# โครงการการเรียนการสอนเพื่อเสริมประสบการณ์

## ศิลาวรรณนาและธรณีเคมีของกลุ่มหินแกรนิต
## บริเวณอำเภอชนแดนและบึงสามพัน จังหวัดเพชรบูรณ์

โดย

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ปีการศึกษา 2560

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# PETROGRAPHY AND GEOCHEMISTRY OF GRANITIC ROCKS
# AT CHON DAEN AND BUENG SAM PHAN DISTRICTS, PHETCHABUN PROVINCE

Mr. Kritanol Naewboonnien

A Project Submitted in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Science Program in Geology
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| Project Advisor | Associate Professor Pitsanupong Kanjanapayont, Dr.rer.nat. |
| Project Co-Advisor | Abhisit Salam, Ph.D. |

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การศึกษานี้มีวัตถุประสงค์เพื่อศึกษาลักษณะทางศิลาวรรณนา และธรณีเคมีของกลุ่มหินแกรนิต บริเวณอำเภอชนแดน และบึงสามพัน จังหวัดเพชรบูรณ์ รวมไปถึงการอธิบายและจำแนกประเภทของลักษณะทางธรณีแปรสัณฐานที่เกี่ยวข้องกับการเกิดกลุ่มหินดังกล่าว การศึกษานี้มีพื้นที่ศึกษาทั้งหมด 3 จุดศึกษา จุดแรกตั้งอยู่ ณ ตำบลดงขุย อำเภอชนแดน จังหวัดเพชรบูรณ์ จุดที่สองและสามนั้นตั้งอยู่ ณ ตำบลพญาวัง อำเภอบึงสามพัน จังหวัดเพชรบูรณ์ โดยมีระยะทางระหว่างจุดศึกษาที่สองและสามประมาณ 5 กิโลเมตร จากการศึกษาพบว่า หินบริเวณจุดศึกษาแรก จุดศึกษาที่สอง และจุดศึกษาที่สาม สามารถจำแนกได้เป็น หินแกรนิต หินไดออไรต์ และหินควอตซ์ไดออไรต์ ตามลำดับ จากผลทางธรณีเคมีที่ได้มาจากเครื่องเอกซเรย์ฟลูออเรสเซนส์ พบว่าปริมาณของสารประกอบออกไซด์ในหินแต่ละบริเวณนั้นมีค่าแตกต่างกันออกไป โดยหินแกรนิตจะมีปริมาณซิลิกอนไดออกไซด์ที่สูงกว่าหินไดออไรต์และหินควอตซ์ไดออไรต์ แต่กลับมีปริมาณแคลเซียมออกไซด์ เหล็กออกไซด์ และแมกนีเซียมออกไซด์ที่ต่ำกว่า ส่วนปริมาณแอลคาไลน์ออกไซด์ เช่น โซเดียมออกไซด์ และโพแทสเซียมออกไซด์นั้นมีค่าที่ใกล้เคียงกัน จากการอภิปรายการกำเนิดศิลา และลักษณะทางธรณีแปรสัณฐานพบว่า หินทั้งสามจุดศึกษานั้นมีองค์ประกอบทางเคมีแบบเมทอลูมินัส และมีต้นกำเนิดมาจากหินหนืดแบบแคลก์-แอลคาไลน์ ไปจนถึงแบบแคลก์-แอลคาไลน์ที่มีโพแทสเซียมสูง ซึ่งสอดคล้องกับลักษณะทางธรณีแปรสัณฐานแบบแนวคดโค้งภูเขาไฟ นอกจากนั้นผลทางธรณีเคมียังระบุว่าหินทั้งสามจุดศึกษามีองค์ประกอบแบบหินแกรนิตชนิด I ดังนั้นจึงสามารถสรุปได้ว่ากลุ่มหินทั้งหมดเกิดจากการมุดตัวของแผ่นมหาสมุทรบรรพกาลในทิศตะวันออกไปสู่แผ่นจุลทวีปอินโดจีน

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต ____________________

สาขาวิชา ธรณีวิทยา ลายมือชื่ออาจารย์ที่ปรึกษาโครงงาน ____________________

ปีการศึกษา 2560 ลายมือชื่ออาจารย์ที่ปรึกษาโครงงานร่วม ____________________

# # 5732702223: MAJOR GEOLOGY
KEYWORD: METALUMINOUS / CALC-ALKALINE / VOLCANIC ARC MAGMATISM / PETROGRAPHY / GEOCHEMISTRY

KRITANOL NAEWBOONNIEN: PETROGRAPHY AND GEOCHEMISTRY OF GRANITIC ROCKS AT CHON DAEN AND BUENG SAM PHAN DISTRICTS, PHETCHABUN PROVINCE. ADVISOR: ASSOCIATE PROFESSOR PITSANUPONG KANJANAPAYONT, Dr.rer.nat. CO-ADVISOR: ABIHISIT SALAM, Ph.D., 45 pp.

This study is aimed to investigate the petrography and geochemistry of granitic rocks at Chon Daen and Bueng Sam Phan districts, Phetchabun province. Moreover, the explanation and classification of tectonic setting which related to the occurrence of the granitic rocks are considered. There are 3 locations in the study. The first location is in Dongkui sub-district, Chon Daen district, Phetchabun province. The second and third locations are in Phaya Wang sub-district, Bueng Sam Phan district, Phetchabun province. The distance between second location and third location is approximately 5 kilometers. According to the study results, the granitic rocks at Chon Daen district can be classified into granite, and Bueng Sam Phan granitic rocks can be classified into diorite and quartz diorite. The geochemical result from X-Ray fluorescence spectrometry showed the variation of major oxides content in each rock unit. Granite has higher amount of $SiO_2$ when compared with diorite and quartz diorite. Nevertheless, it contains lower amount of CaO, $FeO_{total}$ and MgO compared with Bueng Sam Phan granitic rocks. The alkali oxides ($Na_2O$ and $K_2O$) amount are slightly different. Based on the discussion of petrogenesis and tectonic setting, these rock units are geochemically metaluminous originated in Calc-Alkaline to high-K Calc-Alkaline magma series. These qualities are matched with the volcanic arc magmatism. Furthermore, the geochemical evidence indicates these rock units as an I-type affinity. To summarize, these granitic rocks have occurred by the eastward subduction of Paleo-Tethys under Indochina terrane.

Department: Geology Student's Signature ____________

Field of Study: Geology Advisor's Signature ____________

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"Thanks" are given to my friends for being the reason behind my big smiles and joyful laughs.

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# Chapter 1

## Introduction

### 1.1 General statement

Thailand is tectonically comprised of two tectonic terranes, namely Sibumasu terrane on the west and Indochina terrane on the east of the country. These terranes are separated by two fold belts which are Loei Fold Belt and Sukhothai Fold Belt (Bunopas, 1981). The occurrence of the fold belts is caused by the tectonic activity between the two main terranes that is related to the origin of three granitoid belts of Thailand. These three granitoid belts are broadly distributed from Yunnan province to the Malay peninsula in N-S trending. The granitoid belts can be found throughout Thailand except for the northeastern region (Khorat plateau) and can be classified into three belts; the eastern granitoid belt, the central granitoid belt and the western granitoid belt. The classification is based on tectonic evidences, geological environment, geochronological evolution and mineralization of each belt. According to the classification of Chappell and White (1974), the eastern granitoid belt is I-type affinity and yields the age of 245-210 Ma (Early to Late Triassic). The central granitoid belt is S-type and I-type affinity (mostly S-type affinity) and gives the age of 220-180 Ma (Late Triassic to Middle Jurassic). The western granitoid belt is S-type affinity and indicates the age of 80-50 Ma (Late Cretaceous to Paleogene). All dating data are performed by using $^{40}Ar/^{39}Ar$ geochronological technique. (Charusiri et al., 1993)

As a part of Loei Fold Belt, the granitic rocks in this study area belong to the eastern granitoid belt which emplaced during Early to Late Triassic (Charusiri et al., 1993). As reported by Salam (2013), there is an outcrop near Sila Thaweechok stone mill factory in Takut Rai sub-district, Chon Daen district, Phetchabun province which called “Dongkui granite” and yielded the age of 310 ±8 Ma (Late Carboniferous) dated by LA-ICPMS zircon U-Pb technique (Khin Zaw et al., 2007). Therefore, there are some plutons in this granitoid belt which crystallized before Triassic period.

This study focuses on the granitic rocks outcropping around Chon Daen and Bueng Sam Phan districts, Phetchabun province. And to investigate the petrographic and geochemical data of these plutonic rocks. This information is not only providing a better explanation of the complex tectonic processes, but also gives a type of tectonic settings of Loei Fold Belt.

## 1.2 Objectives

This study aims to investigate the petrological and geochemical data of the granitic rocks from some area in Chon Daen and Bueng Sam Phan districts, Phetchabun province. Furthermore, to explain and classify a tectonic setting which occurred in this region.

### 1.2.1 Study area

The study area is geologically situated as a part of Loei Fold Belt. Samples of granitic rocks are collected from two areas. The first area is Takut Rai sub-district, Chon Daen district which contains the first location (latitude 16°10’38’’N / longitude 100°44’41’’E). The second area is Phaya Wang sub-district, Bueng Sam Phan district which consists two localitions (latitude 15°54’14’’N / longitude 100°49’44’’E; the second location and latitude 15° 55’36’’N / longitude 100°47’35’’E; the third location). These localitions are the representative area of Loei Fold Belt.

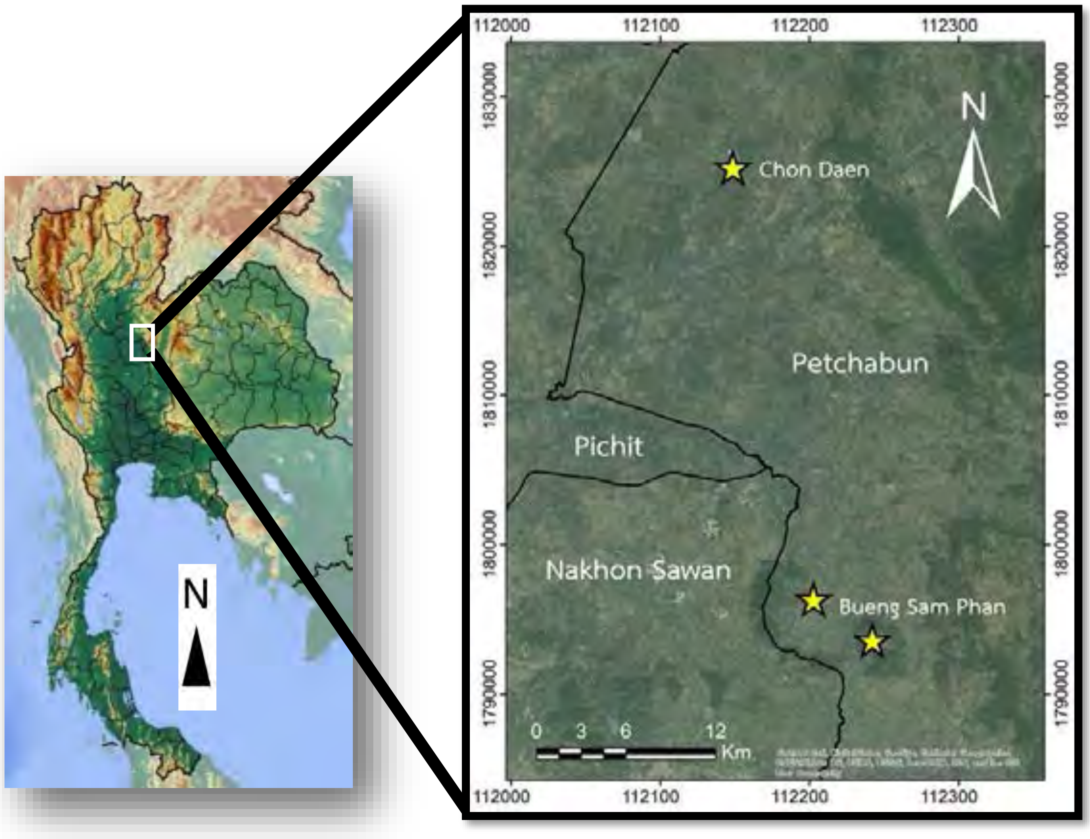


Fig 1.1 The map of study areas and the location of samples collecting. There are three locations, two of them are in Bueng Sam Phan district and the latter is in Chon Daen district, Phetchabun province.

