ศิลาวิทยาและธรณีเคมีของหินอัคนี ที่อำเภอบึงสามพัน จังหวัดเพชรบูรณ์ และจังหวัดฉะเชิงเทรา

นางสาวเมษา วิทยานนทเวช

โครงงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิทยาศาสตรบัณฑิต

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ปีการศึกษา 2559

PETROLOGY AND GEOCHEMISTRY OF IGNEOUS ROCKS

AT AMPHOE BUENG SAM PHAN CHANGWAT PHETCHABUN

AND CHANGWAT CHACHOENGSAO

Miss Maysa Wittayanontawet

A Project Submitted in Partial Fulfillment of the Requirements

for the Degree of Bachelor of Science Program in Geology

Department of Geology, Faculty of Science, Chulalongkorn University

Academic Year 2016

Project Title	PETROLOGY AND GEOCHEMISTRY OF IGNEOUS ROCKS AT AMPHOE BUENG SAM PHAN CHANGWAT PHETCHABUN AND CHANGWAT CHACHOENGSAO
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Field of Study	Geology
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Submitted date..

Approval date..

(Abhisit Salam, Ph.D.)

Project Advisor

เมษา วิทยานนทเวช : ศิลาวิทยาและธรณีเคมีของหินอัคนี ที่อำเภอบึงสามพัน จังหวัดเพชรบูรณ์ และจังหวัดฉะเชิงเทรา. (PETROLOGY AND GEOCHEMISTRY OF IGNEOUS ROCKS AT AMPHOE BUENG SAM PHAN CHANGWAT PHETCHABUN AND CHANGWAT CHACHOENGSAO)

อ.ที่ปรึกษาวิทยานิพนธ์: อาจารย์ ดร.อภิสิทธิ์ ซาลำ, xxหน้า.

โครงงานฉบับนี้มีจุดประสงค์เพื่อศึกษาความแตกต่างของธรณีเคมีและศิลาวรรณาระหว่างหินอัคนีจาก อำเภอบึงสามัน จังหวัดเพชรบูรณ์ และจังหวัดฉะเชิงเทรา โดยมีจุดมุ่งหมายเพื่อสื่อถึงเหตุการณ์ทางธรณีแปรสัณฐานในอดีตที่เกิดขึ้นในทั้งสองบริเวณ

จากการสำรวจในภาคสนามและการศึกษาทางศิลาวรรณา หินอัคนีที่เก็บมาจากพื้นที่อำเภอบึงสามพันได้ถูกแบ่งออกเป็นหกชนิด ได้แก่ แกบโบร, ไดโอไรต์, แกรโนไดโอไรต์, บะซอลต์, บะซอลติกแอนดีไซต์ และ แอนดีไซต์ ในขณะที่หินอัคนีจากบริเวณฉะเชิงเทรา มีเพียงหนึ่งชนิดซึ่งคือ แกรนิต

ลักษณะเด่นของธาตุหลักในหินได้ชี้ให้เห็นว่า หินอัคนีจากอำเภอบึงสามพันมีปริมาณ Mg, Ti, Ca, Al และ Fe สูงกว่าหินอัคนีจากบริเวณฉะเชิงเทรา ในขณะที่หินอัคนีจากบริเวณฉะเชิงเทรา มีปริมาณ K สูงกว่าหินอัคนีจากอำเภอบึงสามพัน

ข้อมูลยังบอกอีกว่าหินอัคนีจากอำเภอบึงสามพันมีที่มาจากหินหนืดประเภท metaluminous และ calc-alkaline ซึ่งการศึกษาธาตุล่องรอยบ่งชี้ถึง สภาพแวดล้อมทางธรณีสัณฐานแบบแนวคัดโค้งภูเขาไฟ (volcanic arc) ส่วนผลการศึกษาทางธรณีเคมีของหินอัคนีจากบริเวณฉะเชิงเทราบ่งชี้ถึงหินหนืดต้นกำเนิดแบบ metaluminous ไปจนถึง peralkaline และ high K calc-alkaline ไปจนถึง shoshonite ซึ่งสภาพแวดล้อมทางธรณีสัณฐานแบบ เกิดในระหว่างการชนของแผ่น (syn-collisional)

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต

สาขาวิชา ธรณีวิทยา ลายมือชื่อ อ.ที่ปรึกษาหลัก

ปีการศึกษา 2559

5632735923: MAJOR GEOLOGY

KEYWORDS: IGNEOUS ROCKS / PETROGRAPHY / GEOCHEMISTRY

MAYSA WITTAYANONTAWET: PETROLOGY AND GEOCHEMISTRY OF IGNEOUS ROCKS AT AMPHOE BUENG SAM PHAN CHANGWAT PHETCHABUN AND CHANGWAT CHACHOENGSAO.

ADVISOR: ABHISIT SALAM, Ph.D., xx pp.

This project is conducted to study the differences in geochemistry and petrography of igneous rock from Amphoe Bueng Sam Phan, Chawat Phetchabun and from Changwat Chachoengsao, aiming to imply to the differences in tectonic activities in the past between the two areas.

Based on field investigation and petrological study, there are six types of igneous rocks collected from Bueng Sam Phan area, which are gabbro, diorite, granodiorite, basalt, basaltic andesite and andesite, while there is only one of igneous rocks collected from Chachoengsao area, which is granite.Major element characteristics indicate that the Bueng Sam Phan plutonic rocks have higher amount of Mg, Ti, Ca, Al and Fe than the Chachoengsao plutonic rocks but the Chachoengsao plutonic have higher amount of K than the Bueng Sam Phan plutonic rocks. They also suggest that the Bueng Sam Phan plutonic rocks derived from metaluminous and calc-alkaline magma series, which the trace element study suggests the volcanic arc tectonic environment. For the Chachoengsao plutonic rocks, they are suggested to have metaluminous to peralkaline and high K calc-alkaline to shoshonite magma source with the syn-collisional tectonic environment.

Department: Geology Student's Signature ....

Field of Study: Geology Advisor's Signature ....

Academic Year: 2016

Acknowledgements

Foremost, I would like to thank my advisors Dr. Abhisit Salam for their advice and encouragement throughout the course of this study.

Sincerely appreciations also provide to Department of Geology, Chulalongkorn University for allow the author to use laboratory facilities, Mr. Pannaruj Ekpatrpaiboon, Miss Thanapan Jongjaingam who helped a lot during field observation and further laboratory analysis, Mrs. Jiraprapa Neampan, Mrs.Banjong Puangthong for kindly assistance and suggestion on geochemical study and Mr. Suriya Choakmau for helpful suggestion on making thin sections .

Special thanks are also delivered to laboratory staff, all teachers and students of Department of Geology, Chulalongkorn University, who are not named here for their helps.

Last, special thanks are given to my parents for their encouragement and helps.

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CHPTER 1

Introduction

1.1 Previous works

Review of previous works will be described separately for each fold belts, namely Loei Fold Belt and Sukhothai Fold Belt.

1.1.1 Sukhothai Fold Belt related magmatism

Srichan et al. (2009) studied geochemistry and geochronology of Late Triassic volcanic rocks in the Chiang Khong region, northern Thailand and supported an extensional rift setting rather than a continental margin arc setting for the Chiang Khong rocks. They were interpreted to have been erupted in a post-orogenic, basin-and-range type setting. The exact timing of the main deformation event that produced the Sukhothai Fold Belt, involving collision between Indochina and the Shan–Thai (or SIBUMASU) terranes was still not well constrained. They suggested that following the latest Middle to early Late Triassic collisional event involving the Indochina and Shan–Thai terranes, crustal thickening resulting from the collision led to gravitational collapse, broad extensional tectonism, and accompanying mainly calc–alkaline magmatism around 230–220 Ma, in a largely non-marine environment. Magmatism may have progressed from high-K felsic-dominant compositions to later more mafic-dominated, transitional tholeiitic compositions as extension accelerated.

Yuejun Wang et al.(2016) studied the petrogenesis of the Triassic post-collisional granitic rocks in NW Thailand and discussed that in Sukhothai zone, the Chiang Khong-Lampang volcanic zone composed of the andesite, rhyolite, dacite and tuff. These volcanic rocks gave age of 242–237 Ma which was interpreted as the arc (or syn-collisional) products. The collision of the SIBUMASU with Indochina blocks initiated in the early Triassic and ended by the later Triassic. The syn-collisional crustal thickening and subsequent post collisional collapse are the potential mechanisms governing the generation of the peraluminous felsic magma. At Permian-early Triassic period (prior to237 Ma), the Paleotethyan ocean plate was subducted easterly beneath the Sukhothai zone or the Indochina block to result into underplating of mantle-derived magma and mix with ancient materials for generating plutons. Sukhothai arc and Nan back-arc basin from west to east, corresponding to the Changning-Menglian suture zone, Lincang arc and the Jinghong back-arc basin in SW Yunnan.

1.1.2 Loei Fold Belt related magmatism

Igneous complex in Bung Samphan, Phetchabun has previously been studied by Jungyusuk et al., 1985 who mapped detail geology with the scale of 1:50,000 of the Khao Phra map sheet. They reported two types of intrusive rocks, namely quartz diorite and hornblende-biotite granodiorite with a subordinate gabbro. These intrusive rocks associated with older volcanic rocks including basalt, andesite porphyry, rhyolite porphyry and pyroclastic rocks of mafic composition.

Intasopa (1993) studied andesite, basaltic andesite and basalt from Amphoe Wichianburi of Phetchabun province. She concluded that such volcanic rocks were subduction-related continental margin derived rocks. Two $^{40}Ar/^{39}Ar$ dating of hornblende in basaltic andesite and andesite yield the ages of 238 ± 4 and 237 ± 12 Ma (Middle Triassic) respectively.

Yaowachirapong and Pakapat (2001) investigated a petrography and geochemistry of igneous rocks at Khao Mae Kae area and found that the intrusive rocks around the Khao Mae Kae show a linear trend of major oxide composition toward the east of the area.

Nantasin (2004) studied petrography and geochemistry of intrusive rocks at Ban Phosawan, Bung Sam Phan, Phetchabun province and concluded that there are four types of rocks namely; gabbro, diorite, hornblende-biotite granodiorite and quartz-diorite. All of them have characteristics of I-type affinity, calc-alkaline and high K calc-alkaline series and metaluminous to peraluminous. The rocks have been interpreted as volcanic arc related rocks. REE analysis suggests that all of them are co-magmatic series which might generate from the fractional partial melting process rather than from the batch partial melting process. These intrusive rocks intruded during Middle Triassic which was the time of amalgamation between Shan-Thai and Indo-China plates. Such event might have taken place as eastward subduction of paleothethys oceanic plate beneath the Indo-China continental plate.

Kamvong et al. (2006) studied petrochemical characteristics of igneous rocks from the Wang Pong area, Phetchabun province which include intrusive and extrusive rocks. The plutonic rocks include biotite granite and granodiorite and the volcanic rocks consist of volcaniclastic rocks (agglomerate and crystal tuft) and coherent rocks (andesite porphyry).

Geochemical data suggest these rocks have I-type affinity. The igneous rock suites (plutonic and volcanic rocks) occur as a result of partial melting of the subducted oceanic slab beneath Indochina plate during Permo-Triassic and were derived from the ocean-island basalt (OIB) - like magma. They have been interpreted as shallow and deep subsurface levels of a single magmatic province.

Marhotorn et al. (2008) studied petrochemistry of plutonic rocks (diorite porphyry) in the southern parts of the Chatree gold deposit, Phichit province and concluded that these rocks belong to the calc-alkaline affinity. Binary plots of trace element data indicate island-arc tholeiites, volcanic arc granite system and volcanic arc basalt in different diagram. Spider diagram of trace and rare-earth elements revealed that calc-alkaline intermediate igneous rocks are consistent with those of the Tertiary intrusive rocks of Azerbaijan, Iran which occurred in the subduction zone related to the magmatic arc environment.

Nakchaiya et al. (2008) studied Petrochemistry of Volcanic Rocks in the Chatree Gold Mine, Central Thailand and concluded that the Chatree gold mine area is dominated by calc – alkaline, andesite to basaltic andesite. These volcanic rocks occurred as a result of compressive eastward subduction of oceanic plate beneath the Indochina block. The volcanic rocks were in the volcanic arc basalts field. The Permo-Triassic calc- alkaline volcanic rocks of the Chatree mine occurred in the volcanic arc environment of the subduction - related tectonic setting. They interpreted that he volcanic rocks may have situated close to the western edge of the Indochina block. These volcanic rock suites may have taken place from the partial melting of the Paleotethys oceanic slab subducted beneath Indochina block and gave rise to the generation of intermediate magma.

Salam (2013) mentioned that the Loei fold belt is the magmatic arc of basaltic, andesitic and rhyolitic composition developed above an east dipping subduction zone between the Shan-Thai and Indochina terranes in the Late Permian. The dominant andesite and rhyolite with minor basalt and associated volcaniclastic products of tholeiitic affinity were emplaced in the Loei fold belt. Basalt and andesite were extruded in the early stage of arc magmatism, whereas rhyolite was emplaced towards the end of the main phase of volcanic activity. Subsequently, emplacement of I-type intrusive rocks occurred (Wang Pong and Khao Rub Chang intrusive rocks) during the Late Early Triassic to Late Middle Triassic. In addition, diorite intrusions also were emplaced along an arc parallel structure inferred to have an Early Triassic age.

Salam et al. (2014) studied geochemistry and geochronology of the Chatree epithermal gold–silver deposit and concluded that the volcanic units have been emplaced in an island arc setting. The stratigraphic and compositional data suggested that the magma source may have evolved through time accompanying an increasing input of fertile magma source.

Kromkhun et al. (2013) studied Petrochemistry of Volcanic and Plutonic Rocks in Loei Province and concluded that the Loei andesitic or intermediate rocks and the western Loei igneous rocks formed ~230-250 Ma are co-magmatic. The geochemical anomalies for these rocks indicated magma mixing processes and/or fractional crystallization of plagioclase, K-feldspar, titanite, mica, apatite and hornblende. The REE study suggested partial melting of a normal mantle source or one that is slightly enriched in incompatible elements and a shallower plagioclase residue in the source region of these rocks. The volcanic and plutonic suites from the Loei were classified as a calc-alkaline, therefore these igneous rocks had been generated as a result of the subduction of an ocean between the Indochina and SIBUMASU blocks. Moreover, trace element study indicated either contamination by continental crust or melting of LILE enriched lithospheric mantle. Given the tectonic setting, these geochemical data reflected the assimilation of thickened continental crust of the Indochina Block above a subduction zone.

Vivatpinyo et al. (2013) studied Volcanic Rocks from Q-Prospect, Chatree Gold Deposit, Phichit and concluded that that those volcanic and the dyke rocks have originated within the island arc environment. Detailed petrological and geochemical studies and absolute age dating indicated that tholeiitic magmas of volcanic rocks of the host and calc-alkaline magmas of the dyke rocks have been erupted in close temporal and spatial proximity. Tholeiitic magma of the host rocks was possibly derived from melting of the subducted slab and surrounding mantle prior to magma differentiation yielding a various volcanic rocks ranging from basaltic to rhyolitic compositions. The mineralogical and geochemical characteristics of the dyke rocks indicated that they are calc-alkali andesite. A major shift in magmatic composition occurred between the host and the dyke rocks from a predominantly tholeiitic to a calc-alkali signature within a few million years. The coexistence of tholeiitic and calc-alkaline magma series can be attributed to shallow-level intra crustal processes. Mechanisms of magma differentiation begin with partial melting of overlying arc or intra crustal which was heated by the prior tholeiitic magma prompting partial melting of the existing magmatic arc and as well as assimilate intra-arc sediments and previous volcanic rocks, while undergoing fractional crystallization to generate calc-alkali andesitic magma of the dyke rocks.

Arboit et al. (2016) studied geochemistry of mafic and intermediate dykes from the Khao Khwang Fold–Thrust Belt and concluded that such volcanic suite has high affinity with a continental volcanic arc tectonic setting and associated with a range of stages in the development of the Indosinian Orogeny from the early tectonic stages in the Mid-Permian to the post collisional stages in the Late Triassic. The REE study suggested the source for the whole KKFTB igneous suite rose to the base of the lithosphere underneath the southwestern Indochina margin from the Mid Permian to Early Triassic. The isotopic study showed that the KKFTB igneous suite possibly underwent to degrees of crustal contamination, whereas the REE study strengthened the dominance of a volcanic arc tectonic setting. In the slab break-off model, the detachment of a lithospheric slab allows the asthenosphere underlying the down going plate to flow up into the broken slab window above the sinking slab. The heat supply from the uprising asthenosphere can affect overlying thickened lithosphere, yielding characteristic isotopic trend. Asthenosphere upwelling induced partial melting of the overlying lithospheric mantle previously metasomatized during subduction. Thermal flux lowered the density of the remnant lithosphere of limited extent, with the possible consequent crustal melting. Heated crust facilitates the involvement of crustal components within mantle-derived melts through assimilation–fractionation–crystallization processes. The two ages of the dacite south of the KKFTB are interpreted to indicate that the break-up of the Sukhothai back-arc slab started during the Early Triassic following the complete subduction and Sukhothai-Indochina collision.

1.2 Purpose of study

The purpose of this investigation is to study and concentrating particularly on petrography and geochemistry of the igneous rocks from Amphoe Bueng Sam Phan Changwat Phetchabun and Changwat Chachoengsao.

1.3 The location and accessibility of the study area

As to compare the result in magmatism and tectonic implications between Loei Belt and Sukhothai Belt, there are 2 study areas for such 2 belts. The representative area of Loei belt is located in Amphoe Bueng Sam Phan Changwat Phetchabun, namely Bueng Sam Phan area and the representative area of Sukhothai Belt is located in Chanthaburi Terrane, the southern part of Sukhothai Belt (Sone et al., 2012), namely Chachoengsao area. The location of both study areas and the relation with tectonic configuration in Thailand are shown in Figure 1.1 and the detailed location maps of each study area are shown in Figure 1.2 and Figure 1.3

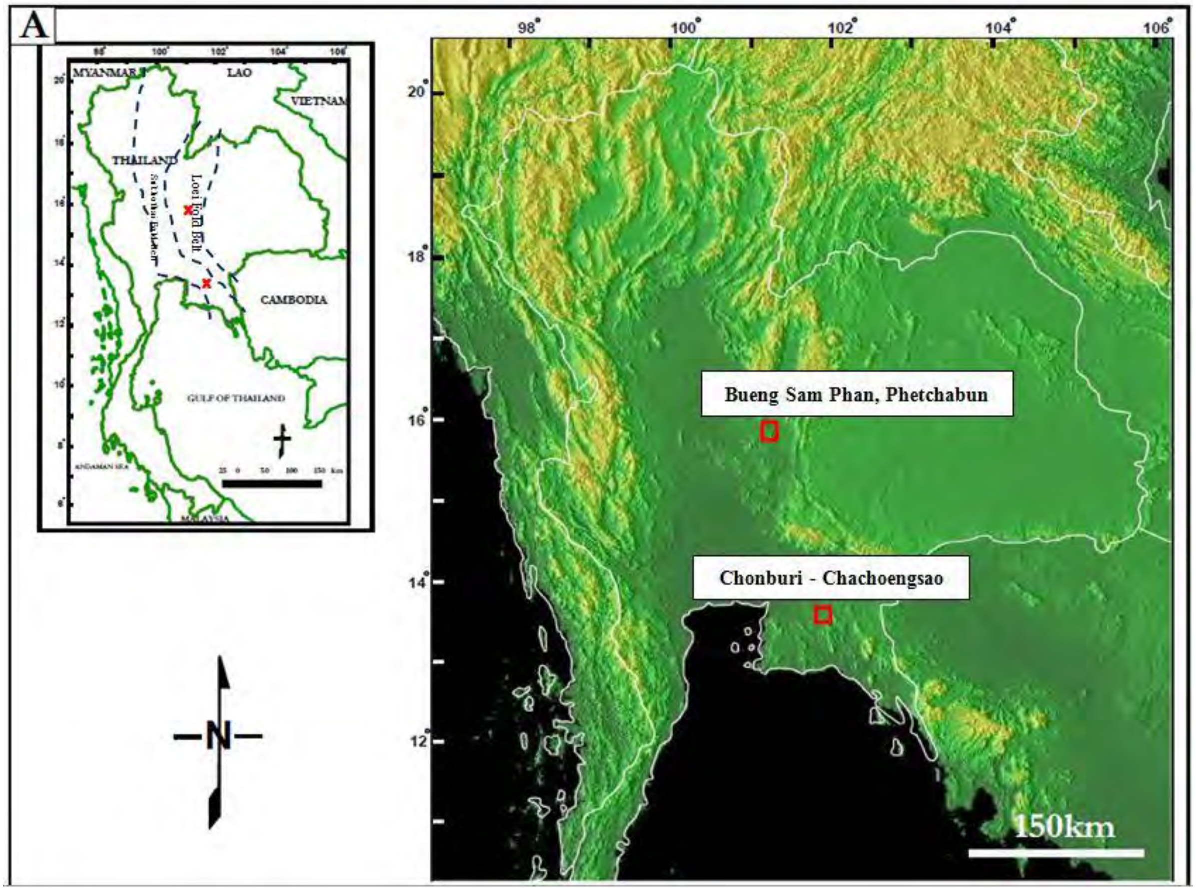

Fig. 1.1 showing the location of the two study areas -Bueng Sam Phan area and Chachoengsao area- and the spatial correlation with Loei Belt and Sukhothai Belt respectively

1.3.1 Sukhothai Belt Section – Chachoengsao Area

The study area is located between the latitude 13°46'46.2"N to 12°56'49.3"N and longitude 101°26'53.1"E to 101°46'37.3"E on the Royal Thai Survey topographic map scale 1:50,000, sheet number L7018, series 5235I Bo Thong, series 5336IV Kabinburi and series 5334I Na Yai Am. The area is situated about 140 kilometres to southeast of Bangkok and covers 2400 square kilometres. The location of study area is shown in Figure 1.2

There are three routes to access three points in the study area. First, from Bangkok to St1 Bo Thong, takes the highway number 3, and then goes further to the southeast along the highway number 34, 3466 and 361 respectively to Ban Suan and then go further along the highway number 344, 3289 and 3340 respectively to Bo thong. From Bangkok to St2 Khao Hin Son, takes the highway number 7, and then goes further to the southeast along the highway number 314 and 304 respectively to the local government way number 17 and then go along the local way number 17 to Khao Hin Son. Finally, from Bangkok to St3 Khao Chamao, takes the highway number 7 to the southeast and go further along 344, 3377 and 4032 respectively to Khao Chamao. All routes accessed to the study area can be used all year round.

