CHAPTER 1

INTRODUCTION

The geology and tectonics of Thailand indicate that Thailand is composed of two terranes, the Shan-Thai and Indochina terranes. The Shan-Thai terrane is located in the western part and the Indochina terrane is located in the eastern part of Thailand and is bounded by the Nan-Uttaradit suture in the north, the Loei-Phetchabun suture and the Sra Kaeo suture in the central part of the country, and the Betong-Raub suture in the south. The Shan-Thai terrane is interpreted to have remained on the margin of northwest Australia Gondwana until Sakmarian time and then, as part of the Cimmerian continental strip, rifted and separated from Gondwana and drifted rapidly north during the Permian (Metcalfe, 2002), based on the evidence of the pebbly mudstone of the Kaeng Krachan Group (Chaodumrong et al., 2004). The second terrane, Indochina, was located at the equator since Early Carboniferous time (Metcalfe, 2002), the character of its rock units and fauna show strong tropical Cathysian province evidence. The question is, since northern Thailand is believed to belong to the Shan-Thai terrane, why are there no pebbly rocks, although there are Late Palaeozoic rocks? This question can be solved by determining the history of Late Palaeozoic rocks in northern Thailand by studying the evidence of depositional processes in carbonate rocks.

1.1 Hypothesis

In this research, two hypotheses are set up using the articles of Ueno and Igo (1997) and Metcalfe (2002). If the Carboniferous-Permian carbonate rocks in the Chiang Dao area were the seamount that belonged to the Chiang Mai suture, they should be an important characteristic of the carbonate seamount and the boundary between the Carboniferous and the Permian.

In the article of Ueno and Igo (1997), the age of carbonate rocks in the Chiang Dao area are younger to the north. Along highway route 107, at km 91, they found foraminifera that indicate an Early Serpukhovian age, late Early Carboniferous. At the

Khao Tham Pong quarry, at km 91.7, they found late Middle Carboniferous latest Moscovian foraminifera faunas. The late Early Permian late Yakhtashian *Pamirina (P.) darvasica* fusulinacean was found at kilometer 93.1. They also found the late Middle Permian Murghabian fusulinid *Verbeekina verbeeki* near the Tham Klaep cave at kilometer 99.5. These foraminifera occurrences indicate that the boundary between the Carboniferous and the Permian should be found between the Khao Tham Pong quarry and kilometer 93.1.

Metcalfe (2002) suggested the Chiang Mai suture, the evolution of the Palaeotethys ocean, and the seamount between the Shan-Thai and Cathysian terranes. He referred the sequences of rocks in this area as being deep marine chert associated with shallow marine limestone and basalt. If this area is a true seamount, the shallow carbonate rocks would have been deposited on the top of an atoll and would be associated with pelagic rocks. There should be a stratrigraphic contact, not a fault contact, between shallow marine limestone, basalt, and associated chert and pelagic shale. If the model is true, the limestone microfacies should represent the shallow marine carbonate rocks that were deposited on the seamount basalt.

1.2 Research objective

1.2.1 To study the lithofacies and stratigraphy of carbonate rocks at the Carboniferous-Permian boundary in the research area.

1.2.2 To interpret depositional processes and depositional environments of the Carboniferous and Permian carbonate rocks in the research area.

1.3 Research area

The research area is located between the Khao Tham Pong quarry in Ban Pang Mo at kilometer 91.7 on route 107 and the outcrops near kilometer 93.5 behind the Pong Tong temple in Chiang Dao District, Chiang Mai Province (Figure 1.1).