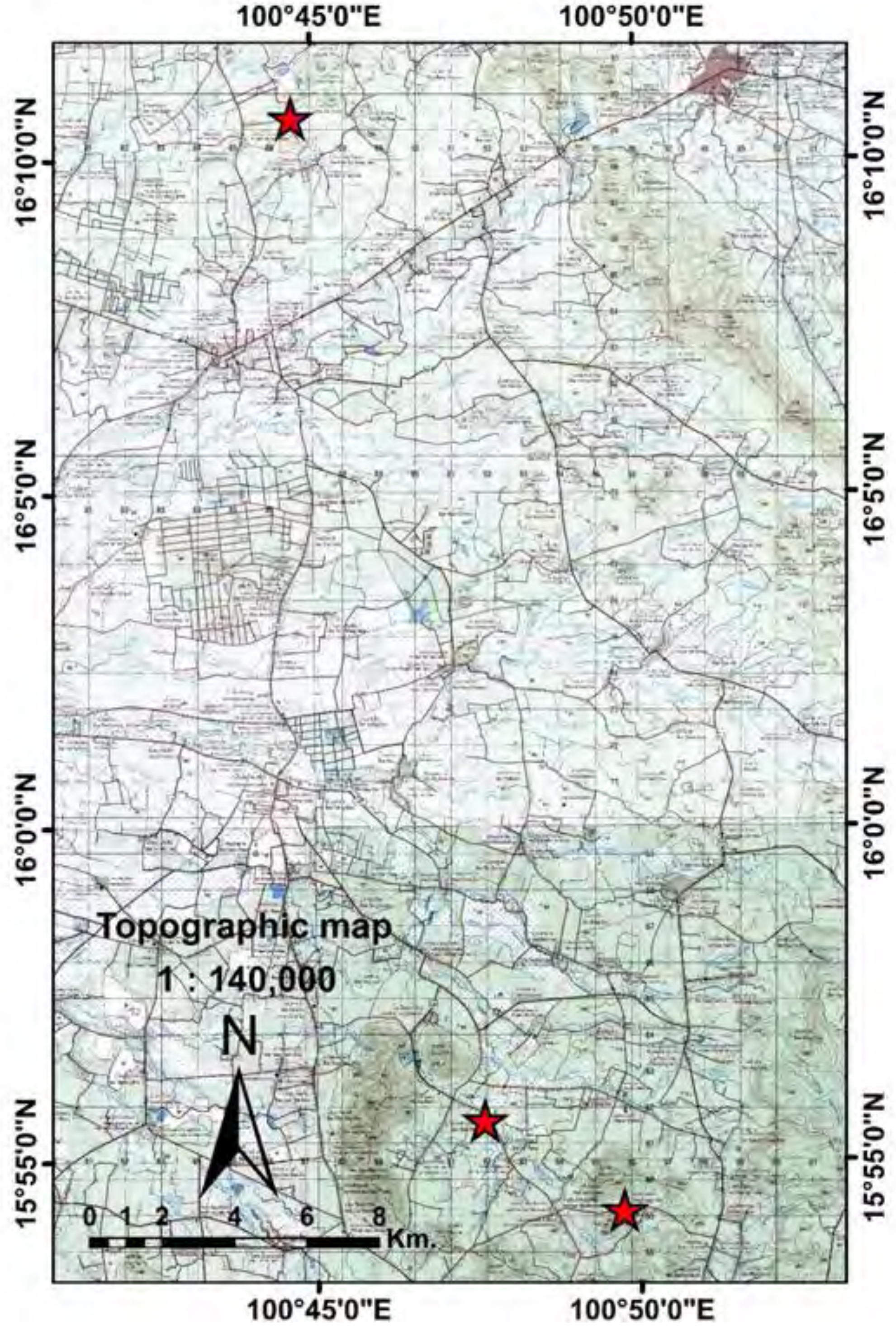


Fig 1.2 The topographic map (1: 140,000) of study areas and the location of samples collecting. Using 4 strips of L7018 series topographic map; 5140 I Ban Sap Mai Daeng, 5141 II Amphoe Chon Daen, 5141 III Amphoe Thap Khlo and 5140 IV Amphoe Nong Bua. Three red stars show the location of samples collecting.

### 1.2.2 Accessibility

The distance from Bangkok to study area is 300 kilometers approximately. The route from Bangkok to Sing Buri province can be traveled via Phahon Yothin road and change to the national highway No.32 (Asian Highway No.2; AH2). Then, head northeasterly using the national highway No.11 from Sing Buri province to Thap Khlo district, Phetchabun province. Next, go northeasterly to road No.2029 road and turn southwesterly to road No.113. Then, we will reach Dongkui municipality and head northerly to the unnamed road (latitude 16°7’11’’N / longitude 100°43’50’’ E) near Kasikornbank Public Company Limited (Dongkui branch). For about 7 kilometers, we will reach Sila Thaweechok mill stone factory which is the first location for samples collecting.

The journey to the second and third location started at Kasikornbank Public Company Limited (Dongkui branch). Then, head northeasterly along road No.113 and turn southeasterly at the junction (latitude 16°9’19’’ N / longitude 100°47’38’’E) to the unnamed road. Next, turn southerly to road No.3021 and turn easterly at the junction (latitude 15°53’48’’N / longitude 100°51’7’’E) to another unnamed road. Head easterly along unnamed road, the outcrop of second location is situated near the pond (latitude 15°54’14’’N / longitude 100°49’44’’E) on the southern side of the road.

Then, head easterly along same unnamed road and turn northwesterly to road No.5056. Drive along road No.5056 for a while the looseblocks of third location are situated in the field of pasture area (latitude 15° 55’36’’N / longitude 100°47’35’’E) on the southwestern side of the road.


Fig 1.3 The accessibility map of study areas, the black line is the route used during field investigation. Three red stars show the location of samples collecting. (modified after Tourism Authority of Thailand)

## 1.3 Previous works

### The eastern granitoid belt

From previous studies, the granitic rocks in Phetchabun province belonged to the Eastern granitoid belt of Thailand (Mitchell, 1977; Charusiri et al., 1993). Petrologically, this granitoid belt contains essentially quartz, alkali feldspar which is mostly orthoclase and plagioclase feldspar. Moreover, the mafic minerals such as brownish green to green hornblende and biotite are also presence in this belt. Geochemically, the petrogenesis of the eastern granitoid belt is come from partial melting or crystal fractionation of true magma (Charusiri et al., 1993). Therefore, the granitoid belt is classified to I-type affinity (Chappell and White, 1974).

Nanthasin (2004) investigated about the relationship among intrusive rocks in Ban Phosawan area, Bueng Sam Phan district, Phetchabun province covering 176 square kilometers. Lithologically, these intrusive rocks can be divided into four types: gabbro, diorite, quartz diorite and hornblende-biotite granodiorite. This shows the trend of composition ranging from mafic to felsic. In addition, most of them are I-type affinity and Calc-Alkaline series. The data from trace elements indicates these intrusive rocks to have emplaced in volcanic arc setting. This rock suite has been originated from the same magma source due to their rare earth spider diagram patterns. According to LA-ICPMS zircon U-Pb technique, the rocks yielded 230 ±4 Ma in age, middle Triassic period.

Kamvong et al. (2006) studied about igneous rocks at Wang Pong district, Phetchabun province. He classified the plutonic rocks in his study area into 2 types; biotite granite and granodiorite. He discussed that plutonic rocks are involved with the late stage arc magmatism. Geological, geochemical and petrological data suggested that these plutonic rocks are related to late to post subduction mechanisms during late Permian period to Early Triassic period (Permo-Triassic). Furthermore, he also concluded that biotite granite is possibly fractionated from granodiorite by crystal differentiation.

Fanka et al. (2017) studied about granitic rocks at Wang Nam Khiao district, Nakhon Ratchasima province and classified it into 3 units; Carboniferous biotite granite, Late

Permian hornblende granite and Triassic biotite-hornblende granite. The various emplacement age implies the multiple phases of arc magmatism caused by subduction of Paleo-Tethys beneath Indochina terrane during Late Carboniferous/Early Permian period, Late Permian period and Middle Triassic period. They were also interpreted as I-type granites based on their mineralogy and petrography. Their petrogenesis is Calc-Alkaline magmatic series and mineral assemblages support the model of hydrous magma with low degree of partial melting. The source of parental magma is likely differentiated from mantle-crust magma.

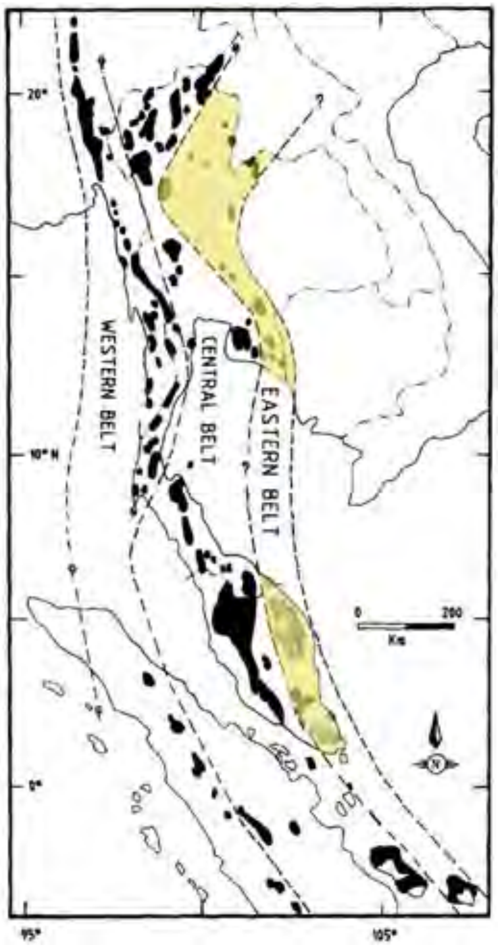


Fig 1.4 The distribution of granitoid rocks in Thailand (modified after Charusiri et al., 1993). The eastern granitoid belt is highlighted in yellow.

## 1.4 Methodology

### 1.4.1 Previous study

The previous studies relevant to study area had been considered. Literature about the petrography, petrogenesis and geochemistry of granitic rocks have been studied. In many aspects, regional geology and tectonic setting of the study area have been considered.

### 1.4.2 Study area selection

The unresearched granitic outcrops locally situated in Phetchabun province are carefully investigated. The suitable study area had been selected. And the easiest route to the site was well planned.

### 1.4.3 Field observation and samples collecting

These processes were completed during 23-26 November 2017. Fresh rock samples were randomly collected, and the geographic coordinate was recorded in the study area. At the site, the rocks were broken into 3 to 7 pieces and labelled the number with permanent pen.

### 1.4.4 Laboratory process

These procedures can be divided into two pathways which are petrography and geochemical analysis.

#### 1.4.4.1 Petrographic analysis

To conduct the petrographic analysis, rock samples were cut into a thin rocks slabs. Then, the slabs were polished to smooth the attached surface. The polished slabs were applied with balsum on the cover glass. Next, the attached slabs were grinded to the thickness at 0.03 mm. Finally, the thin sections were prepared and ready to examine by conducting modal analysis via the polarizing microscope.

1.4.4.2 Geochemical analysis

The thin rock slabs were pulverized into powder using disc mill. The powder samples were weighed at 8 grams and mixed with 1 gram of binder. Then, the mixed powder samples were pressed in the hydraulic pellet press. Finally, the pressed pellets were ready to analyze in X-rays fluorescence spectrometry (model: Pioneer Bruker AXS S4 at Department of Geology, Faculty of Science, Chulalongkorn University).

1.4.5 Discussion and Conclusion

The petrological and geochemical results were discussed in terms of petrogenesis of granitic rocks. The whole discussed results were summarized in the aspect of tectonic setting of Loei Fold Belt. Lastly, the types of tectonic setting were indicated.

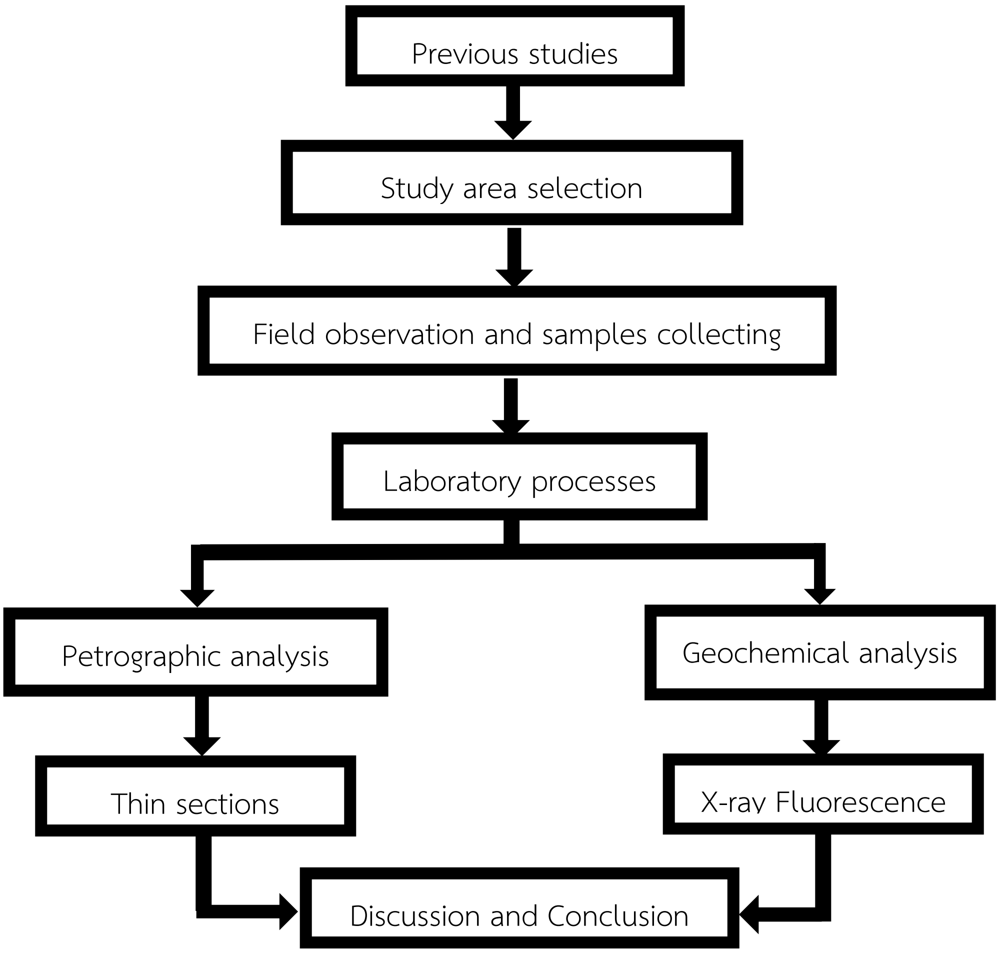


Fig 1.5 The flow chart describes the methodology of this study.

# Chapter 2

## Geological Setting

### 2.1 Regional Geology

Phetchabun province is partially located in the northeastern part of Central plain region and northwestern part of Northeast region. The province is tectonically located on Loei-Phetchabun-Nakhon Nayok Volcanic Belt between the Shan-Thai and Indochina terranes (Bunopas & Vella, 1983; Charusiri et al., 2002). Its regional geological setting is a high area of outcropping Upper Paleozoic and Mesozoic sedimentary and volcanic rocks. These outcrops have been folded and faulted extending in N-S direction. The unconformably overlying rocks are gently folded Upper Mesozoic non-marine sedimentary rocks.

