# CHAPTER 1

# Introduction

## 1.1 Tectonic Background of Northern Thailand

The geology of Northern Thailand is very chaotic, various and obscure. Even though a number of tectonic models were proposed to explain geological history of this region for decades, but it is still controversial. It is widely accepted that Thailand was an amalgamation of at least two ancient terranes, Shan-Thai and Indochina (Bunopas, 1981; Barr and Macdonald, 1991). After that, Metcalfe (1984) recalled Shan-Thai Terrane into SIBUMASU Terrane that is extending from Sino (China) to Sumatra via west Thailand, Burma, and Malaysia. The Indochina and the SIBUMASU Terranes were believed to derive from Gondwana Supercontinent in the Devonian and the late Early Permian, respectively (Metcalfe, 2011; 2013). The Paleo-Tethys Ocean separated these two cratons during the Paleozoic, followed by the Late Triassic–Early Jurassic convergence (Bunopas, 1981; Sone and Metcalfe, 2008).

Many researchers (i.e. 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. They suggested that the tectono–stratigraphy of Sukhothai Terrane differs from those of SIBUMASU and Indochina Terranes. After that, Charusiri *et al*. (2015) interpreted Shan-Thai and Indochina blocks have never been attached to one another, but the interaction between two continental blocks definitely occurred since or prior to the Permo-Triassic time.



## 1.2 Pre-Cretaceous Volcanic Rocks in Thailand

The pre-Cretaceous felsic to mafic volcanic/hypabyssal rocks in the upper part of Thailand may be separated into four belts from west to east as follow (1) Chiang Rai-Chiang Mai volcanic belt, (2) Chiang Khong-Lampang-Tak volcanic belt, (3) Nan-Uttaradit volcanic belt, and (4) Loei-Phetchabun–Nakhon Nayok volcanic belt and (5)

Sra Kaew-Chanthaburi volcanic belt which is the part of Chiang Khong-Lampang-Tak volcanic belt that separate by Mae Ping fault (Sone *et al.*, 2012). In addition to volcanic rocks in central Thailand are grouped to (6) portions of any volcanic belt to the north (Figure 1.1). The Chiang Rai-Chiang Mai volcanic belt forms a broad zone from the western part of Chiang Rai Province through the eastern part of Chiang Mai Province to Li District, Lamphun Province. The Chiang Khong–Lampang-Tak volcanic belt is extended from Chiang Khong District, Chiang Rai Province to Tak Province via Lampang and Phrae Provinces. The Nan-Uttaradit volcanic belt is located between the Chiang Khong-Tak volcanic belt and Loei-Phetchabun-Nakhon Nayok volcanic belt, extending from the Nan to Uttaradit Provinces. The Loei-Phetchabun-Nakhon Nayok volcanic belt runs in NNE-SSW direction from Loei Province through Phetchabun to Nakhon Nayok Provinces.

### 1.2.1 The Chiang Rai-Chiang Mai Volcanic Belt

The Chiang Rai-Chiang Mai volcanic belt extends southward from the Changning-Menglian suture in south China (Haoruo *et al*., 1995; Yang *et al.,* 1994; Charusiri *et al.,* 1999; Ueno, 1999; Barr *et al.,* 2000; Metcalfe, 2002a, 2002b; Metcalfe and Sone, 2008; and Feng *et al.,* 2005). This belt is a scattered zone, extending from Chiang Rai Province, to the northeast, to the Thai-Burma border, in the Mae Hong Son region (Ferrari *et al*., 2008), to Lamphun Province (Li District) (Panjasawatwong *et al.,* 1995) (Figure 1.1). This volcanic belt is made up largely of mafic igneous rocks (i.e. mafic volcanic rocks, pillow breccias/hyaloclastite and dike rocks) and a small amount of ultramafic rocks (i.e. werhlite) (Phajuy, 2008). Mafic volcanic rocks in the Chiang Rai-Chiang Mai volcanic belt are commonly associated with limestone. They are overlain by Lower Carboniferous and Upper Permian shallow water carbonate rocks (Ferrari *et al*., 2008; and Shangyue *et al.,* 2009).

Researchers suggested that the Chiang Rai-Chiang Mai volcanic basalts erupted in Upper Carboniferous (Braun and Hahn, 1976), Permo-Carboniferous (Ferrari *et al*., 2008) or Permian (Barr *et al*., 1990; and Phajuy *et al*., 2005). However, diorite crops around Doi Tung, Chiang Rai Province were dated by U/Pb zircon to be 430±3.8 Ma (Silurian) (Fan *et al.,* 2010; Wang *et al.,* 2010).

