DEPOSITIONAL ENVIRONMENT OF THE KHAO KHAD FORMATION, NORTHEASTERN THAILAND

Hathaichanok Vattanasak

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Geotechnology

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สภาพแวดล้อมการสะสมตัวของหมวดหินเขาขาด ภาคตะวันออกเฉียงเหนือ ประเทศไทย

นางสาวหทัยชนก วัฒนศักดิ์

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรดุษฎีบัณฑิต

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Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

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วัตถุประสงค์ของงานวิจัยนี้คือ เพื่ออธิบายสภาวะแวดล้อมการสะสมตัวและอธิบายการก่อกำเนิดของหมวดหินเขาขาดในภาคตะวันออกเฉียงเหนือ บนพื้นฐานของการศึกษาลำดับชั้นหินและการวิเคราะห์ศิลาวรรณาและธรณีเคมี ภาคตัดที่ทำการศึกษามีจำนวน 7 พื้นที่อยู่ในกลุ่มหินสระบุรีของหมวดหินเขาขวาง หมวดหินหนองโป่ง หมวดหินปางอโศก หมวดหินเขาขาดและหมวดหินซับบอน โดยมีลำดับชั้นหินจากหมวดหินเขาขวางถึงหมวดหินหนองโป่งแสดงสภาพแวดล้อมของการสะสมตัวของตะกอนตั้งแต่บริเวณลานทะเลน้ำตื้นถึงแอ่งทะเลลึก ผลการศึกษาแสดงให้เห็นว่าหมวดหินเขาขาดมีลักษณะแตกต่างจากการสะสมตัวบริเวณลานทะเลน้ำตื้นที่เคยมีการศึกษามาก่อน

หมวดหินเขาขาดประกอบด้วย หินปูนสีเทาถึงเทาดำ ชั้นบางถึงชั้นหนา เป็นชั้นขนานและมีการวางชั้นแบบเรียงขนานของหินแคลซิลูไทต์ หินแคลคาริไนต์ถึงแคลซิรูไดต์ขนาดละเอียด ซึ่งแทรกสลับกับหินดินดานสีเทาดำ ชั้นบาง มีชั้นและกระเปาะของหินเชิร์ต หินปูนเนื้อเม็ดที่ประกอบด้วยไบโอคลาสหลากชนิดและขนาดพบสัมพันธ์กับหินแคลซิรูไดต์ หินดินดานที่เกิดร่วมกับหินโอลิสโตสโตรมและหินเชิร์ตเรดิโอลาเรียน จากลักษณะดังกล่าวสามารถแปลความได้ว่าตะกอนของหมวดหินเขาขาดไม่ใช่ลักษณะการสะสมตัวของตะกอนบริเวณลานทะเลตื้น แต่เป็นลักษณะของการสะสมตัวบริเวณลาดทวีป

ผลการวิเคราะห์ปริมาณธาตุออกไซด์หลัก และธาตุร่องรอย บ่งชี้ว่าหินเชิร์ตของหมวดหินเขาขาดมีต้นกำเนิดจากสิ่งมีชีวิตและสะสมตัวบริเวณขอบทวีปแต่ไม่ถึงแอ่งมหาสมุทร ปริมาณธาตุหายากระบุว่าหินเชิร์ตดังกล่าวมีการสะสมตัวในบริเวณขอบทวีปถึงแอ่งมหาสมุทรลึก แต่อย่างไรก็ตามหินเชิร์ตของหมวดหินเขาขาดจะแสดงปริมาณตะกอนสะสมมากกว่าบริเวณแอ่งมหาสมุทร ซึ่งบ่งชี้ได้ว่าหินเชิร์ตของหมวดหินเขาขาดนั้นเกิดอยู่ติดกับแผ่นทวีป มีการสะสมตัวใกล้กับลานทะเลตื้นบนแผ่นทวีป การเกิดลำดับชั้นหินเช่นนี้สามารถแปลความได้ว่ามีการสะสมตัวแบบโลว์สแตนโปรเกรดดิ้งซิสเต็มแทรค

สาขาวิชา เทคโนโลยีธรณี ลายมือชื่อนักศึกษา____________________________

ปีการศึกษา 2557 ลายมือชื่ออาจารย์ที่ปรึกษา______________________

ลายมือชื่ออาจารย์ที่ปรึกษาร่วม__________________

HATHAICHANOK VATTANASAK : DEPOSITIONAL ENVIRONMENT OF THE KHAO KHAD FORMATION, NORTHEASTERN THAILAND. THESIS ADVISOR : ASST. PROF. AKKHAPUN WANNAKOMOL, Ph.D., 143 PP.

KHAO KHAD FORMATION/ SARABURI GROUP/ PERMIAN CARBONATE ROCK/ LITHOFACIES/ DEPOSITIONAL ENVIRONMENT

The aim of this study is to clarify the depositional environment and to explain the occurrence of the Khao Khad Formation in northeastern Thailand based on the lithostratigraphic sequence and the petrographic and geochemical analyses. The studied sections belonging to the Saraburi Group are confined within 7 areas of the Sap Bon, Khao Khad, Pang Asok, Nong Pong and Khao Khwang Formations. They indicate the deposits of platform to basin as represented by the Khao Khwang to the Sap Bon Formations. The results show that the Khao Khad Formation is different from the platform deposit of shallow marine environment which was suggested by previous studies.

The Khao Khad Formation mainly consists of light gray to dark gray, thin- to thick-bedded, parallel and graded-bedding calcilutite, calcarenite to fine calcirudite interbedded with dark brown, thin-bedded shale and banded and nodular cherts. The grain-supported bioclastic limestones of various types and sizes of grain components are associated with calcirudite, shale with olistostrome and radiolarian chert. These can be interpreted that sediments of the Khao Khad Formation are not the characteristics of the platform deposit, but typical of slope deposit.

The result of the major and trace elements analyses indicate that chert samples from the Khao Khad Formation are from biogenic origin and were deposited in the continental margin, not the oceanic basin. The rare earth elements suggest that they were formed in the continental margin to deep ocean basin. However, the Khao Khad chert shows more terrigenous contribution than the oceanic basin. It indicates that the Khao Khad chert was deposited closer to the continent near the platform on the continental crust. The occurrence of these lithologies is interpreted to be the deposit of a lowstand prograding system tract.

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CHAPTER I

INTRODUCTION

1.1 Background and rationale

The geological evolution of the Permian sedimentary sequences in northeastern Thailand has been achieved in the last decade, but the overall geometry of the basin, its facies distribution and depositional environment of some units are still unclear. The complex tectonic evolution has an effect on structural and stratigraphic configurations which provide favorable conditions for hydrocarbon accumulation. Even though a large number of studies in this area have been carried out on the carbonate rock. Most of them are mainly concerned on the general geology, paleontology and broad stratigraphy of the Permian limestone which belongs to the Saraburi Group. There are numerous localities of rocks strata which some are well exposed and their paleoenvironment has been interpreted in several ways. There is still lacking detailed studies on the carbonate sedimentology to analyze the sedimentary facies and to define the lithostratigraphy. It is known that the Saraburi Group consists of 6 formations, i.e. the Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad and Sap Bon Formations in ascending order (Department of Mineral Resources: DMR, 1985). They represent the intercalation between shallow and deep marine depositional environments while their ages based on fusulinacean are ranging from Asselian to Midian. The Khao Khad Formation of the Saraburi Group has been studied by Thambunya (2005) to explain its depositional environment based on lithological characteristics and sedimentary structures. He concluded that the Khao

Khad Formation is most likely deposited in the marine shelf condition under sub-environments of intertidal to subtidal and zones of lagoonal. However, this formation can be distinguished from shallow platform characteristic by the abundance of largely bioclastic limestone and its intercalation in deep marine formations. Meanwhile, Chutakositkanon et al. (2000) reported the Khao Khad Formation as a deep sea origin and related to ocean bottom deposits based on the associated radiolarian chert. So the conclusion on depositional environment of the Khao Khad Formation is till controversial and is the main aim of the present study to clarify. The objectives, scope and limitation, and methodology of this research are stated as follows.

1.2 Research objectives

The main objectives of this research are 1) to clarify the stratigraphic sequence of the Khao Khad Formation in western Khorat Basin (Northeastern Thailand), 2) to explain the occurence of the Khao Khad Formation and 3) to reconstruct the depositional environment based on stratigraphic, petrographic and geochemical analyses of the Khao Khad Formation.

1.3 Scope and limitation of work

The study is concerned with the lithofacies of the Permian rocks focusing on the Khao Khad Formation of the Saraburi Group. The study sections are composed of 7 localities in Muak Lek district of Saraburi province and Pak Chong district of Nakhon Ratchasima province. Mapping of its lithofacies and lithostratigraphy was based on the geological information from the field work, the geochemical and lithofacies analyses of the collected rock samples. This involved detailed preparation and examination of thin-sections of rock samples in the laboratory. Lithofacies classification is based on Dunham (1962), Folk (1959; 1962) and Carozzi (1989). The chert will be collected for radiolarian extraction and geochemical analyses. The interpretation of lithofacies will be discussed and correlated with several previous works. The paleontological information is referred to the previous works (not the main objective of this research).

1.4 Research methodology

The research methodology comprises 5 steps as shown in Figure 1.1. Each step is described as follows.

1.4.1 Literature review and Data gathering

Relevant literatures will be searched, reviewed, summarized and documented. The summary of the literature review will be given in the thesis which includes regional geology of the Saraburi Group and stratigraphic sequences of the sediments related to this area. The sources of information were from journals, researches, dissertation, geologic and topographic maps and books concerned.

1.4.2 Geological Investigation

The field work was investigated in 7 localities in Muak Lek district of Saraburi province and Pak Chong district of Nakhon Ratchasima province. The 7 measured sections were presented and the lithostratigraphic column of the study area was established. The lithofacies analysis were conducted by using lithology, geometry and sedimentary structures. The results from geological investigation are used to analyze facies characteristics and to interpret the depositional environment.

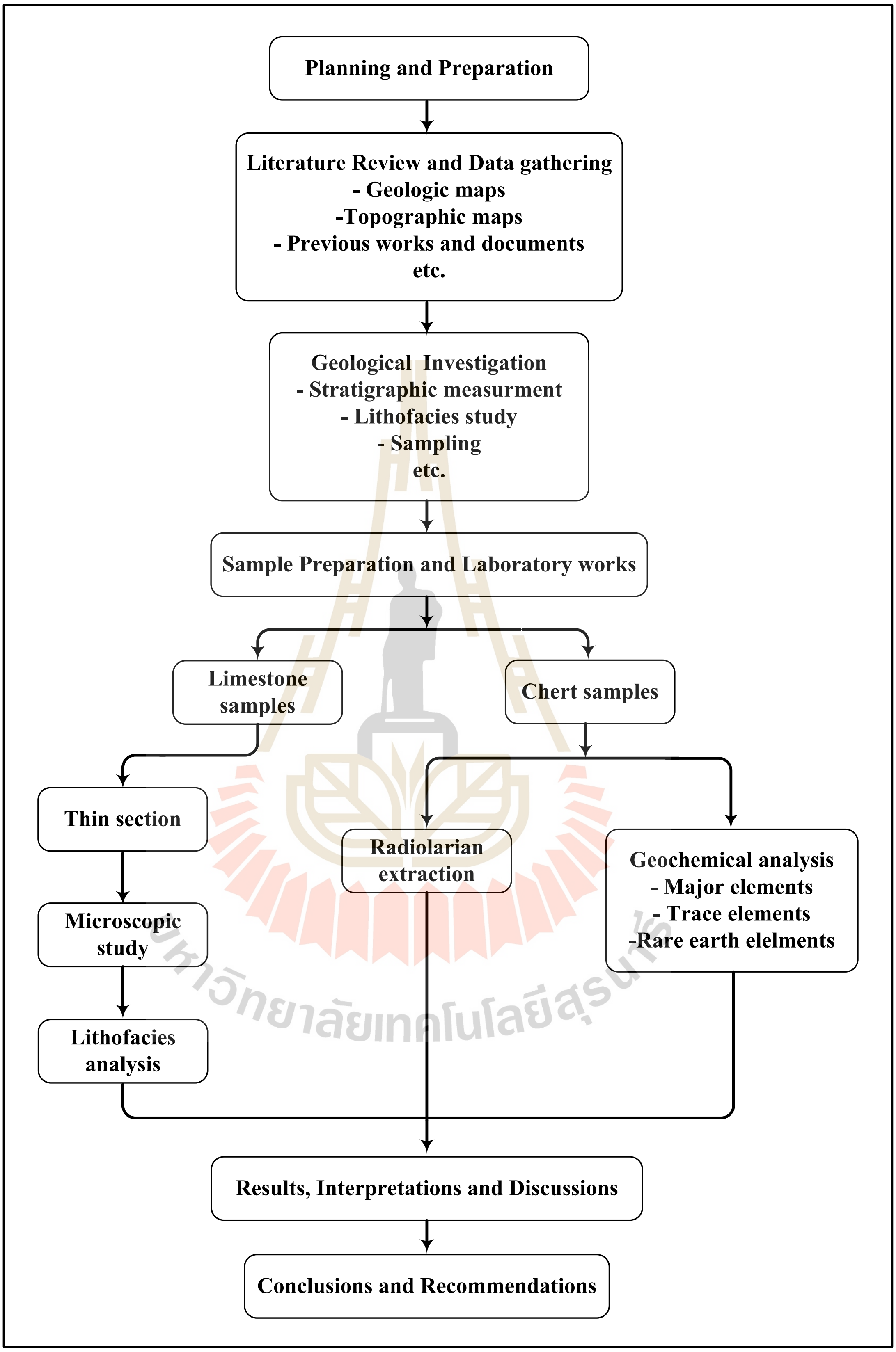


Figure 1.1 Research methodology.

1.4.3 Sample preparation and Laboratory works

In the laboratory, the selected limestone samples were prepared for thin-section study of lithofacies under a stereo microscope. Chert was prepared for geochemical analysis and radiolarian extraction. Geochemical study includes major, trace element and rare earth (REEs) analyses. All experiments were carried out in the laboratory at the China University of Geosciences (CUG: Wuhan, China).

1.4.4 Results, Interpretation and Discussions

The obtained data are analyzed for defining the lithostratigraphy and the depositional environment of the Khao Khad Formation. Interpretation of lithofacies will be discussed and correlated with several previous works. Then, all information will be rechecked in the field to confirm that all stratigraphic data have been correctly represented.

1.4.5 Conclusions and Recommendations

All research activities, results, interpretations, discussions and recommendations will be compiled and documented in this part.

1.5 Thesis contents

Chapter I introduces the thesis by briefly describing the background of problem and significance of the study. The research objectives, methodology, scope and limitation are identified. **Chapter II** summarizes results of the literature review to improve an understanding of the Saraburi Group in the study area and their relevant. **Chapter III** describes the methodologies of sample preparation and experimental procedure for laboratory testing. **Chapter IV** presents the results, data interpretation and discusses. **Chapter V** concludes and recommends the research results.

CHAPTER II

LITERATURE REVIEW

Relevant topics and previous research results are reviewed to improve understanding in the geology and stratigraphy of the Saraburi Group in northeastern Thailand. This chapter also described some information and background briefly.

2.1 The historical geology of Permian in Thailand

Wakita and Metcalfe (2005) explained the paleogeographic maps of the world from Carboniferous to Triassic. They suggest that in the Early Permian, Paleotethyan Ocean is located between Pangea supercontinent and the Cathaysian domain. During Late Permian, Cimmerian continent including Shan-Thai and others translated to tropical realm closed to Indochina and South China of the Cathaysian domain. Then the Cimmerian continental strip moved to the north amalgamated with former derived terranes around the tropical Tethyan province. Thailand is composed of 2 ancient microcontinents (blocks or terranes), i.e. Indochina Block in the east and the Sibumasu (Shan-Thai) block in the west which are divided by the Nan Suture (Metacalfe, 1999; Bunopas, 1992; Ueno and Charoentitirat, 2011). In Figure 2.1, Nan Suture is marked by ophiolite (I=Indochina Block, SC=south China Block, K=Khorat Plateau, ST=Shan-Thai Block). The Shan-Thai terrane consists of stratigraphic belts 1-5 while Indochina includes belts 6 and 7. These Blocks are divided by the Nan Suture. This suture has been inferred as a remnant of Paleotethys. The Indochina Block consists of eastern Thailand, Laos, Cambodia and some parts of Vietnam. This

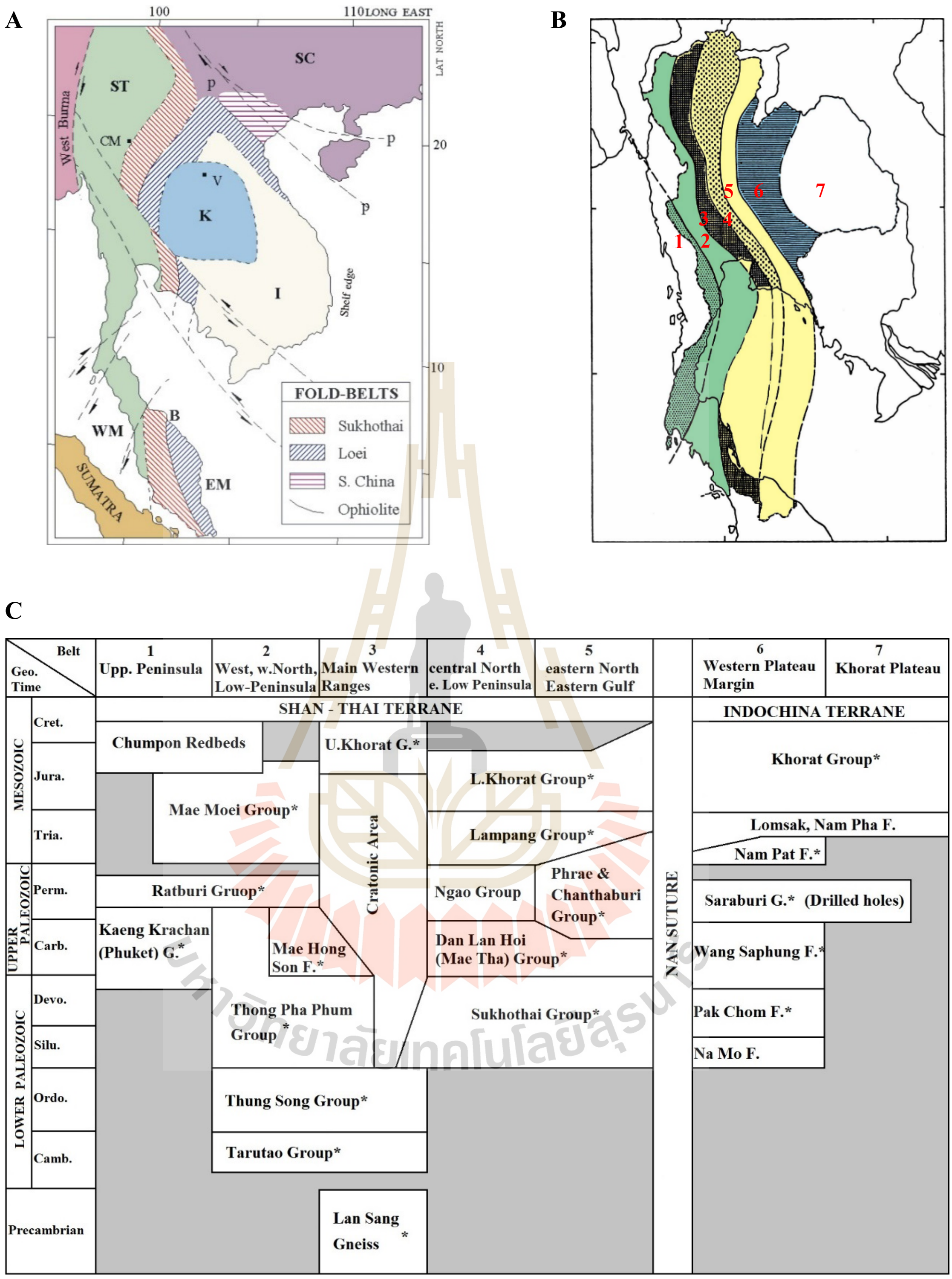


Figure 2.1 A) Tectonic map of Thailand and neighboring area, B) Lithostratigraphic map of Thailand and C) Summary of Shan-Thai and Indochina components with geological time scale (after Bunopas, 1992).

block is composed of middle Paleozoic rock and Permian carbonate and siliciclastic rocks. The Sibumasu block consists of eastern Malaysia, western Thailand, western Peninsular Malaysia and northern Sumatra. It is mainly composed of Precambrian granitoid and high grade of metamorphic rocks overlain by Paleozoic and Mesozoic rocks. Many stratigraphic considerations suggested that the Sibumasu Block has been interpreted as part of Gondwanaland. It is located in the Southern Hemisphere during Early Permian time before rifting and drifting to the north in late Early Permian time while the Indochina block is located in tropical region as part of the Cathaysian domain (Wakita and Metcalfe, 2005; Udchachon, 2007). The accretion of these blocks along the Nan Suture occurred during Triassic time (Gatinsky et al., 1978; Bunopas and Vella, 1978, 1983; Metcalfe, 1990; Chaodumrong, 1992; Udchachon, 2007). However, varying ideas on suturing time have been suggested including Devono-Carboniferous (Hahn et al., 1986; Alterman, 1991), Middle to Late Carboniferous (Wolfart, 1987), Late Permian to Early Triassic (Cooper et al., 1989; Piyasin, 1991) and Middle Permian (Helmcke and Lindenberg, 1983; Helmcke, 1985, 1994). Recently, there are widely accepted that the main Paleotethys should be located further to the west of the Nan Suture along the Thailand-Myanmar border (Helmcke, 1994). The new information on paleontology and geology supported this interpretation (Chonglakmani, 1999, 2002; Wang et al., 2001; Ueno, 2003). The Cimmerian continent is interpreted as Gondwana derived which located in the western part of Thailand along Thailand-Myanmar border (Figure 2.2).

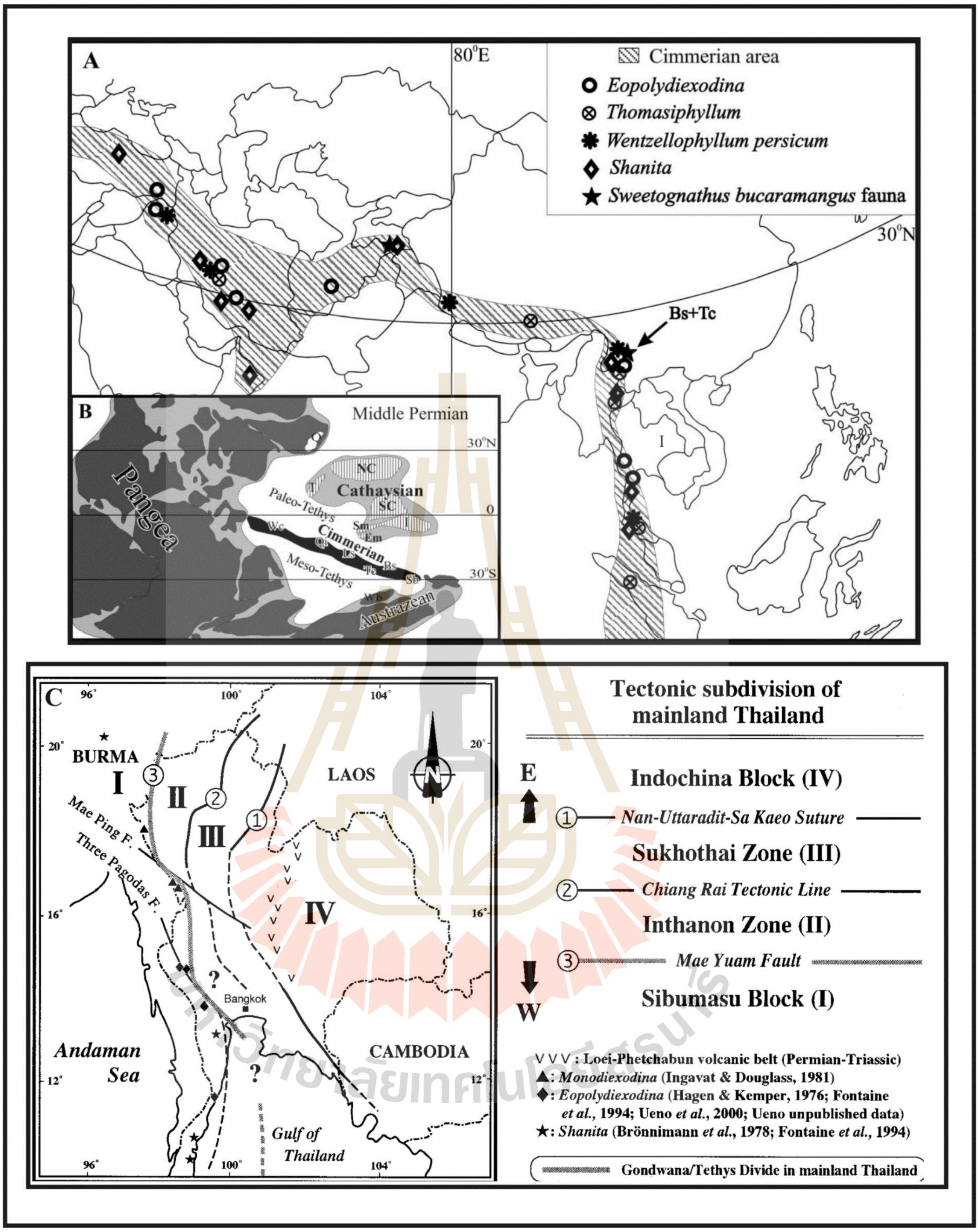


Figure 2.2 A) Geographic map of Asia showing distribution of the Cimmerian continent, B) The Middle Permian paleogeographic map and C) Geographic map showing tectonic subdivision of mainland Thailand (after Wang et al., 2001; Ueno, 2003).

2.2 Regional Permian lithostratigraphy of the Saraburi Group

The Permian rocks are exposed entirely in the country which characterized predominately by carbonate rocks. However, other rocks such as clastic, siliciclastic and volcanic also have been reported. Geographically, Permian strata can be found in all regions except in the northeastern part of the Khorat Plateau and have been assigned with different lithostratigraphic nomenclatures (Figure 2.3 and Tables 2.1 and 2.2). In the northern and upper western regions, the Permian strata are assigned as the Ngao Group. In the southern and lower western regions, Permian rocks include the Ratburi Group and the upper part of the Kaeng Krachan Group (or the Phuket Group). In the eastern region, the Chantaburi Group is predominant and in the northeastern region is occupied by the Saraburi Group.

The Permian strata in this region occupy a slightly longitudinal area tracing northwardly from Saraburi to Phetchabun and beyond to Loei provinces. Formally, the limestone and associated clastic rocks of Permian age were named as the Ratburi Limestone (Brown et al., 1951). Subsequently, the nomenclature has been changed as the Permian sequences which have been designated variously by many authors. The Permian sequence in particular was firstly named by Bunopas (1981) as the Saraburi Group for a mixed carbonate and clastic sequence exposed in the Central Plain from Nakhon Sawan to Saraburi provinces and in the western edge of the Khorat Plateau from Phetchabun to Loei provinces. Generally, the Saraburi Group is conformably underlain by Upper Carboniferous strata and is unconformably overlain by the Upper Triassic conglomerate.

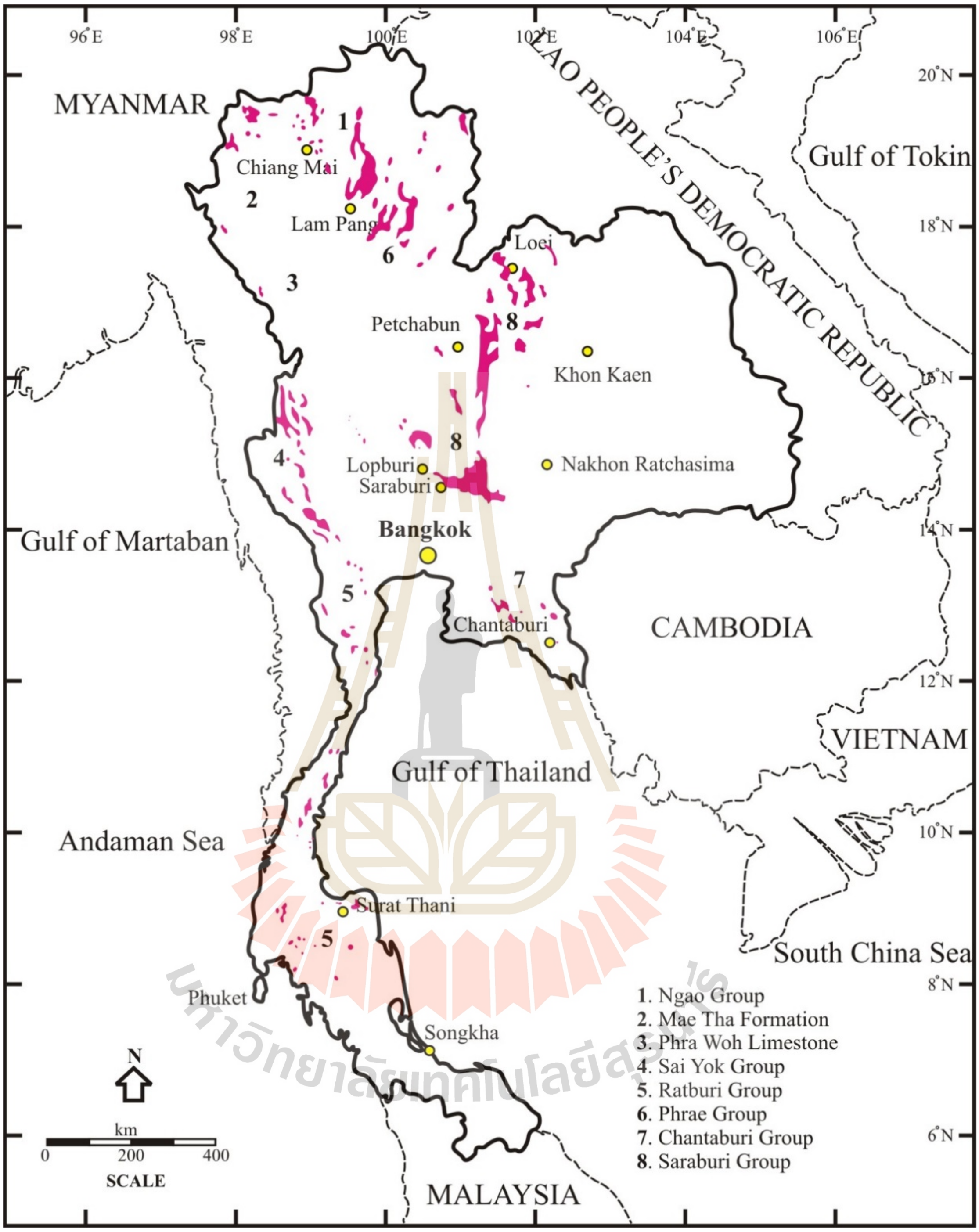


Figure 2.3 Map of Thailand showing lithostratigraphic distribution of Permian rocks. These rocks can be categorized into 8 units that are exposed throughout Thailand except in the area of northeastern Thailand (modified after DMR, 1999).

Table 2.1 Lithostratigraphic correlation of Upper Paleozoic rocks in Thailand (after Raksaskulwong, 2002).

Age (Ma)	Era	Period		Northern & Upper Western: Group	Northern & Upper Western: Formation	Loei - Phechabun Ranges: Group	Loei - Phechabun Ranges: Formation	Eastern: Group	Eastern: Formation	Lower Western & Southern: Group	Lower Western & Southern: Formation
245	Mesozoic	Triassic		Lampang					Pong Nam Ron		Si Bon Chai Buri
	Upper Paleozoic	Permian	Upper	Ngao	Huai Tak	Saraburi	Sap Bon (Nam Duk) Khao Khad	Chantaburi	Khao Chakan (Khao Ta Ngok)	Ratburi	Um Luk Phanom Wang
			Middle		Pha Huat		Pang Asok (Hua Na Kam) Nong Pong (E-lert)		Sra Kaeo (Wang Nam Yen)		Phab Pha Thung Nang Ling
			Lower		Kiu Lom		Khao Khwang (Nam Ma Ho Ran Pha Nok Khao) Phu Phe			Kaeng Krachan (Phuket)	Khao Phra (Ko Yao Noi)
285		Carboniferous	Upper	Dan Lan Hoi (Mae Tha, Phrae)	Khao Luang Pyroclastic (Rong Kwang)		Wang Sa Phung (Huai Som)		C2		Ko He Spill way
			Middle		Lan Hoi (Fang Redbed, Doi Kong Mu)						Khao Wang Kradat
360			Lower		Khao Khi ma Pyroclastic Mae Sai		Nong Dok Bua (Dok Du)		C1	Tong Pha Phum	Khuan Klang (Ya Ha)
410	Lower Paleozoic	Devonian		Sukhothai (Musur)	Mae Hong Son		Pak Chom			Tanaosri	

Table 2.2 Lithostratigraphic correlation of the Permian System in central and northeastern Thailand (modified from Assavapatchara, 1998).

Age (Ma)		Brown et al. (1951)	Javanaphet (1969)	Charoenprawat et al. (1984) Loei-Nong Bua Lumphu		Nakornsri (1977, 1981) Nakorn Sawan-Lopburi		Hinthong (1981, 1985) Saraburi		Bunopas (1981, 1983) Saraburi-Loei		Chonglakmani and Sattayarak (1984) Phetchabun-Chaiyaphum	DMR (1992) Lexicon of stratigraphic names of Thailand	
PERMIAN	245 UPPER	RATBURI LIMESTONE	RATBURI GROUP											
	258 MIDDLE			RATBURI GROUP	Pha Dua Formation E-Lert Formation	RATBURI GROUP	Tak Fa Formation Khao Luak Formation	RATBURI GROUP	Sap Bon Formation Khao Khad Formation Pang Asok Formation	SARABURI GROUP	Dan Sai Shale Saraburi Limestone	Nam Duk Formation Hua Na Kham Formation	SARABURI GROUP	Sap Bon Formation Khao Khad Formation Pang Asok Formation
	268 LOWER				Nam Mahoran Formation		Phu Phe Formation		Nong Pong Formation Khao Khwang Formation Phu Phe Formation		Khao Luak Formation	Pha Nok Khao Formation		Nong Pong Formation Khao Khwang Formation Phu Phe Formation
CARBONIFEROUS														

Sharp Boundary ——— Gradational Boundary .... Unconformity ~~~~

The Saraburi Group has been subdivided by many authors such as, Nakornsri (1976, 1981); Charoenpravat and Wongwanich (1976); Charoenpravat et al. (1976); Chonglakmani and Sattayalak (1979); Chonglakmani et al. (1979); Bunopas (1981, 1983, 1992) and Hinthong (1985). According to Department of Mineral and Resources (DMR, 1992), the Saraburi Group can be divided in to 6 formations, namely, Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad and Sap Bon Formations, in ascending order (Figure 2.4). The fusulinids are well observed in these formations and indicate Lower to Middle Middle Permian (Asselian to Kazanian age) (Hinthong, 1985). Moreover, Dawson (1993), Chonglakmani and Fontaine (1992) and Charoentitirat (1995) has studied on the biostratigraphy of these strata and pointed the age of Early to Late Middle Permian (Asselian to Median) based on fusulinids, small foraminifers, corals and brachiopods. The overall thickness of the Saraburi Group is 4,486 meters (DMR, 1992). Summary of the Saraburi Group is provided below.

Phu Phe Formation (Late Pennsylvanian-Early Permian)

This formation is the lowermost part of the Saraburi Group. It is characterized mainly by well bedded dark to very dark gray, thick- to very thick-bedded limestone and skeleton limestone with lenticular and nodular cherts displaying in the upper part. They occur with intercalations of light brown to brownish gray shale and slaty shale in the lower part of the formation. According to fusulinids (*Pseudoschwagerina* sp. and *Triticites* sp.), this formation is an Early Permian age (Asselian to Sakmarian). It contains about 600 meters thick. The type section locates at Khao Phu Phe, east of Kms 131 to 132, Highway No.2 (Mitraparp Road). This formation is mainly distributed along Phetchabun ranges and in the area northwest of the Khorat Plateau.

