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สาขาวิชาเทคโนโลยีธรณี

มหาวิทยาลัยเทคโนโลยีสุรนารี

ปีการศึกษา 2557

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STRATIGRAPHY AND PALEONTOLOGY OF MARINE PERMIAN AND TRIASSIC ROCKS IN NONG PRUE DISTRICT, KANCHANABURI PROVINCE, THAILAND

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

Thesis Examining Committee

____

(Prof. Dr. Kittitep Fuenkajorn)

Chairperson

____

(Dr. Chongpan Chonglakmani)

Member (Thesis Advisor)

____

(Asst. Prof. Dr. Akkhapun Wannakomol)

Member

__________________________	__________________________
(Prof. Dr. Sukit Limpijumnong)	(Assoc. Prof. Flt. Lt. Dr. Kontorn Chamniprasart)
Vice Rector for Academic Affairs and Innovation	Dean of Institute of Engineering

กรองแก้ว เจนจิตไพบูลย์ : ลำดับชั้นหินและบรรพชีวินวิทยาของหินตะกอนทะเลยุคเพอร์เมียนและไทรแอสซิก บริเวณอำเภอหนองปรือ จังหวัดกาญจนบุรี ประเทศไทย (STRATIGRAPHY AND PALEONTOLOGY OF MARINE PERMIAN AND TRIASSIC ROCKS IN NONG PRUE DISTRICT, KANCHANABURI PROVINCE, THAILAND) อาจารย์ที่ปรึกษา : อาจารย์ ดร.จงพันธ์ จงลักษมณี, 112 หน้า.

การทำวิจัยในครั้งนี้มีจุดประสงค์เพื่อกำหนดลำดับชั้นหินตะกอนทะเลยุคเพอร์เมียนและไทรแอสซิก จำแนกชนิดซากดึกดำบรรพ์หอยสองฝา แอมโมนอยด์ และฟิวซูลินิด และให้อายุของหินตะกอนทะเล รวมไปถึงแปลความหมายสภาพแวดล้อมของการสะสมตะกอน บริเวณอำเภอหนองปรือ จังหวัดกาญจนบุรี ภาคตะวันตกของประเทศไทย หินตะกอนทะเลในพื้นที่ศึกษาสามารถจำแนกออกเป็น 4 หน่วยหิน คือ หน่วยหิน A หน่วยหิน B หน่วยหิน C และหน่วยหิน D โดยมีการเรียงลำดับอายุจากแก่ไปหาอ่อน หน่วยหิน A ประกอบด้วยหินดินดาน หินดินดานเนื้อปูน และหินปูน พบซากดึกดำบรรพ์พวกแอมโมนอยด์ในหินดินดาน หน่วยหิน B วางตัวบนหน่วยหิน A แบบรอยชั้นไม่ต่อเนื่อง ประกอบด้วยหินกรวดมนเนื้อหินปูน หินปูน หินดินดาน และหินดินดานเนื้อซิลิกา โดยกรวดในหินกรวดมนเนื้อหินปูนพบซากดึกดำบรรพ์พวกฟิวซูลินิด หน่วยหิน C วางตัวบนหน่วยหิน B อย่างต่อเนื่อง ประกอบด้วยหินดินดาน และหินดินดานเนื้อซิลิกา และหน่วยหิน D วางตัวบนหน่วยหิน C อย่างต่อเนื่อง ประกอบด้วยหินทราย และหินดินดาน หน่วยหิน C และหน่วยหิน D พบซากดึกดำบรรพ์หอยสองฝาในหินดินดาน ผลการศึกษาตามระบบอนุกรมวิธานของซากดึกดำบรรพ์ที่พบ ประกอบด้วย 2 ไฟลัม คือ ไฟลัมมอลลัสกา และไฟลัมโปรโตซัว ไฟลัมมอลลัสกา ประกอบด้วย 2 ชั้น คือ ชั้นไบวาลเวีย และชั้นเซฟาโลพอด (ชั้นย่อยแอมโมนอยดี) ชั้นไบวาลเวีย จำแนกได้ 3 สกุล คือ *Halobia Posidonia* และ *Daonella. Halobia* จำแนกได้ 3 ชนิด คือ *Halobia (Halobia) talauana* Wanner *Halobia (Halobia) styriaca* Mojsisovics และ *Halobia (Zittelihalobia)* sp. ชั้นเซฟาโลพอด (ชั้นย่อยแอมโมนอยดี) จำแนกได้ 7 ชนิด คือ *Agathiceras* sp. *Adrianites* sp. *Popanoceras* sp. *Cyclolobus* sp. *Metalegoceras* sp. *Parapronorites* sp. และ *Propinacoceras* sp. และไฟลัมโปรโตซัว ประกอบด้วย 1 ชั้น คือ ชั้นฟอรามินิเฟอรา จำแนกได้ 1 ชนิด คือ *Verbeekina* sp. จากหลักฐานของซากดึกดำบรรพ์แอมโมนอยด์ อายุของหินตะกอนในหน่วยหิน A กำหนดให้อายุเพอร์เมียนตอนกลาง (Roadian-Wordian) และจากหลักฐานของซากดึกดำบรรพ์หอยสองฝา อายุของหินตะกอนในหน่วยหิน C และ D กำหนดให้อายุไทรแอสซิกตอนปลาย (Carnian-Norian) กรวดในหินกรวดมนฐานของหน่วยหิน B พบซากดึกดำบรรพ์พวกฟิวซูลินิด บ่งบอกว่าหน่วยหินนี้มีอายุอ่อนกว่าช่วงปลายอายุเพอร์เมียนตอนกลาง และอาจจะมีอายุ

ไทรแอสซิก จากการศึกษาหินตะกอนทะเลยุคเพอร์เมียนและไทรแอสซิก และซากดึกดำบรรพ์หอยสองฝา แอมโมนอยด์ และฟิวซูลินิด มีความสัมพันธ์กับสภาพแวดล้อมดังนี้ หินดินดานในหน่วยหิน A บ่งถึงการสะสมตัวในสภาพแวดล้อมที่สงบ และพบเฉพาะซากดึกดำบรรพ์แอมโมนอยด์ในชั้นหินดินดาน ไม่พบซากดึกดำบรรพ์ที่อาศัยตามพื้นทะเลร่วมด้วย แสดงถึงการสะสมตัวไกลจากชายฝั่ง ในสภาพแวดล้อมที่เป็นบริเวณทะเลลึกซึ่งมีอายุอยู่ในช่วงเพอร์เมียนตอนกลาง หินกรวดมนเนื้อหินปูนในหน่วยหิน B บ่งถึงเหตุการณ์ทางเทคโทนิคของการเกิดแอ่งสะสมตะกอน เกิดการยกตัวและกัดกร่อน ซึ่งแสดงให้เห็นเป็นรอยชั้นไม่ต่อเนื่องหลังจากยุคเพอร์เมียนตอนกลาง หินดินดานในหน่วยหิน C และหน่วยหิน D บ่งถึงการสะสมตัวในสภาพแวดล้อมที่สงบ และพบเฉพาะซากดึกดำบรรพ์หอยสองฝา แต่ไม่พบชนิดที่อาศัยตามพื้นทะเลร่วมด้วย แสดงถึงการสะสมตัวไกลจากชายฝั่ง ในสภาพแวดล้อมที่เป็นบริเวณทะเลลึกซึ่งมีอายุอยู่ในช่วงไทรแอสซิกตอนปลาย

สาขาวิชาเทคโนโลยีธรณี ลายมือชื่อนักศึกษา______________________

ปีการศึกษา 2557 ลายมือชื่ออาจารย์ที่ปรึกษา_________________

KRONGKAEW JENJITPAIBOON : STRATIGRAPHY AND PALEONTOLOGY OF MARINE PERMIAN AND TRIASSIC ROCKS IN NONG PRUE DISTRICT, KANCHANABURI PROVINCE, THAILAND. THESIS ADVISOR : CHONGPAN CHONGLAKMANI, Ph.D., 112 PP.

MARINE TRIASSIC/PERMIAN/BIVALVE/AMMONOID/FUSULINID/STRATIGRAPHY/PALEONTOLOGY

The aims of this study are to define the lithostratigraphy of marine Permian and Triassic sedimentary sequences, to identify the bivalve, ammonoid and fusulinid fauna, and to clarify the geological age and the depositional environment. The area of study is located in the Nong Prue District, Kanchanaburi Province, western Thailand. Marine sedimentary sequences in the study area can be subdivided into four rock units, A, B, C and D, from older to younger respectively. The unit A consists of shale, calcareous shale and limestone and contains an ammonoid assemblage in shales. The unit B overlies unconformably on the unit A. It consists of limestone conglomerate, limestone, shale and siliceous shale. Limestone conglomerate contains fusulinid-bearing clasts. The unit C overlies conformably on the unit B and consists of shale and siliceous shale. The unit D overlies conformably on the unit C. It consists of sandstone and shale. A bivalve assemblage has been discovered in shales of units C and D. The collected fossils are systematically identified and described. They consist of two Phyla, the Mollusca and the Protozoa. The Mollusca consists of two Classes, the Bivalvia and the Cephalopoda (Ammonoidea). The Bivalvia comprises three genera: *Halobia*, *Posidonia* and *Daonella*. *Halobia* consists of three species; *Halobia (Halobia) talauana* Wanner, *Halobia (Halobia) styriaca* Mojsisovics, and *Halobia*

(Zittelihalobia) sp. The Cephalopoda (Ammonoidea) comprises seven species, i.e., *Agathiceras* sp., *Adrianites* sp., *Popanoceras* sp., *Cyclolobus* sp., *Metalegoceras* sp., *Parapronorites* sp. and *Propinacoceras* sp. The Protozoa consists of one Class, the Foraminifera which comprises one species: *Verbeekina* sp. The age of the unit A is assigned to the Middle Permian (Roadian-Wordian) age based on the ammonoid fauna. Unit C and D contain the Halobiid bivalve which indicates a Late Triassic (Carnian-Norian) age. The basal conglomerate of the unit B contains fusulinid-bearing clasts suggesting that the unit is younger than a late Middle Permian age and is most likely the Triassic based on the stratigraphic ground. Based on the lithological and paleontological evidences, the depositional environments of the studied rock units can be inferred. The unit A consists predominantly of laminated shales which indicate a low-energy environment. These shales contain ammonoids but without associated marine benthic fauna suggesting that they were accumulated far from shore on a deep marine (abyssal plain) environment in the Middle Permian time. The limestone conglomerate in the unit B indicates the main tectonic event of the basin with considerable uplift and erosion which is represented by a strong unconformity after the late Middle Permian time. Shales of units C and D also represent a low-energy environment. They contain only pelagic bivalves (Halobiids) suggesting that they were accumulated on a deep marine (abyssal plain) environment in the Late Triassic time.

School of Geotechnology — Student Signature ___________________

Academic Year 2014 — Advisor Signature ___________________

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CHAPTER I

INTRODUCTION

1.1 Background of the Study

Mesozoic rocks of Thailand consist of both marine and non-marine deposits (Chonglakmani, 1983; Meesook *et al*., 2002). Marine Triassic rocks of Thailand are distributed in three sedimentary basins, namely the Lampang-Phrae, the Mae Sariang-Kanchanaburi, and the Songkhla Basins (Chonglakmani and Grant-Mackie, 1993). These marine sedimentary rocks are indicated by index bivalve fossils, *Daonella* and *Halobia*. The studies of stratigraphy of marine Triassic sedimentary rocks were conducted mostly in the central north of Thailand, especially in the area of Lampang-Phrae Basin. Whereas in the western region, especially in Kanchanaburi Province, the marine Triassic rocks has rarely been studied in detail. Thus, this area is selected for detailed study. The result of this stratigraphic study will be the reference sections of the Permian and Triassic rocks in this region. The information can be used to determine the age of the rocks in the nearby areas by the described fossils in this study. The information can also be useful for other future works.

1.2 Research objectives

1. To define lithostratigraphy of marine Permian and Triassic sedimentary rocks.
2. To classify/identify the bivalve, ammonoid and fusulinid fauna.

3. To clarify the detailed geological age and the depositional environment.

1.3 Scope and limitation of the study

The study area is located in Nong Prue District, Kanchanaburi Province on the western part of Thailand. This study is focused mainly on stratigraphy and palaeontology of marine Triassic sedimentary rocks.

1.4 Location of the study area

The study areas are located in Ban Pong Chang, Ban Huai Yai and Ban Nong Makha, Nong Prue Subdistrict, Nong Prue District, Kanchanaburi Province on the western part of Thailand (Figure 1.1). The study area is located between Latitude 14° 30' - 14°45' N and Longitude 99°15' - 99°30' E. The area appears in the reference topographic map, scale 1:50,000, edition 2-RTSD, Series L 7018, map sheets Amphoe Nong Prue (4838II).

