CHAPTER 5

Discussion and Conclusion

The one hundred and forty samples were studied by field observation, lithology, and petrography. They have many rock types including volcanic, pyroclastic, and intrusive rocks. These studied rocks were from Lampang Province (Mae Phrik and Thoen District), Sukhothai Province (Thung Saliam and Ban Dan Lan Hoi Districts), Tak Province (Ban Tak, Meuang Tak, and Wang Chao Districts), and Kamphaeng Phet Province (Phran Kratai District). The studied volcanic rocks are the southern part of Chiang Khong–Lampang–Tak volcanic belt, which mainly lies in the Sukhothai Terrane. Some mafic dikes are intruded into these volcanic rocks as dike. However, some studied rocks (i.e., rhyolite and basaltic dike) might have occurred in conjunction with Triassic granitic rocks (Tak batholith) (Mahawat, 1982).

The least-altered thirty volcanic and gabbroic rock samples were carefully selected from lithology and petrography data for geochemistry study (major oxides, trace elements, and loss on ignition (LOI)). The representatives of the least-altered samples (16 samples) were analyzed for rare-earth elements (REE) for interpretation of magma series and tectonic setting of formations. The representatives of the studied rocks presented in this study show different types of REE patterns, N-MORB normalized multi-element patterns and variation diagrams. Using these patterns, the studied rocks can be separated into 8 magmatic groups that distributed in the study areas. These areas include (1) the Mae Phrik area, (2) the Mae Salaem area, (3) the Pong Daeng area, (4) the Wang Luek area, (5) the Wang Prachop area, and (6) the Wang Chao area (Figure 5.1).

Although, the representatives of the Group I and Group II rocks have molar (K+Na+2Ca)/Al values less than 1 in alteration index diagram, suggested that these rocks have more alteration. Carefully and avoid select the geochemistry data of Group I

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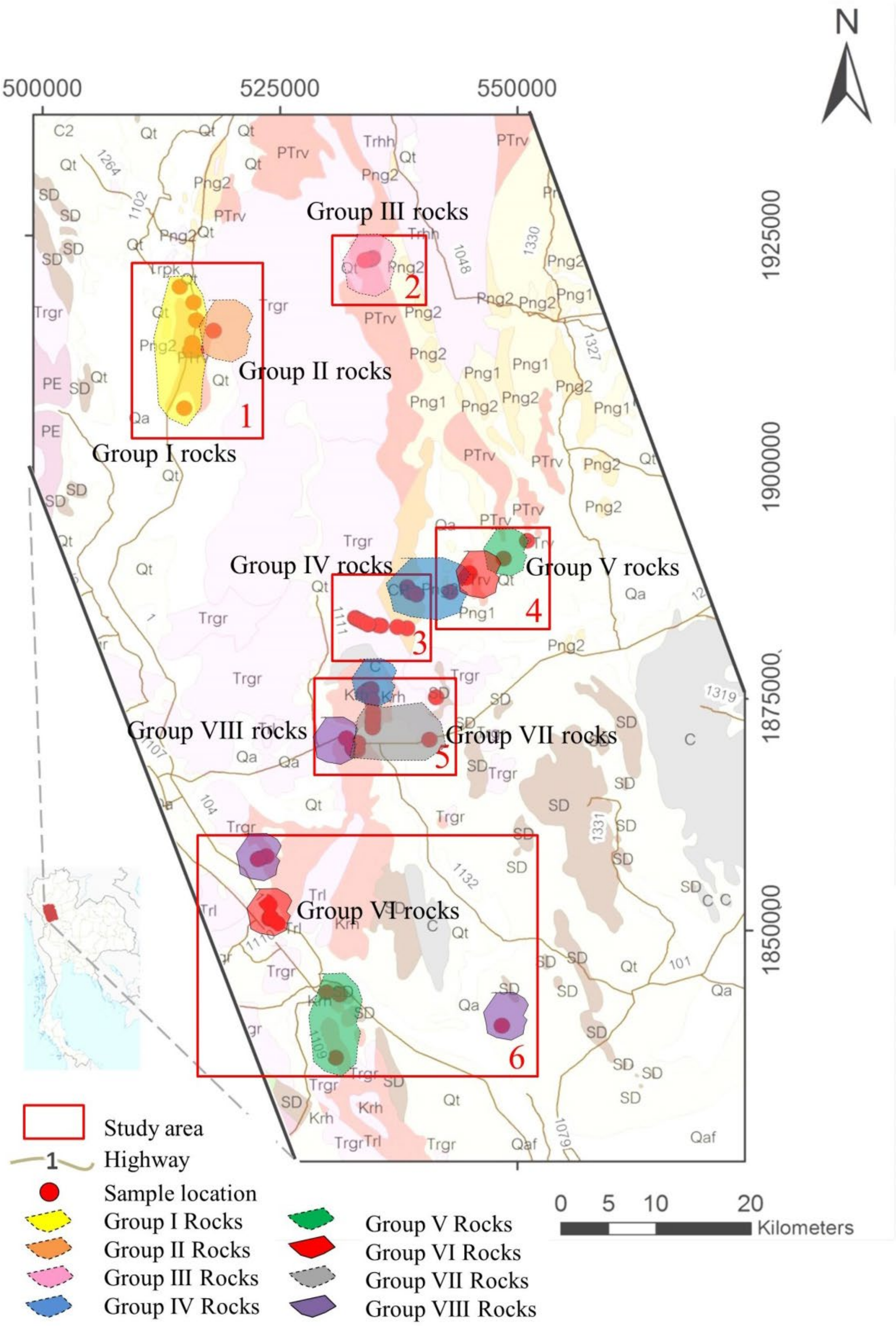