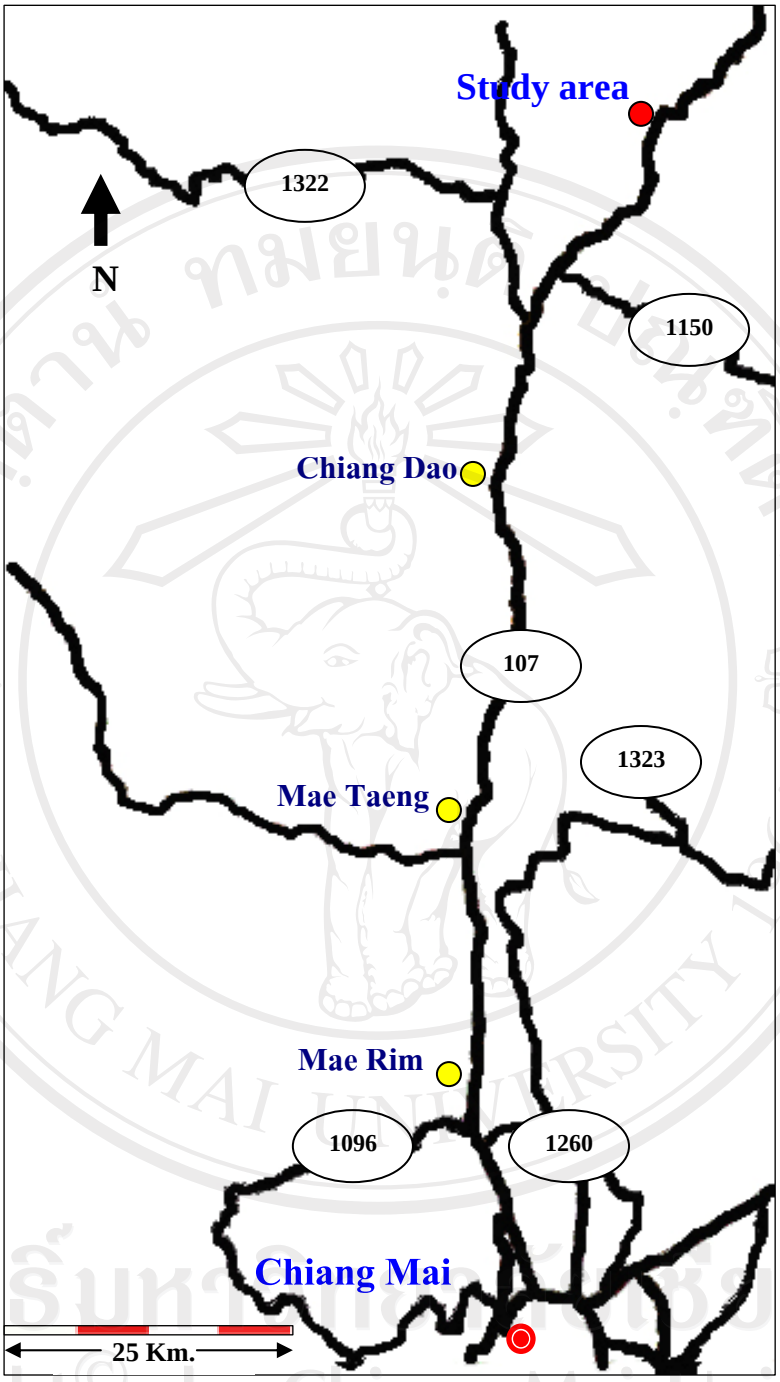

Figure 1.1 Location map showing the study area located at Chiang Dao, about 100 kilometers north of Chiang Mai along route 107.

1.4 Methodology

1.4.1 Collected carbonate rock samples from outcrops at Khao Tham Pong quarry, normal to depositional strike. Sampling interval was 30 centimeters. Samples were studied for their microfacies, depositional environment, age, and stratigraphic position.

1.4.2 Collected carbonate rock samples from the Khao Tham Pong quarry and areas to the north for study of the change of microfacies northward. The objective was to find the Carboniferous-Permian boundary north of the Khao Tham Pong quarry (Figure 1.2).

1.5 Usefulness

The study should result in an understanding of the depositional processes and depositional environments of the carbonate rocks of the Carboniferous-Permian boundary in the research area, Chiang Dao District, Chiang Mai Province.

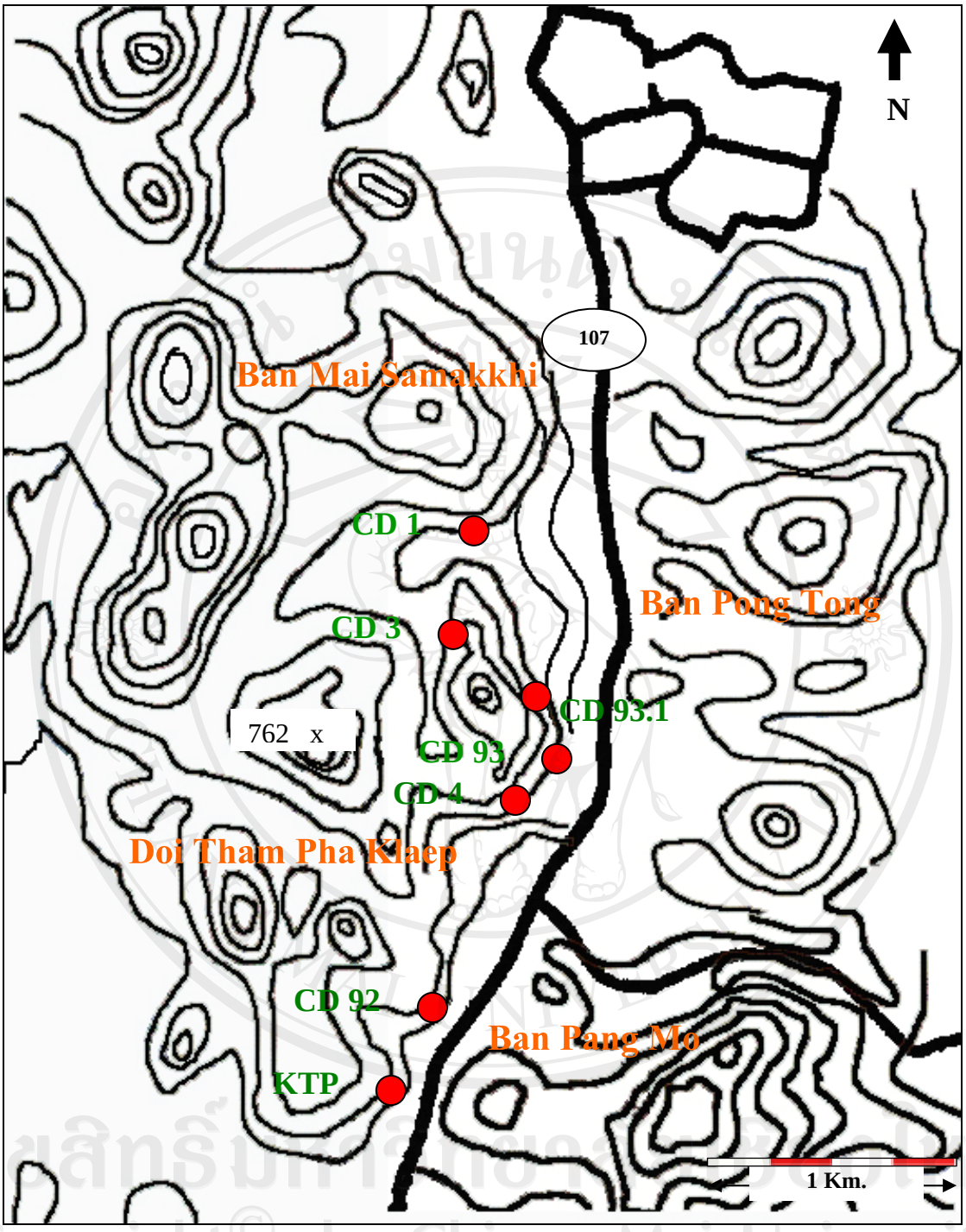

Figure 1.2 This map has been sketched from topographic map 1: 50,000 sheet 4848-III , Amphoe Chai Prakan showing the seven outcrop sections: KTP (Khao Tham Pong quarry), CD 92, CD 4, CD 93, CD 93.1, CD 3, and CD 1.

