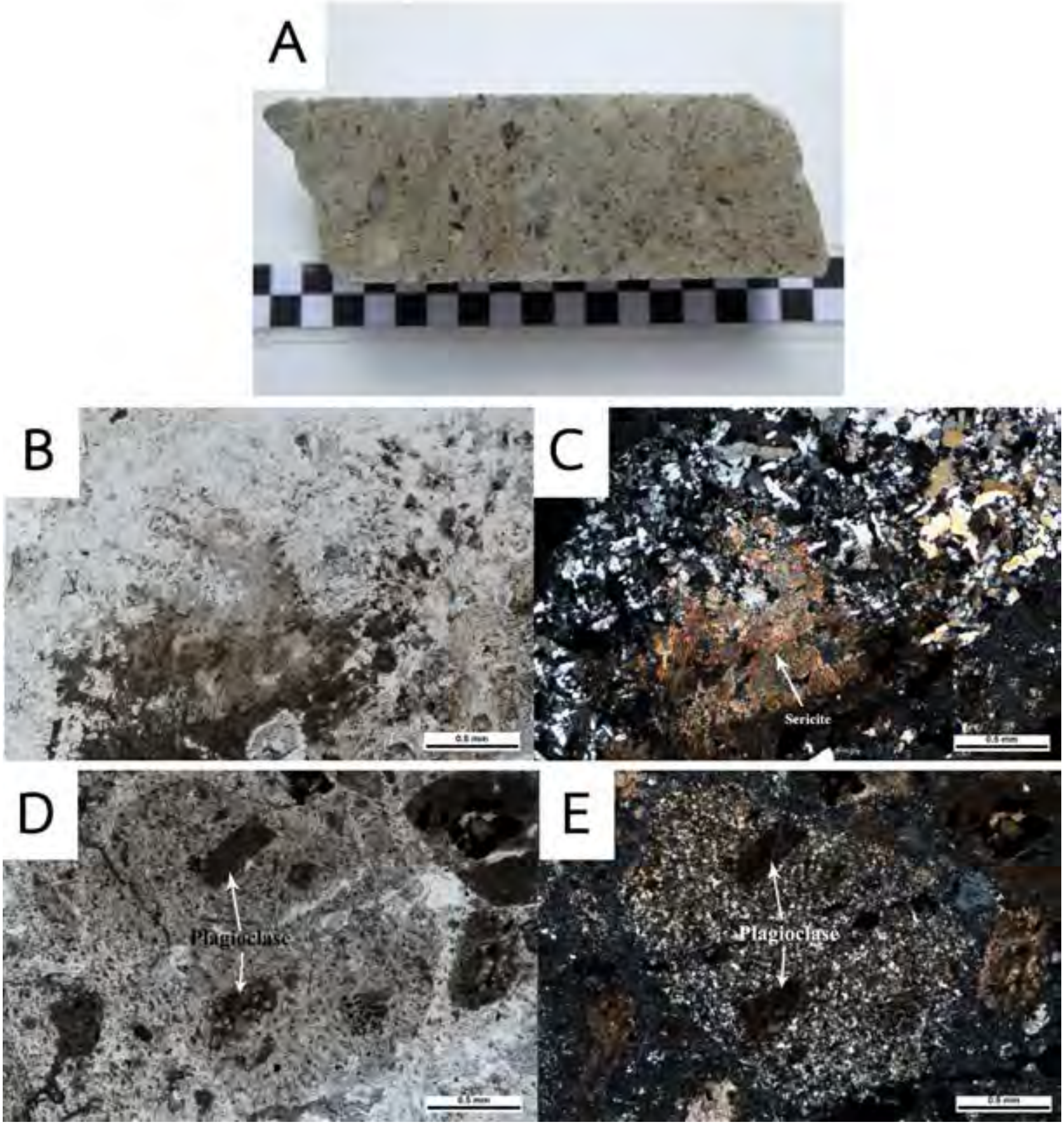



Fig 4.5 Characteristics of polymictic volcanic breccia, **A)** Photograph of diamond drill core of polymictic volcanic breccia showing multiple types of clasts, **B)** Photomicrograph showing altered rhyolite clast in PPL, **C)** Same as Fig. 4.5B in XPL, **D)** Photomicrograph showing rounded andesite clast in PPL, **E)** Same as Fig. D in XPL.

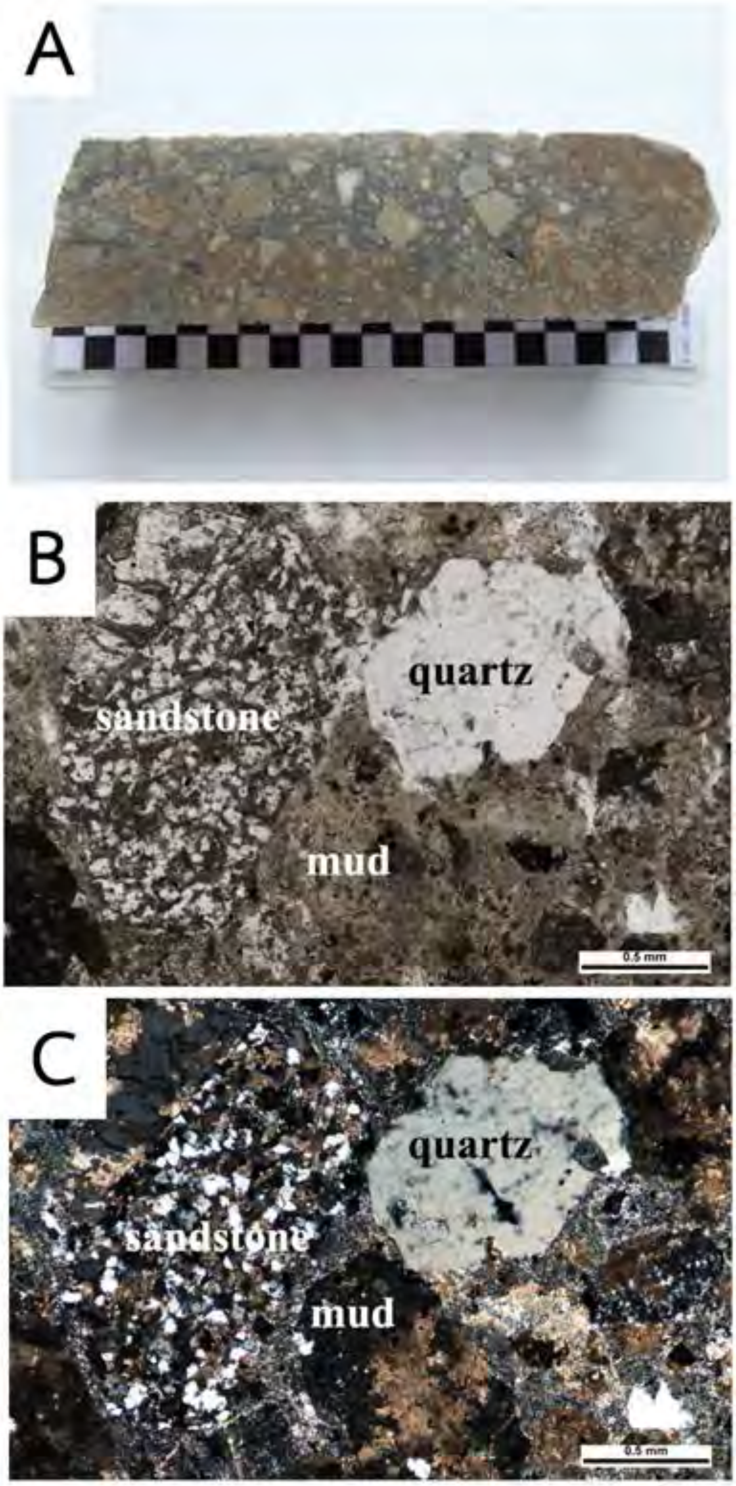



Fig 4.6 Characteristics of polymictic breccia, **A)** Photograph of diamond drill core of polymictic breccia showing multiple types of clasts, **B)** Photomicrograph showing sandstone, mudstone and quartz clasts in PPL, **C)** Same as Fig. 4.5B in XPL

**Unit 3 (Bottom): Siltstone unit:**

The lowest stratigraphic unit comprises siltstone, tuffaceous sandstone, minor polymictic breccia and limestone. Hornblende phyric andesite, andesite and rhyolite dikes are common and cross-cut through the succession.

This unit lies at the bottom of the succession where was dominated by siltstone interbedded by tuffaceous sandstone with minor limestone. Siltstone in this unit contains more quartz and feldspar fragment and size is also bigger compare to the other and had partly replaced by carbonate minerals. Tuffaceous sandstone in this unit obviously shows more rock fragments and crystal fragment compare to the other unit. Another rock found in this unit is limestone which was lies as the base of this unit. Limestone is light grey to grey.

Limestone is light grey to grey (Fig. 4.8A). Fossil could be obviously see in hand specimen. Fossils identified in this limestone mainly include fusulinid (Figs 4.8B and 4.8C), crinoid and gastropod (Figs. 4.8D and 4.8E) which implies the Permian age of rock formation. According to Folk classification, limestone could be considered as biosparite because there are several fossils contain in it.

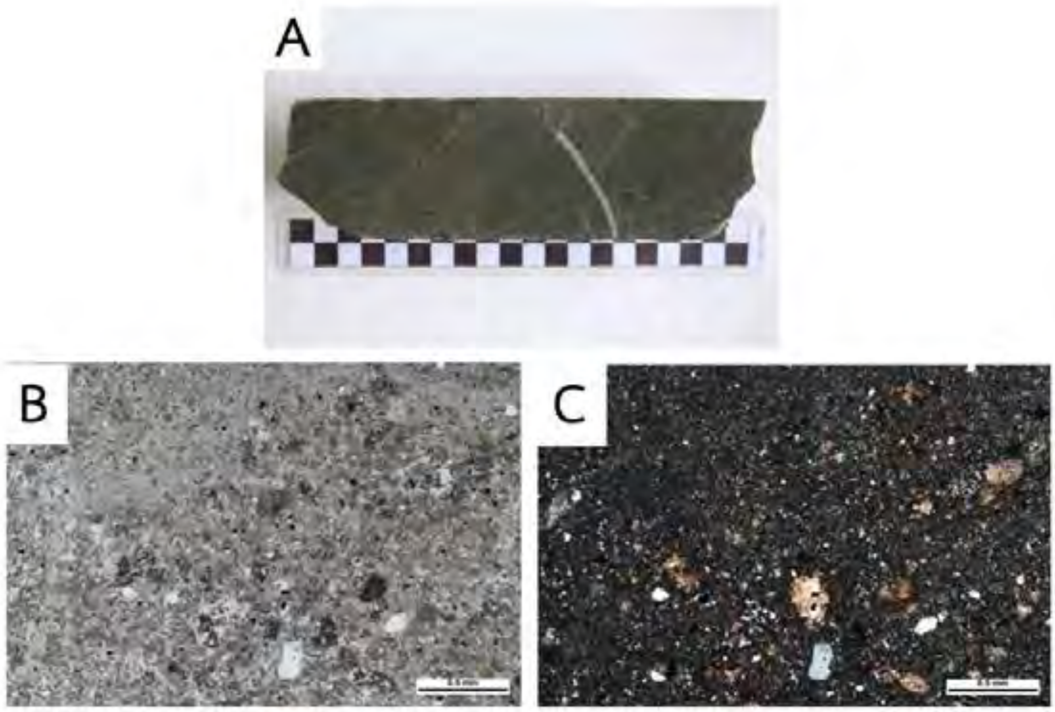



Fig 4.7 Characteristics of siltstone, **A)** Photograph of diamond drill core of siltstone, **B)** Photomicrograph showing siltstone in PPL, **C)** Same as Fig. 4.5B in XPL