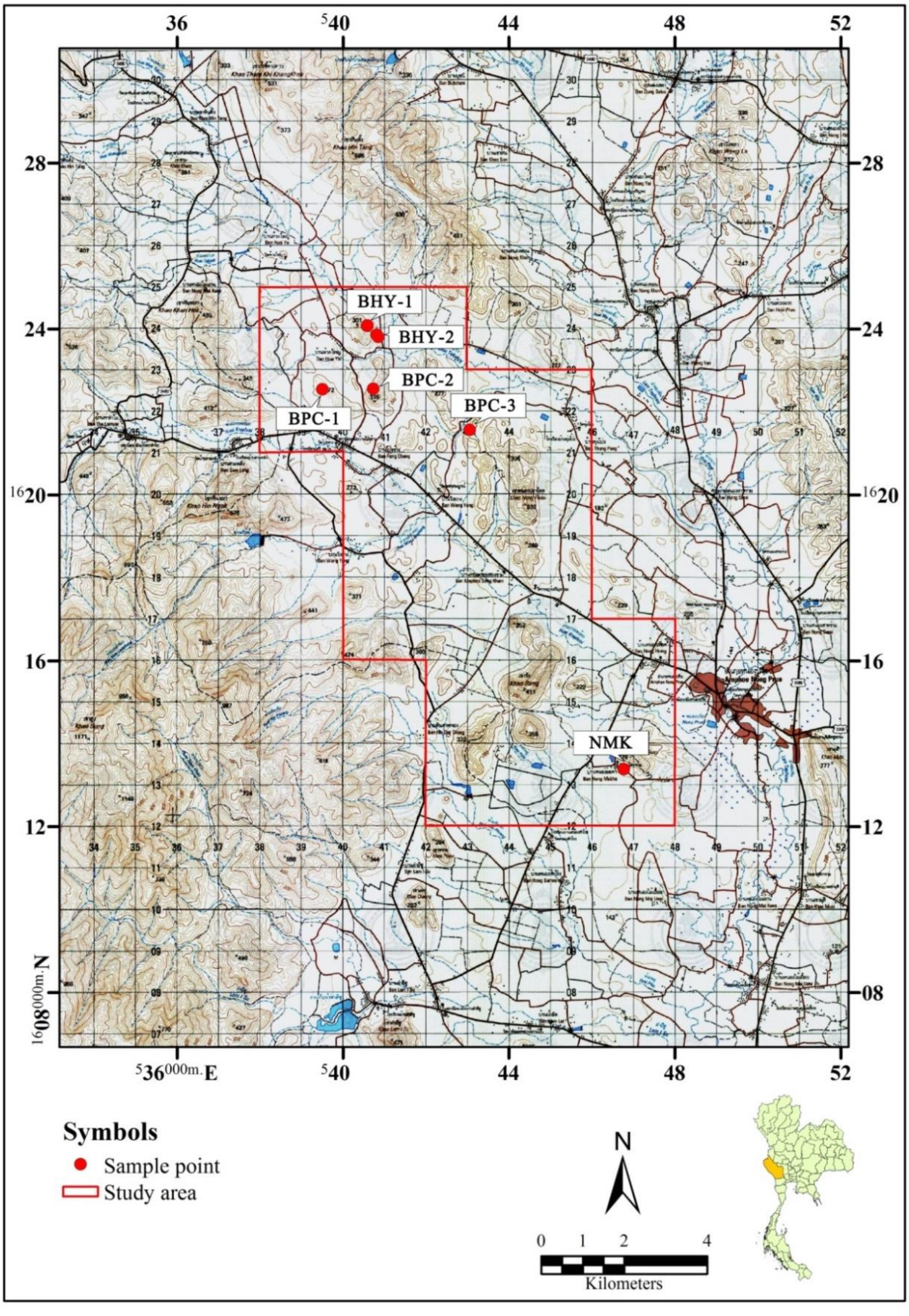


Figure 1.1 Topographic map and sampling localities in the study area (after The Royal Thai Survey Department, 1999).

CHAPTER II

LITERATURE REVIEW

Studies on Marine Triassic rock sequence in Thailand had been carried out by several works (Braun and Jordan, 1976; Bunopas, 1981; Chaodumrong, 1992; Chonglakmani, 1999; Meesook *et al*., 2002, 2005; Srinak *et al*., 2002; Chonglakmani, 2011). The detail of regional geology and marine Triassic rocks in Thailand is explained in this chapter.

2.1 Geological Setting

2.1.1 Regional Geology of Thailand

Mainland Thailand consists of two principal continental blocks: the western Shan-Thai Block (Sibumasu or Sinoburmalaya) and eastern Indochina Block. The boundary between these two blocks is used to be the Nan-Uttradit Suture, represented by remnants of paleo-oceanic sediments and arcs, located between the Shan-Thai Block and Indochina Block (Bunopas, 1981).

The Shan-Thai Block is an elongate continental block trending north-south with a Precambrian basement. The Lower to Middle Paleozoic sequences of this block are Cambrian and Ordovician siliciclastics and carbonate rocks, Silurian and Devonian fine-grained clastics and limestones. The Upper Paleozoic sequences of this block are characterized by Upper Carboniferous to Lower Permian glaciomarine diamictite and Lower Permian cool-water faunas. Geological and paleontological evidence suggest that this block originated in northwest Australia

Gondwanaland. These continental blocks were removed from Gondwanaland after Early Permian time and collided with Indochina in Late Triassic, closing of the Paleotethys Ocean. The Indochina Block is also an elongate stable block, consisting mainly of Precambrian rocks and Paleozoic shallow marine strata with Mesozoic continental deposits. Paleozoic and Mesozoic faunas and floras of this block are confirmed to be of warm climate type (Metcalfe, 1988).

Bunopas (1992) recognized seven longitudinal stratigraphic belts, BS-1, BS-2, BS-3, BS-4, BS-5, BI-6 and BI-7 from west to east, the first five of which cover the Shan-Thai Block in Thailand. The study area is probably within BS-2. Ueno (1999) established a new tectonostratigraphic scheme, mainly for Thailand, based on extensive lithostratigarphic and paleontologic investigations. Ueno (1999) subdivided Thailand into four tectonostratigraphic units, the Sibumasu Block (Shan-Thai), the Inthanon Zone, the Sukhothai Zone, and the Indochina Block, from west to east, which are separated by the Mae Yuam Fault, the "Cryptic" suture Chiang Rai Line, and Nan-Uttradit Suture, respectively (Figure 2.1).

2.1.2 Marine Triassic Rocks in Thailand

Marine Triassic sedimentary rocks are mainly distributed in the northern, western, eastern, and southern parts of Thailand (Figure 2.2). The marine Triassic sediments are distributed in three sedimentary basins, the Mae Hong Son-Kanchanaburi Basin in the northwest and west, the Lampang-Phrae Basin in the central north, and the Songkhla Basin in the south (Chonglakmani and Grant-Mackie, 1993).

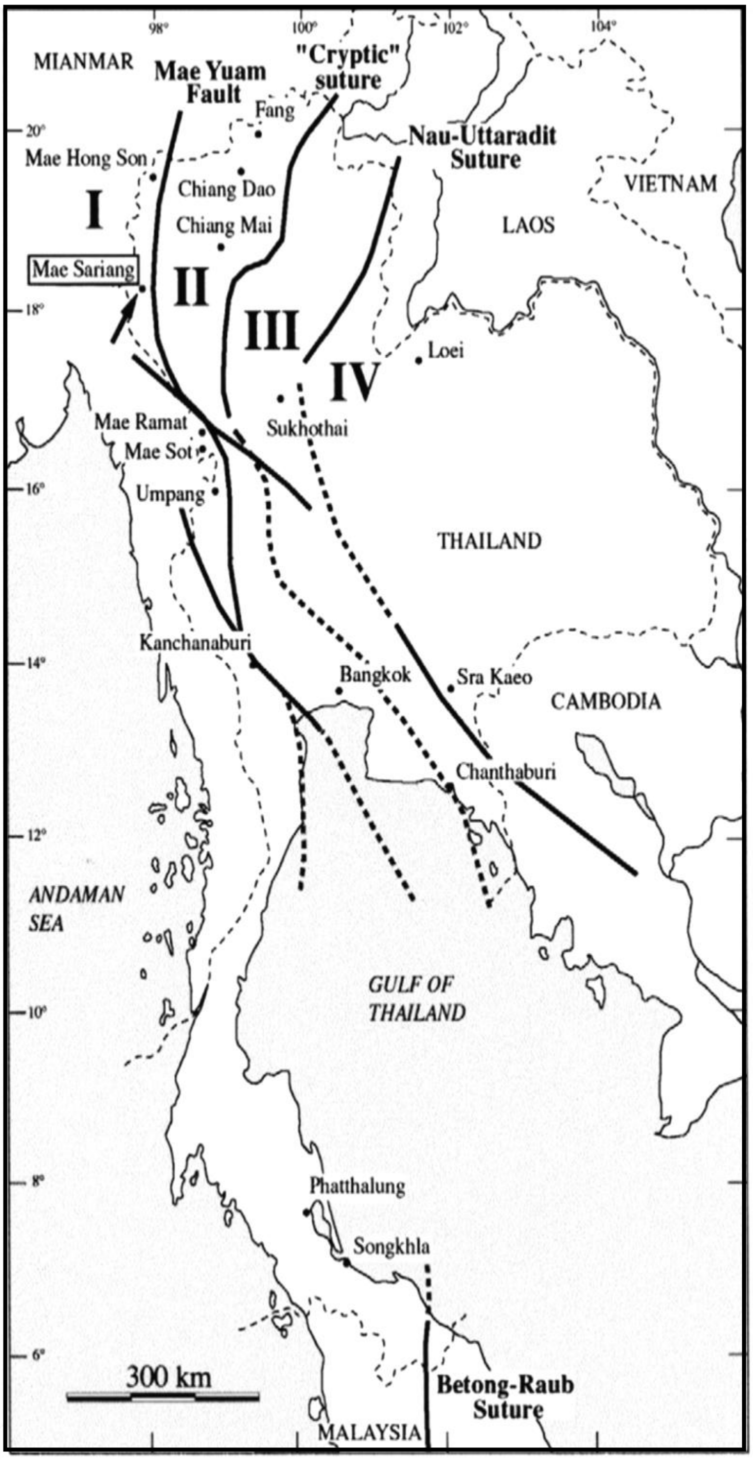


Figure 2.1 Index map showing the tectonic subdivision of mainland Thailand. I: Sibumasu Block, II: Inthanon Zone, III: Sukhothai Zone, IV: Indochina Block (after Ueno, 1999).

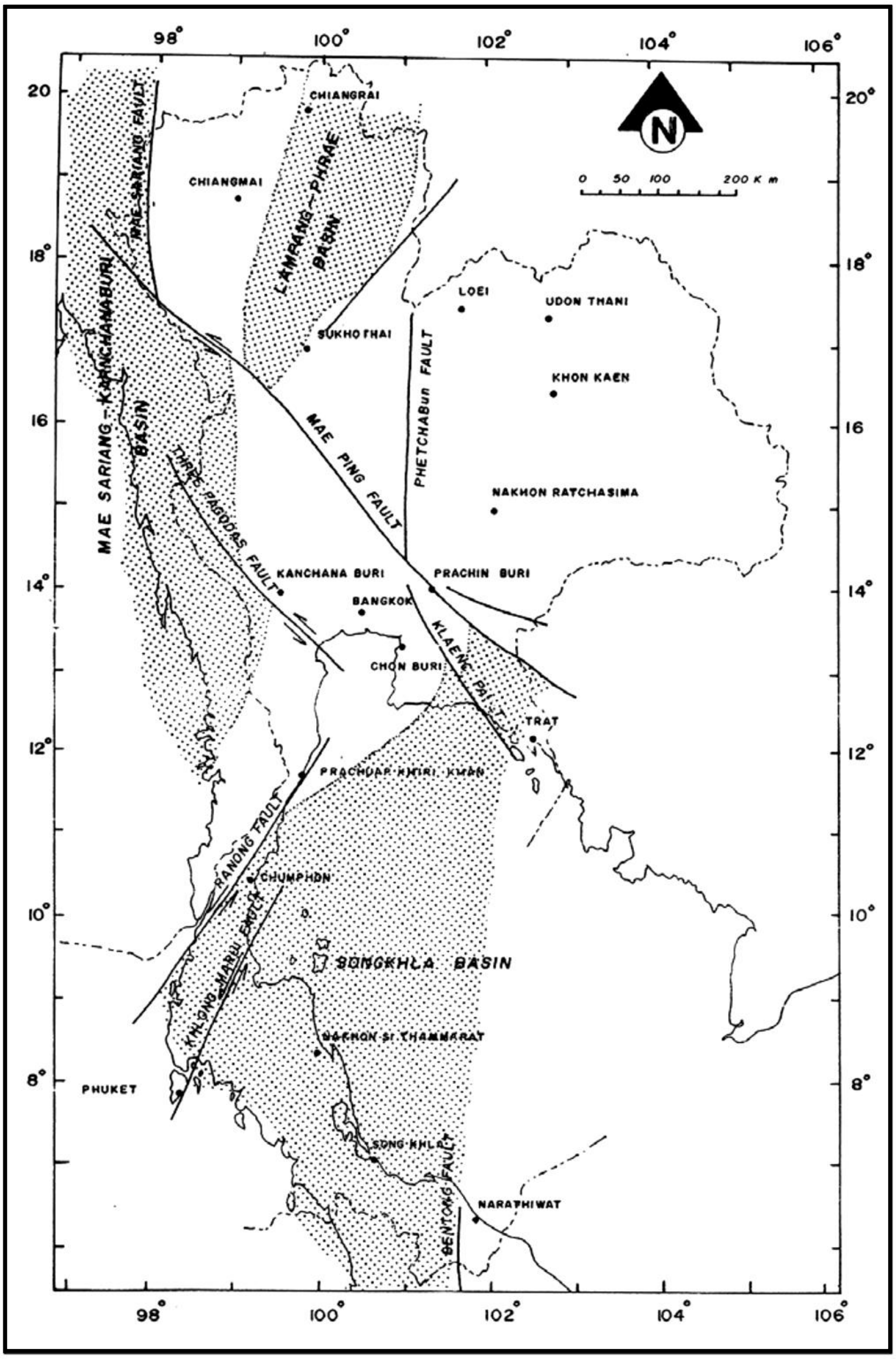


Figure 2.2 Map showing marine Triassic basins in Thailand (after Chonglakmani and Grant-Mackie, 1993).