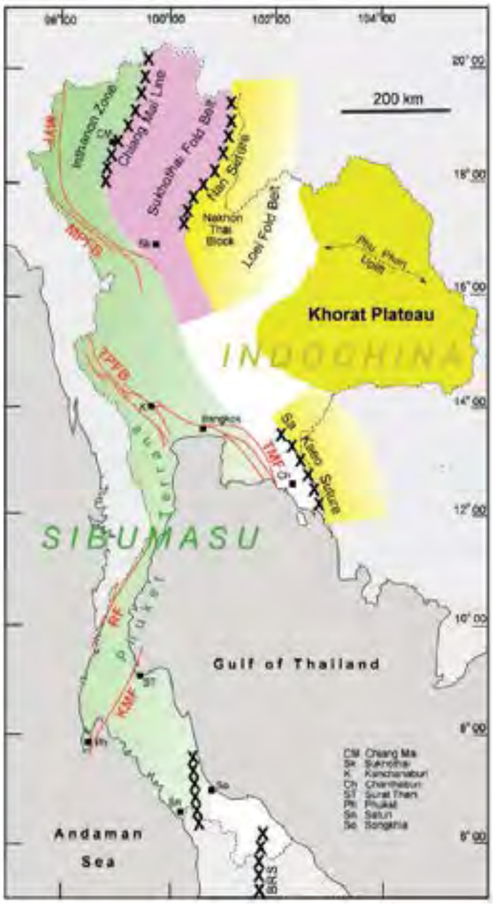


Fig 2.1 Tectonic terranes of Thailand which contain Sibumasu Terrane, Sukhotai Fold Belt, Loei Fold Belt and Khorat Plateau. The XXXX lines are the main tectonic lines which abbreviated as MYF: Mae Yuam Fault; MPFB: Mae Ping Fault Belt; TPFB: Three Pagodas Fault Belt;TMF: Tha Mai Fault; RF: Ranong Fault; KMF: Khlong Marui Fault; BRS: Bentong-Raub Suture. (Ridd et al., 2011)

## 2.2 Stratigraphy

### 2.2.1 Sedimentary Rocks, Metamorphic Rocks and Sediments

The division of these rock units was based on the evidence of fossils of upper Paleozoic rocks and attitude of bedding. The age correlation was based on the geological map scale 1:250,000, Phetchabun province strip (Chonglakmani and Sattayarak., 1979)

2.2.1.1 Carboniferous Rocks (360-286 Ma)

This rock unit (C) discontinuously crop out to the western part of province around Chon Daen district. And can be grouped into Wang Sa Pung Formation. It consists of grey slaty shale, brown shale, grey chert, brown sandstone and conglomerate.

2.2.1.2 Carboniferous to Permian Rocks (360-245 Ma)

Carboniferous to Permian rocks (CP) are scatteringly crops out near the Carboniferous rocks and mainly composes of sandstone, siltstone, black to greenish grey shale and mudstone. Conglomerate and slaty shale can be found in some area. This rock unit is widespread in Wang Pong, Chon Daen and Wichian Buri district.

2.2.1.3 Permian Rocks (286-245 Ma)

Tak Fa Formation ($P_{tf}$) contains massive to laminated grey to black limestone with black chert nodule and grey shale in some part. The distribution is around the central part of the province to the west and the south.

Pha Nok Khao Formation ($P_{pn}$) consists of chert and shale which interbedded with limestone in the lower part. The upper part composes of partially recrystallized massive grey to black limestone intruded by the volcanic rocks. Its distribution covers Chon Daen district continuing to Nong Phai district.

Hua Na Kham Formation ($P_{hn}$), dominated by clastic rocks, also comprises of limestone lens, grey shale, yellow sandstone, siltstone and some pyroclastic rocks such as tuff and agglomerate. It widely distributes in Nam Nao district continuing to western part of province and ends in Si Thep district. Furthermore, it can be found in Wang Pong district which is the central part of the province continuing to Nong Phai district.

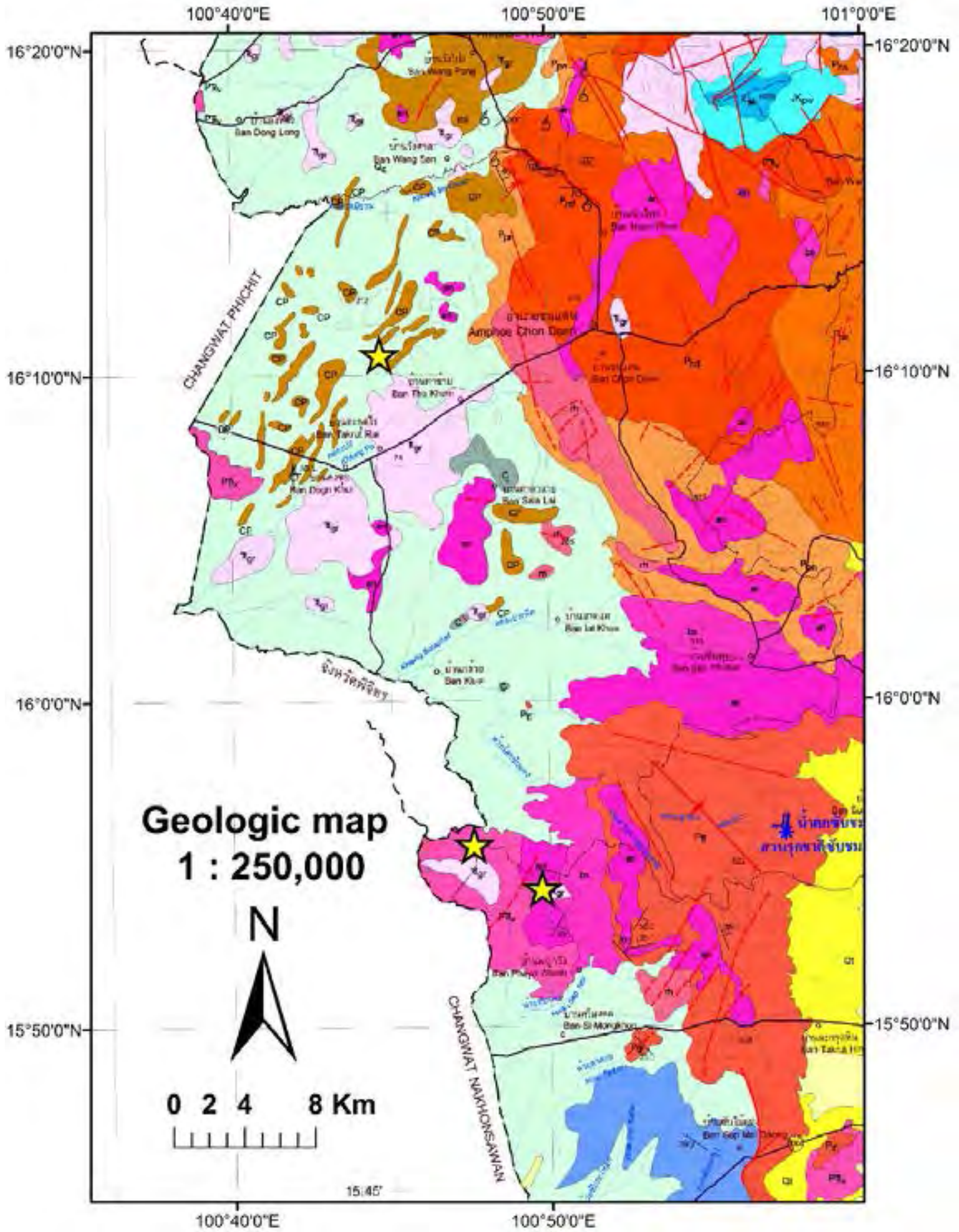


Fig 2.2 The geologic map (1: 250,000) of Chon Daen and Bueng Sam Phan districts covers the study area. The yellow stars are the location of sample collecting. (modified after DMR, 2009)

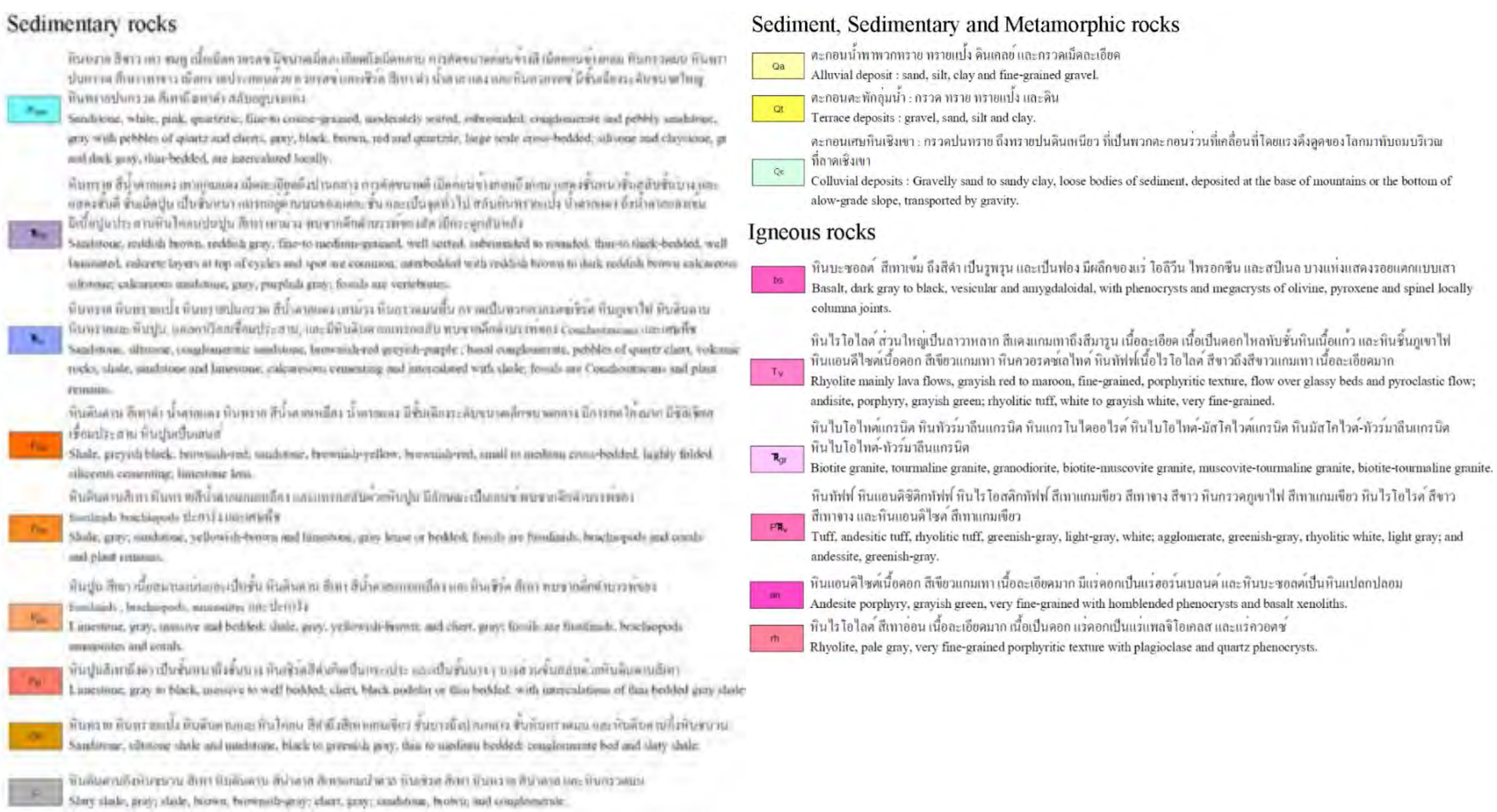


Fig 2.3 The legend shows geological units in the study area including abbreviated form of rock or sediment units, color and lithological information. (DMR, 2009)

Nam Duk Formation ( $P_{nd}$) composes of blackish grey calcareous limestone and yellowish brown calcareous sandstone which are highly folded. Small to medium cross-bedding can be found in clastic rocks. This formation distributes in Lom Kao district and continues to the southern part of the province in Wichian Buri district.

2.2.1.4 Triassic Rocks (245-210 Ma)

Huai Hin Lat Formation ($Tr_{hl}$) of Khorat Group. The lowest part is dominated by basal conglomerate. This formation consists of conglomerate, sub-greywacke, calcarenite and siltstone. Some parts of this rock unit have been intruded by Late Triassic igneous rocks which recrystallizing to quartzite. Epidote and diopside are also occurred in some parts where high calcium carbonate rocks existed. In Phetchabun province, color of the rock unit changes to red which likely caused by the source of sediments were rhyolite or formed in more shallow water condition. Huai Hin Lat formation is widely outcropped in northern part of province and southeasterly continues to Nam Nao district.

Nam Phong Formation ($Tr_{np}$) of Khorat Group. It mainly composes of sub-rounded to rounded fine to medium grained well-sorted reddish brown sandstone interbedded with calcareous dark brown siltstone, calcareous grey mudstone. Distribution covers the northern part to the southeastern part of province at the rim of Huai Hin Lat Formation.

2.2.1.5 Jurassic to Cretaceous rocks (210-66.4 Ma)

Phra Wihan Formation ($JK_{pw}$) of Khorat Group. This rock unit has high resistivity to weathering process. It composes of fine to medium grained well sorted and rounded quartzitic white sandstone with cross-bedding. It widely distributes at the rim of Phu Kradung Formation in the northern and central part of province

2.2.1.6 Quaternary unconsolidated Sediments

These sediments consist of unconsolidated and semi-unconsolidated sediments which have yielded the age at 1.6 Ma – present. The classification of Quaternary sediments is based on geomorphological feature, depositional environment and type of sediment. These sediments deposit in rivers and plains. It can be also used as construction materials and categorized into three types.