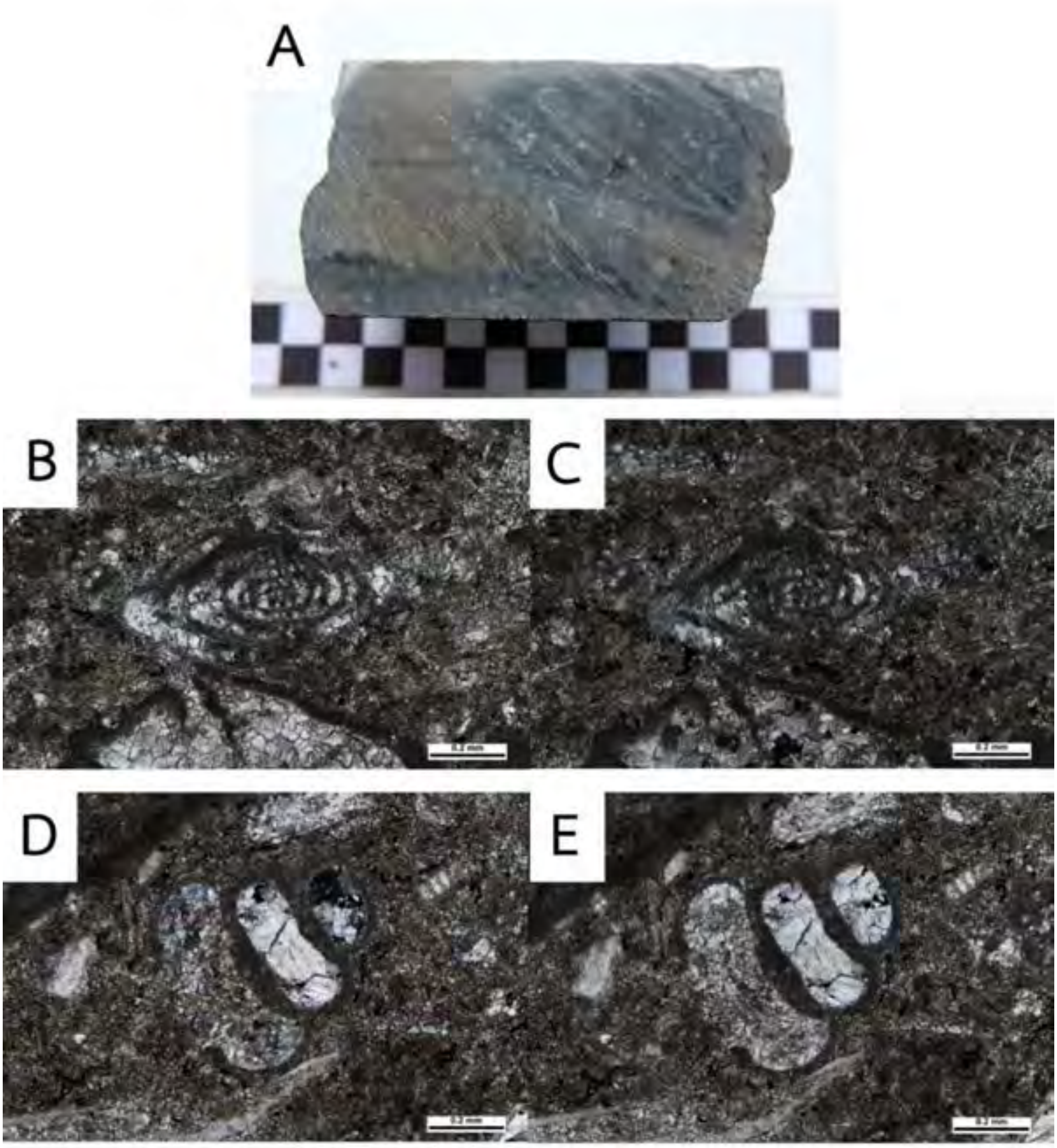



Fig 4.8 Characteristics of limestone, **A)** Photograph of diamond drill core of limestone, **B)** Photomicrograph showing fusulinid in PPL, **C)** Same as Fig. 4.5B in XPL, **D)** Photomicrograph showing gastropod in PPL, **E)** Same as Fig. D in XPL.

**Coherent rocks**

Chokdee prospect has 3 coherent rocks (Fig 4.3) including andesite, hornblende phyric andesite and rhyolite which were considered as dikes. All coherent rocks had sub vertically intruded through all rock units. Coherent rocks are described as a following:

1) Andesite found as a dike cutting through the rock strata and shows sharp contact to all rock units including tuffaceous sandstone unit, polymictic volcanic breccia unit and siltstone unit. The thickness of the coherent andesite unit is not known, however, based on intersections in several drill holes, it is estimated to be 5-10 m thick. Hand specimen shows dark grey color and fine grain crystals could be seen (Fig. 4.9A). Mineral assemblages in andesite facie consist of plagioclase 70 %, opaque minerals 20 %, k-feldspar 10 % which mostly altered and became sericite (Figs. 4.9B and 4.9C). Almost minerals are anhedral to subhedral grain shape and grain size is between fine to very fine in grain size which is considered as an equigranular texture. Groundmass is black and mostly consists of plagioclase shows an acicular texture which implies rapid cooling of lava. Plagioclase is weakly to moderately altered to sericite, illite and carbonate.

2) Hornblende phyric andesite found as a dike cutting through the rock strata and shows sharp contact to siltstone unit. The thickness of the coherent andesite unit is not known, however, based on drill holes data and stratigraphy, it is estimated to be 5 m thick. Hand specimen shows dark grey to black color and phyric grain of carbonate infilled hornblende could be obviously seen (Fig. 4.9D). Mineral assemblages in andesite facie consist of plagioclase 45 %, opaque minerals 30 %, hornblende 15 % and k-feldspar 5 % (Figs. 4.9E and 4.9F). Hornblende is a porphyritic grain which is 0.1-0.6 cm in size. Almost minerals are euhedral to subhedral grain shape and grain size except hornblende is between fine to very fine in grain size which is considered as an equigranular texture. Groundmass is grey to black and mostly consists of plagioclase shows trachytic and microlite textures which implies rapid cooling and flowing direction of lava. Hornblende and weakly to moderately altered to chlorite particularly close to the ore zone. Plagioclase is weakly to moderately altered to sericite, illite and carbonate minerals.

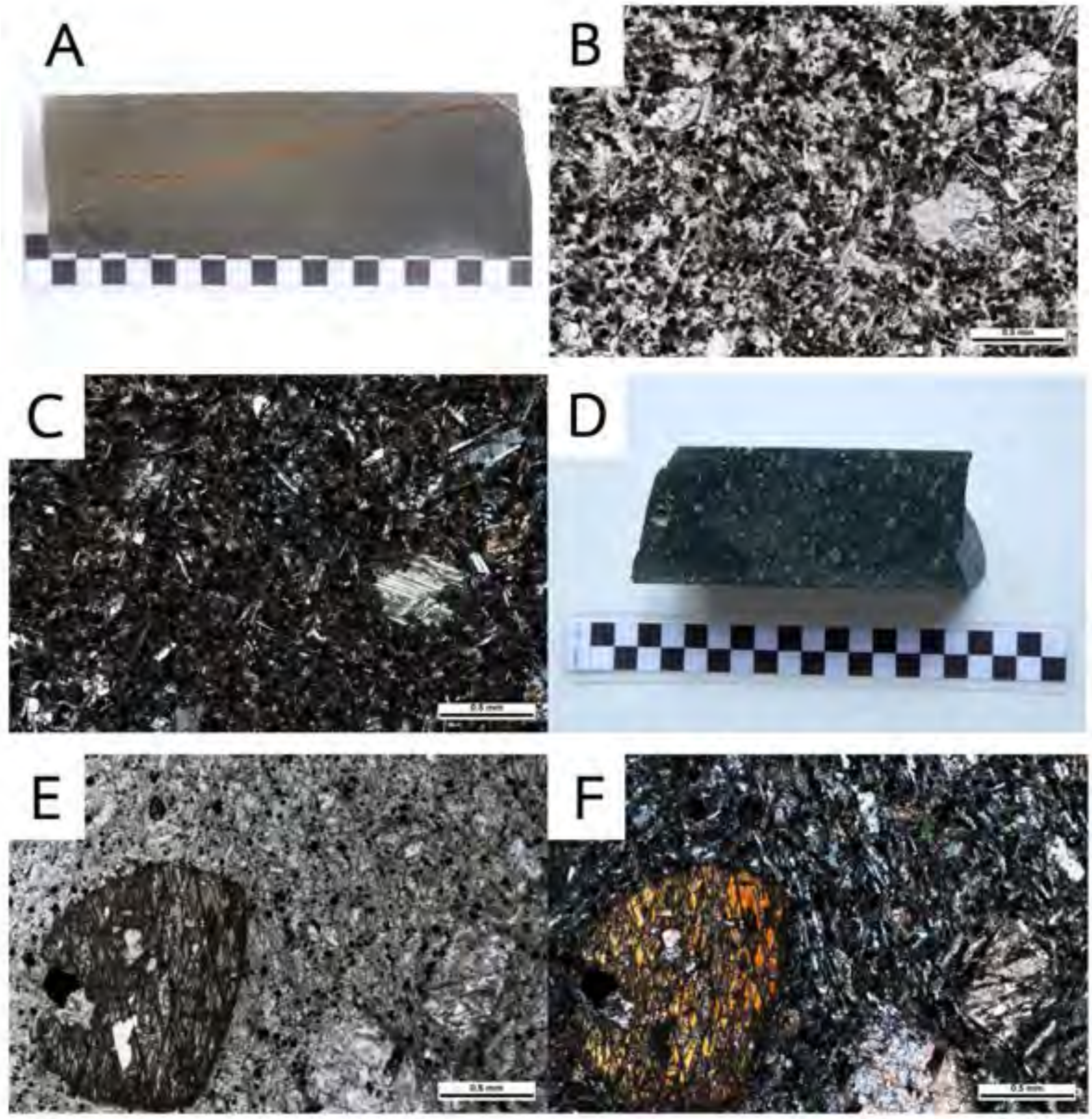



Fig 4.9 Characteristics of andesite, A) Photograph of diamond drill core of andesite, B) Photomicrograph showing andesite in PPL, C) Same as Fig. 4.5B in XPL, D) Photograph of diamond drill core of hornblende phyric andesite, E) Photomicrograph showing hornblende phyric andesite in PPL, F) Same as Fig. 4.5B in XPL

3) Rhyolite (Fig 4.10A) found as a dike cutting through the rock strata and shows sharp contact to all rock units including tuffaceous sandstone unit, polymictic volcanic breccia unit and siltstone unit. The thickness of the coherent andesite unit is not known, however, based on intersections in several drill holes, it is estimated to be 5-10 m thick. Hand specimen shows orange color and could not see any crystals. Mineral assemblages in andesite consist of plagioclase, k-feldspar and quartz (Figs 4.10B and 4.10C). Almost minerals are euhedral grain shape and grain size is between

fine to very fine in grain size which is considered as an equigranular texture. Moreover, ground mass shows microlite texture which implies rapid cooling of lava. Plagioclase is moderately to strongly altered to sericite, illite and carbonate minerals.