Figure 5.1 Distribution of the rock groups; geologic data modified from Dhamdusdi and Chitmanee (1984), Hinthong et al. (1986), Sareerat and Silapalit (1987), Boripatkosol et al. (1987a),Silapalit and Sareerat (1987), Boripatkosol et al. (1987b), Boripatkosol et al. (1989a), Boripatkosol et al. (1989b), Chuaviroj et al. (1992) and Assavapatchara, and Kitisarn (2001).

and Group II rocks for identification of rock types, determining magma characteristics, and interpretation of tectonic setting of formation.

5.1 Volcanic and Associated Rocks in the southern part of Chiang Khong–Lampang–Tak Volcanic Belt

Petrochemically, the studied volcanic and associated rocks can be separated into eight magmatic groups as Group I to Group VIII. They derived from diverse magmatic affinities which are subalkalic to alkaline magma series and have been formed in a different tectonic setting (Table 5.1).

Table 5.1 Summary of the studied rocks and their distribution.

Group	Rocks	Magma series	Tectonic setting of eruption	Study area					
				Mae Phrik	Mae Salaem	Pong Daeng	Wang Luek	Wang Prachop	Wang Chao
I	rhyodacite	mildly calc-alkaline	continental rifting	√					
II	basalt	alkaline	post collision	√					
III	rhyolite	calc-alkaline	post collision		√				
IV	basalt porphyry	mildly alkaline	continental rifting						
	cumulus gabbro								
	andesite porphyry					√	√	√	
V	gabbro	alkaline	active continental margin						
	andesite								
	basalt						√		√
VI	rhyolite	tholeiitic	back arc				√		√
VII	andesite porphyry	mildly calc-alkaline	active continental margin					√	
VIII	rhyolite	mildly calc-alkaline	continental rifting					√	√

The Group I rocks are distributed in the Mae Phrik area and are made up of rhyodacite. Chemically, the Group I rocks are typical of mildly calc-alkaline series REE patterns. The chemical compositions of representative for Group I rocks are closely similar to the Miocene intra-plate rhyolites from Jabal Shama, Saudi Arabia, which have been formed within a plate on the rifting stage in western of Arabia shield.

