การลำดับชั้นหินทางชีวภาพและสภาพแวดล้อมโบราณของหินตะกอนทะเลยุคจูแรสซิก ในพื้นที่แม่สอด-พบพระ จังหวัดตาก

นางสาวโชติมา ยามี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
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BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF MARINE JURASSIC ROCKS IN THE MAE SOT-PHOP PHRA AREAS, CHANGWAT TAK

Miss Chotima Yamee

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Geology
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Thesis Title	BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF MARINE JURASSIC ROCKS IN THE MAE SOT-PHOP PHRA AREAS, CHANGWAT TAK
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Field of Study	Geology
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โชติมา ยามี : การลำดับชั้นหินทางชีวภาพและสภาพแวดล้อมโบราณของหินตะกอนทะเลยุคจูแรสซิก ในพื้นที่แม่สอด-พบพระ จังหวัดตาก (BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF MARINE JURASSIC ROCKS IN THE MAE SOT-PHOP PHRA AREAS, CHANGWAT TAK) อ. ที่ปรึกษาวิทยานิพนธ์หลัก: ผศ. ดร. ฐาสิณีย์ เจริญฐิติรัตน์ อ. ที่ปรึกษาวิทยานิพนธ์ร่วม: อ. ดร. วิชัย จูฑะโกสิทธิ์กานนท์, 162 หน้า.

การทำวิจัยในครั้งนี้ มีจุดประสงค์เพื่อกำหนดลำดับชั้นหินทางชีวภาพของหินตะกอนทะเลยุคจูแรสซิก จำแนกชนิดของซากดึกดำบรรพ์หอยกาบคู่ ให้ความชัดเจนอายุของหินตะกอนทะเล และสภาพแวดล้อมโบราณ บริเวณอำเภอแม่สอด-พบพระ จังหวัดตาก ประเทศไทย

หินตะกอนทะเลในพื้นที่ศึกษา ได้แก่ หินโคลน หินทราย หินทรายแป้ง หินปูน และหินมาร์ล ในกลุ่มหินหัวฝาย ซึ่งประกอบไปด้วย หมวดหินขุนห้วย หมวดหินดอยหยด และหมวดหินพะเด๊ะ ตามลำดับ ซากดึกดำบรรพ์ที่พบมากคือหอยกาบคู่และแอมโมนอยด์ โดยสำรวจ ศึกษา และเก็บตัวอย่างซากดึกดำบรรพ์ จำนวน 7 แนว ของกลุ่มหินหัวฝาย ผลการศึกษาพบซากดึกดำบรรพ์หอยกาบคู่ จำนวน 17 สกุล ดังนี้ *Astarte* sp., *Actenostroen* sp., *Bositra ornati*, *Ceratomya* sp., *Camptonectes* sp., *Entolium* sp., *Gervillia* sp., *Goniomya* sp., *Grammatodon* sp., *Homomya?* sp., *Lima?* sp., *Parvamussism donaiense*, *Pholadomya* sp., *Pinna* sp. *Protocardia* sp., *Thracia* sp. และ *Trigonia* sp. พบร่วมกับแอมโมนอยด์ บราคิโอพอด ปะการัง รอยชอนไช และร่องรอยใบไม้ จากข้อมูลการลำดับชั้นหินทั้ง 7 แนว สามารถแบ่งลำดับชั้นหินทางชีวภาพ โดยใช้ซากดึกดำบรรพ์หอยกาบคู่ *Bositra ornati* ได้เป็น *Bositra* zone ซึ่งสามารถเทียบสัมพันธ์ได้ใน 3 แนว คือ บ้านแม่กื๊ดหลวง ถนนตาก-แม่สอด และห้วยแม่สอด

จากการศึกษาซากดึกดำบรรพ์หอยกาบคู่และแอมโมนอยด์ หินตะกอนทะเลยุคจูแรสสิกในพื้นที่แม่สอด-พบพระ มีอายุอยู่ในช่วงทอร์อาเซียน-อาร์ลีเนียน มีความสัมพันธ์กับสภาพแวดล้อมการสะสมตะกอนแบบชายฝั่ง เขตน้ำทะเลตื้น ดินดอนสามเหลี่ยมปากแม่น้ำรูปพัด ทะเลสาบปิด ที่ราบน้ำขึ้น-น้ำลง และที่ราบใต้ระดับน้ำลงต่ำสุด

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต .....

สาขาวิชา ธรณีวิทยา ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์หลัก T. Charoentitirat

ปีการศึกษา 2552 ลายมือชื่อ อ. ที่ปรึกษาวิทยานิพนธ์ร่วม .....

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KEYWORDS: MARINE JURASSIC, BIVALVE, MAE SOT
CHOTIMA YAMEE: BIOSTRATIGRAPHY AND PALEOENVIRONMENT OF MARINE JURASSIC ROCKS IN THE MAE SOT-PHOP PHRA AREAS, CHANGWAT TAK THESIS ADVISOR: ASST.PROF.THASINEE CHAROENTITIRAT, Ph.D. THESIS CO-ADVISOR VICHAI CHUTAKOSITKANON, Ph.D., 162 pp.

The aims of this study are to define biostratigraphy and paleoenvironment of marine Jurassic sedimentary rocks (Hua Fai Group) based on their lithologies, bivalves and ammonoids in Amphoe Mae Sot-Phop Phra, Changwat Tak, northwestern part of Thailand.

In the Mae Sot area, the lithostratigraphic units have been established in ascending order: Khun Huai, Doi Yot and Pha De Formations of the Hua Fai Group. Mudstone, siltstone, sandstone, limestone and marl have been observed and faunal assemblges are dominated by bivalves and ammonoids.

Lithostratigraphically, seven sections in the study area from north to south (Ban Mae Kut Luang, Tak-Mae Sot Road, Khun Huai Mae Sot, Padaeng-Tak mine, Ban Pu Toe, Doi Huai Mot and Huai Wale) are studied in detail and samples were collected. Marine Jurassic rocks are composed of mudstone, siltstone, sandstone, marl, limestone and oolitic limestone. Fossils are abundant containing bivalves and ammonoids, at least 17 genera of bivalves found together with ammonoids assemblage. Bivalves consist of *Astarte* sp., *Actenostreon* sp., *Bositra ornati*, *Ceratomya* sp., *Camptonectes* sp., *Entolium* sp., *Gervillia* sp., *Goniomya* sp., *Grammatodon* sp., *Homomya?* sp., *Lima?* sp., *Parvamussism donaiense, Pholadomya* sp., *Pinna* sp. *Protocardia* sp., *Thracia* sp., *Trigonia* sp., and a rudist bivalve. Additional fossils contain rhynchonellid brachiopod, nerineid gastropod, coral, trace fossils and plant remains.

Bositra zone has been established. This zone is defined by the first and last occurrences of *Bositra ornati*, representing middle Toarcian-Aalenian. Based on lithological and paleontological aspects along studied sections, it can be interpreted that the depositional environment was in shallow marine continental shelf, intertidal-subtidal, inner to outer continental shelf (neritic), shoreface, fan-deltas, protected lagoon, intertidal, subtidal, and inner to outer ramp environments with occasional carbonate platform and reef flat. The age of rocks based on the bivalves and ammonoids in the study area is assigned as Toarcian-Aalenian (Lower Jurassic).

Department : Geology Student's Signature .....

Field of Study : Geology Advisor's Signature .....

Academic Year : 2009 Co-Advisor's Signature .....

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CHAPTER I

INTRODUCTION

1.1 Rationale

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 sediments are distributed in three sedimentary basins, the Mae Hong Son-Kanchanaburi Basin in the northwest and west, the Chumphon Basin in the northern part of the peninsula, and the Nakhon Si Thammarat and Krabi in the south. Whereas the Mae Hong Son-Kanchanaburi Basin has most fully developed and widely distributed marine Jurassic rocks.

Although numerous investigations have been conducted over the last six decades in these regions, paleontology and biostratigraphy have not yet been studied in detail. Recently, Wirote Saengsrichan (2007) studied marine Jurassic rock in the Mae Sot and Phop Phra areas in terms of general geology, lithostratigraphy, sedimentology, paleoenvironment, and tectonics. In addition, the Mae Sot and Phop Phra areas are selected to be this study area due to abundant and diverse marine Jurassic faunas particularly bivalves and ammonoids with additional corals, gastropods, brachiopods and microfossils. This study deals mainly with the bivalves and ammonoids because they are more common, more widely distributed and form definite faunal zones which are very useful in both local and interregional correlation. A biostratigraphic subdivision obtained from the systematic study of these faunas is proposed and attempts to conduct the detailed biostratigraphy of marine Jurassic rocks and depositional environments.

1.2 Study area and accessibility

1.2.1 Study area

The study area is located in Amphoe Mae Sot and Amphoe Phop Phra, Changwat Tak on the northwestern part of Thailand (Figure 1.1). It is located between latitudes 16° 15′ N to 16° 50′ N and longitudes 98° 30′ E to 98° 50′ E. The area, approximately 1,500 km^2, covers mainly in 2 topographic map sheets (scale 1:50,000): Mae Sot (4742 III) and Ban Phoe Pha (4741 IV) Quadrangles, and partly in 4 map sheets : Mae Ramat (4742 IV), Ban Pang San (4742 I), Ban Mae Lamao (4742 II), and Ban Pha Di (4741 I) Quadrangles.

1.2.2 Accessibility

The highway No.1 (Phahonyothin) can be used to travel from Bangkok to the study area with a total distance of 426 km, and then turn left to the highway No. 105 about 80 km to Amphoe Mae Sot. Moreover, the highway No. 1090 (Amphoes Mae Sot-Umphang) and the highway No. 1206 (Amphoes Mae Sot-Phop Phra) can also be used in the study and adjacent areas (Figure 1.2).

1.3 Objectives and scope of work

The main purposes of this study aim to describe fossils systematically, especially bivalves and ammonoids, and to define biostratigraphy of marine Jurassic sedimentary rocks in Amphoe Mae Sot-Phop Phra, Changwat Tak, western Thailand. Furthermore, it aims to encourage and reconstruct the depositional environments of marine Jurassic basin.

1.4 Methodology

This study has been assigned and summarized as shown in Figure 1.3 and details of methodology consist of 6 steps in ascending order as follows:

1.4.1 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. 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.

1.4.2 Desk Study, Photo Interpretation and Reliability Data Checking

This step was integrated and reinterpreted of all data from previous investigations. Moreover, the interpretation of remote-sensing data, aerial-photography and satellite imaginary, was performed by Wirote Saengsrichan (2007).

1.4.3 Field Investigation

The field investigation method is mainly involved with lithostratigraphy and palaeontology following 7 measured sections undertaken across the Mae Sot-Phop Phra Basin done by Wirote Saengsrichan (2007). The Ban Mae Kut Luang section to the north of the study area is remeasured. The representative rock and fossil samples were collected and carried out for laboratory investigation.

1.4.4 Laboratory Works

The laboratory work is focused on detailed data from fossil samples, preparing samples by using hammers and chiselsn and subsequent identification, especially bivalves and ammonoids which have been studied in detail systematically.

1.4.5 Data Analysis and Interpretation

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

data. Finally, conclusion has been made on the basis of the interpretation of factual data.

1.4.6 Report Writing and Presentation

The report will be prepared in accordance with the objectives of the study. The results will be presented in detail on systematic paleontology, biostratigraphic correlation and reconstruction of depositional environments.

1.5 Data sources and Previous investigations

1.5.1 Data sources

The geological data have been provided by the Bureau of Geological Survey, the Department of Mineral Resources. These data consist of geological map (scale 1:250,000) of Moulmein sheet (NE 47-14), geological maps (scale 1:50,000) of Mae Ramat (4742 IV), Mae Sot (4742 III) and Ban Phoe Pha Quadrangles (4741 IV). In addition, geological map of the study area is based on Wirote Saengsrichan (2007).

1.5.2 Previous investigations

The geology of the regions has been described previously by various workers e.g., Cotter (1924), Heim and Hirschi (1939), Brown *et al*. (1951), Sato (1961), Ward and Din Bunnag (1964), Pumwarn Komalarjun and Sato (1964), Sato (1975), Braun and Jordan (1976), Hagen and Kemper (1976), Kemper *et al*. (1976), Kemper (1976), Chongpan Chonglakmani (1983), Chongpan Chonglakmani *et al*. (1985), Assanee Meesook *et al*. (1985), Adul Charoenpravat *et al*. (1985), Worawut Tantiwanit *et al*. (1987), Fontaine and Varawut Suteethorn (1988), Sato and Westermann (1991), Beauvais and Fontaine (1993), Zuoqi (1993), Assanee Meesook (1994), Assanee Meesook and Grant-Mackie (1994), Assanee Meesook and Grant-Mackie (1996), Assanee Meesook *et al*. (2005), Assanee Meesook *et al*. (2006), and Assanee Meesook *et al*. (2009) Details of these investigations are presented as follows:

The limestone of Ban Yang Puteh, southeast of Amphoe Mae Sot, near tributary of Huai Mae Ku, was accepted to be a continuation of the Kamawkala limestone of eastern Myanmar (Cotter, 1924).

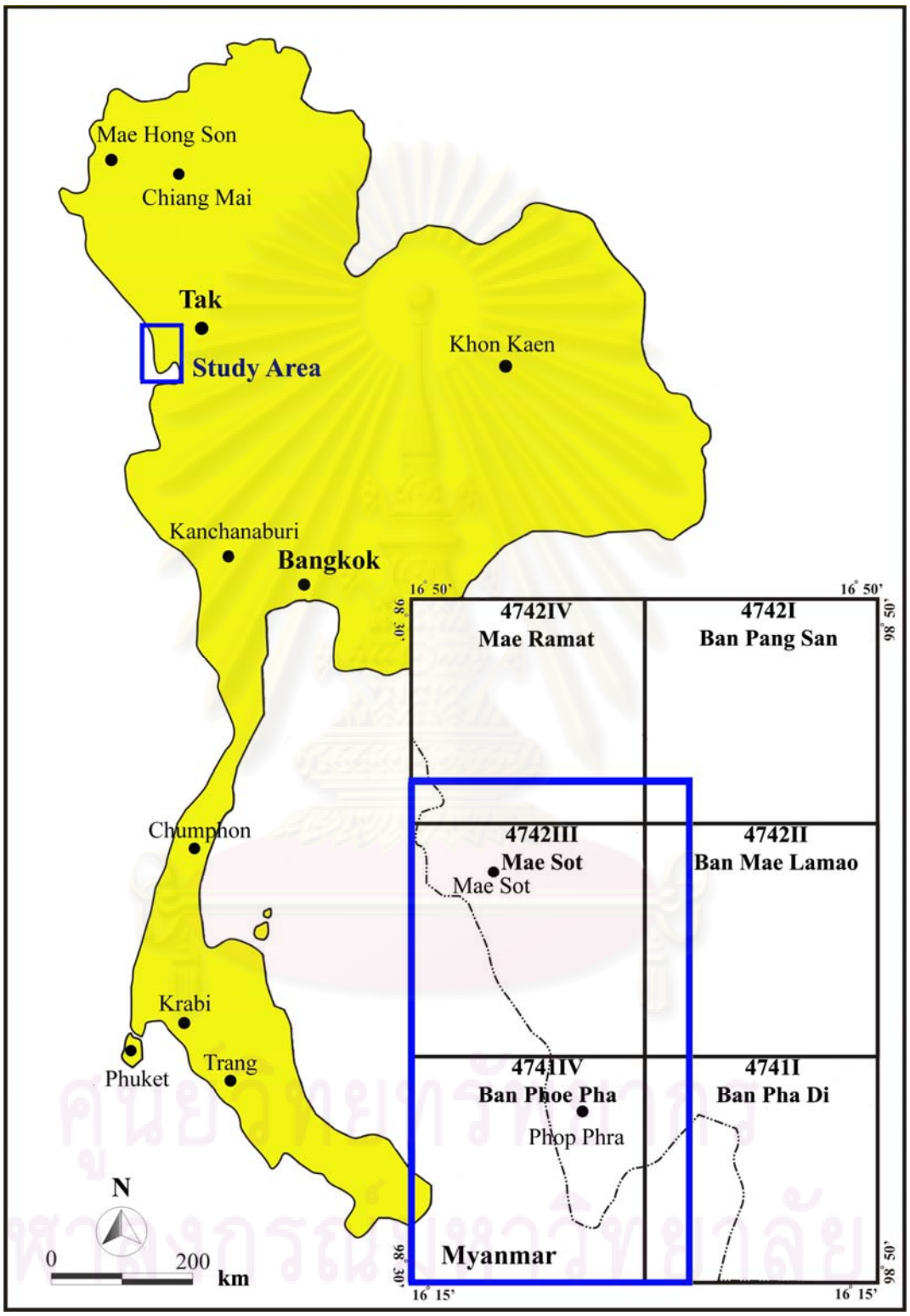


Figure 1.1. Map showing the study area, Amphoe Mae Sot-Phop Phra, Changwat Tak, western Thailand.

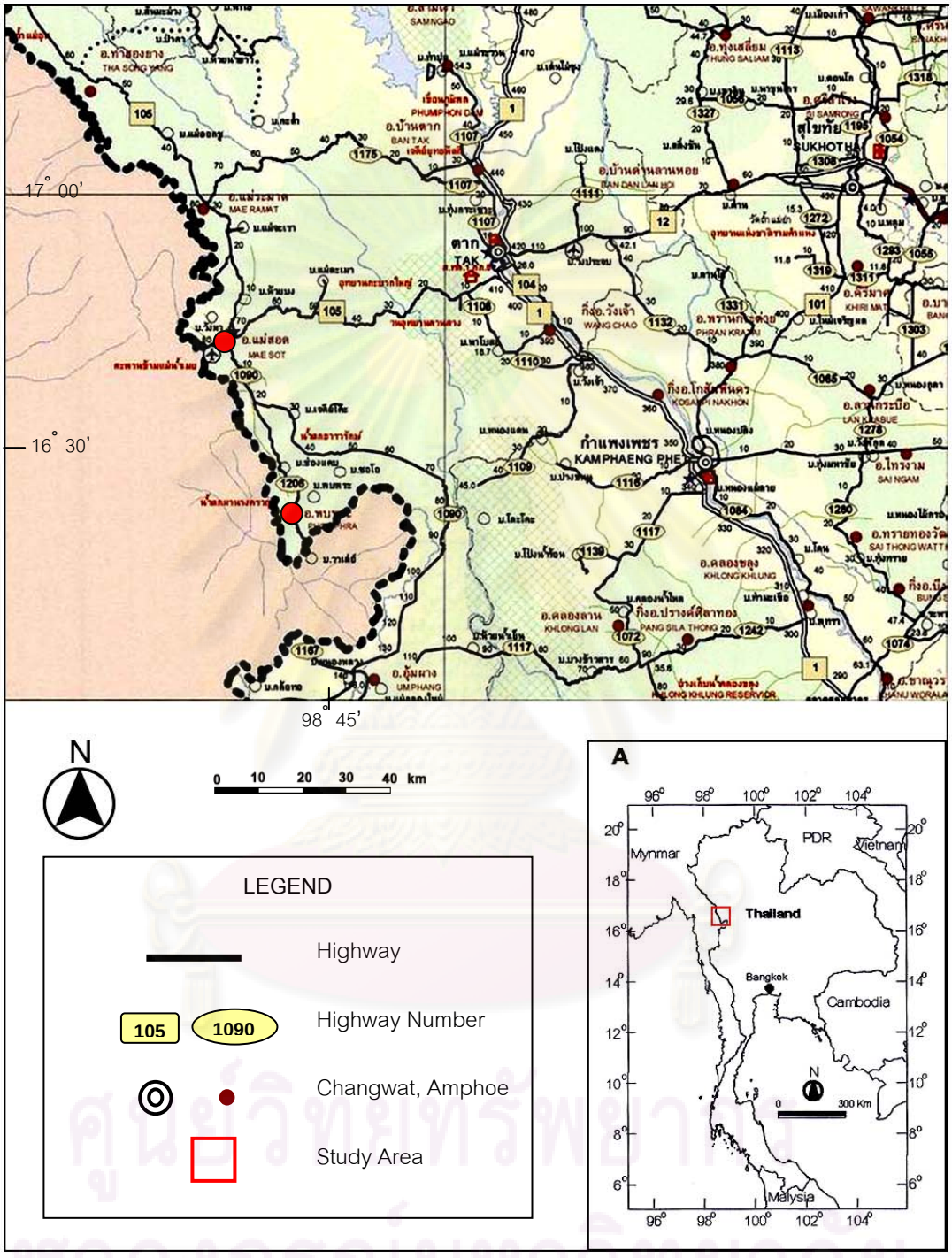


Figure 1.2. Map showing the accessibility to the study area in Amphoe Mae Sot-Phop Phra, Changwat Tak (after Department of Highways, 2006).

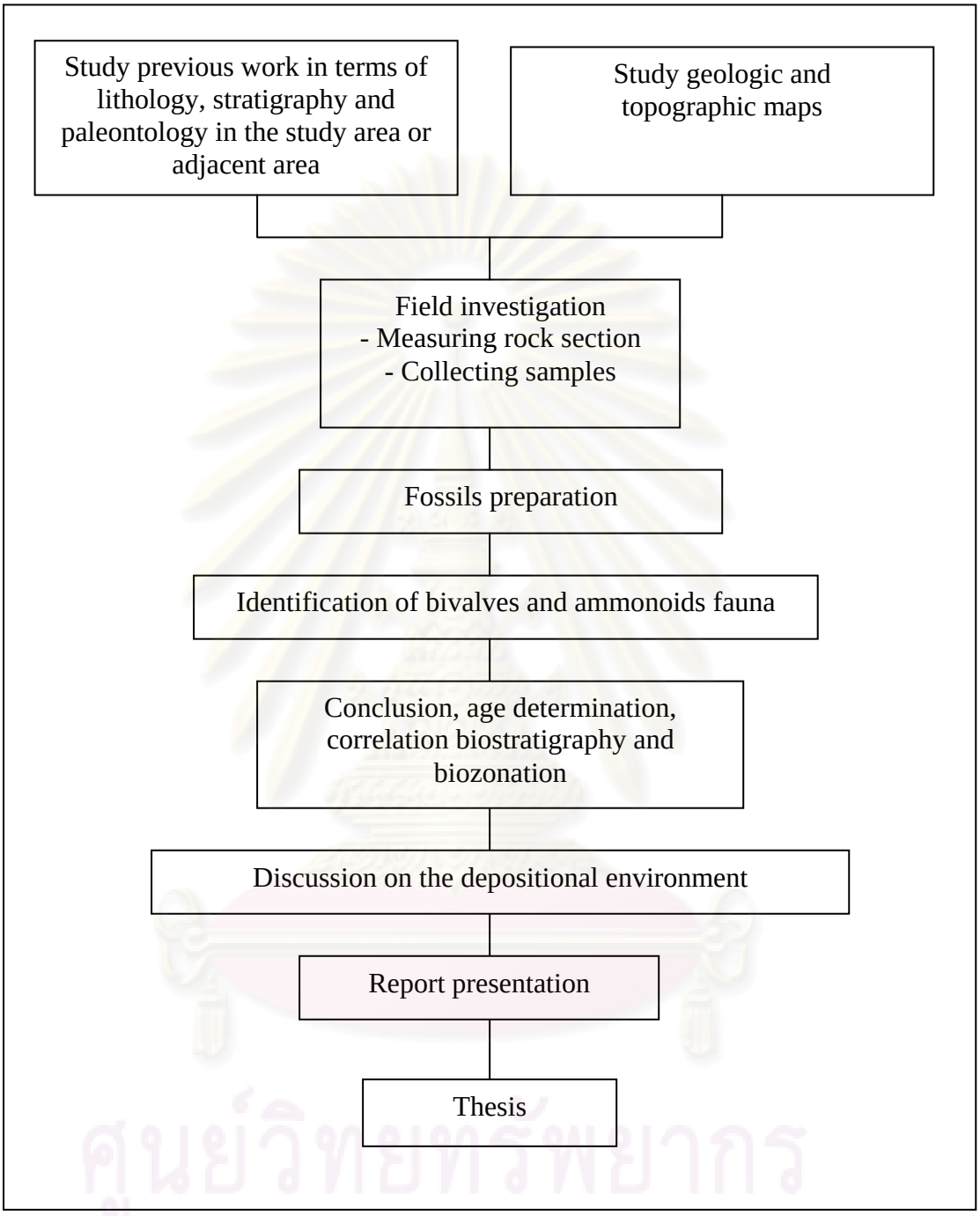


Figure 1.3. The summarized flow chart showing methodology in this study.

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 Amphoe Mae Sot. 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 geologist 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 Amphoe Mae Sot 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,* which indicated early Middle Jurassic age.

Faunas from the Mae Sot area have been described by Sato (1961) as *Erycites* sp. and *Bositra* ex gr. *ornati,* signify the lower Middle Jurassic age.

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

In 1964, Pumwarn 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 reidentified the Ban Yang Puteh ammonites as *Tmetoceras regleyi, Dumortier* and *Graphoceras concavum* Sowerby and proposed an Aalenian age of both faunas.

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 Amphoe Mae Sot. Three assemblages of ammonites were recognized: Late Toarcian (*Pseudolioceras, Lytoceras* and *Onychoceras*), Late Aalenian to Early Bajocian (*Ericites, Tmetoceras, Eumetoceras* and *Docidoceras*), and Middle-Late Oxfordian (*Epimayaites* and *Phylloceras*). The top of Kamawkala Limestone has been considered by the authors as Early Jurassic age.

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, Changwat Kanchanaburi, 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), Chongpan Chonglakmani (1983) and Chongpan Chonglakmani *et al*. (1985).

As a result of the first detailed mapping programme in the Umphang area, Changwat Tak (160 km south of Mae Sot), Assanee 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, totaling about 400 m in thickness.

Adul Charoenpravat *et al*. (1985) reported a new marine Jurassic locality at Ban Pa Lan, Changwat Mae Hong Son, preliminarily concluded as the northern-most marine Jurassic exposed in Thailand.

Worawut 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 Varawut Suteethorn (1988) with contributions from other workers, reviewed the marine Jurassic of western Thailand, reported some new fossil localities and described some of the fossils including bivalves, ammonites, corals, brachiopods, algae and foraminifera.

Four faunas of marine Jurassic sequence in western Thailand were distinguished by Sato and Westermann (1991), in ascending order: *Psuedolioceras, Tmetoceras Skirroceras* and *Epimyaites?*

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, confirms 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.

Assanee Meesook (1994), Assanee Meesook and Grant-Mackie (1994), and Assanee 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 Changwat Chumphon. 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 Changwat Nakhon Si Thammarat consists of mudstone and sandstone of the Toarcian age and summarized the marine Jurassic lithostratigraphy of Thailand in which fourteen new lithostratigraphic units were established.

In 2002 to 2005, both marine and non-marine Mesozoic sedimentary rocks and faunal aspects of Thailand were reported and correlated by Assanee 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 Assanee 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 Amphoe Mae Sot and Amphoe Umphang, Changwat Tak. 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.

Wirote Saengsrichan (2007), reported a details of marine Jurassic lithostratigraphy in the Mae Sot-Phop Phra basin; the Hua Fai Group can be divided into 3 formations, 17 units and the sedimentary sequences are analyzed in terms of lithofacies association representing the shoreface, fan-deltas, protected lagoon, intertidal, subtidal 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.

Finally Assanee Meesook *et al*. (2009), reported on paleoecological analysis and depositional history of the marine Jurassic at Mae Sot, Phop Pha and Umphang areas, based on bivalve assemblages with additional data from ammonites, brachiopods, and microfossils. This implies warm, shallow water and oxygenated conditions except for the Mae Sot area where a deeper setting with restricted basinal anoxic conditions is favored as indicated by the presence of *Bositra*.

1.6 Basic knowledge on bivalves

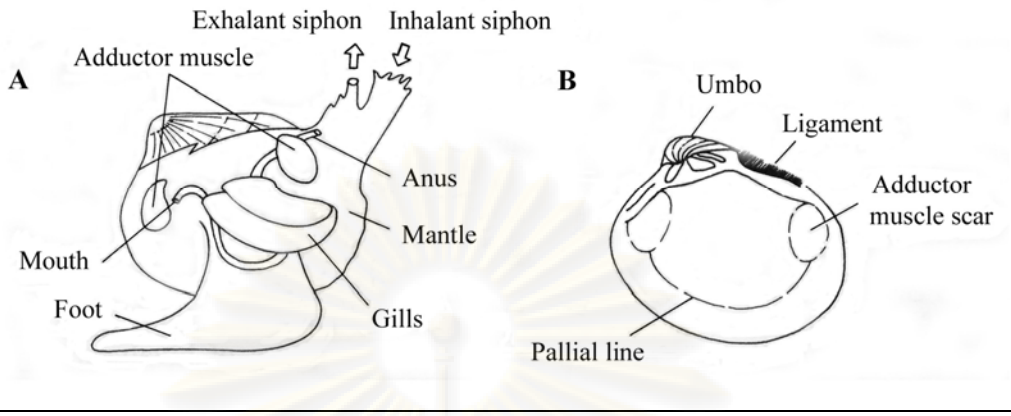
The bivalve belongs to the Phylum Mollusca Linnaeus, 1758, Class Bivalvia (Lamellibranchia or Pelecypoda) Linnaeus, 1758 (Cambrian-Recent). Data of bivalve in this part is based mainly on Doyle (1996) as follows:

General characteristics

Generally, bivalves classified by the features of the hinge margin and other internal features of the shell (Figure 1.4). They are characterised by their two-halved, usually aragonitc calcareous shell which protects the soft parts, and which is hinged by an elastic ligament to allow the functions of burrowing, respiration and feeding. The majority of bivalves live in burrows which are constructed by the muscular contractions of the mantle muscle or foot and mostly feed from food particles suspended in the water column. Suspension-feeding bivalves feed by filtering food particles suspended in the water column, which suspended food particles into the shell through the inhalent siphon and spent water is expelled through the exhalant siphon.

Shell morphology

Bivalve shell morphology is relatively simple and is an important of mode of life. The shell serves as a hinged calcareous cover for the soft body which is variously shaped to suit the function of the bivalve. There are two basic modes of life, burrow-dwelling (infaunal) or surface-dwelling (epifaunal). Most infaunal bivalves can be distinguished by the fact that their shells have two halves with mirror-image symmetry, while many, but not all, epifaunal bivalves do not.



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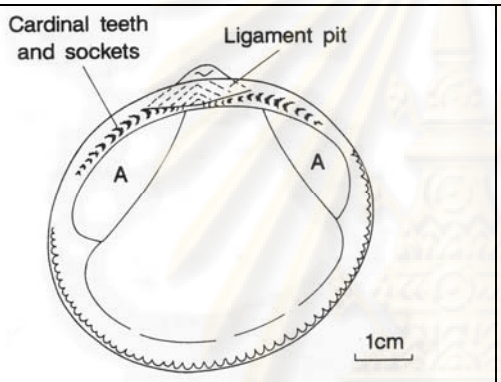
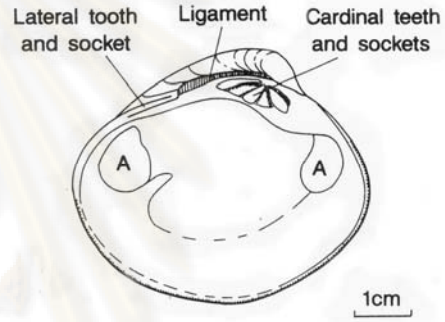
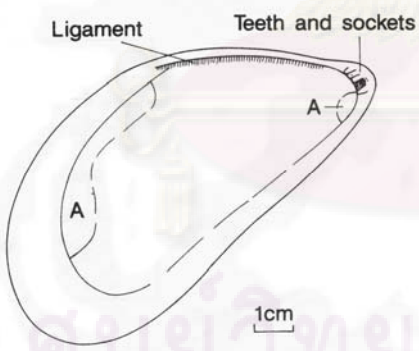


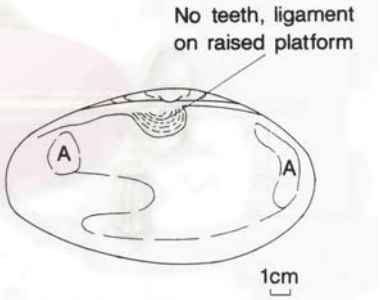
Glycimeris : taxodont dentition



Venus : heterodont dentition



Mytilus : dysodont dentition



Mya : desmodont dentition

Figure 1.4. General characteristics of soft parts (A) and shell (B) of a living bivalve. Details of the hinge area of four typical bivalves (C). Adductor muscle scars denoted by the latter A (after Doyle, 1996).

Bivalve all possess two shells known as valves which are permanently joined at the hinge, and which open and close in order to carry out the function of feeding and respiration. Each valve contains a record of the life history of the individual bivalve shell, as the growth lines on its exterior illustrate the incremental growth of the shell, created by the soft body or mantle. The first formed part of the shell is locked into the umbones which overlap the hinge margin; the last growth increment is represented by the join or commissure. Bivalve shells are all calcareous, aragonitic or calcitic.

The interior of a typical bivalve displays the following information: the hinge contains the ligament either set in a pit outside the shell or set into the hinge margin itself, together with the hinge teeth if present. The hinge teeth are used as an important character in the classification of the bivalves. Commonly, the teeth radiate in a small cluster of cardinal teeth from the umbo. Cardinal teeth are comonly found in two configuration: spread out along the entire length of the hinge margin (taxodont dentition), or limited to a small cluster beneath the umbo but joined by simple lateral teeth which are parallel to the hinge margin (heterodont dentition). Most shallow-burrowing bivalves have heterodont dentition. In some bivalves, particularly epifaunal ones, the hinge teeth are reduced or absent, and the task of opening and closing the shell is taken by a greatly modified ligament and adductor muscle arrangement. The position of the adductor muscle attachments can be seen as muscle scars on the interior of the shell. These scars are paired either side of the hinge margin in equivalve bivalves, or consist of a single large and subcentral muscle scar where the bivalves are inequivalve. Finally, the position of the mantle inside the valves in denoted by the pallial line, a distinct line parallel to the outer margin of the shell forming an arc which either connects the two adductor muscle scars or joins the hinge line. In some cases, there is a distinct embayment within the pallial line, known as the pallial sinus. This is common in infaunal bivalves and represents the position when retracted inside the shell of the siphons used for suspension feeding.

Mode of life

The bivalves can be divided into three main groups on the basis of their mode of life in relation to the substrate: shallow infaunal; deep infaunal; and epifaunal

(Figure 1.5). This represents a simplification but includes the majority of bivalves commonly encountered. Their characteristics are discussed below:

1. Shallow infaunal bivalves.

They have an equivalve shell form, heavily ribbed, a subcircular shell shape, strong hinge teeth, two subequal muscle scars and complete pallial line or small pallial sinus. These characteristics are reflective of the need for shallow-burrowing bivalves to protect themselves if washed out or otherwise exhumed from their burrows.

2. Deep infaunal bivalves.

They have an equivalve shell form usually unornamented with ribs, an elongate shell shape, a shell gape in many cases, reduced or absent hinge teeth, two unequal muscle scars and a large pallial sinus. The equivalve shell and elongate shape promote efficiency in deeper burrowing. A shell gape, at both anterior and posterior for permanent extrusion of foot and siphons, is a common feature of deep-burrowing bivalves, a function of the need for extended periods within the burrow.

3. Equivalve epifaunal bivalves.

They have a lozenge-shaped equivalve shell, largely reduced hinge teeth, unequal muscle scars which posterior scar is larger than anterior scar and an entire pallial line. They are adapted to a byssally attached mode of life in which the byssus is extruded from a gape in the lower surface of the shell. The lozenge shape is a function of this sedentary habit and reflects the need for strength in attachment to a hard substrate.

Palaeoenvironments

Bivalves are great value in palaeoenvironmental analysis because of their association with particular substrates. They are almost all benthonic, and mostly neritic, and are most commonly limited by water depth, substrate, salinity and oxygenation. Typical substrate preferences are infaunal, epifaunal and vagile (freely moving). Infaunal bivalves include rock-borers, burrowers, and nestlers-'squatters' inhabiting pre-constructed burrows or cavities. Epifaunal bivalves include free-living recliners, strongly attached cementers and byssally attached shells. Vagile bivalves are rare but include the partially free-swimming genera *Pecten* and *Lima*. Typical feeding strategies for most bivalves are as infaunal or epifaunal suspension feeders.

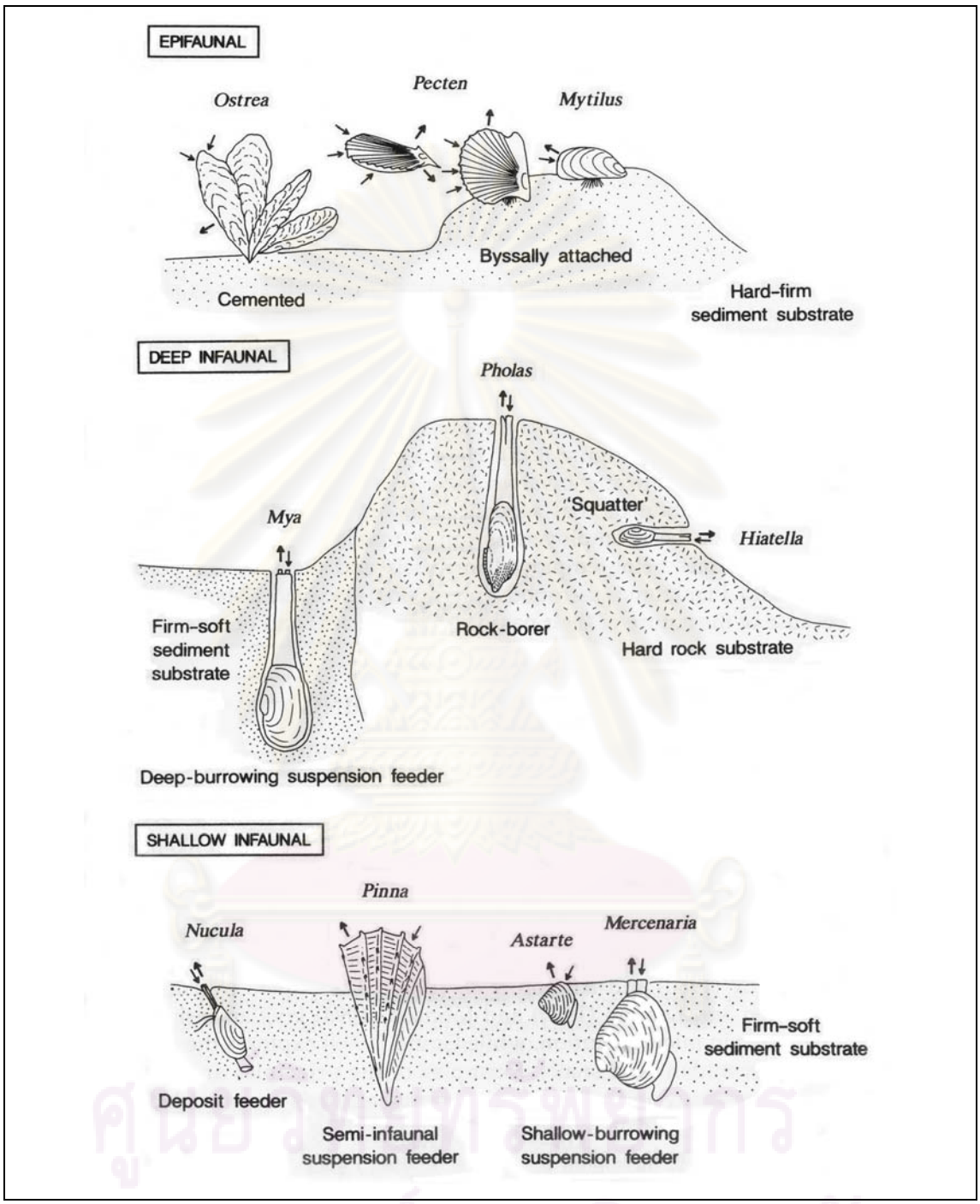


Figure 1.5. Modes of life of typical bivalve shells (after Doyle, 1996).

CHAPTER II

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 (Figure 2.1).

2.1.1.1 Eastern high range mountains zone

The eastern high range mountains zone is located in the eastern flank of the study area, which has high mountains and denses forest. Moreover, this zone is widely covered by sandstone, shale, limestone, metamorphic and igneous rocks of the Upper Paleozoic to Mesozoic. These high mountain ranges are located in the northeastern part of the study area, which distributed approximately 15% of the area and have elevation of the ranges between 500 and 1,157 m (msl) as the highest peak is at Doi Pha Kia with approximate elevation of 1,157 m above mean sea level (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. In addition, this zone covers the area estimate 55% and the elevation between 300 and 400 m (msl). This topography is characterized by small hills with intensive agriculture. The rocks in this undulating landform are composed of 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, Amphoe Mae Sot and Amphoe Phop Phra about 30% of the area. This zone can be divided into 3 sub-basins, namely, Mae Lamao, Mae Sot and Phop Phra Basins (Figure 2.1). The area is covered by floodplain deposits of Moei, Mae Lamao and Wale Rivers with the elevation ranging from 120 to 300 m (msl).

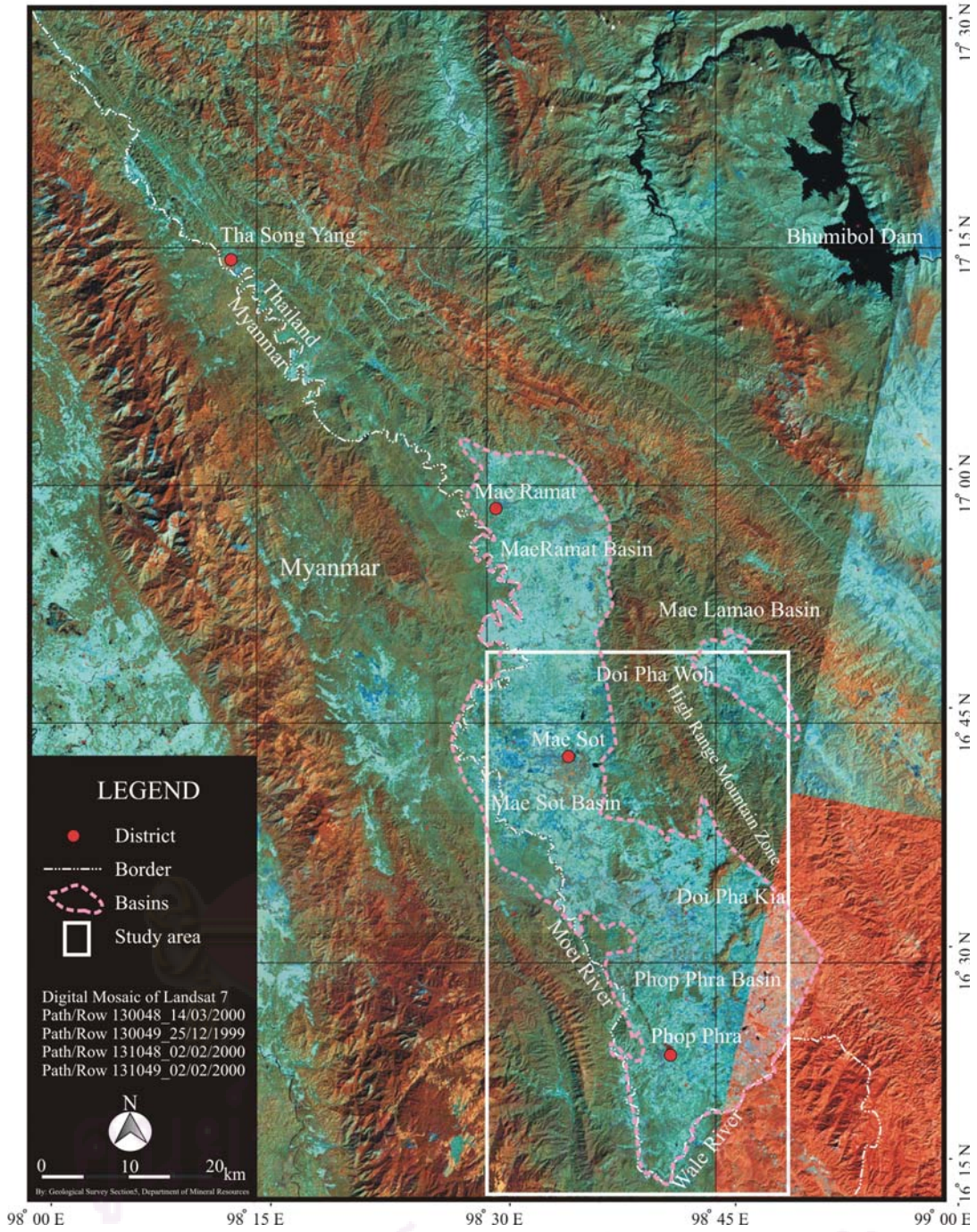


Figure 2.1. Satellite image showing morphological map of the study area, Amphoe Mae Sot-Phop Phra, Changwat Tak, western Thailand (after Wirote Saengsrichan, 2007).

2.1.2 Drainage systems and landform origin

The main rivers compise 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 in 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 (Figure 2.1) as follows:

2.1.2.1 Landform of denudation origin comprises eastern highland, isolated and small hills cover approximately 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 is mainly presented along Mae Lamao, Moei and Wale Rivers covering about 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 Geologic setting

Mainland Southeast Asia is divided into three major tectonic terranes: the western Burma terrane, the Shan-Thai terrane and the Indochina terrane (Sangad Bunopas, 1981; Burrett, 1974; Burrett *et al.*, 1990; Gatinsky *et al.*, 1978; Hutchison, 1975; Mitchell, 1981; Ridd, 1980; Stauffer, 1974). Thailand is a part both of the Shan-Thai terrane in the west and of the Indochina terrane in the eastern part of the country 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 (Panya Charusiri *et al.*, 2002). The Shan-Thai terrane was in contiguous to Indochina and South China terranes in the Middle Triassic time. The continent-continent collision was a part of the Indosinian orogeny. After the collision, mountains were developed along the suture, particularly along the over-thrusting Shan-Thai terrane. The study area is located in the Shan-Thai terrane, west of the Pattani suture (Panya 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 (Sangad Bunopas, 1981; Hahn *et al*., 1986; Yuenyong Panjasawatwong, 1991).

The main marine Jurassic rocks investigated are a long narrow N-S trending strip running along the Thailand-Myanmar border, and occupy more than 7,000 km^2 of the Mae Hong Son, Tak and Kanchanaburi areas, with three isolated areas of Changwat Chumphon, Nakhon Si Thammarat and Krabi in the southern part of Thailand.

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 (Worawut 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 Assanee Meesook *et al*., 2006), and geology of Tak area (Wirote Saengsrichan, 2007). 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 2.2 and 2.3).