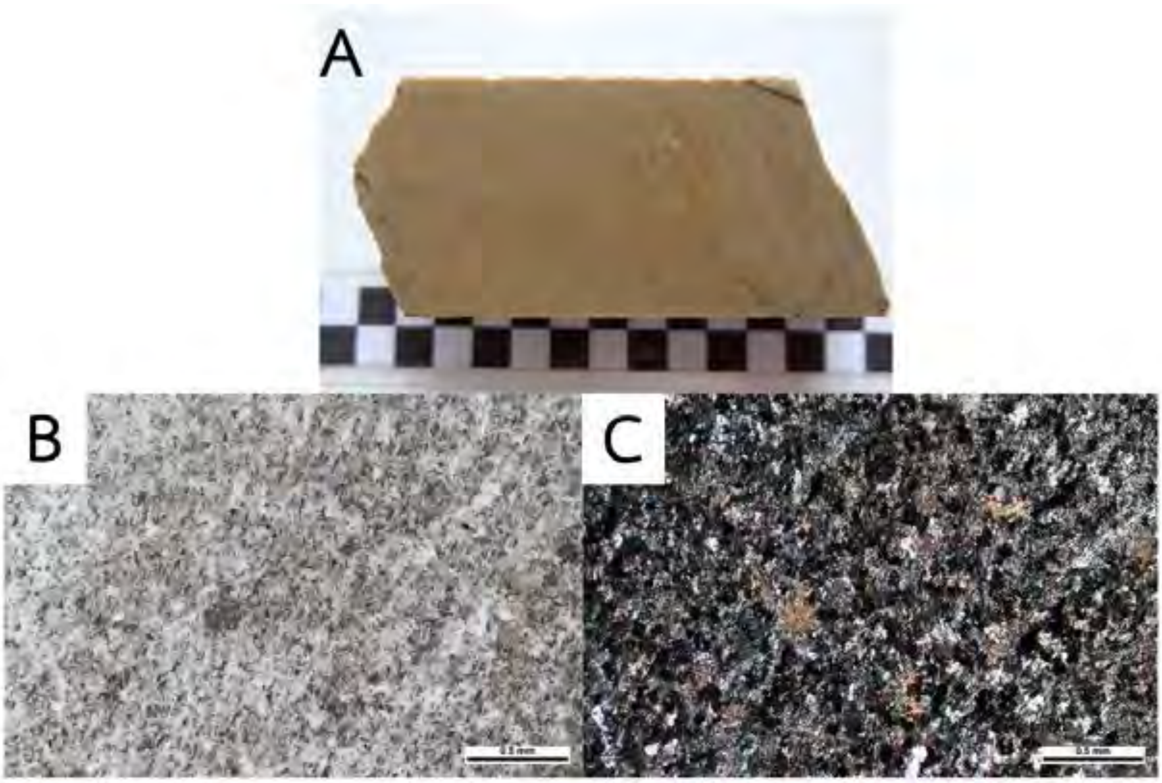



Fig 4.10 Characteristics of siltstone, A) Photograph of diamond drill core of rhyolite, B) Photomicrograph showing rhyolite in PPL, C) Same as Fig. 4.5B in XPL

### 4.3 Mineralization

This section documents gangue and ore mineralogy of mineralized veins/veinlets and established a details vein and mineral paragenesis of Chokdee prospect. Prior to this study, there is no study on mineralization and alteration. In this study observations of vein textures, mineralogy, paragenetic relations from drill core logging were collected and interpreted. In addition, detailed petrographic and textural studies of ore and gangue mineral assemblages also were undertaken.

#### 4.3.1 Paragenesis

Paragenetic relations were carefully established through observation of cross-cutting relationships and differences in mineralogy and textural and structural orientation. The vein and mineral paragenesis can be distinguished into three stages namely, 1) pre-Au mineralization stage (Stage 1), 2) main Au mineralization stage (Stage 2), and 3) post Au mineralization stages (Stage 3; Fig. 4.11) and details paragenesis are given below:

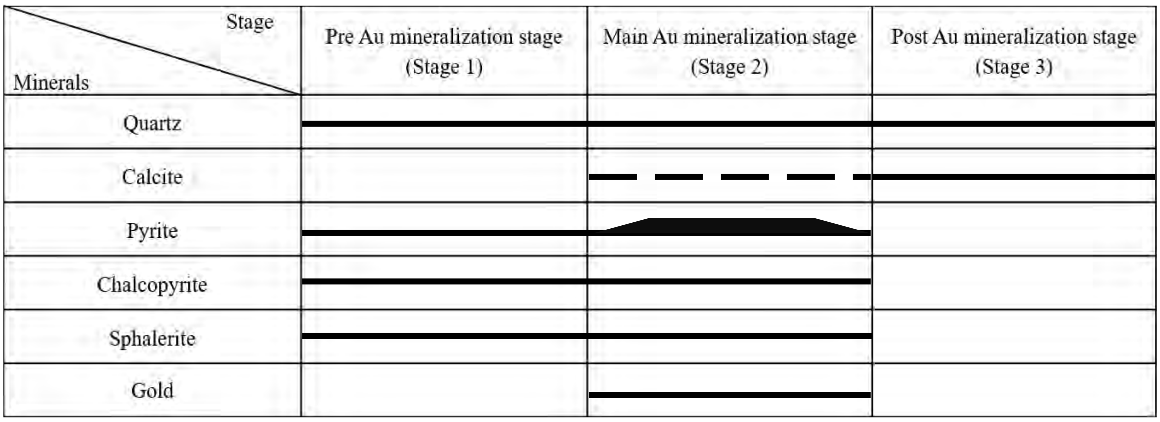



Fig 4.11 Paragenetic diagram showing the occurrence and relative abundance of ore and gangue minerals of infill stages at the Chokdee prospect.

**Stage 1: Pre-Au mineralization stage**

This mineralization stage is referred to the mineralization stages that formed prior to the main Au. This stage occurs as quartz – sulfides veins/veinlets and stockworks that are widely distributed in Chokdee prospect. It is characterized by white to light grey quartz veins with minor fine-grained pyrite (Fig. 4.12A). There is no gold or silver minerals have been identified. Major sulfide minerals are pyrite and chalcopyrite with trace of sphalerite (Figs. 4.12B and C).

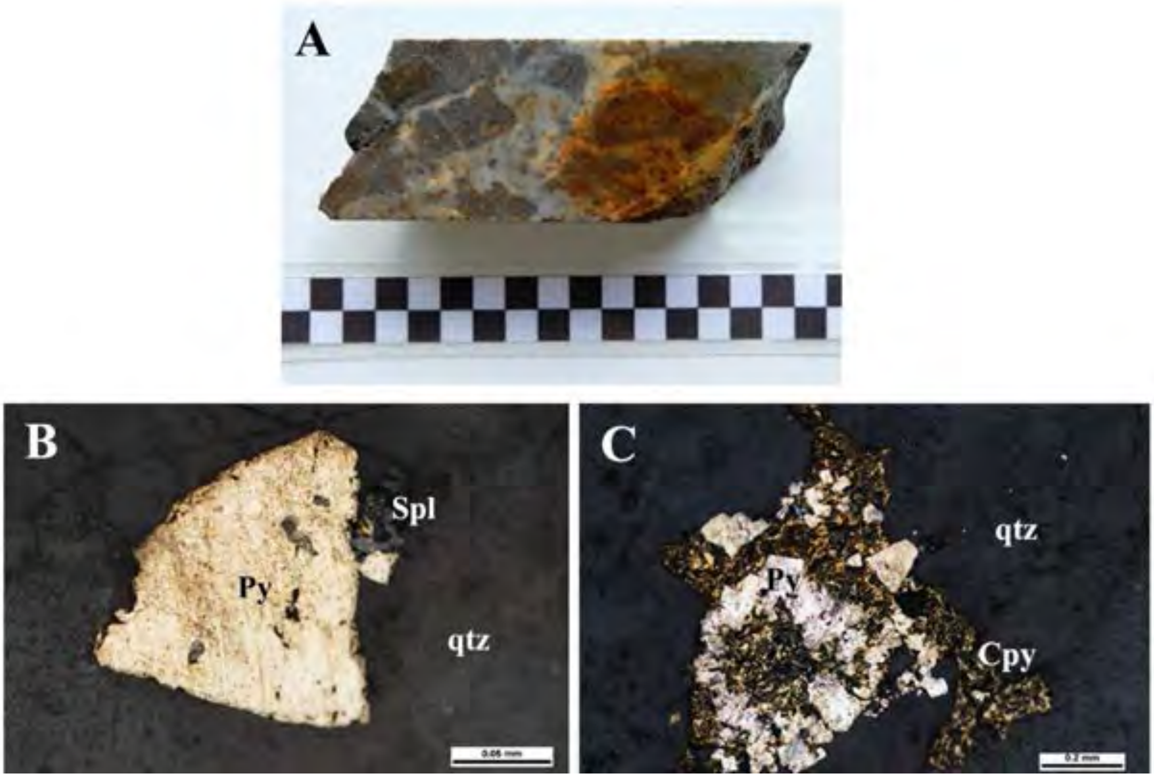



Fig 4.12 Characteristics of post-Au mineralization stage (quartz-sulfides veins). A) Photograph of diamond drill core showing quartz-sulfides veins (white) (Sample No.SM-28). B) Photomicrograph showing pyrite and sphalerite surrounded by quartz, (reflected light). C) Photomicrograph showing pyrite associated with chalcopyrite and surrounded by quartz, (reflected light). Abbreviation: Py = pyrite, Spl = sphalerite, Cpy = chalcopyrite and qtz = quartz

**Stage 2: Main Au mineralization stage**

The main-Au mineralization stage is referred to the mineralization stage that contains significant amount of Au. This stage is represented by quartz ± carbonate - sulfides - gold veins. It mainly occurs as small veins/veinlets and stockworks with minor breccia. This stage is characterized by white to light grey quartz veins (Fig. 4.12A) with or without carbonate minerals. Pyrite is the most common sulfide minerals identified in this stage (Figs. 4.12B, C, D and E). Other sulfide minerals are chalcopyrite (Fig. 4.12C) and sphalerite (Fig. 4.12B) which constitute in small amount. Gold occurs closely associated with pyrite (Figs. 4.12D and E) and less common to associated with chalcopyrite and sphalerite. Sphalerite occurs as fine-grained associated with pyrite and chalcopyrite. Chalcopyrite often partly altered to covellite (Fig. 4.12C). Quartz is the most abundance gangue mineral in Stage 2. Carbonate minerals occur only in small amount and most of them are calcite.