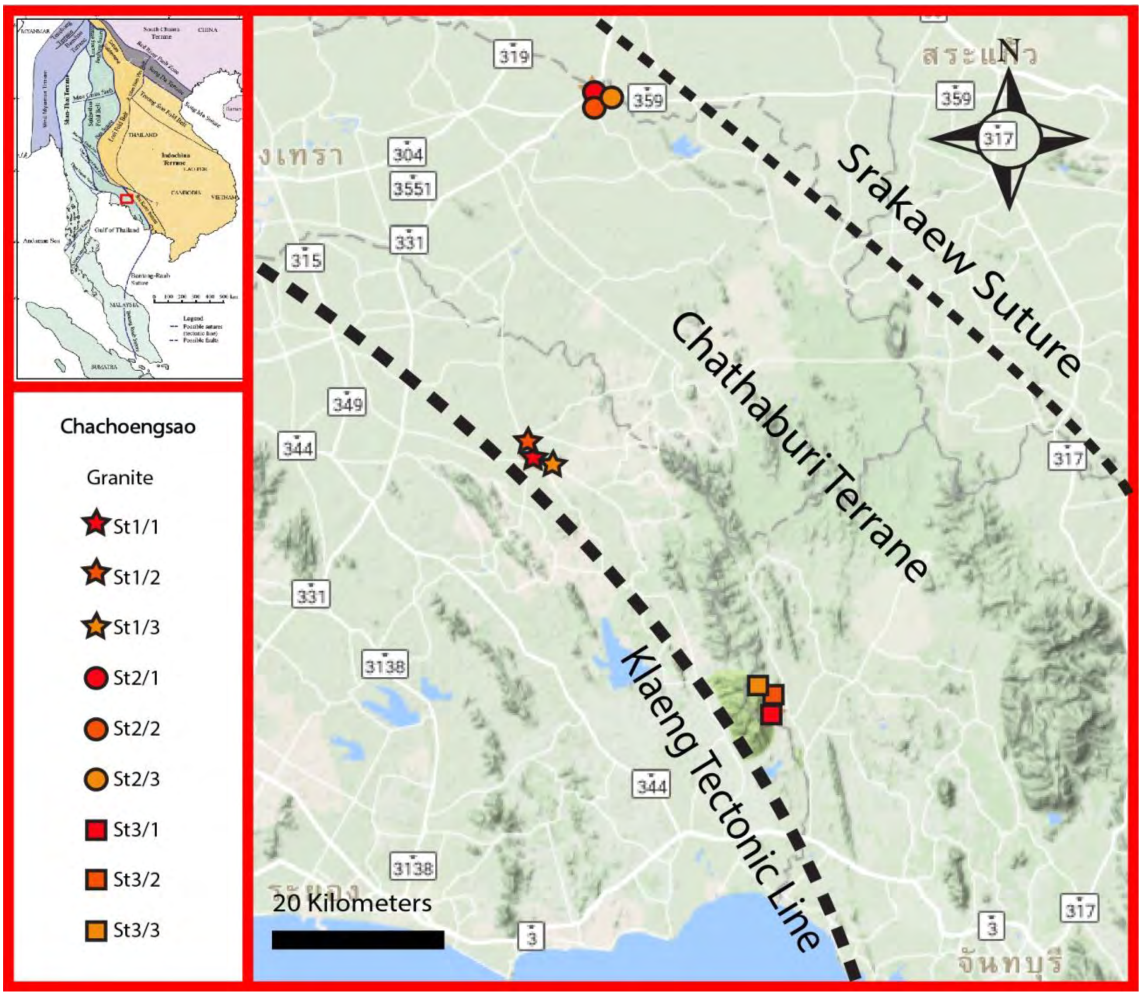

Fig. 1.2 showing the location map of the Chachoengsao area located in Chanthaburi terrane, representative of the Sukhothai Belt section. The map shows the location and spatial distribution of the collected samples with different shaped and colored symbols as shown in the legend but all are in the same unit: Granite.

1.3.2 Loei Belt Section – Bueng Sam Phan Area

The study area is located between the latitude 15˚ 50' N to 15˚ 58' N and longitude 100˚ 45' E to 100˚ 58' E on the Royal Thai Survey topographic map scale 1:50,000, sheet number L7018, series 5140 I, Ban Sap Mai Daeng The area is situated about 340 kilometers to north of Bangkok and covers 336 square kilometers (21km width, 16km height). The location of study area is shown in Figure 1.3

There are at least two routes to access to the study area. Firstly, from Bangkok to Sara Buri province takes the highway number 1, and then goes further north to Amphoe Bung Sam Phan along the highway number 21. From Amphoe Bung Sam Phan it can be reached to the study area by the highway numbers 225 and 1286, respectively. Secondly, starts with the same way on the highway number 1 to Nakorn Sawan, then turns into number 225 from west to east until reaching the highway number 1286. All routes accessed to the study area can be used all year round.

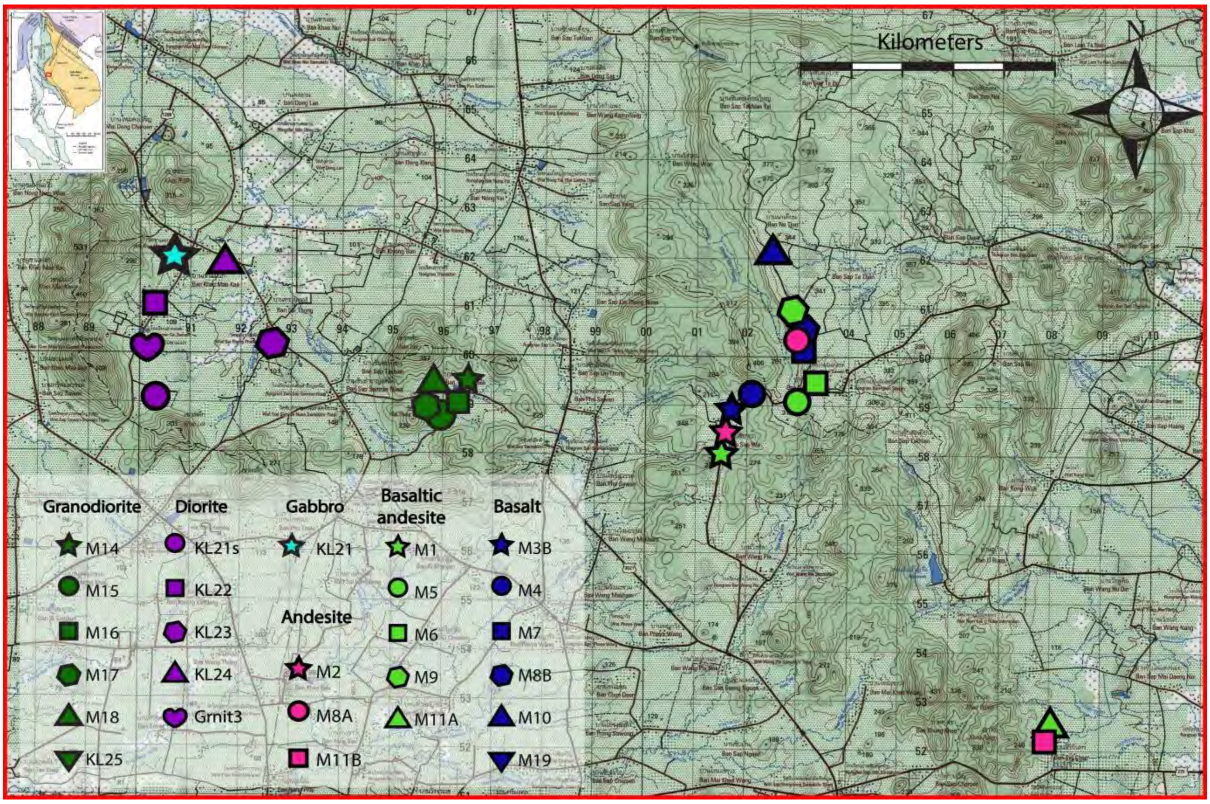

Fig. 1.3 showing the location map of the Bueng Sam Phan area located in Amphoe Bueng Sam Phan, Changwat Phetchabun, representative of the Loei Belt section. The map shows the location and spatial distribution of the collected samples of each unit rock with different shaped and colored symbols as shown in the legend.

1.4 Tectonic Frameworks of Thailand

Thailand is composed of two main tectonic terranes: Indochina on the east and Shan-Thai on the west *(*Fig. 1.4*)*. These two terranes are separated by Sukhothai Belt on the western side and Loei Belt on the eastern side. The Shan-Thai terrane is an elongate continental block containing east Myanmar, western Thailand, western Malaysia Peninsular, and Sumatra. It is widely believed to have been rifted from the northwestern Australian part of Gondwana in the early Permian (Bunopas and Vella 1983; Gatinsky et al., 1984; Metcalfe, 1988; Hutchinson, 1989; Bunopas 1991; Barber et al., 2010). The Indochina and South China Terranes formed as a part of north-eastern Gondwana in the Early Palaeozoic (Audley-Charles, 1988; Burrett et al., 1990; Metcalfe, 1991), and later were rifted from Gondwana in the Silurian or Devonian (Hutchison, 1989).

The Shan-Thai and Indochina Terranes moved north from Australia into Palaeo-Tethys Ocean during the Phanerozoic and this process caused opening and closing of the Palaeo-Tethys and Meso-Tethys between them and they were subsequently amalgamated into Asia (Hall, 2000; Metcalfe, 2002). The earlier workers believed that this movement was compensated by westward subduction of oceanic crust underneath the eastern margin of the Shan-Thai (Bunopas and Vella, 1978; Barr and McDonald 1987; Hada, 1990; Hada et al., 1999; Singharajwarapan and Berry, 2000) and eastward subduction underneath the western margin of Indochina (Mitchell, 1986; Beckinsale et al., 1979). Several workers agree on paired subduction in which subduction occurred on the both side of Palaeo-Tethys Ocean underneath Shan-Thai and Indochina Terranes (Gatinsky et al., 1978; Bunopas, 1981; Hutchison, 1989; Intasopa, 1993; Charusiri, 1989).

Permo-Triassic rocks in Sukhothai Belt and Loei Belt are most likely related to westward subduction underneath the Shan-Thai Terrane and eastward subduction underneath the Indochina Terrane respectively. Subsequently, these subductions were followed by I-type granitoid emplacement in the both areas during late Triassic to Jurassic.

Based on a number of U/Pb zircon ages and on whole rock chemistry, Khin Zaw et al. (2007, 2010) suggested that the Loei Belt has a complex magmatic history and that widespread Permo-Triassic magmatism both in Sukhothai Belt and Loei Belt, occurred as a result of subduction-related magmatism. Khin Zaw et al. (2007, 2010) show that the magmatic rocks are predominantly of I-type affinity. The subduction of oceanic crust underneath the Sukhothai Belt occurred during Late Permian, resulting in the emplacement of volcanic rocks (ranging in composition from basalt to rhyolite) and plutonic rocks (granite to diorite of I-type affinity).

Shan-Thai and Indochina Terranes collided and accreted by the Late Triassic. This collision was subsequently followed by post-collision magmatism which is represented by granitoid rocks in Sukhothai Belt and Loei Belt (Khin Zaw et al., 2007). Later India-Eurasia collision during Cenozoic also affected this region resulting in reactivation of the several strike-slip faults in Thailand.

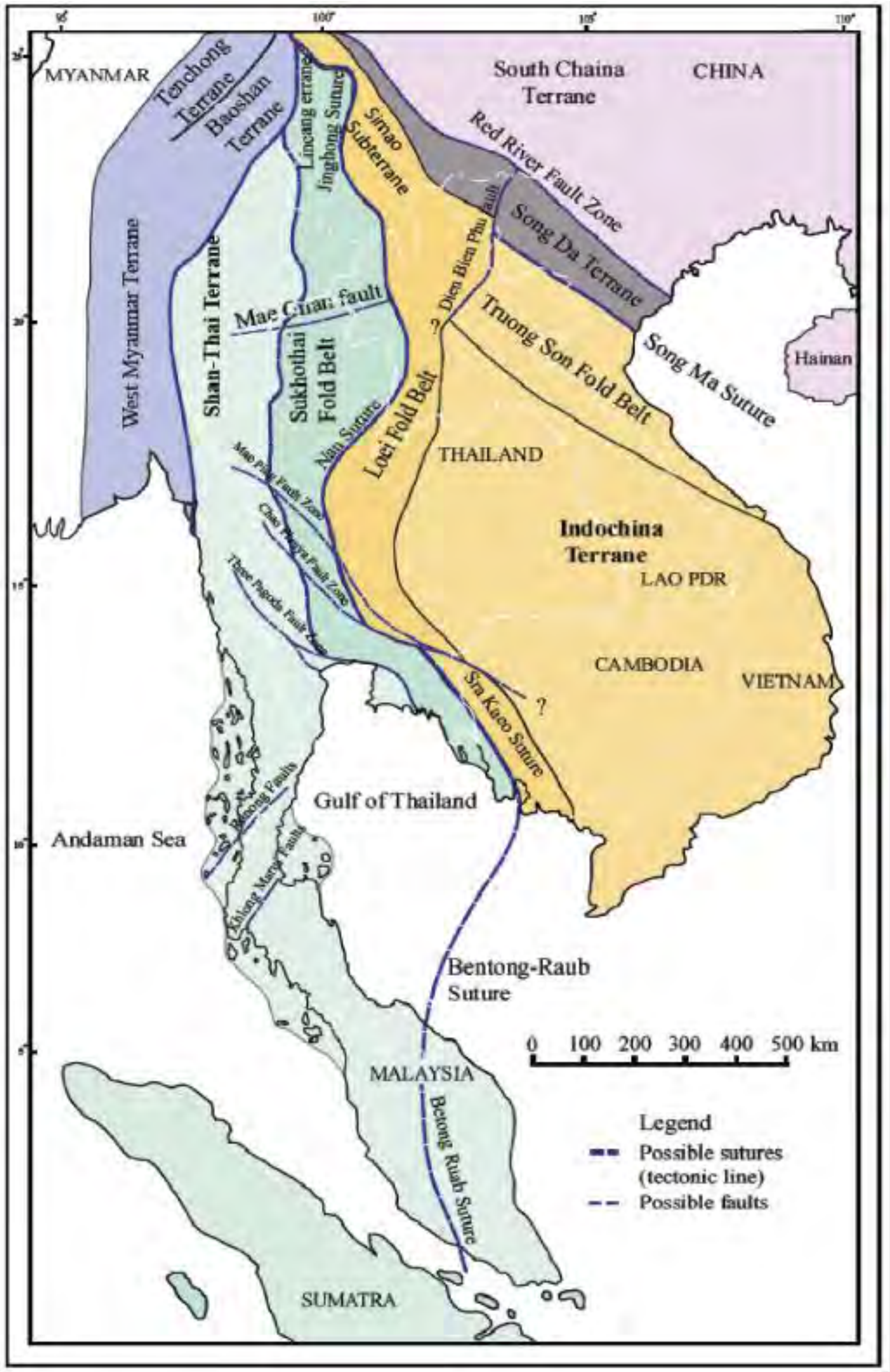

Fig. 1.4 showing the main tectonic terranes and suture zone in Thailand and main land Southeast Asia (Modified after Salam, 2014).

CHAPTER 2

Methodology

Once the aim and purpose of the study have been set, there are main four steps to carry out. First the previous work related to the aspects of this study and the study areas have been review. This step includes the thorough study of geology and geomorphology (aerial photo interpretation) of the study areas aiming to optimize the following field investigation and sample collection which have been done as the second step. After the sample preparation has been done, they have been further analyzed in two aspects: petrographic and geochemical studies whose methodological details have been described in the following topics. When all needed data are ready, they are further interpreted through the accepted principle and reported. All of these steps are summarized and shown in Figure 2.1.

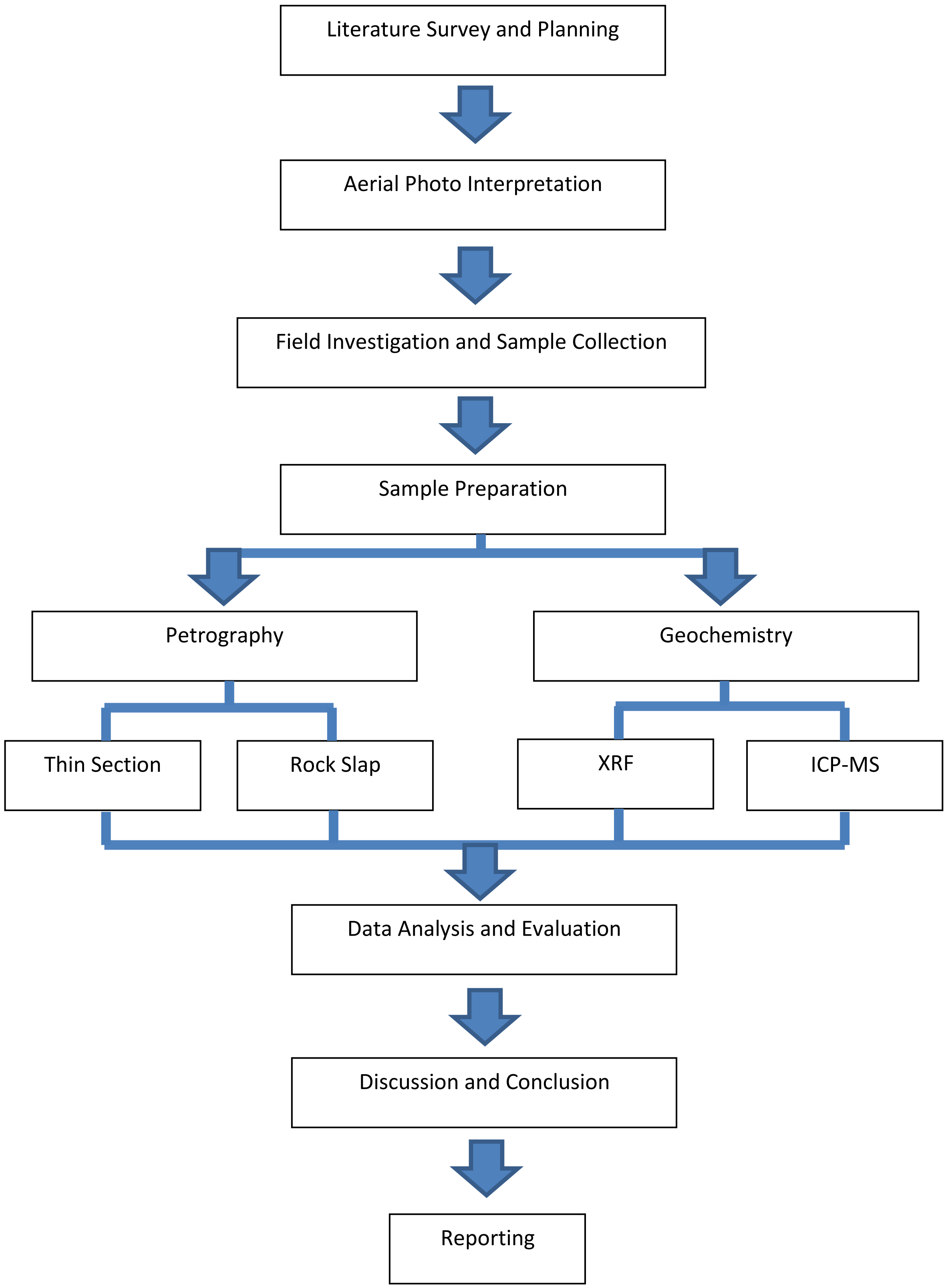

Fig. 2.1 flowchart showing the method of the study

2.1 Data acquisition

2.1.1 Field observation

This step was carried out after the intense study of the geology in the study areas - Bueng Sam Phan area and Chachoengsao area- specifically for collecting the representative igneous rock samples in the study areas to compare between both areas and was done during October 2016 and April 2017. The igneous rocks were categorized based on field evidences into 6 types from Bueng Sam Phan area, namely Granodiorite, Diorite, Gabbro, Andesite, Basaltic andesite and Basalt and 1 type from Chachoengsao area that is Granite.

2.1.2 Sample collection

Altogether 35 rock samples were collected which included 9 samples of Granites from Chachoengsao area and 5 samples of Diorites, 6 samples of Granodiorites, 1 sample of Gabbros, 3 samples of Andesites, 5 samples of Basaltic andesites and 6 samples of Basalts from Bueng Sam Phan area. The samples were collected to represent the variation in each rock type. Their location is given in the maps of Figure 1.2 and Figure 1.3.

2.2 Analysis

Samples were first examined under the microscope to study the petrographic details and the least altered samples were then chosen for whole rock analysis. Two of the thirty-five samples were further analyzed for low-level trace elements and REE using solution ICP-MS, one is from the Chachoengsao area to be the representative of Sukhothai belt magmatism and another one is from the Bueng Sam Phan area to be the representative of Loei Belt magmatism.

2.2.1 Petrography

The rock samples were slab-cut and prepared as thin section. The thin section was usually set at 0.03 mm thick and covered with a covered glass. These thin sections were used for mineral identification and textural study by a polarizing microscope. The text books include

An introduction to the rock-forming minerals (Deer et al., 1966), Atlas of igneous rocks and their textures (MacKenzie et al., 1982), Petrography of Igneous and Metamorphic Rocks (Philpotts, 1989), Rock-forming Minerals in Thin Section (Pichler, 1997) were used for mineral and texture identifications. Consequently, those textures were interpreted after Hibbard (1995) and Bard (1987).

