ลักษณะปรากฏและลำดับชั้นหินตะกอนทะเลยุคจูแรสซิกของกลุ่มหินหัวฝาย บริเวณแอ่งแม่สอด-พบพระ จังหวัดตาก ประเทศไทย

นายวิโรจน์ แสงศรีจันทร์

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SEDIMENTARY FACIES AND STRATIGRAPHY OF THE MARINE JURASSIC HUA FAI GROUP IN MAE SOT-PHOP PHRA BASIN, CHANGWAT TAK, THAILAND

Mr. Wirote Saengsrichan

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Geology
Department of Geology
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Thesis Title	SEDIMENTARY FACIES AND STRATIGRAPHY OF THE MARINE JURASSIC HUA FAI GROUP IN MAE SOT-PHOP PHRA BASIN, CHANGWAT TAK, THAILAND
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วิโรจน์ แสงศรีจันทร์: ลักษณะปรากฏและลำดับชั้นหินตะกอนทะเลยุคจูแรสซิกของกลุ่มหินหัวฝาย บริเวณแอ่งแม่สอด-พบพระ จังหวัดตาก ประเทศไทย (SEDIMENTARY FACIES AND STRATIGRAPHY OF THE MARINE JURASSIC HUA FAI GROUP IN MAE SOT-PHOP PHRA BASIN, CHANGWAT TAK, THAILAND) อ. ที่ปรึกษา ผศ. ดร. ฐาสิณีย์ เจริญฐิติรัตน์ และ ดร. อัศนี มีสุข 163 หน้า

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษารายละเอียดด้านธรณีวิทยาทั่วไป และกำหนดลักษณะปรากฏ หน่วยหิน และลำดับชั้นหินของชั้นตะกอนทะเลยุคจูแรสซิกของกลุ่มหินหัวฝาย บริเวณแอ่งแม่สอด-พบพระ จังหวัดตาก ภาคตะวันตกของประเทศไทย นอกจากนี้มีวัตถุประสงค์เพื่อประเมินลักษณะปรากฏของลำดับชั้นหิน โครงสร้างชั้นตะกอน และเพื่อสร้างรูปแบบใหม่ของสภาพแวดล้อมการสะสมตัว และธรณีวิทยาแปรสัณฐาน

ข้อมูลการวัดลำดับชั้นหิน 7 แนว ของกลุ่มหินหัวฝาย แบ่งเป็น 3 หมวดหิน และ 17 หน่วย มีความหนาชั้นหินแปรผันตั้งแต่ 200-832 เมตร แต่ละหมวดหินมีรายละเอียดดังนี้ หมวดหินขุนห้วย มีความหนาแปรผัน 93-345 เมตร ประกอบด้วย หินกรวดมน หินทรายแทรกสลับกับหินโคลนและหินทรายแป้ง หินปูนและหินปูนปนโดโลไมต์ และหินทรายกับหินปูนเนื้อแบบเม็ดไข่ปลา พบซากดึกดำบรรพ์ หอยกาบคู่ หอยกาบเดี่ยว ร่องรอยสิ่งมีชีวิต เศษพืช และสัตว์มีกระดูกสันหลัง หมวดหินดอยโหยด มีความหนา 103-139 เมตร ประกอบด้วย หินมาร์ลแทรกสลับด้วยหินโคลนและหินปูนเนื้อดิน พบซากดึกดำบรรพ์หอยงวงช้างและหอยกาบคู่ และหมวดหินพะเด๊ะ มีความหนา 67-221 เมตร ประกอบด้วย การแทรกสลับชั้นกันของ หินทราย หินโคลน หินทรายแป้ง หินปูนเนื้อแบบไข่ปลา และหินปูน และพบซากดึกดำบรรพ์ หอยกาบคู่ หอยงวงช้าง หอยกาบเดี่ยว ปะการัง ร่องรอยสิ่งมีชีวิต และเศษพืช จากการวิเคราะห์ข้อมูลด้านลักษณะปรากฏของลำดับชั้นหิน กลุ่มหินหัวฝายมีความสัมพันธ์กับสภาพแวดล้อมการสะสมตะกอนบริเวณชายฝั่ง ดินดอนสามเหลี่ยมปากแม่น้ำรูปพัด ทะเลสาบปิด ที่ราบน้ำขึ้น-น้ำลง และที่ราบใต้ระดับน้ำลงต่ำสุด และที่ลาดทวีปด้านในถึงด้านนอก บางบริเวณพบแนวฐานหินปูนและที่ราบแนวปะการัง

ในสมัยทอร์เซียน-บาโจเซียนตอนต้นวัฏจักรน้ำทะเลมีลักษณะเปลี่ยนแปลงขึ้นลง และระดับน้ำทะเลมีการเปลี่ยนแปลงเพิ่มสูงขึ้น ระดับและความลึกของน้ำทะเลสูงสุดในสมัยอาลีเนียน หลังจากสมัยบาโจเซียนตอนต้นทะเลยุคจูแรสซิกได้ถดถอยจากพื้นที่นี้ การศึกษานี้พบว่าการเปลี่ยนแปลงระดับน้ำทะเลสมัยทอร์เซียน-สมัยบาโจเซียนตอนต้นมีความสอดคล้องกับระดับน้ำทะเลทั่วโลก แต่มีความแตกต่างในช่วงยุคจูแรสซิกตอนปลาย-ยุคครีเทเชียส ผลการศึกษาการเปลี่ยนแปลงระดับน้ำทะเลที่แตกต่างกันนี้ น่าจะมีสาเหตุมาจากการเคลื่อนที่ของเปลือกโลกเฉพาะบริเวณ

พื้นที่ศึกษาตั้งอยู่บริเวณตอนกลางของแผ่นเปลือกโลกฉาน-ไทย การชนกันและเกิดแนวตะเข็บของแผ่นเปลือกโลกระหว่างปลายยุคไทรแอสซิกทำให้ทะเลโบราณพาลีโอเททีสสิ้นสุดลง และทำให้ขอบด้านตะวันออกของแผ่นทวีปฉาน-ไทยยกตัวสูงขึ้นเกิดเป็นศูนย์กลางของพื้นแผ่นดินเอเชียตะวันออกเฉียงใต้ ขณะที่ตอนกลางของแผ่นเปลือกนี้โลกทรุดตัวลงในช่วงยุคจูแรสซิกตอนต้น ในช่วงปลายของยุคจูแรสซิกตอนต้น บริเวณนี้เกิดเป็นแอ่งสะสมตะกอนทะเลสาบ และทะเลตื้นในแนวตะวันตกเฉียงเหนือ-ตะวันออกเฉียงใต้ และตะกอนตกสะสมต่อเนื่องถึงช่วงต้นของยุคจูแรสซิกตอนกลาง ในระหว่างยุคจูแรสซิกตอนปลายถึงยุคครีเทเชียส ด้านตะวันตกและตอนกลางของแผ่นทวีปฉาน-ไทยยกตัวเป็นพื้นทวีปด้านตะวันตกของพื้นแผ่นดินเอเชียตะวันออกเฉียงใต้

ภาควิชา.....ธรณีวิทยา.....	ลายมือชื่อนิสิต.....
สาขาวิชา.....ธรณีวิทยา.....	ลายมือชื่อ อาจารย์ที่ปรึกษา.....
ปีการศึกษา.....2550.....	ลายมือชื่อ อาจารย์ที่ปรึกษาร่วม.....

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KEY WORD: SEDIMENTARY FACIES, MARINE JURASSIC, HUA FAI GROUP, DEPOSITIONAL ENVIRONMENT, TECTONIC SETTING

WIROTE SAENGSRI CHAN: SEDI MENTARY FACIES AN D STRATIG RAPHY OF THE M ARINE JURASSIC HUA FAI GROUP IN MAE SOT-PHOP PHRA BASIN, CHANGWAT TAK, THAIL AND. T HESIS ADVISOR : ASST.PROF.THASINEE CHAROENTITIRAT, Ph.D. AND ASS ANEE MEESOOK, Ph.D. 163 pp.

This study aims to establish detailed studies in terms of general geology and to define facies, rock units, and stratigraphy of marine Jurassic sedimentary strata of the Hua Fai Group in the Mae Sot-Phop Phra Basin, Tak Province, Thailand. Additional purposes are to evaluate the lithostratigraphy , sedim entary structure a nd to reconstruct the depositional environment and tectonic setting.

Based mainly on 7 m easured sections in th e Mae Sot-Phop Phra basin, the Hua Fai Group can be divided into 3 formations, 17 units and the total thickness varies from 200-832 m approximately. The Khun Huai Formation consists of conglomerate, sandstone interbedded with m udstone and siltstone, limestone and dol omitic li mestone, and sandstone and oolit ic limestone with abundan t bivalves, gastropods, tr ace fossils, plant remains and vertebrate fossils. The formation varies approxi mately 93-345 m thick. The Doi Y ot Form ation, approximately 10 3-139 m thick, co nsists of well bedded, m edium- to thick-bedded m arl interbedded with m udstone and argil laceous lim estone with abundant amm onites and bivalves. The formation is composed of intercalation of sandstone, mudstone, siltstone, oolitic limestome and lim estone with abundant bivalves, ammonites, gastropods, cor als, trace fossils and plant re mains. This formation is appro ximately 67-221 m thick. As a whole, the sedimentary sequences of the Hua Fai Group are analyzed in ter ms of lithofacies associati on representing the shoreface, fan-deltas, protected la goon, intertidal, subtid al and inner to outer ramp environments with occasional carbonate platform and reef flat.

The Toarcian rocks were represented by transgressive-regressive (T-R) cycles and gradually changed to the highest sea level and water depth in the Aalenian. In late Aalenian to early Bajocian, sea level was still changing to transgressive phase. After early Bajocian, the sea level was retreated from this area. The eusta tic curves in this study during Toarcian-early Bajocian correspond to the global curves, but differ significantly in the Late Jurassic-Cretaceous. In Late Jurassic-Cretaceous, T-R phases were conversely and probably caused by local tectonic movements.

The study area is located in central part of the Shan-Thai terrane. The m ultiple collisions during Late Triassic term inated completely in the Paleotethys. The eastern part of the Shan-Thai terrane m ay have been uplifte d and em erged, becom ing a central part of Southeast Asian landmass, whilst the central and w estern parts of the terrane was rifted in the Early Jurassic. Subsequently , the lagoon and sh allow m arine sedim entation began in late Early Jurassic and continued to early Middle Jurassic in the NW-SE trend. During Late Jurassic-Cretaceous, the western and central pa rts of Shan-Thai terrane were uplifted and became western Southeast Asian landm ass, which represented by conglom erate and red sandstone units overlying marine Jurassic sequence.

Department.....Geology.....
Field of study .....Geology.....
Academic year.....2007.....

Student's signature....W. Saengsrichan....
Advisor's signature....T. Charoentitirat....
Co-advisor's signature....A. Meesook....

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CHAPTER I

INTRODUCTION

The Jurassic sedimentary rocks of Thailand consist of non-marine, brackish and marine facies. The non-marine and brackish rocks are widespread in northeastern and southern peninsular Thailand, whilst marine Jurassic strata are widely distributed in the western parts of northern, western and peninsular Thailand. The marine Jurassic bivalves and ammonites in these regions are well described, especially in the area under the present investigation of Mae Sot and Phop Phra Districts, Tak Province. Although numerous investigations have been conducted over the last sixth decades in these regions, detailed stratigraphy of the marine Jurassic deposits has rarely been carried out. This may be due to discontinuities of exposures of sedimentary sequences and thick soil covers as well as dense agricultures.

This study attempts to conduct the detailed lithostratigraphy of marine Jurassic rocks in terms of general geology, depositional environment and tectonic setting.

1.1 Study area

The study area is situated within the Mae Sot-Phop Phra Basin (Figure 1.1), west of Tak Province, western Thailand. It is located between latitudes 16° 15′ N to 16° 50′ N and longitudes 98° 30′ E to 98° 50′ E. The area covers 6 topographic map sheets (scale 1:50,000): Mae Ramat (4742 IV), Ban Pang San (4742 I), Mae Sot (4742 III), Ban Mae Lamao (4742 II), Ban Phoe Pha (4741 IV), and Ban Pha Di (4741 I). This study area, approximately 1,400 km^2, is regarded as the eastern flank of an intermontane basin covering Mae Sot-Phop Phra Districts, western Thailand to the east and the Myawadi area, eastern Myanmar to the west. The area is bounded to the east by the high range of Thanon Thong Chai Mountain having the highest elevation of 1,157 m above mean sea level (msl). To the west, the area is connected with undulating terrains of the Moei River, along the Thailand-Myanmar border.

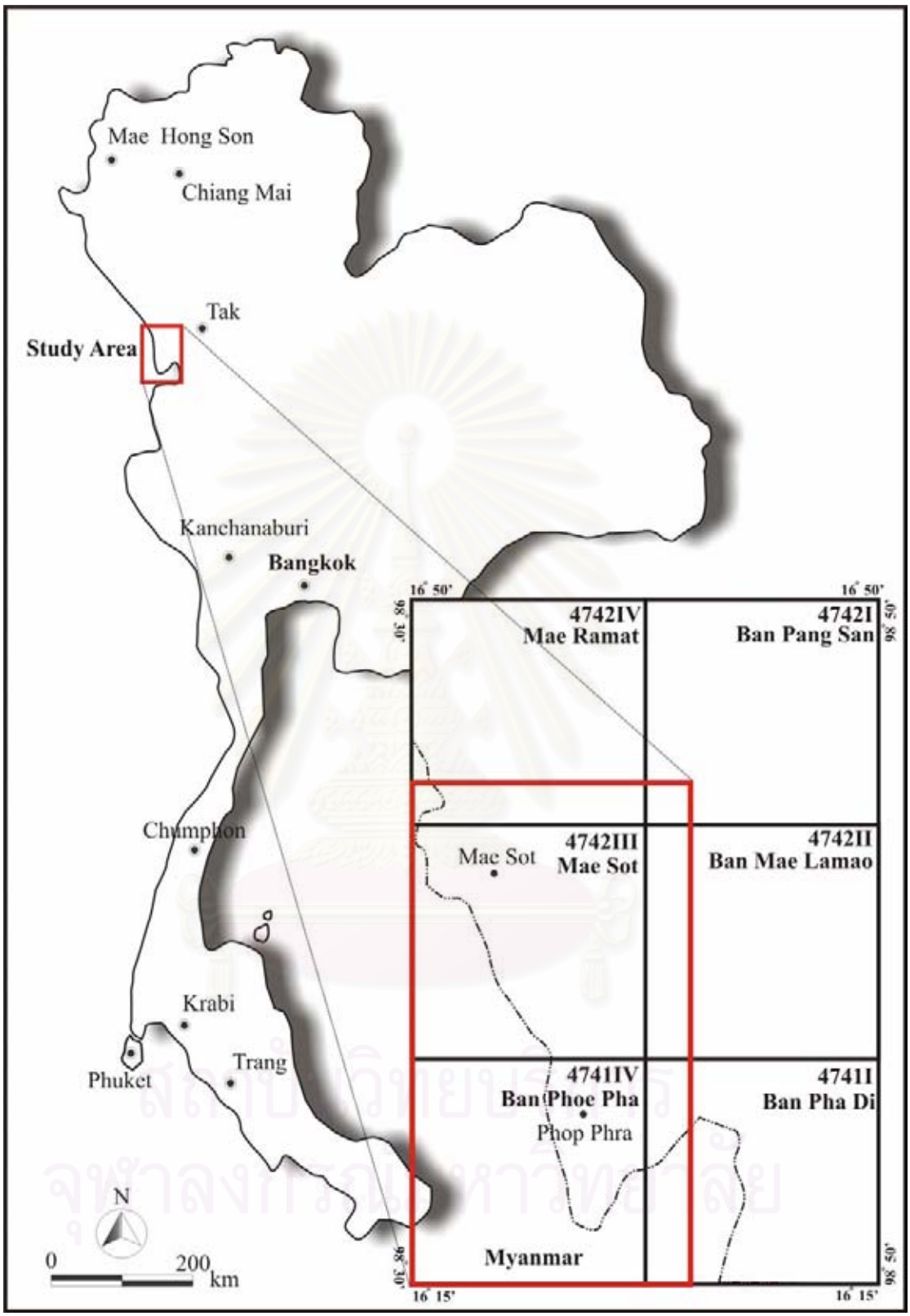


Figure 1.1 Map showing the study area, the Mae Sot-Phop Phra Basin, Mae Sot and Phop Phra Districts, Tak Province, western Thailand.

1.2 Objectives of the study

The main purpose of this study aims to study the details of regional geology (geological mapping) and to define facies, units, and lithostratigraphy of marine Jurassic sedimentary strata (the Hua Fai Group) in the Mae Sot-Phop Phra Basin. Moreover, it aims to reconstruct the depositional environment and tectonic setting. The correlations are largely based on the lithostratigraphic correlation and the geologic age supported by bivalves, ammonites and other macrofossils.

1.3 Methodology and scope of works

Generally, the existing information on regional geology of western Thailand is reviewed as a geological background for the study area. However, the study is currently focused on the geological setting of the Mae Sot-Phop Phra Basin and adjacent areas. Detailed methodology for this study is explained below (Figure 1.2 and Table 1.1).

1.3.1 Planning, Data acquisition and Compilation

The first step involves fieldwork planning as well as data acquisition and compilation relevant to sequences of all activities and time-duration of the study project (see Table 1.1). It also depends partly on the existing data and available financial support. However, the geological data of the study and adjacent areas were collected, reviewed, compiled, and analyzed for further steps of work.

1.3.2 Desk study, Photo interpretation and Reliability data checking

The remote-sensing data interpretation was performed for the reliability of data. All data from previous investigations were subsequently integrated and reinterpreted together with the aerial-photography and satellite imaginary results to prepare the initial geological map for further field investigation (see details in Chapter 2). Photo-geological map will be undertaken in the 1:50,000 scale.

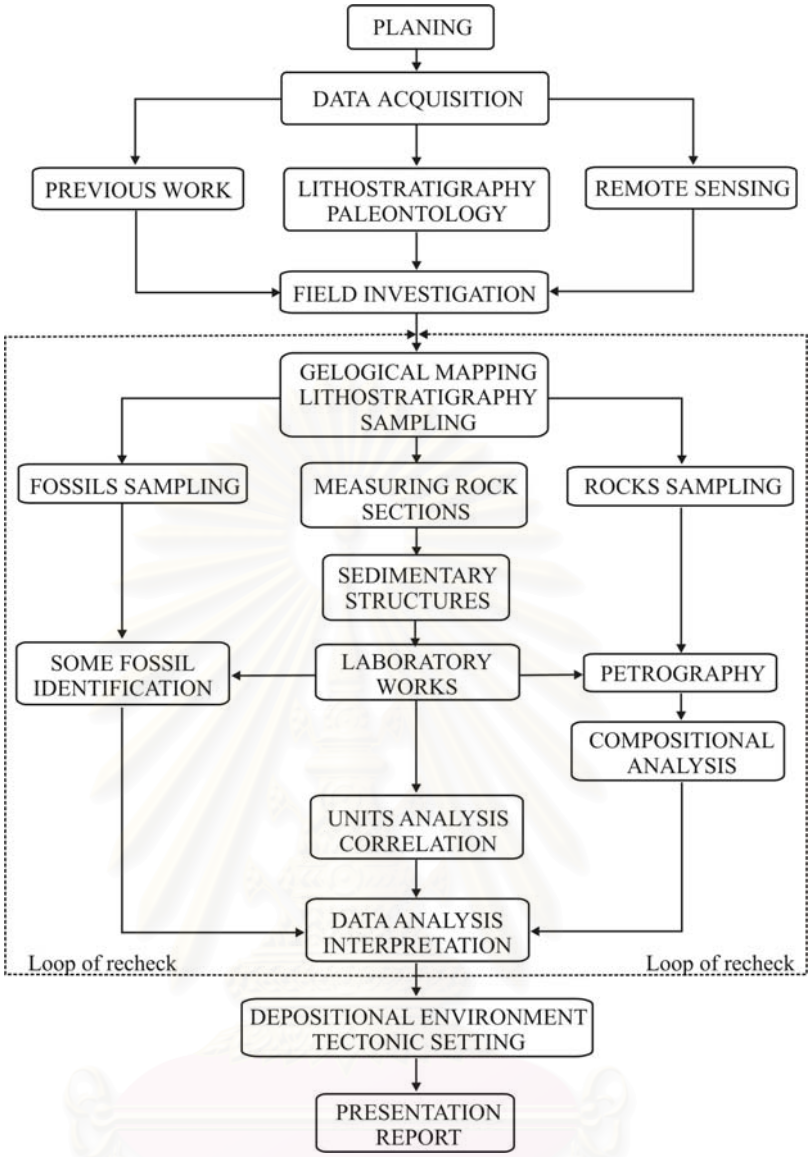


Figure 1.2 Summarized flow chart of methodology in this study.

1.3.3 Field investigation

The field investigation m ethod is m ainly involved with system atic m apping and lithostratigraphy with 7 m easured sections undertaken across the Mae Sot-Phop Phra Basin. The representative rock and fo ssil sam ples of the m apable units were collected and carried out for laboratory investigation.

1.3.4 Laboratory works

The laboratory work is focused on detailed petrographic observations, textures, sedimentary structures and compositional analyses of the Hua Fai Group.

Table 1.1 Time schedule showing the method and scope of work.

Step	Method and scope / To start on October, 2006	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	Planning, Data acquisition and Compilation	▬	▬																
2	Desk study, Photo interpretation Data checking	▬	▬	▬	▬														
3	Field investigation and sampling - Field reconnaissance (general geology of the Hua Fai Group) - Detail mapping of the Hua Fai Group (lithostratigraphy and sampling) - Field recheck					▬				▬	▬					▬			
4	Laboratory works - Field data compilation - Geologic Mapping, lithostratigraphy, rock units and stratigraphic Correlation - Petrography (compositional analyses)						▬	▬	▬	▬	▬	▬	▬	▬	▬				
5	Analysis, evaluation and conclusion					▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬	▬		
6	Presentation and report											▬	▬	▬	▬	▬	▬	▬	▬

The petrography has been undertaken to assist the identification of representative rock and microfossil samples. In order to fully understand facies and units characteristics of this group, the petrographic work includes the determinations of 113 thin-sections from 51 localities. These rock samples represent the marine Jurassic sequences in the study area. Besides, the appropriate classifications of sedimentary and igneous rocks (Wentworth, 1922; Pettijohn, 1975; Fritz and Moore, 1988; Picard, 1971; Blatt, 1982; Folk, 1966; Streckeisen, 1976), as well as textures are used for determination of the present study.

1.3.5 Data analysis and Interpretation

All geological data and related information were then analyzed. The results were evaluated and interpreted with field data and lithostratigraphic columns. During this stage, additional field investigation was carried out in order to obtain missing data.

Finally, conclusion was made on the basis of the interpretation of factual data. The results of the current investigation were presented as the geological map with stratigraphic designation, detailed description and reconstruction of depositional environments as well as tectonic settings.

1.3.6 Report writing and presentation

The report will be prepared in accordance with the objectives of the study. The results will be presented as:

- Geological map.
- Lithostratigraphic designation and proposed nomenclature.
- Reconstruction of depositional environments and tectonic settings.

1.4 Data sources and previous investigations

1.4.1 Data sources

The geological data have been provide d by the Bureau of Geological Survey and Bureau of Mineral Resources, the Depa rtment of Mineral Resources. These data consist of geological m ap (scale 1: 250,000) of Moulm ein sheet (NE 47-14), geological maps (scale 1:50,000) of Mae Ramat (4742IV), Mae Sot (4742III) and Ban Phoe Pha Quadrangles (4741IV) with add itional geological m aps of sheets Mae Sot (4742III), Ban Mae Lamao (4742II), Ban Phoe Pha (4741IV) and Ban Pha Di (4741I) revised by the report on Mineral Resources Exploration and Evaluation, Area Plot No. 1/2001, Bureau of Mineral Resources, Department of Mineral Resources in 2002.

1.4.2 Previous investigations

The geology of the regions has been de scribed previously by various workers e.g., Cotter (1924), Heim and Hirschi (1939), Brown *et al*. (1951), Sato (1961), W ard and Bunnag (1964), Kom alarjun and Sato (1964), Sato (1975), Braun and Jordan (1976), Hagen and K emper (1976), Kem per *et al*. (1976), Kemper (1976), Chonglakmani (1983), Chonglakm ani *et al*. (1985), Meesook *et al*. (1985), Charoenpravat *et al*. (1985), Tantiwanit *et al*. (1987), Fontaine and Suteethorn (1988), Sato and Westerm ann (1991), Naraballobh *et al*. (1992), Beauvais and Fontaine (1993), Zuoqi (1993), Meesook (1994), Mees ook and Grant-Mackie (1994), Meesook and Grant-Mackie (1996), Meesook *et al*. (2005), Meesook *et al*. (2006). Details of these investigations are presented as follows:

The lim estone of Ban Yang Puteh, southeast of Mae Sot District, near tributary of Huai Mae Ku, was considered to be a continuati on of th e Kam awkala limestone of eastern Myanmar (Cotter, 1924).

During reconnaissance geological surveys in northern Thailand, Heim and Hirschi (1939) mentioned the presence of Late Jurassic-Early Cretaceous formation about 18 km south of Mae Sot District. Some small fossils were found in nodular layers and kidneys of limestone occurring in a "red formation". The nature and details of these fossils were not indicated.

Resulting in mineral exploration conducted jointly by geologists of United States Geological Survey and Thai Department of Mineral Resources, the first geological map of Thailand was published in 1951 on scale of 1:2,500,000. Brown *et al*. (1951) described the general stratigraphy of Thailand and recorded the Jurassic ammonites at Ban Yang Puteh (12 km southeast of Mae Sot District near a tributary of Huai Mae Ku) and at a limestone outcrop 3 km south-southwest of Ban Yang Puteh. The ammonites were identified as *Erycites*, *Tmetoceras* and *Ludwigia*, the indicative of early Middle Jurassic age.

In 1961 Sato described fauna with *Erycites* sp. and *Bositra* ex gr. *ornati* from the Mae Sot area, indicative of lower Middle Jurassic age.

The marine Jurassic stratigraphy was considered to be a marine tongue intercalated in the non-marine Khorat Group (Ward and Bunnag, 1964).

In 1964, Komalarjun and Sato identified ammonites from Ban Huai Hin Fon on the Tak-Mae Sot road as *Erycites* sp. and *Tmetoceras dhanarajatai* n.sp. They re-identified the Ban Yang Puteh ammonites as *Tmetoceras regleyi*, *Dumortier* and *Graphoceras concavum* Sowerby and proposed as an Aalenian age.

The section along the road from Tak to Mae Sot in the vicinity of Ban Huai Hin Fon was studied in more detail by von Braun and Jordan (1976) with an additional section along Moei River, northwest of Mae Sot District. Three assemblages of ammonites were recognized: Late Toarcian (*Pseudolioceras, Lytoceras* and *Onychoceras*), Late Aalenian to Early Bajocian (*Erycites, Tmetoceras, Eumetoceras* and *Docidoceras*), and Middle-Late Oxfordian (*Epimyaites* and *Phylloceras*). The authors considered that the age of the top of the Kamawkala Limestone is Early Jurassic.

In 1976, Hagen and Kemper (1976); Kemper *et al*. (1976); Kemper (1976) reported marine Jurassic microfossils, foraminifera and algae found at the Thong Pha Phum-Si Sawat area, Kanchanaburi Province, south of the present study area.

Sukto *et al*. (1978) reported the geologic map of scale 1:250,000 of the Moulmein map sheet (NE47-14), western Thailand.

The reviews of knowledge of the Jurassic stratigraphy and fauna of Thailand have been complied by Sato (1975), Chonglakmani (1983) and Chonglakmani *et al*. (1985).

As a result of the first detailed mapping programme in the Umphang area, Tak Province (160 km south of Mae Sot), Meesook *et al*. (1985) reported on various new Jurassic fossil localities and divided the Jurassic rocks into 3 informal units: Lower mudstone, sandstone, and conglomerate; Middle limestone; and Upper sandstone. The total thickness of this sequence is about 400 m.

Charoenpravat *et al*. (1985) reported a new marine Jurassic locality at Ban Pa Lan, Mae Hong Son Province (400 km north of Mae Sot District), preliminarily interpreted as the northern-most marine Jurassic rocks exposed in Thailand.

Tantiwanit *et al*. (1987) reported the geologic map of scale 1:50,000 the Amphoe Mae Sot (4742 III) and Ban Phoe Pha (4741 IV) map sheets.

Fontaine and Suteethorn (1988) with contributions from other workers, reviewed the marine Jurassic of western Thailand, reporting some new localities and describing some bivalves, ammonites, corals, brachiopods, algal and foraminifers.

Sato and Westermann (1991) distinguished 4 faunas collected from marine Jurassic sequences in the west of Thailand, in ascending order: *Psuedolioceras, Tmetoceras, Skirroceras* and *Epimyaites?*.

Naraballobh *et al*. (1992) studied the biggest secondary zinc deposit in Thailand, owned by Padaeng Industry Company Limited. The mineralization is associated with the sequences of the Huai Hin Fon Formation, Triassic-Jurassic strata and related with vertical dipping faults of northwest-southeast trending and high dipping angle faults of northeast trending.

Beauvais and Fontaine (1993) noted that *Montivaltia numismalis* D'Orbigny) discovered in black shale at the school of Ban Pha De, south of Mae Sot, and considered the occurrence of Middle Jurassic sediments in western Thailand.

Zuoqi (1993) studied the spore-pollen assemblage from red beds of peninsular Thailand, consisting predominantly of gymnosperm pollens (94.46%), some pterophyte spores (5.26%), and rare algae (0.28%). The prevailing gymnosperm genera are *Classopollis* (86.18% of the total amount) and *Dicheiropollis* (4.25%) of Cheirolepidaceae. Age determination for this spore-pollen assemblage is Late Jurassic.

Meesook (1994), Meesook and Grant-Mackie (1994), and Meesook and Grant-Mackie (1996) reported on marine Jurassic stratigraphy, lithostratigraphy and paleontology of Thailand. The marine Jurassic rocks are widely distributed along the northwestern, western, and peninsular Thailand. In the Chumphon area, ammonites and bivalves indicated the Early Bajocian have been found in fine-grained sedimentary rocks at Khao Lak, 80 km north of Chumphon Province. The Khao Lak Formation consists mainly of interbedded sandstone and shale with cherty limestone. They also reported that the Phra Bat Formation in the Chian Yai and Hua Sai areas of Nakhon Si Thammarat Province consists of mudstone and sandstone of the Toarcian age.

In 2002 to 2005, both marine and non-marine Mesozoic sedimentary rocks and faunal aspects of Thailand were reported and correlated by Meesook *et al*. (2005). The authors proposed and reviewed the sequences of the Mesozoic marine and non-marine rocks including the evolution of Jurassic biodiversity of Thailand. Apart from that, Meesook *et al*. (2006) summarized lithostratigraphy and faunal aspects of marine Jurassic rocks in Thailand. Meanwhile, Kozai *et al*. (2006) reported the faunal affinity of the Toarcian-Aalenian bivalves from Mae Sot and Umphang Districts, Tak Province. Thirty-five Toarcian-Aalenian bivalve species from this area were identified. These bivalves can be correlated with those of Southeast Asian countries such as Vietnam and Myanmar.

CHAPTER II

REGIONAL GEOLOGY

2.1 Physiography

2.1.1 Topography

The topography of the area can be subdivided into 3 zones, namely, eastern high range mountains, undulating and flat areas (see Figure 2.1).

2.1.1.1 Eastern high range mountains zone

The topography of the eastern high range mountains zone located in the eastern flank of the study area is generally high mountains with a thick forest and is widely covered by sandstone, shale, limestone, metamorphic and igneous rocks of the Upper Paleozoic to Mesozoic. These high mountain ranges are located in northeastern part of the study area and distributed approximately 15% of the area. The highest peak is at Doi Pha Kia in eastern high ranges with approximate elevation of 1,157 m above mean sea level (msl) and has elevation of the ranges between 500 and 1,157 m (msl).

2.1.1.2 Undulating area zone

The undulating area zone is widely distributed in the Phop Phra Basin and extended from the central, western and southwestern parts of the study area with the elevation between 300 and 400 m (msl) covering about 55% of the study area. This topography is characterized by small hills with intensive agriculture. The rocks in this undulating landform are represented by carbonate and fine-grained sedimentary rocks such as shale and marl.

2.1.1.3 Flat area zone

The flat area zone is widely distributed in the northern and northwestern portions of the study area covering Ban Mae Lamao, Mae Sot and Phop Phra Districts. This zone can be divided into 3 sub-basins, namely, Mae Lamao, Mae Sot and Phop Phra Basins (see Figure 2.1). The area is covered by floodplain deposits of Moei, Mae Lamao and Wale Rivers. The flat area has elevation ranging from 120 to 300 m (msl) and covers approximately 30% of the area.

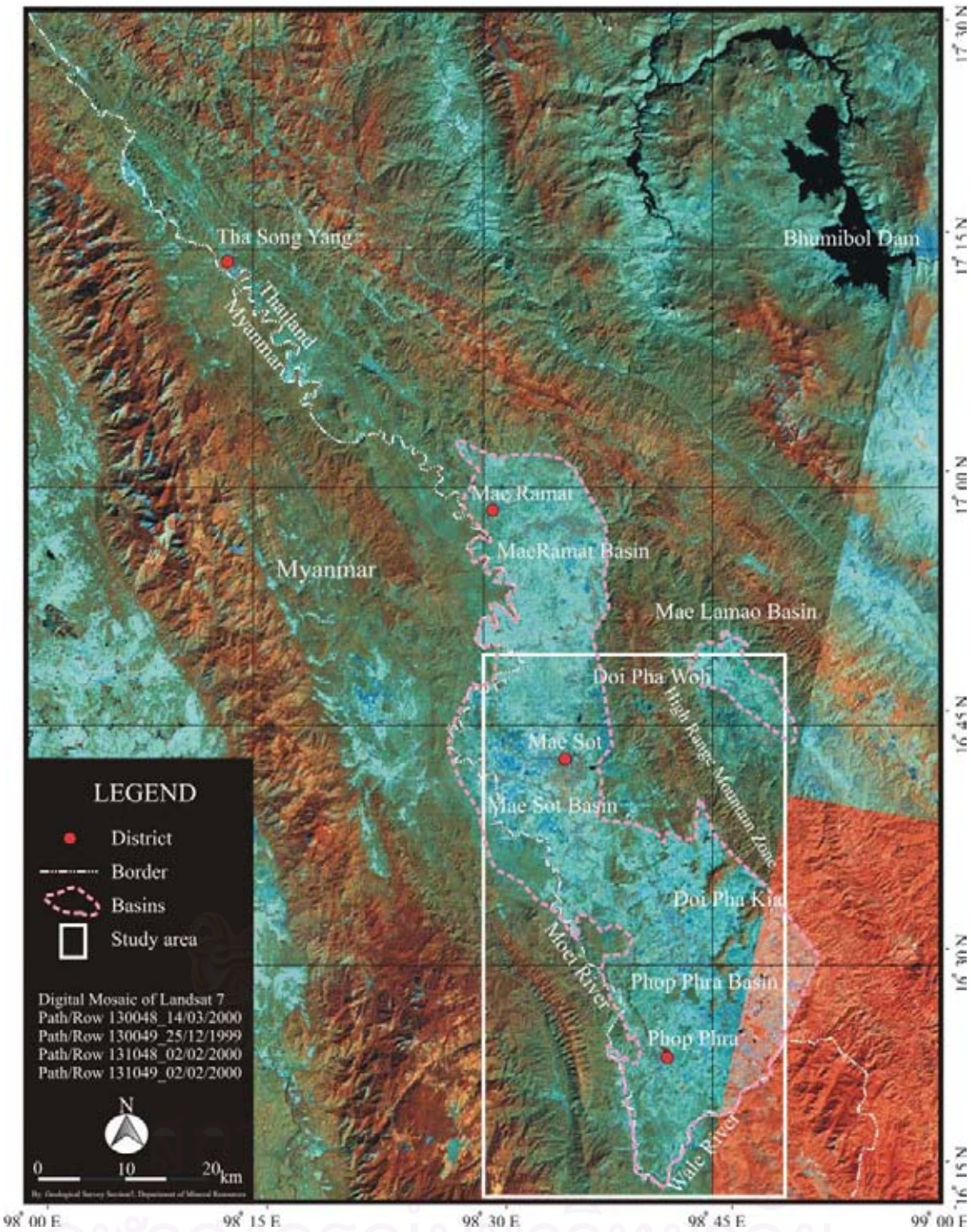


Figure 2.1 Satellite image showing morphological map of the study area, Mae Sot-Phop Phra District, Tak Province, western Thailand.

2.1.2 Drainage systems and landform origin

The main rivers consist of Mae Lamao, Moei and Wale Rivers in the northern, western, and southern parts of the study area. Most of the major drainage systems flow approximately towards the northern, western, and northwestern directions into Salawin River of eastern Myanmar.

The general drainage patterns of the study area are subparallel and subdendritic and the origin of the landform can be subdivided into 2 distinctive types (see Figure 2.1) as follows:

2.1.2.1 Landform of denudation origin consists of eastern highland, isolated and small hills covering about 70% of the area. The high mountain ranges are distributed in the northeast of the area. The isolated and small hills are extended from the central to southern part of the area. This type of landform is underlain by dolomitic limestone, limestone, sandstone, shale, and semi-consolidated gravel beds.

2.1.2.2 Landform of alluvium origin mainly presented along Mae Lamao, Moei and Wale Rivers covers 30% of the study area. This landform is well observed in the north and northwest consisting of river terrace and floodplain deposits of gravel, sand, silt and clay.

2.2 Remote sensing interpretations

Remote sensing image plays a significant role to define geological structures and tectonic frameworks of the study area. Lineaments are deciphered primarily using satellite imageries from digital mosaic of Landsat Thematic Mapper (TM) band 7. The remote-sensing images have been acquired in digital forms as two-dimension arrays or rasters made up of pixels. A digital number that represents the energy of the electromagnetic radiation wave band being monitored assigns each pixel. An image processing normally consists of 3 main steps; namely, rectification, enhancement and data extraction (Neawsuparp and Charusiri, 2004). The rectification is used to improve correspondence of image data within the represented scene.

The enhancement step is normally undertaken to improve ability to identify features of interest in imagery. The data extraction step is used to interpret and classify each project such as geology and land use. Image enhancement is an operation designed to optimally display information from imagery data for visual interpretation.

An image usually contains more information to be displayed in a single picture. The image enhancement entails selection of the subset of information to be displayed as well as the optimum display of that information. In this study, the digital images from Landsat TM 7 are enhanced, displayed, and manually analyzed by the Envi 3.5, Adobe Photoshop 7, and Corel Draw 12 programs.

The satellite image of the Mae Ramat, Mae Sot and Phop Phra Districts were selected to study the systematic lineaments. The remote sensing work aims to establish the detailed studies in terms of geological and structural interpretations, especially fracture analysis of the study region. This study is an attempt to correlate lineaments (geologically linear features) visible on Landsat Thematic Mapper (TM) imagery (see Figure 2.1), which also becomes an essential tool for geological exploration. In this study, details of lineaments, including geometry, pattern, distribution and density, are involved with the structural analysis. The interpretation of major lineaments related to structures and reconstruction of structural geologic map was carried out in this study. Overlaying of all editions of Mae Sot-Phop Phra geological maps (Tantiwanit *et al*., 1987; Meesook and Grant-Mackie, 1994; Department of Mineral Resources, 2002) onto lineament map was undertaken to define these relationships. Not all bands of the Landsat images are applied, only band-7 image depicts good contrast and clarity. In this study, the enhanced images are applied for interpretation together with aerial photo process and field support of ground-truth evidence and have been done together with geological map. In addition, the tectonics in this area has been related to the Mae Ping Fault Zone (MPF) in the north.

2.2.1 Aerial photo interpretation

Based on aerial photo principle, different image textures, morphology, landform and drainage system, rocks and sediments in this area can be divided into 16 units (Figure 2.2). However, the aerial photo geologic units were designed as the geological map units on the scale of 1:50,000 (Department of Mineral Resources, 2002). These units are described in ascending order as follows:

SDC unit: Landform of this unit consists of high resistant ridge covering about 5% in the northeastern part of the area. Most of drainage systems are subparallel and dendritic drainage patterns with medium to coarse texture and dense forest. This

landform is underlain by fine- to medium-grained sandstone interbedded with shale. The subparallel drainage pattern was controlled by the major structures, faults and fractures.

CP unit: Landform of denudation origin consisting about 10% of high resistant ridge, is widely distributed in the northeastern part of the area with northeast-southwest and north-south trends. Most of drainage system is composed of sub-parallel and parallel patterns with fine to medium texture. This type of landform is underlain by slightly deformed sandstone intercalated with shale. The sub-parallel drainage pattern is characterized by the major structures, faults, and fractures.

P unit: Landform of this unit consists of low resistant ridge with rough surface of karst topography, sinkholes and isolate hills covering approximately 15% of the area. This unit is well exposed in the northern and eastern portions of the study area. Most of drainage systems comprise sub-parallel drainage pattern with fine and mottle textures and scanty forest. This type of landform is underlain by limestone, dolomitic limestone and other carbonate rocks.

Tr unit: Landform of this unit consists of low resistant ridge with isolated hills covering about 5% in the northern part of the study area. Most of drainage system is composed of sub-parallel drainage pattern with fine texture. This type of landform is underlain by limestone, dolomitic limestone, shale, and sandstone interbedded with shale.

Jr1 unit: Landform of denudation origin consists of low relief of small hills with low angle dipping slope to the west and northwest, covering about 12% in the northern portion of the area. Most of drainage system is composed of sub-parallel and dendritic patterns with fine to medium texture and slightly vegetation. This type of landform is underlain by sandstone interbedded with mudstone and limestone lenses.

Jr2 unit: Landform of this unit consists of high resistant ridge with isolated hills covering about 5% along the Thailand-Myanmar border to the west of the area. Most of drainage system is dendritic drainage pattern, short distance with coarse texture. This type of landform is underlain by limestone and other carbonate rocks.

K unit: Landform of this unit consists of low relief with isolated hills covering a 2% of the northwestern area. Most of drainage system is unidentified pattern with coarse texture. This type of landform is underlain by coarse-grained clastic, conglomerate and/or igneous rocks.

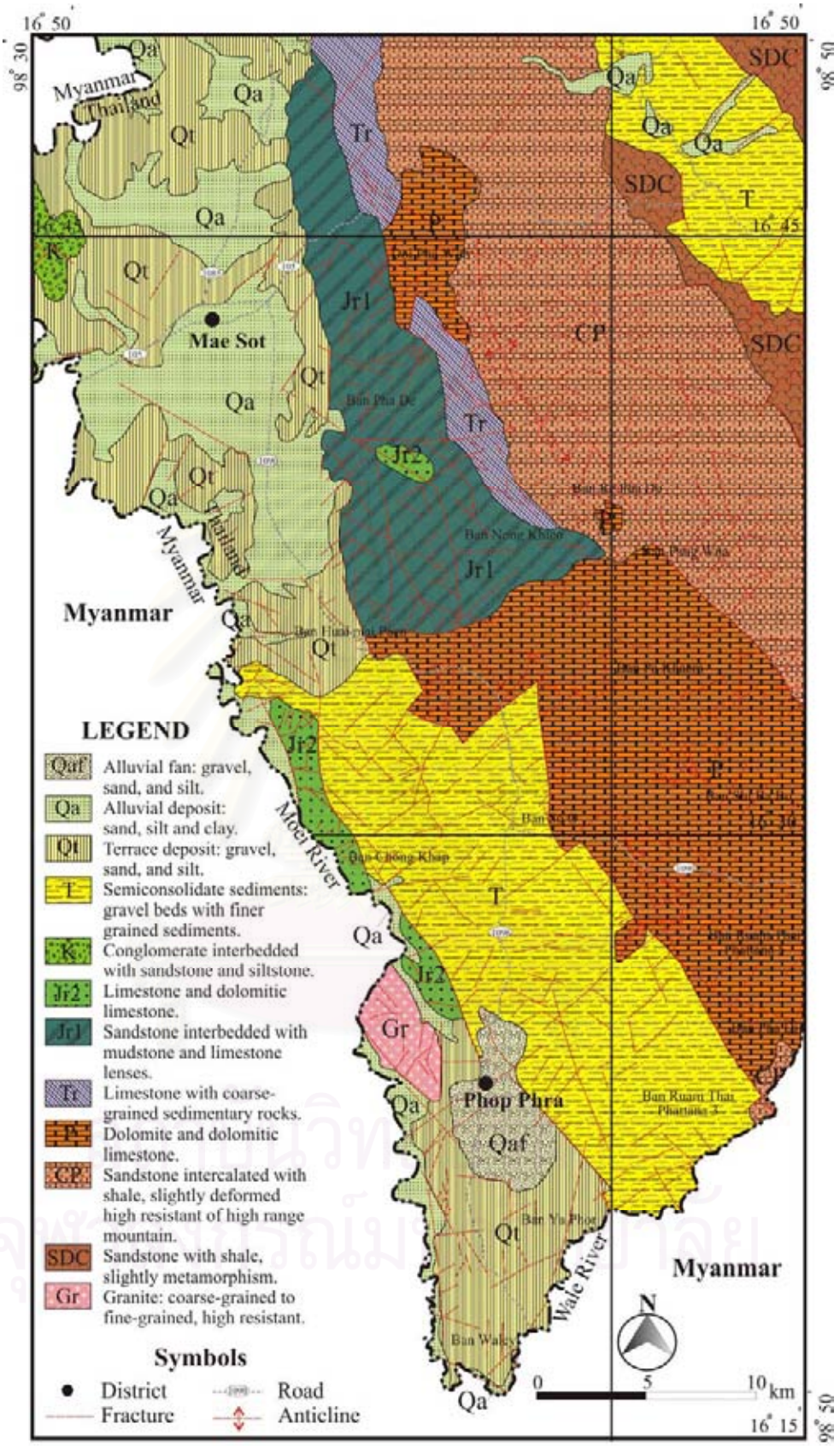


Figure 2.2 Aerial photo image interpretation map of the study area showing the general geology and major lineaments, northwest-southeast and northeast-southwest directions of the Mae Sot, Phop Phra and Umphang Districts, Tak Province.

T unit: Landform of denudation origin consists of low resistant ridge, small hills and undulating terrains with gentle slope dipping to the central and northern parts of Mae Sot Basin, covering about 13% in the southwestern portion of the area. Most of drainage system is composed of sub-parallel and dendritic patterns with fine and mottle textures. This type of landform is underlain by fine-grained clastic rocks, mudstone, sandstone, conglomerate and carbonate rocks. The attitude of bedding plane is mostly gentle dipping to horizontal with normal faults.

Qt unit: Landform of high terrace and slope movement origins consists of the undulating and slope features covering about 12% of the area. It is composed of soil, debris and pebble pavements.

Qa unit: Landform of alluvium origin is mainly located along Moei, Wale and Mae Lamao Rivers covering about 10% of the area. It consists of river terraces and floodplain deposits of gravel, sand, silt and clay.

Qaf unit: Landform of alluvial fan and slope movement origins consists of the undulating and slope features covering about 6% south of the area. It is composed of debris of talus and old landslide masses.

Gr unit: Landform of this unit consists of high resistant ridge with dome structures covering about 5% of the area in the west. Most of drainage system is composed of sub-parallel and dendritic drainage patterns with coarse texture and dense forest. This type of landform is underlain by coarse-grained metamorphic rocks and igneous rocks such as granite, gneiss, and quartzite.

Generally, the regional structures, faults, fractures and bedding traces can be observed clearly on the bird eyes view. The main structural features of the Mae Sot and Phop Phra areas are normally a fold series of synforms and antiforms that align in the northwest-southeast trend but the some units occur in the northeast-southwest trend. Aerial photo data indicate that the main and minor fractures are in the northwest-southeast and northeast-southwest directions. Most of the fractures are interpreted to represent the strike-slip and normal faults with joint sets.

2.2.2 The lineament analysis determined from landsat data

2.2.2.1 Lineament analysis

In this study, interpretation is performed only in the Tha Song Yang, Mae Ramat, Mae Sot, and Phop Phra areas where Huai Wale is southern demarcates of the

end for this analysis. In the current research, the study area can be subdivided into three parts (Figures 2.3 and 2.4), namely, Bhumibol Dam area in the north, Mae Ping Fault Zone in the central, and Mae Sot-Phop Phra area in the south based on the difference in pattern, geometry, and density of lineaments and the special unique lineaments in the north of Bhumibol Dam. In comparison for nature and styles of lineaments, the length of lineaments is described in terms of major (>20 km long), and minor (5 km long) categories. Linear features of this study area can generally be equated with the structural elements such as faults, joints, and fractures. Minor linear features such as small-scale faults and joints rarely appear on the imagery due to limitations of resolution.

The main orientations of major lineaments in Bhumibol Dam are roughly oriented in the north northwest-south southeast direction. Some lineament pattern trends are confined to the northeast-southwest and northwest-southeast directions. In the Mae Ping Fault area, the longest single lineament in this area is observed in the northeast-southwest direction. Major lineaments in the north northwest-south southeast direction of Mae Ping Fault Zone splay into the Mae Sot-Phop Phra area located in the north of Tha Song Yang District (see Figure 2.3), whereas the minor lineaments are in the northeast-southwest direction. These major lineaments run from the northwestern part of the mapped area into Tak Province and extend to the south of the study area. The lineaments in the Bhumibol Dam area and Mae Ping Fault Zone are located almost at the contact and cut into Precambrian-Paleozoic rocks. The lineaments in the west and south of this area are contacted with the Mesozoic to Quaternary sequences. The northwest-southeast trending lineaments in the Mae Ping Fault Zone are created tectonically to the north northwest-south southeast direction in the southern part and are developed the northeast-southwest direction in Mae Ramat, Mae Sot and Phop Phra Basins. The linear features in this zone have formed complex tectonic patterns in which multi-directional lineaments are clearly observed.

Lineament analysis which integrates the analyses of linear patterns, geometry, kinematics and dynamics can be applied to structural interpretation and evolution in an attempt to define the tectonics of the study area. In each lineament direction, its distribution, pattern, and length are considered. The lineaments in this area are divided into 4 patterns (see Figure 2.4), and are defined by their direction and geometry.

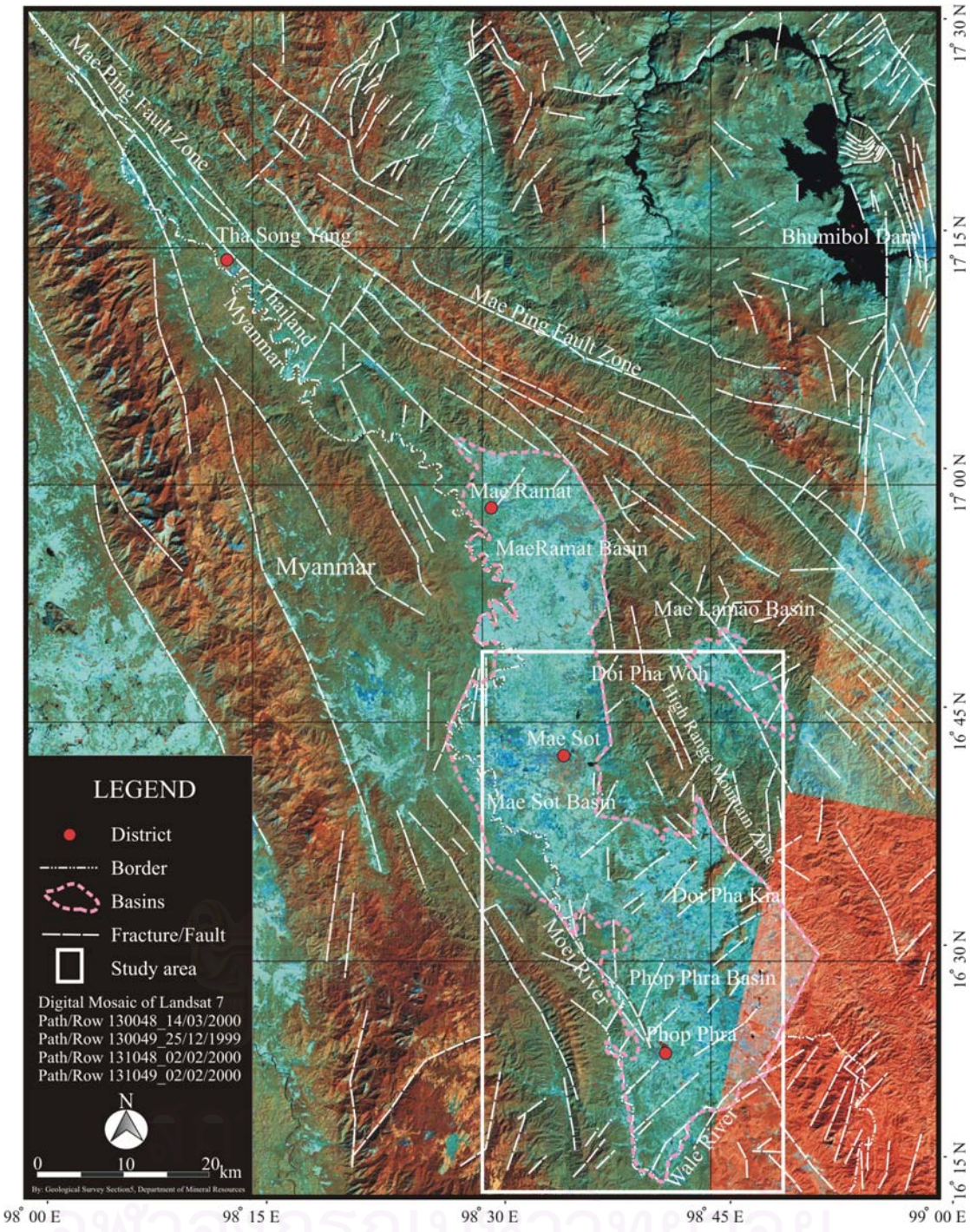


Figure 2.3 Satellite image interpretation map of the Mae Ping Fault Zone showing major lineaments in the northwest-southeast direction and minor north northwest-south southeast and northeast-southeast directions in the Tha Song Yang to Phop Phra Basins, Tak Province.