2.1.2.1 Northern and Upper Western Regions

1) Lampang Group in the Lampang-Phrae area, Northern Thailand

The Lampang Group in central north Thailand was formed in two adjacent sub-basins namely the Lampang in the west and Phrae in the east (Chaodumrong and Rao, 1992) (Figure 2.3). They are similar in their sediments and stratigraphy but slightly different in age in which the age of the Lampang sub-basin and Phrae sub-basin has been younging eastward (Chaodumrong and Burrett, 1997). Piyasin (1971) proposed "Lampang Group" for marine Triassic sedimentary rocks. The Lampang Group is separated from the Khorat Group on the basis of age and lithology. The age of the Lampang Group ranges from Lower Triassic (Scytian) to Upper Triassic (Norian). The Lampang Group, previously divided into five formations, has been revised into seven formations (Chaodumrong, 1992), namely, in ascending order, the Phra That, Pha Kan, Hong Hoi, Doi Long, Pha Daeng, Kang Pla, and Wang Chin Formations (Figure 2.4). The first five formations occur in the Lampang sub-basin whereas the last three formations are in the Phrae sub-basin. Only the Pha Daeng Formation is widespread over both subbasins. Chaodumrong and Burrett (1997) found the Lampang sub-basin occurred earlier than Phrae sub-basin. Several bivalves and ammonites including *Daonella*, *Posidonia*, *Costotaria*, *Claraia* and *Paratrachyceres* indicating Lower to Middle Triassic (Kraiskabian to middle Carnian) have been recognized. The Phrae sub-basin contains three rock formations : Pha Daeng, Kang Pla and Wang Chin Formations (Figure 2.5). Fossils of *Halobia*, *Posidonia* and *Palaeocardita* indicate the age of Middle to Late Triassic (or middle

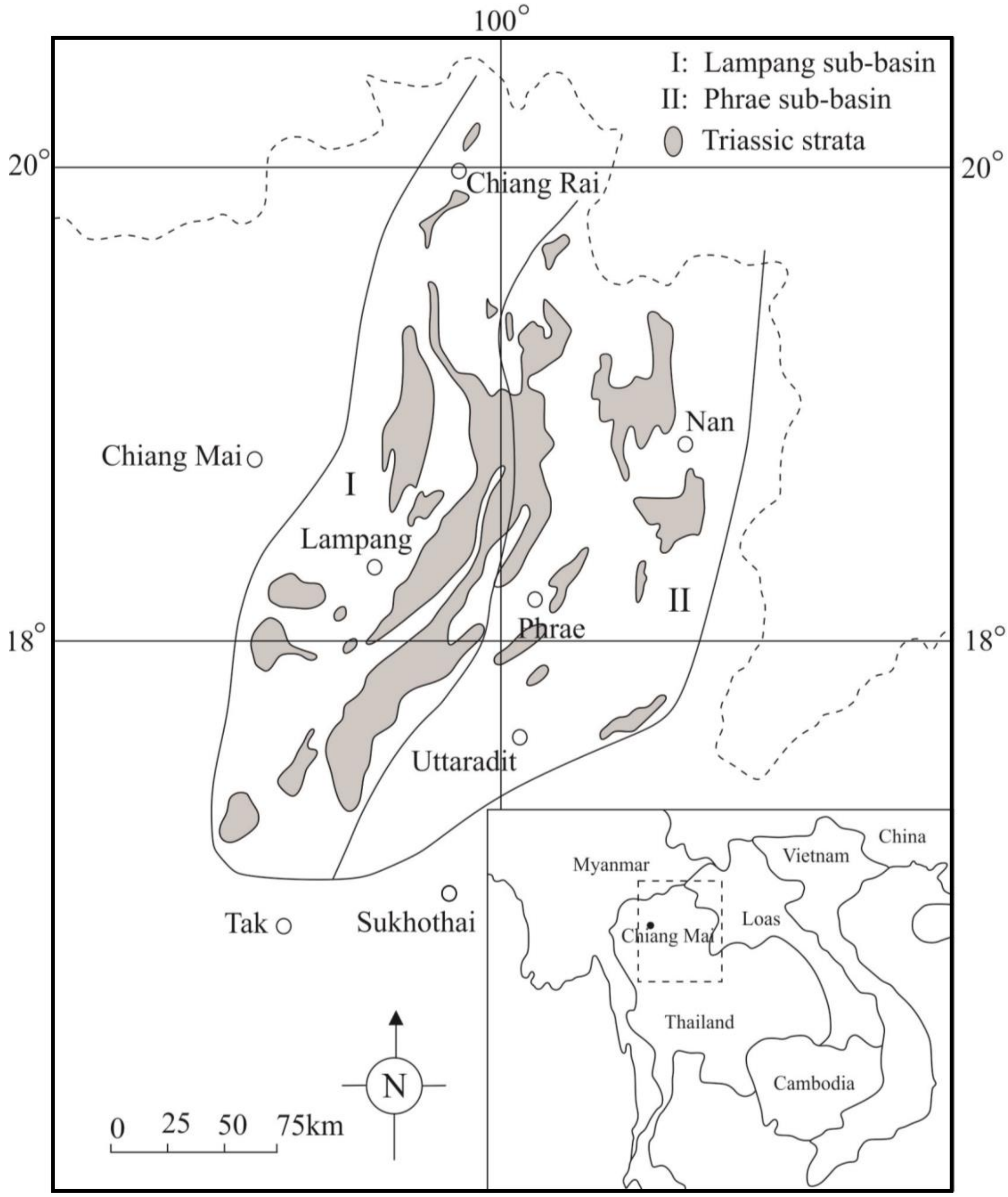


Figure 2.3 Location of Lampang-Phrae Basin and the distribution of the Triassic rock in the basin (after Feng *et al*., 2005).

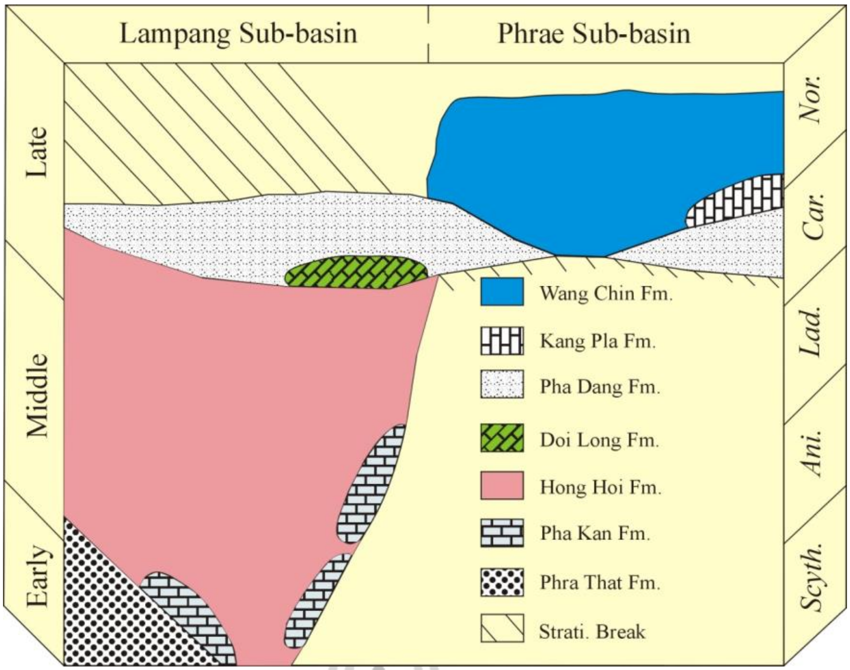


Figure 2.4 Simplified stratigraphic relationships within the Lampang Group (after Chaodumrong, 1992).

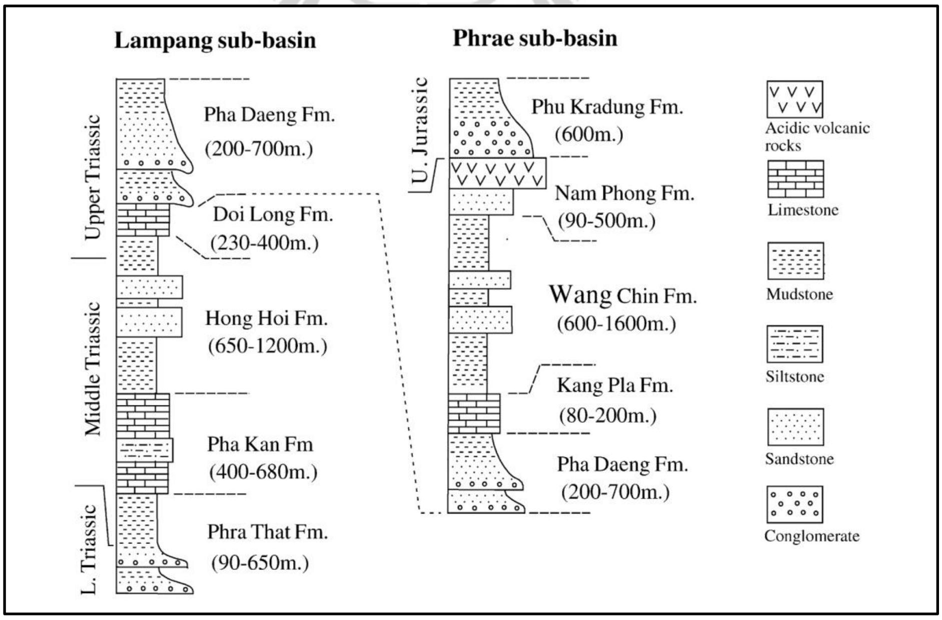


Figure 2.5 Triassic stratigraphic sections of Lampang-Phrae Basin, North Thailand (after Feng *et al.*, 2005).

Carnian to Norian). In most areas, the Lampang Group unconformably overlies inferred Permo-Triassic volcanics. The Lampang-Phrae Basin unconformably and conformably overlies the Permian strata. The conformable contacts occur particularly in the Lampang sub basin. It is both conformably and unconformably overlain by red beds of possibly Jurassic age. The maximum thickness is estimated at 3000 meters and 2000 meters in the Lampang and Phrae sub-basins, respectively.

A) Phra That Formation: the name of this formation is from Phra That Muang Kham temple, and it is 12 kilometers southeast of the town of Lampang. The sequences at the type locality, Phra That Muang Kham temple, are poorly exposed. An additional reference locality is proposed here at km 31+600 to 31+900 on the Lampang-Denchai Highway. The thickness ranges from 90 to about 650 meters. The lower part of the Phra That Formation is characterized mainly by alternating beds of feldspathic sandstone, conglomerate, siltstone and mudstone. These are mainly red, thin to thick and nonparallel beds with normal graded beds. Conglomerate clasts are mainly volcanics. The upper part of the formation generally consists mainly of gray mudstone and rare thin-bedded to thick-bedded gray sandstone and limestone. Fossils, particularly bivalves, occur commonly in this upper part. The age ranges from early Scythian to early Anisian. The lower part of the formation contains *Eumorphotis multiformis* of Scythian age while mudstone in the middle part contains *Costatoria* assemblage of early Anisian age (Chaodumrong and Burrett, 1997). The relationships between the Phra That Formation and its underlying formations can be classified into three types: (1) unconformity on the top of Permian-Triassic volcanic rocks, (2) unconformity on the top of Permian limestones and older formations, and (3) a conformable contact with Permian–Triassic volcanic rocks or Permian sediments (Feng *et al*., 2005).