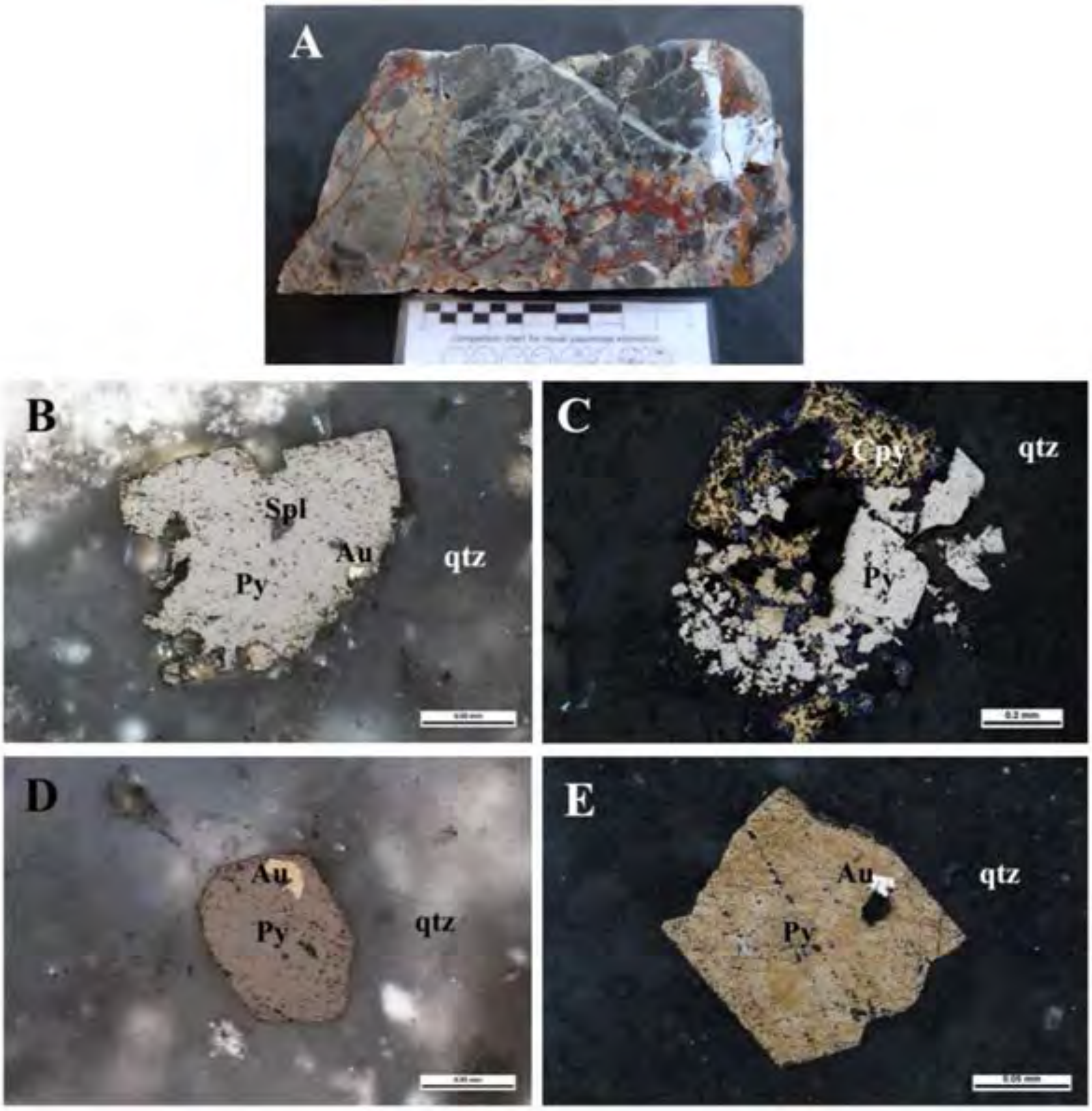



Fig 4.13 Characteristics of main Au mineralization stage (quartz ± carbonate - sulfides - gold veins). A) Photograph of diamond drill core showing quartz-sulfides infill in breccia (black) (Sample No.SM-18). B) Photomicrograph showing gold and sphalerite inclusion in pyrite which was surrounded by quartz, (reflected light). C) Photomicrograph showing pyrite associated with chalcopyrite and surrounded by quartz, (reflected light), D) and E) Same as Fig. 4.13B. Abbreviation: Py = pyrite, Spl = sphalerite, Cpy = chalcopyrite and qtz = quartz

**Stage 3: Post Au mineralization stage**

Post-Au mineralization stage referred to the stage that forms after the main-Au mineralization stage. It cross cut the Stage 2 veins/veinlets. This contains very little or no Au and mainly is represented by quartz and/or carbonate-rich veins. The post Au mineralization was referred as quartz - carbonate mineralized veins. This stage is characterized by white to light grey quartz veins which had no gold and sulfide minerals (Fig 4.14B). Post Au mineralization stage dominant contains quartz and/or carbonate and is present usually as infill veins and breccia matrix. Veins and vugs of this stage had been infilled by fine-grained carbonate (Fig 4.14C) in the inner is characterized by parts.

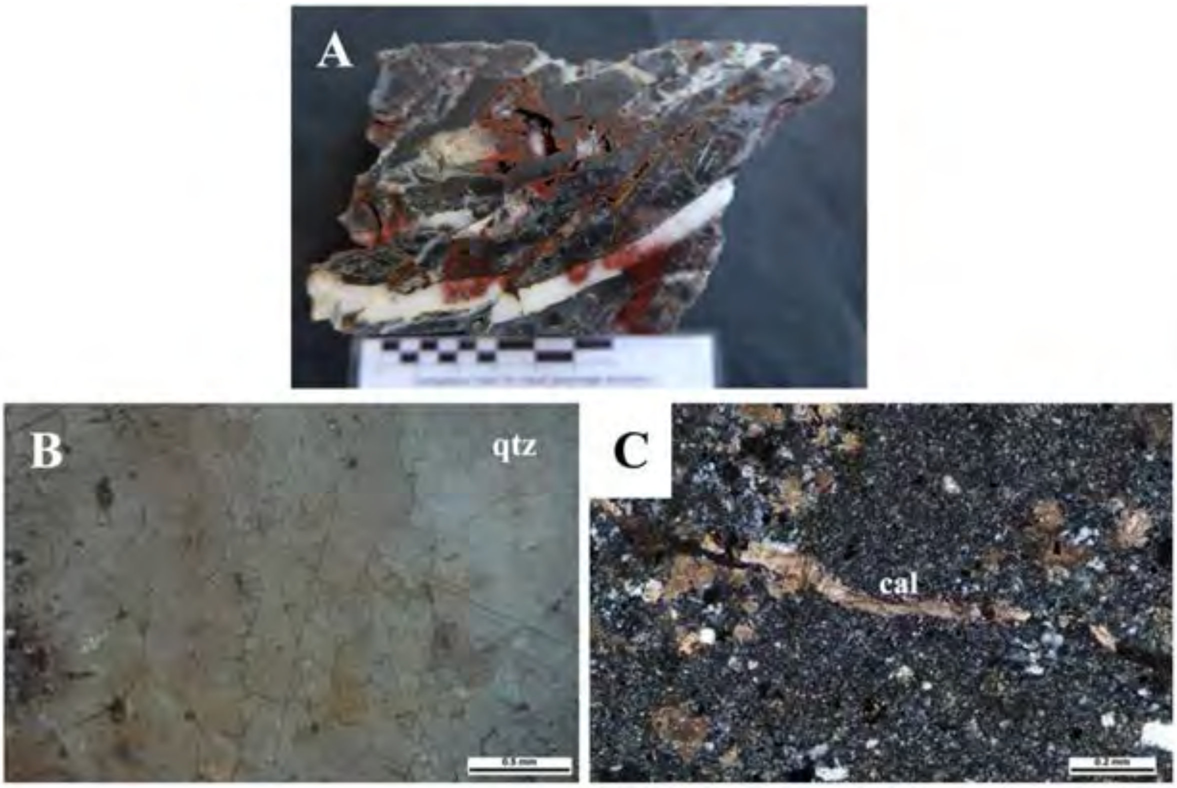



Fig 4.14 Characteristics of post Au minerization stage (quartz-carbonate mineralized veins). A) Photograph of diamond drill core showing quartz-carbonate veins. (black) (Sample No.SM-19). B) Photomicrograph showing quartz veins which had no sulfide minerals, (reflected light). C) Photomicrograph showing calcite veins, (polarized light). Abbreviation: qtz = quartz and cal = calcite

**4.4 Geochemistry**

The selected samples consist of mineralized veins and country rock which located proximal and distal from the mineralized veins (Fig 4.15). All samples were analyzed using SPLP method at pH 4 for leaching out heavy metals including lead (Pb), arsenic (As), nickel (Ni), manganese (Mn), zinc (Zn), copper (Cu), cadmium (Cd) and chromium (Cr). Results of the leaching of heavy metals from both types of samples were plotted in comparison with the Industrial Effluent Standard (IES; Ministry of Natural Resources and Environment, 2559) and Surface Water Quality Standard (SWQS; Ministry of Natural Resources and Environment, 2537). Heavy metals leached out from samples were analyzed by ICP-MS. The results are described as follow:

1. Copper, lead, zinc, manganese, nickel and chromium leaches out from rocks and mineralized veins are lower than IES and SWQS (Figs. 4.16, 4.17 and 4.18).

2. Arsenic and mercury leaches out from mineralized veins samples and cadmium leaches out from distal country rocks samples exceed only SWQS (Fig 4.19, 4.20 and 4.21).

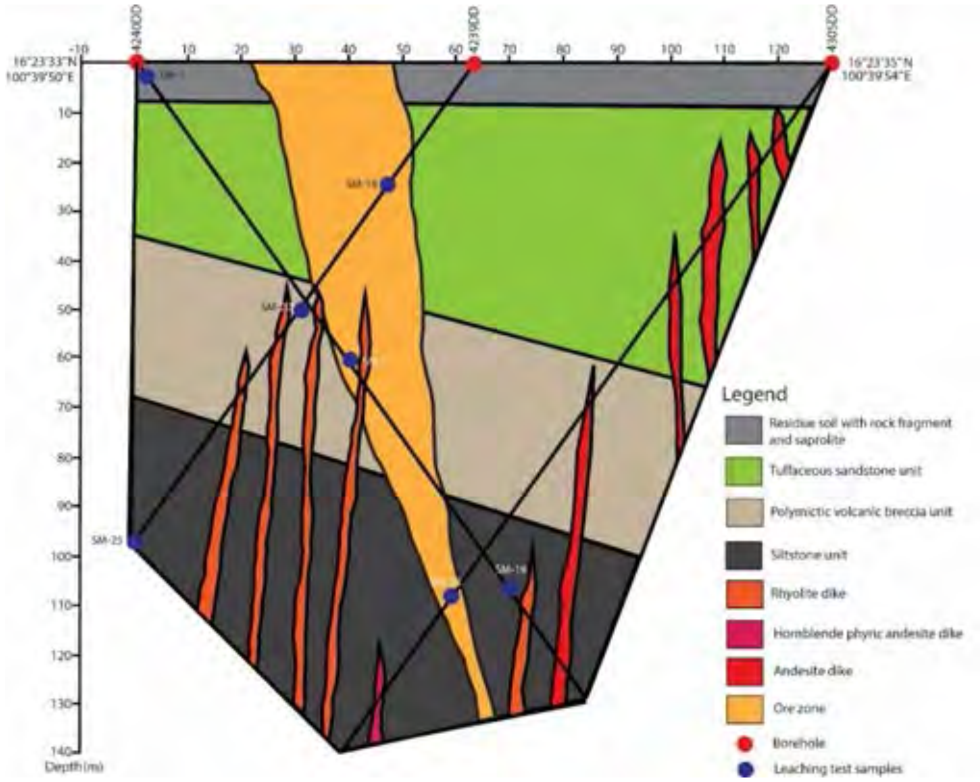



Fig 4.15 Cross section of study area with sampling point for leaching test

Table 4.1 Concentration of heavy metals leaching out from rocks and mineralized veins using SPLP method at pH 4, b.d. = below detection limit

| Sample | Concentration of heavy metals (mg/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Cu | As | Pb | Zn | Mn | Ni | Hg | Cr | Cd |
| SM-1 | 0.0117 | 0.0013 | 0.0282 | 0.8325 | 0.009 | 0.0018 | 0.0012 | 0.0035 | 0.0023 |
| SM-7 | 0.0019 | 0.0028 | 0.0279 | 0.0022 | 0.010 | 0.0019 | 0.0025 | 0.0037 | 0.0023 |
| SM-13 | 0.0081 | b.d. | 0.0277 | 0.0735 | 0.014 | 0.0271 | 0.0012 | 0.0041 | 0.0023 |
| SM-19 | 0.0206 | 0.012 | 0.0284 | 0.8086 | 0.010 | 0.0085 | 0.0011 | 0.0042 | 0.0026 |
| SM-20 | 0.0114 | 0.0033 | 0.0277 | 0.0970 | 0.032 | 0.0067 | 0.0012 | 0.0032 | 0.0023 |
| SM-25 | 0.0095 | 0.0031 | 0.0329 | 0.0530 | 0.007 | 0.0010 | 0.0016 | 0.0029 | 0.0072 |
| SM-28 | 0.0057 | 0.0130 | 0.0280 | 0.0717 | 0.018 | 0.0032 | 0.0012 | 0.0027 | 0.0023 |
| Surface Water Quality Standard | 0.1 | 0.001 | 0.05 | 1.0 | 1.0 | 0.1 | 0.002 | 0.05 | 0.05 |
| Industrial Effluent Standard | 2.0 | 0.25 | 0.2 | 5.0 | 5.0 | 1.0 | 0.005 | 0.25 | 0.03 |