The Group II rocks are distributed in the Mae Phrik area and are composed of basalt. These basaltic rocks of the Mae Phrik area are cut along Triassic granitic

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intrusion as dike. Chemically, the Group II rocks are typical of alkaline series REE patterns. The chemical compositions of representative for Group II rocks are comparable with the Miocene basaltic dike from Miocene magmatism in Tibet, which have been formed as a post-collision between India and the Eurasia plates in the northern Himalayan orogeny and cross cut into granitic rocks.

The Group III rocks are distributed in the Mae Salaem area, and consist of rhyolite. Chemically, rhyolite of Group III rock is typical of calc-alkaline series REE patterns. The chemical compositions of representative for Group III rock is very similar to the Miocene rhyolite porphyry from Miocene magmatism at Yaguila, Tibet, which have been formed as a post-collision between India and the Eurasia plates in the northern Himalayan orogeny.

The Group IV rocks are distributed in the Pong Daeng, Wang Luek, and Wang Prachop areas. They comprise basalt porphyry, cumulus gabbro, and andesite porphyry. Chemically, the Group IV rocks are typical of mildly alkaline series REE patterns. The REE patterns for the cumulus gabbro have positive Eu anomaly, are controlled by cumulative plagioclase. The chemical compositions of representative for Group IV rocks are most comparable with the Cretaceous basalt from the Karoo volcanic rocks, Mozambique, which have been formed as a within-plate in south-eastern Africa.

The Group V rocks are distributed in the Wang Luek and Wang Chao areas. They consist of gabbro, andesite, and basalt. Chemically, the Group V rocks are typical of alkaline series REE patterns. The chemical compositions of representative for Group V rocks are similar to the Quaternary basalt from Central Volcanic Zone in Southern Peru, which have been formed as an active continental margin in the central Andes.

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The Group VI rocks are distributed in the Wang Luek and Wang Chao areas. They comprise gabbro and rhyolite. Chemically, the Group VI rocks are typical of tholeiitic series REE patterns. The chemical compositions of representative for Group VI rocks are most comparable with the Late Miocene Topaz-bearing rhyolite from the Chivinar volcano, NW Argentina, which have been formed as an immature back arc setting in the eastern Andes.

The Group VII rocks are distributed in the Wang Prachop area and are made up of andesite porphyry. Chemically, the Group VII rocks are typical of mildly calc-alkaline series REE patterns. The chemical composition of representative for Group VII rocks are closely similar to the Quaternary aphyric high-K andesite from Ollagüe volcano region, Chile, which have been formed as an active continental margin in the central Andes.

The Group VIII rocks are distributed in the Wang Prachop and Wang Chao areas and are composed of rhyolite. Chemically, the Group VIII rocks are typical of mildly calc-alkaline series REE patterns. The chemical compositions of representative for Group VIII rocks are similar to the Miocene within-plate rhyolite from the Karoo volcanic rocks, Mozambique, which have been formed as a within-plate in south-eastern Africa.

5.2 Tectonic Implications

Thailand is generally believed as being the product of the collision between Shan-Thai continent and the SIBUMASU continent. The major ocean basin that separated the Shan-Thai and SIBUMASU terranes may be interpreted by the Chiang Rai-Chiang Mai volcanic belt**,** Nan-Uttaradit volcanic belt or Loei-Phetchabun-Nakhon Nayok volcanic belt. Many researchers (Ueno and Hisada, 2001; Sone and Metcalfe, 2008) have proposed an existence of the new terrane (Sukhothai Terrane or Sukhothai Arc) between the SIBUMASU and Indochina. The Chiang Khong-Lampnag-Tak volcanic belt is the part of igneous rocks of this Sukhothai Terrane. The researchers believe that the volcanic rocks in this belt erupted in a subduction-related environment or continental arc environment (e.g. Bunopas, 1981; Singharajwarapan, 1994; Crawford and Panjasawatwong, 1996; Phajuy, 2001). Later on, Srichan et al. (2008, 2009) and Wipakul (2012) reported that this belt formed in post-orogenic origin. U-Pb Zircon dating was carried out on the Permo-Triassic arc-related volcanic rocks along the western edge of Mae Moh Basin (Barr *et al.,* 2000) and the northern end of this belt (Barr *et al.,* 2006). The results revealed that the volcanic rocks have U-Pb Zircon ages of 240±1 Ma (Middle Triassic) and 232.9±0.4 Ma (Middle Triassic), respectively. On the other hand, Khositanont et al. (2007) determined U-Pb Zircon ages from the volcanic rocks in the Lampang and Phrae areas and mentioned that they erupted in a