1.6 Geological setting

The limestone in study area was mapped as Permian limestone by Baum and Hahn (1977) and was located at latitude 19°31’42’’N, longitude 99°04’17’’E. The geological setting of this area includes Silurian-Devonian quartzite, phyllite, schist, sandstone, shale, and tuff. These rocks occur in the eastern part of the study area and are in contact with Carboniferous granite. The Devonian rocks are shale, chert, and sandstone and they are conformable with overlying Carboniferous strata. The Carboniferous rocks are divided into two sub-units. Sub-unit C1-2 consists of sandstone, graywacke, and shale. Sub-unit C2-3 includes sandstone, graywacke, shale, chert, and conglomerate. The Permian rocks are very thick bed limestone strata and trend north-south. Basic and ultrabasic rocks occur between Permian limestone and Triassic granite. The study area has minor folds and faults (Figure 1.3).

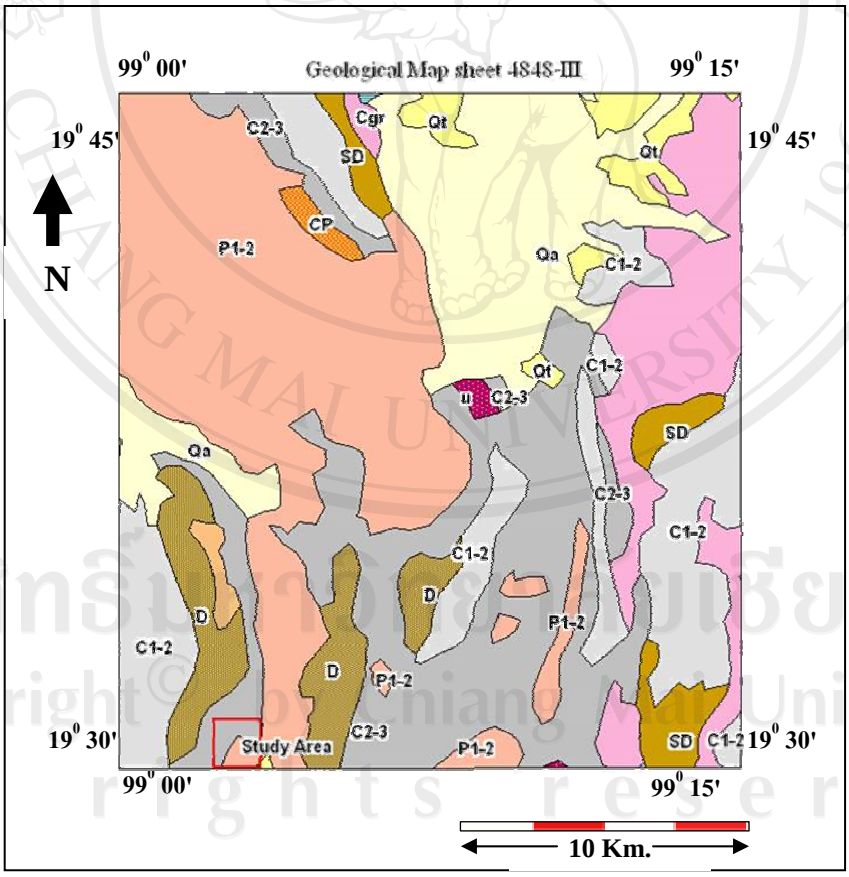

Figure 1.3 Geological map of the study area, map sheet 4848-III, Amphoe Chai Prakan (Modified from Department of Mineral Resource, 1987)

Table 1.1 The explanation of Figure 1.3

Legend		Age	Description
	Qa	Quaternary	Alluvium sediment
	Qt		Terrace gravel, sand, silt, mud, and clay
	P_{1-2}	Permian	Massive to thick bedded limestone, shale, slaty shale, and bedded chert.
	CP	Carboniferous-Permian	Sandstone, shale, chert, conglomerate, and tuff
	Cqr	Carboniferous	Granite
	C_{2-3}	Carboniferous	Sandstone, graywacke, shale, chert, and conglomerate
	C_{1-2}		Sandstone, graywacke, and shale
	D	Devonian	Shale, chert, and sandstone
	SD	Silurian- Devonian	Quartzite, phyllite, schist, sandstone, shale, and tuff
	U	Undifferentiated	Pyroxenite, hornblendite, peridotite,serpentinite and olivine basalt

1.7 Literature review

1.7.1 Groups of Permian limestone in Thailand

Ratburi Group

The Ratburi Group was originally proposed by Javanaphet (1969) to represent the sequences of Permian limestone and shale in the whole of Thailand. Later, the Ratburi Group was limited to the limestone sequence in the Shan-Thai terrane. The Saraburi Group was used for limestone in the Indochina terrane and the Ngao Group was used for limestone in northern Thailand.

Bunopas (1981) studied the Permian rocks in Kanchanaburi Province and named them the Sai Yok Group. The group was divided into three formations: the Khao Muang Krut Sandstone, the Sai Yok Limestone, and the Tha Ma Dua Sandstone.

The Khao Muang Krut Sandstone's type section is located at Khao Muang Krut, about 15 kilometers west of the city. The formation is composed of sandstone interbedded with shale in its lower part. In its upper part, sandstone beds are thin, shale beds are thick, and there are interbeds of limestone lenses. The brachiopod *Chonetinella* sp. indicates the formation to be Carboniferous to Early Permian in age. The thickness of this formation is about 200 meters.

The Sai Yok Limestone's type section is 6 kilometers south of the Sai Yok waterfall. The formation is 480 to 900 meters thick. The lower part of this formation is thick to very thick limestone and has sandstone interbeds. It also has some dolomitic limestone beds. The upper part of the formation is thin beds of light gray limestone interbedded with grayish brown sandstone. Some fossils, especially fusulinids in the limestone, indicate a Middle Permian age.