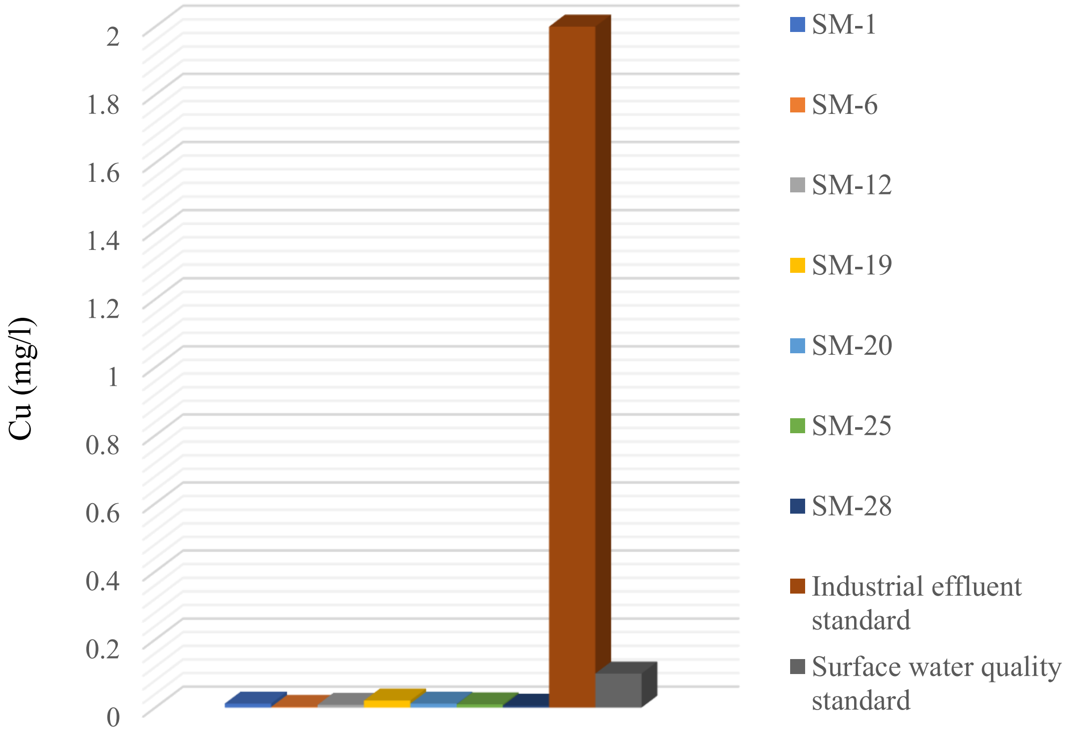



Fig 4.16 Histogram shows concentration of copper (Cu)

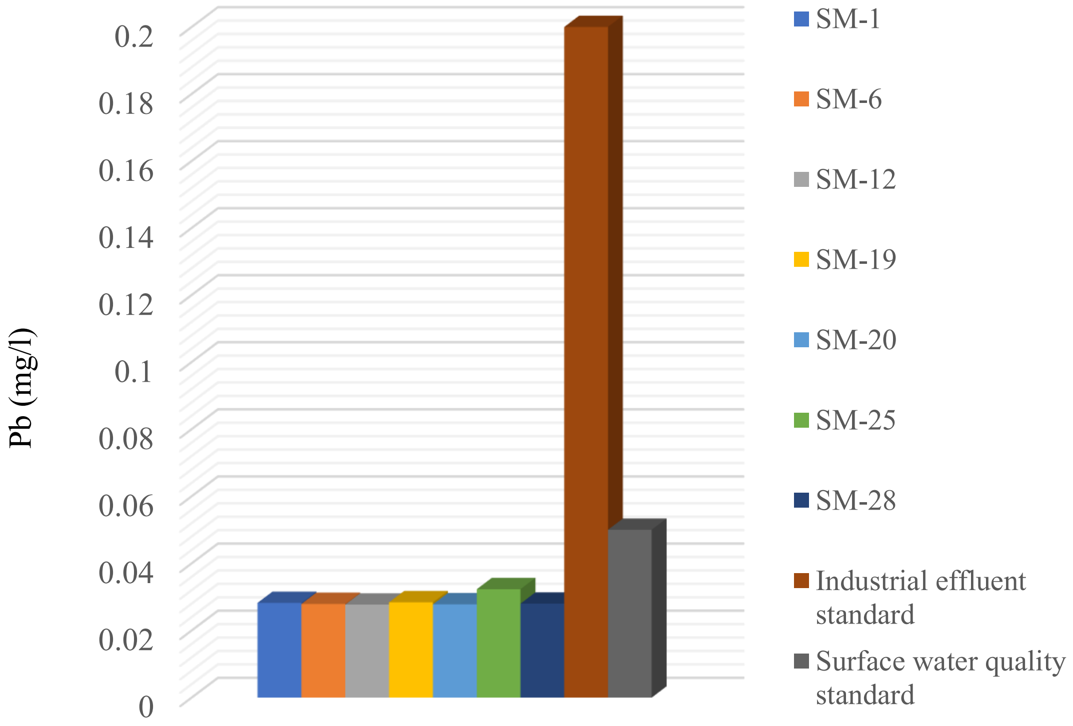



Fig 4.17 Histogram shows concentration of lead (Pb)

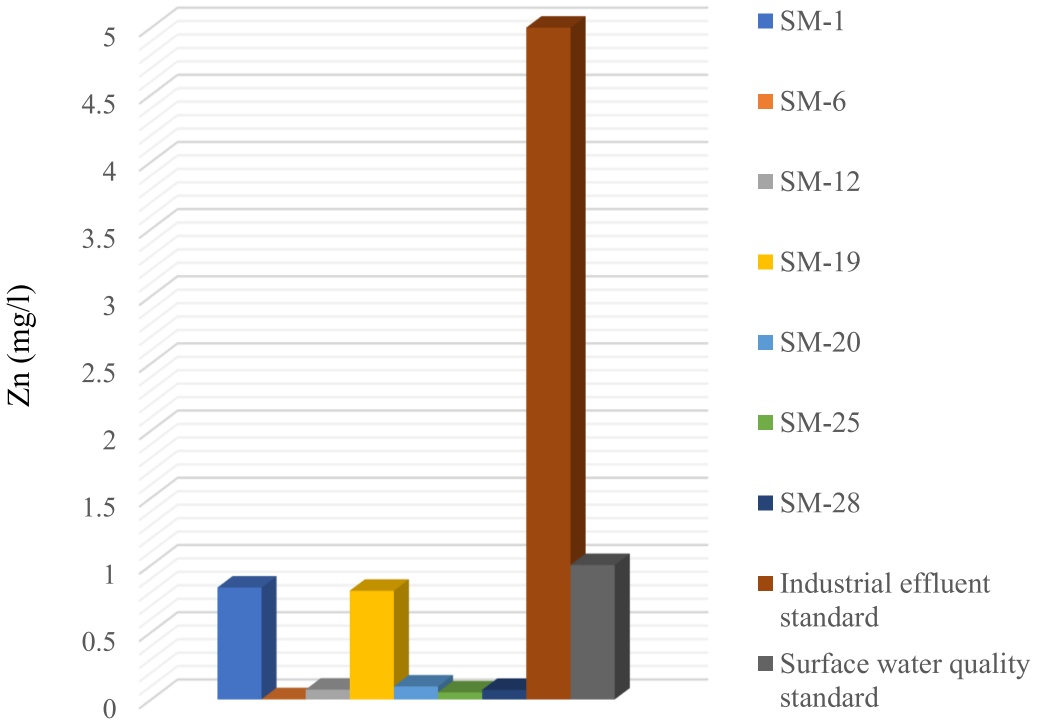



Fig 4.18 Histogram shows concentration of zinc (Zn)

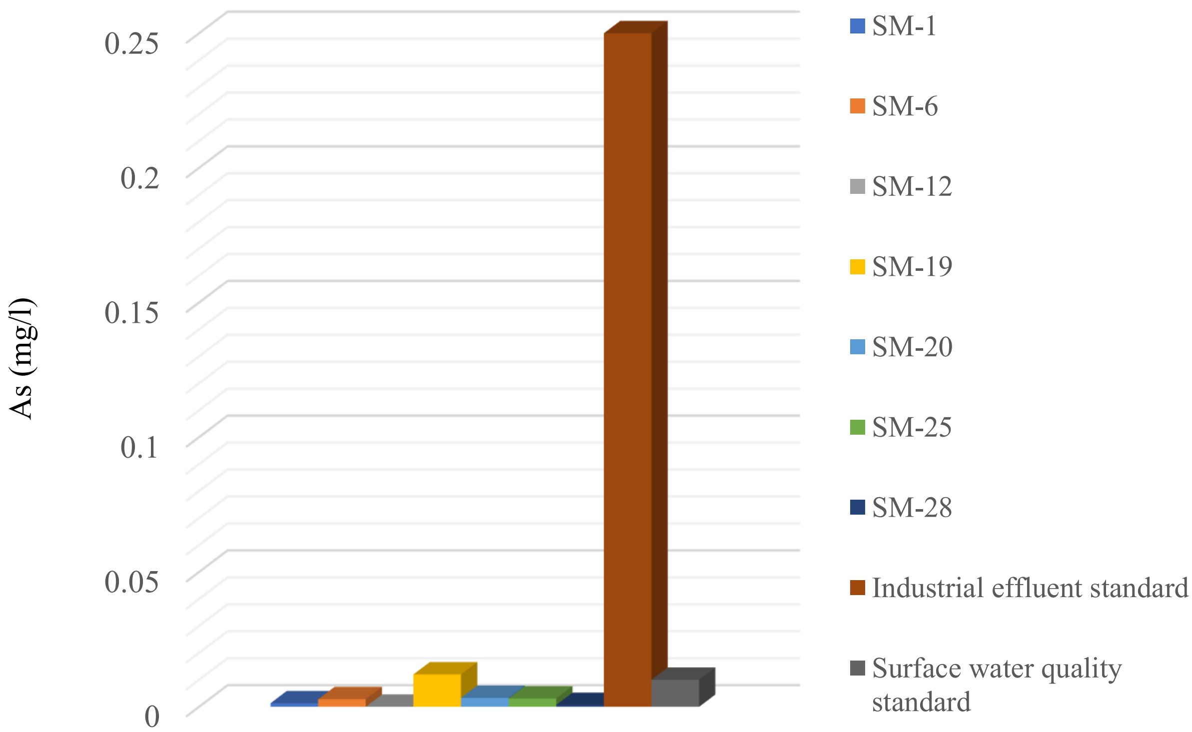



Fig 4.19 Histogram shows concentration of arsenic (As)