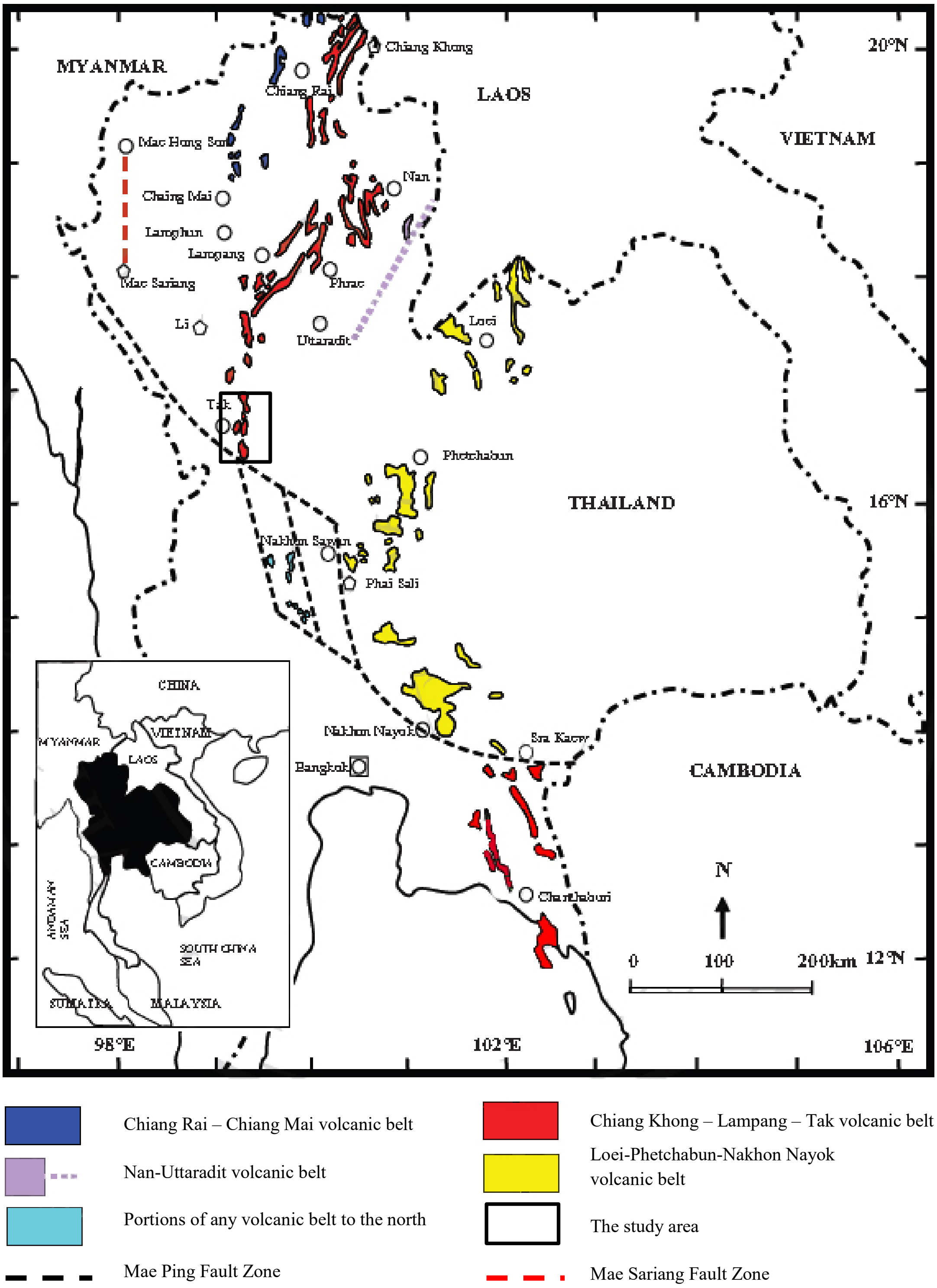


Figure 1.1 Distribution of pre-Cretaceous volcanic rocks in the upper part of Thailand (modified from Jungyusuk and Khositanont, 1992; Kosuwan, 2004; Panjasawatwong *et al.*, 2006; Phajuy, 2008; Boonsoong *et al.*, 2011 and Kosuwan, 2013). The Mae Ping Fault Zone and the Mae Sariang Fault Zone are taken from Morley (2002) and Hisada *et al.*, (2004) respectively.