The Tha Ma Dua Sandstone's type section is at Kho Thon, 6 kilometers from Kho Sai Yok to the south. The formation is composed of medium- to coarse-grained sandstone interbedded with reddish brown shale. The thickness of this formation is 80 meters.

Chaodumrong et al. (2004) divided the Ratburi Group into five formations: the Thung Nang Ling Formation, the Khao Muang Krut Sandstone, the Phap Pha Formation, the Phanom Wang Formation, and the Um Luk Formation.

The Thung Nang Ling Formation; in its lower and upper parts, is light to dark gray limestone, thick- to very thick-bedded, and has abundant crinoid stems. The middle part of the formation is thick-bedded and cross-bedded sandstone interbedded with shale. Some dolomite beds also occur. The age of this formation is Middle Permian, Wordian (Kubergandian). The type section is located in a quarry to the west of Khao Thung Nang Ling, Surat Thani Province.

The Khao Muang Krut Sandstone is coarse-grained, gray sandstone that is thin- to thick-bedded and cross-bedded. The sandstone is quartz-rich and interbedded with shale and mudstone. Limestone is interbedded in the upper part and is very fossiliferous. The age of this formation is Middle Permian, Wordian (Kubergandian). The type section is located at Khao Kaew Noi, Kanchanaburi Province.

The Phap Pha Formation is gray to dark gray, thin- to medium-bedded limestone that has thin interbeds of shale and chert. Its age is Middle Permian, Murghabian. The type section is located at Khao Phap Pha, Surat Thani Province.

The Phanom Wang Formation is coarse-grained, gray to dark gray, medium- to thick-bedded limestone. It contains some chert nodules. Its age is Middle Permian. The type section is located at Khao Phanom Wang, Surat Thani Province.

The Um Luk Formation is a fine-grained, light gray, thick-bedded limestone that has chert lenses. Its age is Middle Permian, Murghabian. The type section is located at Khao Um Luk, Surat Thani Province.

Fontaine and Suteethorn (1988) described six characteristics of the Ratburi Group in southern and western Thailand. These are:

(1) Fossils in the limestone are rare. Although, some areas have abundant fusulinids, these fusulinids have a low diversity. Green algae are rare.

(2) Coral occurs in some areas. Most of these are solitary corals and indicate a poor environment.

(3) The limestone is Middle to Late Permian in age.

(4) The Carboniferous-Permian boundary could be in the Kaeng Krachan Group on the basis of late Asselian brachiopod fossils.

(5) These late Asselian brachiopods are cold water brachiopods and represent late Asselian glacial deposits of Gondwanaland.

(6) The Ratburi Group was deposited in a shelf platform environment.

Saraburi Group

The name of this group was given by Bunopas (1981) to the Permian rocks that are distributed in Uthai Thani, Nakhon Sawan, and Saraburi Provinces. The type section is in Saraburi Province. He divided the Saraburi Group into three formations: the Khao Luak Formation, the Saraburi Limestone, and the Dan Sai Shale. The Khao Luak Formation is well-bedded gray sandstone interbedded with gray shale and limestone. Its thickness is 1,500 meters. The type section is located at Khao Luak. Its age is Early Permian and is based on the occurrence of *Pseudofusulina* sp. and *Triticites* sp. fusulinids.

The Saraburi Limestone is thick- to very thick-bedded limestone with some interbeds of fine-grained sandstone, shale, and chert. Conglomerate occurs in some parts interbedded with chert, siltstone, and mudstone. The fossils in the formation are fusulinids, bryozoa, pelecypods, brachiopods, and coral. The formation's age is Early to Middle Permian.

The Dan Sai Shale is composed of micaceous sandstone, siltstone, shale, and calcareous shale. It thickness is 600 meters. The formation's type section is between kilometers 4 and 20 along the route from Loei to Dan Sai Province. Its age is Middle to Late Permian.

Chonglakmani and Sattayarak (1984) divided the Saraburi Group at Phetchabun, Nongbualumphu, and Chaiyaphum into three formations: the Pha Nok Khao Formation, the Hau Na Kham Formation, and the Nam Duk Formation.

The Pha Nok Khao Formation is thin to very thick beds of gray limestone and interbeds of shale and chert. Its type section is located at Pha Nok Khao, Loei, and its age is Early to Middle Permian.

The Hau Na Kham Formation is gray shale, brown sandstone, and limestone lenses. Its type section is located at Ban Hau Na Kham, Chaiyaphum, and its age is Middle Permain.

The Nam Duk Formation is composed of gray shale and thin- to thick-bedded, gray limestone. The beds have Bouma sequences. The formation's type section is located at Ban Nam Duk, Phetchabun. Its age is Middle Permain.

Charoenprawat et al. (1984) studied the Saraburi Group limestone in Loei Province and divided it into three formations: the Nam Mahoran Formation, the E-Lert Formation, and the Pha Dua Formation.

The Nam Mahoran Formation's type section is located at Nam Mahoran cave, Loei Province. The formation is composed of medium- to thick-bedded, gray limestone interbedded with thin beds of shale and sandstone. It has some chert nodules. Fossils in the formation are fusulinids, brachiopods, algae, corals, and crinoids and they indicate an Early to Middle Permian age. The formation's thickness is more than 500 meters.

The E-Lert Formation's type section is located at Huai E-Lert, Loei Province. The formation is shale interbedded with chert. It has some lime nodules and pyroclatic rocks. There is cross-bedding and ripple marks in the fine-grained clastic rocks. Fossils in the formation are *Agathiceras* sp. and *Parafusulina* sp., which indicate an Early to Middle Permian age.

The Pha Dua Formation's type section is located at Pha Dua, Loei. The formation is shale and greenish-gray to brown, micaceous sandstone. Pyroclastic rocks are rare. The fossil *Agathiceras* sp. and plant fossils indicate a Middle to Late Permian age.