2.2.1 Regional stratigraphy of the study area

Geologic setting of this area has been complied based on Wirote Saengsrichan (2007). The study area is dominated by sediment and sedimentary units ranging in age from the Pre-Cambrian to Quaternary (Figures 2.2 and 2.3). The composite lithologic column of these rocks is shown in Figure 2.3 as follows:

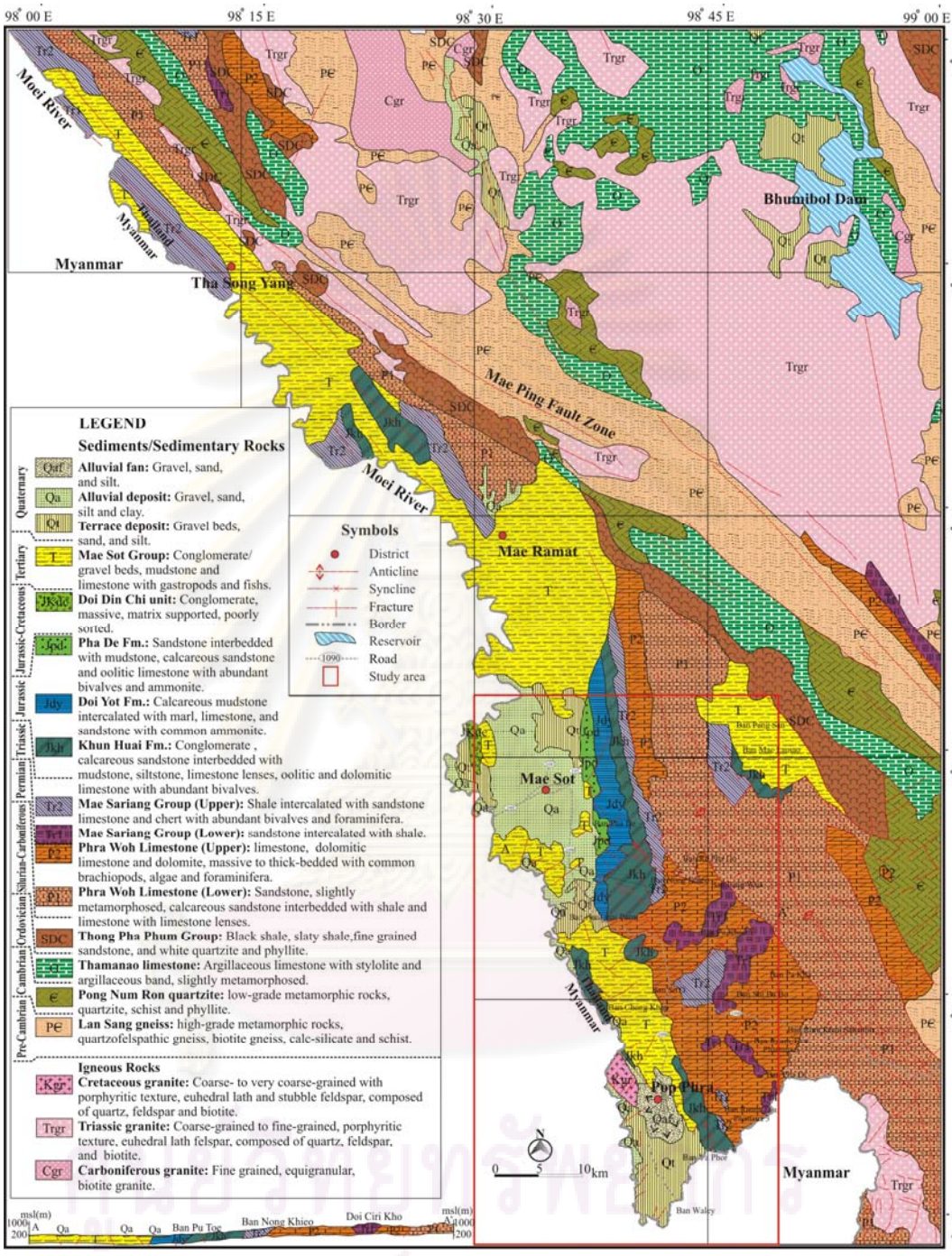


Figure 2.2. Geologic map showing the distribution, age and simple structures of units in the Tak area, western Thailand (after Wirote Saengsrichan, 2007).

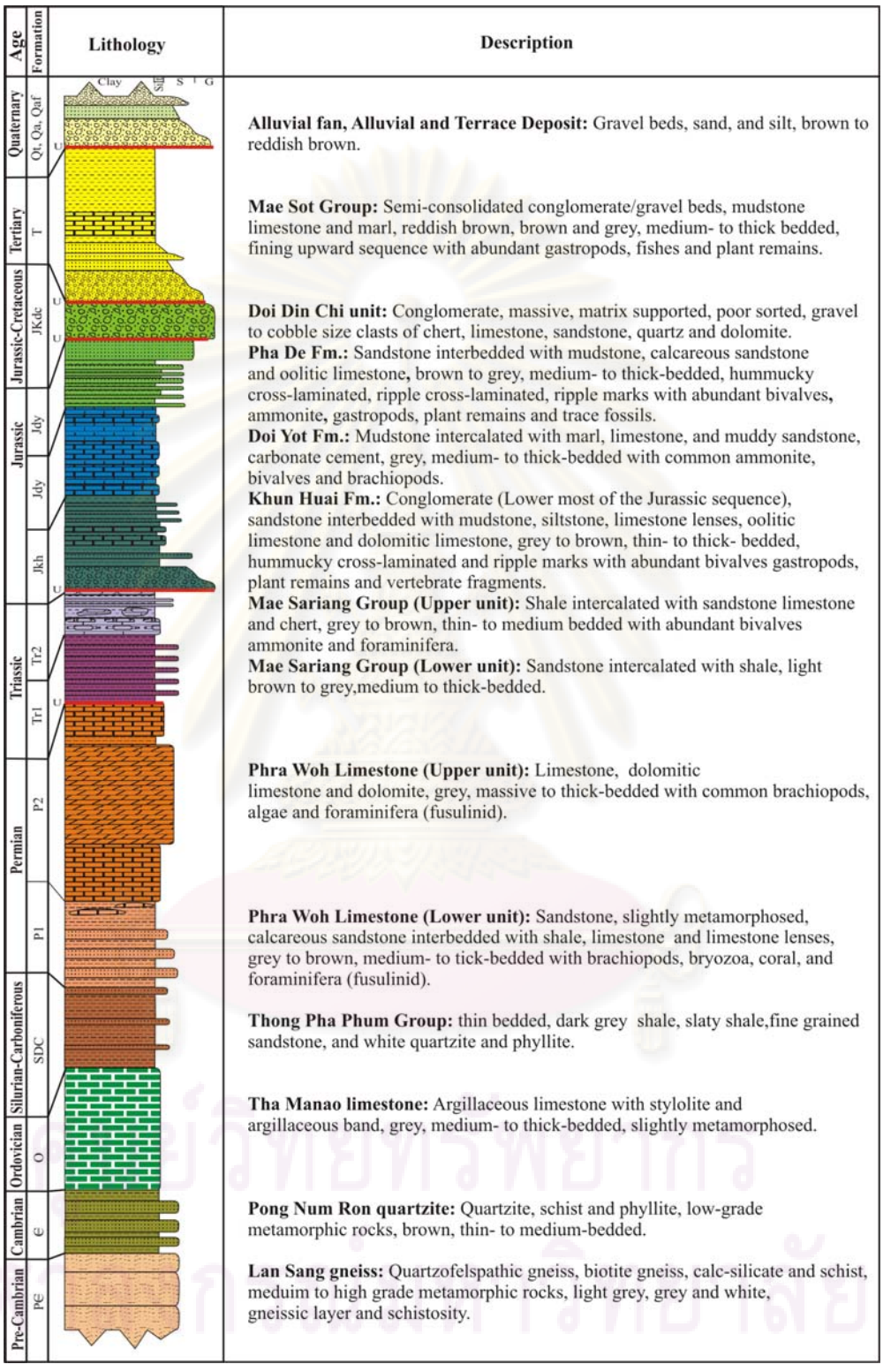


Figure 2.3. Composite stratigraphic column of Upper Paleozoic to Quaternary rocks in the study area and its vicinity (after Wirote Saengsrichan, 2007).

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, Changwat Kanchanaburi. 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 Assanee 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 Amphoe Mae Sot. 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 Varawut 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 Varawut Suteethorn, 1988). Mae Sot Basin is well known as the Mae Sot Group (T) and determined in Tertiary age. The Mae Sot Group (T) is widespread in the Phop Phra area. The unit consists mainly of semi-consolidated conglomerate, mudstone and sandstone. 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 Distribution of marine Jurassic rocks in Thailand

Mesozoic sequences in Thailand can be subdivided on the basis of stratigraphy and paleontology into three main facies (Assanee Meesook and Grant-Mackie, 1996); the marine facies, brackish facies and the younger continental facies. In the west, only marine facies of Triassic and Jurassic ages have been reported. The marine Jurassic sediments are distributed in three 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 2.4) in the lower peninsula. The location and extent of these basins, the structure and orientation of Jurassic strata in each basin and present relationship between basins resulting from both strike-slip and normal faulting are shown in Figure 2.4. Except for the continental basins in northeastern Thailand, most of the marine and brackish basins are the north-northwest trending elongated basins. Of these basins, the Mae Hong Son-Kanchanaburi Basin has been

most fully developed and widely distributed of marine Jurassic strata (Assanee Meesook and Grant-Mackie, 1996).

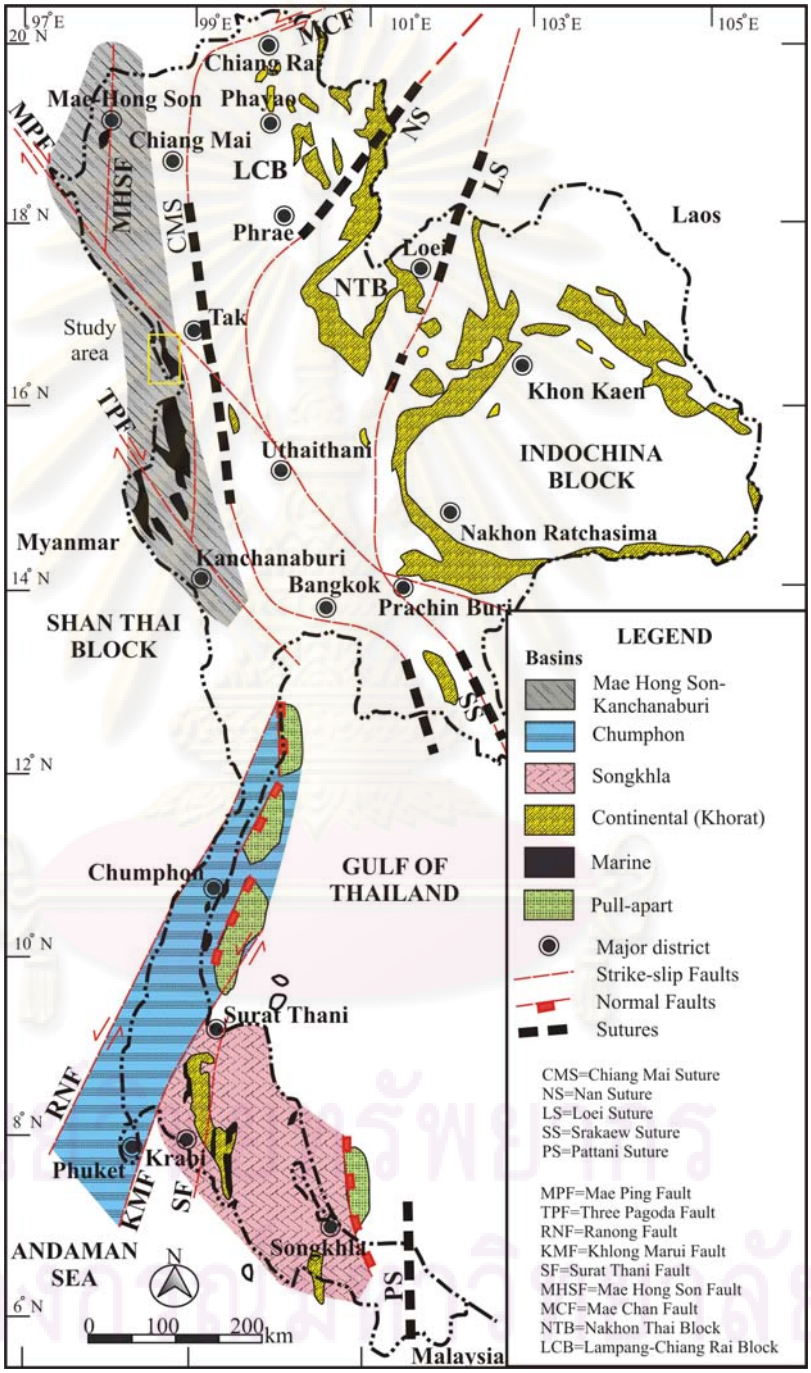


Figure 2.4. Map of Thailand showing major tectonic units and distribution of the Jurassic-Cretaceous sedimentary rocks and basins with some major geological structures (after Wirote Seangsrichan, 2007).

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, Umphang-Phop Phra, Kanchanaburi, Chumphon, Thung Song-Klong Thom and Ao Luk-Plai Phraya areas. These areas are situated in Changwat Mae Hong Son, Tak, Chumphon, Kanchanaburi, Nakhon Si Thammarat and Krabi, respectively (Figure 2.5).

According to Assanee 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 2.1) 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 are composed of mudstones, siltstones, sandstones, limestones and marls. Mudstones, siltstones and sandstones are widespread in all basins; marls are found only in Mae Sot.

2.3.1 Marine Jurassic rocks in north-west Thailand

2.3.1.1 Khun Yuam area, Changwat Mae Hong Son

In Khun Yuam-Mae Hong Son, the area was previously mapped as marine Triassic rocks trending north-south direction along the Thailand-Myanmar border. According to Adul Charoenprawat *et al*. (1985), they discovered the marine Jurassic rocks at Ban Pa Lan and its vicinity, Amphoe Muang and Amphoe Khun Yuam of Changwat Mae Hong Son. Consequently, Assanee Meesook (1994) and Assanee Meesook and Grant-Mackie (1996) have studied the rocks in terms of stratigraphy and paleontology and four new lithostratigraphic units are established: the Huai Pong Group consisting of the Pa Lan, Mai Hung and Kong Mu Formations in an scending order (Figure 2.6). The Huai Pong Group was proposed for Jurassic strata overlying marine Triassic and underlying Quaternary strata and the thickness approximately 200 m. 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. In addition, ammonites, bivalves and foraminifera indicate that the group ranges in age from Toarcian to Aalenian.

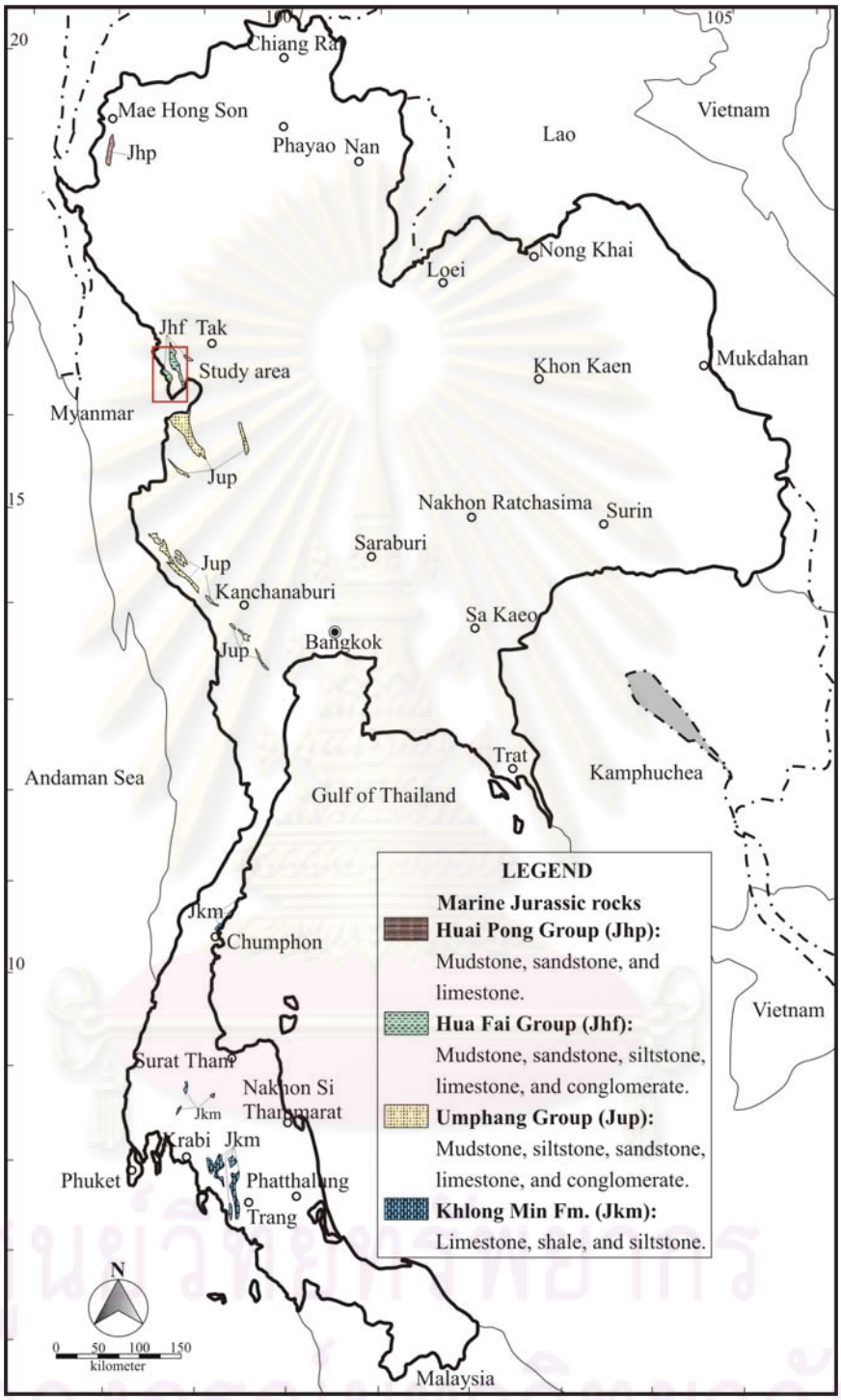
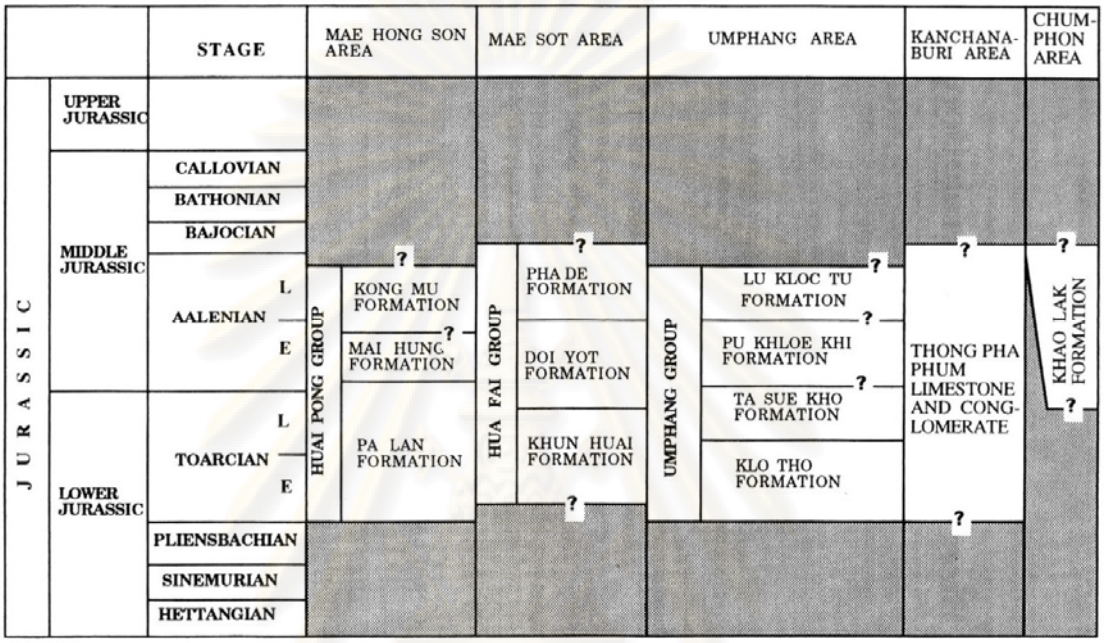


Figure 2.5. Distribution of marine Jurassic rocks of Thailand including sedimentary units (after Assanee Meesook *et al*., 2006).

Table 2.1 Summary of lithologic nomenclature proposed for marine Jurassic strata of Thailand, and correlations made with international stage scheme (after Assanee Meesook and Grant-Mackie, 1996).



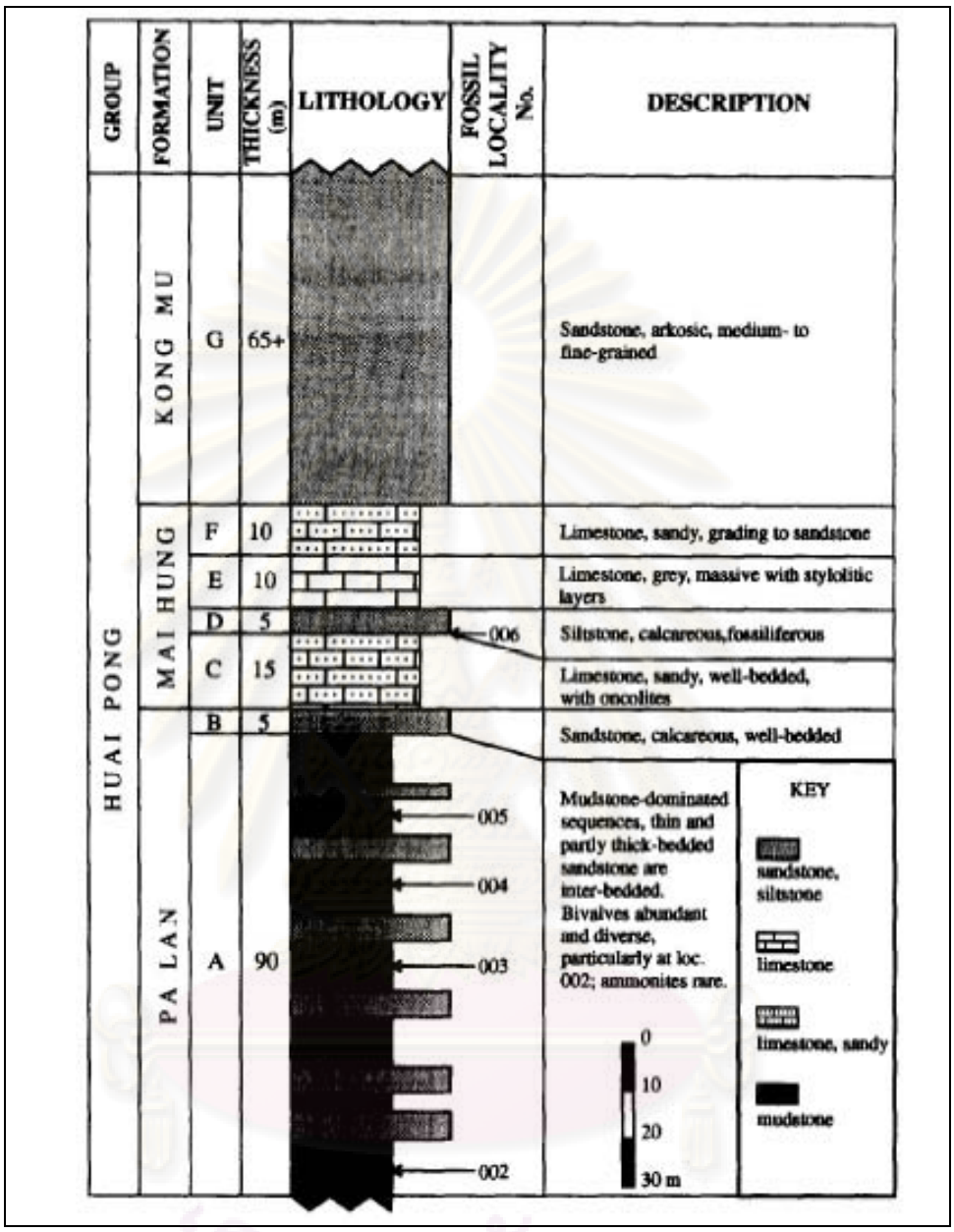


Figure 2.6. Lithologic column at the type section of the Huai Pong Group, Changwat Mae Hong Son (after Assanee Meesook and Grant-Mackie, 1996).

2.3.1.2 Mae Sot area, Changwat Tak

The Mae Sot area of Changwat Tak, northwestern Thailand is well distributed of marine Jurassic rocks and well selected as a pilot area in studying Jurassic faunas due to their abundance and diversity. The marine Jurassic rocks bounded in the eastern and western parts of the Mae Sot basin are composed of marine clastic rocks represented by the Hua Fai Group (Assanee Meesook, 1994). The group is divided into three formations, Khun Huai, Doi Yot, and Pha De Formations, respectively, in ascending order (Figure 2.7). Marine Jurassic strata 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 Varawut 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. The Mae Moei Group is rejected as an appropriate lithostratigraphic term for the Jurassic strata of the region (Assanee 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. 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.

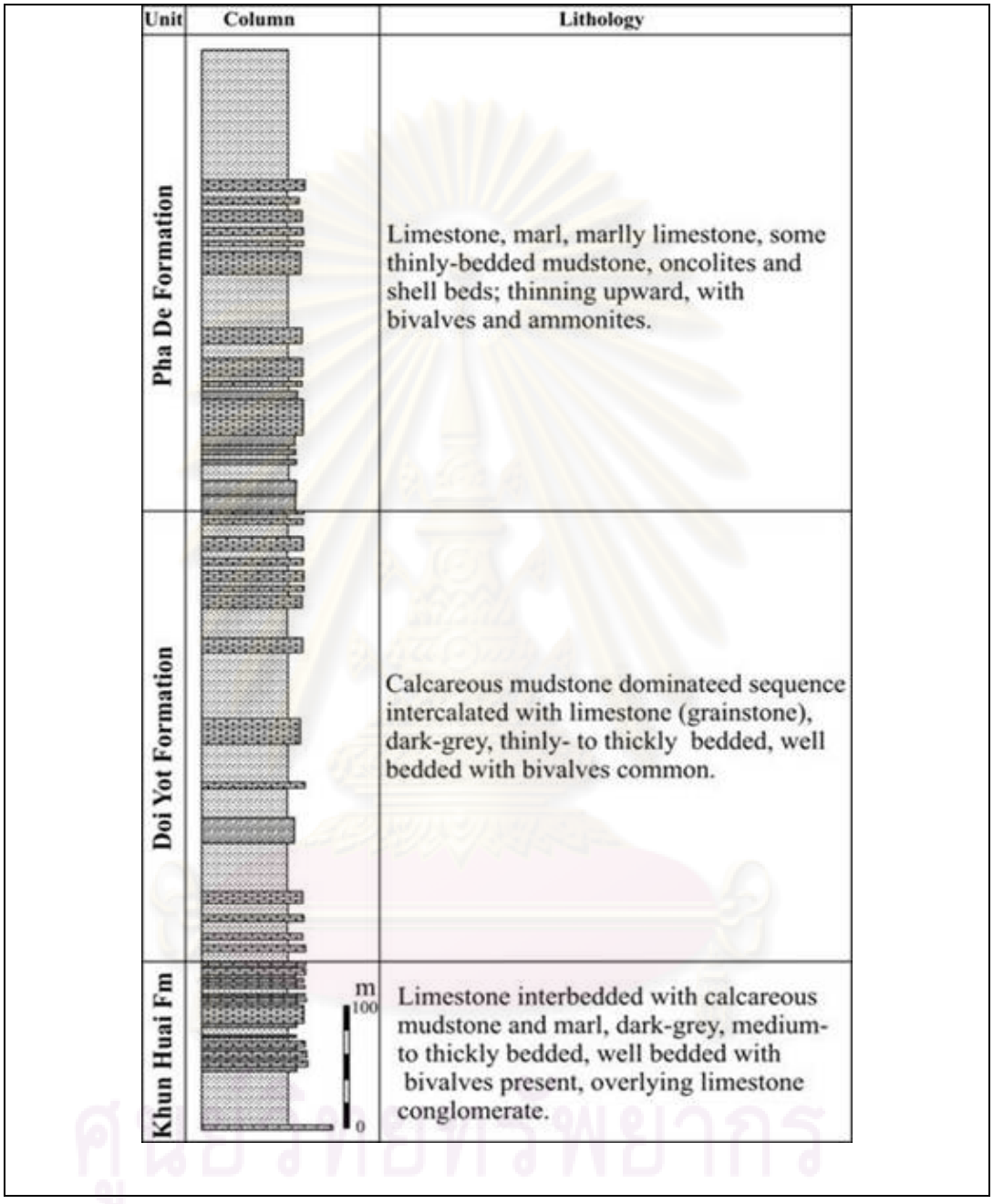


Figure 2.7. Lithologic column at the type section of the Hua Fai Group, Amphoe Mae Sot, Changwat Tak (after Assanee Meesook and Grant-Mackie, 1996).

2.3.1.3 Umphang-Phop Phra area, Changwat Tak

The Jurassic sedimentary rocks in the Umphang-Phop Phra areas, Changwat Tak are mainly composed of the marine to brackish clastic rocks deposited in marine and brackish water environments. Lithostratigraphically, the Umphang Group is proposed by Assanee Meesook (1994) for the marine Jurassic rocks in the Umphang area and this group can be subdivided into four formations, namely, the Klo Tho, Ta Sue Kho, Pu Khloe Khi, and Lu Kloc Tu Formations, respectively, in ascending order. The main lithologies of marine Jurassic rocks in the Phop Phra area consist of sandstone, siltstone, mudstone and limestone of the Klo Tho Formation (Figure 2.8).

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 (Assanee Meesook *et al*., 1985; Fontaine and Varawut Suteethorn, 1988; Assanee Meesook, 1994; Assanee 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 are selected as the type section for the Umphang Group (Figure 2.9).

The Umphang Group (Assanee 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. In addition, ammonites from the Klo Tho Formations indicated an Early Toarcian age and foraminifera and alage from the Pu Khloe Khi Formations suggesting an early Aalenian age.

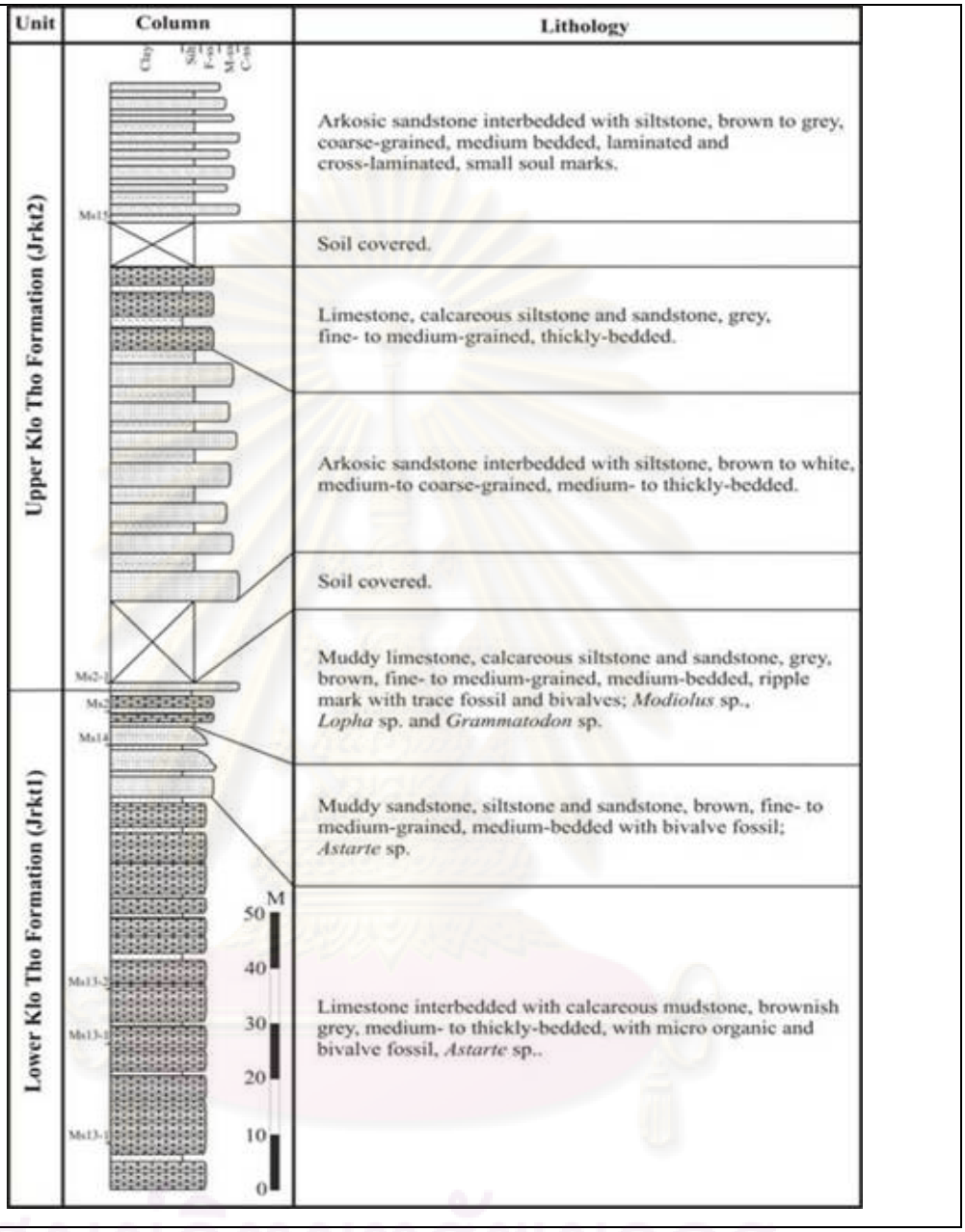


Figure 2.8. Lithologic column showing marine sequence of the Klo Tho Formation of the Umphang Group, Phop Phra area (after Assanee Meesook *et al*., 2006).

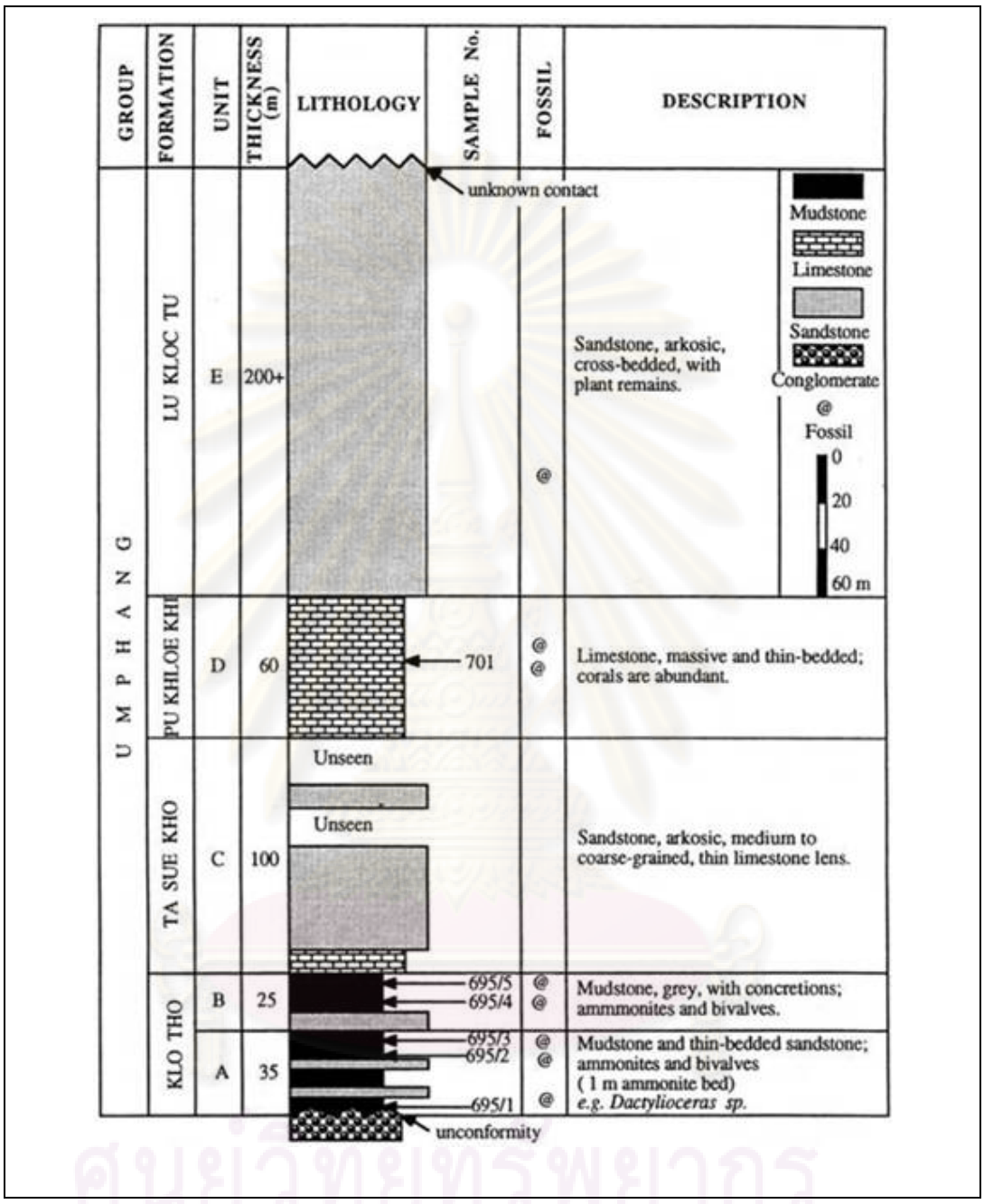


Figure 2.9. Lithologic column at the type section of the Umphang Group, Amphoe Umphang, Changwat Tak (after Assanee Meesook and Grant-Mackie, 1996).

2.3.1.4 Kanchanaburi area, Changwat Kanchanaburi

Marine Jurassic strata in the Kanchanaburi area are 200-300 m thick and are found at various localities in Amphoe Thong Pha Phum, 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 Varawut 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).

2.3.2 Marine Jurassic rocks in peninsular Thailand

2.3.2.1 Chumphon area, Changwat Chumphon

The blackish to non-marine Jurassic-Cretaceous rocks in peninsular Thailand are distributed from Changwat Chumphon to the north, Changwats Nakhon Si Thammarat, Krabi and Trang to the south, particular in the Thung Yai-Klong Thom area of Nakhon Si Thammarat and Krabi, and the Ao Luk-Plai Phraya area of Changwat Krabi and Changwat Surat Thani. Lithostratigraphically, the Thung Yai Group (Lertsin Raksaskulwong, 2002) is proposed for these rocks 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. The Thung Yai Group consists of reddish brown shales, sandstones, conglomerates and reddish brown, fine-grained sandstones of totally 760 m thick. Of these, the Khlong Min Formation is assigned as the Jurassic in age. The Thung Yai Group is unconformably underlain and overlain by Triassic and Quaternary sediments, respectively.

In Changwat Chumphon, the marine, brackish to non-marine Jurassic and Cretaceous rocks (the Thung Yai Group) are mainly composed of the continental red beds with occasional brackish-marine mudstones and siltstones. The distribution of the rocks is confined to Pathiu, Amphoe Tha Sae and Amphoe Langsuan, Changwat Chumphon of approximately 900 km^2. The Jurassic-Cretaceous rocks in Chumphon basin are also recognised as one of the richest faunal assemblages for the marine, brackish to non-marine Jurassic-Cretaceous strata in Thailand. However, these faunal assemblages are previously indetermined as well as those found in brackish-marine mudstones and siltstones of the Khlong Min Formation in the areas of Changwats Nakhon Si Thammarat, Krabi, Chumphon and Trang.

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 Amphoe Pathiu, and Khlong Khut of Amphoe Muang, Changwat Chumphon. 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, Amphoe Pathiu, Changwat Chumphon, 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.

2.3.2.2 Thung Song-Klong Thom area, Changwat Nakhon Si Thammarat

The Khlong Min Formation of the Thung Yai Group, approximately 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, Amphoe Thung Song of Changwat Nakhon Si Thammarat. 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., *Actinostreon* 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.

2.3.2.3 Ao Luk-Plai Phraya area, Changwat Krabi

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 (Naramase Teerarungsigul, 1999; Lertsin Raksaskulwong, 2002). This sequence is well exposed in the Wiang Sa area of Changwat Surat Thani, Thung Yai of Changwat Nakhon Si

Thammarat, Klong Thom, Ao Luk and Plai Phraya of Changwat Krabi and Wang Vi Set of Changwat Trang.

The Thung Yai Group in the Ao Luk-Plai Phraya 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 Amphoe Thung Yai and Amphoe Kian Sa, Changwat Nakhon Si Thammarat and Changwat Surat Thani. 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 Amphoe Thung Yai, Changwat Nakhon Si Thammarat.

The Khlong Min Formation crops out locally at Khlong Min, Ban Mab Ching, south of Amphoe Thung Yai, Changwat Nakhon Si Thammarat. The total thickness of the formation is about 200 m. This facies is widely exposed along Highway no. 44, at km 8-25 (Krabi-Khanom road) and Huai Luk reservoir, Amphoe Ao Luk and Amphoe Plai Phraya, Changwat Krabi and Changwat Surat Thani. This marine sequence is well exposed at km 10+300, western side of the Highway no. 44, Ban Khao Ngam, Amphoe Ao Luk. 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, Amphoe Plai Phraya, 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, Amphoe Ao Luk and Amphoe Plai Phraya, Changwat Krabi and Changwat Surat Thani. 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.

2.4 Marine Jurassic stratigraphy of the study area

The Mae Sot area is located in the northwestern part of Thailand near Thailand-Myanmar border. The area is situated in the Mae Hong Son-Kanchanaburi Basin as parts of Shan-Thai terrane of Changwat Tak. In addition, the Mae Sot-Phop Phra areas are selected to be this study area due to abundant and diverse marine Jurassic faunas particularly bivalves and ammonoids with additional corals, gastropods, brachiopods, and microfossils.

Lithostratigraphic nomenclature for marine Jurassic strata of the Mae Sot area was introduced by Braun and Jordan (1976). These units represent strata according to these authors ranging in age from Early to Late Jurassic based mainly on ammonites and foraminifera. As a result of recent studies (Fontaine and Varawut Suteethorn 1988; Assanee Meesook 1994), new marine Jurassic sections have been studied in detail and previous sections have been reinterpreted. Age determinations are based on ammonites, with bivalves and foraminifera providing useful additional data. These fossils show that the marine Jurassic sequences are largely Toarcian-Aalenian plus some Bajocian.

According to Assanee Meesook and Grant-Mackie (1996), marine Jurassic rocks in the Mae Sot area are generally underlain unconformably by Triassic and overlain by Quaternary strata, respectively. Four new lithostratigraphic units are established: (in ascending order) Khun Huai, Doi Yot, and Pha De Formations of the Hua Fai Group (Figure 2.7). Mudstones, siltstones, sandstones and marls are widespread in this area. Marine Jurassic sequences, approximately 900 m thick, are distributed in the eastern part of the Mae Sot area. The Hua Fai Group consisting of (in ascending order) the Khun Huai, Doi Yot and Pha De Formations is 140, 370 and 400 m thick respectively.

Marine Jurassic rocks in the Mae Sot area have also been studied in detail at a Zinc mine of Tak Mining Co., Ltd (Assanee Meesook *et al*., 2006). In the Zinc mine, marine Jurassic sequences of the Khun Huai Formation (Toarcian-Early Bajocian)

have been studied. The rocks are composed mostly of sandstones, siltstones, mudstones and limestones. Fossils are abundant and diverse throughout the succession. These faunas range in age from Toarcian (upper Lower Jurassic) to Early Bajocian (lower Middle Jurassic) and were living in shallow water environments with restricted basins as indicated by the presence of the bivalve *Bositra* sp.

HUA FAI GROUP

Marine Jurassic strata of the proposed Hua Fai Group 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 new 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 (von Braun and Jordan 1976).

Khun Huai Formation

The formation is named from Ban Khun Huai, Amphoe Mae Sot, Changwat Tak (Assanee Meesook, 1994). The type locality of this formation lies along the unsealed road between Ban Khun Huai and the Huai Mae Sot power station. It crops out along the roadside in the vicinity of the station's weir. Stratigraphically, the lower part of this formation is not exposed but is assumed to be unconformable on marine Triassic strata because of the presence of a limestone conglomerate between the two. This contact is located about half-way between the weir and Ban Khun Huai. The upper portion is conformably overlain by the Doi Yot Formation with a sharp contact between limestone-marl sequences and the younger mudstones. The contact is also well exposed in roadside outcrops. Lithologically, the formation consists

predominantly of limestone-marl-dominated sequences interbedded with mudstones (Figure 2.10). This formation is about 140 m thick at the type section, and approximately 120 m thick. The formation is also exposed at Ban Pha De and Khao Tham Sua 3 and 5 km south of the type section. Early Toarcian age is given for this formation based on the ammonite *Dactylioceras*.

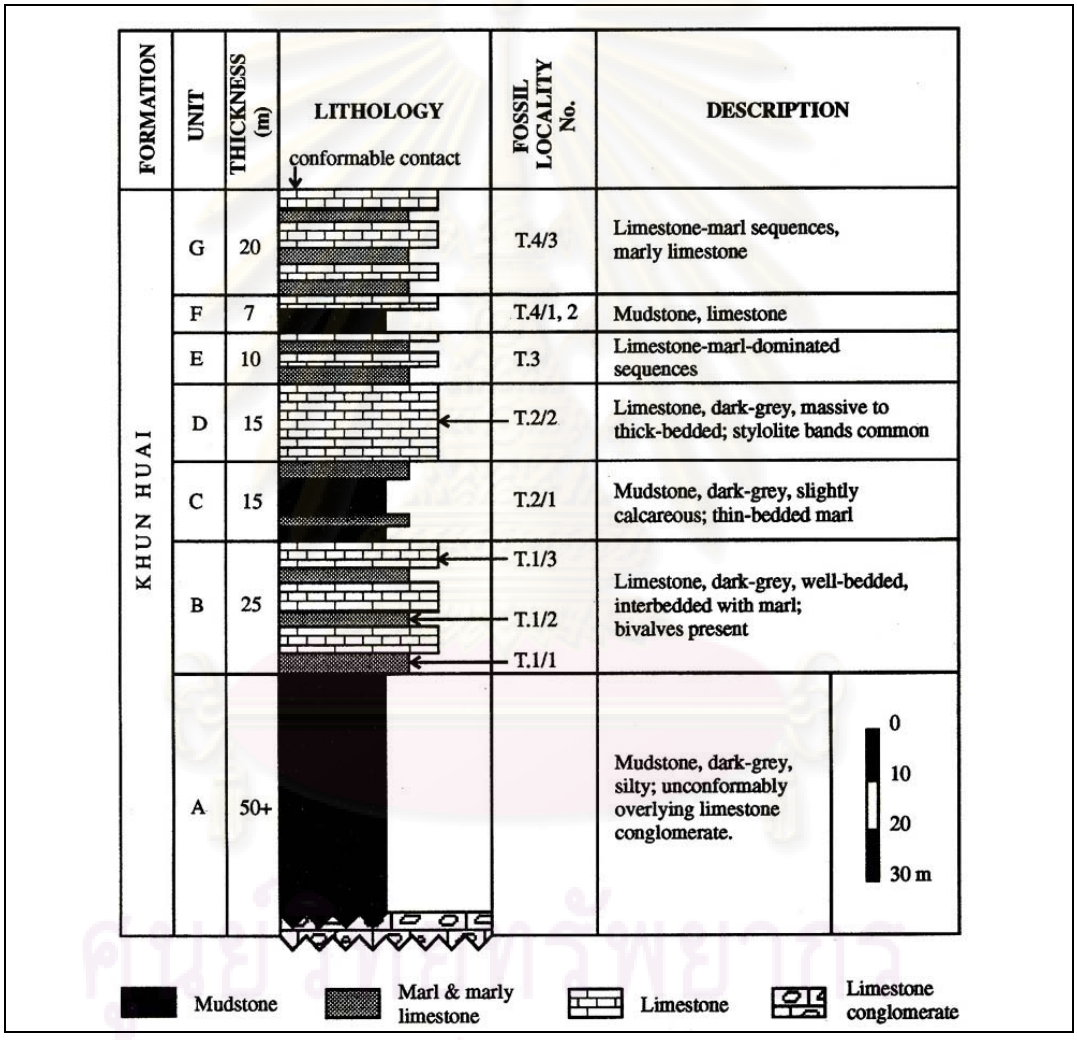


Figure 2.10. Lithologic column for the type section of the Khun Huai Formation (after Assanee Meesook and Grant-Mackie, 1996).