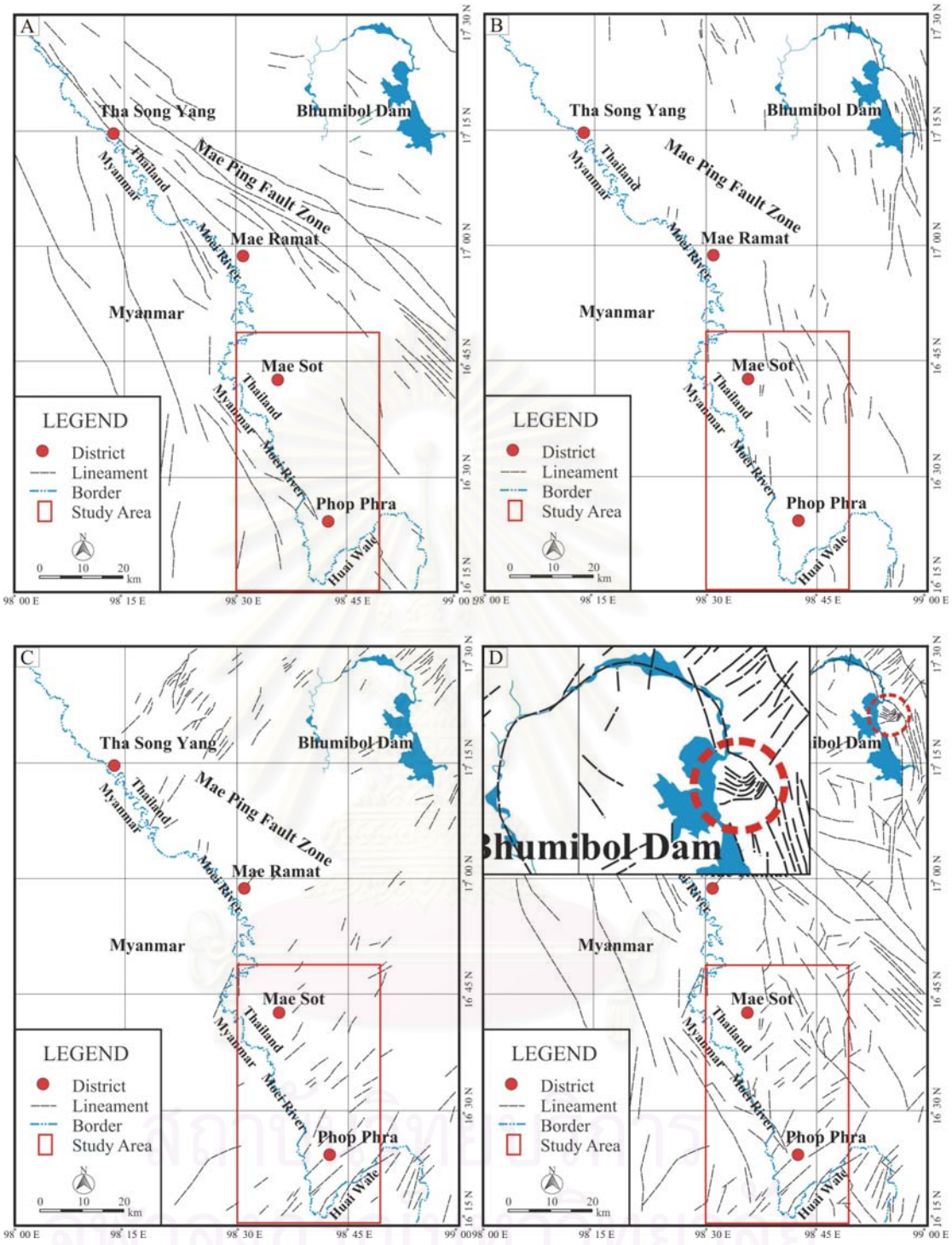


Figure 2.4 Lineament map defined by lineament trends and patterns, A) The map showing major lineaments only the northwest-southeast direction, Mae Ping Fault Zone, B) Lineament map showing only the lineaments in north northwest-south southeast direction, C) Lineament map showing only the northeast-southeast trending lineaments. D) Curve lineament highlighted in red dash line at Bhumibol Dam area, showing a curve in the east-west direction.

The major lineaments in the study area trending the northwest-southeast and north northwest-south southeast directions are shown in Figures 2.4A and 24B, respectively.

Figure 2.4C illustrates the lineaments in the northeast-southwest direction and a special lineament feature in the north of Bhumibol Dam in which the curve trends east-west direction (see Figure 2.4D).

2.2.2.2 Results of lineament analysis

Northwest-southeast lineaments

A number of lineaments in the Mae Ping Fault zone are almost parallel to the major fractures described in Figures 23 and 24A. The main length of lineaments is more than 20 km whereas some short (5 km-long) lineaments are in the zone of the strike-slip fault with right lateral movement. Most patterns of lineaments are straight lines, which indicate the major fault system in this area. The longest lineament is located in the north of Mae Ramat District and extended to the eastern flank of the study area. This lineament pattern is interpreted to represent the strike-slip fault in which highly deformed rocks are found along this zone. More importantly, this lineament pattern is also marked as the boundary of the Mae Sot-Phop Phra Basin. In Myanmar, a set of long lineament pattern (more than 30 km) also exists and bounds the Tertiary basin. However, the spacing between individual lineament is longer (~10 km) than that of Mae Ping Fault (1-5 km).

North northwest-south southeast lineaments

The lineaments of north northwest-south southeast shown in Figures 23 and 24B are remarkably straight having various attitudes from north northwest-south southeast to north-south directions, especially those in the vicinity of Bhumibol Dam and some parts of Myanmar to the west of Phop Phra District. These major lineaments can be divided into two areas, the Bhumibol Dam and the Mae Sot-Phop Phra areas separated by Mae Ping Fault Zone. Most lineament patterns in the northern and Bhumibol Dam areas are straight lines trending nearly north-south direction, whilst the southern part displays the straight pattern which trends in the north northwest-south southeast direction. A number of prominent lineaments (5 up to 15 km long) can be observed clearly on the satellite image. Many lineaments indicate normal faults and joints. Some lineaments display the right lateral movement e.g. at Ban Ruam Thai Pattana 3, others are splayed from the Mae Ping Fault Zone in the northwest of Tha Song Yang and east of Mae Ramat Districts. The Mae Ping Faults, northwest-

southeast direction, have divergently progressed to the north northwest-south southeast direction in the Mae Sot-Phop Phra area.

Northeast-southwest lineaments

Figure 24C illustrates that the straight northeast-southwest trending lineaments vary in length from 5 to 10 km shorter and denser than the other lineaments. These northeast-southwest trending lineaments are widely distributed in the Tha Song Yang, Bhumibol and Mae Sot-Phop Phra areas but less common in the Mae Ramat area. The major lineaments of this direction are considerably essential since they have presumably involved with neotectonic events and active faults. These lineaments are almost represented by the normal faults. Some of the northeast-southwest patterns, particularly in the Mae Ping Fault Zone are important because they are short (4-6 km) but obvious. They truncate the northwest-southeast lineaments in the Mae Ping Fault Zone suggesting that lineaments of the northeast-southwest pattern predate those of the northwest-southeast pattern.

East-west lineaments

Located in the north of Bhumibol Dam, the curve-linear pattern of the east-west direction is the unique feature with an average length of 15 km. These lineaments have indetermined in the above pattern (see Figure 24D). This linear pattern forms a closely spaced, short (5 km) and prominent pattern. The east-west trending curved pattern is clear to have formed as a result of ductile deformation. In the Mae Ping Fault area, between Bhumibol and Mae Sot-Phop Phra areas, the discontinuous, rather discrete minor lineaments of east-west direction are also encountered. In addition, the almost circular feature (about 25 km in diameter) found just northwest of Bhumibol Dam is considered to indicate unexposed igneous intrusions, similar to those mentioned earlier by Charusiri *et al*. (1993).

2.3 Regional geologic setting

Thailand comprises two major tectonic terranes, Shan-Thai and Indochina, which were amalgamated in the Late Triassic (Charusiri *et al*., 2002). The continent-continent collision was a part of the Indosinian orogeny (Meesook *et al*., 2006). After the collision, mountains were developed along the Nan Suture, particularly along the over-thrusting Shan-Thai terrane. Contemporaneously, the tectonic convergence,

much of Indochina, Nakhon Thai, Lampang-Chiang Rai emerged and large quantity of terrigeneous sediments were supplied and widely deposited in this area. The erosion of the mountains resulted in continental depositions on both sides of the suture (Chuaviroj, 1990). However, the continental deposits are mostly developed in the Khorat Plateau, which was formed on the western side of the under thrusting Indochina terrane. The distribution was noted in eight areas (Bunopas, 1981), the rocks are predominantly red clastics.

There are various literatures regarding geology in Mae Sot-Phop Phra and neighboring areas. The previous papers and geological maps include the geological map of Moulmein map sheet on the scale of 1:250,000 (NE47-14) (Sukto *et al*., 1978), geology of Amphoe Mae Sot and Ban Phoe Pha (Tantiwanit *et al*., 1987) on the scale of 1:50,000, geology of Mae Sot-Phop Phra area on the scale of 1:50,000 (Department of Mineral Resources, 2002 and Meesook *et al*., 2006). This study area is underlain by rocks ranging in age from the Pre-Cambrian to Recent which mainly include metamorphic, carbonate, clastic and igneous rocks (Figures 2.5 and 2.6).

2.3.1 Regional stratigraphy of the study area and Western Highland

The following stratigraphic subdivision and their nomenclature follow those adopted and established by the Department of Mineral Resources on the 1:2,500,000 Geological Map of Thailand published in 1897 and 1999. In addition, a few names are proposed and added by other authors to outline the completion of the stratigraphy of the Western Highland (Tables 2.1 and 2.2).

Geologic setting of this area has been complied based on the current field investigation, previous works, satellite image interpretation, and aerial photographs. The study area is dominated by sediment and sedimentary units ranging in age from the Pre-Cambrian to Quaternary (see Figures 2.5 and 2.6). The composite lithologic column of these rocks is shown in Figure 2.6 as follows:

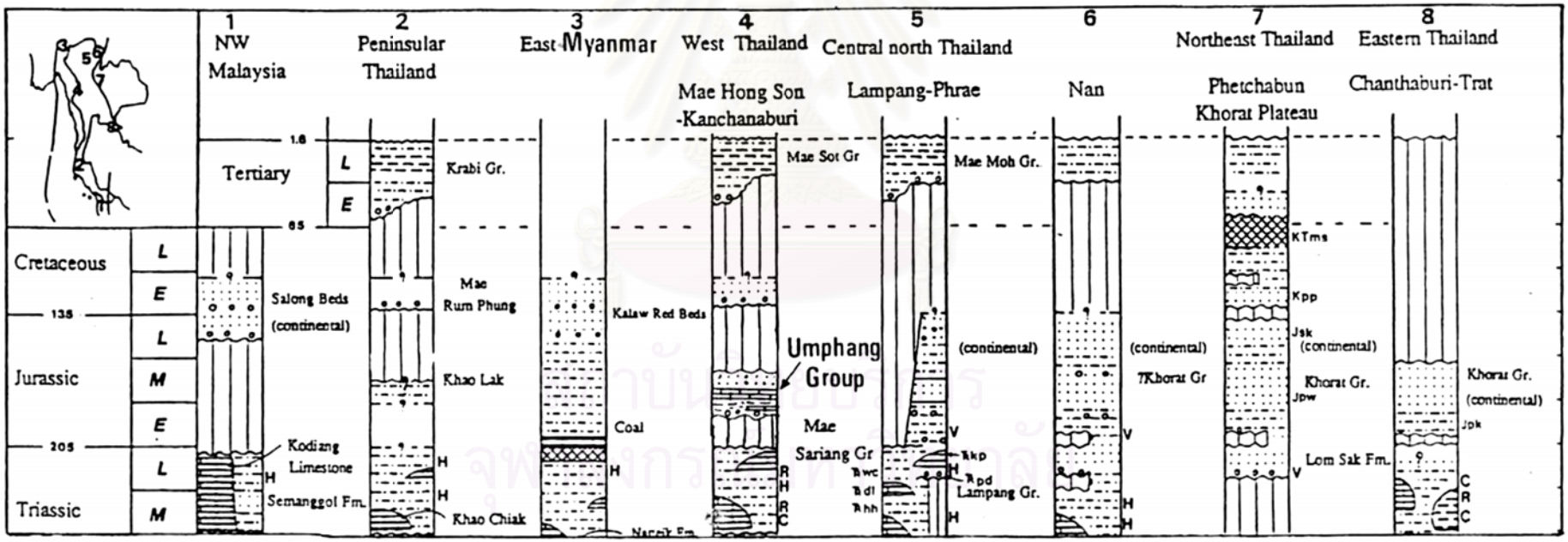
The oldest rock mainly consists of high grade metamorphic rocks such as quartzo-feldspathic gneiss, biotite gneiss, calc-silicate and schist of the Lansang gneiss (Pre-Cambrian rocks, PЄ). The low grade metamorphic rock is conformably underlain by the Lansang gneiss and is well exposed in the northeastern part of this area which was designed as the Pong Nam Ron quartzite (Є). This unit is characterized by quartzite with quartz-schist and quartz-phylitic schist, and is conformably overlain by

the Tha Manao limestone (Ordovician, O). The Tha Manao limestone is predominantly limestone and argillaceous limestone with dolomitic limestone. The age is controlled by supposedly preserved Ordovician fossils, conodont and nautiloid at the type section, Kanchanaburi Province. This unit is unconformably overlain by the Thong Pha Phum Group (Silurian-Carboniferous) characterized by shale, slaty shale and phyllitic shale. The Phra Woh Limestone (Lower-Middle Permian) is underlain by the Thong Pha Phum Group. The Limestone can be divided into 2 units, lower (P1) and upper (P2) parts. The lower part mainly consists of clastic rocks such as calcareous sandstone, siltstone and shale distributed in the central, eastern and southern parts. The fossil assemblages are coral, brachiopod, and bryozoa of Upper Carboniferous-Lower Permian age. The upper part is composed of the thick bedded to massive dolomite and limestones known as the upper Phra Woh Limestone containing fossil assemblages predominantly of coral, bivalve, brachiopod, bryozoa and foraminifera of Permian age. The Mesozoic rocks are widespread in the western and central parts of the study area which includes the Mae Sariang Group (Triassic rocks) and Hua Fai Group (Jurassic rocks). The Mae Sariang Group can be divided into 2 units, lower (Tr1) and upper (Tr2) parts. They are unconformably underlain by the Phra Woh Limestone. This sequence is composed of sandstone, shale, limestone, and chert. The Hua Fai Group is unconformably underlain by the Triassic rocks with the unconformity of conglomerate layers. This group was proposed by Meesook (1994) and can be subdivided into 3 formations, namely, Khun Huai (Jkh), Doi Yot (Jdy) and Pha De (Jpd) Formation, in ascending order. The sequence consists predominantly of sandstone, shale, limestone, argillaceous limestone, dolomitic limestone and conglomerate. These units are unconformably overlain by conglomerate of the Doi Din Chi facie (JKdc), which are well exposed at Doi Din Chi, northwest of the Mae Sot District. The facie consists mainly of massive conglomerate. The conglomerate clasts are composed of gravel to cobble of limestone, chert, sandstone, quartz, and dolomite. According to the previous study, Fontaine and Suteethorn (1988) reported the presence of foraminifera and algae in limestone clasts indicative of Middle Jurassic age. However, this facie was designed as Cretaceous? (Fontaine and Suteethorn, 1988). In Mae Sot Basin, Tertiary rocks are well known as the Mae Sot Group (T) and are widespread in the Phop Phra area. The unit consists mainly of semi-consolidated conglomerate, mudstone and sandstone.

Table 2.1 Stratigeraphic subdivision of Thailand (modified after Department of Mineral Resources, 1992).

<table>
<tr><th>Region
System</th><th>Western
Highland</th><th>Northern
Highland</th><th>Peninsula</th><th>Eastern Gulf</th><th>Centreal Plain</th><th>Phetchabun
Range</th><th>Khorat Plateau</th></tr>
<tr><td>Quaternary</td><td colspan="2">Mae Taeng F</td><td>-</td><td>-</td><td>Bangkok Clay
-</td><td>-</td><td>-</td></tr>
<tr><td>Tertiary</td><td colspan="2">Mae Moh G</td><td>Krabi G</td><td>-</td><td colspan="2">(Mae Moh G)</td><td>-</td></tr>
<tr><td>Cretaceous</td><td rowspan="2">-</td><td rowspan="2">-</td><td>-</td><td rowspan="2">-</td><td rowspan="3">-</td><td rowspan="2">-</td><td>Mahasarakham F</td><td rowspan="3">Khorat G</td></tr>
<tr><td rowspan="2">Undiff.</td><td rowspan="2">Undiff.</td><td>Khok Krut F
Phu Phan F</td></tr>
<tr><td>Jurassic</td><td>Undiff.
Sao Khua F
Phu Kradung F</td><td>Phra Wihan F
Phu Kradung F</td><td>Undiff.
Sao Khua F
Phu Kradung F</td><td>Phra Wihan F
Phu Kradung F</td><td>Undiff.
Sao Khua F
Phu Kradung F</td><td>Sao Khua F
Phra Wihan F
Phu Kradung F</td></tr>
<tr><td>Triassic</td><td colspan="2" rowspan="2">Mae Moei G
Undiff.</td><td rowspan="2">Lampang G
Nam Pat F</td><td>Undiff.
L-Khorat
G</td><td rowspan="2">Lampang G?</td><td rowspan="2">-</td><td>Huai Hin Lat-Nam Pong F</td><td rowspan="2">-</td></tr>
<tr><td>Permian</td><td colspan="3">Ratburi G</td><td>Ratburi G?</td><td colspan="2">Saraburi G</td></tr>
<tr><td>Carboniferous</td><td colspan="2">Mae Hong Son F</td><td>Phrae F
Dan Lan Hoi G</td><td>Kaeng Krachan G</td><td colspan="2">Dan Lan Hoi G</td><td colspan="2">Wang Saphung F</td></tr>
<tr><td>Devonian</td><td colspan="2" rowspan="2">Thong Pha Phum G</td><td rowspan="2">Sukhothai G</td><td colspan="3" rowspan="2">Sukhothai G</td><td rowspan="3">-</td><td>Pak Chom F</td></tr>
<tr><td>Silurian</td><td rowspan="3">-</td></tr>
<tr><td>Ordovician</td><td colspan="2">Thung Song G?</td><td>Thung Song G</td><td colspan="2">Thung Song G?</td></tr>
<tr><td>Cambrian</td><td colspan="2">Tarutao G?</td><td>Tarutao G</td><td colspan="2">Tarutao G?</td></tr>
<tr><td>Pre-Cambrian</td><td colspan="2">Lan Sang Gneiss Complex?</td><td colspan="3">Lan Sang Gneiss Complex?</td></tr>
</table>

Table 2.2 Mesozoic stratigraphic correlation of various areas, western Highland Thailand (modified after Chaodumrong, 1992).



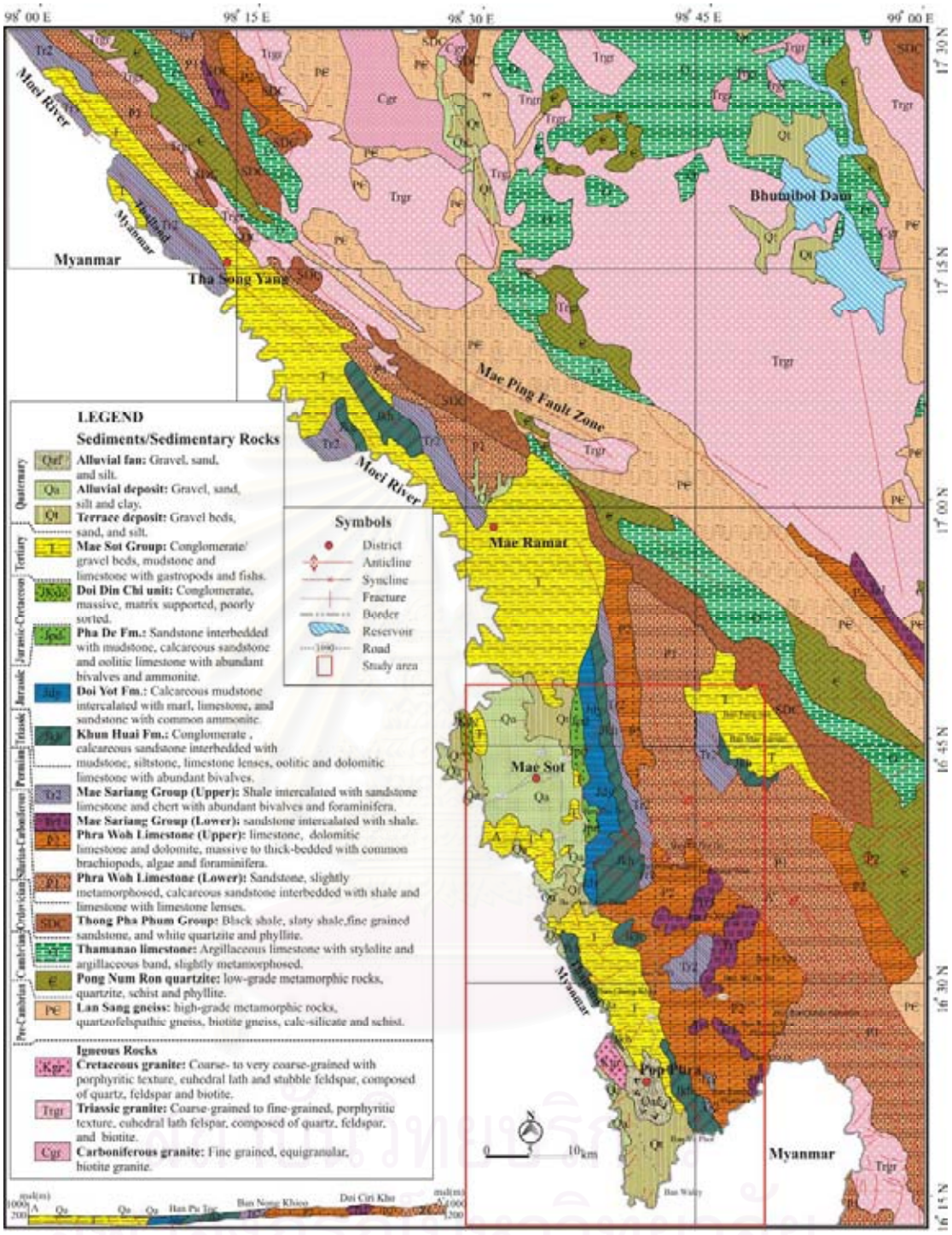


Figure 2.5 Geologic map showing the distribution, age and simple structures of units in the Tak area, western Thailand (modified after Sukto *et al*., 1978; Tantiwanit *et al*., 1987; Department of Mineral Resources, 1987, 1999 and 2002; Meesook *et al*., 2006).

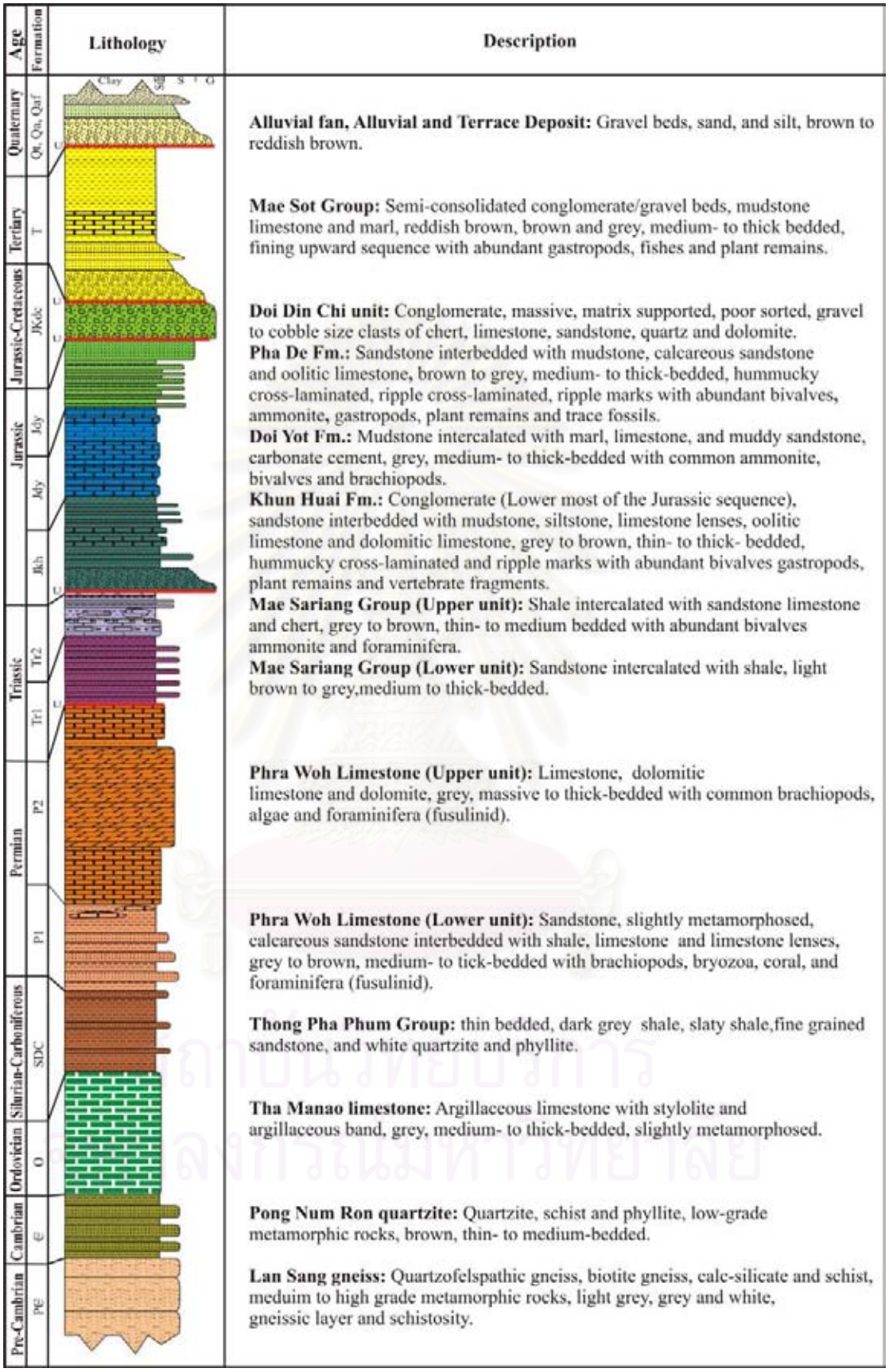


Figure 2.6 Composite stratigraphic column of Upper Paleozoic to Quaternary rocks in the study area and its vicinity (Department of Geology, 2007, unpublished).

The sediments deposited in these basins are caused by alluvial and fluvial processes particularly in the four main rivers, Mae Lamao, Moei, Wale and Mae Klong Khi Rivers having broad flood plains on both sides of the channels. These sediments are deposited in the intermontane basin characterized by sand, silt, clay and gravel. The gravel size ranges from small to cobbles and boulders. The fine sediments such as silt, fine sand and clay intercalated with gravels are found in the flood plain of the main rivers. Channel lag gravels are also found on the river banks. Terrace deposits with thick accumulation of gravels and clayey sand occur along the both rims of the basins.

2.3.2 Granite rocks

The granites crop out as a north-south trending elongated zone more than 60 km long and 20 km wide with small granitic stocks in the western part of the area. The extension of this granite is to Myanmar in the northwest. These granites can be divided into 2 units, the Triassic granite (Trgr) and Cretaceous granite (Kgr) based on their field occurrence, petrography and chemical characteristics. The granite in the study area is apart of the Central Belt Granite (CBG: Triassic) and Western Belt Granite (WBG: Cretaceous) (Department of Mineral Resources, 1999).

WBG contains small to moderate batholiths and plutons of mainly restricted compositional range with a minor amount of the expanded type. Both units occupy mainly the western, south and southeast of the area, along the Thailand-Myanmar border. Lithologically, these granites are coarse- to very coarse-grained porphyritic texture with large (up to 6-7 cm long) K-feldspar phenocrysts and in the matrix comprising quartz, K-feldspar, plagiclase and biotite. These granites are syenogranite, monzogranite, quartz syenite and quartz monzonite.

Geochronologically, the Central and Western Belt Granite (Department of Mineral Resources, 1999) has the emplacement ages of 230-200 Ma with a variable initial $^{87}Sr/^{86}Sr$ ratios range of 0.725-0.730 for the northern Thailand migmatite-related suites and 0.710-0.727 for the others. The S-type characteristics and high to very high I.R. indicate that the granites of this terrain were derived by partial melting of the evolved continental crust. The granites from the 'Western Province is the youngest suite of the Thai granites (130-78 Ma). The dominant S-type granites possess high to very high initial $^{87}Sr/^{86}Sr$ ratios of 0.719-0.744, whereas those of the I-types vary from 0.704-0.714.

2.4 Geological structures

Regionally, the pre-Mesozoic and Mesozoic strata from Mae Sot to Umphang were folded structures in the northwest-southeast direction (see Figures 2.5 and 2.7). However, the folded structures east of Ban So O may have been observed by the northeast-southwest trending. The main and minor fractures are in the northwest-southeast and northeast-southwest directions, respectively.

According to the remote sensing interpretation, field investigation and stereographic analysis of these folded rocks (see Figure 2.7), the main structural features of the Mae Sot to Umphang area is defined as folding and fractures. Generally, a series of folding is represented by synforms that align in the northwest-southeast trend (see Figure 2.7) but in the east and northeast of Ban So O, the unit occurs in the northeast-southwest trend. The general axial trend is in the northwest-southeast direction without plunging.

2.5 Marine Jurassic rocks of Thailand

2.5.1 Distribution of marine Jurassic basins

Mainland Southeast Asia is divided into three major tectonic terranes: the western Burma terrane, the Shan-Thai terrane and the Indochina terrane (Burrett, 1974; Stauffer, 1974; Hutchison, 1975; Gatinsky *et al*., 1978; Bunopas, 1981; Burrett *et al*., 1990). Thailand is a part of the Shan-Thai terrane in the west and the Indichina terrane in the east with two intervened tectonic units, namely the Lampang-Chiang Rai to the east of Shan-Thai and the Nakhon Thai to the west of Indochina (Charusiri *et al*., 2002). The study area is located in the Shan-Thai terrane, west of the Pattani suture (Charusiri *et al*., 2002). This suture is considered to extend southward to connect with the Bentong-Ruab suture in Malaysia. The suture is confirmed to have formed by continent-continent collision of the Indochina and Shan-Thai terranes (Bunopas, 1981; Hahn *et al*., 1986; Panjasawatwong, 1991).

Mesozoic sequences in Thailand can be subdivided on the basis of stratigraphy and paleontology into three main facies (Meesook and Grant-Mackie, 1996); the marine facies, brackish facies and the younger continental facies.

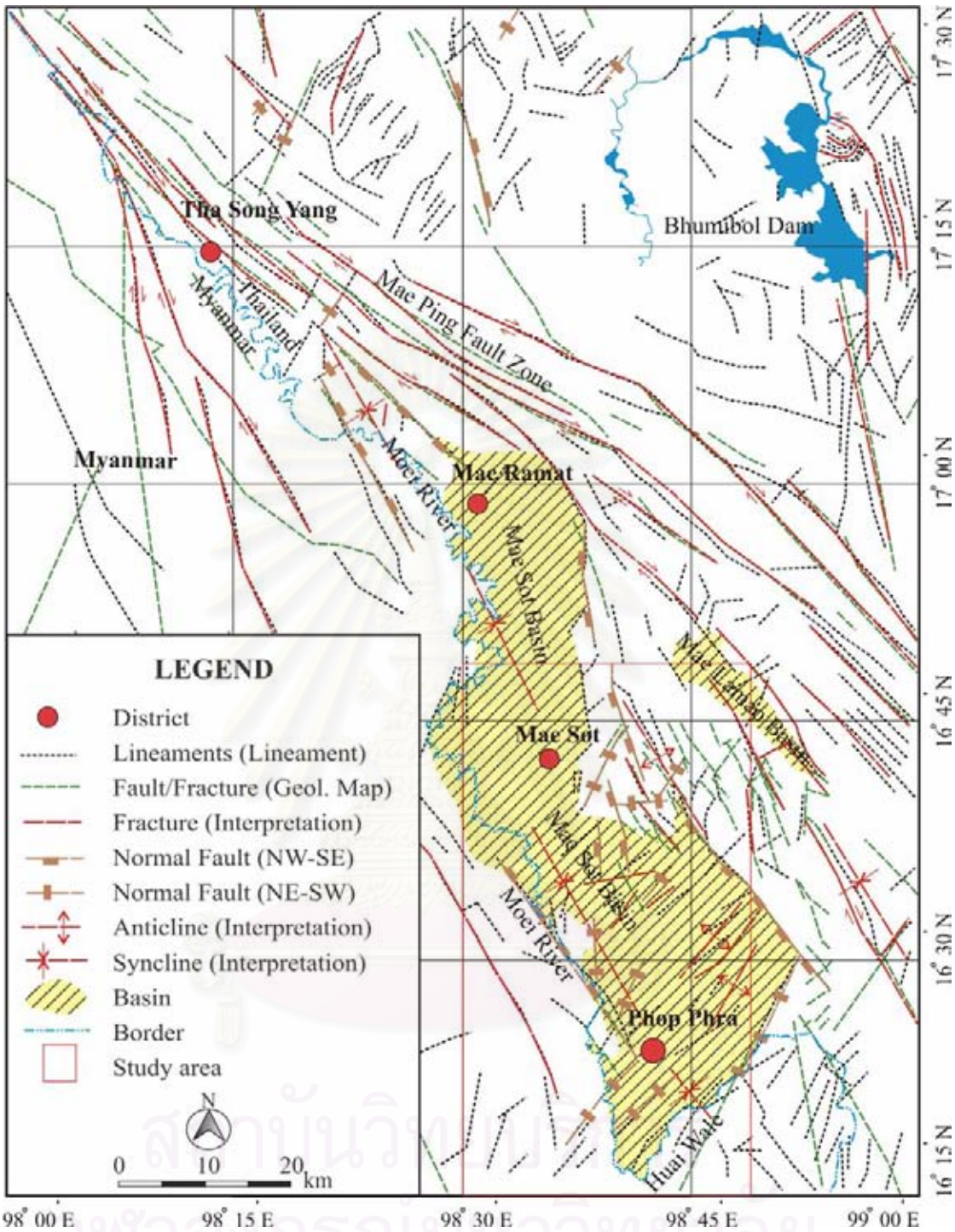


Figure 2.7 Reconstruction of structural map in the study area and adjacent areas with the combination of landsat major lineaments and major structures of geologic map.

In the west, only marine facies of Triassic and Jurassic ages have been reported. The marine Jurassic sediments are distributed in 3 sedimentary basins, namely the Mae Hong Son-Kanchanaburi Basin in the northwest and west, the Chumphon Basin in the upper peninsula and the Songkhla Basin (Figure 2.8) in the lower peninsula. The location and extent of these basins, the structure of Jurassic strata in each basin and the relationship among basins due to both strike-slip and normal faulting are shown in Figure 2.8. Except for the continental basins in northeastern Thailand, most of the marine and brackish basins are the north-northwest trending elongated basins.

Of these, the Mae Hong Son-Kanchanaburi Basin has been most fully developed and widely distributed of marine Jurassic strata (Meesook and Grant-Mackie, 1996). Fossils cited in the text have been collected during fieldwork by authors unless otherwise indicated.

2.5.2 Stratigraphy of marine Jurassic rocks

The marine Jurassic rocks in Thailand are located in seven localities distributed in the northern western and southern peninsular Thailand i.e., the Khun Yuam, Mae Sot-Phop Phra, Umphang, Kanchanaburi, Chumphon, Thung Song-Klong Thom and Ao Luk-Plai Phraya areas. These areas are situated in Mae Hong Son, Tak, Chumphon, Kanchanaburi, Nakhon Si Thammarat and Krabi Provinces, respectively (Figure 2.9).

According to Meesook and Grant-Mackie (1996), marine Jurassic strata in Thailand are generally underlain unconformably by Triassic and overlain by Quaternary strata. The marine Jurassic lithostratigraphic units (Table 2.3) are established: (in ascending order) Pa Lan, Mai Hung and Kong Mu Formations of the Huai Pong in the Mae Hong Son area; Khun Huai, Doi Yot and Pha De Formations of the Hua Fai Group in the Mae Sot-Phop Phra area; Klo Tho, Ta Sue Kho, Pu Khloe Khi and Lu Khoc To Formations of the Umphang Group in the Umphang area. The main lithologies consist of mudstones, siltstones, sandstones, limestones and marls. Mudstones, siltstones and sandstones are widespread in all basins; marls are found only in Mae Sot.

2.5.2.1 Khun Yuam area, Mae Hong Son Province

The Khun Yuam-Mae Hong Son area was previously covered by marine Jurassic rocks trending north-south direction along the Thailand-Myanmar border.

According to Charoenprawat *et al*. (1985), they have reported the marine Jurassic rocks at Ban Pa Lan and its vicinity, Muang and Khun Yuam Districts of Mae Hong Son Province. Since then, Meesook (1994) and Meesook and Grant-Mackie (1996) have studied the rocks in terms of stratigraphy and paleontology. The Huai Pong Group was proposed for Jurassic strata overlying marine Triassic and underlying Quaternary strata. The group is approximately 200 m thick comprising mainly three formations, namely, the Pa Lan, Mai Hung and Kong Mu Formations in an ascending order. As a result, many bivalves, ammonites and microfossils have been found and can be correlated with those of the Mae Sot-Umphang, and Phop Phra areas.

2.5.2.2 Mae Sot area, Tak Province

The Mae Sot-Phop Phra area of Tak Province, northwestern Thailand is well selected as a pilot area in studying Jurassic faunas due to their abundance and diversity. Marine Jurassic strata are common around the Cenozoic Mae Sot Basin. They are exposed at various localities at Kamawkala Gorge to the northwest and Doi Din Chi in the middle of the basin, in road-cuts from Tak to Mae Sot and along Huai Mae Sot. Some detailed investigations of this area have previously been made by Braun and Jordan (1976) and Fontaine and Suteethorn (1988). Braun and Jordan (1976) established the Mae Moei Group for the Triassic-Jurassic sequence and recognized informal upper (Jurassic) and lower (Triassic) divisions. Their Kamawkala Limestone was not re-examined during the present study. The Mae Moei Group is rejected as an appropriate lithostratigraphic term for the Jurassic strata of the region (Meesook and Grant-Mackie, 1996). The Jurassic sequence near Mae Sot is now clear to lack basal (Hettangian-Pliensbachian) correlatives and to lie unconformably on Triassic strata. It should, therefore, be separated at group level from the Triassic, and the same name should not be applied to both, even if the informal “upper” and “lower” divisions of Braun and Jordan (1976) were otherwise acceptable. Furthermore, these authors recognised no formal formational divisions within the Jurassic sequence of the area. Marine Jurassic strata along Huai Mae Sot are well exposed. Ammonites and bivalves are common in mudstones and marly limestones and range from Toarcian to Early Bajocian in age. These strata therefore constitute a suitable type section for the Jurassic in the Mae Sot area and the Huai Fai Group is proposed to replace the “upper Mae Moei Group” which is much less well-exposed and with less precise age determinations.

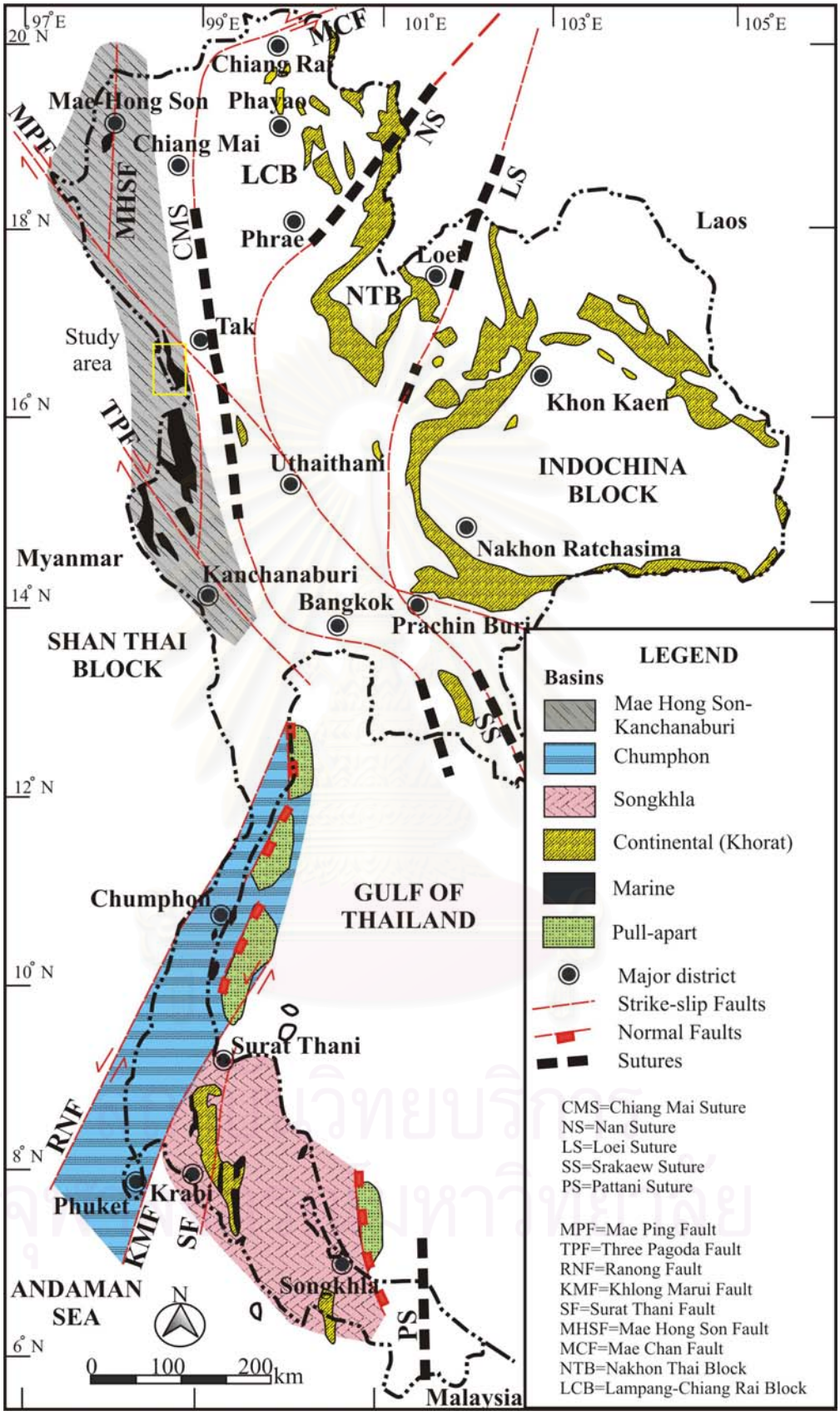


Figure 2.8 Map of Thailand showing major tectonic units and distribution of the Jurassic-Cretaceous sedimentary rocks and basins with some major geological structures (modified after Polachan and Sattayarak, 1989 and Charusiri *et al*., 2002).

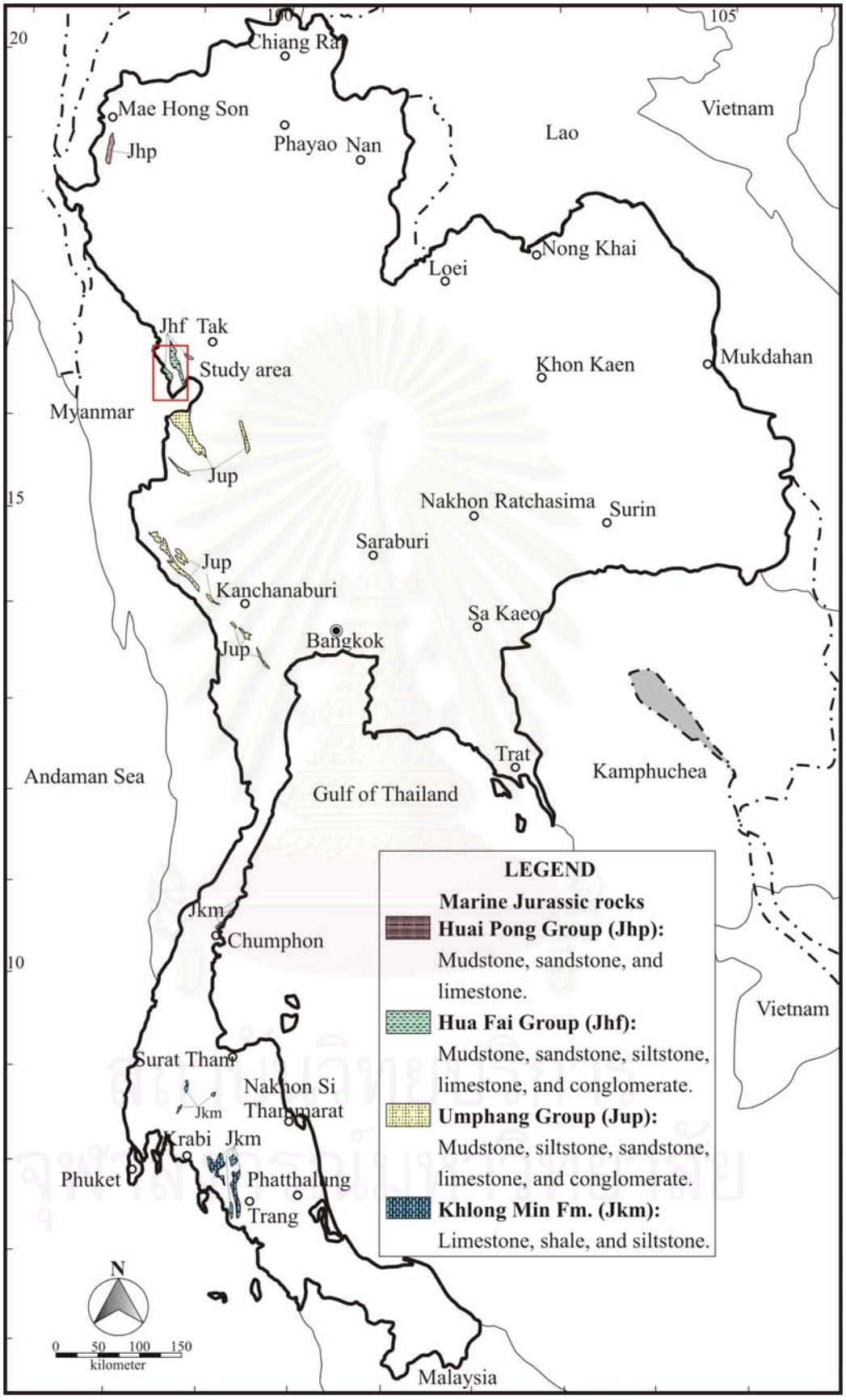
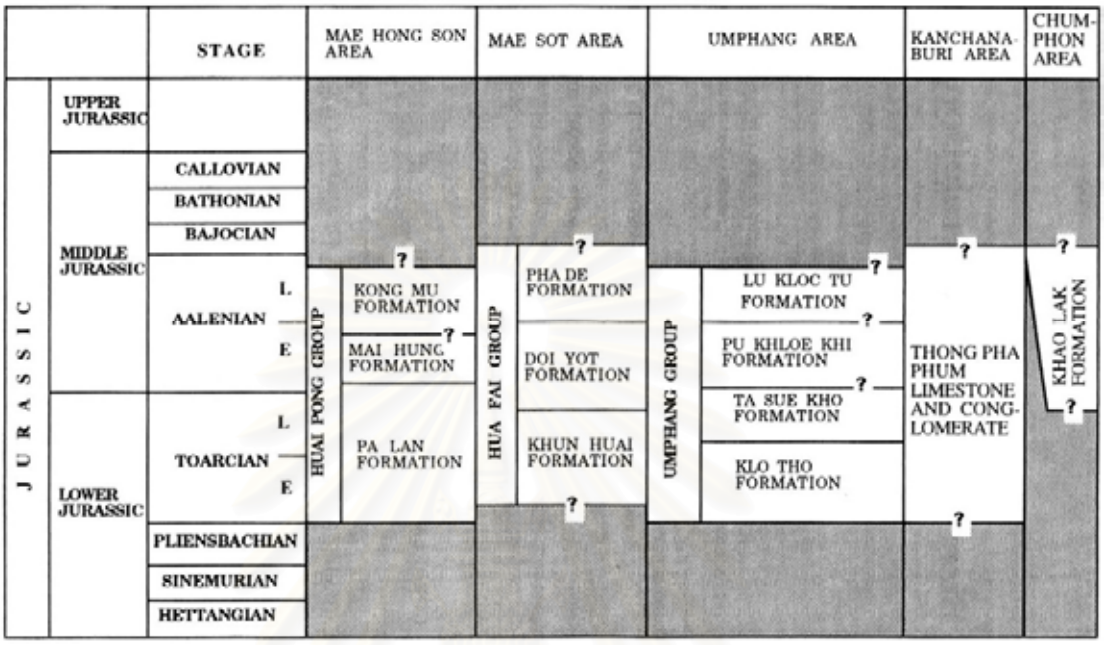


Figure 2.9 Distribution of marine Jurassic rocks of Thailand including sedimentary units (Meesook *et al*., 2006).

Table 2.3 Summary of lithologic nomenclature proposed for marine Jurassic strata of Thailand, and correlations made with international stage scheme (Meesook and Grant-Mackie, 1996).



Marine Jurassic strata of the Hua Fai Group (Meesook and Grant-Mackie, 1996) are well exposed along the unsealed road to the Huai Mae Sot power station 10 km east of Mae Sot and along Huai Mae Sot. The group consists of limestone-marl-mudstone-dominated sequences which have yielded macrofaunas of bivalves and ammonites. Its thickness is approximately 900 m with its base unconformable on the underlying Triassic strata and its top is unknown, interrupted at the fault-bounded margin of the Tertiary basin of Mae Sot west of the section. Three formations are included in the Hua Fai Group: Khun Huai Formation (basal), Doi Yot Formation, and Pha De Formation (at the top). The group is also exposed from the Tak-Mae Sot highway (formerly upper Mae Moei Group) passing southwards through the type locality, Ban Pha De, Pha Daeng zinc mine and Khao Tham Sua 7 km south of the type locality. The Hua Fai Group can be tentatively correlated with the lower part of the Mae Moei Group because the upper part of that group ranges from Middle to Upper Oxfordian (Braun and Jordan 1976).

2.5.2.3 Umphang-Phop Phra area, Tak Province

Marine Jurassic strata are well exposed in the Umphang region, a district within Tak Province located 160 km south of Mae Sot.

The Jurassic strata are widely spread in the west of Umphang township, Ban Klo Tho, Ban Pa La Tha and with local exposures scattered throughout the area. The region has previously been investigated by many workers (Meesook *et al.*, 1985; Fontaine and Suteethorn, 1988; Meesook, 1994; Meesook and Grant-Mackie, 1996). The strata exposed along the track from Ban Klo Tho on the Thai side of the border to Ban Pu Khloe Khi in Myanmar is selected as the type section for the Umphang Group which includes four formations: Klo Tho Formation (basal), Ta Sue Kho Formation, Pu Khloe Khi Formation, and Lu Kloc Tu Formation at the top.

The Umphang Group (Meesook and Grant-Mackie, 1996) consists predominantly of limestones, mudstones and sandstones and is distinguished from the Hua Fai Group which lacks sandstones and in which limestone and marl or mudstone is intimately interbedded. The thickness of the group is more than 430 m, the lower and the upper parts being presumed to have unconformable relations with adjacent strata because of the absence of older and younger Jurassic rocks, although no sedimentary contacts were seen.

2.5.2.4 Kanchanaburi area, Kanchanaburi Province

Marine Jurassic strata in the Kanchanaburi area are 200-300 m thick and are found at various localities in Thong Pha Phum District, i.e. 15 km southeast of Sai Yok Yai, an area east and southeast of Song Tho, and an area straddling the road from Song Tho to Ban Khiti in the north. Of these, the vicinity of Thong Pha Phum is best known because of its good exposures and accessibility.

The Jurassic strata in this area consist of light grey limestones, predominantly oncoid-micrite containing a rich foraminiferal fauna (Hagen and Kemper, 1976; Kemper *et al*., 1976; Kemper, 1976). The Jurassic sequence can be correlated with the Ta Sue Kho and Pu Khloe Khi Formations. The lower part of the Jurassic shows a non-marine influence on sedimentation by red-coloured elastic-calcareous lithologies in the Si Sawat area, and red sandstones and limestone conglomerates in the Thong Pha Phum area (Hagen and Kemper, 1976). The overlying Jurassic sediments and their faunas indicate shallow marine facies with confined endemic species (Fontaine and Suteethorn, 1988). The limestone is generally late Early Jurassic to Middle Jurassic; a Late Jurassic age has been occasionally reported, but remains very doubtful, being based on the uncertain identification of a few sections of poorly preserved foraminifera identified as *Kurnubia* (Kemper *et al*., 1976; Kemper, 1976).