- Colluvial Deposits ($Q_c$)

  The deposit is mostly gravel, sand and clay. It formed by the avalanche of unconsolidated sediments near the foothills.

- Terrace Gravels ($Q_t$)

  It exposes at the west and east of Phetchabun basin showing the small dune-like geometry. The height of each depends on its laterite layer. The formation of these gravels may relevant to Pa Sak river.

- Alluvial Deposits ($Q_a$)

  The deposition of these sediments is occurred by gullies erosion and overflow of the main rivers such as Pa Sak river. The alluvial deposits comprise of clay sand or silty sand which overlying gravel layer and bedrock.

**2.2.2 Igneous Rocks**

Igneous rocks can be classified by the mode of occurrence into 2 types: plutonic rocks and volcanic rocks. The plutonic rocks emplace in the deep depth and are crystallized from the magma. The texture is medium-coarse or coarse-grained (the grain size is up to 1 millimeter). Granite, the best well-known plutonic rocks, is closely related to the occurrence of many economic minerals e.g. tin, tungsten, fluorite and barite. The volcanic rocks are made by the volcanic eruption and cool down at the Earth's surface. The texture of volcanic rocks is aphanitic texture (fine-grained texture). Its occurrence is very closely relevant to gold, copper and other metals mineralization. Soil, which eroded from these volcanic rocks, is the abundant source of nutrients for plants and plays the significant role for agriculture.

2.2.2.1 Permian Volcanic Rocks (286-245 Ma)

This igneous rock unit can be divided into two sub-groups of volcanic rock based on lithological differences; andesite unit (an) and rhyolite unit (rh). Andesite unit contains very fine-grained grayish green andesite porphyry with hornblende phenocrysts and basalt xenoliths. Rhyolite unit consists of very fine-grained pale gray rhyolite porphyry with plagioclase feldspar and quartz phenocrysts.

2.2.2.2 Permo-Triassic Volcanic Rocks (286-210 Ma)

The volcanic rocks in Phetchabun province is mainly composed of rhyolite, basaltic andesite, agglomerate, tuff, welded tuff and andesite in some area. The mode of occurrences is dyke, sill, lava flow and layer of pyroclastic deposits. It widely covers in the northern, central and southern part of province.

2.2.2.3 Triassic Plutonic Rocks (245-210 Ma)

These plutonic rocks consist of biotite granite, tourmaline granite and biotite-muscovite granite. The distribution is in the central and western part of province. Most of them have two crystal sizes which hornblende, tourmaline and feldspar are phenocryst.

2.2.2.4 Cenozoic Volcanic Rocks (66.4-1.6 Ma)

Cenozoic volcanic rocks can be divided into two sub-groups: rhyolite to andesite unit ($T_v$) and basalt unit (bs). The felsic to intermediate volcanic rock unit is composed of fine-grained grayish red to maroon rhyolite lava flows with porphyritic texture, grayish green andesite porphyry, very fine-grained white to grayish white rhyolitic tuff. Basalt unit consists of vesicular and amygdaloidal dark gray to black basalt with phenocrysts and megacrysts of olivine, pyroxene and spinel. Columnar jointing is observed in some parts.

## 2.3 Structural Geology

2.3.1 Unconformity

The feature indicates the gap of ages between the older and younger stratum which has been eroded or experienced in some geological processes such as uplifting. This gap changed the type and depositional environment of sediments. These unconformities can be divided into 3 periods based on the age of tectonism.

2.3.1.1 Early Triassic Period

The angular unconformity lies between late Paleozoic rocks and Triassic sedimentary rocks. And nonconformity lies between Permo-Triassic volcanic rocks and Triassic sedimentary rocks. The evidence indicating these gaps is basal conglomerate layer which contains the older gravel and the changed of sedimentary feature.

2.3.1.2 Late Triassic Period

The disconformity and nonconformity situated between late Jurassic rocks and the older rocks. The evidence is the variation of composition in sedimentary rocks. Triassic rocks are mostly formed by the rock fragments of the older rocks such as pyroclastic rocks and chert. Jurassic rocks are formed by quartz gravel which presumably eroded from late Triassic granite. However, the unconformity between Triassic and Jurassic rocks is likely to be disconformity. Moreover, Jurassic rocks have overlied the volcanic rocks in some areas without Triassic rocks showing the feature of nonconformity.

2.3.1.3 Early Paleogene Period

This stage is marked by the extension tectonic forming Phetchabun basin. The unconformity lies between Paleogene and the older rocks.

### 2.3.2 Folds

The characteristic of folded late Paleozoic rocks is open fold where the axial plane paralleling with the present bedding plane in N-S direction and low plunging degree. This structure is a syncline with an axial plane conformably lies with Triassic sedimentary rocks. The distribution covers the area of Wang Pong southward to Chon Daen district. The western and eastern outer limb are Carboniferous rocks and Permian rocks respectively. The whole Carboniferous rocks has been faulted in N-S direction making it to depression topography which is a basement rock of Phetchabun basin.

### 2.3.3 Faults and Fractures

Topographically, the aerial photograph and field data show the trends of faults and fractures occurred in Phetchabun province into 3 trends.

2.3.3.1 NNE-SSW and NNW-SSE Faults

These trends can be obviously observed by aerial photograph and categorized as normal fault. The fault length is higher than 5 kilometers and can be up to 15 kilometers.

2.3.3.2 NE-SW and NW-SE Faults

These faults are likely to be strike-slip or oblique fault which make little displacement to the rocks. But these trends are less prominent than the first trend.

2.3.3.3 E-W faults

The small faults with low displacement and unable to identify the type of faults. It may have occurred in Triassic period related to the emplacement of granitic rocks.

# Chapter 3

## Results

### 3.1 Geology

Based on the locations and lithological characteristics from hand specimens, the granitic rocks in this study can be divided into two groups: Chon Daen granitic rocks and Bueng Sam Phan granitic rocks.

Chon Dean granitic rocks, first location, are medium to coarse grained with rounded-shape colorless quartz crystals (0.2-0.7 cm.), rusty red feldspar (0.3-0.6 cm.) and some flaky deep brown to black biotite (0.1-0.4 cm.) as major minerals. Accessory minerals are pyrite, chlorite and opaque minerals. Locally, these Chon Daen granitic rocks can be called "Dongkui granite" (Salam, 2013). In accordance with Khin Zaw et al. (2007), it yielded the age of 310 ±8 Ma (Late Carboniferous). In this chapter, Chon Daen granitic rocks are abbreviated as DK1 based on the location of this outcrop.


Fig 3.1 (A) The picture shows the outcrop of Chon Daen granitic rocks (DK1) near Sila Thaweechok mill stone at Takut Rai sub-district, Chon Daen district, Phetchabun province.

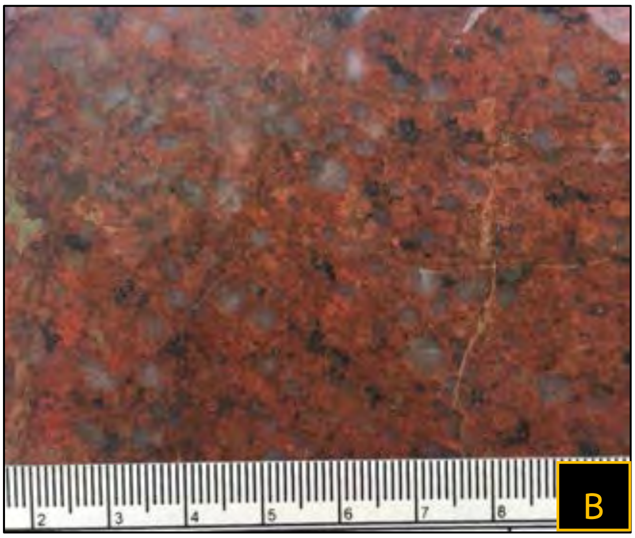


Fig 3.1 (B) The slab of Chon Daen granitic rocks. The interval of ruler scale is 1 cm.

Bueng Sam Phan granitic rocks can be divided into two sub-groups: the second location and third location. These sub-groups share some similar features such as color, mineral assemblages and mafic xenoliths (Fig 3.2 C). The second location is fine grained rocks which compose of quartz, feldspar and biotite as major minerals. Some pyrite and opaque minerals are present as accessory minerals. The average grain size is in range of 0.1-0.3 cm. (Fig 3.2 B). The third location is fine to medium grained rocks which has yielded the age of 249.4 ±4.9 Ma (Khositanont, 2008). (Fig 3.3 B). It contains mafic minerals more than another one with average crystal size of 0.2- 0.4 cm. Lath-shaped of feldspar crystals are obvious. These Bueng Sam Phan granitic rocks at second and third locations are abbreviated as BSP1 and BSP2 respectively.


Fig 3.2 (A) The picture shows the outcrop of Bueng Sam Phan granitic rocks (BSP1) located at Phaya Wang sub-district, Bueng Sam Phan district, Phetchabun province. Geological hammer for scale. (B) The slab of the second location of Bueng Sam Phan granitic rocks. The interval of ruler scale is 1 cm. (C) The picture shows the mafic xenolith which comprises of fine-grained dark mafic minerals such as biotite and hornblende. Geological hammer for scale.


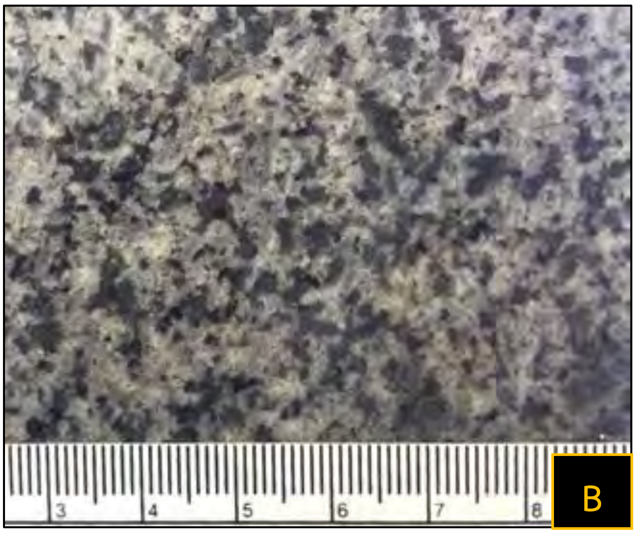


Fig 3.3 (A) The picture shows the looseblocks of the Bueng Sam Phan granitic rocks (BSP2) located at Phaya Wang sub-district, Bueng Sam Phan district, Phetchabun province. (B) The slab of the third location of Bueng Sam Phan granitic rocks. The interval of ruler scale is 1 cm.

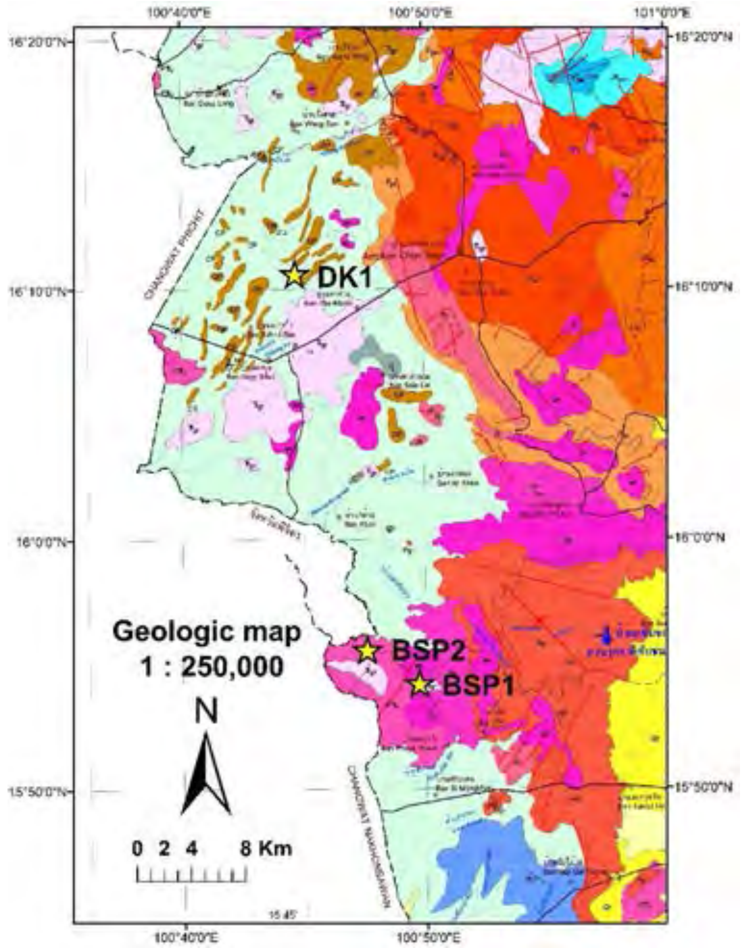


Fig 3.4 The geologic map of study area, showing the location of samples collecting.

### 3.2 Petrography

Petrography investigation of this study includes texture description and mineral abundance of the rocks. All rock samples were cut into slab, then attached with glass slide and polished until the thickness has reached to 0.03 mm. Next, the thin sections were covered with cover glass and ready for examination. The texture description is based on its optical diagnostic property of each mineral which are extinction angle, birefringence and relief of mineral grains. Mineral abundance is focused on the content of each minerals (especially on quartz, K-feldspar and plagioclase feldspar) and counted in percent by performing NIS-Elements BR software. By using the polarized light microscope, the overall information is gathered.

### 3.2.1 Chon Daen granitic rocks

**DK1**

Under polarized light microscope, these medium to coarse grained plutonic rocks show holocrystalline (almost) and inequigranular texture. Individual crystal forms are subidiomorphic to allotriomorphic form ( subhedral crystal form in quartz and plagioclase feldspar, anhedral form in K-feldspar and biotite). So, the whole-rock crystal form is hypidiomorphic to allotriomorphic form. Chon Daen granitic rocks also show a deformational feature such as micro-fault which tearing the single crystal apart. The rocks also experienced in low degree of alteration shown by the existence of pale green chlorite (Fig 3.6 A).