Geochemically, Barr *et al.* (1990) and Panjasawatwong (1999) classified the mafic volcanic rocks in Chiang Rai-Chiang Mai volcanic belt as tholeiitic basalts and/or transitional tholeiitic basalts. Later, Phajuy *et al.* (2005) and Phajuy (2008) classified thest rocks into two groups as subalkalic basalts and alkali basalts. The volcanic rocks in the Chiang Rai-Chiang Mai volcanic belt have also been claimed that erupted in a subduction environment by Barr and Macdonald (1987). Later on, Barr *et al*. (1990) interpreted that this volcanic belt is related to a continental within-plate environment, while Panjasawatwong *et al*. (1995) and Panjasawatwong (1999) believed that they formed in an oceanic within-plate environment as ocean islands and seamounts in either a major ocean basin or a mature back-arc basin. Phajuy *et al*. (2005) reported that there are mid-ocean ridge and ocean-island basalts in the Phrao area. After that, Phajuy (2008) analyzed that the mafic volcanic rocks in the Chiang Rai-Chiang Mai volcanic belt formed in back-arc basin, ocean-island and mid-ocean ridge environment. The ultramafic rocks in the Phrao area were study and likely derived from MORB magma, whereas associated gabbro and basalt are geochemically comparable to OIB rather than MORB (Viriyasuksing, 2016). These mafic – ultramafic rocks are likely remnants of oceanic crust, which were faulted and dismembered to tectonic blocks subsequently emplaced in accretionary complex above the subduction zone. These tectonic blocks are evidence of disrupted ophiolite along Paleo-Tethys suture in Northern Thailand (Viriyasuksing and Phajuy, 2015).

### 1.2.2 The Chiang Khong -Lampang-Tak Volcanic Belt



The Chiang Khong–Lampang–Tak volcanic belt is a far voluminous. It is a possible southern extension of the Lincang–Jinghong volcanic belt in China (Yang *et al*., 1994; Yang, 1998; Barr *et al*., 2006), which is a part of the Lancangjiang igneous zone in SW China and the rocks in the southwestern Yunnan can be correlated with Triassic Lampang-Phrae basin in Thailand (Feng *et al*., 2005; and Qian, 2016). The Chiang Khong–Lampang-Tak volcanic belt is to the east of the Chiang Rai-Chiang Mai volcanic belt, extending from Chiang Khong District, Chiang Rai Province via Lampang and Phrae Province to Tak Province (Barr *et al*., 2000; Phajuy, 2001; Panjasawatwong *et al*., 2003, Barr *et* *al.,* 2006, Qian *et al.,* 2013) (Figure 1.1). This belt were referred to those of mafic to felsic volcanic, volcaniclastic and associated intrusive rocks in the Sukhothai Terrane (Panjasawatwong *et al*., 2003 and Srichan *et al*., 2009). Associated sedimentary rocks are largely shallow marine that is Permian (Ngao Group and Uttaradit Group)–Triassic (Lampang Group) sedimentary rocks. The Permian–Triassic strata were interpreted to have deposited in the fore-arc basin of Sukhothai Terrane (Singharajwarapa and Berry, 2000). There are two main volcanic suites (Permo–Triassic suite and Late Triassic–Early Jurassic suite) exposed as the Chiang Khong–Lampang–Tak Volcanic belt (Jungyusuk and Khositanont, 1992; and Srichan *et al*., 2009). Geochemically, researchers classified the volcanic rocks in the Chiang Khong-Lampang-Tak volcanic belt as continental calc-alkalic volcanic rocks; along the western edge of Mae Moh Basin (Lampang Province) (Barr *et al.,* 2000), the northern end of Chiang Khong-Lampang-Tak volcanic belt (Chiang Rai and Phayao Province) (Barr *et al.*, 2006), and in the Long area (Phrae Province) (Osataporn, 2007). Panjasawatwong *et al.*, (2003) present a tholeiitic series of mafic rocks along the northern end of Chiang Khong-Lampang-Tak volcanic belt. After that, Srichan *et al*. (2008, 2009) provided into two groups as tholeiitic series and calc-alkalic series.

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 period of Early to Late Triassic (247±5 to 219±3 Ma), corresponded to the Srichan (2008), reported that the Chiang Khong-Lampang-Tak volcanic rocks occurred in the Middle-Late Triassic (233±5 to 220±5 Ma). However, missing Late Carboniferous–Early Permian has been suggested by Hara *et al*. (2013) from the U-Pb age of zircon considerably derived from the arc.

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. Qiang (2016) reported that volcanic rocks from the Chiang Khong area yields a zircon U–Pb age of 229±4 Ma, significantly younger than that of the continental-arc and syn-collisional volcanic rocks (238–241 Ma) and was possibly related to the upwelling of the asthenospheric mantle during the Late Triassic, shortly after slab detachment, which induced the melting of the metasomatized mantle wedge. After, red bedded clastic sedimentary rocks deposited in Phayao Province, and then mafic dikes are intruded into these rocks. Singtuen and Phajuy (2015) reported that these mafic dikes are the part of the Chiang Khong-Lampang-Tak Volcanic Belt and erupted in continental within – plate environment.