2.5.2.5 Chumphon area, Chumphon Province

The brackish to marine Khlong Min Formation of the Thung Yai Group in the Chumphon area crops out in two selected areas; Huai Khun Krathing of Pathiu District, and Khlong Khut of Muang District, Chumphon Province. The group at least 300 m thick, is generally reconsidered in terms of lithostratigraphy and can be subdivided into three formations, namely, the Khlong Min, Lam Thap, and Khao Phang Formations, respectively in ascending order. The group is unconformably underlain by the Permian rocks (Ratburi Group) and unconformably overlain by Tertiary and Quaternary rocks as indicated by the presence of fanglomerate and grevel beds of the Fhang Daeng formation.

The Khlong Min Formation in this area, 200 m thick, consists of greenish grey, greyish brown mudstone and siltstone intercalated with fossiliferous limestone. Calcareous concretions are abundant in mudstone with some ammonoids and septarian calcite veins are also present. The formation, distributed at Khao Lak and Map Ammarid, is well exposed at Huai Khun Krathing, Pathiu District, Chumphon Province, and is unconformably underlain by bedded limestone of the Permian limestone. The fossil assemblages reflect marine to lagoonal environment during lower Middle Jurassic, with gradual change of depositional environment from marine to lagoonal.

In the Khlong Khut area 10 km east of Chumphon town, the Khlong Min Formation is well exposed a long a canal. The sequence consists of brown to reddish brown, calcareous sandstones, siltstones, and mudstones. Thin-bedded conglomeratic sandstones and conglomerates are occasionally intercalated in mudstones and siltstones. Bivalves are abundant in the conglomerate bed.

2.5.2.6 Thung Song-Klong Thom area, Nakhon Si Thammarat Province

Regionally, the Thung Yai Group consists of reddish brown shales, sandstones, conglomerates and reddish brown, fine-grained sandstones of totally 760 m thick. This group is proposed by Raksaskulwong (2002) and assigned as Middle Jurassic to Cretaceous age. This sequence unconformably overlies the Triassic rocks and is exposed in the area of Pathiu and Tha Sae of Chumphon procince, Wiang Sa of Surat Thani Province, Thung Song and Thung Yai of Nakhon Si Thammarat Province, Khlong Thom and Ao Luk-Plai Phraya of Krabi Province, and Wang Vi Set of Trang Province.

The Thung Yai Group, at least 65-1,145 m thick, is reconsidered in terms of lithostratigraphy and this group can be subdivided into four formations, namely, the Khlong Min, Lam Thap, Sam Chom and Phun Phin Formations, respectively, in ascending order (Teerarungsigul *et al*., 1999). The group is unconformably underlain by the marine Triassic rocks (Sai Bon Formation) as indicated by the presence of conglomerates in many localities around the Thung Yai and the hill beside the road 10 kilometres north of Chumphon Province, and is unconformably overlain by Tertiary rocks indicated by the basal conglomerates exposed near Sin Pun Basin. The following is the general description of the marine-brackish Jurassic Khlong Min Formation in detail.

The Khlong Min Formation, 58-116 m thick, consists of four lithofacies; the mudstone intercalated with fossiliferous limestone, siltstone, sandstone and fossiliferous limestone with abundant vertebrate and invertebrate fossils. This formation is unconformably underlain by calcareous siltstones, reddish-brown to maroon, with thin-bedded limestones and limestone lenses of the Triassic Sai Bon Formation, and is conformably overlain by the sandstones and siltstones of the overlying Cretaceous Lam Thap Formation. The fossil assemblages reflect lagoonal environment during lower Middle Jurassic, with gradually change of depositional environment from lagoonal to fluviatile.

The Khlong Min Formation in this area consists of mudstone intercalated with fossiliferous limestone, siltstone, and fossiliferous limestone with abundant vertebrate and invertebrate fossils. This formation is well exposed at a road-cut in the vicinity of Mab Ching, Thung Song District of Nakhon Si Thammarat Province. The rocks here are composed of well-bedded, calcareous siltstones and sandstones interbedded with thin-bedded, pale grey limestones and limestone lenses. Brackish bivalve assemblages e.g., *Protocardia* sp., *Myrene* sp., *Actinostroen* sp., and *Praemytilus* sp. are abundant. In some beds, ligneous shale and siltstone contains ostracodes, plant remains, and conchostracans. In the upper part of this sequence, the rocks are grading up to non-marine lacustrine deposits containing vertebrate bones and fragments indicative of Jurassic age (Buffetaut *et al*., 1994). These fossil assemblages reflect lagoonal environment during lower Middle Jurassic, with gradual change of depositional environment from lagoonal to fluviatile and lacustrine.

2.5.2.7 Ao Luk-Plai Phraya area, Krabi Province

The Mesozoic succession includes the Sai Bon Formation and Thung Yai Group. The Sai Bon Formation is more than 150 m-thick and consists of brown to reddish brown sandstone interbedded with siltstone, greyish mudstone and greyish limestone with fossils, such as foraminiferas, bivalves, brachiopods of Triassic age (Teerarungsigul, 1999).

The Thung Yai Group consists chiefly of greyish brown shales and reddish brown, fine-grained sandstones and conglomerates. This group is about 700 m-thick and its age is assigned as Middle Jurassic to Cretaceous (Teerarungsigul, 1999; Raksaskulwong, 2002). This sequence is well exposed in the Wiang Sa area of Surat Thani Province, Thung Yai of Nakhon Si Thammarat Province, Klong Thom, Ao Luk and Plai Phraya of Krabi Province and Wang Vi Set of Trang Province.

The Thung Yai Group in the Ao Luk-Plai Phraya study area, which has the thickness of at least 300 m, is reconsidered here in terms of lithostratigraphy and can be subdivided into two formations, namely, the Khlong Min and Lam Thap in an ascending order. This group is unconformably underlain by marine Triassic rocks (the Sai Bon Formation) as indicated by the presence of conglomerates in several localities around Thung Yai and Kian Sa Districts, Nakhon Si Thammarat and Surat Thani Provinces. The conglomerates are mainly polymictic orthoconglomerate containing pebble- to cobble-size limestone, sandstone, siltstone, and quartz clasts. The Thung Yai Group is unconformably overlain by Tertiary semi-consolidated clastic deposits as indicated by the presence of basal conglomerates exposed at Thung Yai District, Nakhon Si Thammarat Province.

The Khlong Min Formation crops out locally at Khlong Min, Ban Mab Ching, south of Thung Yai District, Nakhon Si Thammarat Province. The total thickness of the formation is about 200 m. This facie is widely exposed along Highway no. 44, at km 8-25 (Krabi-Khanom road) and Huai Luk reservoir, Ao Luk and Plai Phraya Districts, Krabi and Surat Thani Provinces. This marine sequence is well exposed at km 10+300, western side of the Highway no. 44, Ban Khao Ngam, Ao Luk District. The sequence includes greenish grey, thin- to medium-bedded mudstone intercalated with ripple cross-laminated sandstone and fossiliferous limestone with common invertebrate and vertebrate fossils. The sedimentary strata exposed at Huai Luk reservoir, Plai Phraya District, are composed chiefly of greenish grey to reddish

brown, thin- to thick-bedded mudstone intercalated with fossiliferous limestone, ripple cross-laminated sandstone with abundant invertebrate and plant remains.

The Lam Thap Formation is mainly distributed at Khao Chong Mai Dam, east of Khao Hua Sing To and Huai Luk reservoir, Ao Luk and Plai Phraya District, Krabi and Surat Thani Province. The formation is more than 100 m thick comprising mainly two lithofacies, the medium- to thick-bedded arkosic sandstones, and siltstone intercalated with greyish mudstone. The sandstone facie is mainly composed of brown or reddish brown, medium- to coarse-grained, subangular to subrounded, and moderate sphericity. It consists of 30% feldspar and 70% quartz grain with siliceous cements and iron oxide coated.

CHAPTER III

GEOLOGY AND STRATIGRAPHY OF THE HUA FAI GROUP

Based on the systematic mapping and lithostratigraphy of 7 measured sections across the Mae Sot-Phop Phra Basin, the sedimentary sequence can be subdivided on the basis of their physical characteristics and fossil contents or their time relationships. According to these features, the Hua Fai Group can be subdivided into 3 formations, the Khun Huai, Doi Yot, and Pha De Formations, in ascending order. These formations are classified as 17 units, 8 units of the Khun Huai Formation, 4 units of the Doi Yot Formation, and 5 units of the Pha De Formation.

3.1 Stratigraphic classification and measured sections

3.1.1 Stratigraphic classification and nomenclature

In this study, an attempt has been made to classify sedimentary sequences in the Mae Sot-Phop Phra area into different lithostratigraphic units in order to fulfill the sedimentological purpose of the study. Boundaries separating lithostratigraphical units may be placed at transition, abrupt and erosive contacts, which in turn reflect the changes of conditions of depositional environment.

The ultimate objective for subdividing the strata is to identify all of them and then to assemble a framework of non-overlapping units for designating hierarchies of lithostratigraphic units employed in the present study to cover the group, formation, facies, and units. However, regarding to the nomenclature of lithostratigraphic units, informal names have been used for the purpose of tentative references.

The Hua Fai Group was proposed by Meesook and Grant-Mackie (1996) for marine Jurassic rocks cropping out 10 km east of Mae Sot District, which the type location is well exposed along the Mae Sot power station's canal. The group is also exposed from the Tak-Mae Sot Highway passing southwards through the type locality, Ban Pha De, Padaeng mine, and Ban Khao Tham Sua 7 km south of the type locality. The group is approximately 900 m thick with its base is unconformable on underlying Triassic strata and its top is unknown, interrupted at the fault-bounded margin of the

Tertiary basin of Mae Sot west of the s ection. The Hua Fai Group is subdivided into three form ations, nam ely, the Khun Huai, Doi Yot, and Pha De Form ations in ascending order. The group consists chiefl y of lim estone-marl-mudstone-dominated sequences which have yielded m acrofaunas of bivalves and am monites. Som e detailed investigations of this area have previously been m ade by Braun and Jordan (1976) and Fontaine and Suteethorn (1988). Braun and Jordan (1976) established the Mae Moei Group for the Triassic-Jurassic sequence and recognized inform al upper (Jurassic) and lower (Triassic) divisions . The Mae Moei Group is rejected as an appropriate lithostratigraphic term for Jurassic strata of the region (Meesook and Grant-Mackie, 1996). The Jurassic sequence n ear Mae Sot is now confirm ed to lack of basal (Hettangian-Sinem urian-Pliensbachian) correlatives. It is unconform ably underlain by Triassic strata. Furtherm ore, these authors recognized no form al formational divisions within the Jurassi c sequence of the area. Am monites and bivalves are com mon in m udstones and m arly lim estones ranging from Toarcian to Early Bajocian age. These strata, theref ore, constitute a suitable type section f or Jurassic rocks in the Mae Sot area and the Huai Fai Group is proposed to replace the "upper Mae Moei Group" which is m uch less well-exposed and with less precise age determinations.

In order to establish the lithostratigraphy of the Hua Fai Group, 7 m ajor traverse lines and m any other lines in th e vicinity have been investigated. The lithostratigraphic units are described a nd defined based on the International Stratigraphic Guide (Murphy and Salvador, 1999). The m arine Jurassic sequences are widely distributed throughout the Mae Sot-Phop Phra Basin.

3.1.2 Measuring sections and sample localities

This study em braces two parts: field investigation and laboratory work. During the field investigation, about 97 sam ple localities have been collected from 7 traverse lines and adjacent areas in the Mae Sot-Phop Phra area (Figure 3.1). Details of these lines are listed as follows:

3.1.2.1 Ban Mae Kut Luang section in the north of the study area (m ap sheet 4742 IV).

3.1.2.2 Tak-Mae Sot Highway section at km 67-71 on the Tak-Mae Sot (m ap sheets 4742 III and 4742 IV).

3.1.2.3 Huai Mae Sot section at Huai Mae Sot from Ban Hua Fai, Mae Sot power station to Ban Khun Huai Mae Sot (map sheet 4742 III).

3.1.2.4 Padaeng-Tak mines section along the small road separated from Highway no. 1090 (Mae Sot-Umphang Highway) to Ban Pha De, Tak and Padaeng mines (map sheet 4742 III).

3.1.2.5 Ban Pu Toe section at the road separated from Highway no. 1090 to Ban Nam Khieo (map sheet 4742 III).

3.1.2.6 Doi Huai Mot section on bypass road of Highway no. 1090 and a small road to television station (map sheet 4742 III).

3.1.2.7 Huai Wale section on the security road along Huai Wale, Thailand-Myanmar border. It is the southern most section of the area (map sheets 4741 I and 4741 IV).

3.2 Geology of the study area

Geologically, the Mae Sot-Phop Phra area, western Tak Province consists of lithologic units ranging in age from Permian to Quaternary (Figure 3.2). The geology of this area has been described previously by various workers i.e. Cotter (1924), Heim and Hirschi (1939), Brown *et al*. (1951), Sato (1961), Ward and Bunnag (1964), Komalarjun and Sato (1964), Sato (1975), Braun and Jordan (1976), Hagen and Kemper (1976), Kemper *et al*. (1976), Kemper (1976), Chonglakmani (1983), Chonglakmani *et al*. (1985), Meesook *et al*. (1985), Charoenpravat *et al*. (1985), Tantiwanit *et al*. (1987), Fontaine and Suteethorn (1988), Sato and Westermann (1991), Naraballobh *et al*. (1992), Beauvais and Fontaine (1993), Zuoqi (1993), Meesook (1994), Meesook and Grant-Mackie (1994), Meesook and Grant-Mackie (1996), Meesook *et al*. (2005), and Meesook *et al*. (2006). General stratigraphic sequences (Figure 3.3) in the study area consist mainly of dolomite, dolomitic limestone, and limestone known as the Phra Woh Limestone and the marine Mesozoic rocks of the Mae Sariang Group (Triassic rocks) and Hua Fai Group (Jurassic rocks) which are unconformably underlain and overlain by the Phra Woh Limestone and Mae Sot Group (Tertiary rocks), respectively. The description of these units is given below in ascending order.

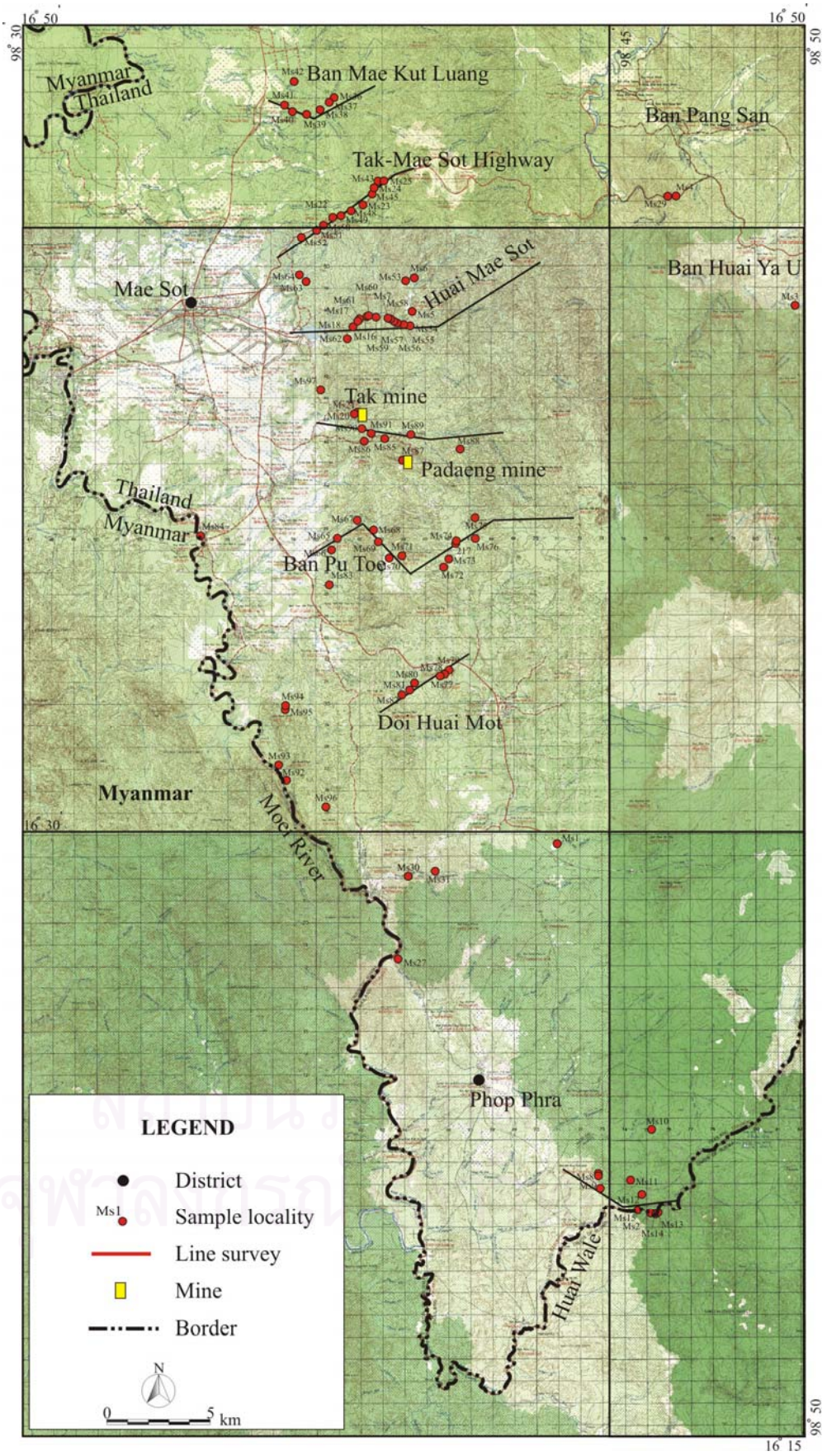


Figure 3.1 Topographic map of the study area showing 7 traverse lines and 97 locations of colleted samples.

3.2.1 Phra Woh Limestone

The oldest rock of the area consists mainly of grey to dark grey sandstone interbedded with mudstone, siltstone, dolomitic limestone, and limestone of the Phra Woh Limestone. This formation is unconformably overlain by Triassic rocks and is distributed in the northeastern and eastern parts of the area. The Phra Woh Limestone can be divided into 2 units, lower (P1) and upper (P2) units totaling more than 1,000 m thick. The lower part (P1) consists mainly of clastic rocks such as brownish, thick-bedded, calcareous sandstone interbedded with brownish, thin-bedded siltstone and grey to dark grey, thin-bedded shale containing coral, brachiopod, fusulinid, and bryozoa of late Early-Middle Permian age. The upper part (P2) comprises grey to dark grey, thick-bedded to massive dolomite and dolomitic limestone described as the type section of the Phra Woh Limestone (Bunopas, 1981). The fossil assemblages are predominantly of coral, brachiopod, bryozoa, and fusulinid of Middle-Late Permian age.

3.2.2 Mae Sariang Group

Marine Triassic rocks in the vicinity of Mae Sot and Phop Phra Districts, Tak Province are unconformably underlain and overlain by the Phra Woh Limestone and Hua Fai Group, respectively. The rocks can be divided into two informal formations i.e. the lower (Tr1) and upper (Tr2) units having 200-400 m thick. The lower formation consists of brownish, thick-bedded sandstone intercalated with greyish, thin-bedded mudstone displaying prominent Bouma sequence including gradded bedding, and fining upward sequence. Fossils in this part are very rare with a few gastropod, bivalve, and plant remains. The upper formation is characterized by fine-grained lithologies grading up from the lower unit. This sequence consists mainly of greenish grey, thick-bedded shale intercalated with brownish, medium-bedded sandstone and very thick-bedded limestone lenses with chert nodules. The upper most sequence is predominantly represented by grey and brown, thin-bedded cherts interbedded with greenish grey, very thin-bedded shale. Fossils are abundant in some shales and chert beds, consisting of the bivalves *Halobia* sp., *Posidonia* sp., ammonites indicative of Middle-Late Triassic age (Braun and Jordan, 1976; Chonglakmani, 1981; Caridroit *et al*., 1993).

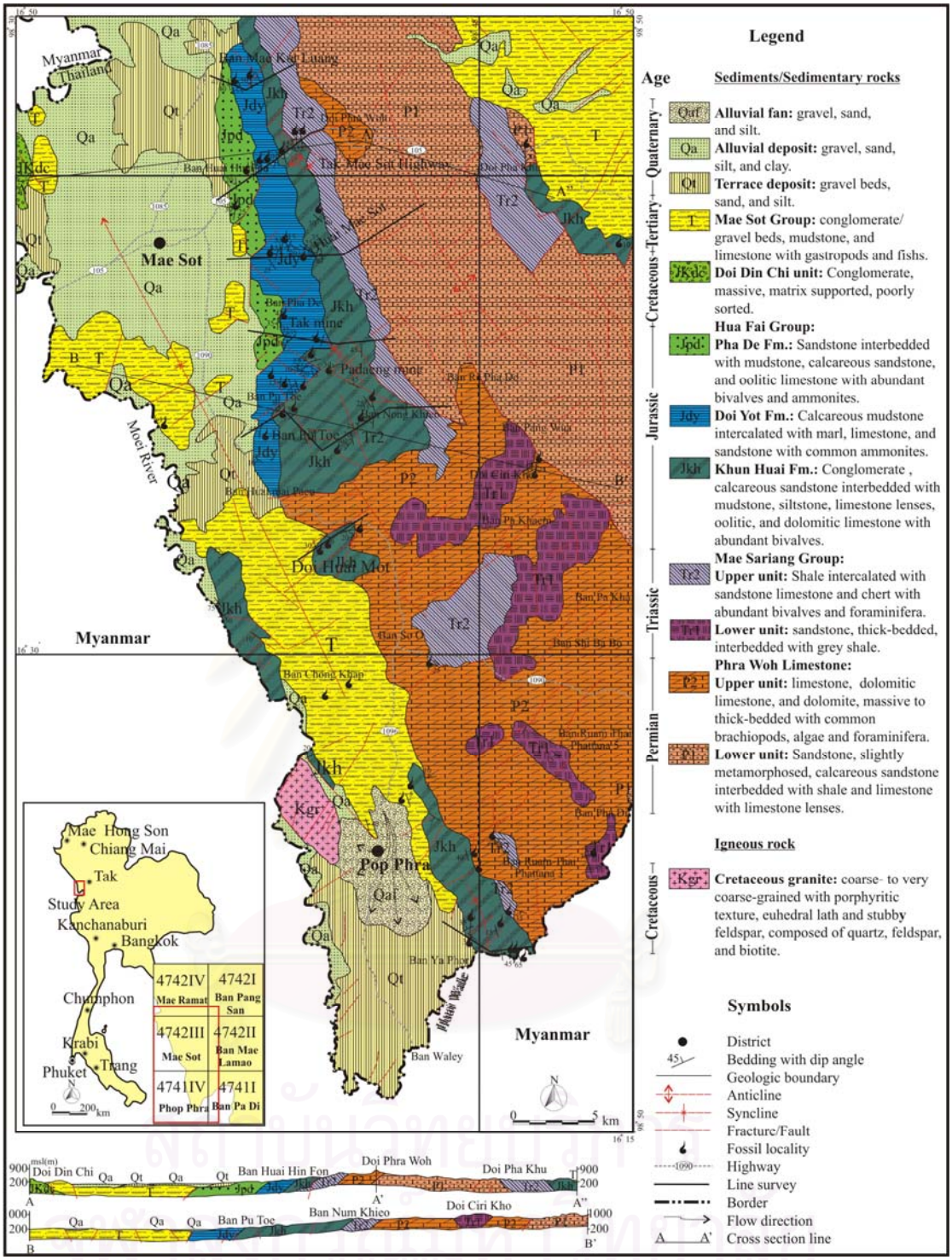


Figure 3.2 Geologic m ap and cross-sections showing the distribution, ages and sim plified geological structures of lithologic units in Mae Sot and Phop Phra Districts, Tak Province.

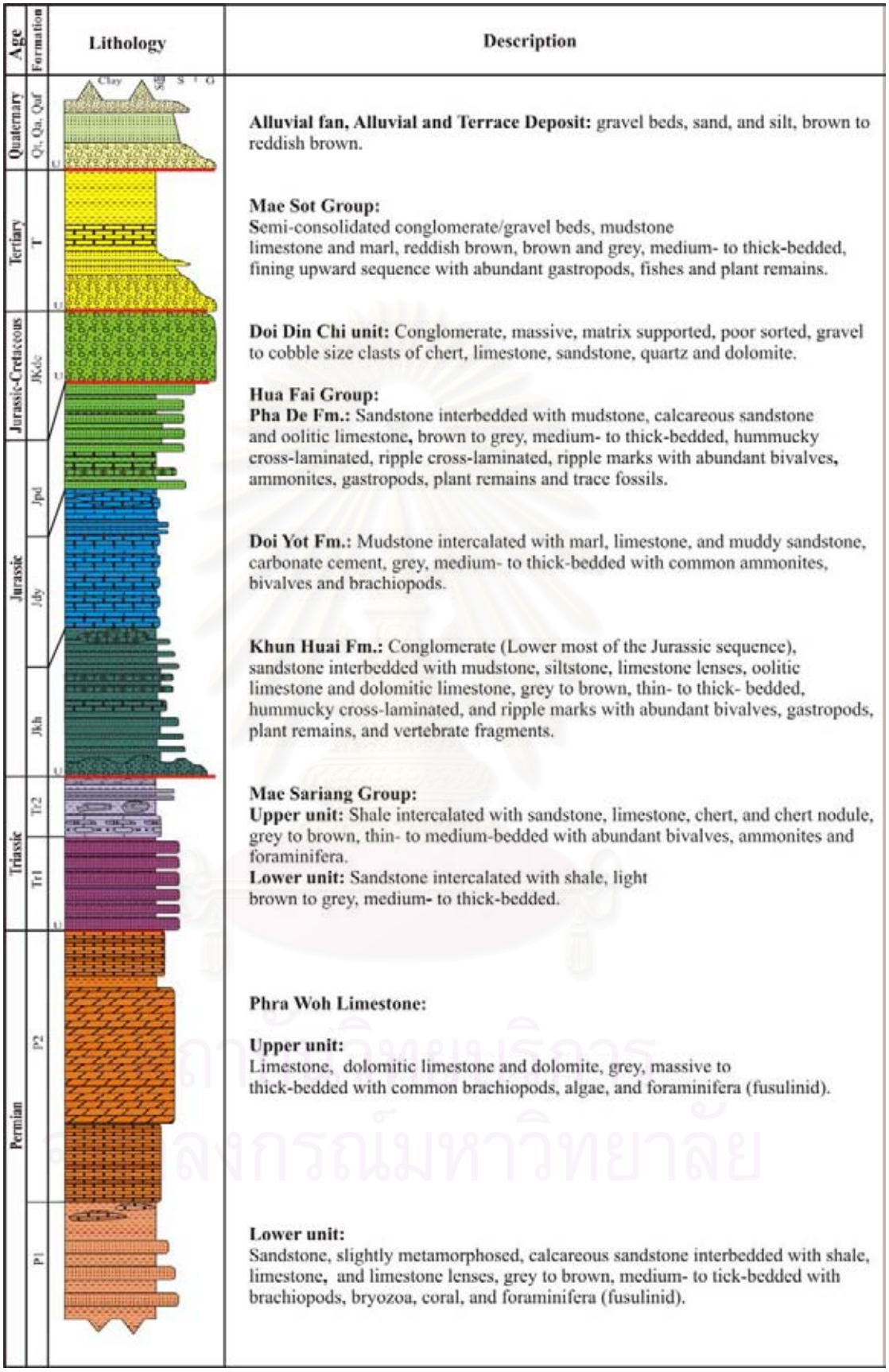


Figure 3.3 Stratigraphic column showing the sequence of units of the study area (not to scale).

Some chert beds are rich in microfossils of Middle to Late Triassic (Anisian to Rhaetian) radiolarians (Ishida *et al*., 2006; Weerahong, 2007). Based on these fossil assemblages, the Mae Sariang Group in this area is assigned as the Middle-Late Triassic age (Anisian to Rhaetian) (Ishida *et al*., 2006; Weerahong, 2007).

3.2.3 Hua Fai Group

The type section of marine Jurassic sequences, the Hua Fai Group (Meesook and Grant-Mackie, 1996), is well exposed along the unsealed road to the Huai Mae Sot power station's canal 10 km east of Mae Sot District. The group is unconformably underlain and overlain by the Triassic rocks and Tertiary sequences respectively as indicated by the presence of conglomeratic layers. The group consists of conglomeratic limestone, sandstone, marl, shale, limestone, and oolitic limestone with approximately 200-832 m thick. The Hua Fai Group can be divided into 3 formations as the Khun Huai (Jkh), Doi Yot (Jdy), and Pha De (Jpd) Formations in ascending order. This group is also well exposed in various areas i.e. the Tak-Mae Sot Highway (formerly upper Mae Moei Group) passing southwards through the type locality, Ban Pha De, Padaeng mine, Tak mine, Ban Pu Toe, Doi Huai Mot, and Phop Phra District. Fossils are abundant and diverse, consisting of bivalves, ammonites, corals, gastropods, brachiopods, trace fossils, and plant remains. Based on the fossil assemblages, late Early-middle Middle Jurassic (Late Toarcian-Early Bajocian) age is given for the group. The Hua Fai Group can be tentatively correlated with the lower part of the Mae Moei Group because the upper part of that group ranges from Middle to Upper Oxfordian (Braun and Jordan 1976).

3.2.4 Doi Din Chi unit

The Doi Din Chi unit is well exposed at a small hill northwest of the study area. The hill, trending north-south directions, is extended into the eastern Myanmar. The Doi Din Chi unit is unconformably underlain by the Pha De Formation, Hua Fai Group and overlain by the Mae Sot Group. The unit is mainly characterized by very thick-bedded, grey to reddish brown conglomerate. This conglomerate is matrix-supported with clasts are made up mainly of limestone, sandstone, chert, quartz, and dolomitic limestone and diameter size varying from 1-35 cm. Based on the previous study, Fontaine and Suteethorn (1988) reported the presence of foraminifera and algae

in limestone clasts indicative of the Middle Jurassic age. However, this unit should be the Cretaceous? sequence (Fontaine and Suteethorn, 1988).

3.2.5 Mae Sot Group

The Mae Sot Group (Tertiary rocks) is well exposed in Phop Phra District located in the southern part of the north-south trending Mae Sot basin and is also extended along the eastern and western flanks of the basin. Generally, this Tertiary basin is characterized by a syncline with gentle plunging to the north direction. The thickness of this group is probably at least 2,000 m thick (Thanom sap and Sitahirun, 1992). The Mae Sot Group can be divided into 3 formations, namely, the Mae Ramat, Mae Pa, and Mae Sot Formations in ascending order. Stratigrapically, the group comprises mainly semi-consolidated sediments and units including gravel beds, clay, oolitic limestone, marl, oil shale, and coal seems. Some beds are rich in freshwater gastropods, fishes, insect fragments, snakes, and plants indicative of Late Tertiary age.

3.2.6 Quaternary deposits

The sediments deposited in these intermontane basins were caused by alluvial and fluvial processes of three main rivers, Mae Lamao, Moei, and Wale Rivers, that developed broad flood plains on both sides of the channels. These sediments are characterized by sand, silt, clay, and gravels beds. The gravel size ranges from pebble to boulders. Fine-grained sediments such as fine sand, silt, and clay intercalated with gravels are found in the flood plains of these main rivers. Channel lag gravels are also found in the river banks. Terrace deposit (Qt) with thick accumulation of gravels and clayey sand are occurred along both rims of the basin.

3.2.7 Igneous rocks

The granite crops out as small stocks extended more than 10 km into Myanmar to the southwestern part of the area (see Figure 3.2). This granite is designed as the Cretaceous granite (Kgr) based on their field occurrence, petrography and chemical characteristics, and is apart of the Western Belt Granite (WBG: Cretaceous) (Department of Mineral Resources, 1999).

WBG consists of small to moderate batholiths and plutons of mainly restricted compositional range with a minor amount of the expanded type. Both units occupy

mainly in the western, southern, and sout heastern parts of the area along Thailand-Myanmar border. Lithologically, these granite s are coarse- to very coarse-grained porphyritic texture with large (up to 6-7 cm long) K-feldspar phenocrysts and in the matrix com prising quartz, K-f eldspar, pl agiclase, and biotite. These granites are syenogranite, monzogranite, quartz syenite, and quartz m onzonite. The granites along the central and eastern parts of Thailand are m ainly of Triassic to Jurassic age whereas those in the western part are Cr etaceous to Tertiary (Charusiri, 1989). The granites from the western province are th e youngest suites of granite of Thailand (130-78 Ma). The dom inant S-type granites possess high to very high initial $^{87}Sr/^{86}Sr$ ratios of 0.719-0.744, whereas those of the I-types vary from 0.704-0.714 (Department of Mineral Resources, 1999). Th e S-type characteristics with high to very high initial ratios indicate that the granites of this terrain were derived by partial melting of the evolved continental crust.

3.3 Geological structures of the Mae Sot-Phop Phra area

The regional geological structures incl uding folds and fractures are m ainly orientated in the northwest-southeast dir ection in rocks ranging in age from Upper Paleozoic to Quaternary (see Figures 3.2 and 3.4). In the study area, various geological structures are m easured and de scribed throughout the area including folds, fractures, and faults. Subsequently, all data of attitudes are com piled and analyzed by the stereographic projection, StereoNett software, i.e. the Schm idt m ethod of computing and equal area projection technique.

3.3.1 Folds

Generally, folding in Upper Paleozoic and Mesozoic strata from Mae Sot to Phop Phra District is m ainly orientated in the north northwest-south southeast direction (see Figures 3.2 and 3.4). The beddi ng planes recognized in all outcrops of the study area are shown in an appendix. Th e m ajor trend of bedding in the north northwest-south southeast direction with dipping to the west and northeast is com mon in this area. Folded structures in the eas t of Ban So O have been observed in the northeast-southwest trending for the Triassic rocks. However, the poles of bedding of

the Hua Fai Group, (Figure 3.5A) are quite variable as compared with other formations.

According to the remote sensing interpretation, current field investigation and stereographic projection analysis in folded rocks of the Hua Fai Group (see Figures 3.4 and 3.5A), the main series of folding is represented by antiforms and synforms trending in the north northwest-south southeast direction (see Figure 3.4). The general fold axis is in the northwest-southeast direction with plunging to the northwest (see Figure 3.5A).

3.3.2 Fractures

As the results of remote sensing interpretation, current field investigation and stereographic projection analysis, the fractures of the Hua Fai Group (see Figures 3.4 and 3.5B) in the study area are mainly in the northeast-southwest and northwest-southeast directions. All directions of fractures of the Hua Fai Group are presented by the rosette diagram (see Figure 3.5B) and shown in an appendix.

Evidences from the remote sensing interpretation and current field observation indicate the northwest-southeast faults in the study area. According to the field investigations, at km 68 (magic hill) on the Tak-Mae Sot Highway, the northwest-southeast faults are characterized as dextral strike-slip (fault plane 125/90) and reverse (fault plane 310/65) faults, and sinistral strike-slip fault (Figure 3.6, fault plane 310/80) is clearly exposed at the Ban Ruam Thai Phatana 3, southwest of the study area. However, the remote sensing lineaments in northwest-southeast and northeast-southwest directions indicate normal fault sets.

3.4 Lithostratigraphy of the Hua Fai Group

3.4.1 Measured sections

Marine Jurassic strata are commonly distributed around the Mae Sot-Phop Phra Basin. They are well exposed along the unpaved road to the Huai Mae Sot power station 10 km east of Mae Sot District. The Hua Fai Group is well exposed from the Tak-Mae Sot Highway passing southwards through the type locality of this group, Ban Pha De, Padaeng mine, Tak mine, Ban Pu Toe, Doi Huai Mot, and Phop Phra District. Based on the remote sensing and aerial photograph

interpretations and field reconnaissance su rvey, trending exposures of these strata are well exposed in the north northwest -south southeast direction. During field investigation, seven traverse lines have been designed as shown in Figure 3.1 and 97 sample localities have been collected from these traverse lines and around the Mae Sot-Phop Phra area.

3.4.1.1 Ban Mae Kut Luang section

Ban Mae Kut Luang section is locat ed at Huai Khanun, Mae Kut Luang reservoir, Taad waterfall, and Ban Mae Kut Luang, 9 km north of Mae Sot District (see Figure 3.1). The section, approximately 420 m thick, includes 7 sample localities and 19 rock sam ples (Figure 3.7) collected from sandstone, shale, lim estone, oolitic lim estone, and m arl with f ossil layers. The general dip direction of bedding planes at this m easured section is in the southwestern direction (245°-260°) with moderately dipping angles (35°-65°).

3.4.1.2 Tak-Mae Sot Highway section

Tak-Mae Sot Highway section is situated along km 67-71 on the Tak-Mae Sot Highway, Ban Huai Hin Fon, 7 km northeast of Mae Sot District (see Figure 3.1). The total thickness is approxim ately 468 m , and 13 sam ple localities, and 41 rock sam ples (Figur e 3.8) have been collected from sandstone, shale, lim estone, and m arl with fossil layers. The general dip direction of bedding planes at this m easured section varies from west to northeast (220°-300° and 5°-225°) with moderately dipping angles (20°-50°).

3.4.1.3 Huai Mae Sot section

Huai Mae Sot section is situated at Huai Mae Sot passing from Ban Hua Fai, Mae Sot power station to Ban Khun Huai Mae Sot (see Figure 3.1). This section is well exposed along the canal of the power station located at the type section of the Hua Fai Group. The total thickness is approxim ately 378 m, and 16 sam ple localities, and 37 ro ck samples (Figure 3.9) have been collected from sandstone, shale, lim estone, m arl, sandstone, and chert with fossil layers. The general dip direction of bedding planes at this m easured section varies from southwest to west (200°-290°) with gentle to m oderately dipping angles (15°-50°).

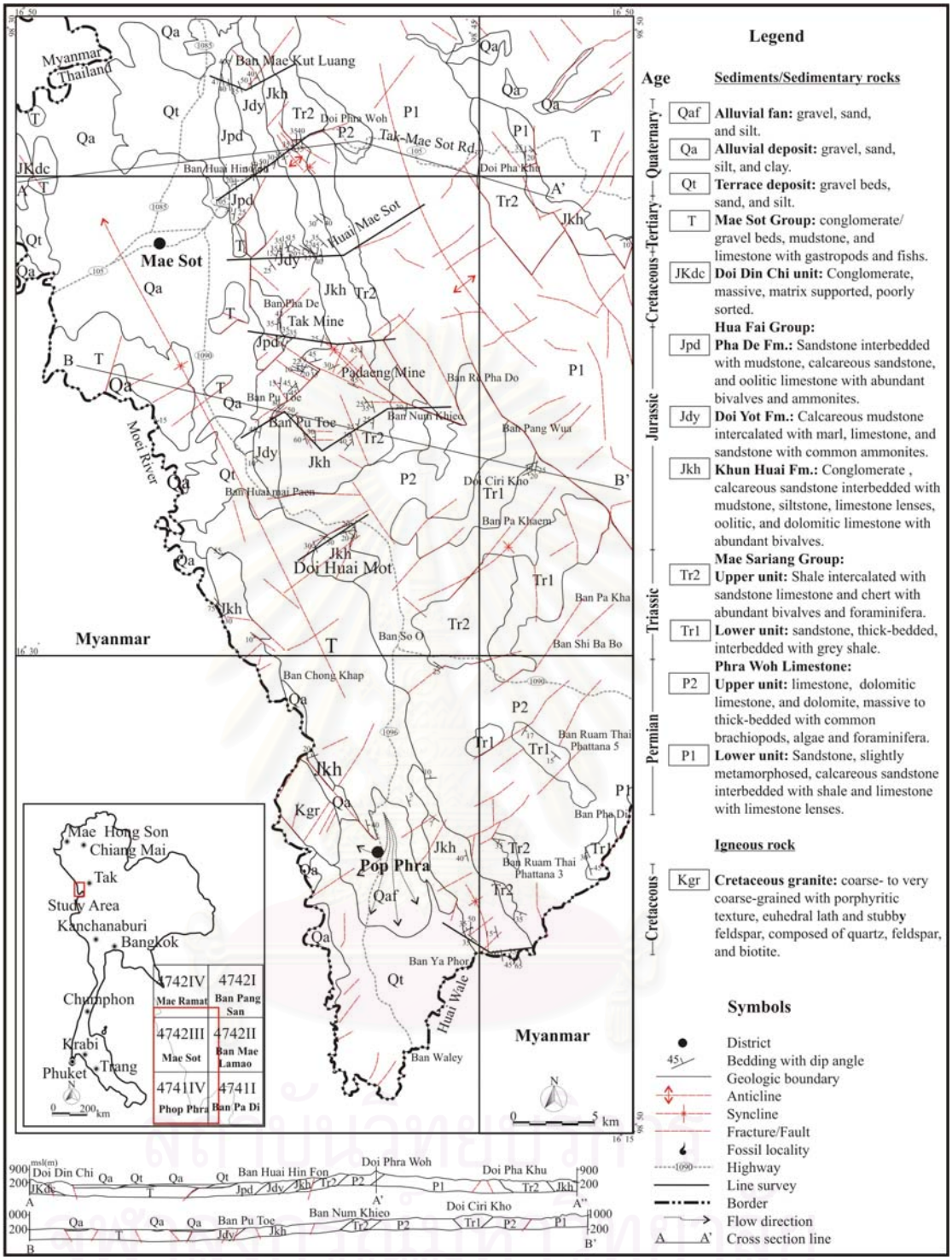


Figure 3.4 Map showing interpretation structures in the study area based on remote sensing major lineaments, aerial photograph, and current field investigation data.

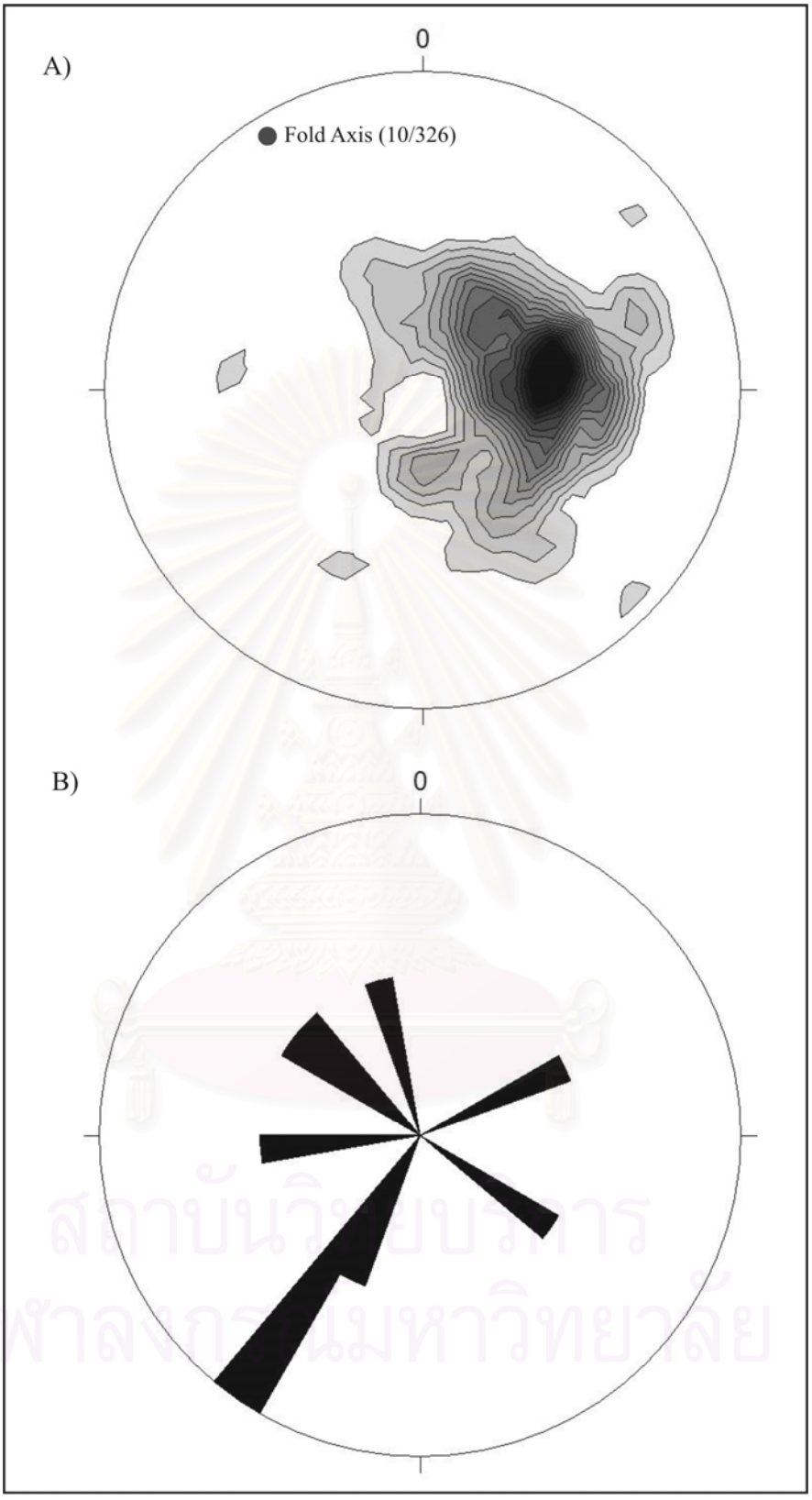


Figure 3.5 Stereographic projection A) Schm idt method plotted showing average trending of folded rocks. B) Rosette diagram plotted s howing major SW-trending fractures in the study area.

Figure 3.6 Outcrop showing right lateral strike-slip fault, northwest southeast trending (310/80) at Ban Ruam Thai Pattana 3.

The section is well exposed along Huai Mae Taow, at Ban Pha De, Tak m ine, Padaeng m ine, and Ban Khao Tham Sua. The section, approxim ately 622 m thick, includes 10 sam ple localities and 62 rock samples (Figure 3.10) collected from sandstone, shale, limestone, marl, dolomite, and conglomerate with fossiliferous beds. The general dip direction of bedding planes at this measured section varies from west to north (0°-265°) with gently dipping angles (20°-42°).

3.4.1.5 Ban Pu Toe section

Ban Pu Toe section is situated at the local road separated from the Highway no. 1090, from Mae Sot to Um phang, 17 km southeast of Mae Sot District (see Figure 3.1). The section is well exposed at Ban Pu Toe, Ban Ko Chuai, and Ban Nam Khieo. The total thickness is approxim ately 397 m , and 14 sam ple localities and 24 rock sam ples (Figure 3.11) have been collected from sandstone, limestone, shale, and marl with fossil layers. The general dip direction of bedding pl anes at this m easured section is in the west (260°-320°) with moderately to steeply dipping angles (25°-80°).

3.4.1.6 Doi Huai Mot section

Doi Huai Mot section is located at the bypass road of the Highway no. 1090 and the small road to a television station, Doi Huai Mot, Ban Nam Tok Hin Lek Fai, 25 km south of Mae Sot District (see Figure 3.1) . The section, approximately 102 m thick, includes 6 sample localities and 15 rock samples (Figure 3.12) collected from sandstone and limestone with fossil layers. The general dip direction of bedding planes at this measured section varies from the southwest to west (160°-250°) with gently dipping angles (20°-30°).

3.4.1.7 Huai Wale section

Huai Wale section is located along the security road near Huai Wale, Thailand-Myanmar border, 7 km southeast of Phop Phra District (see Figure 3.1). This section lies in the southern-most part of the study area. The section is approximately 286 m thick including 9 sample localities and 28 rock samples (Figure 3.13) which have been collected from sandstone and limestone with fossiliferous beds. The general dip direction of bedding planes at this measured section varies in the west, south, and east (095-330 degrees) with moderately dipping angles (30-60 degrees).

3.4.2 Lithostratigraphy and correlation

Marine Jurassic rocks in the Mae Sot, Phop Phra, and Umphang areas have long been described previously by various workers i.e. Heim and Hirschi (1939), Brown *et al*. (1951), Braun and Jordan (1976), Chonglakmani *et al*. (1985), Fontaine and Suteethorn (1988), Meesook (1994), Meesook and Grant-Mackie (1994), Meesook and Grant-Mackie (1996), Meesook *et al*. (2005), and Meesook *et al*. (2006). According to Meesook and Grant-Mackie (1996), marine Jurassic strata in Thailand are generally underlain unconformably by Triassic and overlain by Quaternary strata. The marine Jurassic lithostratigraphic units (Table 2.3) are established in ascending order: the Pa Lan, Mai Hung, and Kong Mu Formations of the Huai Pong Group in the Mae Hong Son area; Khun Huai, Doi Yot, and Pha De Formations of the Hua Fai Group in the Mae Sot-Phop Phra area; Klo Tho, Ta Sue Kho, Pu Khloe Khi, and Lu Khoc To Formations of the Umphang Group in the Umphang area. The main lithologies consist of mudstones, siltstones, sandstones, limestones, and marls. Mudstones, siltstones, and sandstones are widespread in all basins; marls are found only in Mae Sot.

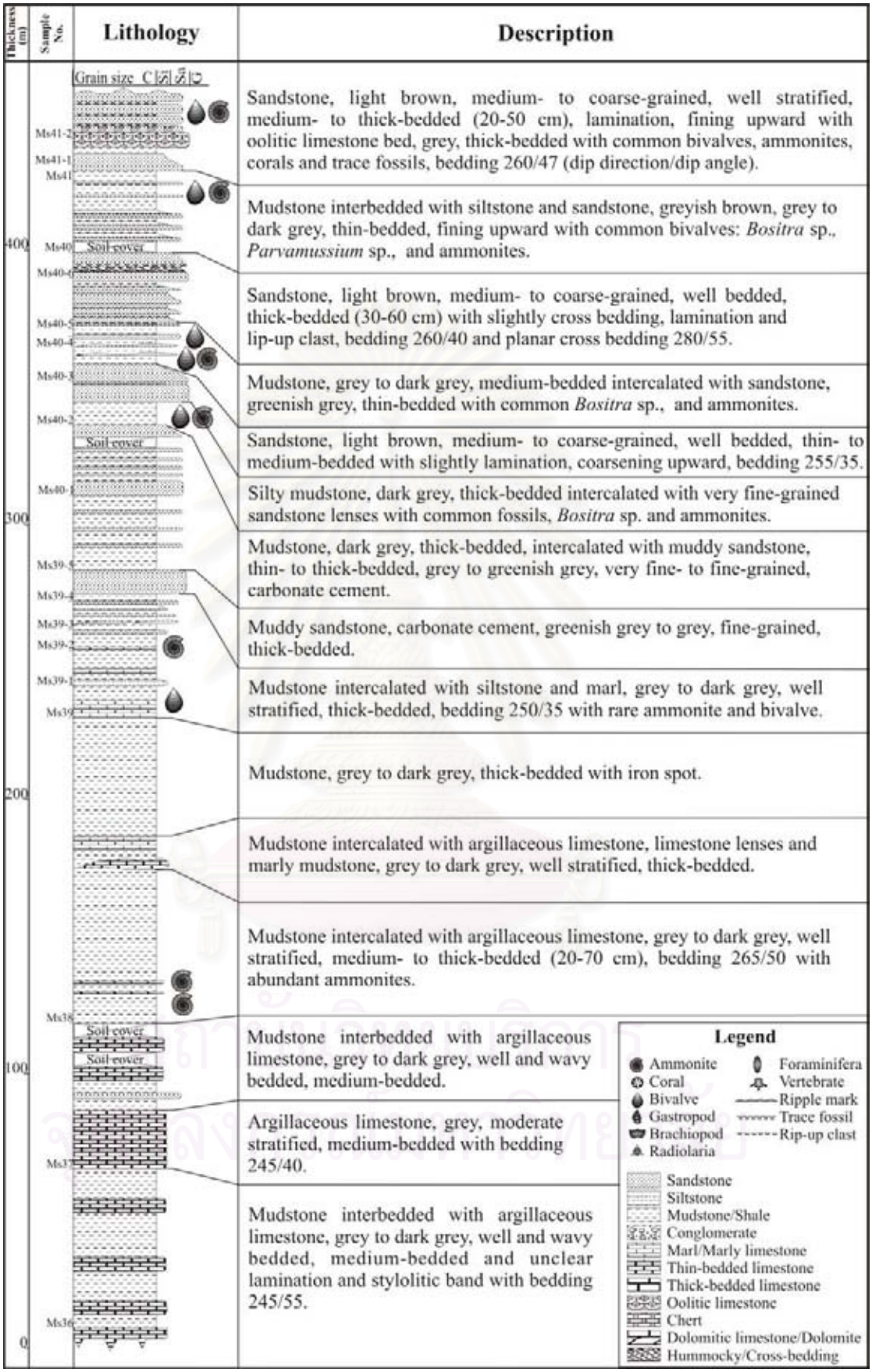


Figure 3.7 Lithostratigraphic colum n of the Hua Fai Group at Huai Khanun, Mae Kut Luang reservoir, Taad waterfall, and Ban Mae Kut Luang, Mae Sot District (not to scale).