Assavapatchara (1998) studied the lithostratigraphy of the Upper Palaeozoic Nam Mahoran Formation carbonate rocks in the southeastern part of Loei Province. This succession is dated by fossils as Late Carboniferous to late Early Permian. The 500 meters thick sequence has three members: Tham Suae Mop, Ban

Nong Hin, and Phu Pha Khao. On the basis of petrographic study, the formation has seven microfacies: packed biomicrite, sparse biomicrite, biosparite, crystalline, algal lamination, ooparudite, and pelmicrite. These microfacies, together with the diversity of fossils, suggest intertidal and subtidal depositional environments in a low to high energy shallow shelf sea that had partly restricted water conditions. The formation's lithology and fossils suggest that it accumulated in a tropical climate, close to the equator of Palaeotethys.

Charoentitirat (1995) studied the fusulinacean faunas in Carboniferous-Permian limestone in the eastern part of Loei Province. The fusulinids found in the investigated areas belong to 13 genera: *Triticites* sp., *Daixina* sp., *Pseudoschwagerina* sp., *Darvasites* sp., *Jigulites* sp., *Pamirina* sp., *Chalaroschwagerina* sp., *Sphaerulina* sp., *Schubertella* sp., *Pseudofusulina* sp., *Parafusulina* sp., *Verbeekina* sp., and *Yangchienia* sp. These 13 genera indicate a Late Carboniferous to Middle Permian age. Petrographic study indicated that this limestone has many compositions: dolomitic, micritic, biomicritic wackestone, biopelmicritic wackestone, packstone, grainstone, stromatolitic boundstone, and foreslope talus. These various composition types were deposited in six shallow marine sub-environments: shelf lagoon, winnowed edge, organic build-ups, foreslope, deep shelf margin, and open sea shelf.

1.7.2 Paleontology

Sashida et al. (2000) documented Late Permian to Middle Triassic radiolarian faunas from two chert outcrops in a quarry at Ban Huai Tin Tang, about 20 kilometers north of Chiang Dao. This chert is thought to be an extension of the Fang Chert. The radiolarian faunas are identical to the faunas of the Late Permian *Neoalbaillella ornithoformis* and *N. optima* Assemblage Zone and the Triassic *Parentactinia nakatsugawaensis* and *Triassocampe coronata* Assemblage Zones reported in chert sequences of Japan. These radiolarian faunas apparently indicate Late Permian and Early Triassic ages.

Ueno and Igo (1997) reported Late Paleozoic diversified foraminiferal faunas from widely spread carbonate rocks in the Chiang Dao area of northern Thailand. These faunas indicate various ages: Middle or Late Visean, Early Serpukhovian, Moscovian, Late Yakhtashian, Late Bolorian or Early Kubergandian, probably Late Kubergandian, Late Murghabian, and Murghabian or Midian. All of these Late Paleozoic foraminiferal faunas have a close Tethyan affinity, although the Early Carboniferous ones should be defined as cosmopolitan. Characteristics and succession of these Late Paleozoic foraminiferal faunas in northern Thailand are quite similar to those found in the Indochina block rather than to those in the Shan-Thai block. These Thai faunas strongly suggest that the carbonate rocks in northern Thailand were deposited in a tropical environment. This means that the northern Thailand area should be excluded from the currently defined Shan-Thai domain. These faunas suggest that in the northern part of Thailand, the eastern limit of the Shan-Thai domain corresponds to the Mae Yuam fault zone that trends north-south near the border between Thailand and Myanmar.

Caridroit (1993) studied the Upper Paleozoic and Triassic radiolaria in the Chiang Dao region, from Chiang Dao to Ban Nawai. He concluded that the deposition of radiolarite over a long period of time can be possible only in a large ocean, very far from all detrital sources and below the carbonate compensation depth. Thus, the present structural position of radiolarites can be explained only in an accretional and obductional context. He proposed a new tectonic model: the Carboniferous-Permian limestone unit lies on an olistostrome unit which, in turn, lies on an Upper Paleozoic-Triassic radiolarite unit. This geometry is possible only in a nappe and thrust sheet tectonic context. This tangential structural development can be explained in a collisional environment, collision between the Shan-Thai continental block and the Indochina continental block during Triassic-Early Jurassic time.

Fontaine et al. (1993) studied Carboniferous and Permian limestone in the Sop Pong area, located along the road from Pai to Mae Hong Son. The limestone outcrops are widespread and commonly consist of grainstones. They discovered Late Carboniferous *Triticites* south of Ban Mae Lana at kilometer 58.4 on the road from

Pai to Mae Hong Son. This fossil is in very thick limestone and indicates Kasimovian age. The outcrop is a grainstone that contains fusulinids. In thin section, this grainstone is rich in microfossils: fragments of alga *Epimastopora*, smaller foraminifers *Tetrataxis, Climacammina*, *Bradyina*, and fusulinids *Triticites* and *Schubertell*. Moreover, it contains crinoids and very rare fragments of brachiopods. Oolites are abundant and some have foraminifers and crinoid debris in their centers. Southwest of Ban Mae Lana, a dark gray limestone contains Middle Asselian fusulinids. This limestone is a packstone and includes scattered dolomite rhombs. The fossils are small foraminifera *Climacammina*, fusulinids *Sphaeroschwagerina* cf. *moelleri*, *Rugosofusulina* sp., *Schubertella* sp., and probably *Biwaella*, and very rare small fragments of Fenestellidae. Fontaine et al. (1993) commented that such a limestone is unknown in the Middle-Late Carboniferous and Early Permian of peninsular Thailand. This suggests a great difference exists between northwest Thailand and peninsular Thailand.