B) Pha Kan Formation: The name of the formation comes from Doi Pha Kan, located north of Ban Tha Si. This formation was proposed by Piyasin (1971). The type section is at the Phra That Muang Kham temple but Doi Chang and the Phra Thu Pha limestone quarry are regarded as the reference sections (hypostratotypes) of the Pha Kan Formation. The Pha Kan Formation consists of three limestone members and one intervening clastic member: Wiang Sawan, Chang Garb, Cave Temple, and Muang Kham Members. In some areas, the formation is made up almost entirely of limestone; in the other it has an intervening clastic member (Figure 2.6) (Chaodumrong and Burrett, 1997). The formation, 250 to 600 meters in thickness, overlies the Phra That Formation conformably consisting mainly of thin-bedded to massive limestones and oolitic limestones, interbedded with shales, sandstones and mudstones, and contains an Anisian bivalve fauna represented by *Costatoria goldfussi mansuyi* (Chonglakmani and Grant-Mackie, 1993). Middle Triassic is proposed for the age of the Pha Kan Formation (Charusiri *et al*., 1994).

C) Hong Hoi Formation: Pitakpaivan (1955) proposed the name "Hong Hoi Shale and Sandstone" to represent sandstone and grayish green shale containing ammonoids and bivalves in the Mae Moh area. Later, Piyasin (1971) renamed it to Hong Hoi Formation. The type locality at a good exposure of the Hong Hoi Formation crops out from Huai Mae Dum to Huai Muang, northeast of Ban Tha Si. The Hong Hoi Formation is generally lying between the limestones of the overlying Doi Long Formation and the underlying Pha Kan Formation. However, in some places it may be conformably overlain by the Pha Daeng Formation, conformably

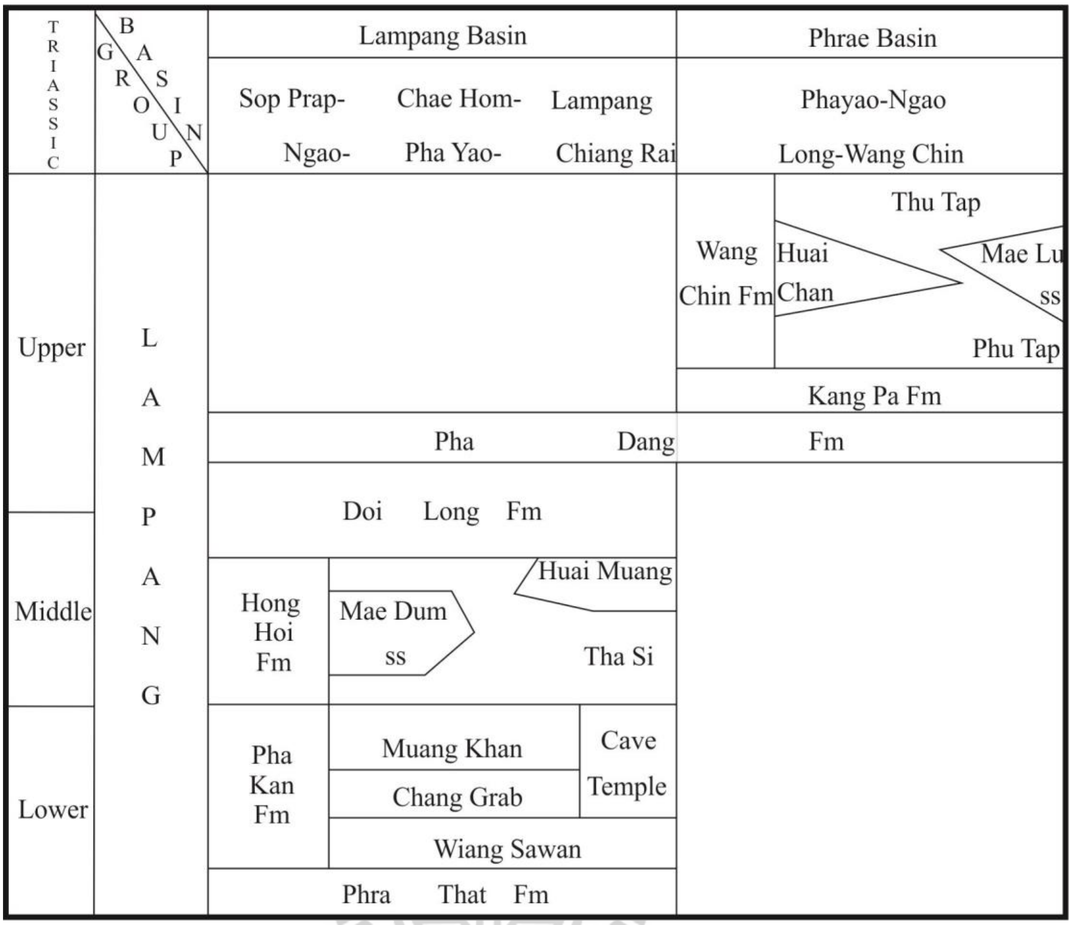


Figure 2.6 Stratigraphic columnar sections of the Lampang Group in Lampang Basin and Phrae basins (after Chaodumrong and Burrett, 1997).

underlain by the Phra That Formation or Permian strata. It consists mainly of fine-grained turbidites that can be subdivided into three members: the Tha Si, Mae Dum Sandstone and Huai Muang (Chaodumrong and Burrett, 1997). The formation with the thickness of 650 to 1000 meters in thickness, overlies conformably the Pha Kan Formation. It is characterized by a succession of alternating gray to greenish gray mudstones, siltstones, sandstones and conglomerates, containing Ladinian to early Carnian bivalves and ammonoids, such as *Daonella indica* Bittner, *Halobia* cf. *subcomata* Kittl, *Protrachyceras* cf. *longobardicum* (Mojs), *P.* cf. r*egoledanum* (Mojs), and *Trachyceras* cf. *aon* (Munster) (Chonglakmani and Grant-Mackie, 1993).

D) Doi Long Formation: The formation was named after the Doi Huai Long, is situated 40 kilometers northeast of the town of Lampang (Chonglakmani, 1981). The Doi Long Formation is characterized by massive bedded, light gray to gray packstone to grainstone of peloids, oncoids and algal debris with minor bioclasts, oolite and stromatolite beds or lenses. Macrofossils are scarce but abundant locally, especially in the upper part of the formation. The formation has the thickness 230 meters at the Doi Huai Long area (Chaodumrong and Burrett, 1997). The middle Carnian *Hollandites– Balatonites* fauna was found in this formation (Chonglakmani and Grant-Mackie, 1993). Charusiri *et al*. (1994) confirmed that the formation occurred locally, formed as lens-shaped strata, and changed laterally with the underlying the Hong Hoi Formation. In the upper part, the Doi Long Formation grades vertically into gray to reddish brown limestone conglomerate.

E) Pha Daeng Formation: The formation was named after Doi Pha Daeng by Piyasin (1972). Limestone conglomerates occurring within the red beds in the lower part of the sequences are considered as part of the Pha Daeng Formation which was contrast to the original proposal. This formation occurs in both Lampang and Phrae sub-basins. The type section is located along Doi Pha Daeng through Huai Ting Tue. An additional reference locality is situated along km 50+500 to 61+000 and km 45+020 to 45+400 on the Rong Kwang-Ngao Highway. The formation has thickness ranging from 200 to 700 meters and possibly, in places, up to 1000 meters in thickness (Chaodumrong and Burrett, 1997). This formation consists mainly of red shales, sandstones, and conglomerates in the basal part, and grades up into gray shales, siltstones, and sandstones. Late Carnian *Halobia parallela* and *H.* cf.

yunnanensis, and typical early Norian forms reported from Europe, such as *Halobia distincta* and *H. dilatata*, were found in gray siltstones of this formation (Chonglakmani and Grant-Mackie, 1993). Chonglakmani (1972) reported fossils of *Hettangia* in siltstone sorting upon basal conglomerates. Charusiri *et al*. (1994) considered that the Pha Daeng Formation took place in the non-marine environment but Chaodumrong and Burrett (1997) confirmed that the formation was deposited in the fan-deltas environment.

F) Kang Pla Formation: The type section is at km 45+500 to 1045+625 on the Rong Kwang-Ngao Highway. The formation varies in thickness from 76 meters at the type locality at km 45+500 on the Rong Kwang-Ngao Highway to 38 meters at the section in the south at km 69+000 on the Lampang-Denchai Highway. These two locations are possibly only the feather edges of a large lensoidal limestone body. The Kang Pla Formation consists mainly of thin to massive bedded, light to dark gray limestone with minor interbedded clastics. The lithology varies laterally; in some areas oolite or skeletal grainstone is developed, in the others lime mudstone and peloidal packstone are dominant. The formation ranges in age from middle Carnian to lower Norian. Middle Carnian *Halobia comata* and *Spiriferina* were reported from gray limestone in Ban Pha Kho, 15 kilometers north of Tam Bon Ban Pin. The Lower Norian conodont, *Epigondolella abneptis*, is found in limestone at km 69+000 on the Lampang-Denchai Highway (Chaodumrong and Burrett, 1997). The formation is interpreted to have been deposited in the shallow environment (Chaodumrong and Rao, 1992).

G) Wang Chin Formation: The formation was proposed for the Huai Chan Member at Huai Chan of Song District, and for the Mae Lu

Sandstone and Phu Tap Members at km 54+730 to 55+930 and km 66+350 to 66+770 along the Lamphang-Denchai Highway. The formation is subdivided into three members as the Huai Chan, Mae Lu Sandstone, and Phu Tap. *Halobia* is a typical fossil that often found in the Mae Lu Sandstone and Phu Tap Members (Chaodumrong and Burrett, 1997). The thickness of this formation is ranging from 600 to 1600 meters in thickness. It is composed of gray to greenish gray shales and sandstones with interbeds of mudstones, siltstones and conglomerates. It contains late Carnian to early Norian bivalves (Feng *et al*., 2005). The Wang Chin Formation is confirmed to have occurred in the deeper and outer shelf environment (Chaodumrong and Rao, 1992).

2) Nam Pat Group in the Nan-Uttharadit area, Northern Thailand

Marine Triassic rocks exposed in the vicinities of Na Noi, Tha Wang Pha, and Song Khwae Districts, and Nam Pat District of Nan, and Uttaradit Provinces, repectively can be classified into two formations, in ascending order: Hin Lat Formation and Huai Bo Khong Formation on the basis of their lateral facies changes (Meesook *et al*., 2002). The Nam Pat Group, approximately 1400 meters in thickness, consists of greenish gray to red conglomerates with clasts mainly of volcanic rocks with subordinate sandstones, granites, limestones, cherts and white quartz, and sandstones interbedded with dark gray to greenish gray mudstones displaying graded beds of Bouma's sequence. Based on the conodont *Pachycladina* sp. indet, the Scythian age is given for the Nam Pat group. According to the limestone unit (trI) (not include in the Nam Pat group), the rocks consist of dark gray, thin-bedded to thick-bedded limestones interbedded partly with mudstones and sandstones. The limestone unit (trI), interpreted as the lateral facies changes with the Huai Bo Khong formation is well exposed as isolated hills north of Na Noi District and west of Bo Klua District of Nan Province. Based on the ammonite, *Unionites* and the bivalve, *Costatoria goldfussimansuyi*, the Middle Triassic age is given for the limestone unit (Meesook *et al*., 2002).

3) Mae Sariang Group in the Mae sariang area, northwestern Thailand

Bunopas (1981) first proposed the name Mae Sariang Group (Figures 2.7) and stated that the type section of the Mae Sariang Group is at the western part of the road between km 5+000 to 10+000 from Mae Hong Son Province to Mae Sariang District. In his brief description, the Mae Sariang Group consists of 50 meters in thickness conglomerate in the lower part, 700 meters in thickness interbedded gray shale/siltstone and sandstone, and 100 meters in thickness sandy shale. Marine Triassic rocks in the vicinity of Mae Sariang District, Mae Hong Son Province, are unconformably underlain and overlain by Paleozoic and Jurassic rocks, respectively. The rocks can be divided into two informal formations as upper and lower formations with total thickness of 220 meters, consisting of (from bottom to top) greenish red, thin-bedded (< 10 centimeters) cherts intercalated with thin-bedded claystones and partly with limestones. Besides, reddish brown to gray conglomerates, sandstones and mudstones are also present. The sedimentary characteristics show the Bouma sequence with graded beds, and fining upward sequence. Clasts of conglomerate and sandstone consist of chert, metamorphic rock, and granite. Based on the radiolarians (Caridrot *et al*., 1993; Tofke *et al*., 1993) and bivalves *Halobia* *comata*, *Posidonia, Halobia styriaca* Mojs, *Daonella* cf. *sumatrensis* Volz found in this sequence, they indicate Middle Triassic age.