**1.2.3 Nan –Uttaradit Volcanic Belt**

The Nan –Uttaradit volcanic belt is an extensive mélange zone that may be related to the Jinghong suture in southwestern China (Metcalfe and Sone, 2008; Metcalfe, 2011). The Nan-Uttaradit volcanic belt is exposed in the eastern most part of northern Thailand along the Nan River, at the eastern margin of Sukhothai fold belt, between the sukhothai Terrane and the Indochina Terrane (Ueno, 1999; Ferrari *et al*., 2008, Sone and Metcalfe, 2008) (Figure 1.1). It is composed of blocks of mafic-ultramafic rocks and minor sedimentary rocks in a sheared serpentinite matrix. Igneous rocks are constituted by lavas, microgabbro/dolerites, isotropic gabbros, cumulus gabbroic and ultramafic rocks, and chromitites. Of these, lavas and microgabbro/dolerites are the least abundant, whereas cumulus gabbroic and ultramafic rocks are the most abundant rock types.

The mafic volcanic blocks include Middle Permian (256 Ma) ocean-island basalts, Carboniferous incipient back arc basin basalts/andesites, and ocean island-arc basalts/andesites (Panjasawatwong, 1991; Crawford and Panjasawatwong, 1996). Also, Singharajwarapan and Berry (2000) and Singharajwarapan *et al*. (2000) have mentioned that coherent volcanic rocks located east of the Nan-Uttaradit mélange zone are oceanic island-arc basalt. This belt is regarded as representing the main Paleotethys ocean (Bunopas, 1981; Panjasawatwong, 1991; Chaodumrong, 1992; Singharajwarapan, 1994; Hada *et al*., 1999; Wakita and Metcalfe, 2005). It has recently been re-interpreted as the back arc basin which opened in Carboniferous (Barr and Macdonald, 1987; Fontaine *et al*., 2002; Metcalfe, 2002a, 2002b; Wakita and Metcalfe, 2005) or Permian (Sone and Metcalfe, 2008; Ferrari *et al*., 2008; Metcalfe, 2011). In the case of the Paleotethys ocean, the volcanic belt is a northern extension of the Sra-Kaew Chanthaburi volcanic belt (Sone and Metcalfe, 2008; Metcalfe, 2011).

### 1.2.4 Loei-Phetchabun-Nakhon Nayok Volcanic Belt

Loei-Phetchabun-Nakhon Nayok volcanic belt trends NE-SW from Loei Province through Phetchabun, Nakhon Sawan and Prachinburi Provinces to Sra Kaew Province (Panjasawatwong *et al*., 2006) (Figure 1.1). In the Loei area, they can be provided into Eastern, Central and Western sub-belts. Igneous rocks of the Eastern sub-belt are mainly rhyolite, whereas those of the Western sub-belt are largely andesite (Jungyusuk and Khositanont, 1992; Della-Pasqua and Khin Zaw, 2002). The Eastern and Western sub-belts can be interpreted that they formed as arc volcanism in the Permo-Triassic (e.g. Bunopas, 1981). Panjasawatwong *et al*. (2006) reported that the Central sub-belt is made up largely of pillow basaltic lava, hyaloclastite and pillow breccia with some intrusions. They formed in the Late Devonian–Early Carboniferous and can be separated into three magmatic groups: transitional tholeiitic basalt, tholeiitic microgabbro and calc-alkalic basalt/andesite. The Central Loei volcanic rocks comprise MORBs and oceanic island-arc lavas. The arc lavas of its may have erupted on an oceanic basement in the same ocean basin as those in the Chiang Rai–Chiang Mai volcanic belt.

The rhyolites of the Eastern sub-belt have a whole-rock Rb–Sr isochron age of 374±33 Ma (Devonian–Carboniferous). The Central sub-belt has a whole-rock Rb–Sr isochron age of 361±11 Ma (Upper Devonian-Lower Carboniferous) (Intasopa and Dunn, 1994). The Western sub-belt has an intercept Ar-Ar age of 237±12 Ma (Intasopa, 1993). Also, The U-Pb zircon from Khao Lek yield the age of 254 ± 10 Ma and the U-Pb isotopic from Khao Mae Kae granodiorite yield the result of 250 ± 5 Ma (Khositanont, 2008).