Sashida et al. (1993) reported the occurrence of Paleozoic and Early Mesozoic radiolarians in Thailand. They collected samples from 18 outcrops between kilometers 105.5 and 107.5 from Chiang Mai and identified Devonian? to Middle Permian radiolarians from the type section of the Fang Chert. They also found Early Permian radiolarians in a chert exposed at kilometer 86.3 along the same road. Here, a thin-bedded green chert contained poorly preserved radiolarians, including *Entactinia* sp. and *Entactinosphaera* sp. The detailed geologic age of these radiolarians is uncertain, but unidentified species of the genus *Entactinosphaera* have a close affinity with Devonian species, such as *Entactinosphaera cancellicula* and *E. variacenthina*. A gray to black, thin-bedded chert exposed at kilometer106.1 from Chiang Mai has well-preserved radiolarians: *Entactinosphaera* cf. *grandis*, *Entactinosphaera* sp., *Pylentonema?* sp., *Cyrtisphaeractenium?* sp., and *Palaeoscenidium cladopholum*. The geologic age of this outcrop is uncertain because of a lack of short-ranging genera and species. However, these radiolarians probably indicate an Early Carboniferous age. Poorly perserved conodonts and radiolarians were recovered from a gray and green chert that crops out at kilometer 106.4 from Chiang Mai. Moderately well-preserved conodonts, *Gnathodus commutatus* and *Spathoganthodus crassidentatus*,

were also identified in this chert. These two species are the common representatives of the upper Early Carboniferous in the U.S.A. and Europe.

Samples from a gray and green chert exposed at about kilometer 107 contains many albaillellid radiolarians. These radiolarians are *Albaillella sinuate, Pseudoalbaillella scalprata,* and *Pseudoalbaillella* sp. A and sp. B. The first two species are known to occur in Lower to Middle Permian chert sequences. Samples of this chert exposed at kilometer 107 also contained both albaillellid and other spumelarian radiolarians. Identified species are *Pseudoalbaillella elegans, Pseudoalbaillella* cf. *Ornate, Entactinosphaera* sp., *Lathetibifustula* sp., and *Nazarovella* sp. The age of this chert is estimated as Early Permian on the basis of these radiolarians. A greenish-gray chert exposed at kilometer 107.5 from Chiang Mai contains *Follicucullus monacanthus* and other unidentified radiolarians. The occurrence of *Follicucullus monacanthus* is restricted to the upper Middle Permian *F. monacanthus* Zone. Gray and green chert outcrops at kilometer 86.3 from Chiang Mai contain the radiolarians *Pseudoalbaillella lomentalia, Pseudoalbaillella* sp., *Grandetortula* sp., *Pseudoalbaillella* cf. *scalpratam, Pseudoalbaillella* sp., *Pseudoalbaillella lomentalia,* and *Pseudoalbailella scalprata*. These radiolarians occur in Early Permian rocks. Although the radiolarian study in the Fang area is not complete, the presence of Carboniferous and Permian radiolarian chert within the Fang Chert, which has previously been considered as a Late Devonian unit, should not be overlooked.

1.7.3 Tectonic setting

Chaodumrong et al. (2004) compared the Permian rocks in the Shan-Thai block to those in the west Yunnan block. As a result, the lithostratigraphic classification of both the Kaeng Krachan and Ratburi Groups were revised. Nine lithofacies for the clastic rocks and four for the carbonate rocks were designated. The Kaeng Krachan Group is an Early Permian, Asselian, to early Middle Permain, Bolorian, sequence and the Ratburi Group is a middle Middle Permian, Roadian (Kubergandian), to early Late Permian, Dzhulfian, sequence. Permian stratigraphy of the Shan-Thai block is comparable to that of the Baoshan and Tengchong blocks. This

means that the Kaeng Krachan Group is comparable to the Dingjiazhai and Yongde Formations of Baoshan and to the Kongshuhe Formation of Tenchong. The Ratburi Group is then comparable to the Daaizi, Shazipo, and Dadongchang Formations.

Metcalfe (2002) reported on the main Palaeotethys ocean in northern Thailand and identified it as being represented by the Chiang Mai suture. The rocks in the Chiang Mai-Chiang Dao area, ranging in age from Devonian to Triassic, were interpreted as representing the main Palaeotethys suture zone. These rocks include basalt, ribbon-bedded chert dated by radiolarians as Devonian, Carboniferous, Permian, and Triassic, pelagic limestone associated with bedded chert, pelagic mudstone, rhythmic mudstone, graywacke and very thick turbidite sandstone, and shallow marine fusulinid limestone interpreted as carbonate caps to seamounts. Examples of ocean-plate stratigraphy have been discovered in this area and are exposed in a road cut south of Chiang Mai at latitude 18°30’70”N, longitude 99°05’60”E, where Permian ocean island pillow basalt is overlain by interbedded chert and pelagic limestone and mudstone. Thick, but laterally restricted, outcrops of shallow marine fusulinid limestone dated as Early Carboinferous, Visean, to Late Permian, Dorashamian, north of Chiang Mai are interpreted as seamount caps. The rock associations of the Chiang Mai suture in the Chiang Mai and Chiang Dao areas equate well with similar rock suites of the same age in the Changning-Menglian suture in western Yunnan to the north.

Panjasawatwong (1999) studied the petrology and tectonic setting of eruption of basaltic rocks penetrated in well GTE-1 in the San Kamphaeng geothermal field in Chiang Mai. This well was drilled close to Ban On Laui and penetrated 500 meters of a basaltic pile of Permian to Early Triassic age. This basalt was considered to be part of the Chiang Mai volcanic belt and includes flows, pillow breccias, and hyaloclastites. The basalt conformably overlies Permian sedimentary strata and it has been intruded by Late Triassic granite. Thus, the time of eruption was sometime from the Permian to the Early Triassic. The REE and N-MORB normalized patterns are analogous to the patterns for tholeiites and transitional tholeiites from the Loihi seamount in the Hawaiian-Emperor chain. Consequently, the basalt in well GTE-1 is

inferred to have tholeiitic affinities and to have erupted in an ocean-island environment. This oceanic intra-plate basalt might have formed a chain of islands, like the Hawaiian-Emperor chain, or seamounts, like the Tasmantid seamounts in the Tasman Sea, in either a major ocean basin or in a mature back-arc basin.