Quartz composes at least 20 to 25% of all minerals. It shows a round-shaped and typically 3 to 5 mm. in size. Moreover, it shows colorless, low relief and birefringence with subhedral form. Some of them are isotropic grain with no extinction occurred, however the rest always shows undulatory extinction.

K-feldspar is about 30 to 35%, and always show anhedral form. It exhibits pale brownish red under plane polarized light and has 4 to 5 mm. in size. The crystals are always occupied the dusty feature. Some part of the crystal is altered to clay minerals and sericite.

Plagioclase feldspar is dominated at 25 to 30%, 3 to 5 mm. in size and exhibits the albite or carlsbad twin. Some of them show zoning when rotating the stage and are slightly weathered. The crystals form is subhedral.

Biotite comprises about 15 to 20% which usually shows flaky and tabular habit with strong pleochroism (pale brown to dark brown). It always shows one direction cleavage. The size is approximately at 1 to 4 mm.

Chlorite is present in amount of 1 to 3% and always coexists with a biotite grain nearby exhibiting a weak pale green pleochroic color. It might be altered from the mafic mineral.

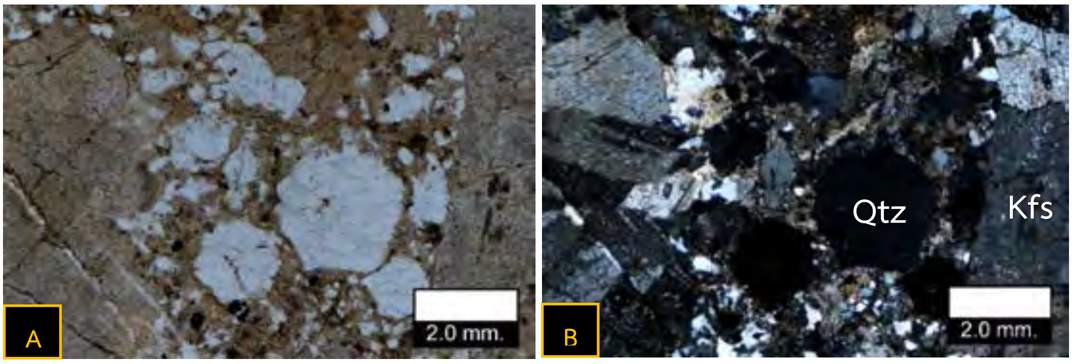


Fig 3.5 (A and B) The photomicrographs show Chon Daen granitic rocks (DK1). Round-shaped subhedral quartz grains and anhedral K-feldspar grains are present. Notice that K-feldspar crystals are more weathered than quartz grains. The length of scale bar is 2.0 mm. (Kfs: K-feldspar, Qtz: Quartz) (1X)

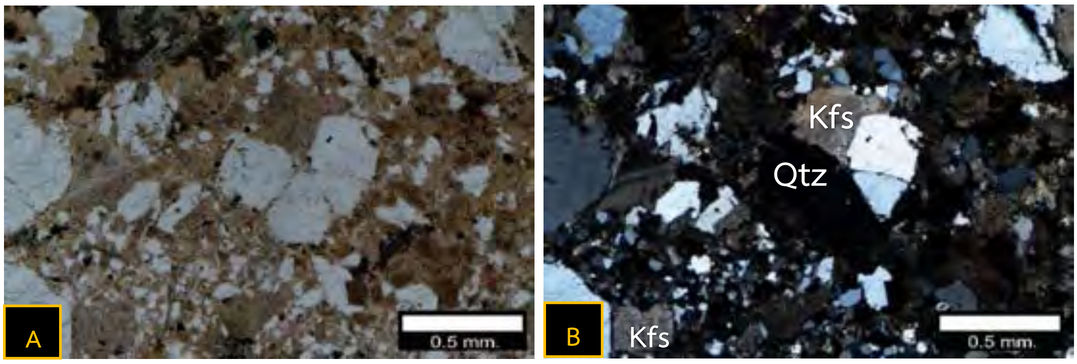


Fig 3.6 (A and B) Fine-grained quartz and K-feldspar crystals are existed. The flake of chlorite is shown in plane polarized light photomicrograph. The length of scale bar is 0.5 mm. (Kfs: K-feldspar, Qtz: Quartz) (5X)

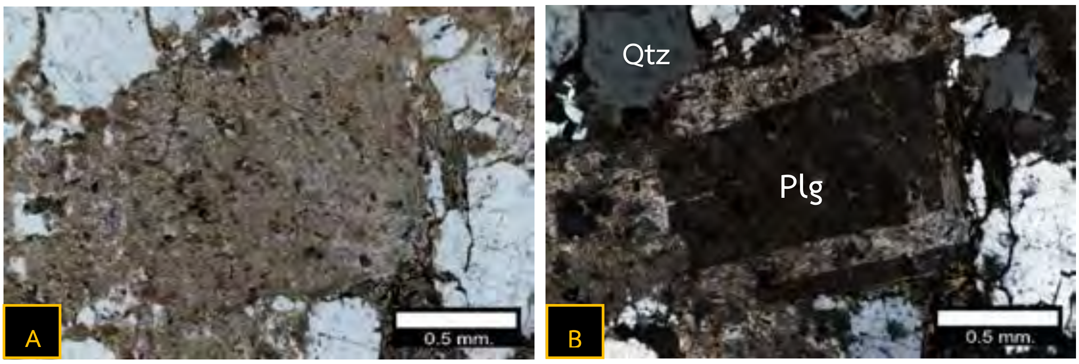


Fig 3.7 (A and B) Lath-shaped of plagioclase feldspar crystal exhibits the albite twin and is altered to clay minerals in some parts. The length of scale bar is 0.5 mm. (Qtz: Quartz, Plg: Plagioclase feldspar) (5X)

### 3.2.2 Bueng Sam Phan granitic rocks

**BSP1**

Microscopically, the granitic rocks at second location exhibits a fine grained holocrystalline, inequigranular texture that showing seriated porphyritic texture. The entire crystal form is roughly hypidiomorphic. Quartz, K-feldspar and biotite crystals are anhedral, while plagioclase feldspar crystals show subhedral form. Sutured grain boundary, allotriomorphic feature, is common between quartz and other minerals. Quartz, K-feldspar Some opaque minerals, apatite and zircon are existed in low content.

Quartz is about 15 to 20%, showing undulatory extinction and sutured grain boundary. The average grain size is in range of 0.5 to 1.5 mm. It always shows the anhedral form.

Plagioclase feldspar is in range from 40 to 45% that is the most abundant mineral of the sample. The crystal size is in range of 0.4 to 1.2 mm. Texturally, plagioclase always has a blade-like or lath shape crystal. Carlsbad and albite twin are the typical feature of this mineral. Zoning texture is typically observed. According to the determination of composition in plagioclase feldspar by performing Michel-Levy method on more than ten grains, the anorthite content is in the range of $An_{37-60}$ reflecting the composition of andesine ($An_{30-50}$) to labradorite ($An_{50-70}$). Some crystals are moderately altered to sericite showing a orangish yellow spots interference color.

K-feldspar is only about 5 to 10%. Its anhedral form with slightly weathered crystal is a distinctive feature of this mineral. It possesses a very low birefringence and relief.

Biotite is approximately 10 to 15% in content. Its optical properties are obviously distinct from other minerals. The crystal size is about 0.4 to 1 mm. Strong pleochroism (pale brown to dark brown) and flaky habit with one direction cleavage are prominently noticeable. Under cross polarized light, it displays a high birefringence with orange and pinkish red interference color.

Hornblende is commonly in average of 10 to 15%. Its crystal form is subhedral to anhedral with rhombohedral shape cleavage in two directions along the crystal at the angle of 56 or 124 degrees. The relief is moderate to high relief with moderate birefringence. The size of crystals is in range of 0.5 to 0.8 mm. It exhibits a moderate pleochroism from dark green to pale brownish green under plane polarized light. Moreover, some crystals are altered to pale green chlorite.

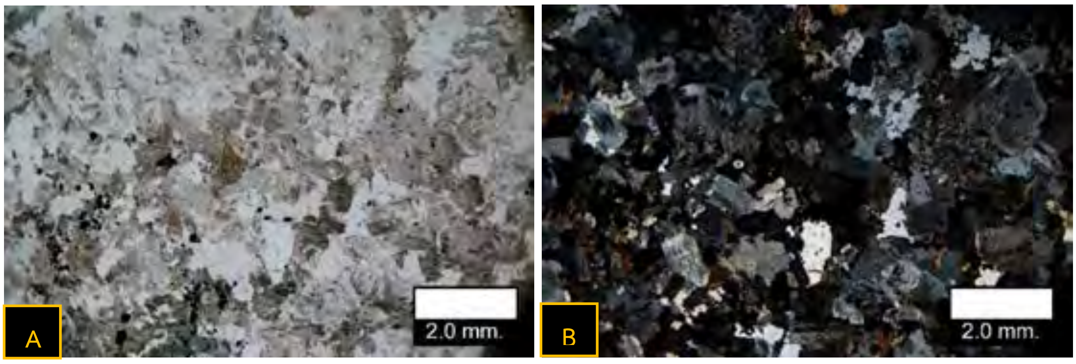


Fig 3.8 (A and B) The photomicrographs exhibit the Bueng Sam Phan granitic rocks (BSP1). Quartz and plagioclase feldspar are mainly dominated in this rock. With minor amount of pleochroic biotite and hornblende. The length of scale bar is 2.0 mm. (1X)

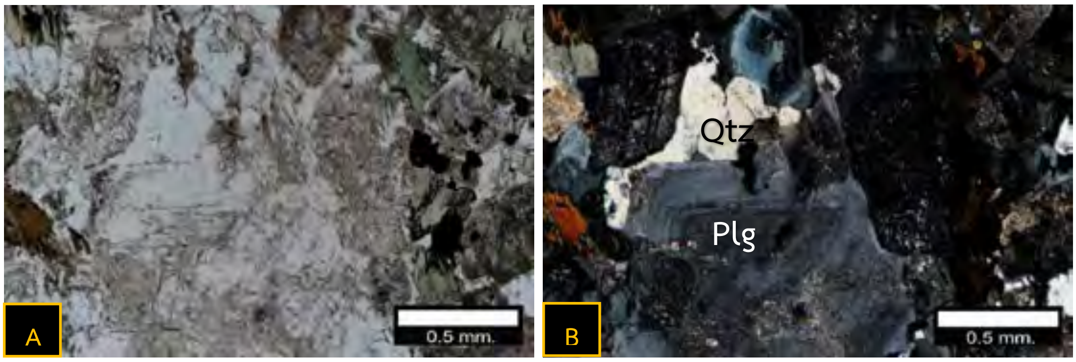


Fig 3.9 (A and B) In plane polarized light photomicrograph, pale green chlorite and strongly pleochroic dark brown biotite are present. In cross polarized light photomicrograph, a large slightly weathered plagioclase feldspar shows zoning feature. Some part in crystal is altered to sericite. The length of scale bar is 0.5 mm. (Qtz: Quartz, Plg: Plagioclase feldspar) (5X)


Fig 3.10 (A and B) Subhedral to anhedral form of hornblende crystals are shown with two direction cleavages and pale greenish brown pleochroic color. The length of scale bar is 0.5 mm. (Plg: Plagioclase feldspar, Hb: Hornblende) (5X)

BSP2

By studying mineralogical features under polarizing microscope, this rock unit has more mafic minerals than BSP1 rocks. Especially, hornblende and biotite are existed in significant amount. The rocks are holocrystalline, hypidiomorphic, inequigranular and seriated porphyritic texture. Poikilitic texture is shown by the overprinting of plagioclase feldspar or opaque minerals on hornblende crystals. The major minerals are quartz, plagioclase feldspar, hornblende and biotite, the accessory minerals are K-feldspar, pyrite, apatite and opaque minerals.

Quartz is about 20 to 25% of entire crystals. It always possesses the undulatory extinction and anhedral crystal form. The average size is in range of 0.5 to 0.8 mm. No pleochroism, low birefringence and relief are the main optical features which can be easily observed.

Plagioclase feldspar dominates at the amount of 45 to 50%. Crystal size is varying from 0.5 to 2 mm. with blade-like or lath shaped. With low birefringence and relief, plagioclase feldspar always displays albite and Carlsbad twin. From Michel-Levy method using for the determination of composition of plagioclase feldspar, the anorthite content is in the range of $An_{39-68}$ reflecting the composition of andesine ($An_{30-50}$) to labradorite ($An_{50-70}$). Sericite is commonly occurred in some crystals indicating the alteration.

Alkali feldspar is rarely found in this unit. It composes from 5 to 10%. The size is in range of 0.2 to 0.5 mm. The relief and birefringence are low with anhedral crystal form.

Biotite is about 10 to 15% in content. It shows a one direction cleavage along the crystal. The size is varying from 0.5 to 1.3 mm. with flaky habit and anhedral crystal form. The pleochroism is strong which changes from pale brown to dark brown. In cross polarized light, biotite displays a high birefringence and moderate to moderately high positive relief. Some crystals are altered to chlorite and pyrite.

Hornblende is up to 10 to 15%. It is about 1 to 2 mm. in size with subhedral to anhedral crystal form. It exhibits a moderately birefringence and moderate to moderately high relief. Its two directions cleavages at the angle at 56 or 124 degrees are typically observed. Moderate pleochroism in various shades of green and brown are obviously noticed. Some crystals have an embedded chadacryst of plagioclase feldspar. Chlorite is coexisted with some parts in the crystal.

Opaque minerals are embedded within hornblende and biotite crystal. The crystal size is 0.1 to 0.2 mm. with cubic shape. Based on the observation of hand specimens via handlens, these opaque minerals have a gold shining color. Based on these information, these should be pyrite.