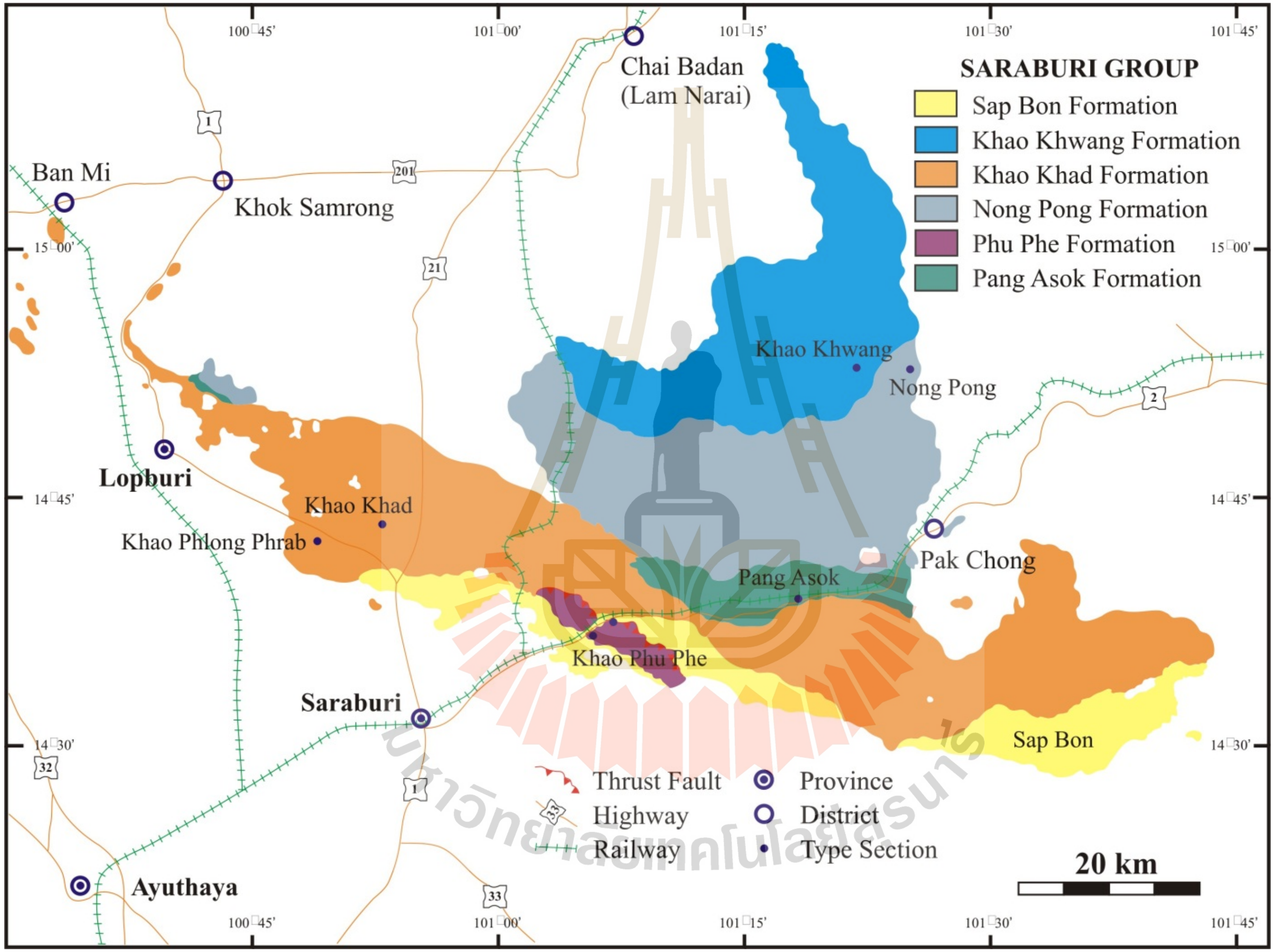


Figure 2.4 Geological map of the Saraburi Group (modified from Ueno and Charoentitirat, 2011).

Khao Khwang Formation (Late Pennsylvanian-Middle Permian)

This formation is composed of dark to light gray, thin-to-thick, well-bedded and massive limestone. Brownish gray nodular chert is abundant and scattered throughout the sequence. Dolomite, dolomitic limestone, sandstone, tuffaceous sandstone, volcanic rocks and shale intercalations have been observed. Fossils in the sequence contain the brachiopods, bryozoans, bivalves, trilobites, crinoid stems and fusulines may be indicating an Early Permian age (Sakmarian). Based on fusuline occurrences from the Khao Somphot area to the east of Chai Badan in Lopburi province, the rocks are preferred as a Middle Permian age (Murgabian). Total thickness of the formation is about 490 meters. The type section is designed at Khao Khwang in eastern Lopburi province. The rocks of this formation are mainly exposed in the northern part of the area under present assessment Khao Khwang, Phetchabun ranges and northwest of the Khorat Plateau.

Nong Pong Formation (Early-Middle Permian)

It is composed predominantly of brownish gray, light to dark gray, laminated to thin- or thick-bedded shale and interbedded with limestone. Shale are mostly brownish gray, grayish brown to light gray, bluish gray and occasionally silty, sandy or siliceous. The limestone are characterized by medium to dark gray, thin-bedded, banded to well laminated and argillaceous in some intervals. Bedded chert is intercalated while limestone become lenses and lenticular beds in the upper part of the sequence. Fossil assemblages contain the ammonoid *Agathiceras* sp. and fusulines that indicate an Early Permian age (Artinskian to Kungurian). Total thickness is about 670 meters. The type section is located east of Khao Khwang. The formation is also distributed along the Phetchabun ranges and the northwest of the Khorat Plateau.

Pang Asok Formation (Early-?Middle Permian)

This formation consists mainly of siliciclastic rocks e.g. shale, slaty shale and sandstone. In the lower part, it contains light greenish gray to pale reddish brown sandstone intercalated with shale and slaty shale. This interval is overlain by pale reddish brown shale interbedded with light greenish gray arkosic sandstone and brownish gray limestone. The middle part is composed of gray to grayish brown shale. The upper part is brown to dark shale, slaty shale and greenish gray lenticular arkosic sandstone. Some limestone lenses contain fossils including bivalves, crinoid stems, coral fragments and plant leaves. The age of this formation is obtained from *Agathiceras* sp. which indicates an Early Permian age (Artinskian to Kungurian). It is about 360 meters of total thickness. The type section is located in the vicinity of the Pang Asok village close to the Pang Asok railway station. This formation is distributed along the Phetchabun ranges and the northwest of the Khorat Plateau.

Khao Khad Formation (Early-Middle Permian)

This formation contains predominant light to dark gray, thin- to very thick-bedded limestone, argillaceous limestone and dolomite. Nodular and bedded cherts are common. The rocks are shale, siltstone, sandstone and conglomerate intercalated with limestone in some intervals. Marble, calc-silicate rocks, hornfels and volcanic rocks are locally exposed. This formation contains fossiliferous rocks in several areas. Fusulines, brachiopods, gastropods and minor ammonoids are abundant in this formation together with its largely bioclastic limestone lithology. The age of the formation is Early Permian (Artinskian to Kungurian) to upper Middle Permian

(Midian or Capitanian). The formation is about 1,800 meters in total thickness. The type section is designated at Khao Khad, Phra Phuttabat district of Saraburi province. The rocks of this formation are trending approximately in east-west direction and widely exposed in several areas of Lopburi and Saraburi provinces, the Phetchabun ranges and northwest of the Khorat Plateau.

Thambunya (2005) reported that the Khao Khad Formation consists of dismicrite, biomicrite, packed biomicrite, biosparite, intrasparite and biolithite. The depositional environments of these rocks represent the shallow restricted marine of inner shelf with barrier bar or shallow platform in the open shelf. The situation may vary from low energy to slightly high energy conditions. The low energy condition was dominated by the deposition of micrite and large fusulines. The high energy condition was dominated by the deposition of crinoid fragments and intraclasts. The barrier bar in the outer shelf was changed from shallow bioaccumulated platform at the Khao Khad and Pak Chong to Khao Yai areas into crinoidal barrier at the Khao Khad area. The paleogeography was shallow restricted marine with outer barrier bar of shallow platform. However, there was a turbidite sequence in the Khao Chan area indicating the foreslope environment. The age can be marked at the lower part by *Robustoschwagerina* sp. indicating the Asselian age of Lower Permian (Borax and Steward, 1966). The presence of *Yabeina* sp. in limestone associated with silty shale upper boundary indicates the Capitanian age of Middle Permian (Borax and Steward, 1966). Therefore, the age of the Khao Khad Formation lies between Lower and Middle Permian. The transgressive sequence occurs during the sub-environments might varies from subtidal and intertidal zones of restricted marine to barrier bar. Meanwhile, the regressive sequence is changed from intertidal to subtidal zones of back barrier bar to intertidal zone of near shore. The diagenesis of the Khao Khad Formation is divided into 2 phases. The early diagenetic processes involve grain abrasion, grain micritization, microcrystalline calcite cement, microcrystalline dolomitization, radiaxial fibrous calcite cement, dog-tooth calcite cement, early compaction, blocky calcite cement, dissolution and silicification. The processes during late diagenesis are calcitization or dedolomitization, macrocrystalline dolomitization and dissolution compaction.

Chutakositkanon et al. (2000) reported the Lower to lower Upper Permian sedimentary facies of the Khao Khad Formation in the Khao Pun area, Kaeng Khoi district, Saraburi province which indicate the transgressive/regressive succession of shelf sea/platform environment to pelagic or abyssal environment below the carbonate compensation depth. Their sedimentological and paleontological reveal that his oldest studied unit might indicate an Early Permian sheltered shallow or lagoonal environment. Then the depositional basin became deeper, as suggested by the prolonged occurrence of bedded chert-limestone intercalation with the local exposure of shallower carbonate build-up. The depositional environment had changed to pelagic deposition, as indicated by laminated radiolarian (e.g. *Follicucullus* sp.) cherts which represented deep-sea origin and related to ocean bottom deposit. This cryptic evidence might indicate the abyssal environment during middle Middle to early Late Permian, whereas, previous studies advocated shelf-facies environments. He concluded that the depositional condition might be a major regression on the microcontinent close to Indochina, from the minor transgressive/regressive cycles. It had developed within a skeletal barrier and through the lagoon with limited circulational and anaerobic conditions, on to the tidal flat to the sheltered lagoon without effective land-derived sediments.

Sap Bon Formation (Middle-?Late Permian)

The Sap Bon Formation consists mainly of gray to brown tuffaceous sandstone, shale, chert and gray, thin-bedded limestone. The upper part of this sequence is mainly light gray to dark gray and thin-bedded limestone interbedded with light brown to rusty brown shale, siltstone and nodular chert. In some places, the rocks are metamorphosed to slaty shale, phyllite and schist. This formation is assigned a Middle Permian age (Kungurian to Roadian) on the basis of the ammonoid (*Agathiceras* sp.). The fusulines *Pseudofusulina* sp., *Colania* cf. *douvillei* and *Neoschwagerina* cf. *margaritae* are reported. Total thickness of this formation is approximately 1,100 meters. The type section is located at Ban Sap Bon teak plantation, Ban Sok Luk and Huai Sap Tai of Muak Lek district, Saraburi Province. The rocks of this formation are exposed in many areas along Ban Phu Kae, Ban Nong Chan and Ban Sap Bon, northwest of the Khorat Plateau.

However, in the Loei and Nong Bua Lamphu area, Chareonpravat and Wongwanich (1976) and Chareonpravat et al. (1976, 1984) proposed a different lithostratigraphic division of the Permain rocks, namely, the Nam Mahoran, E-Lert, and Pha Dua Formations, in ascending order. In the Nakhon Sawan and Lopburi area, the Permian rocks have been divided into 2 formations including the Khao Luak and Tak Fa Formations (Nakornsri, 1976, 1981). Bunopas (1981) subdivided the Saraburi Group which exposes in Phetchabun, Lopburi, Saraburi and Loei area into 3 formations. There are the Khao Luak Formation, Saraburi limestone and Dan Sai shale respectively in ascending order. In addition, Chonglakmani and Sattayarak

(1979, 1984) and Chonglakmani et al. (1979) also assigned the Permian rocks in the Phetchabun, Chaiyaphum and Udonthani area into 3 formations, namely, the Pha Nok Khao, Hua Na Kham and Nam Duk Formations. The lithostratigraphic correlation of the Permian rocks in these regions is summarized in Table 2.2.

Based on regional facies variation, Wielchowsky and Young (1985) studied the Lower to Middle Permian rocks of the Phetchabun fold and thrust belt and recognized 6 carbonate facies representing basin plain, basin margin, outer platform, platform interior, restricted platform and marginal marine depositional environments. The rocks in this belt can be grouped into 3 main paleogeograhic provinces ranging in age from Early to Middle Permian. They also recognized 3 siliciclastic facies representing deep, shallow and marginal marine depositional environments. The western carbonate platform is called the Khao Khwang Platform, the central mixed siliciclastic-carbonate basin is called the Num Duk basin and the eastern mixed carbonate-siliciclastic platform is called the Pha Nok Khao Platform (Figure 2.5). Depositional environments in the carbonate platform include restricted platform, platform interior and platform margin (Figure 2.6). They have been reproduced a coastal-onlap curve which is based on sediment response to changes in sea level (Figure 2.7). The curve is approximated eustatic sea level and shows a highstand in the Asselian and Sakmarian, a radical fall in the early Artinskian, a major lowstand and slow rise from the Artinskian through the early Guadalupian and a highstand in the middle and late Guadalupian with a major fall in the Ochoan.

Chonglakmani (2001, 2005) subdivided the Saraburi Group in the Saraburi-Pak Chong area into severals lithofacies representing the shelf or platform, the basin margin and the deep basin environments. Strata of the shallow marine environment

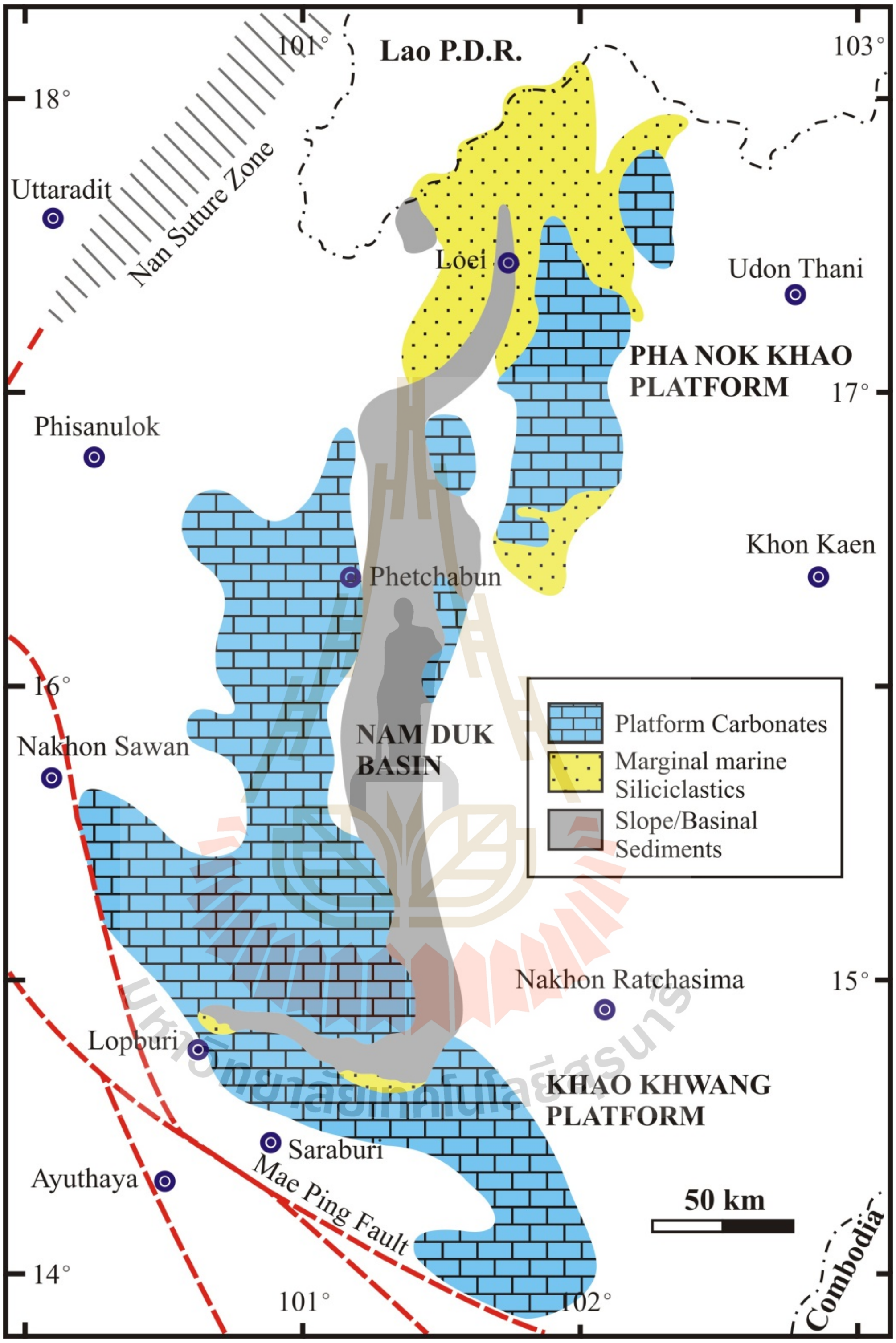


Figure 2.5 Simplified geological map showing the Permian carbonate platform and siliciclastic basin along the western portion of the Khorat plateau (Indochina Block) (modified from Ueno and Charoentitirat, 2011).

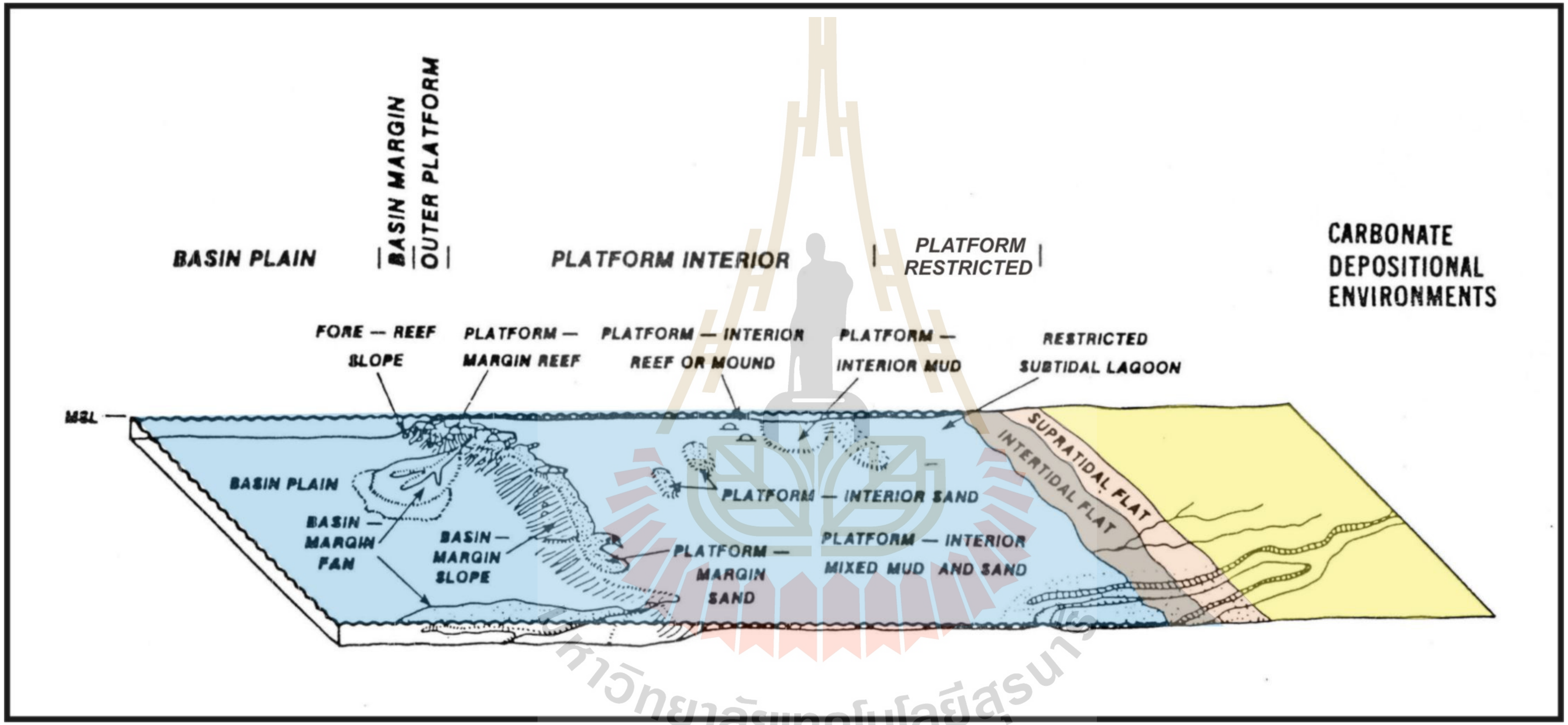


Figure 2.6 Carbonate depositional environments and sub-environments of a carbonate platform in northeastern Thailand (modified from Wielchowsky and Young, 1985).

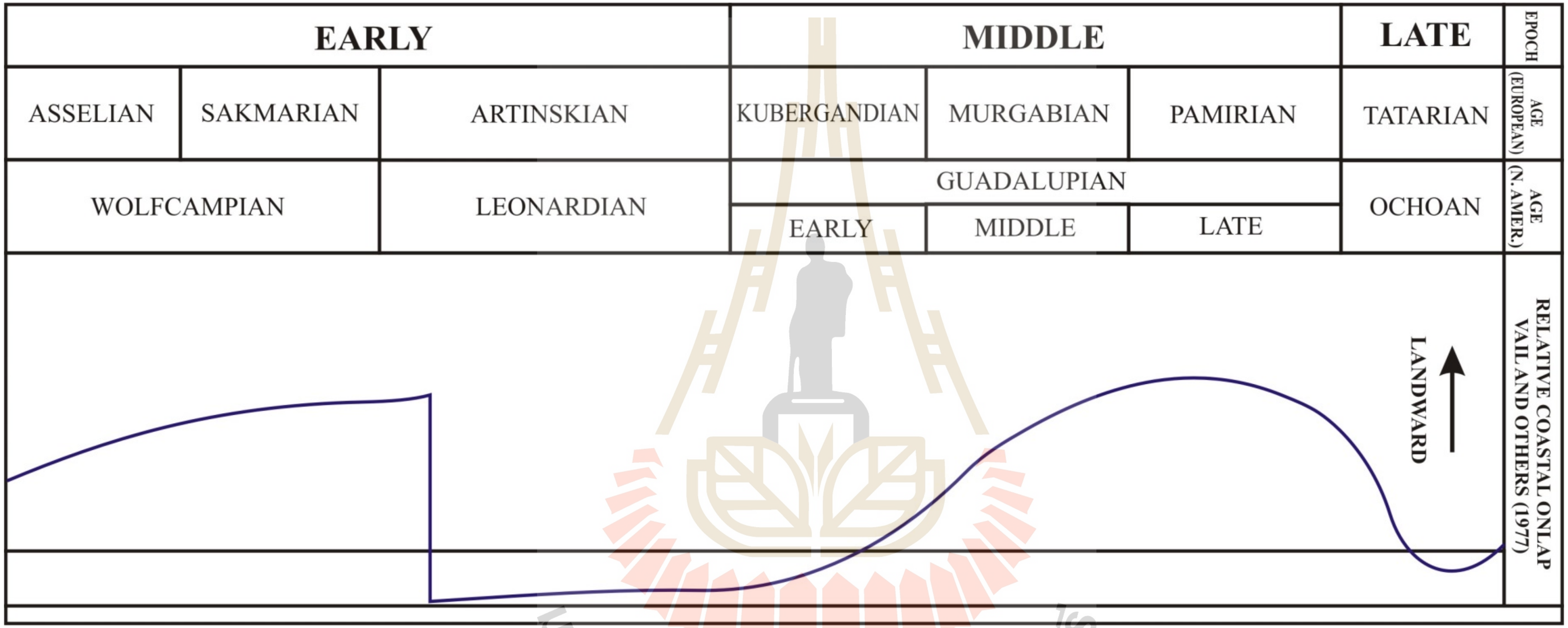


Figure 2.7 Permian chrono-stratigraphic and coastal-onlap chart (modified from Wielchowsky and Young, 1985).

consist of thin- to thick-bedded limestone and dolomite, boundstone and dolomite, and sandstone, shale and limestone facies. The basin margin and deep basin environments comprise crinoidal limestone, limestone conglomerate, graywacke and shale, shale with limestone block and allodapic limestone, shale and chert. The platform to basin margin belt consists of the Khao Khwang, Khao Phaeng Ma and Sap Bon Formations respectively in ascending order. The Khao Phaeng Ma Formation consists of thin-to-thick, graded-bedded, hummocky and cross-bedding limestone which is interbedded shale, chert and limestone conglomerate. The basin belt consists of the lower Nong Pong and the upper Pang Asok Formations. The Khao Khwang Platform is considered to be equivalent to the Pha Nok Khao Platform based on stratigraphic, paleontologic, sedimentologic and structural evidences.

Chonglakmani and Helmcke (2001) suggested that the so-called Pang Asok, Sap Bon and part of Nong Pong Formations (Sudasna and Pitakpaivan, 1976) are equivalent to the Nam Duk Formation. But the Nam Duk Formation exhibited the deep sea characteristic of geosynclinal facies and more deformation (Chonglakmani and Sattayarak, 1978; Winkel et al., 1983; Wielchowsky and Young, 1985; Alterman, 1989; Malila, 2005; Ueno and Charoentitirat, 2011).

CHAPTER III

METHODOLOGY

3.1 Fieldwork Investigation

Details of field investigation and sampling are planned to collect based on geological data in the study areas. The measured sections were presented and the lithostratigraphic column on the study area was established. The lithofacies analysis were conducted by using geometry and sedimentary structures from geological investigation. All rock specimens are sampled for laboratory test. The rock specimens were prepared as standard thin-sections which were stained with the potassium ferricyanide and Alizarin Red S solution at Department of Geotechnology, Faculty of Technology, Khon Kaen University. The thin-sections of limestone and the other rocks were studied under a stereo microscope. This is to identify the mineral of various types of grain components and cement as well as their textural and compositional variations. These were also useful for the interpretation of depositional environment.

However, all information is integrated and rechecked in the field to confirm all stratigraphic information which has been correctly interpreted and represented.

The study areas are located in the western edge of the Khorat Plateau (Figure 3.1). It consists of sedimentary sequences mapped as the Permian Saraburi Group according to the Geological Map of Thailand scale 1:2,000,000 (DMR, 1999).

The study areas can be conveniently accessed from Bangkok to Nakhon Ratchasima province along the Highway No.1 (Phaholyothin road) then take the

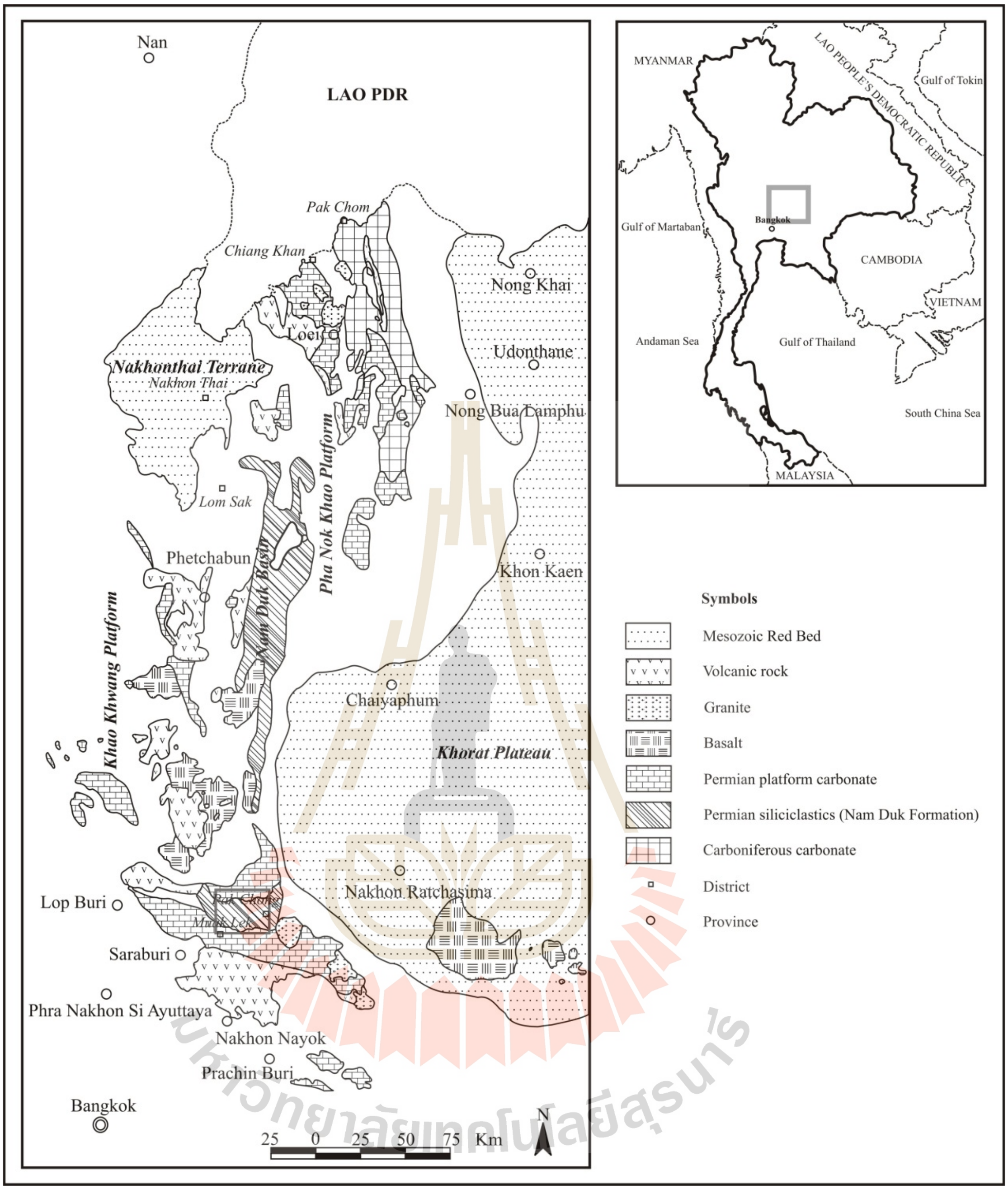


Figure 3.1 Geological map within the study areas in the western part of the Khorat Plateau (modified from DMR, 1999).

Highway No.2 (Mitraparp road) to Muak Lek district. It consists of 7 sections which are named as 1) Sideways of Mitraparp road, 2) Sukhato area, 3) Thai-Danish dairy area, 4) Sap Takhian area, 5) Old quarry, 6) Khao Sai Sayan temple and 7) Nong Pong area.

3.1.1 Sideways of Mitraparp road

This section is located along Mitraparp road in Muak Lek district, Saraburi province (map sheet 5238III, Amphoe Muak Lek) (Figure 3.2), Kms 133 to 142. The section consists mainly of thin- to thick-bedded limestone and siliceous shale. The thick-bedded limestone is gray to dark gray displaying graded-bedding and cross-bedding. Shale with limestone boulders and blocks are common. The limestone blocks contain large fragment of fossils. The strata trend NW-SE and dip to S. The weathered surface is usually yellowish brown on these shale but it turns brownish black on the silicified part.

3.1.2 Sukhato area

The section is exposed along the rolling hill around Sukhato temple about 150 meters from Mitraparp road in Muak Lek district of Saraburi province (map sheet 5238III, Amphoe Muak Lek). The strata trend NW-SE and dip to SW (Figure 3.3). The limestone are gray to dark gray, thin-bedded and parallel. It is interbedded with dark brown, thin-bedded shale, black nodular and banded cherts. Some red banded cherts contain radiolarian. The thick-bedded dolomitic limestone appeas light gray 'elephant skin'. The north of this area, it is thin-bedded limestone interbedded with sandstone on the small hill.

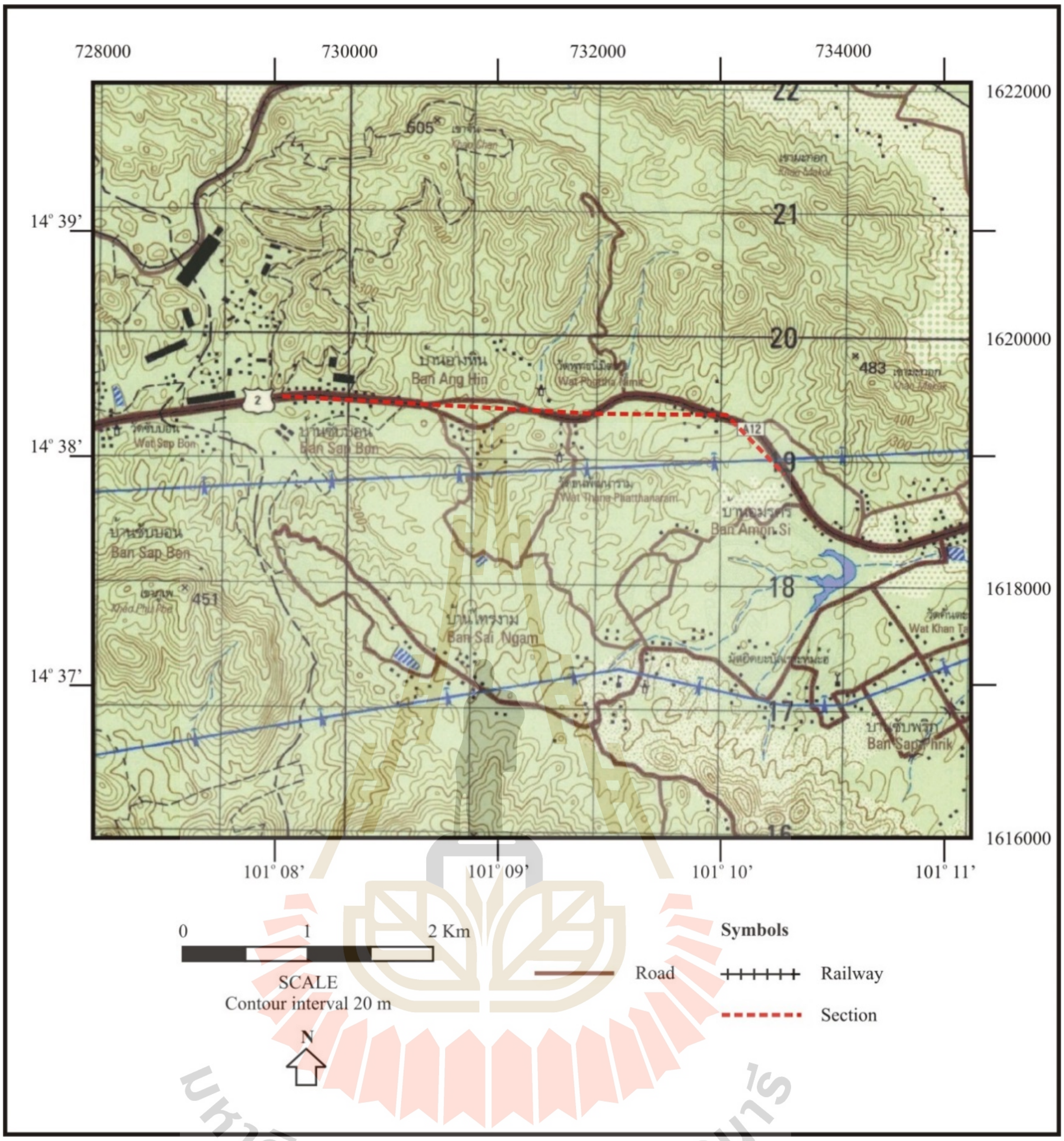


Figure 3.2 Topographic map of the sideways of Mitraparp road showing line of the section (modified from Royal Thai Survey Department, 2006).

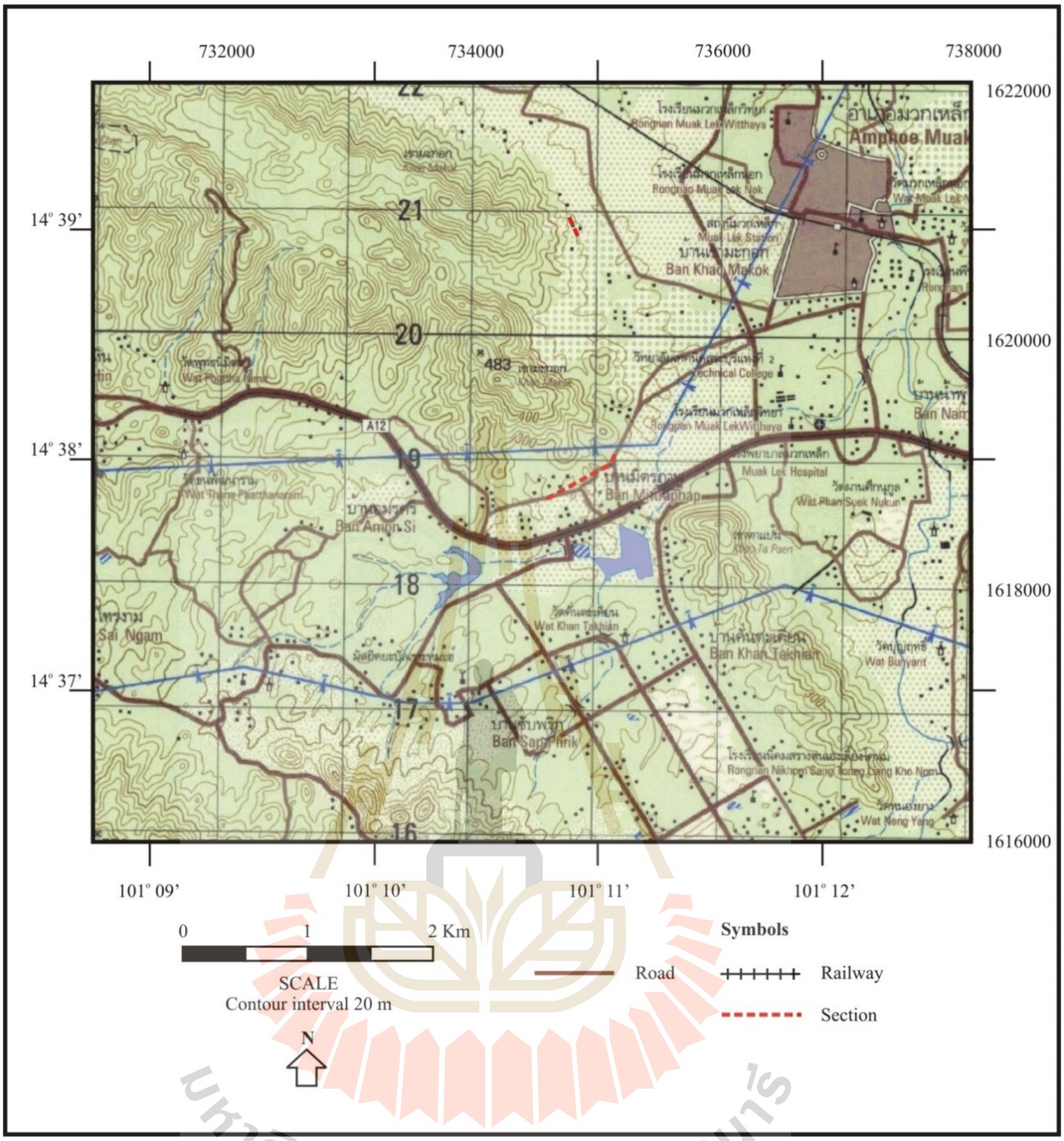


Figure 3.3 Topographic map of the Sukhato area showing line of the section (modified from Royal Thai Survey Department, 2006).