Tofke *et al*. (1993) made a detailed study on three sequences of Triassic sedimentary rocks along the road from Mae Sariang to Mae La Noi Districts. They reported that these marine Triassic rocks consist mainly of red, green, and gray ribbon chert beds in the lower sequence with radiolarian fossils and intercalation of claystone and siltstone. Each chert bed is about 10 centimeters in thickness. The middle sequence is composed largely of pelagic limestone ranging in color from reddish to greenish and light to dark gray with individual beds do not exceed 10 centimeters, and the overall thickness is about 20 meters. Radiolarian and shell fragments are found only in the light gray limestone bed along the road at km 119+625, Highway number 108. The upper sequence is regarded as turbidite sequence mainly containing graded to crossed-bedded siliciclastic strata of sandstone intercalated with shale. The thickness is varied from 5 to 20 centimeters and some strata are up to 100 centimeters. The total thickness of these three sequences is more than 100 meters. Well-preserved bivalves found in shale indicate the age of Middle to Late Triassic (Ladinian to Carnian).

Chonglakmani (1999) proposed the Triassic sedimentary belt exposed in the Mae Sariang area as the Mae Sariang Group. It extends southward to Tak, Mae sot, Kanchanaburi, and to Songkhla in peninsular Thailand, where the sequence is known as the Na Thawi Formation. He considered that this belt is deep marine and oceanic facies.

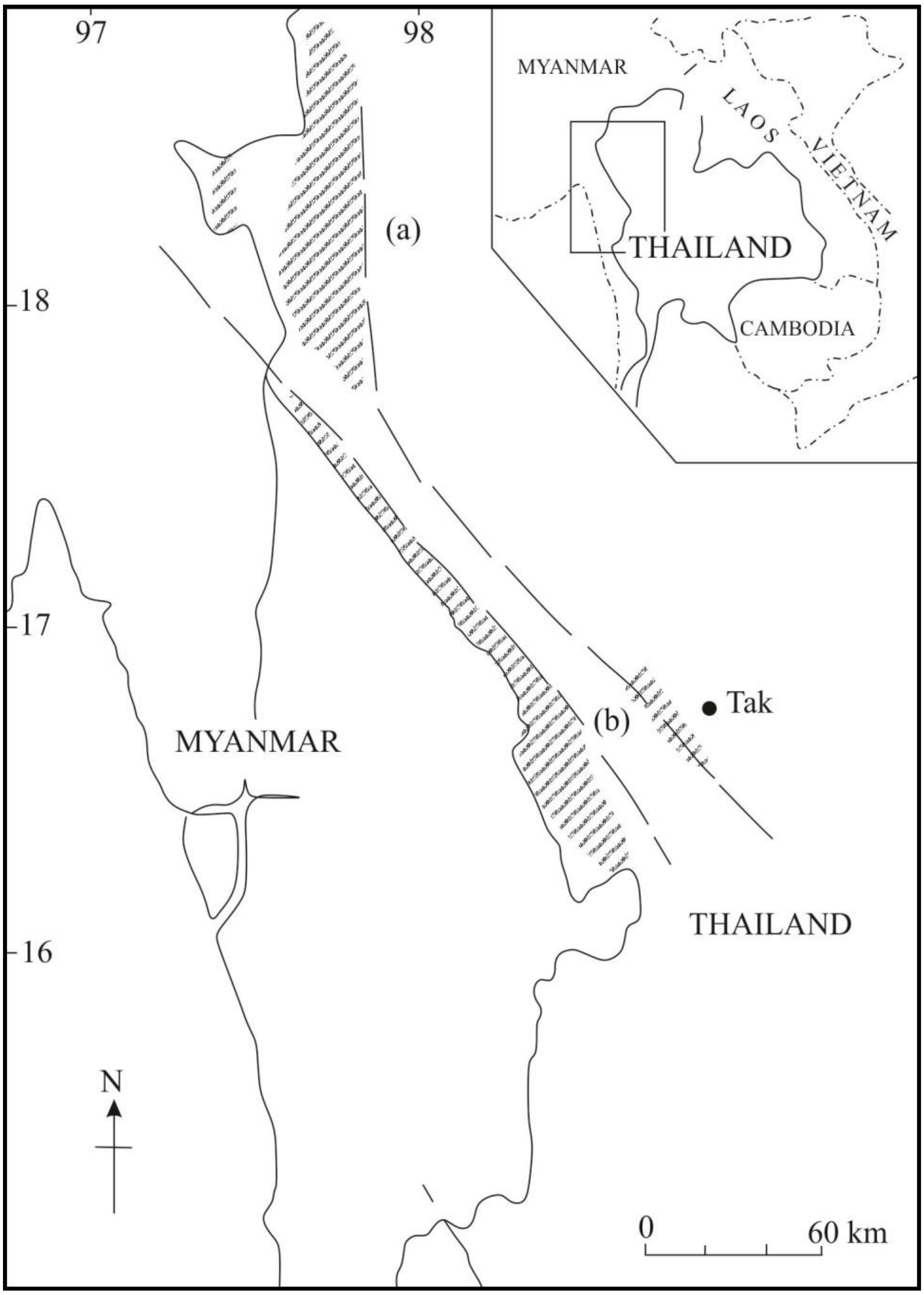


Figure 2.7 Map showing distribution of marine Triassic rocks of the Mae Sariang Group (a) and the Mae Moei Group (b) (after Bunopas, 1981).

4) Mae Moei Group in Mae Sot area, Western Thailand

This sedimentary rock unit was proposed by von Braun and Jordan (1976) for Mesozoic sedimentary sequence. It is exposed in the Mae Moei and Mae Sot areas of western Thailand (Figures 2.8). The Mae Moei Group consists of two major units-the Lower and Upper Units. Two sections were stratigraphically studied in detail by von Braun and Jordan (1976), one along Kamawkala gorge of the Mae Moei River (Kamawkala section) and the other along Huai Hin Fon stream at the Tak-Mae Sot Highway (Mae Sot section).

The Huai Hin Fon area (Mae Sot section), the observed oldest rock sequence overlies unconformably the Permian sediments at km 67+500 road from Tak to Mae Sot. These sequences are called the Pang Manora Sandstone (390 meters in thickness) consisting mainly of yellow to red sandstone and shale in the upper part, gray to red sandstone in the middle, and poorly sorted limestone conglomerate in the lower. The younger unit is the Mae Pa Luang shale (470 meters in thickness) consisting of red to gray shale with *Myoshoria* sp. and *Gonodon* aff. *mellingii* and thinly bedded sandstone and limestone intercation. The almost top sequence is the Huai Hin Fon Limestone (680 meters in thickness) consisting of clayey to silty limestone, and the topmost sequence is the Huai Hin Fon shale (770 meters in thickness) composed mainly of greenish gray siltstone, shale, and sandstone with *Posidonia* in the upper part and dark gray shale with ammonoids in the lower part.

The Mae Moei area (Kamawkala section), two sections were recognized. The lower sequence is about 900 meters in thickness. It contains greenish gray shale with interbedded sandstone in the lower part. This sequence is almost similar

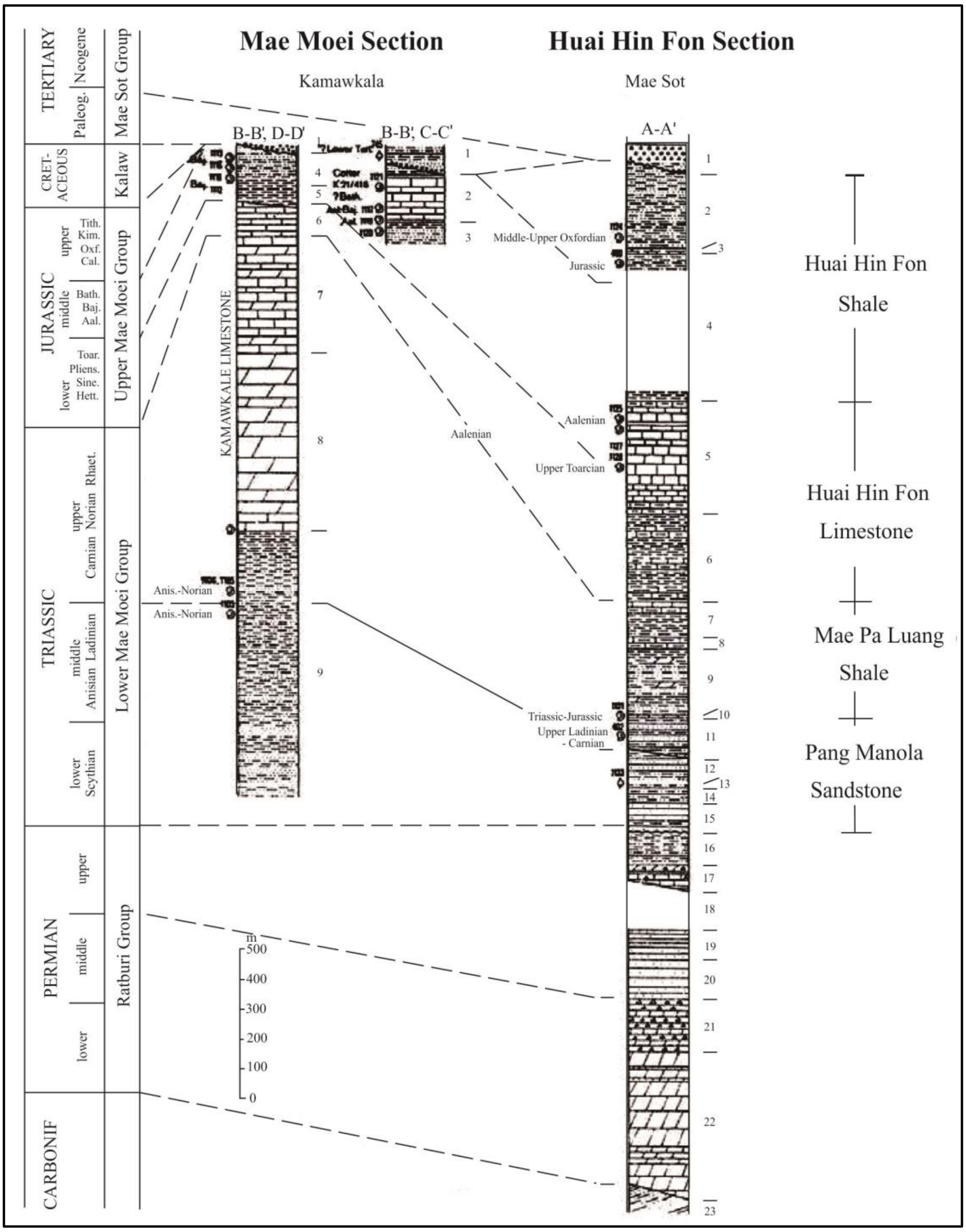


Figure 2.8 Composite stratigraphic columns in the Kamawkala and Mae Sot areas (after Von Braun and Jordan, 1976).

to that of the Pang Manola Sandstone and the Mae Pa Luang shale of the Huai Hin Fon section. *Halobia* and *Posidonia* bivalves and ammonidia fossils in shale suggest the age of Late Triassic. The middle sequence is characterized by the Kamawkala Limestone. The age was subsequently proved as Jurassic which is similar to the Huai Hin Fon Limestone. The upper sequence is dominated in the lower part by 235 meters in thickness. It is composed of red conglomerate with poorly sorted of chert, volcanic, limestone, sandstone and quartz rock fragments and intercalated with sandstone and limestone beds. In the upper part (140 meters in thickness), the sequence is intercalation of gray mudstone and sandstone with abundant fossils of *Daonella samatrenis* volz, suggesting the age of Middle Triassic.

The Kamawkala limestones have been confirmed as the Jurassic age. These limestones are related to the Triassic rocks with fault contacts. The Triassic rocks exposed in the vicinity of Tak Province as a narrow strip trending NW-SE along the Mae Ping Fault Zone, are three kilometers wide and 20 kilometers long. The rocks here are 350 to 500 meters in thickness (Meesook *et al*., 2002).

5) Tak Group in the Tak area, Westhern Thailand

This sedimentary stratigraphic unit was proposed by Bunopas (1976) for a Triassic sequence of 400 meters in thickness sedimentary strata exposed as narrow and long outcrops in the western part of the east-dipping Lansang thrust fault. It is about 12 kilometers west of Tak city. The Tak Group comprises mainly red beds of conglomerates interbedded with sandstone and gray beds of sandstone, limestone and shale. The bivalve *Daonella sumatnensis*-suggests the age of Ladinian (Middle Triassic) (Bunopas,1981).