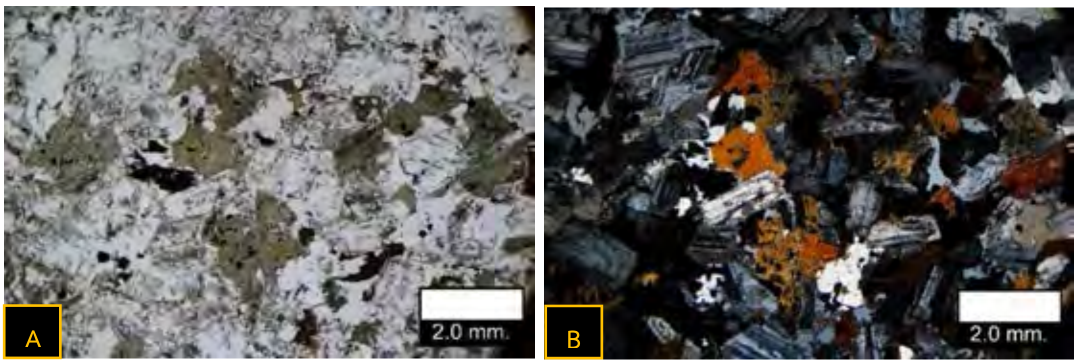


Fig 3.11 (A and B) The photomicrographs show of Bueng Sam Phan granitic rocks (BSP2). In plane polarized light, the greenish brown hornblende crystals display a moderate pleochroism. Moreover, it exhibits poikilitic texture with opaque minerals. The length of scale bar is 2.0 mm. (1X)

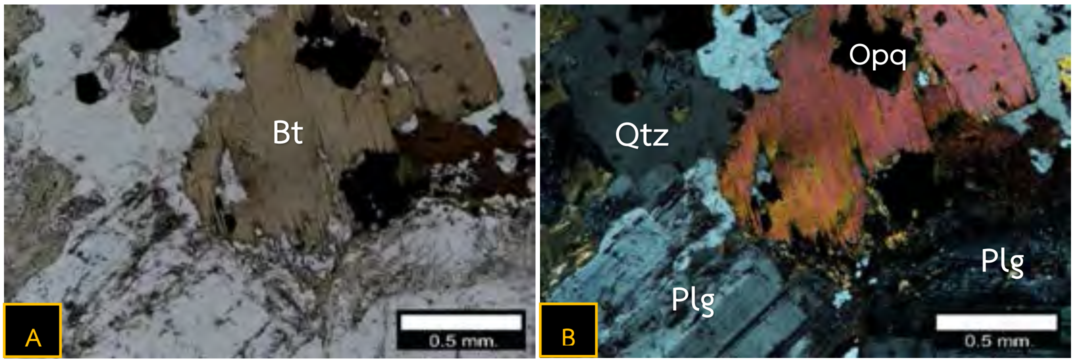


Fig 3.12 (A and B) The photomicrographs of biotite, quartz and plagioclase feldspar shows an allotriomorphic and intergranular texture. Chadacrysts such as quartz and opaque mineral are embedded in biotite crystals. The length of scale bar is 0.5 mm. (Qtz: Quartz, Plg: Plagioclase feldspar, Bt: Biotite, Opq: Opaque minerals) (5X)

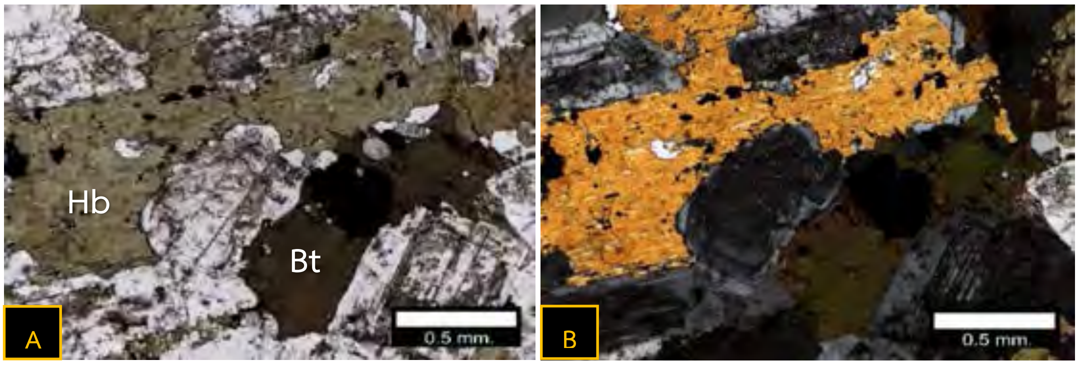


Fig 3.13 (A and B) The photomicrographs show anhedral hornblende with moderate pleochroism and flaky biotite with strong pleochroism. The length of scale bar is 0.5 mm. (Hb: Hornblende, Bt: Biotite) (5X)

### 3.3 Modal analysis

The purpose of modal analysis is to classify these plutonic rocks. Modal analysis of this study is mainly based on the classical point counting method by using NIS-Element BR software. All thin sections have been selectively counted only in quartz, alkali feldspar and plagioclase feldspar. Then, the percentage of these three minerals is calculated and plotted in the triangular QAP diagram (Streckeisen, 1974) established by International Union of Geological Sciences. Note that, QAP diagrams are also not used if mafic minerals make up more than 90% of the whole rock composition.

The results are shown in the Table 3.1 and plotted in QAP diagram (Streckeisen, 1974) in Fig 3.14. These granitic rocks have a compositional variation ranging from granite to tonalite. Chon Daen granitic rocks, the DK1 group, which have the content of modal quartz about 40.60 to 55.95%, modal alkali feldspar about 28.57 to 36.90% and modal

| Location | Group | Sample No. | Quartz (%) | Alkali feldspar (%) | Plagioclase feldspar (%) |
|---|---|---|---|---|---|
| Chon Daen | DK1 | DK1A | 40.60 | 28.57 | 30.83 |
| | | DK1B | 49.91 | 30.53 | 19.56 |
| | | DK1C | 55.95 | 36.90 | 7.14 |
| Bueng Sam Phan | BSP1 | BSP1A | 49.62 | 9.77 | 40.60 |
| | | BSP1B | 38.68 | 14.15 | 47.17 |
| | | BSP1C | 43.52 | 10.19 | 46.30 |
| | | BSP1D | 38.94 | 7.08 | 53.98 |
| | | BSP1E | 36.88 | 1.64 | 61.47 |
| | | BSP1F | 38.28 | 4.69 | 57.03 |
| | | BSP1G | 51.45 | 14.49 | 34.06 |
| | BSP2 | BSP2A | 34.74 | 0.85 | 64.41 |
| | | BSP2B | 37.04 | 1.85 | 59.26 |
| | | BSP2C | 32.69 | 3.84 | 63.46 |
| | | BSP2D | 29.81 | 5.77 | 64.42 |
| | | BSP2E | 29.91 | 3.74 | 66.35 |

Table 3.1 The percentage modal amount of quartz, alkali feldspar and plagioclase feldspar by classical point counting method via NIS-Element BR software.

plagioclase feldspar from 7.14 to 30.83% are categorized as granite. While, Bueng Sam Phan granitic rocks, the BSP1 group, are mostly named as granodiorite. The BSP1 samples have a modal quartz content ranging from 36.88 to 51.45%, modal alkali feldspar about 1.64 to 14.49% and modal plagioclase feldspar from 34.06 to 61.47%. The BSP2 samples fall within granodiorite to tonalite field. This group comprises of modal quartz from 29.81 to 37.04%, modal alkali feldspar from 0.85 to 5.77% and modal plagioclase feldspar from 59.26 to 66.35%.

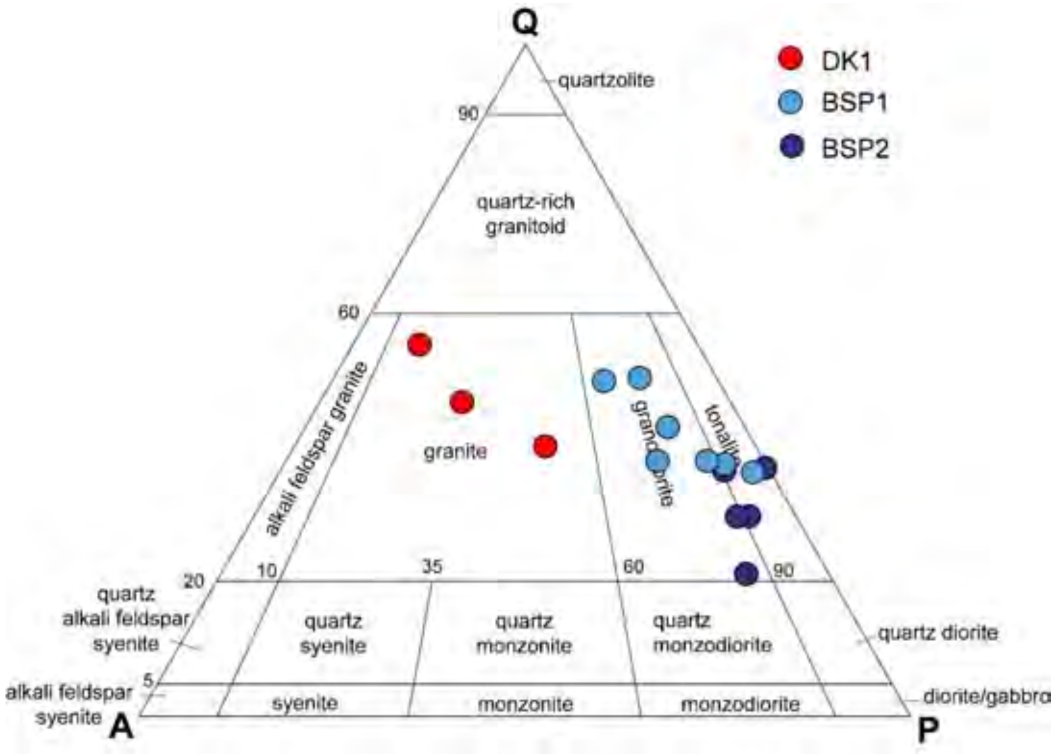


Fig 3.14 This QAP triangular diagram (Streckeisen, 1974) shows the granitic rocks in this study that can be categorized into three groups: granite, granodiorite and granodiorite to tonalite.

### 3.4 Whole-rock Geochemistry

The whole-rock geochemical results can be provided more details about petrogenesis and tectonic settings. The geochemical analysis is based on whole-rock geochemistry which is X-Rays Fluorescence Spectrometry elemental analysis. The weight percentage of ten major and minor oxides ($SiO_2$, $TiO_2$, $Al_2O_3$, $FeO_{(total)}$, MnO, MgO, Cao, $Na_2O$, $K_2O$ and $P_2O_5$) of fifteen rock samples were carried out by X-ray Fluorescence Spectrometry (model: Pioneer Bruker AXS S4) at Department of Geology, Faculty of Science, Chulalongkorn University. The results are presented in Table 3.2. By using the major oxides content, as displayed in Fig 3.15, the TAS diagram (Cox et al., 1979) shows the relations between $SiO_2$ and alkali oxides ($Na_2O$ and $K_2O$) of these granitic rocks. The DK1 group is fallen in granite field. The BSP1 and BSP2 group are plotted into diorite and quartz diorite field.

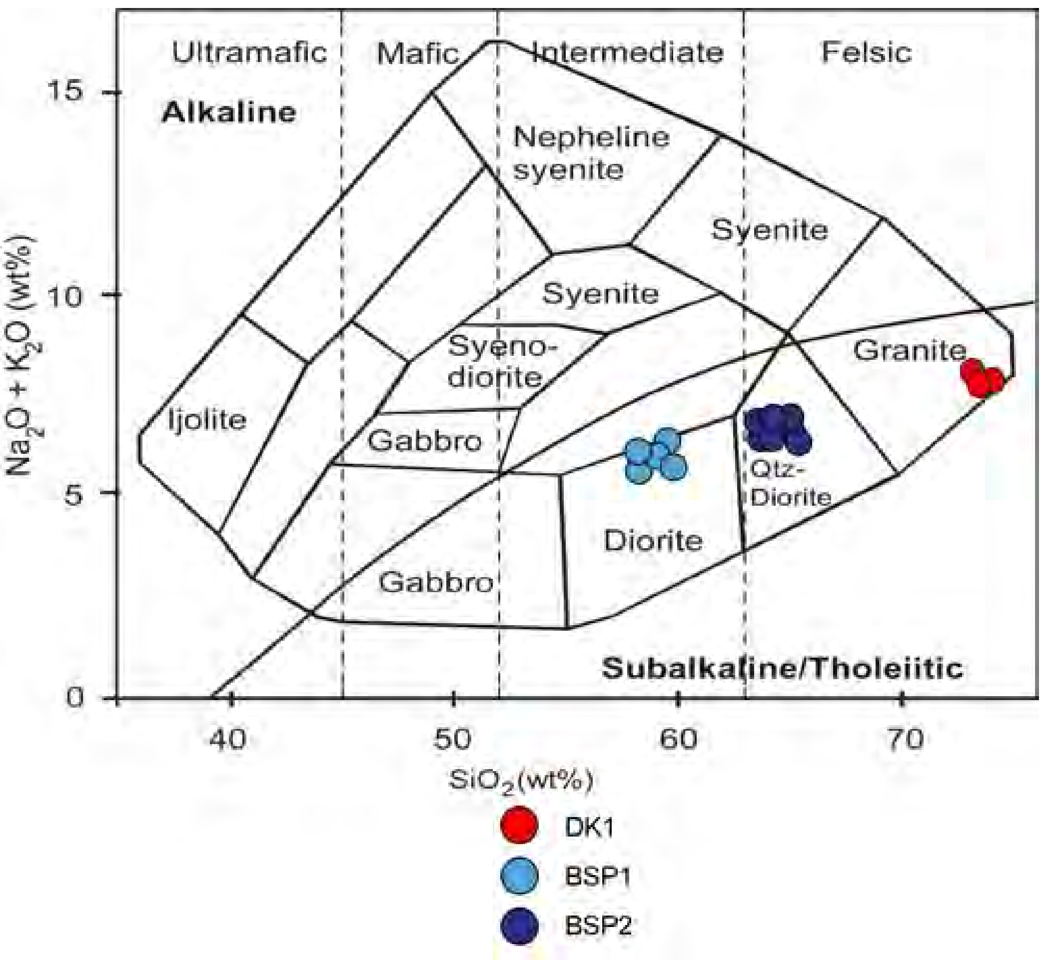


Fig 3.15 TAS discrimination diagram (Cox et al., 1979) of granitic rocks plotting with the total alkali oxides ($Na_2O$+$K_2O$) and $SiO_2$.