2.2.2 Geochemistry: Whole Rock Analysis

The least altered samples from rocks in the study area were selected for whole rock analysis. Firstly, about 1-2 kg of each sample was crushed by a geological hammer to about 1 – 1.5 cm pieces. In order to avoid weathering effect, such weathered pieces were removed before sub-sampling by the quartering method. Secondly, the samples were pulverized by a tungsten carbide disc mill into size of minus 200 mesh. All powdered-rock samples were dried at 105 0C for 2 hours to remove the moisture before keeping in glass containers.

2.2.2.1 XRF: Major and Minor Elements Analysis

In this study, major and minor elements were carried out by X-ray fluorescence spectrometer (XRF). The XRF method was done at the Department of Geology, Chulalongkorn University. All the major and minor elements content were reported as oxide.

The set of powdered rock samples were prepared as pressed pellets by using HBO3 (boric acid) as the binding material at the ratio of sample: binder of 8:1 and mixed in the tungsten carbide mill and pressed at the pressure of 400 kg/cm2 for 1 minute. The analyses were done for major and minor elements by XRF model S4 Pioneer Wavelength dispersive X-Ray Fluorescence (WDXRF) Spectrometry by using SPECTRA Plus software of the Bruker with the standardless analysis at the Department of Geology, Chulalongkorn University by the following conditions.

Range 0.2 – 20 A (60 – 0.6 keV)

Total resolution 3 – 100 eV

Typical measurement time 2 – 10 s per element

2.2.2.2 ICP-MS: Low-abundance trace elements and REE analysis

Two selected samples were prepared in the form of solutions for ICP-MS analysis using PicoTrace® high-pressure acid (HF/H2 SO4) digestion. Aliquots (100 mg) of powdered sample were weighted into 30 ml PTFE digestion containers. Samples were then wetted with few drops of ultra-pure water and adding 0.1 ml of µg g-1 indium solution to each digestion container, 3 ml HF and 3 ml H2SO4 were slowly added. Thoroughly mixing by shacking a few times, the PTFE containers were placed in digestion block at 180^{o}C for 16 hours. The digestion mixture was then evaporated at 180^{o}C for four days in the evaporation block. HCLO4 (1 ml) was added to the residue and dried before adding 2 ml HNO3 and 1 ml HCL. The residue was dissolved by warming the solution in the digestion block at 60 to 70^{o}C for about 1 hour. Once the solution became clear, it was transferred into a polypropylene bottle and diluted to 100 ml then analyses. The samples (solution) were analyzed using a HP4500 Inductivity Coupled Plasma Mass Spectrometer (ICP-MS).

CHPTER 3 RESULT AND INTERPRETATION

3.1 Petrography

This chapter reports the petrographic investigation. The results of petrographic study are separately reported by the study areas: Bueng Sam Phan area and Chachoengsao area respectively.

3.1.1 Bueng Sam Phan Area

At Bueng Sam Phan area, the igneous rocks are classified into 5 units based on mineralogy and textures: Gabbro, Diorite, Granodiorite, Basalt, Basaltic andesite and Andesite. The spatial distribution of each unit is shown in the Figure 3.1.

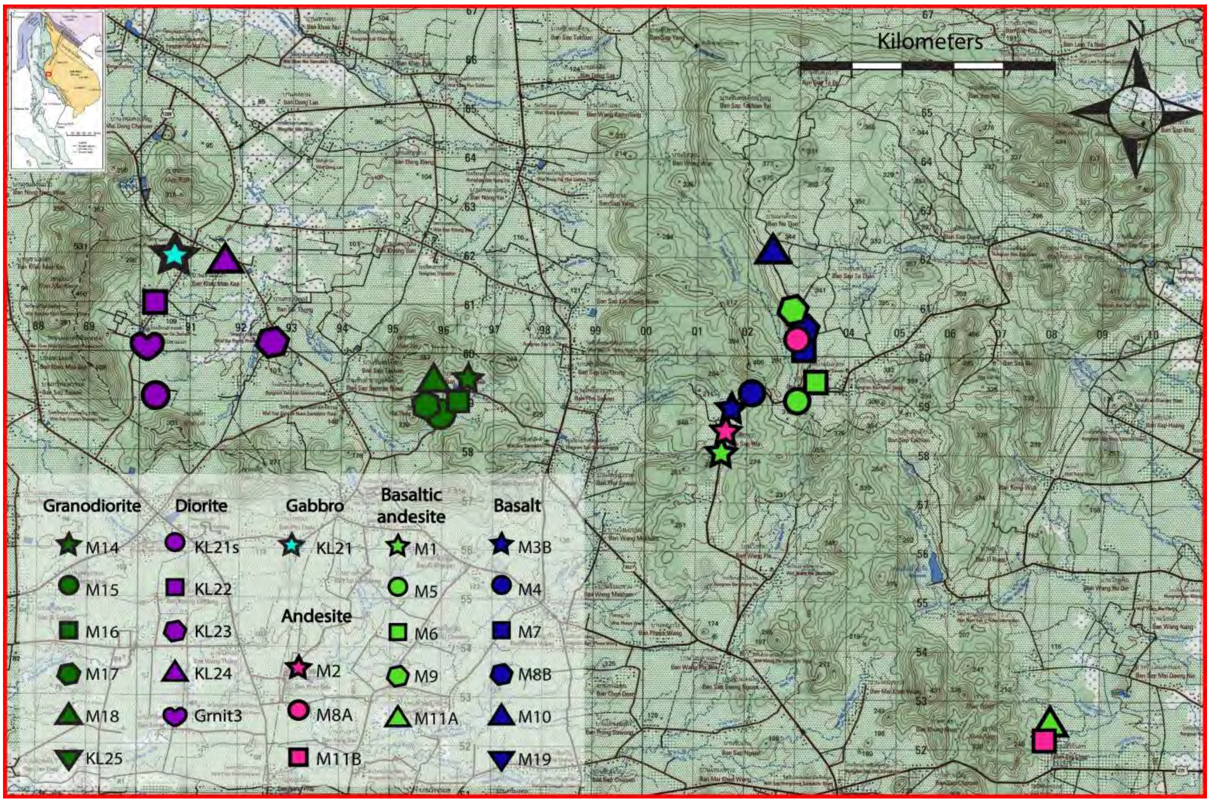

Fig. 3.1 showing the location map of the Bueng Sam Phan area located in Amphoe Bueng Sam Phan, Changwat Phetchabun, representative of the Loei Belt section. The map shows the location and spatial distribution of the collected samples of each unit rock with different shaped and colored symbols as shown in the legend.

Unit 1 Gabbro

This rock unit occurs at the eastern side of Khao Lek and is shown in the light blue symbol in the map (Fig. 3.1). In the field, gabbro occurs as boulders which is characterized by dark green in hand specimen, fine-grained and equigranular texture (Figs. 3.2A and B).

Microscopically, it is composed of approximately 20% of 5 mm long subhedral lath shaped plagioclase with typical albite twin and antiperthitic texture and 80% of 2 mm anhedral clino-pyroxene showing subophitic texture in the plagioclase (Figs. 3.2C and D). Texturally, it shows holocrystaline, equigranular, hypidiomorphic, intergranular, poikilitic (subophitic) and antiperthitic texture (Fig. 3.2D).

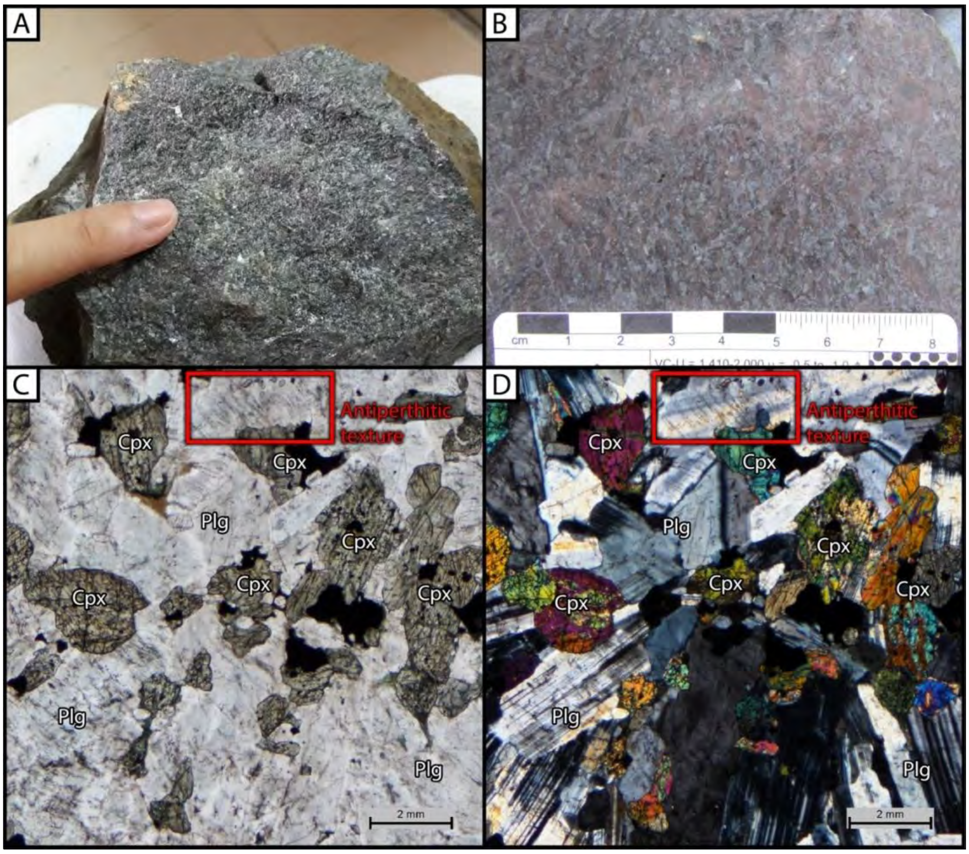

Fig. 3.2 Representative of gabbro sample from Bueng Sam Phan area, A. Hand specimen showing macroscopic texture of gabbro sample, B. Slab showing more details of macroscopic texture, C. and D. Photomicrographs (plane polarized light and cross nicol respectively) showing clino-pyroxene and plagioclase with intergranular, subophitic and antiperthitic texture. Abbreviation: Plg = plagioclase, Cpx = pyroxene.

The QAPF diagram (Strekeisen, 1975) is given in Figure 3.3 and the rock is identified as gabbro/ diorite.

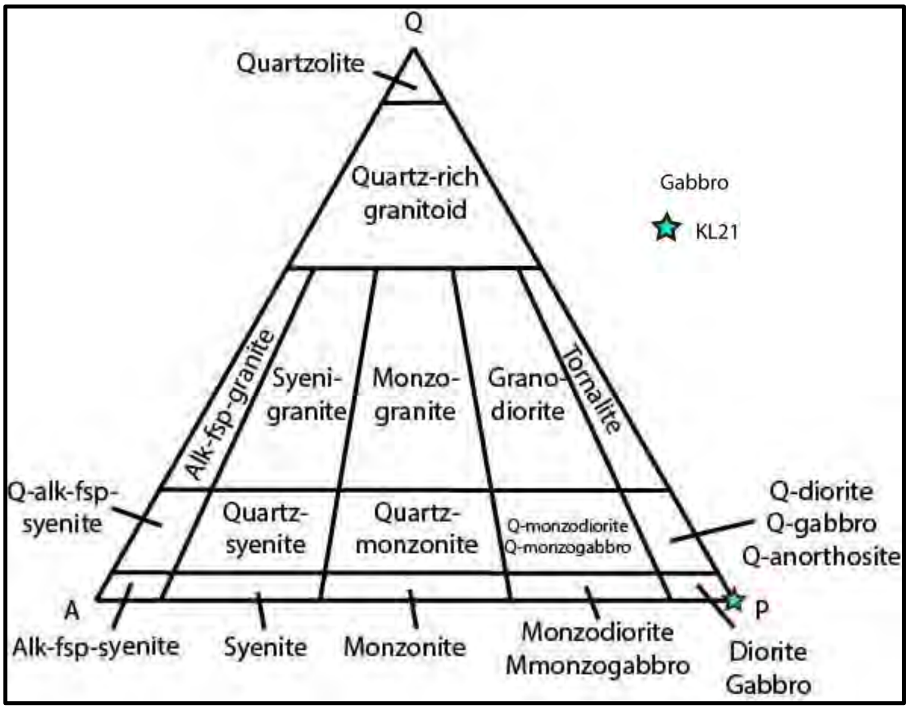

Fig. 3.3 QAPF diagram (Strekeisen, 1975) showing mineral compositions of gabbro (Unit 1)

Unit 2 Diorite

This rock unit occurred at the eastern area of Khao Lek and is shown in the violent symbols in the map (Fig. 3.1).

Megascopically, the rock is medium grained, dark grey, phaneritic texture (Figs. 3.4A and B).

Microscopically, it is composed of approximately 70% of 2-5 mm long plagioclase, 15% of 1-4 mm anhedral hornblende, 10% of 1-4 mm biotite and 5% of 2-3 mm quartz (Figs. 3.4C and D) and can be plotted in the Diorite and Granodiorite area of the QAPF diagram (Strekeisen, 1975; Fig. 3.5).

Texturally, it shows holocrystaline, inequigranular, hypidiomorphic, interlocking and interstitial texture of hornblende and biotite grains between plagioclase grains (Fig. 3.4D).

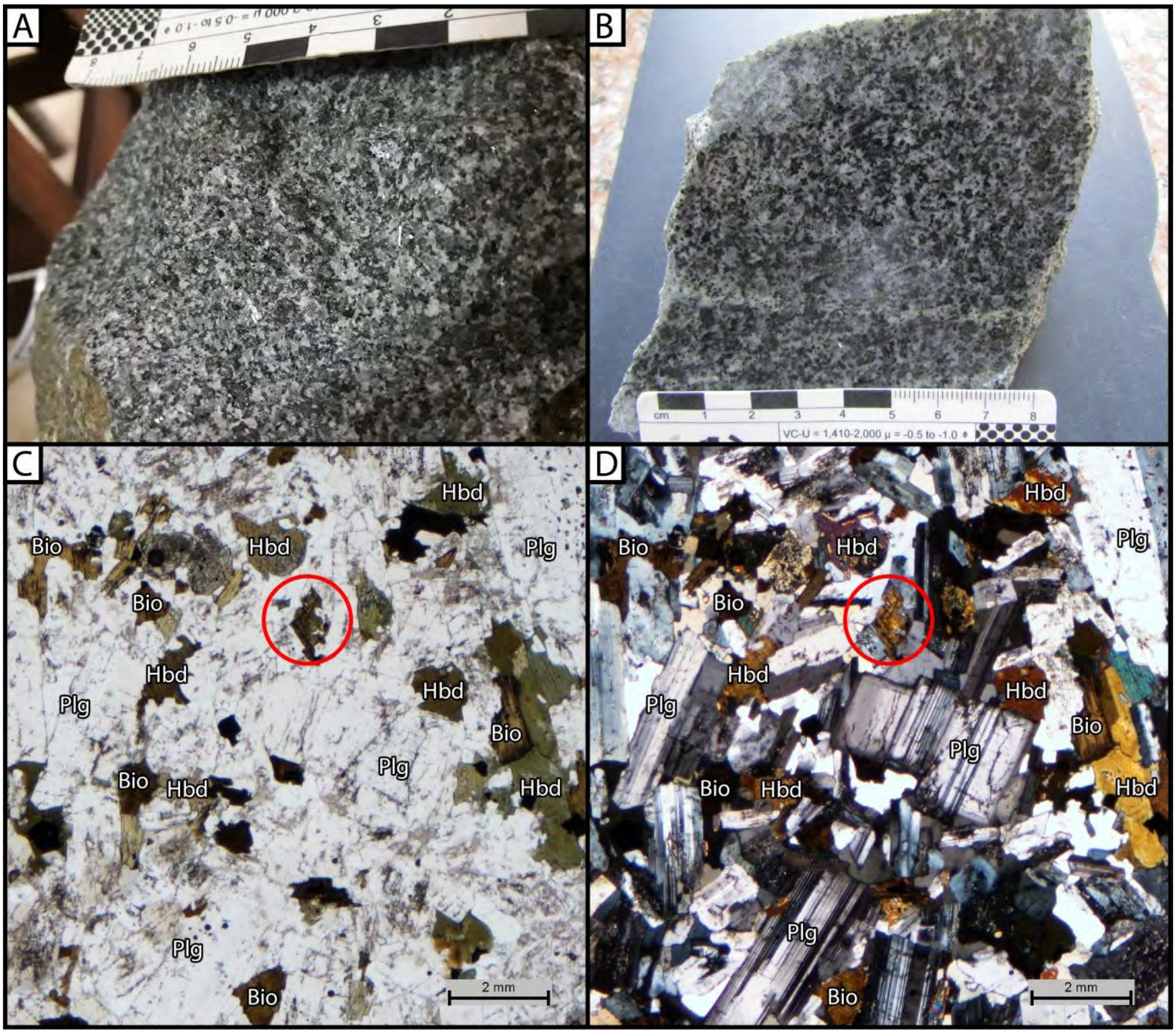

Fig. 3.4 showing the representative of diorite unit from Bueng Sam Phan area, **A.** Hand specimen showing macroscopic texture, **B.** Slab showing more details of macroscopic texture, **C.** and **D.** Photomicrographs (plane polarized and cross nicol respectively) showing hornblende, biotite and plagioclase crystals. In the red circle shows the biotitization texture with the remaining hornblende in the middle of the grain. Abbreviation: Plg = plagioclase, Hbd = hornblende, Bio = biotite.

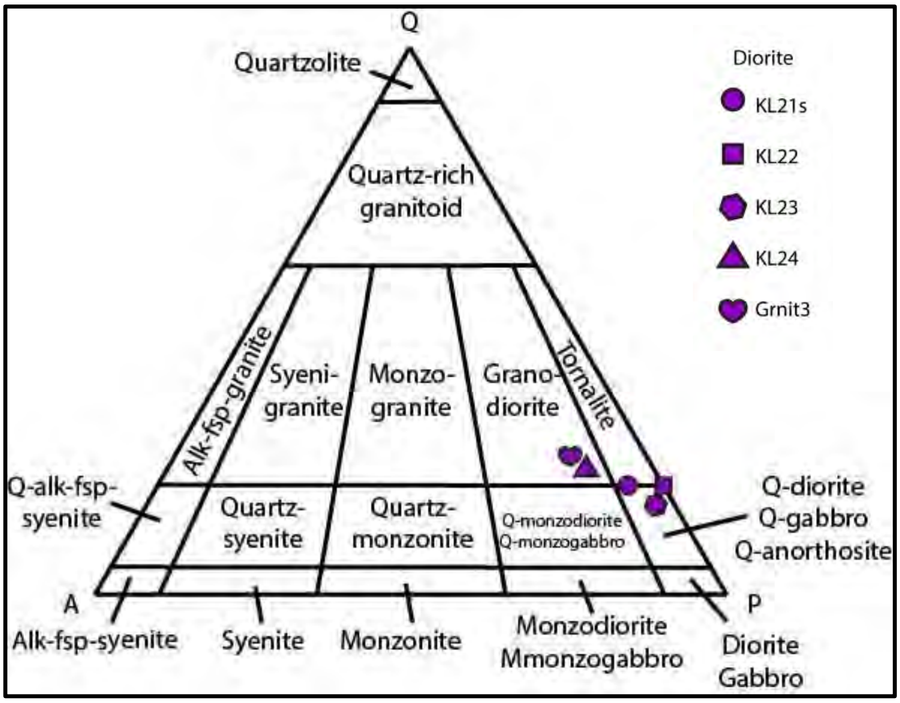

Fig. 3.5 QAPF diagram (Strekeisen 1975) showing mineral compositions of diorite (Unit 2)

Plagioclase occurred in medium sized euhedral grain with tabular shape interlocking to each other (Fig. 3.6A). Almost all of them have albite twin (Figs. 3.6B and 3.7A) while some show zoning (Figs. 3.6B and 3.7B) and some show poikilitic texture with hornblende inclusion (Fig. 3.6B).

Hornblende formed in fine to medium sized irregular shaped anhedral grain which usually shows embayment and corroded texture (Figs. 3.6A, B and 3.7). Few of them are affected from biotitization (Figs. 3.6C and 3.7) and some of them also show simple twin on (001) (Figure).

Biotite occurred in medium sized subhedral grain with platy habit (Figs. 3.6C and D). Few of them also formed in smaller size from biotitization of old hornblende grains (Figs. 3.6C and 3.7).