6) Marine Triassic rocks of Kanchanaburi, Western Thailand

Kemper *et al*. (1976) proposed the Si Sawat Limestone for a stratigraphic unit consisting largely of Triassic to Jurassic limestones exposed in areas of Si Sawat District, northwest of Kanchanaburi Province (Figure 2.9). The type section of the Si Sawat Limestone is at Huai Chongkrong stream, parallel with the road from Si Sawat to Noen Sawan, about six kilometers west of Si Sawat town. Marine Triassic rocks crop out in the vicinities of Si Sawat and Thong Pha Phum Districts of Kanchanaburi Province (Kemper, 1976; Bunopas, 1981), consisting of the 200 meters in thickness sequence of limestones, siltstones, mudstones and sandstones. Whereas mudstones display the distinctive pencil structures; limestones are replaced by dolomites. At Si Sawat District, the bivalves *Halobia* and *Posidonia* were found and early Anisian conodonts *Neogondolella mombergensis* (Tatge), *Neospathodus aegaeus* (Bender), *Gondollella* cf. *constricta* (Mosher & Clark), were discovered in limestones together with the Norian conodont *Epigondolella abneptis* (Huckriede). Previously known Triassic conglomerates and sandstones at Kaeng Raboet have been reassigned as Jurassic in age because of the presence of Jurassic fossils in limestone clasts (Meesook *et al*., 2002).

2.1.2.2 The Eastern Regions

1) Marine Triassic Rocks of Eastern Thailand

Marine Triassic rocks in eastern Thailand can be divided into four formations, namely, in ascending order: the Sookpriwun, Noen Po, Pong Nam Ron and Noen Phu Yai Yua Formations (Meesook *et al*., 2002).

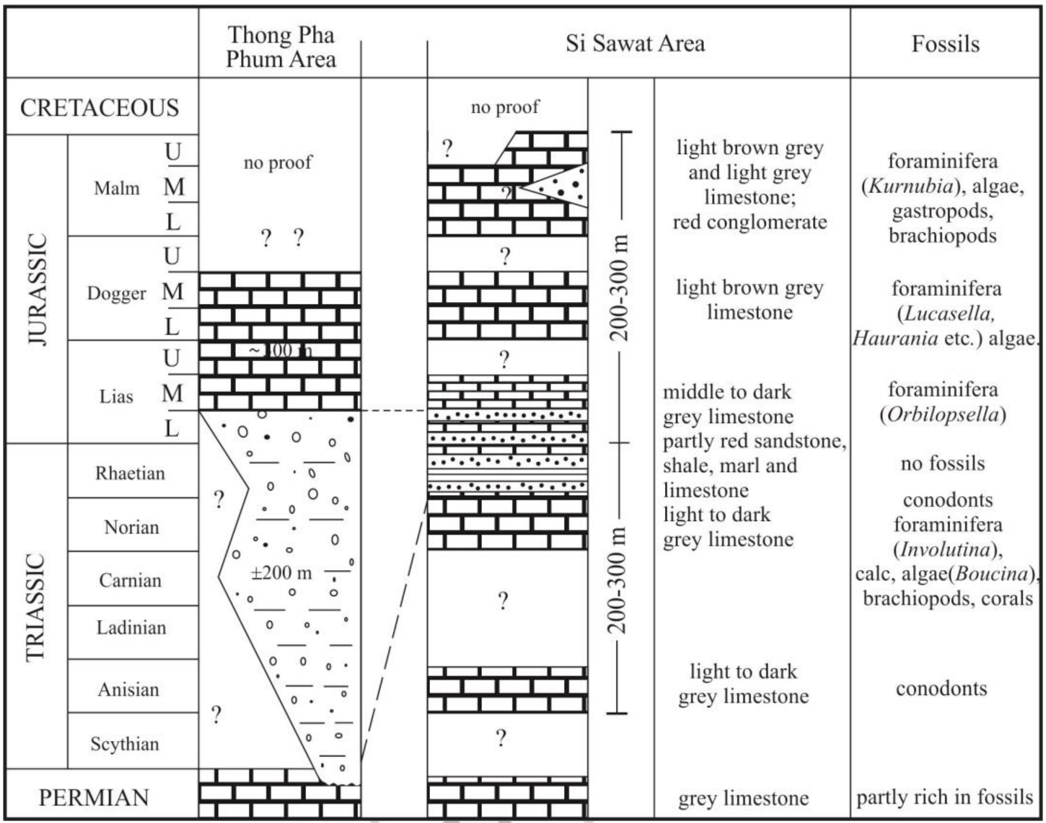


Figure 2.9 Stratigraphic column of Triassic and Jurassic rocks of Si Sawat District, northwest of Kanchanaburi Province (after Kemper, Maronde, and Stoppel, 1976).

A) Sookpriwun Formation, 100 meters plus in thickness, consists of gray, dark gray and violet brown limestones having slightly deformation. The formation is unconformably underlain by Late Permian rocks containing the foraminifera *Meandrosptra pusilla* Ho, *GIomospira tenurfistula* Ho, and algae *Aeolissacus tintinniforis* Misik indicative of Scythian-Ladinian age.

B) Noen Po Formation is composed of gray to dark gray mudstones and shales intercalated with three to five centimeters in thickness gray cherts yielding the Middle to Late Triassic radiolaria *Triassocampe, Syringocapsa,* *Archaeospong oprunum*. The age of Noen Po Formation is younger than ones of the Sookpaiwun Formation. Its type section is at Khao Noen Po, west of Chantaburi Province. This formation is mainly mudstone interbedded with volcaniclastic sandstone and about 250 meters in thickness.

C) Pong Nam Ron Formation is well exposed at KIong Pong Nam Ron, Pong Nam Ron District, Chantaburi Province. The rocks observed in the northwestsoutheast trend expose from Wang Nam Yen District, Sra Khaeo Province southward to east of Trat Province. The formation is composed largely of thin- to thick-bedded, partly overturned and cleaved graywacke and mudstone with conglomerate intercalation (Figure 2.10). The occurrence of abundant volcanic clasts and fusulinid-bearing limestone and the alternating bed of turbiditic sandstone and shale of Bouma sequence, led to suggest that the Pong Nam Ron Formation took place as submarine fan environment depositing in an active margin nearby continents (Srinak, 2002). The Pong Nam Ron Formation, 200 meters in thickness, consists of dark gray, poor-sorted, thick-bedded, feldspathic sandstones. The sandstone composition is mainly of volcanic and feldspar, and subordinate quartz. In some places, sandstones are intercalated with mudstones and conglomerates having clasts of well-rounded, poor to moderate sorted volcanic rocks, and fusulinid-bearing limestones. The conglomerates also display fining upward sequence grading up to the Noen Phu Yai Yua Formation.

D) Noen Phu Yai Yua Formation, 300 meters in thickness, is conformably underlain by the Pong Nam Ron Formation. It contains dark gray, medium-grained, well-bedded (10-20 centimeters) sandstones interbedded with parallel-bedded mudstones displaying prominent Bouma sequence and graded

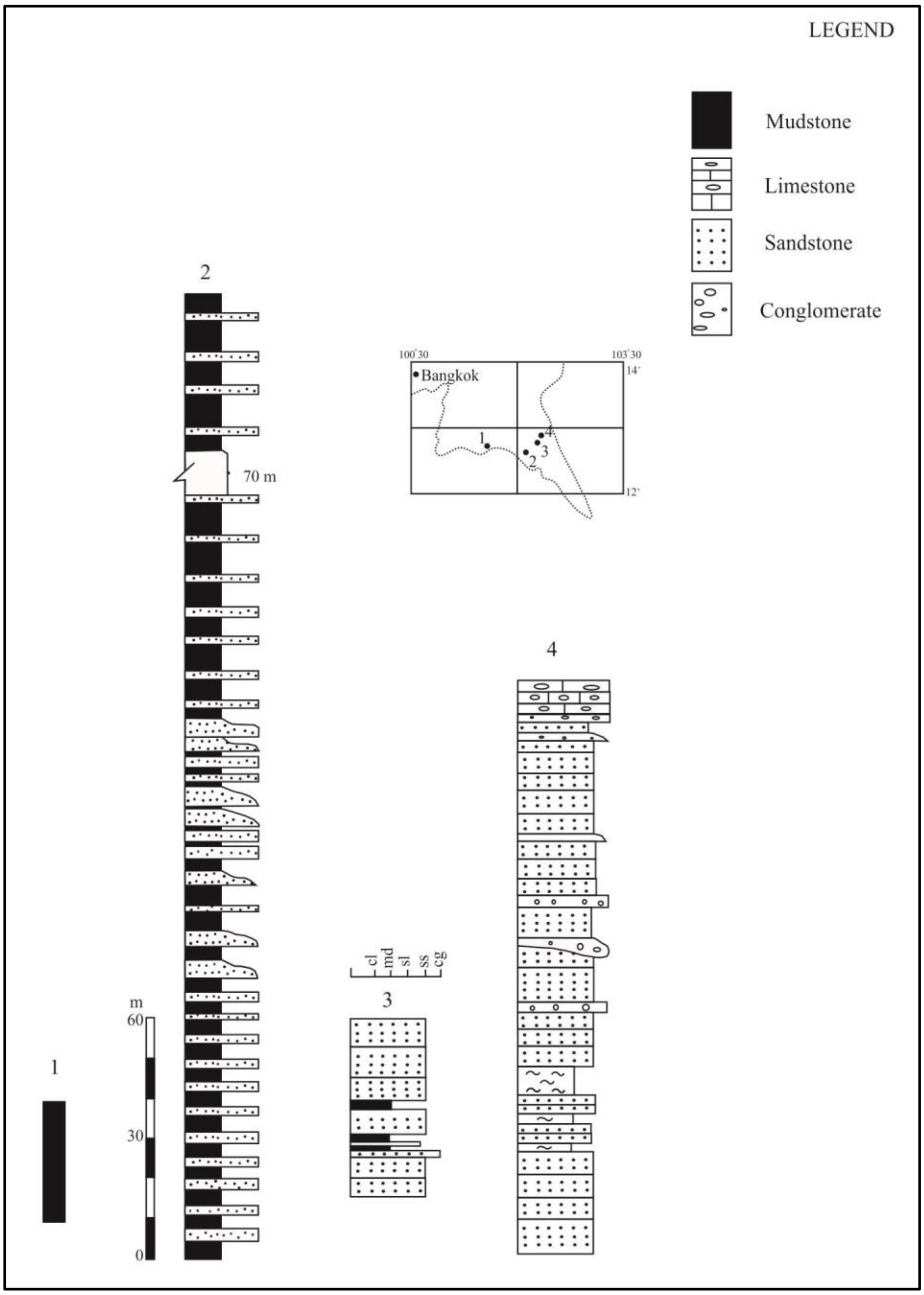


Figure 2.10 Stratigraphic sequence of the Pong Nam Ron Formation in eastern Thailand 1. Ban Tha Rua, 2. Noen Punyai Yua, 3. Khao Klua, and 4. Klong Nam Ron (after Srinak, 2002).

beds particularly in sandstone beds grading up to mudstones with sharp and planar contacts and sandstone : shale ratios of 2:1 to 1:1. This formation is interpreted as having been deposited in the submarine fan environment.

2.1.2.3 Southern Regions

1) Marine Triassic Rocks of Southern Thailand

Marine Triassic sedimentary sequences in southern Thailand are widely exposed in two main areas of Songkhla and Phattalung Provinces.

In Saba Yoi District of Songkhla Province, Grant-Mackie *et al*. (1980) have divided the rocks into four units, namely, the Suan Cham Formation, Chedi Conglomerate, Khlong Kon Limestone and Sani Formations in ascending order. The Suan Cham Formation consists of the 1,700 meters in thickness siltstones and well-bedded sandstones. The Chedi Conglomerate comprises thick-bedded conglomeates and sandstones with lenses of medium-grained sandstones. The Khlong Kon Limestone is composed mostly of 600 meters in thickness, gray, thick-bedded limestones. Sashida *et al*. (1999) mentioned that the Khlong Kon Limestone is interpreted to be deposited in the low energy, back-reef or lagoon environments and this formation ranges in age from Middle to Upper Triassic on the basis of the foraminifera. The Sani Formation consists of siltstones, fine-grained sandstones, dark gray cherts and fine- to medium-grained conglomerates with total 4,300 meters in thickness (Meesook *et al*., 2002).

The Na Thawi area, Songkhla Province, the marine Triassic rocks contain the bivalve *Daonella sumatrensis* Volz collected from Khlong Mak along the Highway Number 42 indicating Carnian age (Late Triassic). Grant-Mackie *et al*. (1980) have established new lithostratigraphic units, namely, in ascending order: the Mi Kiat Conglomerate, Na Thawi Formation, Wang Yai Siltstone and Lam Long Sandstone. The Mi Kiat Conglomerate is approximately 500 meters in thickness, consisting of conglomerates and sandstones. The Na Thawi Formation is composed of siltstones and siliceous sandstones with 3,000 meters in thickness sequence. The bivalve *Daonella multilineata* (Jones) collected from siltstones indicates the Middle Carnian age (lower Late Triassic). Sashida *et al*. (1998) reported the presence of the Carboniferous radiolarian in chert lenses at Ban Wang Yai along Highway number 42. The gray, thin-bedded, calcareous siltstones of the Wang Yai Siltstone and fine- grained, thin-bedded sandstones of the Lam Long Formation are 225 and 3,700 meters in thickness, respectively (Meesook *et al*., 2002).