Doi Yot Formation

The formation is named from Doi Yot a mountain located 2 km south of the Huai Mae Sot power station (Assanee Meesook, 1994). The type section lies along the same road as of the Khun Huai Formation and about 2 km south of Doi Yot. Stratigraphically, the Doi Yot Formation conformably overlies the limestone-marl-dominated Khun Huai Formation. The upper boundary is a gradational contact to limestone-marl sequences of the overlying Pha De Formation. Lithologically, the main characteristic lithology of this formation is mudstone with interbedded limestones, and limestone lenses. Mudstones are grey to purple-grey in colour; limestones are thin and well-bedded; sandstones are mostly intercalated as lenses. The lower part of the formation is characterized by l-2 m thick limestone and calcareous sandstone lenses in dark grey mudstone, showing cross-stratification. A detailed lithologic column is shown in Figure 2.11. Bivalves are common throughout. The middle part is dominated by mudstones with some interbedded dark-grey limestones; fossils are less common here than in the lower part of the formation. The upper part displays alternations of mudstone and limestone with fining-upwards sequences and abundant fossils. The total thickness of the Doi Yot formation is approximately 370 m at the type section, The formation also crops out along the unsealed road from the Pha Daeng zinc mine and Ban Tham Sua, about 7 km south of the type locality. Age determination based on the ammonites *Onychoceras* sp., *Pseudolioceras* sp. and *Leioceras* sp., and the bivalve *Bositra* sp. is Late Toarcian-Early Aalenian.

Pha De Formation

The name of this formation is from Ban Pha De, Amphoe Mae Sot, Changwat Tak and the type section is along the same road as the type section of the Doi Yot Formation and about 3 km north of Ban Pha De (Assanee Meesook, 1994). Stratigraphically, the Pha De Formation is underlain conformably by the Doi Yot Formation; its top is obscured beneath overlying strata of the eastern boundary of the Mae Sot Tertiary Basin. Lithologically, the formation consists mainly of limestone-marl-dominated sequences with some minor mudstones. Thinning-upwards sequences are common, particularly at the base of the formation. Stylolitic and oncolitic bands are also common, although confined to marl and marly limestone parts of the

sequence. The youngest exposed part of the formation is characterized by marls extending beneath the Tertiary strata. A detailed lithologic column is shown in Figure 2.12. This unit is approximately 390 m thick in its type section, 400 m at Ban Huai Hin Fon, and 350 m thick at the Pha Daeng zinc mine. Late Aalenian-Early Bajocian age is assigned for the formation on the basis of the ammonites *Graphoceras* sp., *Eutmetoceras* sp. and *Docidoceras* sp.

According to Wirote Saengsrichan (2007), 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. The details of lithofacies in each formation are shown in Figures 2.13, 2.14, and 2.15 in ascending order as follows:

Khun Huai Formation

The type locality of the Khun Huai Formation lies along the unsealed road between Ban Khun Huai and Mae Sot power station. 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 boundary of the Khun Huai and Doi Yot Formations is represented by the gradational contact of coarse-grained to fine-grained sedimentary rocks.

This formation is approximately 93-345 m thick, consists mainly of 8 units as follow in ascending order:

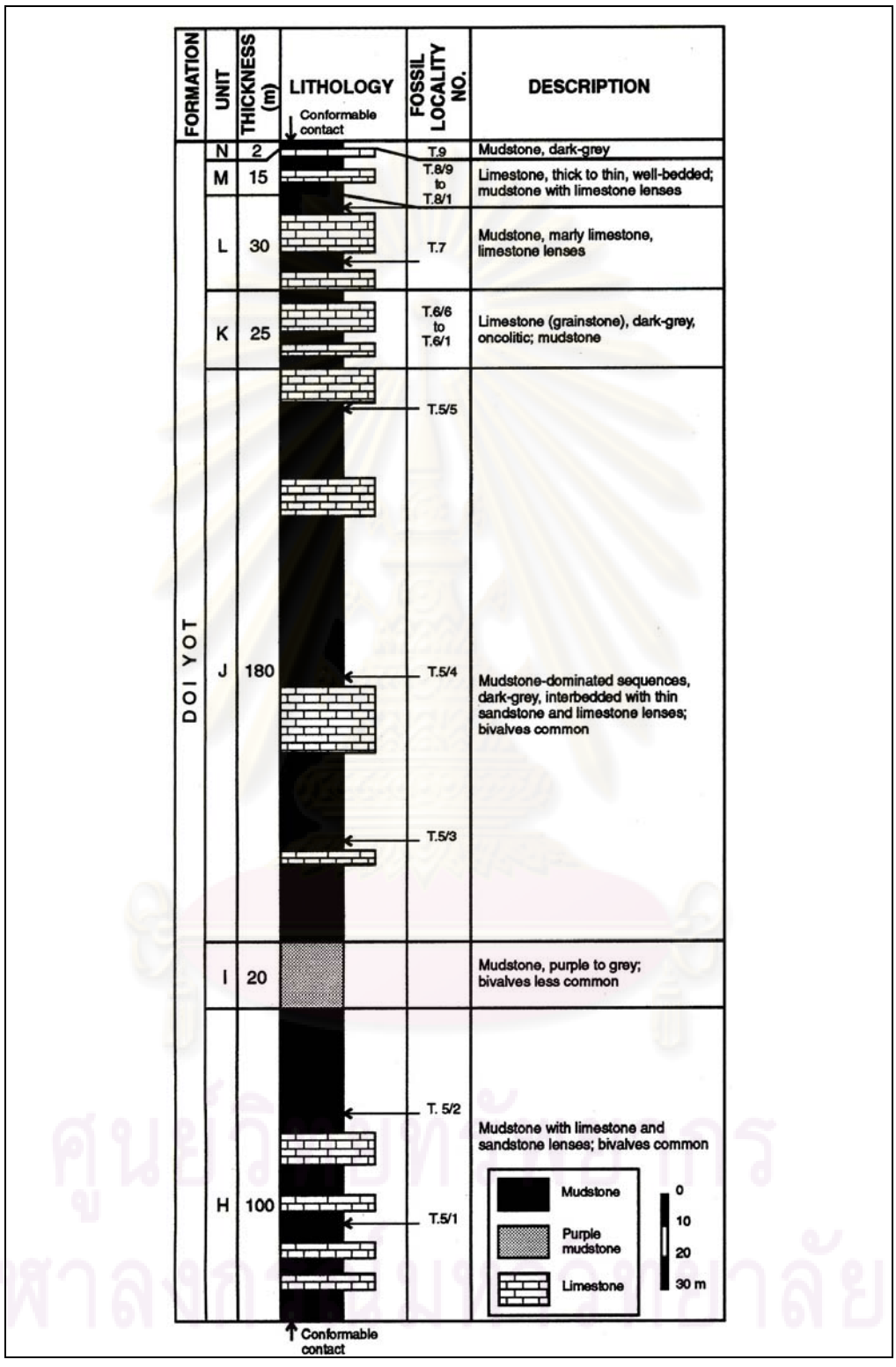


Figure 2.11. Lithologic column for the type section of the Doi Yot Formation (after Assanee Meesook and Grant-Mackie, 1996).

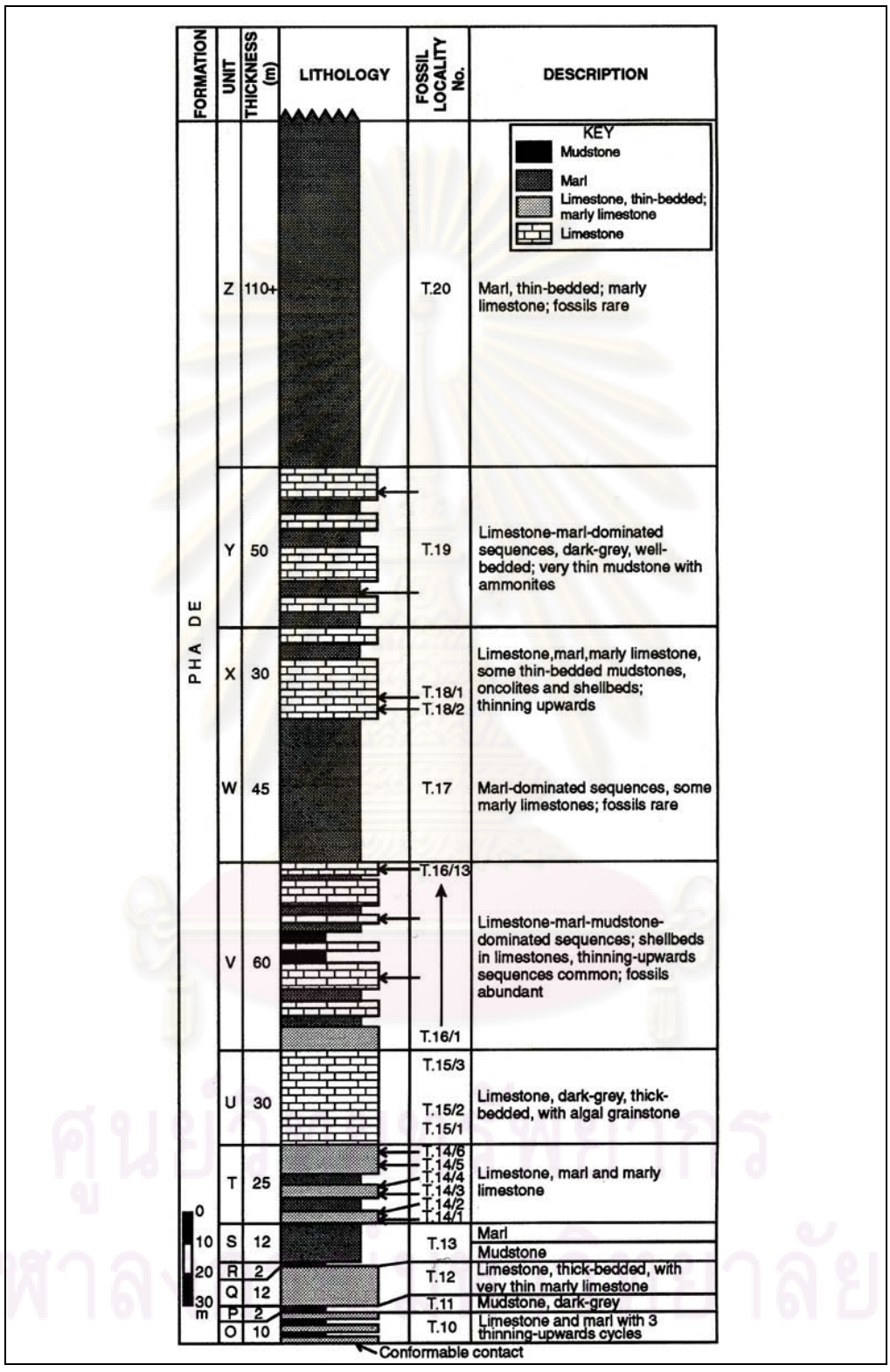


Figure 2.12. Lithologic column for the type section of the Pha De Formation (after Assanee Meesook and Grant-Mackie, 1996).

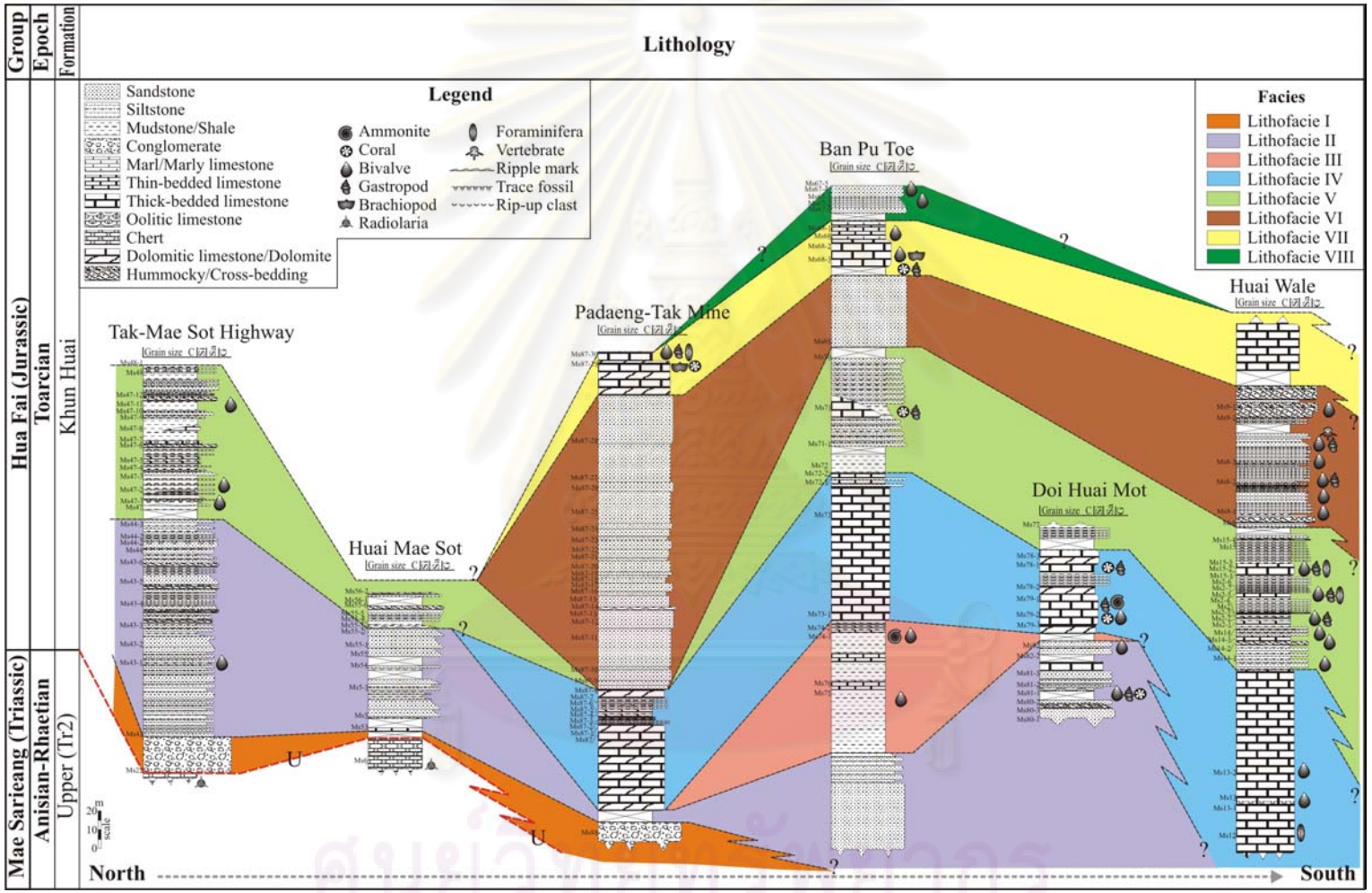


Figure 2.13. Detailed stratigraphic columns of the Khun Huai Formation at Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, Ban Pu Toe, Doi Huai mot and Huai Wale (after Wirote Saengsrichan, 2007).

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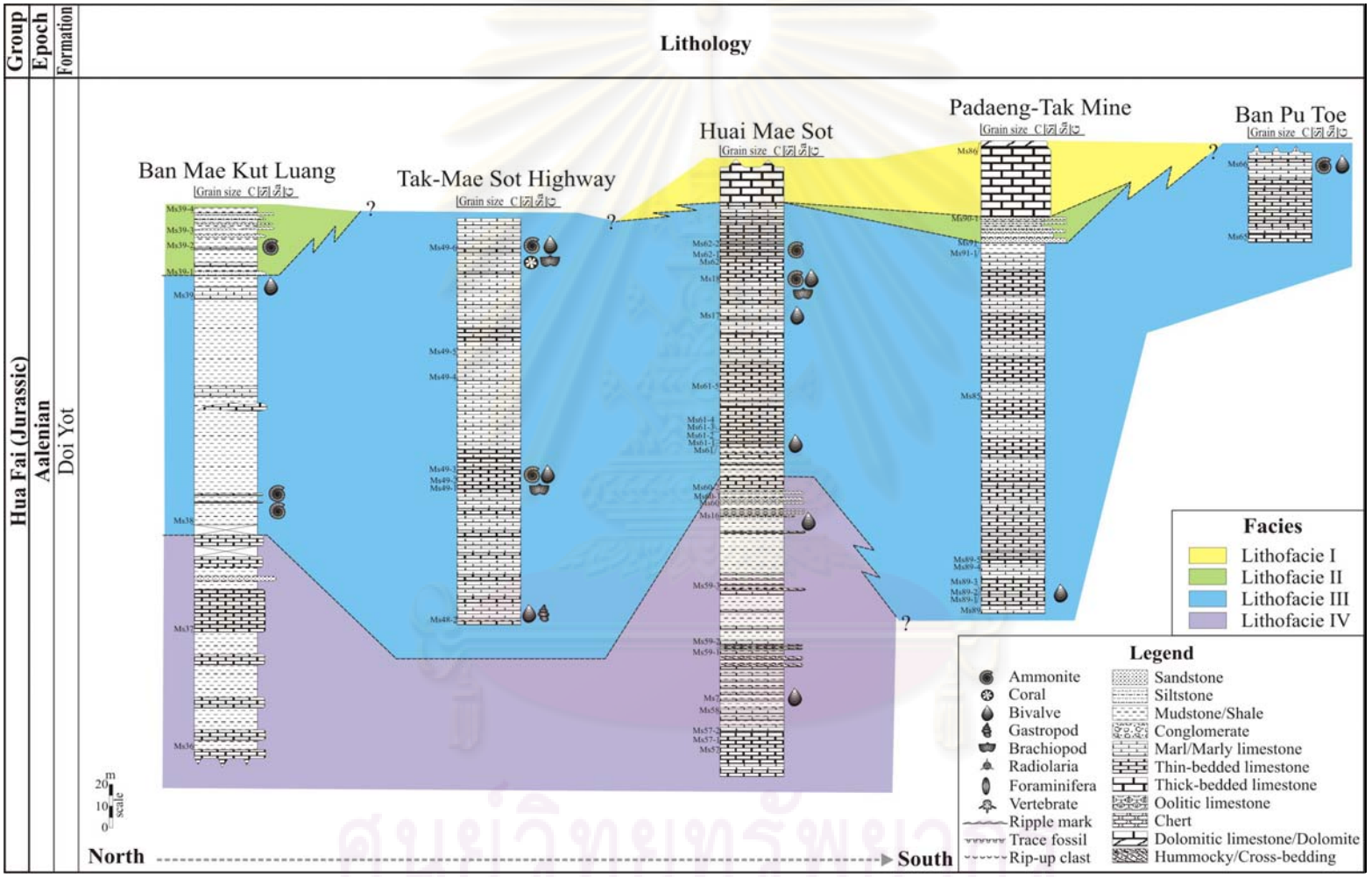

Figure 2.14. Detailed stratigraphic columns of the Doi Yot Formation at Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, and Ban Pu Toe (after Wirote Saengsrichan, 2007).

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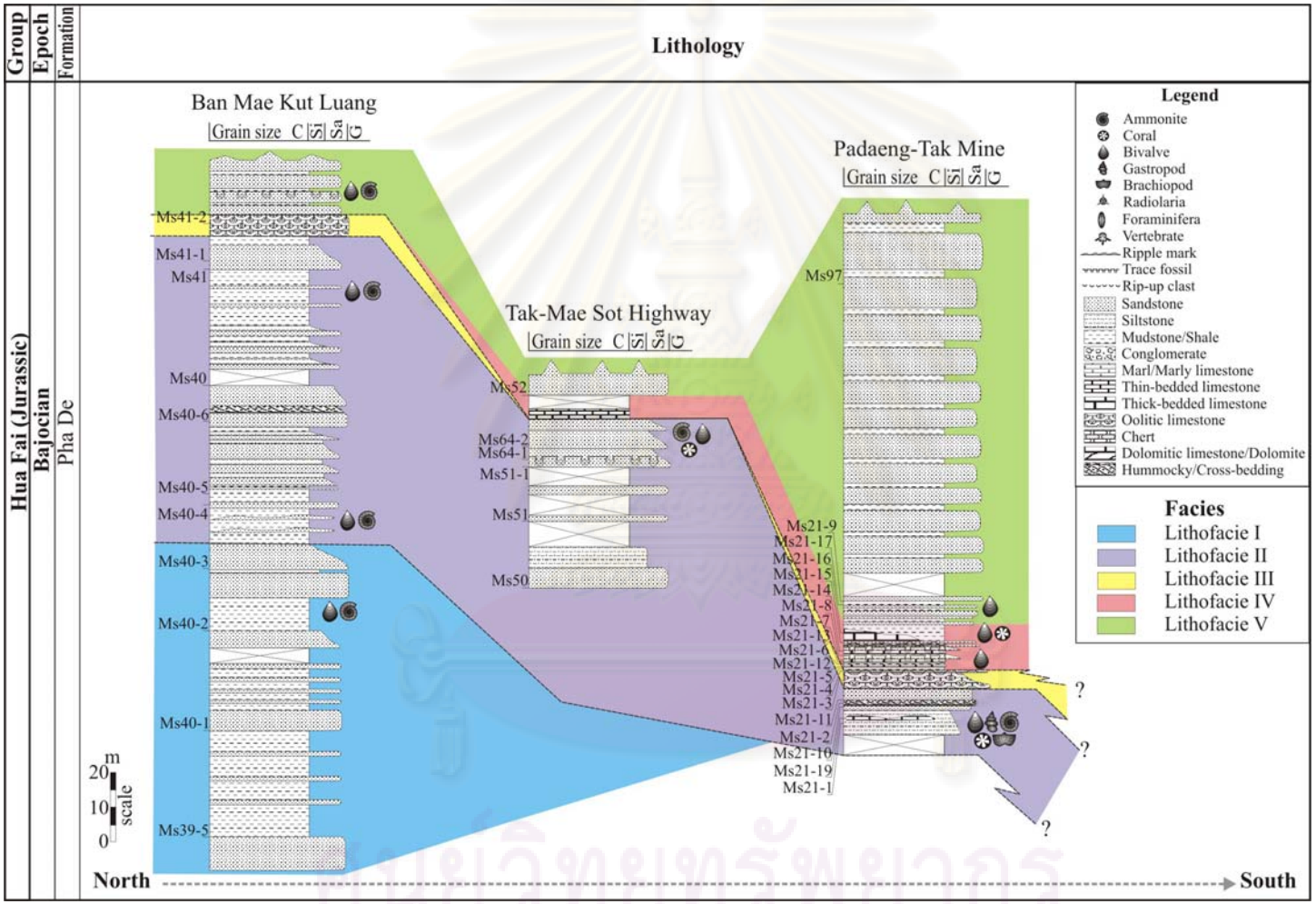

Figure 2.15. Detailed stratigraphic columns of the Pha De Formation at Ban Mae Kut Luang, Tak-Mae Sot Highway and Padaeng-Tak mine (after Wirote Saengsrichan, 2007).

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Unit I: the conglomerate, represented as locally basal conglomerate of the marine Jurassic basin in the Mae Sot-Phop Phra area.

Unit II: sandstone interbedded with mudstone and siltstone, The characteristic lithology of unit is brown to grey, medium- to thick-bedded, sandstone interbedded with mudstone and siltstone.

Unit III: shale intercalated with limestone, composed mainly of grey to greenish grey, thick-bedded, shale intercalated with dark grey, thick-bedded argillaceous limestone. The unit is well stratified of shale which contains common fossils of bivalves such as *Trigonia* sp., *Pteria* sp., *Parvamussium* sp., *Protocardia* sp., and ammonites.

Unit IV: limestone and dolomitic limestone, This unit is chacterized 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 consisting of the bivalves *Protocardia* sp., *Entolium* sp., and *Astarte* sp., gastropods, trace fossils, and ammonites.

Unit V: sandstone interbedded with mudstone and intercalated with limestone, The unit predominantly consists of alternating beds of sandstone, mudstone, limestone, and limestone lenses. The fossils contain abundant bivalves: *Grammatodon* sp., *Modiolus* sp., *Astarte* sp., *Parvamussium* sp., *Actinostreon* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Trigonia* sp., gastropods, trace fossils, foraminifera, and plant remains.

Unit VI: sandstone with oolitic limestone, 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 with abundant bivalves: *Modiolus* sp., *Astarte* sp., *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.?, gastropods, vertebrate, and plant remains.

Unit VII: limestone, 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 limestone Brachiopods, corals, gastropods, bivalves, foraminifera, and vertebrates are abundant.

Unit VIII: sandstone, This unit is mainly characterized by sandstone. The lower part consists of the sequence of brown, medium-bedded sandstone interbedded with grey, thin-bedded, clayey sandstone with slightly lamination. 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.

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., *Actinostreon* sp.?, *Myophorella* sp.?, *Protocardia* sp., *Thracia* sp., *Gervillia* sp., *Lycetia* sp., *Trigonia* sp., *Pteria* sp.? and *Camptonectes* sp. 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.

Doi Yot Formation

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 mountain. The Doi Yot Formation conformably overlies the Khun Huai Formation and conformably underlies the Pha De Formation at the type locality. 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.

This formation is approximately 40-266 m thick, mainly consists of 4 units as follow in ascending order :

Unit I: the limestone with mudstone, marl, and sandstone, 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 grey and dark grey limestone, mudstone, and marl contain common bivalves *Bositra* sp. *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.

Unit II: marl interbedded with mudstone and limestone, The unit consists mainly of the alternation of dark grey, medium- to thick-bedded marl, mudstone, and grey, medium- to thick-bedded, argillaceous limestone. This unit is characterized by the fine-grained sedimentary rocks. The marl and mudstone beds contain abundant and well preserved ammonites.

Unit III: mudstone intercalated sandstone, siltstone, and limestone, 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. 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.

Unit IV: limestone, The unit is composed mainly of grey to dark grey, thick to massive argillaceous limestone. Oolitic limestone layers are also present in several places.

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.

Pha De Formation

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.

This formation is approximately 67-221 m thick, mainly consists of 5 units in ascending order as follows:

Unit I: the mudstone interbedded with muddy calcareous sandstone, It predominantly consists of grey to dark grey, thick-bedded mudstone interbedded with grey to brown, thin- to thick-bedded calcareous sandstone. 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.

Unit II: muddy calcareous sandstone interbedded with mudstone, It is predominantly composed of greenish grey to brown, thick-bedded sandstone

interbedded with grey to greenish grey, medium- to thick-bedded mudstone. 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 *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).

Unit III: oolitic limestone, The characteristic lithology of this unit predominantly consists of grey to dark grey, thick-bedded oolitic limestone with hummocky cross bedding and lamination. The oolitic nucleus is composed of quartz, calcite, foraminifera, and fossiliferous grains with a concentric layer overgrowth.

Unit IV: mudstone with limestone, siltstone, and sandstone, 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. 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.

Unit V: and sandstone interbedded with mudstone, It is predominantly composed of brown, thick-bedded arkosic sandstone interbedded with grey to light grey, medium- to thick-bedded mudstone. The sandstone is mainly characterized by coarse-grained, subangular, moderately sorted aspects with lamination and cross lamination. The fossils contain common bivalves and ammonites.

According to previous paleontological studies by Assanee Meesook (1994) and Assanee 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.

The composite section has been made to combine and correlate the sedimentary sequences of all 7 measured sections of the Hua Fai Group (Wirote Saengsrichan, 2007), the total thickness varies from 200 to 832 m whereas the combined section is approximately 750 m. 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 2.16 and 2.17. 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.

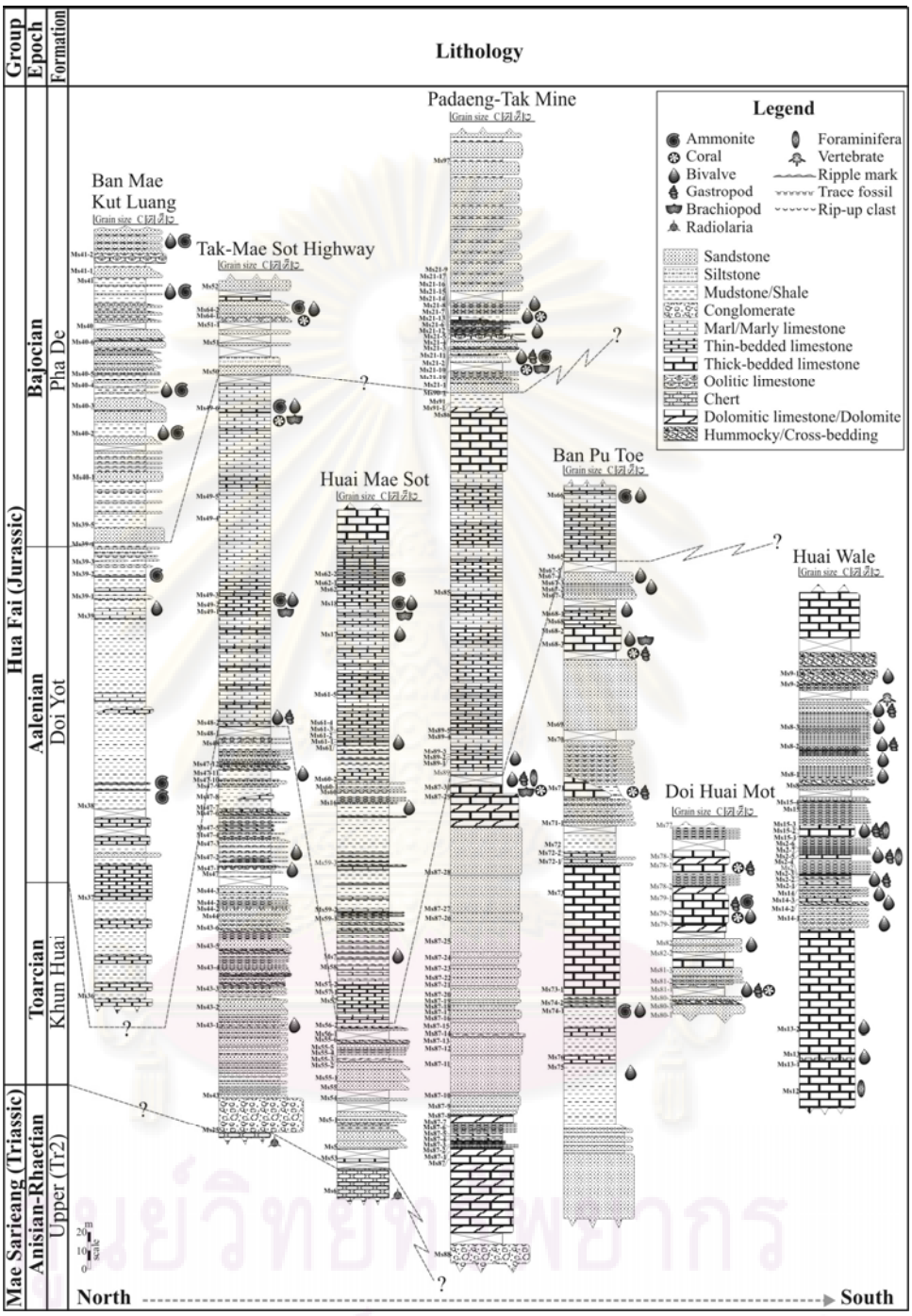


Figure 2.16. Correlation of the Hua Fai Group consisting of 3 Formations, the Khun Huai, Doi Yot, and Pha De Formations, in ascending order, with 7 measured sections include Ban Mae Kut Luang, Tak-Mae Sot Highway, Huai Mae Sot, Padaeng-Tak mines, Ban Pu Toe, Doi Huai Mot, and Huai Wale from north to south, respectively (after Wirote Saengsrichan, 2007).

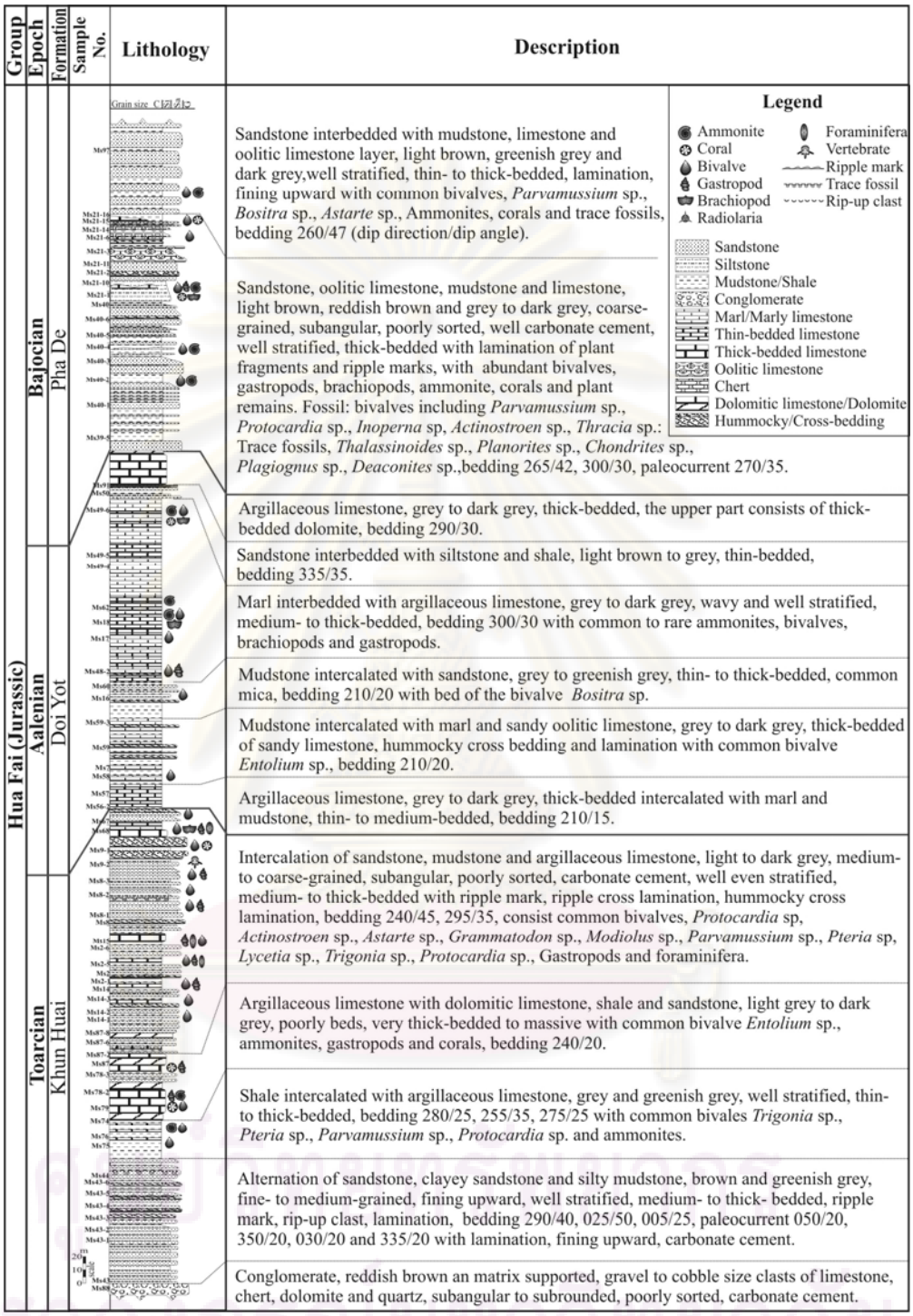


Figure 2.17. Composite section of the Hua Fai Group (after Wirote Saengsrichan, 2007).

CHAPTER III

RESULTS

3.1 Stratigraphy

The study area is located in Amphoe Mae Sot and Amphoe Phop Phra, Changwat Tak on the northwestern part of Thailand which located in the Shan-Thai Block (Sangad Bunopas, 1981).

Wirote Saengsrichan (2007) reported a details of marine Jurassic lithostratigraphy in the Mae Sot-Phop Phra basin based on the systematic mapping and lithostratigraphy of 7 measured sections across the Mae Sot-Phop Phra Basin, the Hua Fai Group can be subdivided into 3 formations and 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, in ascending order.

This study comprises two parts: field investigation and laboratory work. The main purpose of this study is to describe fossils systematically, especially bivalves and ammonoids, define biostratigraphy of marine Jurassic sedimentary rocks, and encourage and reconstruct the depositional environments of marine Jurassic basin. The field investigation method has been mainly involved with lithostratigraphy and palaeontology following 7 sections undertaken across the Mae Sot-Phop Phra Basin done by Wirote Saengsrichan (2007). During the field investigation, approximately 100 point samples have been collected from 7 traverse lines in the Mae Sot-Phop Phra area (Figure 3.1 and Figure 3.2). Details of 7 lines are listed as follows:

1. Ban Mae Kut Luang section in the north of the study area (map sheet 4742 IV).

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

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).

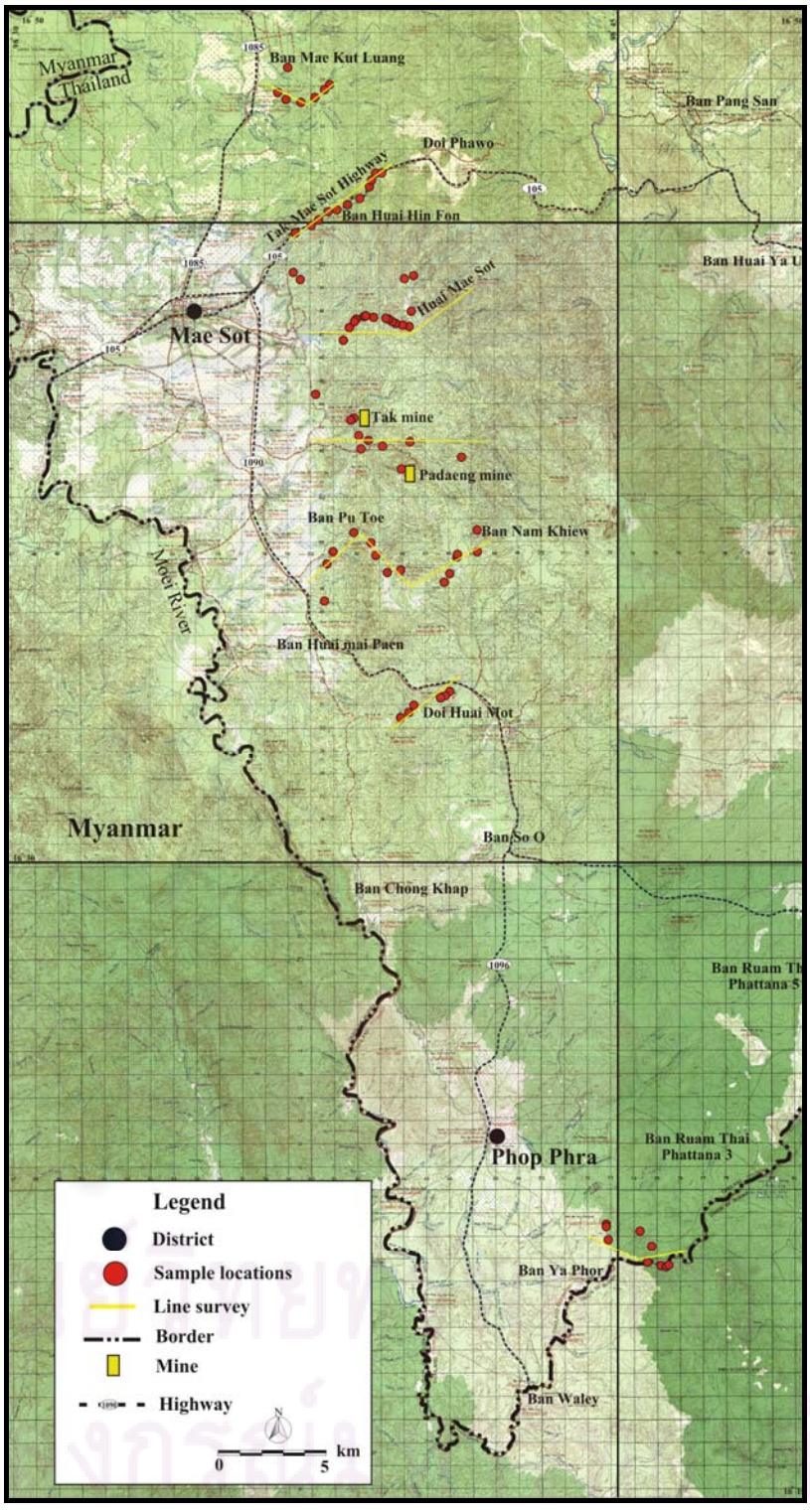


Figure 3.1. Topographic map of the study area showing 7 traverse lines (yellow) and 100 locations (red) of colleted fossil samples.

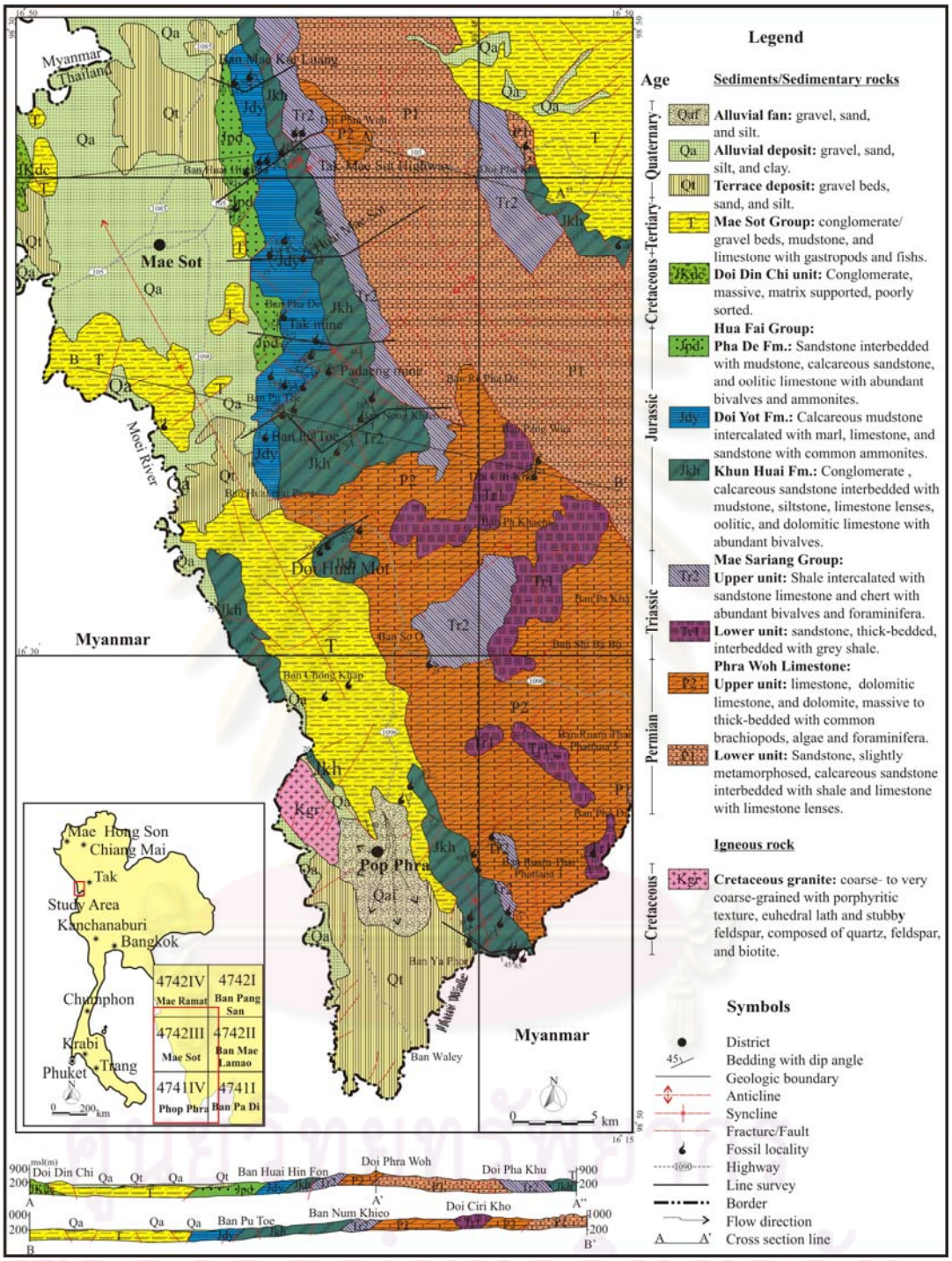


Figure 3.2. Geologic map of the study area showing 7 traverse lines and cross-sections showing the distribution, ages and simplified geological structures of lithologic units in Amphoe Mae Sot and Amphoe Phop Phra, Changwat Tak (after Wirote Saengsrichan, 2007).

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).

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

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

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).

3.1.1 Ban Mae Kut Luang section

The measured section is well exposed outcroups along the agriculture way from the east to the west which across the Hua Fai Group in N-S trending at Ban Mae Kut Luang, approximately 10 km north of the Mae Sot's township, Amphoe Mae Sot.

This section is composed mostly of mudstones, siltstones, sandstones, marl, limestone and oolitic limestone. Lithologic column of the Ban Mae Kut Luang section is summarised in Figure 3.3, done by Wirote Saengsrichan (2007). Mainly mudstones are grey to dark grey, thick- to thin-bedded, micaceous, calcareous and fossiliferous. The sandstone is characterized by very fine- to medium-grained, sub-angular to moderately rounded, moderately to well sorted, feldspatic, laminated, rip-up clasts and thin- to medium- beded. Fining upward sequences are present. The siltstone is dark grey, micaceous, calcareous and plant remains. The oolitic limestone is characterized by light grey, oolitic nucleus is composed of quartz, calcite, foraminifera, and fossiliferous grains with a concentric layer overgrowth. The upper unit at Ban Mae Kut Luang section is characterized by sandstone interbedded with siltstone, thin-bedded, very fine-grained, having fining upward sequence. Photographs of some marine Jurassic rocks at Ban Mae Kut Luang from the base to the top are selected to be shown respectively in Figures 3.4. The section, approximately 460 m thick, includes 11 sample locations, 31 points

of fossil samples are collected. The general dip direction of bedding planes at this measured section is in the southwestern direction (250°-280°) with moderately dipping angles (35°-50°).

Fossil assemblages are abundant and diverse, and have been found through the section and common in dark grey mudstones (Figures 3.5). These faunas contain marine bivalves including *Bositra ornati* (Quenstedt), *Camptonectes* sp., *Entolium* sp., *Grammatodon* sp., *Parvamussism donaiense* (Mansuy), *Pinna* sp., *Modiolus* sp., *Goniomya* sp., *Thracia* sp., and *Pecten?* sp., ammonoids; *Tmetoceras* sp. and *Harpoceras* sp., rhynchonellid brachiopods, trace fossils; *Chondrites* isp. and *Taenidium* isp., coral and plant remains.

3.1.2 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 Amphoe Mae Sot. This section done by Wirote Saengsrichan (2007), the lithostratigraphic column is shown in Figure 3.6. The total thickness is approximately 470 m, and 6 sample locations, 15 points of fossil samples have been collected from shale, mudstone, siltstone, limestone, and marl.