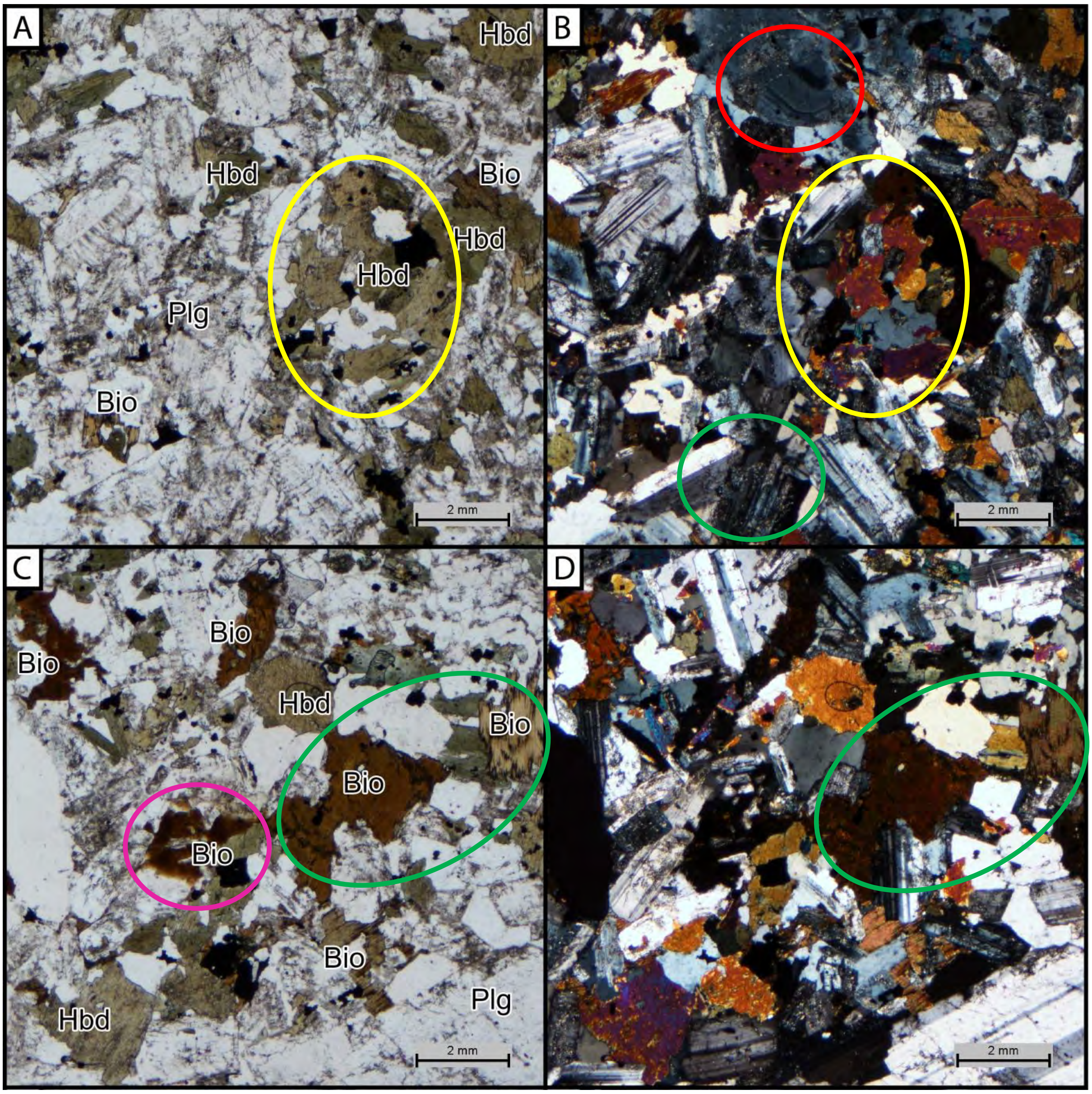

Fig. 3.6 photomicrographs (left is plane polarized and right is cross nicol view of the same photo) showing more textural details of the diorite unit, A. and B. showing zoned plagioclase in the red circle, poikilitic texture of hornblende inclusion in plagioclase in the green circle and corroded hornblende in the yellow circle, C. and D. showing biotitization in the pink circle and platy habit of biotite in the green circle. Abbreviation: Plg = plagioclase, Hbd = hornblende, Bio = biotite.

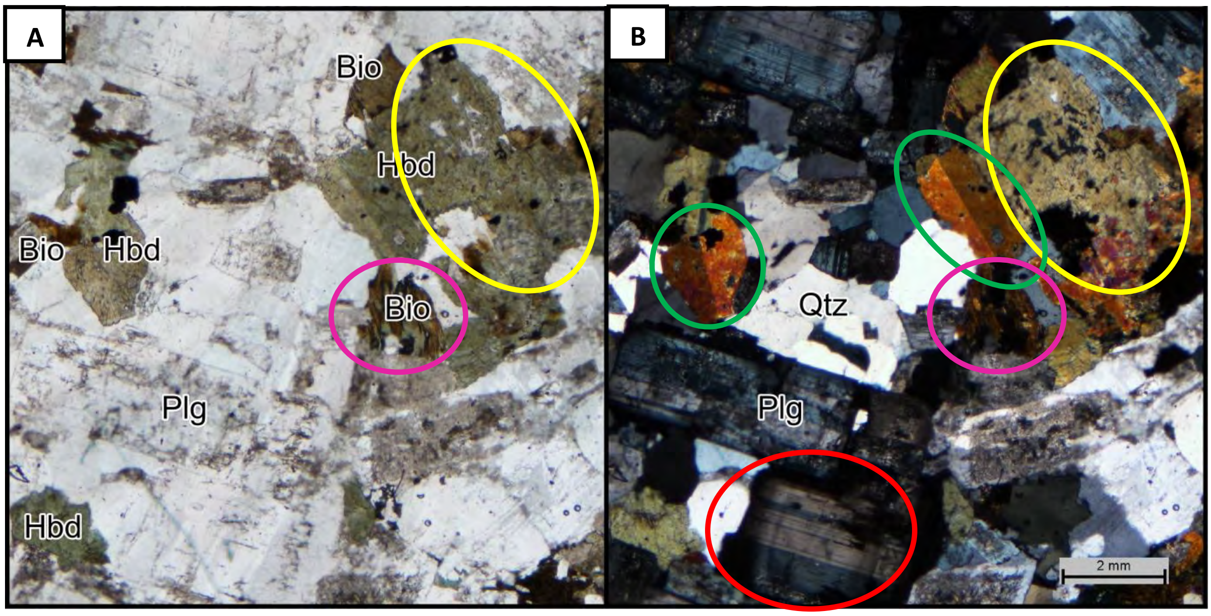

Fig. 3.7 photomicrographs (left is plane polarized and right is cross nicol view of the same photo) showing more textural details of the diorite unit, **A.** and **B.** showing embayed and corroded hornblende in the yellow circle, biotitization in the pink circle, zoned plagioclase in the red circle and hornblende with simple twin on (001) in the green circle. Abbreviation: Qtz = quartz, Plg = plagioclase, Hbd = hornblende, Bio = biotite.

Unit 3 Granodiorite

This rock unit occurred at the eastern area of Ban Sap Takhian and is shown in the dark green symbol in the map (Fig 3.1).

Megascopically, the rock is medium grained, light grey, phaneritic texture. (Figs. 3.8A and B)

Microscopically, it is composed of approximately 50% of 2-5 mm long euhedral-subhedral plagioclase, approximately 30% of 1-2 mm quartz, 10% of 0.5-2 mm biotite and 10% of 0.4-4 mm hornblende (Figs. 3.8C, 3.8D) and can be plotted in the Granodiorite and Tornalite area of the QAPF diagram (Strekeisen, 1975; Fig. 3.9).

Texturally, it shows holocrystaline, inequigranular, hypidiomorphic, interlocking crystals and some replacement textures discussed below.

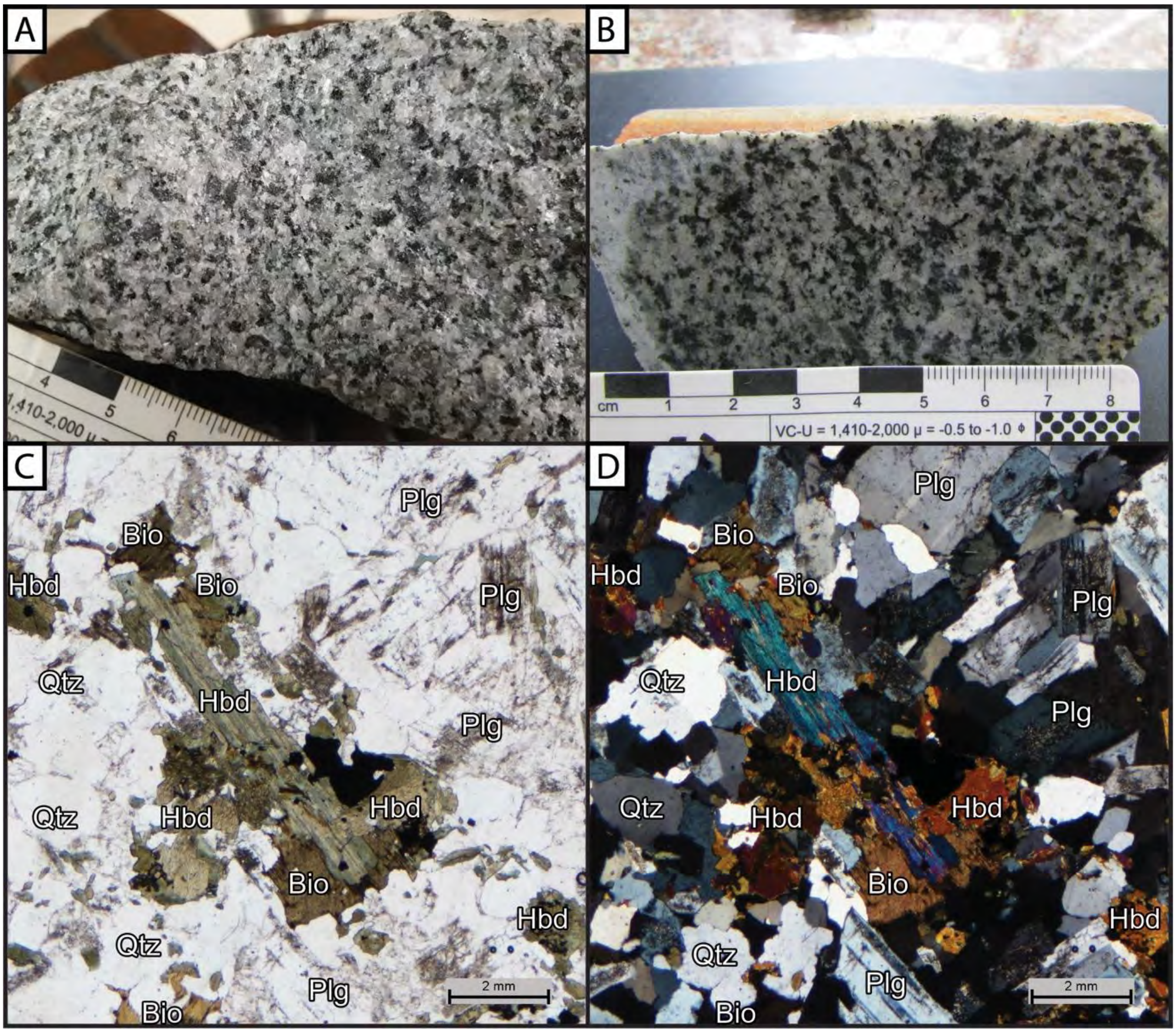

Fig. 3.8 showing the representative of granodiorite unit from Bueng Sam Phan area, **A.** Hand specimen showing macroscopic texture, **B.** Slab showing more details of macroscopic texture, **C.** and **D.** Photomicrographs (plane polarized and cross nicol respectively) showing hornblende, biotite with platy habit, plagioclase and quartz crystals. Abbreviation: Qtz = quartz, Plg = plagioclase, Hbd = hornblende, Bio = biotite.

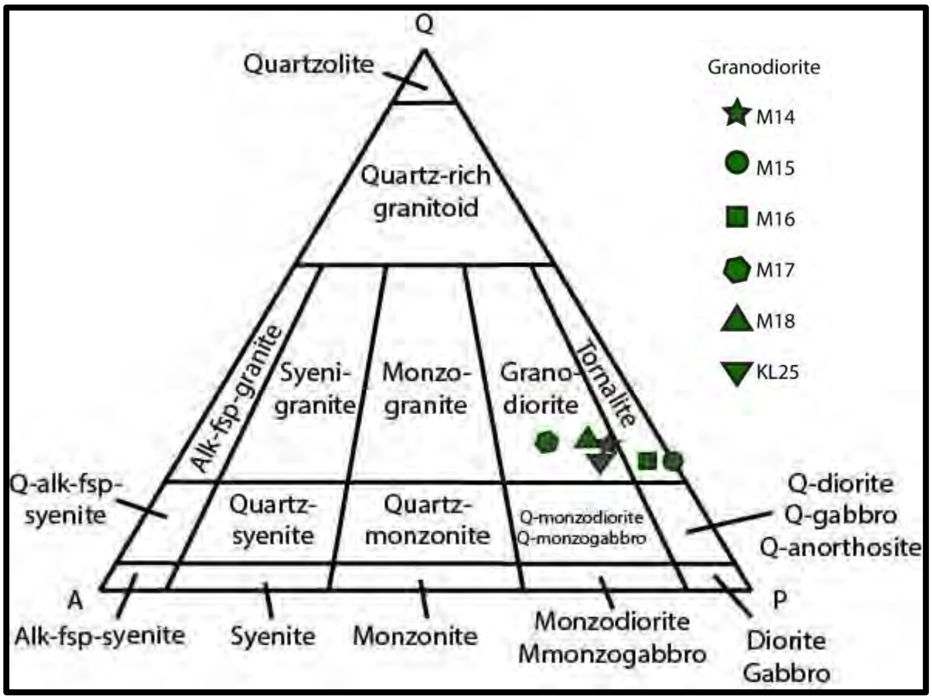

Fig. 3.9 QAPF diagram (Strekeisen 1975) showing mineral compositions of granodiorite (Unit 3).

Plagioclase grains usually appear in medium sized and well-formed euhedral to subhedral tabular shape with occasionally found albite twin (Fig. 3.10A) and oscillatory zoning texture (Fig. 3.10B) which means that the composition of the crystals had switched from the high temperature to the lower temperature endmember a number of times during growth. Some of them also show seritization.

Hornblende occasionally shows simple twin on (001) (Fig. 3.10C) and usually appears in fine to medium sized irregular shaped anhedral grain which has often been either partially replaced by biotitization along the rim (Fig. 3.10D) or corroded and shows embayment.

Biotite occurred in both primary and secondary processes. Primary biotite formed in 2-4 mm long subhedral grain with platy habit showing corroded and embayed texture (Figs. 3.11A and B) while secondary biotite, formed by biotitization of hornblende grains, has smaller size and irregular shape yet shows platy habit (Figs. 3.11C and D).

Comparably, this unit is similar to the prior unit but having more amount of quartz, less albite twin appeared, more commonly found zoning in plagioclase grains and more pervasive biotitization.

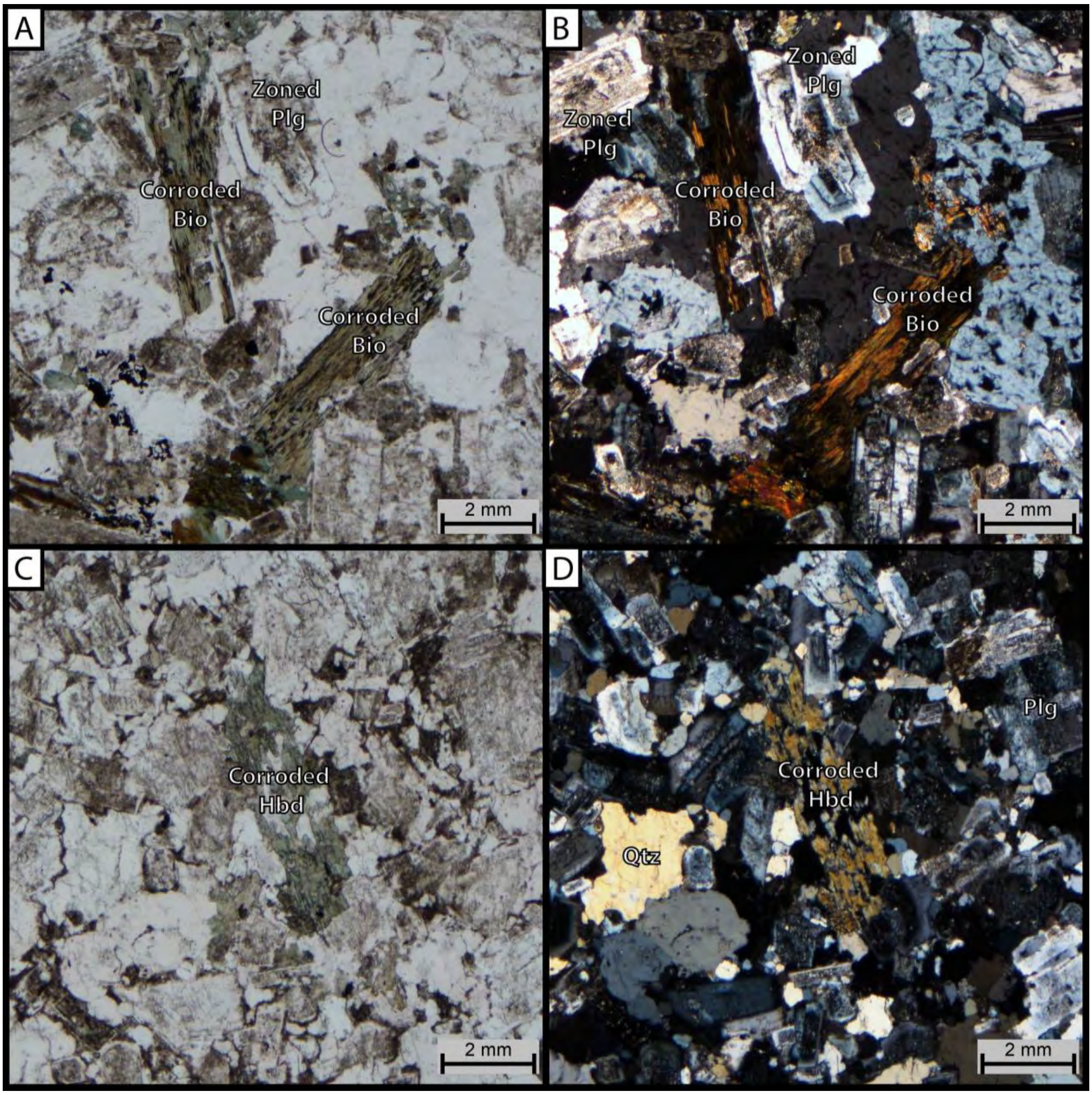

Fig. 3.10 photomicrographs (left is plane polarized and right is cross nicol view of the same photo) showing more textural details of the granodiorite unit, A. and B. showing plagioclase with oscillatory zoning texture and corroded biotite, C. and D. showing corroded hornblende. Abbreviation: Qtz = quartz, Plg = plagioclase, Hbd = hornblende, Bio = biotite.

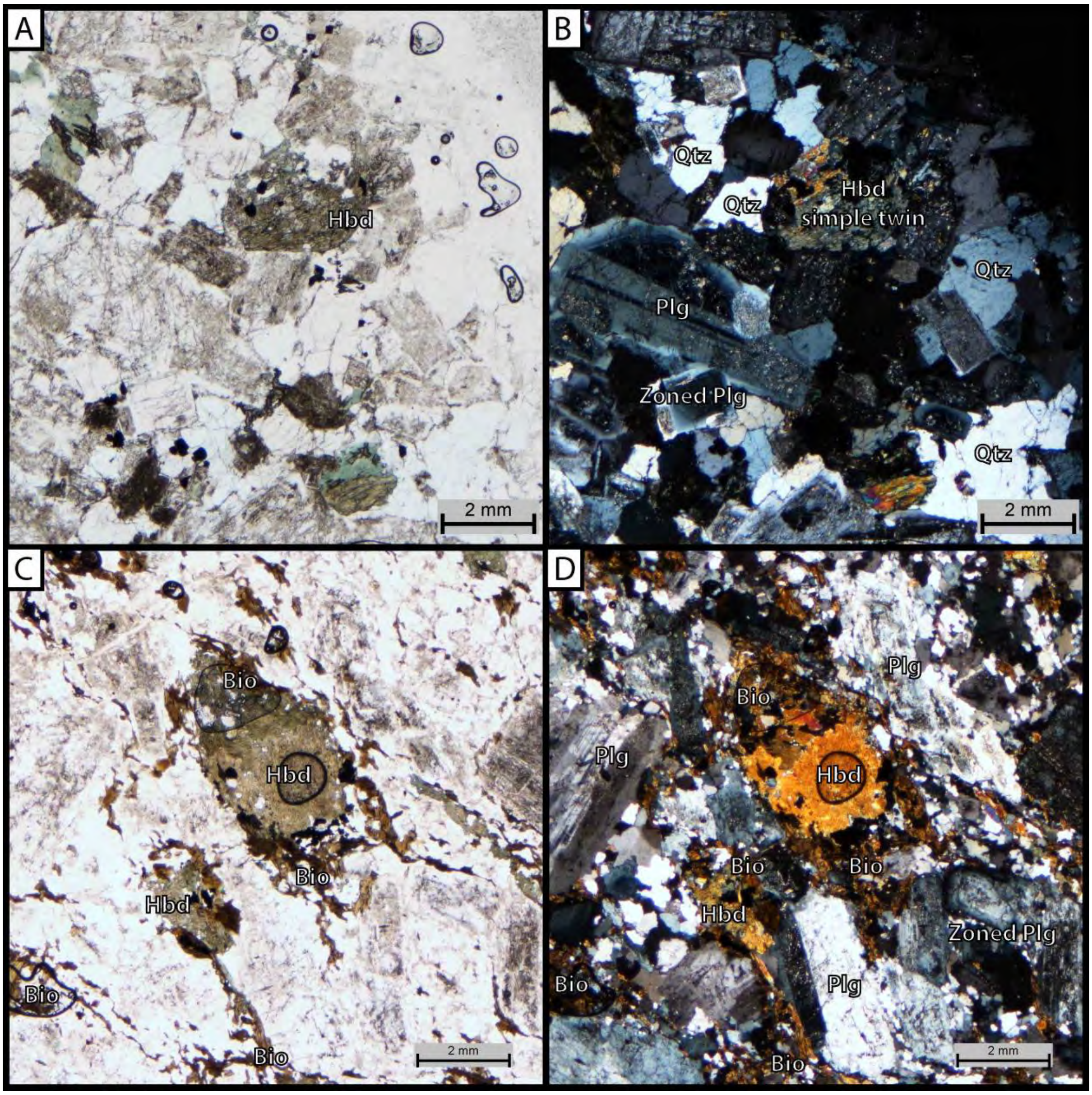

Fig. 3.11 photomicrographs (left is plane polarized and right is cross nicol view of the same photo) showing more textural details of the granodiorite unit, **A.** and **B.** showing plagioclase with albite twin, plagioclase with zoning texture and hornblende with simple twin on (001), **C.** and **D.** showing biotitization embracing hornblende. Abbreviation: Plg = plagioclase, Hbd = hornblende, Bio = biotite.