Barr and Macdonald (1991) proposed a Late Palaeozoic-Early Mesozoic tectonic model for Thailand. Their interpretation was based on the concept of tectonostratigraphic terranes. They studied volcanic and granitic rocks and tectonostratigraphic zones. This study found that the distribution of granitic rocks, the change from S-type to I-type, suggests that a major change in the character of the underlying crust occurs east of the Chiang Mai volcanic belt. They interpreted this change to indicate the position of a cryptic suture between the Inthanon zone, representing the eastern margin of the Shan-Thai craton, and the Sukhothai zone. This suture is in part marked by faults and mylonites. Thus, the Sukhothai zone is located between cryptic and ophiolitic sutures and, therefore, qualifies as a distinct tectonostratigrphic terrane. The Inthanon zone and the western Thai zone are not separate terranes but are part of the larger Shan-Thai terrane. Similarly, the Phetchabun zone is not a separate terrane but forms the western margin of the Indosinian terrane. Their model differs from previous terrane models in the recognition of the intervening Sukhothai terrane. Geological contrasts are consistent with the interpretation of the Sukhothai terrane as a separate tectonostratigraphic terrane distinct from either the Shan-Thai or Indosinian terranes. The Sukhothai terrane has a thick accumulation of arc-related sedimentary and volcanic deposits, possibly as old as Silurian and Devonian but certainly Carboniferous to Middle Permian in age. Blue schists and related trench deposits occurring along its eastern border, as defined by the ophiolitic Nan-Uttaradit-Sra Kaeo suture, are a Permian metamorphic uplift. There are no clear analogues in either of the adjacent zones for these units, although isolated occurrences of metatuffs of inferred Silurian and Devonian age in the Inthanon zone may yet prove to be such. They further concluded that the Sukhothai terrane and Phetchabun zone were amalgamated by Middle Permian time and thereafter shared essentially the same volcanic and sedimentary history leading up to the collision with the Shan-Thai terrane in the Early Mesozoic.

By analogy with the North American Cordillera, both the metamorphic core complexes and the S-type granites of the Inthanon zone are a consequence of collision and subsequent telescoping between the amalgamated Indosinian-Sukhothai terranes and the Shan-Thai terrane. This terrane model provides a viable explanation for generation of the Permian-Triassic S-type granitic rocks of the Inthanon zone. Earlier models related these granite rocks to subduction and subsequent terrane amalgamation at the Nan-Uttaradit-Sra Kaeo suture. However, these models were not convincing because their timing of Carboniferous-Permian predated granite generation and the suture seems spatially too remote from the zone of S-type granite to be directly related to S-type granite. The development of metamorphic-plutonic complexes along the margin of the Shan-Thai terrane requires east-dipping subduction and underthrusting during collision with the amalgamated Sukhothai-Indosinian terranes. This is consistent with models for collision between the Main Range province and Eastern province in Malaysia, now marked by the Bentong-Raub suture. Hence, their model implies that the Nan-Uttaradit-Sra Kaeo suture does not correlate with the Betong-Raub suture in peninsular Malaysia. Instead, the Betong-Raub suture is more likely to correlate with a cryptic suture in Thailand between the Inthanon zone, Shan-Thai terrane, and the Sukhothai terrane.

1.7.4 Geophysical data

Aeromagnetic intensity data from the 1985-1989 airborne geophysical survey of the Department of Mineral Resources show that basic to ultrabasic rocks underlie the carbonate rocks of the study area (Figure 1.4). The magnetic intensity trends are generally north-south and follow the trend of the limestone in the study area (Figure 1.5).