The volcanic rocks in the Phetchabun areas erupted along an active continental margin in the Middle Triassic as evidence by an Ar-Ar dating in amphibole which gave age of 238±4 Ma (Intasopa, 1993; Kamvong *et al*., 2006). The geochemically of volcanic rocks in the Nakhon Nayok area, a southern part of the Western sub-belt are arc-related magma (Kosuwan, 2004). Phajuy *et al*. (2005) reported that the basaltic dikes intrude into the Permian sedimentary sequence of Nam Duk Formation formed in a volcanic arc environment. Panjasawatwong *et al.* (2006) and Kamvong *et al*. (2006) suggested that the Loei-Phetchabun-Nakhon Nayok volcanic belt may be correlative with the Sra-Kaew-Chanthaburi volcanic rocks.

### 1.2.5 Sra Kaew-Chanthaburi Volcanic Belt

The Sra Kaew-Chanthaburi volcanic belt is situated between the The Chiang Khong–Lampang–Tak volcanic belt and the Loei-Phetchabun-Nakhon Nayok volcanic belt.

The Sra Kaew-Chanthaburi volcanic belt was interpreted to represent the Late Triassic suture formed when westward subduction beneath the Shan-Thai Terrane (Panjasawatwong, 1991; Singharajwarapan, 1994; Crawford and Panjasawatwong, 1996; Hada *et al,*. 1999; Singharajwarapan and Berry, 2000). The Pre-Jurassic volcanic rocks along this suture zone occur as variably sized blocks embedded in foliated serpentinite matrix (serpentinite melange?). The researchers indicate that they comprise Early to Middle Permian ocean-island basalt, Carboniferous incipient backarc basin basalt and andesite, Permo-Triassic (?) arc basalt and andesite, and mid-ocean ridge basalt (Yoshikura, 1990; Crawford and Panjasawatwong, 1996).

The Sukhothai Terrane was probably analogous to those from Chanthaburi Terrane in Eastern Thailand (Sone *et al.*, 2012) based on *Leptodus* -Genus *Oldhamina sp.* in Permian Limestone of Huai Tak and Khao Yai Pring formations.

Those fossil and geochemistry of igneous rocks in Chanthaburi Terrane suggested that Sra Kaew-Chanthaburi volcanic belt is the part of Chiang Khong-Lampang-Tak volcanic belt (Figure 1.1).

#### 1.2.6 Portions of any Volcanic Belt to the North

The felsic to mafic volcanic/hypabyssal rocks in the area of Nakhon Sawan and Uthai Thani Provinces are the portion of any volcanic belt in the north (Figure 1.1). Igneous rocks, including plutonic, volcanic and volcaniclastic rocks are widespread in several isolated N-S trending hills and mountains in the study area, and occur as lava flows, stocks, and dikes. They are possibly the portion of Chiang Khong - Tak volcanic belt and Loei - Phetchabun - Nakhon Nayok volcanic belt, Thailand (Kosuwan *et al*., 2013). They are least altered, and probably formed in Carboniferous and late Triassic. They comprise (1) calc-alkalic rhyodacite/dacite, andesite/basalt and gabbro, (2) calc-alkalic diorite, (3) tholeiitic andesite/basalt and microdiorite/microgabbro and (4) shoshonitic rhyodacite/dacite. All of these rocks have been characterized as subduction-related magma (Kosuwan, 2013).

### 1.3 Aim, Scope, and Theory of Study

This research will show the occurrence and petrogenesis of volcanic rocks and their relationship with associated rocks for interpretation of the tectonic setting of the formation. The study may also clarify a problematic tectonic evolution of the Sukhothai Terrane in Northern Thailand. It might reveal a historical geology of Thailand and mainland Southeastern Asia as well.



Volcanic and associated rocks will be collected 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 associated rocks are all of rock types that are occurred with the studied volcanic rocks (all of sample numbers show in Appendix). The study includes field investigations, sample collection, petrography, and chemical compositions of least-altered rocks. Tectonic setting of eruption of these rocks could be interpreted based on their petrochemistry.

Petrographic study (Cox *et al*., 1979; Hess, 1989; Wilson, 1989; and Winter, 2010) under polarizing microscope is used for analyzing mineral composition and texture of rocks, including alteration, replacements or metamorphism, resulting in classification of rocks and their alteration/weathering. These results are evidence for field relation and modes of field occurrence. Geochemical composition can be divided by volume into major oxides, minor elements, trace elements and rare earth elements. Many researchers (Best *et al*., 2001; Philpotts *et al*., 2009; Winter, 2010) have proposed the many hypotheses in predicting the source of a particular magma based on chemical composition of igneous rocks especially trace elements. Trace elements occur in very low concentrations in common rocks. They are therefore more useful in formulating models for magmatic differentiation and predicting the source of a particular magma. Large ion lithophile elements (LILE) will therefore preferentially concentrate in the liquid until a particular phase with large enough sites to accommodate them begins to crystallize. These elements will therefore be largely "incompatible" particularly with respect to mantle. High field strength elements are also excluded from mantle phases and more concentrated in residual liquids. Transition elements are strongly partitioned in the solid phases that crystallize during the early stages of magmatic evolution, and are therefore "compatible" with mantle phases. Rare earth elements (REE) is a group of elements with atomic numbers between 57 (La) and 72 (Lu). They are incompatible elements and have proven to be very important for petrogenetic interpretations. Applications of trace elements for igneous petrogenesis are as follow:

1) REE: Their concentrations as an igneous rock are usually divided by their concentrations in standard chondrites or normal mid-oceanic ridge basalt in order to smooth out large differences in concentration between one REE and the other. These normalized values are then plotted on diagrams, where the REE are arranged on the X-axis from the lightest element to the heaviest. A group of co-magmatic rocks, the REE concentrations will increase systematically with progressive differentiation as they are largely

incompatible. REE diagrams are also useful in identifying which phase or phases fractionate from magma and determine the type of basalt.

2) Discriminant diagrams: Trace elements can also be used to identify the paleotectonic setting of some volcanic rocks. The absolute concentrations of trace elements which may have been affected by such post-magmatic processes as weathering, alteration or metamorphism, ratios of relatively immobile trace elements as these are least affected by post magmatic processes.

**1.4 Location and Accessibility**

The study areas are located in 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). They are located in the topographic maps at scale 1:50,000, series L7018, sheet 4842I (Ban Nam Dip), sheet 4842II (King Amphoe Kosamphi Nakhon), 4842III (King Amphoe Wang Chao), 4842IV (Changwat Tak), sheet 4843I (Ban Huai Rin), sheet 4843II (Ban Pong Daeng), 4843III (Amphoe Ban Tak), 4843IV (Amphoe Mae Phrik), 4942III (Amphoe Phran KraTai), 4942IV (Amphoe Ban Dan Lan Hoi), 4943III (Amphoe Ban Dan Lan Hoi), and 4943IV (Amphoe Thung Saliam), approximately between latitudes 16º30’ N and 17º30’ N and longitudes between 99º00’ E and 99º45’ E. The studied samples were collected from six areas as follow: (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. The study areas can be conveniently accessed by car via the route from Chiang Mai, take highway number 11 and number 1 to Tak province via Mae Phrik and Thoen District, Lampang Province (approximately 300 kilometers). Sukhothai Province can be accessed using highway number 12, from Tak Province to Sukhothai Province for a distance of approximately 80 kilometers. Phran Kratai District and Kamphaeng Phet Province can be made from Tak Province via highway number 1and number 101 with a distance of approximately 75 kilometers or can be reached from Sukhothai Province via highway number 101 with a distance of approximately 70 kilometers (Figure 1.2).