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period of early to late Triassic (247±5 to 219±3 Ma), correspond to Srichan (2008) reported that the Chiang Khong-Lampang-Tak volcanic rocks occurred in the middle-late Triassic (233±5 to 220±5 Ma) as a post collisional activity. Qiang (2016) reported that volcanic rocks from the Chiang Khong area yields a zircon U–Pb age of 229±4 Ma, significantly younger than the continental-arc and syn-collisional volcanic rocks (238–241 Ma) (Qiang *et al.,* 2013).

The northern and central part of Chiang Khong–Lampang–Tak volcanic belt have completely report and interpret tectonic model, except the southern end that is complex from volcanic eruption period (Chapter 1). For this study, tectonic setting of the studied volcanic and associated rocks in the southern part of Chiang Khong–Lampang–Tak volcanic belt can be separated into active continental margin (Group V and Group VII), back arc (Group VI), post collision (Group II and Group III) and continental rifting (Group I, Group IV, and Group VIII).

However, missing age dating of the studied rocks has been not clearly reconstructing a tectonic model. The age of rocks discussed with their analogue that is volcanic rocks in the Chiang Khong–Lampang–Tak volcanic belt. The representatives of the Group III rocks are chemically comparable with microdiorite in the Chiang Khong Area (Srichan, 2009). Their Chondrite-normalized REE patterns show a relatively flat REE patterns from Sm to Yb, and slightly LREE enriched (Figure 5.2). This REE patterns are typical of calc-alkaline series and shows post-collision pattern like their modern analogue. The Group III rocks may have the same age with microdiorite that have erupted in the middle-late Triassic (223±8 Ma) (Srichan, 2009).

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The Group VII rocks are closely similar in chemical composition to andesite in Doi Yao Volcanic Zone, Chiang Khong area (Qian *et al.,* 2013). Their Chondrite-normalized REE patterns of Group VII Rocks and their analogue; Their Chondrite-normalized REE patterns show a relatively flat REE patterns from Sm to Yb, and slightly LREE enriched (Figure 5.3). This REE patterns are typical of calc-alkaline series and shows indicative of geochemical affinity to arc pattern like their modern analogue. The microdiorite was analyzed by Qian (2013) and has age in 241.2±4.6 Ma (early Middle Triassic), that may consistent with the Group VII rocks.