3.1.3 Thai-Danish dairy area

The study section is located on the backside of Thai-Danish dairy farm, Muak Lek district of Saraburi province (map sheet 5238III, Amphoe Muak Lek). In the east, it is the sequence of thin-bedded limestone, chert and shale. The limestone blocks and boulders with shale strata are observed. The weathered surface in this part is yellowish brown to light gray. These rocks trend NW-SE and dip to SW in the east (Figure 3.4). Thin- to thick-bedded limestone with some thin-bedded shale are observed in the southern part of this section.

3.1.4 Sap Takhian area

The section is started from Sap Takhian temple, Sap Sanun of Muak Lek district, Saraburi province trending along road No.2243 to Pak Chong district, Nakhon Ratchasima province (map sheet 5238I, Ban Sap Muang). It is light to medium gray limestone with black banded and nodular cherts. The large gastropods and brachiopods are common. The thin- to medium-bedded limestone interbedded with black banded chert and some laminated shale dip to SE. In places, it shows a sequence of gray to dark gray limestone associated with thin-bedded silty shale, shale and sandstone (Figure 3.5).

3.1.5 Old quarry

It is the old quarry in Ban Nong Phaksen along the road No.2243 of Pak Chong district, Nakhon Ratchasima province (map sheet 5238I, Ban Sap Muang). This area is dominated by a sequence of light gray to dark gray, thin-bedded and laminated limestone grading into clastics association of reddish brown, thin-bedded mudstone, siltstone, shale and sandstone (Figure 3.6). The limestone shows grain-supported with various types and sizes of grain components.

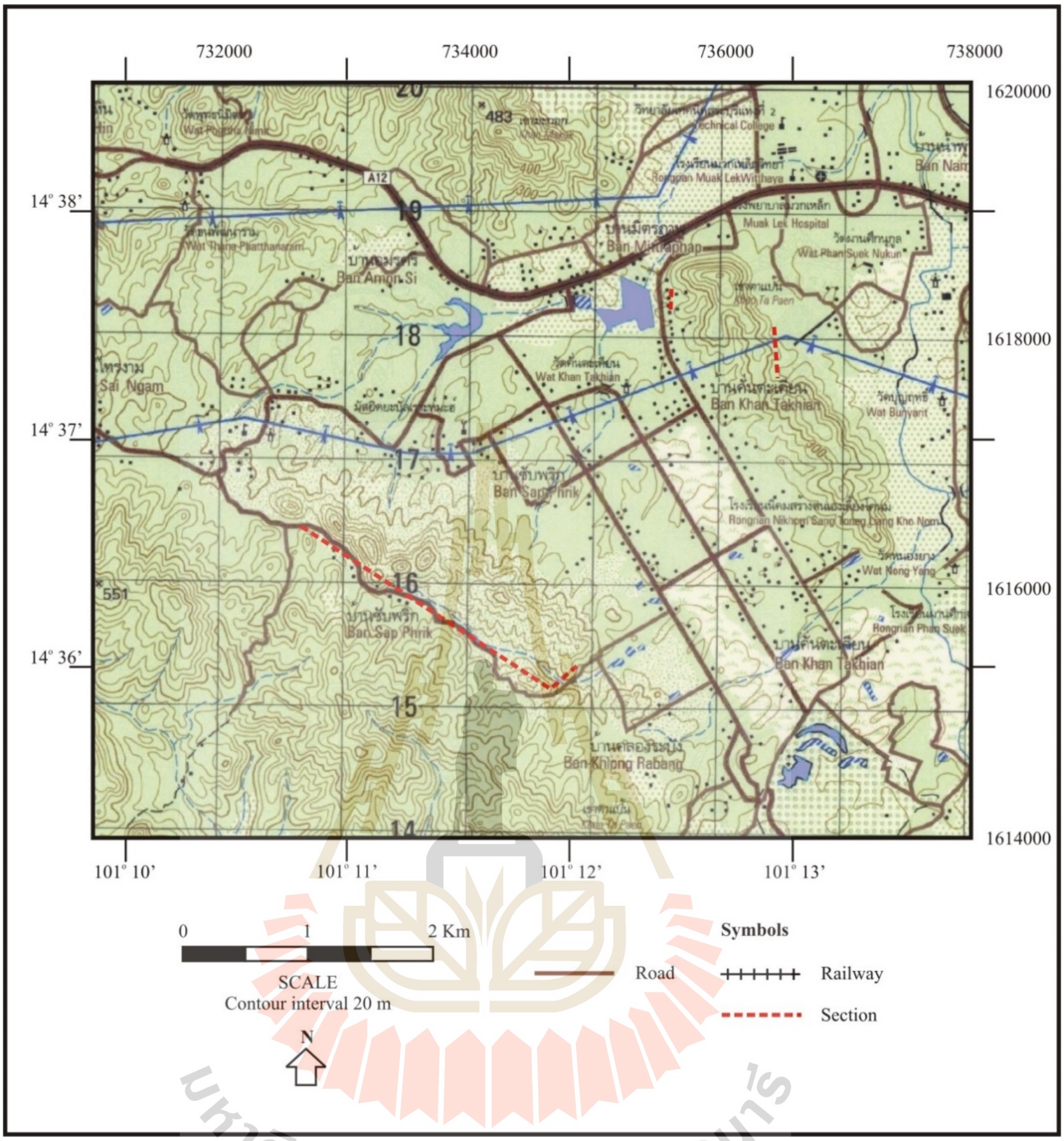


Figure 3.4 Topographic map of the Thai-Danish dairy area showing line of the section (modified from Royal Thai Survey Department, 2006).

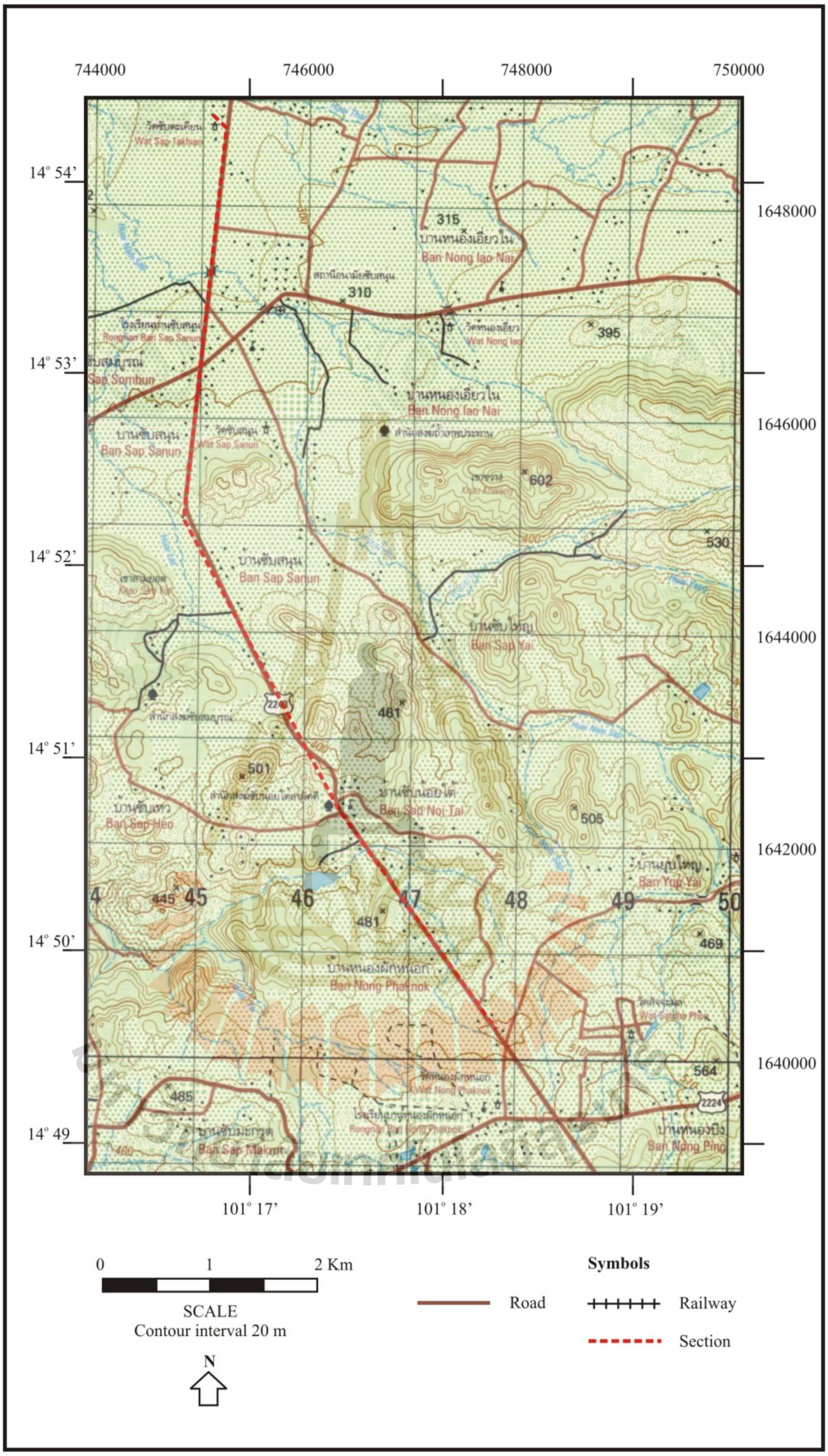


Figure 3.5 Topographic map of the Sap Takhian area showing line of the section (modified from Royal Thai Survey Department, 2006).

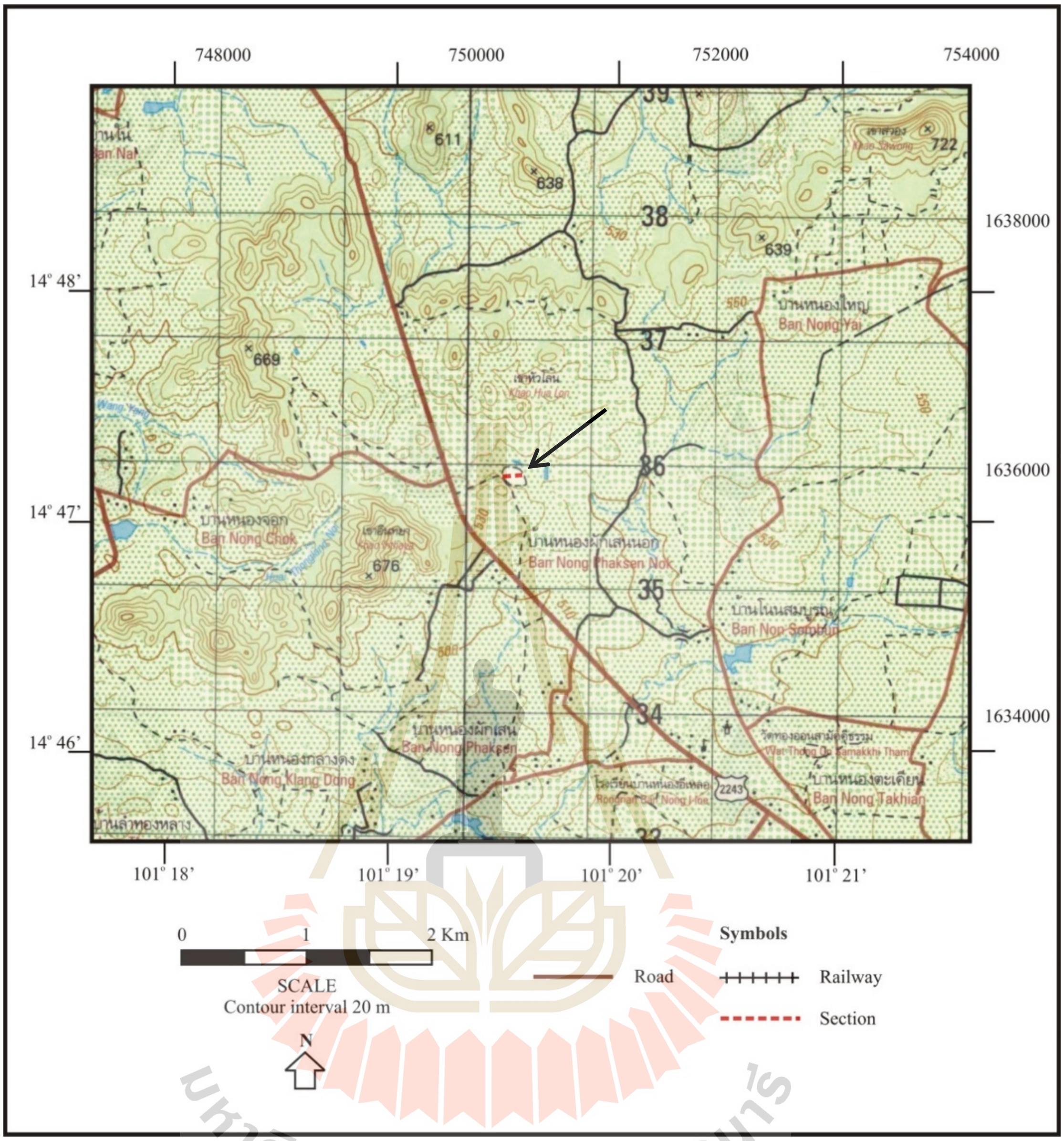


Figure 3.6 Topographic map of the old quarry showing line of the section (modified from Royal Thai Survey Department, 2006).

3.1.6 Khao Sai Sayan temple

This location is in Khao Sai Sayan temple, Pak Chong district of Nakhon Ratchasima province (map sheet 5238II, Amphoe Pak Chong). The top of the hill consists of dark gray to black, medium-bedded limestone with scattered black nodular chert and dolomite patches. The nodular chert beds are varies in sizes having partly elongated shape. The lower part of this hill is dominated by grayish brown to black and thin-bedded shale and limestone which trend NW-SE and dip to SW (Figure 3.7).

3.1.7 Nong Pong area

The section is along the road No.2224, Kms 36 to 38 Lamphaya Klang of Muak Lek district, Saraburi province (map sheet 5238I, Ban Sap Muang) then forwards to Tham Dao Khao Kaeo temple (Figure 3.8). The section comprises gray to dark gray, thin- to thick-bedded limestone and many dolomitic limestone beds. The numerous black nodular chert, dolomite patches and banded, pinkish gray argillaceous limestones with laminated shale are abundant. In the middle part of this section, it is dark gray, thin- to medium-bedded, poorly sorted limestone with large grain components such as, crinoid stems, fusulines, shells and unidentified fragments. Along the road No.2224, it is a sequence of dark gray, thin-bedded and laminated limestone interbedded with thin-bedded shale, siltstone and sandstone. Shale are gray to dark gray and turn to yellowish brown on weathered surface.

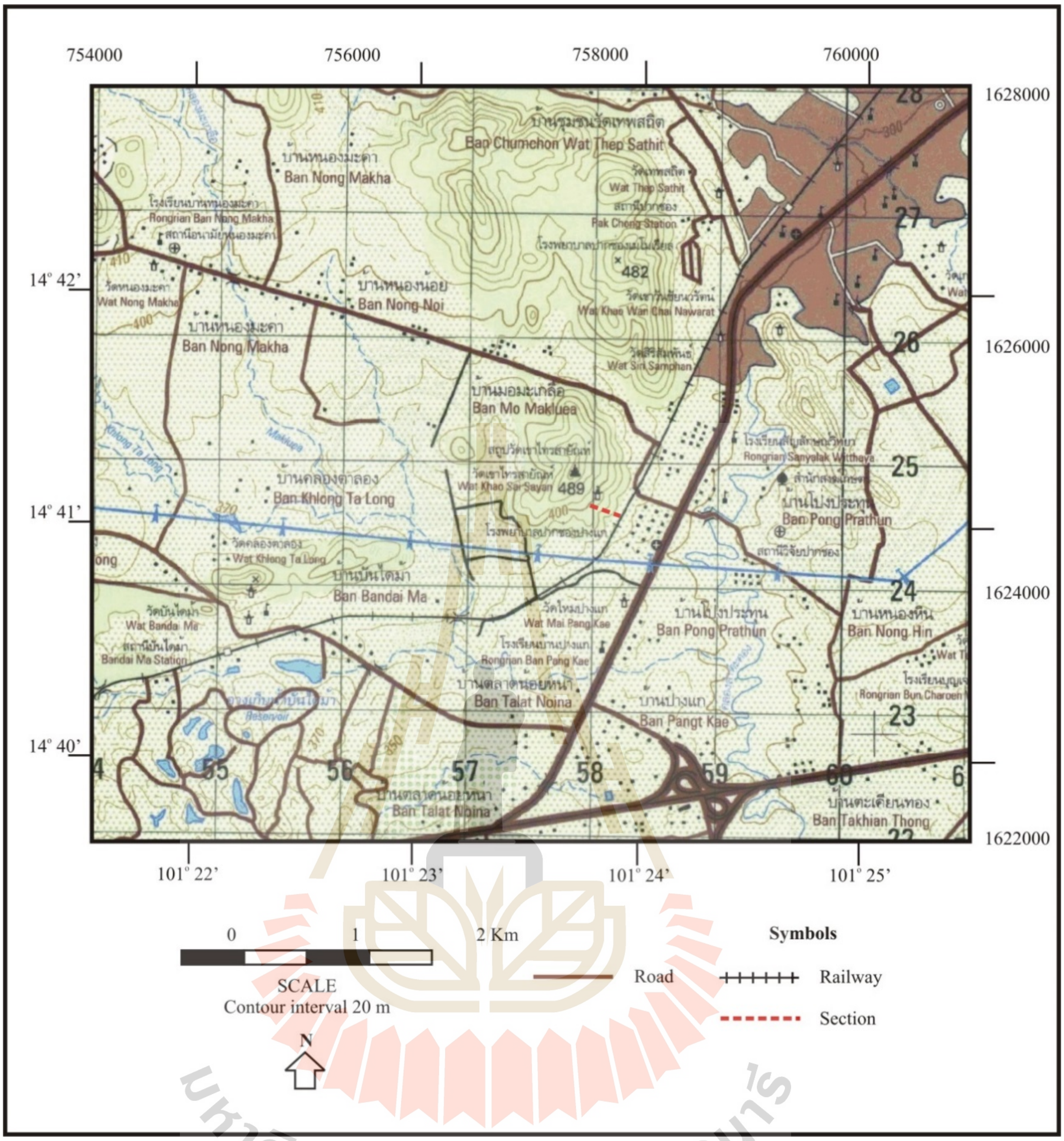


Figure 3.7 Topographic map of the Khao Sai Sayan temple showing line of the section (modified from Royal Thai Survey Department, 2006).

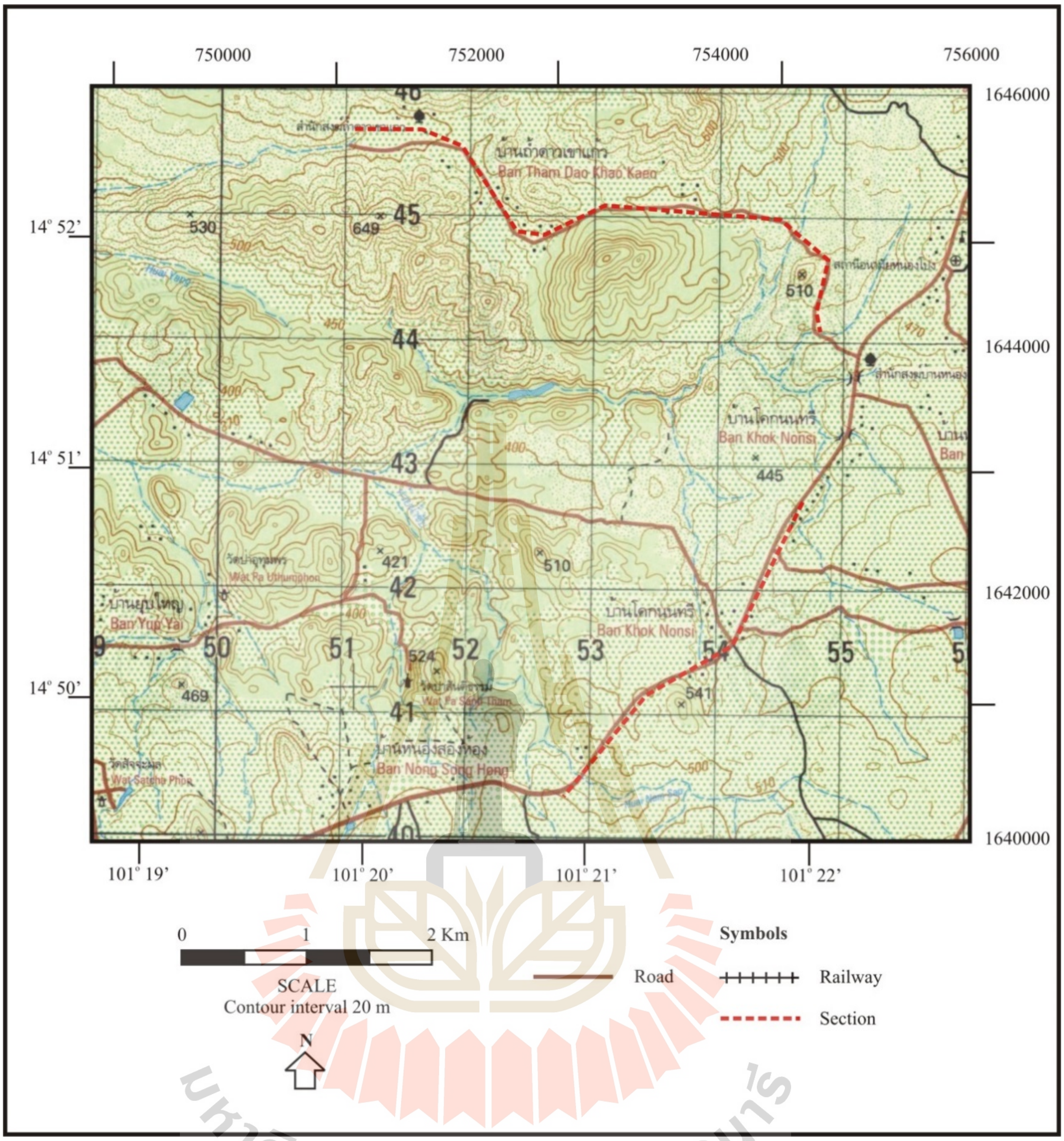


Figure 3.8 Topographic map of the Nong Pong area showing line of the section (modified from Royal Thai Survey Department, 2006).

3.2 Lithofacies and Petrographic Analyses

3.2.1 Lithofacies analysis

In this study, the sections are dominated by carbonate rocks especially limestone and dolomite. Lithologic differentiation of these rocks is a primary objective for field investigation. Lithological data and lithologic unit recognition lead to formal lithostratigraphic descriptions. Details of the lithology of these rocks are largely determined in the laboratory by lithofacies analysis. Both field information and lithofacies data are the basis of carbonate classification and interpretation of depositional environment. The term facies for sedimentary rocks are included lithology, composition, color, geometry, physical, chemical or biological sedimentary structures and fossil content but some cases, can be alternatively used either in a genetic sense or as interpreted depositional environment (Pirrie, 1998). The term "lithofacies" is used for describing facies that are primarily based on lithological data. In addition, the term "microfacies" has been used to refer to the total or sum of all sedimentological and paleontological data that can be described and classified from thin sections, peel, polished slabs or rock samples (Flügel, 1982, 2004).

The limestone classification proposed by Folk (1959, 1962) is based conceptually mainly on water energy related to limestone components (Figure 3.9). Generally, in low-water energy conditions carbonate mud (micrite) with or without grains are likely to be accumulated while in higher-energy environments, while fine-grained material is winnowed away into lower-energy settings. In the high-energy case, sparry cement later fills in interstitial space between grains. According to this classification, limestone is composed of 3 end members including allochems, micrite and sparry cement. These rocks are divided into 2 broad categories based on the interstitial materials which are micrite and sparite. Both of these can be further subdivided into 4 subclasses depending on predominating allochemical constituents. These constituents include bioclast, ooid, peloid and intraclast. They are briefly assigned as bio-, oo-, pel- and intra-, respectively. These prefixes are then used as an adjective extension of micrite and sparite types.

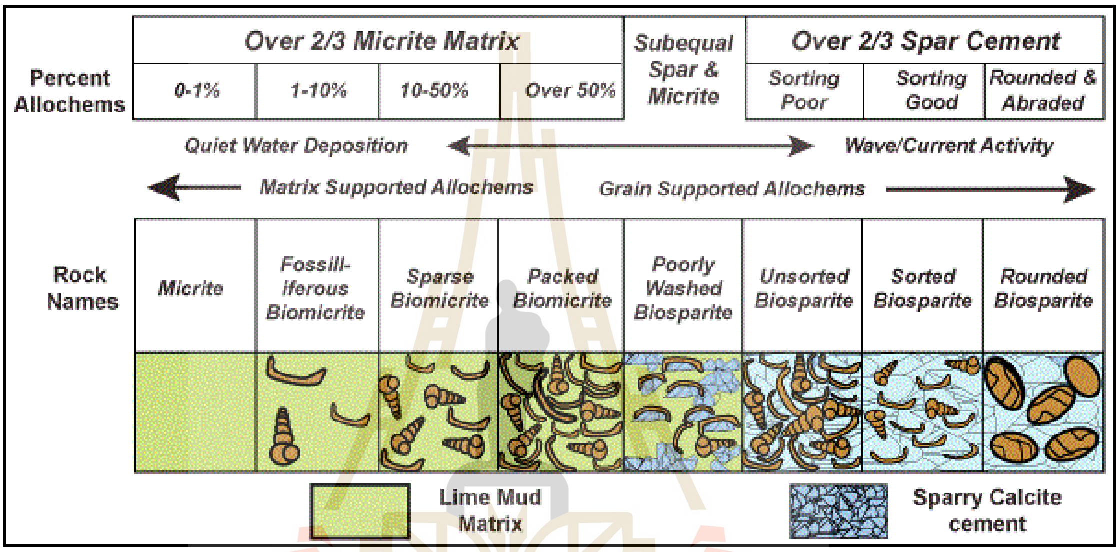


Figure 3.9 Folk's texture classification of carbonate sediments (after Folk, 1959).

According to the limestone classification of Dunham (1962), and after modification by Embry and Klovan (1971), the primary emphasis is most concerned with limestone depositional fabric (Figures 3.10 and 3.11). Two types of carbonates are distinguished. They include carbonate which the original components were not bounded during deposition (allochthonous) and carbonate which original components were bounded during deposition (autochthonous). The first type was further divided into 4 categories including mudstone, wackestone, packstone and grainstone. The first 3 categories contain mud with different mud/grain ratio. There is mud-supported texture in mudstone and wackestone while grain-supported texture is found in packstone. Mudstone contains less than 10 percent of allochems while wackestone has more than 10 percent of allochems. Grainstone was characterized by grain-supported texture without mud. This allochtonous fabric can be separately classified into floatstone and rudstone if the size of allochems exceeds 2 millimeters. Allochems were floated in floatstone but densely packed in rudstone. Autochthonous deposits can be separated into bindstone, bafflestone and framestone. Organically binding organisms serve as the main substance in bindstone. Branching or stalk-shaped organisms play a baffling role in bafflestone. Framstone has rigid framework organisms as main reef-builders.

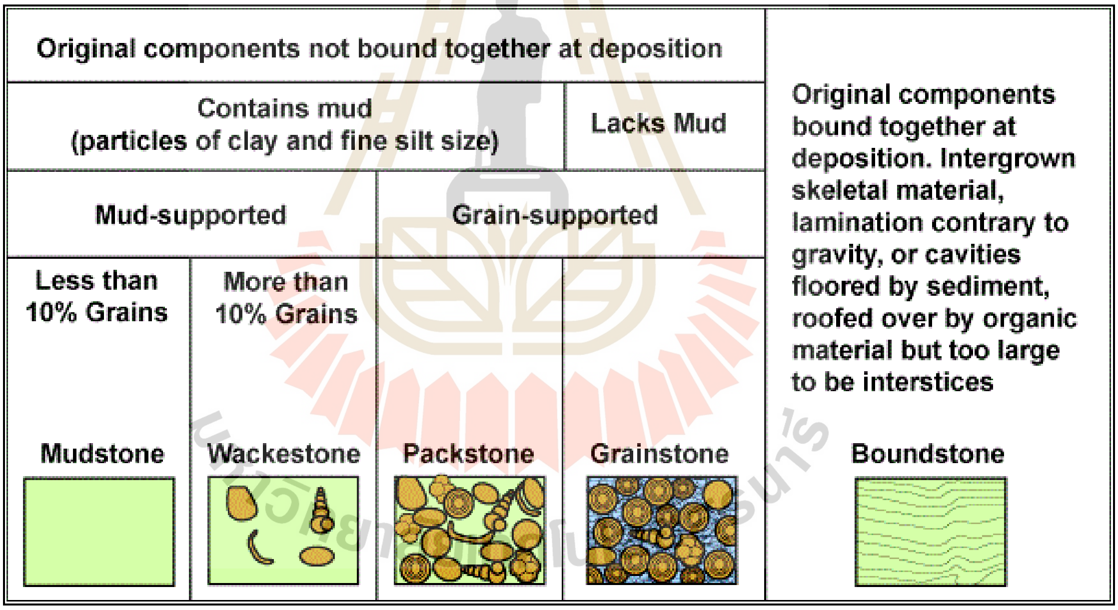


Figure 3.10 Dunham classification (after Dunham, 1962).

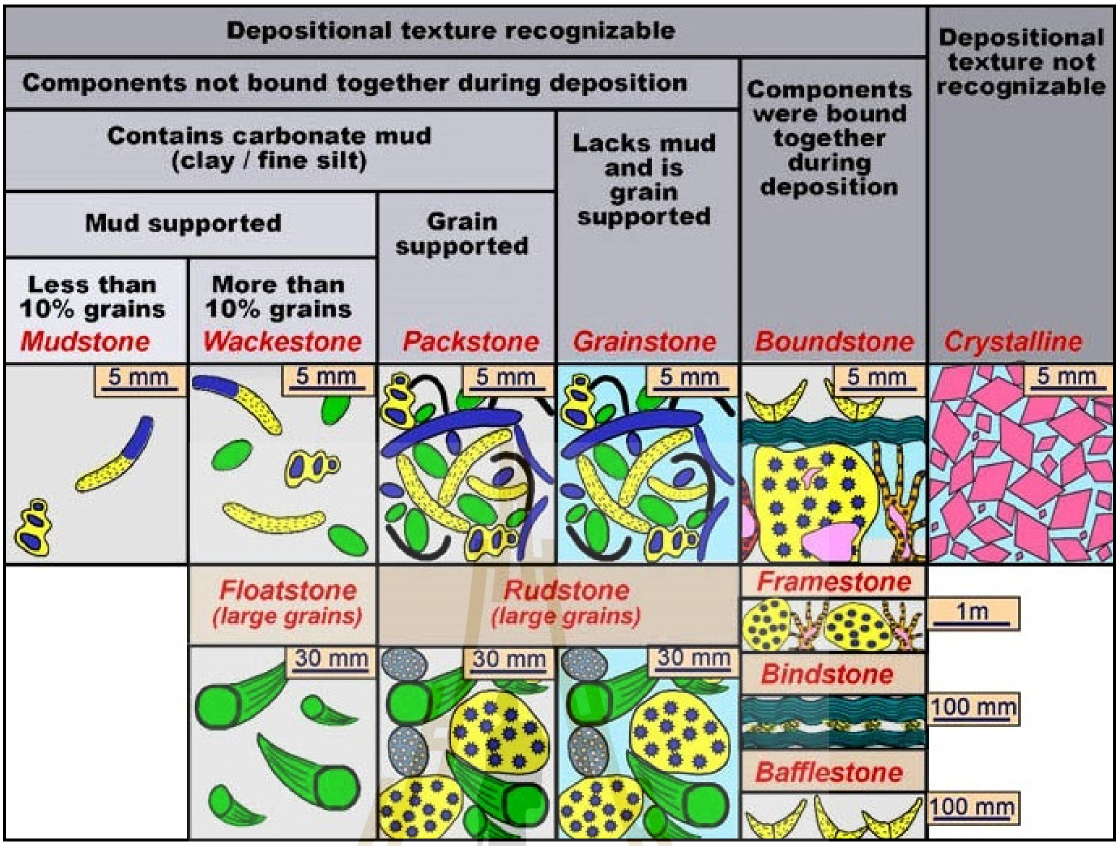


Figure 3.11 The Dunham classification of carbonate sedimentary rock (after Embry and Klovan, 1971).

However, an additional problem was introduced by the fact that both classifications are in fact oversimplifications and no longer precise enough to account for many petrographic features, such as the relative role played by various constituents, the variability of depositional textures and the fundamental effects of diagenetic processes. A simple term like biosparite or packstone, even with qualifiers, simply does not express the complex image of a limestone as seen under the petrographic microscope. Carozzi (1989) has been developed a more elaborate classification of carbonate rocks which is described and based on a modified

Wentworth grain-size scale combined with the textural concept of mud supported versus grain supported (Table 3.1).

3.2.2 Petrographic analyses

More than 200 samples were prepared for 300 thin-sections to validate the field data petrographically. Based mainly on Carozzi (1989), Dunham (1962), Folk (1959, 1962) and Flügel (2004), these samples were classified, correlated and summarized into different rock units.

Rock thin-section preparation

The process to obtain the thin-section is started by breaking the rock sample to a small size enough to cut on diamond saw and used a sliding brace to cut the rock into a thin rectangular block as smaller than a slide. Put a little coarse grit and water to making a slurry in the plate and grind the flat sample. When the rock surface looks smooth, grind it again with the medium-to-fine grit until it has a very smooth flat rock sample surface. Wash the sample clean and put on the hot plate to ensure it is completely dry. Drop a little mixed epoxy and put a slide on the warming plate and wait until the bubbles come out. Carefully place the smooth side of the rock sample and gently press them together tightly. When it is sticky, grind the sample thinly by using 400 grit. The goal is exactly 30 microns (0.03 millimeter) of thickness across the entire sample. Finally, cement a cover slip on the rock, being careful to make the cement free of bubbles with the warming plate. The slide cover has to be stuck with a similar cement to stick the sample on the slide and it is stored vertically in boxes which can be protected from the sun.

Table 3.1 Practical classification of carbonate rocks (after Carozzi, 1989).

INCREASING ENERGY OF DEPOSITIONAL ENVIRONMENT (↓ from 2 to 7)

1.	CALCILUTITE (micrite, 10 to 30 µm)	With up to 10% of sand-size components (bio-litho)
2.	CALCISILTITE (30 to 60 µm)	With up to 10% of sand-size components (bio-litho)
3.	MUD-SUPPORTED CALCARENITE (floating grains, bio-pel-litho)	10 to 20 (30)% sand-size components (60 µm to 2.5-5 mm), bio-litho in: A. Calcilutite matrix B. Calcisiltite matrix C. Bioclastic matrix
4.	GRAIN-SUPPORTED CALCARENITE (grain framework, bio-pel-litho-ool)	More than 20 (30)% of sand-size components (60 µm to 2.5-5 mm), bio-pel-litho-ool in interstitial material of: A. Calcilutite matrix B. Calcisiltite matrix C. Bioclastic matrix D. Cement, drusy to sparite, overgrowth, 20 µm to no upper crystal size limit E. Pressure-welded
5.	MATRIX-SUPPORTED CALCIRUDITE (floating pebbles, bio-litho)	10 to 20 (30)% pebble-size components (2.5-5 mm to no upper size limit) with interstitial material of types 1 through 4 (except 4D)
6.	CLAST-SUPPORTED CALCIRUDITE (pebble framework, bio-litho)	More than 30% of pebble-size components (2.5-5 mm to no upper size limit) with interstitial material of types 1 through 4
7.	BIOACCUMULATED LIMESTONE (loose accumulation)	Accumulation by sessile non-framework builder organisms with interstitial material of types 1 through 3 (low energy)
8.	BIOCONSTRUCTED LIMESTONE (constructed framework)	Colonial framework builder organisms with interstitial material of types 1 through 6 (entire low to high energy spectrum)

3.3 Geochemical Analysis

Nowadays, the geochemical analysis is acceptable to determine the depositional condition of sediments. Only chert samples are collected from the Sukhato area for geochemical analysis. The outcrop and rock descriptions of this locality are mentioned in chapter II. Several cherts are collected for radiolarian extraction then 9 selected samples from the Sukhato area are used for geochemical analysis

The samples for geochemical analysis are chosen the least weathered samples. Each sample is trimmed to remove the weathered surface, crushed, and split into small pieces. Then take the fresh rocks into the grinding machine and sieving with mesh No.200 to make a powder. After used agate ball mill and mortar for each sample, it will be washed and cleaned clearly with alcohol to prevent any contaminations for the next sample.