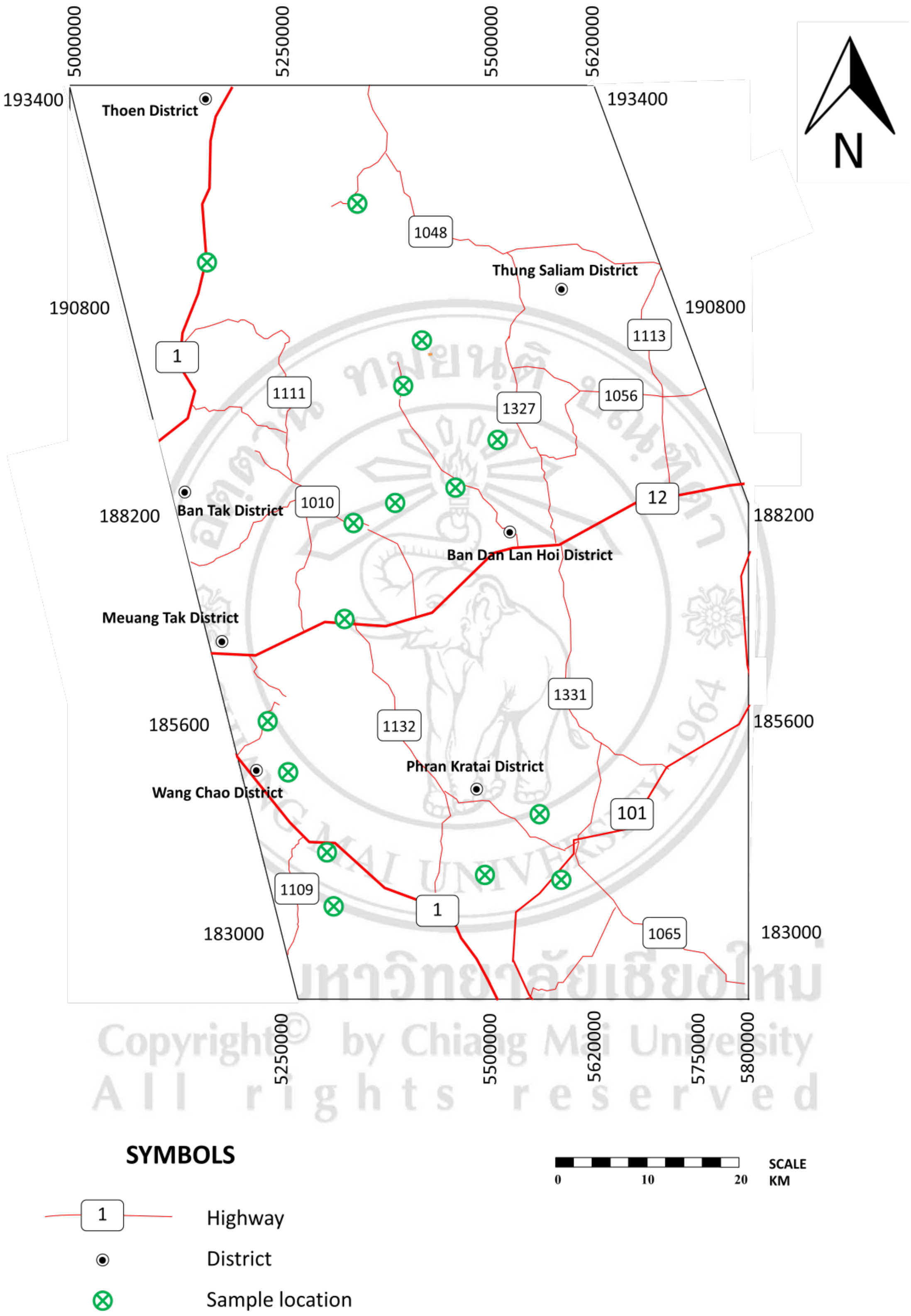



Figure 1.2 Map of the study area showing accessibility to the sample location (modified from Tourism Authority of Thailand, 2007).

## 1.5 Topography and Physiography

The study area consists mainly of alluvial sediments and a few kilometer-scale hills widely distributed around the study area that was separated by now-active northward branches of the Mae Ping Fault Zone (Morley *et al.,* 2011).

Mountains are mostly distributed on the northern side and central of the study area (Mae Wa National Park). The west northern flank of the study area comprises volcanic and pyroclastic small mountains include Doi Ma Thao, Doi Kia Khot, Doi Nok Iang, and Doi Waing. While the east northern flank of the study area is made up of limestone mountain ranges that are Thung Saliam limestone and shows karst topography, for example Khao Cha On, Khao Khok, Khao Mahat Thai, Khao Pui, Khao Daeng, and Khao Tham Chao Ram. These are shown in the north-south mountain range. The granite mountains are mostly scattered on the central along highway number 1 in Tak Province such as Doi Lan, Doi Ta Chi, Doi Pu Thang, and Khao Luang mountain ranges. However, the old pyroclastic and sedimentary mountains are distributed in the eastern flank that is Khao Luang and Khao Kheo. The Khao Luang is the highest mountain in the study area and is about 1244 meters above mean sea level and located in Sukhothai province.

Plain areas are generally distributed on the study area that has many built-up areas, villages, rice swamps and streams.

The study area has two main rivers, the Wang and Ping Rivers. The Wang River forms in Phi Pan Nam Range (Chiang Rai Province) and flows southward to Lampang Province. Then the Wang River joins the Ping River at Ban Tak District (Tak Province). The Ping River is the biggest river in the study area and flows in a NW to SE direction.

In addition, the study area has many reservoirs that are the result from many gullies and canals which are distributed in this area such as Huai Mae Salaem Luang, Huai Mae Mok, Huai Mae Kong Khai, Khlong Kha Yang, Huai Nam Dip, and Khlong Mae Ramphan. These streams can be divided into 2 groups based on flow direction; (1) north-south and (2) west-east. The Huai Mae Salaem Luang forms in the northern flank of Mae Wa National Park and flows southward to Ban Mae Salaem. It joins the Huai

Mae Mok at Thoen District, Lampang Province and then the Huai Mae Mok flows eastward to Thung Saliam District, Sukhothai Province. The Mae Mok reservoir is the biggest reservoir of the study area and an embankment dam on the Huai Mae Mok. The Huai Mae Kong Khai forms in the Mae Wa National Park and flows southward to Ban Wang Luek, Ban Dan Lan Hoi District, Sukhothai. It is a tributary of the Khlong Mae Ramphan in Ban Pong Daeng, Ban Tak District, Tak Province and flows eastward to Sukhothai Province. On the other hand, the Khlong Kha Yang flows southward and joins the Huai Nam Dip at Meuang Tak District, Tak Province. Then the Huai Nam Dip flows southward to Phran Kratai District, Kamphaeng Phet Province and joins the Ping River at Mueang Kamphaeng Phet District (Figure 1.3).