The Phatthalung area, marine Triassic rocks have been established by Ampornmaha (1995) as the Chaiburi Formation, consisting of three members in ascending order (Figures 2.11): the Phukhaothong Dolomite, Chiak Limestone and Phanomwang Limestone Member, respectively. The formation consists of pale gray to violet gray, wellbedded, thin-bedded to thick-bedded limestones, dolomitic limestones and dolomites with 500 meters in thickness. The rocks are trending N-S and dipping 40° E; its lower part consists of dolomites, described the new ichthyopterygian (Reptilia) indicating Early Triassic age; the middle part comprises limestones intercalated with nodular and thin-bedded cherts; the upper part is composed of thick to massive limestones on the basis of the microfacies analysis. Age determination of the rocks is based mainly on the conodont indicating Lower to Upper Triassic (Meesook *et al*., 2002).

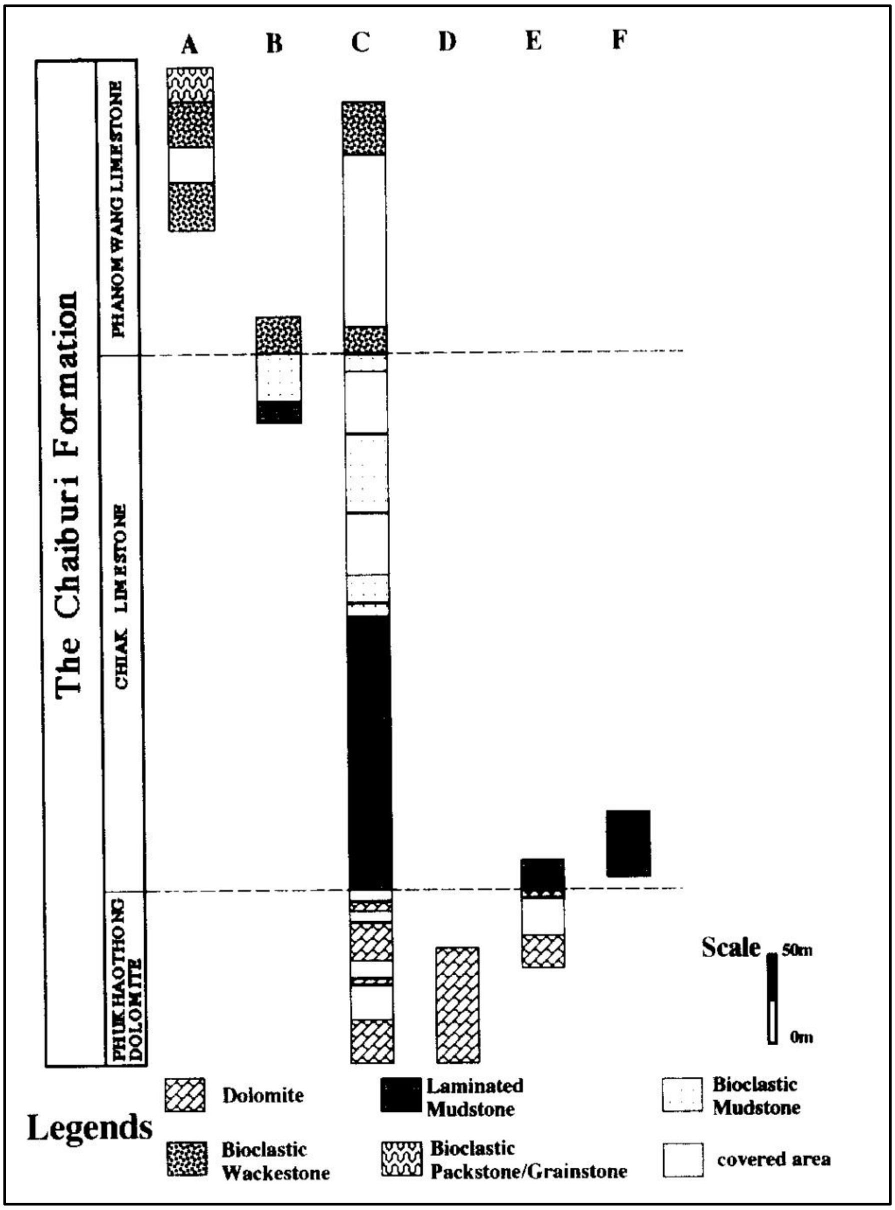


Figure 2.11 Chaiburi Formation consists of five microfacies in each section (after Ampornmaha, 1995).

2.1.3 Regional Geology of Study Area

The study areas are situated in Ban Pong Chang, Ban Huai Yai and Ban Nong Makha, Nong Prue Subdistrict, Nong Prue District, Kanchanaburi Province. Geologic map of study area and adjacent areas is illustrated in Figure 2.12. It was modified from geologic map of Kanchanaburi Province. Generally, rocks distributed in the study areas consists of sedimentary and metamorphic rocks ranging in age from the Ordovician to the Quaternary.

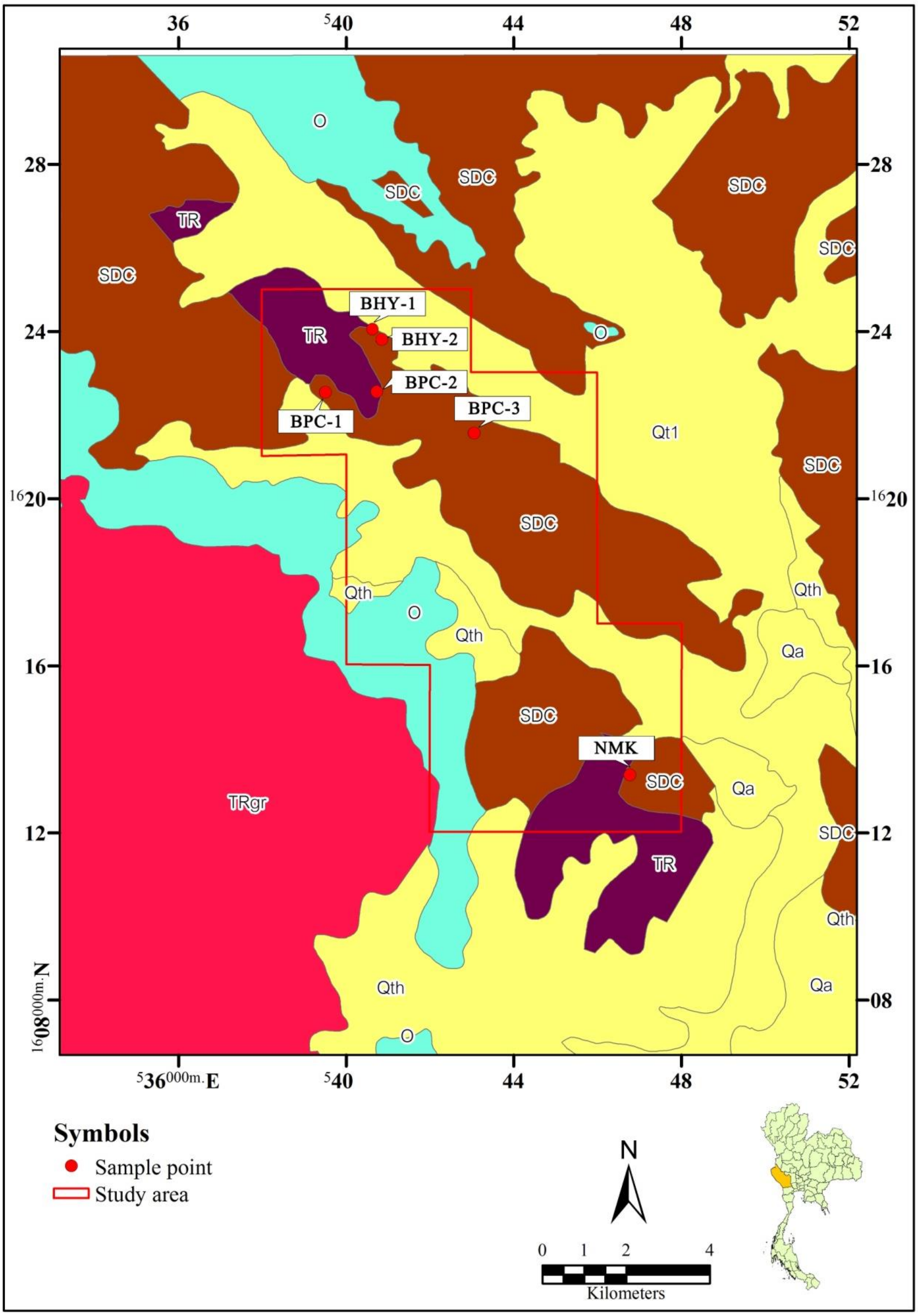


Figure 2.12 The geological map and sampling localities in the study area (after Sudasna *et al*., 1976).

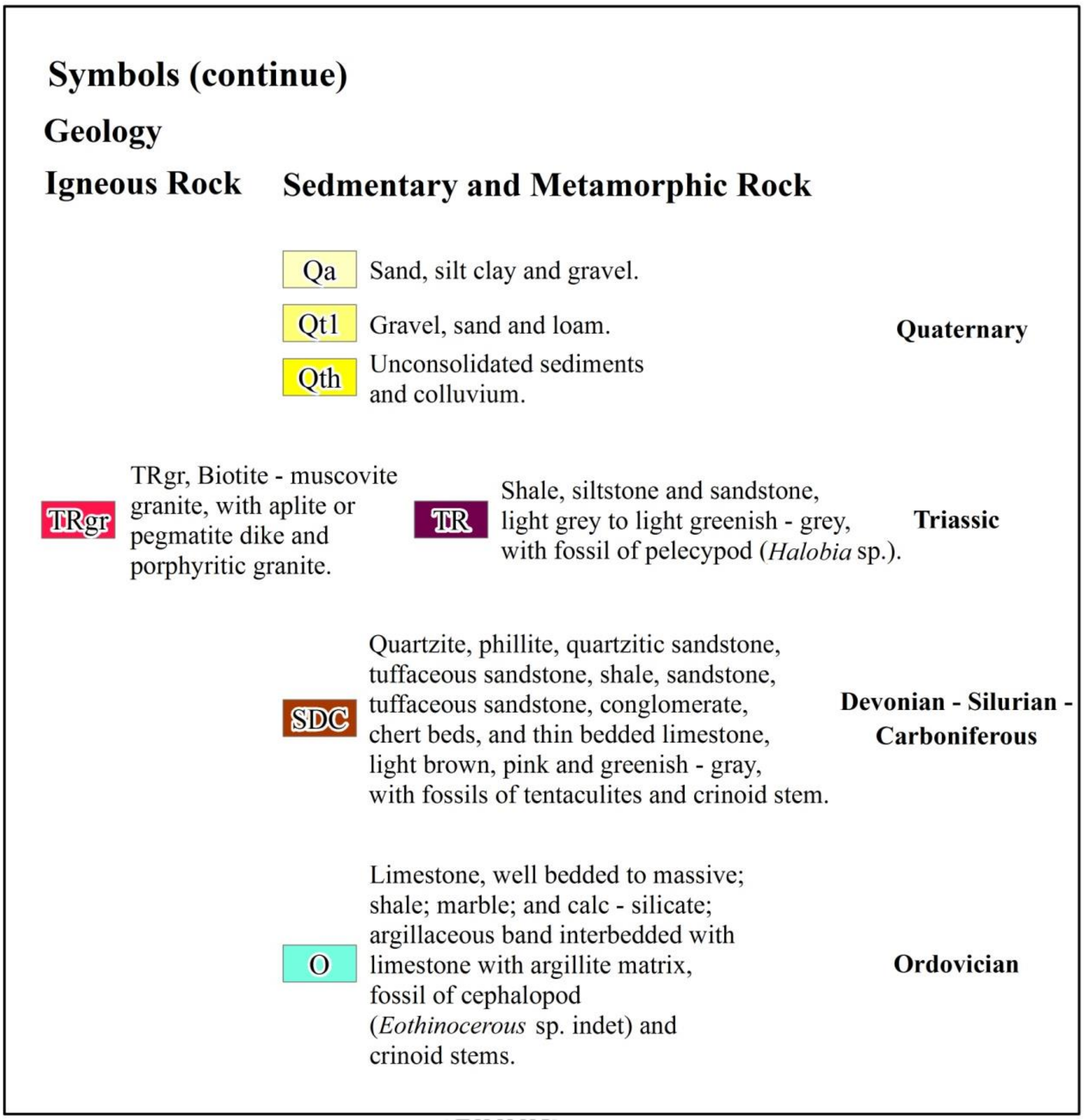


Figure 2.12 The geological map and sampling localities in the study area (after Sudasna *et al*., 1976) (cont.).