In the laboratory works, 3 groups of elements have been analyzed. They are major, trace and rare earth elements. Major elements determination and their abundances are performed by wavelength-dispersive X-Ray Fluorescence (XRF-1800) at the State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (CUG: Wuhan, China). Rare Earth elements (REEs) are measured by Agilent 7500a inductively coupled plasma mass spectrometry (ICP-MS) at the State Key Laboratory of Biogeology and Environmental Geology of the Ministry of Education, CUG: Wuhan, China.

3.3.1 Major and Trace Elements

The main concept of this method is based on X-ray excitation technique. The primary X-ray beam from the instrument is used for exciting the secondary X-rays (elements in sample). Each element has unique wavelength characteristic which can be converted into elemental concentration. It mainly comprises SiO_2, TiO_2, Al_2O_3, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O and P_2O_5. These elements are measured with fused glass beads using a XRF-1800 based on wavelength-dispersive X-ray fluorescence (XRF) analysis. This method commonly used as geochemical criteria of sediment maturity of the SiO_2/Al_2O_3 ratio (Potter, 1978), which reflects the abundance of quartz and the clay and feldspar contents. The element source was forming by Al-Fe-Mn diagram and equivalent to shale standard of Post Archaean average Australian Shale (PAAS) (Adachi et al., 1986; Yamamoto, 1987). The MnO/TiO_2 ratio can be used to evaluate the origin of chert because the MnO content is derived from the deep ocean and TiO_2 is related with the terrigenous materials (Murray, 1994). The ratio of $Al_2O_3/(Al_2O_3+Fe_2O_3)$ can also be used to infer the sedimentary environment of chert (Sugitani et al., 1996). The origin of chert is deduced from the Al-Fe-Mn diagram. High Fe and Mn contents represent the hydrothermal origin while high Al indicates the terrigenous input (Zhang et al., 2000; Adachi et al., 1986; Yamamoto, 1987).

Trace elements, concentrations of trace element and their ratios can be useful as discriminators of tectonic settings because some trace elements are considered to be immobilized during sedimentation (Bhatia and Crook, 1986). Amount of Ba, Sr, Sc, Co, Th, U and their element ratios such as U/Th, Sc/Th and Sr/Ba are useful as indicators for the sedimentation source (Li et al., 2013). Taylor and McLennan (1985) and Bhatia and Crooks (1986) regard REE, Y, Th, U, Sc, and Co as the most useful elements in determining upper crustal abundances from clastic sedimentary rocks and as discrimination of tectonic settings. The immobile elements have also been used for the same proposed as major elements.

3.3.2 Rare Earth Elements (REEs)

The rare earth elements (REEs) are useful and important applications in igneous, sedimentary and metamorphic petrologies. The REEs comprise of 17 chemical elements in the periodic table that include Scandium, Yttrium and the 15 Lanthanides of metals earth atomic numbers 57 to 71 (Lanthanum: La , Cerium: Ce, Praseodymium: Pr, Neodymium: Nd, Promethium: Pm, Samarium: Sm, Europium: Eu, Gadolinium: Gd, Terbium: Tb, Dysprosium: Dy, Holmium: Ho, Erbium: Er, Thulium: Tm, Ytterbium: Yb, and Lutetium: Lu). REEs are not easily fractionated during sedimentation and diagenesis, thus sedimentary REEs patterns reflect the REE pattern of the sources (Taylor and McLennan, 1985). Therefore, the REE's are particularly useful in provenance investigation and concentration in sedimentary rocks as usually normalized to a sedimentary standard such as North American shale composite (NASC), European shale, PAAS, and Upper crust. Trace elements and REEs can be analyzed by inductively coupled plasma mass spectrometry (ICP-MS). The objective of this machine is to serve as an ion source for a mass spectrometer. The samples are introduced into a nebuliser which converts it into an aerosol and disperses in argon gas. Droplet of aerosol is transmitted into a plasma torch by spray chamber. The aerosol is separated into a mixture of atoms, ions, undissociated molecular fragments and unvolatilized particles in the mount of the torch. Ions are extracted from the axial zone of the torch and are transmitted into the mass spectrometer. In general, a mass spectrometry is used for measuring isotopic ratios. There are various methods which relate to chemical separation of elements. Ion charges are separated from the element in form of ion beam. Atoms are split up when the ion beam is fired along a curved tube through an electromagnet. This process produces mass spectrum in which lighter ions are deflected with a smaller radius of curvature than heavy ions. The range of detection limit is 0.003 to 0.1 μg/g for heavier elements and 0.01 to 1 μg/g for lighter elements. Analytical precision for REEs is better than 5 percent. These REEs abundances are normalized to NASC (Gromet et al., 1984). The ratio of high REEs (HREE) relative to light REEs (LREE) is presented as a NASC-normalized La_n/Yb_n ratio (Murray, 1994; Chen et al., 2006; Thassanapak et al., 2011). Cerium (Ce/Ce*) and europium (Eu/Eu*) anomalies are calculated from $Ce/Ce^*=Ce_n/(La_n \times Pr_n)^{1/2}$ and $Eu/Eu^*=Eu_n/(Sm_n \times Gd_n)^{1/2}$ respectively (Taylor and McLennan, 1985). The depositional setting of chert is interpreted mainly by diagram La_n/Ce_n vs. $Al_2O_3/(Al_2O_3+Fe_2O_3)$ (Murray, 1994).

3.4 Radiolarian and Sponge Extraction

Radiolarians and sponge spicules were extracted from chert samples and associated siliceous rocks from the Sukhato area. Their composition and texture are more complex than chert so the separation by geochemical method can be used (Jones and Murchey, 1986). The Pessagno and Newport (1972) technique to extract the radiolarians and sponges is followed in this study. The radiolarian fauna in the study area is very poorly preserved. All of them are recrystallized and hardly to classify.

Sample preparation

1) Broke the selected rock samples into small pieces with fresh surface.

2) Placed the samples in dilute (4 percent) hydrofluoric acid (HF) for 8 hours and then rinsed. Repeated these steps for 3 weeks or until enough specimens are obtained.

3) The residues are washed and sieved by mesh No.300 (0.0054 mm) and dried in the oven.

The best preserved specimens are recovered from dried residue with a fine brush under a stereoscopic microscope for taxonomic identification. The best preserved specimens are mounted on stubs and photographed with scanning electronic microscope (SEM). Extraction and SEM methods were done at State Key Laboratory of Geological Processes and Mineral Resources, China University of Geosciences (CUG: Wuhan, China).

CHAPTER IV

RESULTS, INTERPRETATION AND DISCUSSIONS

This chapter presents the results of the lithofacies and geochemical analyses. They will be interpreted and discussed in this chapter.

4.1 Measured sections and Lithofacies analysis

The sedimentary sequences of the Sap Bon, Khao Khad, Pang Asok, Nong Pong and Khao Khwang Formations are appeared in the study areas. The sequences from the fields were mapped as rock units based on the differences in lithological characteristics in 7 mapping areas which are shown in Chapter II. The lithological characteristics of each area will be described in detail from field observation and microscopic study. The measured sections will be correlated based on the lithological characteristics for depositional environment interpretation.

4.1.1 Sideways of Mitraparp road (HW2)

There are 3 units to define the characteristics of sedimentary sequence in this area (Figure 4.1). These units were differentiated on the basis of lithologic and sedimentologic characteristics. The descriptions are presented as follows.

Unit 1A

This unit is exposed as a road cut outcrop in front of TPI Cement Factory Co., Ltd. of Kaeng Khoi district, Saraburi province (47P 729477E/1619492N). It is characterized by brownish black, thin-bedded, silicified and banded shale interbedded with gray to dark gray, thin-bedded calcarenite (Figure 4.2).

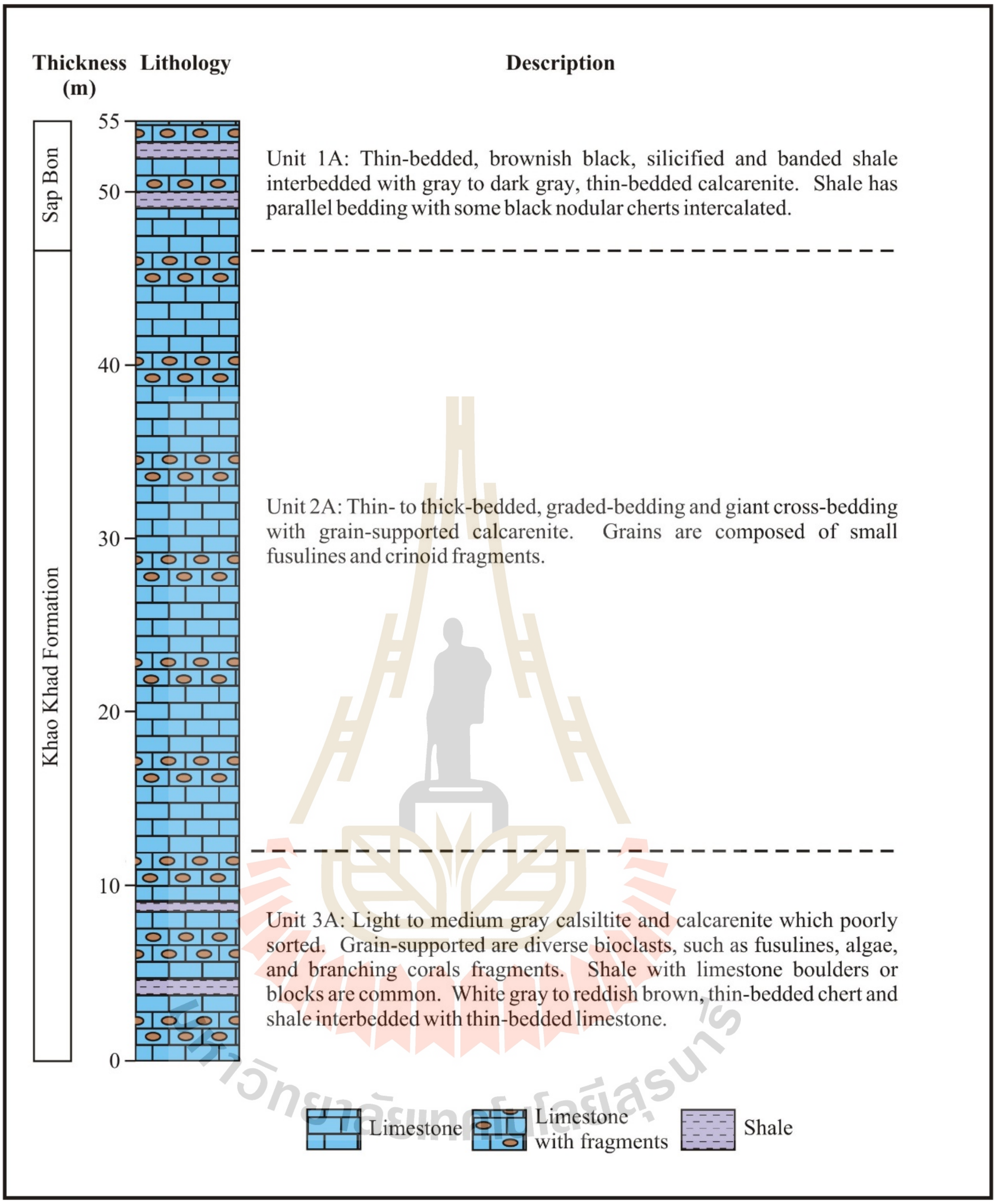


Figure 4.1 The lithostratigraphic column of the Sideways of Mitraparp road.

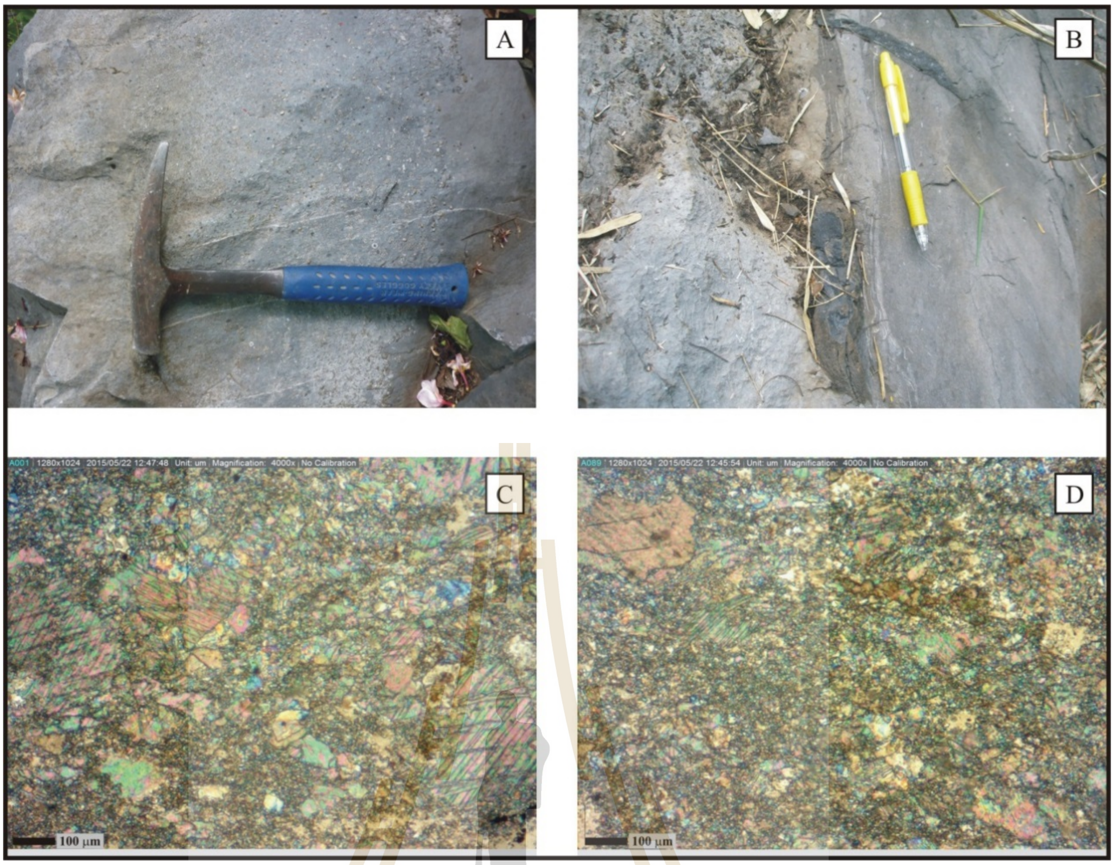


Figure 4.2 A and B are field photographs of Unit 1A exposed in front of the TPI Cement Factory Co., Ltd.; C and D are photomicrographs of poorly-washed biosparite.

The beds lie in the NW-SE direction and dip S. Shale has parallel bedding with some black nodular cherts intercalated.

Petrographically, the limestone of this unit consists of poorly-washed biosparite with very fine- to fine-grained bioclastic matrix. Grains are sub-angular and poorly sorted. Their varying sizes range from less than 0.06 to 2.5 millimeters and contain more than 20 percent of sand size components. The matrix consists of bioclastics fragments of fusulines, crinoids and brachiopods. The sizes of fragments are ranging from 0.03 to 2 millimeters.

Unit 2A

This unit is located on the mountain in Puttanimith temple, Muak Lek district of Saraburi province (47P 731538E/1619419N, 731899E/1619389N). It is characterized by grain-supported calcarenite and calcirudite. The limestone is thin- to thick-bedded and displays fining and coarsening upward sequences and graded-bedding. The giant cross-bedding set with high dip angle is dominant in the upper part while the lower part is gentle. The stylolite features are common (Figures 4.3). Grains are composed of small fusulines and crinoid fragments of 1 to 2 millimeters in size.

Microscopically, this unit is composed of packed biosparite and poorly-washed biosparite containing fine-grained bioclastic matrix. It is sub-angular to sub-rounded and poorly sorted. Grain sizes range from 0.06 to 2.5 millimeters and are more than 50 percent of sand size components. The bioclastic matrix is composed of fragments of fusulines, crinoids and brachiopods. The size of matrix is about 0.01 to 0.05 millimeter.

Unit 3A

This locality is located opposite to the National Sport Training Center, Muak Lek district of Saraburi province (47P 733599E/1618930N). There are light to medium gray, poorly sorted calcisiltite and calcarenite (Figure 4.4). With un-aided eyes, the rock contains large fragments of crinoid between 0.5 to 1 centimeter in diameter. The rocks are grain-supported and the grains have varying types and sizes. They are slightly silicified. Shale with limestone boulders or blocks are common. Grains are composed of diverse bioclasts, such as fusulines, algae and branching corals fragments. The lower part of this unit is usually yellowish brown on the weathered surface but it is brownish black on the silicified part. The rocks are abundant white gray to reddish brown, thin-bedded chert and shale interbedded with thin-bedded limestone.

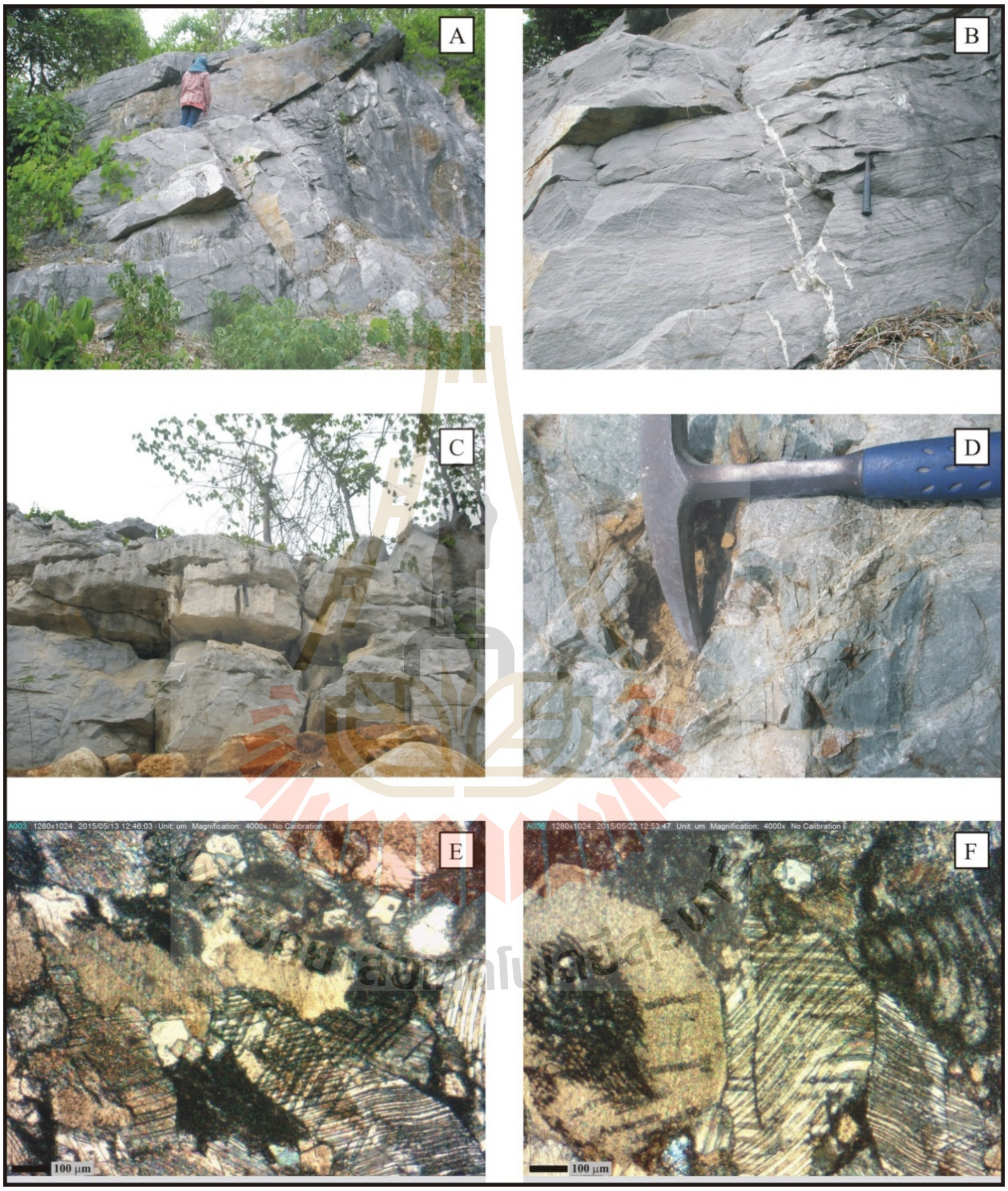


Figure 4.3 A, B, C and D are field photographs of Unit 2A exposed in the Puttanimith temple; E and F are photomicrographs of poorly-washed biosparite.

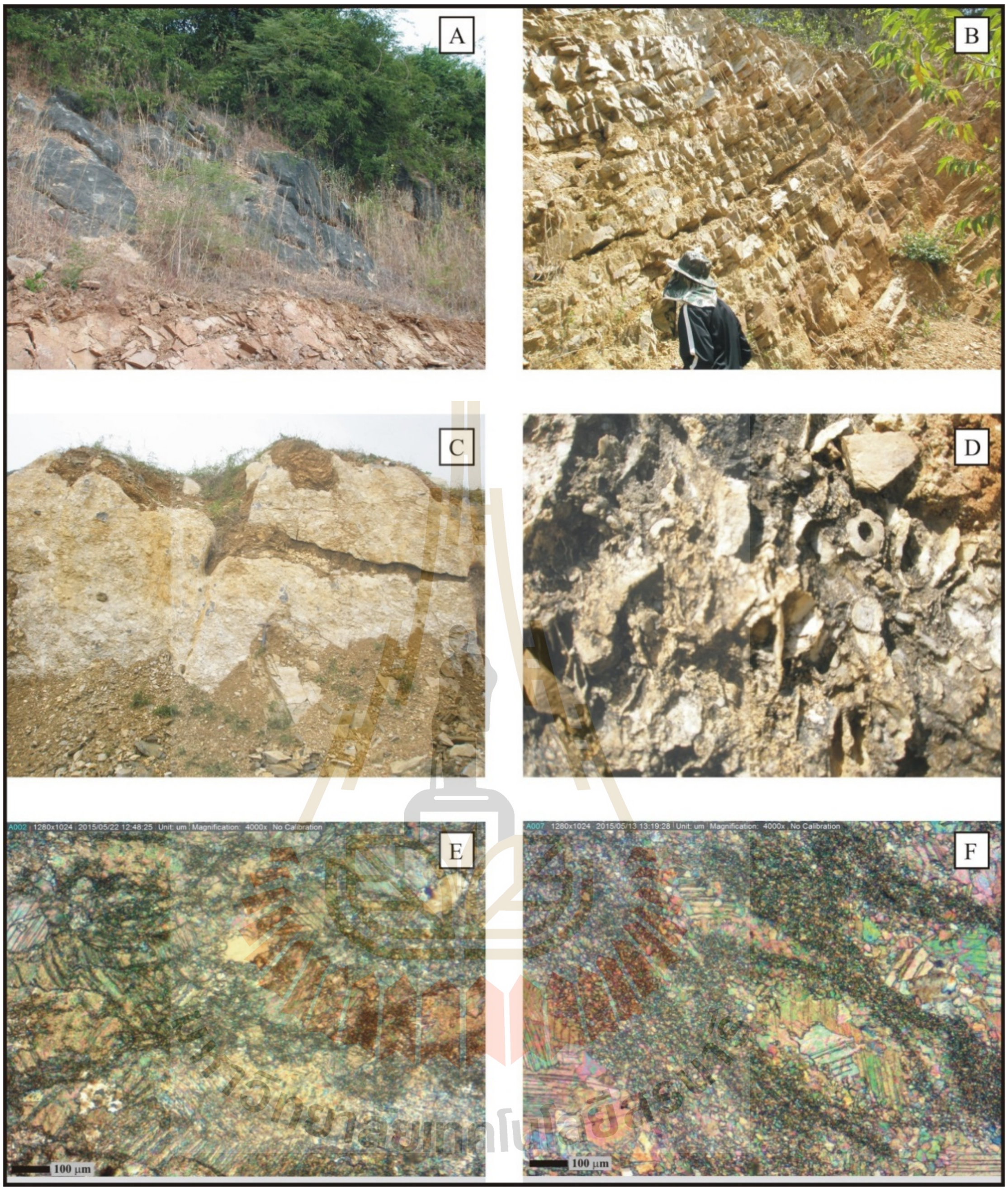


Figure 4.4 A, B, C and D are field photographs of Unit 3A exposed opposite to the National Sport Training Center; E and F are photomicrographs of poorly-washed biosparite.

Petrographically, it represents the packed biomicrite, biomicrite, biosparite and poorly-washed biosparite. The packed biomicrite is characterized by grain-supported of various types of grains in a micrite matrix. This packed biomicrite is graded to biomicrite as grain components decrease. There are small size bioclasts of crinoid and unidentified fragments which are cemented by sparry calcite. The grains consist of algae, fusulines and shell fragments.

4.1.2 Sukhato area

The overall rock units in the Sukhato area are mapped as 5 units. The sedimentary sequences of all sections are shown in Figure 4.5. The description of each unit is presented as follows.

Unit 1B

This area is exposed on a small hill at Masi resort, Muak Lek district of Saraburi Province (47P 734614E/1618696N). The rocks of this unit are characterized by gray to dark gray, parallel and thin-bedded calcarenite to fine calcirudite with black nodular chert. The weathered surface usually light gray and rough with protruded chert nodules (Figure 4.6). They are grain-supported of fusulines with matrix composed of small shell fragments (1 to 3 millimeters in size). The chert nodules are 5 to 20 centimeters in size and scattered throughout the limestone beds.

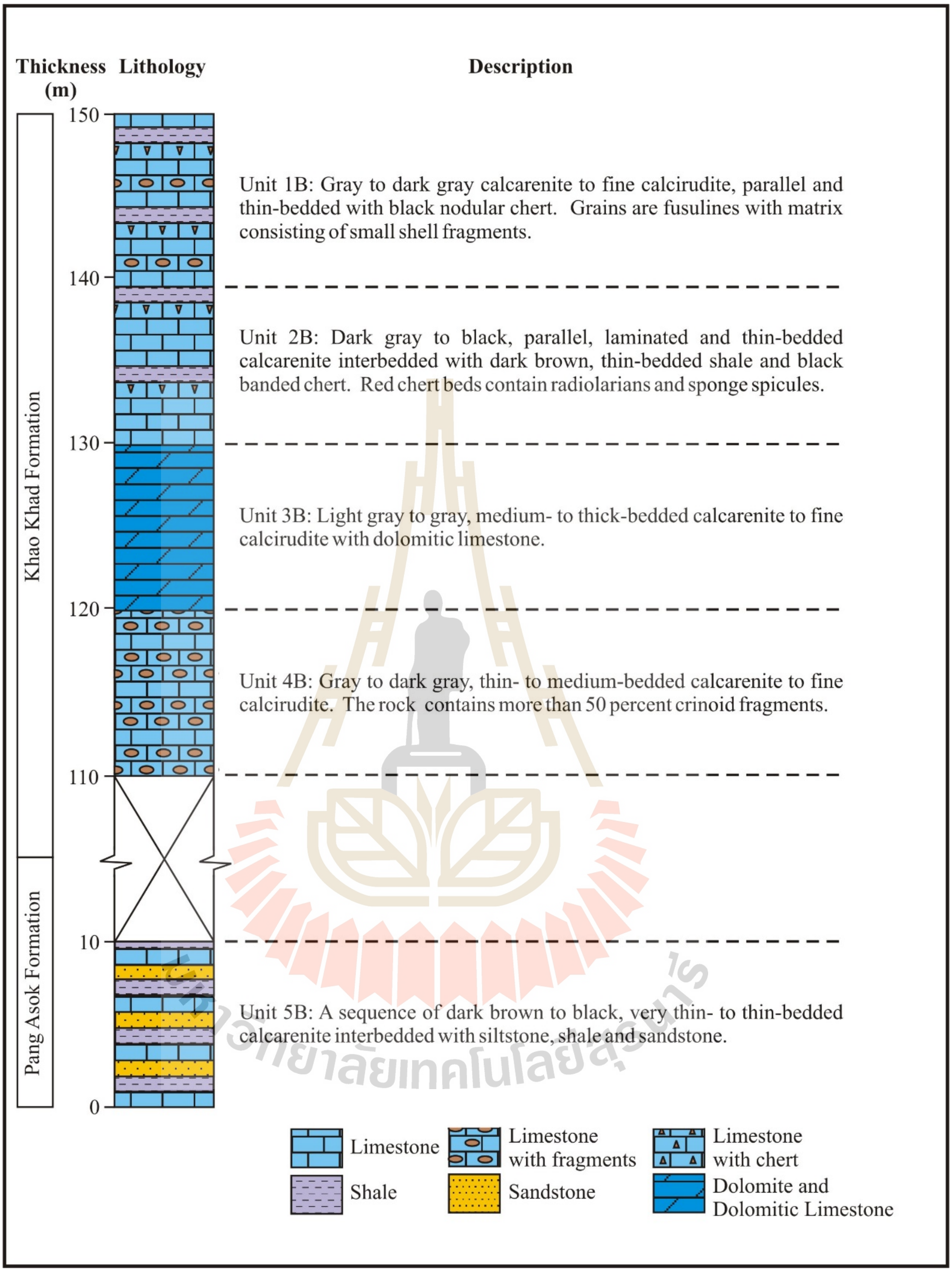


Figure 4.5 The lithostratigraphic column of the Sukhato area.

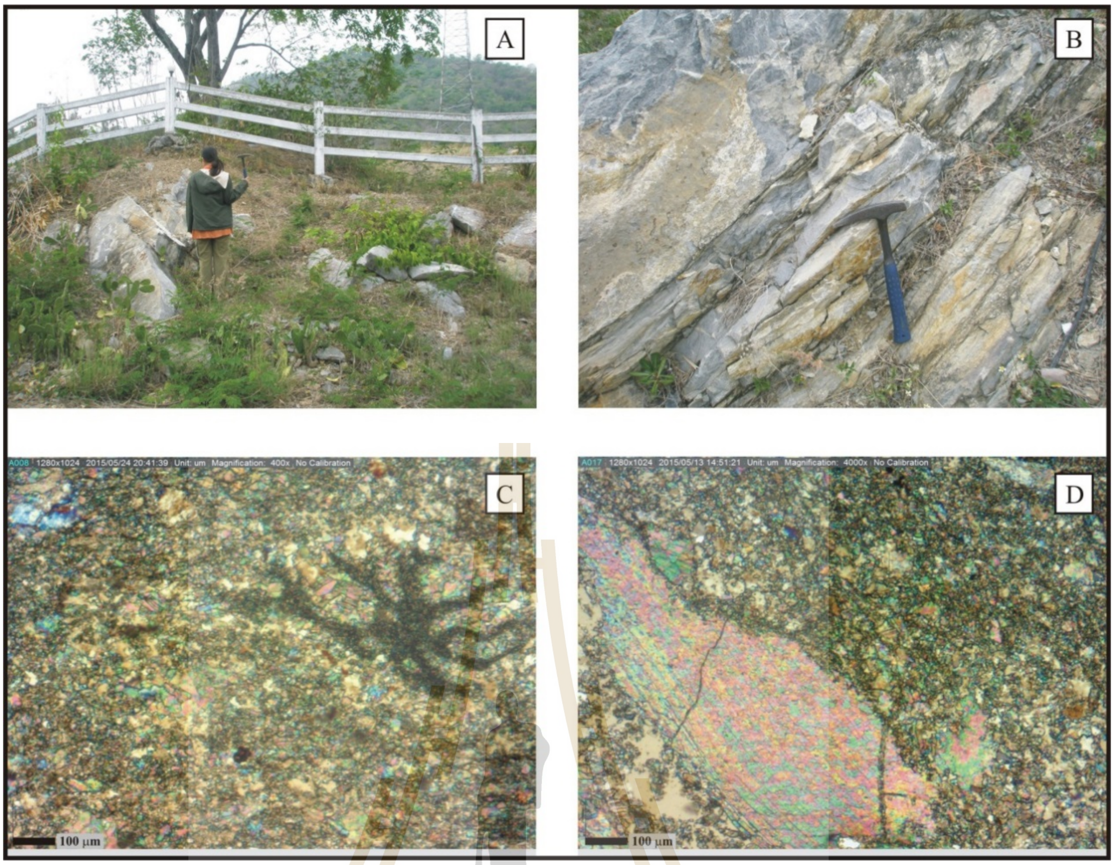


Figure 4.6 A and B are field photographs of Unit 1B exposed in front of the Masi resort; C and D are photomicrographs of poorly-washed biosparite.

Petrographically, the limestone in this unit consists of biomicrite and poorly-washed biosparite. The biomicrite contains more than 50 percent of bioclasts in micrite matrix. The poorly-washed biosparite are cemented by sparry calcite. The grain-supported calcarenite are lacked of micrite in intergranular pores.

Unit 2B

It is exposed on a small hill near Sukhato temple (47P 734945E/1618823N). There is parallel and thin-bedded limestone (Figure 4.7). It is dark gray to black, laminated calcarenite interbedded with dark brown, thin-bedded shale and black banded chert. Red chert beds contain radiolarians and sponge spicules which is yellowish brown on weathered surface.

Petrographically, the unit is exhibited laminated biomicrite with some microcrystalline chert bands. The laminated layer is abundant and contains grain-supported fabric in micrite matrix. The internal pores of bioclasts are filled with finely crystalline sparry calcite cement. Chert is banded and composed of microcrystalline quartz with some calcareous patches. It contains abundant radiolarians and sponge spicule structures.

Unit 3B

It locates on the foothill of unit 2B with dominantly by medium- to thick-bedded calcarenite to fine calcirudite with dolomitic limestone. It appears light gray 'elephant skin' and dark spots on the weathered surface. The boundary between Units 2B and 3B is not clear (Figure 4.8).

The petrographic studies of limestone reveal that it consists of poorly-washed biosparite and unsorted biosparite. They have abundant skeletal fragments of crinoids, corals, fusulines and unidentified fragments cemented by sparry calcite. The calcite grains are 0.01 to 0.02 millimeter in size. However, some parts are composed of fine to coarse dolomite rhombs.

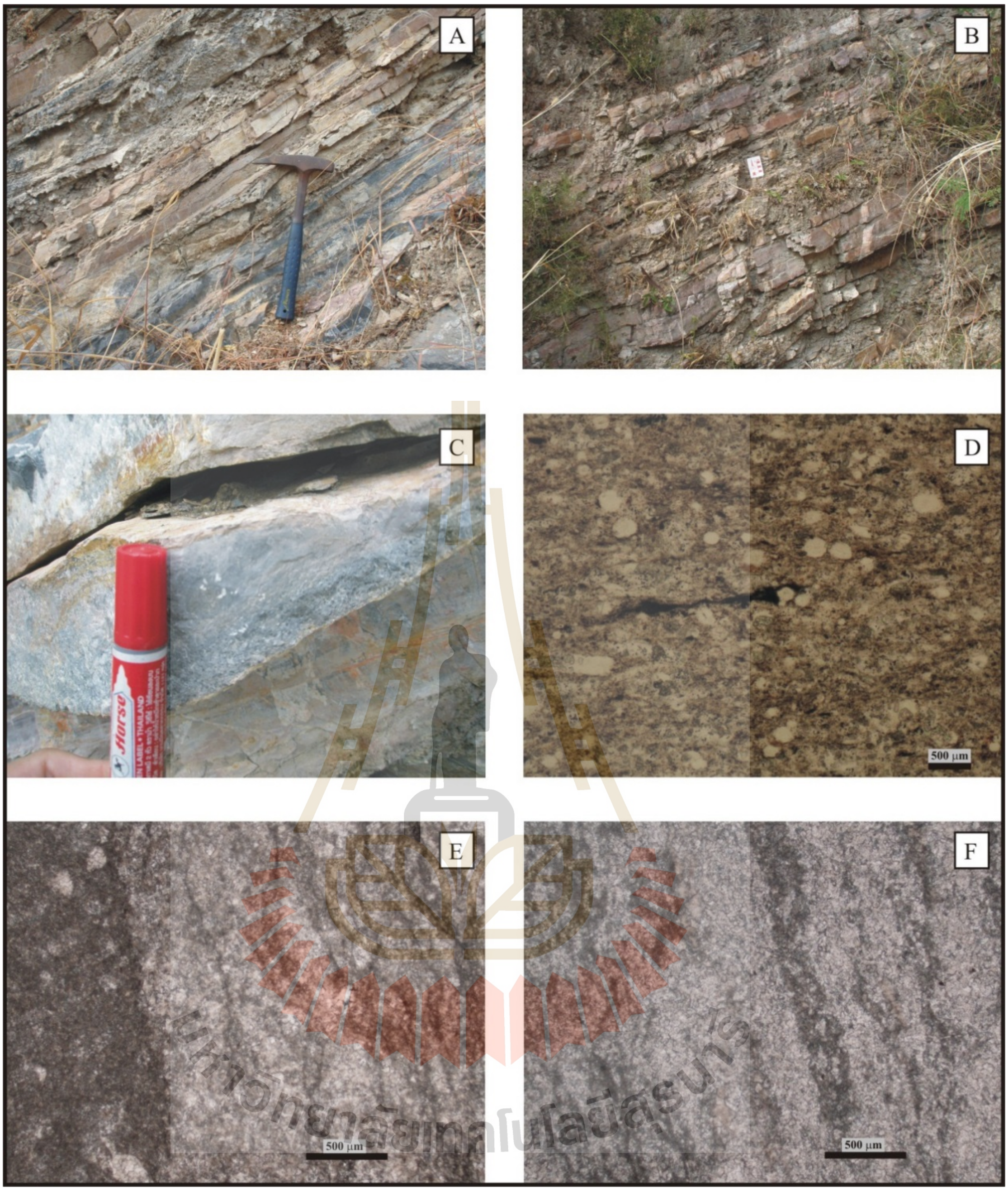


Figure 4.7 A, B and C are field photographs of Unit 2B exposed on a small hill near Sukhato temple; D is photomicrograph of radiolarian chert; E and F are photomicrographs of biomicrite.