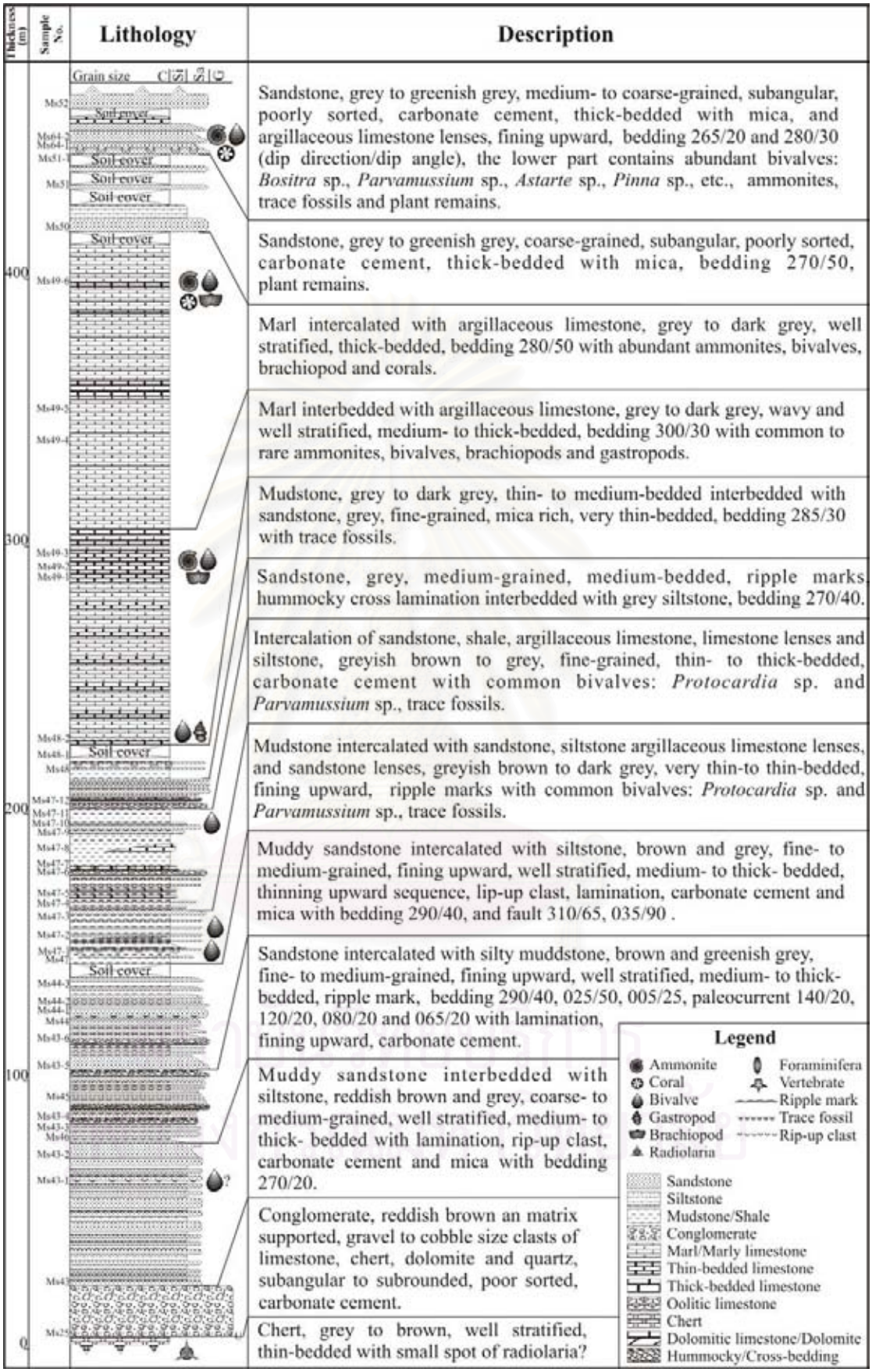


Figure 3.8 Lithostratigraphic colum n of the Hua Fai Group at km 67-71 on the Tak-Mae Sot Highway, 7 km northeast of Mae Sot District (not to scale).

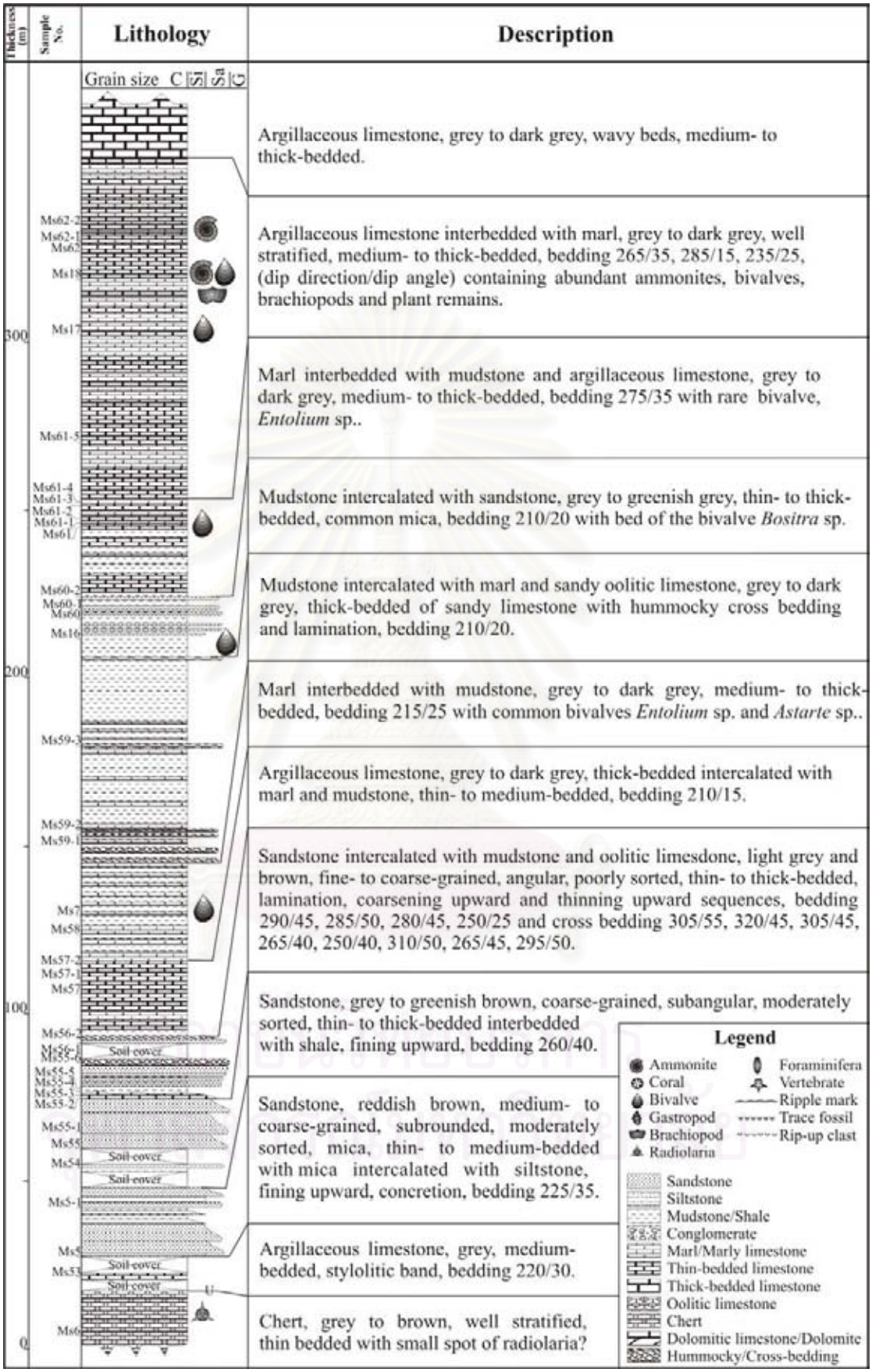


Figure 3.9 Lithostratigraphic colum n of the Hua Fai Group at Huai Mae Sot, Mae Sot power station's canal, and Ban Khun Huai Mae Sot, Mae Sot District (not to scale).

In 1994 and 1996 Meesook and Grant-Mackie have proposed the type locality of the Hua Fai Group, which are well exposed along the unsealed road to the Huai Mae Sot power station, 10 km east of Mae Sot and along Huai Mae Sot. This group consists of limestone-marl-mudstone-dominated sequences which have yielded macrofaunas of bivalves and ammonites. Its thickness is approximately 900 m with its base is unconformable on the underlying Triassic strata and its top is unknown, interrupted at the fault-bounded margin of the Tertiary basin of Mae Sot west of the section. Three formations are included in the Hua Fai Group: Khun Huai Formation (basal), Doi Yot Formation, and Pha De Formation (at the top). The group is also exposed from the Tak-Mae Sot Highway (formerly upper Mae Moei Group) passing southwards through the type locality, Ban Pha De, Padaeng mine, and Khao Tham Sua 7 km south of the type locality. The Hua Fai Group can be tentatively correlated with the lower part of the Mae Moei Group because the upper part of that group ranges from Middle to Upper Oxfordian (Braun and Jordan 1976).

In this study, a newly proposed marine Jurassic lithostratigraphy of the Hua Fai Group is as follows in ascending order: the Khun Huai, Doi Yot, and Pha De Formations, respectively. The Khun Huai Formation consists of 8 units which is composed of conglomerate, sandstone, siltstone, mudstone, limestone, dolomite, and oolitic limestone with abundant bivalves, gastropods, trace fossils, plant remains, and vertebrate fossils (turtle bone and shark teeth). The Doi Yot Formation consists mainly of 4 units which can be distinguished by marl interbedded with limestone and contains abundant ammonites and bivalves. The upper most part of the Hua Fai Group, Pha De Formation consists of 5 units, predominantly intercalation of sandstone, mudstone, siltstone, oolitic limestome, and limestone with abundant bivalves, ammonites, gastropods, corals, trace fossils, and plant remains. Based on lithostratigraphic significance in this study, the Hua Fai Group can be subdivided into 3 formations in an ascending order, namely, the Khun Huai, Doi Yot, and Pha De Formations in which detailed lithofacies in each formation are shown in Figures 3.14, 3.24, and 3.29 as follows.

3.4.2.1 Khun Huai Formation

A) Type locality: The Khun Huai Formation is named from Ban Khun Huai, a small village 10 km east of Mae Sot District, Tak Province (Meesook, 1994; Meesook and Grant-Mackie, 1996).

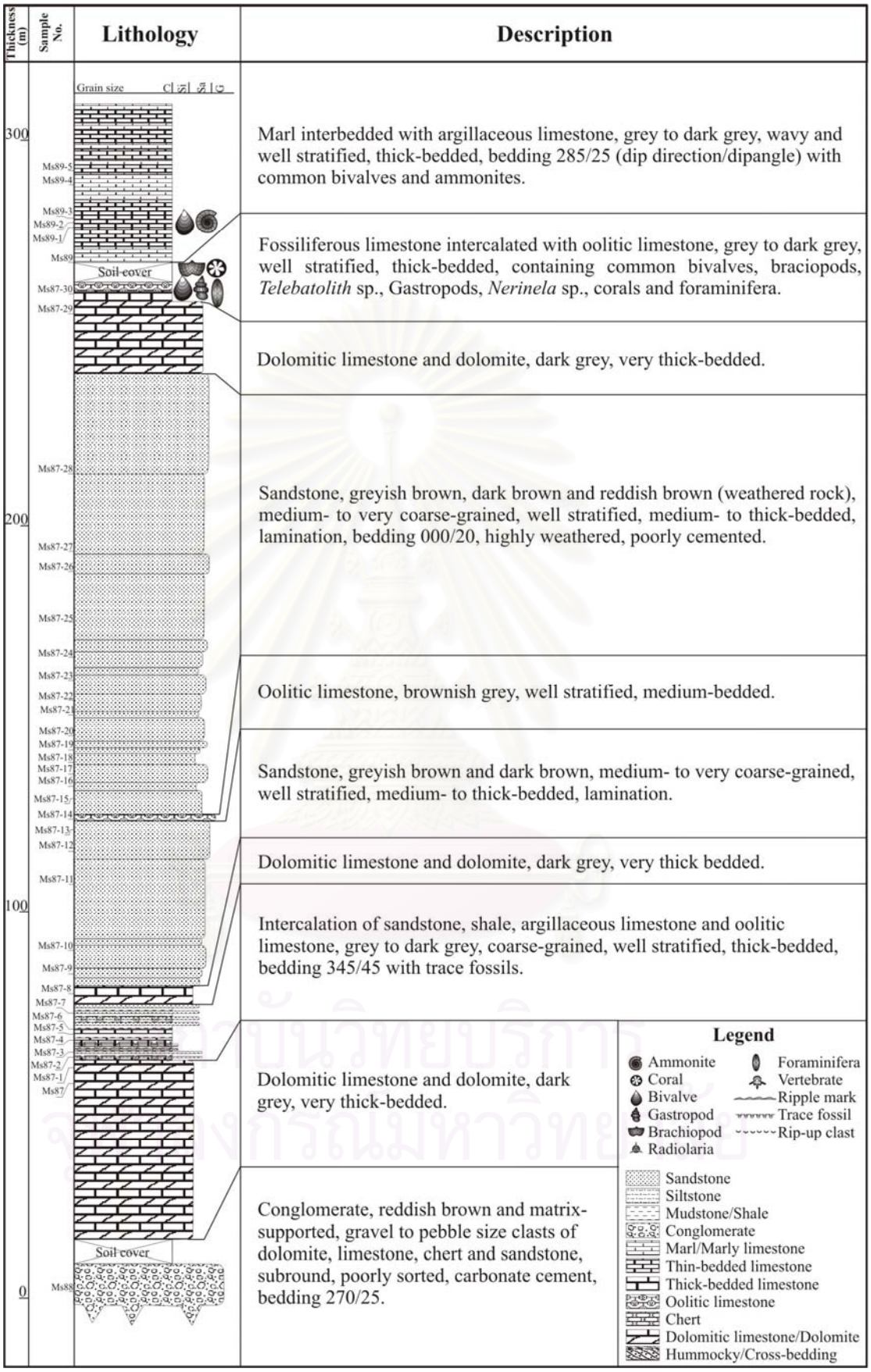


Figure 3.10 Lithostratigraphic colum n of the Hu a Fai Group at the local road and Huai Mae Taow, 12 km southeast of Mae Sot District (not to scale).

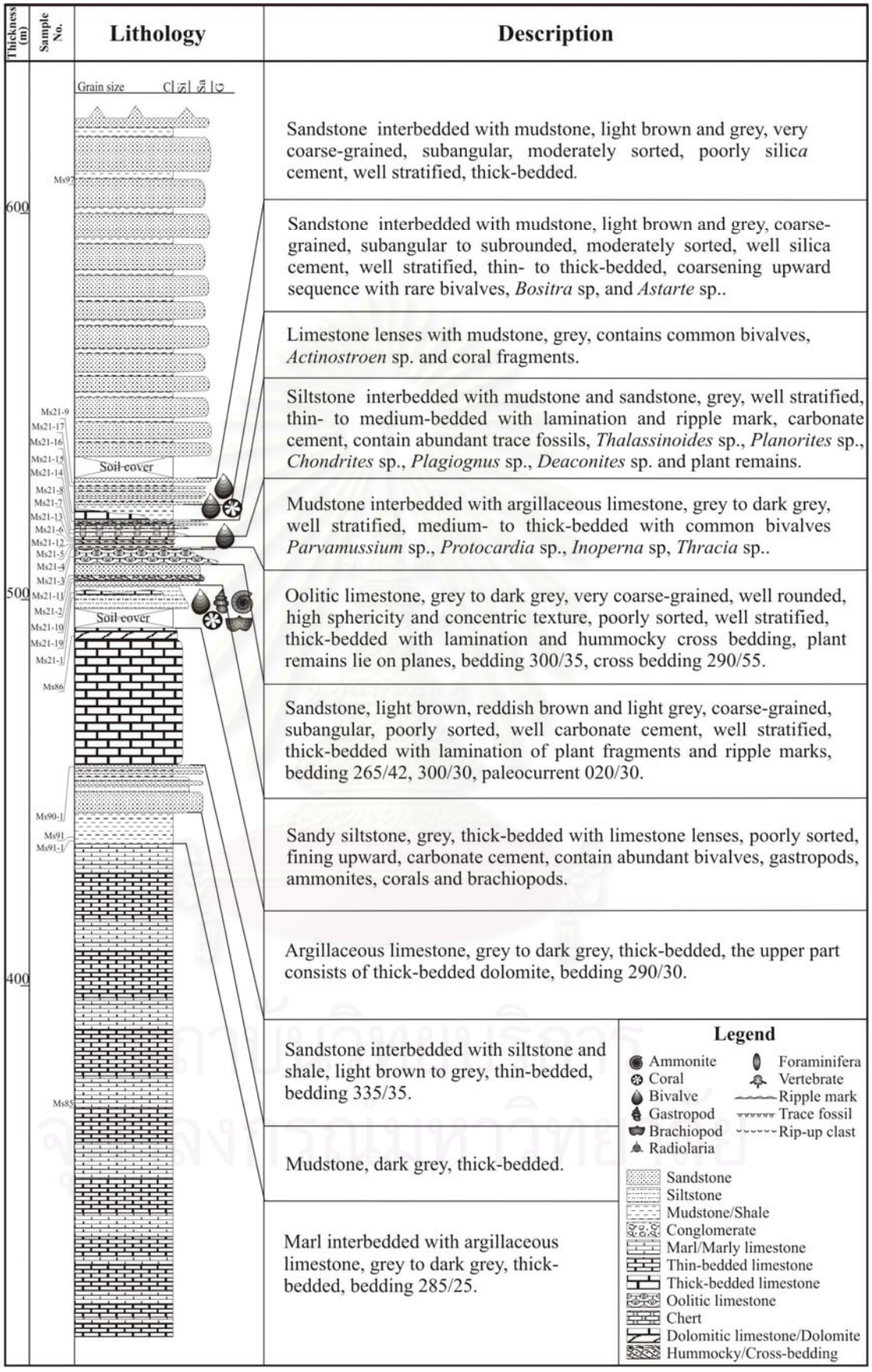


Figure 3.10 Lithostratigraphic colum n of the Hu a Fai Group at the local road and Huai Mae Taow, 12 km southeast of Mae Sot District (not to scale) (continued).

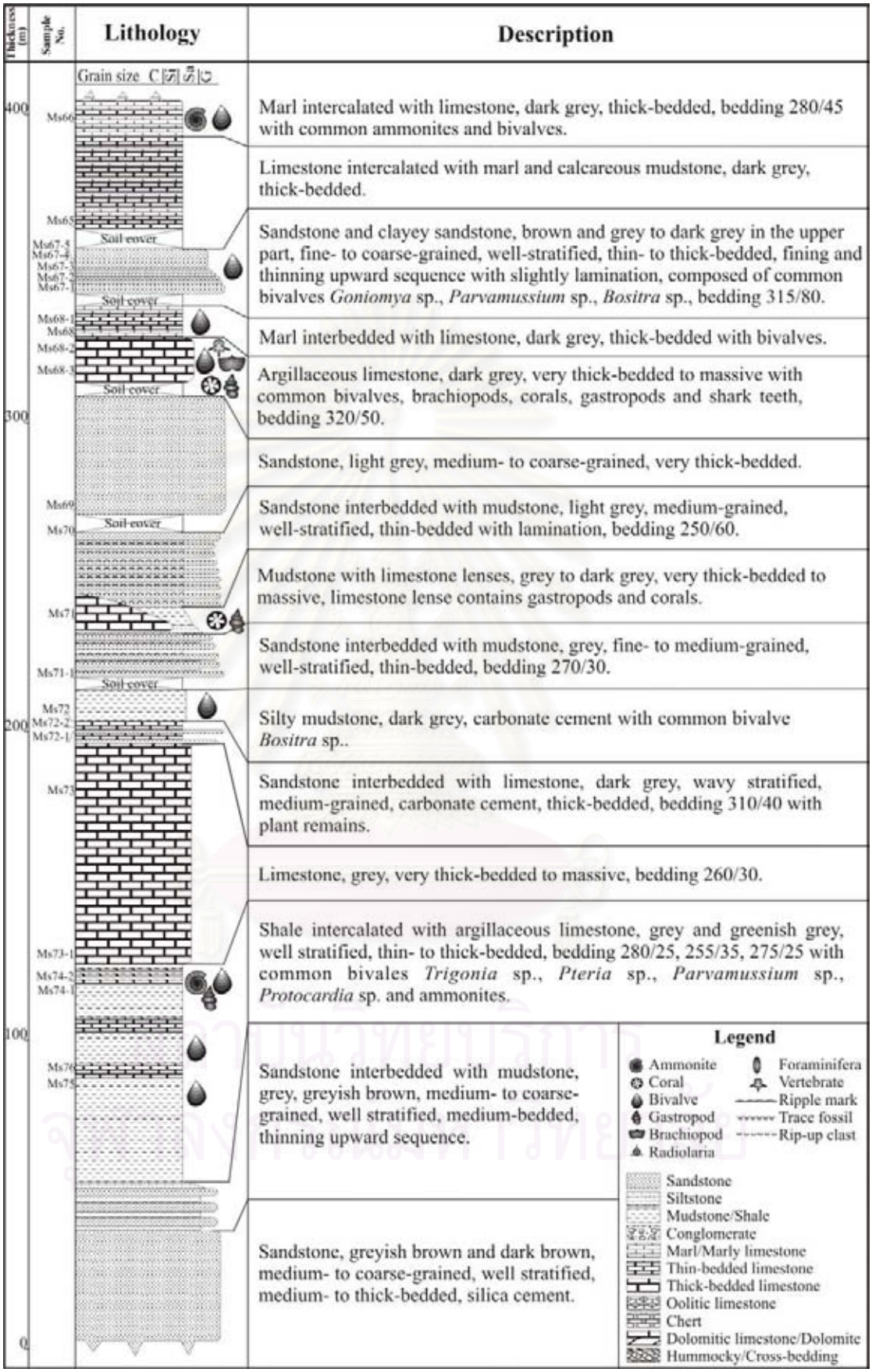


Figure 3.11 Lithostratigraphic column of the Hua Fai Group at the unpaved road from Ban Pu Toe to Ban Nam Khieo, 17 km southeast of Mae Sot District (not to scale).

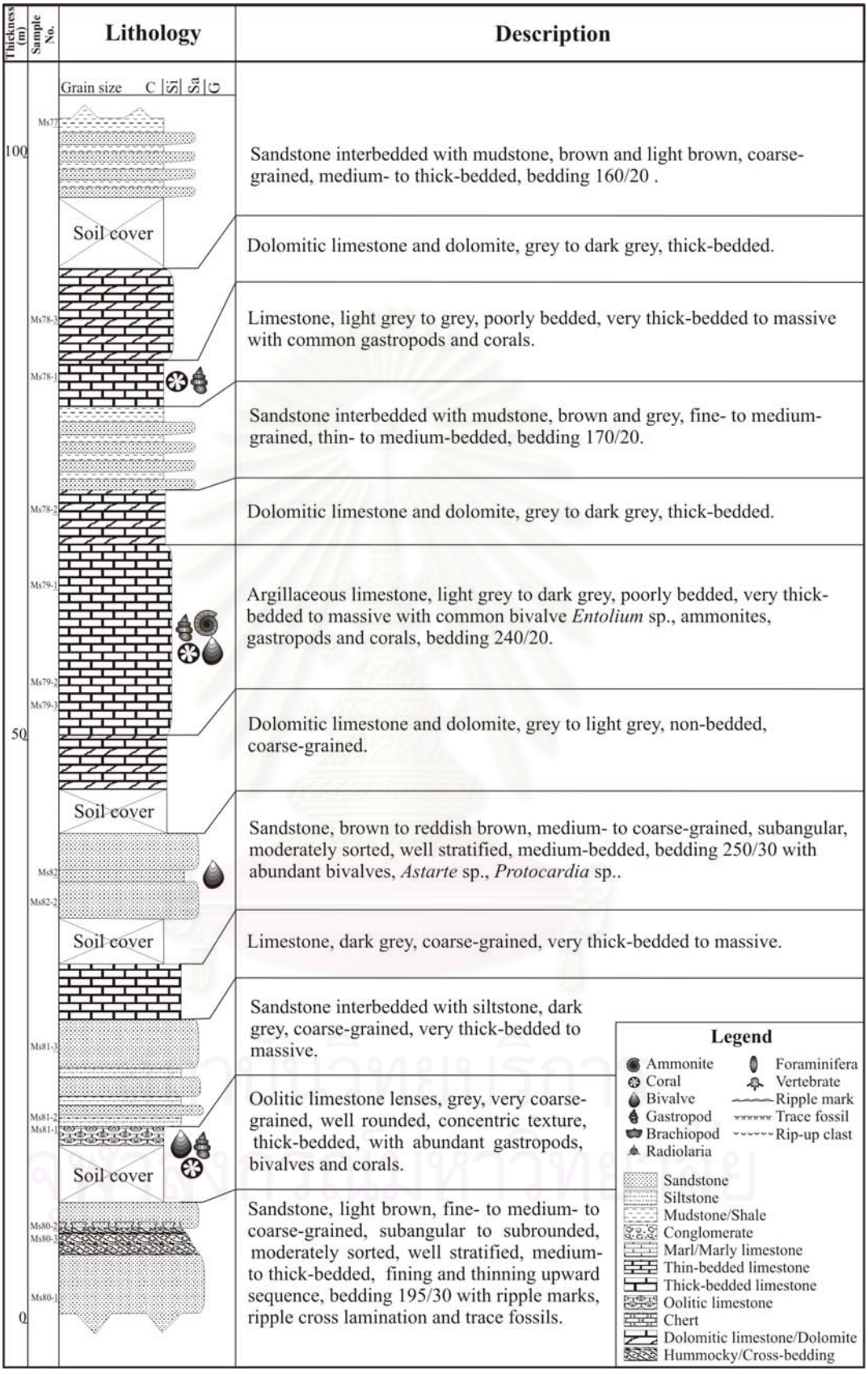


Figure 3.12 Lithostratigraphic colum n of th e Hua Fai Group at the by pass road of the Highway no. 1090 and a small road to a television station of Doi Huai Mot, Ban Nam Tok Hin Lek Fai, 25 km south of Mae Sot District (not to scale).

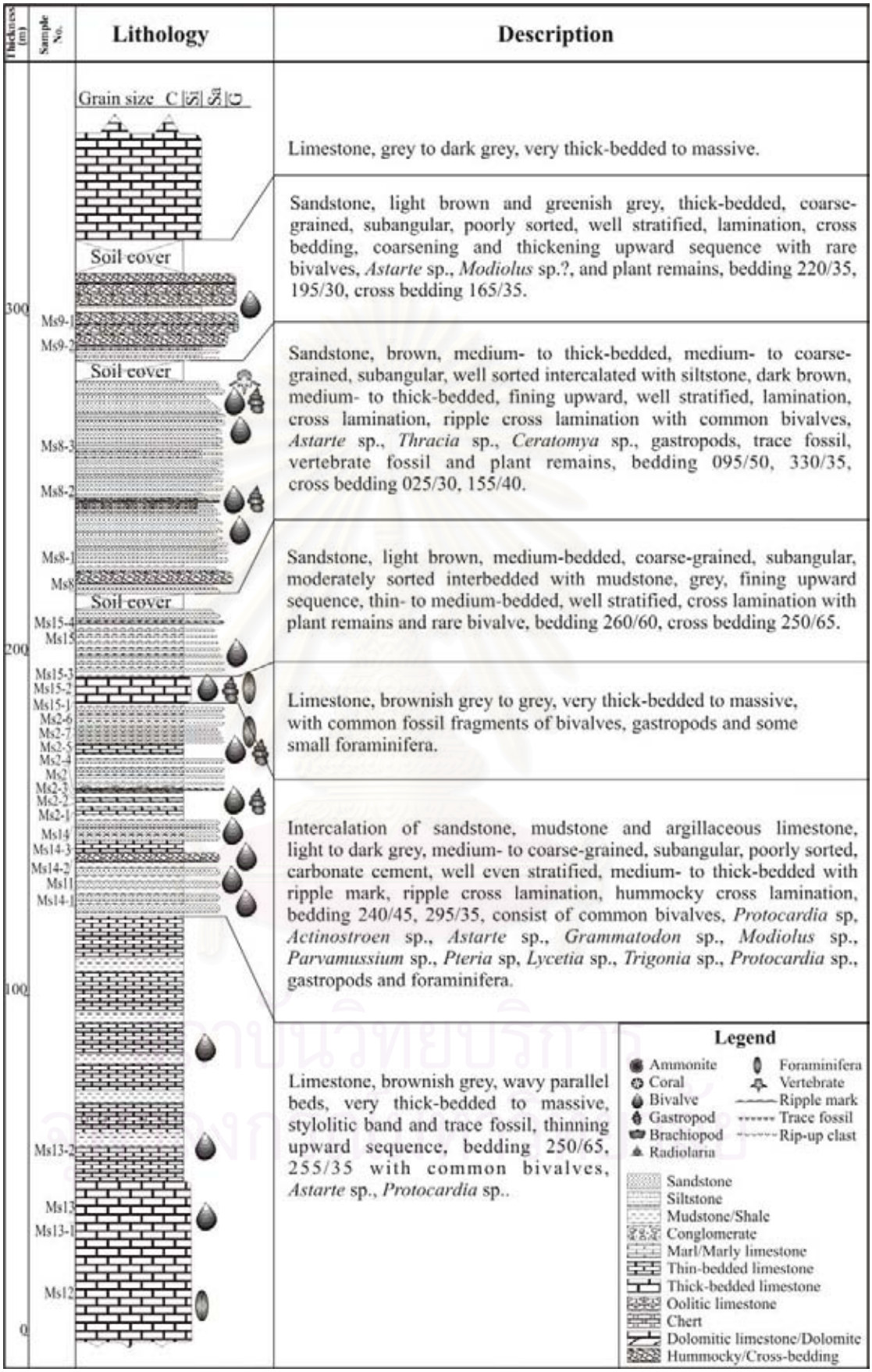


Figure 3.13 Lithostratigraphic colum n of the Hua Fai Group at the security road near Huai Wale, Thailand-Myanmar border, 7 km southeast of Phop Phra District (not to scale).

The type locality of the Khun Huai Formation lies along the unsealed road between Ban Khun Huai and Mae Sot power station. It crops out along the roadside in the vicinity of the power station's canal.

B) Stratigraphic relationship: The Khun Huai Formation is unconformably underlain by shale and chert of the Upper Mae Sariang Group (Middle-Upper Triassic) and dolomitic limestone of the Phra Woh Limestone (Upper Permian) and conformably overlain by marl and argillaceous limestone of the Doi Yot Formation, Hua Fai Group. The lower part of this formation consists generally of conglomeratic lenses considered as the lower-most part of the Jurassic sequence in this area. The sequences of thick-bedded calcareous sandstone interbedded with medium-bedded grey siltstone and mudstone are underlain conformably by the conglomerate unit. The middle part consists mainly of thick-bedded grey to dark grey limestone and dolomitic limestone. The carbonate unit is conformably overlain by the sequences of brown, medium- to thick-bedded sandstone intercalated with grey, medium- to thick-bedded and brownish grey mudstone and argillaceous limestone with abundant fossils of bivalves, gastropods, foraminifera, plant remains, and some vertebrates (turtle bone). The upper part comprises mainly brown to grey, thin- to thick-bedded sandstone, oolitic limestone, massive limestone, and dolomitic limestone lenses with cross bedding, hummocky cross bedding, and lamination which contain common bivalves, gastropods, corals, brachiopods, foraminifera, and plant remains. The boundary of the Khun Huai and Doi Yot Formations is represented by the gradational contact of coarse-grained to fine-grained sedimentary rocks. Therefore the thinning and fining upward sequences can be observed in the Khun Huai Formation.

C) Thickness and distribution: This formation is approximately 93-345 m thick (Figure 3.14) in all measured sections. The thickness for measured sections at Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, Ban Pu Toe, Doi Huai Mot, and Huai Wale are 232, 93, 258, 345, 101, and 279 m, respectively (see Figure 3.14). At the type section of the Khun Huai Formation, the total thickness measured by Meesook (1994) is at least 140 m and this section is also well exposed at km 67 on the Tak-Mae Sot Highway with thickness of approximately 120 m. In this study, the formation is widely distributed at km 67-68 on the Tak-Mae Sot Highway, Ban Khun Huai Mae Sot, and Mae Sot power station's canal, Huai Mae Taow at Padaeng mine,

Ban Ko Chuai, Ban Nam Khieo, Doi Huai Mot, and the security road along Thailand-Myanmar border at Huai Wale, (see Figure 3.14).

D) Lithology: The Khun Huai Formation consists mainly of 8 units (see Figure 3.14): the conglomerate (highlighted in orange), sandstone interbedded with mudstone and siltstone (light violet), shale intercalated with limestone (light pink), limestone and dolomitic limestone (blue), sandstone interbedded with mudstone and intercalated with limestone (yellowish green), sandstone with oolitic limestone (brown), limestone (yellow), and sandstone (green) units in ascending order as follows:

I. Conglomerate unit:

The conglomerate unit lies unconformably upon marine Triassic rocks. The main characteristic lithology of this unit is reddish brown, matrix-supported conglomerate (Figure 3.15). Clasts are made up mainly of limestone, chert, dolomitic limestone, quartz, and rock fragments, angular to sub-rounded, average gravel to cobble size with maximum size of approximately 0.25 m. This unit is underlain by the Triassic chert. Some chert beds (see Figure 3.15D) and clasts of chert are rich in microfossils of Middle to Late Triassic (Anisian to Rhaetian) radiolarians (Ishida, *et al*., 2006; Weerahong, 2007).

This unit is represented as locally basal conglomerate of the marine Jurassic basin in the Mae Sot-Phop Phra area.

II. Sandstone interbedded with mudstone and siltstone unit:

This unit is well exposed at the Magic hill, km 67-68 on the Tak-Mae Sot Highway, Huai Mae Sot, Ban Pu Toe, and Doi Huai Mot. The characteristic lithology of unit is brown to grey, medium- to thick-bedded, sandstone interbedded with mudstone and siltstone (Figure 3.16). At Ban Khun Huai Mae Sot, this sequence is quite different from several places which consist of reddish-brown, medium-bedded, medium- to coarse-grained, sub-angular sandstone with abundant mica flakes. Cross bedding, lamination, ripple cross lamination, fining upward sequence, rip-up clasts, and hummocky cross lamination are common, particularly at the middle and upper parts. Bivalves are rare in this sequence.

III. Shale intercalated with limestone unit:

This unit is well exposed at Ban Nam Khieo, Ban Pu Toe measured section (see Figure 3.11). The unit is composed mainly of grey to greenish grey, thick-bedded, shale intercalated with dark grey, thick-bedded argillaceous limestone (Figure 3.17).

The unit is well stratified of shale which contains common fossils of bivalves (see Figure 3.17) such as *Trigonia* sp., *Pteria* sp., *Parvamussium* sp., *Protocardia* sp., and ammonites.

IV. Limestone and dolomitic limestone unit:

This unit is chacterized by grey to brownish grey, massive to thick-bedded limestone, dolomitic limestone, and dolomite lenses (Figure 3.18) with the sequences of sandstone interbedded with mudstone and argillaceous limestone. Dolomitic limestone and dolomite occur locally and are distributed at the Padaeng mine and Doi Huai Mot. Fossils are common in the southern areas of Doi Huai Mot and Huai Wale measured sections, consisting of the bivalves *Protocardia* sp., *Entolium* sp., and *Astarte* sp., gastropods, trace fossils, and ammonites.

V. Sandstone interbedded with mudstone and intercalated with limestone unit:

The unit predominantly consists of alternating beds of sandstone, mudstone, limestone, and limestone lenses (Figure 3.19). The sandstone is well stratified, thin- to medium-bedded, fine- to coarse-grained, sub-angular, poor to moderate sorted with lamination, ripple mark, wave-formed flaser, wavy bedding, and wave ripple cross lamination. Mudstone and sandy siltstone are grey to brownish grey, very thin- to medium-bedded. Fining and thinning upward sequences are distinguished in its sequence. The fossils contain abundant bivalves (Figure 3.20): *Grammatodon* sp., *Modiolus* sp., *Astarte* sp., *Parvamussium* sp., *Actinostroen* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Trigonia* sp., gastropods, trace fossils, foraminifera, and plant remains.

VI. Sandstone with oolitic limestone unit:

The characteristic lithology of this unit is mainly light brown to brown, well stratified, thick-bedded, medium- to very coarse-grained, subrounded, moderately to well sorted sandstone with layers of oolitic limestone and sandy siltstone (Figure 3.21). In the southern area, cross bedding, lamination, and fining upward sequence are well present with abundant bivalves (see Figure 3.21): *Modiolus* sp., *Astarte* sp., *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.?, gastropods, vertebrate, and plant remains.

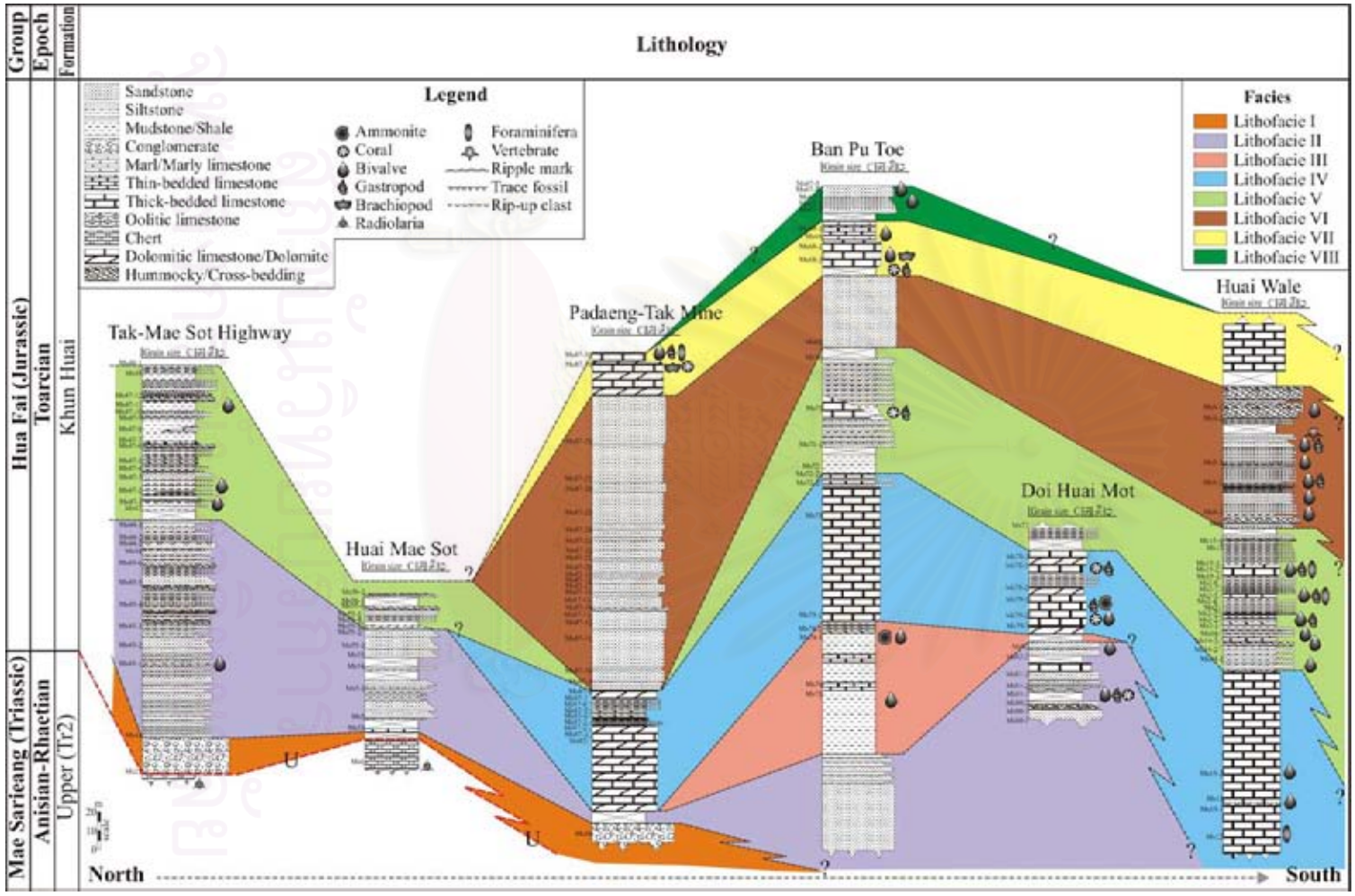


Figure 3.14 Detailed stratigraphic columns of the Khun Huai Formation at Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, Ban Pu Toe, Doi Huai mot and Huai Wale.

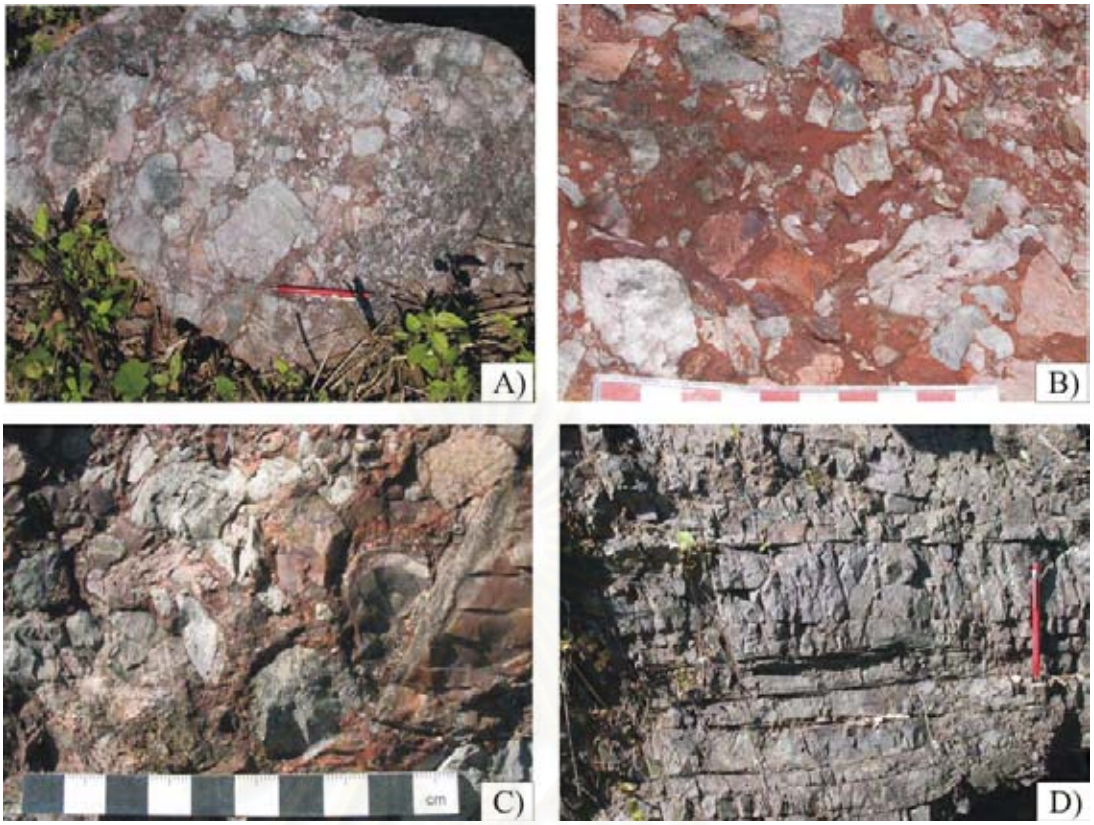


Figure 3.15 Photographs of the Khun Huai Form ation, basal conglom erate (unit I), A, B, and C) Conglomerate with matrix-supported texture showing clasts mainly of chert and limestone, well exposed as outcrop at km 67-68 on the Tak-Mae Sot Highway, D) Thin-bedded ribbon chert of the Mae Sariang Group (Middle-Late Triassic) overlain by B and C.

VII. Limestone unit:

This unit consists predominantly of grey to dark grey, massive to thick-bedded argillaceous limestone with grey, massive to thick-bedded, fossiliferous limestone and oolitic lim estone (Figure 3.22). Brachi opods, corals, gastropods, bivalves, foraminifera, and vertebrates are abundant. Some fossiliferous beds of foram inifera, brachiopods, and fossil fragm ents (Figure 3.22) are present and well exposed in the northern part of Padaeng m ine. Oolitic lim estone occurs as wavy layers with slightly fining upward sequence.

VIII. Sandstone unit:

This unit is m ainly characterized by sandstone. The lower part consists of the sequence of brown, m edium-bedded sandstone interbedded with grey, thin-bedded, clayey sandstone with slightly lam ination (Figure 3.23). The upper part is

predominantly composed of grey to dark grey, thick-bedded, clayey sandstone with common the bivalves *Bositra* sp., *Parvamussium* sp., and *Goniomya* sp. (see Figure 3.23). The fining upward sequence is present.

E) Paleontology and age: According to previous paleontology studied by Meesook (1994), and Meesook and Grant-Mackie (1996) for the Khun Huai Formation in the Mae Sot area, they recorded abundant marine Jurassic bivalves and ammonites including gastropods, brachiopods, foraminifera, trace fossils, and plant remains. These previous studies also reported the Toarcian faunas, ammonites, and bivalves.

Toarcian strata at Ban Huai Hin Fon along the Tak-Mae Sot Highway were determined on the presence of *Pseudolioceras* sp. and *Onychoceras* sp. (Braun and Jordan, 1976); *Osperioceras gr. Bicarinatum* (Zittel), *Dactylioceras*? sp., and *Pleydellia* sp. at Ban Huai Hin Fon, and *Parvamussium donaiense* Mansuy (Fontaine and Suteethorn, 1988). At the type section along Huai Mae Sot, the faunas contain the Early and Late Toarcian ammonites *Dactylioceras* sp., *Onychoceras* sp. and *Pseudolioceras* sp. with bivalves, *Parvamussium donaiense* Mansuy and *P. Palanicus*. Until recently, fossils collected from this study in the Khun Huai Formation contain abundant bivalves *Goniomya* sp., *Bositra* sp., *Grammatodon* sp., *Modiolus* sp., *Astarte* sp., *Parvamussium* sp., *Actinostroen* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.? and *Camptonectes* sp. According to the current field investigations, many marine Jurassic faunas such as gastropods, brachiopods, ammonite, corals, vertebrates, foraminifera, trace fossils, and plant remains are also found in the Khun Huai Formation. Based on fossils collected from this field investigations and previous studies, especially bivalves and ammonites, the Khun Huai Formation is considered as Late Toarcian age.

3.4.2.2 Doi Yot Formation

A) Type locality: The Doi Yot Formation takes its name from Doi Yot, a mountain 2 km south of Mae Sot power station, Mae Sot District, Tak Province (Meesook, 1994; Meesook and Grant-Mackie, 1996). The type locality of the formation lies along the unsealed road between Ban Khun Huai and the Mae Sot power station. It crops out along power station's canal about 2 km west of Doi Yot.

Figure 3.16 Photographs of sandstone interbedded with mudstone and siltstone (unit II) of the Khun Huai Formation, A) Reddish brown micaceous sandstone outcrop exposed at Ban Khun Huai school, B and C) Outcrops of calcareous sandstone with mudstone clasts, rip-up clasts at the Magic Hill, km 68 on the Tak-Mae Sot Highway , D and E) Outcrops of grey to greyish brown, medium-bedded sandstone with ripple marks indicating two paleocurrent directions, northeast (030), and northwest (335), at km 68 on the Tak-Mae Sot Highway , F) Outcrop of grey to greyish brown, medium-bedded sandstone, well stratified at magic hill, Tak-Mae Sot Highway.

Figure 3.17 Photographs of the mudstone and limestone (unit III) of the Khun Huai Formation well exposed at Ban Nam Khieo: A) Sequence of grey, thick-bedded, argillaceous limestone, B) Thick-bedded argillaceous limestone interbedded with dark grey mudstone containing the bivalves *Trigonia* sp. (C) and *Modiolus* sp.? (D).

B) Stratigraphic relationship: The Doi Yot Formation conformably overlies the Khun Huai Formation and conformably underlies the Pha De Formation at the type locality. The lower part of formation comprises mainly limestone interbedded with calcareous mudstone and intercalated with very fine-grained sandstone and sandstone lenses with wavy ripple and hummocky cross laminations. The middle part is mainly characterized by fine-grained sedimentary rocks, alternation of mudstone, marl, and limestone with common ammonites, bivalves, brachiopods, and corals. In the upper part, thick-bedded limestone lies conformably on mudstone and marl, it is well exposed at Huai Mae Sot and Tak mine. The upper unit at Ban Mae Kut Luang measured section is characterized by mudstone interbedded with thin-bedded, very fine-grained sandstone having fining upward sequence to the overlying Pha De Formation.

Figure 3.18 Photographs of dolomite, dolomitic limestone, and limestone (unit IV) of the Khun Huai Formation: A and B) Grey, massive to thick-bedded dolomite breccia and dolomitic limestone at a small hill, 2 km southeast of Padaeng mine, C and D) Grey, thick-bedded limestones outcrop at a small hill near Ban Nam Khieo, E and F) Brownish grey, thick-bedded limestones contain the bivalve *Astarte* sp.

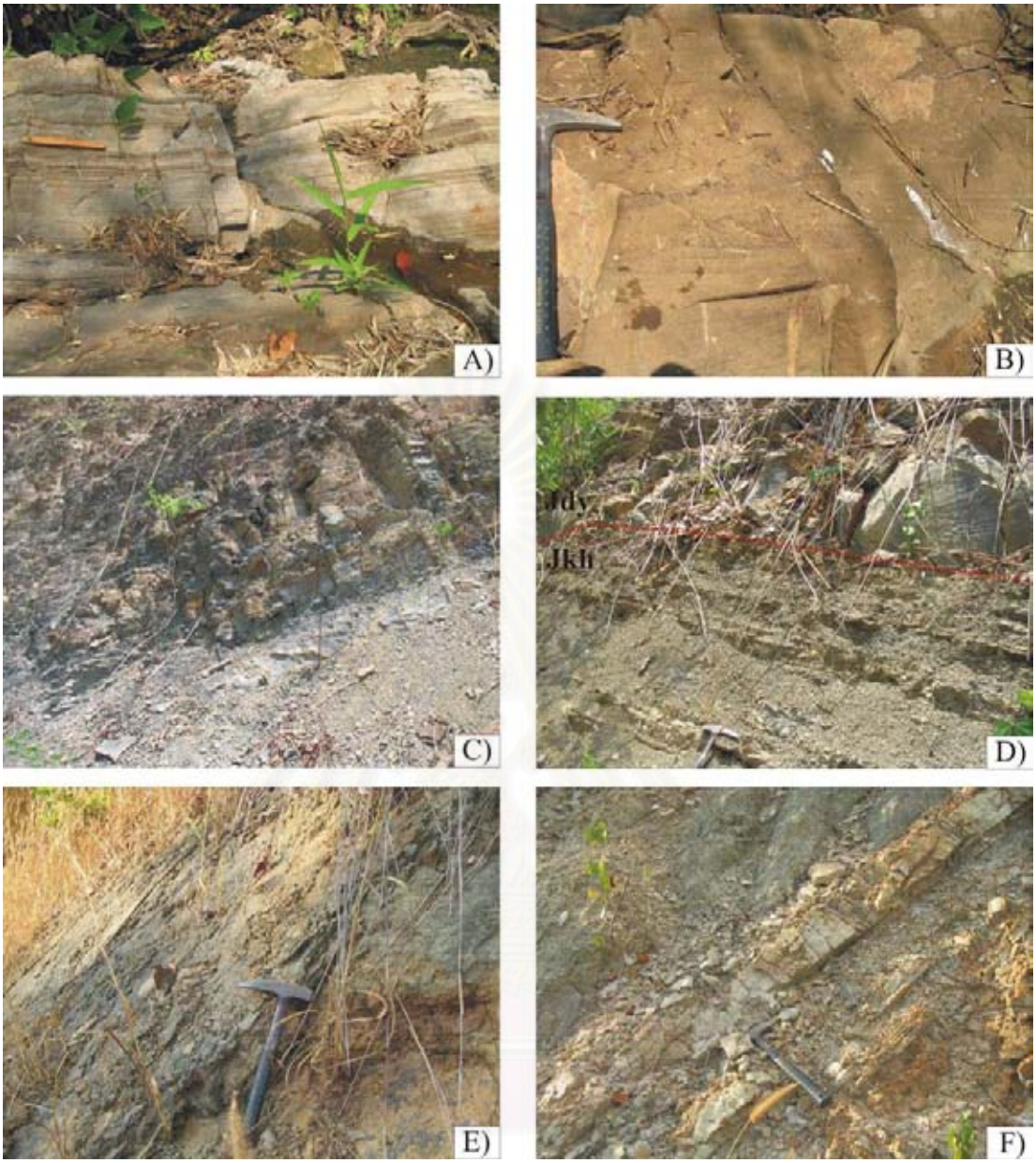


Figure 3.19 Photographs of sandstone interbe dded with m udstone and intercalated with limestone (unit V) of the Khun Huai Form ation, A and B) Thick-bedded, oolitic lim estone and sandstone with lam ination and hum mocky cr oss lam ination, well exposed at Huai Mae Sot, C) Thin-bedded sandstone interbedded with shale and calcareous sandstone lenses, flaser bedding, with common bivalves at km 68, Tak-Mae Sot Highway, D) Contact boundary of the Khun Huai and Doi Yot Formations, thin-bedded m uddy sandstone interbedded with mudstone and thick-bedded lim estone in th e upper part, at grid reference 0463844E and 1847380N, E and F) Calcareous sandstone, medium- to thick-bedded intercalated with thin-bedded fossiliferous lim estone and thick-bedded lim estone containing abundant bivalves and plant remains at road cut outcrop at Huai Wale.

Figure 3.20 Photographs of the Khun Huai Formation contain abundant bivalves, A, B, C, and D) *Parvamussium* sp., *Trigonia* sp., *Thracia* sp., and *Protocardia* sp. from outcrops in Figure 3.19C, and E and F) *Modiolus* sp., and *Grammatodon* sp. from the outcrop in Figure 3.19E.