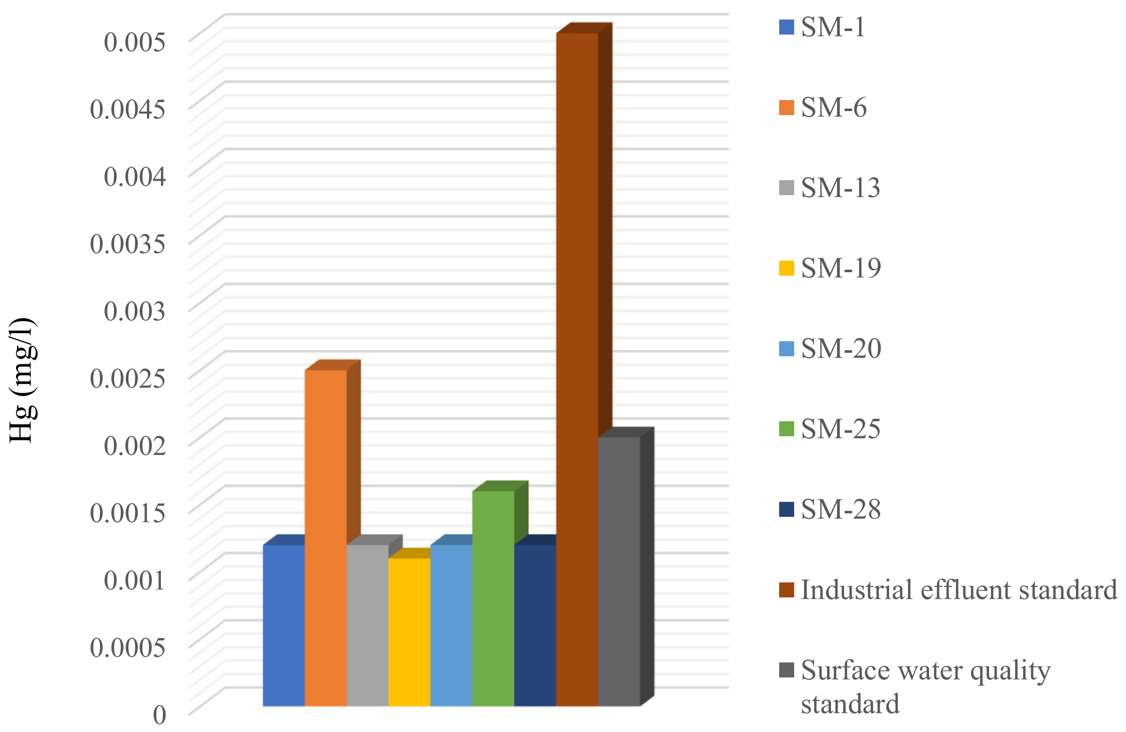



Fig 4.20 Histogram shows concentration of mercury (Hg)

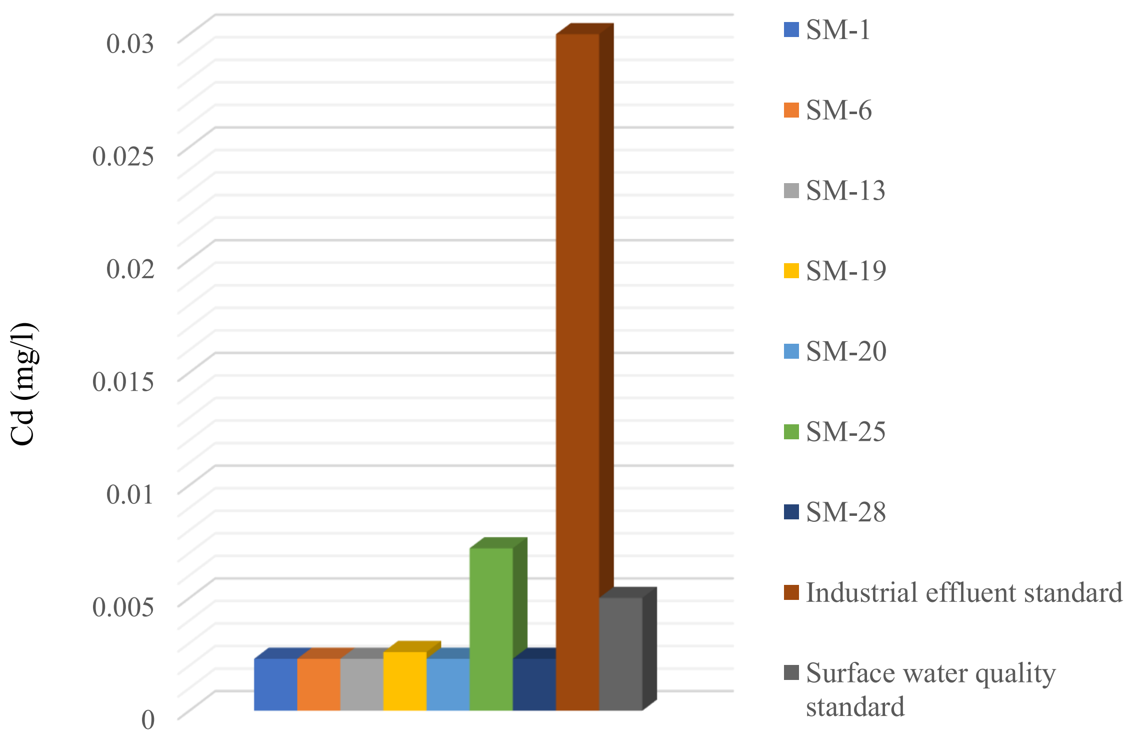



Fig 4.21 Histogram shows concentration of cadmium (Cd)

# Chapter 5
# Discussion and Conclusion

## 5.1 Discussion

### 5.1.1 Volcanic stratigraphy

Base on stratigraphy of Chokdee prospect, all 3 units can be correlated with unit 2 (volcanogenic sedimentary unit) of Chatree volcanic sequence of Salam (2013) particularly at A pit (Fig 5.1 and 5.2) which is characterized by predominantly of volcanogenic sedimentary rocks including tuffaceous sandstone, siltstone and minor polymictic breccia. However, at Chokdee the rock tends to be more sandstone and siltstone than Chatree area which also includes, sandy-matrix polymictic breccia and fiamme breccia. In addition, rhyolitic breccia is also present in Chatree. These different may be suggest that Chokdee prospect may have been deposited always from the volcanic sources whereas, A pit of Chatree might be deposited relatively close to volcanic sources. However, both area may have been deposited during calm period or no volcanic activities.

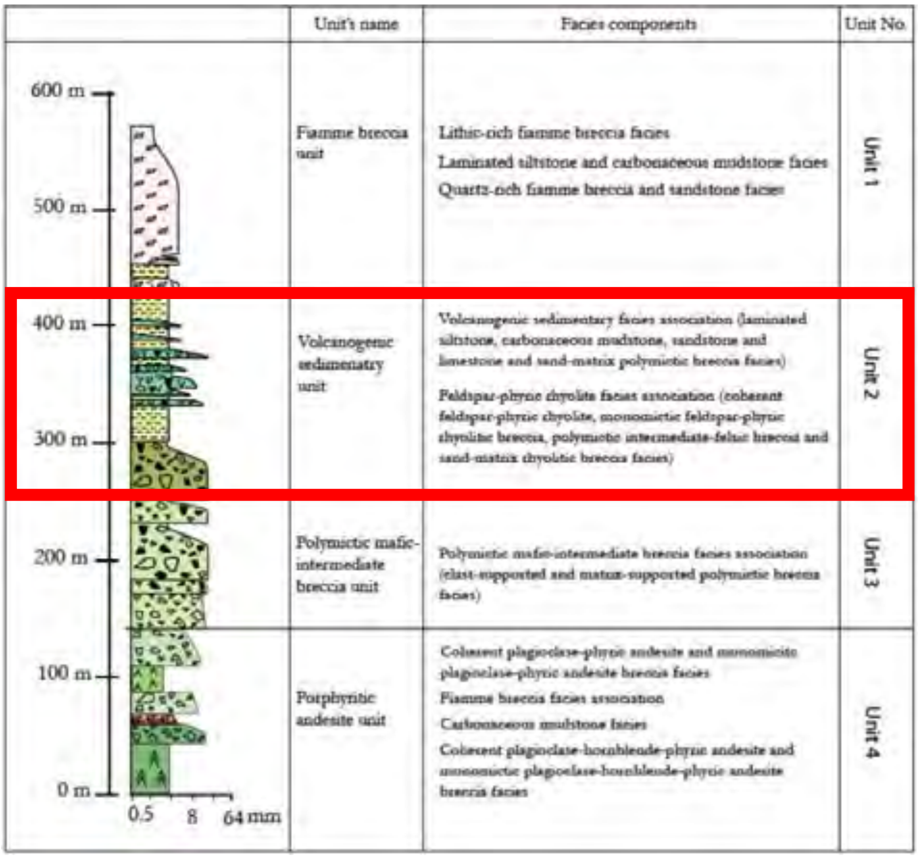



Fig 5.1 Stratigraphy of the Chatree deposit, central Thailand (Salam, 2013)