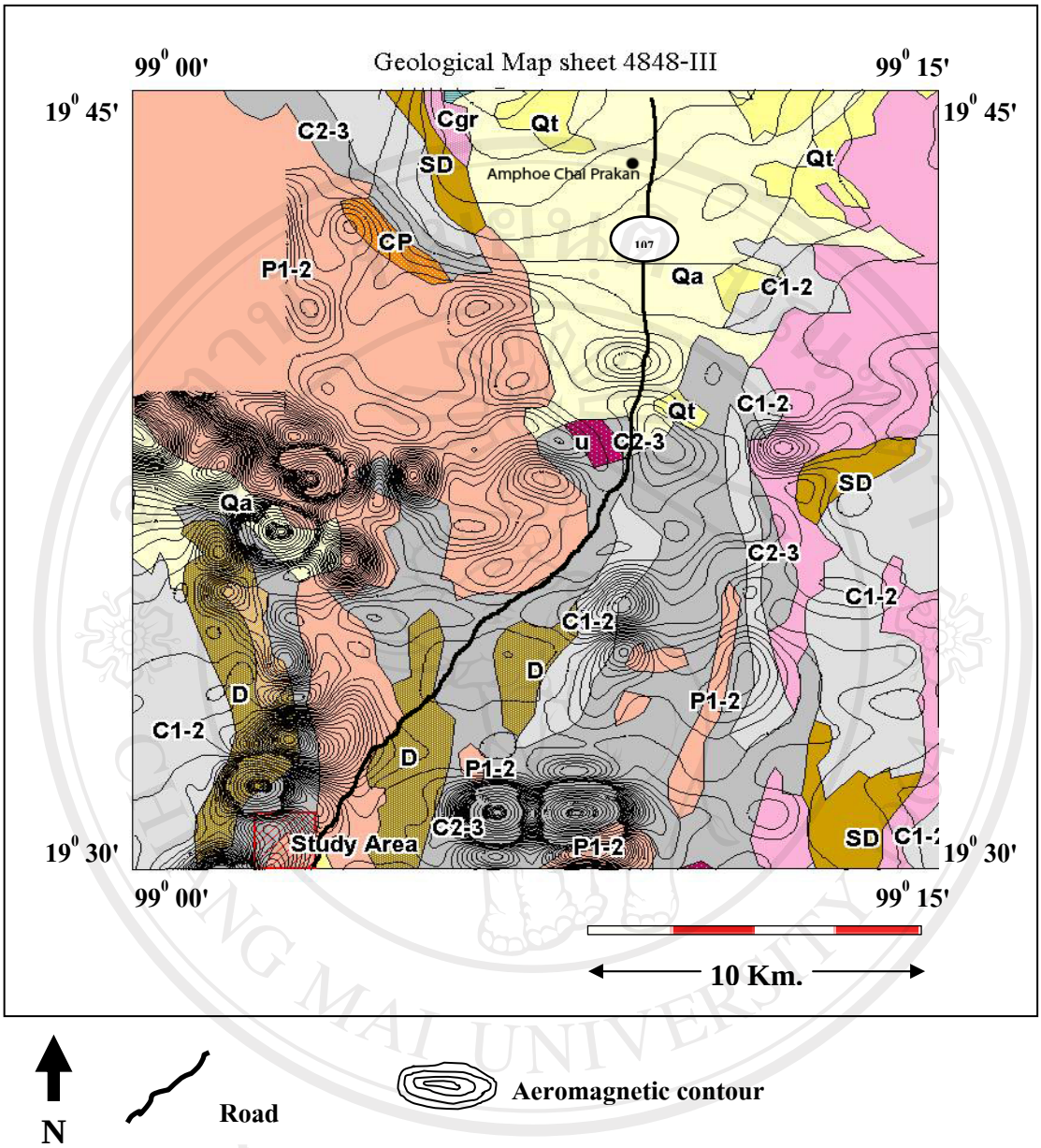

Figure 1.4 Aeromagnetic intensity contours overlain on a geological map of the study area (sheet 4848-III, Amphoe Chai Prakan).

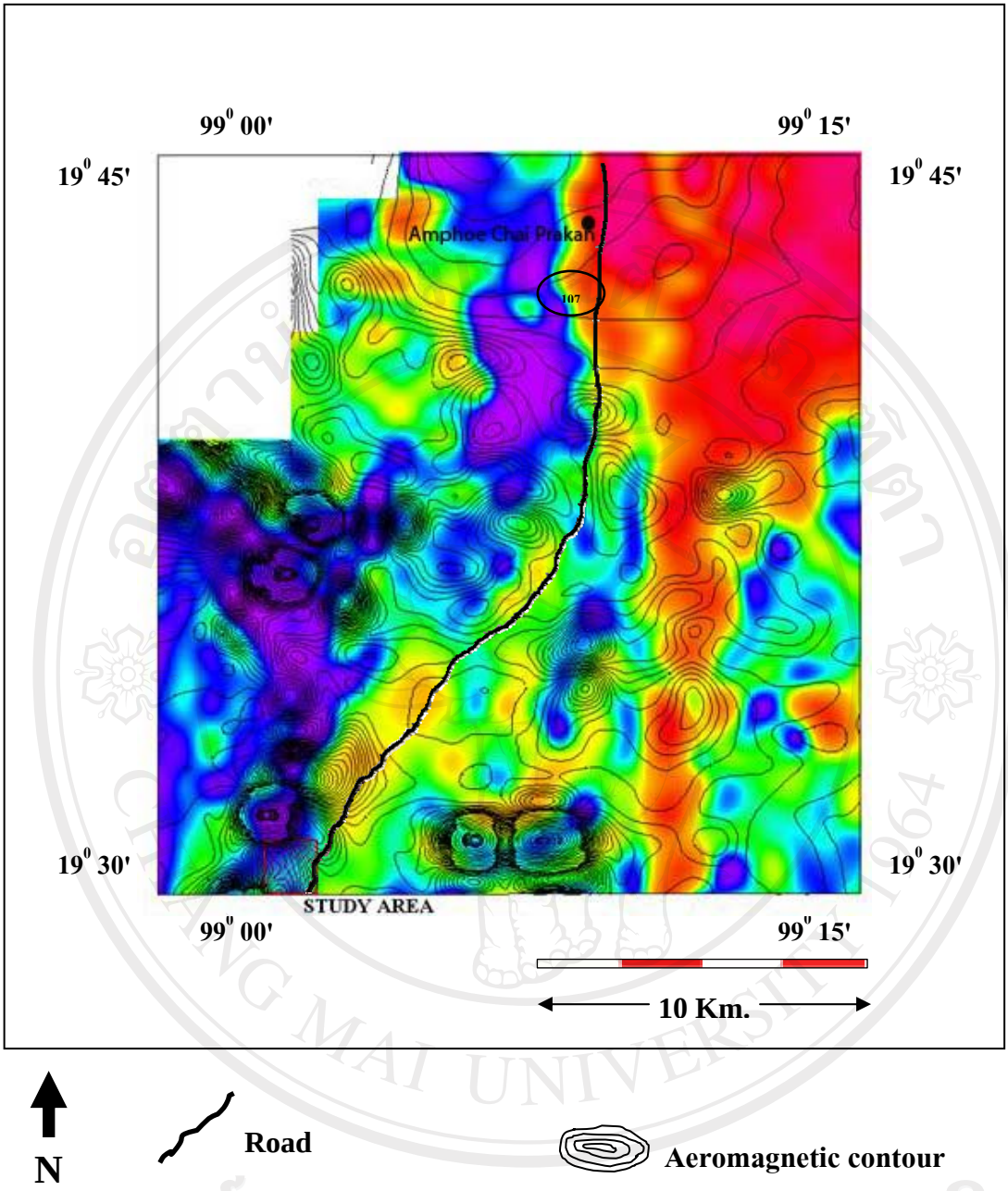

Figure 1.5 Aeromagnetic intensity contours of the study area overlain on total count images (sheet 4848-III, Amphoe Chai Prakan).