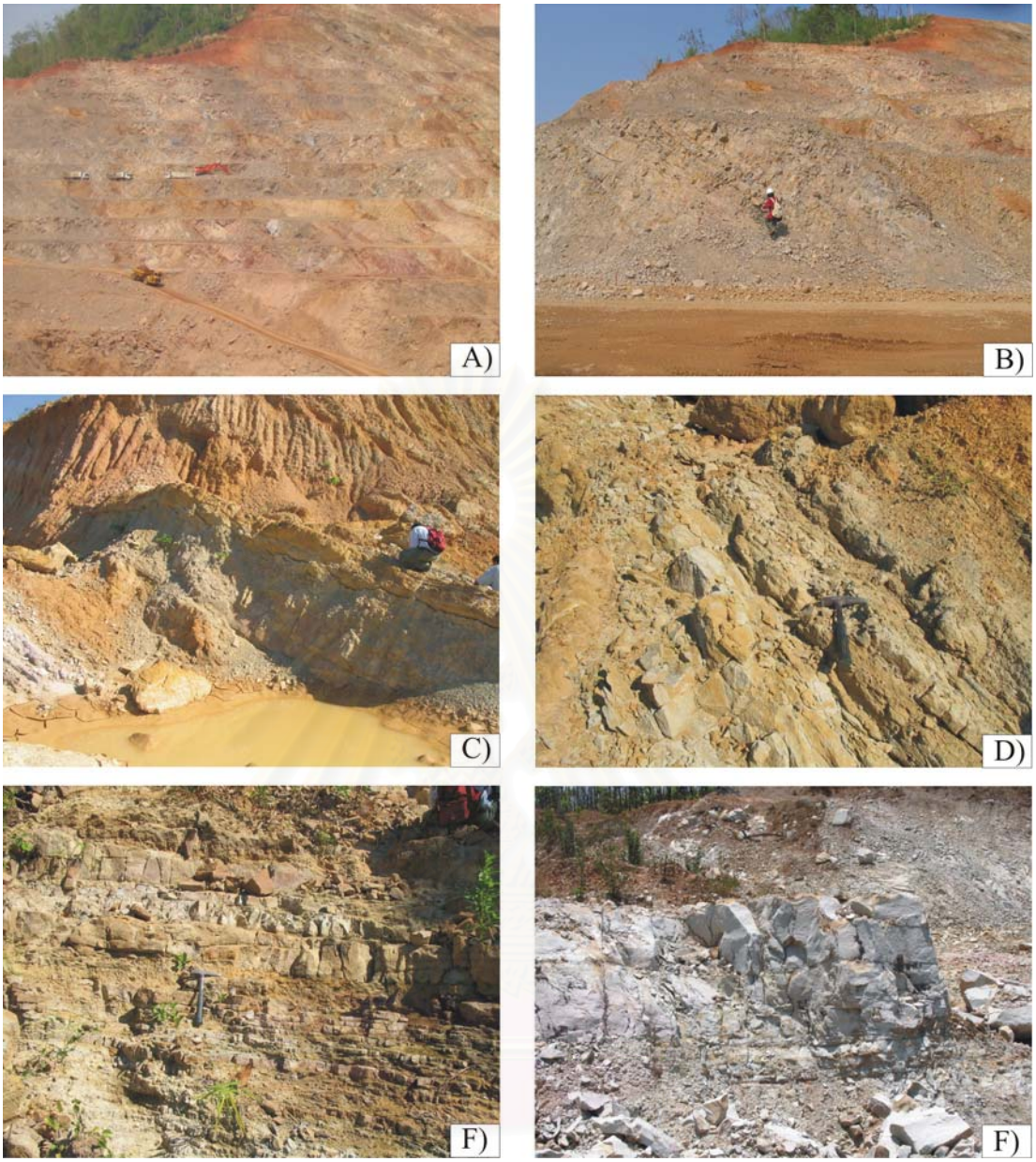


Figure 3.21 Photographs of the Khun Huai Formation, sandstone with layer of oolitic limestone (unit VI), A and B) Sequence of thick-bedded sandstone and a layer of oolitic limestone at Padaeng mine with bedding attitude of 000/20, C-F) Outcrop of thick-bedded sandstone with clayey sandstone, fining upward beds, lamination, and cross bedding with common bivalves at road cut outcrop, 7 km southeast of Phop Phra District.

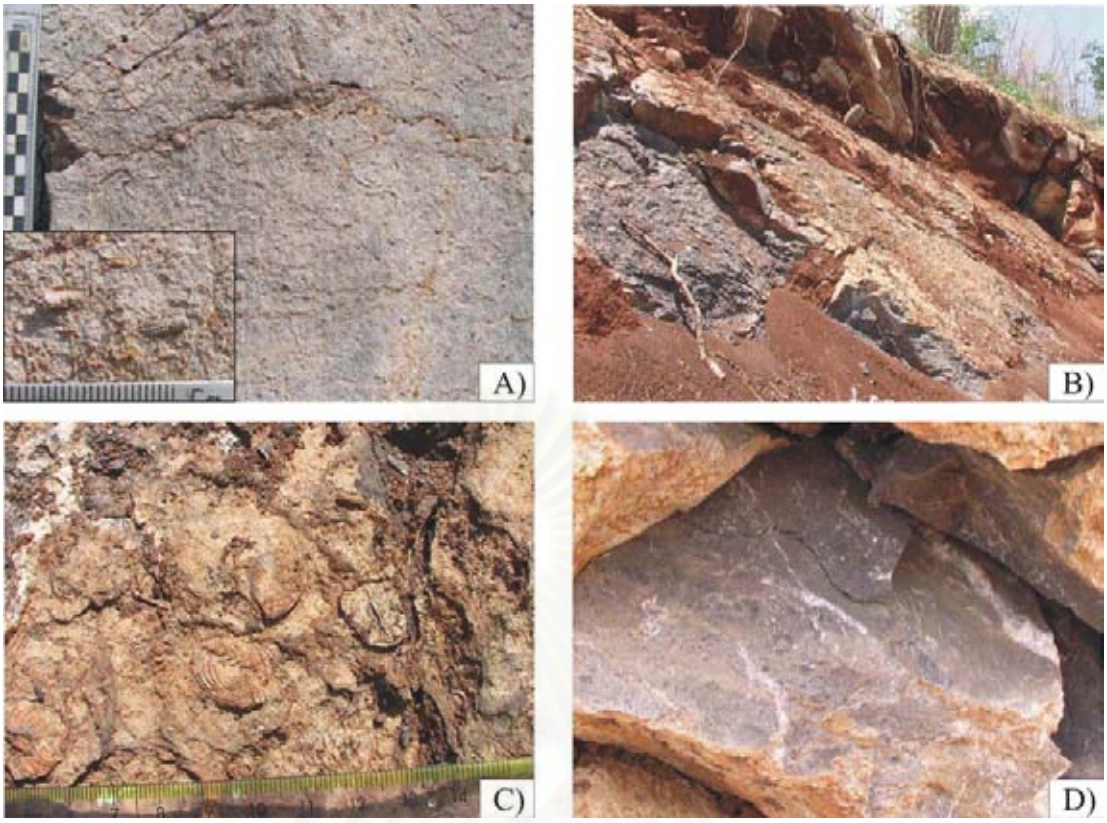


Figure 3.22 Photographs of the Khun Huai Formation, fossiliferous limestone and oolitic limestone (unit VII), quarry outcrop of northern Padaeng mine, A) Grey, thick-bedded, stylolitic, fossiliferous limestone, with small foraminifera, B and C) Grey to dark grey, thick-bedded limestone with layer of oolitic limestone (D) and contains abundant brachiopods (C).

Boundary of the Doi Yot and Pha De Formations is represented by the gradational contact of fine-grained to coarse-grained sedimentary rocks. Sharp contact of mudstone with thick-bedded sandstone between the Doi Yot and Pha De Formations can be observed in some measured sections.

C) Thickness and distribution: This formation is approximately 40-266 m thick (Figure 3.24) in all measured sections. The thicknesses of the measured sections at Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines and Ban Pu Toe are 231, 177, 266, 210, and 40 m, respectively (see Figure 3.24). At the type section of the Doi Yot Formation, the total thickness as measured by Meesook (1994) is at least 370 m. It is also well exposed (see Figure 3.1) along the Tak-Mae Sot Highway and unsealed road from Padaeng mine to Ban Tham Sua.

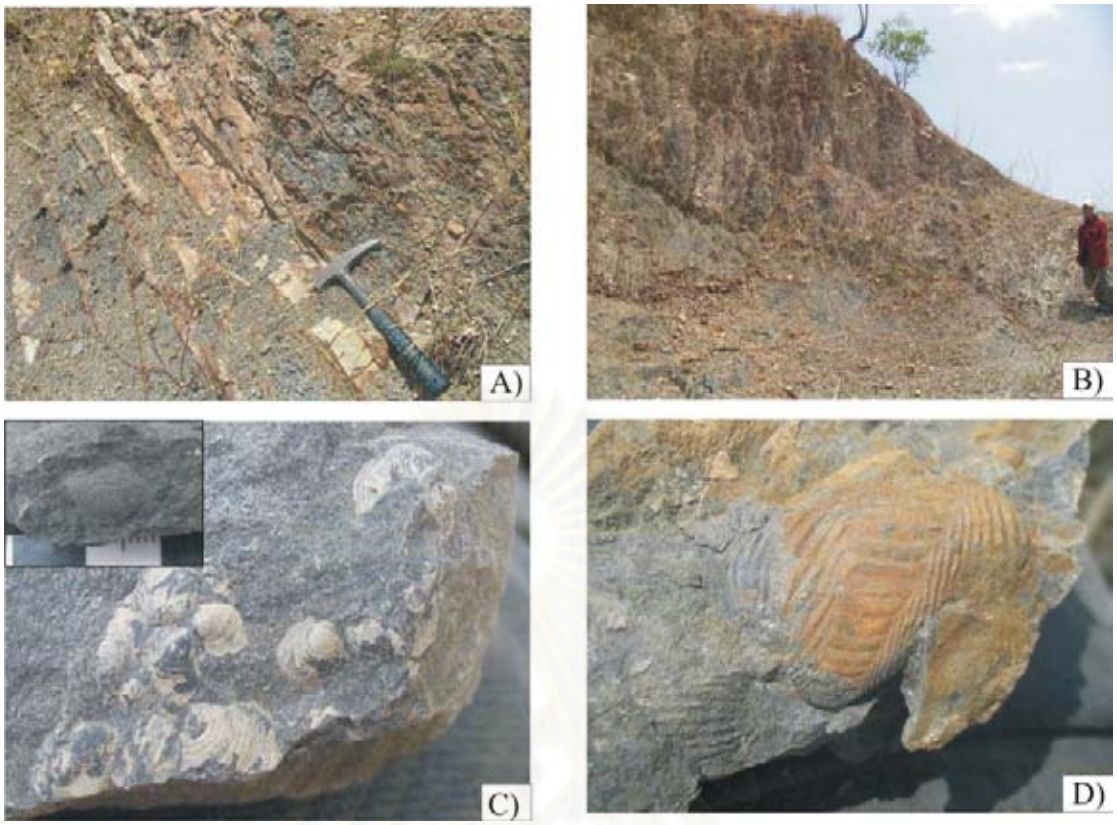


Figure 3.23 Photographs of the Khun Huai Formation, sandstone unit (unit VIII), road-cut outcrop at Ban Pu Toe, A) Thin- to thick-bedded, sandstone and grey to dark grey, clayey sandstone with common bivalves *Parvamussium* sp. (small picture of C), *Bositra* sp. (C), and *Goniomya* sp. (D).

In this study, the formation is widely distributed at Huai Khanun, Mae Kut Luang reservoir, 9 km north of Mae Sot District; Ban Huai Hin Fon, km 68-70 on the Tak-Mae Sot Highway, 7 km northeast of Mae Sot District; Huai Mae Sot, along the Mae Sot power station's canal; local road of Padaeng-Tak mines, along Huai Mae Taow and Ban Pha De, 12 km southeast of Mae Sot District; and at the local road separated from the Highway no. 1090, Ban Pu Toe, 17 km southeast of Mae Sot District (see Figure 3.24).

D) Lithology: The Doi Yot Formation mainly consists of 4 units (see Figure 3.24): the limestone with mudstone, marl, and sandstone (highlighted in light violet), marl interbedded with mudstone and limestone (blue), mudstone intercalated sandstone, siltstone, and limestone (yellowish green), and limestone (yellow) units in ascending order as follows:

I. Limestone with mudstone, marl, and sandstone unit:

The limestone with mudstone and sandstone unit lies conformably upon the Khun Huai Formaton. The main characteristic lithology of this unit is grey to dark grey, medium- to thick-bedded, argillaceous limestone interbedded with mudstone and marl, dark grey, medium- to thick-bedded. The Huai Mae Sot measured section has light grey medium- to thick-bedded, sandy limestone and calcareous sandstone layers with lamination and hummocky cross lamination (Figure 3.25). The grey and dark grey limestone, mudstone, and marl contain common bivalves *Bositra* sp. (see Figure 3.25), *Entolium* sp., and *Astarte* sp. The sandy limestone and calcareous sandstone are characterized by very fine- to fine-grained, sub-angular, and well sorted aspects. Most of the grains are cemented by calcite and mud supported.

II. Marl interbedded with mudstone and limestone unit:

This unit overlies the limestone with mudstone, marl, and sandstone unit with sharp contact.

The unit consists mainly of the alternation of dark grey, medium- to thick-bedded marl, mudstone, and grey, medium- to thick-bedded, argillaceous limestone (Figure 3.26). This unit is characterized by the fine-grained sedimentary rocks. At the measured section at Ban Mae Kut Luang, this unit is mainly composed of grey to dark grey, thick-bedded mudstone with well preserved abundant ammonites. The marl and mudstone beds contain abundant and well preserved ammonites (see Figure 3.26).

Based on previous works, the Aalenian ammonites have been found in the Mae Sot area e.g., *Erycites* sp., *Tmetoceras* sp., *Ludwigia* sp. (Brown *et al*., 1951), *Tmetoceras regleyi* Dumortier and *Graphoceras concavum* Sowerby (Komalarjun and Sato, 1964) at Ban Yang Pu Teh; and *Erycites* sp. and *Tmetoceras dhanarajatai* Sato (Komalarjun and Sato, 1964).

III. Mudstone intercalated sandstone, siltstone, and limestone unit:

This unit overlies upon the unit II with gradational contact and lateral variation. It predominantly consists of grey to dark grey, thin- to medium-bedded mudstone intercalated with light brown, thin-bedded calcareous sandstone, siltstone and grey, argillaceous limestone (Figure 3.27). The calcareous sandstone is mainly characterized by fine- to medium-grained, thin-bedded, sub-angular, well sorted, carbonate cemented aspects with rare ammonites. The fossils are rare throughout this unit.

IV. Limestone unit:

The unit is composed mainly of grey to dark grey, thick to massive argillaceous limestone (Figure 3.28). Oolitic limestone layers are also present in several places. At Padaeng-Tak mines, the rocks are composed of grey, thick-bedded dolomite and dolomitic limestone.

E) Paleontology and age: According to previous paleontology studied by Brown *et al*. (1951), Komalarjun and Sato (1964), Meesook (1994), and Meesook and Grant-Mackie (1996) for the Doi Yot Formation at the Mae Sot area, abundant Jurassic ammonites and bivalves with gastropods, brachiopods, and corals are recorded.

According to these previous studies, the Aalenian ammonites have been found in the Mae Sot area including *Erycites* sp., *Tmetoceras* sp., *Ludwigia* sp. (Brown *et al*., 1951), *Tmetoceras regleyi* Dumortier, and *Graphoceras concavum* Sowerby (Komalarjun and Sato, 1964) at Ban Yang Pu Teh; and *Erycites* sp. and *Tmetoceras dhanarajatai* Sato (Komalarjun and Sato, 1964). Early Aalenian *Leioceras* sp. and Late Aalenian *Graphoceras* sp have been reported in the upper Doi Yot and lower Pha De Formations. At type section, Huai Mae Sot, the lower formation contains common bivalve *Bositra* sp. (Meesook, 1994). Based on collected fossils from this field investigation and previous studies, especially ammonites and bivalves, the Doi Yot Formation is considered as Late Aalenian age.

3.4.2.3 Pha De Formation

A) Type locality: The Pha De Formation takes its name from Ban Pha De, a small village, 9 km southeast of Mae Sot District, Tak Province (Meesook, 1994; Meesook and Grant-Mackie, 1996). The type locality of the formation lies along the unsealed road from Ban Hua Fai to the Mae Sot power station, in the vicinity of the station's office and is about 3 km north of Ban Pha De.

B) Stratigraphic relationship: The Pha De Formation conformably overlies the Doi Yot Formation. The lower part of formation consists mainly of dark grey mudstone intercalated with greenish grey, thin- to thick-bedded calcareous muddy sandstone (Figure 3.29).

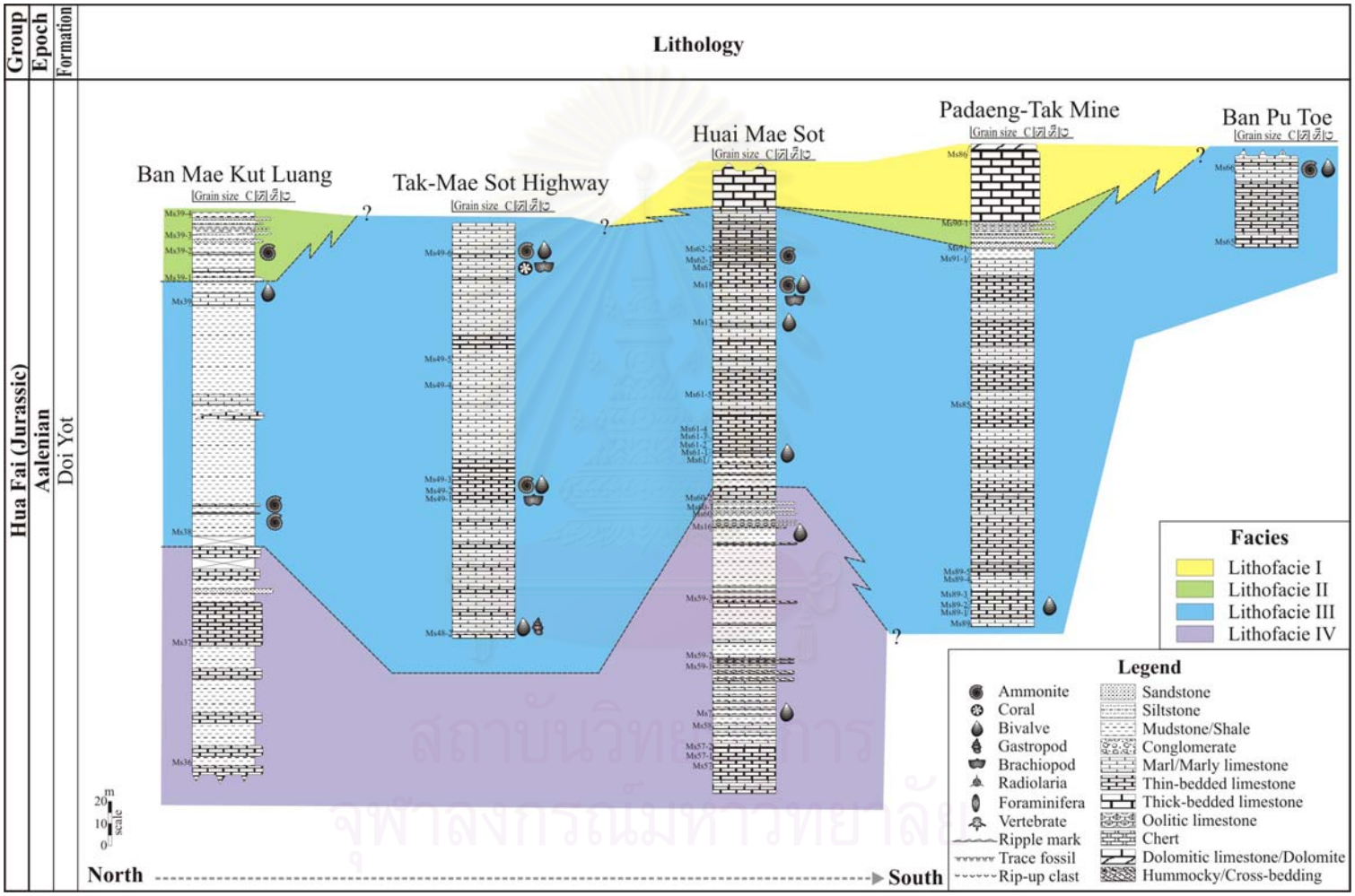


Figure 3.24 Detailed stratigraphic columns of the Doi Yot Formation at Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, and Ban Pu Toe.

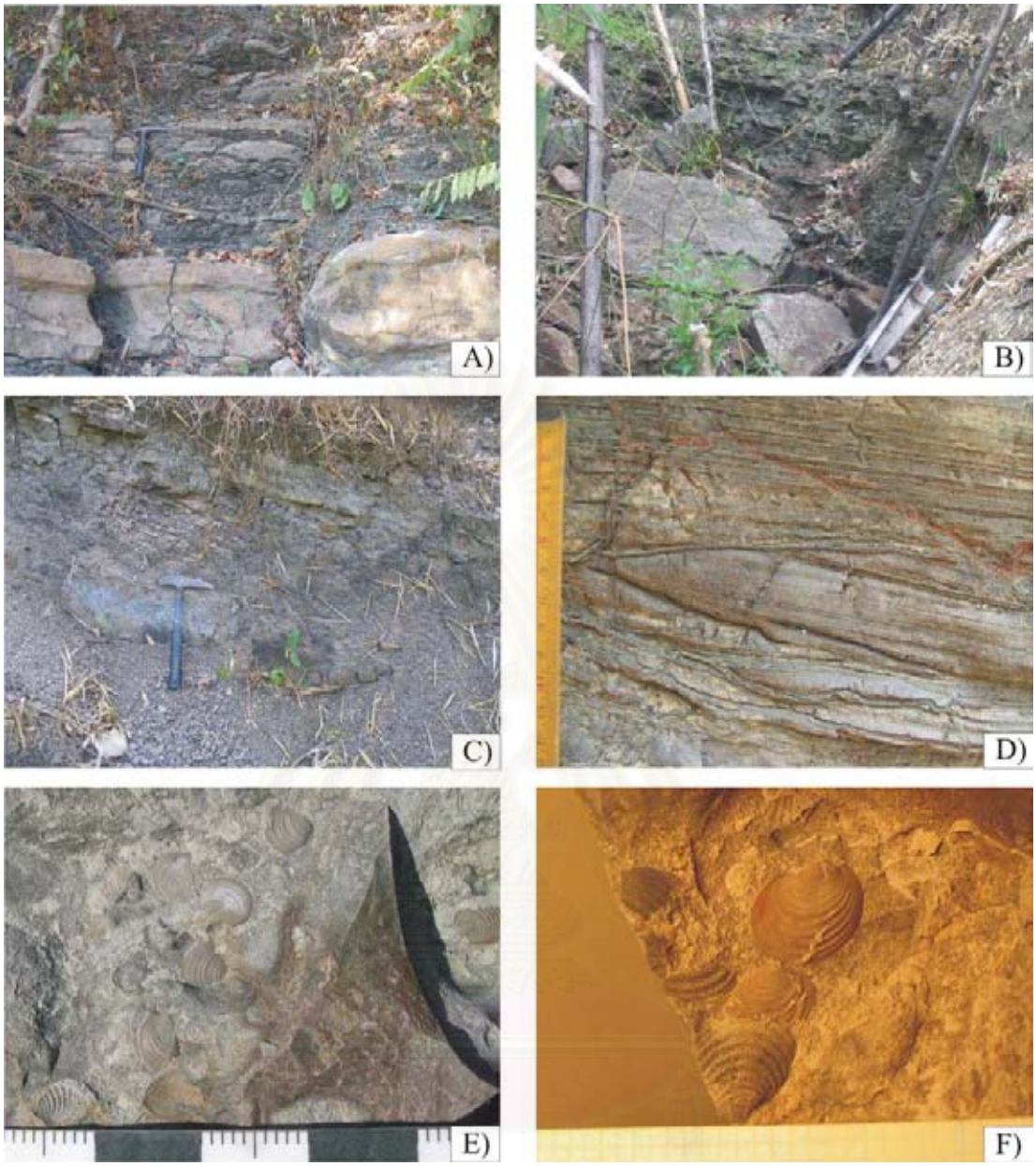


Figure 3.25 Photographs of the lim estone with mudstone and sandstone unit (unit I) of the Doi Yot Form ation, A) Thick-bedded marl interbedded with dark grey , thick-bedded, calcareous mudstone at unsealed road from the power station's office to Ban Khun Huai Mae Sot, B and C) Thin-bedded calcareous m udstone interbedded fine-grained sandstone with common bivalve *Bositra* sp. lay er (E and F), well exposed at the ty pe section, along power station canal, 9 km east of Mae Sot District.

Figure 3.26 Photographs of the lim estone with mudstone and sandstone unit (unit II) of the Doi Yot Form ation, A) Marl interbedded with m udstone and lim estone (B), thick-bedded, dark grey with com mon bivalves and am monites, outcrop at unsealed road, in the vicinity of power station's canal, C) Thick-bedded m arl contains common ammonites, road cut outcrop at the Tak-Mae Sot Highway , Ban Huai Hin Fon, D) Grey, thick-bedded, calcareous mudstone at the Ban Mae Kut Luang section, E and F) Ammonites, bivalves and brachiopods are common in this sequence.

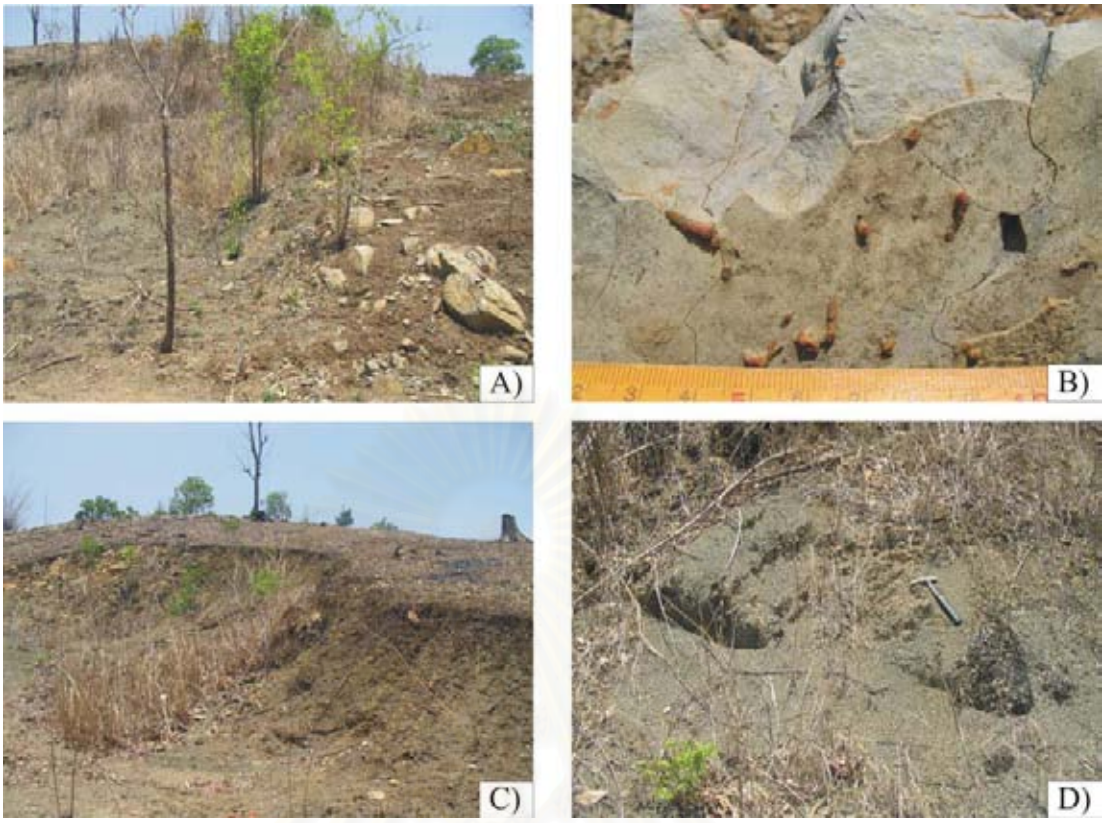


Figure 3.27 Photographs of the mudstone intercalated sandstone, siltstone, and limestone unit (unit III) of the Doi Yot Formation, A) Quarry outcrop of marl interbedded with mudstone and limestone, B) Closed-up texture of the weathering surface of marl with trace fossils? (reddish brown rods), C) Unclear outcrop of calcareous mudstone, closed-up mudstone characteristics of pencil-like structure (D), greenish grey, thick-bedded mudstone exposed at the Mae Kut Luang reservoir, Ban Mae Kut Luang section.

The sandstone is characterized by very fine- to coarse-grained, sub-angular, poorly to moderately sorted, laminated aspects with fossils of ammonites and bivalves. Fining upward sequences are present. The characteristic lithology of the middle part of this formation consists mainly of brown, greenish grey to grey, fine- to medium-grained sandstone interbedded with grey, thin- to medium-bedded mudstone. The formation contains abundant bivalves, ammonites, corals, brachiopods, gastropods, trace fossils, and plant remains. The upper part is mainly characterized by brown, thick-bedded sandstone interbedded with grey mudstone and a layer of the hummocky cross laminated oolitic limestone. Fining upward sequences are present.

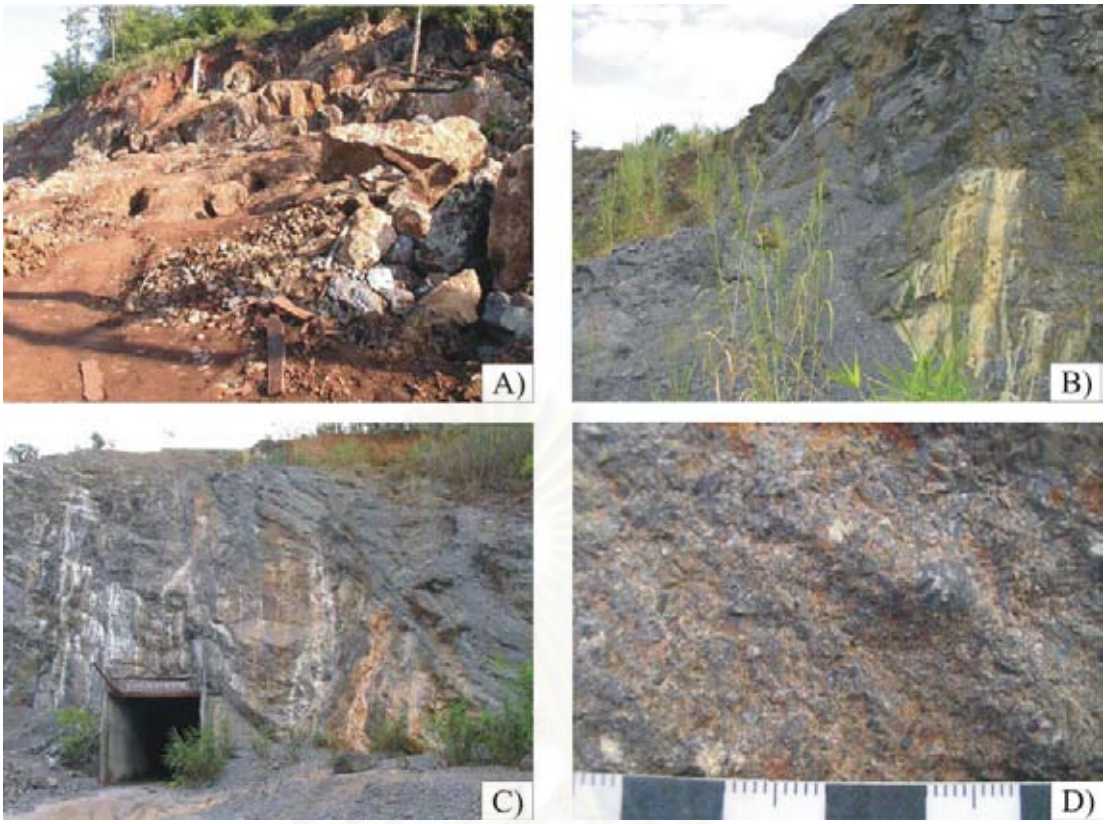


Figure 3.28 Photographs of the Lim estone unit (unit IV) of the Doi Yot Formation which underlies conformably on units of the Pha De Form ation, A, B, and C) Quarry mine outcrops at Tak mine showing thick- to m assive lim estone and fossiliferous lim estone (D), fossil fragments are well preserved.

The upper boundary of the Pha De Form ation is probably defined as overlain unconformably by the Mae Sot Group (Tertiary sequence) and Quaternary sedim ents, and are also bounded by faults in some places.

C) Thickness and distribution: This form ation is approxim ately 67-221 m thick (Figure 3.29) in all m easured sections. The thicknesses of m easured sections at Ban Mae Kut Luang, Tak-Mae Sot Highway and Padaeng-Tak mines are 221, 67, and 168 m , respectively (see Figure 3.29). At th e type section, the total thickness as measured by Meesook (1994) is approximately 390 m, and the formation also extends northward to Ban Huai Hin Fon and southward to Padaeng m ine where it is partly well exposed with approximately 400 and 350 m thick, respectively. In this study, the formation is widely distributed at Taad wa terfall, Ban Mae Kut Luang, 9 km north of Mae Sot District; Ban Huai Hin Fon, km 70-71 on the Tak-Mae Sot Highway and Ban Nong

Bua, 5 km northeast and 3 km east of the Mae Sot District. This formation is also well exposed at Tak mine (see Figure 3.29).

D) Lithology: The Pha De Formation mainly consists of 5 units (see Figure 3.29): the mudstone interbedded with muddy calcareous sandstone (highlighted in blue), muddy calcareous sandstone interbedded with mudstone (light violet), oolitic limestone (yellow), mudstone with limestone, siltstone, and sandstone (pink), and sandstone interbedded with mudstone (yellowish green) units in ascending order as follows:

I. Mudstone interbedded with muddy calcareous sandstone unit:

This unit overlies conformably upon the Doi Yot Formation with gradational contact. It predominantly consists of grey to dark grey, thick-bedded mudstone interbedded with grey to brown, thin- to thick-bedded calcareous sandstone (Figure 3.30). The calcareous sandstone is mainly characterized by fine- to coarse-grained, sub-angular, moderately sorted. The sand grains are cemented by calcite. The bivalve *Bositra* sp. and ammonites are rare but can also be found throughout this unit.

II. Muddy calcareous sandstone interbedded with mudstone unit:

The unit overlies conformably upon the unit I with gradational contact. It is predominantly composed of greenish grey to brown, thick-bedded sandstone interbedded with grey to greenish grey, medium- to thick-bedded mudstone (Figure 3.31). The sandstone is mainly characterized by fine- to coarse-grained, subangular, moderate sorted, lamination, and cross lamination with rip-up clasts. The muddy fine-grained sandstone layers have calcite cementing, whilst the coarse-grained thick-bedded arkosic sandstone is represented by poor silica cement. The fossils contain abundant bivalves, ammonites, gastropods, corals, trace fossils, brachiopods, and plant remains. The Tak mine section contains the bivalves (Figure 3.32) *Bositra* sp., *Plagiostoma* sp., *Parvamussium* sp., *Trigonia* sp., *Astarte* sp., *Thracia* sp., *Brosita* sp., *Pinna* sp., *Protocardia* sp., *Inoperna* sp., *Pholadomya* sp., *Mytilus* sp., *Modiolus* sp., *Lima* sp., *Entolium* sp., *Eomiodon* sp., *Protocardia* sp. (Kozai *et al*., 2006).

III. Oolitic limestone unit:

The characteristic lithology of this unit predominantly consists of grey to dark grey, thick-bedded oolitic limestone with hummocky cross bedding and lamination

(Figure 3.33). The oolitic nucleus is composed of quartz, calcite, foraminifera, and fossiliferous grains with a concentric layer overgrowth.

IV. Mudstone with limestone, siltstone, and sandstone unit:

The lower part of unit consists mainly of dark grey, medium- to thick-bedded mudstone interbedded with limestone. The fossils contain abundant bivalves, *Parvamussium* sp., *Protocardia* sp., *Inoperna* sp., and *Thracia* sp. (Figure 3.34). The upper part is characterized by the sequence of grey, medium-bedded calcareous sandstone, siltstone, and mudstone with abundant trace fossils such as *Thalassinoides* sp., *Planorites* sp., *Chondrites* sp., *Plagiognus* sp., *Deaconites* sp. (Tansathien, pers. comm., 2007). This unit is graded to coarsening and thickening upward sequences of the unit V.

V. Sandstone interbedded with mudstone unit:

The unit overlies as sharp contact conformably upon the units III and IV. It is predominantly composed of brown, thick-bedded arkosic sandstone interbedded with grey to light grey, medium- to thick-bedded mudstone (Figure 3.35). The sandstone is mainly characterized by coarse-grained, subangular, moderately sorted aspects with lamination and cross lamination. The fossils contain common bivalves and ammonites.

E) Paleontology and age: According to previous paleontological studies by Meesook (1994) and Meesook and Grant-Mackie (1996), the Pha De Formation at the Mae Sot area contains abundant ammonites *Eutmetoceras* sp. and *Docidoceras* sp. (*Hypolioceras discites* zone). This formation is assigned as the Early Bajocian age on the basis of the ammonites and the bivalve *Parvamussium* sp.

3.4.3 Composite section

According to the present study, an attempt has been made to combine and correlate the sedimentary sequences of all 7 measured sections (Figure 3.36) of the Hua Fai Group. Because of the Hua Fai Group is composed of Khun Huai, Doi Yot and Pha De Formations deposited under the shallow marine environments, therefore, the sedimentary sequence has been subdivided into facies and units. On the basis of lithological characteristics, the Hua Fai Group can be divided into 17 units and the synthesis of combined sections is illustrated in Figures 3.36 and 3.37.

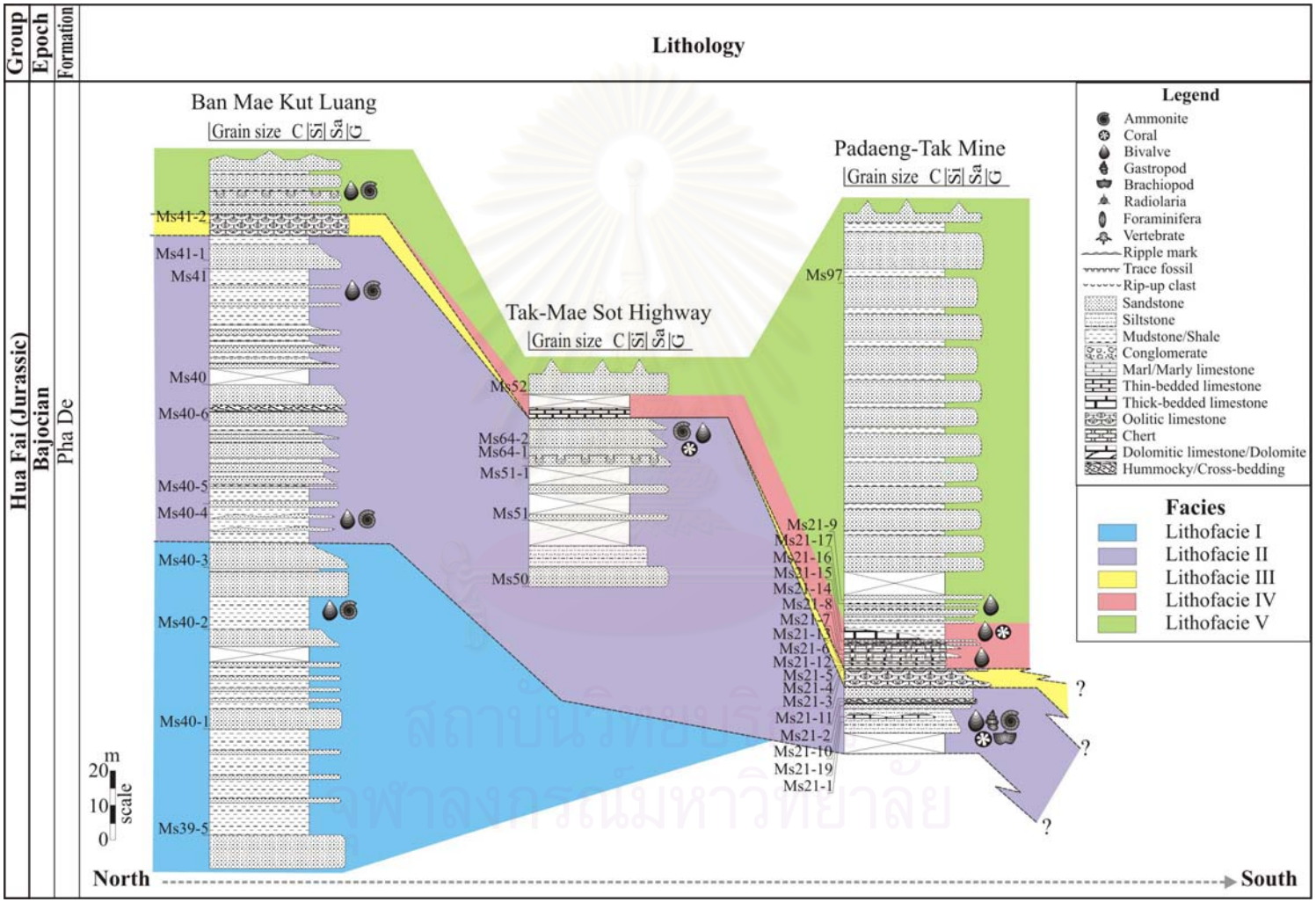


Figure 3.29 Detailed stratigraphic columns of the Pha De Formation at Ban Mae Kut Luang, Tak-Mae Sot Highway and Padaeng-Tak mine.

The total thickness of the Hua Fai Group based on 7 measured sections varies from 200 to 832 m whereas the combined section is approximately 750 m. The lateral facies change of the shallow marine sedimentary, complicated correlation and tectonic setting are considered to be the reasons of this thickness reduction of the combined section of the Hua Fai Group.

3.5 Petrography

The petrographic study is focused on detailed lithological characteristics and paleontology of the Hua Fai Group. Fourth steps are involved: samples collection, thin section preparation, photography, and identification. In order to fully understand the lithological characteristics of the Hua Fai Group, approximately 113 hand specimen have been collected for detailed microscopic study. Locations of collected rock sample represent all formations and units. Thin-section examination is focused upon the mineral composition, textures, microstructures, and fossils. It can be evaluated and interpreted together with mapping and stratigraphic column. The unit is defined on the basis of lithology, geometry, sedimentary structures, and fossil associations in order to reconstruct their depositional environments. These detailed petrographic descriptions of the representative samples are as follows:

3.5.1 Petrography of the Khun Huai Formation

Details of petrographic studies of the Khun Huai Formation (Figures 3.38-3.47) are focusing upon representative rock samples collected from 6 measured sections (see Figure 3.36). These sections are well exposed at the Tak-Mae Sot Highway, Huai Mae Sot, Pha Daeng mine, Ban Pu Toe, Doi Huai Mot, and Huai Wale. The conglomerate, sandstone, mudstone, and limestone units are confined to the lower part of this formation. The middle and upper parts consist of the oolitic limestone, sandstone, and limestone.

Petrographically, the lower part of this unit is composed mainly of sandy conglomerate (see Figure 3.38), quartz arenite (Figures 3.39 and 3.40), sublitharenite (Figures 3.41 and 3.42), sublitharenite interbedded mudstone (Figure 3.43), biomicrite and micrite (Figures 3.44 and 3.45), and oosparite (Figures 3.46 and 3.47).

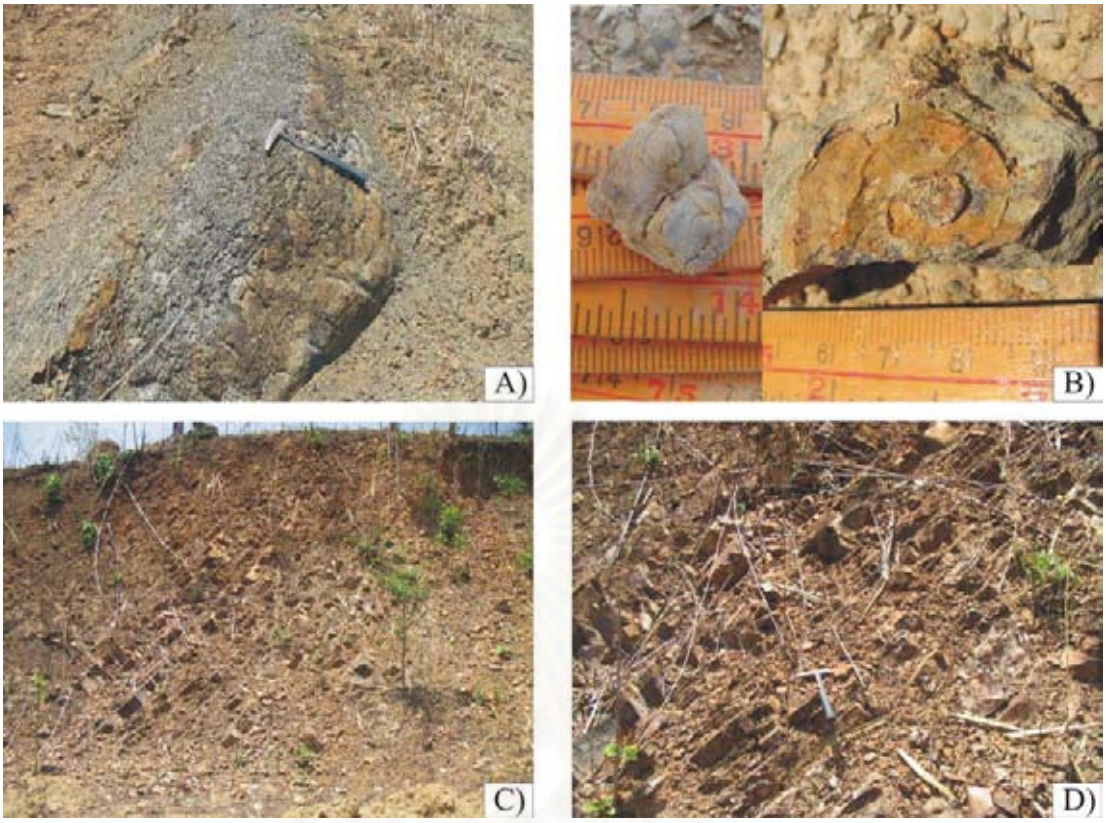


Figure 3.30 Photographs of the mudstone interbedded with muddy calcareous sandstone unit (unit I) of the Pha De Formation exposed at Taad waterfall, Ban Mae Kut Luang section, A and B) Calcareous clayey sandstone, grey, thick-bedded with common bivalves *Bositra* sp. and ammonites, C and D) Outcrops of medium-bedded, parallel, and even bedded, medium- to coarse-grained, well cemented sandstone.

The sandy conglomerate (sample no. Ms25-1) with mainly matrix-supported texture consists mainly grains of quartz (15%) and rock fragments (70 %, composed of biomicrite, micrite, and chert), and calcite grains (15%). The grains are average granule to cobble sizes, angular shape, and low sphericity. The sediments are very poorly-sorted, containing many small quartz grains and rock fragments with carbonate cements. The rock fragments are coated with a thin brown rim of iron oxide and carbonate cement.

The medium-grained quartz arenite (samples Ms9-2 and Ms8) shows some pressure-solution and grain contacts texture containing mainly quartz (90%), rock fragments (5%), and 5% of feldspar, mica, and zircon (heavy mineral). The contacts are irregular and wavy because of pressure-solution. Silica dissolved during the process may be precipitated as cementing material.

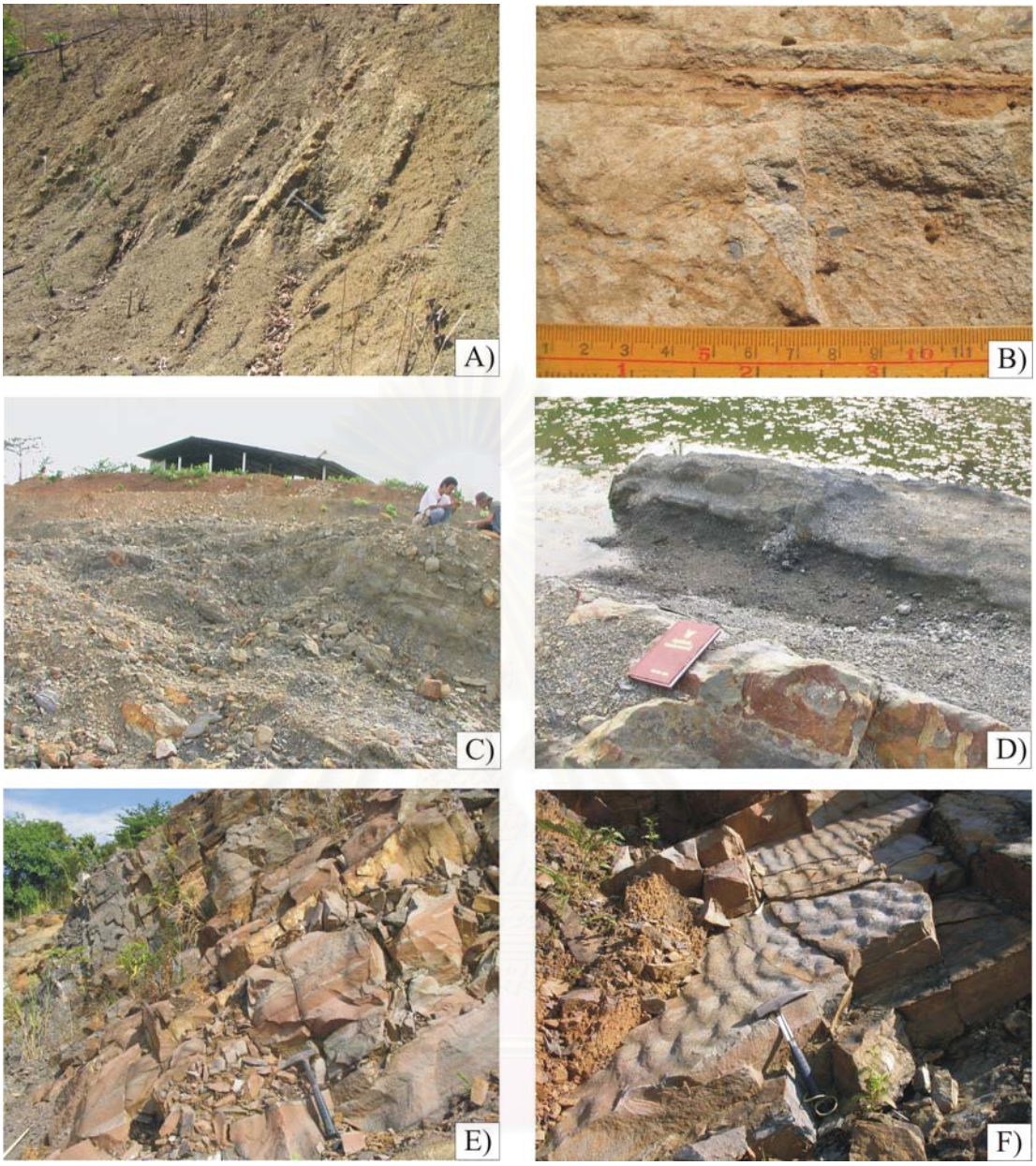


Figure 3.31 Photographs of the muddy calcareous sandstone interbedded with mudstone unit (unit II) of the Pha De Formation, A and B) Calcareous clayey sandstone, greenish grey, medium-bedded with common bivalve *Bositra* sp. and ammonites, and sandstone (B), brown, thick-bedded, coarse-grained with rip-up clasts, cross lamination, the outcrop at Taad waterfall, Ban Mae Kut Luang section, C and D) Calcareous sandstone, greenish grey, thick-bedded, interbedded with clayey siltstone with abundant bivalves and ammonites, open-pit crop out at Ban Nong Bua, 4 km east of Mae Sot District, E and F) Well exposed section at the Tak mine shows laminated sandstone, brown, thick-bedded with ripple marks and plant remains lying on bedding and cross bedding planes.