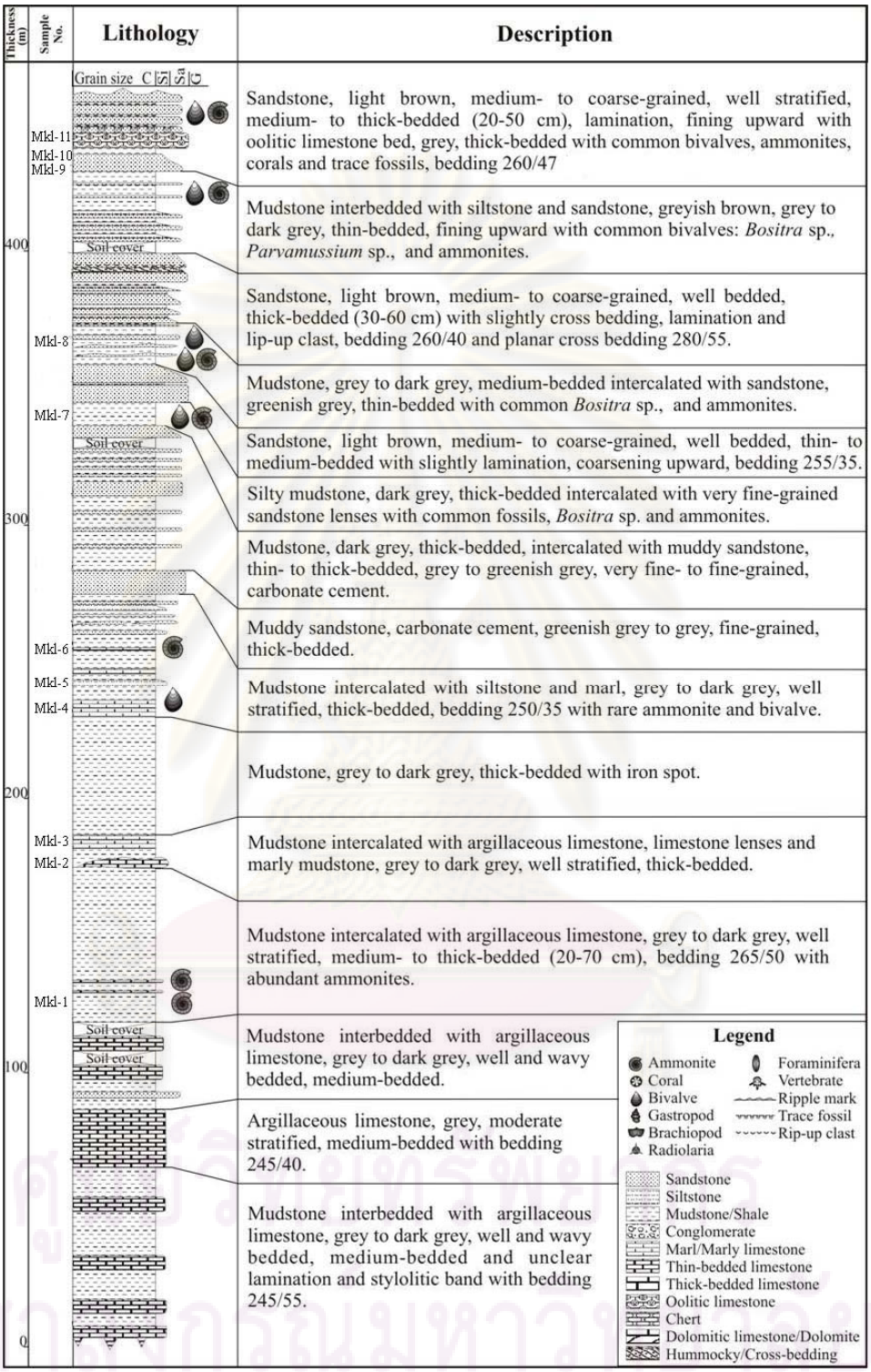


Figure 3.3. Lithostratigraphic column of the Hua Fai Group at Ban Mae Kut Luang, Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sampling locations.

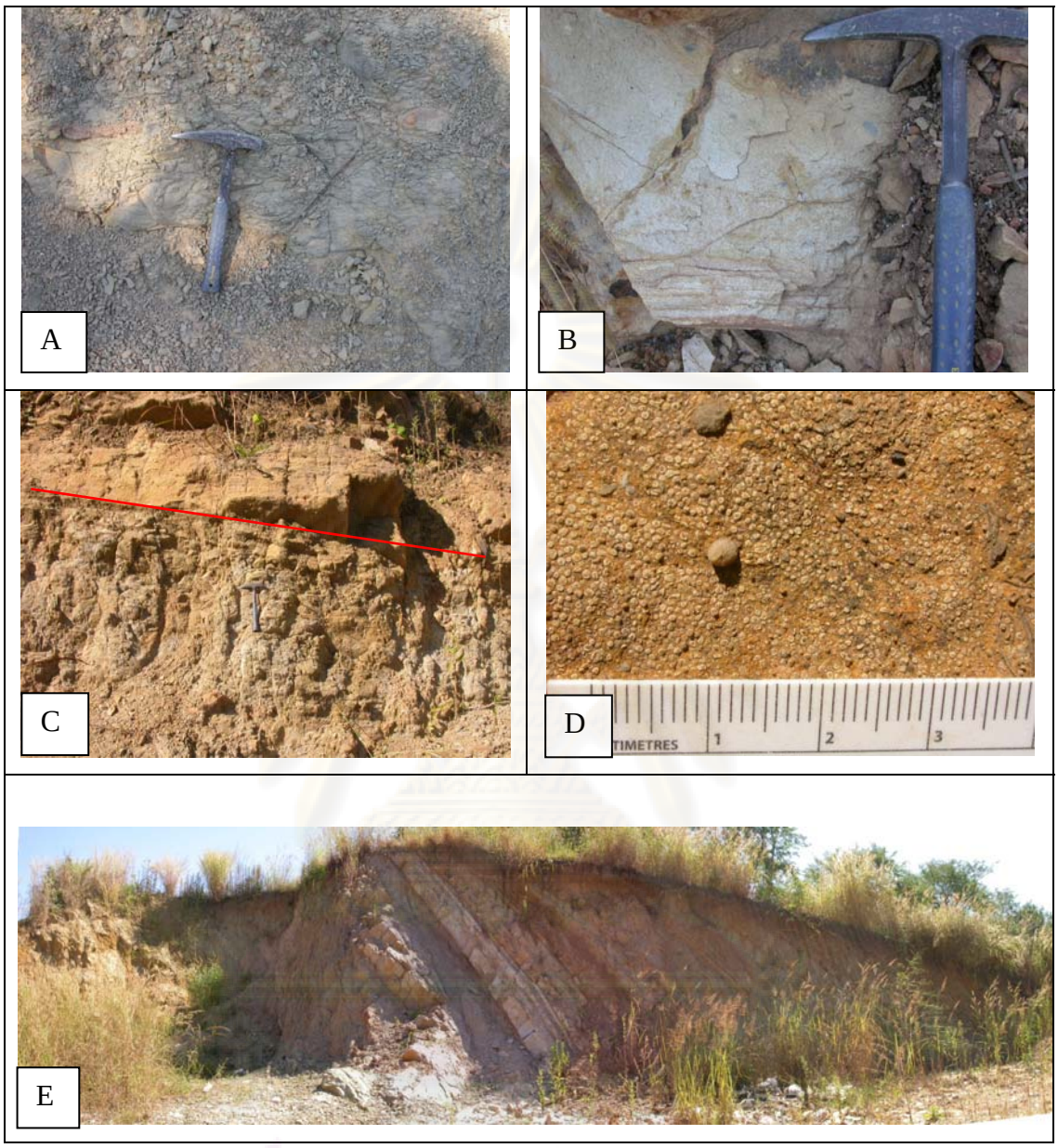


Figure 3.4. Photographs of the Ban Mae Kut Luang section, dark grey mudstones (A), sandstone showing rip-up clasts (B), sandstone (bottom) and oolitic limestone (top) (C), closed-up photographs of oolitic limestone (D), and sandstone interbedded with siltstone, and mudstone (parallel even bed) (E) in the upper part of section showing fining and thining upward sequecce of the Pha De Formation.

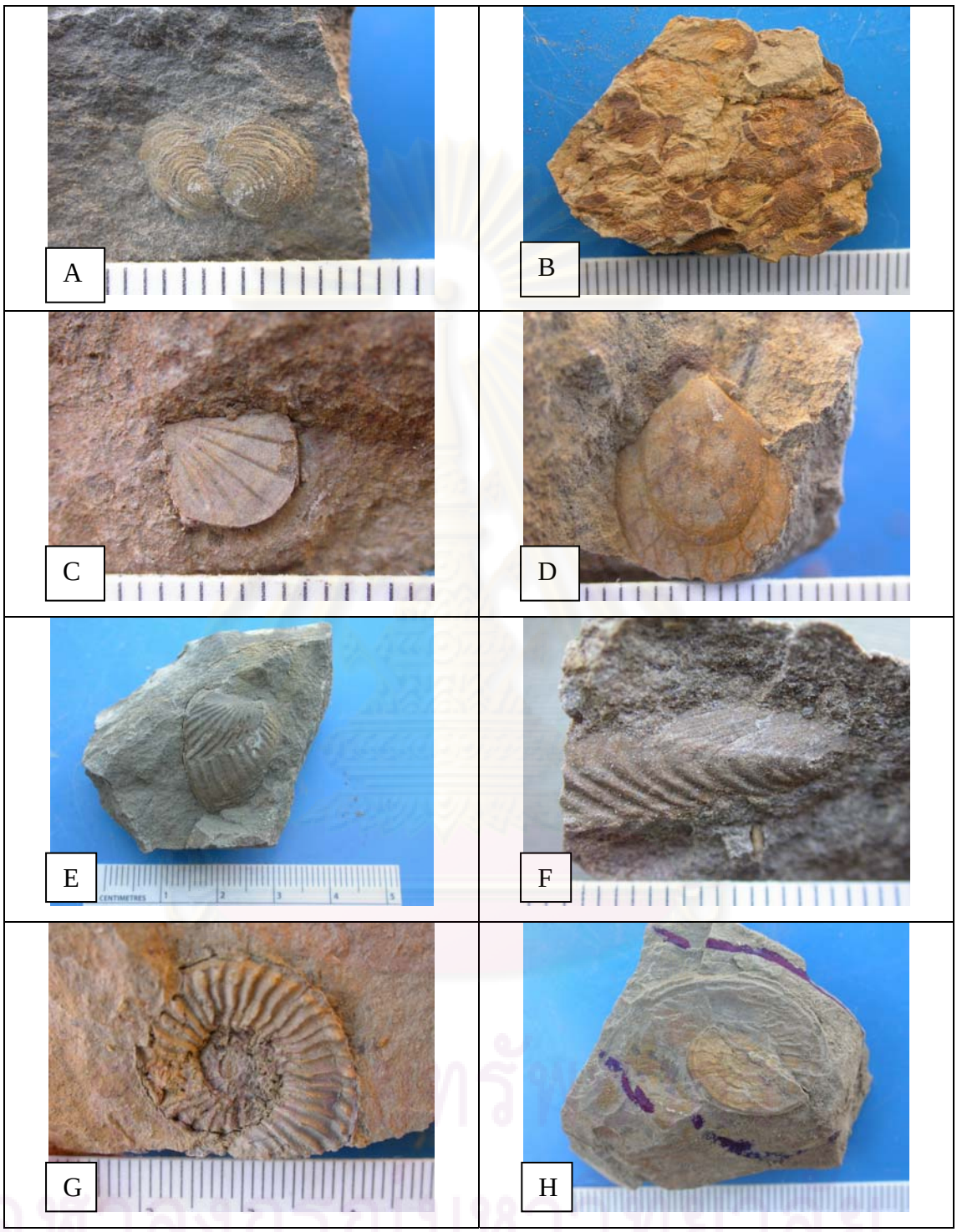


Figure 3.5. Photographs of faunas at the Ban Mae Kut Luang section, *Bositra ornati* (Quenstedt) (A and B), *Parvamussism donaiense* (Mansuy) (C), *Entolium* sp. (D), *Goniomy* sp. (E), *Pinna* sp. (F), and ammonoids; *Tmetoceras* sp. (G), and *Harpoceras* sp. (H).

This section is composed of mudstones, siltstones, sandstones, marl and limestone. The lower part (140 m thick) comprises mainly conglomerate, muddy sandstone interbedded with siltstone with lamination and rip-up clast, sandstone intercalated with silty mudstone, fining upward and well tratified, muddy sandstone intercalated with siltstone, fining upward and well stratified. The middle part (160 m thick) comprises mainly mudstone intercalated with sandstone, siltstone, argillaceous limestone lenses, fining upward and ripple marks with common bivalves, intercalation of sandstone, shale, argillaceous limestone and siltstone with common bivalves, sandstone with ripple marks, mudstone interbedded with sandstone, and marl interbedded with argillaceous limestone with common ammonite but not well preserved. The upper part (170 m thick) comprises mainly marl intercalated with argillaceous limestone with abundant ammonites, sandstone with plant remains, and sandstone, mudstone, siltstone, and argillaceous limestone lenes with abundant bivalves, ammonites, trace fossils and plant remains. Photographs of Tak-Mae Sot Highway section are selected to be shown in Figures 3.7. The general dip direction of bedding planes at this measured section varies from west to northeast (230°-300° and 5°-215°) with moderately dipping angles (20°-55°).

Fossil assemblages have been found and they are common in dark grey mudstones, siltstone, marl and limestone (Figures 3.8). These faunas contain marine bivalves including *Bositra ornati* (Quenstedt), *Parvamussism donaiense* (Mansuy), *Goniomya* sp., *Pholadomya* sp., *Protocardia* sp., *Entolium* sp., *Pinna* sp., *Grammatodon* sp., *Trigonia* sp., *Thracia?* sp., *Ceratomya?* sp., *Plagiostoma?* sp., and *Pecten?* sp., ammonoids; *Harpoceras* sp., *Tmetoceras* sp., rhynchonellid brachiopods, trace fossils, and plant remains.

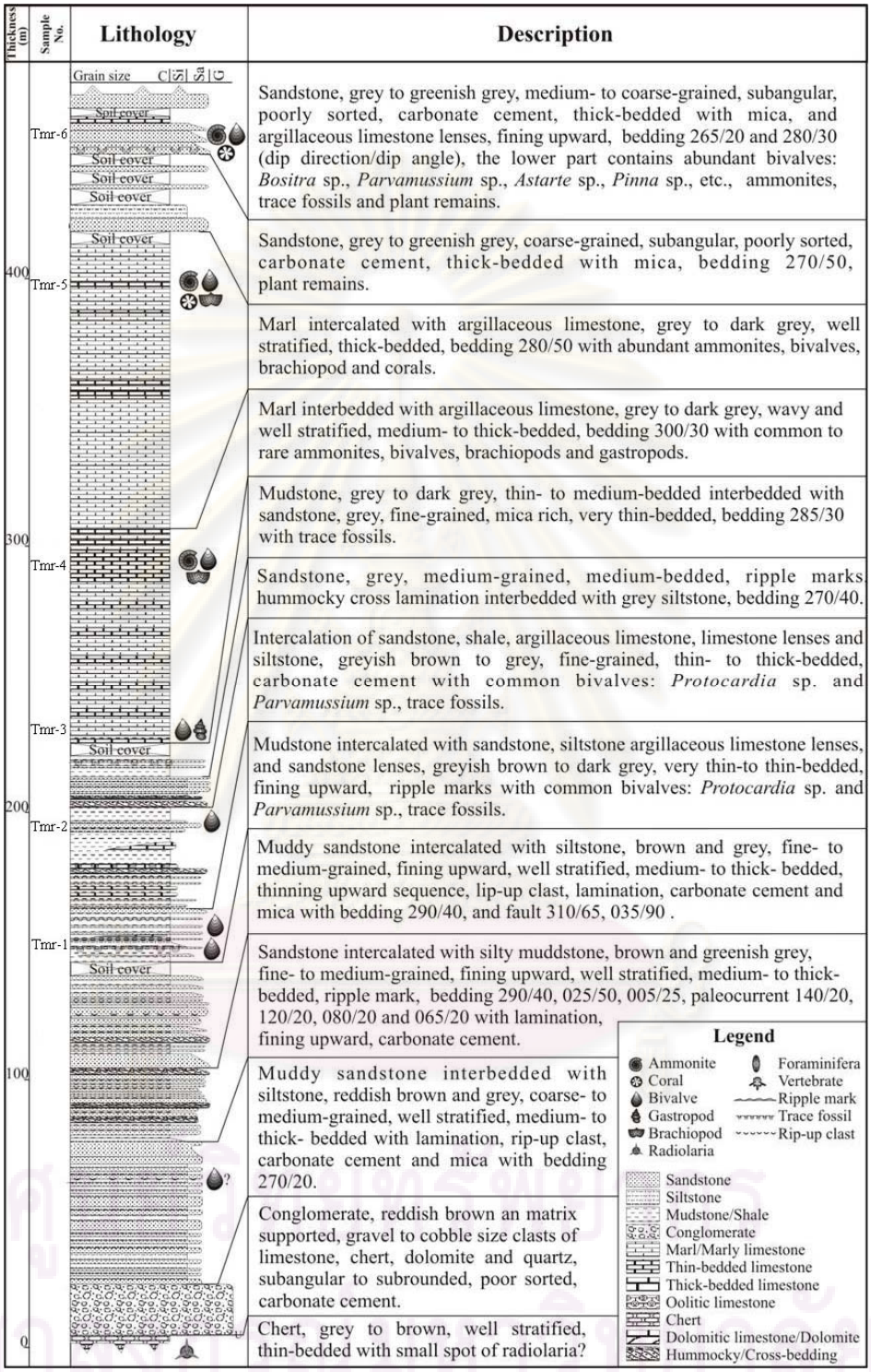


Figure 3.6. Lithostratigraphic column of the Hua Fai Group at km 67-71 on the Tak-Mae Sot Highway, 7 km northeast of Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sample locations.

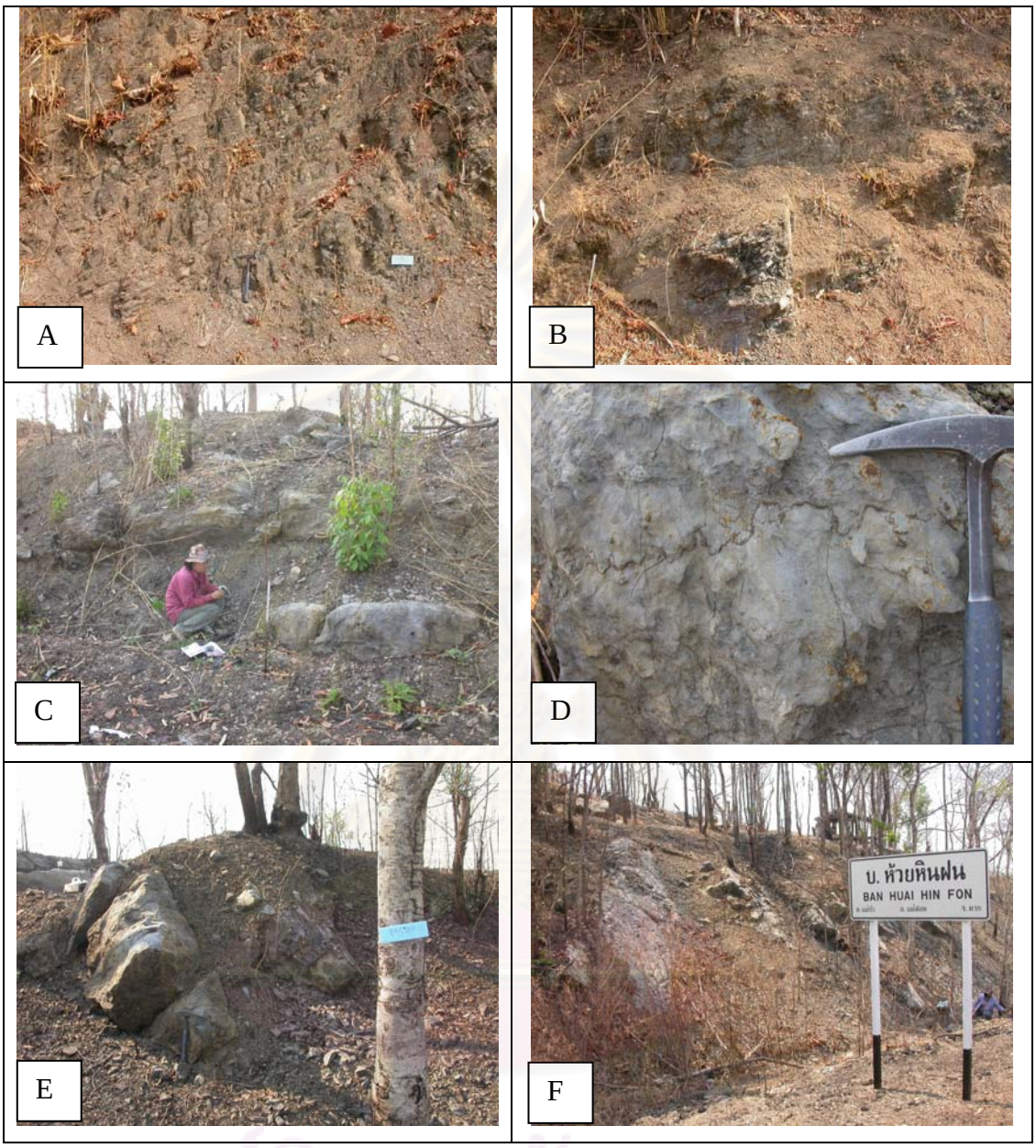


Figure 3.7. Photographs of the Tak-Mae Sot Highway section, mudstone intercalated with sandstone, siltstone and argillaceous limestone lenses (A), intercalation of sandstone, shale, argillaceous limestone and siltstone (B), mudstone, siltstone interbedded with argillaceous limestone (C), argillaceous limestone with stylolites (D), and thick-bedded marl intercalated with argillaceous limestone (E and F).

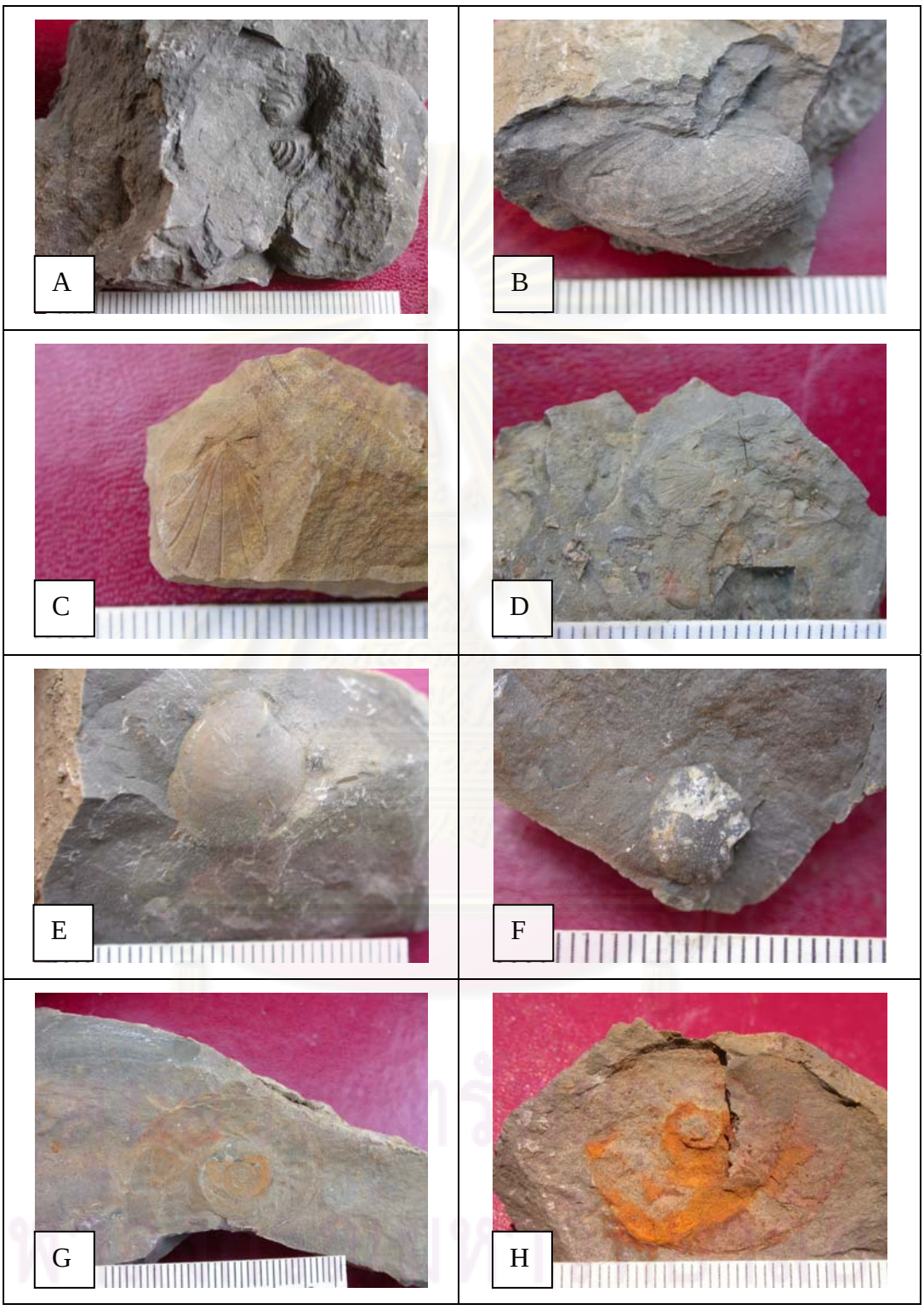


Figure 3.8. Photographs of fossils at the Tak-Mae Sot Highway section, *Trigonia* sp. (A), *Pholadomya* sp. (B), *Parvamussism donaiense* (Mansuy) (C and D), *Protocardia*? sp. (E), brachiopod (F), and ammonoid *Harpoceras* sp. (G and H).

3.1.3 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. 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 approximately 380 m, and 20 sample locations, 32 points of fossil samples (Figure 3.9) have been collected from mudstone, siltstone, limestone, and marl.

This section is composed of mudstones, siltstones, sandstones, marl and limestone. The lower part (100 m thick) comprises mainly sandstone, thin to medium bed intercalated with siltstone and mudstone, fining upward. The middle part (120 m thick) comprises mainly argillaceous limestone, marl interbedded with mudstone, medium to thick bed, mudstone intercalated with marl, and mudstone intercalated with sandstone, thin to thick bedded with bivalve *Bositra* sp. The upper part (160 m thick) comprises mainly marl interbedded with mudstone and argillaceous limestone, medium to thick-bedded, and argillaceous limestone interbedded with marl, well stratified, medium to thick-bedded with abundant ammonites and brachiopod. Photographs of Huai Mae Sot section are selected to be shown in Figures 3.10. The general dip direction of bedding planes at this measured section varies from southwest to west (210°-290°) with gentle to moderately dipping angles (15°-50°).

Fossil assemblages have been found in dark grey mudstones, siltstone, marl and limestone (Figures 3.11 and 3.12). These faunas contain marine bivalves including *Bositra ornati* (Quenstedt), *Pinna* sp., *Grammatodon* sp., *Goniomya* sp., *Pholadomya* sp., *Protocardia* sp., *Actenostreon* sp., *Thracia* sp., *Gervillia* sp., *Homomya* sp., *Trigonia* sp., *Pecten?* Sp., and *Entolium* sp., ammonoids; *Tmetoceras* sp. *Harpoceras* sp., and ammonoite sp.A, rhynchonellid brachiopods, telebratulid brachiopods, Nerinellid gastropod, coral, trace fossils: *Chondrites* isp., and plant remains.

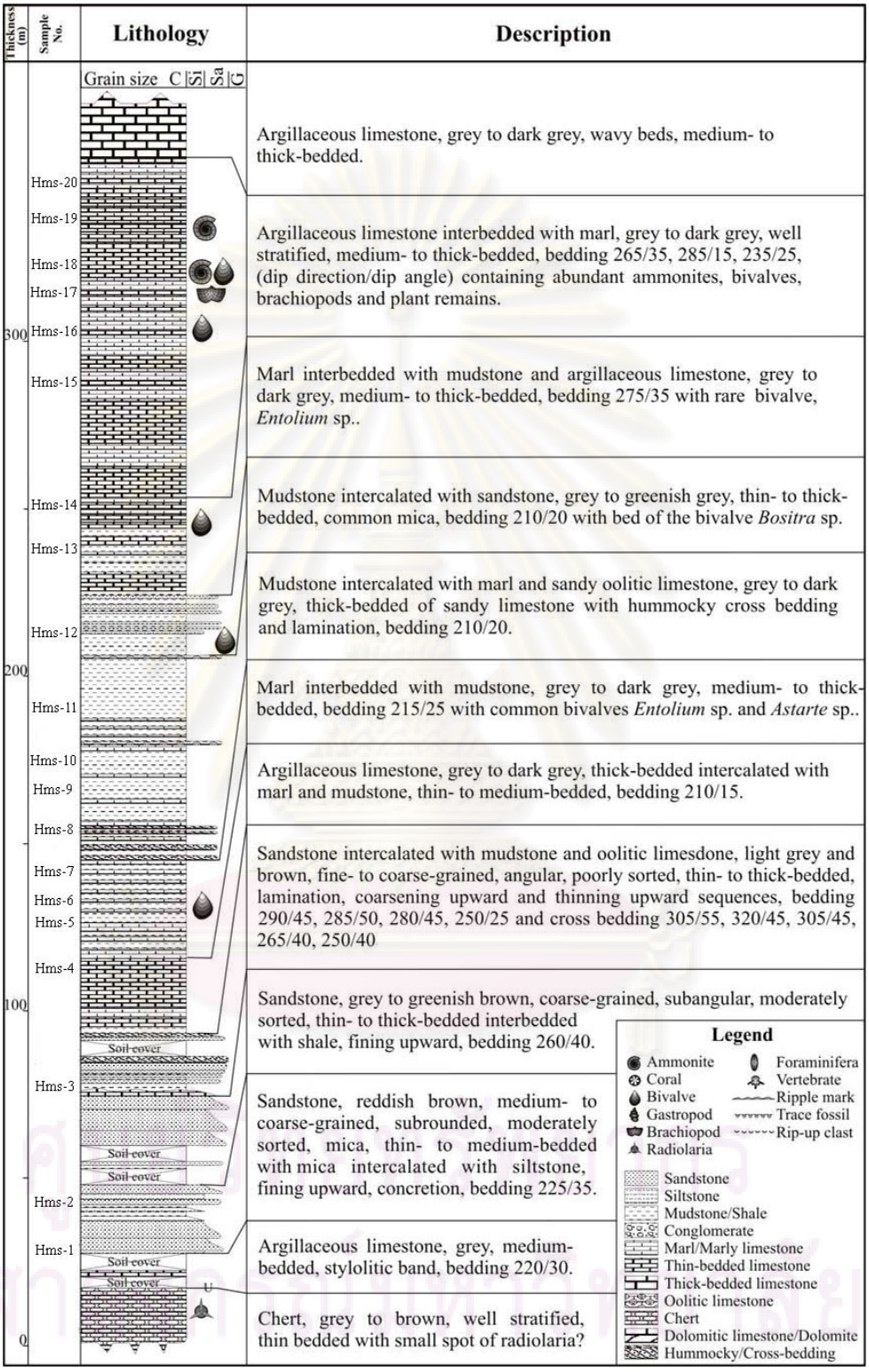


Figure 3.9. Lithostratigraphic column of the Hua Fai Group at Huai Mae Sot, Mae Sot power station's canal, and Ban Khun Huai Mae Sot, Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sample locations.

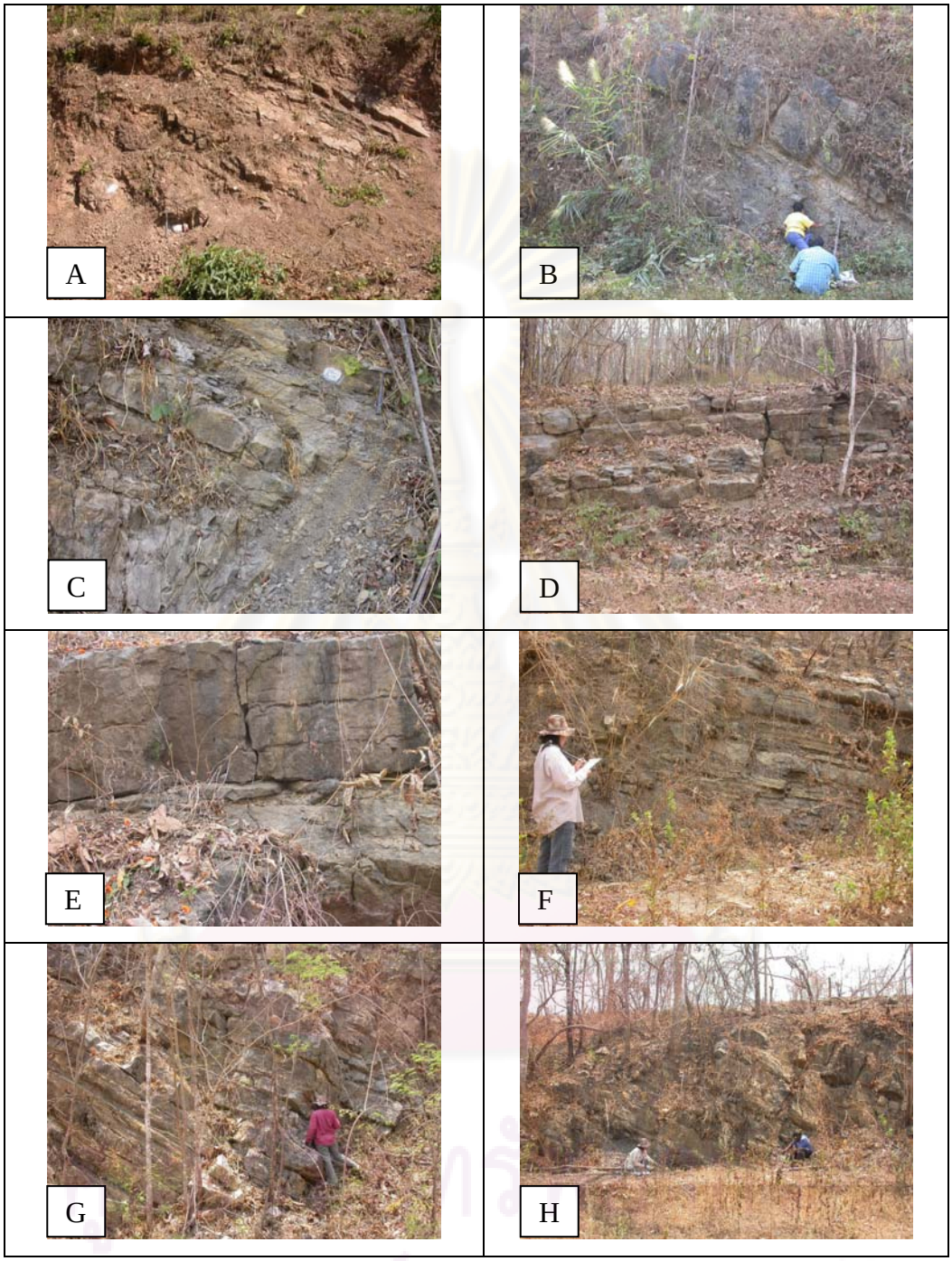


Figure 3.10. Photographs of the Huai Mae Sot section, siltstone interbedded with mudstone and sandstone, reddish brown and micaceous (A), mudstone interbedded with marl and limestone (B, C and D), stylolites in limestone (E), marl, mudstone, and limestone dominated, thin to thick bed (F), mudstone, and marl dominated, dark grey, medium to thick bed (G), and marl, mudstone and limestone dominated (H).

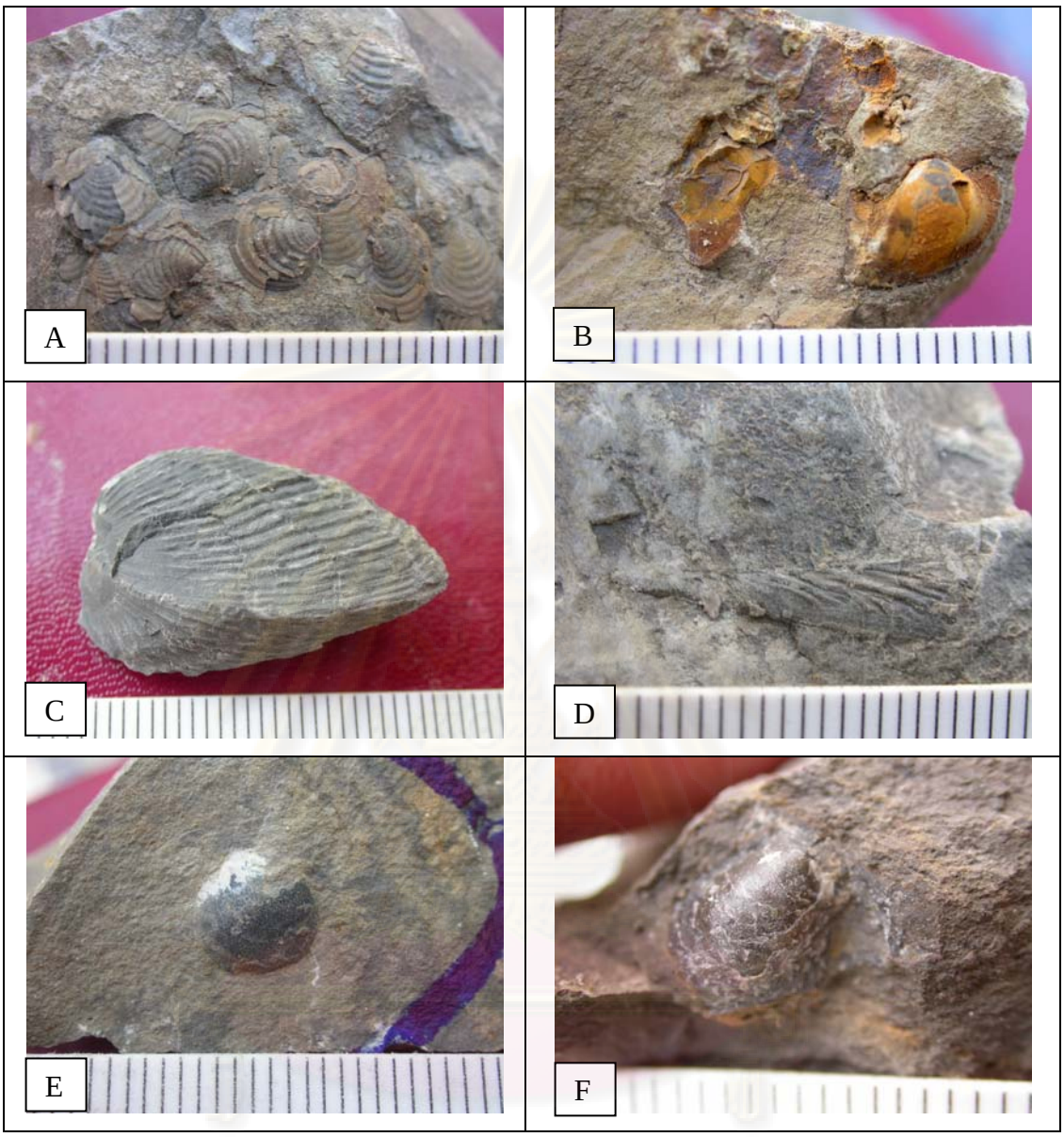


Figure 3.11. Photographs of fossil bivalves at the Huai Mae Sot section, abundant *Bositra ornati* (Quenstedt) in dark grey mudstone (A), *Grammatodon* sp. (B), *Pholadomya* sp. (C), *Pinna* sp. (D), *Entolium* sp. (E), and *Actenostreon* sp. (F).

Figure 3.12. Photographs of fossils at the Huai Mae Sot section, ammonites at the upper part of section (A and B), brachiopod: telebratulid (C) and rhychonellid (D), coral (E) and gastopod: nerinellid (F) in limestone.

3.1.4 Padaeng-Tak mines section

The section is well exposed along Huai Mae Taow, at Ban Pha De, Tak mine, Padaeng mine, and Ban Khao Tham Sua. The section, approximately 622 m thick, includes 4 sample locations (Figure 3.13) collected from shale, limestone and marl with fossiliferous beds.

This section is composed largely of conglomerate, mudstones, siltstones, sandstones, marl, limestone and oolitic limestone. The lower part (230 m thick) comprises mainly conglomerate with matrix-supported, and poorly sorted, dolomitic limestone, very thick bedded, intercalation of sandstone, shale, argillaceous limestone and oolitic limestone, well stratified, thick-bedded, and sandstone, medium- to very coarse-grained, well stratified, medium- to thick-bedded with lamination. The middle part (280 m thick) comprises mainly dolomitic limestone, fossiliferous limestone intercalated with oolitic limestone, well stratified, thick-bedded with common bivalves, brachiopods, gastropods, corals and foraminifera, and marl interbedded with argillaceous limestone, well stratified, thick-bedded with common bivalves and ammonites. The upper part (112 m thick) comprises mainly mudstone, thick-bedded, sandstone interbedded with siltstone and shale, thin-bedded, argillaceous limestone, thick-bedded, sandy siltstone, sandstone, well stratified, thick- bedded, oolitic limestone, thick-bedded, mudstone interbedded with argillaceous limestone, well stratified, medium- to thick-bedded with common bivalves, siltstone interbedded with mudstone and sandstone, well stratified, thin- to medium-bedded with lamination and ripple mark, contain abundant trace fossils, and sandstone interbedded with mudtone, well stratified, thin- to thick-bedded, coarsening upward sequence. Photographs of Padaeng-Tak mines section section are selected to be shown in Figures 3.14. The general dip direction of bedding planes at this measured section varies from west to north (0°-265°) with gently dipping angles (22°-45°).

Fossil assemblages have been found in dark grey mudstones, siltstone, marl and limestone (Figures 3.15). These faunas contain marine bivalves including *Bositra ornati* (Quenstedt), *Thracia* sp., *Parvamussim ornati*, *Actenostreon* sp. and *Lima?* sp., ammonoids; *Tmetoceras* sp., rhynchonellid brachiopods, telebratulid brachiopods, Nerinellid gastropod, coral, trace fossils: *Chondrites* isp., and plant remains.

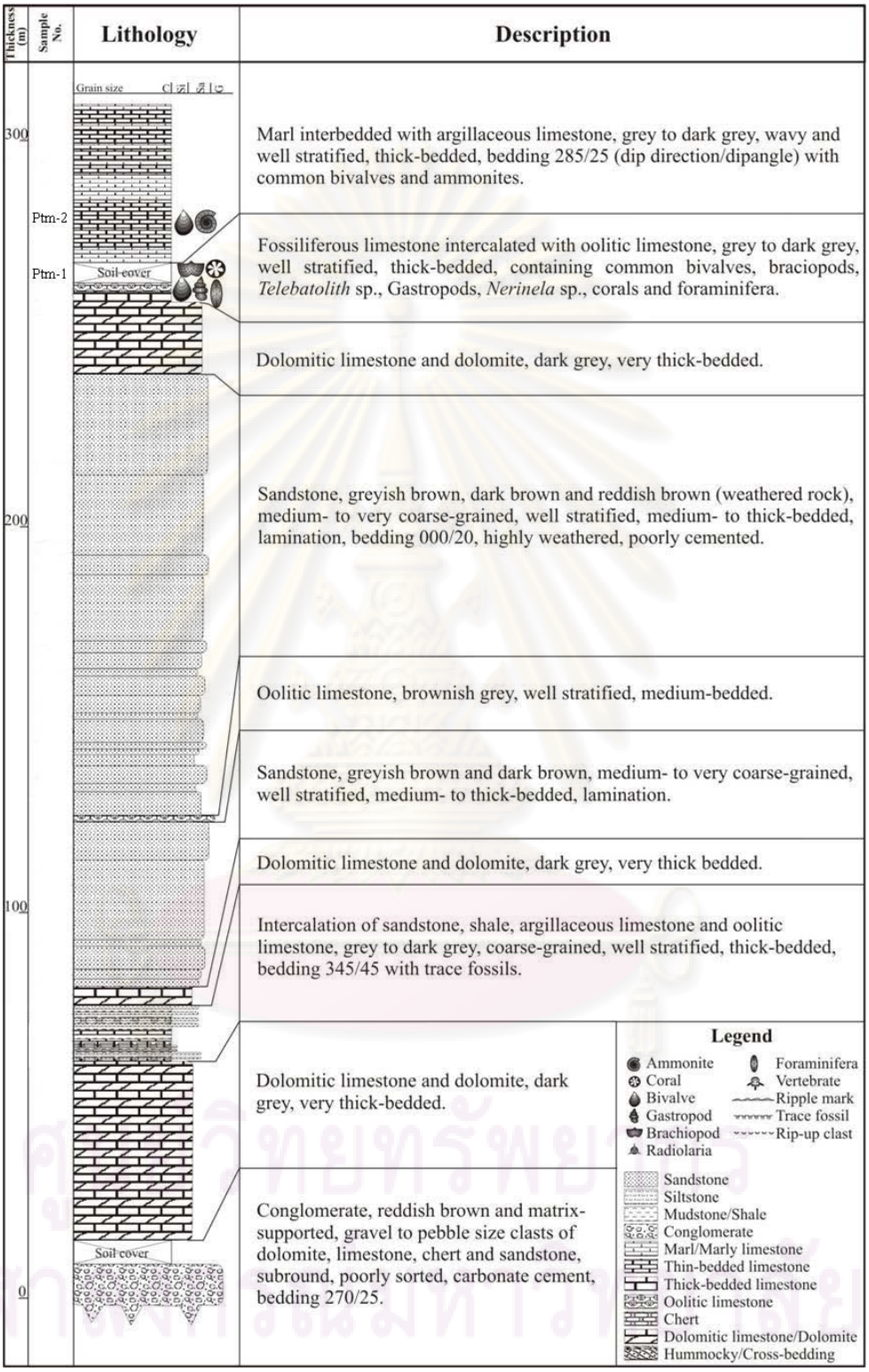


Figure 3.13. Lithostratigraphic column of the Hua Fai Group at the local road and Huai Mae Taow, 12 km southeast of Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sample locations.