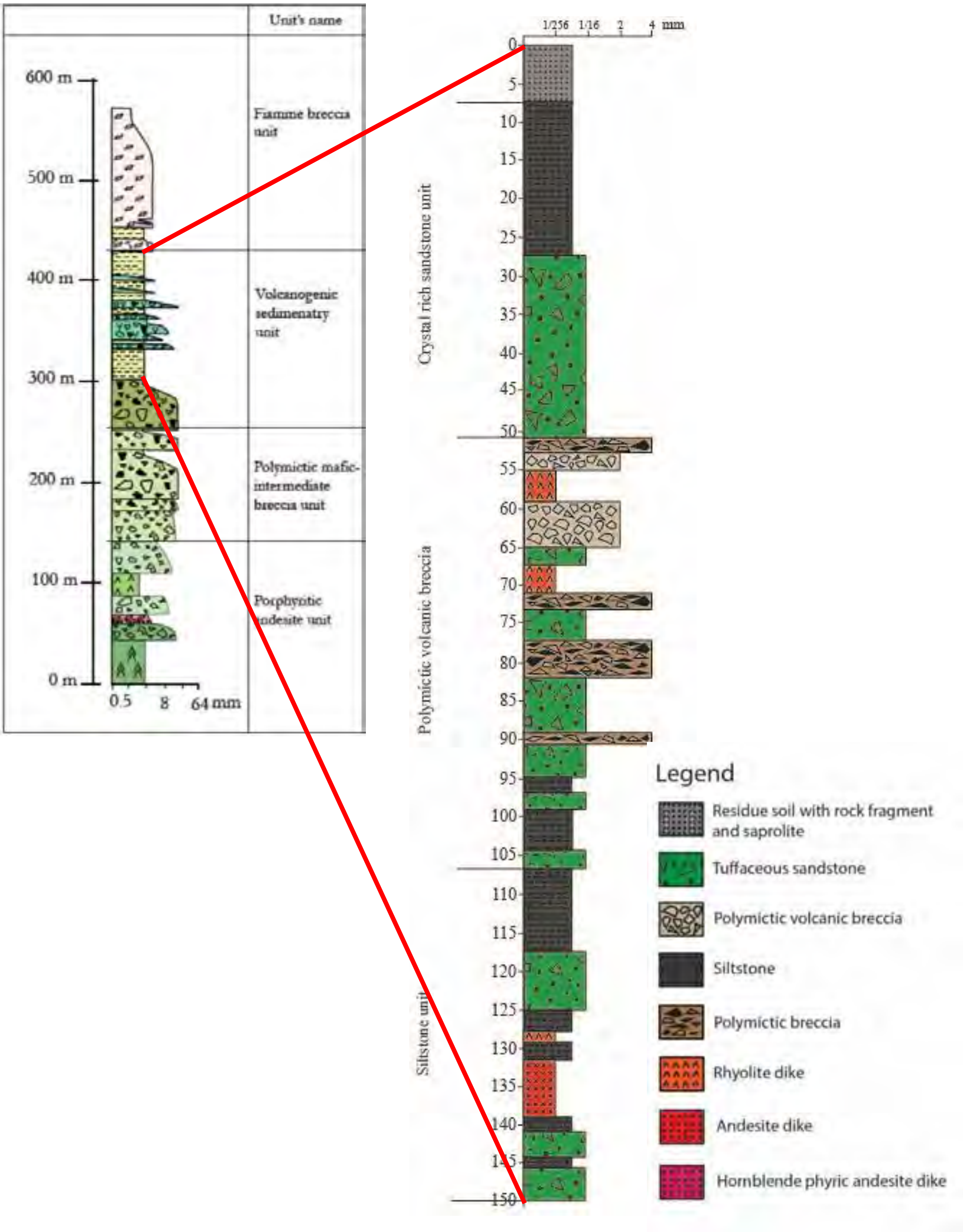



Fig 5.2 The comparation between stratigraphy of the Chatree deposit, central Thailand. (Salam, 2013) and drilling core stratigraphic column 4240DD

For fiamme breccia unit (Unit 1) which lies on the top of the sequence of Chatree deposit (Salam, 2013) had not been identified in Chokdee area possibly due to this fiamme breccia unit might have been removed or eroded. As this fiamme breccia unit often found at high elevation area such as Khao Kiaw which is located between Chokdee prospect and A pit.

### 5.1.2 Mineralogy

The mineralization occurs as quartz veins, stockworks and minor breccia hosted in volcanic clastic rocks. According to paragenesis sequence which could be divided into 3 stages comprising: pre-Au mineralization, main Au mineralization, and post-Au mineralization. Paragenesis sequence was similar to Chatree mineralization which had three main mineralization stage and mineralization in each stage was considered to be the same. Sulfide minerals assemblage in mineralized veins appears in small quantities consisting mainly pyrite and chalcopyrite with minor sphalerite. According to Salam (2013), Chatree deposit composed of many types of sulfide minerals compared to Chokdee prospect e.g. pyrite, chalcopyrite, arsenopyrite, galena, sphalerite etc. These details imply that in acid mine drainage condition, Chatree deposits have high heavy metal leachate potential than Chokdee prospect.

Table 5.1 The comparation of sulfide mineral assemblages in Chokdee prospect and Chatree deposit

| Sulfide/precious minerals | Chokdee prospect | Chatree deposit |
|---|---|---|
| Pyrite ($FeS_2$) | ✓ | ✓ |
| Sphalerite (ZnS) | ✓ | ✓ |
| Chalcopyrite ($CuFeS_2$) | ✓ | ✓ |
| Galena (PbS) | | ✓ |
| Boulangerite ($Pb_5Sb_4S_{11}$) | | ✓ |
| gold (Au) | ✓ | ✓ |
| Argentite ($Ag_2S$) | | ✓ |

| | | |
|---|---|---|
| Tetrahedrite ($(Cu,Fe)_{12}Sb_4S_{13}$) | | ✓ |
| Arsenopyrite (FeAsS) | | ✓ |

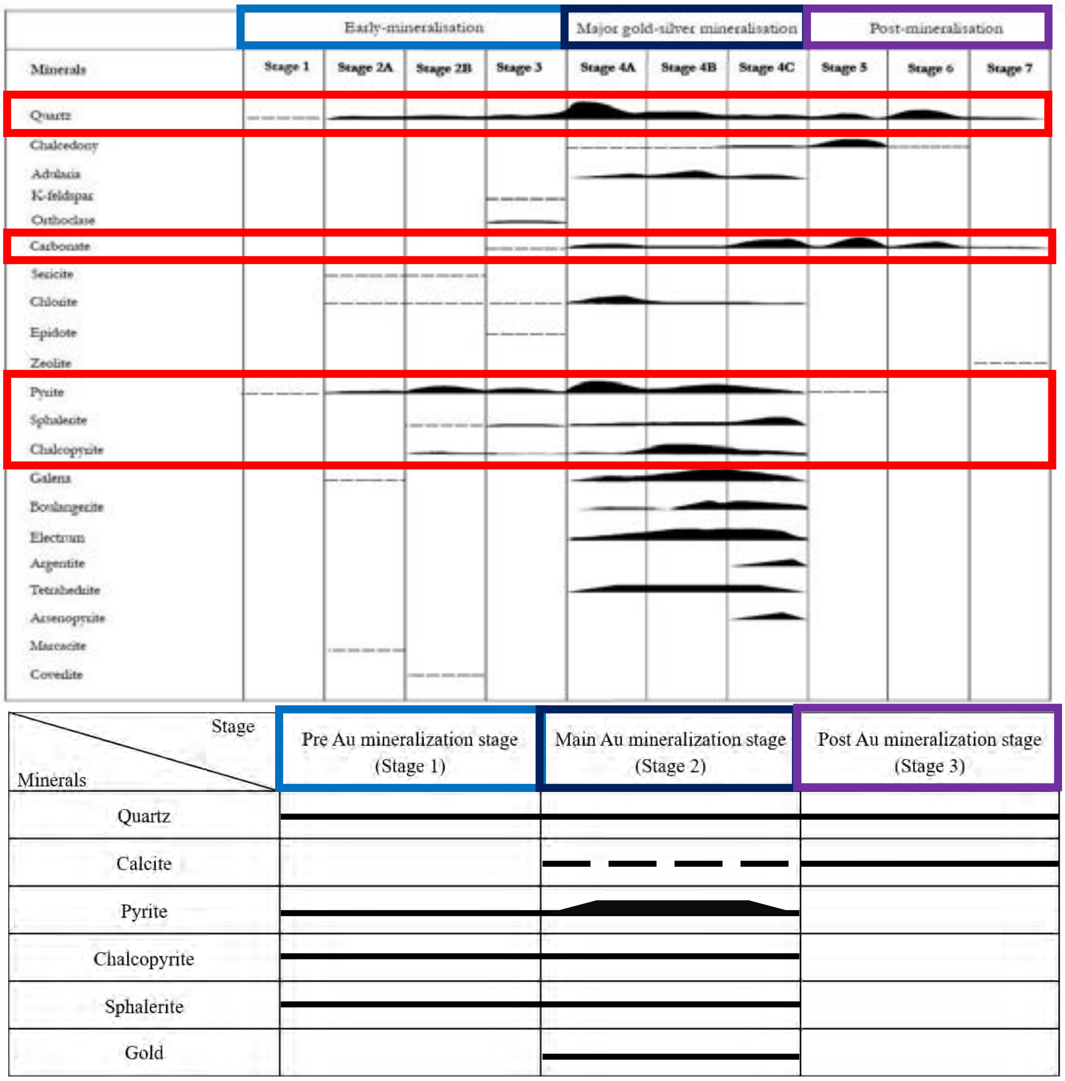



Fig 5.3 The comparation between Chokdee paragenesis and Chatree paragenesis

### 5.1.3 Geochemistry

The leaching test at pH 4 of rocks and mineralized veins by SPLP method revealed that most of the element such as Zn, Mn, Cu, Cr, Pb, Ni are below Industrial Effluent Standard (IES) and Surface Water Quality Standard (SWQS) except arsenic, mercury and cadmium for SM-6, SM-19 and SM-25 from mineralized veins and country rocks samples are higher than (SWQS). However, petrographic study suggested that the amount of sulfides present in both types of samples are very low in comparison to some other mineral deposits. Therefore, there is less chance that these types of materials to cause acid mine drainage even exposed to the surface. According to Changul et al., (2009), who studied the acid generation in Chatree deposit and concluded that the condition of pH 4 appears to have less chance to occur in natural condition and pH values less than 4 are even less likely to occur in normal condition. The acidic condition of pH 4 is considered to be the worst-case scenario. Hence, pH level in natural area in this region rarely occur at pH 4. It is further suggested that there is very low chance that the materials from Chokdee prospect will pollute the environment if it happens to be mined. The results of this study will also help in managing waste rocks during the mine operation if it became a mine in future.

## 5.2 Conclusion

Volcanic stratigraphy can be referred to the volcanogenic sedimentary unit (Salam, 2013) and can be divided into 3 units from old to young as follow: 1. tuffaceous sandstone unit, 2. polymictic volcanic breccia unit and 3. siltstone unit respectively.

Unit 1: Tuffaceous sandstone unit lies on the top of the sequence which hornblende phyric andesite dikes are common and crosscut through the succession. This unit consists of 2 mainly rock types as follow: Tuffaceous sandstone, siltstone, and minor polymictic breccia. Unit 2: Polymictic volcanic breccia unit lies underneath unit 1 and above unit 3. Rhyolite dike is common and crosscut through this succession. This unit consists of 3 mainly rock types as follow: polymictic volcanic breccia, polymictic breccia, and tuffaceous sandstone with minor siltstone. Unit 3: Siltstone unit is the lowest unit lies underneath unit 2. This unit was dominated by siltstone where tuffaceous sandstones are common with minor polymictic breccia and limestone. Andesites were found as dike cutting through this succession where hornblende phyric andesite and rhyolite are minor.

The mineralization occurs as quartz veins, stockworks and minor breccia hosted in volcanic clastic rocks. Mineralization stage could be subdivided into 3 stage including pre-Au mineralization stage, main Au mineralization stage, and post-Au mineralization stage. Two first stage found sulfide minerals contain in quartz veins including mainly pyrite and chalcopyrite with minor sphalerite. The diversity of sulfide minerals were less than Chatree deposit

The leaching test of waste rocks and mineralized veins at pH 4 using SPLP method indicated that amount of all heavy metal except arsenic and mercury leaching out from mineralized veins and cadmium leaching out from the distal country from mineralized veins are below surface water quality standard and industrial effluent standard. Hence, heavy metal which must be concerned is arsenic and mercury in mineralized veins and cadmium in country rocks. These results lead to management and monitoring plan for reducing the environmental problem causing in future.

## 5.3 Recommendation for future work

It should be more in the detail about acid forming potential for the acid forming material eg. waste rocks and surface soils. There are many methods to do which are described as a following:

1) Acid/Base Accounting (ABA) consists mainly 3 steps

1.1) Identification of the maximum potential acidity (MPA)

1.2) Identification of the acid neutralization capacity (ANC)

1.3) Calculating the net acid production potential (NAPP) from the equation: NAPP = MPA – ANC

2) Identification of the net acid generation (NAG) which is the method for predicting the sulfuric acid forming potential from sulfide minerals. Hydrogen peroxide is used for the oxidizing reaction which is catalyzed by heat. Then, leave it in the room temperature for cooling and measure the final pH.