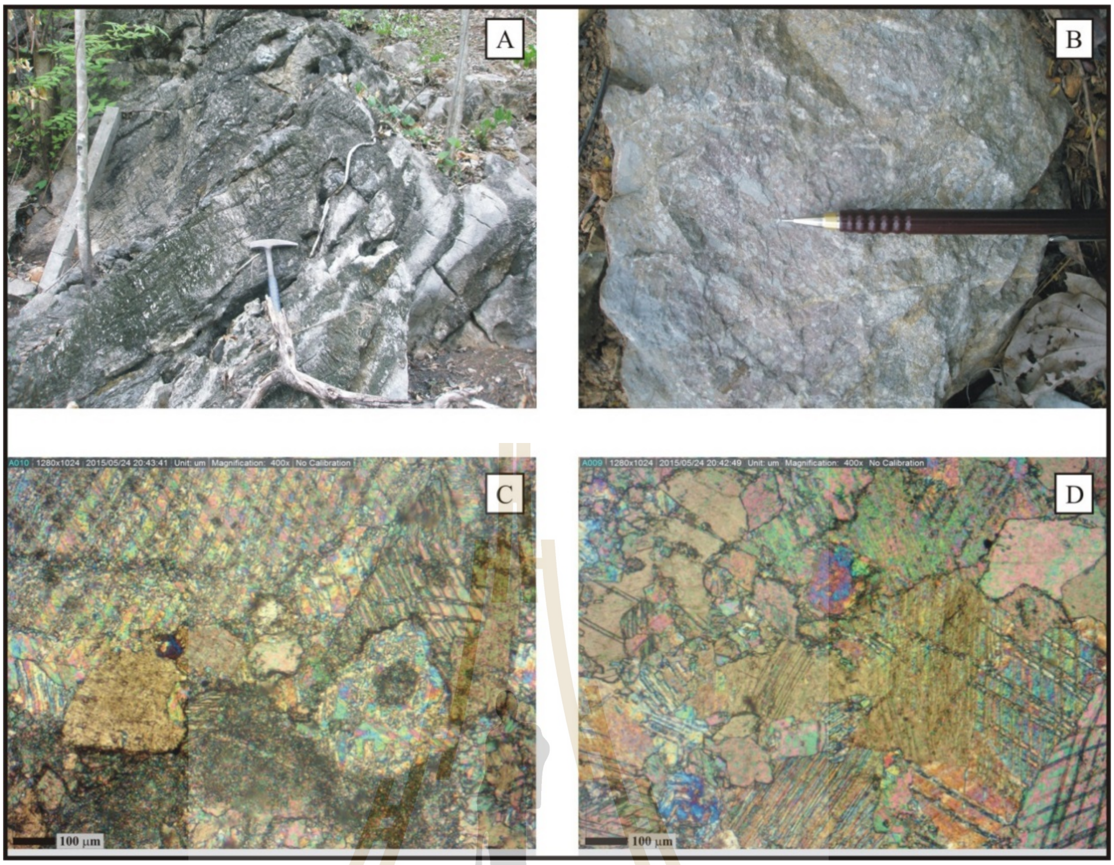


Figure 4.8 A and B are field photographs of Unit 3B exposed on a foothill near Sukhato temple; C and D are photomicrographs of poorly-washed biosparite and unsorted biosparite.

Unit 4B

This locality is in the mountain in Sukhato temple (47P 735037E/1619059N) consisting mainly of gray to dark gray, thin- to medium-bedded calcarenite to fine calcirudite (Figure 4.9). With un-aided eyes, the rock contains more than 50 percent crinoid fragments between 0.5 to 1 centimeter in diameter.

Petrographic study shows that it is unsorted biosparite and biosparite which contains more than 50 percent crinoid and bryozoan fragments. The cements are coarsely crystalline. The fine-grained matrix is micrite. The dolomitic rhombs are fine- to coarse-grained which are replaced in pores of fragments.

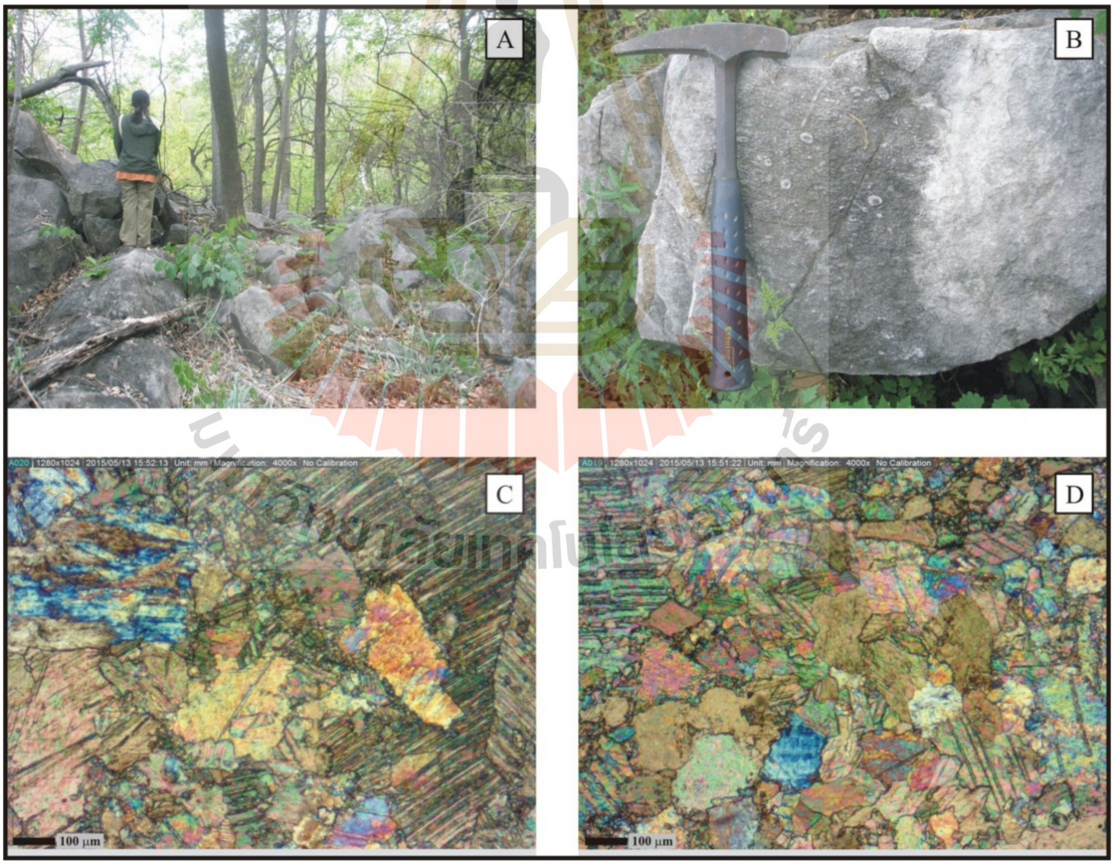


Figure 4.9 A and B are field photographs of Unit 4B exposed in Sukhato temple; C and D are photomicrographs of unsorted biosparite.

Unit 5B

This area is on the top of Khao Makok range (47P 734830E/1620960N). The outcrop is exposed along both sides of the road (Figures 4.10). There are sequences of very thin- to thin-bedded calcarenite interbedded with siltstone, shale and sandstone. The calcarenite is dark brown to black while sandstone beds are grayish green and compact.

Petrographically, sandstone of this unit is characterized by lithic arenite with hematite cement. It consists of a medium- to coarse sand size of feldspar, calcite and mica and is moderately sorted. The grains are sub-angular to sub-rounded and some are weathered which can be observed from iron traces. The size of grains is about 0.04 to 0.07 millimeter in average.

4.1.3 Thai-Danish dairy area

The overall rock units in the Thai-Danish dairy area are mapped as 3 units. The sedimentary sequences of all sections are shown in Figure 4.11. The description of each unit is presented as follows.

Unit 1C

This area is located on a mountain range west of Khao Ta Paen (47P 734945E/1615339N). There are medium- to thick-bedded, grain-supported calcarenite with some thin-bedded shale (Figure 4.12). The weathered surface is usually gray and rough. The grains contain bioclasts of fusulines and unidentified fragments (1 to 5 millimeters in size). Shale are yellowish brown to dark brown and appeared as soil cover with highly weathered.

Figure 4.10 A and B are field photographs of Unit 5B exposed on Khao Makok range; C and D are photomicrographs of lithic arenite.

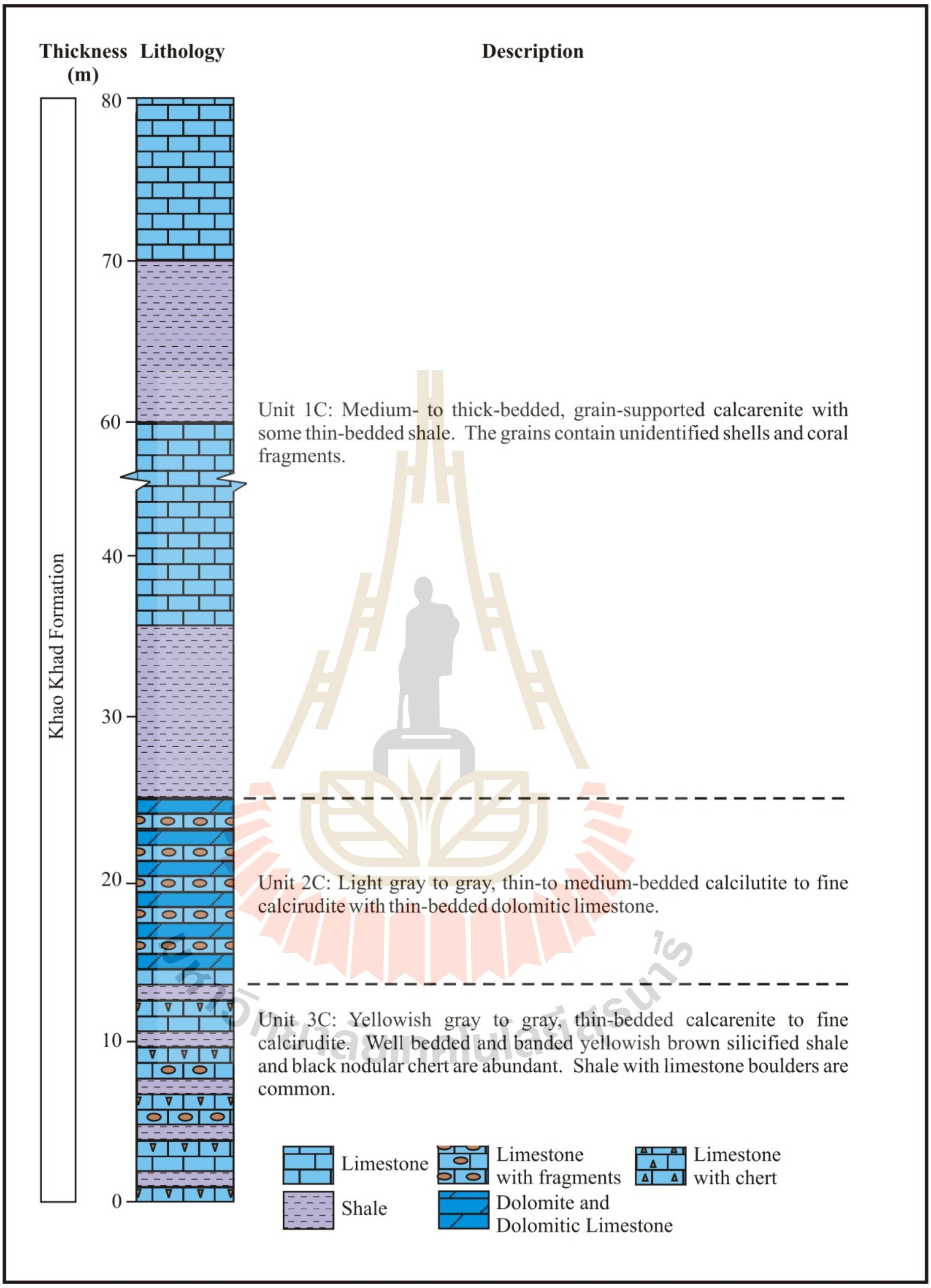


Figure 4.11 The lithostratigraphic column of the Thai-Danish dairy area.

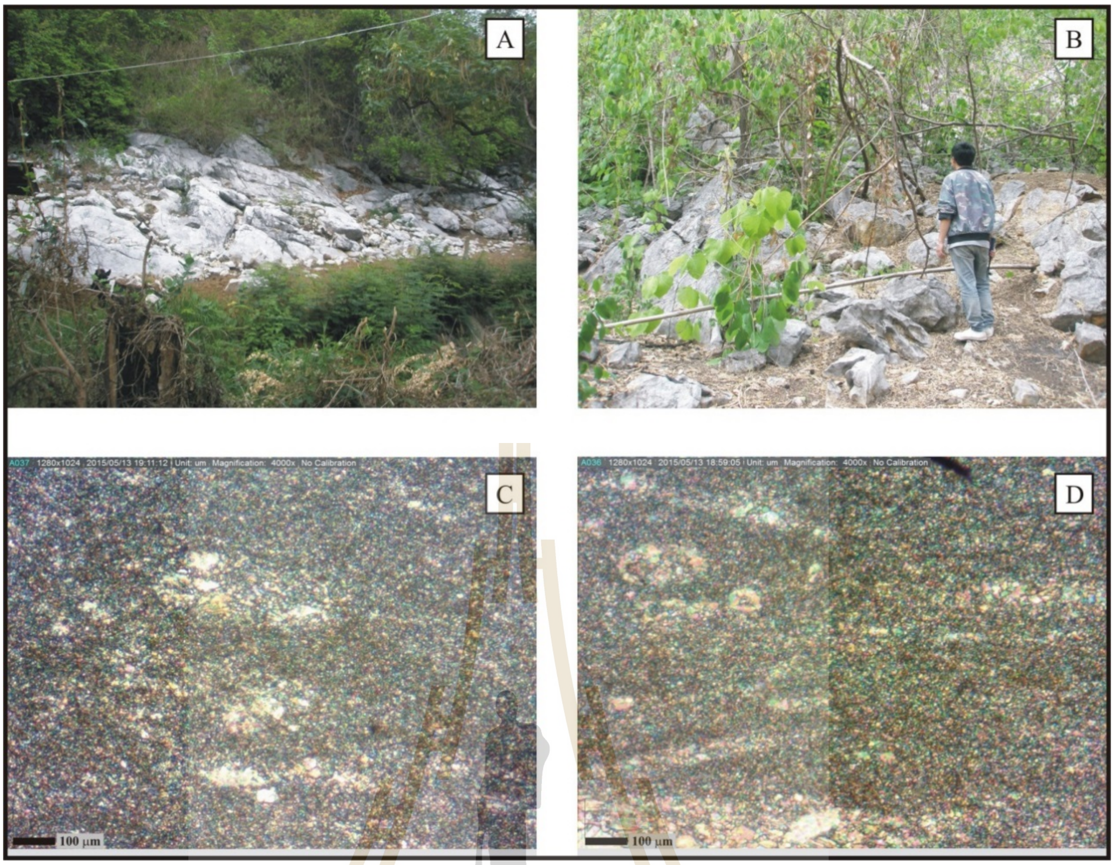


Figure 4.12 A and B are field photographs of Unit 1C exposed on Khao Ta Paen west; C and D are photomicrographs of packed biomicrite.

Petrographically, it consists of biosparite and packed biomicrite. The biosparite is commonly cemented by sparry calcite. The internal pores of bioclasts are filled by sparry calcite cement. Grains are unidentified shells and coral fragments. The packed biomicrite consists of closely packed grains in micrite matrix.

Unit 2C

This unit is on Khao Ta Paen range in Thai-Danish dairy farm (47P 736404E/1618096N). There are light gray to gray, thin- to medium-bedded calcilutite to fine calcirudite with thin-bedded dolomitic limestone. The gray dolomitic limestone has 'elephant skin' on the weathered surface (Figure 4.13).

Petrographic studies show that it is poorly-washed biosparite. The poorly-washed biosparite is commonly cemented by sparry calcite. Grains are fusulines and shell fragments of brachiopods. The matrix is fine-grained.

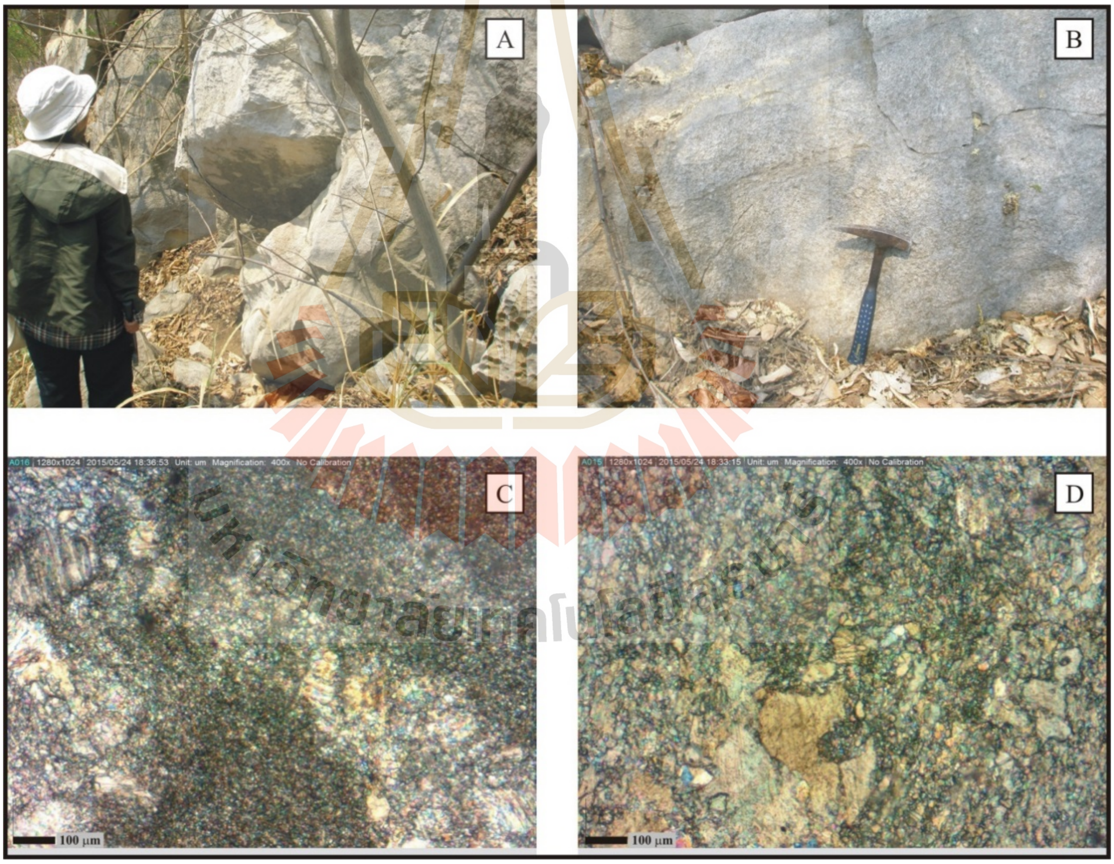


Figure 4.13 A and B are field photographs of Unit 2C exposed on Khao Ta Paen range; C and D are photomicrographs of poorly-washed biosparite.

Unit 3C

It is exposed in a waste disposal pit of the Dairy Farming Promotion Organization of Thailand (Thai-Danish dairy farm), Muak Lek district of Saraburi province (47P 736574E/1617844N). The unit consists of yellowish gray to gray, thin-bedded calcarenite to fine calcirudite. With un-aided eyes, the limestone contains large fragment of crinoids ranging in size from 0.5 to 1 centimeter in diameter. It also shows yellowish brown, well bedded and banded silicified shales and black nodular chert (Figure 4.14). Shale with limestone boulders are common.

Petrographic study shows that the limestone is characterized by biomicrite and poorly-washed biosparite. The biomicrite contains bioclasts in micrite matrix. The internal pores of bioclasts are filled by sparry calcite cement. The poorly-washed biosparite consists of abundant skeletal fragments of crinoids, corals and unidentified fragments with some intraclasts. The matrix is fine-grained and cement contains sparry ferroan calcite.

4.1.4 Sap Takhian area

There are 3 units which can be recognized in the Sabtakien area (Figure 4.15). The traverse lines were located along the road No.2243. The descriptions are presented as follows.

Unit 1D

The locality is in Sap Noi Tai Samakee temple (47P 746215E/ 1642467N). This unit displays a sequence of gray to dark gray, thin-bedded calcarenite (Figure 4.16). It is graded into clastic association of thin-bedded silty shale, silty sandstone and sandstone. The cumulative thickness ratio of carbonate/clastic is approximately 1:4. Shale are grayish brown to black, thin-bedded and turns to yellowish brown on weathered surface. Shale with limestone blocks are found.

Petrographically, the limestone comprises biomicrite and biosparite. The biomicrite contains skeletal fragments embedded in fine-grained matrix. The biosparite is cemented by sparry ferroan calcite. It contains abundant small fragments of fusulines and crinoids.

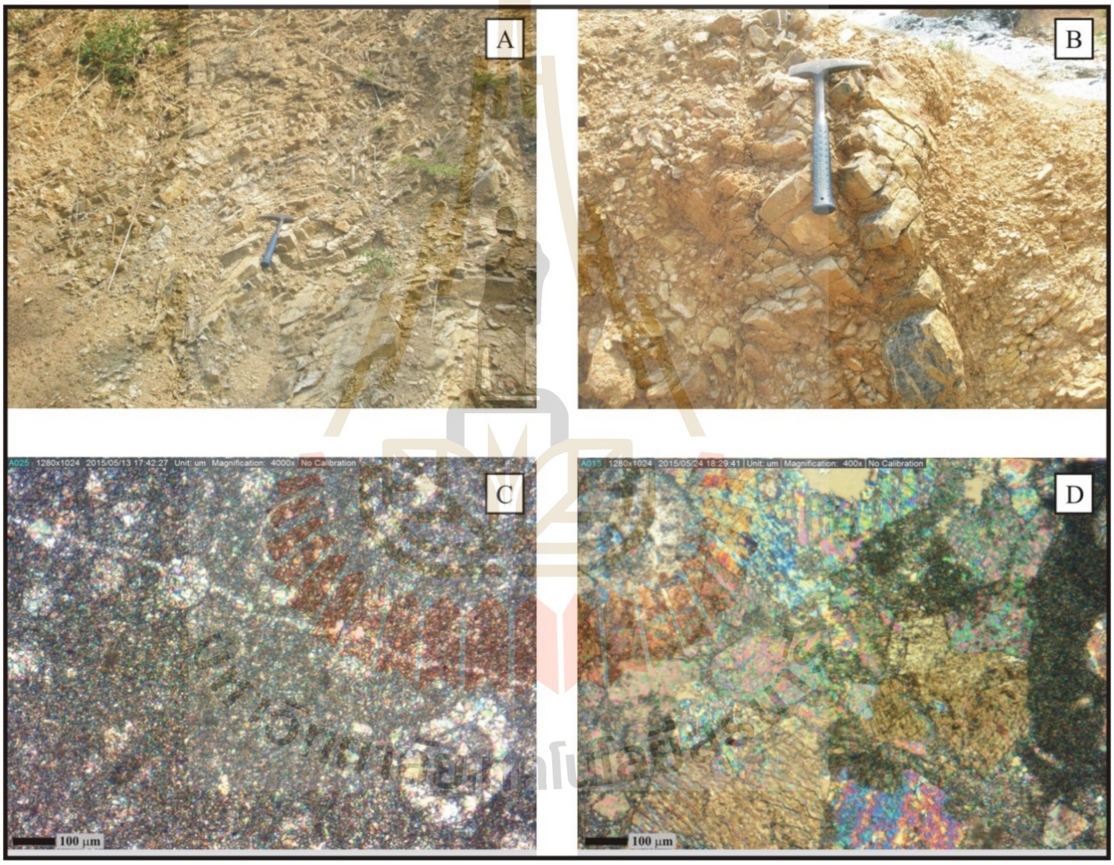


Figure 4.14 A and B are field photographs of Unit 3C exposed in waste disposal pit; C and D are photomicrographs of biomicrite and poorly-washed biosparite.

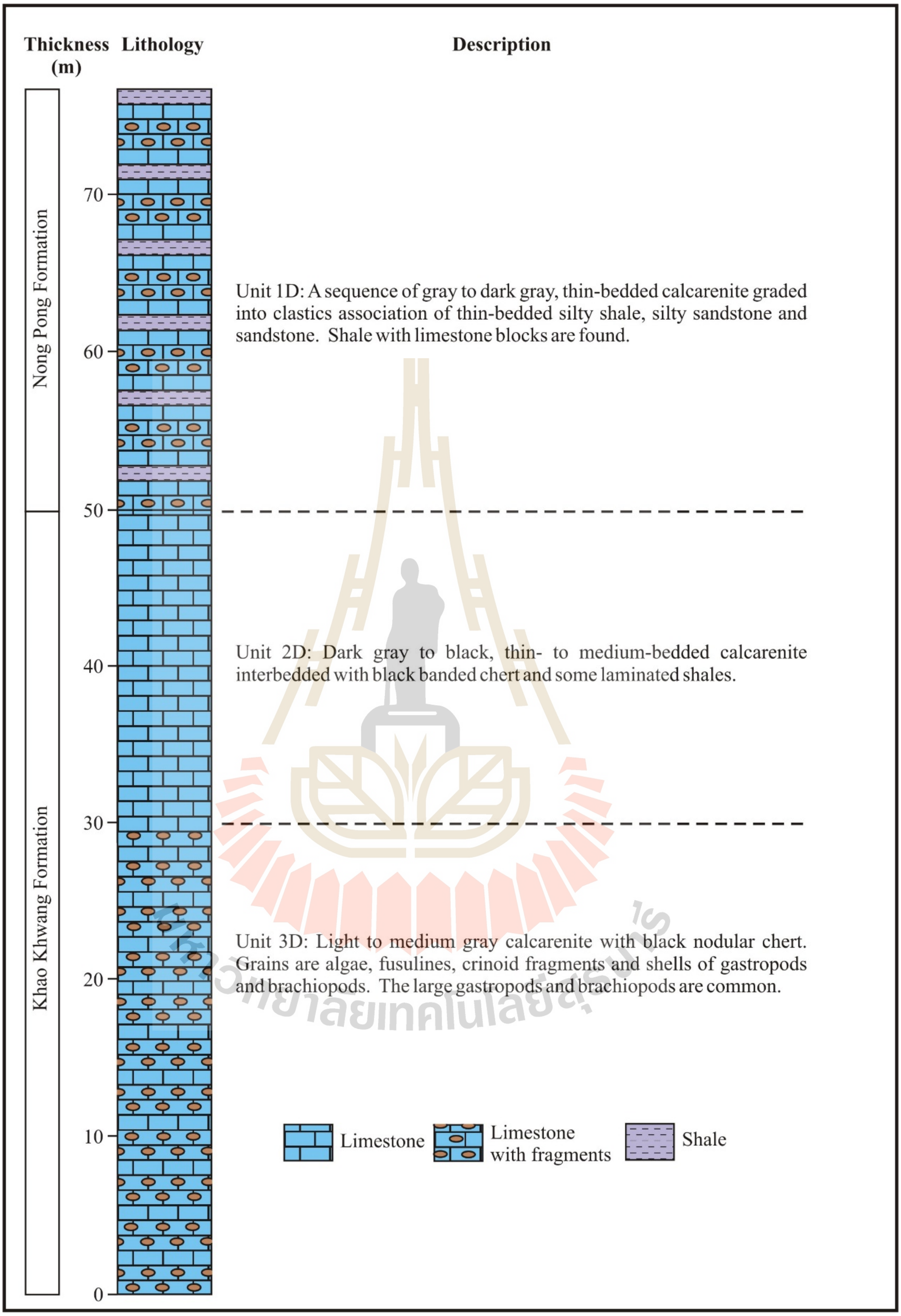


Figure 4.15 The lithostratigraphic column of the Sap Takhian area.

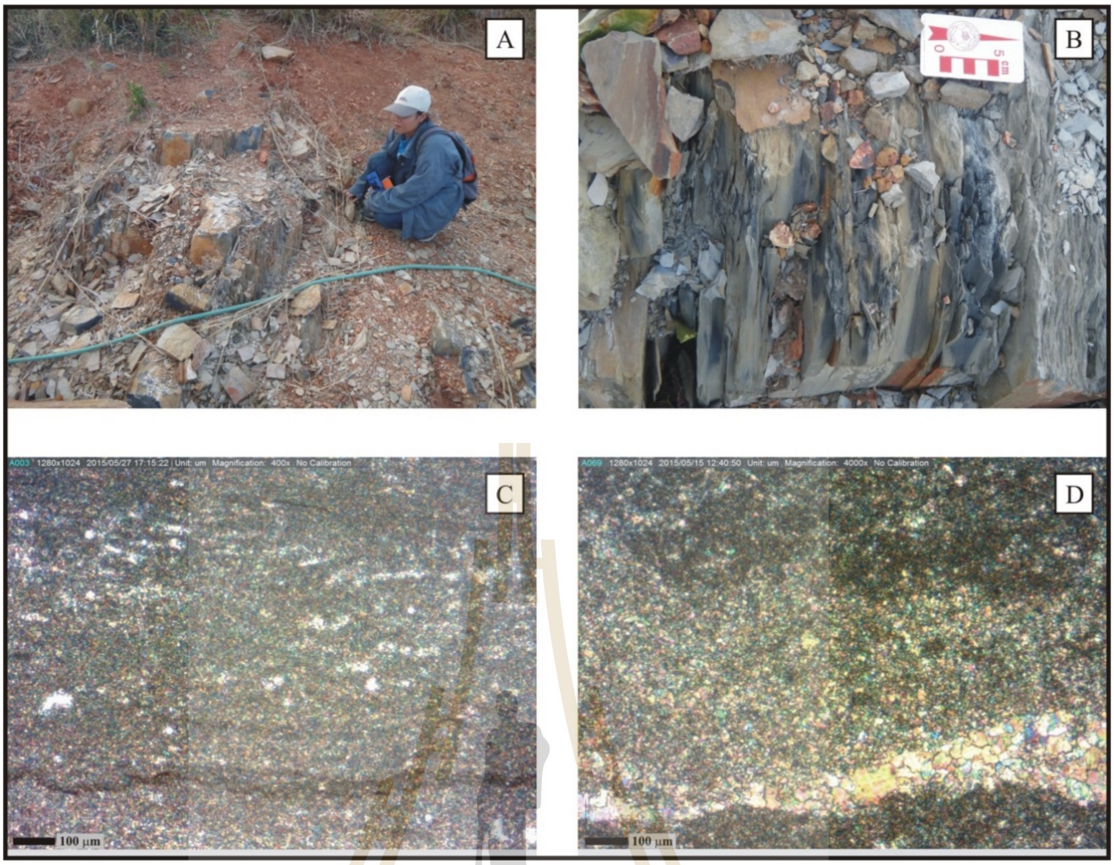


Figure 4.16 A and B are field photographs of Unit 1D exposed in Sap Noi Tai Samakee temple; C and D are photomicrographs of biomicrite and biosparite.

Unit 2D

The locality is in Sap Takhian temple (47P 745186E/1648654N). This unit contains dark gray to black, thin- to medium-bedded calcarenite interbedded with black banded chert and some laminated shales. Shale are yellowish brown and mostly weathered into pale gray soil (Figure 4.17). The calcarenite shows grain-supported, laminated and moderately sorted.

Petrographically, this unit consists of biosparite. The rock contains 10 to 20 percent grains and is commonly cemented by sparry calcite. The bioclasts are small fusulines, shells and unidentified fragments. The internal pores of bioclasts are filled by sparry calcite cement. The banded chert consists of microcrystalline quartz with some calcareous patches.

Unit 3D

This unit is located on a mountain, backside of Sap Takhian temple in Muak Lek district, Saraburi province (47P 745155E/1648660N). It comprises light to medium gray calcarenite with black nodular chert (Figure 4.18). Grains are moderately sorted and composed of algae, fusulines, crinoid fragments and shells of gastropods and brachiopods. The large gastropods and brachiopods are common. Chert nodules are scattered in this unit about 10 to 20 centimeters in size.

Petrographic study shows characteristics of biomicrite, biosparite and poorly-washed biosparite. The rock contains various types of grains such as, fusulines and shell and algae fragments with sparry calcite cement. The biomicrite contains skeletal fragments of crinoids, fusulines, bryozoans and shells embedded in fine-grained matrix. The poorly-washed biosparite contains micrite and sparry calcite cement. It shows large grains of shell fragments.

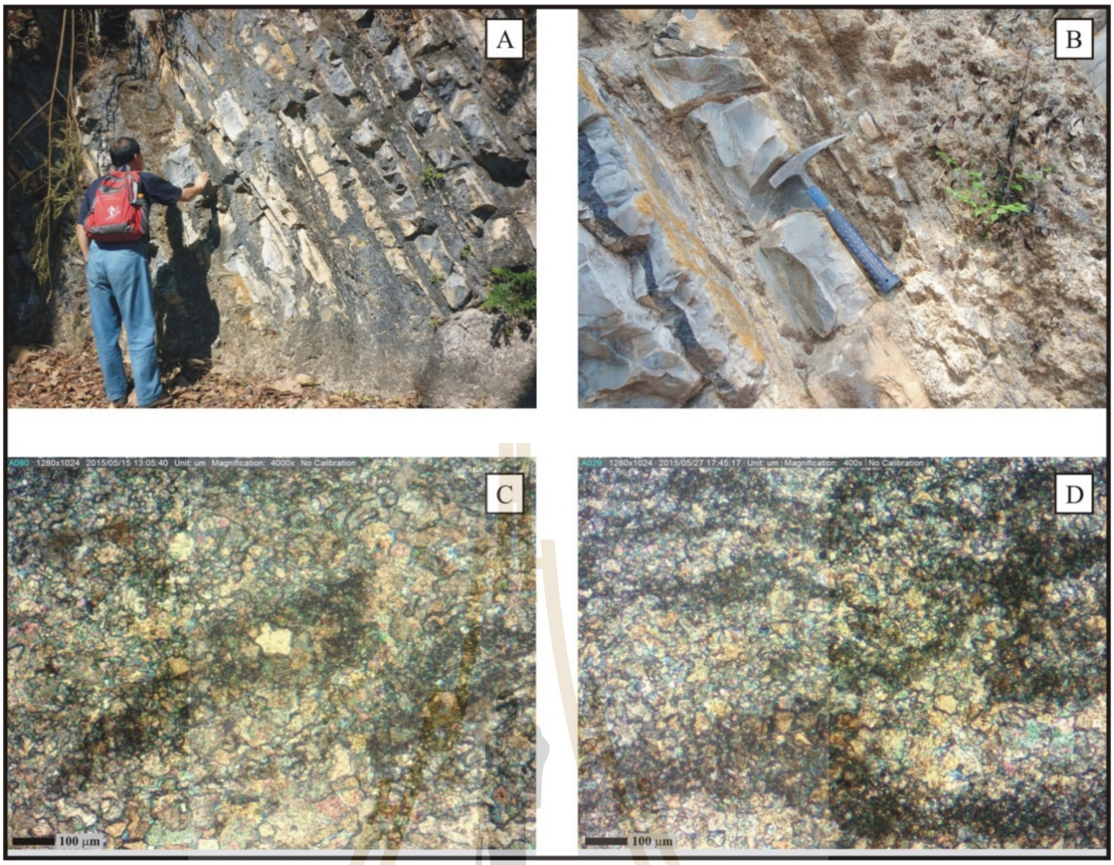


Figure 4.17 A and B are field photographs of Unit 2D exposed in Sap Takhian temple; C and D are photomicrographs of biosparite.