### 3.4.1 Granite

The geochemical characteristics of granite unit can be explained as follow. $SiO_2$ content ranges from 72.81 to 73.32% and $TiO_2$ from 0.22 to 0.25%. $Al_2O_3$ amount varies from 12.89 to 13.47%. $FeO_{(total)}$ is in the range of 2.29 to 2.53%. Amount of MnO is about 0.01 to 0.04%. MgO values range from 0.83 to 1.09%. CaO content varies from 0.94 to 1.15%. $Na_2O$ content is about 3.65 to 4.89%. $K_2O$ content ranges from 3.01 to 4.33%. $P_2O_5$ content is about 0.05 to 0.08%. The loss on ignition value is 0.964 to 1.128%. In conclusion, as revealed in Fig 3.16 of Harker variation diagram, $Na_2O$ and $Al_2O_3$ show a negative correlation to $SiO_2$.

### 3.4.2 Diorite

The geochemical characteristics of diorite unit can be summarized as follow. $SiO_2$ content is about 62.02 to 63.96%. Amount of $TiO_2$ is ranged from 0.48 to 0.58%. Amount of $Al_2O_3$ varies from 16.01 to 16.81%. $FeO_{(total)}$ is about to 3.91 to 4.24%. MnO, MgO and CaO content are 0.04 to 0.06%, 2.10 to 2.83% and 4.19 to 4.59% respectively. While, the alkali oxides i.e. $Na_2O$ and $K_2O$ content are 4.25 to 4.49% and 2.24 to 2.63% respectively. Amount of $P_2O_5$ ranges from 0.15 to 0.19%. And the loss on ignition is ranged from 1.652 to 1.753%. As shown in Fig 3.16, Harker variation diagram displays a positive correlation between $SiO_2$ and $Na_2O$. But, it shows a negative correlation between $SiO_2$ and $K_2O$, MgO, CaO, $P_2O_5$ and $TiO_2$. The others oxide element exhibits a narrow composition range with ambiguous correlation. To illustrate, the declination in $FeO_{(total)}$ and MgO against the increasing $SiO_2$ content indicates the magmatic differentiation. While, the increase in $Na_2O$ and decrease in CaO implies the crystal fractionation in plagioclase feldspar solid solution from high temperature to low temperature.

### 3.4.3 Quartz diorite

The geochemical characteristics of quartz diorite unit can be described as follow. $SiO_2$ content is about 57.97 to 59.46%. $TiO_2$ value ranges from 0.78 to 1%. $Al_2O_3$ content is 15.49 to 17.24%. $FeO_{(total)}$, MnO and MgO content are 5.63 to 6.82%, 0.08 to 0.11% and 3.04 to 4.42% respectively. CaO value is about 6.33 to 7%. $Na_2O$ and $K_2O$, the alkali oxides, are about 3.73 to 4.34% and 1.63 to 2.13% respectively. $P_2O_5$ content is from 0.27 to 0.35%. And the loss on ignition is from 0.763 to 1.092%. Harker variation diagram (Fig 3.16), shows the trend of negative correlation between $SiO_2$ and CaO, $FeO_{(total)}$, MgO, $P_2O_5$ and $TiO_2$. The value of $K_2O$, $Al_2O_3$ and $TiO_2$ show a scattering composition range with obscure correlation. Notice that, the lowering content of $FeO_{(total)}$ and MgO toward $SiO_2$ content imply the magmatic differentiation.

| Rock type | Granite | | | Diorite | | | | | | | Quartz diorite | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Chon Daen | | | Bueng Sam Phan | | | | | | | | | | | |
| Group | DK1 | | | BSP1 | | | | | | | BSP2 | | | | |
| Sample No. | DK1A | DK1B | DK1C | BSP1A | BSP1B | BSP1C | BSP1D | BSP1E | BSP1F | BSP1G | BSP2A | BSP2B | BSP2C | BSP2D | BSP2E |
| $SiO_2$ | 72.93 | 73.32 | 72.81 | 62.61 | 63.82 | 63.96 | 63.44 | 62.02 | 62.35 | 63.08 | 59.46 | 59.09 | 57.97 | 58.91 | 58.19 |
| $TiO_2$ | 0.22 | 0.24 | 0.25 | 0.56 | 0.50 | 0.48 | 0.52 | 0.58 | 0.50 | 0.51 | 0.78 | 0.93 | 0.80 | 0.72 | 1.00 |
| $Al_2O_3$ | 13.47 | 12.89 | 13.02 | 16.42 | 16.35 | 16.47 | 16.48 | 16.81 | 16.01 | 16.43 | 16.77 | 15.84 | 17.24 | 17.19 | 15.49 |
| $FeO_{(total)}$ | 2.53 | 2.31 | 2.29 | 4.17 | 3.91 | 4.02 | 3.93 | 4.16 | 4.04 | 4.24 | 5.66 | 6.33 | 6.08 | 5.63 | 6.82 |
| MnO | 0.01 | 0.03 | 0.04 | 0.06 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.05 | 0.08 | 0.10 | 0.10 | 0.09 | 0.11 |
| MgO | 0.83 | 0.96 | 1.09 | 2.83 | 2.24 | 2.10 | 2.60 | 2.80 | 2.45 | 2.57 | 3.60 | 3.98 | 3.51 | 3.04 | 4.42 |
| CaO | 0.94 | 1.15 | 1.15 | 4.59 | 4.42 | 4.19 | 4.37 | 4.56 | 4.45 | 4.52 | 6.33 | 6.65 | 6.71 | 6.94 | 7.00 |
| $Na_2O$ | 4.89 | 3.65 | 3.69 | 4.27 | 4.45 | 4.49 | 4.30 | 4.33 | 4.25 | 4.36 | 4.17 | 3.73 | 4.34 | 4.34 | 3.76 |
| $K_2O$ | 3.01 | 4.32 | 4.33 | 2.49 | 2.35 | 2.24 | 2.33 | 2.63 | 2.33 | 2.31 | 1.89 | 2.13 | 1.79 | 1.63 | 1.82 |
| $P_2O_5$ | 0.05 | 0.06 | 0.08 | 0.19 | 0.15 | 0.16 | 0.17 | 0.18 | 0.16 | 0.15 | 0.27 | 0.32 | 0.29 | 0.27 | 0.35 |
| LOI | 0.994 | 0.964 | 1.128 | 1.693 | 1.652 | 1.725 | 1.689 | 1.753 | 1.752 | 1.689 | 0.862 | 0.763 | 1.027 | 1.092 | 0.929 |
| Total | 99.874 | 99.894 | 99.878 | 99.883 | 99.882 | 99.875 | 99.879 | 99.873 | 94.302 | 99.909 | 99.872 | 93.533 | 99.857 | 99.852 | 99.889 |

Table 3.2 The weight percent of major and minor oxide of granitic rocks.

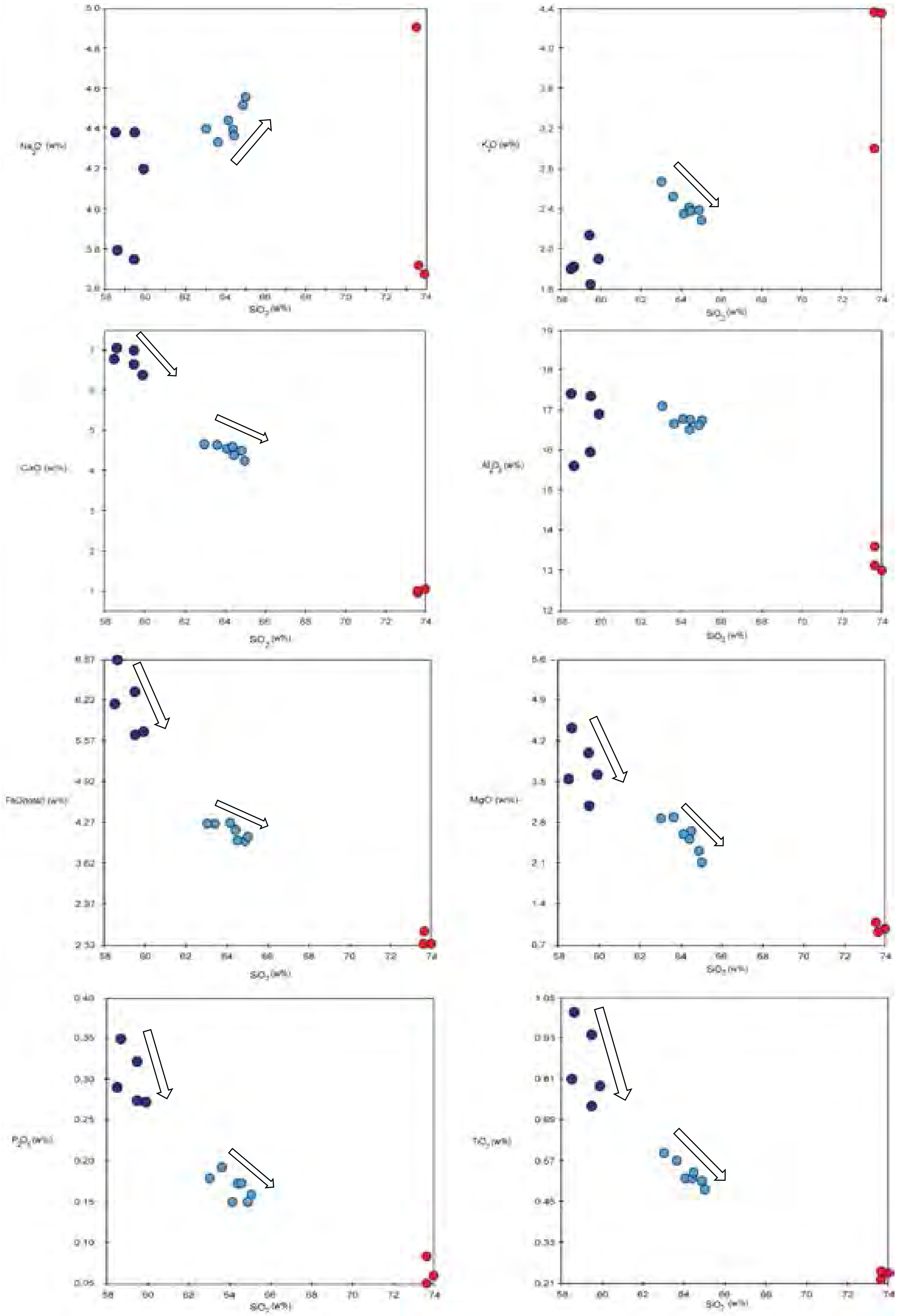


Fig 3.16 Harker variation diagrams (Harker, 1909) of $SiO_2$ plotted against other oxide elements.

# Chapter 4

## Discussions

In this chapter, the discussions are explained in two aspects: petrogenesis and tectonic setting.

### 4.1 Petrogenesis

The interpretation on petrogenetic issues is mainly on the basis of whole-rock geochemical data. According to TAS diagram (Cox et al., 1979) in Fig 3.15, the plutonic rocks are classified as subalkaline/tholeiitic composition. Considering Harker variation diagram (Fig 3.16), the discrete trends of each rock group implies the separate magmatic source. However, the trends between diorite and quartz diorite encourage the fractional crystallization of magma. By using Shand's index diagram (modified from Maniar and Piccoli, 1989) in Fig 4.1, the mol ratio of $Al_2O_3$ is lower than the sum of CaO, $Na_2O$ and $K_2O$. While, the mol proportion between $Al_2O_3$ and the combination of $Na_2O$ and $K_2O$ is greater than 1. Therefore, the granitic rocks in this study are fallen within metaluminous field.

According to Khin Zaw et al. (2007), plagioclase-hornblende diorite at N-prospect (Chatree mine) yielded the age of 238 ±5 Ma (Middle Triassic) by LA-ICPMS zircon U-Pb technique. This plutonic rock is peraluminous in composition. As stated by Salam et al. (2013), granodiorite at Wang Pong district which has yielded the age of 249.2 ±4.4 Ma (Early Triassic) is metaluminous. It can be assumed that the composition had changed through the time from metaluminous (310 ±8 to 249.2 ±4.4 Ma) to peraluminous (238 ±5 Ma).

By observation on hand specimens, the existence of mafic xenoliths in diorite and quartz diorite is a typical characteristic of Calc-Alkaline granitic magma (Barbarin, 2005). Moreover, Fig 4.2, the diagram plotted between $K_2O$ and $SiO_2$ (Peccerillo and Taylor, 1976; Rickwood, 1989) reveals that the granitic rocks were crystallized from Calc-Alkaline to high-K Calc-Alkaline magma series. However, plagioclase-hornblende diorite at N-prospect and granodiorite at Wang Pong districts which contain a low amount of $K_2O$ were originated from arc tholeiite magma series.