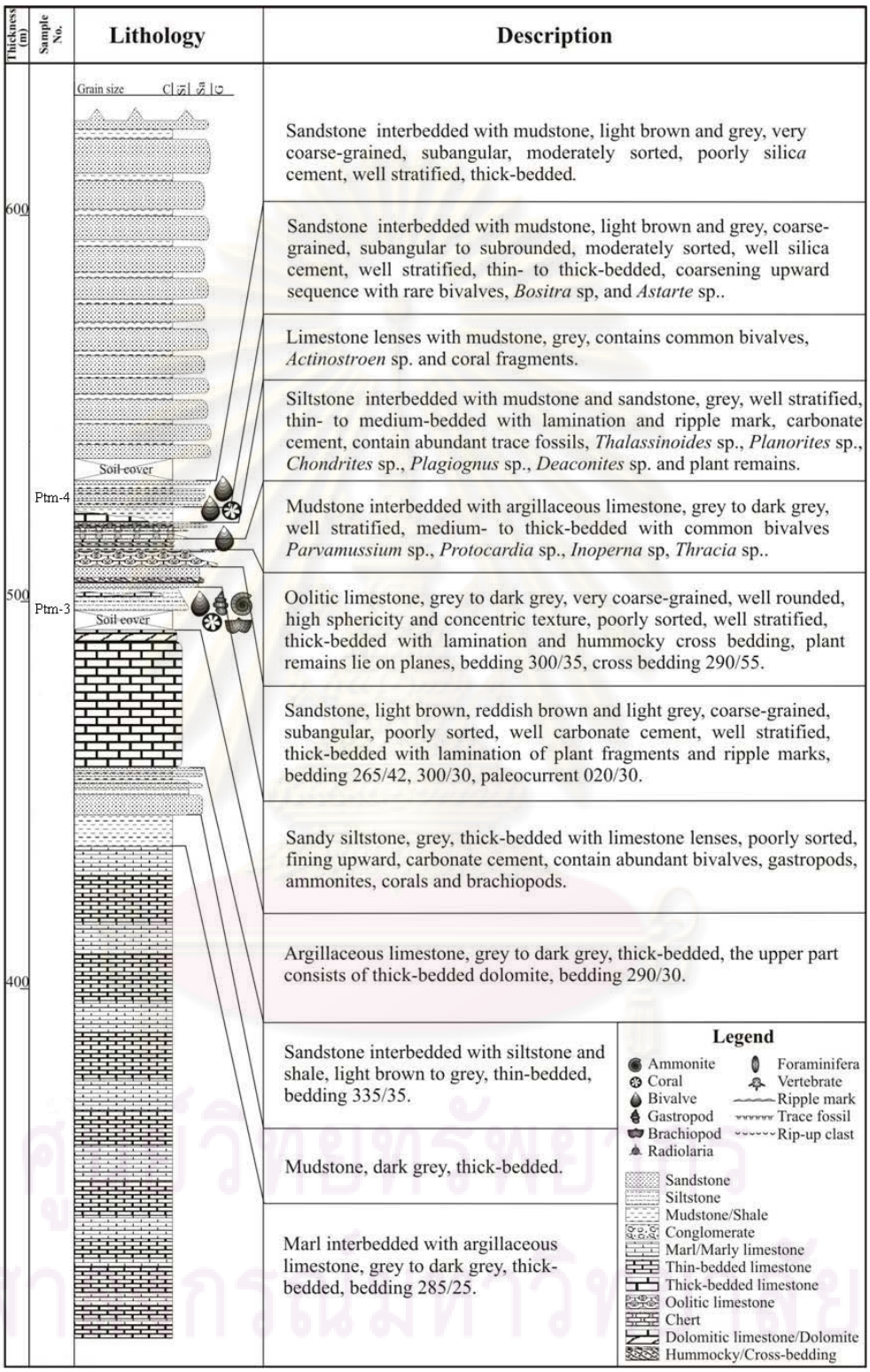


Figure 3.13. Lithostratigraphic column of the Hua Fai Group at the local road and Huai Mae Taow, 12 km southeast of Amphoe Mae Sot (continued) (Wirote Saengsrichan, 2007), showing the number of sample locations.

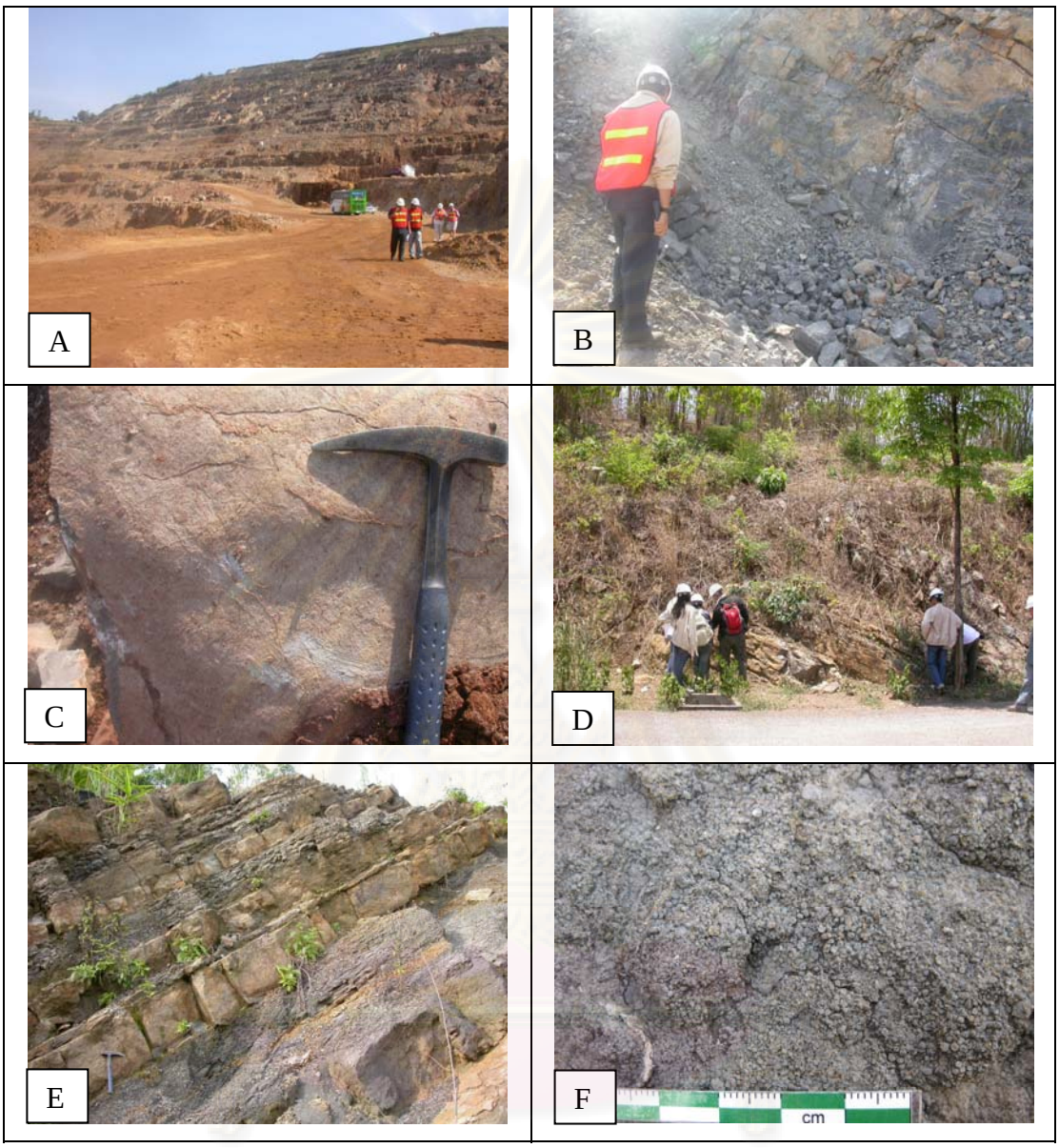


Figure 3.14. Photographs of the Padaeng-Tak mines section, sandstone interbedded with mudstone in the upper part of section at the Padaeng mine (A), dark grey limestone at the Padaeng mine (B and C), mudstone with bivalves and ammonites at the Padaeng mine (D), sequence of limestone interbeded with mudstone, dark grey, thick-bedded, with common bivalves at Tak mine (E), and closed-up of oolitic limestone at Tak mine (F).

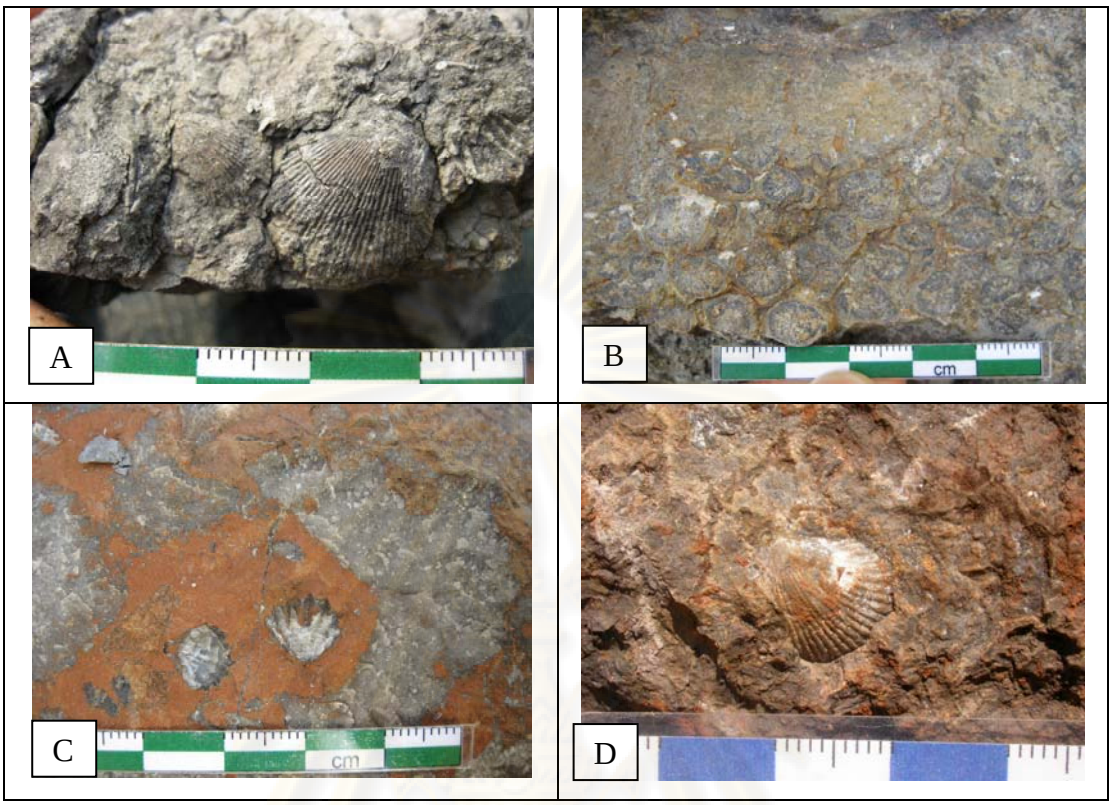


Figure 3.15. Photographs of fossil fauna Padaeng-Tak mines section, *Lima?* sp. (A), coral (B), and rhynchonellid brachiopod (C and D).

3.1.5 Ban Pu Toe section

Ban Pu Toe section is situated at the local road separated from the Highway no. 1090, from Mae Sot to Umphang, 17 km southeast of Amphoe Mae Sot. The section is well exposed at Ban Pu Toe, Ban Ko Chuai, and Ban Nam Khieo. The total thickness is approximately 397 m, and and 6 sample locations (Figure 3.16) have been collected from limestone, mudstone, and marl.

This section is composed chiefly of sandstone, shale, limestone, marl and mudstone. The lower part (200 m thick) comprises mainly sandstone, well stratified, medium- to thick- bedded, sandstone interbeded with mudstone, well stratified, medium-bedded, thinning upward sequence, shale intercalated with argillaceous limestone, well stratified, thin- to thick-bedded with common bivalves *Parvamussium* sp., *Grammatodon* sp., limestone, very thick-bedded to massive. The middle part (100 m thick) comprises mainly sandstone interbedded with limestone, wavy stratified, thick-bedded, silty mudstone, mudstone with limestone lenses, very thick-bedded to

massive, sandstone interbedded with mudstone, well stratified, thin- bedded with lamination, sandstone, very thick-bedded. The upper part (97 m thick) comprises mainly argillaceous limestone, very thick- bedded to massive with common bivalves *Actenostreon* sp., rudist, brachiopods, corals, gastropods and shark teeth, marl interbeded with limestone, thick-bedded, sandstone, well stratified, thin- to thick-bedded, fining and thinning upward sequence with slightly lamination, composed of common bivalves *Goniomya* sp., *Parvamussium* sp., and *Thracia* sp., limestone intercalated with marl and calcareous mudstone, thick- bedded, and marl intecalated with limestone, thick-bedded with common ammonites and bivalves. Photographs of Ban Pu Toe section section are selected to be shown in Figures 3.17. The general dip direction of bedding planes at this measured section is in the west (260°-322°) with moderately to steeply dipping angles (25°-83°).

Fossil assemblages have been found commonly in dark grey mudstones, siltstone, marl and limestone (Figures 3.18). These faunas contains marine bivalves including *Bositra ornati*, *Thracia* sp., *Parvamussim donaiense*, *Grammatodon* sp., *Pinna* sp., *Actenostreon* sp., *Goniomya* sp., *Entolium* sp., *Protocardia?* sp., and rudist bivalves, ammonoids; *Tmetoceras* sp., rhynchonellid brachiopods, telebratulid brachiopods, Nerinellid gastropod, coral, shark teeth, trace fossils, and plant remains.

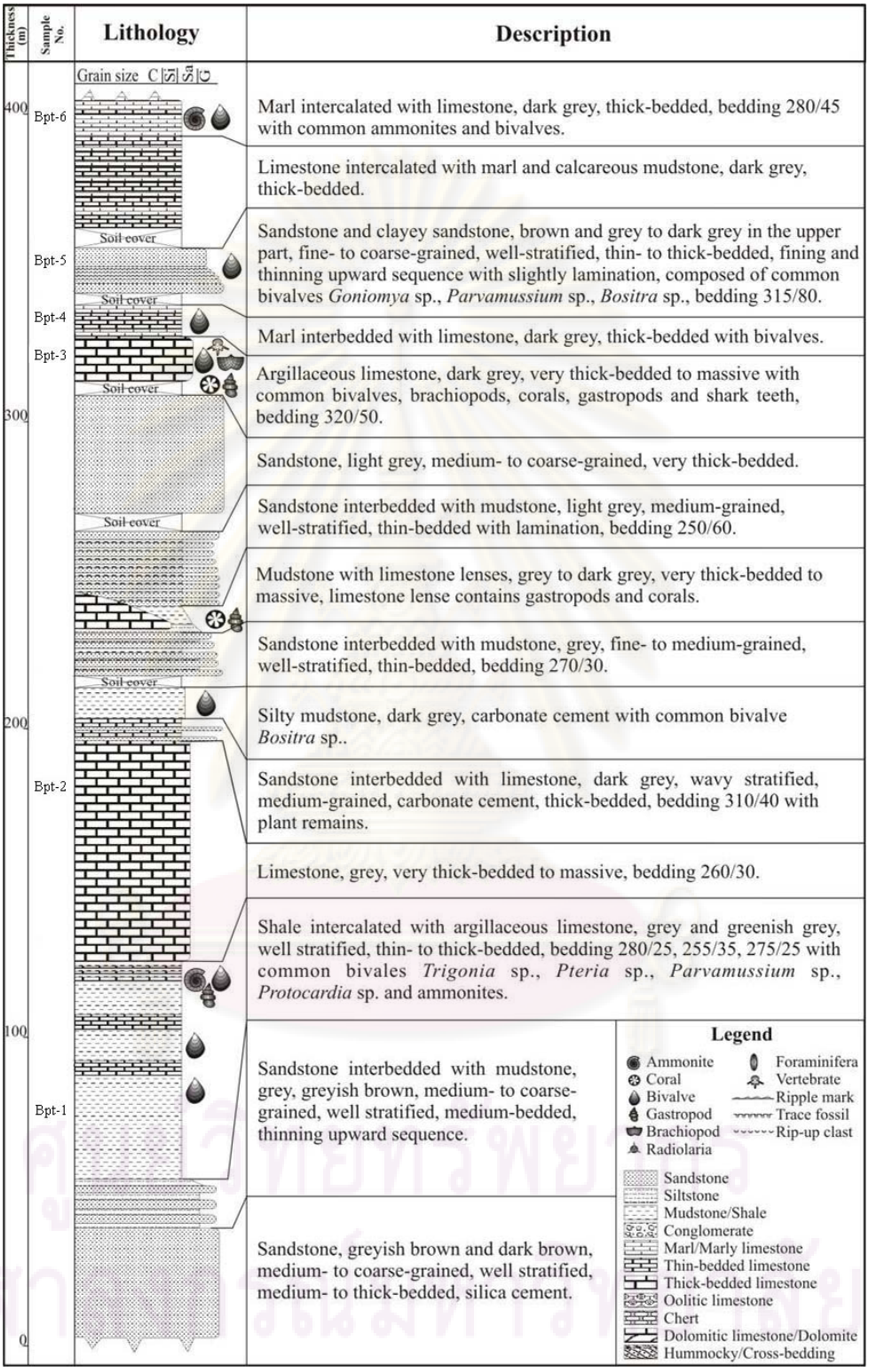


Figure 3.16. Lithostratigraphic column of the Hua Fai Group at the unpaved road from Ban Pu Toe to Ban Nam Khieo, 17 km southeast of Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sample locations.

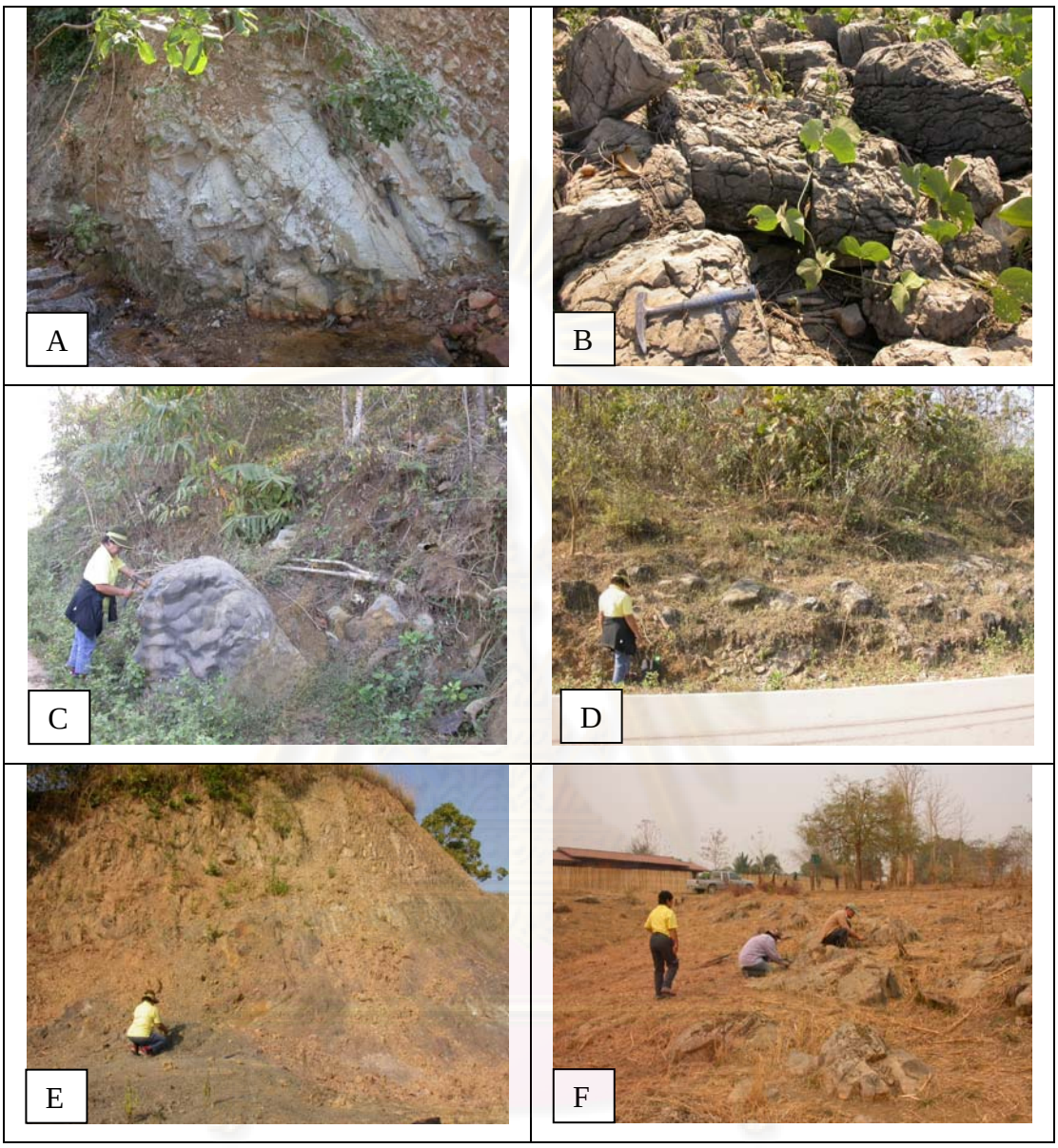


Figure 3.17. Photographs of Ban Pu Toe section, mudstone intercalated with siltstone, common bivalves (A), stylolites in dark grey limestone (B), dark grey limestone in the middle part (C and D), sandstone and siltstone, thin- to thick-bedded, grey to dark grey with common bivalves (E), and dark grey marl intercalated with limestone in the upper part of this section (F).

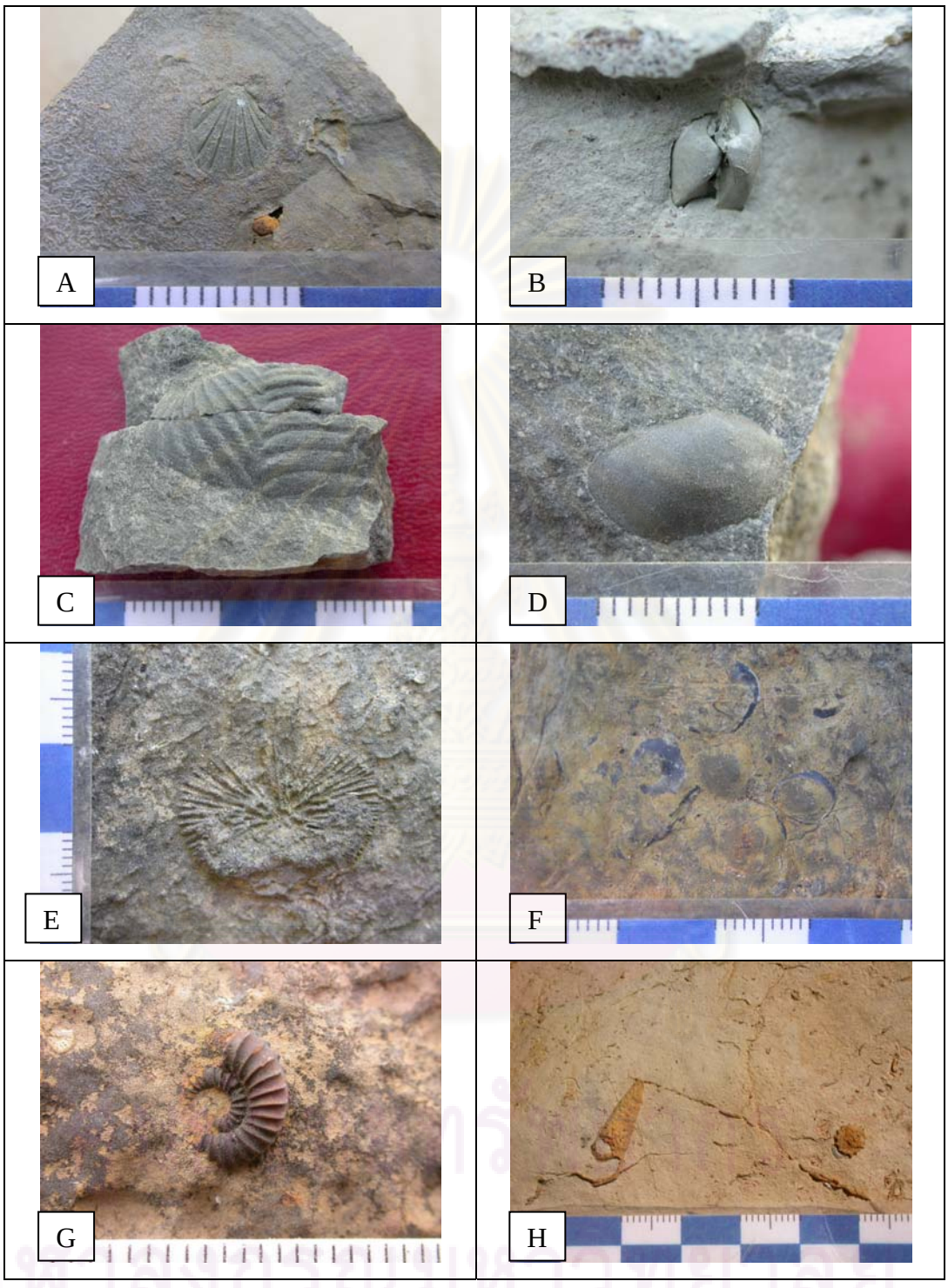


Figure 3.18. Photographs of fossils Ban Pu Toe section, bivalves: *Parvamussium* sp. (A) and *Grammatodon* sp. (B) in mudstone at the lower part of section, rudist bivalve (C) and *Actenostreon* sp. (E) in dark grey limestone in the middle part, ammonite: *Tmetoceras* sp. (G) in marl, and nerinellid gastropod (H) in limestone.

3.1.6 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 Amphoe Mae Sot. The section, approximately 102 m thick, includes 4 sample locations (Figure 3.19) collected from limestone.

This section is composed maimly of sandstone, siltstone, limestone, dolomitic limestone and oolitic limestone. The lower part (50 m thick) comprises mainly sandstone, well stratified, medium- to thick- bedded, fining and thinning upward sequence, oolitic limestone lense, sandstone interbedded with siltstone, very thick-bedded to massive, limestone, very thick-bedded to massive, and sandstone, well stratified, medium-bedded. The upper part (52 m thick) comprises mainly dolomitic limestone and dolomite, argillaceous limestone, very thick-bedded to massive with common bivalve *Entolium* sp., gastropods and corals, sandstone interbedded with mudstone, thin- to medium-bedded, limestone, very thick-bedded to massive with common gastropods and corals, and sandstone interbedded with mudstone, medium to thick bedded. Photographs of Doi Huai Mot section are selected to be shown in Figures 3.20. 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°).

Fossil assemblages have been found in dark grey limestone. These faunas contain marine bivalves including *Astarte* sp., *Entolium* sp., ammonites, nerinellid gastropod and corals.

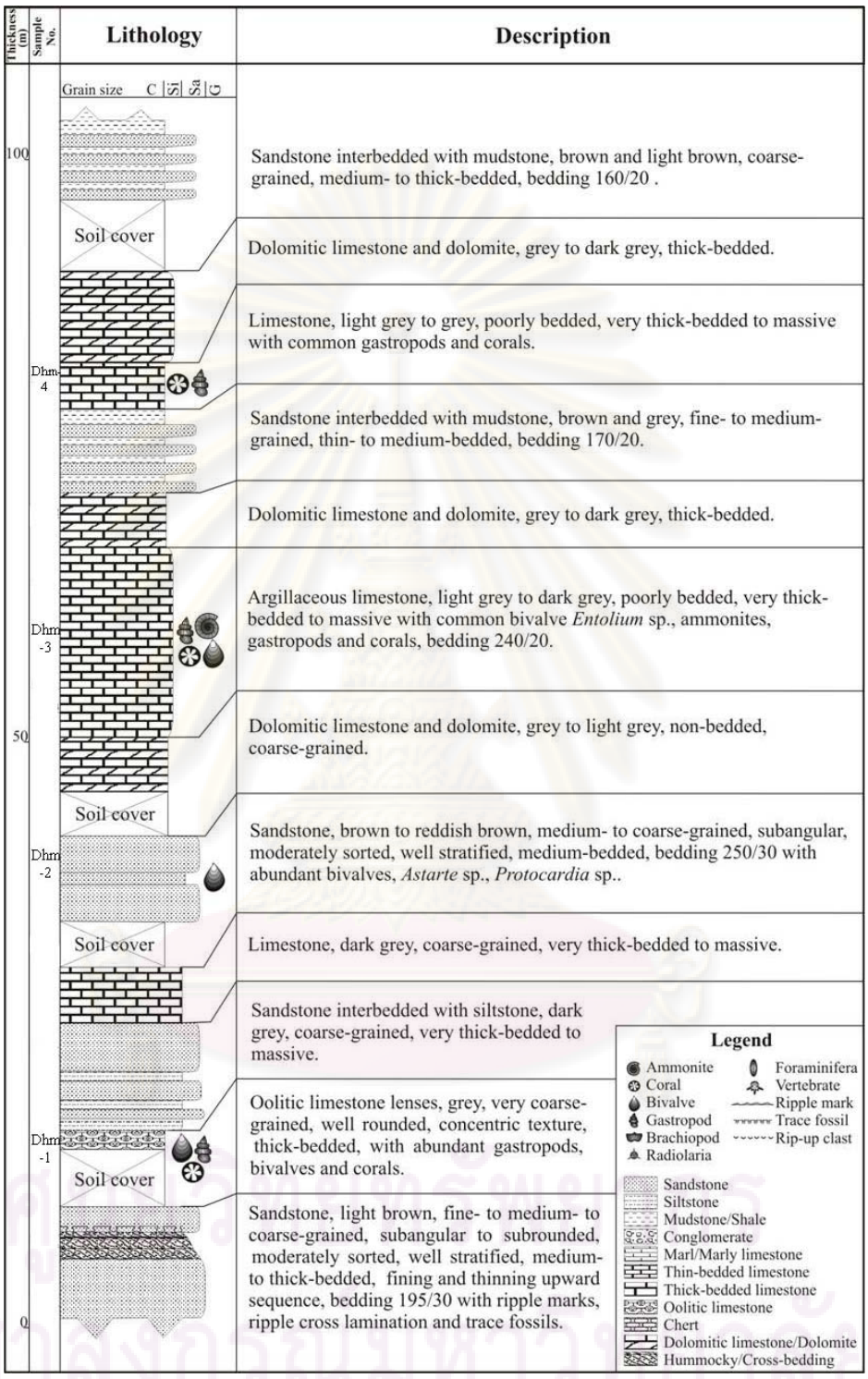


Figure 3.19. Lithostratigraphic column of the Hua Fai Group at the bypass road of the Highway no. 1090 and a small road to a television station of Doi Huai Mot, Ban Nam Tok Hin Lek Fai, 25 km south of Amphoe Mae Sot (Wirote Saengsrichan, 2007), showing the number of sample locations.

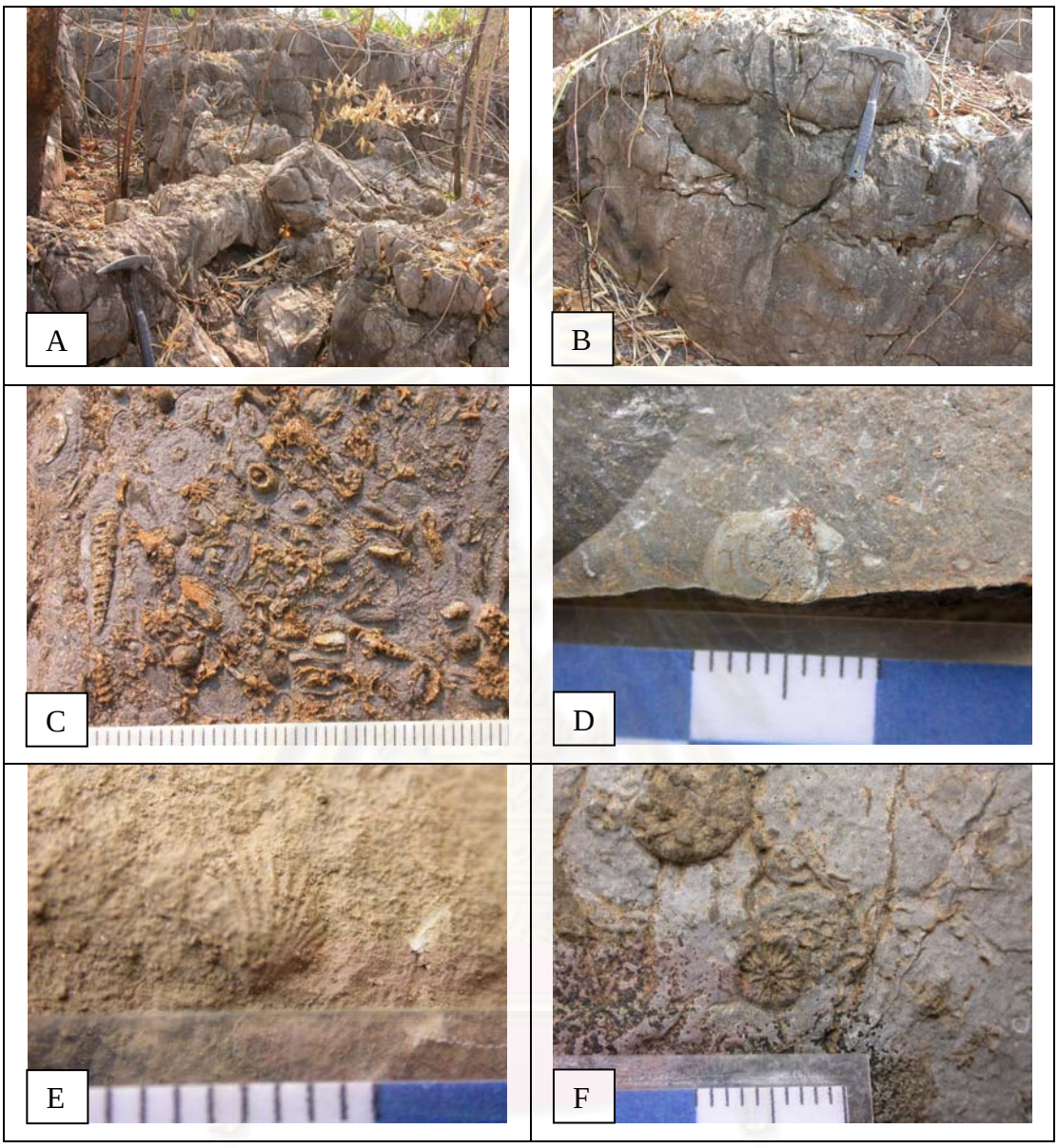


Figure 3.20. Photographs of Ban Pu Toe section, dark grey limestone with stylolites (A and B), fossiliferous limestone showing nerinellid gastropod (C) and fossil fragments, bivalve *Entolium* sp. (D), rhynchonellid brachiopod (E), and corals (F).

3.1.7 Huai Wale section

Huai Wale section is located along the security road near Huai Wale, Thailand-Myanmar border, 7 km southeast of Amphoe Phop Phra. This section lies in the southern-most part of the study area. The section is approximately 320 m thick including 8 sample locations (Figure 3.21) which have been collected from sandstone and limestone.

This section is composed of limestone, sandstone, siltstone, and mudstone. The lower part (200 m thick) comprises mainly limestone, wavy parallel beds, very thick-bedded to masive, thining upward sequense, intercalation of sandstone, mudstone and argillaceous limestone, well even stratified, medium- to thick-bedded, ripple cross lamination, consist of common bivalves *Astarte* sp., and *Trigonia* sp., and limestone, very thck- bedded to massive, with common fossil fragments of bivalves and gastropod. The upper part (120 m thick) comprises mainly sandstone, medium- bedded, interbedded with mudstone, fining upward sequence, thin- to medium-bedded, well stratified, sandstone intercalated with siltstone, sandstone, thick-bedded, well stratified, and limestone, very thick-bedded to massive. Photographs of Huai Wale section are selected to be shown in Figures 3.22. The general dip direction of bedding planes at this measured section varies in the west, south, and east (095-325 degrees) with moderately dipping angles (30-65 degrees).

Fossil assemblages have been found in siltstone and sandstone (Figures 3.23). These faunas contain marine bivalves including *Actenostreon* sp., *Astarte* sp., *Trigonia* sp., *Pholadomya* sp., *Ceratomya* sp., and *Gervillia* sp., gastropod, corals, trace fossil and plant remains.

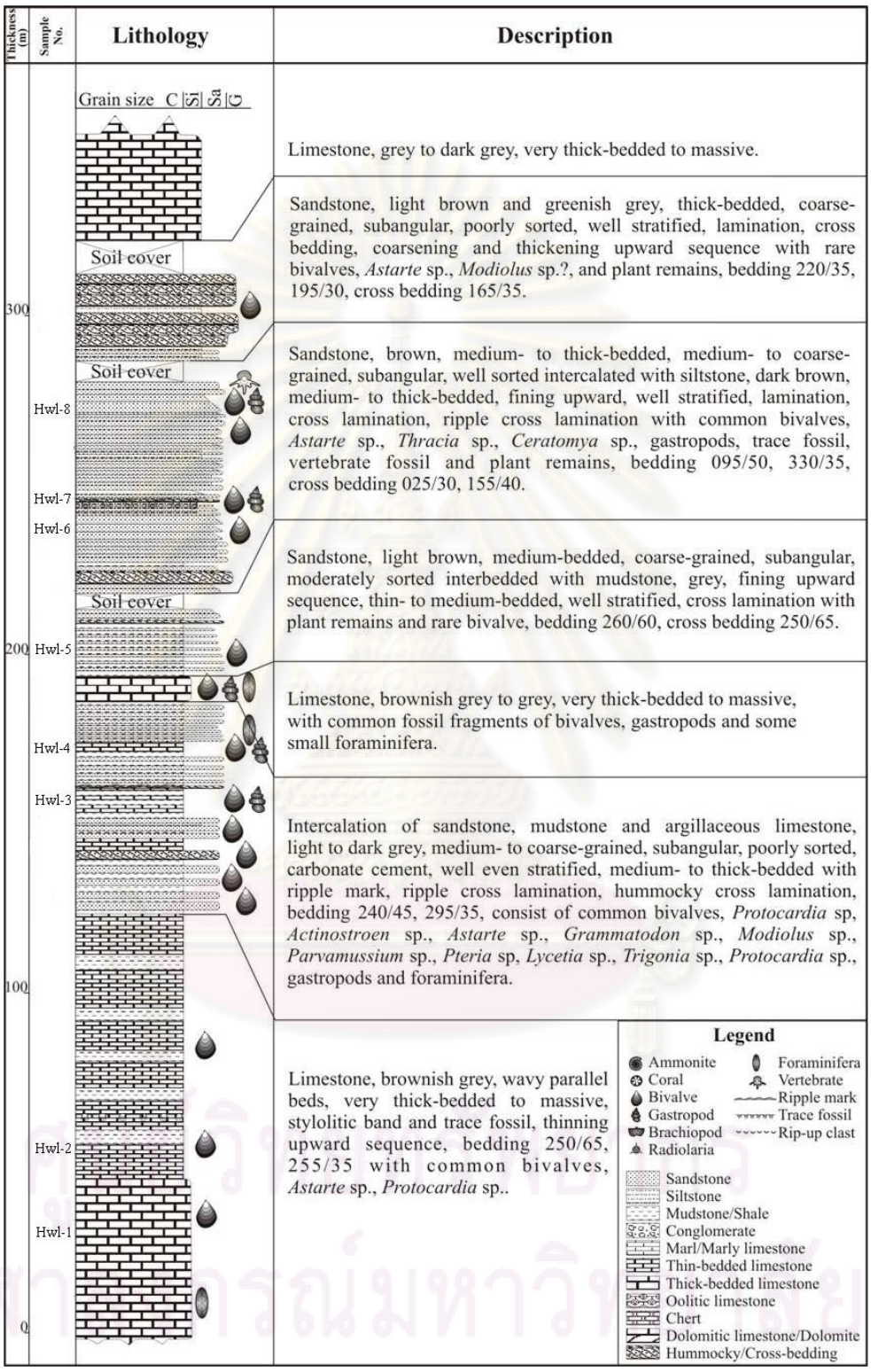


Figure 3.21. Lithostratigraphic column of the Hua Fai Group at the security road near Huai Wale, Thailand-Myanmar border, 7 km southeast of Amphoe Phop Phra (Wirote Saengsrichan, 2007), showing the number of sample locations.

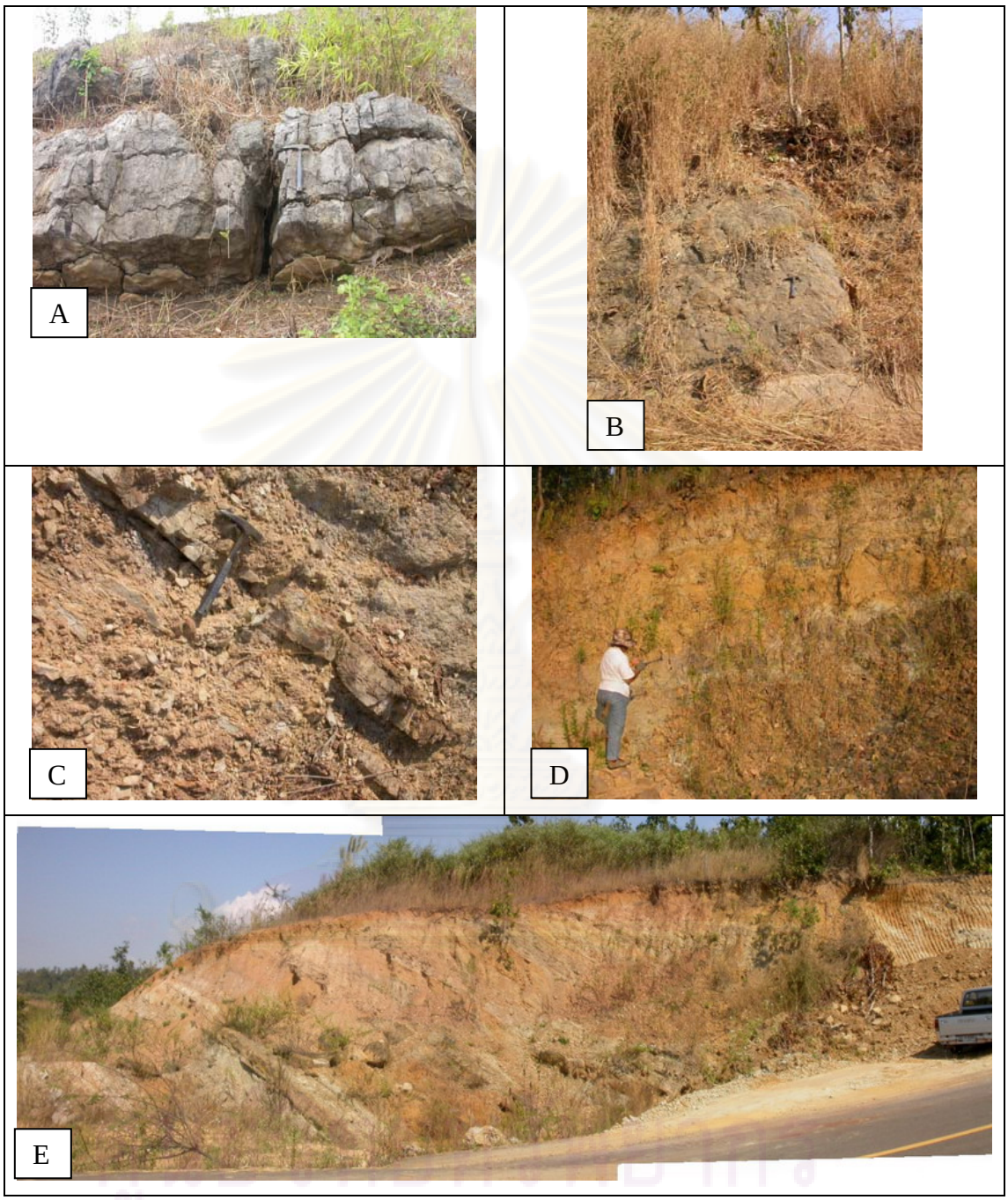


Figure 3.22. Photographs of Huai Wale section, dark grey limestone with stylolites (A)at the lower part, siltstone with common fossil bivalve, *Actenostreon* sp. and coral (B), sandstone intercalated with siltstone, thick-bedded, common bivalve *Astarte* sp., *Trigonia* sp., and plant remains (C, D and E).

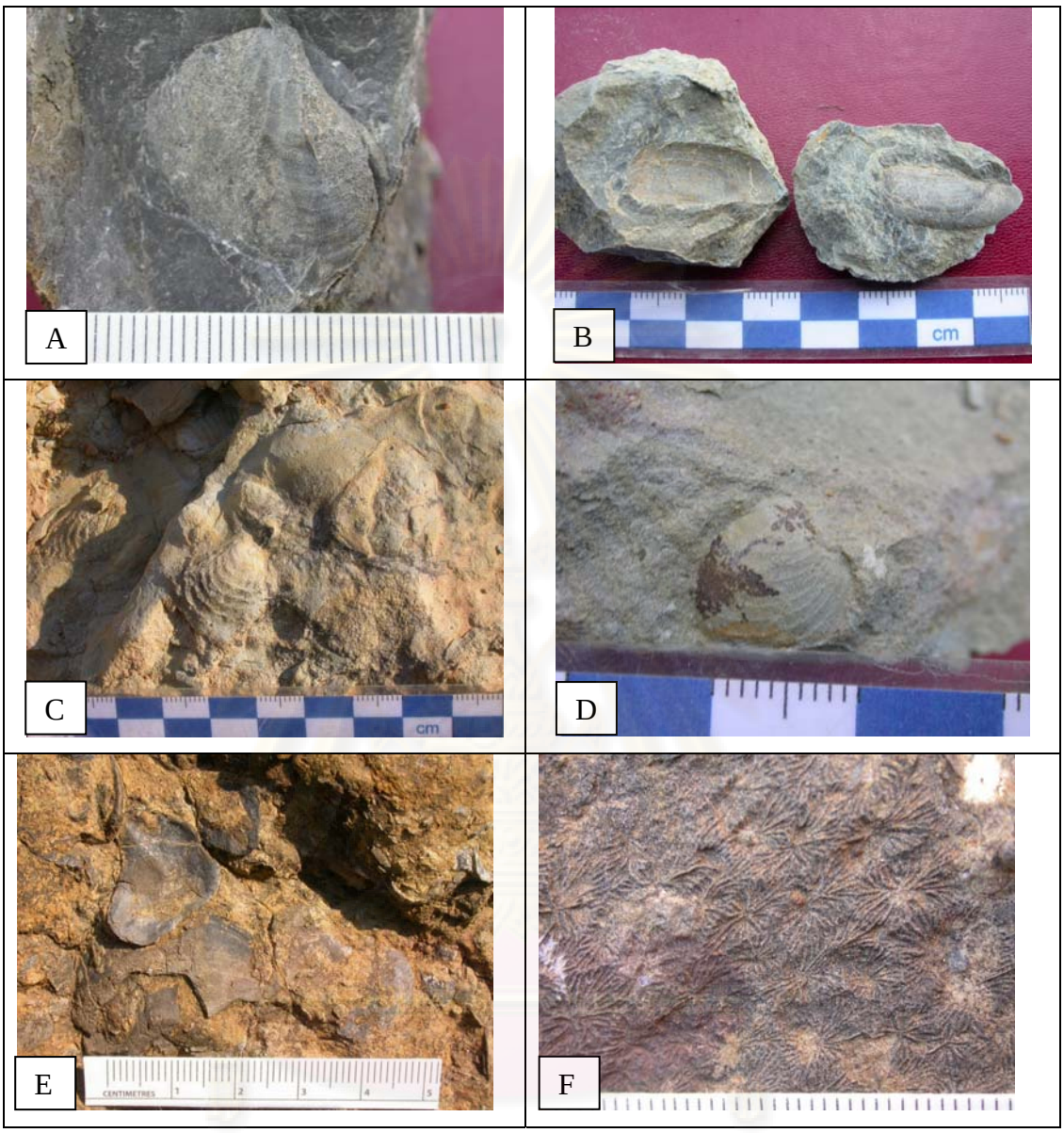


Figure 3.23. Photographs of fossils Huai Wale section, *Pholadomya* sp. in dark grey limestone at the lower part of section (A), *Gervillia* sp., in dary grey mudstone (B), *Trigonia* sp., in sandstone (C), *Astarte* sp., (D), *Actenostreon* sp. (E), and corals (F).