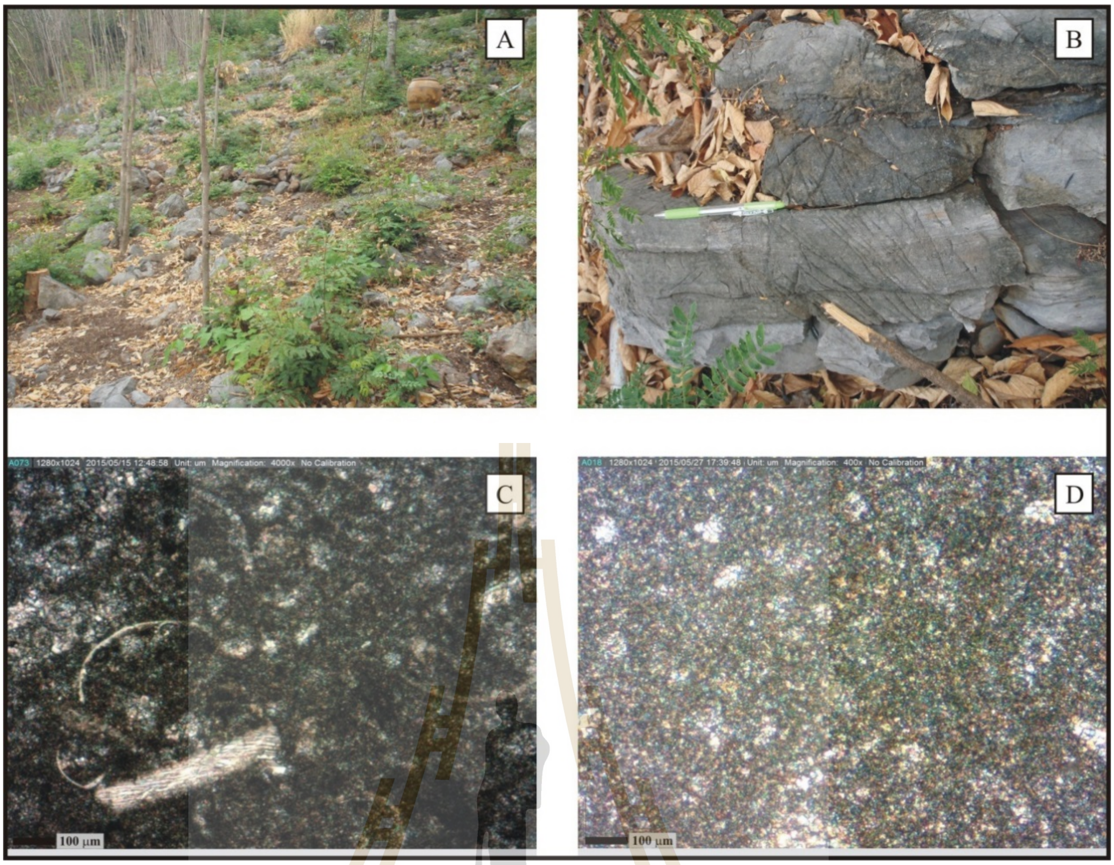


Figure 4.18 A and B are field photographs of Unit 3D exposed backside of Sap Takhian temple; C and D are photomicrographs of biomicrite and biosparite.

4.1.5 Old quarry

This locality is well exposed in an old quarry of Nong Phaksen village, Pak Chong district of Nakhon Ratchasima province along road No.2243 (47P 750350E/1635930N). The descriptions of 2 units with different characteristics are presented as follows (Figure 4.19).

Unit 1E

This unit is dominated by a sequence of dark gray, thin-bedded calcarenite graded into clastic association of thin-bedded chert, shale, siltstone and sandstone. Chert and shale are black and are yellowish brown in silicified parts (Figure 4.20).

Unit 2-1E

This unit displays gray calcilutite, calcarenite to fine calcirudite interbedded with shale and sandstone (Figure 4.21). The weathered surface is usually light gray and slightly rough. The shale and sandstone are yellowish brown to reddish brown, thin-bedded and turn to yellow soil on the weathered surface. The rocks exhibit graded-bedding and lamination.

Petrographically, the unit consists of packed biomicrite and biomicrite. It is closely packed grains are micrite matrix. The grains are skeletal fragments of crinoids, fusulines, shells and unidentified fragments embedded in fine-grained matrix.

Unit 2-2E

This unit comprises gray calcarenite and calcirudite (Figure 4.22). The weathered surface of the unit is slightly rough and clearly reveals diverse types of grains such as, crinoids and fusulines fragments. The calcarenite is coarse grained and displays grain-supported texture with various bioclasts of fusulines, algae, branching corals and crinoid fragments. The calcirudite displays matrix-supported texture. The bioclasts are large fossil fragments and other limestone clasts.

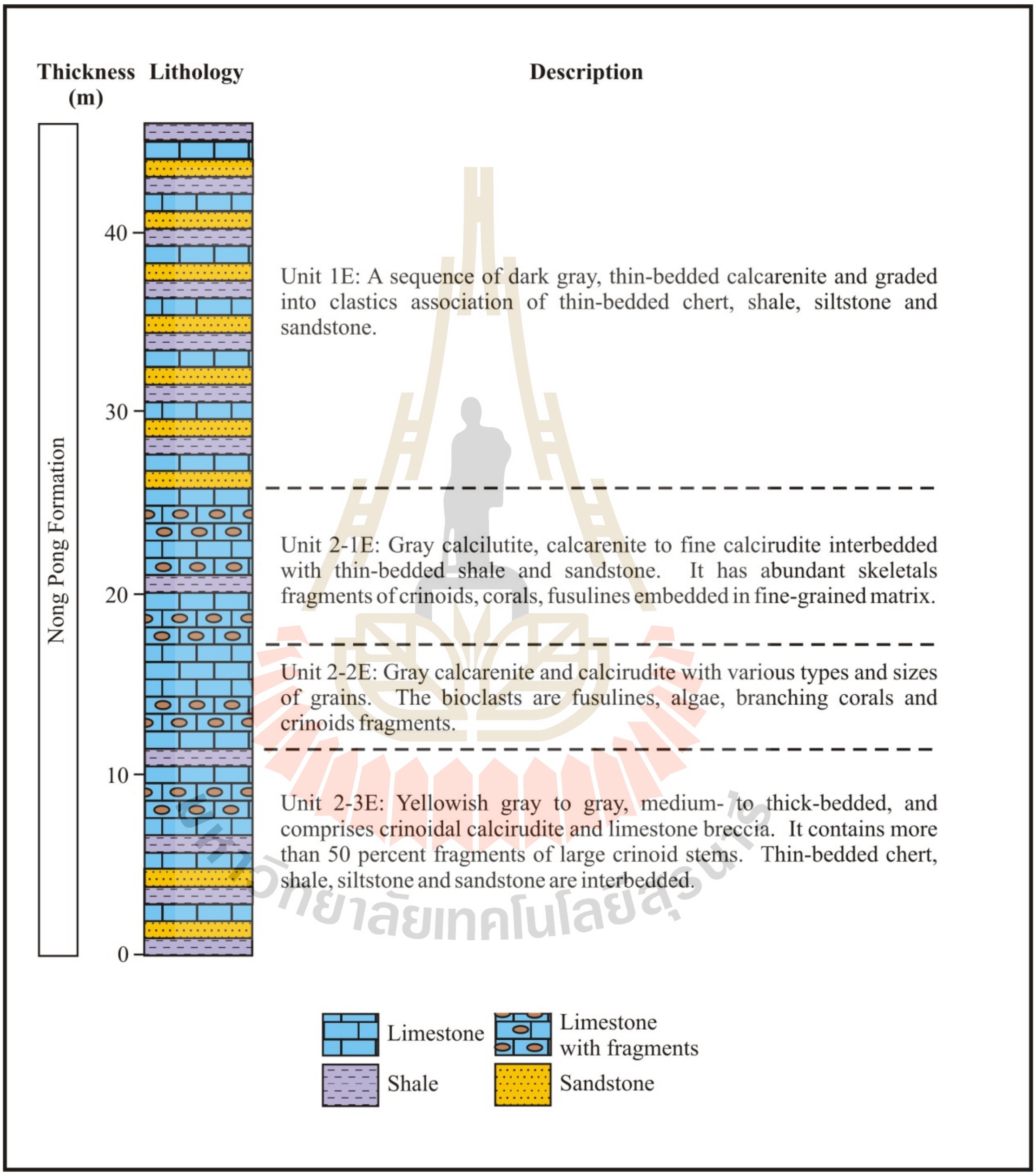


Figure 4.19 The lithostratigraphic column of the Old quarry.

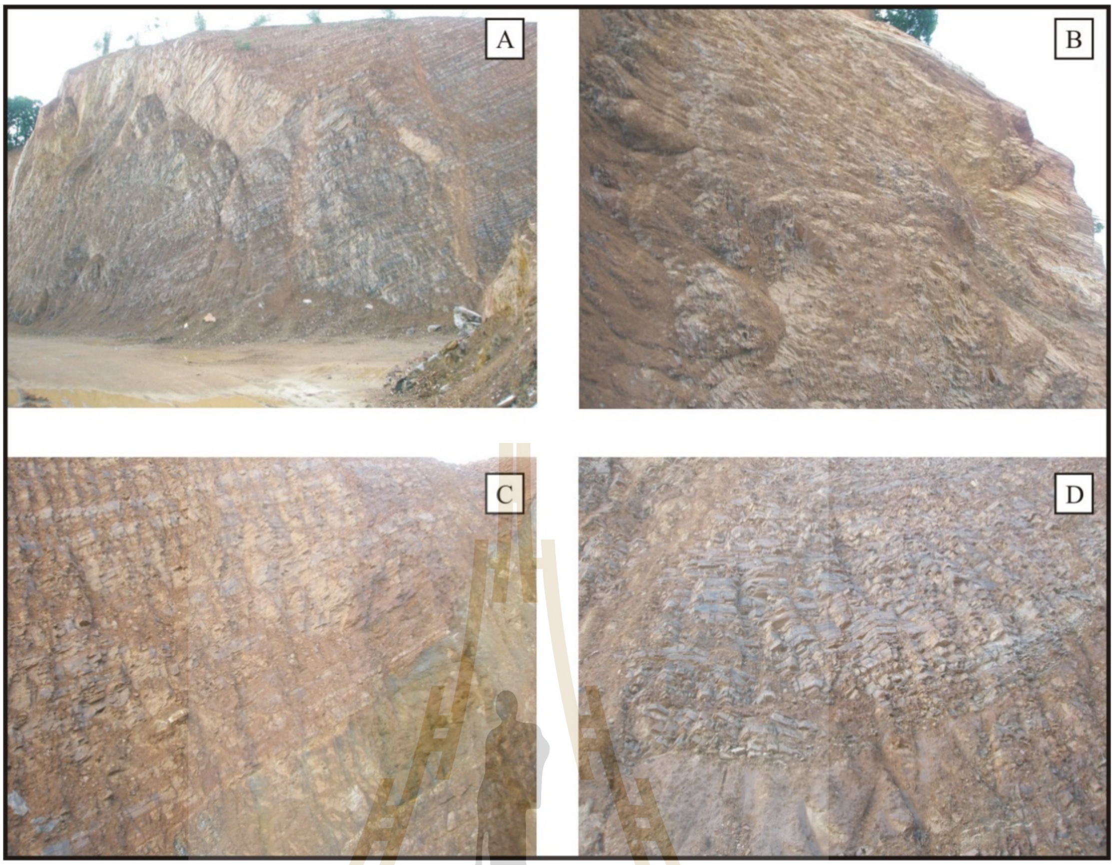


Figure 4.20 Field photographs of Unit 1E exposed in an old quarry of Nong Phaksen village.

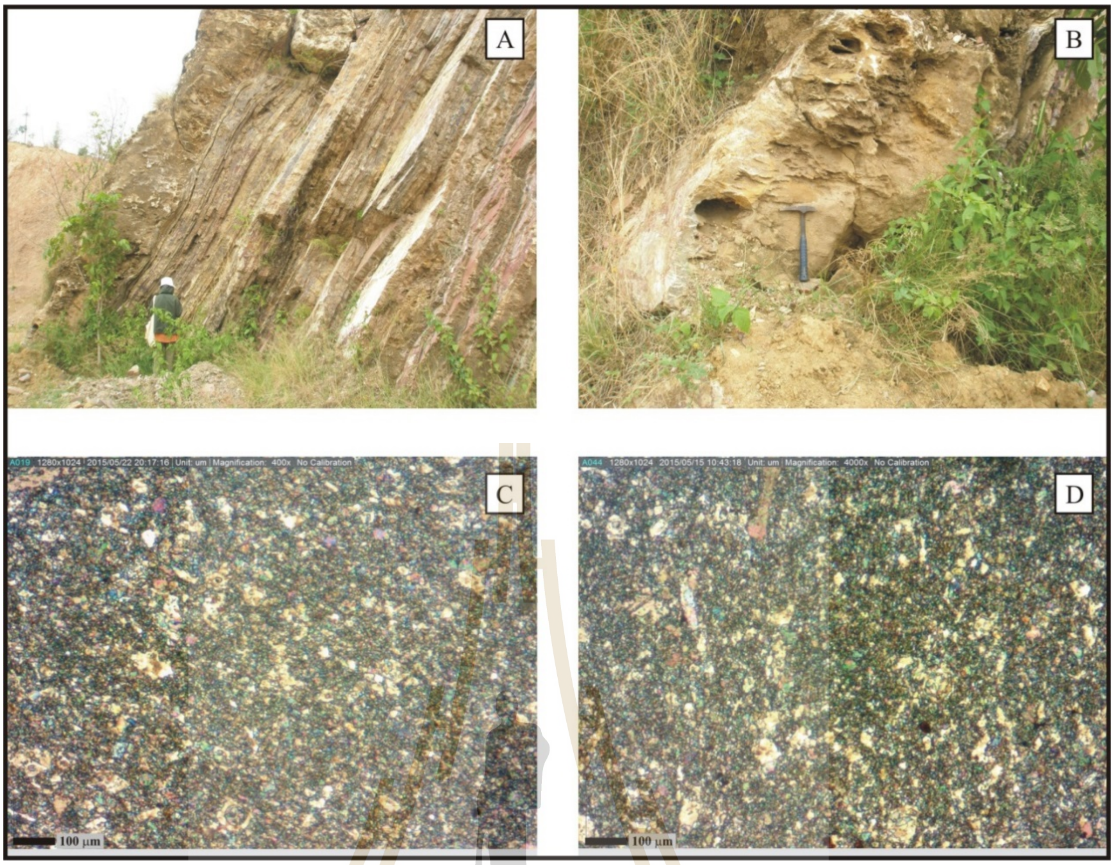


Figure 4.21 A and B are field photographs of Unit 2-1E exposed in an old quarry of Nong Phaksen village; C and D are photomicrographs of biomicrite.

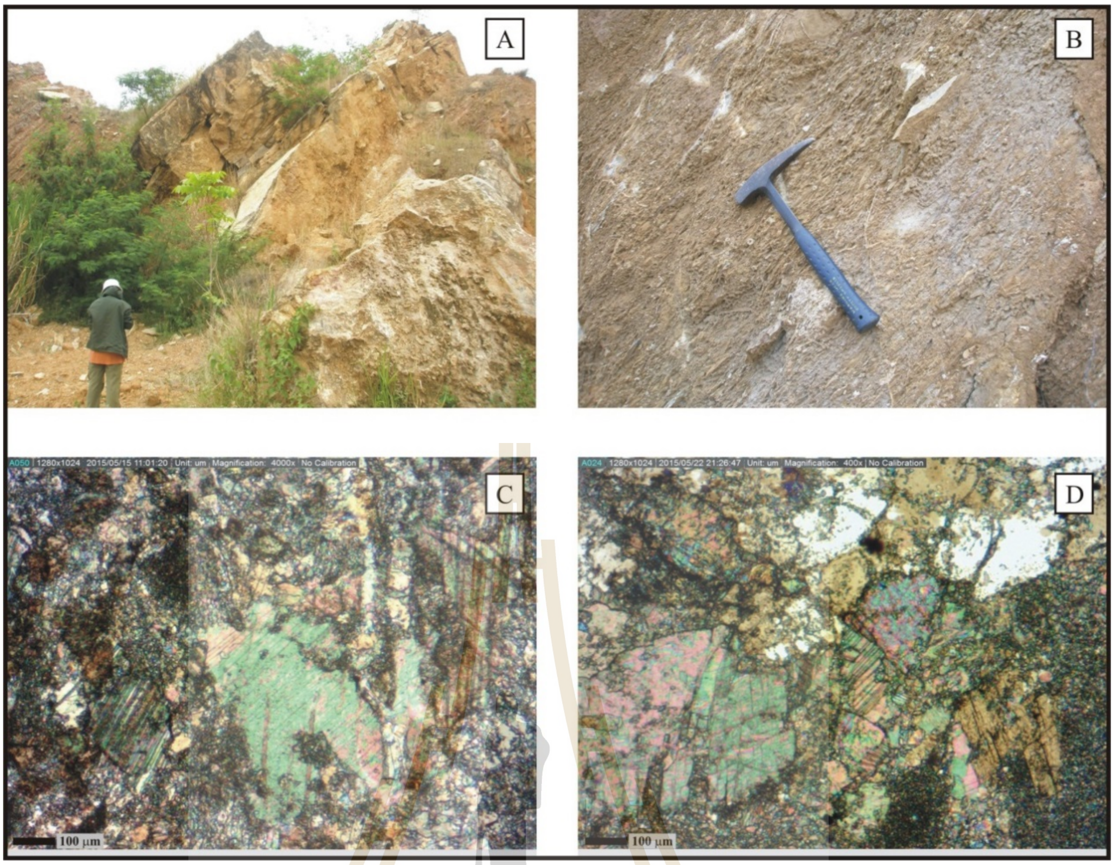


Figure 4.22 A and B are field photographs of Unit 2-2E exposed in an old quarry of Nong Phaksen village; C and D are photomicrographs of as poorly-washed biosparite.

Under a microscopic, this unit can be classified as biosparite and poorly-washed biosparite. It contains abundant skeletal fragments of crinoids, bryozoans and unidentified fossils. It is grain-supported with sparry calcite cement. The calcite crystals have various sizes but some of them are eroded.

Unit 2-3E

This unit is yellowish gray to gray, medium- to thick-bedded crinoidal calcirudite and limestone breccia (Figure 4.23). These rocks show a grain-supported fabric with various types and sizes of grain components. With un-aided eyes, the rock contains more than 50 percent fragments of large crinoid stems from 0.5 to 2 centimeters in diameter. The breccia clasts have various sizes and shapes, varying in size from 2 to 15 centimeters. The lower part of this unit is composed of thin-bedded chert, shale, siltstone and sandstone.

Petrographic study reveals that this unit is poorly-washed biosparite, unsorted crinoidal biosparudite and crinoidal biosparite which contain mainly of crinoid and bryozoan fragments. The breccia clasts consist of biomicrite and biosparite. The poorly-washed biosparite is characterized by abundant skeletal fragments of crinoids, fusulines and unidentified fossils. It is grain-supported with sparry ferron calcite cement. The crinoidal biosparudite and crinoidal biosparite are cemented by sparry calcite. Some fine-grained micrite are found as matrix. The calcite crystals are commonly cracked and eroded.

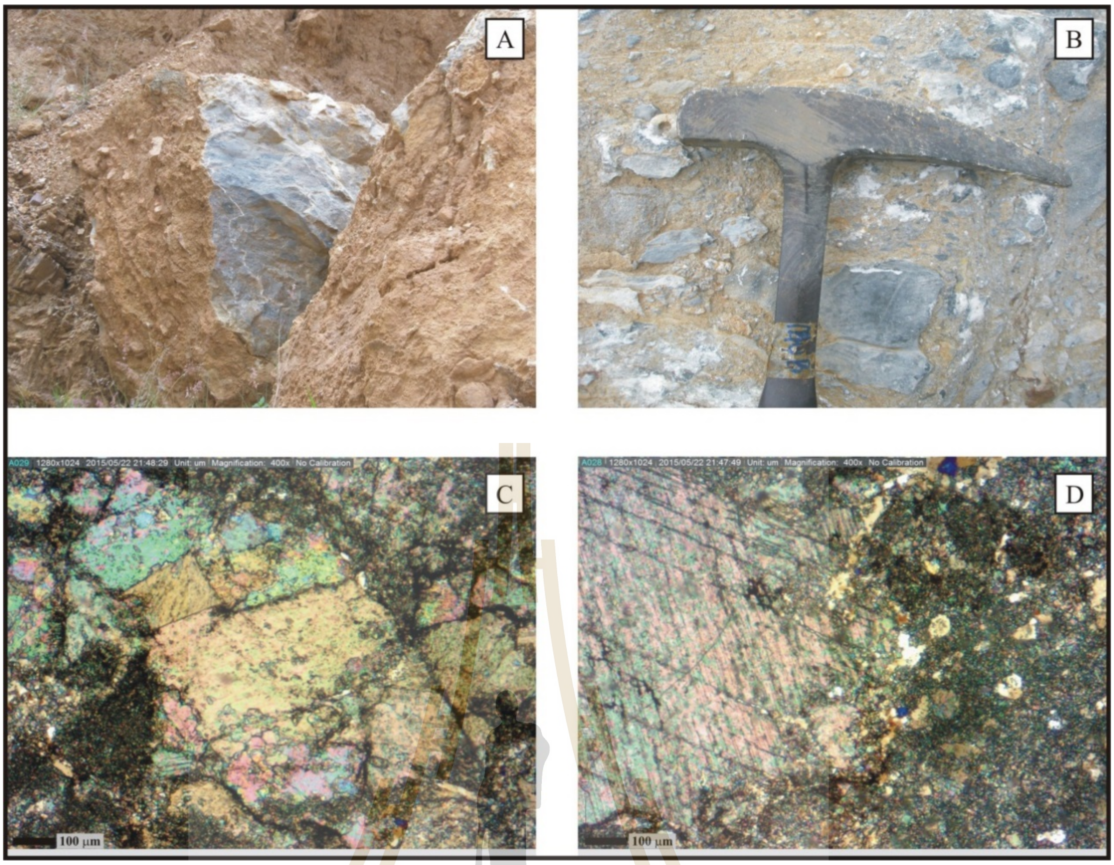


Figure 4.23 A and B are field photographs of Unit 2-3E exposed in an old quarry of Nong Phaksen village; C and D are photomicrographs of poorly-washed biosparite.

4.1.6 Khao Sai Sayan temple

The location is in the Khao Sai Sayan temple, Pak Chong district of Nakhon Ratchasima province. There are 2 units in this area which will be presented as follows (Figure 4.24).

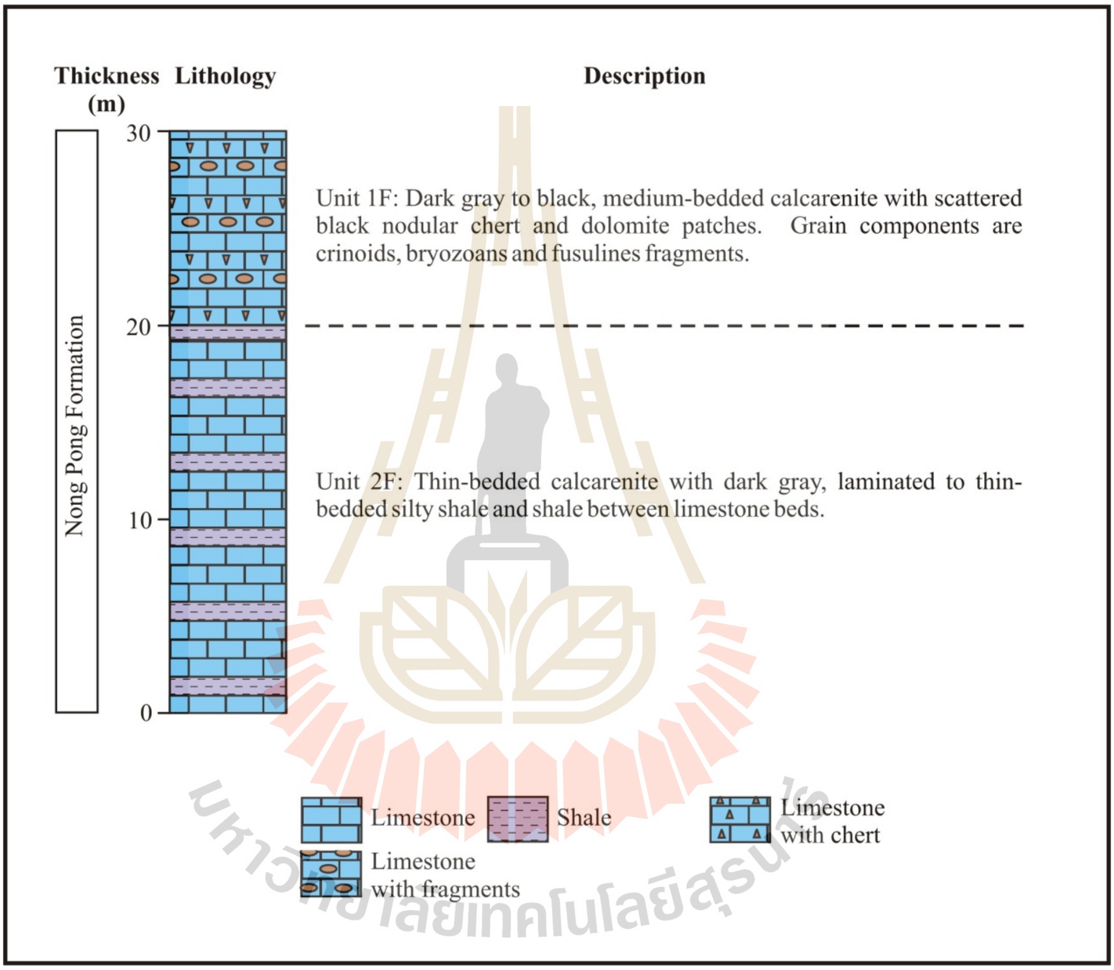


Figure 4.24 The lithostratigraphic column of the Khao Sai Sayan temple.

Unit 1F

The top of Khao Sai Sayan temple (47P 758001E/1624730N) consists of dark gray to black, medium-bedded calcarenite with scattered black nodular chert and dolomite patches (Figure 4.25). The nodules range in size from 5 to 20 centimeters and partly elongated shape. The grain components are crinoids, bryozoans and fusulines fragments.

Microscopically, this unit comprises biosparite with broken fragments of crinoids, bryozoans and unidentified fossils. The moderately sorted grains are cemented together by mosaic of fine-grained and relatively clear calcite. The black microcrystalline chert appears as lenses and elongated nodular shape embedded in the carbonate rock.

Unit 2F

This unit is located at the foothill (47P 758233E/1624744N). It is thin-bedded calcarenite (Figure 4.26). The dark gray, laminated to thin-bedded silty shale and shale are abundant between limestone beds.

Microscopically, the limestone comprises biomicrite. It consists of closely packed grains with sparry calcite cement. It contains skeletal fragments embedded in micrite matrix. Grains are rounded to sub-rounded and unidentified.

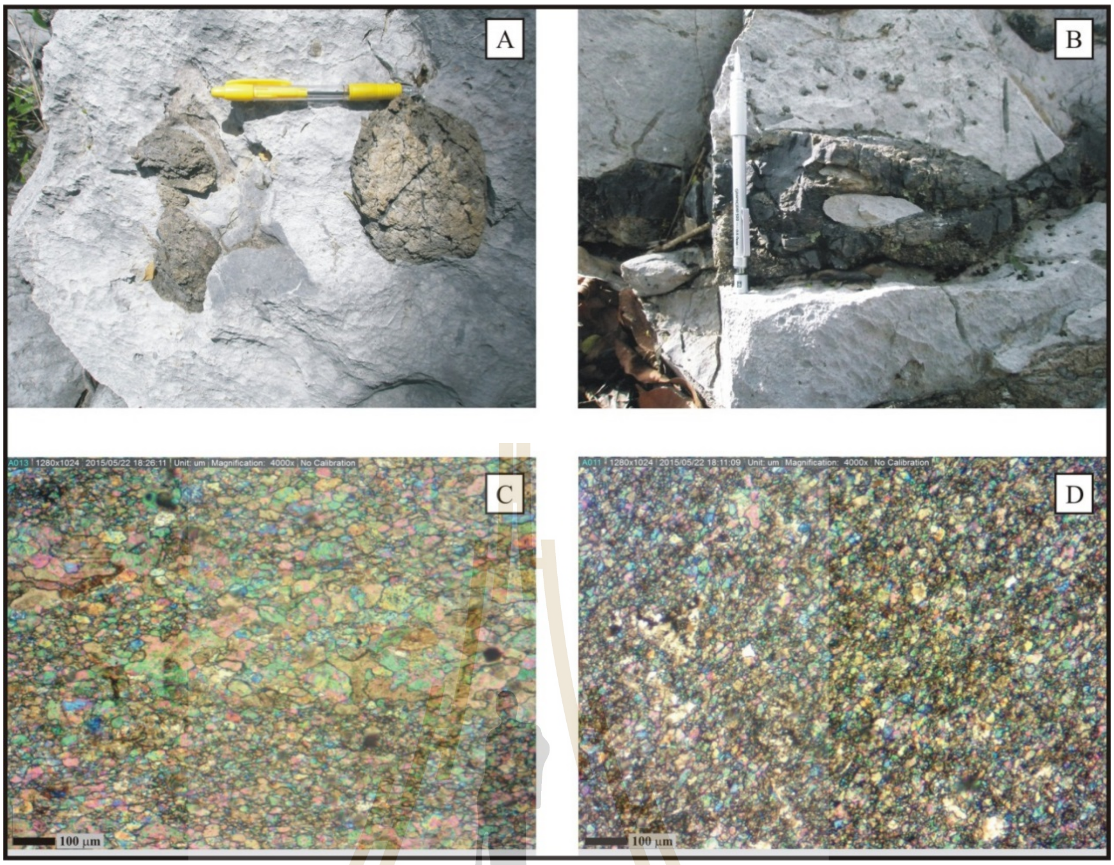


Figure 4.25 A and B are field photographs of Unit 1F exposed on the top of Khao Sai Sayan temple; C and D are photomicrographs of biosparite.

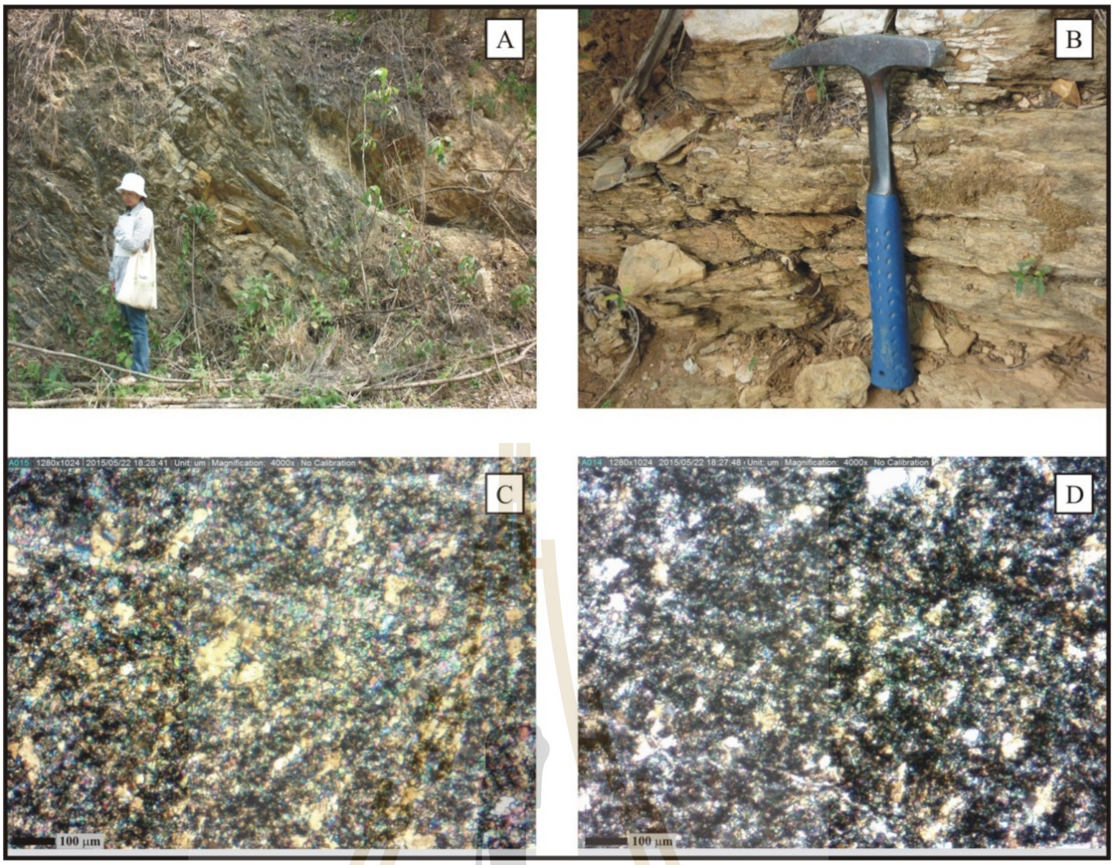


Figure 4.26 A and B are field photographs of Unit 2F exposed at a foothill of Khao Sai Sayan temple; C and D are photomicrographs of biomicrite.

4.1.7 Nong Pong area

This area is located around Nong Pong village of Muak Lek district, Saraburi province. There are 4 units with different characteristics. The descriptions are presented as follows (Figure 4.27).

Unit 1G

The outcrop exposes along both sides of the road No.2224, Kms 36 to 38 (47P 754684E/1642761N). This unit is a sequence of dark gray, thin-bedded and laminated calcarenite which is graded into clastic association of reddish brown, thin-bedded shale, mudstone, siltstone and sandstone (Figure 4.28). The weathered surface of clastics usually show yellowish brown but turn to dark brown in the silicified parts. In the upper part, the ratio of carbonate/clastic is approximately 4:1 while in the lower part this ratio changes to 1:4.

Petrographically, this unit presents poorly-washed biosparite and biomicrite. The poorly-washed biosparite is characterized by abundant skeletal fragments of crinoids, corals, fusulines and unidentified fragments with some intraclasts. It is grain-supported with sparry calcite cement. The biomicrite contains skeletal fragments embedded in fine-grained matrix.

Unit 2G

This unit is characterized by gray to dark gray, thin- to medium-bedded, poorly sorted calcarenite to calcirudite (47P 754710E/1644763N). With un-aided eyes, the major grains components are fusulines, crinoid stems, intraclasts, bryozoans, shells and unidentified fragments (Figure 4.29).

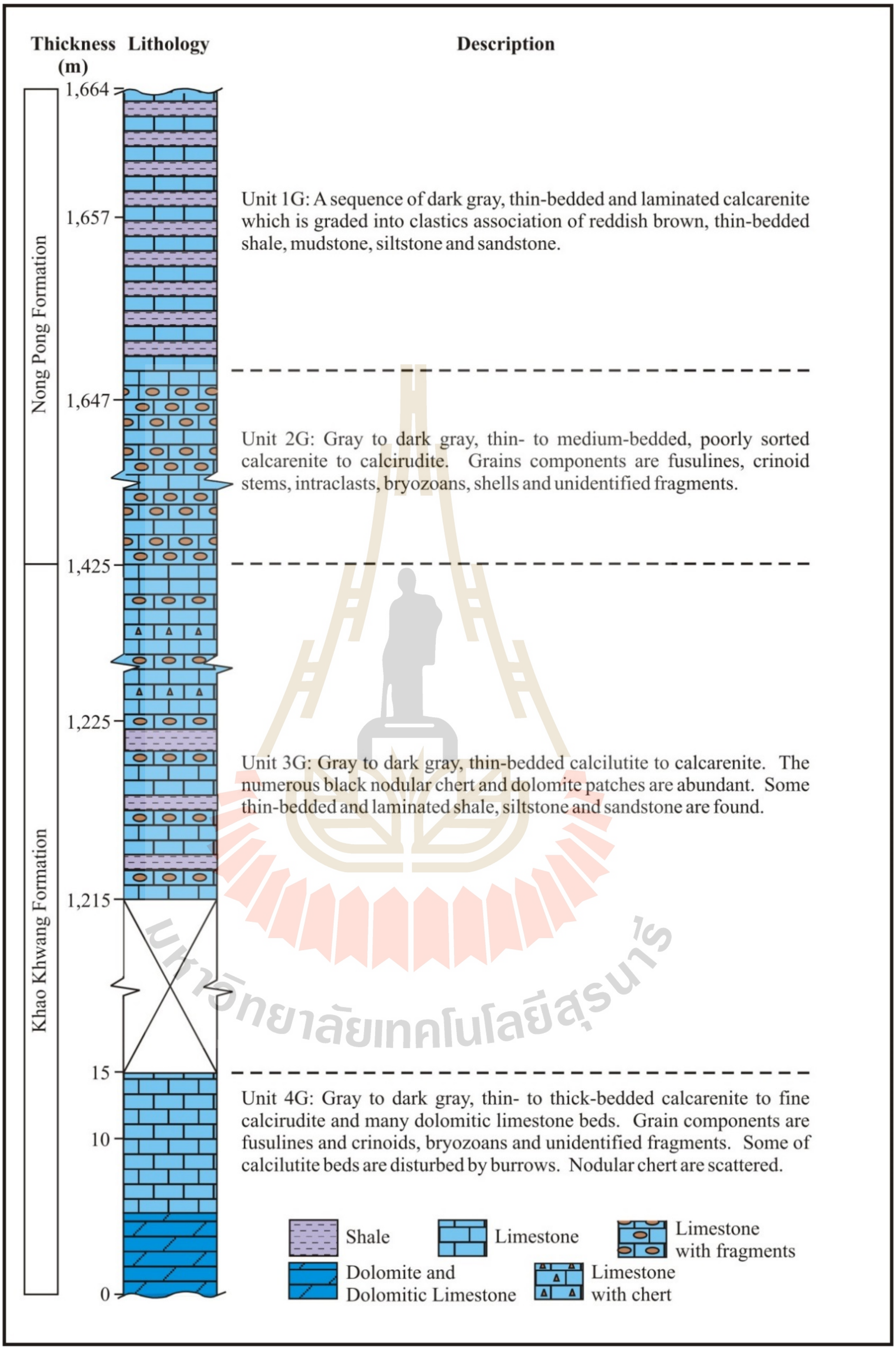


Figure 4.27 The lithostratigraphic column of the Nong Pong area.