Unit 4 Basalt

This rock unit occurred along the area of Ban Sap Wa, Ban Neun Sawan, Ban Ta Then and Ban Na Tian and be shown in the dark blue symbols in the map (Fig. 3.1).

Megascopically, the rock is fine grained, dark grey, aphanitic porphyry texture.

Microscopically, it is composed of approximately 70% of 0.5-1 mm lath shaped subhedral plagioclase and 20% of 0.5-2 mm anhedral pyroxene as the phenocrysts and 10% of glass groundmass (Figs. 3.12A and B).

Texturally, it shows hypocystalline, hiatial porphyritic, vitrophyric, hipidiomorphic, ophitic texture of palgioclase in clinopyroxene, intergranular texture of clinopyroxene between plagioclase grains and intersertial texture of glass between plagioclase grains (Figs. 3.12C and D).

Unit 5 Basaltic andesite

This rock unit occurred along the area of Ban Neun Sawan and be shown in the light green symbols in the map (Fig. 3.1).

Megascopically, the rock is fine grained, dark grey, aphanitic porphyry texture.

Microscopically, it is composed of approximately 10% of 1-2 mm anhedral to subhedral hornblende phenocryst, 5% of 0.25-2 mm anhedral pyroxene phenocryst, 5% of 0.5-2 mm anhedral-subhedral sanidine and 80% microcrystalline groundmass (Figs. 3.13A and B).

Texturally, it shows hypocystalline, hiatial porphyritic, allotriomorphic, embament texture, megaphenocryst and microlitic graoundmass (Figs. 3.13C and D).

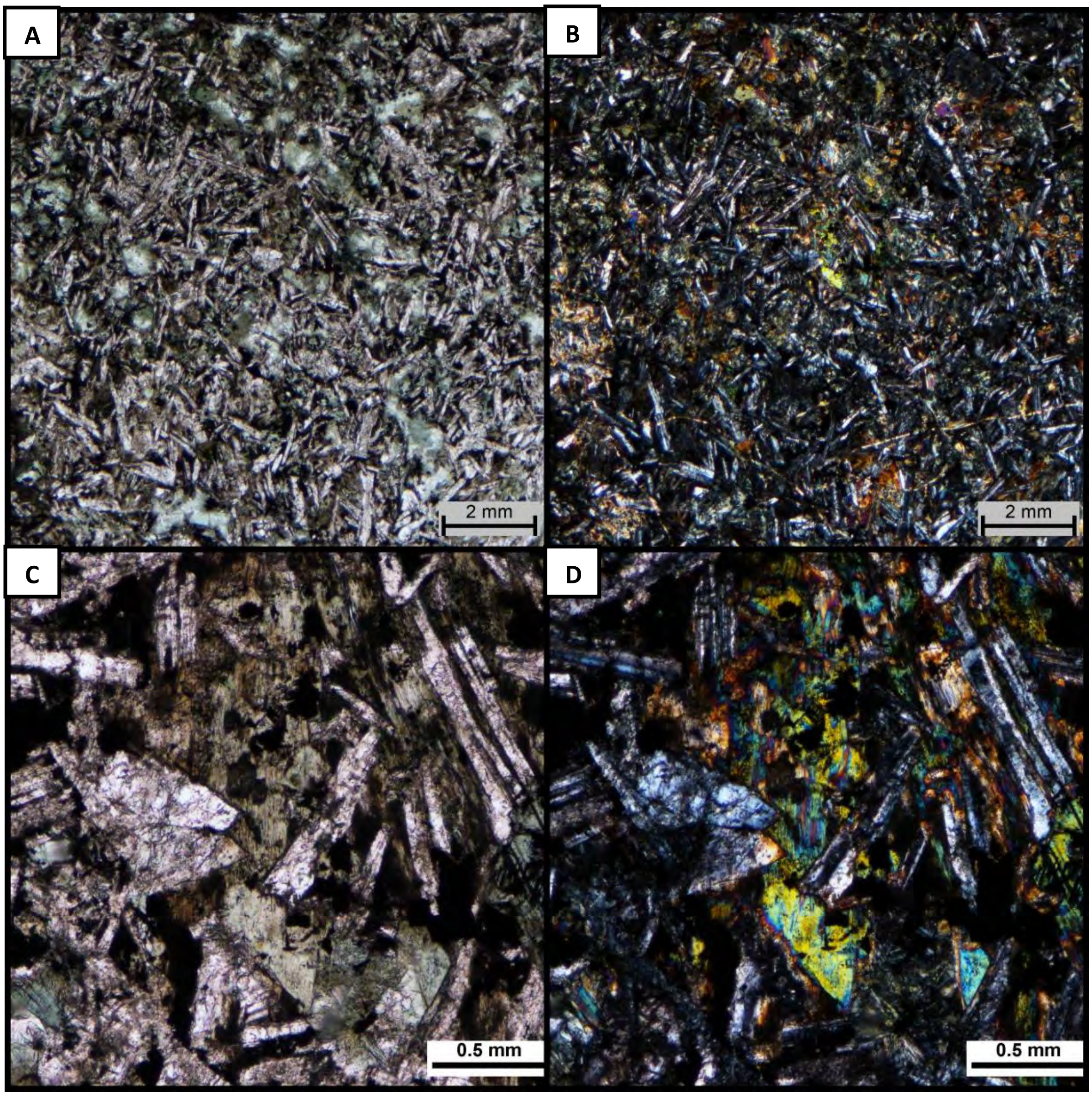

Fig. 3.12 showing the representative of basalt unit from Bueng Sam Phan area, **A.** and **B.** 10X photomicrographs plane polarized and cross nicol respectively) showing microlite texture, **C.** and **D.** 50X photomicrographs (plane polarized and cross nicol respectively) showing ophitic, intergranular and intersertial texture.

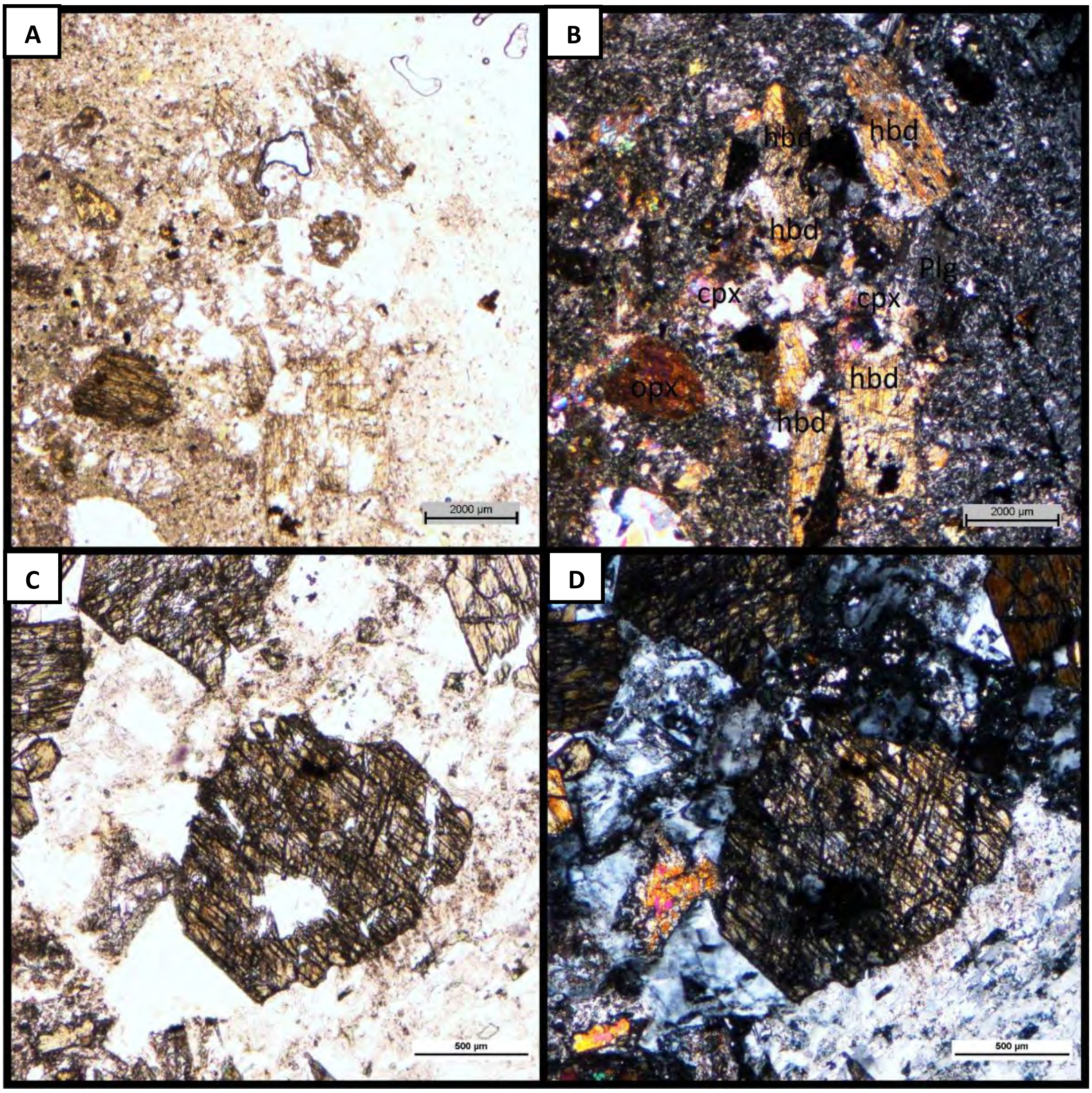

Fig. 3.13 showing the representative of basaltic andesite unit from Bueng Sam Phan area, **A.** and **B.** 10X photomicrographs (plane polarized and cross nicol respectively) showing glomerophyric texture of hornblende and pyroxene phenocrysts and microlitic groundmass, **C.** and **D.** 50X photomicrographs (plane polarized and cross nicol respectively) showing embayment texture in hornblende megaphenocryst and sanidine. Abbreviation: Cpx = clinopyroxene, Opx = orthopyroxene, Hbd = hornblende.

Unit 6 Andesite

This rock unit occurred at the area of Ban Neun Sawan, Ban Sap Wa and Ban Sri Chan and be shown in the pink symbols in the map (Fig. 3.1).

Megascopically, the rock is fine grained, light grey, aphanitic porphyry texture.

Microscopically, it is composed of approximately 10% of 1-2 mm lath shaped subhedral hornblende phenocrysts and 90% microcrystalline groundmass (Fig. 3.14A).

Texturally, it shows hypocystalline, hiatial porphyritic, hipidiomorphic, megaphenocryst and microlitic graoundmass (Fig. 3.14B).

Hornblende phenocrysts usually show simple twin on (001) and dark alteration rim resulting from microcystalline alteration to Mag+Cpx (Opacite) in Kaersutitic hornblende (Figs. 3.14C and D).

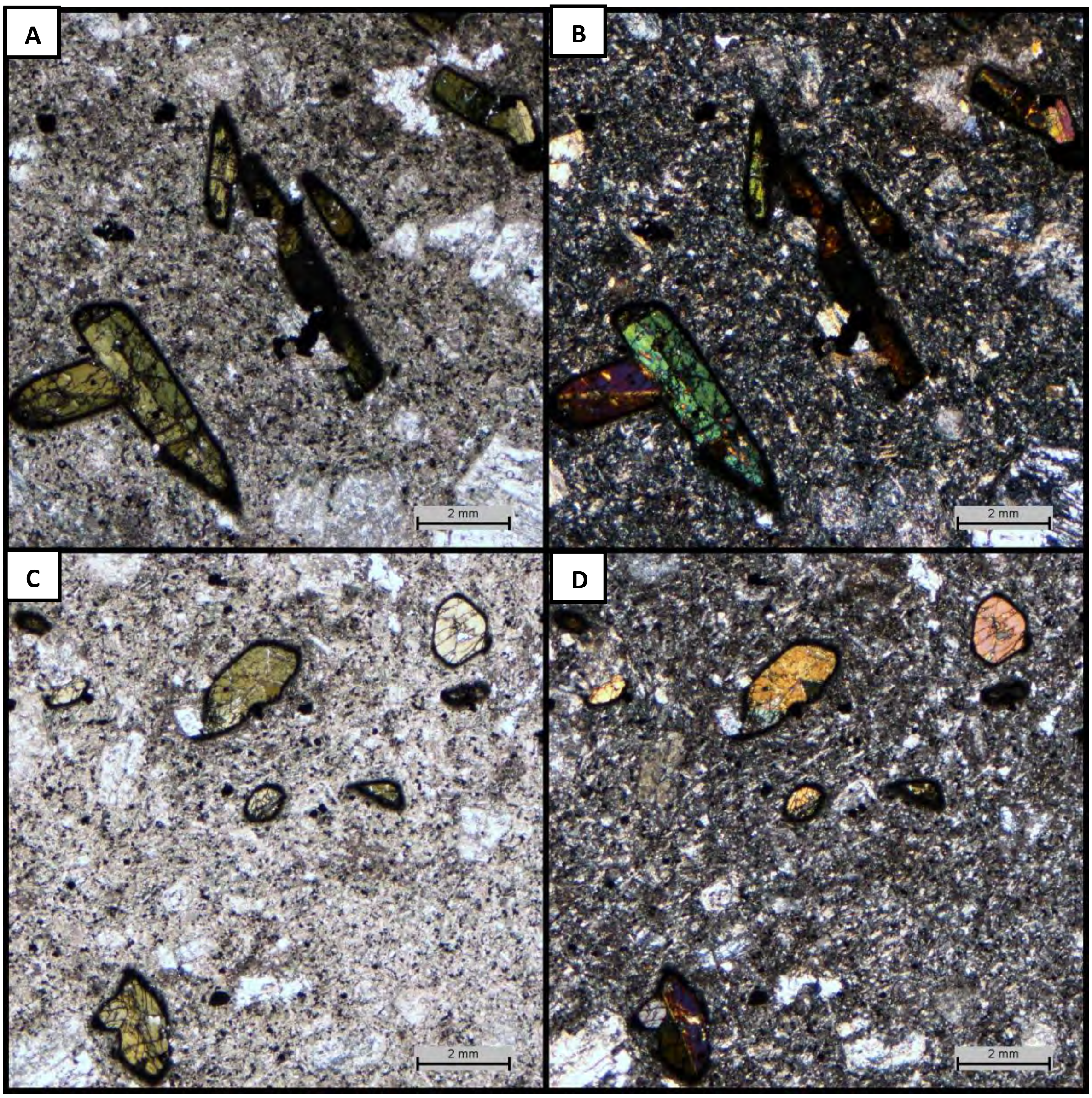

Fig. 3.14 showing the representative of Andesite unit from Bueng Sam Phan area, A. and B. 10X photomicrographs (plane polarized and cross nicol respectively) showing lath shaped subhedral hornblende phenocrysts and microlitic groundmass, C. and D. 10X photomicrographs (plane polarized and cross nicol respectively) showing subhedral hornblende phenocrysts.

3.1.2 Chachoengsao Area

Although the spatial distribution of the collected samples in the Chachoengsao area (Fig. 3.15) is distributed into 3 areas, they are all common in chemical composition and petrographic characteristics. Hence, the results in Chachoengsao area are reported in one unit that is granite which is organized to be the unit 7.

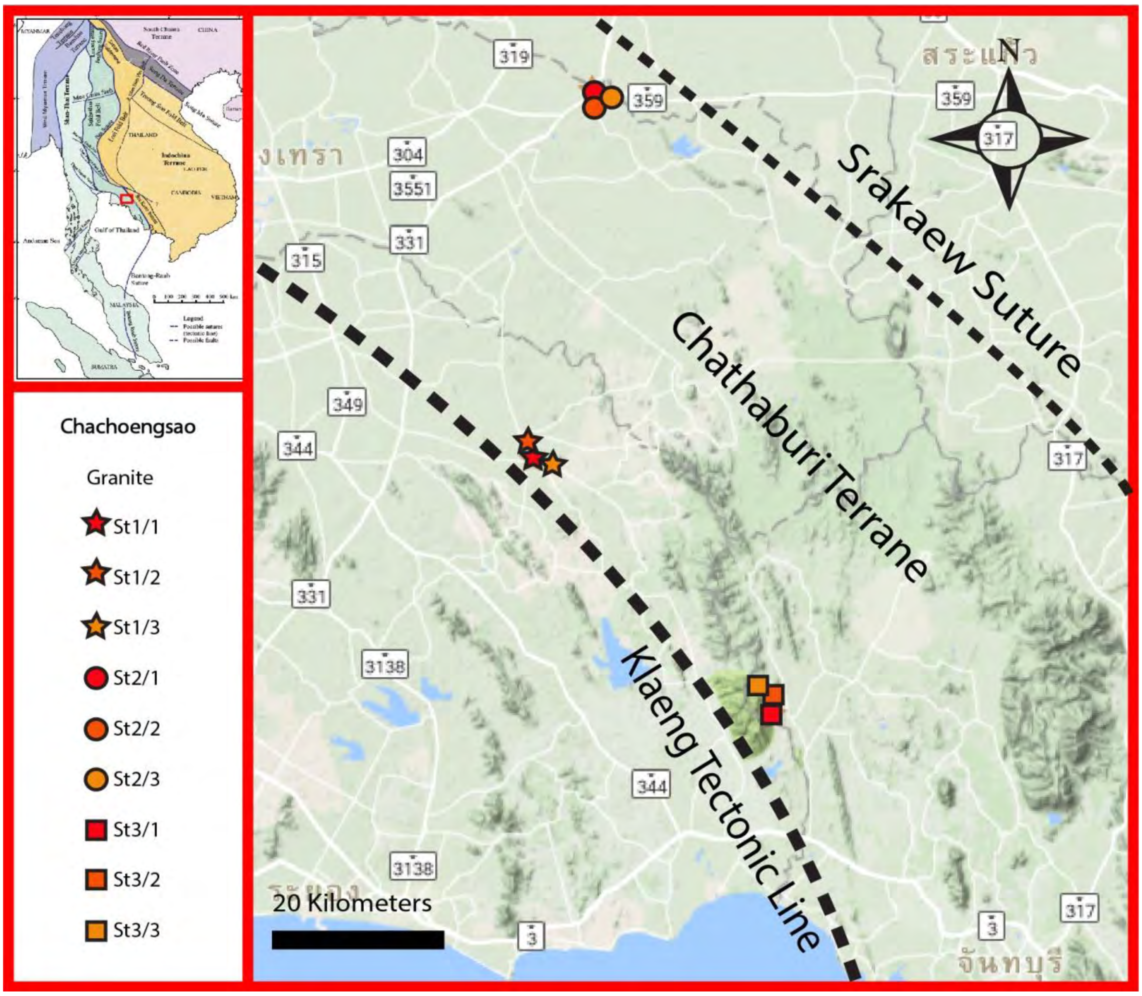

Fig 3.15 showing the location map of the Chachoengsao area located in Chanthaburi terrane, representative of the Sukhothai Belt section. The map shows the location and spatial distribution of the collected samples with different shaped and colored symbols as shown in the legend but all are in the same unit: Granite.

Unit 7 Granite

This rock unit occurred at Ban Ompanom, Amphoe Bo Thong, Changwat Chonburi (St1), Khao Hin Son, Amphoe Kabinburi, Changwat Prachinburi (St2) and Khao Chamao, Amphoe Bo Thong, Changwat Chonburi (St3) as shown in the Figure 3.15.

Megascopically, the rock has porphyritic texture and is composed of white to grey phenocrysts and light grey groundmass with foliation (Figs 3.16A and B).

Microscopically, the rock is holocystalline, seriate porphyritic, granophyric, hipidiomorphic. The phenocrysts are plagioclase and k-feldspar while the groundmass is composed of k-feldspar, plagioclase, quartz and biotite. There also are the deformed textures especially with the groundmass such as elongate biotite (Figs 3.16C and D).

Plagioclase phenocrysts are averagely 2-3 mm long with the maximum length of 5 mm while k-feldspar phenocrysts are usually 2-4 mm long and the groundmass size is around 0.2-0.5 mm.

Overall, the rock is composed of 20-25% euhedral to subhedral plagioclase, 35-40% subhedral k-feldspar, 30-35% quartz, 10-15% biotite and can be plotted in the monzo-granite, quartz-monzonite and syenite area of the QAPF diagram (Strekeisen, 1975; Fig. 3.17).

There are also perthitic texture, elongate biotite, crushed quartz into the small pieces and the belt of k-feldspar aggregation which suggest that the rocks have undergone tectonic deformation (Figs 3.16C and D).