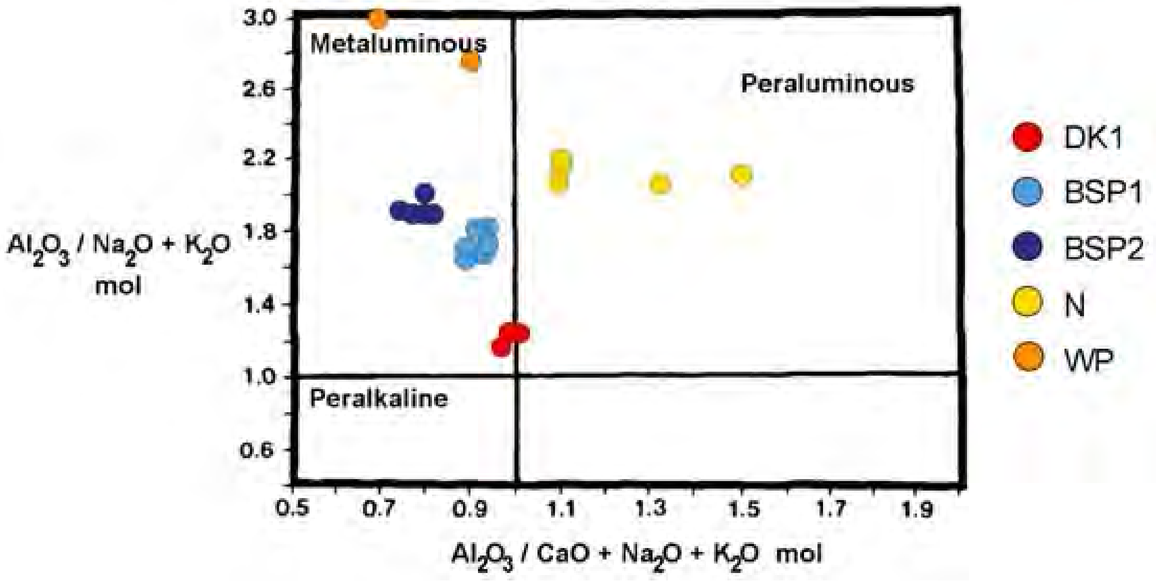


Fig 4.1 Shand's index diagram (modified from Maniar and Piccoli, 1989) shows the composition of granitic rocks in this study compared with samples from N-prospect and Wang Pong district.

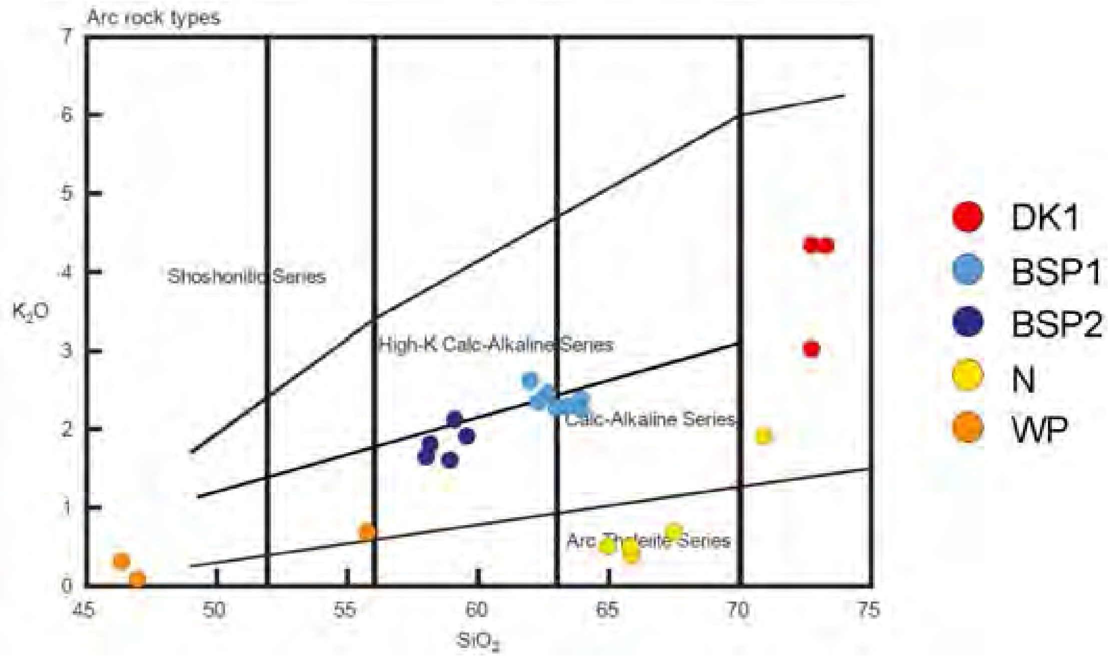


Fig 4.2 The diagram plotted between $K_2O$ and $SiO_2$ (Peccerillo and Taylor, 1976; Rickwood, 1989) indicates that the granitic rocks in this study were crystallized from Calc-Alkaline to high-K Calc-Alkaline magma series. However, the rocks from N-prospect and Wang Pong district were derived from arc tholeiite magma series.

The relatively high sodium content which is $Na_2O$ normally higher than 3.2% in felsic varieties and decreasing to more than 2.2% in more mafic type. In addition, the mol ratio between $Al_2O_3$ and the sum of CaO, $Na_2O$ and $K_2O$ is less than 1.1. These two conditions are distinctive chemical characteristics of I-type granitoid rocks (Chappell and White, 1974). The plot between $Na_2O$ and $K_2O$ diagram (Chappell and White, 1974) shows that the granitic rocks in this study are I-type affinity (Fig 4.3). Similarly, plagioclase-hornblende diorite and granodiorite are chemically fallen in I-type affinity field.

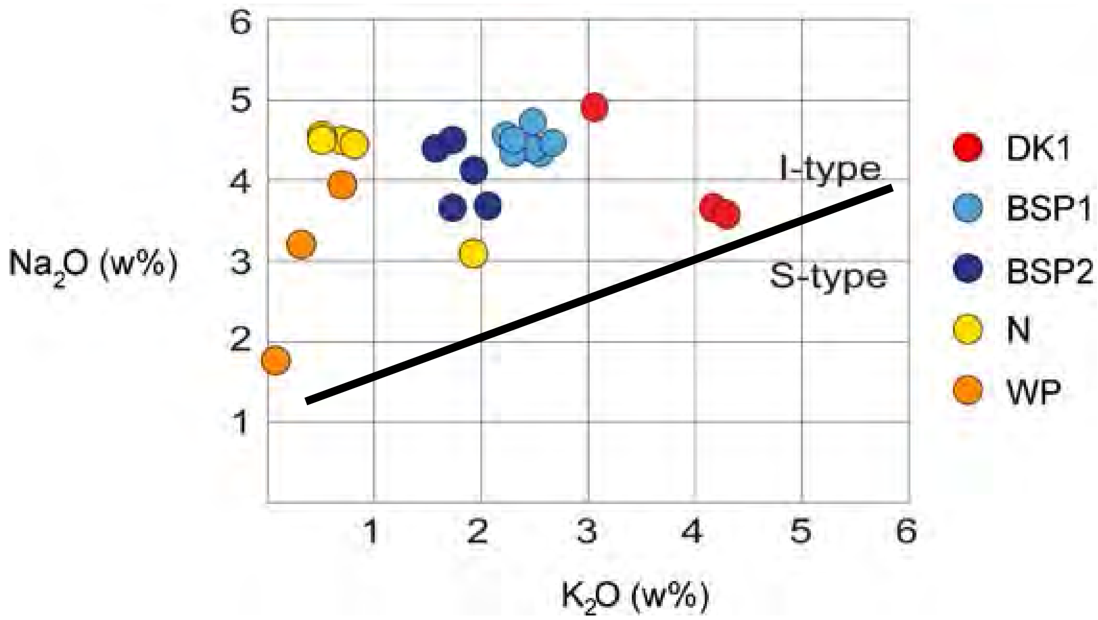


Fig 4.3 The diagram plotted between $Na_2O$ and $K_2O$ (Chappell and White, 1974) indicates the granitic rocks of this study as I-type affinity. Likewise, the granitic rocks from N-prospect and Wang Pong district are also I-type affinity.

### 4.2 Tectonic Setting

The geochemical results indicate that the granitic rocks are metaluminous, arc related Calc-Alkaline to high-K Calc-Alkaline magma series and I-type affinity. These can be concluded that the granitic rocks were occurred in volcanic arc setting (Fig 4.4). It can be interpreted that; the rocks may have originated in continental arc setting which refers to the subduction of Paleo-Tethys under Indochina terrane.

| | OROGENIC | | | TRANSITIONAL | ANOROGENIC | |
|---|---|---|---|---|---|---|
| | Oceanic Island Arc | Continental Arc | Continental Collision | Post-Orogenic Uplift/Collapse | Contintntal Rifting, Hot Spot | Mid-Ocean Ridge, Ocean Islands |
| **Examples** | Bougainville, Solomon Islands, Papua New Guinea | Mesozoic Cordilleran batholiths of west Americas Gander Terrane | Manaslu and Lhotse of Nepal, American Massif of Brittany | Late Caledonian Plutons of Britain, Basin and Range, late Variscan, early Northern Proterozoic | Nigerian ring complexes, Oslo rift, British Tertiary Igneous Province, Yellowstone hotspot | Oman and Troodos ophiolites; Iceland, Ascension, and Reunion Island intrusives |
| **Geo-chemistry** | Calc-alkaline > thol.<br>M-type & I-M hybrid<br>Metaluminous | Calc-alkaline<br>I-type > S-type<br>Met-Al to sl. Per-Al | Calc-alkaline<br>S-type<br>Peraluminous | Calc-alkaline<br>I-type S-type (A-type)<br>Metalum. to Peralum | Alkaline<br>A-type<br>Peralkaline | Tholeitic<br>M-type<br>Metaluminous |
| **Rock types** | qtz-diorite in mature arcs | tonalite & granodior. > granite or gabbro | migmatites & leucogranite | bimodal granodiorite + diroite-gabbro | Granite, syenite + diorite-gabbro. | Plagiogranite |
| **Associated Minerals** | Hbl > Bt | Hbl, Bt | Bt, Ms, Hbl, Grt, Als, Crd | Hbl > Bt | Hbl, Bt, aegirine fayalite, Rbk, arfved. | Hbl |
| **Associated Volcanism** | Island-arc basalt to andesite | Andesite and dacite in great volume | often lacking | basalt and rhyolite | alkali lavas, tuffs, and caldera infill | MORB and ocean island basalt |
| **Classification** Barbarin (1990) | $T_{IA}$ tholeiite island arc | $H_{CA}$ hybrid calc-alkaline | $C_{ST}$ $C_{CA}$ $C_{CI}$ continental types | $H_{LO}$ hybrid late orogenic | A alkaline | $T_{OR}$ tholeiite ocean ridge |
| Pearce *et al. (1984)* | VAG (volcanic arc granites) | | COLG (collision granites) | | WPG and ORG (within plate and ocean ridge granites) | |
| Maniar & Piccoli (1989) | IAG island arc granite | CAG contin. arc granite | CCG cont. collision gran. | POG post-orogenic gran. | RRG CEUG rift & aborted/hotspot | OP ocean plagiogranite |
| **Origin** | Partial melting of mantle-derived mafic underplate | PM of mantle-derived mafic underplate + crustal contribution | Partial melting of recycled crustal material | Partial melting of lower crust+ mantle and mid-crust contrib | Partial melting of mantle and/or lower crust (anhydrous) | Partial melting of mantle and frac-tional crystallization |
| **Melting Mechanism** | Subduction energy: transfer of fluids and dissolved species from slab to wedge. Melting of wedge, transfer of heat upward | | Tectonic thickening plus radiogenic crustal hea | Crustal heat plus mantle heat (rising asthen. + magmas) | Hot spot and/or adiabatic mantle rise | |

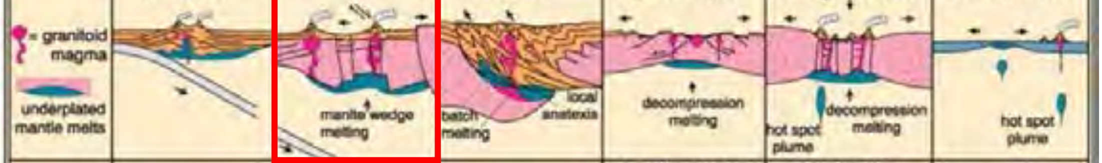


Fig 4.4 A classification of granitoid rocks based on tectonic setting (modified after Pitcher, 1983 and Barbarin, 1990)

# Chapter 5

## Conclusions

Based on the petrological and geochemical results, this chapter can be concluded in many perspectives.

1. Chon Daen granitic rocks (DK1) are mainly composed of quartz, alkali feldspar and plagioclase feldspar with minor amount of biotite and chlorite. Bueng Sam Phan granitic rocks (BSP1 and BSP2) are mainly composed of plagioclase feldspar and quartz. Alkali feldspar, biotite and hornblende are accessory minerals.
2. The granitic rocks from Chon Daen district (DK1) can be categorized as granite. While, the granitic rocks from Bueng Sam Phan district which are BSP1 and BSP2 can be classified as granodiorite and granodiorite to tonalite respectively. These names are based on the modal amount of quartz, alkali feldspar and plagioclase feldspar plotted into the QAP triangular diagram.
3. Based on whole-rock geochemical results by plotting in TAS discrimination diagram, DK1 granitic rocks can be named as granite. BSP1 and BSP2 granitic rocks are named as diorite and quartz diorite.
4. According to Shand's index diagram, the granitic rocks in this study are geochemically metaluminous.
5. In addition, the plot between $K_2O$ and $SiO_2$ indicates the Calc-Alkaline to high-K Calc-Alkaline magma series.
6. According to the plot between $Na_2O$ and $K_2O$, the granitic rocks in this study are I-type affinity.
7. As a result of geochemical data, the granitic rocks were occurred in volcanic arc setting. It may have originated in continental arc magmatism relevant to the subduction of Paleo-Tethys under Indochina terrane.

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