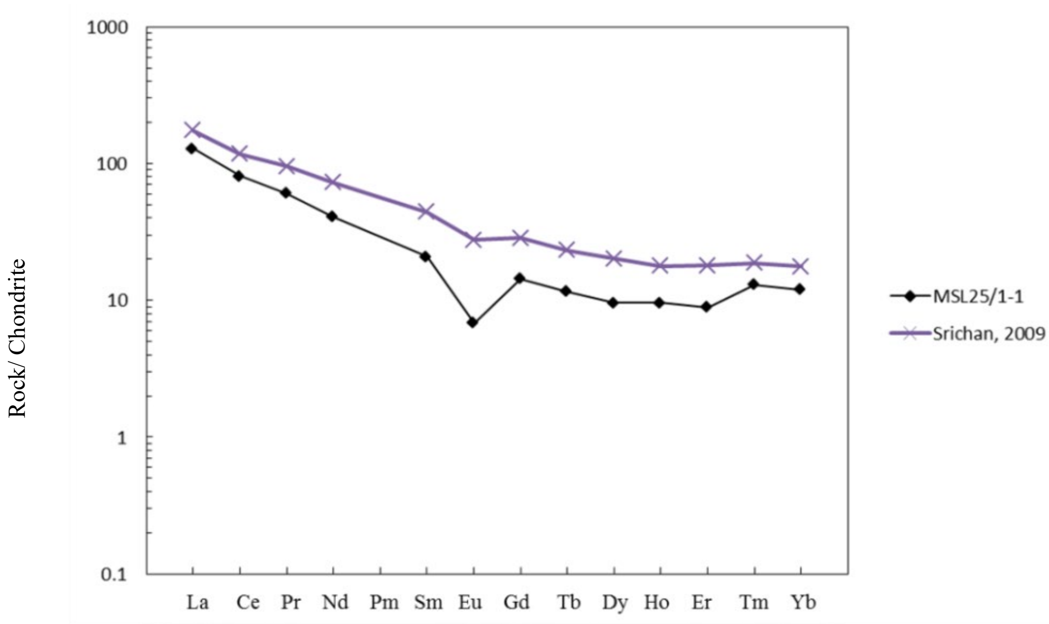

Figure 5.2 Chondrite-normalized REE patterns of Group III Rocks and their analogue; microdiorite in the Chiang Khong area (Srichan, 2009). Chondrite-normalized values are those of Taylor and Gorton (1977).

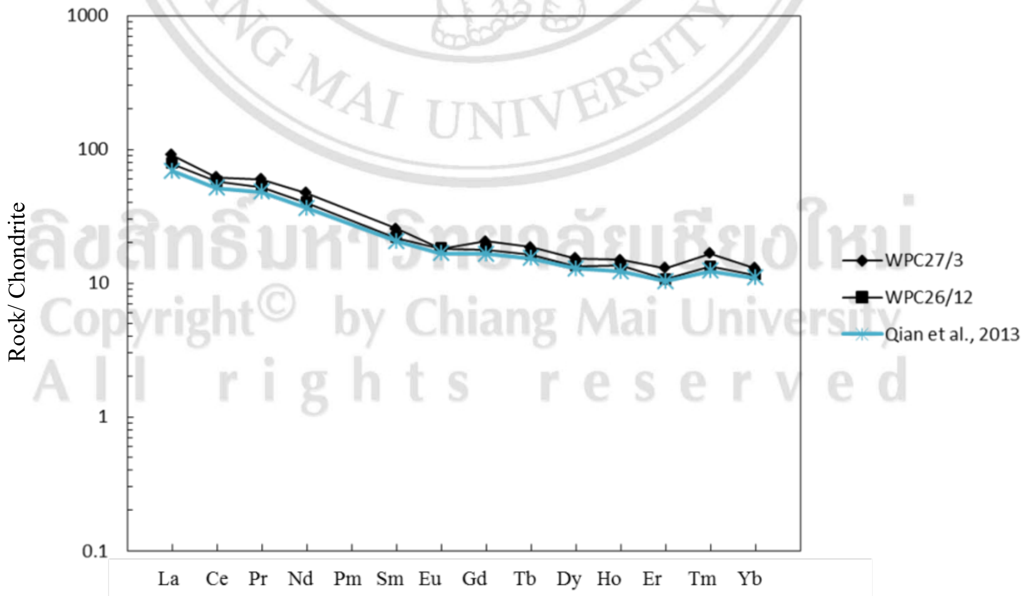

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Figure 5.3 Chondrite-normalized REE patterns of Group VII Rocks and their analogue; andesite in Doi Yao Volcanic Zone, Chiang Khong area (Qian *et al.,* 2013). Chondrite-normalized values are those of Taylor and Gorton (1977).