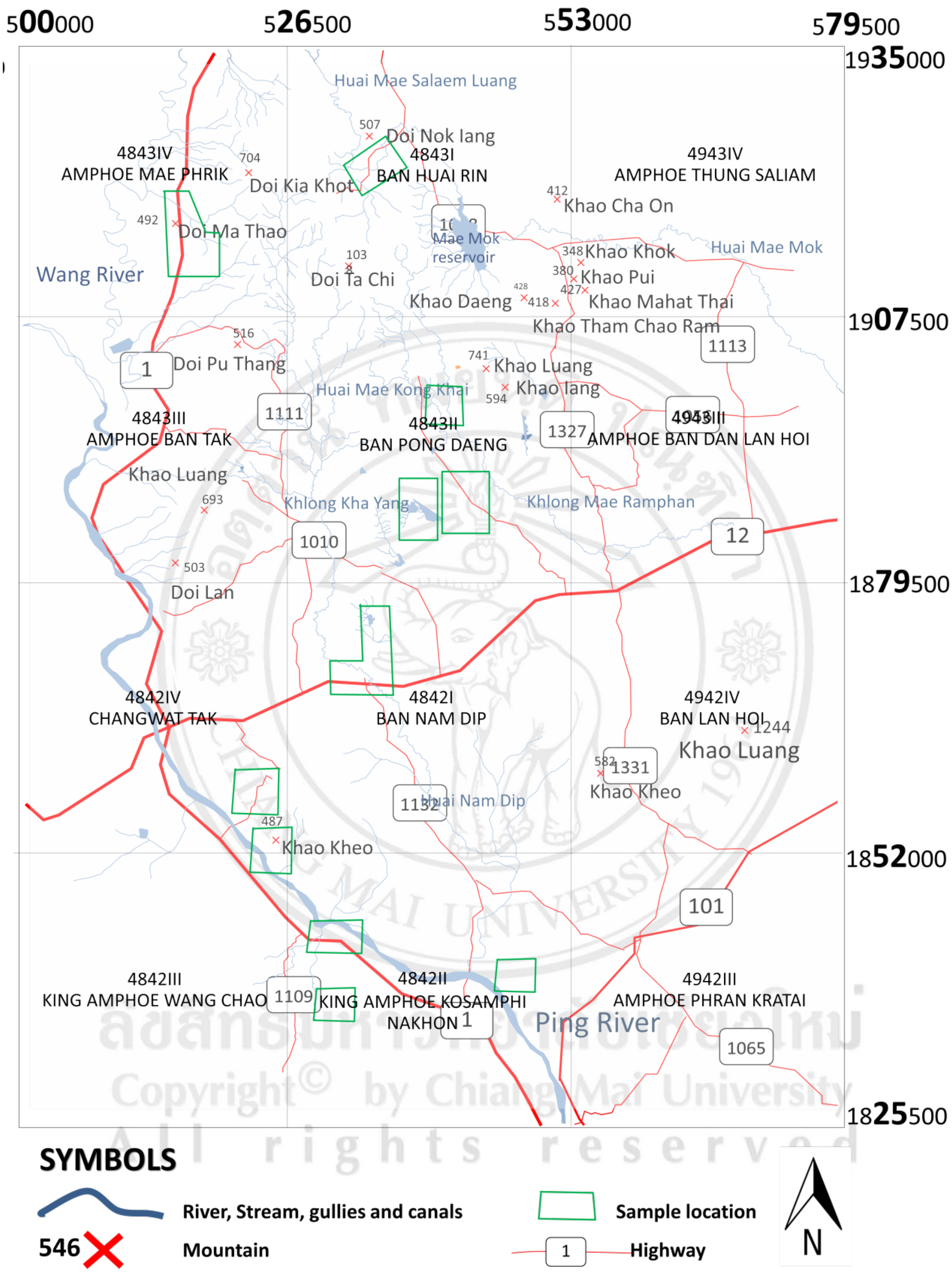


Figure 1.3 Topographic map showing the study area and the locations of collected volcanic and associated rocks (red solid polygon) (modified from the Royal Thai Survey Department, 1999a, b, c, d, e, f, g, h, i, j, k, l).