3.2 Biostratigraphy

3.2.1 Distribution of bivalves and ammonoids

Marine Jurassic rocks in the study areas, seven sections from north to south, are composed of mudstone, siltstone, sandstone, marl, limestone and oolitic limestone ranging in thickness from 200-832 m. Fossils are abundant containing bivalves and ammonoids, at least 17 genera of bivalves found together with ammonoids assemblage. Bivalves consist of *Astarte* sp., *Actenostreon* sp., *Bositra ornati*, *Ceratomya* sp., *Camptonectes* sp., *Entolium* sp., *Gervillia* sp., *Goniomya* sp., *Grammatodon* sp., *Homomya?* sp., *Lima?* sp., *Parvamussism donaiense*, *Pholadomya* sp., *Pinna* sp., *Protocardia* sp., *Thracia* sp., *Trigonia* sp., *Modiolus* sp., and a rudist bivalve. Ammonoids consist of *Harpoceras* sp., *Tmetoceras* sp., and ammonite sp. A. Additional fossils contain rhynchonellid brachiopod, nerineid gastropod, coral, trace fossils and plant remains.

The distribution of bivalves and ammonoids in the study area is shown in Table 3.1. List of fossil assemblages and biostratigraphic units in the study area can be summarized in each section shown in Figure 3.24 (Ban Mae Kut Luang section), Figure 3.25 (Tak-Mae Sot Highway section), Figure 3.26 (Huai Mae Sot section), Figure 3.27 (Padaeng-Tak mines section), Figure 3.28 (Ban Pu Toe section), Figure 3.29 (Doi Huai Mot section) and Figure 3.30 (Huai Wale section) as follow respectively from north to south.

Bositra zone can be established in the Ban Mae Kut Luang section, Tak-Mae Sot Highway section and Huai Mae Sot section. This zone is defined by the first and last occurrences of *Bositra ornati*, representing middle Toarcian-Aalenian in age. However *Parvarmussium donaiense* was found in the upper part of the Ban Mae Kut Luang and Padaeng-Tak mines sections. It is represented Toarcian age which is biostratigraphically older than *Bositra ornati*. However *Parvarmussium donaiense* from the Ban Mae Kut Luang section was found above the *Bositra* zone. This may be because the faults movement might transport older rock unit (containing *Parvarmussium donaiense*) over the younger rock unit.

Table 3.1 Distribution of bivalves and ammonoids from the study area

section	*Astarte* sp.	*Actenostroen* sp.	*Bositra ornati*	*Ceratomya* sp.	*Camptonectes* sp.	*Entolium* sp.	*Gervillia* sp.	*Goniomya* sp.	*Grammatodon* sp	*Homomya?* sp.	*Parvamussism donaiense*	*Pholadomya* sp.	*Pinna* sp.	*Protocardia* sp.	Rudist	*Thracia* sp.	*Trigonia* sp.	*Modiolus* sp.	Rhynchonellid	*Harpoceras* sp.	*Tmetoceras* sp.	Ammonoid sp. A
1. Ban Mae Kut Luang			●		●	●		●	●		●		●			●		●	●	●	●	●
2. Tak-Mae Sot Highway			●	●		●			●		●	●	●	●		●	●		●	●	●	
3. Huai Mae Sot	●?	●	●			●	●		●	**●?**		●	●	●		●	●		●	●	●	
4.Padaeng-Tak Mines											●					●			●			
5. Ban Pu Toe	●	●	**●?**				●?	●	●		●		●		●	●					●	
6. Doi Huai Mot	●					●								●					●			
7. Huai Wale	●	●					●		●	●		●		●		●	●					

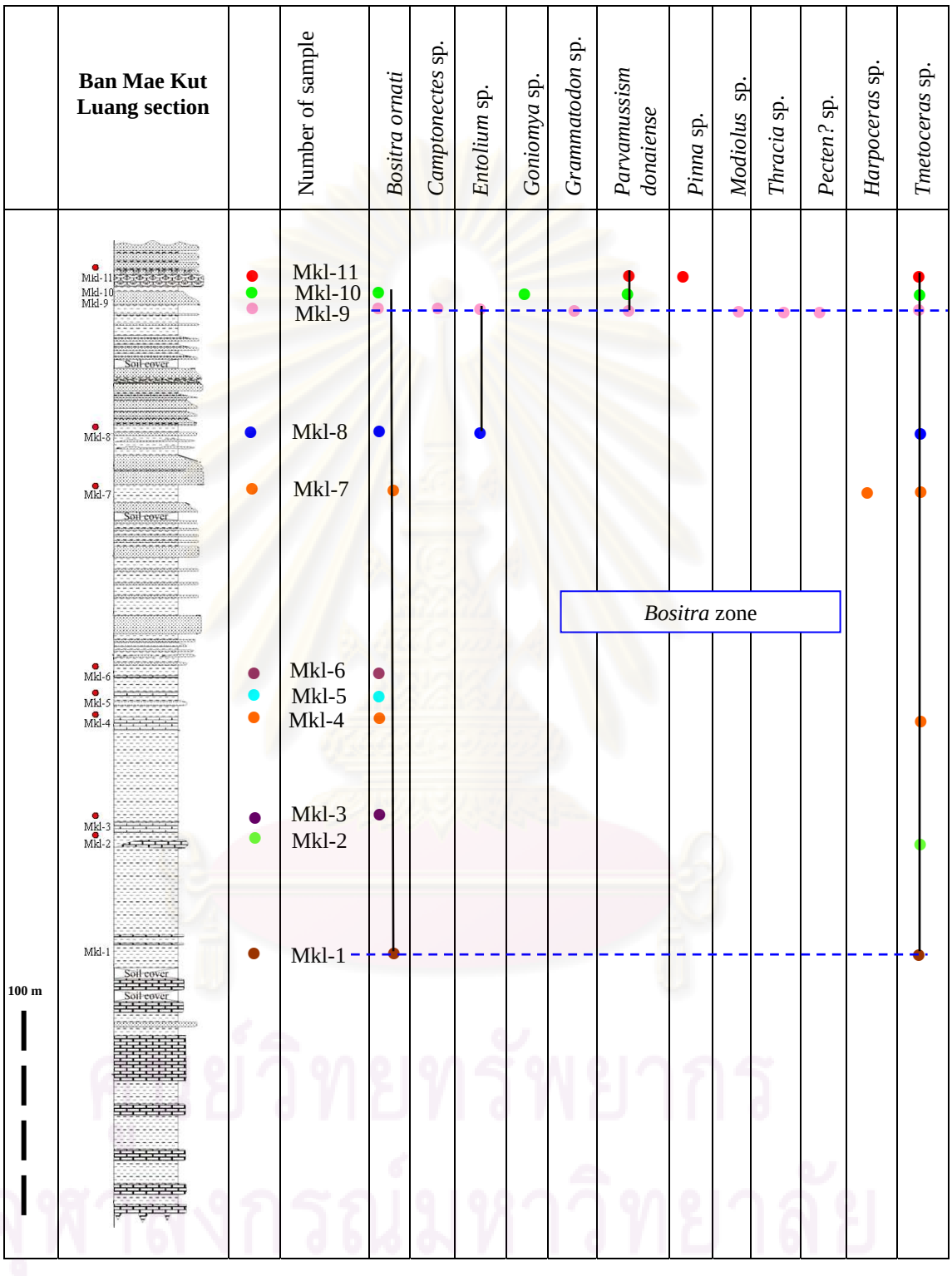


Figure 3.24. Distribution of fossils from section Ban Mae Kut Luang, Amphoe Mae Sot, Changwat Tak, showing the *Bositra* zone.

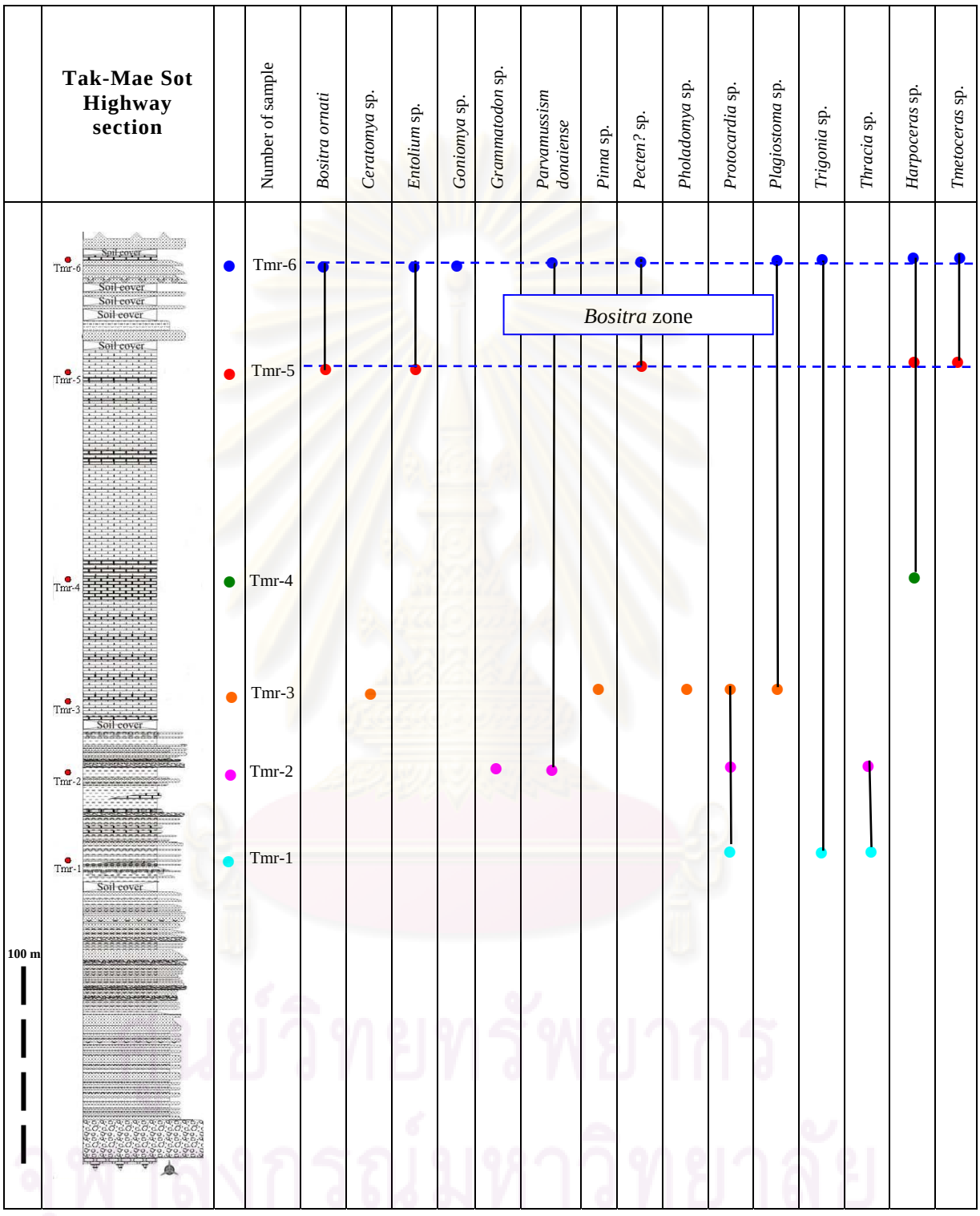


Figure 3.25. Distribution of fossils from section Tak-Mae Sot Highway, Amphoe Mae Sot, Changwat Tak, showing the *Bositra* zone.

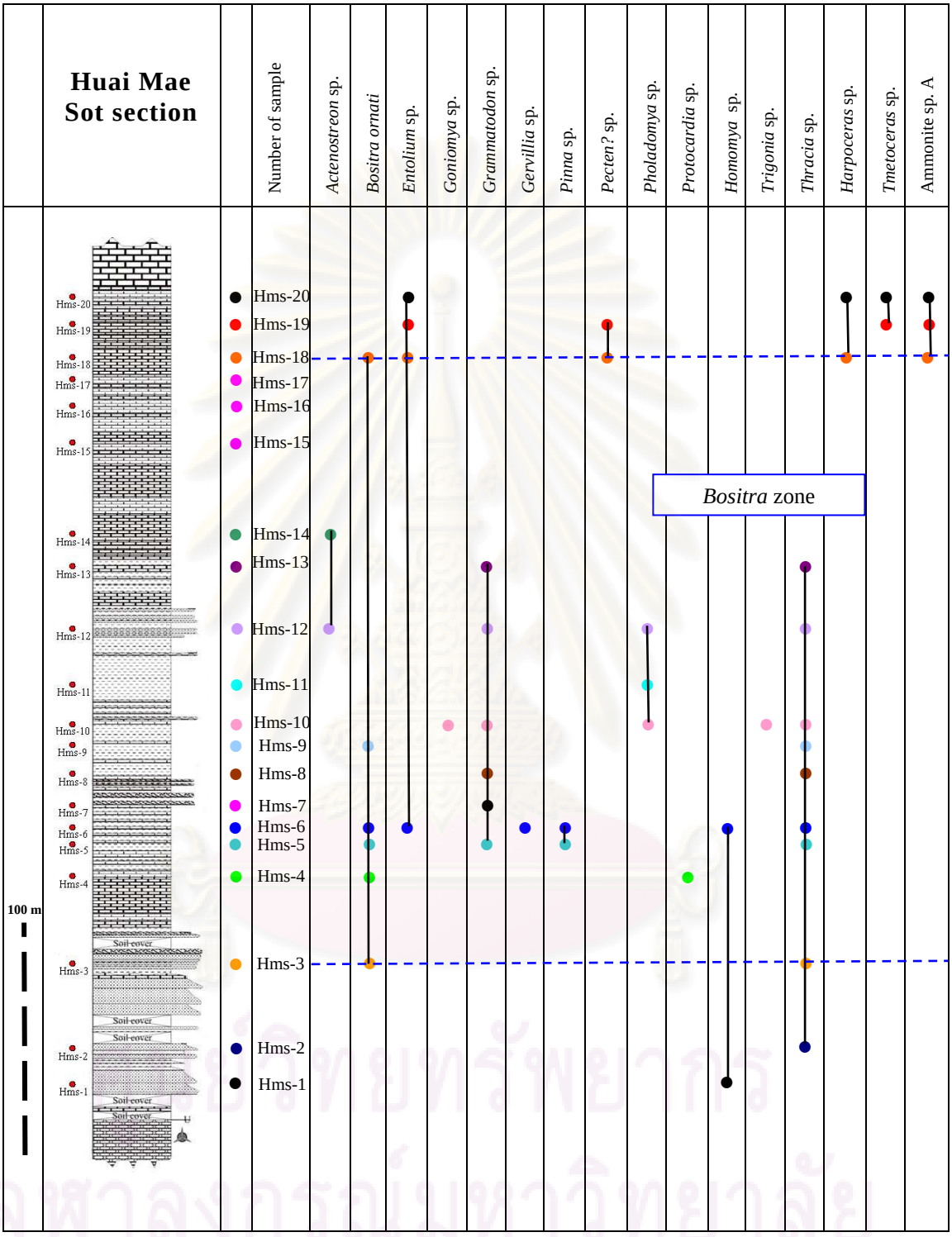


Figure 3.26. Distribution of fossils from section Huai Mae Sot, Amphoe Mae Sot, Changwat Tak, showing the *Bositra* zone.

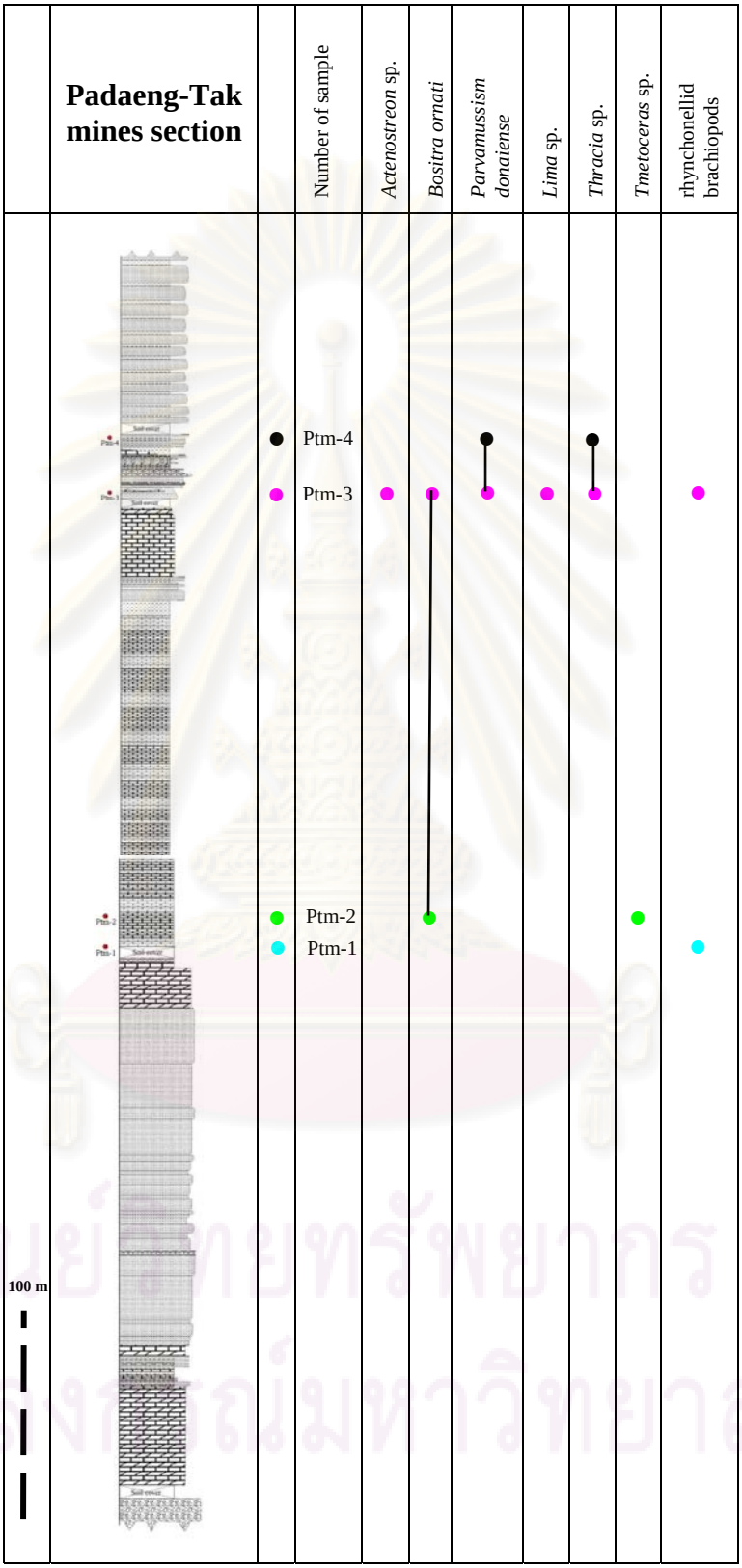


Figure 3.27. Distribution of fossils from section Padaeng-Tak mines, Amphoe Mae Sot, Changwat Tak.

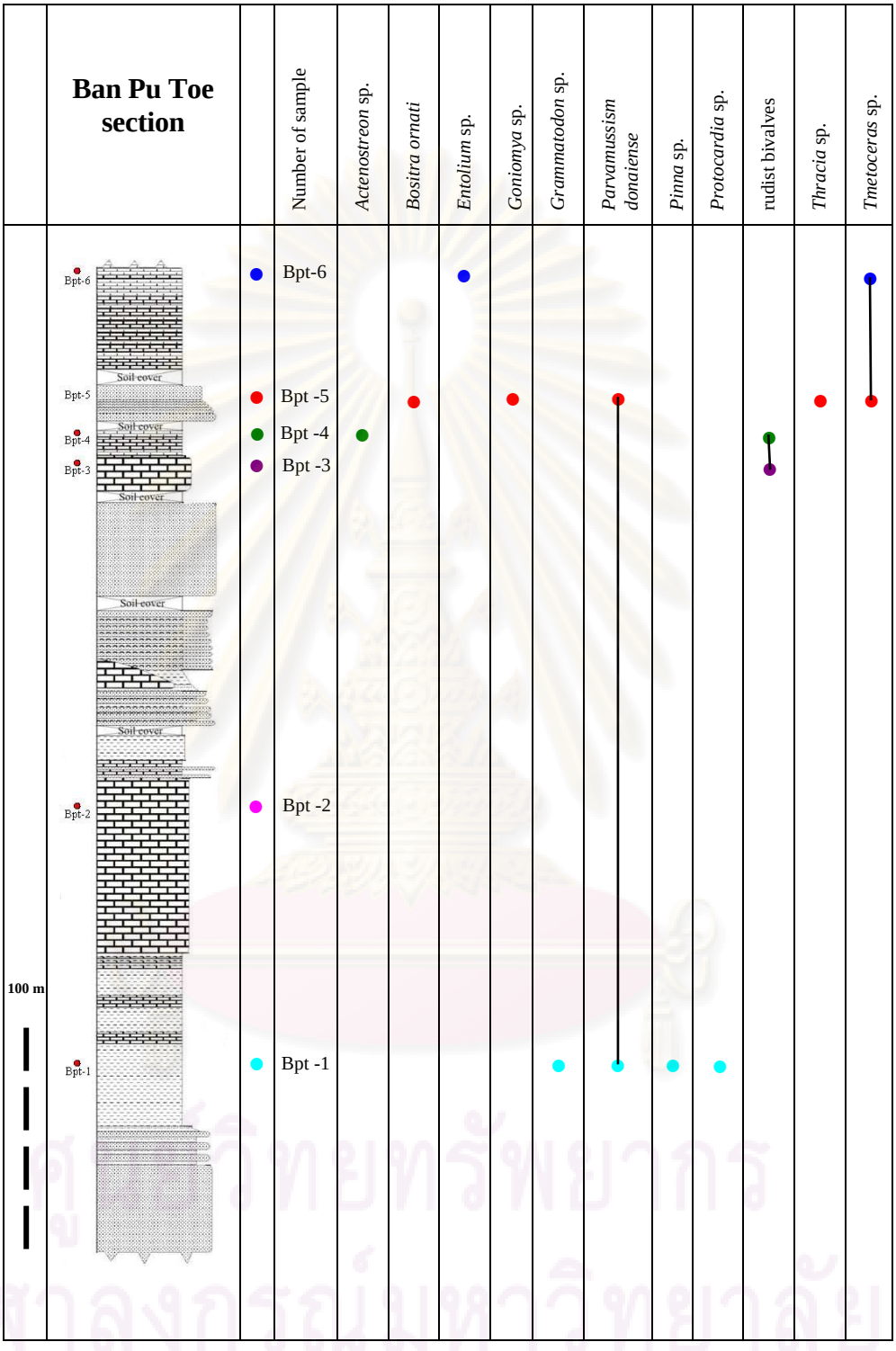


Figure 3.28. Distribution of fossils from section Ban Pu Toe, Amphoe Mae Sot, Changwat Tak.

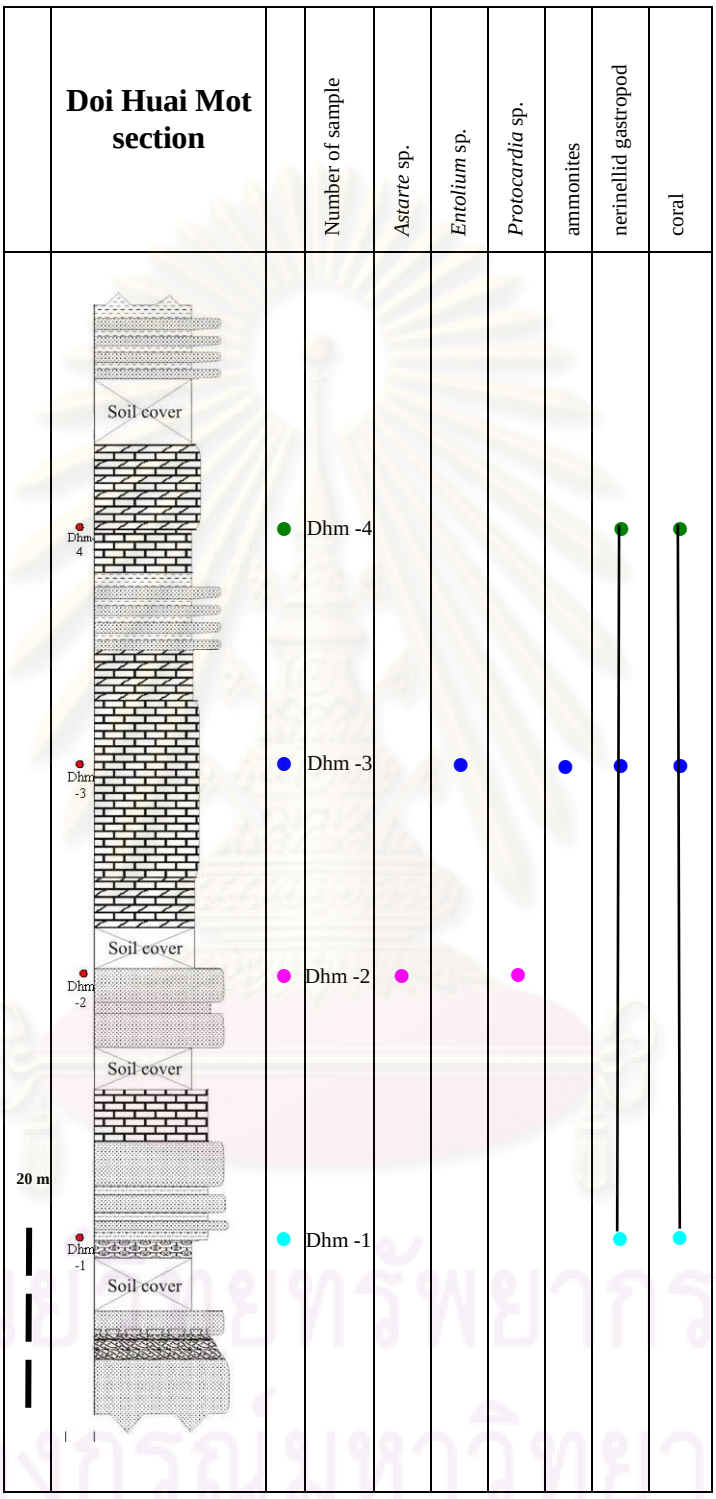


Figure 3.29. Distribution of fossils from section Doi Huai Mot, Amphoe Phop Phra, Changwat Tak.

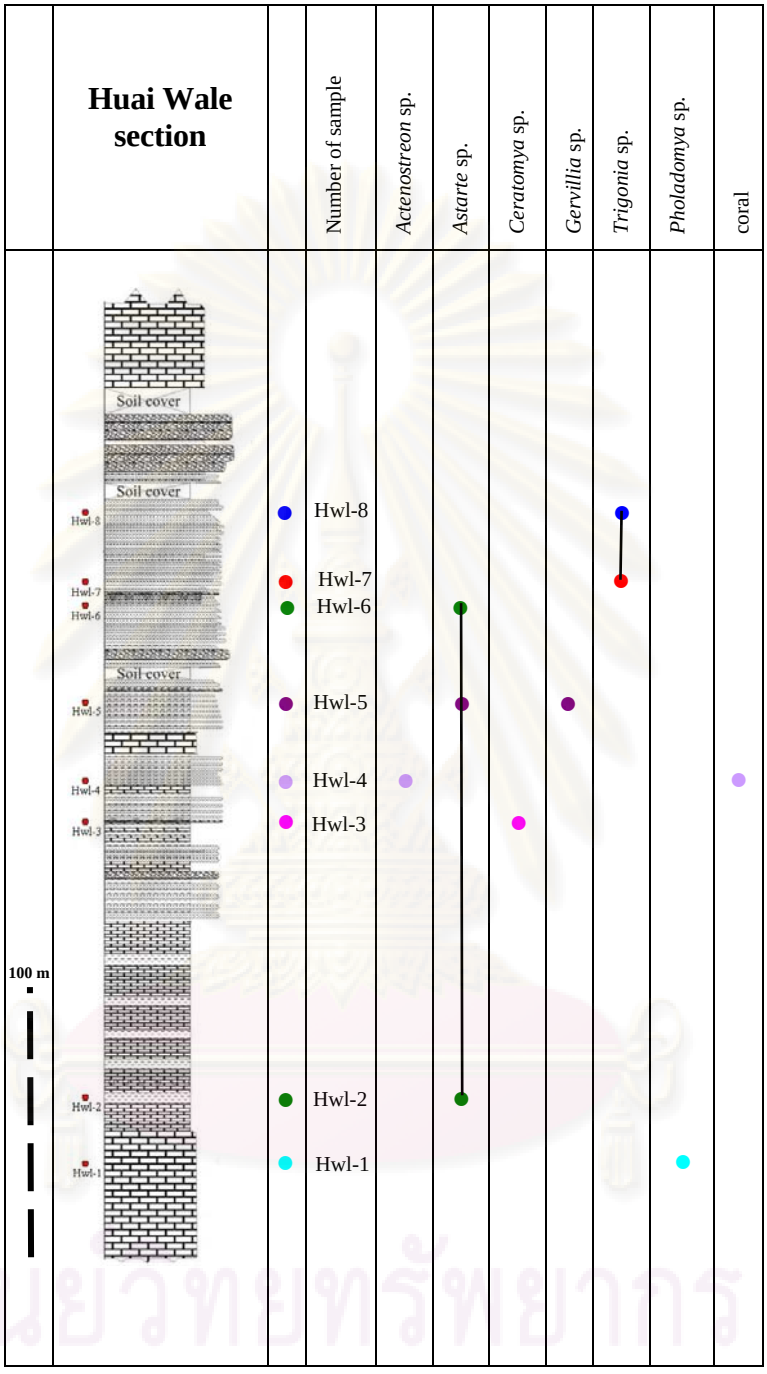


Figure 3.30. Distribution of fossils from section Huai Wale, Amphoe Phop Phra, Changwat Tak.

3.2.2 Biostratigraphic Correlation and Age

In biostratigraphic correlation ammonites are the most useful and reliable indicators because of their apparently instantaneous migration, wide distribution and rapid morphological evolution. Unfortunately, not all of the Thai Jurassic sequences have yet either yielded ammonites or they are not well preserved.

Some genera and species of bivalves which have been studied in detail in some sections provide a good evidence for correlation. Biostratigraphic correlation in this study is, therefore, based on mainly bivalves.

The sequence of sedimentary rocks in the study area is mainly confined to Toarcian-Aalenian age, lithologies being generally marl, marly limestone and limestone. Fossils occur almost throughout the sequences and commonly in mudstones, marly limestones and limestones. In coaser lithologies, marine fossils are rare and only plant remains were found. The sequence seems confined to upper Lower-lower Middle Jurassic with a relatively rich fauna of bivalves, ammonites, corals and brachiopods. The biostratigraphic correlation can be summarized as Figure 3.31. *Bositra* zone has been established. This zone is defined by the first and last occurrence of *Bositra ornati*, representing middle Toarcian-Aalenian in age. The Ban Mae Kut Luang section, Tak-Mae Sot Highway section and Huai Mae Sot section can be correlated based on *Bositra* zone. The other sections, Padaeng-Tak mines section, Ban Pue Toe section, Doi Huai Mot section and Huai Wale section, are Toarcian in age represented by *Astarte* sp., *Camptonectes* sp., *Entolium* sp., *Gervillia* sp., *Goniomya* sp., *Grammatodon* sp., *Parvamussism donaiense*, *Pholadomya* sp., *Protocardia* sp., *Thracia* sp., and *Trigonia* sp.

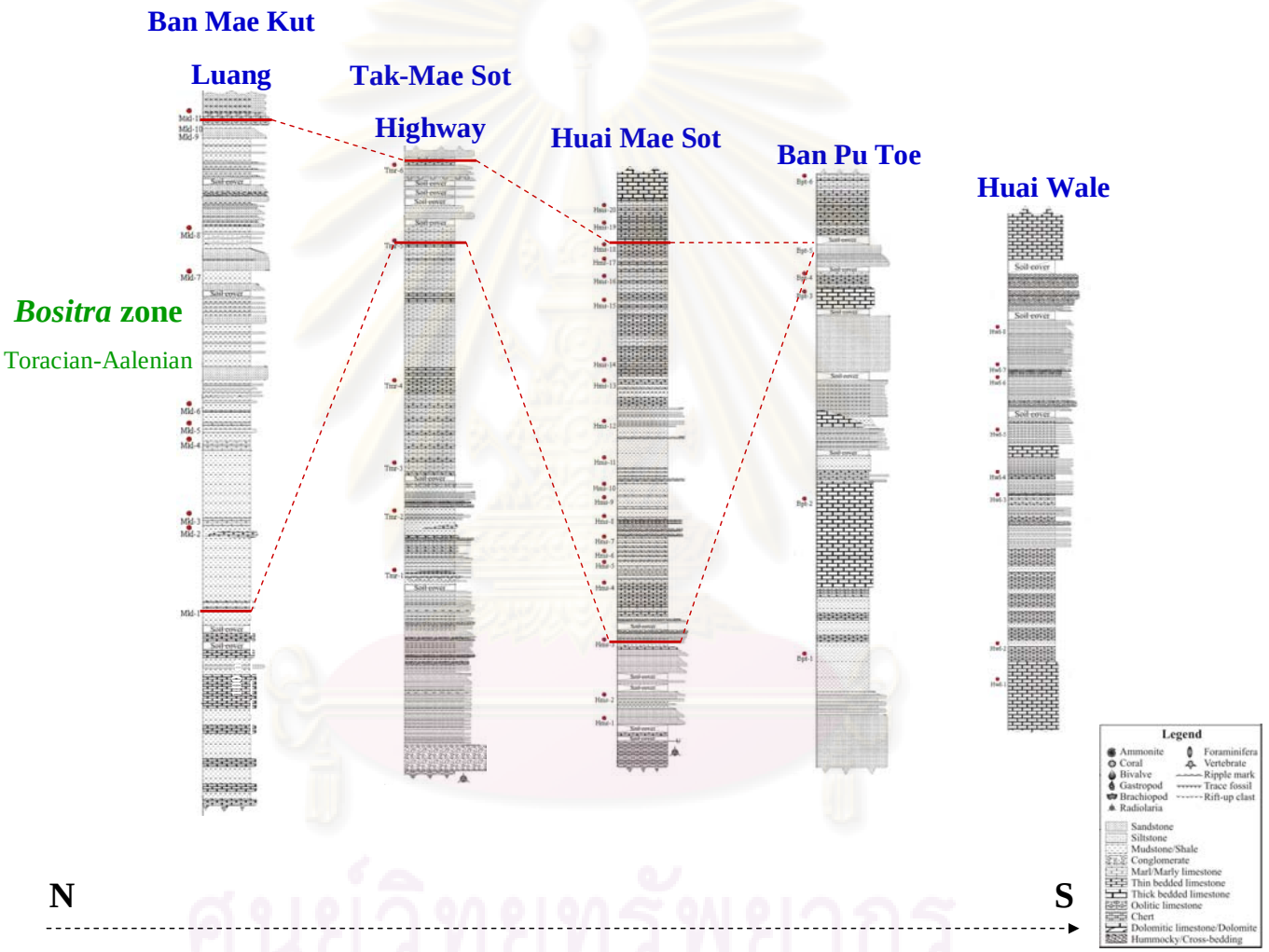


Figure 3.31. Biostratigraphic correlation of marine Jurassic fossils in the Mae Sot-Phop Phra areas, Changwat Tak.

3.3 Paleoenvironment

The reconstruction of the depositional environments of the Hua Fai Group done by Wirote Saengsrichan (2007) is shown in Figures 3.32 as follows:

Khun Huai Formation

The Khun Huai Formation in Mae Sot-Phop Phra area is considered to be deposited in the shallow shelf environment, the lowest part, as alluvial fan, fan delta, distal mouth bar, delta front, due to tide dominated or marine transgression during late Early Jurassic (Toarcian), fluvial deposits, indicates sedimentation under the transitional zone of delta front platform, distal mouth bar environment, protected bay or lagoon, low-energy environment, carbonate platform environment, mixed intertidal and reef flat depositional environments, subtidal and intertidal sand flat depositional environment and carbonate platform. Finally, the uppermost part of the Khun Huai Formation is represented by sandstone unit. According to facies analysis, depositional environment is designed as intertidal mixed flat.

Doi Yot Formation

The Doi Yot Formation conformably overlies the sequence of the Khun Huai Formation. The contact of both formations is represented by gradational contact, fining upward sequences. In the lowest unit of the Doi Yot Formation the rocks have been deposited under the inner shallow ramp buildups, transitional of inner to outer ramp environment, inner shallow ramp. Finally, the limestone unit consists mainly of thick to massive argillaceous limestone, oolitic limestone, and dolomitic limestone facies. Based on the facies analysis, this unit can be deposited in the shoal-rimed platform, reef flat.

Pha De Formation

The Pha De Formation conformably overlies the sequence of the Doi Yot Formation. The lower unit of the Pha De Formation is mudstone interbedded with muddy calcareous sandstone unit underlain by the Doi Yot Formation with sharp contact. It is predominantly composed of grey mudstone interbedded with muddy calcareous sandstone facies. The bivalves *Bositra* sp. and ammonites are commonly found in some sandy mudstone facies, presented to intertidal depositional environment.

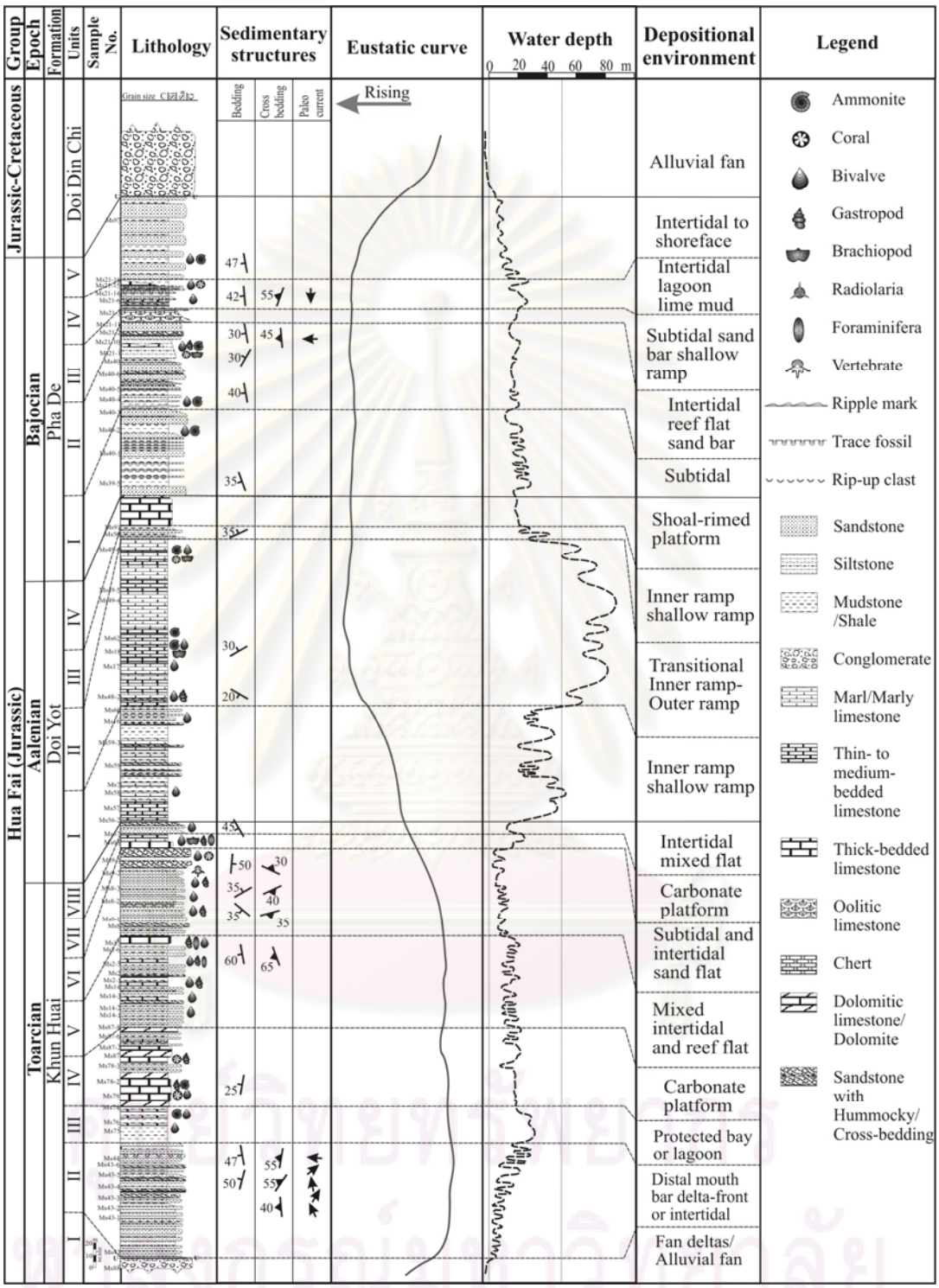


Figure 3.32. Eustatic sea level curves and depositional environments of the Hua Fai Group, Mae Sot-Phop Phra area (after Wirote Saengsrichan, 2007).

Muddy calcareous sandstone interbedded with mudstone unit, the fossils contain abundant bivalves represented the zones of shoal-rimmed carbonate shelf, intertidal, reef flat, and sand bar. The characteristic lithology of oolitic limestone unit is considered as subtidal sand bar and shallow ramp. The lower part of mudstone with limestone, siltstone, and sandstone unit and the fossils contain the abundant bivalves, the depositional environment is interpreted to be intertidal to lagoonal lime mud. The upper part of the mudstone with limestone, siltstone, and sandstone unit could be probably deposited in the intertidal to shoreface.

The marine Jurassic of Thailand predominantly contains bivalves, ammonites and brachiopods. Bivalves constitute the largest proportion of the total fauna in terms of both abundance and diversity. Although ammonites can be used in analyzing the environment (Westermann, 1989), bivalves are therefore more useful in ecologic interpretation. The Toarcian fauna of the Mae Sot-Phop Phra areas are summarised in Table 3.2. The Thai marine Jurassic is also shelf facies. Assanee Meesook (1994) described the sequence of marine sediments in detail in the Mae Sot area and the Toarcian-Aalenian age is given to the sequence based on common bivalves *Bositra ornati* (Quenstedt) as Aalenian age for the Doi Yot Formation while *Parvamussium donaiense* (Mansuy) as Toarcian age for the Khun Huai Formation. Moreover, Assanee Meesook (1994), and Assanee Meesook and Grant-Mackie (1997) also studied marine Jurassic rocks in terms of paleoecology, paleoenvironment, and faunal association. *Bositra* Facies (Assanee Meesook and Grant-Mackie, 1997) is characterised by the presence of one species, *Bositra ornati*, having epibenthic mode of life, dominated only in the Toarcian mudstones in the Mae Sot area where restricted basinal anoxic conditions and a rather shallow (neritic) continental shelf prevailed. *Bositra* is found in organic-rich shales and is a soft substrate dweller associated with known soft substrate dwellers such as corbulids and protobranchs (Fürsich *et al*., 1991).

Paleoenvironmental analysis of the sequence is based on feeding habits, the ecology of the faunas and lithology. The following discussion of the faunal facies will be followed by interpretation of paleoenvironments through the sequence. Shallow marine shelf environment were cosidered, carbonate platform environment as indicated by thick-bedded to massive limestone lenses of the limestone and dolomitic

Table 3.2 Lift habit and tropic group of genera of the benthic bivalves in the study area.

Superfamily	**Fauna**	**Life habit**	**Trophic group**
Arcoidea	*Grammatodon* sp.	shallow infaunal	suspension feeder
	Modiolus sp.	semi-infaunal	suspension feeder
Pteroidea	*Gervillia* sp.	epibyssate	suspension feeder
Pinnoidea	*Pinna* sp.	semi-infaunal	suspension feeder
Pectinoidea	*Entolium* sp.	epifaunal free-swimming	suspension feeder
	Camptonectes sp.	epibyssate	suspension feeder
	Parvamussium donaiense	epifaunal free-swimming	microcarnivore
Trigonoidea	*Trigonia* sp.	shallow infaunal	suspension feeder
Astartoidea	*Astarte* sp.	shallow infaunal	suspension feeder
Cardioidea	*Protocardia* sp.	shallow infaunal	suspension feeder
Pholadomyoidea	*Pholadomya* sp.	deep infaunal	suspension feeder
	Goniomya sp.	deep infaunal	suspension feeder
	Homomya sp.	deep infaunal	suspension feeder
Pandoroidea	*Thracia* sp.	deep infaunal	suspension feeder
Pectinacea	*Bositra ornati*	epifaunal free-swimming	suspension feeder

limestone. Sandstone with oolitic limestone has been deposited in the subtidal and intertidal sand flat depositional environment. The limestone, mudstone, and marl facies contain the common bivalves which have been deposited under the inner shallow ramp buildups. The marl and mudstone facies contain abundant ammonites, bivalves, and brachiopods, interpreted as having been deposited in the transitional of inner to outer ramp environment. Mudstone intercalated calcareous sandstone, siltstone, and argillaceous limestone, should be the inner shallow ramp depositional environment. Mudstone interbedded with muddy calcareous sandstone with the bivalves, *Bositra* sp. and ammonites are commonly found, could be presented to intertidal depositional environment. Muddy calcareous sandstone interbedded with mudstone, fossils contain abundant bivalves, ammonites, gastropods, corals, trace fossils, brachiopods, and plant remains are the zones of shoal-rimmed carbonate shelf, intertidal, reef flat, and sand bar.

CHAPTER IV

SYSTEMATIC DESCRIPTION

Marine Jurassic fossils of Thailand have been reported by Many workers, for example von Braun and Jordan (1976), Kemper (1976), Améres (1988), Beauvais (1988), Fontaine and Varawut Suteethorn (1988), etc. In addition to Assanee Meesook (1994), studied and described marine Jurassic bivalves of Thailand, which 39 species, including 32 new species from the north to the south.

Bivalves and ammonoids in the study area are included within 20 genetic and subgeneric level taxa and show a distinct Tethyan affinity. Bivalves are abundant and diverse. Ammonites are not described in more detail because of their moderately poor preservation and additional fossils contain nerineid gastropod, rhynchonellid brachiopods, telebratilid brachiopods, coral, trace fossils and plant remains.

The systematic classification and morphological terms used in this study are those of Cox et al. (1969) for Bivalvia, modified after Waller (1978), and Arkell et al. (1957) have been described as follows:

Phylum MOLLUSCA

Class BIVALVIA Linné, 1758

4.1 Subclass PTERIOMORPHIA Beurlen, 1944

4.1.1 Order ARCOIDA Stoliczka, 1871

Superfamily ARCOIDEA Vaught, 1989

Family PARALLELODONTIDAE Dall, 1898

Subfamily GRAMMATODONTINAE Branson, 1942

Genus: *Grammatodon* Meek& Hayden, 1861

***Grammatodon* sp.**

(Plate 1, Figures 1-9)

Material: Ten complete and five incomplete internal moulds from 4 localities.

Range: Jurassic-Cretaceous, cosmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Hms-5-1	9.25	5.25	1.76
Hms-5-2	7.75	5.50	1.41
Hms-5-3	7.25	5.00	1.45
Hms-5-4	7.25	4.50	1.61
Bpt-1-1	10.25	6.00	1.71
Bpt-1-2	5.00	4.25	1.17
Bpt-1-3	8.75	5.25	1.66
Bpt-1-4	6.00	3.00	2.00
Bpt-1-5	8.00	5.50	1.45
Bpt-1-6	6.25	3.75	1.66

Description: Shell of medium size, inequilateral, ovoid, length less than twice height, longer than high, hinge margin nearly straight or slightly curved, anterior and dorsal margins meet in obtuse angle, anterior evenly convex, ventral margin broadly and shallowly convex, umbo prominent, beak prosogyrous, valve margins closed.