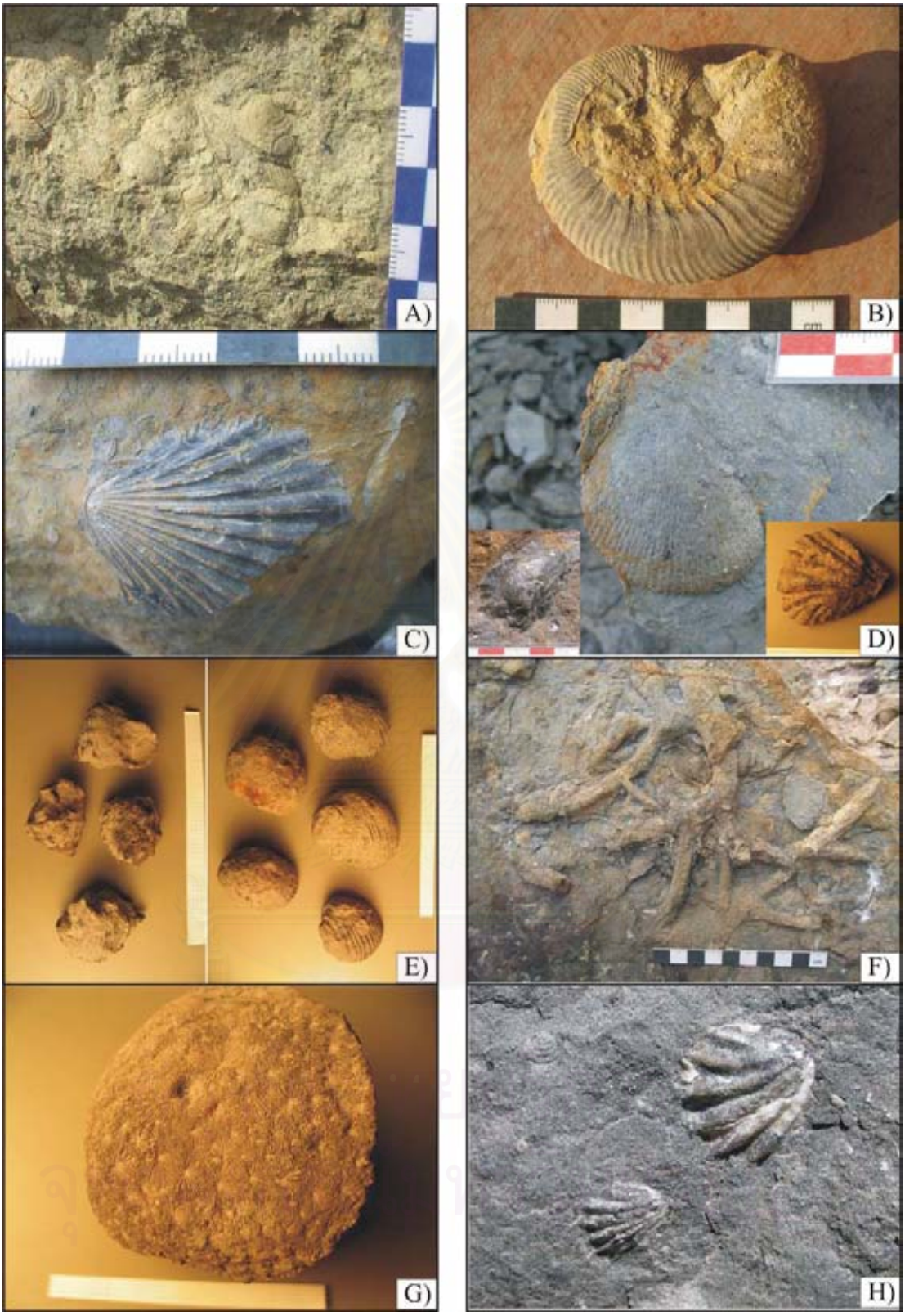


Figure 3.32 Photographs of the Pha De Formation of unit II containing abundant bivalves (A, C, and D), ammonites (B), gastropods (E), trace fossils (F), corals (G), and brachiopods (H).

Figure 3.33 Photographs of the oolitic limestone unit (unit III) of the Pha De Form ation at Tak mine, A) Overview of the grey , thick-bedded, oolitic limestone layer, approximately 8 m thick, B and C) Outcrops of the oolitic lim estone showing lamination and hum mocky cross lamination, D) Closed-up of grains of rounded, poor cemented oolite.

The sam ples are texturally sub-m ature, lacking clay, and m oderately-sorted. Roundness of the grains is sub-angular with high sphericity. Some rock fragments are disseminated with iron oxide.

The very fine- to medium-grained sub quartzwacke is recognized from thin- to medium-bedded calcareous sandstone (sam ples no. Ms43-1, Ms55-1, and Ms43-4). It shows clastic texture and contains m ainly quartz (85%), rock fragm ents (10%), and mica with heavy m ineral (5%). The sedim entary grains are texturally im mature to sub-mature, clay m atrix (5%), m oderately-sorted. Roundness of grains is angular to sub-angular. The rock sam ple Ms 43-4 (see Figure 3.43) shows thinly-layers, alternation of very fine sandstone with mudstone. There are small structures, probably the bioturbation. In several sam ples com monly show sandstone lenses, load clasts, and cross lamination.

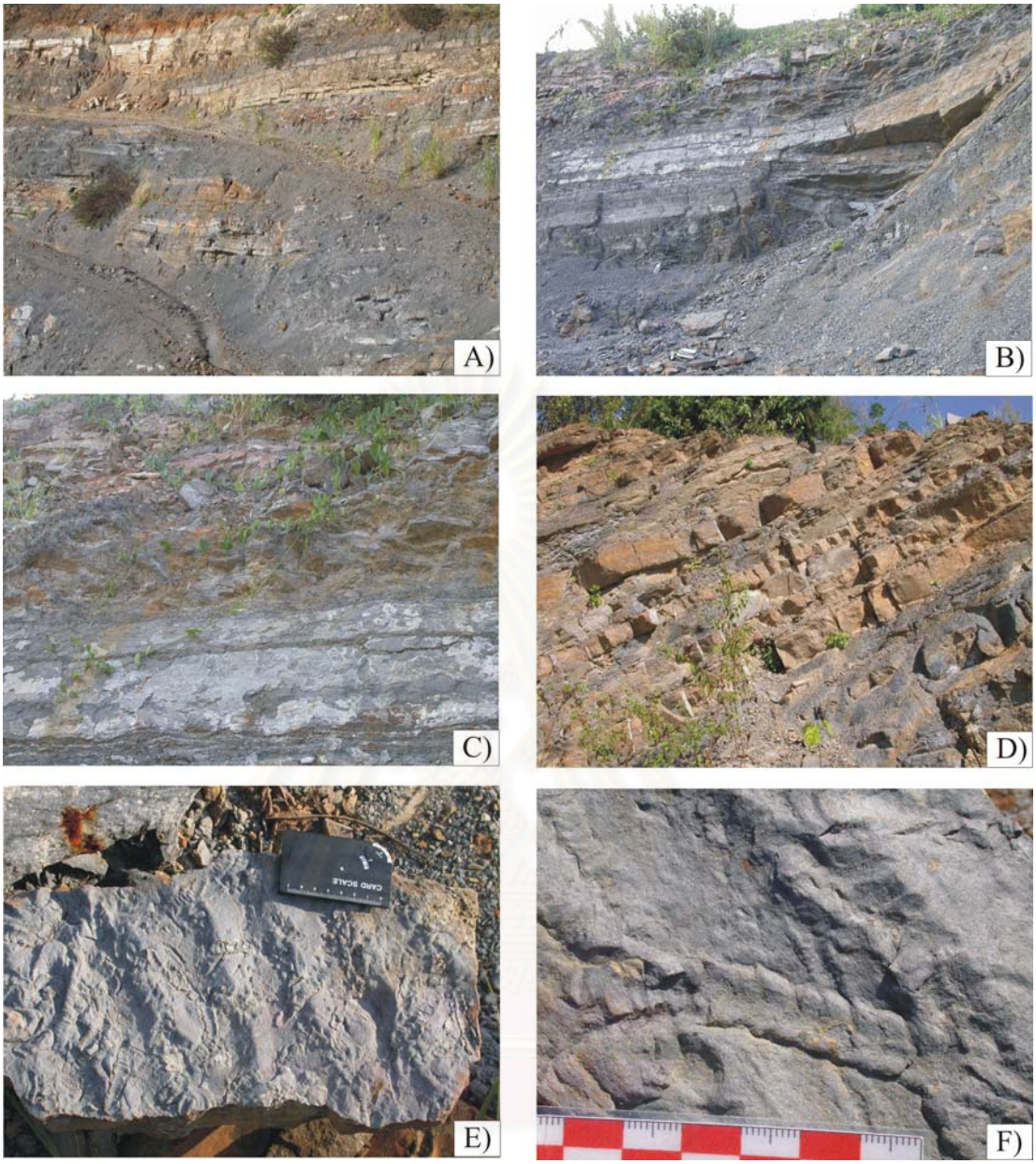


Figure 3.34 Photographs of the mudstone with limestone, siltstone, and sandstone unit (unit IV) of the Pha De Formation at Tak mine, A, B and C) Parallel even beds of calcareous sandstone, grey to greenish grey, medium- to thick-bedded, lamination, cross lamination and ripple marks which contain abundant trace fossils (E and F), D) Sequence of limestone interbedded with mudstone, dark grey, thick-bedded, with common bivalves.

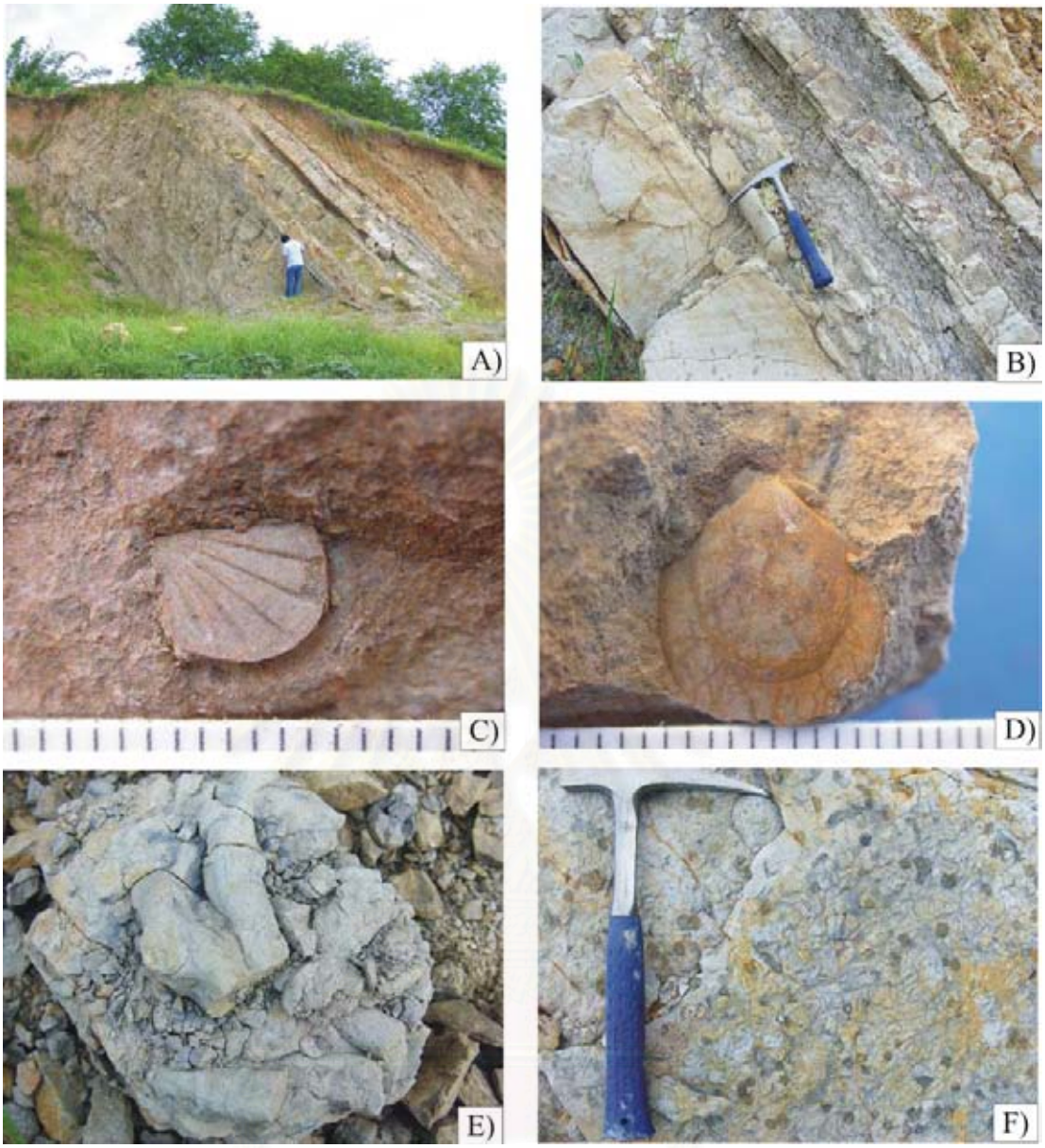


Figure 3.35 Photographs of the sandstone interbe dded with mudstone unit (unit V) of the Pha De Formation at unsealed road from Ban Mae Kut Luang to Mae Kut Luang reservoir, A and B) The sequence consists of light brown, thic k-bedded, coarse-grained sandstone interbedded with mudstone, grey, medium-bedded, load cast, parallel even beds with common bivalves (C and D), and trace fossils (E and F).

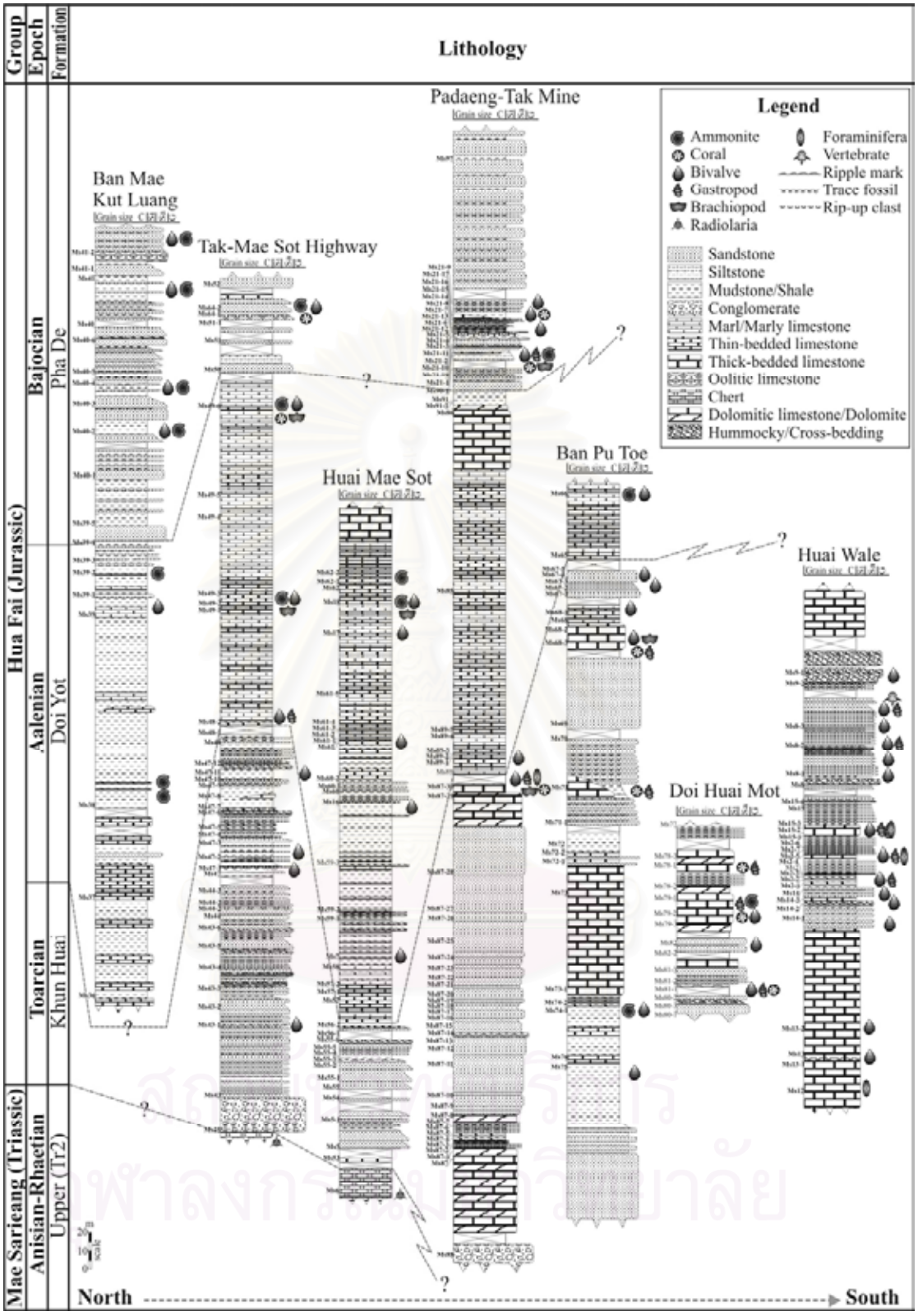


Figure 3.36 Correlation of the Hua Fai Group consisting of 3 Formations, the Khun Huai, Doi Yot, and Pha De Formations, in ascending order, with 7 measured sections include Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, Ban Pu Toe, Doi Huai Mot, and Huai Wale from north to south, respectively.

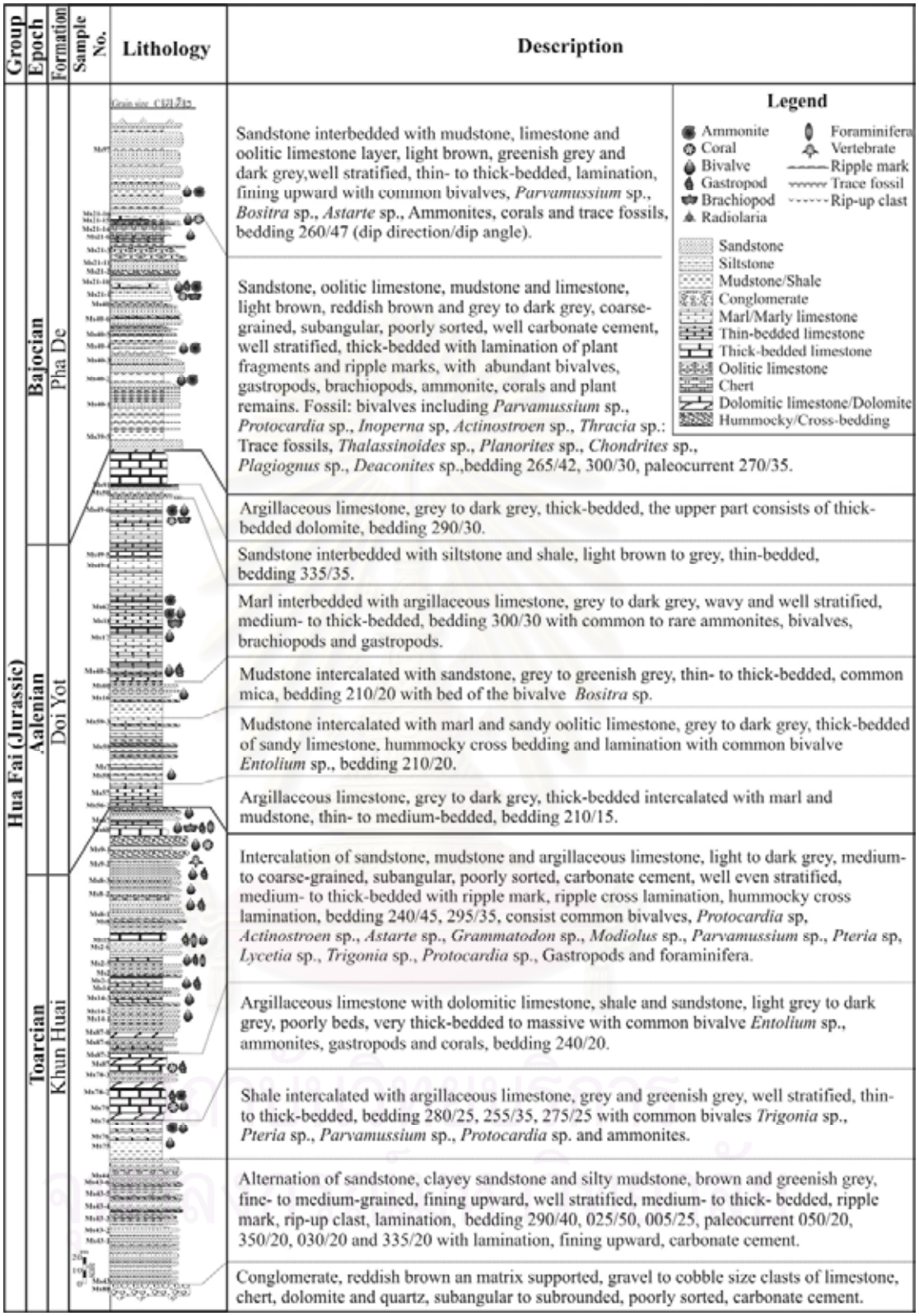
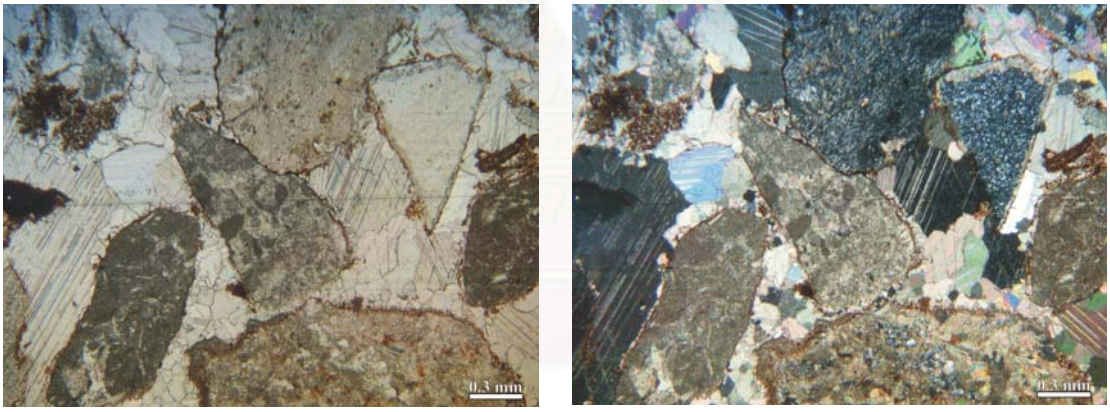


Figure 3.37 Composite section of the Hua Fai Group.

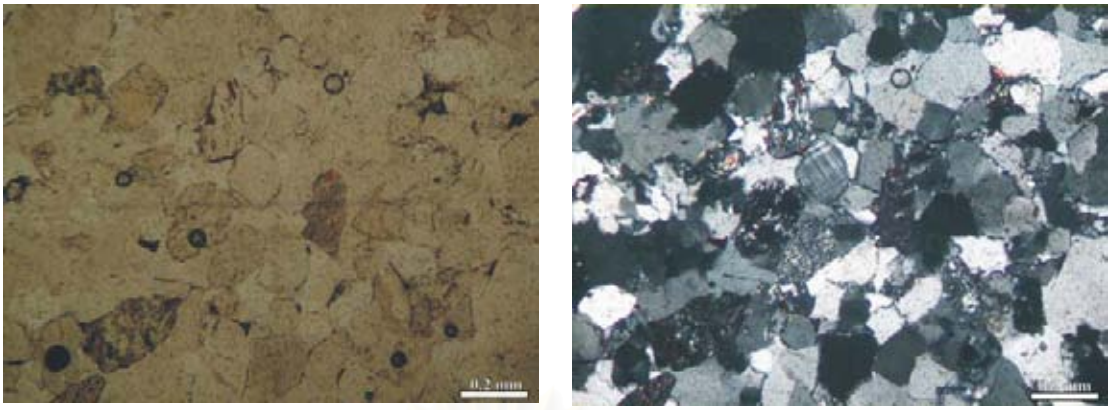
The biomicrite and micrite are recognized from thick-bedded to massive limestone (samples Ms2-5 and Ms12). They display the matrix-supported (see Figure 3.44) mudstone (see Figure 3.45) with more than 10% allochems. In this sample the allochems consist mainly of foraminifera and show the stylolite structures.

The oosparite in Figures 3.46-3.47 shows the importance of envelops in preserving allochems, ooids, quartz, and fossil fragments during diagenesis. Radial and concentric textures have clearly been seen in ooid grains which quartz, calcite and fossil fragments are nucleus. There are also two generations of cementing in sample Ms55-4 (see Figure 3.46). The first appears slightly as rim of very thin crystal layers, such cement is similarly isophachous. The final pore was filled by micritic and sparry calcite. The fossils consist of foraminifera, sponges, bivalve fragments, and unidentified small-sized faunas.



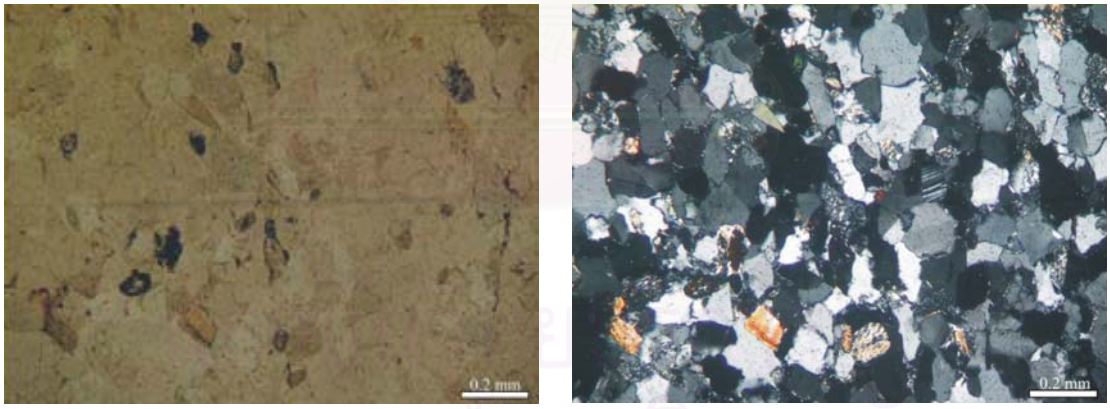
A) B)

Figure 3.38 Photomicrographs of sandy conglomerate (sample Ms25-1) in the unit I of the Khun Huai Formation, showing mainly matrix-supported texture which grains consist of quartz, rock fragments (biomicrite, micrite, and chert) with granule to cobble sizes, angular shape, low sphericity, poorly-sorted, and brown rim of iron oxide. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



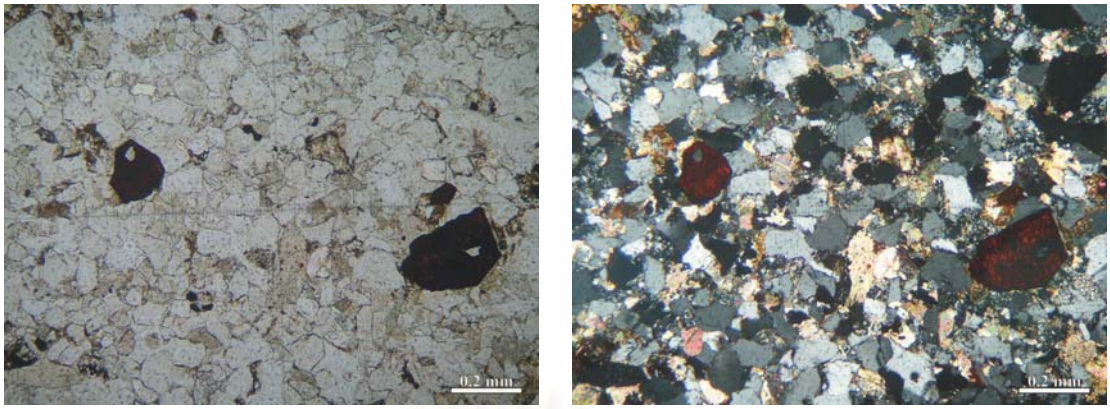
A) B)

Figure 3.39 Photomicrographs of thick-bedded sandstone in the unit VI of the Khun Huai Formation; medium-grained quartz arenite (sample Ms9-2) show some pressure-solution and grain contacts texture, and irregular and wavy features which consist of quartz, rock fragments, feldspar, zircon, and mica. The samples are texturally sub-mature, lacking clay, and moderately-sorted, sub-angular with high sphericity. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



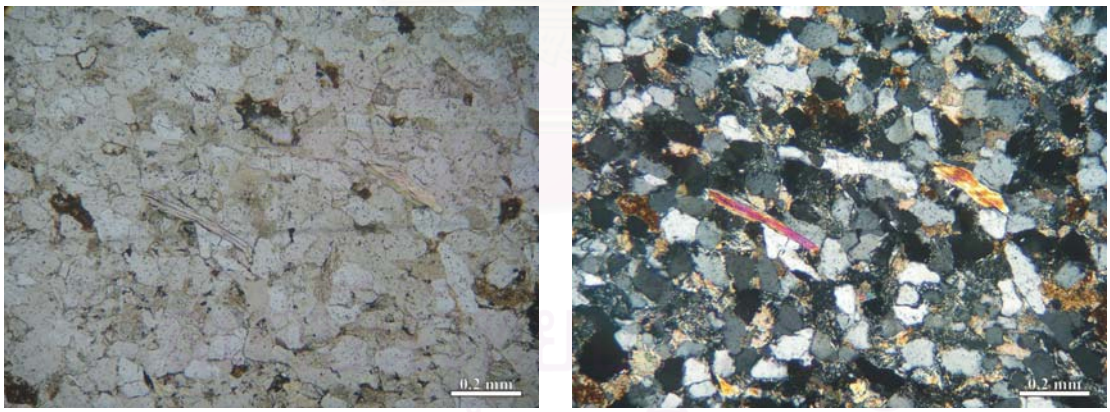
A) B)

Figure 3.40 Photomicrographs of thick-bedded sandstone in the unit VI of the Khun Huai Formation, quartz arenite (sample Ms8) show grains compact texture which consists mainly of quartz, rock fragments, feldspar, zircon, and mica. The samples shown are texturally sub-mature, lacking clay, medium-grained moderately-sorted, and sub-angular with high sphericity. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



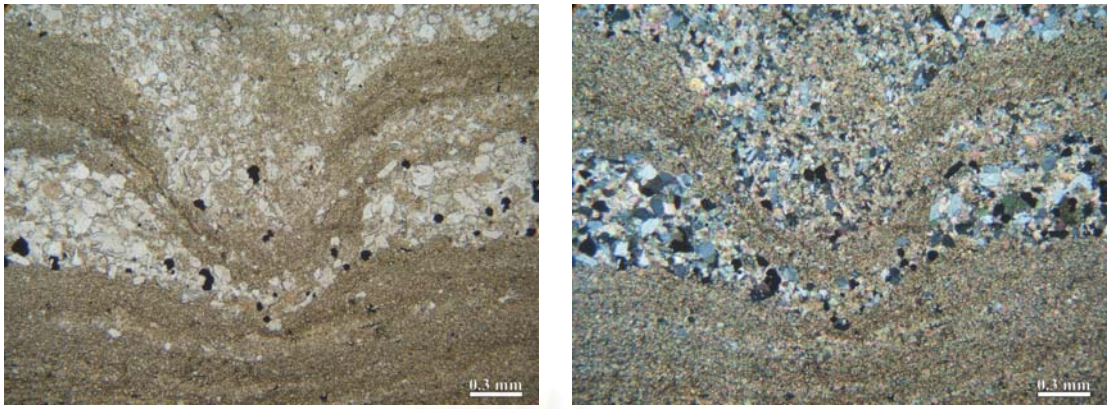
A) B)

Figure 3.41 Photom icrogrphs of sandstone in th e unit II of the Khun Huai Form ation, very fine- to m edium-grained sublitharenite (sam ple Ms43-1) display clastic texture and contains mainly quartz, rock fragm ents, and heavy mineral, im mature to sub-m ature, clay m atrix, moderately-sorted, angular to sub-angular with carbonate cement. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



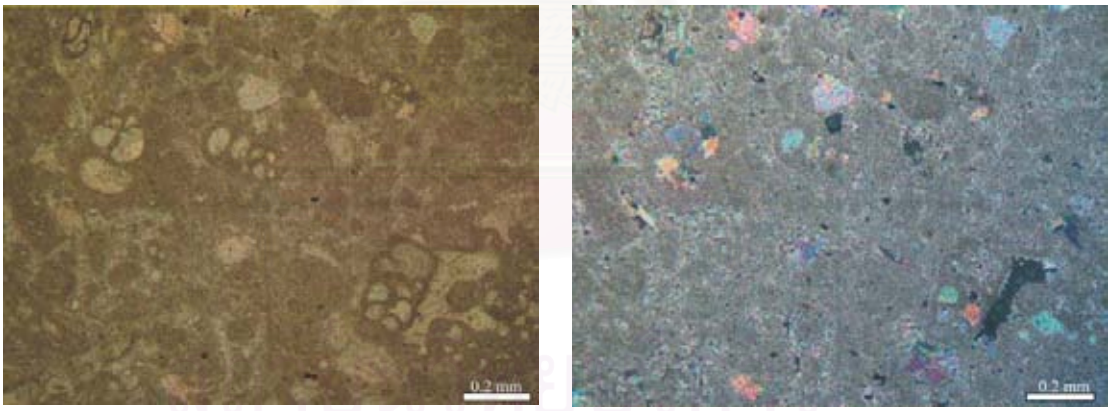
A) B)

Figure 3.42 Photom icrogrphs of sandstone in th e unit II of the Khun Huai Form ation, very fine- to m edium-grained sublitharenite (sam ple Ms55-1) show clastic texture and contains mainly quartz, and rock fragm ents, immature to sub-mature, clay matrix, moderately-sorted, angular to sub-angular with carbonate cem ent. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



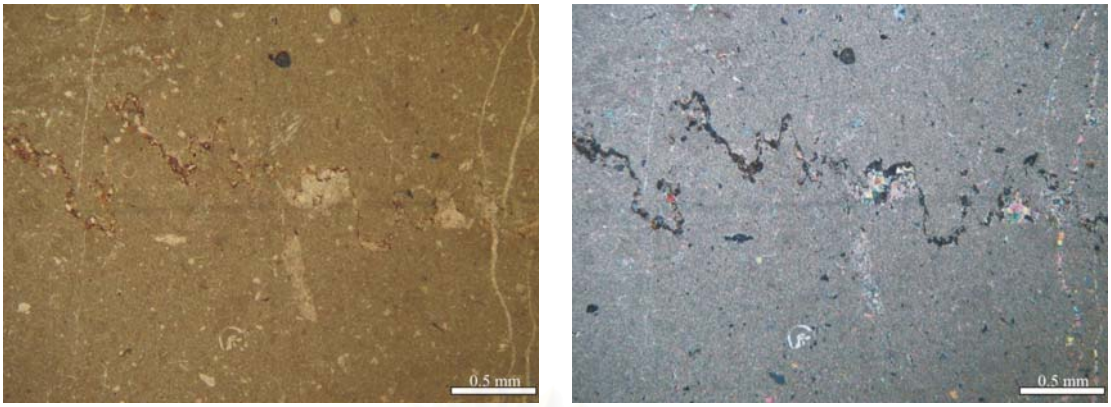
A) B)

Figure 3.43 Photomicrographs of quartzwacke in terbedded with m udstone (sam ple Ms43-4) in the sandstone of the unit II of the Khun Huai Formation show thinly-layers, alternation of very fine sandstone with m udstone. There are small structures indicating the bioturbation. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



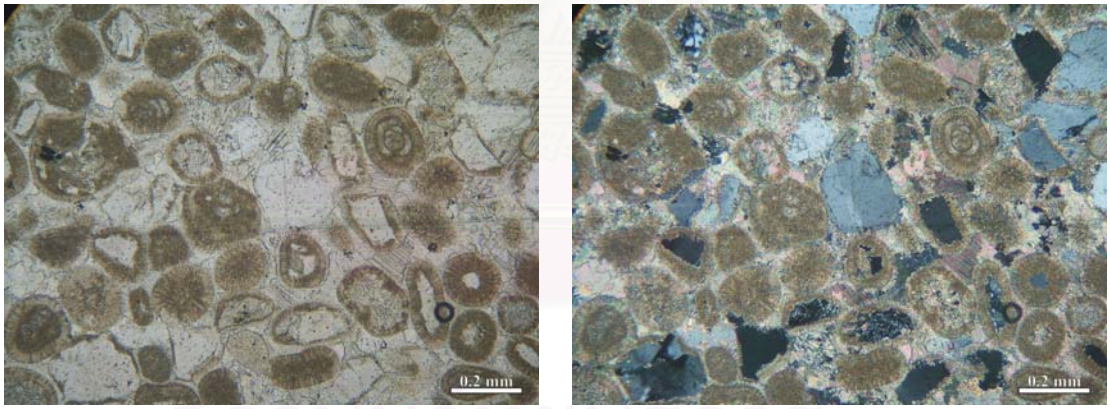
A) B)

Figure 3.44 Photom icrographs of biom icrite (sample Ms2-5) in the unit V of the Khun Huai Formation display the m atrix-supported texture with m ore than 10% allochem s. In this sample, the allochem s consist m ainly of fora minifera. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



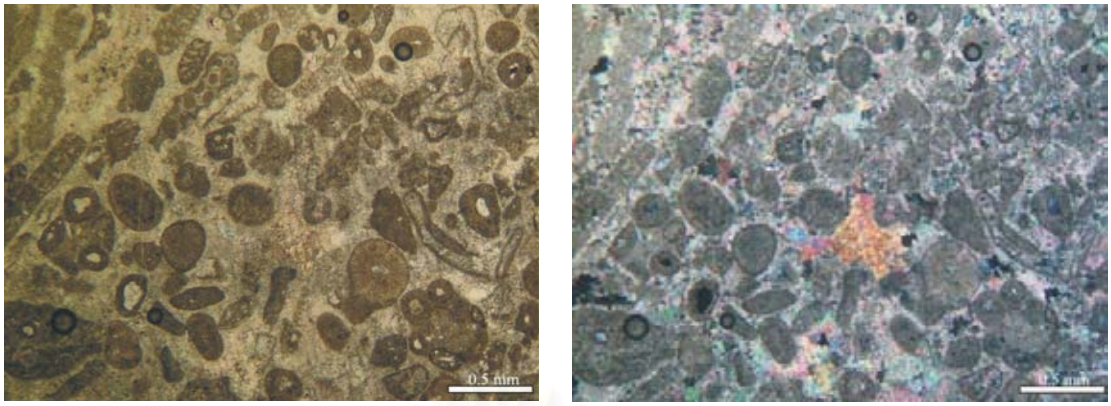
A) B)

Figure 3.45 Photomicrographs of micrite (sample Ms12) in the unit IV of the Khun Huai Formation show micritic texture with less than 10% allochems. In this sample, the stylolitic structure is present. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



A) B)

Figure 3.46 Photomicrographs of oosparite (sample Ms55-4), in the unit V of the Khun Huai Formation, show envelops in preserving allochems, ooids, quartz, and fossil fragments. The ooid grains have clearly displayed radial and concentric textures which quartz and bioclasts are nucleus. The cements are similarly isophachous and pores are filled by micrite and sparry calcite. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



A) B)

Figure 3.47 Photomicrographs of oosparite (sample Ms14-3), in the unit V of the Khun Huai Formation, show envelops in preserving allochems, ooids, quartz, and fossil fragments. The ooid grains have clearly shown radial and concentric textures which quartz and bioclasts are nucleus. The cements are similarly isophachous and pores are filled by micrite and sparry calcite. The fossils are sponge, bivalve fragments, and unidentified small-sized fossils. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).

3.5.2 Petrography of the Doi Yot Formation

Details of petrographic studies of the Doi Yot Formation (Figures 3.48-3.52) are focusing upon representative rock samples collected from 5 measured sections (see Figure 3.36). These sections are well exposed at Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, and Ban Pu Toe. The fine-grained sandstone, siltstone, and mudstone units are confined to the lower part of this formation. The middle and upper parts consist mainly of limestone, mudstone, and marl units.

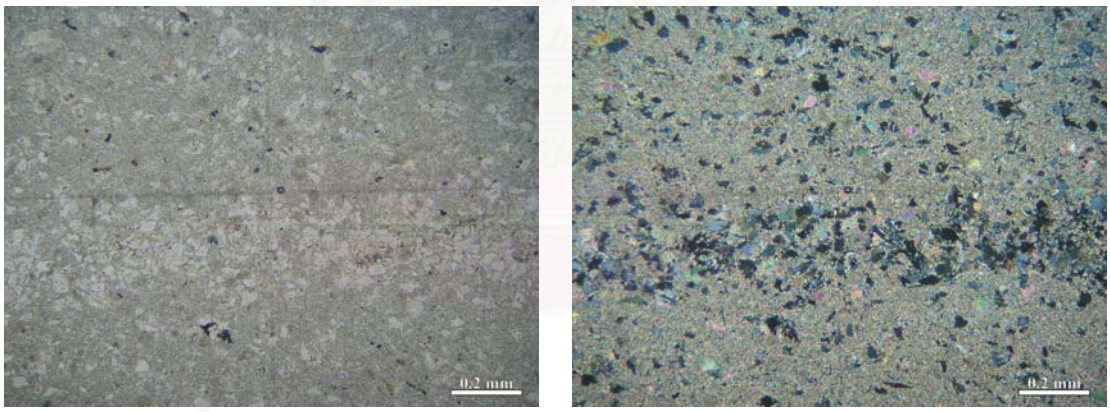
Petrographically, the lower part of this unit is composed mainly of mudstone, limestone, siltstone intercalated with sandstone and fossiliferous limestone. Under the microscopics texture these rocks are characterized by mudstone and siltstone (see Figures 3.48 and 3.49), quartzwacke (see Figures 3.50 and 3.51), and biomicrite (see Figure 3.52).

The very fine-grained mudstone interbedded with siltstone are recognized from thin- to medium-bedded, very fine sandstone (samples Ms36 and 56-2) interbedded with siltstone and mudstone. It shows clastic texture and contains mainly matrix (60-70) and quartz (30-40%). The sedimentary grains are texturally immature,

clay m atrix m ore than 70%, m oderately-sorted, angular to sub-angular. This sample MS36 (see Figure 3.48) shows lamination of mudstone and siltstone.

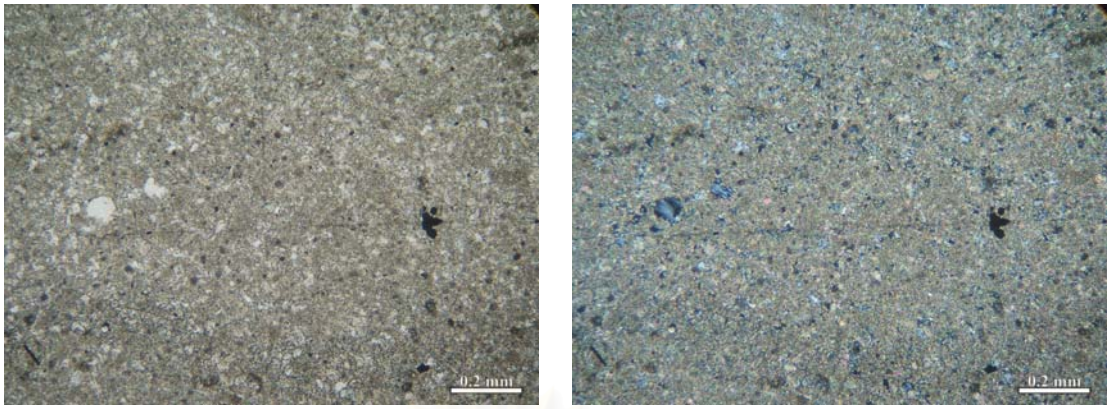
The very fine-grained quartzwacke (see Figures 3.50 and 3.51) is recognized from thin- to m edium-bedded calcareous sandstone (sam ples Ms59-3 and 48-1). It shows clastic texture and contains m ainly quartz (70%), m ica with heavy m ineral (5%). The sedim entary gr ains are texturally im mature, fine-grained m atrix and carbonate cem ent (25%). The grain shape is m oderately-sorted, angular to sub angular, low sphericity, and poorly sorted.

The biom icrite are recognized from m edium- to thick-bedded lim estone (sample Ms57-2). It shows the m atrix-supported texture (see Figure 3.52) with more than 70% allochem s. In this sa mple, the allochem s consist m ainly of foraminifera, gastropod, bivalve fragm ents, and pelloids. These allochem s were coated by the f ine particle or m atrix during diagenesis. The ooid and pelloid grains have unclearly radial and concentric textures.



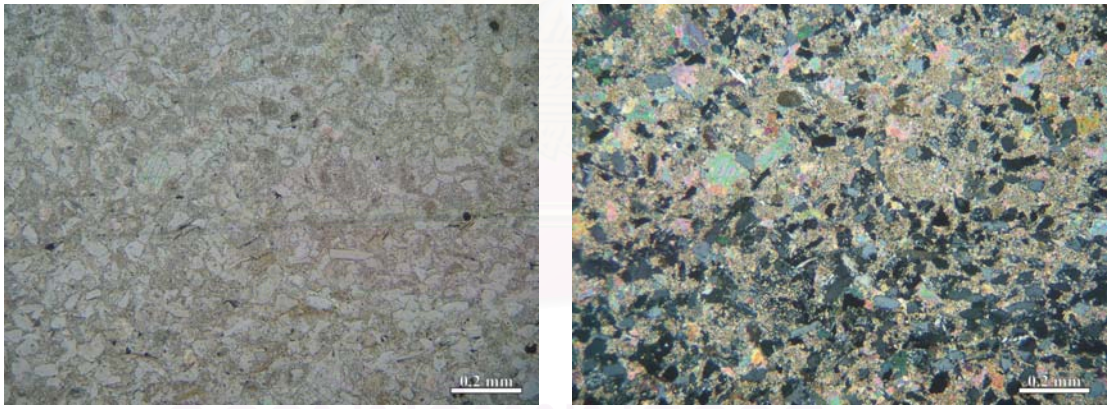
A) B)

Figure 3.48 Photom icrographs of mudstone and siltstone (sample Ms36) in the unit I of the Doi Yot Formation show thinly -layers, altern ation of very fine-grained m udstone and siltstone, sub-angular shape. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



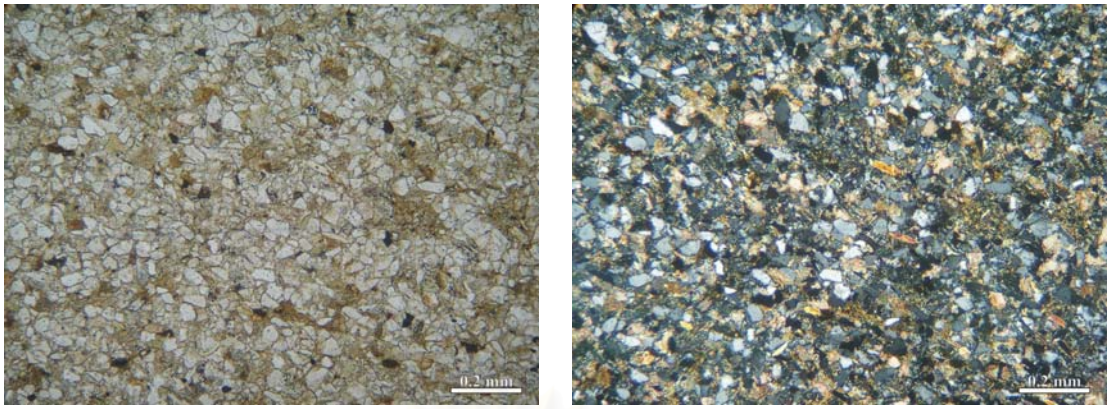
A) B)

Figure 3.49 Photomicrographs of mudstone (sample Ms56-2) in the unit I of the Doi Yot Formation show very fine-grained quartz and opaque minerals. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



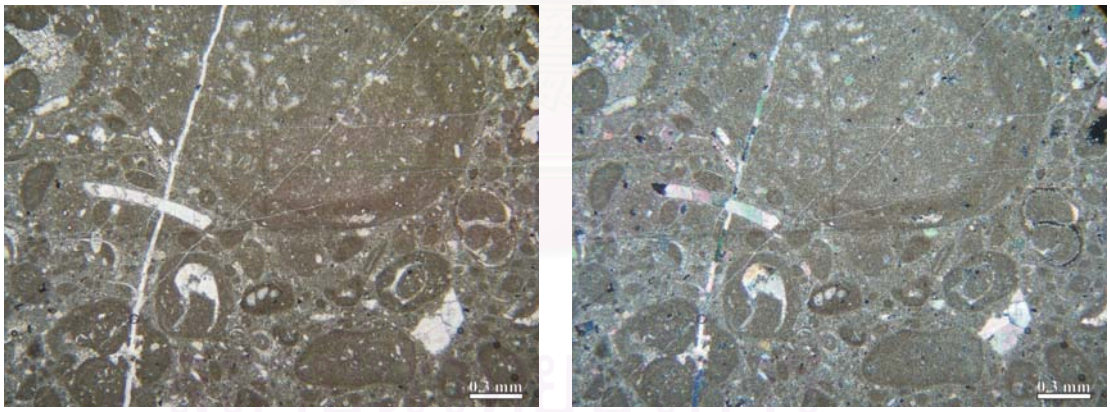
A) B)

Figure 3.50 Photomicrographs of quartzwacke (sample Ms59-3) in the sandstone interbedded with mudstone in the unit I of the Doi Yot Formation show thinly-layers, alternation of very fine-grained quartz of angular to sub-angular, moderately sorted, with mica flakes and fine particle matrix. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



A) B)

Figure 3.51 Photomicrographs of quartzwacke (sample Ms48-1) in thin-bedded sandstone in the unit I of the Doi Yot Formation show mainly very fine-grained quartz of angular to sub-angular shape, moderately sorted, with mica and fine particle matrix. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



A) B)

Figure 3.52 Photomicrographs of biomicrite (sample Ms57-2) in the unit I of the Doi Yot Formation show envelops in preserving allochems, peloid/ooid, and fossil fragments. The fossils consist of foraminifera, gastropod, bivalve fragments, and unidentified small-sized fossils. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).

3.5.3 Petrography of the Pha De Formation

Details of petrographic studies of the Pha De Formation (Figures 3.53-3.62) are focusing upon representative rock samples collected from 3 measured sections (see Figure 3.36). These sections are well exposed at Ban Mae Kut Luang, Tak-Mae Sot Highway, and Pha Daeng-Tak mines. The sandstone, mudstone, and oolitic limestone units are confined to the lower to middle part of this formation. The upper part consists of the sandstone and oolitic limestone units.

Petrographically, this formation is composed mainly of sublitharenite (see Figures 3.53 and 3.54), quartzwacke (see Figures 3.55 and 3.56), quartz arenite (see Figure 3.57), oosparite and sublitharenite (see Figures 3.58-3.60), oobiomicrite with quartz grains (see Figure 3.61), and intrasparite (see Figure 3.62).

The fine-grained sublitharenite is recognized from medium-bedded calcareous sandstone (see Figures 3.53 and 3.54, samples Ms21-1 and Ms21-5). It shows clastic texture and contains mainly quartz (80%), rock fragments (10%), mica, and zircon with carbonate cement (10%). The sedimentary grains are texturally immature to sub-mature, clay matrix (5%), moderately-sorted. Roundness of the grains is sub-angular.

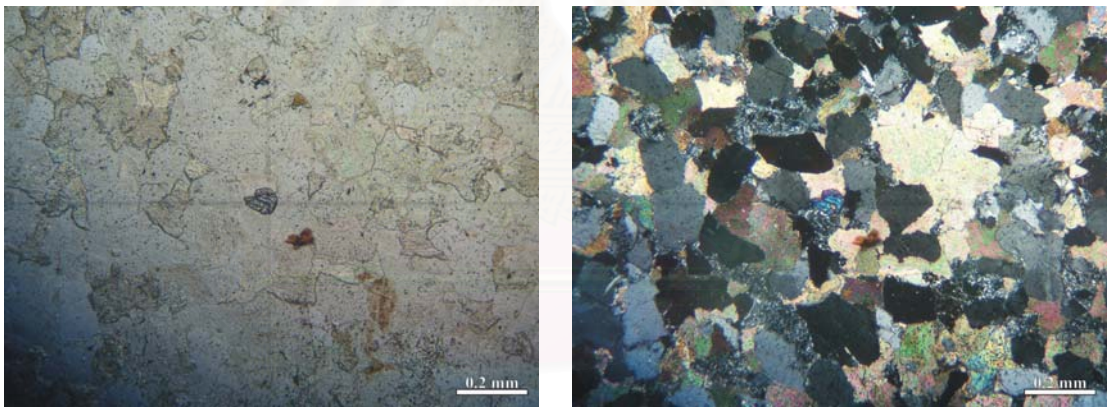
The very fine-grained quartzwacke is recognized from medium-bedded calcareous sandstone (see Figures 3.55 and 3.56, samples Ms21-11, and Ms40-4). It shows clastic texture and contains mainly quartz (60%), ooid (10%) mica, and plant remains (5%). The sedimentary grains are texturally immature, fine-grained matrix and carbonate cement (25%). The grain shape is moderately-sorted, angular, high sphericity, and poorly sorted. The plant remains in Figure 3.55 display a structure of organism which may be represented as the cell wall of this species. Plant remains in Figure 3.56 are mainly deposited on the beds and mixed with quartz, mica, and fine particles.

The fine- to medium-grained quartz arenite (see Figure 3.57, samples Ms41-1) shows some pressure-solution and grain contacts texture which contains mainly quartz (95%) and rock fragments (5%). Some contacts of grains are irregular and wavy because of pressure-solution. Silica dissolved during the process may be precipitated as cementing material. The samples are texturally sub-mature, lacking clay, and poorly-sorted. Roundness of the grains is sub-angular with high sphericity.

The oosparite, sublitharenite, and oobiomicrite in Figures 3.58-3.61 shows the importance of envelops in preserving allochems, ooids, quartz, and fossil fragments

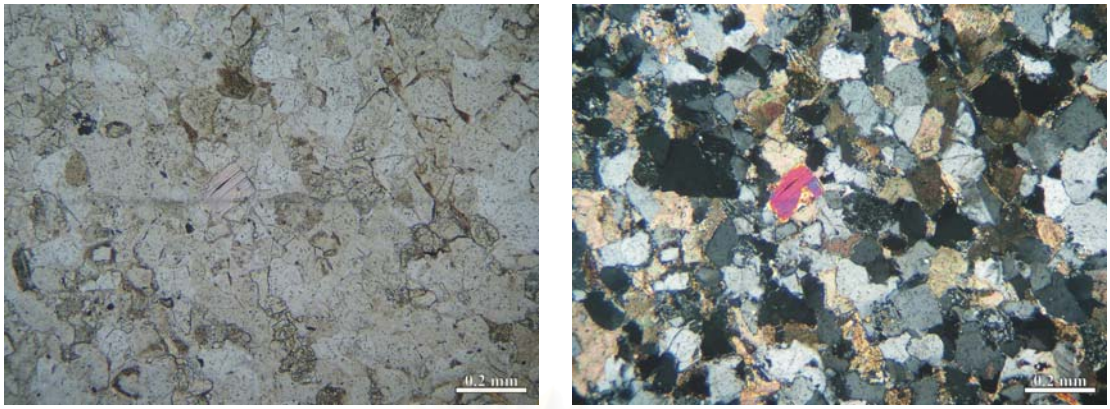
during diagenesis. The allochem s consis t m ainly of the ooid (75%), f ossil fragments (5%), quartz (10%) and m atrix (10%). The ooid grains have clearly shown radial and concentric textures which quartz and bioclasts are nucleus. There are two generations of cem entation in sam ples Ms20-12 and Ms21-3. The first appears slightly as rim of very thin crystals layer, such cem ent is sim ilarly isophachous. The final pore was filled by m icrite and sparry calcite. The fossils consist of foram inifera, bivalve fragm ents, and unidentified sm all-sized fossils. The ooids in Figures 3.59-3.61 show eviden ce of reworked sedim ents. Ooids are generally broken (see Figure 3.60) and m ixed of ooids, m atrix, and foram inifera (see Figure 3.61).