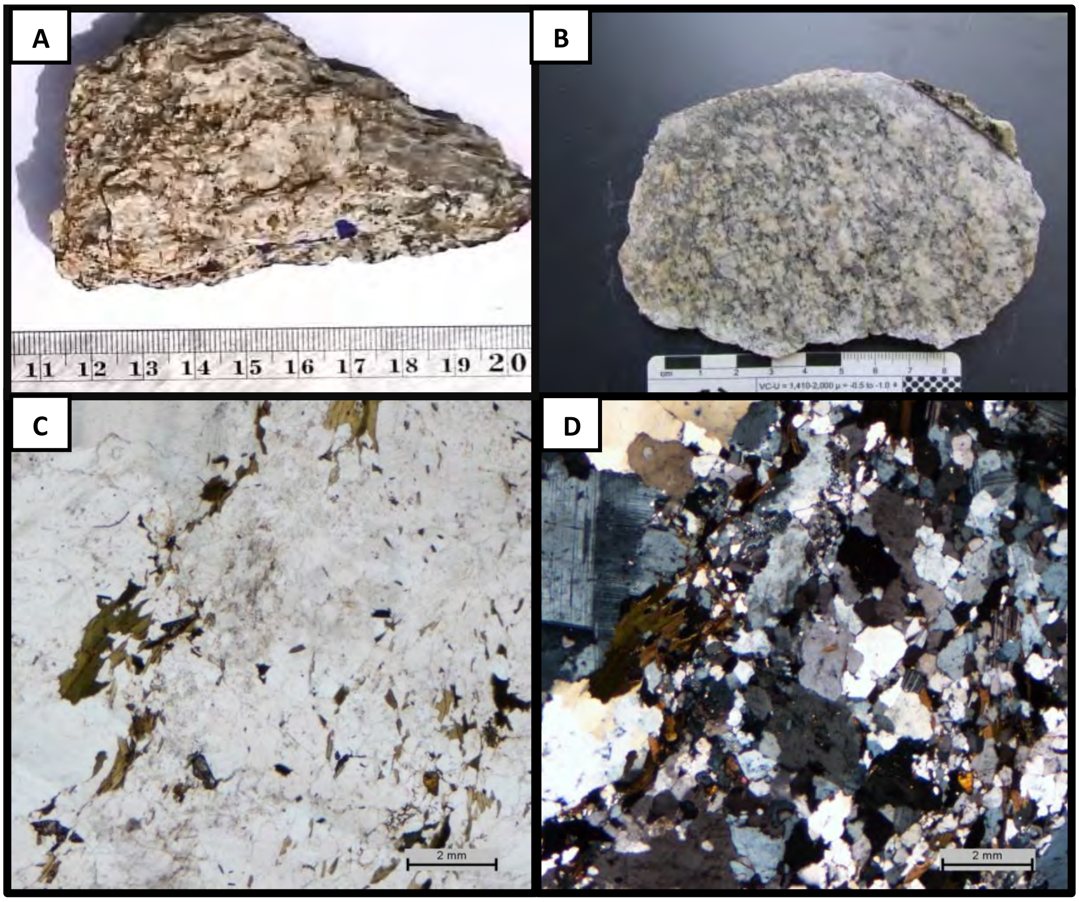

Fig 3.16 showing the representative of granite unit from Chachoengsao area, A. Hand specimen showing macroscopic texture, B. Slab showing more details of macroscopic texture, C. and D. Photomicrographs (plane polarized and cross nicol respectively) showing deformed texture and mineral composition: k-feldspar, biotite, plagioclase and quartz

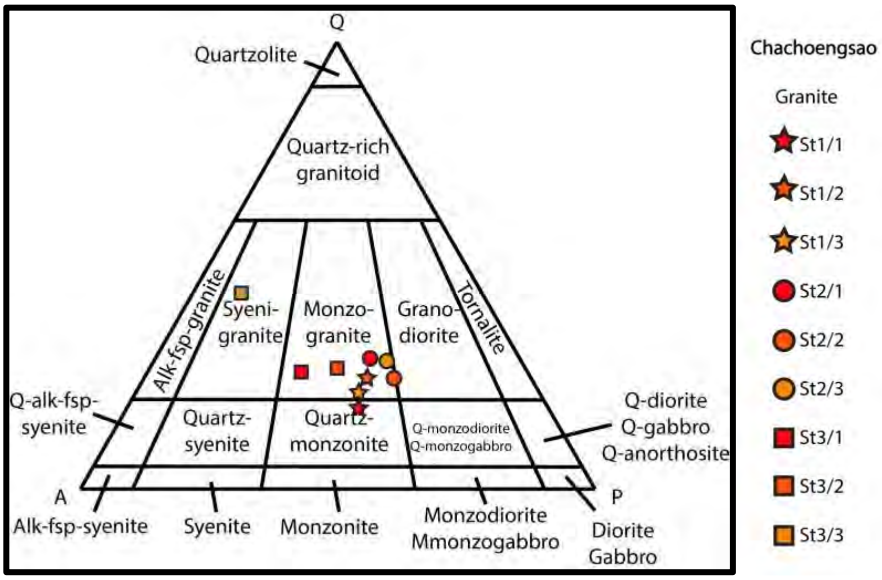

Fig. 3.17 QAPF diagram (Strekeisen, 1975) showing mineral compositions of granite (Unit 7)

3.2 Geochemistry

The geochemical results are separately reported by the occurrences of the igneous rocks: Volcanic and Plutonic.

3.2.1 Volcanic unit

The Volcanic unit is composed of Basalt unit, Basaltic andesite unit and Andesite unit from Bueng Sam Phan area.

3.2.1.1 Chemical Classification

The chemical composition of the volcanic rocks from Bueng Sam Phan area are plotted in the Total Alkaline versus Silica Discrimination Diagram (Cox et al., 1979; Fig. 3.18) and result in that the rocks in Basalt unit from the previous petrographic classification (in the dark blue symbols) are plotted in the Basalt area in this diagram, the rocks in Basaltic andesite unit from the previous petrographic classification (in the light green symbols) are plotted in the Basaltic andesite, trachy-andesite(for M6) and Mugearite (for M11A) area in this diagram and the rocks in Andesite unit from the previous petrographic classification (in the pink symbols) are plotted in the Andesite, Trachy-andesite and Mugearite(for M11B) area in this diagram. Those show that both aspects of classification in this study are consistent and according.

In the Figure 3.18, the magmatic composition of the volcanic rocks are plotted along the separation line between Alkaline and Subalkaline/Tholeiitic magma with the noted samples number M11A and M11B that contain the distinct high amount of Alkaline composition and fall into the Mugearite zone.

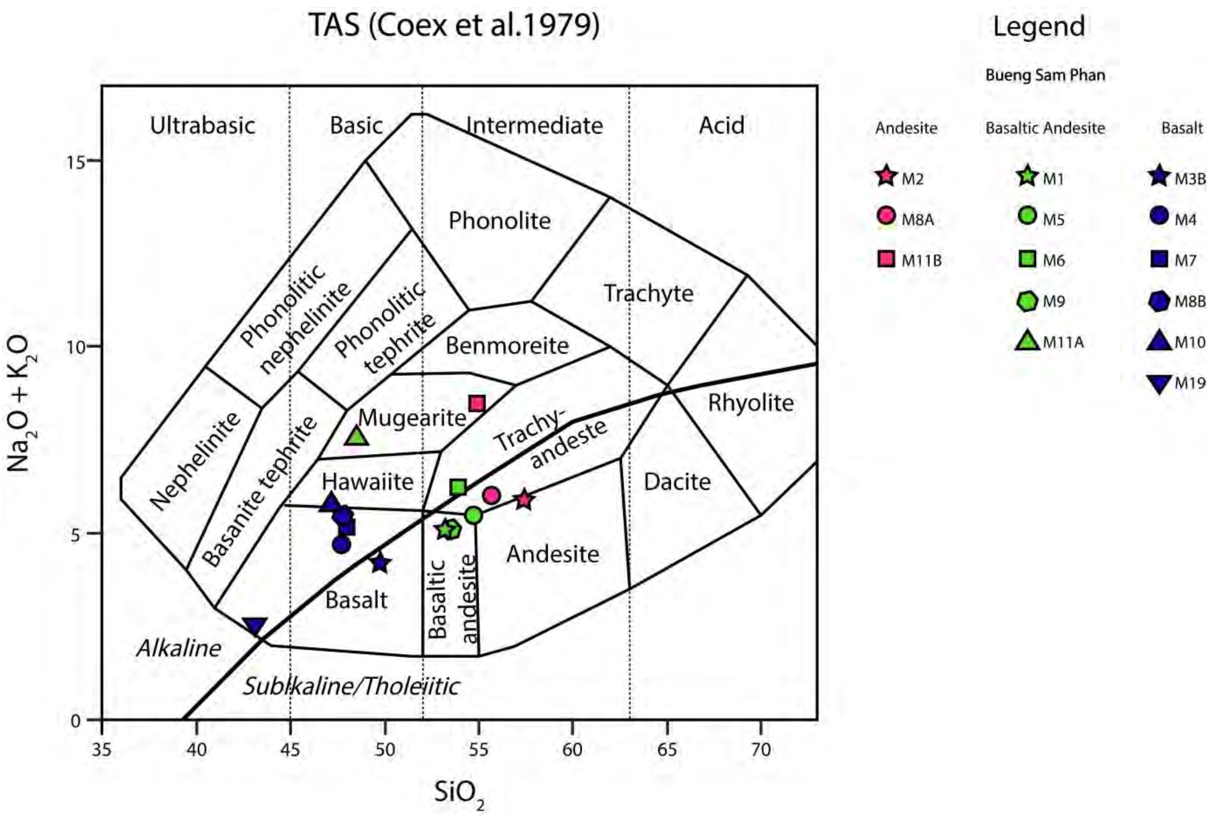

Fig. 3.18 showing the chemical composition plot of the volcanic samples from Bueng Sam Phan area in the total alkaline versus silica diagram (Cox et al. 1979).

3.2.1.2 Major element geochemistry

The rocks in basalt unit contain SiO_2 content between 43.1 to 49.7 wt.% among which M19 contains the lowest amount (the most mafic) and M3B contains the highest amount (the most felsic). All basalts contain 16.6 to 18.5 wt.% Al_2O_3, 5.9 to 10.9 wt.% CaO, 9.01 to 13.1 wt. % Fe_2O_3, 0.27 to 1.54 wt.% K_2O, 4.53 to 8.68 wt.% MgO, 0.14 to 0.25 wt.% MnO, 2.23 to 4.9 wt.% Na_2O, 0.21 to 0.36 wt.% P_2O_5, 0 to 0.6 wt.% SrO and 0.84 to 1.7 wt.% TiO_2. The K_2O, Na_2O, P_2O_5. SrO and Al_2O_3 contents increase with the increasing SiO_2 while the CaO, Fe_2O_3, MgO, MnO and TiO2 contents decrease with the increasing SiO_2, especially Fe_2O_3, MgO and TiO that decrease with the obvious linear trend as a result of the fractional crystallisation and removal of titanomagnetite clinopyroxene, plagioclase and apatite (Fig. 3.19). The K_2O versus SiO_2 plot shows that basalts in this area belong to the medium K calc-alkaline to high K calc-alkaline magma series (Fig. 3.20). Moreover, their aluminum saturation index indicates metaluminous type of magma (Fig. 3.21).

The rocks in basaltic andesite unit contain SiO_2 content between 48.5 to 54.7 wt.% among which M11A contains the lowest amount (the most mafic) and M5 contains the highest amount (the most felsic). All basaltic andesites contain 16.2 to 18.4 wt.% Al_2O_3, 5.68 to 9.74 wt.% CaO, 6.86 to 8.39 wt. % Fe_2O_3, 0.3 to 1.96 wt.% K_2O, 1.42 to 4.6 wt.% MgO, 0.14 to 0.27 wt.% MnO, 4.14 to 7.28 wt.% Na_2O, 0.23 to 0.5 wt.% P_2O_5, 0 to 0.5 wt.% SrO and 0.54 to 0.99 wt.% TiO_2. The K_2O, SrO and Al_2O_3 contents increase with the increasing SiO_2 while the CaO, Fe2O3, Na_2O, MgO, MnO, TiO2 and P_2O_5 contents decrease with the increasing SiO_2 as a result of the fractional crystallization (Fig. 3.19). The K_2O versus SiO_2 plot shows that basaltic andesite in this area belong to the medium K calc-alkaline to high K calc-alkaline magma series (Fig. 3.20). Moreover, their aluminum saturation index indicates metaluminous type of magma (Fig. 3.21).

The andesite unit contains SiO_2 between 54.9 to 57.4 wt.% which M11B contains the lowest amount (the most mafic) and M2 contains the highest amount (the most felsic). All andesites contain 16.8 to 17.4 wt.% Al_2O_3, 6.01 to 6.42 wt.% CaO, 6.04 to 7.33 wt. % Fe_2O_3, 1.59 to 2.14 wt.% K_2O, 0.66 to 2.31 wt.% MgO, 0.11 to 0.23 wt.% MnO, 4.31 to 6.34 wt.% Na_2O, 0.29 to 0.45 wt.% P_2O_5, 0 to 0.32 wt.% SrO and 0.55 to 0.96 wt.% TiO_2. The MgO and MnO contents increase with the increasing SiO_2 while the Na_2O, Al_2O_3, K_2O, TiO2 and P_2O_5 contents decrease with the increasing SiO_2 (Fig. 3.19). The K_2O versus SiO_2 plot shows that andesites in this area belong to the medium K calc-alkaline to high K calc-alkaline magma series (Fig. 3.20). Moreover, their aluminum saturation index indicates metaluminous type of magma (Fig. 3.21).

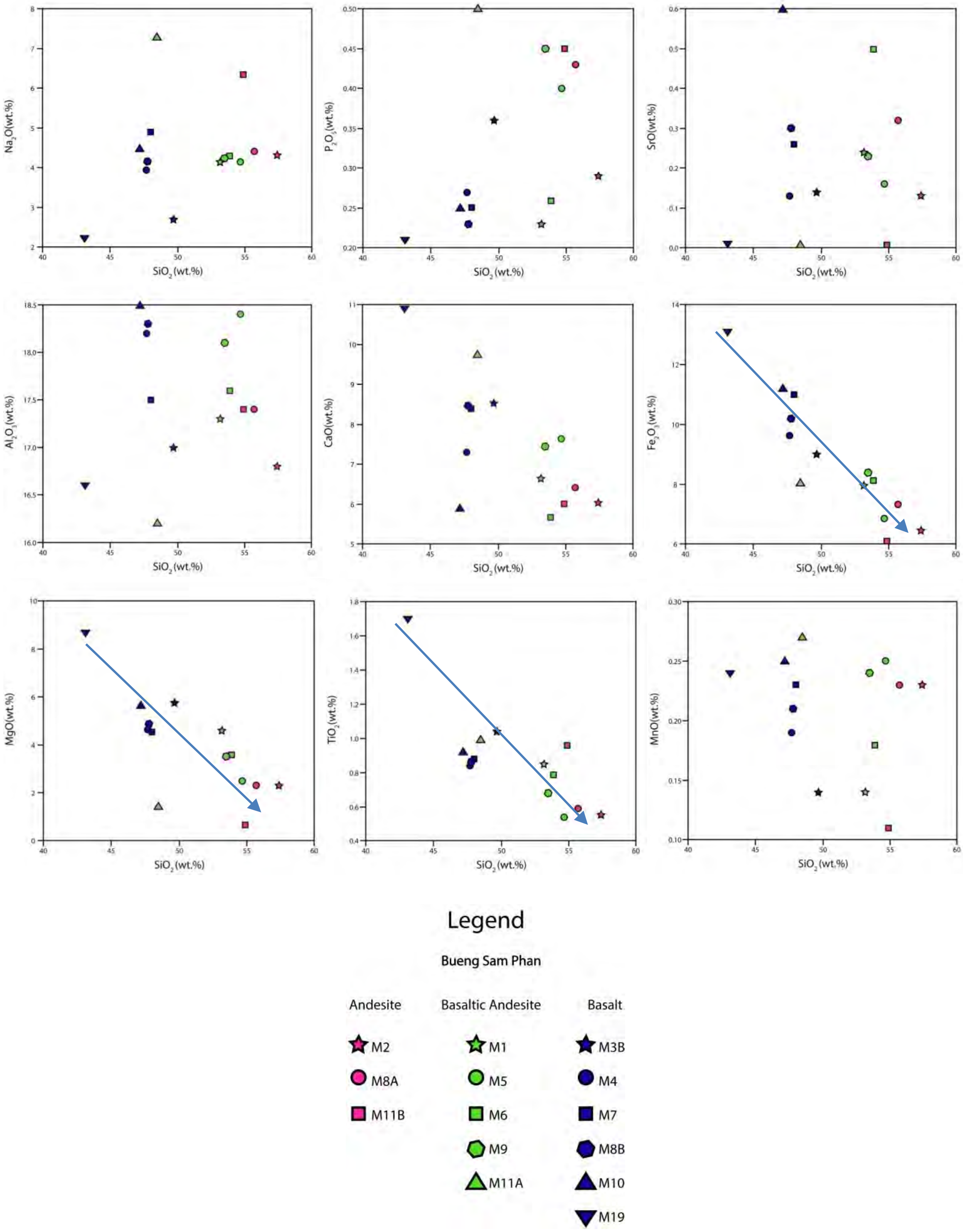

Fig. 3.19 showing the major chemical composition plot of the volcanic samples from Bueng Sam Phan area in the Harker variation diagram with the blue arrows showing the trend of the crystal fractionation

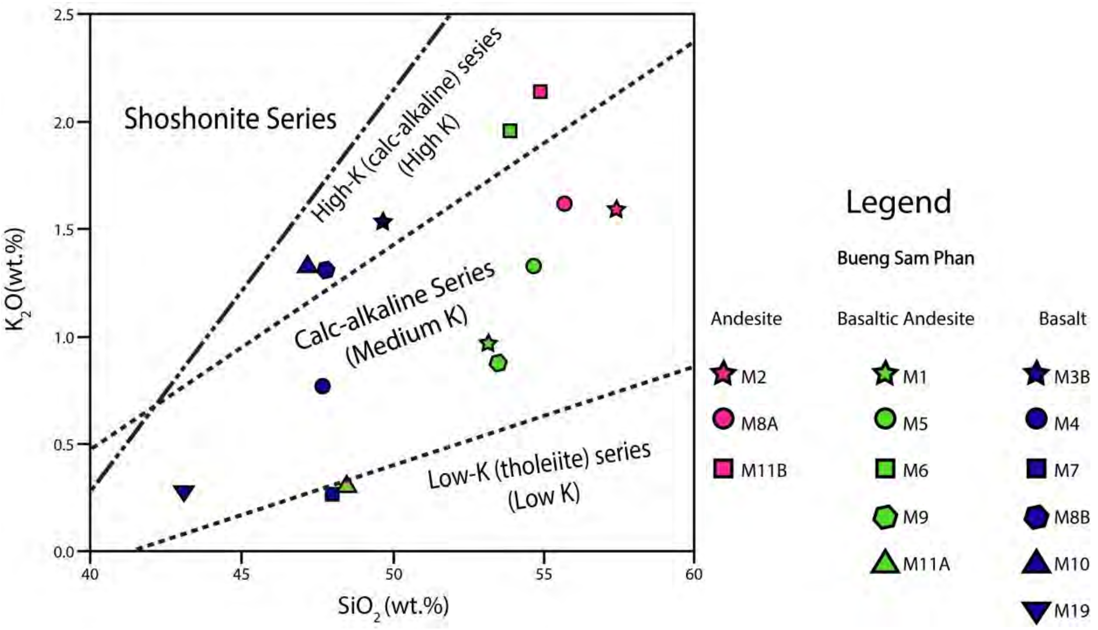

Fig. 3.20 showing the major chemical composition plot of K_2O versus SiO_2 of the volcanic samples from Bueng Sam Phan area in the Harker variation diagram, showing the alkaline content and magmatic type of each sample (Rickwood, 1989)

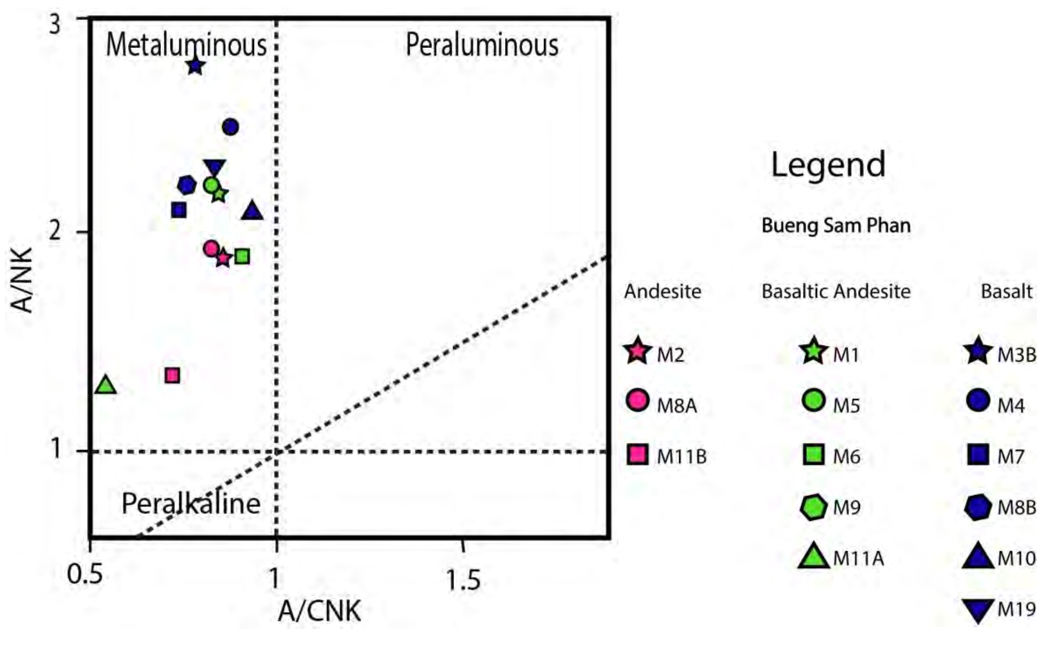

Fig. 3.21 showing the major chemical composition plot of Al_2O_3 /(Na_2O+K_2O) versus Al_2O_3 / (CaO+Na_2O+K_2O) (Maniar and Piccoli, 1989) of the volcanic samples from Bueng Sam Phan area (Abbreviation; A=Al_2O_3, C=CaO, N=Na_2O, N=K_2O)

3.2.2 Plutonic unit

The Plutonic unit is composed of Gabbro unit, Diorite unit, Granodiorite unit from Bueng Sam Phan area and Granite unit from Chachoengsao area, separated by different symbols.

3.2.2.1 Chemical Classification

The chemical composition of the plutonic rocks from Bueng Sam Phan area are plotted in the Total Alkaline versus Silica Discrimination Diagram (Cox et al., 1979; Fig. 3.22) and result in that the rocks in Gabbro unit from the previous petrographic classification (in the light blue symbols) are plotted in the Gabbro area in this diagram, the rocks in Diorite unit from the previous petrographic classification (in the violet symbols) are plotted in the Diorite area in this diagram, the rocks in Granodiorite unit from the previous petrographic classification (in the dark green symbols) are plotted in the Granodiorite area in this diagram and the rocks in Granite unit from the previous petrographic classification are plotted in the Granite area in this diagram. Those show that both aspects of classification in this study are consistent and according.