Remark: This species can be compared with *Grammatodon tenuis* Hayami, from Lower Jurassic of Vietnam (Hayami, 1972) also resembles these species but has less prominent umbones, and is more rounded posteroventrally.

Occurrence: Common in brown silty mudstones and grey mudstones of the Khun Huai Formation from sections Huai Mae Sot, Ban Mae Kut Luang, Tak-Mae Sot Highway, and Ban Pu Toe.

Age: Early Toarcian.

4.1.2 Order MYTILOIDA Férussac, 1822

Superfamily MYTILACEA Rafinesque, 1815

Family MYTILIDAE Rafinesque, 1815

Subfamily MODIOLINAE Keen, 1958

Genus: *Modiolus* Lamarck, 1799

***Modiolus* sp.**

(Plate 2, Figure 10)

Material: Two completes from Ban Mae Kut Luang section.

Range: Devonian-Recent, cosmopolitan.

Description: Shell of moderate size, modioliform, More or less inflated, elongate subtrapezoidal, rounded anteriorly, ventral margin slightly excavate, umbones obtuse, hinge line smooth and long, ligament fairly long, surface covered with fine concentric growth lines, Inflated, smooth, periostracum commonly hirsute.

Remark: This species can be distinguished from *Modiolus sestiniae* Hayami, from the Lower Jurassic of Ho Chi Minh City (Hayami, 1972) by its larger size and more elongate outline, the smaller posterodorsal angle, and its finer concentric lines.

Occurrence: Few in mudstone of the Doi Yot Formation.

Age: Toarcian.

4.1.3 Order PTERIOIDA Newell, 1965

4.1.3.1 Suborder PTERINA Newell, 1965

Superfamily PTERIOIDEA Vaught, 1989

Family BAKEVELLIIDAE King, 1850

Genus: *Gervillia* Defrance, 1820

***Gervillia* sp.**

(Plate 2, Figures 1-5)

Material: Five completes specimens from sections Huai Mae Sot and Huai Wale.

Range: Upper Jurassic – Upper Cretaceous, conmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Hwl-4	23.75	7.25	3.28
Hwl-5	24.00	9.00	2.66
Hwl-6	18.25	6.75	2.70
Hwl-7	20.25	7.50	2.70

Description: Elongate-oval, shell of Medium-sized, oblique, faintly falciform, probably moderately inflated, longer than high, hinged line straight, umbone terminal, longitudinally elongated, narrow, ensiform, slightly curved, posterior margin short and bluntly rounded. shell surface smooth except for close consicuous commarginal growth lines.

Remark: This Thai species is similar to *G. saggersoni* Cox from the Oxfordian of northeastern Kenya (Cox, 1965), in general outline but can be separated by its smaller size, and less prominent posterior wing.

Occurrence: Common in brown silty mudstones of the Klo Tho Formation.

Age: Toarcian.

4.1.3.2 Suborder PINNINA Vaught, 1989

Superfamily PINNOIDEA Vaught, 1989

Family PINNIDAE Leach, 1819

Genus: *Pinna* Linne, 1758

***Pinna* sp.**

(Plate 2, Figures 6-8)

Material: Five incompletes from sections Ban Mae Kut Luang Tak-Mae Sot Highway, Huai Mae Sot and Ban Pu Toe.

Range: Lower Carboniferous-Recent, cosmopolitan, living ones worldwide in tropical or subtropical seas.

Description: Shell of small size, with slightly concave ventral margin, shell elongate cuneiform, straight median carina, equivalve, wedge-shaped, umbones at extreme anterior end, margin incomplete but growth lines show it to be faintly convex dorsally, strongly curved ventrally, shell surface is ornamented by regularly spaced radial ribs which cover all dorsal and dorsal half to ventral areas; ribs usually low, straight, about 8 to 12 on dorsal and 3 to 5 on ventral regions which vary with size of shell, ribs crossed by growth-lines and comarginal folds of irregular strength and spacing.

Remark: It can be distinguished from *P. (Pinna)* cf. *folium*, from the Early Jurassic of Argentina (Damborenea, 1987) by its smaller size, smaller apical angle, more obvious median carina, and fewer radial ribs.

Occurrence: Several in dark grey mudstone of the Khun Huai Formation.

Age: Toarcian.

4.1.4 Order OSTREOIDA Vaught, 1989

Suborder PECTINNINA Vaught, 1989

Superfamily PECTINACEA Rafinesque, 1815

4.1.4.1 Family POSIDONIIDAE Frech, 1909

Genus: *Bositra* de Gregorio, 1886

***Bositra ornati* (Quenstedt, 1851)**

(Plate 3, Figures 1-9)

1851 Posidonia ornate sp. nov., Quenstedt, p. 517; Taf. 42, Fig. 16.

1852 Posidonomya alpina so. nov., Grass, p. 11, pl, fig. 1.

1856 Posidonia opalina Quenstedt,p. 324, Taf. 45 Fig. 11.

1857 Posidonia ornati Quenstedt, p.501, 551, Taf, 67, Fig. 27, Taf. 72, Fif. 29.

1867 Posidonia ornati Quenstedt, p. 615, Taf. 53, Fig. 16.

1876 Posidonai ornati Tribolet, p. 254-255.

1881 Posidonomya cf. ornati Steinmann, p. 257-259 ,Taf. 10, Fig. 3-4 (only)

1899 Posidonomya bronni Goldfuss (sic) - R Philippi, p.41, lam. 22, fig.3 (only)

1899 Posidonomya orniti-R.Philippi, p. 41, lam. 22, fig. 9 (copy from Steinmann, 1881).

1900 Posidonia opalina - Burckhardt, p.29, pl. 20. fig. 8.

1903 Posidonomya alpina - Bruckhardt, p. 20, Taf. 2, fig. 8.

1918 Posidonomya alpina - Bruckhardt, p. 20, Taf. 2, Fig. 11.

1918 Posidonomya alpina - Groeber, p. 17, 67.

?1923 Posidonamya orniti - Stehn, p. 141.

?1923 Posidonomya buchii - Stehn, p. 143.

1925 Posidonomya alpina - Gerth, p. 25.

1925 Posidonomya ornati - Gerth, p. 23.

1925a Posidonomya ex grupo alpinae - Jaworski, p. 155-157.

1926 Posidonomya ex grupo alpinae - Jaworkski, p. 388-390.

1928 Posidonomya alpina - Guilaume, p. 222, text-fig. 4-5, pl. 10, fig. 4-13.

1931 Posidonomya from the group of p. alpina - Weaver, p. 216-218, pl. 18, fig. 80

?1936 Posidonomya alpina - Piatnitzky, p. 90, 101-102.

1940 Posidonomya ornati - Cox, p. 103-105, pl. 7, fig 10-11 (with synonymy).

?1942 Posidonomya alpina - Suero, p. 40.

v.1943 Posidonomya sp. del group P. alpina- Garcia - Vizcarra, p.29, 43.

v1943 Posidonomya cf. alpina - Fernandez, p. 22, 27, 43, 58, 61.

1953 Posidonomya alpina - Groeber al., p. 160, 162, 164.

p.1978 Bositra ornati - Camacho & Ricccardi, cuadro 2 (only Weaver's reference).

1980 Bositra bochi - Hillebrandt, lam. 1, fig. 6.

V1982 Bositra ornati - Damborenea, p. 207-212, lam. 46, fig. 1-3, lam. 64, fig. 11.

1987 Bositra ornati – Damborenea, p. 163-166, pl. 4, fig. 7.

Material: sixty internal moulds of left and right valves from 3 localities.

Range: Toarcian-Aalenian.

Dimensions: in mm.

Specimen	L	H	L/ H
Hms-6-1	5.50	3.80	1.44
Hms-6-2	3.25	2.50	1.30
Hms-6-3	7.50	6.25	1.20
Hms-6-4	6.25	4.25	1.47
Hms-6-5	5.50	4.00	1.38
Hms-6-6	6.25	5.00	1.25
Hms-6-7	5.25	4.75	1.10
Hms-6-8	6.25	6.25	1.00
Hms-6-9	6.25	4.25	1.47
Hms-6-10	6.50	4.75	1.37
Hms-6-11	6.75	5.25	1.29
Hms-6-12	6.50	6.00	1.08
Hms-6-13	6.75	7.25	0.93
Hms-6-14	8.00	6.50	1.23
Hms-6-15	6.25	6.00	1.04
Hms-6-16	6.25	6.50	0.96
Hms-6-17	6.75	5.50	1.23
Hms-6-18	7.50	6.25	1.20
Hms-6-19	6.00	4.75	1.26
Hms-6-20	6.00	4.50	1.33

Description: Shell small, thin, oval in outline, equivalve, and inequilateral, without anricles, length exceeding height, concentric folds regular but less conspicuous towards anterior margin in some large specimens, rounded concentric ribs, hinge-line short.

Remarks: The specimens are closely similar to *B.ornati* (Quenstedt) from the Middle Toarcian of Argentina (Damborenea, 1987) in general outline although of smaller size, and with a more prosogyrous beak and more conspicuous ribs. These specimens also differ from B. somaliensis from the Upper Kimmeridgian of Tanzania (Cox, 1965) by having a less oval outline and rounded concentric ribs.

Occurrence: Abundant in dark-grey mudstones of the Doi Yot Formation from sections Ban Mae Kut Luang, Huai Mae Sot and Ban Pu Toe.

Age: Toarcian-Aalenian.

4.1.4.2 Family ENTOLIDAE Korobkov, 1960

Genus: *Entolium* Meek, 1865

***Entolium* sp.**

(Plate 4, Figures 1-9)

Material: seven completes from 4 localities.

Range: Middle Triassic-Upper Cretaceous, cosmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Mkl-9-2-1	9.75	9.50	1.02
Mkl-9-2-2	8.75	8.00	1.09
Mkl-9-2-3	8.50	9.25	0.92
Mkl-9-2-4	5.25	6.75	0.77
Mkl-9-3-1	8.75	11.25	0.77
Mkl-9-3-2	8.00	9.50	0.84
Mkl-9-4-1	7.50	6.75	1.11

Description: Shell of medium size, slightly inflated, equivalve, almost equilateral, dorsoventrally suboval in outline so that height greater than length, auricular persent and triangular**,** anterior and postreior auricles equal, relatively small, of similar size and

shape, hinge line straight, shell surface smooth except for faint commarginal growth lines.

Remarks: This species is similar to *Entolium partilum* (Sowerby) from the Callovian-Oxfordian of Kutch, India (Cox, 1952) and *Entolium* sp. aff, *E. partilum* (Sowerby) from the Lower Jurassic of Vietnam (Hayami, 1972) but differs from both by its shorter hinge line, smaller length/height ratio, and smaller apical angle.

Occurrence: common in dark grey mudstones of the Doi Yot Formation.

Age: Toarcian.

4.1.4.3 Family RPOPEAMUSSIDAE Vaught, 1989

Genus: *Parvamussium* Sacco, 1897

***Parvamussium donaiense* (Mansuy, 1914)**

(Plate 5, Figures 1-15)

1914 Pecten (Amusium) donaiense Mansuy, Mem. Serv. Geol. Indochine 3 (2); 37, pl. 4, fig. 3.

1935 Pecten (Amusium) pumilus Lamarck var.donaiense Mansuy: Saurin, Bull. Serv. Geol, Indochine 22 (1) : 155, pl. 12, figs. 8-9

1988 Parvamussium donaiense : Fontaine & Suteethorn, CCOP, Tech. Bull. 20, p,89.

Material: twenty complete and thirty incomplete internal and external molds from 4 localities.

Range: Lower Jurassic-Recent, cosmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Mkl-9-2-a1	7.25	7.50	0.96
Mkl-9-2- a2	7.00	6.50	1.07
Mkl-10-a1	12.50	11.25	1.11
Tmr-2-a1	6.50	7.25	0.89
Tmr-2- a2	8.25	8.50	0.96
Tmr-2- a3	7.25	9.00	0.80
Tmr-2- a4	5.50	5.75	0.95
Tmr-2- a5	6.75	7.50	0.90
Tmr-2- a6	7.75	9.25	0.84
Tmr-2- a7	9.75	10.25	0.95
Tmr-2- a8	8.25	9.00	0.92
Tmr-2- a9	8.00	9.25	0.84
Tmr-2- a10	8.50	10.25	0.83
Tmr-2- a11	8.50	10.50	0.80
Tmr-2- a12	5.50	4.75	1.16
Tmr-2- a13	4.00	4.75	0.84
Bpt-1-a1	5.50	6.00	0.92
Bpt-1-a2	5.75	6.00	0.96
Bpt-5-a1	14.00	14.50	0.96
Bpt-5-a2	11.00	9.75	1.13
Bpt-5-a3	9.50	11.75	0.80
Bpt-5-a4	9.75	10.25	0.95
Bpt-5-a5	8.50	9.75	0.87
Bpt-5-a6	4.50	5.25	0.85

Description: Small to medium-sized, rarely exceeding 15 mm in height, subcircular in outline, inequivalve, nearly equilateral, slightly convex, slightly higher than long, test thin, auricles unequal, anterior usually larger than posterior, surface of right valve generally smooth but with faint concentric threads; left valve with weak spaced radial riblets approximately corresponding to internal rib; interspaces of external ribs with numerous faint radial threads in some specimens but lacking any concentric ornament on left valve; 6-7 internal ribs very sharp and straight, extending from umbo nearly to valve margin, gradually strengthening ventrally.

Remarks: The following characters confirm their identity with Mansuy's species: faint concentric plicae on the right valve, and 6-7 sharp straight internal ribs which extend nearly to the valve margin.

Occurrence: Common in dark grey mudstone and silty mudstone in the Khun Huai Formation.

Age: Toarcian.

Genus: *Camptonectes* Agassiz in Meek, 1864

***Camptonectes* sp.**

(Plate 2, Figure 9)

Material : Two complete from one locality.

Range: Lower Jurassic-Upper Cretaceous, cosmopolitan.

Description: Shell of medium size, inequilateral, suborbicular outline, height greater than length, slightly inflated**,** acutely triangular**,** beak not projecting above short straight hinge line; anterior margin almost straight; posterior margin steep, anterior auricle longer than posterior, anterior auricle of left valve large, shall surface ornamented by fine dense striae, party seen in some specimens, and commarginal growth lines.

Remarks: This Thai species is similar to *C. (Camptonectes*) *fromageti* Hayami, from the Lower Jurassic of Vietnam (Haymai, 1972) in general outline but can be distinguished by its more subequilateral outline, larger apical angle, and shorter anterior auricles.

Occurrence: Few in grey mudstone of the Doi Yot Formation.

Age: Toarcian.

4.2 Subclass PALEOHETERODONTA Newell, 1965

4.2.1 Order TRIGONIOIDA Dall, 1889

Superfamily TRIGONOIDEA Vaught, 1989

Family TRIGONIIDAE Lamarck, 1819

Genus: *Trigonia* Bruguiere, 1789

***Trigonia* sp.**

(Plate 4, Figures 10-15)

Material: Twelve complete and five incomplete from 3 localities.

Range: Middle Triassic-Upper Cretaceous, cosmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Tmr-1-1	8.25	7.00	1.18
Tmr-1-2	6.50	5.50	1.18
Tmr-1-3	7.50	6.75	1.11
Tmr-1-4	11.75	12.25	0.96
Tmr-1-5	10.50	9.25	1.14
Hms-10-1	16.75	14.25	1.18
Hwl-7-1	21.25	20.75	1.02
Hwl-7-2	17.75	21.50	0.82
Hwl-7-3	24.75	19.75	1.25
Hwl-7-4	21.50	15.25	1.41
Hwl-7-5	23.75	33.75	0.70
Hwl-7-6	14.75	18.25	0.80

Description: Shell of medium size, shell thick, trigonal, highly triangular, inequilateral, longer than high, beak moderately prominent and acute, posterior area very sloping, situated at anterior third of shell; ventral margin broadly rounded, convex centrally, slightly sinuous posterily where it meets narrow sharp nearly straight posteron ventral carina**,** short upright posterior margin forms right angle ventrally and obtuse angle with long straight oblique posterodoral margin, rounded concentric ribs**.**

Remarks: This species can be distinguished from the Toarcian Thai forms *T. (Trigonia) fontainei* and *T. (Trigonia) maesot* by its smaller size, more rounded and curved concentric ribs and shorter posterior cairna.

Occurrence: common in silty mudstones from the Khun Huai Formation.

Age: Toarcian.

4.3 Subclass HETERODONTA Neumayr, 1884

4.3.1 Order VENEROIDA H.Adams & A.Adams, 1856

4.3.1.1 Superfamily ASTARTOIDEA Vaught, 1989

Family ASTARTIDAE d'Orbigny, 1844

Genus: *Astarte* J.Sowerby, 1816

***Astarte* sp.**

(Plate 6, Figures 1-15)

Meterial: Thirty complete and twenty incomplete from 4 localities.

Range: Jurassic-Recent, cosmopolitan.

Dimensions: in mm.

Specimen	L	H	L/ H
Hwl-6-b1	12.75	12.00	1.06
Hwl-6-b2	14.25	11.75	1.21
Hwl-6-b3	13.50	12.50	1.08
Hwl-6-b4	10.75	8.00	1.34
Hwl-6-b5	12.25	14.00	0.88
Hwl-6-b6	17.00	14.25	1.19
Hwl-6-b7	11.50	10.25	1.21
Hwl-6-b8	14.75	12.50	1.18
Hwl-6-b9	13.25	11.00	1.20
Hwl-6-b10	11.00	10.75	1.02
Hwl-6-b11	9.50	10.50	0.90
Hwl-6-b12	6.75	5.50	1.22
Hwl-6-b13	10.75	11.25	0.95
Hwl-6-b14	8.25	8.00	1.03
Hwl-6-b15	10.50	8.25	1.27
Hwl-6-b16	11.00	8.25	1.33
Hwl-6-b17	11.25	10.75	1.04
Hwl-6-b18	14.00	12.25	1.14
Hwl-6-b19	15.50	14.50	1.07
Hwl-6-b20	14.00	11.25	1.24
Hwl-6-b21	10.25	11.75	0.87
Hwl-6-b22	13.00	13.50	0.96

Specimen	L	H	L/ H
Hwl-6-b23	11.75	9.25	1.27
Hwl-6-b24	9.50	11.50	0.82
Hwl-6-b25	14.75	11.75	1.25

Description: Shell of medium size, inequilateral, transversely trigono-elliptical to subtriangular in outline, moderately inflated, height nearly equals length, beak prosogyrous, located slightly anteriorly; margins internally smooth; posterodorsal margin slightly convex, forming a rounded obtuse angle with vertically truncate posterior margin; ventral and anteroventral margins broadly and evenly convex, ascending more rapidly anteriorly; anterodorsal margin slightly concave; ornament consists of narrow symetrial sharp-crested concentric ribs.

Remarks: This Thai species is similar to *Astarte (Astarte) plingarmi* in general outline but can be distinguished by its smaller size, greater inflation, and more crowded concentric ribs.

Occurrence: common in silty mudstone from the Khun Huai Formation.

Age: Toarcian.

4.3.1.2 Superfamily CARDIOIDEA Vaught, 1989

Family CARDIIDAE Lamarck, 1809

Subfamily PROTOCARDIINAE Keen, 1951

Genus: *Protocardia* Beyrich, 1845

***Protocardia* sp.**

(Plate 9, Figures 1-3)

Meterial: Nine complete and six incomplete from 2 localities.

Range: Upper Triassic- Upper Cretaceous

Dimensions: in mm.

Specimen	L	H	L/ H
Tmr-2-c1	7.00	5.50	1.27
Tmr-2-c2	5.75	4.00	1.43
Tmr-2-c3	7.50	6.25	1.2
Tmr-2-c4	14.75	12.25	1.2
Tmr-2-c5	10.25	7.75	1.32
Tmr-3-c1	19.50	17.25	1.13
Tmr-3-c2	14.50	13.00	1.12
Tmr-3-c3	13.50	15.25	0.88

Description: Shell of medium size, suboval, nearly equilateral, longer than high, moderately inflated. Umbo large, Beak orthogyrous, prominent, projecting above dorsal margin ; anterodorsal margin well excavated, anterior and ventral margins strongly convex ; posterior margin slightly less convex than anterior, forming obtuse angle with ventral margin; posterior area generally with fine radial ribs, with 16 radial riblets fading towards anterior margin; anterior concentric lines regular and moderately conspicuous; interspaces with very fine subsidiary threads. Anterior concentric and posterior radial ribs well developed.

Remarks: This Thai species is similar to *P. (Protocardia) striatula* in general outline but can be distinguished by its larger size, less circular outline and less conspicuous radial riblest.

Occurrence: common in mudstone from the Khun Huai Formation.

Age: Toarcian.

4.4 Subclass ANOMALODESMATA Dall, 1889

4.4.1 Order PHOLADOMYOIDA Newell, 1965

4.4.1.1 Superfamily PHOLADOMYOIDEA Vaught, 1989

Family PHOLADOMYOIDE Gray, 1847

Genus : *Pholadomy*a Sowerby, 1823

***Pholadomya* sp.**

(Plate 7, Figures 1-9)

Meterial: Nine complete and seven incomplete from 3 localities.

Range: Upper Triassic-Recent, cosmopolitant.

Dimensions: in mm.

Specimen	L	H	L/ H
Hwl-1-d1	22.75	19.75	1.51
Tmr-3-d2	12.75	9.50	1.34
Hms-10-d1	12.50	13.25	0.94
Hms-10-d1	20.50	19.25	1.06

Description: Shell of small to medium sized and subtrigonal outline, strongly inequilateral, moderately elongate, strongly inflated, test thin, umbo large, beak slightly orthogyrous, prominent, rising above hinge margin, posterodorsal margin moderately long, slightly concave, passing into subangled posterior margin; ventral margin broad, gently curved; 5-9 radial ribs of irregular spacing and strength, surface covered by concentric wrinkles of slightly variable strength and spacing, generally a little more than 1 mm apart, and forming low gemmules at intersections with radials,

Remarks: This species is similar to *P. reticulata* Agassiz from the Toarcian of Kenya (Cox, 1965) in general outline but can be separate by its more conspicuous radial ribs and broader ventral margin.

Occurrence: common in mudstone from the Khun Huai Formation.

Age: Toarcian.

Genus: *Goniomya* Agassiz, 1841

***Goniomya* sp.**

(Plate 7, Figures 10-14)

Meterial: Five complete and nine incomplete from 2 localities.

Range: Lower Jurassic (Lower Liassic)-Eocene, cosmopolitan.

Description: Shell of medium-large size, ovate, inequilateral, elongate elliptical, slightly inflated, length greater than height; beak orthogyrous, prominent, located at anterior third, anterodorsal and posterodorsal margins nearly straight, anterior margin incomplete, posterior margin slightly concave, meeting almost straight ventral margin in obtuse angle, surface ornamented with about 11 V-shaped costae which become stronger anterior and faint and broader posteriorly; apical angle of V's about 40° and nearly constant throughout growth.

Remarks: This specimen is very close *to G. (Goniomya) knorri* Agassiz from the Lower Jurassic of Vietnam (Hayami, 1972), but differs by having a smaller angle between the rib segments, and less conspicuous costae posteriorly.

Occurrence: several in silty mudstone of the Doi Yot Formation.

Age: Toarcian.

Genus: *Homomya* Agassiz, 1843

***Homomya* sp.**

(Plate 2, Figures 11-12)

Meterial: Two complete from 2 localities.

Range: Middle Triassic-Upper Jurassic (Tithonian), cosmopolitan.

Description: Shell of medium size, elongate-oval, strongly inequilateral moderately inflated ; length about twice height ; umbo low, rising little above dorsal margin, slightly

opisthogyrous, located at anterior third ; anterior margin smoothly rounded, ventral and posterodorsal margins long, straight and subparallel ; posterior margin broadly rounded, joining ventral at an obtuse angle ; irregular concentric wringles cover shell but generally are weak ventrally.

Remarks: This species is similar to the *H. gibbosa* (Sowerby) from the Middle Jurassic (Bathonian) of England (Cox et al., 1969) in genaral outline but can be distinguished by its less prominent umbo and has a less concave posterodorsal margin.

Occurrence: Few in silty mudstone in the Khun Huai Formation.

Age: Toarcian.

4.4.1.2 Superfamily PANDOROIDEA Vaught, 1989

Family THRACIIDAE Stoliczka, 1870

Genus*: Thracia* Sowerby, 1923

***Thracia* sp.**

(Plate 8, Figures 1-12)

Meterial: Ten complete and twelve incomplete from 6 localities.

Range: Jurassic-Recent.

Dimensions: in mm.

Specimen	L	H	L/ H
Tmr-1-e1	21.75	12.25	1.77
Mkl-9-1-e1	18.75	11.75	1.59
Mkl-9-2-e1	23.25	14.00	1.66
Mkl-9-3-e1	19.25	11.75	1.64
Hms-9-e1	10.25	7.25	1.41
Hms-10-e1	16.75	14.25	1.17
Hms-10-e2	15.50	8.75	1.77
Hms-10-e3	16.50	11.50	1.43
Hms-10-e4	12.50	9.50	1.31
Hms-10-e5	12.50	11.75	1.06
Hms-10-e6	11.50	9.75	1.18

Specimen	L	H	L/ H
Hms-10-e7	15.00	11.50	1.30
Hms-13-e1	20.00	10.50	1.90

Description: Shell small to medium size, hinge margin long, subequivalve, moderately inflated, oblong, nearly equilateral, subelliptical to roundly trapezoidal in general outline, not strongly inflated, posterior region slightly boarder than anterior, anterodorsal margin oblique, gently convex, slightly longer than straight to gently concave posterodorsal margin, anterior bluntly angular, posterior margin upright, straight to gentry convex.

Remarks: This species resembles *T. loducensis* (Hayami, 1972) from the Lower Jurassic of Ho Chi Min City, Vietnam, in general outline but can be distinguished by its smaller size, less conspicuous umbo, and longer posterodorsal margin.

Occurrence: common in dark grey mudstone in the Khun Huai and Doi Yot Formation.

Age: Toarcian.

CHAPTER V

DISCUSSION AND CONCLUSION

5.1 Discussion

During Late Triassic, multiple episodes of collision and suturing of all tectonic terranes resulted in the closure of Paleotethys (Figure 5.1). The Indochina and the eastern part of Shan-Thai terranes may have been dramatically uplifted and emerged, becoming a central part of Southeast Asian landmass (Panya 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 Assanee Meesook (1994), Naramase Teerarungsigul (1999), Naramase Teerarungsigul *et al*. (1999), Lertsin Raksaskulwong (2002), and Assanee Meesook *et al*. (2006). 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; Vail *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.

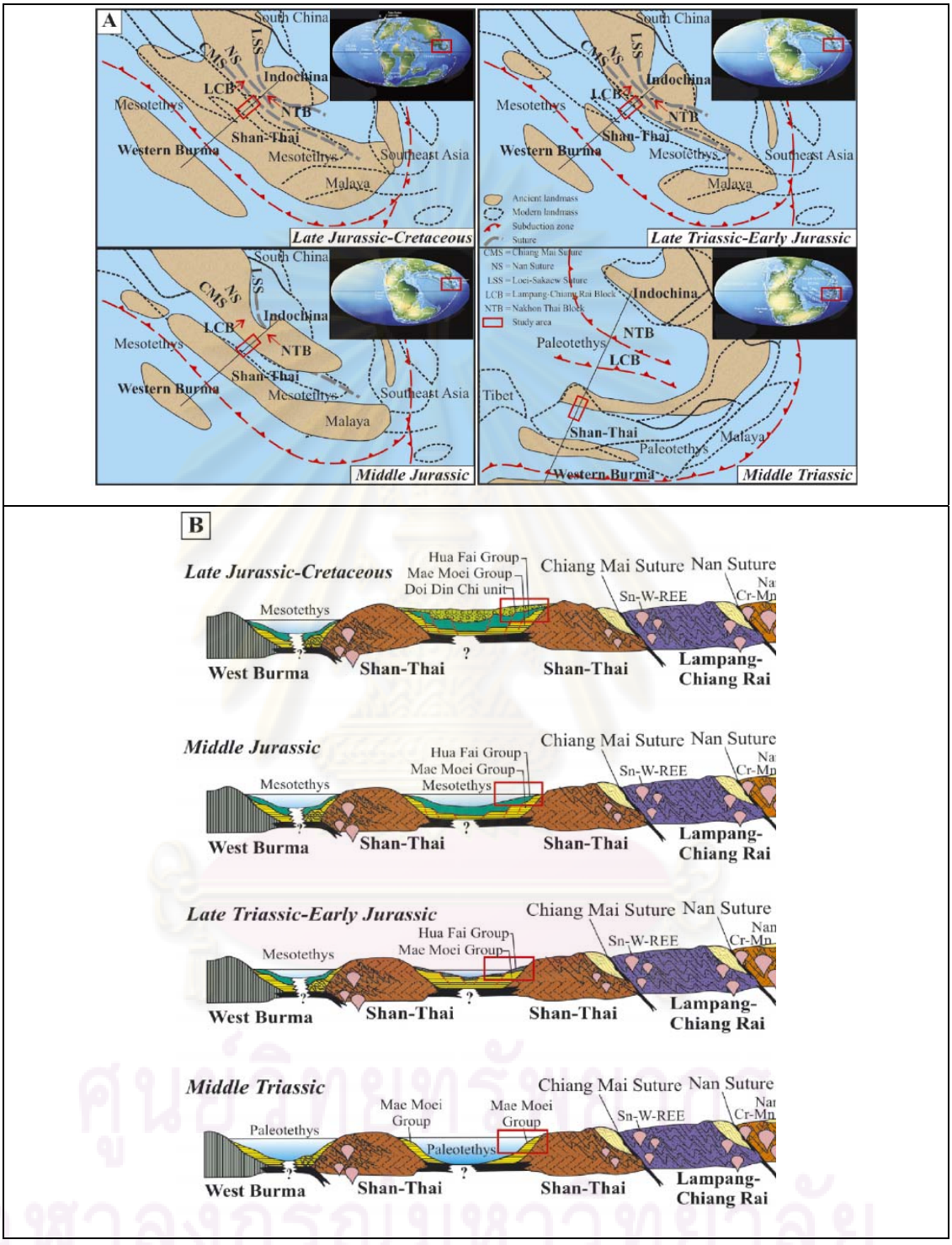


Figure 5.1. A) Paleogeographical distribution of Shan-Thai, Indochina, Lampang-Chiang Rai and Nakhon Thai terranes compared to other tectonic terranes. B) Plate tectonic reconstruction of major tectonic terranes of mainland Southeast Asia showing the occurrence of the Mae Moei and Hua Fai Groups, and Doi Din Chi unit during Middle Triassic to Cretaceous (modified after Wirote Saengsrichan, 2009).

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 5.1b). 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.

Faunas in the study area of the Toarcian, Khun Huai Formation are abundant and diversed of bivalves and rare ammonoid to be harmonious with model in Figure 5.2. The Aalenian, Doi Yot Formation is abundant in bivalves especially *Bositra ornati* and ammonoids are increased more and more in many species to be harmonious with trangression sea level. Bajocian stage, Pha De Formation is reduced of bivalves and ammonoids to be harmonious with regression sea level.

In the study area, *Bositra ornati* and *Parvarmussium donaiense* can be found together in the same bed of dark grey mudstone at Tak-Mae Sot Highway section indicating that the environment is rich in high nutrients, high oxygen and moderate to low energy level. Generally, *Bositra ornati* represents Aalenian stage and *Parvarmussium donaiense* represents Toarcian stage. The discovery of these two bivalves in the same bed in the study area may be the first time in, at least, Southeast Asia in which the two genera having epifaunal and free-swimming modes of life but different in age were found together.

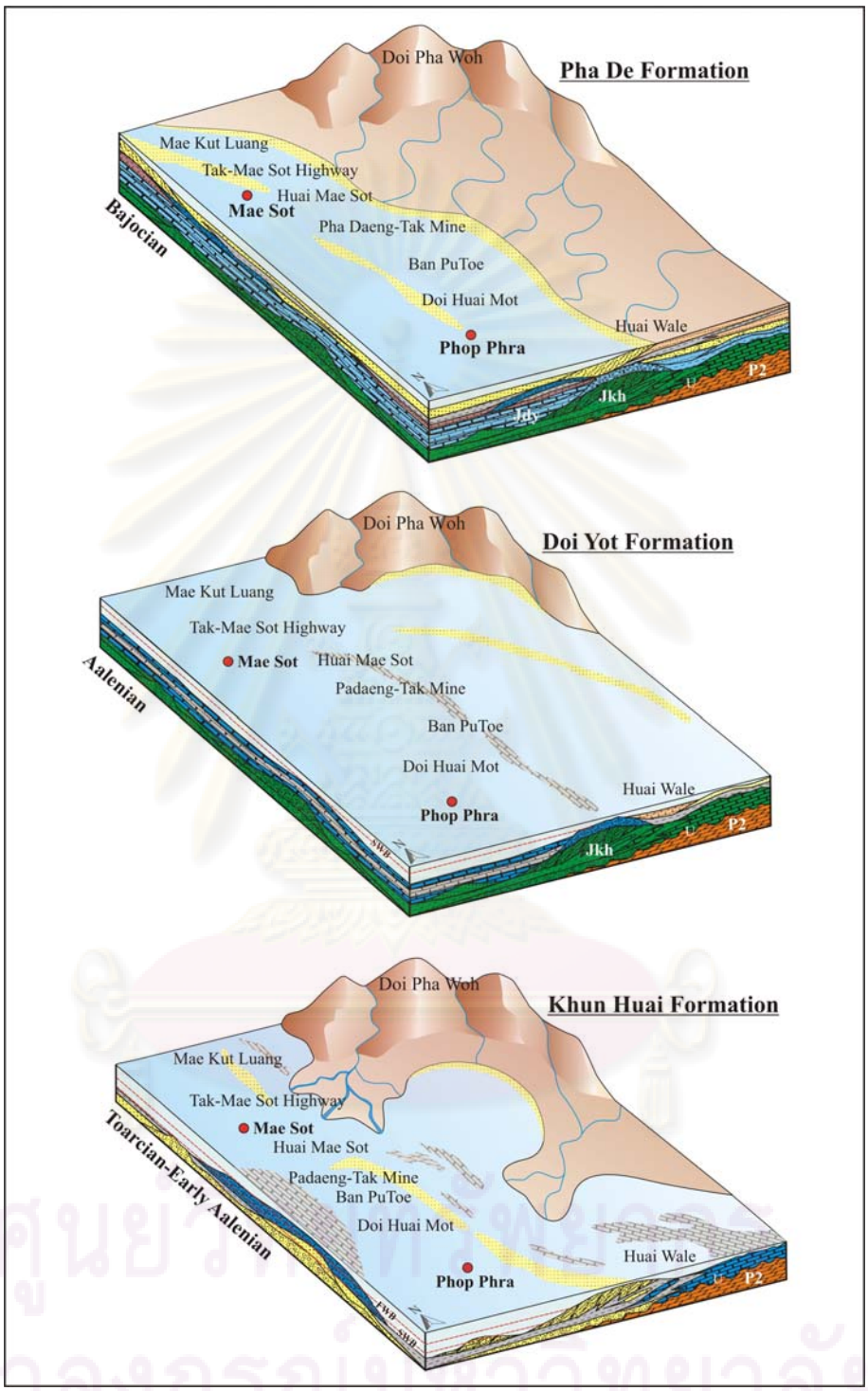


Figure 5.2. Schematic models illustrating of depositional environment of the Hua Fai Group, Mae Sot-Phop Phra area in the Jurassic (after Wirote Saengsrichan, 2007).

5.2 Conclusion

The present study is based mainly on 7 sections of the marine Jurassic, Hua Fai Group, within Mae Sot-Phop Phra Basin, and attemps to understand the marine Jurassic of Thailand in terms of biostratigraphy, age, systematic paleontology, and paleoenvironment. The results can be concluded as follows:

5.2.1 Biostratigrahy

Fossils collected from Marine Jurassic rocks in the Mae Sot-Phop Pha area yileds abundant and diversed bivalves, at least 17 genera of bivalves found together with ammonoids assemblage. Bivalves consist of *Astarte* sp., *Actenostreon* sp., *Bositra ornati*, *Ceratomya* sp., *Camptonectes* sp., *Entolium* sp., *Gervillia* sp., *Goniomya* sp., *Grammatodon* sp., *Homomya?* sp., *Lima?* sp., *Parvamussism donaiense*, *Pholadomya* sp., *Pinna* sp., *Protocardia* sp., *Thracia* sp., *Trigonia* sp., and a rudist bivalve. Additional fossils contain rhynchonellid brachiopod, nerineid gastropod, coral, trace fossils and plant remains. Ammonites are more abundant in the Aalenian-Early Bajocian sequences. Marine Jurassic rocks in the study area consist mainly of mudstones, siltstones, sandstones, marls, limestones and oolitic limestones.

Based on the fauna and sediment associations, the facies can be recongnised in the Thai Jurassic sequence (Assanee Meesook *et al*., 1997) as: *Bositra* Facies, Benthic bivalves Facies, Mixed Facies, Ammonites Facies and Brachiopod Facies. With the low Tethys sea level, transgression in the Toarcian is indicated by mudstones and high faunal diversity, while regression in the Aalenian-Early Bajocian is represented by sandstone and limestone conglomerates in most places.

Biostratigraphic correlation of marine Jurassic fossils in the Mae Sot-Phop Phra areas, Changwat Tak can be divided as the *Bositra* zone.

Age determination is based mainly on the bivalves *Parvamussium donaiense* and *Bositra ornati*, and some ammonites, and the Toarcian-Aalenian age is given for the rocks.

5.2.2 Paleoenvironment

The sedimentary sequences of the Hua Fai Group have been reported by Wirote Saengsrichan (2007**)**, 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.

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.

The rocks and abundant bivalves are interpreted as having been deposited in shallow marine environments and restricted basins in these areas during the Jurassic Period as indicated by the presence of primary sedimentary structures and oolitic limestones, and dark grey mudstones with abundant fossil bivalves.

REFERENCES

Adul Charoenprawat, et al. 1985. Geology of Changwat Mae Hong Son (4547I) and Ban Huai Pong (4547II). scale 1: 50,000. Geological Survey Division, Department of Mineral resources. pp.1-24 (in Thai, unpublished).

Alméras, Y. 1988. Jurassic brachiopods from the Klo Tho-Mae Sot area. CCOP. Technical Bulletin. 20: 211-216.

Arkell, W. J., Kummel, B., and Wright, C. W. 1957. Cephalopoda Ammonoidea. In Treatise on Invertebrate Paleontology L, Mollusca 4. R. C. Moore (ed), Geological Society of America And University of Kansas Press.

Assanee Meesook, et al. 1985. Geology of Ban Chi Cho Chi (4740 IV), Ban Pa La Tha (4740 I), Ban Klo Tho (4741 III), and Amphoe Umphang (4741II) Quadrangles scale 1:50,000. Amphoe Umphang, Changwat Tak, western Thailand. Stratigraphic Correlation Research Unit. Report (2). Geological Survey Division, Department of Mineral Resources. Bangkok: 40., 40., 35., and 36. (in Thai)

Assanee Meesook. 1994. Marine Jurassic stratigraphy and bivalve paleontology of Thailand. Unpublished Doctoral dissertation, University of Auckland, New Zealand.

Assanee Meesook, and Grant-Mackie, J.A. 1994. Biostratigraphic correlation of marine Jurassic rocks within Thailand and Southeast Asia. In: Angsuwathana, P., Wongwanich, T., Tansathien, W., Wongsomsak, S., and Tulyatid, J. (eds), Proceedings of the International Symposium on Stratigraphic Correlation of Southeast Asia. Department of Mineral Resources, Bangkok, Thailand. 15-20: 160-169.

Assanee Meesook, and Grant-Mackie, J.A. 1996. Marine Jurassic lithostratigraphy of Thailand. Journal of Southeast Asian Earth Science. 14. 5: 377-391.

Assanee Meesook, and Grant-Mackie, J.A. 1997. Faunal associations, paleoecology and paleoenvironments of the Thai Marine Jurassic: a preliminary investigation, Proceedings of International Conference on Stratigraphy and Tectonic Evolution of Southeast Asia and the South Pacific. Bangkok. pp. 164-176.

Assanee Meesook, Naramase Teerarungsigul, and Wirote Saengsrichan. 2005. Mesozoic stratigraphy and faunal aspects of Thailand. Final report, submitted to the project entitled, the Evolution of Mesozoic biodiversity in Thailand. Bureau of Geological Survey, Department of Mineral Resources, Bangkok, Thailand.

Assanee Meesook, Wirote Saengsrichan, and Naramase Teerarungsigul, 2005. Stratigraphy and faunal aspects of the marine Jurassic rocks in southern peninsular Thailand. Internatinal Conference on Geology, Geotechnology and Mineral Resources of Indochina (GEOINDO 2005). Khon Kaen, Thailand. pp. 558-569.

Assanee Meesook, Sha, J., Naramase Teerarungsigul, and Surachet Poonpun. 2006. Non-marine Jurassic rocks of Thailand: A summary. Progress in Natural Science. Marine and Non-marine Jurassic: Boundary Events and Correlation. National Natural Science Foundation and Chinese Academy of Sciences of China, Beijing, China. 16 (special issue): 153-162.

Assanee Meesook, Sha, J., Wirote Saengsrichan, and Naramase Teerarungsigul. 2006. Lithostratigraphy and faunal aspects of marine Jurassic rocks in Thailand. Progress in Natural Science (Special Issue). 16: 152-199.

Assanee Meesook, Sha, J., Chotima Yamee, and Wirote Saengsrichan. 2009. Faunal associations, paleoecology and paleoenvironment of the marine Jurassic rocks in the Mae Sot, Phop Pha, and Umphang areas, western Thailand. Science in China press. 52. 12: 2001-2023

Beauvais, L. 1988. Jurassic corals and coral bearing limestones of Thailand and Burma. CCOP Technical Bulletin. 20: 152-184.

Beauvais, L., and Fontaine, H. 1993. Montlivaltia numismalis (D'Orbigny). A Middle Jurassic coral newly found in west Thailand. Thanasuthipitak, T. (ed), Proceedings of BIOSEA Symposium. Chiang Mai, Thailand. 1: 63-70.

Braun, E. Von, and Jordan, R. 1976. The stratigraphy and palaeontology of the Mesozoic sequence in the Mae Sot area in western Thailand. Geologisches Jahrbuch. Reihe B. Heft. 21: 5-51.

Brown, G.F., et al. 1951. Geologic reconnaissance of the mineral deposits of Thailand. USGS Bulletin. 984: 1-183.

Buffetaut, E., Tong, H., and Varawut Suteethorn. 1994. First post-Triassic labyrinthodont amphibian in Southeast Asia: a temnospondyl intercentrum from Jurassic of Thailand, Neues Jahrbuch für Geologie and Paläontologie. 11: 659-666.

Burrett, C.F. 1974. Plate tectonics and the fusion of Asia. Earth and Planetary Sciences Letters 21. 2: 181-189.

Burrett, C.F., Long, J.A., and Stait, B. 1990. Early-Middle Palaeozoic biogeography of Asian terranes derived from Gondwanaland. In Palaeozoic Palaeogeography and Biogeography. McKerrow, W.S. and Scotese, C.R., editors. Geological Society Memoir 12: 63-174.

Chongpan Chonglakmani. 1983. The marine Mesozoic stratigraphy of Thailand. In: Nutalaya, P., (ed), Proceedings of the Workshop on stratigraphic correlation of Thailand and Malaysia. Haad Yai, Thailand. Technical Paper. 1: 105-127.

Chongpan Chonglakmani, Assanee Meesook, and Varawut Suteetorn. 1985. Jurassic stratigraphy of Thailand. In: Thanvarachorn, P., Hokjaroen, S., and Youngme, W., (eds), Proceedings of Conference on Geology and Mineral Resources Development of the Northeast Thailand. Khon Kaen University. Thailand: pp. 77-83.

Cotter, G. de P. 1924. The oil shales of eastern Amherst. Burma, with a sketch of the geology of the neighbourhood. Record : Geological Survey of India. 55: 282-286.

Cox, L.R. 1952. The Jurassic lamellibranch fauna of Cuth (Kuchh), no. 3, Families Pectinidae, Amusiidae, Plicatulidae, Limidae, Ostreidae and Trigoniidae (Suppl.): Geological Survey of India. Mem. Palaeontological Indica. ser. 9, 3(pt.4): 1-128, pl. 1-12.

Cox, L.R. 1965. Jurassic Bivalvia and Gastropoda from Tankanyica and Kenya. Bulletin British Museum (Natural History) supplement 1: 1-213.

Cox, L., et al. 1969. Pt. N. Mollusca 6 Bivalvia. In : Treatise on Invertebrate Paleontology. Lawrence, Kansas, University Kansas Print. Service: N1-N952.

Damborenea, S.E. 1987. Early Jurassic Bivalvia of Argentina. Part 1, Superfamiy Nuculanacea, Arcacea, Mytilacea and Pinnacea, and stratigraphical introduction. Part 2, Superfamily Pteriacea, Buchiacea and Part of Pectinacea. Palaeontolographica Abt. A, Lfg. 1-3, 4-6, 199: 23-111, 113-216.

Department of Mineral Resources. 2002. The mineral potential exploration project. project area 1/2001, Mae Sot District, Tak Province. Department of Mineral Resources, Bangkok. Thailand.

Doyle, P. 1996. Understanding Fossils. An Introduction to Invertebrate Palaeontology. Chichester, New York, Brisbane, Toronto, Singapore: John Wiley & Sons.

Fontaine, H., and Varawut Suteethorn. 1988. Late Paleozoic and Mesozoic fossils of West Thailand and their environments. CCOP. Technical Bulletin. 20: 1-108.

Fürsich, F.T., Oschmann, W., Jailty, A. K. And Singh, I.B. 1991. Faunal response to Trangressive-regressive cycles: example from the Jurassic of western India. Palaeogeography. Palaeoclimatology. Palaeoecology. 85: 149-159.

Gatinsky, Y.G., Mischina, A.V., Vinogradov, I.V., and Kovalev, A.A. 1978. The main metallogenic belts of Southeast Asia as the result of different geodynamic conditions and interference. In: Nutalaya, P., (ed), Proceedings of the Third Regional Conference on Geology and Mineral Resources of Southeast Asia (GEOSEA III). Bangkok. Thailand: 313-318.

Hagen, D., and Kemper, W. 1976. Geology of the Thong Pha Phum area (Kanchanaburi Province, Western Thailand). Geologisches Jahrbuch. Reihe B. Heft. 21: 53-91.

Hahn, L., Koch, K.E., and Wittekindt, H. 1986. Outline of the geology and the mineral potential of Thailand. Geologisches Jahrbuch. Reihe B. Hannover. Heft 59: 3-49.

Hallam, A. 1988. A revaluation of Jurassic eustasy in the light of new data and the revised Exxon curve. In: Wilgus, C.K., Posamentier, H., Ross, C.A., and Kendall, C.G.St.C. (eds), Sea-level changes: an integrated approach. SEPM Special Publications. 42: 261-274.

Hayami, I. 1972. Lower Jurassic Bivalvia from the environs of Saigon. Geology and Paleontology of SE Asia. 10: 179-230.

Heim, A., and Hirschi, H. 1939. A section of the mountain ranges of northwestern Siam. Eclogae Geologicae Helvetiae. 39: 1-16.

Hutchison, C.S., 1975. Ophiolite in Southeast Asia. Bulletin of the Geological Society of America. 86: 797-806.

Kemper, E. 1976. The foraminifera in the Jurassic limestone of west Thailand. Geologisches Jahrbuch. Reihe B. Heft. 21: 129-153.