Tectonically, Group V and Group VII rocks might have located in an active continental margin in 241.2$\pm$4.6 Ma (early Middle Triassic) (Figure 5.4a). At the same time, Group VI rocks erupted in back-arc basin that might have started rifting after Middle Triassic and before the late Triassic period for the short time. Group II and Group III rocks might have erupted in post collision setting in 223$\pm$8 Ma (Late Triassic) (Figure 5.4b). Group I, Group IV, and Group VIII rocks might have erupted in continental rifting in late Triassic to early Jurassic (Figure 5.4c). This time have main tectonic evolution of Indosinian orogeny stage that as a result from SIBUMASU and Indochina collision in Malaysia Peninsular and Sumatra (Barber *et al*., 2005). The Indosinian orogeny is the main cause of block faulting in Sukhothai foldbelt (Hahn, 1984) that it might make thin plate in this area and rifting magmatic activity.

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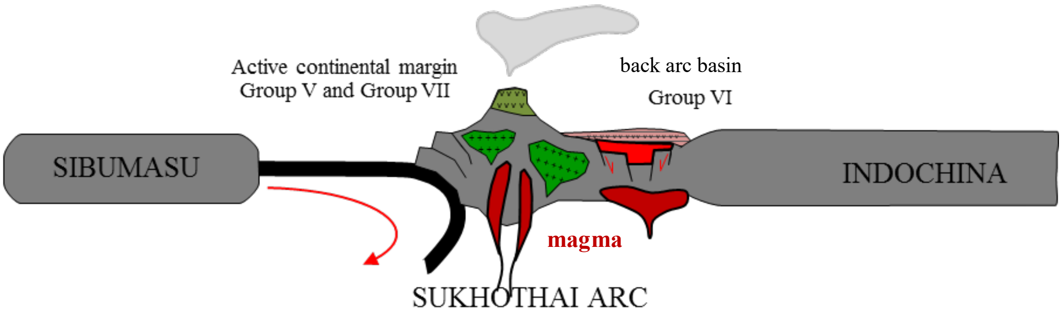
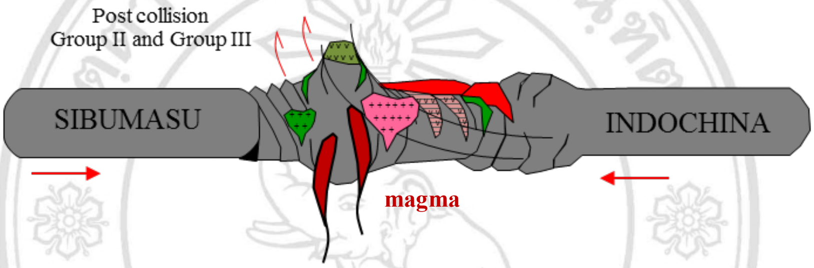
Early Middle Triassic



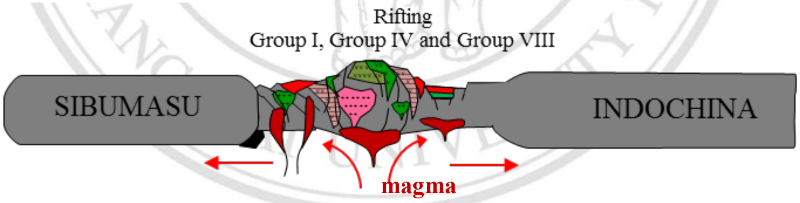
a)

Late Triassic



b)

Late Triassic-Early Jurassic



c)

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Figure 5.4 Schematic diagrams showing tectonic evolution of SIBUMASU and Indochina terranes. a) active continental margin and back arc stage in Middle Triassic, b) completely collision stage in Early late Triassic, c) post collision stage in Late Triassic, and d) rifting stage during Late Triassic to Early Jurassic. (vvv mafic volcanic, vvv felsic volcanic rocks, +++ mafic intrusive rocks, +++ felsic intrusive rocks, and vvv pyroclastic rocks).