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# Appendix

Acid mine drainage is usually characterized elevated concentrations of dissolved sulfate ($SO_4^{2-}$), ferrous iron ($Fe^{2+}$) and ferric iron ($Fe^{3+}$) that are produced by the oxidation of reduced forms of sulfur and iron in sulfide minerals egpyrite ($FeS_2$), pyrrhotite ($Fe_{1-x}S$), marcasite ($FeS_2$) and arsenopyrite (FeAsS)in waste rocks as a following equation.

1. $2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$
2. $2Fe^{2+} + 1/2\ O_2 + 2H^+ \rightarrow 2Fe^{3+} + H_2O$
3. $Fe^{3+} + 3H_2O \leftrightarrow Fe(OH)_3 + 3H^+$
4. $FeS_2\,(s) + 15/4\ O_2 + 7/2\ H_2O \rightarrow 4H^+ + 2SO_4^- + Fe(OH)_3\,(s)$

Whenever these sulfide minerals are exposed to the air and water by mining activities especially opencast mines, oxidizing reaction would be occurred as well as the releasing of heavy metals and hydrogen ions from sulfide minerals in waste rocks into environment. Moreover, waste rocks or mine dumps can be oxidized by meteoric water and ground water that a product is sulfuric acid. These would make more acidity in water which increase the heavy metals leaching potential. Initial factors for acid generation are: sulfide minerals in the waste rocks, water or a humid atmosphere and an oxidant (usually oxygen in the form of $O_2$). Leaching of heavy metals and acid water would impact to environment and life in many ways such as water contamination, human health, living of animals and plants and erosion of the building. (Todd and Reddick, 1997) and (Sutthirat, 2011)

Generally heavy metals in the environment are only present in very small quantities which are not harmful. Whenever these heavy metal concentration rises by anthropogenic activities or mineralizing processes, the environmental pollution must be concerned. The heavy metals threatening the environment and ecosystem include copper, lead, zinc, chromium, antimony, cadmium, barium, arsenic and mercury. The effects caused by heavy metals vary in that dissolved for example lead, cadmium and mercury can affect environment more than copper because they can be accumulated through the food chain and transmitting a toxic risk to species higher in the food chain and eventually to humans. (Estifanos, 2013)

The Synthetic Precipitation Leaching Procedure (SPLP): SW-846 EPA Method 1312 (U.S. EPA, 1994) is a method designed to evaluate the mobilization potential of any impurities in wastes rocks and soils. The extraction fluid must be simulated natural precipitation then it consists of slightly acidified de-ionized water. The pH of the de-ionized water is adjusted with the 60/40 $H_2SO_4$//$HNO_3$ mixture. The appropriate pH of extraction fluid is depending on a worst condition that would be occurred if there is a heavy metals leaching. The SPLP extraction method use for 100% solids and no volatiles sample which requires reduction of particle size < 9.5 mm. Then, the extraction fluid is added into a solid at a 20:1 ratio on an end-over-end rotary agitator for 18 hours. Next, The slurry is filtered through a 0.7 µm glass fiber filter. Finally, the slurry is analyzed for contaminant.

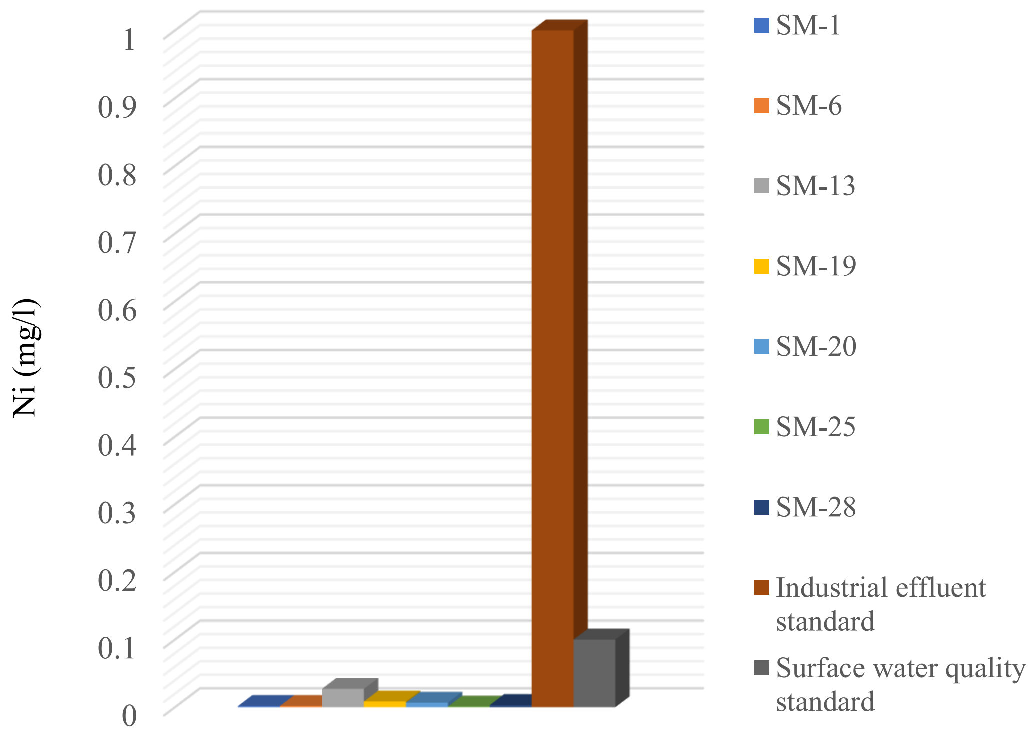
Production of acid mine drainage can occur long after mines have been abandoned if waste rock are in contact with air and water which introduce hydrogen by oxidizing reaction. Acidity is commonly measured by pH values, which are easy to collect and compare. However, it is not always a good indicator of acid mine drainage because it only indicates the concentration of hydrogen ions. When evaluating the extent of acid mine drainage, it is important to know the amount of hydrogen ions remaining in solution after the completion of natural buffering. For example, pH measurements may not detect heavy acid mine drainage in a stream because of high alkalinity due to enough dissolved carbonates. Acid mine drainage depletes the buffering ability of water by neutralizing carbonate and bicarbonate ions to form carbonic acid ($H_2CO_3$) and then the carbonic acid readily breaks down into water and carbon dioxide as the following equation:

$$H^+ + CO_3^{2-} \rightarrow HCO^{3-}$$

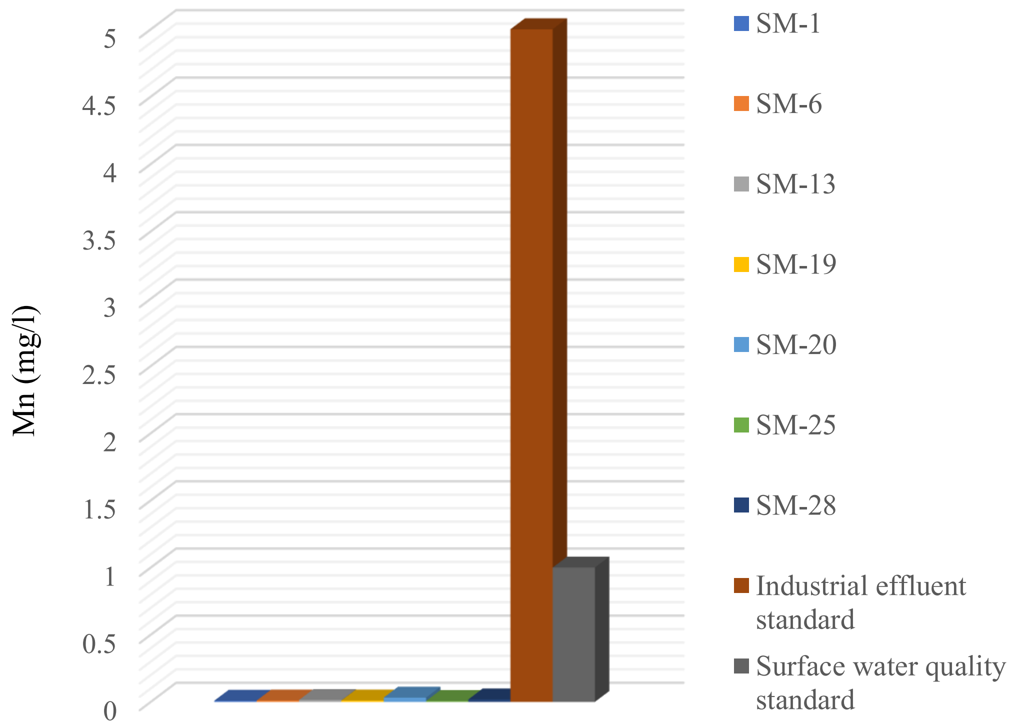
$$H^+ + HCO^{3-} \rightarrow H_2CO_3$$

$$H_2CO_3 \rightarrow H_2O + CO_2$$

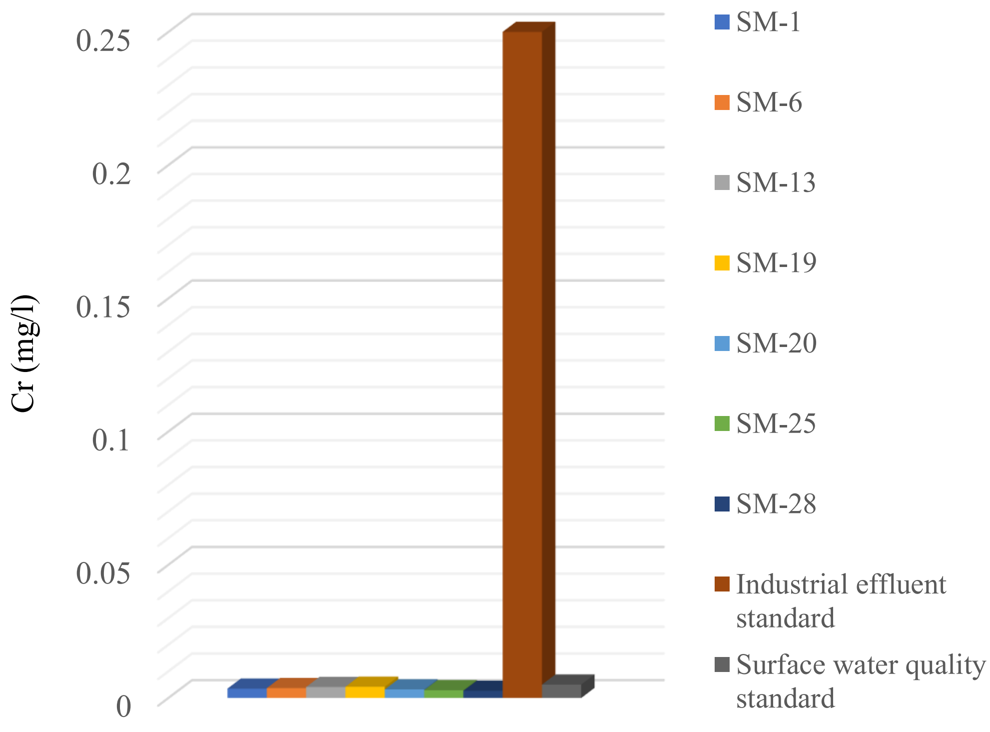
**Leaching test histogram**




Histogram shows concentration of nickel (Ni)




Histogram shows concentration of manganese (Mn)




Histogram shows concentration of chromium (Cr)