Kemper, E., Maronde, H., and Stoppel, D. 1976. Triassic and Jurassic limestone in the region northwest and west of Si Sawat (Kanchanaburi Province, western Thailand). Geologisches Jahrbuch. Reihe B. Heft. 21: 93-127.

Kozai, T., Hirsch, F., Ishida, K., and Assanee Meesook. 2006. Faunal affinity of Toarcian-Aalenian (Early Jurassic) bivalve from Mae Sot and Umphang (Tak Province), Northwestern Thailand. Geoscience Journal. 10. 3: 205-215.

Lertsin Raksaskulwong. 2002. Thung Yai Group: Jurassic-Cretaceous transition and continental deposits in Southern Thailand. Geological Survey Division, Department of Mineral Resources. 260/2545: 1-49. (in Thai).

Mitchell, A. H. G. and Garson, M.S. 1981. Mineral Deposits and Global Tectonic Settings. Academic Press Inc. London, (London) Ltd.: 405.

Naramase Teerarungsigul. 1999. Lithostratigraphy of non-marine Mesozoic rocks: Thung Yai-Khlong Thom area, in southern part of Thailand. Master' s Thesis. Department of Geology, Faculty of Science, Chulalongkorn University.

Naramase Teerarungsigul, Lertsin Raksaskulwong, and Chaiyudh Khantaprab. 1999. Reconsideration of the lithostratigraphy of non-marine Mesozoic rocks in Thung Yai-Khlong Thom area, southern Thailand. In: Proceedings of Symposium on Mineral, Energy, and Water resources of Thailand. pp. 98-114.

Panya Charusiri, Veerote Daorerk, Archiblad D., Hisada K., and Tianpan Ampaiwan. 2002. Geotectonic Evolution of Thailand: A New Synthesis. Journal of the Geological Society of Thailand. April. ISBN 1513 2587. 1: 1-20.

Pumwarn Komalarjun. and Sato, T. 1964. Aalenian (Jurassic) ammonites from Mae Sot, northwestern Thailand. Geology and Palaeontology of Southeast Asia. 1: 237-251.

Ridd, M.F. 1980. Possible Palaeozoic drift of S.E. Asia and Triassic collision with Chaina. Journal of the Geological Society of London. 137: 635-640.

Sangad Bunopas, S. 1981. Paleogeographic history of western Thailand and adjacent parts of southeastern Asia-A plate-tectonics interpretation. Ph.D thesis. Victoria University of Wellington. New Zealand: 1-810.

Sato, T. 1961. Une ammonite aalenienne de la region de Mae Sot, Thailande. Japanese Jounal of Geology and Geography. 32. 1: 137-139 (1 pl.).

Sato, T. 1975. Marine Jurassic Formations and Faunas in Southeast Asia and New Guinea. Geology and Palaeontology of Southeast Asia. 15: 151-189.

Sato, T., and Westermann, G. E. G. 1991. Japan and South-East Asia. In : Westermann, G.E.G. and Riccardi, R.C. (eds.), Jurassic Taxa Ranges and Correlation Charts for the Circum-Pacific Newsletter of Stratigraphy. 24: 81-108.

Stauffer, P. 1974. Malaya and Southeast Asia in the pattern of continental drift. Bulletin of Geological Society of Malaysia. 7: 84-138.

Sukto, P., Varawut Suteethorn, and Somchat Boripatgosol. 1978. Geological map of Maulameun Quadrangle (NE 47-14), 1:250,000. Geological Survey Division, Department of Mineral Resources.

Vail, P.R., Mitchum, Jr. R.M., and Thompson, S. III. 1977b. Seismic Stratigraphy and Global Changes of Sea Level, Part 4: Global Cycles of Relative Changes of Sea Level. In: Payton, C.E. (ed), Seismic Stratigraphy-applications to hydrocarbon exploration. The American Association of Petroleum Geologists, Tulsa, Oklahoma, Memoir. 26: 83-97.

Waller, T. R. 1978. Morphology, morphoclines and a new classification of the Pteriomorphia (Mollusca: Bivalvia). In: C. Yonge and T. Thompson (eds), Evolutionary systematics of bivalve molluscs. Philosophical transactions of the Royal Society of London. Series B, Biological sciences. 284. 1001: 345-365.

Ward, D.E., and Din Bunnag. 1964. Stratigraphy of the Mesozoic Khorat Group in Northeast Thailand. Department of Mineral Resources, Report of Investigation. 6: 1-95.

Westermann, G. E. G. 1989. Regional geology and stratigraphy: Papua New Guinea. In : The Jurassic of the Circum-Pacific. G. E. G. Westermann (ed), Cambridge University Press: 187-193.

Wirote Saengsrichan. 2007. Sedimentary facies and Stratigraphy of the marine Jurassic Hua Fai Group in Mae Sot-Phop Phra basin, Changwat Tak, Thailand. Master's Thesis. Department of Geology, Faculty of Science, Chulalongkorn University.

Wirote Saengsrichan, Jingeng, S., Assanee Meesook, and Ken-Ichiro, H. 2009. Lithostratigraphy and petrography of marine Jurassic rocks in the Mae Sot area, Tak Province, western Thailand: Implications for depositional environment and tectonics. GFF. 131: 1, 83-103.

Worawut Tantiwanit, et al. 1987. Geology of Amphoe Mae Sot (4742 III) and Ban Phoe Pha (4741 IV) scale 1:50,000. Geological Survey Division, Department of Mineral Resources.

Yuenyong Panjasawatwong. 1991. Petrology, geochemistry and tectonic implications of the igneous rocks in the Nan Suture, Thailand, and an empirical study of the effects of Ca/Na, Al/Si and H2O on plaioclase-melt equilibria at 5-10 kb pressure. Unpublished Doctoral dissertation, University of Tasmania.

Zuoqi, L. 1993. The discovery and significance of the Late Jurassic sporopollen assemblage in Peninsular Thailand. In: Proceedings of International Symposium on Biostratigraphy of Mainland Asia: Facies and Palaeontology. Thanasuthipitak, T. (ed), Chiang Mai, Thailand. 2: 361-380.

APPENDIX

PLATES 1-12

EXPLANATION OF PLATE 1

Figure **Page**

1-9 ***Grammatodon* sp.** 105

1-2 left valve, Tak –Mae Sot Highway section

3-4 left valve, Huai Mae Sot section

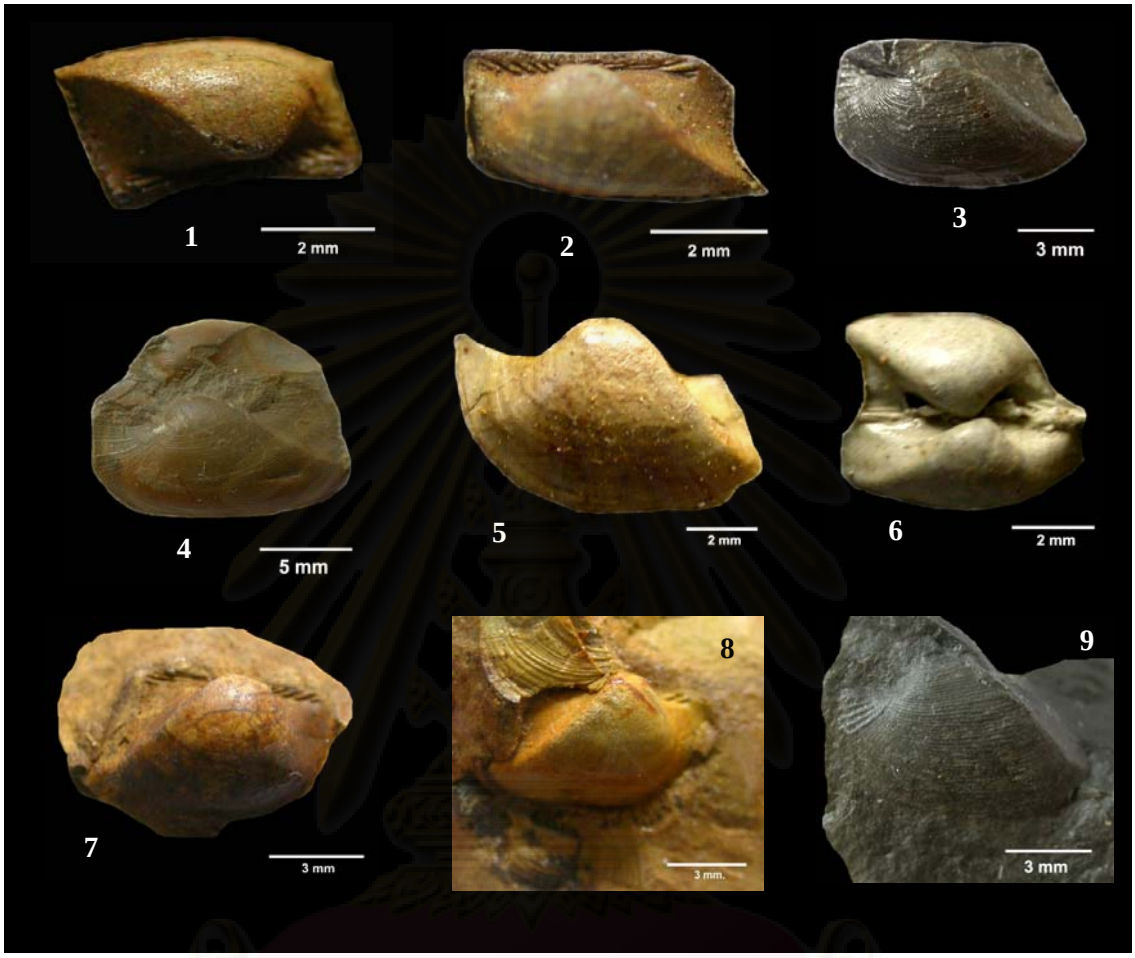
5 left valve, Ban Pu Toe section

6 Ban Pu Toe section

7-8 right valve, Huai Mae Sot section

9 left valve, Huai Mae Sot section

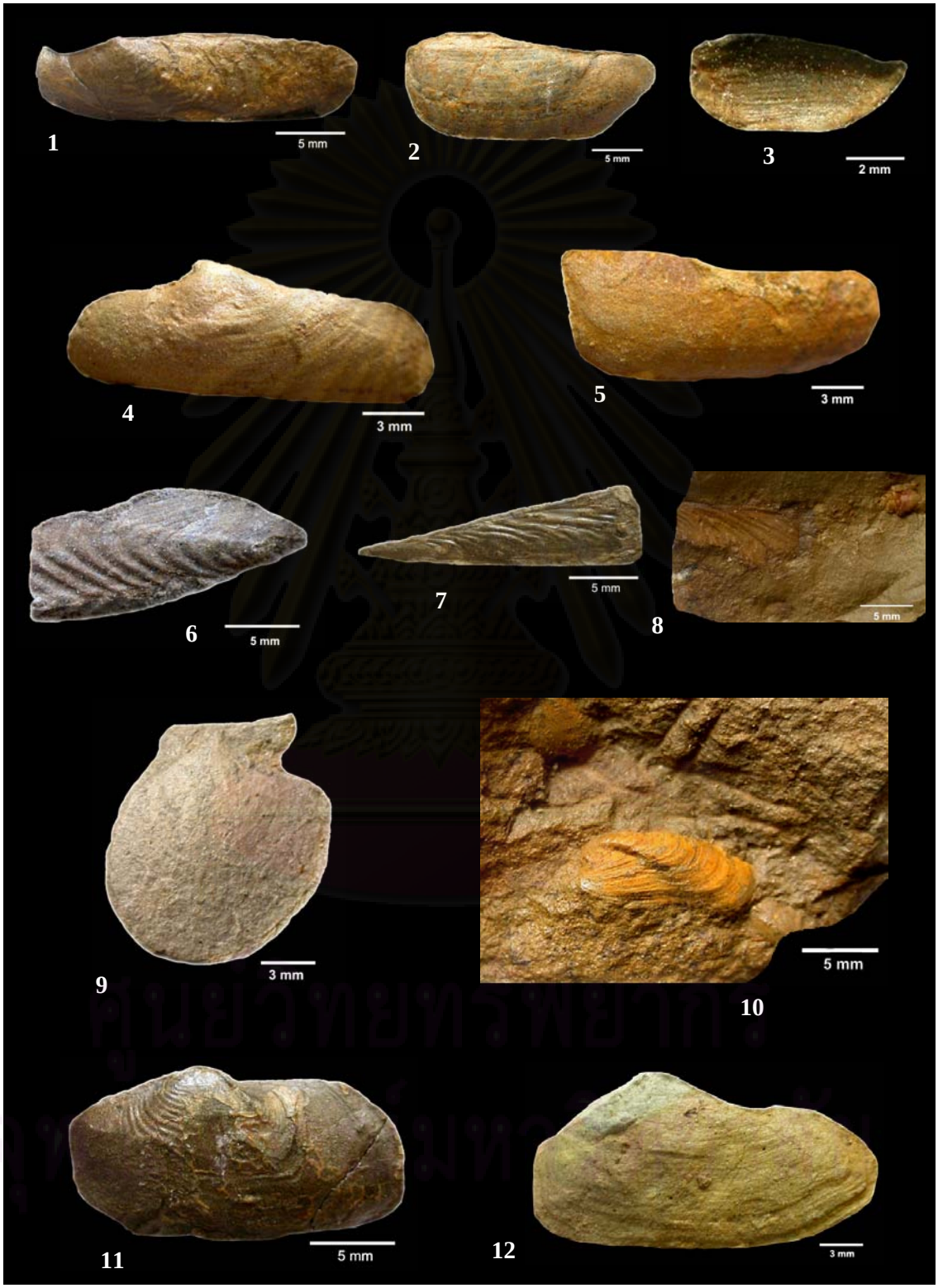
Plate 1



EXPLANATION OF PLATE 2

Figure		Page
1-5	***Gervillia* sp.**	107
	1 Mae Sot section	
	2-5 Huai Wale section	
6-8	***Pinna* sp.**	108
	6 Ban Mae Kut Luang section	
	7-8 Huai Mae Sot section	
9	***Camptonectes* sp.**	114
	9 Ban Mae Kut Luang section	
10	***Modiolus* sp.**	106
	10 Ban Mae Kut Luang section	
11-12	***Homomya* sp.**	120
	11 Huai Mae Sot section	
	12 Huai Wale section	

Plate 2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EXPLANATION OF PLATE 3

Figure **Page**

1-9 ***Bositra ornati*** **(Quenstedt)** 109

1-3 Ban Mae Kut Luang section.

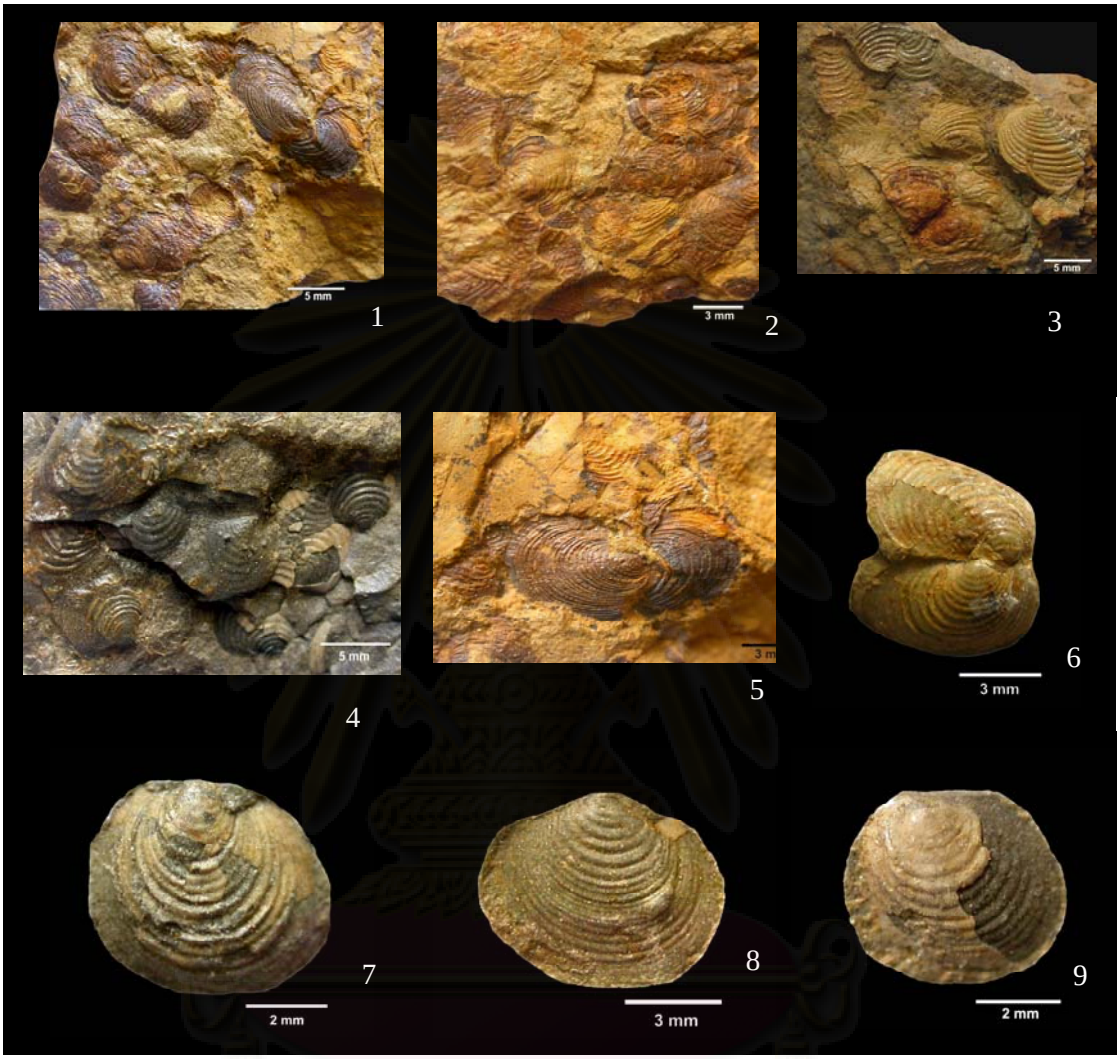
4 Huai Mae Sot section.

5 Ban Mae Kut Luang section.

6 Huai Mae Sot section.

7-9 Ban Mae Kut Luang section.

Plate 3



EXPLANATION OF PLATE 4

Figure **Page**

1-9 ***Entolium*** **sp.** 111

1-4 Ban Mae Kut Luang section.

5 Tak –Mae Sot Highway section.

6 Ban Mae Kut Luang section.

7-8 Huai Mae Sot section.

9 Ban Mae Kut Luang section.

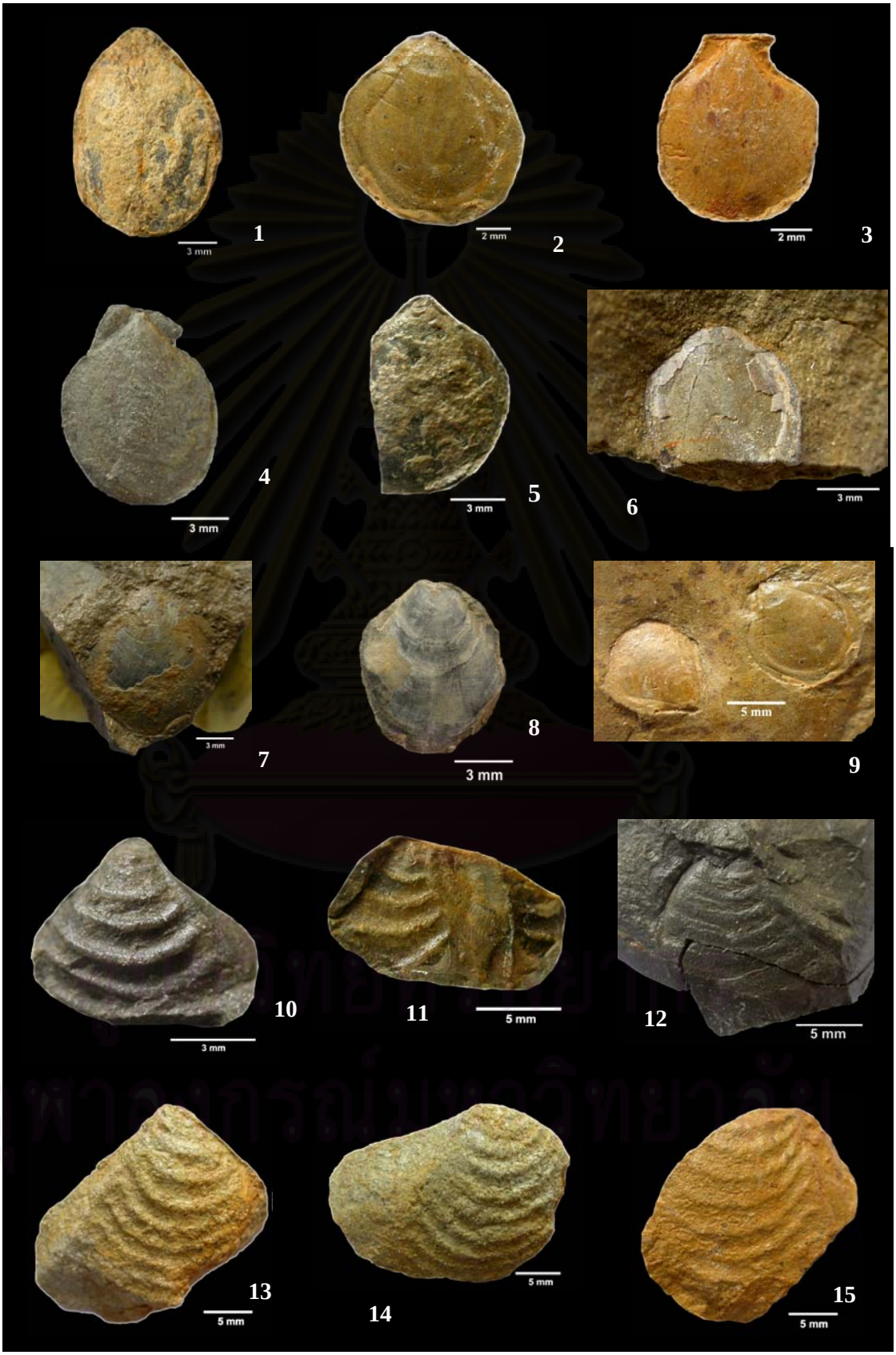
10-15 ***Trigonia*** **sp.** 115

10-11 Tak-Mae Sot Highway section

12 Huai Mae Sot section

13-15 Huai Wale section

Plate 4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EXPLANATION OF PLATE 5

Figure **Page**

1-15 ***Pavarmussium donaiense*** **(Mansuy)** 112

1 Internal mould, Ban Pu Toe section.

2 Internal mould, Ban Mae Kut Luang section.

3-6 External mould, Ban Mae Kut Luang section.

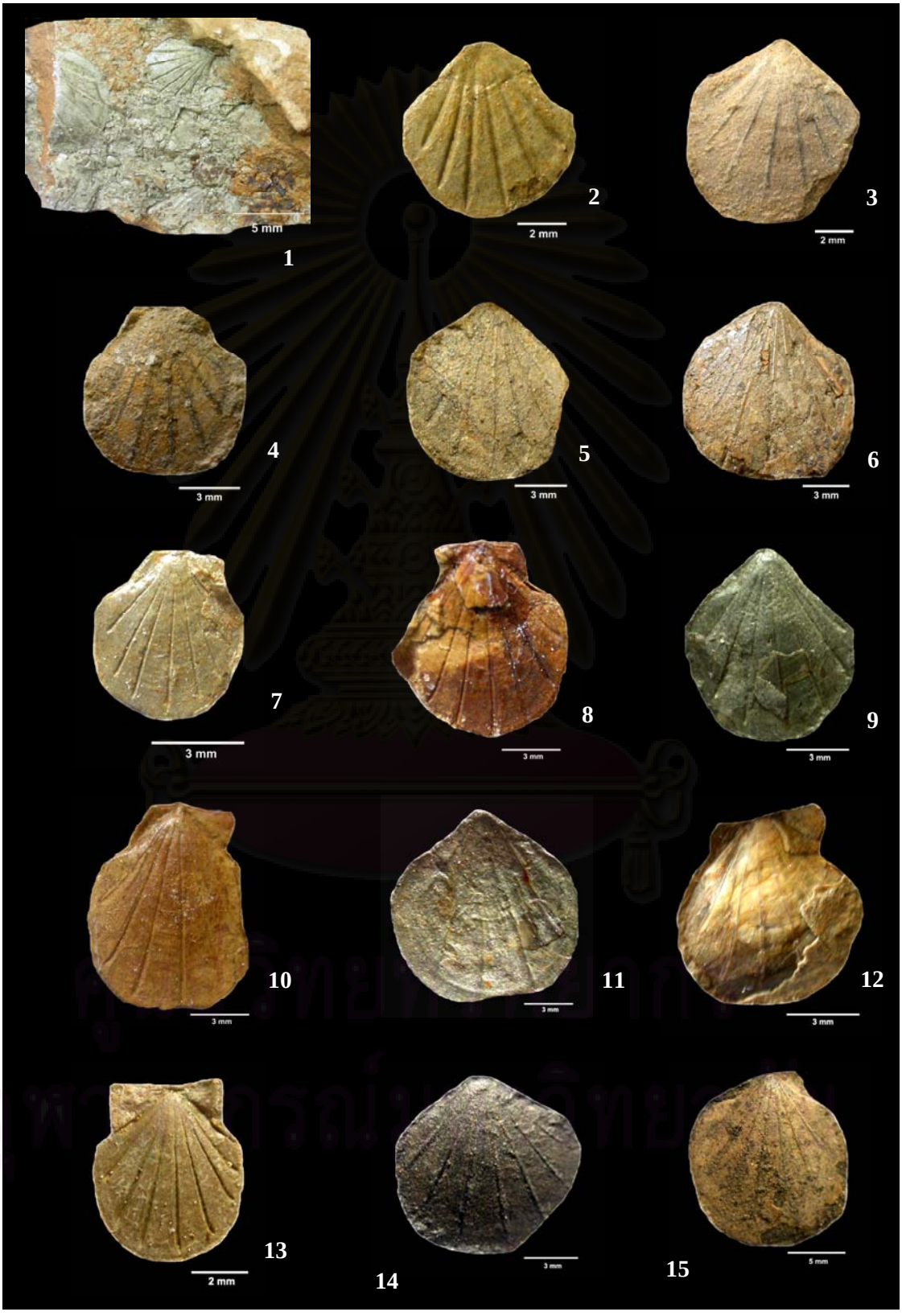
7-11 Internal mould, Tak-Mae Sot Highway section.

12 External mould, Tak-Mae Sot Highway section.

13 Internal mould, Ban Pu Toe section.

14-15 External mould, Ban Pu Toe section.

Plate 5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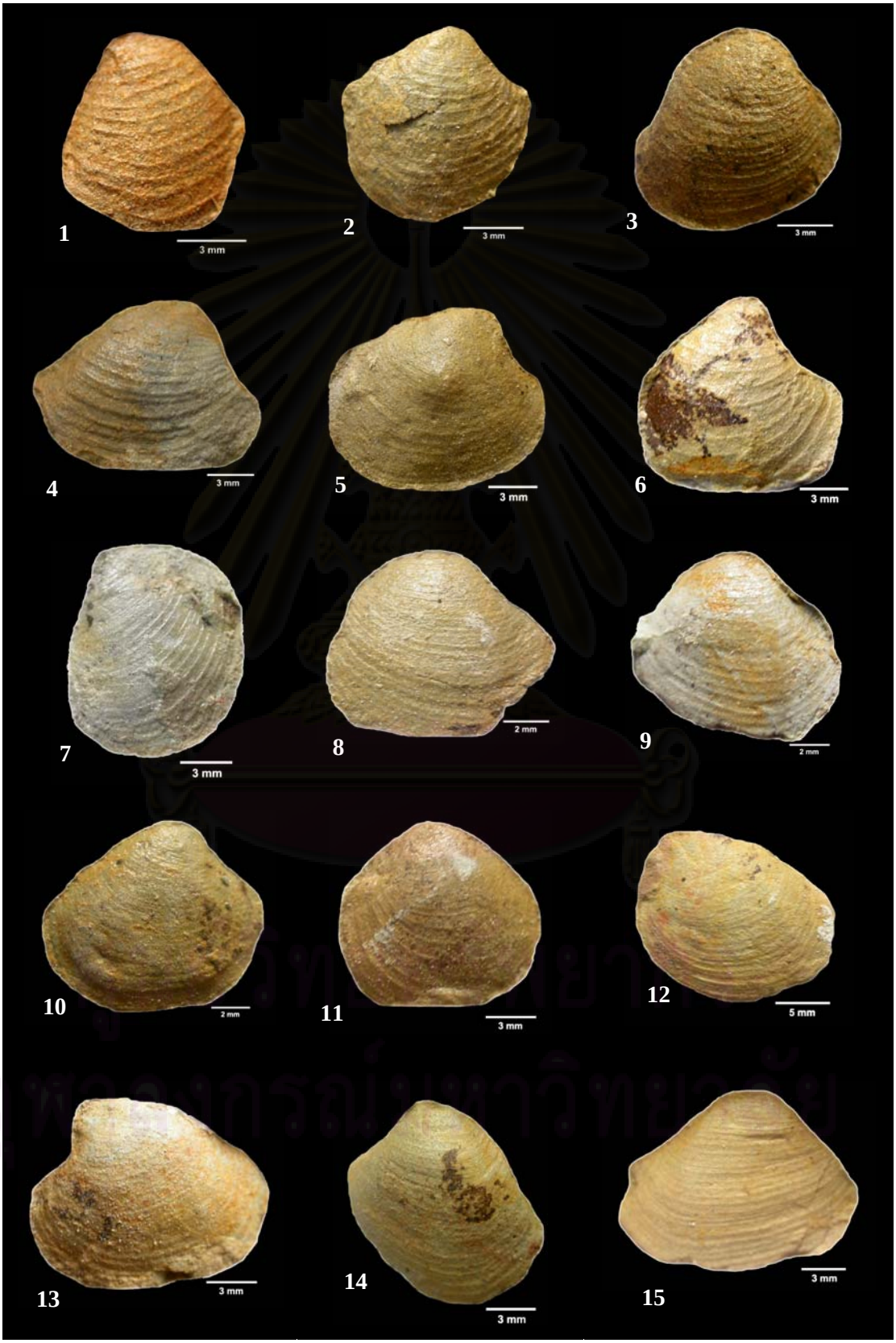
EXPLANATION OF PLATE 6

Figure **Page**

Plate 6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EXPLANATION OF PLATE 7

Figure **Page**

1-9 ***Pholadomya*** **sp.** 119

1-2 Tak-Mae Sot Highway section

3-8 Huai Mae Sot section

9 Huai Wale section

10-14 ***Goniomya*** **sp.** 120

10-11, 14 Ban Pu Toe section

12-13 Ban Mae Kut Luang section

Plate 7


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EXPLANATION OF PLATE 8

Figure **Page**

1-12 ***Thracia*** **sp.** 121

1-4 Ban Mae Kut Luang section

5-6 Tak-Mae Sot Highway section

7-10 Huai Mae Sot section

11 Ban Pu Toe section

12 Huai Wale section

Plate 8

EXPLANATION OF PLATE 9

Figure **Page**

1-3 ***Protocardia*** **sp.** 117

1, 3 Tak-Mae Sot Highway section

2 Huai Mae Sot section

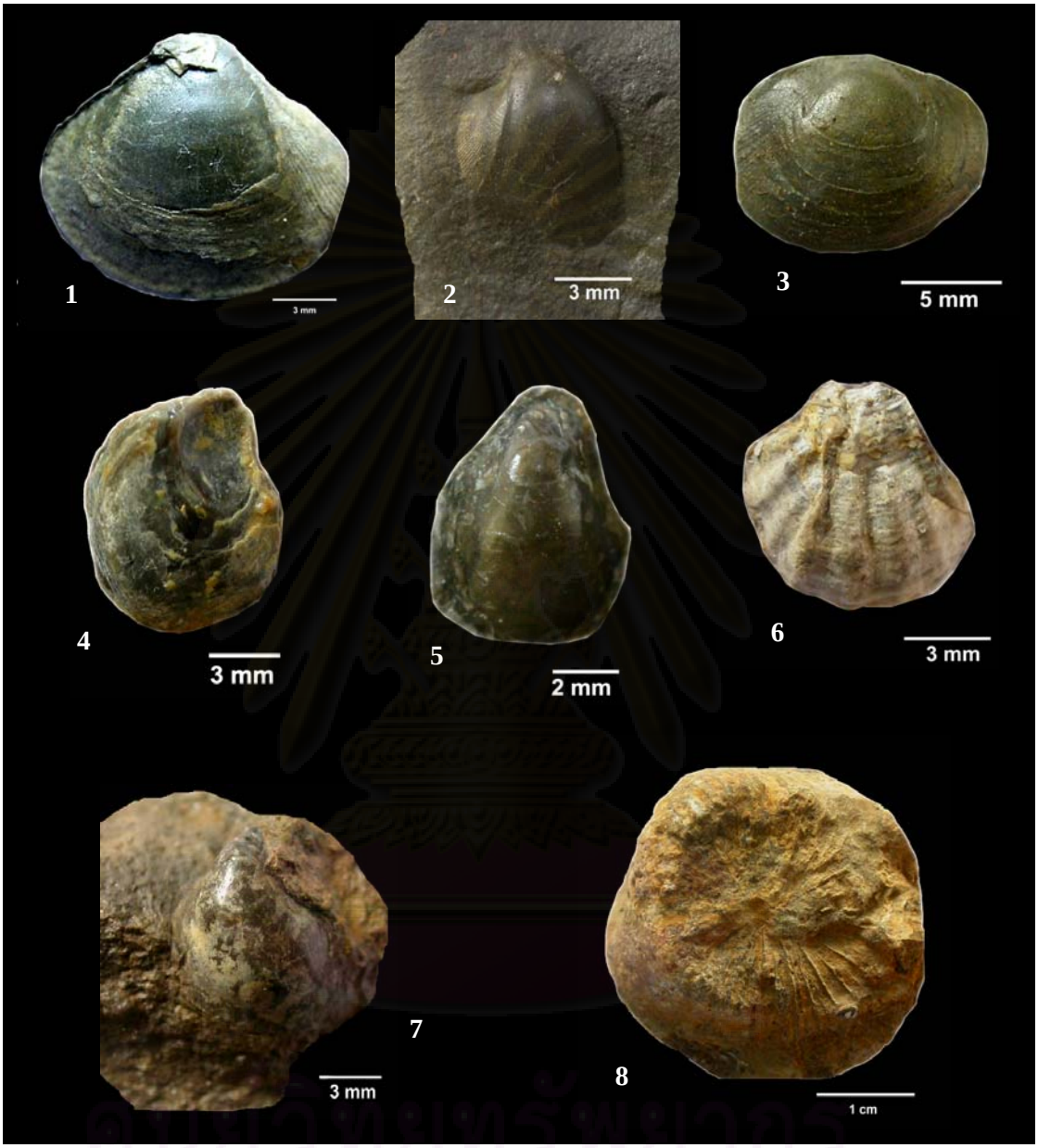
4-7 ***Actenostreon*** **sp.**

4-7 Huai Mae Sot section

8 **Rudist bivalve**

8 Ban Pu Toe section

Plate 9



EXPLANATION OF PLATE 10

Figure

1-5 ***Tmetoceras*** **sp.**

1-2 Ban Mae Kut Luang section

3 Ban Pu Toe section

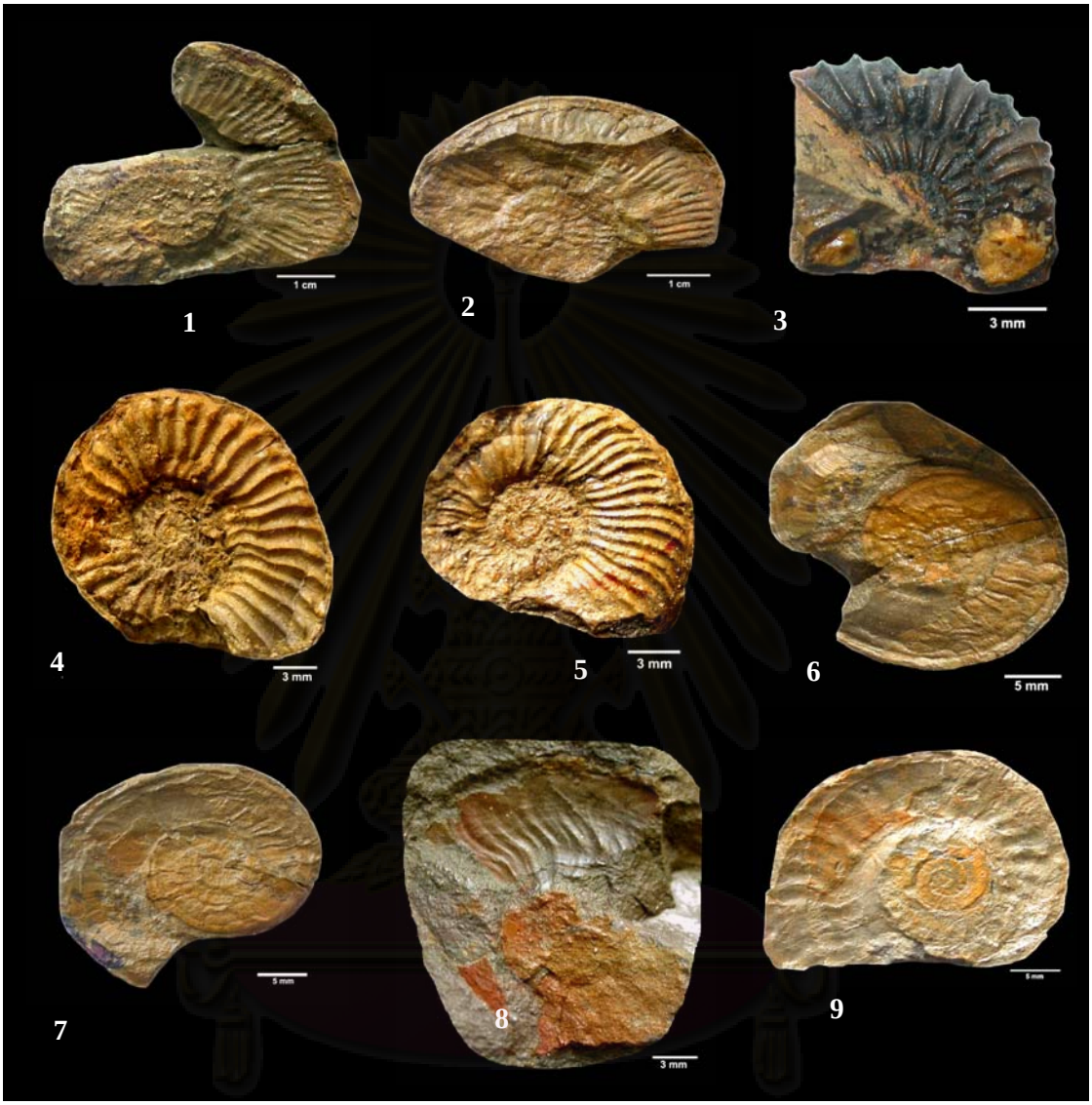
4-5 Ban Mae Kut Luang section

6-9 ***Harpoceras*** **sp.**

6-7 Ban Mae Kut Luang section

9 Tak-Mae Sot Highway section

Plate 10



EXPLANATION OF PLATE 11

Figure

1-5 *Harpoceras* sp.

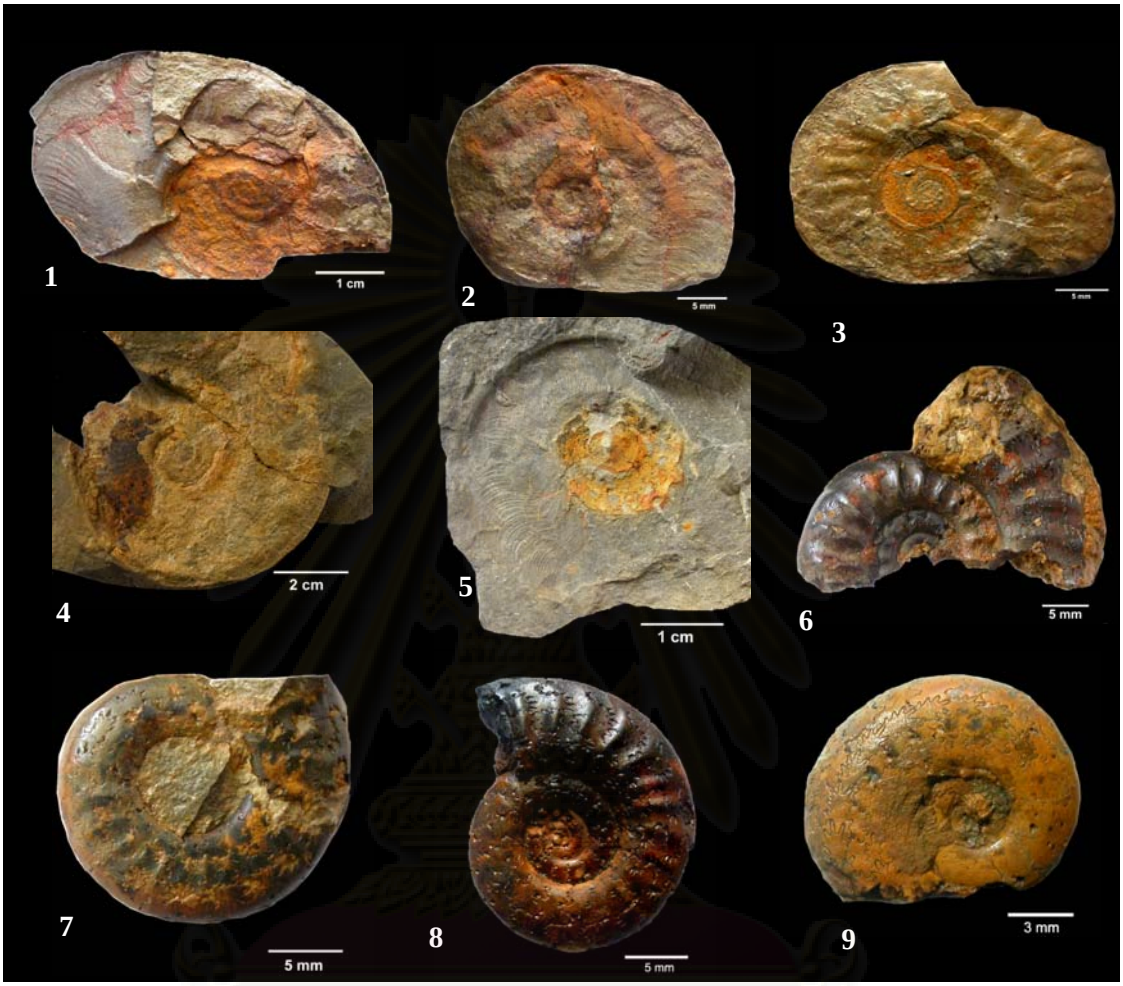
1-3 Tak-Mae Sot Highway section

4-5 Huai Mae Sot section

6-9 ammonite sp.A

6-9 Huai Mae Sot section

Plate 11



EXPLANATION OF PLATE 12

Figure

1-11 Rhynconellid brachiopod

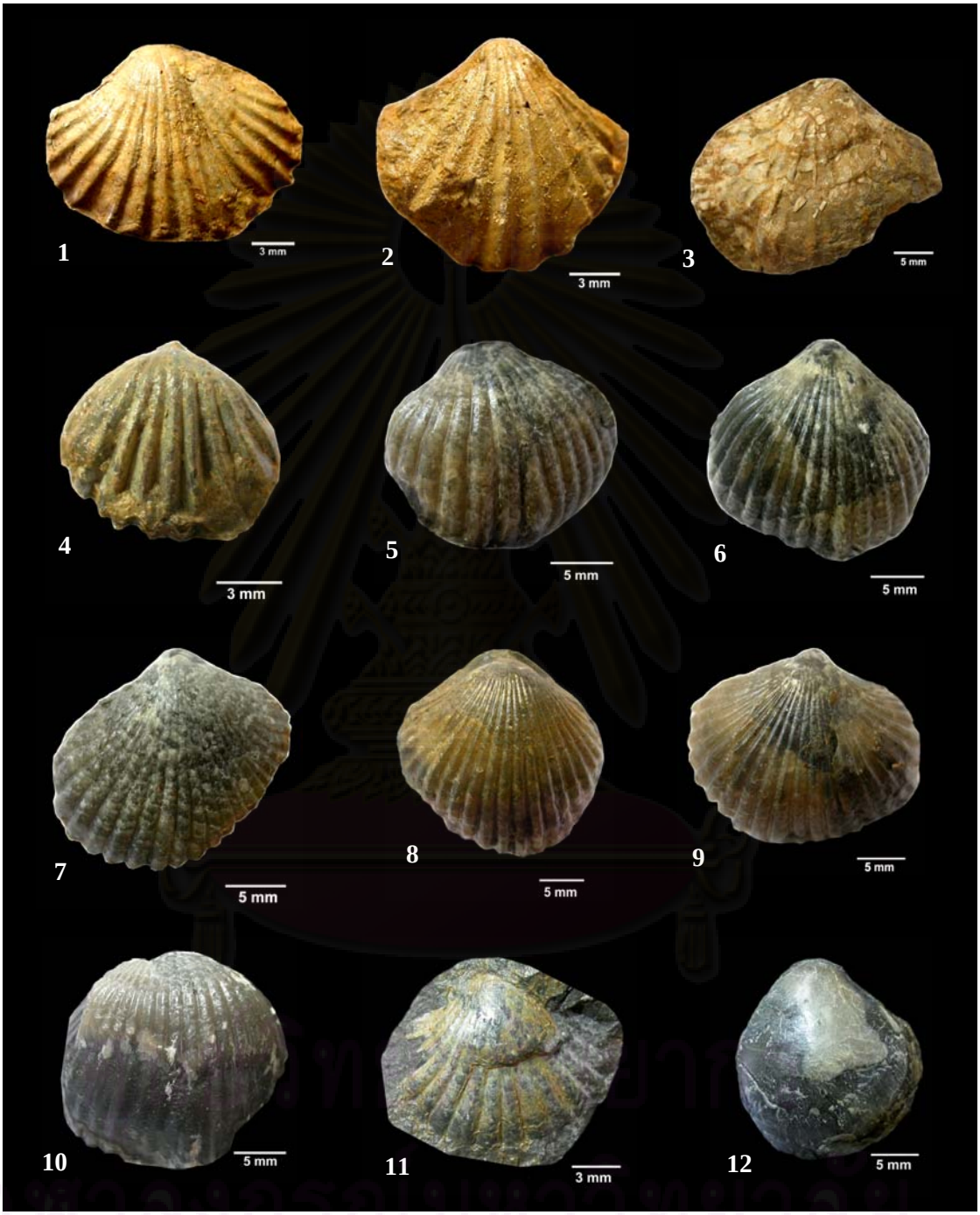
1-3 Ban Mae Kut Luang section

4-11 Huai Mae Sot section

12 Telebratulid brachiopod

12 Huai Mae Sot section

Plate 12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BIOGRAPHY

Miss Chotima Yamee was born on 11 May 1976 in Khon Kaen Province. In 1998, she graduated with a B.Sc degree from Department of Geological Sciences, Faculty of Science, Chiang Mai University. After graduation, she has been working with the Geological Survey Division, Department of Mineral Resources, Thailand. Later on, she has decided to continue her post-graduate study leading to the M.Sc degree in Geology at Chulalongkorn University. Her major research over there was mainly focused on the fossils of marine Jurassic in Tak Province.