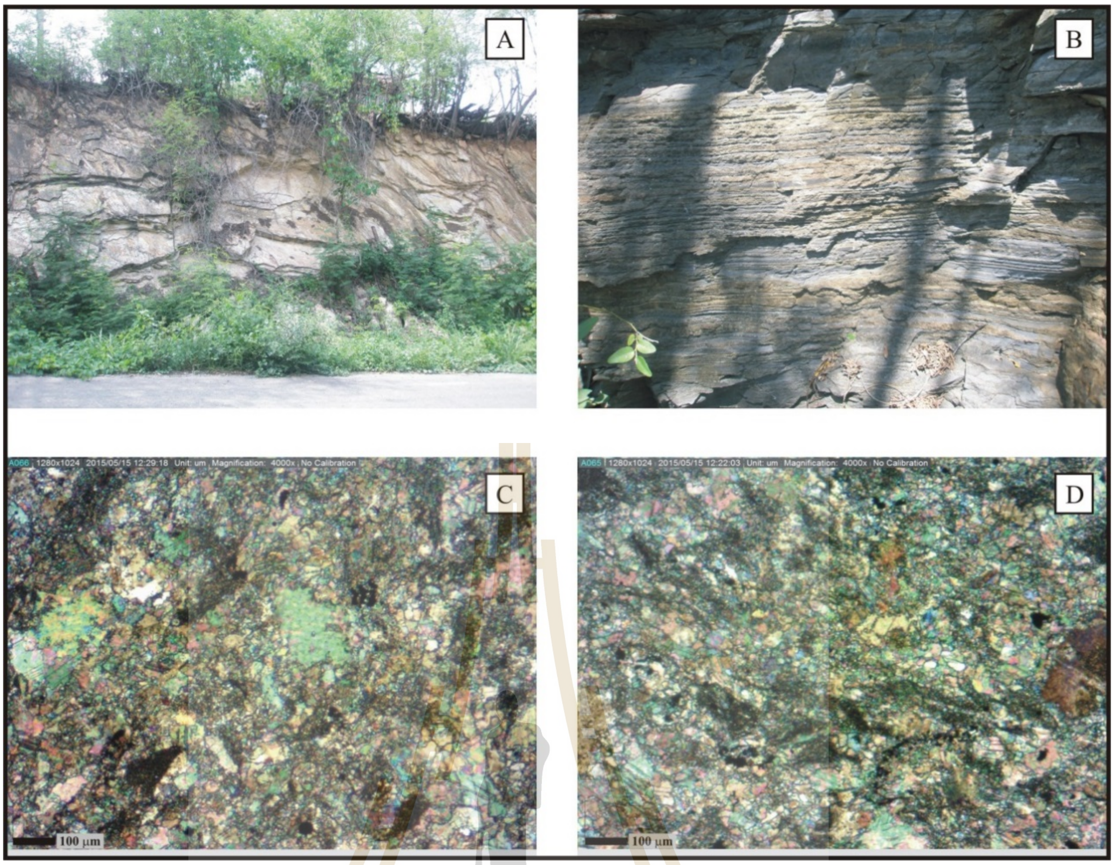


Figure 4.28 A and B are field photographs of Unit 1G exposed on a road cut in Nong Pong village; C and D are photomicrographs of poorly-washed biosparite.

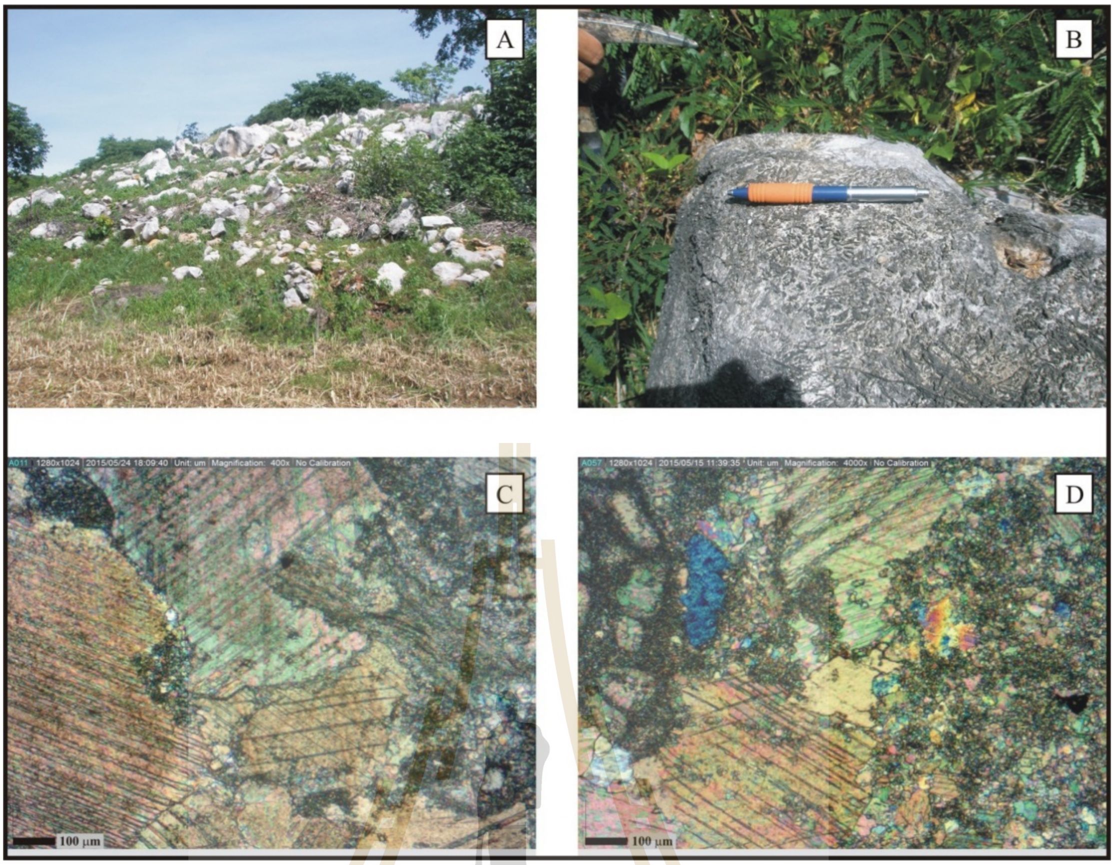


Figure 4.29 A and B are field photographs of Unit 2G exposed in Nong Pong village; C and D are photomicrographs of poorly-washed biosparite.

The petrographic study presents unsorted biosparite, unsorted biosparudite and poorly-washed biosparite. The unsorted biosparite and unsorted biosparudite contain shell fragements, crinoid stems and intraclasts of various sizes (0.5 to 5 centimeters) which are cemented by sparry calcite. The poorly-washed biosparite contains abundant grains of fusulines, crinoids, bryozoans, intraclasts and unidentified skeletal fragments and micrite matrix. There are cemented by sparry calcite.

Unit 3G

This unit is presented in Nong Pong village (47P 754310E/1645078N, 754605E/1644924N). It is abundant thin-bedded and laminated clastics of chert, shale, siltstone and sandstone in the upper part. The mostly of unit is in the upper part with gray to dark gray, thin- to medium-bedded, laminated calcarenite to calcilutite (Figure 4.30). The numerous black nodular chert and dolomite patches are abundant and parallel in this unit.

Microscopically, the limestone comprises poorly-wash intrasparite and packed biomicrite. The poorly-washed intrasparite consists of intraclasts and skeletal fragments with some micrite and sparry calcite. The packed biomicrite contains skeletal fragments of crinoids, fusulines, corals and bryozoans embedded in fine-grained matrix. The banded chert consists of microcrystalline quartz.

Unit 4G

This unit is located at Tham Dao Khao Kaew temple (47P 751131E/1645784N). It is characterized by gray to dark gray, thin- to thick-bedded calcarenite to fine calcirudite and many dolomitic limestone beds (Figure 4.31). The numerous black nodular cherts, dolomite patches and pinkish gray, banded argillaceous calcilutite with laminated shale are abundant. These rocks are associated with dolomitic limestone. Some of calcilutite beds are disturbed by burrows. The skeletal grain components are fusulines and crinoids, bryozoans and unidentified fragments. The chert nodules are usually protruded from the surface due to differential weathering.

Figure 4.30 A, B, C and D are field photographs of Unit 3G exposed in Nong Pong village; E and F are photomicrographs of packed biomicrite.

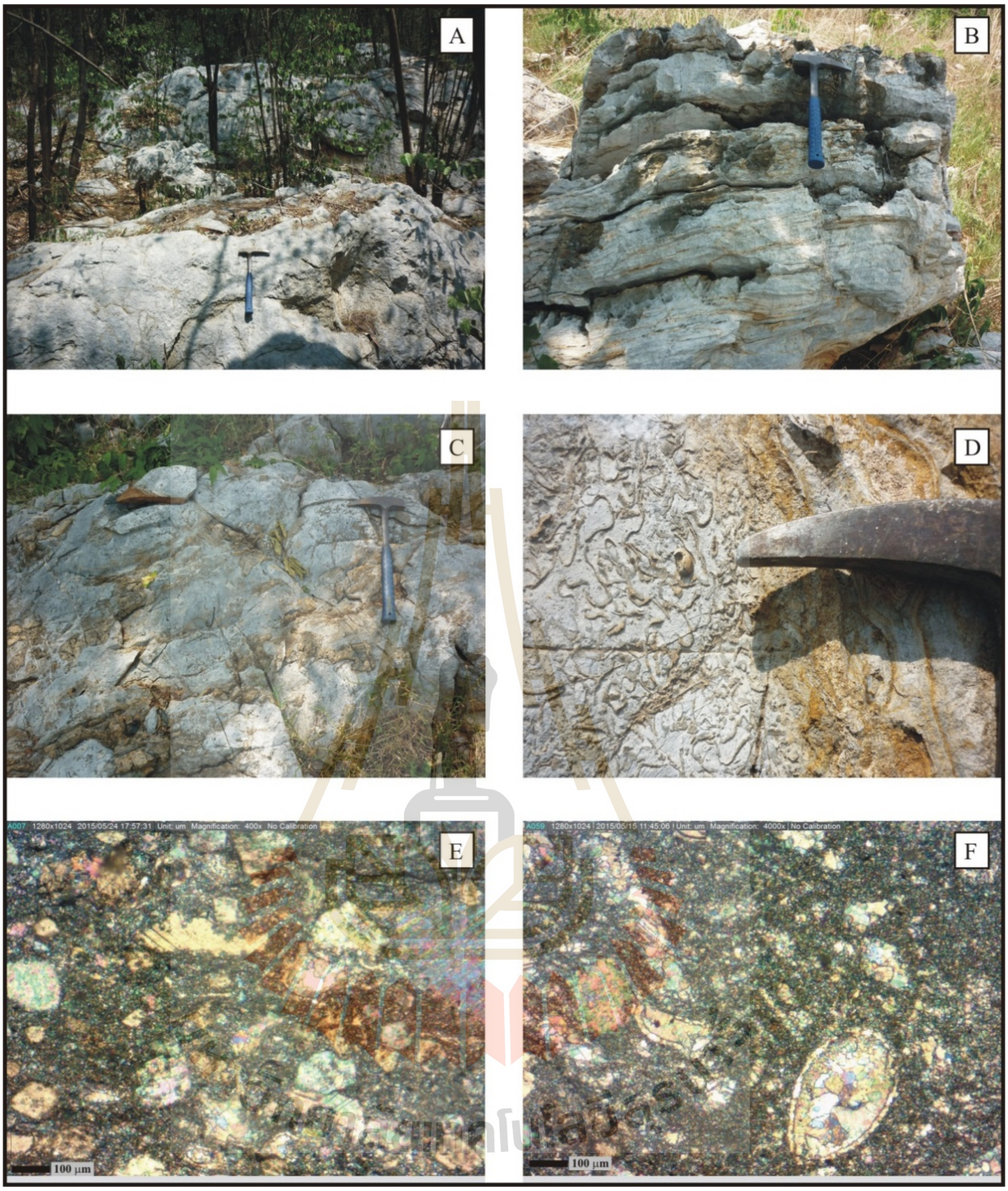


Figure 4.31 A, B, C and D are field photographs of Unit 4G exposed in Tham Dao Khao Kaew temple; E and F are photomicrographs of poorly-washed biosparite.

Microscopically, the rock comprises packed biomicrite, unsorted biosparite and poorly-washed biosparite. The packed biomicrite is the broken bioclasts consist of fusulines, crinoids and abundant unidentified fragments embedded in the micrite matrix. The unsorted biosparite contains shells and crinoids fragments of various sizes. The poorly-washed biosparite contains abundant grains of fusulines and crinoids, bryozoans and unidentified skeletal fragments with some micrite matrix. It is cemented by sparry calcite. The chert nodules are microcrystalline quartz. The burrows are abundant in the micrite matrix and filled by microcrystalline dolomite and sparry calcite cement.

4.2 Lithostratigraphic Correlation

Based on the earlier descriptions, it can be noted that the rock sequences of 7 measured sections are resembled. Some rock units have similar lithological characteristics which can be used as criteria for correlation between measured sections (Figure 4.32). The key bed No.1 is grain-supported, thin- to thick-bedded calcarenite and calcirudite. Grains are small fusulines and crinoid fragments. The key bed No.2 is light to medium gray, medium- to thick-bedded, parallel and graded-bedding calcarenite to fine calcirudite. The key bed No.3 is a sequence of dark gray, thin-bedded and laminated calcarenite grading into clastic association of reddish brown, thin-bedded shale, mudstone, siltstone and sandstone. Limestone consists of various types and sizes of grains. The key bed No.4 is gray to black, thin- to medium-bedded, graded and laminated calcarenite to calcilutite with black banded and nodular cherts and some laminated shales.

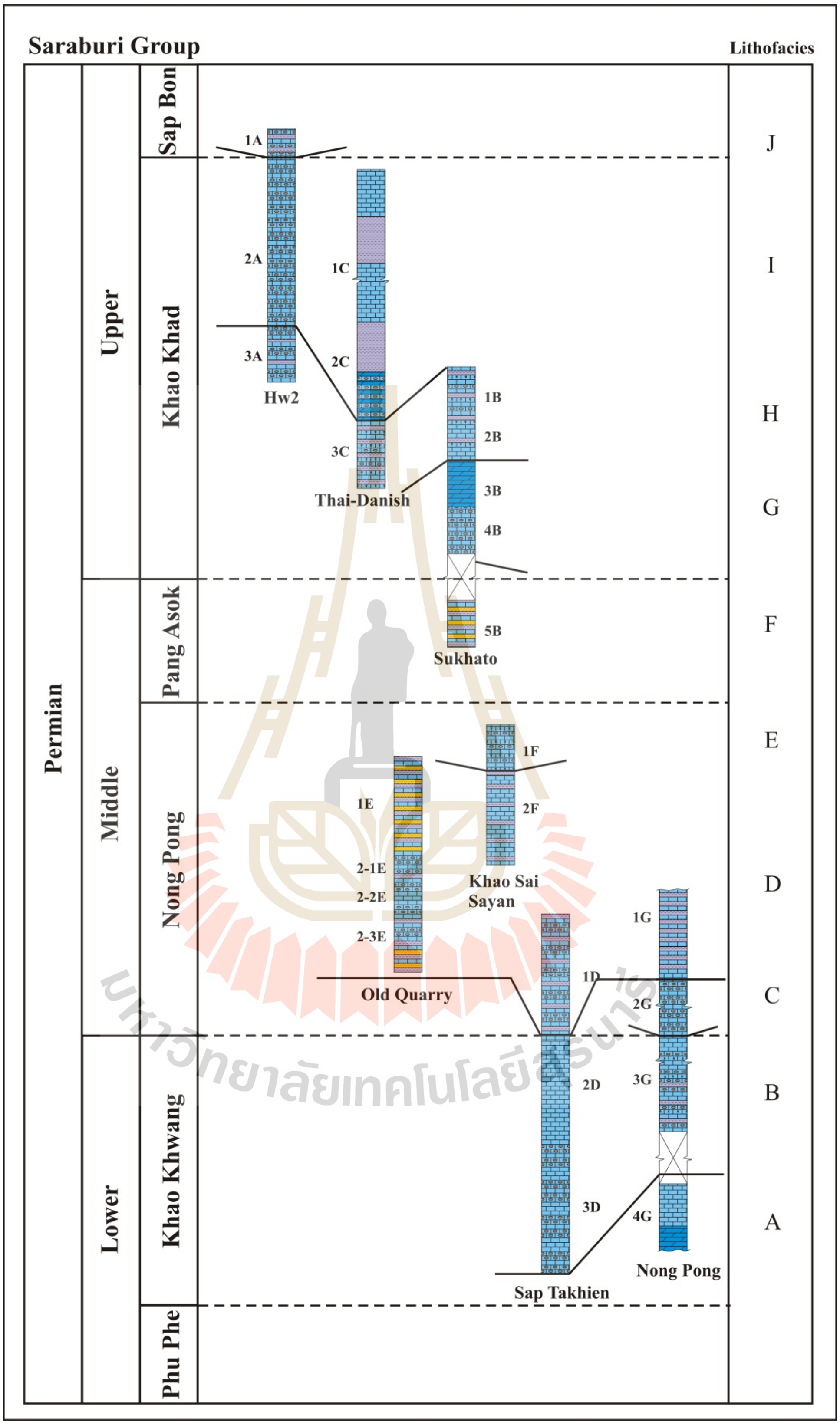


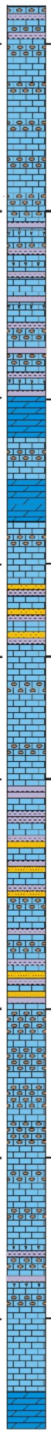
Figure 4.32 The lithostratigraphic correlation of the studied sections.

The composite stratigraphic column of the 7 measured sections in the study areas can be established as shown in Figure 4.33. It can be divided into 11 different lithologic units which are called lithofacies. The characteristics of each lithofacies are summarized as follows.

4.2.1 Lithofacies A: Calcarenite and dolomitic limestone

Description: The unit is characterized by gray to dark gray, thin- to thick-bedded calcarenite to fine calcirudite and many dolomitic limestone beds. The numerous black nodular cherts, dolomite patches and pinkish gray, banded argillaceous calcilutite with laminated shale are abundant. Some of calcilutite beds are disturbed by burrows. The skeletal grain components are fusulines and crinoids, bryozoans and unidentified fragments. This lithofacies comprises Unit 4G.

Microscopically, the rock comprises packed biomicrite, poorly-washed biosparite and unsorted biosparite. The packed biomicrite is the broken bioclasts consist of fusulines, crinoids and abundant unidentified fragments embedded in the micrite matrix. The poorly-washed biosparite contains abundant grains of fusulines and crinoids, bryozoans and unidentified skeletal fragments with some micrite matrix. It is cemented by sparry calcite. The unsorted biosparite contains shell and crinoid fragments of various sizes. The chert nodules are microcrystalline quartz with some calcareous patches. The burrows are abundant in the micrite matrix and filled by microcrystalline dolomite and sparry calcite cement.



	Description of lithofacies in the study area	Depositional Environment
J	**Lithofacies J: Shale with limestone lenses** Brownish black, thin-bedded, silicified and banded shales interbedded with gray to dark gray and thin-bedded calcarenite. Shale are parallel bedding with some black nodular cherts intercalated.	Basin
I	**Lithofacies I: Calcarenite and calcirudite** Thin- to thick-bedded, grain-supported calcarenite and calcirudite with some thin-bedded shales. Limestone shows graded-bedding and the stylolite features. Grains are composed of small fusulines and crinoids fragments. The matrix of calcirudite is fine-grained bioclasts of fusulines and unidentified fragments.	Slope
H	**Lithofacies H: Graded-bedding calcarenite with radiolarian chert and shale** Gray to dark gray, parallel, thin and graded-bedding calcarenite to fine calcirudite and compacted intraclasts interbedded with dark brown, thin-bedded shale and black banded or nodular cherts. Grain-supported are fusulines with matrix consisting of small shell fragments. The chert nodules are scattered throughout the limestone beds while red chert beds display radiolarians. Shale with limestone boulders or blocks are common.	Slope
G	**Lithofacies G: Calcirudite and dolomitic limestone** Gray to dark gray, medium- to thick-bedded calcilutite, calcarenite to fine calcirudite with dolomitic limestone. It appears light gray 'elephant skin' and dark spots on the weathered surface without significant grains.	Slope
F	**Lithofacies F: Calcarenite with lithic-arenite** A sequence of dark brown to black and very thin- to thin-bedded clacarenite, siltstone, shale and sandstone.	Slope to Basin
E	**Lithofacies E: Calcarenite** Dark gray to black, medium-bedded calcarenite with scattered black nodular chert and dolomite patches. The chert nodules have varing sizes and partly elongated shape. The grain components are crinoids, bryozoans and fusulines fragments.	Basin
D	**Lithofacies D: Laminated and bedded calcarenite interbedded with thin-bedded shale, siltstone and sandstone** A sequence of dark gray, thin-bedded and laminated calcarenite which is graded into clastic association of reddish brown, thin-bedded shale, mudstone, siltstone and sandstone. The limestone exhibits graded-bedding and lamination. These rocks show a grain-supported fabric with various types and sizes of grain components.	Basin
C	**Lithofacies C: Crinoidal calcarenite** Gray to dark gray, thin- to medium-bedded and poorly sorted calcarenite to calcirudite. With un-aided eyes, the major grains components are crinoid stems, fusulines, intraclasts, bryozoans, shells and unidentified fragments.	Platform to Slope
B	**Lithofacies B: Laminated calcarenite with banded and nodular cherts** Gray to black, thin- to medium-bedded, graded-bedding and laminated calcarenite to calcilutite with black banded and nodular cherts and some laminated shales. Grains are composed of algae, fusulines, crinoid fragments and shells of gastropods and brachiopods. The large gastropods and brachiopods are common.	Platform
A	**Lithofacies A: Calcarenite and dolomitic limestone** Gray to dark gray and thin- to thick-bedded calcarenite to fine calcirudite and many dolomitic limestone beds. Some of calcilutite beds are disturbed by burrows. The skeletal grain components are fusulines and crinoids, bryozoans and unidentified fragments.	Platform

Figure 4.33 The lithofacies of the studied sections.

4.2.2 Lithofacies B: Laminated calcarenite with banded and nodular cherts

Description: It comprises gray to black, thin- to medium-bedded, graded-bedding and laminated calcarenite to calcilutite with black banded and nodular cherts and some laminated shales. This rock shows a grain-supported fabric with various types and sizes of grain components. Grains are moderately sorted and consist of algae, fusulines, crinoid fragments and shells of gastropods and brachiopods. The large gastropods and brachiopods are common. Chert nodules are scattered in this unit. Shale are yellowish brown and mostly weathered into pale gray soil. This lithofacies consists of Units 2D, 3D and 3G.

Petrographic study shows characteristic of packed biomicrite, biosparite, poorly-washed intrasparite and poorly-washed biosparite. The packed biomicrite is presents in the part of calcarenite. It contains skeletal fragments of crinoids, fusulines, corals and bryozoans embedded in fine-grained matrix. It shows various types of grains such as, fusulines and shells and algae fragments with sparry calcite cement. The bioclasts are completely micritized. The poorly-washed intrasparite consists of intraclasts and skeletal fragments with some micrite and sparry calcite. The poorly-washed biosparite contains micrite and sparite cement. It shows closely packed grains of shell fragments. The banded chert consists of microcrystalline quartz.

4.2.3 Lithofacies C: Crinoidal calcarenite

Description: This unit is characterized by gray to dark gray, thin- to medium-bedded and poorly sorted calcarenite to calcirudite. With un-aided eyes, the major grains components are crinoid stems, fusulines, intraclasts, bryozoans, shells and unidentified fragments. This lithofacies comprises Unit 2G.

The petrographic study presents poorly-washed biosparite, unsorted biosparite and unsorted biosparudite. The poorly-washed biosparite contains abundant grains of fusulines, crinoids, bryozoans, intraclasts and unidentified skeletal fragments with micrite matrix. There are cemented by sparry calcite. The unsorted biosparite and unsorted biosparudite contain shell fragements, crinoid stems and intraclasts of various sizes which are cemented by sparry calcite.

4.2.4 Lithofacies D: Laminated and bedded calcarenite interbedded with thin-bedded shale, siltstone and sandstone

Description: The unit is a sequence of dark gray, thin-bedded and laminated calcarenite which is graded into clastic association of reddish brown, thin-bedded shale, mudstone, siltstone and sandstone. Shale are grayish brown to black, thin-bedded and turn to yellowish brown on weathered surface. The limestone exhibits graded-bedding and lamination. It is gray to dark gray, thin- to medium-bedded calcilutite, calcarenite to fine calcirudite, calcirudite, crinoidal calcirudite and limestone breccia. These rocks show a grain-supported fabric with various types and sizes of grain components. The calcarenite is coarse-grained and displays grain-supported texture with diverse bioclasts (fusulines, algae, branching corals and crinoids fragments). The calcirudite displays matrix-supported texture. The bioclasts are large fossil fragments and other limestone clasts. The breccia clasts have various sizes and shapes. This lithofacies consists of Units 1D, 1E, 2E, 2F and 1G.

Petrographically, this unit presents biomicrite, biosparite, poorly-washed biosparite, unsorted crinoidal biosparudite and crinoidal biosparite which contain mainly of crinoid and bryozoan fragments. The biomicrite consists of closely grains in micrite matrix. It contains skeletal fragments embedded in fine-grained matrix. The biosparite is cemented by coarse sparry calcite. The poorly-washed biosparite is characterized by abundant skeletal fragments of crinoids, corals, fusulines and unidentified fragments with some intraclasts. It is grain-supported with sparry ferroan calcite cement. The crinoidal biosparudite and crinoidal biosparite are cemented by sparry calcite. Some fine-grained micrite are found as matrix. The calcite crystals are commonly cracked and eroded. The breccia clasts consist of biomicrite and biosparite.

4.2.5 Lithofacies E: Calcarenite

Description: This unit comprises dark gray to black, medium-bedded calcarenite with scattered black nodular chert and dolomite patches. The chert nodules have varying sizes and partly elongated shape. The grain components are crinoids, bryozoans and fusulines fragments. This lithofacies consists of Unit 1F.

Microscopically, the rock comprises biosparite with broken fragments of crinoids, bryozoans and unidentified fossils. The moderately sorted grains are cemented together by mosaic of fine-grained and relatively clear calcite. The black microcrystalline chert appears as lenses and elongated nodular shape embedded in the carbonate rock.

4.2.6 Lithofacies F: Calcarenite with lithic-arenite

Description: It is a sequence of very thin- to thin-bedded calcarenite, siltstone, shale and sandstone. The calcarenite are dark brown to black while sandstone beds are grayish green and compact. This lithofacies comprises Unit 5B.

Petrographically, this unit is characterized of lithic-arenite with hematite cement. It consists of a medium- to coarse sand size of feldspar, calcite and mica and is moderately sorted. The grains are sub-angular to sub-rounded and some are weathered which can be observed from iron traces.

4.2.7 Lithofacies G: Calcirudite and dolomitic limestone

Description: It comprises gray to dark gray, medium- to thick-bedded calcilutite, calcarenite to fine calcirudite with dolomitic limestone. It appears light gray 'elephant skin' and dark spots on the weathered surface without significant grains. This lithofacies consists of Units 3B and 4B.

Petrographic study shows biosparite, poorly-washed biosparite, unsorted biosparite and biosparudite. It contains more than 50 percent crinoid and bryozoan fragments. The cements are coarsely crystalline. The poorly-washed biosparite is characterized by closely packed fragments of fusulines and brachiopods with micrite matrix. Grains consist of crinoid fragments and intraclasts which are closely packed in the form of grain-supported fabric. The cement is sparry calcite. Some parts are composed of fine- to coarse crystalline dolomite rhombs which are replaced in pore of fragments.

4.2.8 Lithofacies H: Graded-bedding calcarenite with radiolarian chert and shale

Description: The rocks of this unit are characterized by gray to dark gray, parallel, thin and graded-bedding calcarenite to fine calcirudite and compacted intraclasts interbedded with dark brown, thin-bedded shale and black banded or nodular cherts. They are grain-supported of fusulines with matrix consisting of small shell fragments. The chert nodules are scattered throughout the limestone beds while red chert beds display radiolarians. Shale with limestone boulders and blocks are common. This lithofacies consists of Units 1B, 2B, 3A and 3C.

Petrographic study shows that limestone is characterized by laminated, packed biomicrite, biomicrite and poorly-washed biosparite. The laminated layer is abundant and contains grain-supported fabric in micrite matrix. The biomicrite contains more than 50 percent of bioclasts in micrite matrix. The internal pores of bioclasts are filled with finely crystalline sparry calcite cement. The poorly-washed biosparite consists of abundant skeletal fragments of crinoids, corals and unidentified fragments with some intraclasts. The matrix is fine-grained and cement contains sparry ferroan calcite. The grain-supported calcarenite are lacked of micrite in intergranular pores. Chert is banded and composed of microcrystalline quartz with some calcareous patches. It contains abundant radiolarians and sponge spicule structures.

4.2.9 Lithofacies I: Calcarenite and calcirudite

Description: It is characterized by thin- to thick-bedded, grain-supported calcarenite and calcirudite with some thin-bedded shales. Limestone shows graded-bedding and displays fining and coarsening upward. The stylolite features are common which clearly visible on the weathered surface. Grains are composed of small fusulines and crinoids fragments. The matrix of calcirudite is fine-grained bioclasts of fusulines and unidentified fragments. This lithofacies consists of Units 2A, 1C and 2C.

Microscopically, limestone of this unit consists of packed biomicrite, biosparite, packed biosparite and poorly-washed biosparite with fine-grained bioclastic matrix. The packed biomicrite consists of closely packed grains in micrite matrix. The biosparite is commonly cemented by sparry calcite. The internal pores of bioclasts are filled by sparry calcite cement. Grains are unidentified shells and coral fragments. It is sub-angular to sub-rounded and poorly sorted. The bioclastic matrix is composed of fragments of fusulines, crinoids and brachiopods.

4.2.10 Lithofacies J: Shale with limestone lenses

Description: It is characterized by brownish black, thin-bedded, silicified and banded shales interbedded with gray to dark gray and thin-bedded calcarenite. Shale are parallel bedding with some black nodular cherts intercalated. This facies recognizes as Unit 1A.

Petrographically, limestone of this unit comprises poorly-washed biosparite with very fine- to fine-grained bioclastic matrix. Grains are sub-angular, poorly sorted and contain more than 20 percent of sand size components. The matrix consists of bioclastic fragments of fusulines, crinoids and brachiopods.

4.3 Geochemical Characteristics

The geochemical analysis of major, trace and rare earth elements of the chert from the Sukhato area are carried out in this study to explain the origin and depositional environment.

4.3.1 Major and Trace Elements

The result of geochemical analysis of major and trace elements of chert samples from the Sukhato area is listed in Tables 4.1 and 4.2. It shows high SiO_2 ranging from 68.11 percent to 94.86 percent with an average of 89.05 percent, Al_2O_3 varies from 1.50 to 3.0 9 percent and is averaging 2.01 percent. The content of TiO_2 ranges between 0.06 and 0.14 percent with an average of 0.08 percent. The content of Fe_2O_3 varies from 0.32 to 2.06 percent and is 0.73 percent on the average. Based on Adachi et al. (1986), the ratios of Al/(Al+Fe+Mn) vary from 0.01 for hydrothermal origin to 0.60 for biological source. The Al/(Al+Fe+Mn) of the studied samples ranges from 0.67 to 0.82 and is 0.75 on the average. They are located away from the center of the hydrothermal field which is consistent with the Al-Fe-Mn diagram. All of the plotted samples are close to the biological field as shown in Figure 4.34A (Adachi et al., 1986; Yamamoto, 1987). This result is agreed with low Fe_2O_3/TiO_2 ratios (7.87 on average) according to Li et al. (2013). These data are also compatible with the biogenic origin of chert which is determined from the ratios of $SiO_2/(SiO_2+Al_2O_3+Fe_2O_3)$ (varying from 0.95 to 0.97) (Rangin et al., 1981). The MnO/TiO_2 ratio can be used to evaluate the origin of chert because MnO content is derived from the deep ocean and TiO_2 is related with the terrigenous materials (Murray, 1994). MnO/TiO_2 is higher than 0.5 for chert occurred in the open ocean environment. While the continental slope and the marginal sea cherts show the values lower than 0.5 (Murray, 1994). The ratios of chert from the Sukhato area are generally low with an average of 0.14 which indicates the origin in the continental margin setting. Assuming the concentration of MnO is zero as the samples show values below the XRF detection limit of 0.001 percent.

Table 4.1 Major element concentrations as weight percent for environment discrimination.

	NP-1	NP-2	NP-3	NP-4	NP-5	NP-6	NP-7	NP-8	NP-9	MEAN	STDEV
SiO_2	94.39	68.11	85.97	94.86	92.07	95.89	91.77	89.94	88.44	89.05	8.48
TiO_2	0.09	0.06	0.11	0.11	0.14	0.06	0.06	0.07	0.07	0.08	0.03
Al_2O_3	2.46	1.58	2.77	2.37	3.09	1.50	1.19	1.64	1.54	2.01	0.67
Fe_2O_3	0.69	0.43	0.59	1.15	2.06	0.40	0.32	0.52	0.39	0.73	0.56
MnO	0.00	0.03	0.01	UD	UD	0.01	0.01	0.01	0.01	0.01	0.01
MgO	0.40	0.33	0.28	0.35	0.46	0.29	0.21	0.55	0.27	0.35	0.11
CaO	0.17	15.56	4.49	0.11	0.08	0.43	3.21	3.50	4.68	3.58	4.89
Na_2O	0.05	UD	0.03	0.04	0.06	0.02	0.02	0.03	0.02	0.03	0.01
K_2O	0.18	0.29	0.26	0.68	0.84	0.33	0.18	0.31	0.38	0.38	0.23
P_2O_5	0.01	0.02	0.01	0.00	0.01	0.02	0.02	0.02	0.02	0.01	0.01
Al_2O_3/ (Al_2O_3+Fe_2O_3)	0.78	0.79	0.82	0.67	0.60	0.79	0.79	0.76	0.80	0.76	0.07
SiO_2/(SiO_2+ Al_2O_3+Fe_2O_3)	0.97	0.97	0.96	0.96	0.95	0.98	0.98	0.98	0.98	0.97	0.01
Al_2O_3/(Al_2O_3+ Fe_2O_3+MnO)	0.78	0.78	0.82	0.67	0.60	0.79	0.78	0.76	0.79	0.75	0.07
MnO/TiO_2	0.05	0.51	0.09	0.00	0.00	0.16	0.17	0.14	0.14	0.14	0.15
Fe_2O_3/TiO_2	7.91	7.20	5.36	10.73	15.07	6.63	5.34	7.21	5.40	7.87	3.19
100x (Fe_2O_3/SiO_2)	0.73	0.62	0.69	1.21	2.24	0.42	0.35	0.57	0.44	0.81	0.59
100x (Al_2O_3/SiO_2)	2.61	2.32	3.22	2.49	3.36	1.56	1.30	1.82	1.74	2.27	0.72
Fe_2O_3/ (100-SiO_2)	0.12	0.01	0.04	0.22	0.26	0.10	0.04	0.05	0.03	0.10	0.09

Note: UD = under detect limited

Table 4.2 Trace element compositions in ppm.