In the Figure 3.22, the samples from both study areas are obviously separated into two groups which mean they are apart in chemical composition. Moreover, the magmatic composition of the Bueng Sam Phan plutonic rocks are mostly plotted in the Subalkaline/Tholeiitic magma zone while the magmatic composition of the Chachoengsao plutonic rocks are plotted in both Subalkaline/Tholeiitic and Alkaline magma zone. This suggest that the Chachoengsao plutonic rocks tend to be more alkalic in composition than the Bueng Sam Phan plutonic rocks.

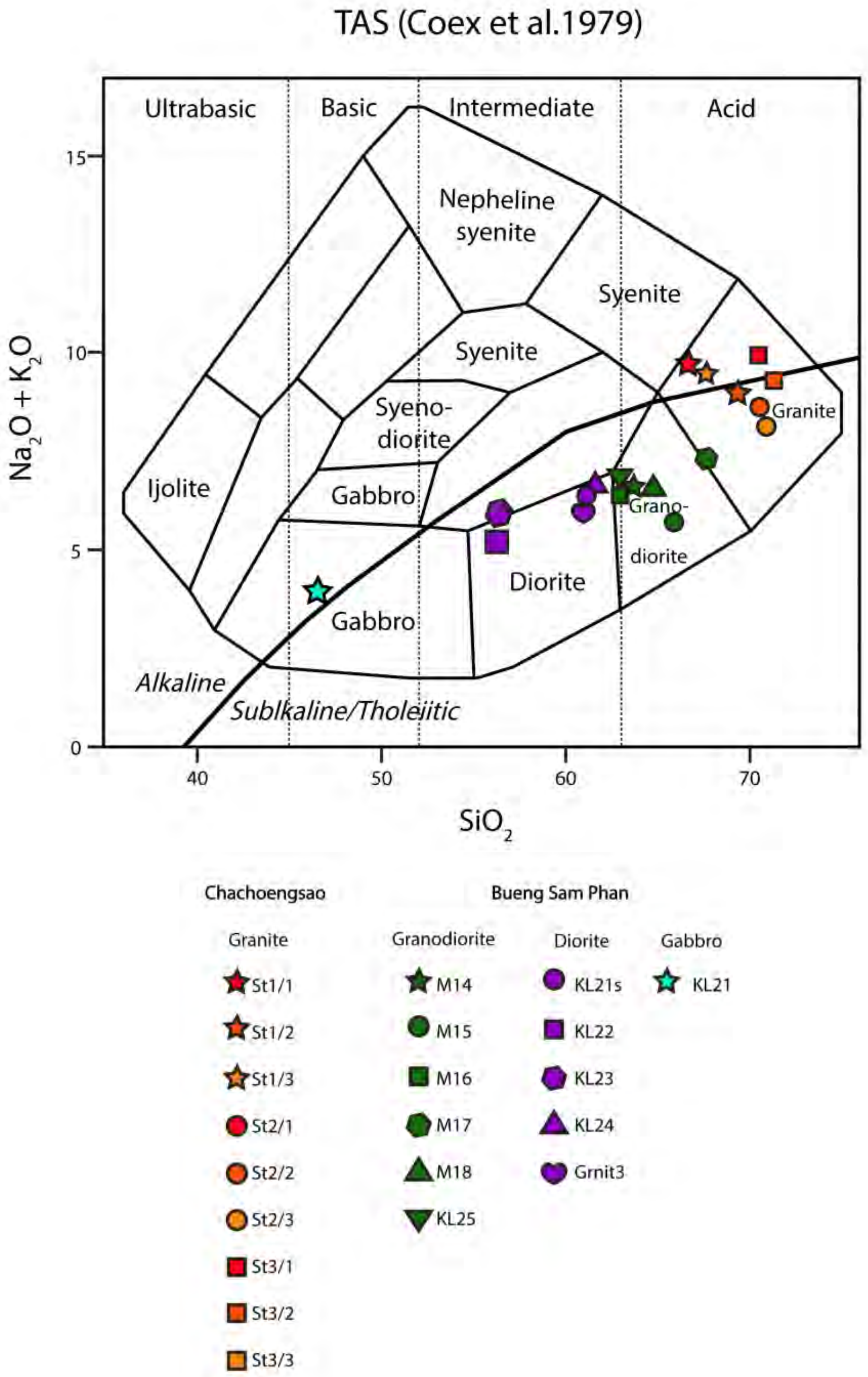

Fig. 3.22 showing the chemical composition plot of the plutonic samples from Bueng Sam Phan area and Chachoengsao area in the Total Alkaline versus Silica Diagram (Cox et al. 1979)

3.2.2.2 Major element geochemistry

The rocks in diorite unit contain SiO_2 content between 56.1 to 61.3 wt.% among which KL22 contains the lowest amount (the most mafic) and KL24 contains the highest amount (the most felsic). All diorites contain 15.6 to 17.2 wt.% Al_2O_3, 54.79 to 8.45 wt.% CaO, 2.57 to 7.21 wt. % Fe_2O_3, 1.52 to 2.64 wt.% K_2O, 3.03 to 4.62 wt.% MgO, 3.43 to 4.41 wt.% Na_2O, 0.24 to 0.29 wt.% P_2O_5 and 0.65 to 0.95 wt.% TiO_2. The MgO, Fe_2O_3, TiO_2, CaO, P_2O_5, and Al_2O_3 contents decrease with the increasing SiO_2 while the K_2O content increases with the increasing SiO_2, all with the obvious linear trend, as a result of the fractional crystallization (Fig. 3.23). The K_2O versus SiO_2 plot shows that diorites in this area belong to the medium K calc-alkaline to high K calc-alkaline magma series. Moreover, their aluminum saturation index indicates metaluminous type of magma.

The rocks in granodiorite unit contain SiO_2 content between 63 to 67.6 wt.% among which KL25 contains the lowest amount (the most mafic) and M17 contains the highest amount (the most felsic). All granodiorites contain 15.2 to 16.4 wt.% Al_2O_3, 3.07 to 5.93 wt.% CaO, 1.88 to 4.3 wt. % Fe_2O_3, 0.45 to 2.99 wt.% K_2O, 1.28 to 2.85 wt.% MgO, 4.13 to 5.27 wt.% Na_2O, 0.11 to 0.2 wt.% P_2O_5 and 0.32 to 0.67 wt.% TiO_2. All the major oxides change versus SiO_2 with the same obvious linear trend as of the diorite unit, that is MgO, Fe_2O_3, TiO_2, CaO, P_2O_5, and Al_2O_3 contents decrease with the increasing SiO_2 while the K_2O content increases with the increasing SiO_2 , as a result of the fractional crystallization (Figs. 3.23 and 3.24). The K_2O versus SiO_2 plot shows that granodiorites in this area belong to the low K tholeiite to medium K calc-alkaline magma series (Fig. 3.24). Moreover, their aluminum saturation index indicates metaluminous type of magma (Fig. 3.25).

As mentioned above and shown in the Figures 3.23, 3.24 and 3.25, all the plutonic rocks in the Bueng Sam Phan area –both diorite and granodiorite units- share the same trend of changing versus SiO_2 and are restricted along the linear trend pretty straightly which means they are all derived from the same magma chamber and are later fractional crystalized into the suite of different composition.

For Chachoengsao area, the rocks in granite unit contain SiO_2 content between 66.6 to 71.3 wt.% among which St1-1 contains the lowest amount (the least felsic) and St3-2 contains the highest amount (the most felsic). All granites contain 14.3 to 16.5 wt.% Al_2O_3, 1.62 to 2.85 wt.% CaO, 1.85 to 3.88 wt.% Fe_2O_3, 4.32 to 7.25 wt.% K_2O, 0.32 to 0.96 wt.% MgO, 0 to 4.31 wt.% Na_2O, 0 to 0.16 wt.% P_2O_5 and 0.17 to 0.45 wt.% TiO_2. All the major oxides change versus SiO_2 with the same aspect as of the two Bueng Sam Phan plutonic units above, that is MgO, Fe_2O_3, TiO_2, CaO, P_2O_5, and Al_2O_3 contents decrease with the increasing SiO_2 while the K_2O content increases with the increasing SiO_2, as a result of the fractional crystallization within the unit, but this unit doesn't share the same linear trend with the two previous plutonic units at all (Figs. 3.23 and 3.24). They are plotted in the distinctly different group and different linear trend from those Bueng Sam Phan units. In addition, K_2O versus SiO_2 plot shows that granites in this area belong to the high K calc-alkaline to shoshonite magma series which is obviously distinctive from all the Bueng Sam Phan igneous rocks mentioned before (Fig. 3.24). Moreover, their aluminum saturation index indicates metaluminous type, which is very close to the margin between them and peraluminous and peralkaline type (Fig. 3.25).

These aspects suggest that the Chachoengsao plutonic rocks and the Bueng Sam Phan plutonic rocks are derived from the different magma sources during the different magmatic and igneous processes, which are probably the different tectonic mechanisms, resulting in different chemical composition as reported.

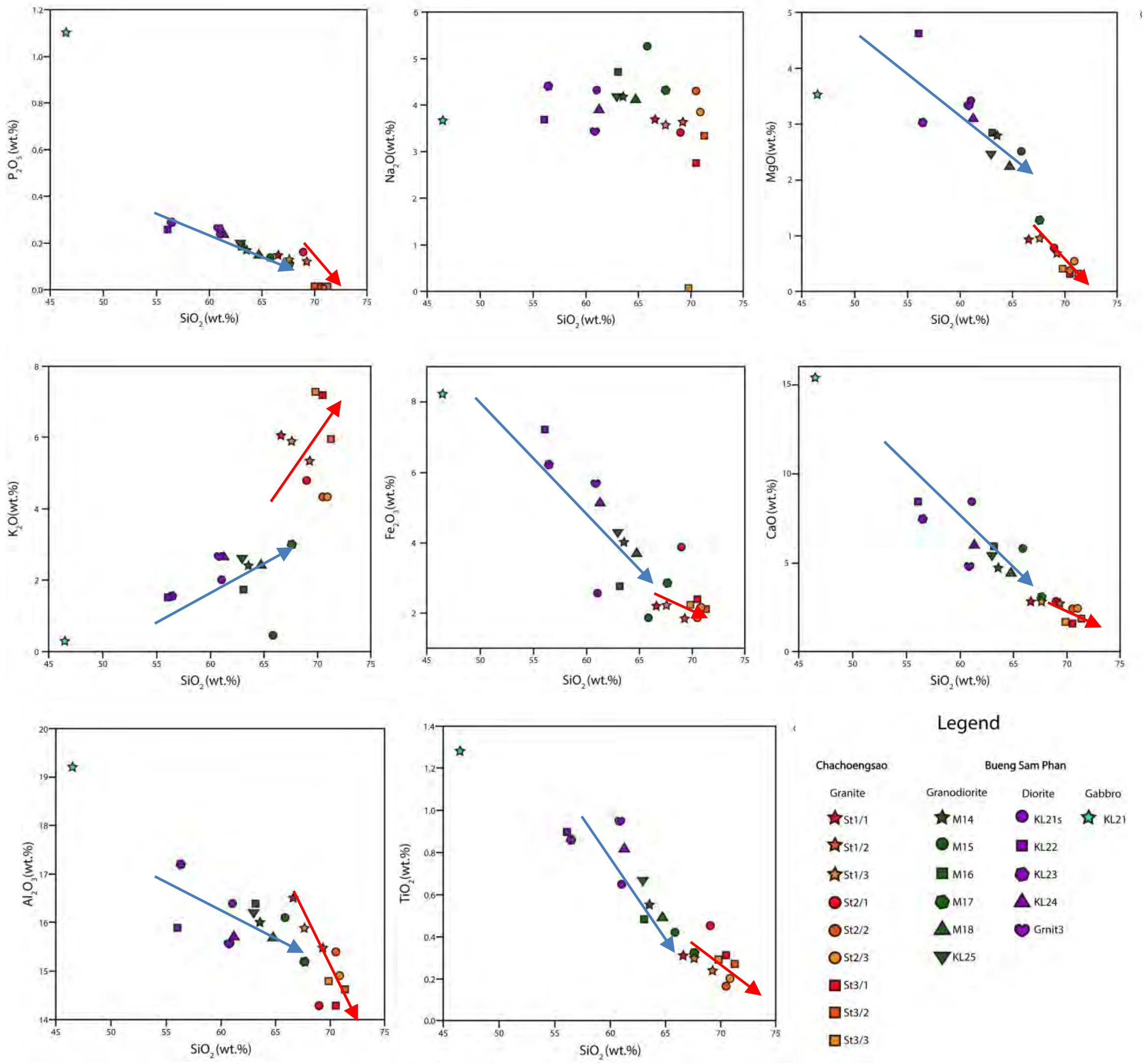

Fig. 3.23 showing the major chemical composition plot of the plutonic samples from Bueng Sam Phan area and Chachoengsao area in the Harker variation diagram with the blue arrows showing the trend of the crystal fractionation of the Bueng Sam Phan plutonic rocks and the red arrows showing the trend of the crystal fractionation of the Chachoengsao plutonic rocks

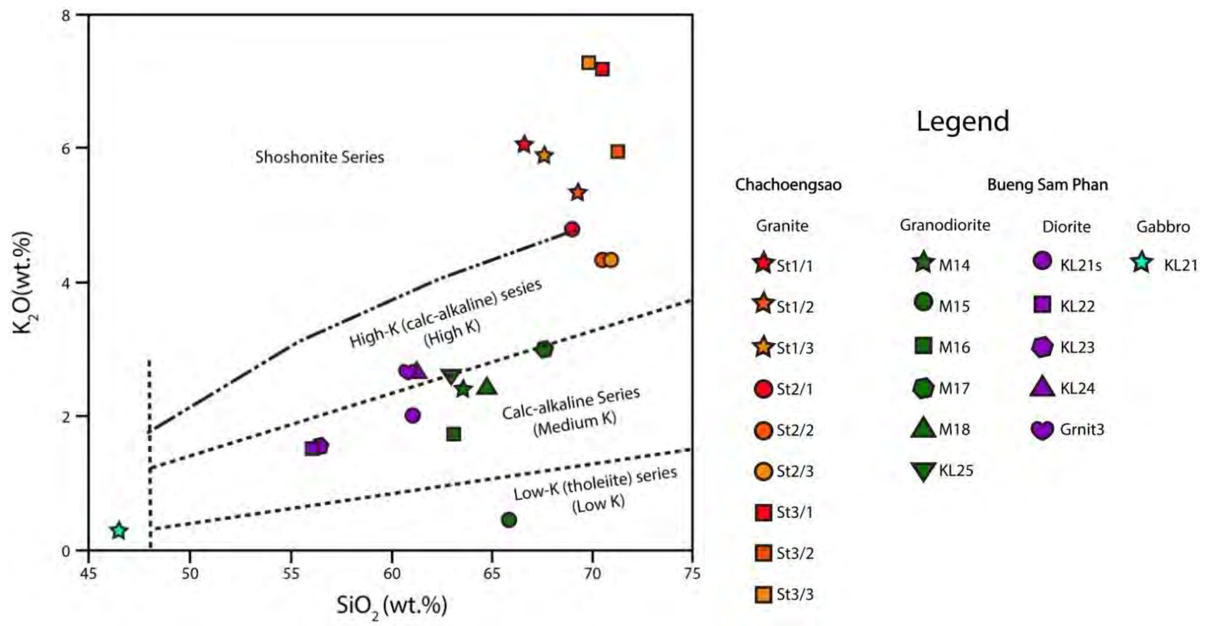

Fig. 3.24 showing the major chemical composition plot of K_2O versus SiO_2 of the plutonic samples from Bueng Sam Phan area and Chachoengsao area in the Harker variation diagram, showing the alkaline content and magmatic type of each sample (Rickwood, 1989)

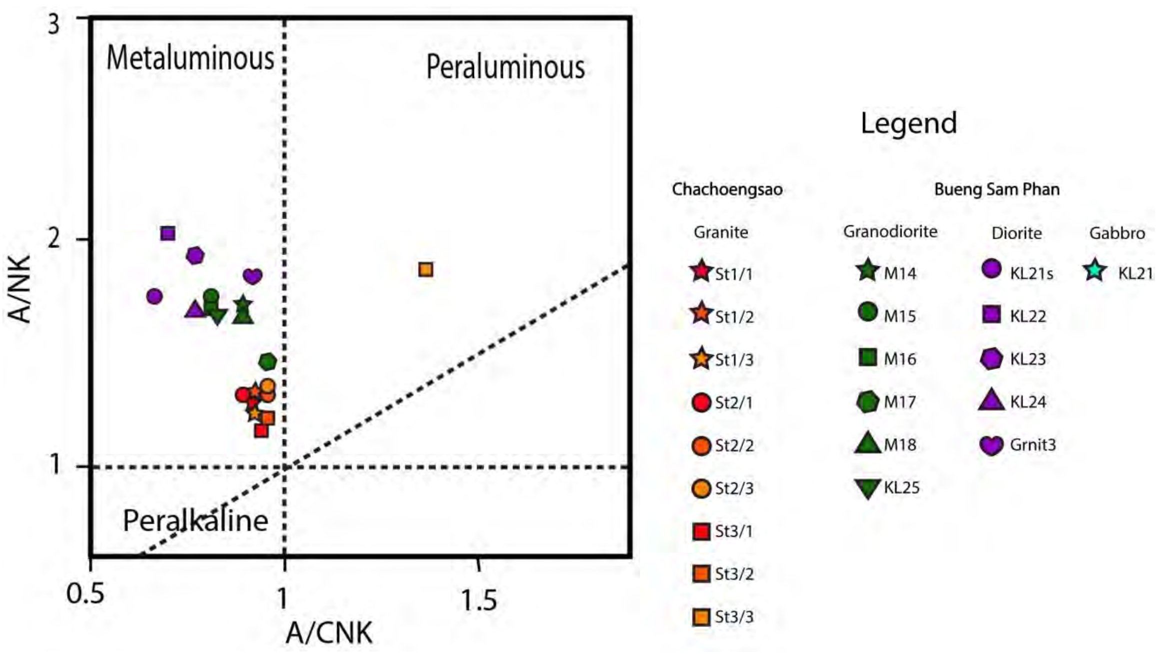

Fig. 3.25 showing the major chemical composition plot of Al_2O_3 /(Na_2O+K_2O) versus Al_2O_3 / (CaO+Na_2O+K_2O) (Maniar and Piccoli, 1989) of the plutonic samples from Bueng Sam Phan area and Chachoengsao area (Abbreviation; A=Al_2O_3, C=CaO, N=Na_2O, N=K_2O).

3.2.2.3 Trace element geochemistry

Two best representative rocks from each study area were chosen by the aspects of degree of representation to their study areas and being least altered so that they can optimally represent their magmatic source composition.

Samples M14 (granodiorite) and St1-2 (granite) were chosen from the Bueng Sam Phan area and Chachoengsao area respectively for trace and rare earth elements composition and the results are shown in Table 3.3. Trace elements plot for tectonic discrimination is given in Figure 3.26 and multi-element diagram of normalized data has been proposed by different authors (Figs. 3.27A to E).

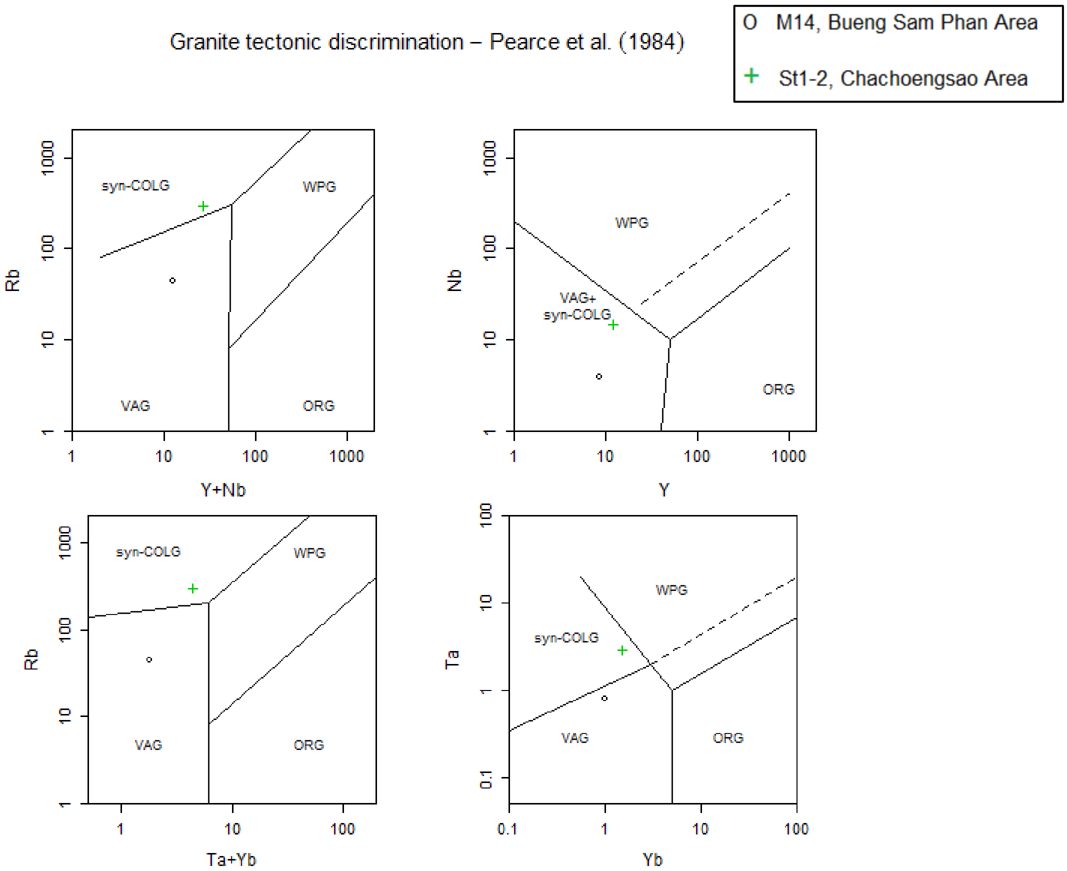

Fig. 3.26 showing trace element plot in the tectonic discrimination diagram for plutonic rocks (Pearce et al. 1984) (Abbreviation; VAG = Volcanic arc granite, Syn-COLG = Syn collisional granite, WPG = Within-plate granite, ORG = Oceanic ridge granite).