The coarse-grained intrasparite (see Figure 3.62, Ms41-2) is well defined only in the upper part of this form ation. The allochem s are the carbonate grains (80%) and matrix (20%, micrite, and quartz) with carbonate cement.



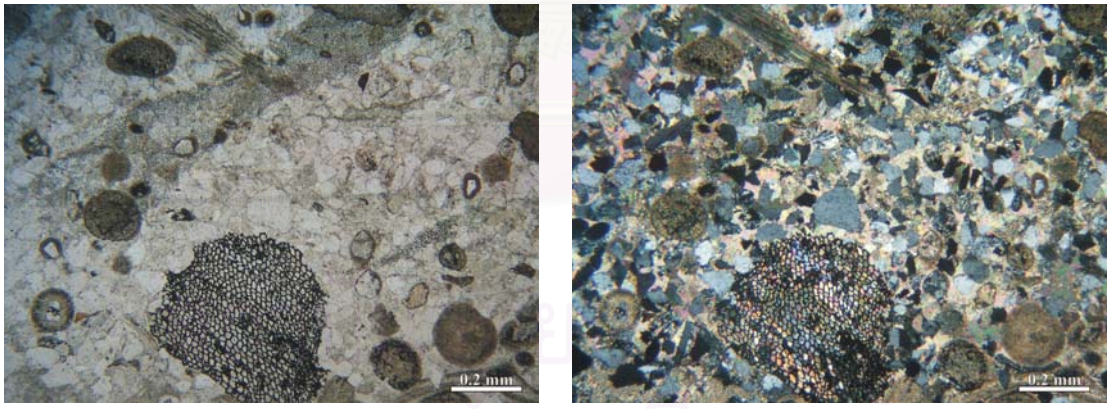
A) B)

Figure 3.53 Photom icrographs of sandstone in the unit II of the Pha De Formation, sublitharenite (sam ple Ms21-1), fine- to m edium-grained, shows clastic texture and contains mainly quartz, rock fragm ents (chert), and zi rcon, im mature to sub-m ature, clay matrix, moderately-sorted, sub-angular with carbonate cem ent. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



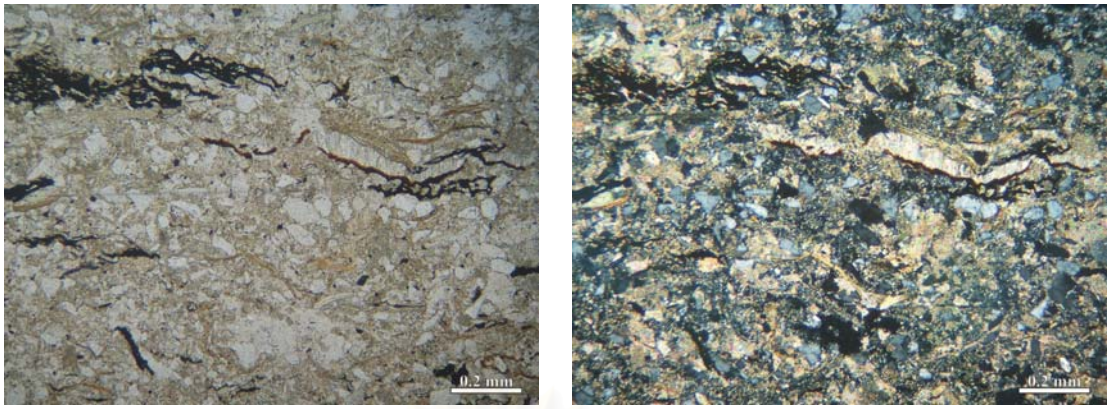
A) B)

Figure 3.54 Photomicrographs of sandstone in the unit IV of the Pha De Formation, sublitharenite (sample Ms21-5), fine-grained, display clastic texture and contains mainly quartz, rock fragments (chert), mica, and zircon, immature to sub-mature, clay matrix, moderately-sorted, sub-angular with carbonate cement. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



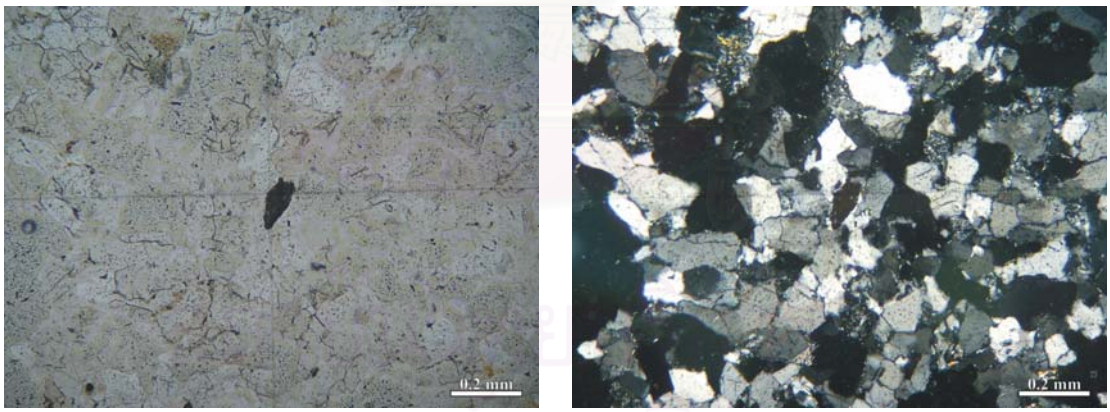
A) B)

Figure 3.55 Photomicrograph of sandstone in the unit II of the Pha De Formation, quartzwacke (sample Ms21-11), very fine-grained, show clastic texture and contains mainly quartz, rock fragments (chert), ooid, and plant remains, immature to sub-mature, clay matrix, poorly-sorted, sub-angular with carbonate cement. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



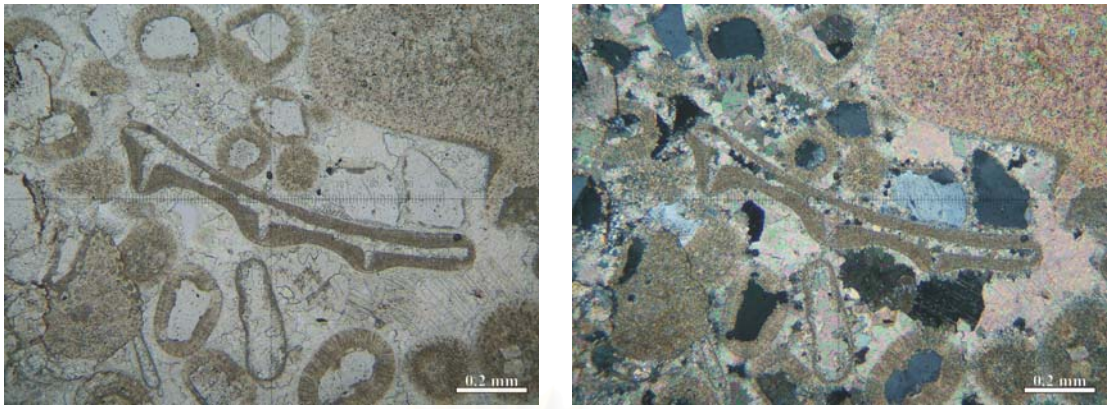
A) B)

Figure 3.56 Photomicrographs of sandstone in the unit II of the Pha De Formation, quartzwacke (sample Ms40-4), silt to very fine-grained, show clastic texture, and contains mainly quartz, rock fragments (chert), and plant remains, immature to sub-mature, clay matrix, poorly-sorted, sub-angular with carbonate cement. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



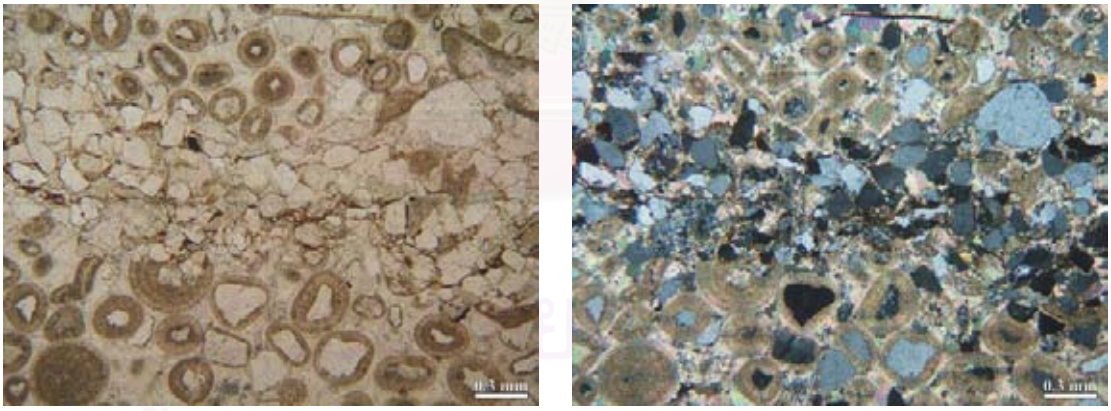
A) B)

Figure 3.57 Photomicrographs of thick-bedded sandstone in the unit II of the Pha De Formation, quartz arenite (sample Ms41-1), fine - to medium-grained, show grains compact and pressure solution texture, which composed mainly of quartz, zircon? and rock fragments. The samples are texturally sub-mature, lacking clay, and poorly-sorted, sub-angular with low sphericity with silica cement. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



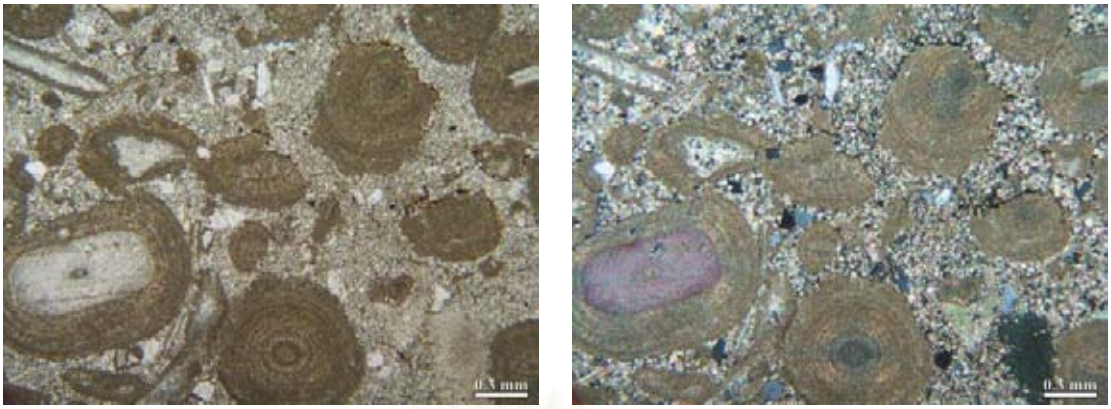
A) B)

Figure 3.58 Photom icrographs of oosparite (sample Ms20-12) in the unit III of the Pha De Formation show envelops in preserving alloch ems, ooids, quartz, and fossil fragments. The ooid grains have clearly shown radial textur e which quartz and bioclasts are nucleus. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



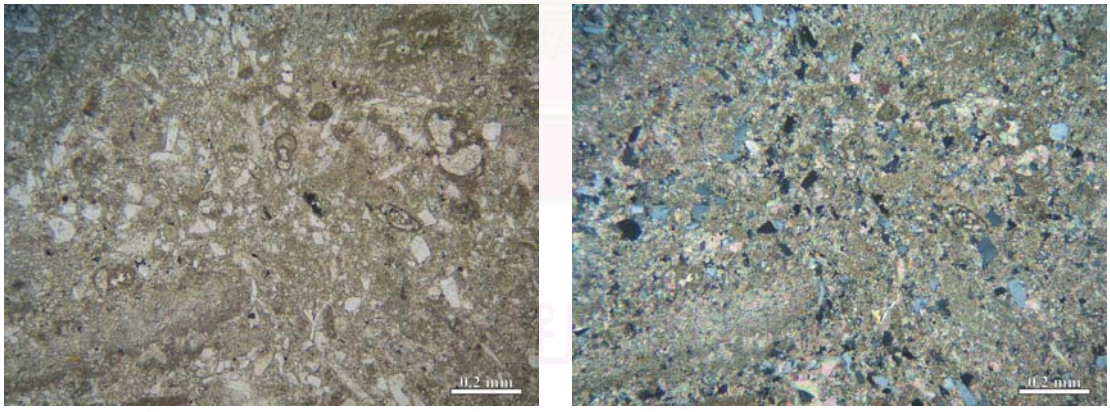
A) B)

Figure 3.59 Photom icrographs of oosparite with lay er of sublitharenite (sam ple Ms21-3) in the unit III of the Pha De Formation show envelops in preserving allochems, ooid, quartz, and fossil fragments. The ooid grains have clearly displayed radial and concentric textures which quartz and bioclasts are nucleus. A) = PPL (P lane Polar Light) and B) =XPL (Cross-Polar Light).



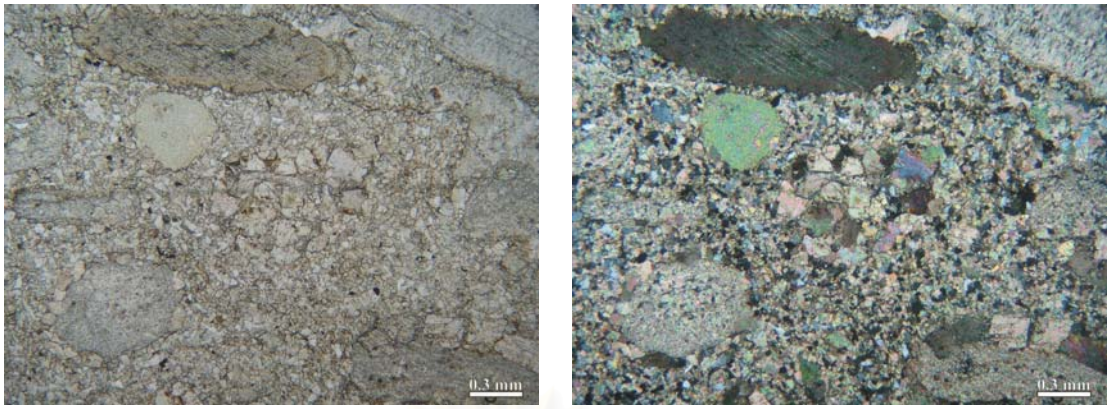
A) B)

Figure 3.60 Photom icrographs of oosparite (sam ple Ms21-4) with very fine-grained matrix (quartz and m icrite) in the unit III of the Ph a De Formation show the broken ooids surface with brown rim of iron oxide. This sample is represented as reworked sedim ents. The ooids have preserved the radial and concentric stru ctures. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light).



A) B)

Figure 3.61 Photom icrographs of oobiom icrite (sam ple Ms21-14) with very fine-grained matrix (quartz and micrite) in the unit IV of the Pha De Formation. This sample is represented as reworked sedim ents. A) = PPL (Plane Polar Light) and B) =XPL (Cross-Polar Light). Foraminifera are well observed in this sample.



A) B)

Figure 3.62 Photom icrographs of coarse-graine d intrasparite (Ms41-2) are well defined only in the unit III of the Pha De Form ation. The allochems are the carbonate grains and matrix (micrite and quartz) with carbonate cement.

CHAPTER IV

DEPOSITIONAL ENVIRONMENTS

Lithostratigraphic units of the Hua Fai Group in Mae Sot-Phop Phra area consists of the Khun Huai, Doi Yot, and Pha De Formations in ascending order. The complete stratigraphic sections were measured on a 1-m by 1-m scale recording grain size, mineralogy, paleontology, sedimentary structures, and bedding morphology; observations from rock slabs and thin sections supplemented field data. At the facies level, depositional environments were reconstructed. Facies could be grouped into units at which level depositional environments were interpreted. The outcrop does not permit architectural element analysis necessary for detailed interpretation of ancient environment systems. Vertical changes in facies and units in the Khun Huai, Doi Yot, and Pha De Formations, however, permit generalized depositional environments to be reconstructed, from which pertinent information can be gleaned concerning the tectonic history of the west and south Thailand.

4.1 Unit analysis

In Khun Huai Formation, the rock can be divided into 8 units consisting of conglomerate, sandstone, siltstone, mudstone, limestone, dolomite, and oolitic limestone facies with abundant bivalves, gastropods, trace fossils, plant remains, and vertebrate fossils. The Doi Yot Formation is composed mainly of 4 units, which have been distinguished by marl, mudstone interbedded with limestone facies containing abundant ammonites and bivalves. Finally, the Pha De Formation, consisting of 5 units, comprises the alternation facies of sandstone, mudstone, siltstone, oolitic limestome, and limestone containing abundant bivalves, ammonites, gastropods, corals, trace fossils, and plant remains. The significant units of the Hua Fai Group are summarized in Table 4.1 and Figure 4.1.

Table 4.1 Summarized units analysis of the Hua Fai Group consists of 3 formations with 17 units.

Formation	Units	Lithology		Geometry		Sedimentary structures	Petrography	Fossil
		Color	Characteristic	Thickness (m)	Distribution/shape			
Khun Huai	VIII	Brown and grey to dark grey	Sandstone	14	Only the central part/Lenses	Lamination	Sub litharenite, quartz arenite	*Bositra* sp., *Parvamussium* sp., *Goniomya* sp.
	VII	Grey to dark grey	Limestone	20-30	Central part passing to south/Thick-bedded lenses	Uneven and wavy beds	Micrite,biosparite, biomicrite, oomicrite	Brachiopods, corals, gastropods, bivalves, vertebrate, foraminifera
	VI	Light brown to brown	Sandstone with oolitic limestone	40-160	Central part passing to south/Thick-bedded and thinning southward	Cross bedding, ripple cross-lamination, well bedded and lamination	Quartz arenite, sub litharenite	*Modiolus* sp., *Astarte* sp., *Protocardia* sp., *Thracia* sp. etc.
	V	Brown and grey	Sandstone interbedded with mudstone and intercalated with limestone	20-83	North to south/ Wedge and planar, thinning to central	Lamination, ripple mark, flaser bedding, wavy beds, cross- and lamination	Sub litharenite, oosparite, biomicrite	*Grammatodon* sp., *Modiolus* sp., *Parvamussium* sp. etc.
	IV	Grey to brownish grey	Limestone and dolomitic limestone	43-100	Central part and extend to south/ Lenses	Thick-bedded with stylolitic band	Micrite, biosparite, biomicrite, dolomitic limestone	*Protocardia* sp. *Entolium* sp. *Astarte* sp.
	III	Grey to greenish grey	Shale intercalated with limestone	73	Only central part/Lenses	Well stratified, even parallel beds	Micrite and mudstone	*Trigonia* sp. *Pteria* sp. *Parvamussium* sp. *Protocardia* sp.
	II	Brown and greenish grey	Sandstone interbedded with mudstone and siltstone	51-117	Northeast, east and southeast/ Wedge and planar thinning to central	Cross lamination, ripple cross lamination, ripple mark, and rip-up clasts	Sub litharenite, quartzwacke, mudrocks with calcite cement	-
	I	Reddish brown and grey	Conglomerate matrix supported	10-20	Northwest, central part and south/Massive lenses	Massive lenses, poorly sorted	Sandy conglomerate matrix supported	-

Table 4.1 Summarized units analysis of the Hua Fai Group consists of 3 formations with 17 units (continued).

Formation	Units	Lithology		Geometry		Sedimentary structures	Petrography	Fossil
		Color	Characteristic	Thickness (m)	Distribution			
Pha De	V	Brown and grey	Sandstone interbedded with mudstone	15-103	North passing to central part/thick-bedded, wedge, thickening to central	Well stratified,even parallel beds with load cast and bioturbation	Sub litharenite, Quartz arenite, quartzwacke	Bivalves, trace fossils and ammonite
	IV	Grey to dark grey	Mudstone with limestone, siltstone and sandstone	13	Only central part/ Wedge, thinning to north	Wavy parallel beds, ripple marks and bioturbation	Micrite sub litharenite, biomicrite	*Parvamussium* sp., *Protocardia* sp., *Inoperna* sp., *Thracia* sp., etc.
	III	Grey to dark grey	Oolitic limestone	> 6	North, central and southwest/planar and lenses	Hummocky cross bedding and lamination	Oosparite, sub litharenite, oobiomicrite, intrasparite	Fossil fragments and foraminifera
	II	Greenish grey, grey, brown	Muddy calcareous sandstone interbedded with mudstone	13-87	North to central part/Wedge, thinning to south	Lamination, cross lamination, ripple marks, rip-up clast	Sub litharenite, quartz arenite, quartzwacke	*Bositra* sp., *Plagiostoma sp., Parvamussium Astarte* sp. etc.
	I	Grey to dark grey	Mudstone interbedded with muddy calcareous sandstone	92	Only north part/ Wedge, thickening to north	Well stratified, even parallel beds	Sub litharenite, siltstone, mudstone	*Bositra* sp., ammonite
Doi Yot	IV	Grey to dark grey	Limestone	16.5-34	Only central part/ Lenses	Massive	Biosparite, oomicrite, micrite	-
	III	Grey to dark grey and light brown	Mudstone intercalated with sandstone siltstone and limestone	12-30	Only north and central part/ Lense	Well stratified, even and parallel beds lamination	Mudstone, sub litharenite, micrite	-
	II	Grey to dark grey	Marl interbedded with mudstone and limestone	40-185	North passing to central part/Thick-bedded, parallel and planar beds	Well stratified, even parallel beds	Biomicrite, micrite	*Erycytes* sp., *Tmetoceras* sp., *Ludwigia* sp., *Graphoceras* sp.
	I	Grey to dark grey	Limestone with mudstone and sandstone	103-139	North passing to central part/Thick-bedded parallel and planar beds	Hummocky cross lamination, lamination, flaser bdding	Mudstone, siltstone, quartzwacke, biomicrite, micrite	*Bositra* sp., *Entolium* sp., *Astarte* sp.

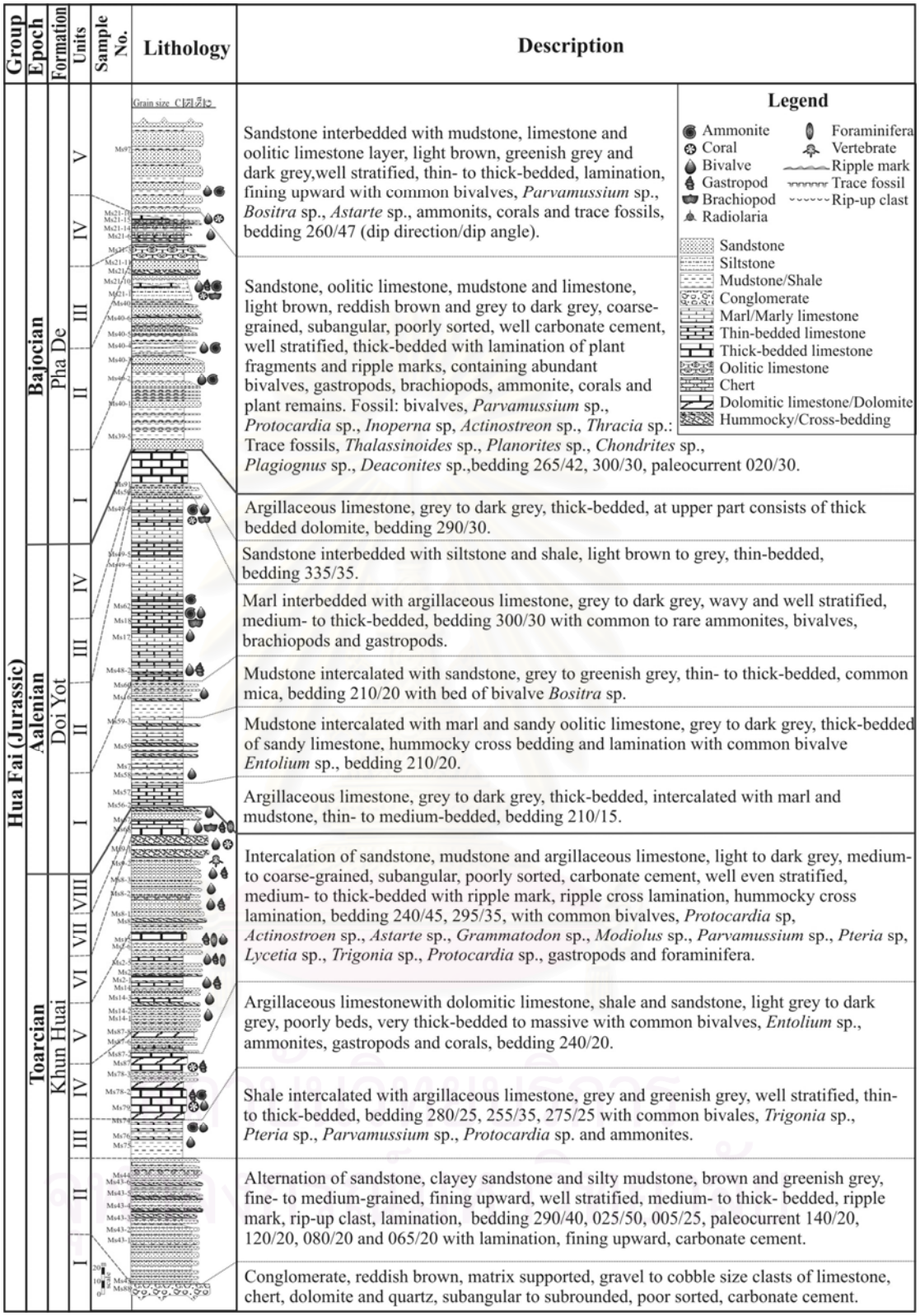


Figure 4.1 Com posite lithostratigraphic sections with units analysis of the Hua Fai Group consists of 8 units of the Khun Huai, 4 units of the Doi Yot, and 5 units of the Pha De Formations.

4.1.1 Units of the Khun Huai Formation

The lowest unit of the Khun Huai Formation within the Mae Sot-Phop Phra area is mainly matrix-supported conglomerate facie of unit I. The unit unconformably overlies the Triassic Mae Sariang Group. This facie is commonly characterized by reddish brown, matrix-supported conglomerate with clasts are composed mainly of limestone, chert, dolomitic limestone, limestone, quartz, and rock fragments. The grains feature is angular to subrounded, poorly sorted, averaging from gravel to cobble size with 0.25 m diameter of a maximum grain size. The general geometry is presented by the massive lenses of matrix-supported conglomerate with 10-20 m thick and distributed in some local areas in the northern and eastern flanks of the Mae Sot basin and the eastern part of Phop Phra. Based on the previous study, the chert grains contain Middle to Late Triassic (Anisian to Rhaetian) radiolarians (Ishida *et al*., 2006). Petrographically, the facie is sandy conglomerate recognized from very thick-bedded conglomerate. It shows matrix-supported texture and contains predominantly grains of rock fragments (biomicrite, micrite, chert, and dolomitic limestone), quartz, and matrix (calcite and quartz grains with carbonate cement) coated by a thin brown layer of iron oxide. This unit underlies the sandstone interbedded with mudstone and siltstone unit (unit II).

The sandstone interbedded with mudstone and siltstone unit (unit II) conformably overlies the conglomerate unit (unit I). This unit consists mainly of brown to greenish grey sandstone interbedded with mudstone and siltstone facies. The sandstone facie is reddish brown, medium-bedded, medium- to coarse-grained, sub-angular sandstone rich in mica and carbonate cement. Generally, geometry of this unit is wedge-shaped and planar thinning to the central part of basin and a range of thickness approximately 51-117 m. It is well exposed at Megic hill and km 67-68 of Tak-Mae Sot highway to the northeast, Huai Mae Sot to the east, Ban Pu Toe, and Doi Huai Mot to the southeast of Mae Sot District. Cross lamination, lamination, ripple cross lamination, ripple mark, fining upward sequence, and rip-up clasts are also found in sandstone facie. Petrographically, sublitharenite, quartzwacke, and mudstone are confined to medium-bedded texture in sandstone and mudstone facies. The sublitharenite and quartzwacke are generally characterized by clastic, very fine- to medium-grained textures containing mainly quartz, rock fragments, and heavy

mineral; moderately sorted, angular to sub-angular with clay matrix and carbonate. This sequence contains rare undetermined bivalves.

The measured section of shale intercalated with limestone facies of unit III is exposed at Ban Nam Khieo in which the overview of geometry is distributed only the central part of the study area. The unit consists mainly of grey to greenish grey, thick-bedded shale facie intercalated with dark grey, thick-bedded, argillaceous limestone facie. The general geometry is characterized by lenses of fine-grained clastic rock with total thickness approximately 73 m. This unit is located only central area. The unit is well stratified which contains common fossils of bivalves and ammonites. The bivalves include *Trigonia* sp., *Pteria* sp., *Parvamussium* sp., and *Protocardia* sp. Petrographically, micrite and mudstone are confined to the thick-bedded limestone and calcareous mudstone.

Approximately 43-100 m thick of the limestone and dolomitic limestone unit (unit IV) are characterized by grey to brownish grey, massive to thick-bedded limestone, dolomitic limestone, and dolomite lenses with the sequences of sandstone interbedded with mudstone and argillaceous limestone of the Doi Huai Mot section in the central part of the study area. The upper part of this unit in Padaeng-Tak mine and Ban Pu Toe sections are represented by intercalation of sandstone, shale, argillaceous limestone, and oolitic limestone facies. Dolomitic limestone and dolomite facies occur locally and are distributed at the Padaeng mine and Doi Huai Mot sections. The carbonate lenses geometry is widely distributed in the central to southern part of the study area. This unit overlies the units II and III with sharp contacts. Petrographically, micrite, biomicrite, biosparite, and dolomitic limestone are recognized from thick-bedded to massive limestone. It shows the carbonate mudstone with less than 5% allochems and stylolitic structure. Fossils are common in the Doi Huai Mot and Huai Wale measured sections, consisting of bivalves such as *Protocardia* sp., *Entolium* sp., and *Astarte* sp., gastropods, trace fossils, ammonites, and small foraminifera.

The sandstone interbedded with mudstone and intercalated with limestone unit (unit V) consists mainly of alternation of sandstone, mudstone, limestone, and limestone facies. The sandstone facie is brown to light brown, well stratified, thin- to medium-bedded. The sandstone grain is characterized by fine- to coarse-grained, sub-angular, poorly- to moderately-sorted. The sedimentary structures include laminations, ripple-mark, wave-formed flaser bedding, wavy bedding, and wave ripple cross

lamination. Mudstone and sandy siltstone are grey to brownish grey, very thin- to medium-bedded. Fining and thinning upward sequences are distinguished in its sequence. The overall geometry is represented by wedge-shaped and planar beds thinning to the central area widely distributed in the northern to southern part of the study area. This unit overlies the units II and IV with sharp and gradational contacts, respectively. The sandstone facie has common showing lateral facie changes with the thickness ranging from 20-83 m. Petrographically, oosparite, and biomicrite are confined to the thin- to thick-bedded oolitic limestone and sandstone. The fossils contain the abundant bivalves *Grammatodon* sp., *Modiolus* sp., *Astarte* sp., *Parvamussium* sp., *Actinostroen* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Trigonia* sp.. The gastropods, trace fossils, foraminifera, and plant remains are also found.

The sandstone with oolitic limestone unit (unit VI) is characterized mainly by sandstone facie with layers of oolitic limestone and sandy siltstone facies, light brown to brown, well-stratified, thick-bedded. The characteristics of sandstone facie are medium- to very coarse-grained, subrounded, moderately- to well-sorted. The sedimentary structures in sandstone facies such as cross bedding, ripple cross lamination, and well-bedded with lamination are well distributed in the southern part of the study area. The overall geometry is thick-bedded sandstone sequence thinning southward at Padaeng mine with approximately 160 m thick. This unit shows common thinning upward sequence and lateral facies changes from the central to southern part. The thickness ranges from 40-160 m. This unit conformably overlies the unit V with sharp contact. Petrographically, quartz arenite and sub litharenite are confined to the thick-bedded sandstone facies. Quartz arenite shows grains compact texture, consisting mainly of quartz, rock fragments, feldspar, zircon, and mica. The samples are texturally submature, lacking clay, medium-grained, moderately-sorted, and sub-angular with high sphericity. Oosparite and oomicrite are predominantly envelops in preserving allochems, ooids, quartz, and fossil fragments. The ooid grains have clearly seen radial and concentric textures having quartz and bioclasts as nucleus. The cements are similarly isophachous and pore filled by micrite and sparry calcite. The bivalves contain *Modiolus* sp., *Astarte* sp., *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.? Gastropods, vertebrates, and plant remains are also found.

The limestone unit (unit VII) consists predominantly of grey to dark grey, massive to thick-bedded, argillaceous limestone facie with massive and thick-bedded, grey, fossiliferous limestone and oolitic limestone facies. This unit conformably overlies the unit VI and underlies unit VIII with sharp contacts. The thickness of this unit is approximately 20-30 m. The overall geometry is characterized by thick-bedded and argillaceous limestone, fossiliferous limestone, and oolitic limestone lenses with abundant well preserved brachiopods, corals, gastropods, bivalves, foraminifera, and vertebrates. This unit is distributed in the central part extending to the south of Huai Wale. The fossiliferous limestone beds at the Padaeng mine are rich in foraminifera, brachiopods, and fossil fragments, whilst oolitic limestone occur as wavy layers with gradded-bedding. Petrographically, micrite, biosparite, biomicrite, and oosparite were described from the thick-bedded limestone and oolitic limestone.

The sandstone unit (unit VIII) is the upper-most unit of the Khun Huai Formation mainly characterized by sandstone facie. The lower part consists of the sequence of brown, medium-bedded sandstone interbedded with grey, thin-bedded, clayey sandstone facies with slightly lamination. The upper part is predominantly composed of grey to dark grey, thick-bedded, clayey sandstone facie. The fining upward sequence and lamination are also presented. The overall geometry of this unit is lenses and distributed only the Ban Pu Toe section, central part of the study area. The total thickness is approximately 14 m. The fossils include common bivalves *Bositra* sp., *Parvamussium* sp., and *Goniomya* sp.

4.1.2 Units of the Doi Yot Formation

The Doi Yot Formation conformably overlies the sequence of the Khun Huai Formation, which consists mainly of 4 units, limestone with mudstone and sandstone, marl interbedded with mudstone and limestone, mudstone intercalated with sandstone, siltstone, and limestone, and limestone units in ascending order. The contact of both formations is represented by gradational contact with fining upward sequences.

The lowest unit of the Doi Yot Formation, limestone with mudstone and sandstone unit (unit I) conformably overlies upon the Khun Huai Formation. The main characteristic lithology of this unit is grey to dark grey, medium- to thick-bedded argillaceous limestone facie interbedded with mudstone and marl facies, dark grey, medium- to thick-bedded. At the Huai Mae Sot section, the unit has light grey,

medium- to thick-bedded, sandy limestone and calcareous sandstone facies with lamination, flaser beds, and hummocky cross lamination. The grey and dark grey limestone, mudstone, and marl facies contain the common bivalves *Bositra* sp., *Entolium* sp., and *Astarte* sp. The sandy limestone and calcareous sandstone facies are characterized by very fine- to fine-grained, sub-angular, well sorted with calcite and mud cement. The total thickness is approximately 103-139 m. Geometrically, thick-bedded, parallel, and well planar beds are distributed from north passing to the central part of the study area. The lower part consists of sandstone facie, well stratified, and hummocky cross lamination gradually changing from sandstone facie to mainly mudstone facie in the upper part. Petrographically, mudstone, siltstone, quartzwacke, micrite, and biomicrite are confined to thick-bedded calcareous sandstone and sandy mudstone facies. The quartzwacke shows thinly-layers, alternation of very fine-grained quartz, angular to sub-angular, moderately sorted, with mica flakes and fine particle matrix, whereas mudstone has the dissemination of very fine-grained quartz and opaque minerals with calcite and clay cements.

About 40-185 m thick of the marl interbedded with mudstone and limestone unit (unit II) overlies the limestone with mudstone, marl, and sandstone unit (unit I) with transitional contact. This unit consists mainly of the alternation of dark grey, medium- to thick-bedded marl, mudstone, and grey, medium- to thick-bedded, argillaceous limestone facies. The overall geometry of the unit is thick-bedded, parallel and well planar beds and is widely distributed from the northern part passing to the central part of the study area. The petrography is mainly characterized by micrite and biomicrite. The marl and mudstone facies are rich in well preserved ammonites, bivalves, and brachiopods. However, the ammonite such as *Erycites* sp., *Tmetoceras* sp., *Ludwigia* sp. (Brown *et al*., 1951), *Tmetoceras regleyi* Dumortier, and *Graphoceras concavum* Sowerby (Komalarjun and Sato, 1964); *Erycites* sp. and *Tmetoceras dhanarajatai* Sato (Komalarjun and Sato, 1964) are also found in the central area.

The unit III, mudstone intercalated sandstone, siltstone, and limestone overlies upon unit II with transitional contact. This unit is very thin and has lateral variation. It predominantly consists of grey to dark grey, thin- to medium-bedded mudstone facie intercalated with light brown, thin-bedded calcareous sandstone, siltstone, and grey, argillaceous limestone facies. The calcareous sandstone facie is mainly characterized

by fine- to medium-grained, thin-bedded, sub-angular, well sorted, carbonate cement. The geometry is lenses and exposed locally in the northern and central areas with totaling 12-30 m thick. The sandstone facie has very common showing lateral variation. The fossils are rare throughout of unit. The petrography is mainly presented by mudstone, sub litharenite, and micrite.

The limestone unit (unit IV) conformably overlies the unit III with sharp contact. The characteristics of this unit are mainly composed of grey to dark grey, thick to massive argillaceous limestone facie. At the Tak mine, the oolitic limestone layers and dolomitic limestone facies are also found. The overall geometry is massive carbonate platform and distributed in the central area only with approximately 16.5-34 m thick. The fossil fragments are also found in the massive limestone. Petrographically, biosparite, oomicrite, and micrite are recognized from massive limestone.

4.1.3 Units of the Pha De Formation

The Pha De Formation conformably overlying the Doi Yot Formation mainly consists of 5 units, namly, mudstone interbedded with muddy calcareous sandstone, muddy calcareous sandstone interbedded with mudstone, oolitic limestone, mudstone with limestone, siltstone and sandstone, and sandstone interbedded with mudstone unit in ascending order as follows:

The lower unit of the Pha De Formation is mudstone interbedded with muddy calcareous sandstone unit (unit I) underlain by the Doi Yot Formation with sharp contact. It is predominantly composed of grey to dark grey, thick-bedded mudstone facie interbedded with grey to brown, thin- to thick-bedded calcareous sandstone facie. The sandstone facie is mainly characterized by fine- to coarse-grained, sub-angular, moderately sorted with calcite cement. The overall geometry is wedge-shaped sequence thickening to the north. They are well exposed about 92 m thick in the northern part of the study area. The petrography is predominantly presented by sub litharenite, mudstone, and siltstone. The unit boundary is sharp contact with the upper unit of the Doi Yot Formation. The bivalve *Bositra* sp. and ammonites are commonly found in some sandy mudstone layers.

The muddy calcareous sandstone interbedded with mudstone unit (unit II) overly conformably upon the unit I with gradational contact. The total thickness is

approximately 13-87 m . It predom inantly c onsists of greenish grey to brown, thick-bedded sandstone facie interbedded with grey to greenish grey, m edium- to thick-bedded m udstone facie. The sandstone f acie is m ainly characterized by coarse-grained, lam ination, cross lam ination, a nd ripple m arks with rip-up clasts. Geometrically, the unit has wedge-shaped and even beds thinning to the south and is well extended from the northern to the central parts of the study area. Petrographiccally, sublitharenite, quartz ar enite, and quartzwacke show f ine- to medium-grained, with com pact and pressure solution textures, consisting m ainly of quartz, zircon, and rock fragm ents. The qua rtz arenite are texturally subm ature, lacking clay, and poorly-sorted, sub-angular, low sphericity with silica cem ent. The quartzwacke is characterized by fine-grain ed clastic textures containing m ainly quartz, rock fragm ents (chert), ooid, and plant rem ains, immature to sub-m ature, clay matrix, poorly-sorted, sub-angular with carbonate cem ent. The fossils contain abundant bivalves, am monites, gastropods , corals, trace fossils, brachiopods, and plant rem ains. All m easured sections of this unit contains abundant am monites and bivalves including *Bositra* sp., *Plagiostoma* sp ., *Parvamussium* sp ., *Trigonia* sp ., *Astarte* sp ., *Thracia* sp ., *Bositra* sp ., *Pinna* sp ., *Protocardia* sp., *Inoperna* sp ., *Pholadomya* sp., *Mytilus* sp., *Modiolus* sp., *Lima* sp., *Entolium* sp., *Eomiodon* sp., and *Protocardia* sp. (Kozai *et al*., 2006).

The characteristic lithology of the oolitic lim estone unit (unit III) is predominantly com posed of grey to dark grey, thick-bedded oolitic lim estone f acie with hum mocky cross bedding and lam ination. The overall geom etry is well planar and lenses. This facie is exposed in the northern, central, and southwestern parts of the study area. The total thickness is approxim ately more than 6 m with sharp contact between the lower and upper units. Petrographically, the unit characteristics com prise mainly oosparite, sublitharenite, oobiom icrite, and som e layers of intrasparite. The ooid grains have been characterized by radi al and concentric textures with qurartz, calcite, foraminifera, and fossil fragments as nuclei.

The lower part of mudstone with lim estone, siltstone, and sandstone unit (IV) consists m ainly of dark grey, m edium- to thick-bedded m udstone interbedded with argillaceous lim estone facies. The overall geometry is wedge-shaped with thinning sequence towards north. The total thickness is approximately 13 m and well exposed

only at the Tak mine section. The fossils contain abundant bivalves including *Parvamussium* sp., *Protocardia* sp., *Inoperna* sp., and *Thracia* sp. In the upper part, this unit is characterized by the sequence of grey, medium-bedded calcareous sandstone, siltstone, and mudstone with abundant trace fossils such as *Thalassinoides* sp., *Planorites* sp., *Chondrites* sp., *Plagiognus* sp., *Deaconites* sp. (Tansthien, pers. comm., 2007). The petrography is characterized by the micrite, sub litharenite, and biomicrite. This unit shows coarsening and thickening upward sequences which gradually change to the sandstone interbedded with mudstone unit (unit V). The unit V conformably overlies the units III and IV with sharp contacts. The unit is the upper-most portion of the marine Jurassic sequences in the Mae Sot-Phop Phra basin. It predominantly consists of brown, thick-bedded, sandstone facie interbedded with grey to light grey, medium- to thick-bedded mudstone facie. The sandstone facie is mainly characterized by coarse-grained, sub-angular, moderately sorted aspects with even parallel beds, load cast, and bioturbation. The overall geometry is thick-bedded to massive, wedge-shaped with thickening to the central area. The thickness is approximately 15-103 m and exposed at the central part passing to the northern area. The bivalves, trace fossils and ammonites are also found.

4.2 Sedimentary cycles and sea level change

The comprehensive chart of marine Jurassic sedimentary cycles has been established for the Jurassic sequence in the Mae Sot-Phop Phra area (Figure 4.2). Age and boundary determination were followed by Vail *et al*. (1977b), Haq *et al*. (1987), Haq *et al*. (1988), Hallam (1988), Surlyk (1991), Li and Grant-Mackie (1993) and Haq and Al-Qahtani (2005) (Table 4.2). The eustatic sea level curves for the Mae Sot-Phop Phra area summarized in Figure 4.2, shows the relation of Jurassic sea level change on the basis of facies and units analysis and fossil assemblages. Interpretation of sea level changes of the marine Jurassic in the study area has been facilitated by the development of sequence-stratigraphic concept. Zero marks represent sea level and relative sea level changed during Early-Middle Jurassic derived from Hallam (1988)'s estimation as well as Haq *et al*. (1987). The sea level rise and fall patterns described by Hallam (1988) will be generally used in this study. Based on previous global sea level curves and a simplified long term curves (Figure 4.2) derived from the

composite stratigraphic colum ns, the trend of sea level changes corresponds to the marine Jurassic sea level in Thailand.

4.2.1 Eustatic sea level curves of the Khun Huai Formation

The rocks and fossils of the Khun Huai Formation consist of 8 units including conglomerate, sandstone, siltstone, m udstone, lim estone, dolom ite, and oolitic lim estone facies with abundant bivalves, gastropod, trace fo ssils, plant rem ains, and vertebrate fossils. Based on the unit analysis and fossil assem blages, a conglom erate facies in the lower part (early Toarcian) of the Khun Huai Form ation is represented by regressive cycles (see long term curve in Figure 4.2 and Table 4.2). These conglomerates comprise the lowstand systems tract. In the middle to upper part of form ation (middle-late Toarcian), a slightly high sea level is marked, which has been confirm ed globally by many previous studies (Table 4.2). W ith a slower rise, there m ay be a greater or lesser development of a trangressive system tract blanketing the shelf.

4.2.2 Eustatic sea level curves of the Doi Yot Formation

Aalenian sea level curve in the Mae Sot- Phop Phra area has been revealed as a transgressive phase continuing from late Toarci an. This is confirm ed by changing in units of the Khun Huai Form ation to Doi Yot Form ation. The Khun Huai Form ation consists m ainly of sandstone intercalated with m udstone and limestone. Whereas, the Doi Yot Form ation is characterized by m arl, m udstone, and argill aceous lim estone facies, indicating quiet depositional environm ent in deeper level. The sea level transgress to m iddle-late Aalenian, which was probably the highest sea level in the study area. During the high sea level, provided that there is an ample sediment supply, a thick sedimentary sequence is developed comprising the highstand system s tract. After late Aalenia n, sea level was still high, in the transgressive phase. This transgression could be corresponded to transgression of the global sea level curves (Table 4.2).

4.2.3 Eustatic sea level curves of the Pha De Formation

Late Aalenian-early Bajocian sea level wa s represented by the end of transgresive phase. Based on the units of the Pha De Formation (see Figure 4.2 and Table 4.2), the characteristic units of this f ormation are m ainly sandstone interbedded with m udstone and intercalated with oolitic limestone and argillaceous limestone facies.

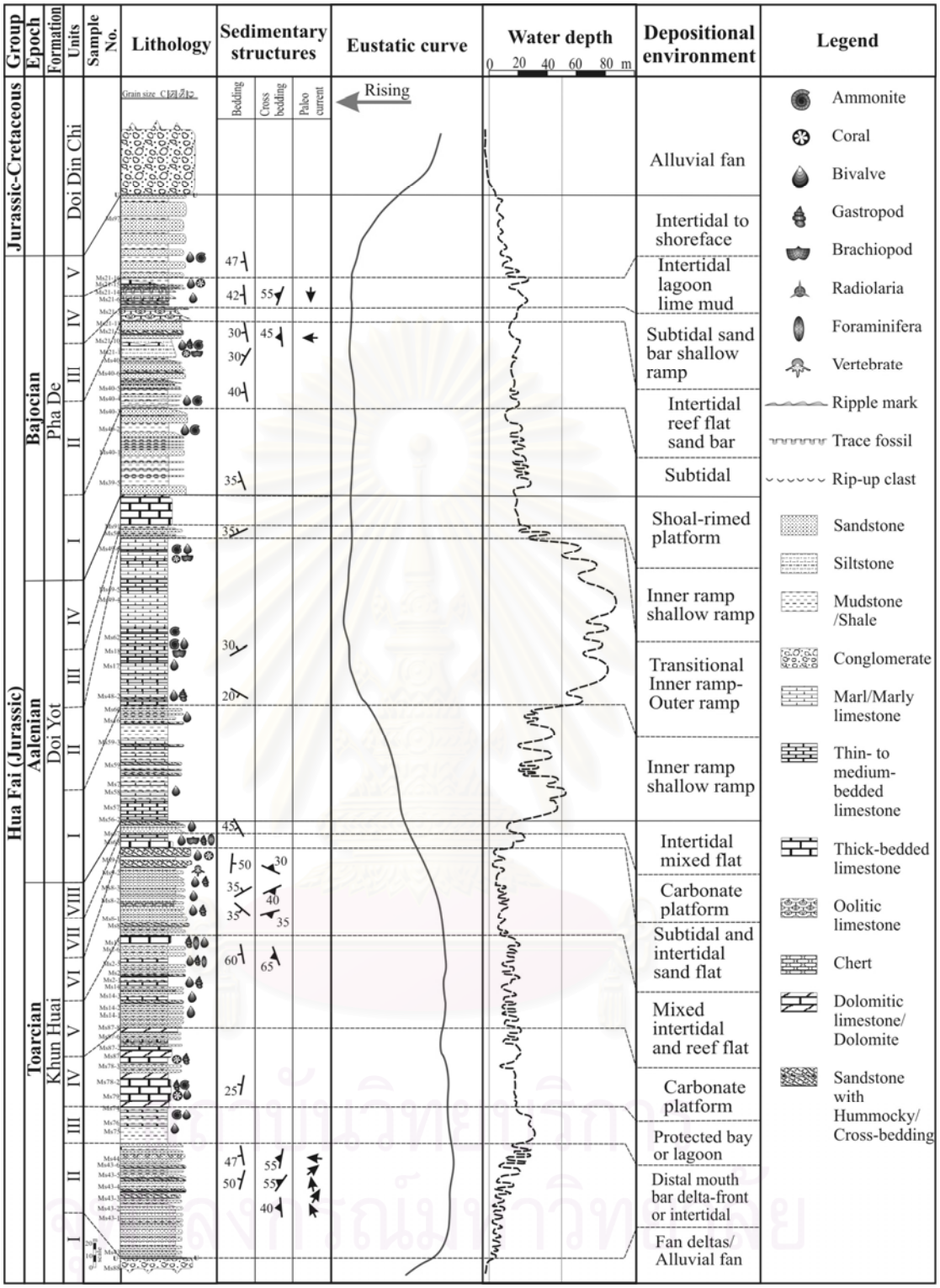


Figure 4.2 Eustatic sea level, short term and long term curves of the Hua Fai Group in the Mae Sot-Phop Phra area.

It is represented as the shallow marine depositional environment, shallow water depth (Figure 4.2) in which the water depth has not yet revealed the global sea level change. Whereas the high sea level, highstand systems tract, enormous sediments were supplied to this basin. As a result, the sea floor became shallower than the Aalenian period. During early to middle Bajocian, the eustatic sea level curves in this basin could be corresponded to the global sea level curves. After middle Bajocian, the eustatic sea level curves of the Mae Sot-Phop Phra Basin were gradually regressed as regressive phase which could not be conformed with the global ones. As a result the non-marine system will gradually progress across the shelf and deposit thick sequences of alluvial sediments of the Doi Din Chi unit (Late Jurassic-Cretaceous). As there are no exposures of marine Jurassic sequences, it is concerned that they were terminated from this basin and various areas in Thailand.

4.3 Depositional environments

The interpretation of the depositional environments of the Hua Fai Group is essentially based on lithology, geometry, sedimentary structure, petrography, and fossils.

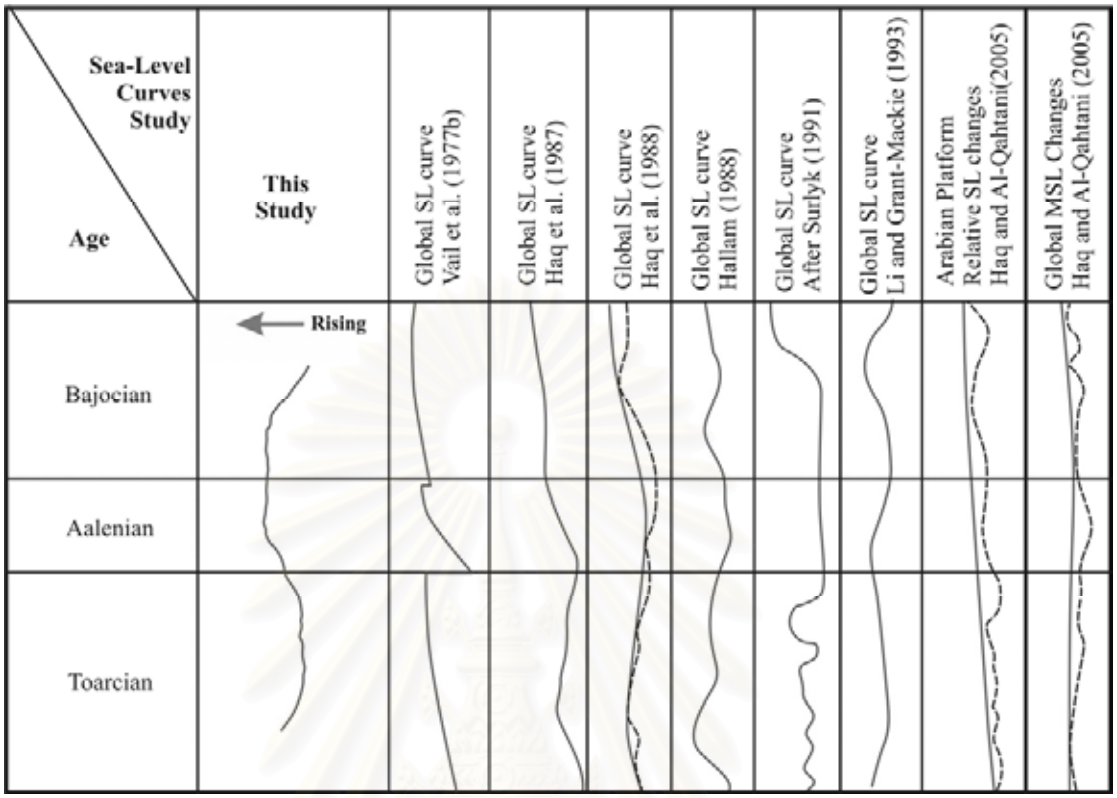
The reconstruction of all possible depositional environments of the Hua Fai Group is shown in Table 4.3 and Figures 4.3 and 4.4.