	NP-1	NP-2	NP-3	NP-4	NP-5	NP-6	NP-7	NP-8	NP-9	MEAN	STDEV
Ba	52.40	102.36	92.88	88.36	109.12	92.45	184.40	93.30	118.25	103.72	35.31
Sr	2.94	100.23	93.95	5.77	7.75	14.75	54.62	45.69	48.37	41.56	37.17
Sc	3.50	3.48	4.49	4.49	5.57	2.75	2.43	2.17	2.46	3.48	1.16
V	19.33	14.24	16.59	32.50	47.51	18.39	10.25	13.50	12.60	20.55	11.99
Cr	14.53	7.98	9.79	34.42	29.00	17.23	12.00	13.93	20.34	17.69	8.86
Co	42.61	45.04	54.51	103.29	62.70	240.20	192.30	156.00	175.70	119.15	73.76
Ni	9.14	7.14	4.29	8.88	10.80	175.40	99.90	92.84	96.96	56.15	61.99
Cu	18.79	11.22	15.45	12.74	17.66	15.54	11.28	15.58	12.33	14.51	2.75
Zn	16.98	11.54	17.08	11.43	17.93	19.83	16.61	24.23	17.48	17.01	3.91
Rb	8.33	12.45	9.56	25.20	31.48	11.49	5.22	9.01	9.97	13.63	8.72
Y	11.04	19.23	8.37	4.61	6.26	20.10	4.99	3.22	5.40	9.25	6.34
Zr	19.54	13.33	48.63	25.67	33.43	18.70	13.80	19.70	19.20	23.55	11.20
Nb	0.97	1.02	2.26	1.44	2.07	0.34	0.31	0.78	0.89	1.12	0.69
Mo	1.14	0.45	0.14	0.23	0.32	0.57	0.56	0.37	0.44	0.47	0.29
Sn	0.42	0.21	0.61	0.46	0.71	0.89	0.59	0.63	0.66	0.58	0.19
Cs	0.23	0.33	0.31	0.87	1.10	0.21	0.16	0.28	0.37	0.43	0.33
Hf	0.52	0.36	1.19	0.00	0.83	0.78	0.48	0.52	0.51	0.58	0.33
Ta	0.26	0.14	0.23	0.29	0.41	0.34	0.32	0.72	0.76	0.39	0.21
Pb	3.99	3.39	3.52	3.13	4.47	3.60	3.68	4.90	4.23	3.88	0.57
Th	1.29	0.84	1.13	1.33	1.84	0.57	0.49	0.44	0.61	0.95	0.48
U	0.40	0.44	0.37	0.51	0.56	0.29	0.25	0.26	0.28	0.37	0.11
U/Th	0.31	0.52	0.33	0.38	0.30	0.51	0.51	0.59	0.46	0.39	0.24
Sc/Th	2.70	4.14	3.99	3.37	3.03	4.80	4.98	4.92	4.01	3.67	2.43
Sr/Ba	0.06	0.98	1.01	0.07	0.07	0.16	0.30	0.49	0.41	0.40	1.05

In addition, the ratio of $Al_2O_3/(Al_2O_3+Fe_2O_3)$ can also be used to infer the sedimentary environment of chert (Sugitani, 1996). The $Al_2O_3/(Al_2O_3+Fe_2O_3)$ ratios in the chert samples are of 0.60 to 0.82 (0.76 on the average) which is close to the ratio of the continental margin. All samples are also fallen within the continental margin field following the $100\times(Fe_2O_3/SiO_2)$ vs. $100\times(Al_2O_3/SiO_2)$ diagrams of Murray and Buchholtz (1992) as shown in Figure 4.34B. Most samples are related to the continental margin field in the $Fe_2O_3/(100\text{-}SiO_2)$ vs. $Al_2O_3/(100\text{-}SiO_2)$ diagram (Figure 4.34C) but they are fallen within the oceanic basin and the continental margin fields based on the Fe_2O_3/TiO_2 vs. $Al_2O_3/(Al_2O_3+Fe_2O_3)$ diagram (Figure 4.34D). From these analyses, the chert samples from the study area display high value and indicate biogenic origin. However, the diagenetic processes can cause some additional silica content in chert.

The trace element contents from the result of analysis are less than 100 ppm with the high values in Ba and Co. The U/Th ratios are of 0.30 to 0.59 (0.39 on average) which is lower than sediments from the hydrothermal source. The average of Sc/Th ratios is 3.67 (varying from 2.70 to 4.98) which indicates that the samples were deposited in the continental margin (Sc/Th higher than 1) (Li et al., 2013). The chert samples from the studied section yield Sr/Ba ratio ranging from 0.06 to 1.01 (0.40 on average) which agrees with the siliceous rock formed in a shallow to deep ocean (Sr/Ba lower than 1) as shown in Table 4.3.

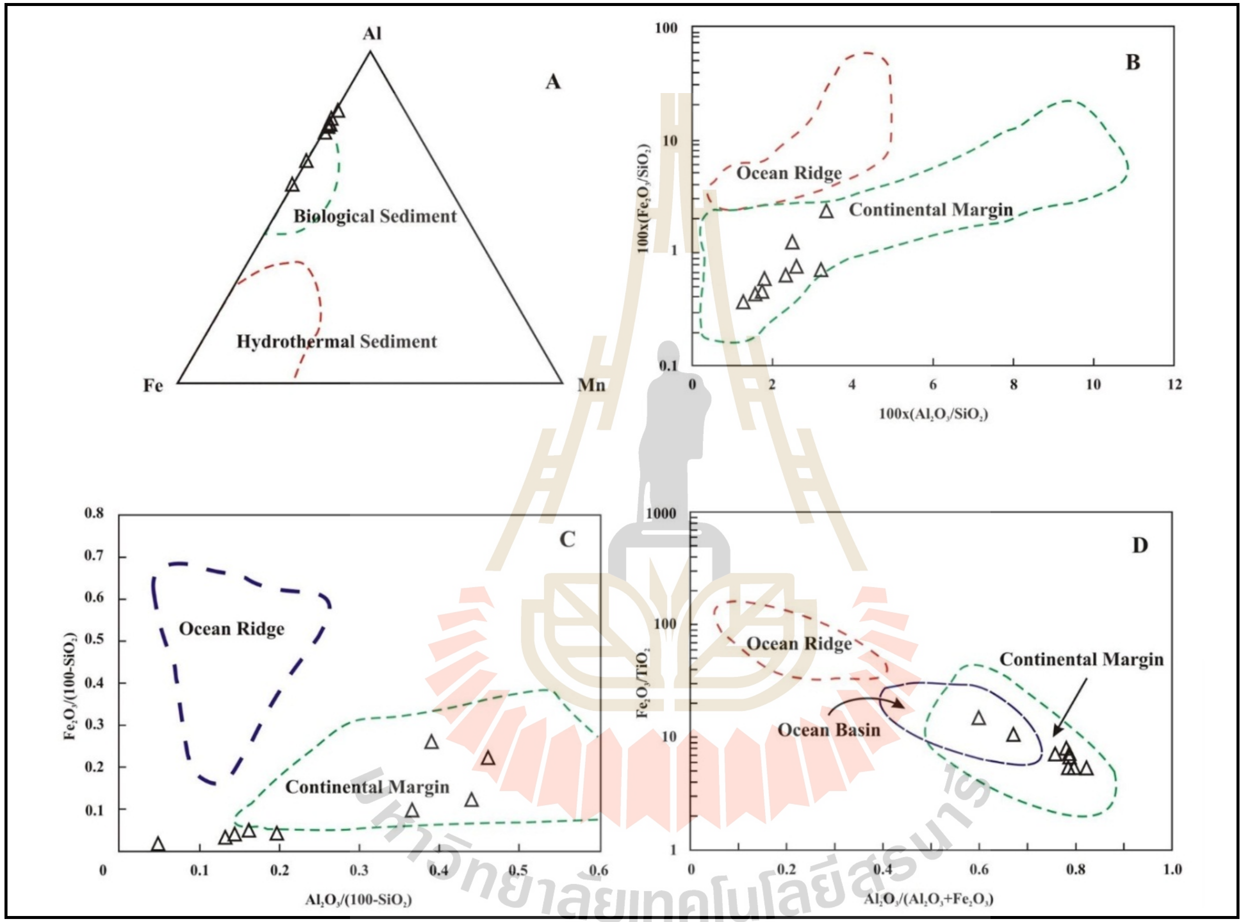


Figure 4.34 Major element discrimination diagrams of chert samples from the Sukhato area (A from Adachi et al., 1986; B, C and D from Murray, 1994).

Table 4.3 Rare earth element concentrations in ppm.

	NASC	NP-1	NP-2	NP-3	NP-4	NP-5	NP-6	NP-7	NP-8	NP-9	MEAN	STDEV
La	**32.00**	18.30	25.00	6.44	8.10	11.25	22.81	4.71	2.01	5.00	11.51	8.46
Ce	**73.00**	12.05	10.36	9.56	5.79	9.42	9.29	4.25	1.88	3.86	7.39	3.50
Pr	**7.90**	4.16	5.62	1.79	1.79	2.67	5.35	1.12	0.51	1.24	2.69	1.90
Nd	**33.00**	15.86	22.88	7.34	6.53	9.81	22.77	4.19	2.10	5.01	10.72	7.90
Sm	**5.70**	2.67	4.28	1.54	1.00	1.69	4.44	0.89	0.48	1.02	2.00	1.48
Eu	**1.24**	0.48	0.88	0.34	0.16	0.29	0.89	0.26	0.16	0.25	0.41	0.28
Gd	**5.20**	2.06	3.66	1.39	0.77	1.26	3.66	0.75	0.47	0.90	1.66	1.23
Tb	**0.85**	0.31	0.57	0.26	0.12	0.20	0.61	0.12	0.07	0.14	0.27	0.20
Dy	**5.20**	1.66	2.92	1.43	0.77	1.07	3.10	0.61	0.39	0.77	1.41	0.99
Ho	**1.04**	0.31	0.55	0.27	0.16	0.22	0.59	0.12	0.08	0.14	0.27	0.19
Er	**3.40**	0.93	1.50	0.79	0.50	0.74	1.55	0.32	0.21	0.36	0.77	0.49
Tm	**0.50**	0.13	0.20	0.12	0.08	0.10	0.23	0.05	0.03	0.05	0.11	0.07
Yb	**3.10**	0.76	1.17	0.75	0.56	0.70	1.36	0.27	0.18	0.34	0.68	0.40
Lu	**0.48**	0.12	0.17	0.12	0.09	0.11	0.16	0.04	0.02	0.05	0.10	0.05
REE	172.61	59.79	79.77	32.13	26.42	39.54	76.83	17.67	8.59	19.13	39.99	27.13
Ce/Ce*		0.30	0.19	0.61	0.33	0.37	0.18	0.40	0.41	0.34	0.35	0.13
Eu/Eu*		0.91	0.96	1.03	0.81	0.88	0.97	1.41	1.47	1.17	1.07	0.24
La_n/Yb_n		2.34	2.06	0.84	1.40	1.56	1.62	1.67	1.10	1.44	1.56	0.46
La_n/Ce_n		3.46	5.53	1.54	3.19	2.72	5.60	2.53	2.43	2.95	3.33	1.38

4.3.2 Rare Earth Elements

Rare earth elements (REEs) can be a good geochemical tracer for studying the chert origin as well as the oxidation and reduction conditions. REEs are less affected by post-burial diagenesis, whereas some of the major and trace elements appear to be modified (Murray et al., 1991). The REEs of chert are obtained from the seawater and the continental and volcanic scraps which the total REE concentrations (ΣREE) trend is increasing from the minimum value of 10.9×10^{-6} in the mid-ocean ridge to the ocean basin and the continental margin respectively. ΣREE of chert from the studied samples are 39.99 ppm on the average which is lower than NASC values. The depositional environment of chert can be interpreted using Ce anomalies which is extremely low in the spreading ridge (Ce/Ce*~0.29), slightly increasing in the oceanic basin (Ce/Ce*~0.55) and highly negative to lowly positive values from continental margin (Ce/Ce*~0.90 to 1.30) (Murray, 1994). The studied samples show Ce/Ce* values range from 0.19 to 0.61 which are closely related to the oceanic basin in consistent with Chen et al. (2006), while Eu/Eu* show slightly positive values (0.81 to 1.47).

There are distinctive differences among La_n/Ce_n values in chert from different environmental settings. The continental margin environment shows no apparent fractionation (La_n/Ce_n~1). By contrast, sites close to the spreading ridge have a high ratio (La_n/Ce_n~3.5), whereas intermediate values are observed in the oceanic basin (Murray et al., 1991). NASC-normalized values of La_n/Ce_n ratios of the studied samples are relatively high ranging from 1.54 to 5.60 which may represent the continental margin or the ocean basin. The relative abundance between LREE and HREE can be obtained from La_n/Yb_n ratio. It is suggested that if significant amounts of terrigenous input is reached, the ratios range from 1.0 to 1.3 (Udchachon et. al., 2011). NASC-normalized values of La_n/Yb_n are slightly high within the range of 0.84 to 2.34 (1.56 on average) which shows significant signatures of terrigenous sediments. The relationship between LREE and HREE can also be determined from the diagram of NASC-normalized relative REEs abundances as shown in Figure 4.35. The result shows slightly flattening but extremely low Ce anomalies which indicate the oceanic basin (Murray et al., 1991).

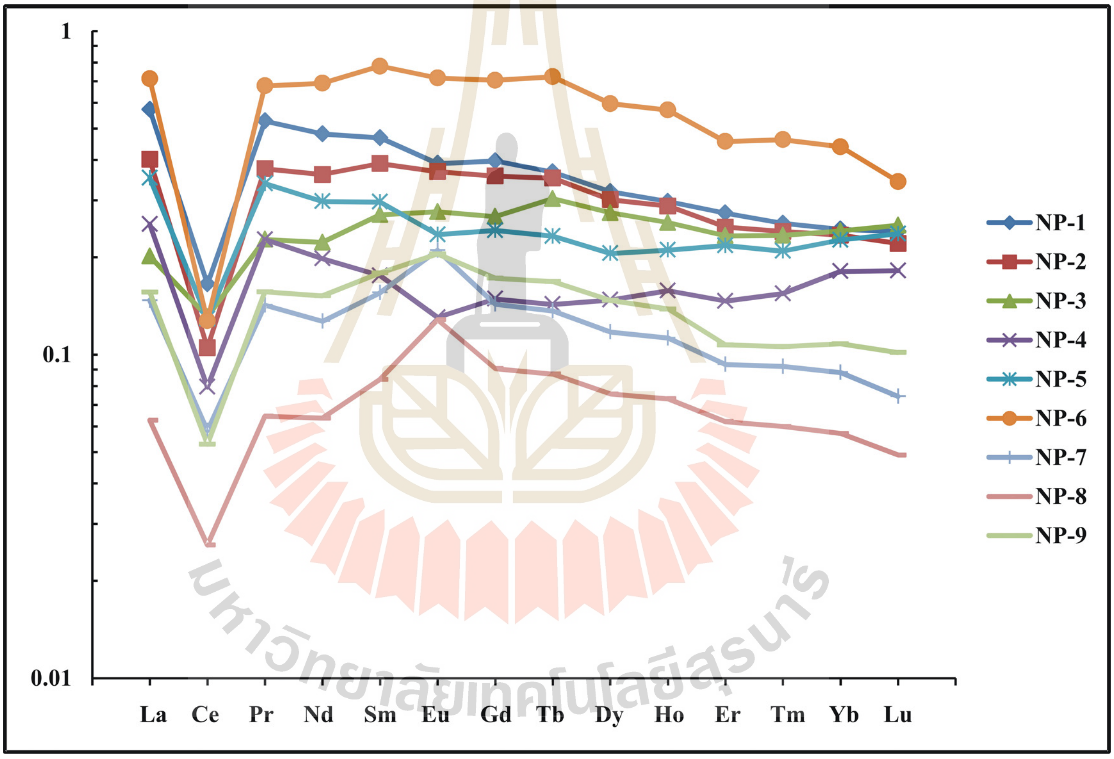


Figure 4.35 NASC-normalized REEs distribution diagram of chert samples from the Sukhato area.

4.4 Radiolarians and Sponge spicules Assemblage

The radiolarian fauna is analyzed in order to determine the age and the depositional environment of the Sukhato area which presents the well-beded red chert. According to the previous study, the carbonate rock in this area is regarded as the Early to early Late Permian age based on the fusulinid biostratigraphy (Hinthong, 1981; Chonglakmani, 2005). The chert samples generally contain siliceous fossils of radiolarians and sponge spicules but some cherts also yield ostacods (Figure 4.36). The poorly-preserved radiolarians from the siliceous sedimentary rock are collected and recovered.

The radiolarian specimens are damaged and extremely poorly preserved. They consist of *Follicucullus porrectus* Rudenko, *Cocicyntra*? sp., *Archaeospongoprunum?* sp. and others. The radiolarian fauna can be compared with the late Middle Permian radiolarian assemblage. For example, *Follicucullus porrectus* Rudenko is a common species of Late Guadalupian (Jasin, 1997; Sashida and Salyapong, 2002; Wonganan and Caridroit, 2006; Kawai and Takeuchi, 2001; Suzuki et al., 2005).

Abundant siliceous spicules were discovered from the strata bearing the radiolarian assemblage. They can be recognized as *Acanthostyles* sp., *Calthrops* sp., *Orthohexactines* sp., and others. The siliceous sponge assemblage is characterized by complex structures, such as spinous and branching, and indicates a deep-sea environment (Palmer, 1988; Liu et al., 2008).

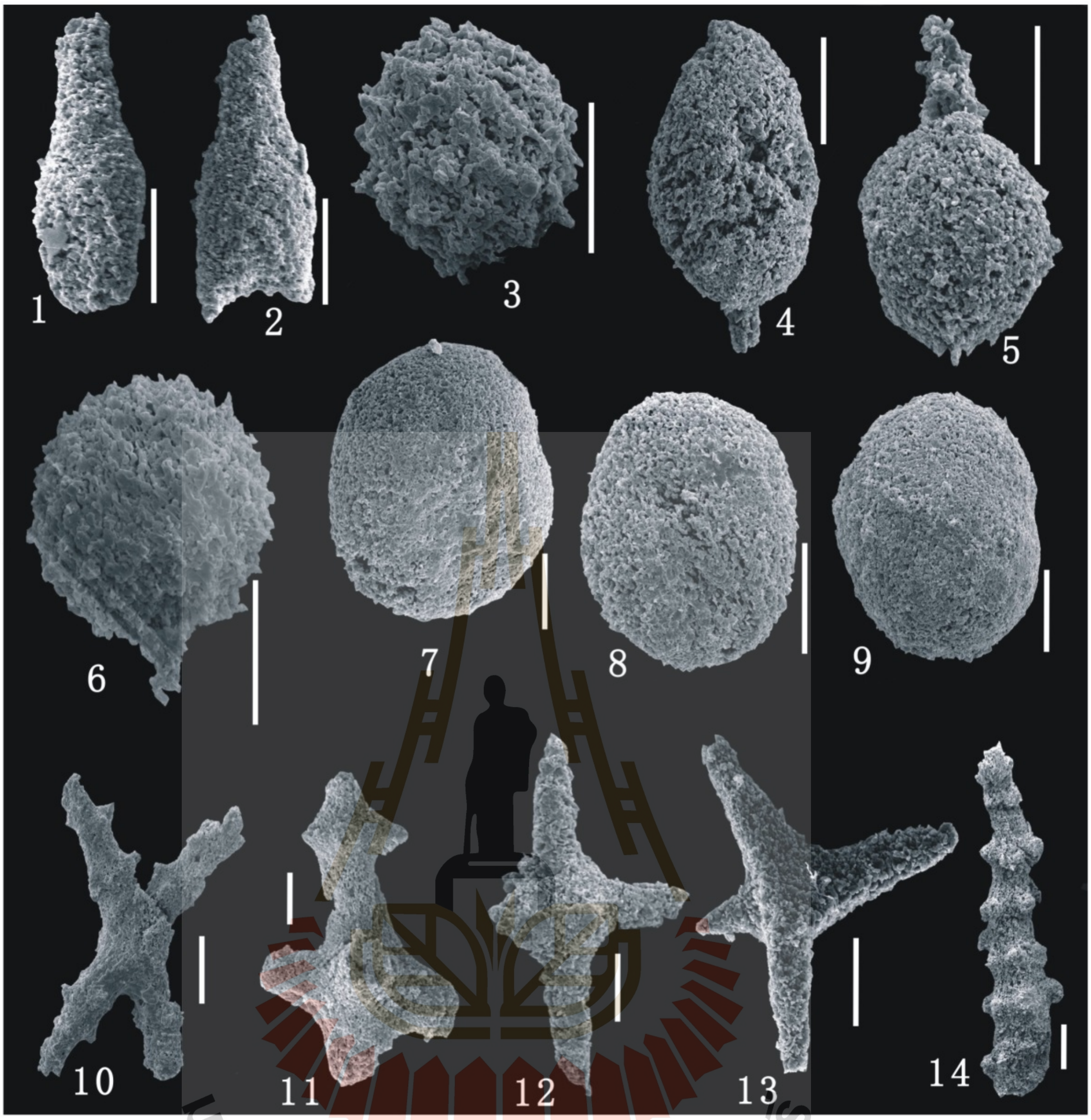


Figure 4.36 Radiolarians (1 to 9) and sponge spicules (10 to 14) from the Sukhato area (Scale bar = 100 μm).

1-2	: *Follicucullus porrectus* Rudenko	3	: *Copicyntra?* sp.
4	: *Archaeospongoprunum?* sp.	5-9	: radiolarians
10-12	: *Orthohexactines* sp.	13	: *Calthrops* sp.
14	: *Acanthostyles* sp.		

4.5 Interpretation and Discussions

4.5.1 Depositional setting of the Permian sequences

In this study, the results identified the lithofacies distribution along platform to basin of the Khao Khwang to Sap Bon Formations. The stratigraphic relation of the formations is conformable as suggested in Geological Map of Thailand, scale 1:250,000, Changwat Pranakhon Si Ayutthaya; sheet ND47-8 (DMR, 1985) as shown with the study sections in Figure 4.37. The results of lithofacies analysis show variations of distinct facies association from the platform margin in the north to the basin in the south. The Khao Khwang Formation is dominated by calcilutite and calcarenite to fine calcirudite. The rocks are gray to dark gray, thin- to thick-bedded associated with dolomitic limestone and dolomite. The numerous black nodular cherts, dolomite patches and pinkish gray, banded argillaceous calcilutite with laminated shale are abundant. Some of calcilutite beds are disturbed by burrows. The skeletal grain components are fusulines, crinoids and bryozoans fragments and unidentified clasts. The calcilutite indicates low energy of depositional environment. The bioturbations such as burrows usually occur in the intertidal zone of shallow restricted marine environment (Flügel, 2004).

The transition between platform and basin is characterized by light gray to gray, thin- to medium-bedded and poorly sorted calcisiltite, calcarenite to calcirudite. With un-aided eyes, the major grain components are crinoid stems, fusulines, bryozoans and shell fragments, intraclasts and unidentified clasts. It shows grain-supported limestone of varying types and sizes associated with graded-bedding which suggests that it was formed by turbidity current.

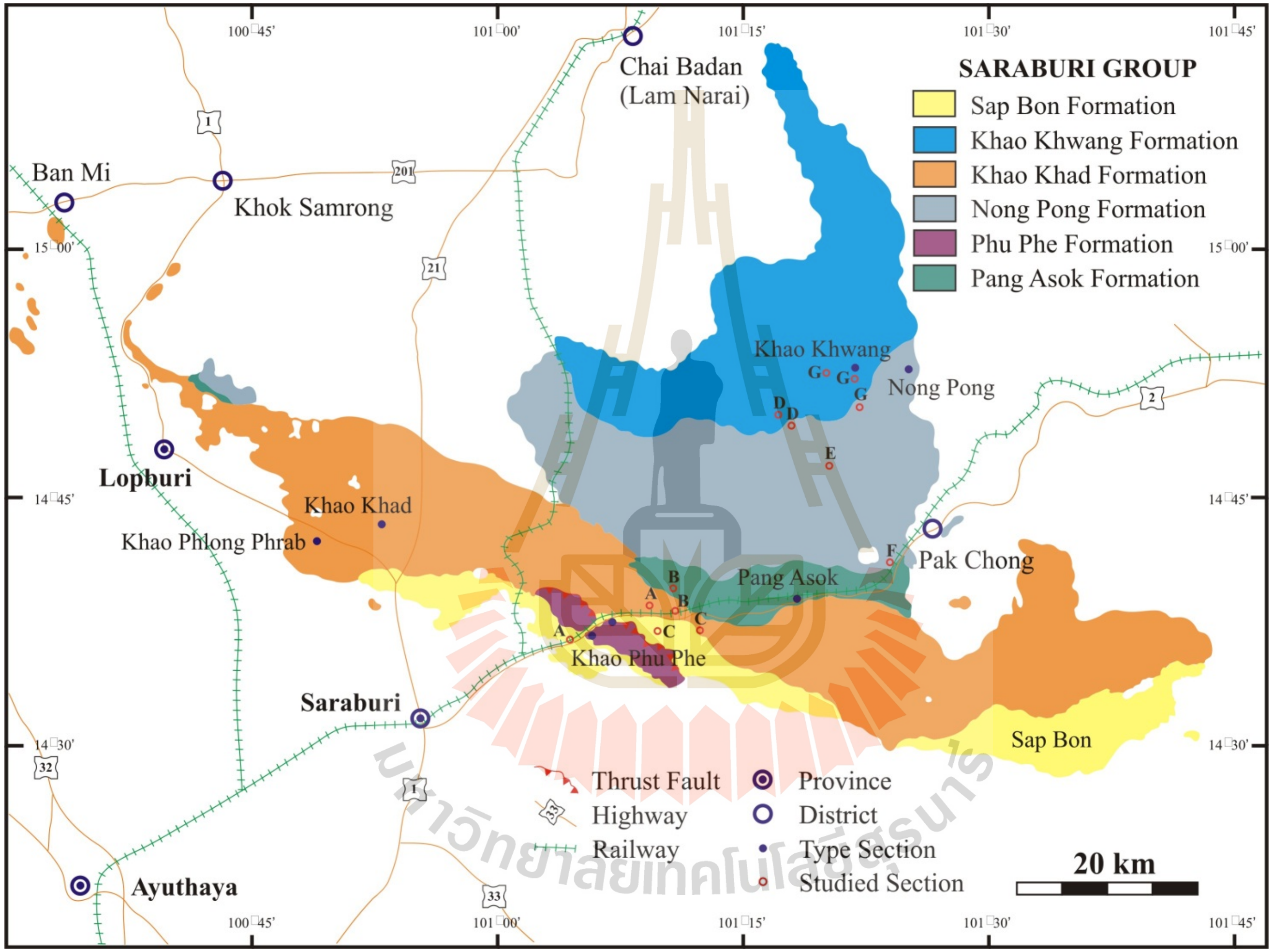


Figure 4.37 The Geological Map of the Saraburi Group and the studied sections (modified from Ueno and Charoentitirat, 2011).

The Nong Pong Formation consists of a sequence of dark gray, laminated to thin-bedded calcilutite and some calcarenite which are graded into clastic association of reddish brown and thin-bedded shale, mudstone, siltstone and sandstone. The limestone consist of calcilutite, calcarenite to fine calcirudite, calcirudite, crinoidal calcirudite and limestone breccia. They show graded-bedding and lamination. A sequence of thin-bedded and laminated shale indicates a low energy of depositional environment. The gradual decreasing of clastic sediments shows that the depth of the depositional basin was increasing.

The result of this study shows that the platform of Lithofacies A and B is different from the Khao Khad Formation (Lithofacies G, H and I). Although, in Geological Map of Thailand, scale 1:250,000, Changwat Pranakhon Si Ayutthaya: sheet ND47-8 (DMR, 1985) and Thambunya (2005) suggested that the Khao Khad Formation was a platform deposit of shallow marine environment. Thambunya (2005) reported that the Khao Khad Formation represented the shallow restricted marine of inner shelf with barrier bar or shallow platform in the open shelf. It consists of dismicrite, biomicrite, packed biomicrite, biosparite, intrasparite and biolithite. The deposition condition of micrite and large fusulines are low-energy while crinoid fragments and intraclasts are high-energy. The barrier bar in the outer shelf was changed from shallow bioaccumulated platform into crinoidal barrier and foreslope environment as indicate by turbidity sequence. The age of the Khao Khad Formation lies between Lower and Middle Permian.

4.5.2 Depositional Setting of the Khao Khad Formation

The Khao Khad Formation in this study is mainly light gray to dark gray, thin- to thick-bedded, parallel and graded-bedding calcilutite, calcisiltite, calcarenite to fine calcirudite interbedded with dark brown and thin-bedded shale and black banded or nodular and radiolarian cherts. The calcarenite shows large cross-bedding. The limestones contain bioclasts of various types and sizes associated with calcirudite. Shale with limestone boulders or blocks or olistostrome are common. Abbate et al. (1970) suggested the term 'olistostrome' is a sedimentary deposit composed of a chaotic mass of heterogeneous material, such as blocks and mud that accumulates as a semifluid body by submarine gravity sliding or slumping of the unconsolidated sediments. It is a mappable stratigraphic unit which is intercalated among shale and thin-bedded limestone sequences. These rocks are not the platform characteristics. The genetic approaches to classify this carbonate platform are a function of the type of sediments, especially in terms of bioclasts contribution to the sediment, the location of sediments production, the energy of depositional environment and the geometry of the deposit (Selly, 2000). It can be explained as follows:

1. The Khao Khad Formation is enclosed in deep marine deposit of the Pang Asok and Sap Bon Formations without any structural discontinuity.

2. The Khao Khad Formation represents bioclasts of various types and sizes. It consists of typical slope deposit such as, graded calcarenite, poorly sorted calcarenite and calcirudite.

3. The geometry of platform is based on the initial structural topography, sedimentary pattern and thickness variation. The carbonate platform is commonly a blanket shape but the Khao Khad Formation is a wedge shape with a limited areal distribution.

4. The geochemical analysis of chert samples from the Sukhato area shows that they are from biogenic origin far from hydrothermal source based on high ratios of $SiO_2/(SiO_2+Al_2O_3+Fe_2O_3)$ and the plot of Fe-Al-Mn diagram. The MnO/TiO_2 and $Al_2O_3/(Al_2O_3+Fe_2O_3)$ ratios suggest that they were deposited in a continental margin which is compatible to the plots of $100\times(Fe_2O_3/SiO_2)$ vs. $100\times(Al_2O_3/SiO_2)$ and $Fe_2O_3/(100\text{-}SiO_2)$ vs. $Al_2O_3/(100\text{-}SiO_2)$ diagrams. The trace elements, U/Th, Sc/Th and Sr/Ba ratios suggest that the chert samples were formed in a shallow to deep ocean basins. This interpretation is supported by Ce anomalies in NASC-normalized REEs distribution diagram. The result of geochemical and lithofacies analyses suggests that the chert from the Sukhato area of the Khao Khad Formation belongs to a continental margin basin, not an oceanic basin as suggested by Chutakosikanon et al. (2000). The cherts of the Khao Khad Formation and the Nan area of the Nan-Uttaradit Suture Zone contain radiolarian fauna. They show similar Al/(Al+Fe+Mn) and $Al_2O_3/(Al_2O_3+Fe_2O_3)$ which are ranging from 0.67 to 0.82 and 0.60 to 0.82 respectively (Yang et al., 2008). However, La_n/Yb_n ratios are 1.56 on the average. The chert sequence of the Nan area is associated with the oceanic island basalt which represents a small ocean with oceanic islands close to the continental margin. But the Khao Khad chert was deposited in a continental margin basin far from the oceanic basalt. It was deposited near the platform on the continental crust and shows much less deformation than the chert in the Nan Suture Zone.

The Khao Khad Formation of the Saraburi Group has been interpreted as a shallow marine platform deposit (DMR, 1985; Thambunya, 2005). However, the lithostratigraphic sequences of this formation at the Sideways of Mitraparp road, Sukhato and Thai-Danish dairy areas (Lithofacies G, H and I) do not represent the platform characteristics. The Khao Khad limestones were deposited during lowstand sea level on the slope where they received sediments from the exposed platform (Figure 4.38). The Khao Khad Formation, therefore, developed during time of alternating lowstand which provided a long period of widespread platform emergence and erosion. During highstand period, the platform carbonate was deposited on shelf and was pragraded and aggraded at this time (Figure 4.39). However, the hemipelagic and pelagic sediments were deposited in the slope and basin. The sediments in slope deposit are thin-bedded of micrite. The lowstand is developed during relative sea level fall. The clastic fluvial sediments were probably advanced onto the shelf during sea level fall. At some point, near shelf edge sediments were transported down slope to basin by gravity flows. Shelf are mostly exposed and eroded during this time and no deposit on the platform. The Khao Khad Formation was probably deposited as a prograding wedge of lowstand period.

The age of the Khao Khad Formation can be assigned from radiolarian of the Sukhato area. The radiolarian fauna in chert comprises *Follicucullus porrectus* Rudenko which is a common species of Late Guadalupian (late Middle Permian age). The age is corresponding to the previous fusulinid study (Early to Middle Permian).

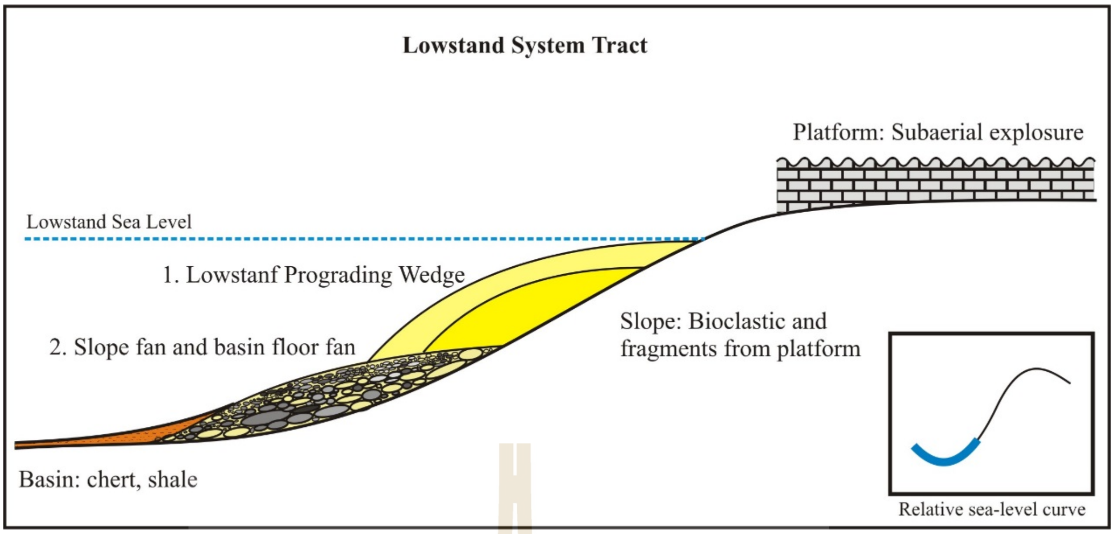


Figure 4.38 Depositional model during lowstand sea level.

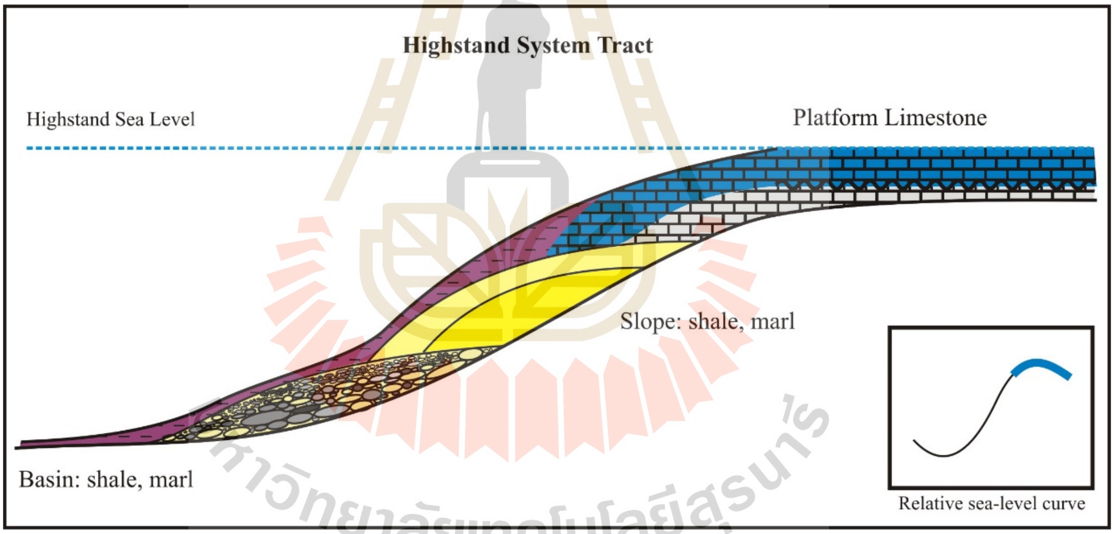


Figure 4.39 Depositional model during highstand sea level.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study sections belonging to the Saraburi Group are confined within 7 areas of the Sap Bon, Khao Khad, Pang Asok, Nong Pong and Khao Khwang Formations. The results indicate distribution of deposits along platform to basin as represented by the Khao Khwang to Sap Bon Formations. Based on the lithostratigraphic sequence, the Khao Khad Formtion is mainly composed of light gray to dark gray, thin- to thick-bedded, parallel and graded-bedding calcilutite, calcarenite to fine calcirudite interbedded with dark brown, thin-bedded shale and black banded and nodular cherts. The grain-supported bioclastic limestone of various types and sizes of grain components associated with calcirudite, shale with olistostrome and radiolarian chert can be interpreted that the Khao Khad Formation are not the characteristics of the platform deposit, but the formation is typical for the slope deposit. The occurence of these lithologies is interpreted to be the deposit of a lowstand prograding system tract.

The Khao Khad chert shows more terrigenous contribution than the oceanic basin of the Nan chert and indicates that the Khao Khad chert was closer to the continent.

5.2 Recommendations for further research

1. The radiolarian chert beds from other sections of the Khao Khad Formation should be collected to compare their age and depositional environment. The future study should concentrate also on carbonate rocks for geochemical and petrological analyses.

2. The depositional environment of the Khao Khad Formation in this study is based on an available data from field investigation in 7 studied areas. More stratigraphic, paleontologic and sedimentologic data should be obtained in neighboring areas for more accurate depositional interpretation.

3. Detailed study in terms of structural analysis is needed to be investigated in order to provide the precise litostratigraphic sequence of the Khao Khad Formation.

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