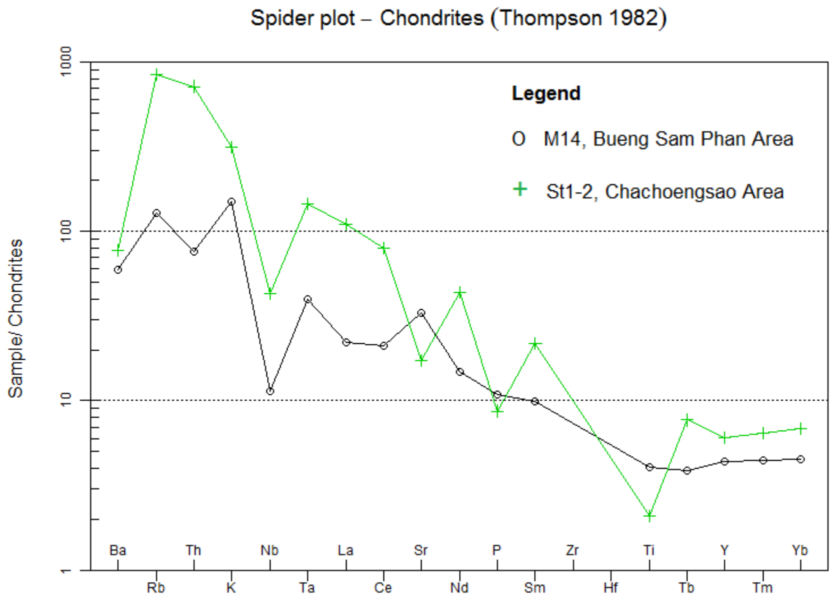

Fig. 3.27A Chondrite normalized plot in multielement diagram showing slightly different pattern.

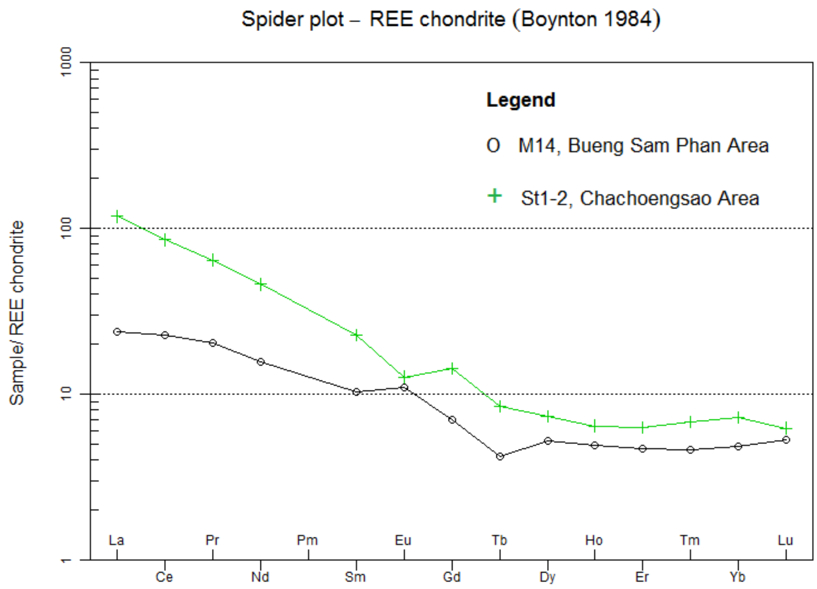

Fig. 3.27B Chondrite normalized plot in spider diagram showing slightly different REE pattern.

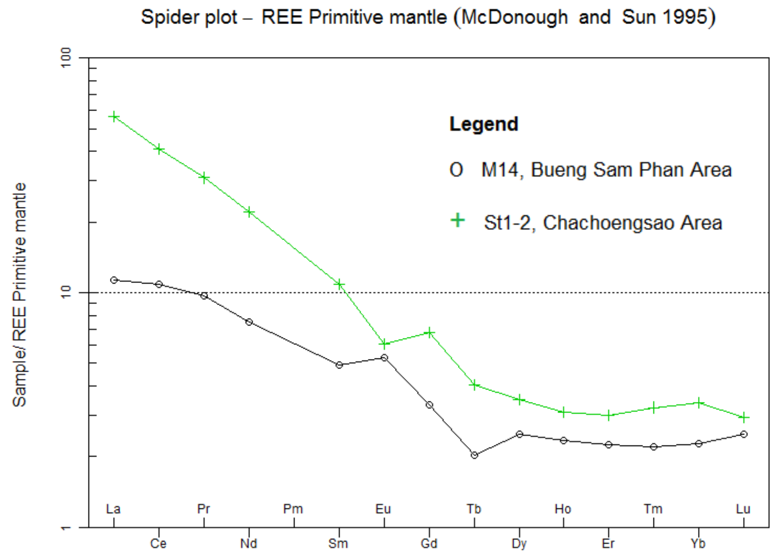

Fig. 3.27C Primitive mantle normalized plot in multielement diagram showing slightly different pattern.

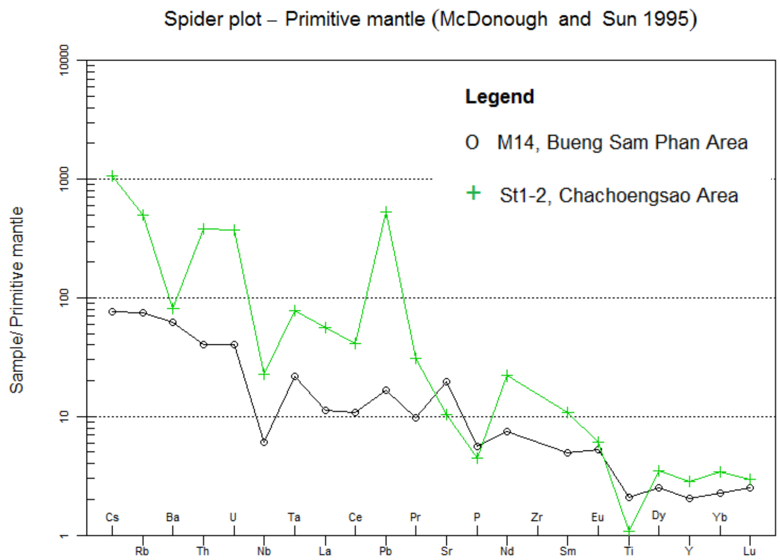

Fig. 3.27D Primitive normalized plot in spider diagram showing slightly different REE pattern.

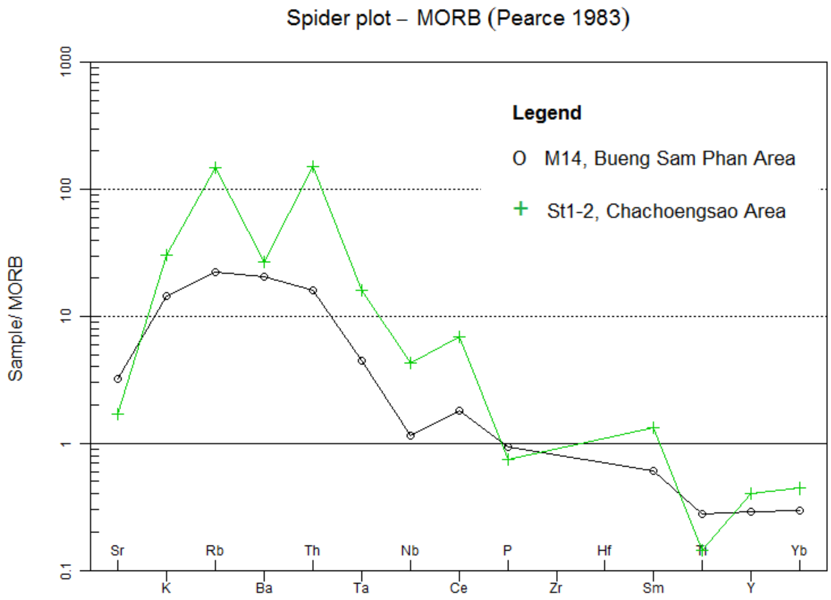

Fig. 3.27E MORB normalized plot showing slightly different pattern.

Chondrite normalized plots based on various authors suggesting that the REE patterns of representative samples and areas are slightly different especially when compared pattern of different diagrams.

Chapter 4 Conclusions

1. The igneous rocks collected from the Bueng Sam Phan area can be categorized into six types which are gabbro, diorite, granodiorite, basalt, basaltic andesite and andesite while the igneous rocks collected from the Chachoengsao are compiled into one type which is granite.

2. For the Bueng Sam Phan plutonic rocks, the equigranular, medium-grained gabbro is composed of plagioclase and pyroxene. The equigranular, medium-grained diorite is mainly composed of plagioclase, hornblende and biotite. The equigranular, medium-grained granodiorite consists of plagioclase, biotite, hornblende, K-feldspar and quartz.

3. For the Chachoengsao plutonic rocks, the granophyric biotie-granite is composed of quartz, k-feldspar, plagioclase and biotite.

4. According to major element geochemistry, the plutonic rocks from Bueng Sam Phan area have high Mg, Ti, Ca, Al and Fe but low K and the plutonic rocks from Chachoengsao area are low Mg, Ti, Ca, Al and Fe but high K.

5. According to Rickwood, 1989, the Bueng Sam Phan plutonic rocks belong to the calc-alkalic magma series while the Chachoengsao plutonic rocks belonging to the high K calc-alkalic to shoshonite magma series.

6. According to Maniar and Piccoli, 1989, the Bueng Sam Phan plutonic rocks indicate the magma composition of metaluminous but the Chachoengsao plutonic rocks indicate metaluminous and subordinate peraluminous.

7. According to trace element geochemistry and the granite discrimination diagram adopted from Pearce, et al. 1984, the Bueng Sam Phan plutonic rocks indicate volcanic arc environment and the Chachoengsao plutonic rocks indicate syn-collisional environment.

8. According to trace earth element geochemistry, the Chachoengsao plutonic rocks tend to have higher amount of large ion lithophile elements (LILE) than the Bueng Sam Phan plutonic rocks while their high field strength elements (HFSE) amount are quite equal.

Reference

Barr, S. M. and MacDonald, A. S. (1991). Toward a Late Paleozoic-Early Mesozoic tectonic model for Thai land. Journal of Thai Geosciences. 1: 11-22.

Boonsoong, A., Panjasawatwong, Y., Metparsopsan, K., 2011. Petrochemistry and tectonic setting of mafic volcanic rocks in the Chon Daen–Wang Pong area, Phetchabun, Thailand. Island Arc 20, 107–124.

Bunopas, S., 1981. Paleogeographic history of western Thailand and adjacent parts of Southeast Asia — a plate tectonic interpretation. Doctoral Thesis, Victoria University of Wellington, New Zealand, 810 pp.

Charusiri, P., Daorerk, V., Archibald, D., Hisada, K., Ampaiwan, T., 2002. Geotectonic evolution of Thailand: a new synthesis. Journal of the Geological Society of Thailand 1, 1–20.

Intasopa, S., Dunn, T., 1994. Petrology and Sr–Nd isotopic systems of the basalts and rhyolites, Loei, Thailand. Journal of Southeast Asian Earth Sciences 9, 167-180.

Kamvong, T., 2013. Geology and Genesis of Porphyry–skarn Cu–Au Deposits of the Northern Loei and Truong Son Fold Belts. Unpublished PhD thesis, ARC Centre of Excellence in Ore Deposits (CODES), University of Tasmania, Hobart, Australia, p. 169.

Kamvong, T., Khin Zaw,Meffre, S.,Maas, R., Stein, H., Lai, C.K., 2014. Adakites in the Truong Son and Loei fold belts, Thailand and Laos: genesis and implications for geodynamics and metallogeny. Gondwana Research

Khin Zaw, Meffre, S., higher degree students, 2007. Metallogenic relations and deposit scale studies, final report: geochronology, metallogenesis and deposit styles of Loei Fold Belt in Thailand and Laos PDR. ARC Linkage Project. CODES with Industry Partners.University of Tasmania, Hobart.

Khin, Z., Meffre, S., Lai, C.K., Burrett, C., Santosh, M., Graham, I., Manaka, T., Salam, A., Kamvong, T., and Cromie, P., 2014, Tectonics and metallogeny of mainland Southeast Asia-A review and contribution: Gondwana Research, v. 26, p. 5– 30.

Khositanont, S., 2008. Gold and Iron–Gold Mineralization in the Sukhothai and Loei–Phetchabun Fold Belts. Unpublished PhD thesis, Chiang Mai University, Chiang Mai, Thailand University of Tasmania, Hobart, Australia, p. 185.

Khositanont, S., Panjasawatwong, Y., Ounchanum, P., Thanasuthipitak, T., Khin Zaw, Meffre, S., 2008. Petrochemistry and zircon age determination of Loei–Phetchabun volcanic rocks. In: Chutakositkanon, V., Sutthirat, C., Charoentitirat, T. (Eds.), International Symposia on Geoscience Resources and Environments of Asian Terranes (GREAT 2008), 4th IGCP 516 and 5th APSEG, Bangkok, pp. 272–278.

Morley, K., Charusiri, P., Watkinson, I.M., 2011. Structural geology of Thailand during the Cenozoic. In: Ridd, M.J., Barber, M.F., Crow, A.J. (Eds.), The Geology of Thailand. The Geological Society, London, pp. 273–334.

Salam, A., 2013. A geological, geochemical and metallogenic study of the Chatree epithermal deposit, Petchabun Province, Central Thailand. Unpublished PhD thesis, ARC Centre of Excellence in Ore Deposits (CODES), University of Tasmania, Hobart, Australia, p. 250.

Salam, A., Khin Zaw,Meffre, S.,McPhie, J., Lai, C.K., 2014. Geochemistry and geochronology of epithermal Au-hosted Chatree volcanic sequence: implication for tectonic setting of the Loei Fold Belt in central Thailand. Gondwana Research

Sone, M. & Metcalfe, I. 2008. Parallel Tethyan sutures in mainland SE Asia: New insights for Palaeo-Tethys closure. Compte Rendus Geoscience, 340, 166–179.

Sone, M., Metcalfe, I., Chaodumrong, P., 2012. The Chanthaburi terrane of southeastern Thailand: Stratigraphic confirmation as a disrupted segment of the Sukhothai Arc. J. Asian Earth Sci. 61, 16–32.

Ueno, K., Hisada, K., 2001. The Nan–Uttaradit–Sa Kaeo Suture as a main Paleo-Tethyan suture in Thailand: is it real? Gondwana Research 4, 804–806.

Appendix

Table 3.1 major elements in wt. % determined by XRF of Bueng Sam Phan volcanic rocks

Sample ID	M8A	M11B	M2	M1	M5	M6	M9	M11A	M7	M8B	M10	M19	M3B	M4
Lithology	Andesite	Andesite	Andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basaltic andesite	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt
SiO2	55.7	54.9	57.4	53.2	54.7	53.9	53.5	48.5	48	47.8	47.2	43.1	49.7	47.7
Al2O3	17.4	17.4	16.8	17.3	18.4	17.6	18.1	16.2	17.5	18.3	18.5	16.6	17	18.2
CaO	6.42	6.01	6.03	6.65	7.64	5.68	7.45	9.74	8.4	8.47	5.9	10.9	8.53	7.3
Fe2O3	7.33	6.04	6.44	7.96	6.86	8.15	8.39	8.03	11	10.2	11.2	13.1	9.01	9.63
K2O	1.62	2.14	1.59	0.97	1.33	1.96	0.88	0.3	0.27	1.31	1.33	0.28	1.54	0.77
MgO	2.31	0.66	2.28	4.6	2.49	3.61	3.52	1.42	4.53	4.86	5.64	8.68	5.76	4.64
MnO	0.23	0.11	0.23	0.14	0.25	0.18	0.24	0.27	0.23	0.21	0.25	0.24	0.14	0.19
Na2O	4.42	6.34	4.31	4.14	4.16	4.3	4.24	7.28	4.9	4.16	4.48	2.23	2.71	3.95
P2O5	0.43	0.45	0.29	0.23	0.4	0.26	0.45	0.5	0.25	0.23	0.25	0.21	0.36	0.27
SO3	0	0	0.13	0	0	0	0	0	0	0	0	0	0	0
SrO	0.32	0	0.13	0.24	0.16	0.5	0.23	0	0.26	0.3	0.6	0	0.14	0.13
TiO2	0.59	0.96	0.55	0.85	0.54	0.79	0.68	0.99	0.88	0.86	0.92	1.7	1.04	0.84
Loss of Ignition	3.07	4.82	3.67	3.58	3.02	2.9	2.25	6.66	3.61	3.31	3.62	2.79	3.84	6.34
Original Sum	99.84	99.83	99.85	99.86	99.94	99.83	99.93	99.89	99.83	100.02	99.88	99.83	99.76	99.97

Table 3.2 major elements in wt. % determined by XRF of Bueng Sam Phan and Chachoengsao plutonic rocks

Lithology	Diorite	Diorite	Diorite	Diorite	Diorite	Gabbro	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granite	Granodiorite	Granodiorite	Granodiorite	Granodiorit	Granodiorite	Granodiorite
Sample ID	KL21s	KL22	KL23	KL24	Grnit3	KL21	ST1-1	ST1-2	ST1-3	ST2-1	ST2-2	ST2-3	ST3-1	ST3-2	ST3-3	KL25	M14	M15	M16	M17	M18
SiO2	61.1	56.1	56.5	61.3	60.9	46.5	66.6	69.3	67.6	69	70.5	70.9	70.5	71.3	69.8	63	63.6	65.9	63.1	67.6	64.8
Al2O3	16.4	15.9	17.2	15.7	15.6	19.2	16.5	15.5	15.9	14.3	15.4	14.9	14.3	14.6	14.8	16.2	16	16.1	16.4	15.2	15.7
CaO	8.45	8.42	7.44	6.03	4.79	15.4	2.85	2.73	2.84	2.81	2.47	2.49	1.62	1.84	1.65	5.44	4.67	5.83	5.93	3.07	4.45
Fe2O3	2.57	7.21	6.23	5.14	5.67	8.21	2.2	1.85	2.22	3.88	1.86	2.15	2.4	2.1	2.22	4.3	4.02	1.88	2.77	2.87	3.69
K2O	2.01	1.52	1.53	2.64	2.63	0.28	6.05	5.34	5.89	4.79	4.33	4.32	7.17	5.94	7.27	2.61	2.4	0.45	1.72	2.99	2.41
MgO	3.42	4.62	3.03	3.1	3.34	3.52	0.93	0.69	0.96	0.78	0.38	0.55	0.33	0.32	0.41	2.47	2.79	2.51	2.85	1.28	2.24
Na2O	4.32	3.69	4.41	3.91	3.43	3.66	3.69	3.64	3.58	3.41	4.31	3.85	2.76	3.34	0	4.18	4.18	5.27	4.72	4.32	4.13
P2O5	0.24	0.26	0.29	0.24	0.26	1.1	0.15	0.12	0.13	0.16	0	0	0	0	0	0.2	0.17	0.14	0.19	0.11	0.15
TiO2	0.65	0.9	0.86	0.82	0.95	1.28	0.31	0.24	0.3	0.45	0.17	0.2	0.31	0.27	0.29	0.67	0.55	0.42	0.48	0.32	0.49
Loss of Ignition	0.67	0.96	2.21	0.82	1.86	0.38	0.47	0.34	0.34	0.18	0.38	0.35	0.27	0.08	0.47	0.63	1.38	1.35	1.61	1.97	1.49
Original Sum	99.83	99.72	99.8	99.7	99.75	99.76	99.76	99.75	99.76	99.76	99.8	99.71	99.66	99.78	96.9	99.71	99.76	99.85	99.77	99.73	99.72

Element	Unit	M14	ST1/2	Element	Unit	M14	ST1/2
		Bueng Sam Phan	Chachoengsao			Bueng Sam Phan	Chachoengsao
		Granodiorite	Granite			Granodiorite	Granite
Al	%	7.70	7.62	Mo	ppm	<2	<2
Ba	ppm	407.40	535.10	Nb	ppm	4.00	15.00
Be	ppm	<5	8.00	Nd	ppm	9.40	27.50
Ca	%	2.90	1.70	Ni	ppm	14.00	6.00
Cd	ppm	<0.2	<0.2	P	%	0.05	0.04
Ce	ppm	18.20	68.70	Pb	ppm	<5	79.00
Co	ppm	9.30	3.30	Pr	ppm	2.46	7.84
Cr	ppm	93.00	211.00	Rb	ppm	45.00	296.30
Cs	ppm	1.60	22.20	Sb	ppm	<1	<1
Cu	ppm	26.00	9.00	Sc	ppm	9.00	<5
Dy	ppm	1.68	2.35	Sm	ppm	2.00	4.40
Er	ppm	0.98	1.31	Sn	ppm	<5	<5
Eu	ppm	0.81	0.93	Sr	ppm	389.30	204.60
Fe	%	2.74	1.15	Ta	ppm	0.80	2.90
Ga	ppm	16.00	18.00	Tb	ppm	0.20	0.40
Gd	ppm	1.80	3.67	Th	ppm	3.20	30.20
Ge	ppm	<1	1.00	Ti	%	0.25	0.13
Ho	ppm	0.35	0.46	Tl	ppm	<0.5	2.10
In	ppm	<0.2	<0.2	Tm	ppm	0.15	0.22
K	%	1.80	3.80	U	ppm	0.81	7.49
La	ppm	7.30	36.50	V	ppm	64.00	21.00
Li	ppm	22.00	43.00	W	ppm	<5	<5
Lu	ppm	0.17	0.20	Y	ppm	8.70	12.10
Mg	%	1.12	0.37	Yb	ppm	1.00	1.50
Mn	ppm	335.00	285.00	Zn	ppm	37.00	29.00

Table 3.3 trace elements determined by ICP-MS of the representatives from Bueng Sam Phan area and Chachoengsao area