4.3.1 Depositional environment of the Khun Huai Formation

According to the present investigation, the Khun Huai Formation in Mae Sot-Phop Phra area is considered to be deposited in the shallow shelf environment (Figures 4.2, 4.3, and 4.4). The characteristics of facies and unit associations of the Khun Huai Formation and their depositional environment reconstruction are summarized and shown in Table 4.3 and Figures 4.2, 4.3, and 4.4.

The lowest part, conglomerate unit (unit I) consists predominantly of reddish brown, matrix-supported conglomerate facie. Clasts are composed mainly of limestone, chert, dolomitic limestone, limestone, quartz, and rock fragments. Conglomerate facie deposited as massive lenses locally and is generally distributed in north-northeastern and southwestern portions of the study area. The unit I can be compared to the studies of Ethridge (1985) and Einsele (2000).

Table 4.2 Comparison of Jurassic eustatic sea level curves of the Hua Fai Group in the Mae Sot-Phop Phra area with previous studies.



It can be conclusively determ ined to be deposited under gently subsiding lagoon or shore face environment. The streams were carrying a high bedload, reach the standing water body. They drop their coarse materials at the lagoon or shore face. This unit can be designed as alluvial fan, fan delta, partially as subaerial debris flow deposits as indicated by the presence of reddish brown of iron oxide.

After conglom erate unit (unit I) deposited, the environm ent is gradually changed to distal mouth bar, delta front, due to tide dominated or marine transgression during late Early Jurassic (Toarcian). Beside s, sandstone interbedded with m udstone and siltstone unit (II) contains cross lam ination, lam ination, ripple cross lam ination, ripple m ark, fining upward sequence and ri p-up clasts. In places, this unit is characterized by reddish m icaceous sandstone facie which indicates the effect of fluvial deposits. In conclusion, this unit (unit II), as com pared with Tankard and Barwis (1982) and Allen (1970), indicates sedimentation under the transitional zone of delta front platform, distal mouth bar environment (Figures 4.3 and 4.4).

After sandstone interbedded with m udstone and siltstone unit (unit II), depositional environment has changed from distal mouth bar, delta front in the lower

part gradually passing upward to protected bay or lagoon, low-energy environment (Purser, 1973; Schwarz *et al*., 1975; Butler *et al*., 1982; Schreiber, 1986). This is indicated by the presence of shale intercalated with limestone facies (unit III) containing the common bivalves *Trigonia* sp., *Pteria* sp., *Parvamussium* sp., and *Protocardia* sp. (Table 4.3 and Figure 4.3). Geometrically, the unit is characterized by lenses of well stratified and parallel beds with exposed only at Ban Nong Khieo in the central portion of the area.

Following the shale intercalated with limestone unit (unit III), the depositional environment have changed from protected bay or lagoon passing to carbonate platform environment as indicated by thick-bedded to massive limestone lenses of the limestone and dolomitic limestone facies (unit IV). The bivalves such as *Protocardia* sp., *Entolium* sp., and *Astarte* sp. are also found. This carbonate platform was isolated from mainland and surrounded by deeper water (James, 1983; Sellwood, 1986).

According to sandstone interbedded with mudstone and intercalated with limestone facies (unit V), the lithology and sedimentary structures (Table 4.3 and Figures 4.3 and 4.4) of this unit indicate the mixed intertidal and reef flat depositional environments. The unit characteristic is fining and thinning upwards and widely distributed in the northern to southern part of the study area. The fossils contain the abundant bivalves *Grammatodon* sp., *Modiolus* sp., *Astarte* sp., *Parvamussium* sp., *Actinostroen* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Trigonia* sp.. Gastropods, trace fossils, foraminifera, and plant remains are also found.

Sandstone with oolitic limestone unit (unit VI) comprises mainly sandstone with layers of oolitic limestone and sandy siltstone facies with cross bedding, lamination, and fining upward sequences. The overall geometry is thick-bedded sandstone sequence. This unit has common thinning and showing lateral facies changes from the central to southern part and is conformably underlain by the unit V with sharp contact. Under the petrography studies, quartz arenite is confined from thick-bedded sandstone and oolitic limestone. The unit contains abundant bivalves *Modiolus* sp., *Astarte* sp., *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.? Gastropods, vertebrates, and plant remains are also found. Based on the mentioned facies, sedimentary structures, petrography, and fossil assemblages, the unit VI has been deposited in the subtidal and intertidal sand

flat depositional environment (Straaten, 1954; Klein, 1970; Ginsburg, 1975, and Reineck, 1984) (Table 4.3, and Figures 4.3 and 4.4).

After the unit VI was already deposited in subtidal zone, the limestone unit (unit VII) was subsequently built up overlying the tidal sand flat of the unit VI. The unit VII is characterized by argillaceous limestone, fossiliferous limestone, and oolitic limestone facies with well preserved abundant brachiopods, corals, gastropods, bivalves, foraminifera, and vertebrates. This unit is thick-bedded and widely distributed in the central part extending to the south of Huai Wale. According to facies characteristic analysis, the depositional environment of the unit VII is interpreted to be carbonate platform with some parts of the reef flat (Einsele, 2000) as indicated by fossil fragments at the Padaeng mine.

Finally, the uppermost part of the Khun Huai Formation is represented by sandstone unit (unit VIII) mainly characterized by medium-bedded, brown and grey to dark grey sandstone facie interbedded with thin-bedded, grey, clayey sandstone facie with unclear lamination. Fining upward sequences are also present. The unit geometry is shown as lenses and distributed only at the Ban Pu Toe section. The fossils include common bivalves *Bositra* sp., *Parvamussium* sp., and *Goniomya* sp. According to facies analysis, depositional environment is designed as intertidal mixed flat.

As a whole, sedimentary sequences of the Khun Huai Formation are analyzed in terms of facies and units association (units I-VIII) representing the shoreface and inner shelf, fan-deltas, intertidal, and subtidal environments with occasional carbonate platform (Table 4.3). However, the proposed depositional environment of the Khun Huai Formation has been related with the long term eustatic sea level curve having regression in the lower part. In the middle to upper part, the characteristics of long term sea level curve are gradually changed into transitional phase of the Doi Yot Formation (Figure 4.3).

4.3.2 Depositional environments of the Doi Yot Formation

The Doi Yot Formation conformably overlies the sequence of the Khun Huai Formation, which consists mainly of 4 units, limestone with mudstone, and sandstone, marl interbedded with mudstone and limestone, mudstone intercalated with sandstone, siltstone and limestone, and limestone unit in ascending order. The contact of both formations is represented by gradational contact, fining upward sequences.

Table 4.3 Summarized interpretation of depositional environments of the Hua Fai Group.

Formation	Units	Lithology		Geometry		Sedimentary structures	Petrography	Fossil	Depositional environment
		Color	Characteristic	Thickness (m)	Distribution/shape				
Khun Huai	VIII	Brown and grey to dark grey	Sandstone	14	Only the central part/Lenses	Lamination	Sub litharenite, quartz arenite	*Bositra* sp., *Parvamussium* sp., *Goniomya* sp.	Intertidal mixed flat
	VII	Grey to dark grey	Limestone	20-30	Central part passing to south/Thick-bedded lenses	Uneven and wavy beds	Micrite,biosparite, biomicrite, oomicrite	Brachiopods, corals, gastropods, bivalves, vertebrate, foraminifera	Carbonate platform
	VI	Light brown to brown	Sandstone with oolitic limestone	40-160	Central part passing to south/Thick-bedded and thinning southward	Cross bedding, ripple cross-lamination, well bedded and lamination	Quartz arenite, sub litharenite	*Modiolus* sp., *Astarte* sp., *Protocardia* sp., *Thracia* sp. etc.	Subtidal and intertidal sand flat
	V	Brown and grey	Sandstone interbedded with mudstone and intercalated with limestone	20-83	North to south/ Wedge and planar, thinning to central	Lamination, ripple mark, flaser bedding, wavy beds, cross- and lamination	Sub litharenite, oosparite, biomicrite	*Grammatodon* sp., *Modiolus* sp., *Parvamussium* sp. etc.	Mixed intertidal and reef flat
	IV	Grey to brownish grey	Limestone and dolomitic limestone	43-100	Central part and extend to south/ Lenses	Thick-bedded with stylolitic band	Micrite, biosparite, biomicrite, dolomitic limestone	*Protocardia* sp. *Entolium* sp. *Astarte* sp.	Carbonate platform
	III	Grey to greenish grey	Shale intercalated with limestone	73	Only central part/Lenses	Well stratified, even parallel beds	Micrite and mudstone	*Trigonia* sp. *Pteria* sp. *Parvamussium* sp. *Protocardia* sp.	Protected bay or lagoon
	II	Brown and greenish grey	Sandstone interbedded with mudstone and siltstone	51-117	Northeast, east and southeast/ Wedge and planar thinning to central	Cross lamination, ripple cross lamination, ripple mark, and rip-up clasts	Sub litharenite, quartzwacke, mudrocks with calcite cement	-	Distal mouth bar delta-front or intertidal
	I	Reddish brown and grey	Conglomerate matrix supported	10-20	Northwest, central part and south/Massive lenses	Massive lenses, poorly sorted	Sandy conglomerate matrix supported	-	Fan deltas/ Alluvial fan

Table 4.3 Summarized interpretation of depositional environments of the Hua Fai Group (continued).

Formation	Units	Lithology		Geometry		Sedimentary structures	Petrography	Fossil	Depositional environment
		Color	Characteristic	Thickness (m)	Distribution				
Pha De	V	Brown and grey	Sandstone interbedded with mudstone	15-103	North passing to central part/thick-bedded, wedge, thickening to central	Well stratified,even parallel beds with load cast and bioturbation	Sub litharenite, Quartz arenite, quartzwacke	Bivalves, trace fossils and ammonite	Intertidal to shoreface
	IV	Grey to dark grey	Mudstone with limestone, siltstone and sandstone	13	Only central part/ Wedge, thinning to north	Wavy parallel beds, ripple marks and bioturbation	Micrite sub litharenite, biomicrite	*Parvamussium* sp., *Protocardia* sp., *Inoperna* sp., *Thracia* sp., etc.	Intertidal lagoon lime mud
	III	Grey to dark grey	Oolitic limestone	> 6	North, central and southwest/planar lenses	Hummocky cross bedding and lamination	Oosparite, sub litharenite, oobiomicrite, intrasparite	Fossil fragments and foraminifera	Subtidal sand bar shallow ramp
	II	Greenish grey, grey, brown	Muddy calcareous sandstone interbedded with mudstone	13-87	North to central part/Wedge, thinning to south	Lamination, cross lamination, ripple marks, rip-up clast	Sub litharenite, quartz arenite, quartzwacke	*Bositra* sp., *Plagiostoma sp., Parvamussium Astarte* sp. etc.	Intertidal reef flat sand bar
	I	Grey to dark grey	Mudstone interbedded with muddy calcareous sandstone	92	Only north part/ Wedge, thickening to north	Well stratified, even parallel beds	Sub litharenite, siltstone, mudstone	*Bositra* sp., ammonite	Intertidal
Doi Yot	IV	Grey to dark grey	Limestone	16.5-34	Only central part/ Lenses	Massive	Biosparite, oomicrite, micrite	-	Shoal-rimed platform
	III	Grey to dark grey and light brown	Mudstone intercalated with sandstone siltstone and limestone	12-30	Only north and central part/ Lenses	Well stratified, even and parallel beds lamination	Mudstone, sub litharenite, micrite	-	Inner ramp shallow ramp
	II	Grey to dark grey	Marl interbedded with mudstone and limestone	40-185	North passing to central part/Thick-bedded, parallel and planar beds	Well stratified, even parallel beds	Biomicrite, micrite	*Erycytes* sp., *Tmetoceras* sp., *Ludwigia* sp., *Graphoceras* sp.	Transitional Inner ramp-Outer ramp
	I	Grey to dark grey	Limestone with mudstone and sandstone	103-139	North passing to central part/Thick-bedded parallel and planar beds	Hummocky cross lamination, lamination, flaser bedding	Mudstone, siltstone, quartzwacke, biomicrite, micrite	*Bositra* sp., *Entolium* sp., *Astarte* sp.	Inner ramp shallow ramp

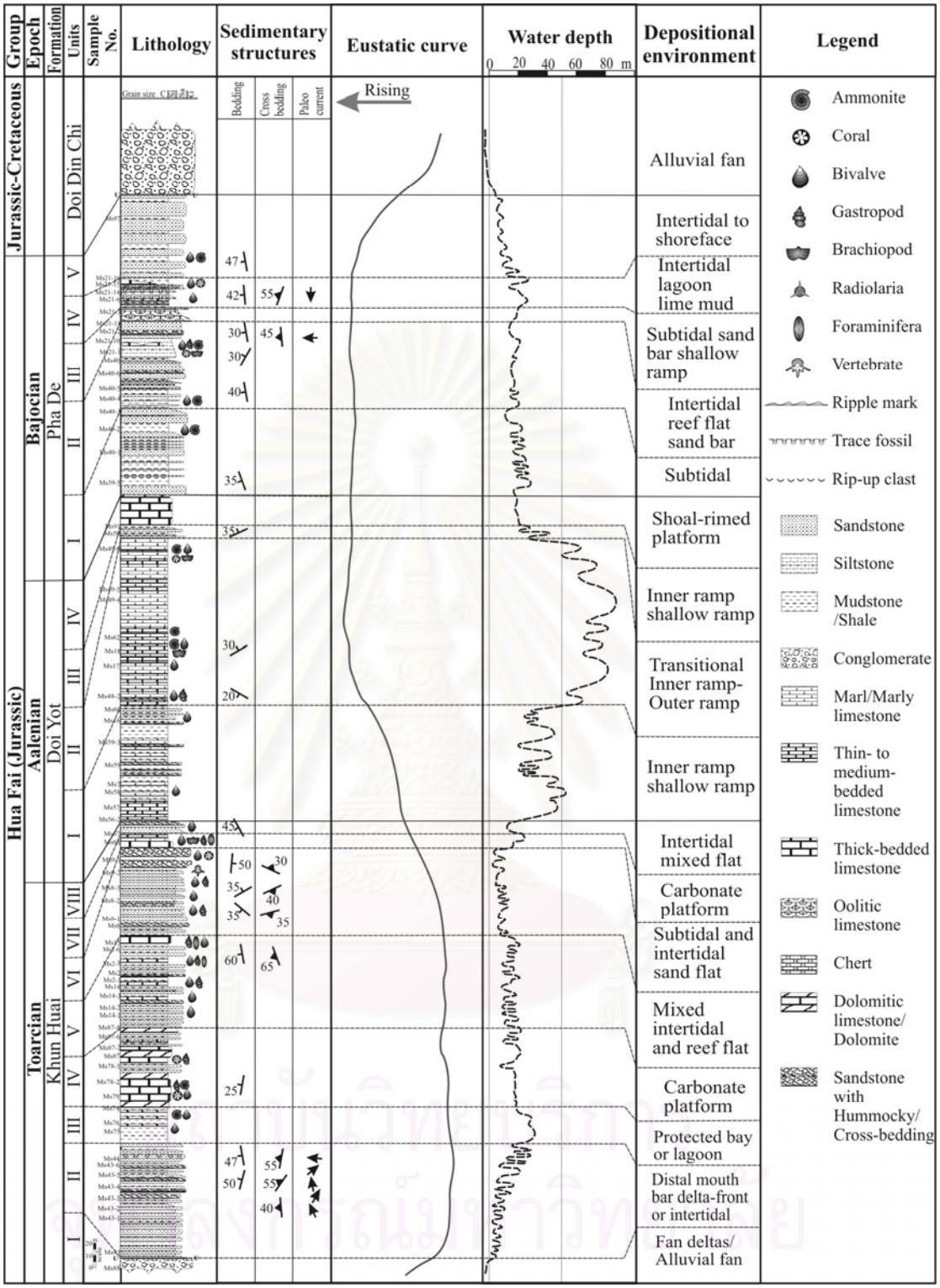


Figure 4.3 Eustatic sea level curves and depositional environments of the Hua Fai Group, Mae Sot-Phop Phra area.

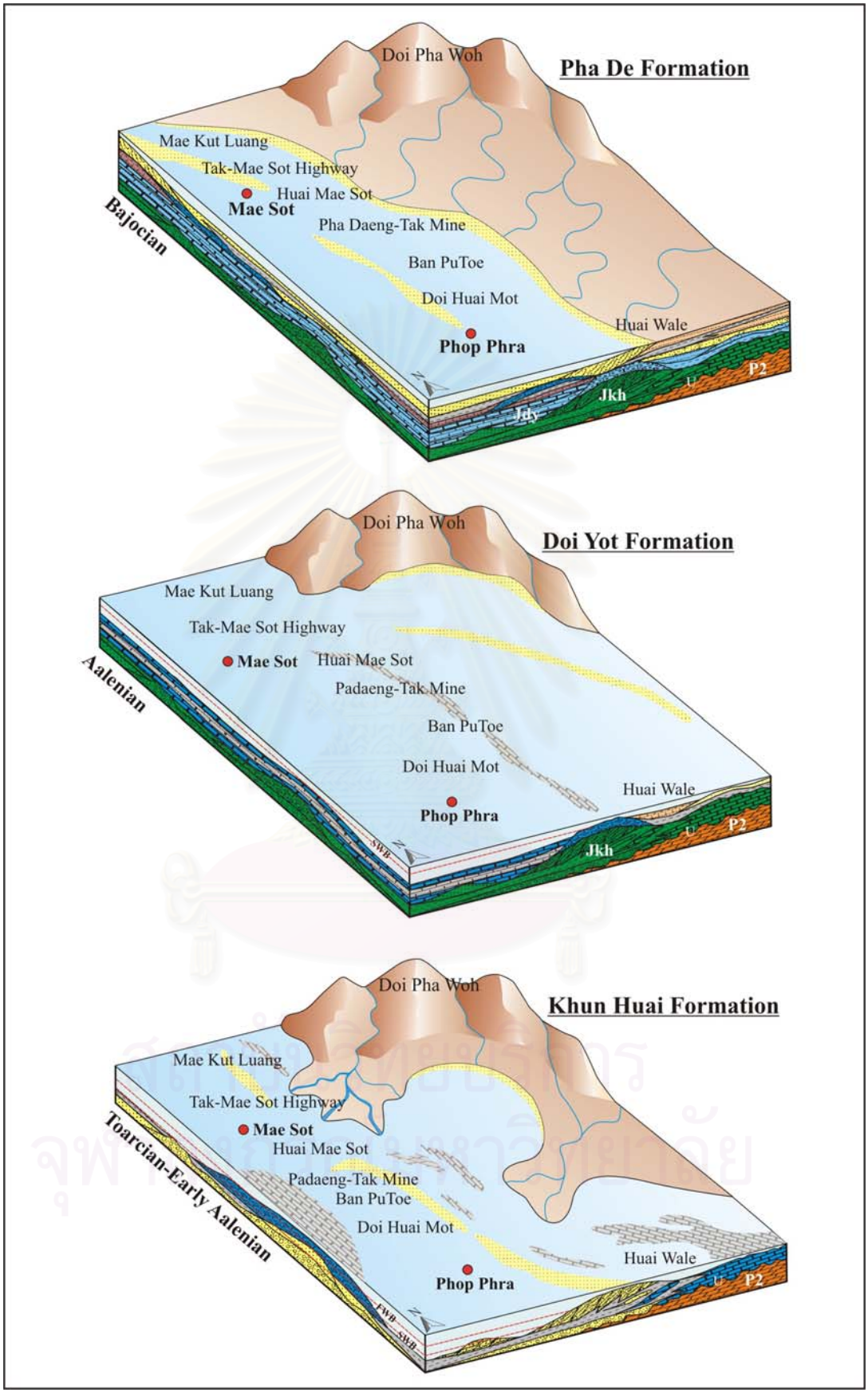


Figure 4.4 Schematic models illustrating of depositional environment of the Hua Fai Group, Mae Sot-Phop Phra area in the Jurassic.

The characteristics of facies and unit association of the Doi Yot Formation and their depositional environment reconstruction are summarized and presented in Table 4.3 and Figures 4.2, 4.3, and 4.4.

In the lowest unit of the Doi Yot Formation, limestone with mudstone and sandstone unit (unit I) conformably overlies upon the Khun Huai Formaton. The main characteristic lithology of this unit is argillaceous limestone interbedded with mudstone and marl, sandy limestone and calcareous sandstone facies with lamination, hummocky cross lamination and flaser beds. The limestone, mudstone, and marl facies contain the common bivalves *Bositra* sp., *Entolium* sp., and *Astarte* sp. The unit is thick-bedded, parallel, and planar beds, which distributed from north passing to central part of the study area. Petrographically, mudstone, siltstone, quartzwacke, and biomicrite are confined as thick-bedded calcareous sandstone and sandy mudstone. As compared with idealized carbonate ramp (Read, 1982; Aigner, 1985; Buxton and Pedley, 1989), the sediments of unit I have been deposited under the inner shallow ramp buildups.

Marl interbedded with mudstone and limestone unit (unit II) overlies the limestone with mudstone, marl, and sandstone unit (unit I) with gradational contact. This unit consists mainly of marl, mudstone alternative with argillaceous limestone facies. The geometry of the unit is thick- bedded and parallel well planar beds, which widely distributed from north passing to the central part of the study area. The marl and mudstone facies contain abundant ammonites, bivalves, and brachiopods. The ammonites include *Erycites* sp., *Tmetoceras* sp., *Ludwigia* sp. (Brown *et al*., 1951), *Tmetoceras regleyi* Dumortier, and *Graphoceras concavum* Sowerby (Komalarjun and Sato, 1964); *Erycites* sp. and *Tmetoceras dhanarajatai* Sato (Komalarjun and Sato, 1964). Based on the facies analysis, sedimentary structures, and fossil assemblages, the unit II is interpreted as having been deposited in the transitional of inner to outer ramp environment.

The unit III, mudstone intercalated sandstone, siltstone, and limestone, overlies upon unit II with transitional contact. It predominantly consists of mudstone intercalated calcareous sandstone, siltstone, and argillaceous limestone facies. The geometry is lenses and exposed locally in the north and central parts. The fossils are rare throughout of unit. As compared with the unit I, this unit should be similar depositional environment of the inner shallow ramp.

Finally, limestone unit (unit IV) conformably overlies the unit III with sharp contact. The characteristic of this unit is mainly thick to massive argillaceous limestone, oolitic limestone, and dolomitic limestone facies. The geometry is lenses of thick-bedded massive carbonate distributed only in the central area. The fossil fragments are commonly found in the massive limestone facie. Based on the facies analysis, this unit can be deposited in the shoal-rimed platform, reef flat (Zankl, 1971; Wilson, 1975; James, 1983; Sellwood, 1986).

4.3.3 Depositional environment of the Pha De Formation

The Pha De Formation conformably overlies the sequence of the Doi Yot Formation, which consists mainly of 5 units, namely, mudstone interbedded with muddy calcareous sandstone, muddy calcareous sandstone interbedded with mudstone, oolitic limestone, mudstone with limestone, siltstone and sandstone, and sandstone interbedded with mudstone unit in ascending order. The characteristics of facies and unit associations of the Pha De Formation and their depositional environment reconstruction are summarized and presented in Table 4.3 and Figures 4.2, 4.3, and 4.4.

The lower unit of the Pha De Formation is mudstone interbedded with muddy calcareous sandstone unit (unit I) underlain by the Doi Yot Formation with sharp contact. It is predominantly composed of grey mudstone interbedded with muddy calcareous sandstone facies. The overall geometry characteristic is wedge-shaped and sequence thickening to northward. The bivalves, *Bositra* sp. and ammonites are commonly found in some sandy mudstone facies. Based on the facies associations analysis, the unit I could be presented to intertidal depositional environment.

Muddy calcareous sandstone interbedded with mudstone unit (unit II) overlies conformably upon the unit I with gradational contact. It consists predominantly of sandstone interbedded with mudstone facies. The sedimentary structures comprise lamination, cross lamination, and ripple marks with rip-up clasts. Geometrically, the unit has wedge-shaped beds with thinning southward and is extended from north of the study area to the central area. The fossils contain abundant bivalves *Bositra* sp., *Plagiostoma* sp., *Parvamussium* sp., *Trigonia* sp., *Astarte* sp., *Thracia* sp., *Bositra* sp., *Pinna* sp., *Protocardia* sp., *Inoperna* sp., *Pholadomya* sp., *Mytilus* sp., *Modiolus* sp., *Lima* sp., *Entolium* sp., *Eomiodon* sp., *Protocardia* sp. (Kozai *et al*., 2006). Ammonites, gastropods,

corals, trace fossils, brachiopods, and plant remains are also found. As compared with the topographic and unit zones of shoal-rimmed carbonate shelf (Zankl, 1971; Wilson, 1975; James, 1983; Sellwood, 1986), the sediments of this unit (unit II) has been deposited in the intertidal, reef flat, and sand bar.

The characteristic lithology of oolitic limestone unit (unit III) predominantly consists of grey to dark grey, thick-bedded, oolitic limestone facie with hummocky cross bedding and lamination. The geometry of this unit is characterized by planar beds and lenses. It is well exposed in the northern, central, and southwestern parts of the study area. Petrographically, the unit is composed mainly of oomicrite, oobiomicrite, and some layers of litharenite. The ooid grains have characterized by radial and concentric textures in which quartz, calcite, foraminifera, and fossil fragments are nuclei. Based on the facie analysis and sedimentary structures, this unit is considered as subtidal sand bar (Purser, 1973; Schwarz *et al*., 1975; Schreiber, 1986) and shallow ramp (Read, 1982; Aigner, 1985; Buxton and Pedley, 1989).

The lower part of mudstone with limestone, siltstone, and sandstone unit (unit IV) consists mainly of dark grey, medium- to thick-bedded mudstone facie interbedded with argillaceous limestone facie gradually changing to the sequence of grey, medium-bedded calcareous sandstone, siltstone, and mudstone facies in the upper part. The overall geometry is characterized by wedge-shaped beds thinning northward. The fossils contain the abundant bivalves including *Parvamussium* sp., *Protocardia* sp., *Inoperna* sp., and *Thracia* sp. with abundant trace fossils such as *Thalassinoides* sp., *Planorites* sp., *Chondrites* sp., *Plagiognus* sp., and *Deaconites* sp. (Tansathien, pers. comm., 2007). According to the facies analysis, the depositional environment is interpreted to be intertidal to lagoonal lime mud (Read, 1982; Aigner, 1985; Buxton and Pedley, 1989).

The upper part of the mudstone with limestone, siltstone, and sandstone unit (unit IV) continues to be deposited as the sandstone interbedded with mudstone unit (unit V). The unit is the upper most of the marine Jurassic sequences in the Mae Sot-Phop Phra basin. It predominantly consists of sandstone interbedded with mudstone facies. The lamination and cross lamination are well observed in the sandstone facie. The geometry is thick-bedded, wedge-shaped beds thickening in the central area. It is well exposed from the central through the north of the area. The bivalves, trace fossils, and ammonites are also found. Based on the facies analysis, sedimentary structures, and fossil assemblages, this unit could be probably deposited in the intertidal to shoreface.

CHAPTER V

DISCUSSION AND CONCLUSION

5.1 Discussion

5.1.1 Tectonic setting

To date, most tectonic studies in Thailand have dealt with Triassic Period because continental collision between the Shan-Thai and Indochina terranes and their intervene terranes (Charusiri *et al*., 1993) occurred in this time. Although the geology of this region has been described previously by various workers, tectonic evolution during Jurassic in the Mae Sot-Phop Phra area, western Thailand has not yet been studied in detail.

Since Late Triassic, the terranes of mainland Southeast Asia have been already amalgamated (Charusiri *et al*., 2002). Due to the contrast in plate interactive from north-south to northeast-southwest directions respectively during the Jurassic to Cretaceous Periods, the changes in tectonic regimes may have happened. During Late Triassic northward drifting of Western Burma Block started to underthrust in the northwest-southeast direction with Shan-Thai terrane. Based on geochronological data of granites in western Thailand and eastern Myanmar (Charusiri *et al*., 1993; Darbyshire and Swainbank, 1988), the drifting of western Burma block (Mitchell and Garson, 1981) and perhaps from the southern hemisphere (Metcalfe, 1995) may have caused subduction of oceanic slab beneath the amalgamated mainland Southeast Asia terrain during Middle to Late Cretaceous. Such compressive tectonics may have provided enormous stress roughly in the north-south direction to the study area. Their kinematic relationships can be described on the basis of assuming simple shear mechanisms and using the strain ellipsoid (Figure 5.1). After Jurassic Period, the en echelon north northeast-trending strike-slip faults with dextral displacements may have been formed due to this tectonic stress (see Figure 2.7).

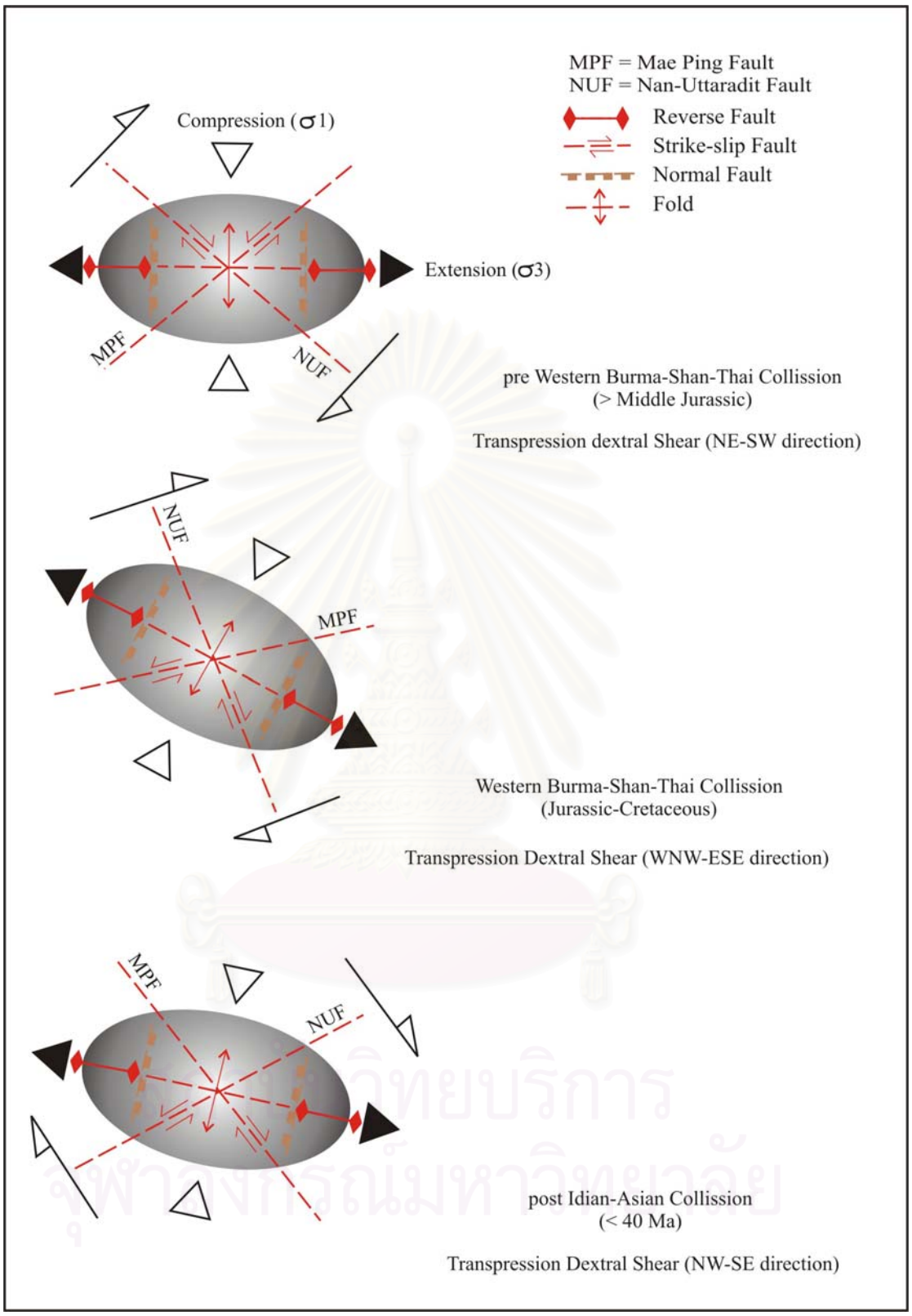


Figure 5.1 Strain ellipsoids illustrating com pressional, extensional and total shear stresses, giving rise to major fault orientations of the study area.

Multiple episodes of collision and suturing of all tectonic terranes during Late Triassic resulted in the closure of Paleotethys (see Figure 5.2). The Indochina and the eastern part of Shan-Thai terranes (Nakhon Thai and Lampang-Chiang Rai) may have been dramatically uplifted and emerged, becoming a central part of Southeast Asian landmass (Charusiri *et al*., 2002). The study area was uplifted-subsided and eroded during early-middle Early Jurassic (Hettangian-Pliensbachian) to early Middle Jurassic (Bajocian). Lower Jurassic sequences were unconformably underlain by Middle Triassic rocks as indicated by limestone basal conglomerates at the base of Jurassic strata. These sequences were also reported by Meesook (1994), Teerarungsigul (1999), Teerarungsigul *et al*. (1999), Raksaskulwong (2002), and Meesook *et al*. (2006) and widely distributed in the northwestern, western, and southern Thailand and eastern Myanmar. After this mild collision and rifted basin with global sea level transgression, Mesotethys sedimentation began in late Early Jurassic (Toarcian) and continued to early Middle Jurassic (Bajocian). The Mae Sot-Phop Phra Basin (central Shan-Thai terrane) was occupied by the Hua Fai Group, shallow shelf sediments, shallow carbonate and mixed clastic shelf facies without the volcanic materials and considered as having been deposited onto a passive continental margin. During Late Triassic to Cretaceous, westward upthrusting of Shan-Thai terrane was continued beneath western rim of this terrane. Although the global sea level rose continuously during Early Jurassic to Cretaceous (Hallam, 1988; Vial *et al*, 1977b), the Shan-Thai terrane had been highly uplifted than that sea level transgression in the Late Jurassic-Cretaceous. As a result, the western and central Shan-Thai terrane was uplifted becoming landmass in Late Jurassic-Cretaceous. This is indicated by the presence of non-marine Jurassic-Cretaceous conglomerate and red sandstone of the Doi Din Chi unit overlying marine Jurassic sequences in this study area. However, these sequences have been clearly seen in the southern peninsula gradually changing from marine to brackish and non-marine deposits (Thung Yai Group) in the Mab Ching area, Nakhon Si Tham marat Province (Teerarugsigul, 1999).

5.1.2 Paleogeography

Paleogeograpically, mainland Southeast Asia is divided into three major tectonic terranes, the Western Burma, Shan-Thai, and Indochina terranes.

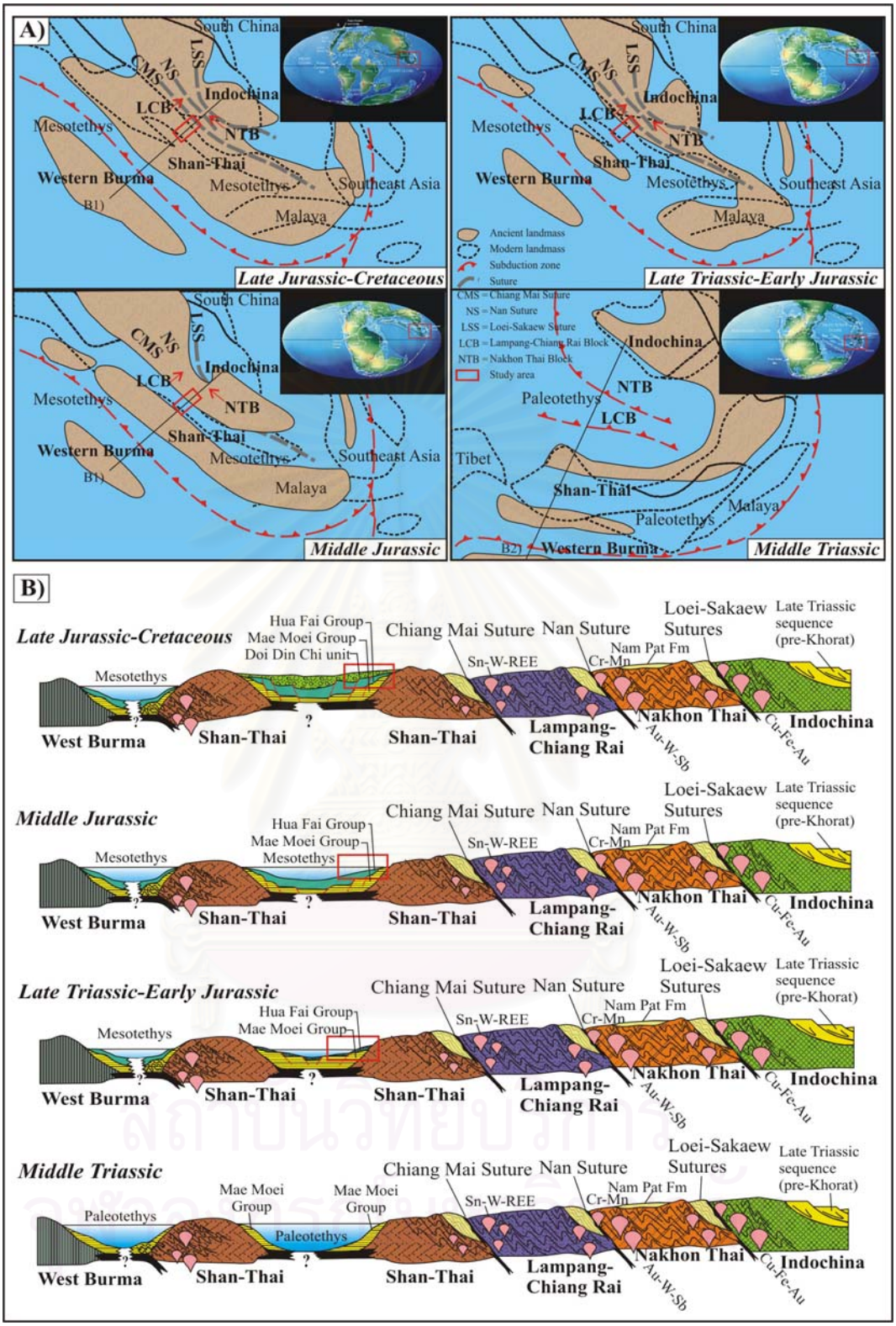


Figure 5.2 A) Paleogeographical distribution of Shan-Thai, Indochina, Lam pang-Chiang Rai and Nakhon Thai terranes compared to other tectonic terranes. B) Plate tectonic reconstruction of major tectonic terranes of m ainland Southeast Asia showing the occurrence of the Mae Moei and Hua Fai Groups, and Doi Din Chi unit during Middle Triassic to Cretaceous (modified after Charusiri *et al*., 2002; Scotese, 2002; Metclaft, 2006).

Thailand is mainly composed of the Shan-Thai terrane in the west and the Indochina terrane in the east. Charusiri *et al*. (2002) proposed 2 new tectonic terranes, Nakhon Thai and Lampabg-Chiang Rai synthesis, which these terranes were completely amalgamated in the Late Triassic. In 2002, the geotectonic evolution of Thailand and 4 main tectonic stages have been recognized based on tectonostratigraphic and geochronological grounds, namely, Archaeotectonic, Paleotectonic, Mesotectonic, and Neotectonic.

During late Early Jurassic to early Middle Jurassic (Mesotectonic stage), the Mesotethyan transgression proceeded into the west flank and central part of Shan-Thai (Figure 5.2b). As a result, this area was mainly occupied by shallow continental shelf carbonate and clastic rocks, whilst the continental sediments were deposited into Lampang-Chianng Rai, Nakhon Thai, and Indochina terranes, and widely extended into the southern peninsular Thailand, respectively (see Figure 5.2).

The transgression and regression events happening in the Mae Sot-Phop Phra area can be compared with the global sea level changes (see Table 4.2) studied by various specialists (Vail *et al*., 1977b; Haq *et al*., 1987b, 1988; Hallam, 1988; Surlyk, 1991; Li and Grant-Mackie, 1993; Haq and Al-Qahtani, 2005). Generally, during the Early Jurassic to Cretaceous, the global sea level curves were rising continuously and falling distinctively in the Late Cretaceous. However, the eustatic curves of the study area for Toarcian-early Bajocian correspond to the global curves, but differ significantly for post early Bajocian (see Table 4.2). According to these results, the Late Jurassic-Cretaceous transgression-regression (T-R) phases were conversely probably caused by the local tectonic movements. However, detailed study in terms of paleontology and tectonics will be needed for precise interpretation of marine Jurassic of Thailand.

5.2 Conclusion

The present study is the attempt to conduct the detailed lithostratigraphy for 7 measured sections of the marine Jurassic Hua Fai Group within Mae Sot-Phop Phra Basin in terms of general geology, depositional environment, and tectonic setting. Additional purpose is to define the eustatic sea level curves and paleogeography. The results can be concluded as follows:

5.2.1 Remote sensing interpretation

Based on the remote sensing and aerial photographs interpretation, field investigation, and stereographic analysis of folded rocks, the regional structures such as folds, fractures are mainly orientated in the northwest-southeast direction in the Mae Sot-Phop Phra area. The main series of folding in this area is represented by antiforms and synforms trending in the northwest-southeast and northeast-southwest directions. The fractures in the study area are mainly in the northeast-southwest and northwest-southeast directions. Whilst the northwest-southeast faults are characterized as dextral strike-slip and reverse faults, the lineaments in northwest-southeast and northeast-southwest directions indicate normal fault sets.

5.2.2 Units and petrography of the Hua Fai Group

On the basis of lithological characteristics, the Hua Fai Group can be divided into 17 units and the total thickness of the group based on 7 measured sections ranges from 200 to 832 m, and the combined section is approximately 750 m. A newly proposed marine Jurassic lithostratigraphy of the Hua Fai Group consists of 8 units of the Khun Huai Formation, 4 units of the Doi Yot Formation, and 5 units of the Pha De Formation in ascending order.

The Khun Huai Formation, 93-345 m thick, is characterized by conglomerate, sandstone, siltstone, mudstone, limestone, dolomite, and oolitic limestone facies containing abundant bivalves, gastropods, trace fossils, plant remains and vertebrate fossils (turtle bones and shark teeth). Petrographically, this formation is composed mainly of sandy conglomerate, quartz arenite, sub litharenite, sub litharenite with mudstone, biomicrite, biosparite, micrite, dolomitic limestone, and oosparite.

The Doi Yot Formation, 40-266 m thick, consists mainly of marl interbedded with limestone and mudstone facies containing abundant ammonites, bivalves, and brachiopods. Petrographically, this formation is composed mainly of micrite, biomicrite, oomicrite, mudstone, siltstone, quartzwacke, and biosparite.

The Pha De Formation, 67-221 m thick, the upperm ost part of the group, consists predominantly of intercalation of sandstone, mudstone, siltstone, oolitic limestome, and limestone facies with abundant bivalves, ammonites, gastropods, corals, brachiopods, trace fossils, and plant remains. Petrographically, this formation

is composed mainly of sub litharenite, quartzwacke, quartz arenite, micrite, oosparite and oobiomicrite with quartz grains, siltstone, mudstone, and intrasparite.

5.2.3 Eustatic sea level curves

Based on 8 units of the Khun Huai Formation (Toarcian), these sequences are characterized by fining upward sequences. In the Toarcian, a sea level was risen continuously into Aalenian with higher water depth as represented by fining upward sequences and gradually changed to early-middle Aalenian of the Doi Yot Formation. This formation is composed mainly of marl, mudstone, and argillaceous limestone facies. These facies are designed as the quiet and deep depositional environment. The sea level transgression commences to the middle-late Aalenian i.e. the highest sea level and deep water in the study area. This transgression corresponds to the global sea level curves. During late Aalenian to early Bajocian, the sea level was still transgressive phase, whilst water depth was gradually changing to the shallow depositional environment. It is represented by the coarsening upward sequences of the Pha De Formation. During Late Jurassic to Cretaceous, the eustatic curves of the Mae Sot-Phop Phra Basin were gradually regressed, which cannot be corresponded to global sea level curves. This can be indicated by lacking of marine Jurassic exposures and sea water was retreated from this basin as well as various areas in Thailand.

5.2.4 Depositional environment

According to the sedimentary sequences of the Hua Fai Group, the depositional environments were analyzed in terms of facies and unit associations representing the shoreface, fan-deltas, protected lagoon, intertidal, subtidal, and inner to outer ramp environments with occasional carbonate platform and reef flat.

Based on the units and eustatic sea level curves in the Mae Sot-Phop Phra Basin during the Toarcian, the marine Jurassic sequences should be deposited in the marine influxes lagoon or shore face, delta front platform with distal mouth bar, protected bay or lagoon, low-energy, carbonate platform, mixed intertidal and reef flat, subtidal and intertidal sand flat, carbonate platform with some parts of the reef flat, and intertidal mixed flat environments. In the Aalenian, the sequences were represented by the quiet and deeper depositional environments such as inner shallow ramp buildups, transitional of inner to outer ramp, shoal-rimed platform, and reef flat.

In the Early Bajocian, these units can be considered as the shallow marine environments probably deposited in the intertidal to shore face including intertidal reef flat and sand bars, subtidal sand bars, and lagoonal lime mud.

5.2.5 Tectonic setting and paleogeography

After multiple episodes of all terrane's collisions during the Late Triassic, the Indochina and eastern part of Shan-Thai terranes (Nakhon Thai and Lampang-Chiang Rai) have been uplifted and became a Southeast Asian landmass (Charusiri *et al*., 2002). The Mae Sot-Phop Phra Basin situated in the central part of Shan-Thai terrane, was uplifted-subsided and eroded during early-middle Early Jurassic (Hettangian-Pliensbachian). In this study area, the lowermost part of the Jurassic sequences is unconformably underlain by the Middle Triassic and Permian rocks as represented by the basal limestone conglomerate unit. This unit was also reported by various workers and is widely distributed in the northwestern, western and southern of Thailand and extended to eastern Myanmar. After Late Triassic collision, this area have been rifted basin and sea level transgressed, the Mesotethys sedimentation began in late Early Jurassic (Toarcian) and continued to the early Middle Jurassic (Bajocian). The study area was occupied by the Hua Fai Group, shallow shelf sediments, carbonate and mixed clastic shelf facies without the volcanic materials and considered as having ben deposited onto a passive continental margin. During the Late Jurassic to Cretaceous, the Western Burma block may have come close to Shan-Thai. This block may have been eastwardly subducted beneath western Shan-Thai terrane (Charusiri *et al*., 2002). As a result, the western and central parts of Shan-Thai terrane were uplifted becoming the western Southeast Asia landmass. This is indicated by the presence conglomerate and red sandstone facies of the Doi Din Chi unit (continental facies of the Late Jurassic-Cretaceous) overlying the marine Jurassic sequences in the study area and extended to several places in Thailand.

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APPENDICES

Field works information

No.	UTM grid		Bedding (dip direction)	X-Bedding (dip direction)	Ripple current	Fault/ Fracture	Remarks
	East	North					
MS 1	0471081	1823799	215 25				Triassic
MS 2	0475196	1806623	240 45				
MS 3	0481862	1848370	160 10				
MS 4	0476265	1853204	220 20				
MS 5	0464436	1848012	225 35				
MS 6	0464326	1849404	200 25 210 40				Triassic
MS 7	0463223	1847621	215 25				
MS 8	0472908	1808462	095 50 330 35	025 30 155 40		215 80	
MS 9	0473023	1807901	220 35 195 30	165 35			
MS 10	0475152	1810574					Permian dolomitic ls
MS 11	0474295	1808173	255 15				
MS 12	0474860	1807450					
MS 13	0475482	1806684	250 65 255 35				
MS 14	0475262	1806536	295 35				
MS 15	0474632	1806786	260 60	250 65			
MS 16	0462448	1847650	250 15				
MS 17	0462167	1847544	265 35				
MS 18	0462051	1847487	285 15				
MS 19	0461852	1847188	240 30			340 65	
MS 20	0461872	1842851	260 30 270 35	265 45 320 15	270 35	260 50 215 65	
MS 21	0461964	1842975	265 42 300 35 300 30	290 55	180 05		
MS 22	0460848	1852250	275 50				
MS 23	0462222	1852873	255 35				
MS 24	0462630	1853622	250 35				
MS 25	0463122	1853971	160 35				
MS 26	0463223	1847621	215 25				
MS 27	0463780	1818355	340 20			300 75	
MS 29	0475958	1853 149	270 35 260 35				Triassic
MS 30	0464145	1822132					Tertiary
MS 31	0465404	1822303					Tertiary
MS 32	0477966	1828210					Permian
MS 33	0480257	1831 256	270 20				Triassic

No.	UTM grid		Bedding (dip direction)	X-Bedding (dip direction)	Ripple current	Fault/ Fracture	Remarks
	East	North					
MS 34	0445968	1852774				205 60	
MS 35	0446970	1847857	325 20				Tertiary
MS 36	0460799	1857762	245 55			065 55	
MS 37	0460585	1857324	245 40				
MS 38	0460115	1857324	265 50				
MS 39	0459642	1857094	250 35				
MS 40	0459052	1857211	260 40 255 35				
MS 41	0458625	1857419	260 47 250 55	280 55			
MS 42	0459043	1858677					
MS 43	0462855	1853870	290 40 270 20		275 40	310 65 125 90	reverse fault left lateral fault
MS 44	0462627	1853658					
MS 45	0462493	1853433					
MS 46	0462536	1853214	025 50 005 25 005 20		050 20 350 20 030 20 335 20		
MS 47	0462288	1852884	270 40				
MS 48	0461635	1852637	300 30 285 30				
MS 49	0461154	1852307	280 50				
MS 50	0460413	1851793	270 50				
MS 51	0460086	1851744					
MS 52	0459430	1851452	265 20				
MS 53	0464299	1849193	220 30				
MS 54	0464266	1847412	260 40				
MS 55	0464079	1847446	290 45 285 50 280 45	305 55 320 45 305 45 265 40 250 40 310 50 265 45 295 50			
MS 56	0463844	1847380	250 25				
MS 57	0463660	1847449	210 15				
MS 58	0463478	1847572					
MS 59	0462840	1847636	210 20				
MS 60	0462448	1847650	290 15				
MS 61	0462127	1847547	275 35				

No.	UTM grid		Bedding (dip direction)	X-Bedding (dip direction)	Ripple current	Fault/ Fracture	Remarks
MS 62	0461533	1846723	235 25				
MS 63	0459673	1849479	220 25				
MS 64	0459365	1849563	280 30				
MS 65	0461027	1837782					
MS 66	0460592	1837069	280 45				
MS 67	0461966	1838173	315 80				
MS 68	0462692	1837988	320 50				
MS 69	0462874	1837538					
MS 70	0463307	1836879	250 60				
MS 71	0463862	1836794	270 30				
MS 72	0465865	1836254	310 40				
MS 73	0466003	1836514	260 30				
MS 74	0466427	1837352	280 25				
MS 75	0467137	1838337	255 35				
MS 76	0467308	1837410	275 25				
MS 77	0465628	1831235	160 20				
MS 78	0465894	1831447	170 20				
MS 79	0466054	1831734	240 20				
MS 80	0464274	1830874	195 30				
MS 81	0464274	1830847					
MS 82	0463999	1830521	250 30				
MS 83	0460737	1835499	215 10				
MS 84	0454800	1837552	070 15				Tertiary
MS 85	0462916	1842293					
MS 86	0462237	1841965	290 30				
MS 87	0463939	1841077	000 20 345 45				
MS 88	0466727	1841700	270 25				
MS 89	0464111	1842264	285 25				
MS 90	0462199	1842490	335 35				
MS 91	0462442	1842377	320 35				
MS 92	0458531	1826419	155 30				
MS 93	0458287	1827014	230 75				
MS 94	0458695	1829976	325 55	315 65			
MS 95	0458678	1829843					
MS 96	0460342	1825265	320 40 350 25				
MS 97	0460255	1844479					

BIOGRAPHY

Mr. Wirote Saengsrichan was born on June 25, 1976 in Phayao Province. In 1999, he graduated with a B.Sc degree from Departm ent of Geological Sciences, Faculty of Science, Chiang Mai University. After graduation, he has been working with the Geological Survey Division, Depa rtment of Mineral Resources, Thailand. Later on, he has decided to continue his post-graduate study leading to the M.Sc degree in Geology at Chulalongkorn Universit y. He spent alm ost 1 year (Decem ber, 2004 to Novem ber, 2005) at University of Tsukuba, Japan (Exchange Student Program). His m ajor researched over ther e was m ainly focused on the sedim entary basin and tectonic setting of marine Jurassic in Tak Province.