2.2 The Study of Bivalves Ammonoids and Fusulinids

2.2.1 The Study of Pelecypods (bivalves)

The typical pelecypod is bilaterally symmetrical in both soft and hard parts and can generally be distinguished from all other Mollusca by its bivalve shell, which is calcareous and has two valves that are alike (except along the hinge line) but reversed one to the other. The organism itself is laterally compressed, and has a prominent ventral foot. When the shell is closed all soft parts are usually completely enclosed within the two valves (Robert and William, 1953).

Throughout their long geologic history, beginning almost certainly in the Cambrian most pelecypods have been free-moving bottom dwellers. Today many live partly or completely buried in the bottom mud or sand, others bore into wood and rock, a few attach their shells loosely by tuft of horny threads (byssus), and a few others become permanently cemented to objects on the bottom. It is known from the fossil record that ancient pelecypods were similarly adapted. The more common adaptations of modern pelecypods are shown in the Figure 2.13 (Only one valve is shown in D and F-K, and the muscles are indicated by black spots. The foot is shown by complex crosshatching. A few of these forms may be exposed a low tide. A. *Pholas*, the common rock borer, B. *Ostrea*, the familiar edible oyster, C. *Hippurites*, an unusual extinct pelecypod in which one valve, highly modified to a conical shape, was attached to the bottom whereas the other, also much modified, served as a lid, D. *Mytilus*, the black sea mussel, attached to the surface of a wooden piers by a byssus, E. *Teredo*, the shipworm, which bores into wooden piers and similar structures. The pier is sectioned vertically to show the path of the boring, F. *Mya*, the mud clam, a burrowing form with a long siphon, G. *Tagelus*, a burrowing form with a long double siphon, H. *Ensis*, the razor clam, with a short double siphon, I. *Venus*, the familiar quahog, almost completely buried in bottom sediment, J. *Grassatellites*, nestling in a depression in the sand, K. *Nucula*, a form which moves over the surface of the sand, L. *Pecten*, shown swimming (at left) and lying on the bottom (at right).

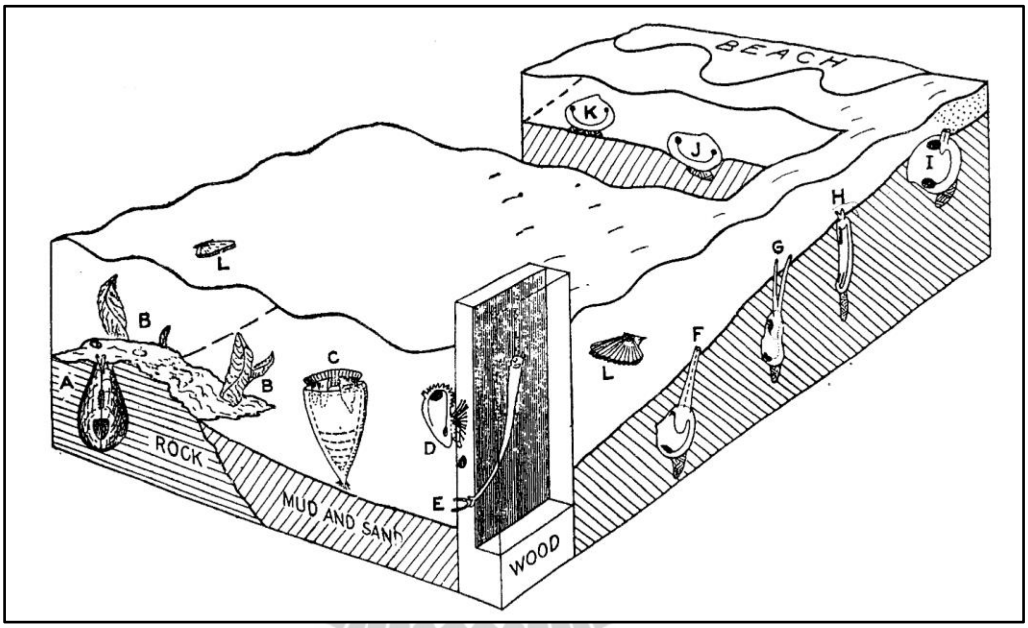


Figure 2.13 Diagrams (not all to same scale) showing adaptations among pelecypods (Robert and William, 1953).

Most marine bivalves live in shallow waters from the intertidal zone to a few hundred fathoms of depths, but many deep-water forms are also known. Certain pelecypods can also live in brackish water, and the members of three families (Unionidae, Mutelidae, Sphaeridae) flourish in lakes, streams, and other bodies of fresh water (Robert and William, 1953).

2.2.1.1 Morphology

The soft parts of the pelecypod are enclosed within a shell composed of two hinged calcareous valves (hence the common term “bivalve”), to the inner surfaces of which the soft body is attached (Figure 2.14). One or two transverse adductor muscles pull the valves together, whereas the ligament and resilium force them apart. The body proper consists of four parts (Robert and William, 1953):

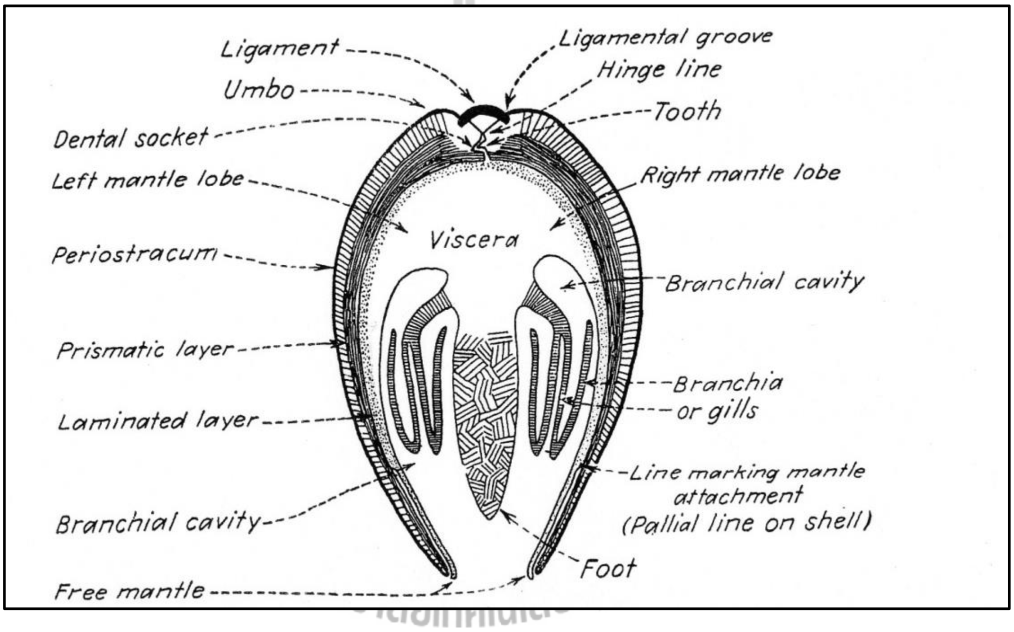


Figure 2.14 Diagrams illustrating internal morphology of shells, at right angles to the plane of symmetry, showing the general nature of both and the relations of the different soft parts to the shell (Robert and William, 1953).

2.2.1.2 Visceral Mass

The visceral mass lies chiefly in the dorsal part of the body and is attached dorsally to the inner surfaces of the two valves. The alimentary tract consists of a mouth, esophagus, stomach (into which two digestive glands discharge), a coiled intestine, and an anus. The mouth is anterior and lacks the radula that is present in all other classes of Mollusca. The anus is posterior and opens directly to the outside or in more advanced forms near the excurrent siphon. The circulatory system consists of heart and a system of tubes through which blood is pumped to the different organs. The nervous system includes three pairs of ganglia with interconnecting fibers, light-sensitive organs on the mantle, and certain other sensory structures. Kidneys (nephridia) discharge nitrogenous wastes, and gonads produce the sex products. In many species the sex are separate (Robert and William, 1953).

2.2.1.3 Foot

The foot is an anteroventral extension of the visceral mass and is a muscular organ that can be extended beyond the shell margin, when the valves are apart, and used for locomotion and burrowing. It lies in the median plane, which is also the plane of bilateral symmetry, and divides the mantle cavity into a right and a left part. It is typically wedge-shaped, but in some species it is cylindrical; in sedentary forms it is essentially functionless. In a few species it has a gland that secretes horny threads, collectively designated the byssus, which are used for temporary or permanent attachment (Figure 2.13D). Many species use byssal threads for anchorage in their younger growth stages, abandoning them in early maturity, and Anomia becomes permanently attached by byssus impregnated with calcite (Robert and William, 1953).

2.2.1.4 Mantle Lobes

The mantle hangs freely from the visceral mass and consists of two thin fleshy sheets, the mantle lobes, each adhering to the inner surface of a valve

(Figure 2.14). The marginal edges of the mantle are free of the shell, and the line along which they become free and which marks the marginal limit of mantle attachment is indicated on the shell by a prominent groove, the pallial line, paralleling the shell margin. The mantle edges are muscular and can be brought together to enclose the mantle cavity within (Robert and William, 1953).

The free edges of the mantle secrete the two outermost layers of the three-layered shell, whereas the outer surfaces of the mantle lobes deposit the innermost layer. In the more primitive pelecypods the posterior edges of the mantle lobes are so folded as to produce an upper (dorsal) exhalant and a lower (ventral) inhalant channel. In the folding of the mantle lobes to produce extensible siphons, the mantle itself is pulled away from the shell to some extent so that the pallial line has a rounded reentrant marking the position of the siphons. This reentrant is the pallial sinus (Figure 2.15) and, if present on fossil shells, indicates that the animal has extensible siphons. Furthermore, since extensible siphons are best developed in burrowing bivalves, fossil shells with pallial sinuses may be assumed to have belonged to such forms. Pelecypods with nonextensible siphons do not burrow deeply, and their shells lack a pallial sinus (Robert and William, 1953).

2.2.1.5 Gills

Most modern pelecypods have two pairs of gills, but the number may have been different in extinct species. The gills arise from ridges on each side of the body and lie in the two gill cavities, which are the spaces between the foot and the two mantle lobes. They exhibit considerable variety in morphology, structure, and arrangement and are of great importance for classification of living species. One of the more common earlier classifications of the Pelecypoda was based on gill structure and morphology and consisted of the following five orders: Protobranchia, Filibranchia, Pseudolamellibranchia, Eulamellibranchia, and Septibranchia. This classification cannot be used by paleontologists, however, because fossil bivalve shells yield no evidence as to the nature of the gills possessed by the animals that produced them (Robert and William, 1953).

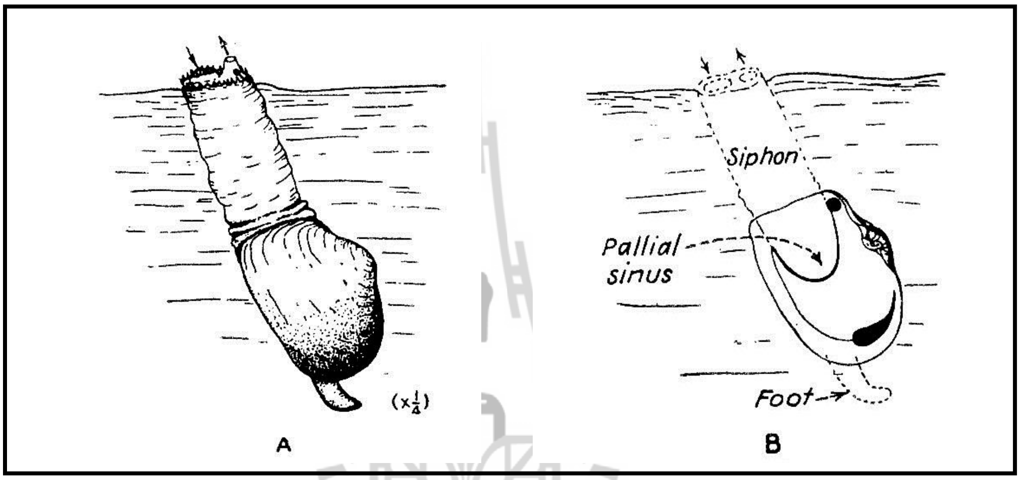


Figure 2.15 A-B. *Mya truncata,* a typical burrowing form with two siphons encased in a tubular sheath : A, animal in living position; B, interior of left valve and trace of siphonal sheath to show conspicuous pallial sinus (Robert and William, 1953).

2.2.1.6 Shell

Pelecypod shells consist essentially of two convex calcareous valves that articulate along a dorsal hinge line. The two valves, designed right and left, respectively, because they are attached to the right and left sides of the animal, are generally equal in size and asymmetrical in outline (Figure 2.16). In shells cemented to other objects by one valve, the attached valve tends to be the larger, and the smaller acts as a lid. The earliest part of each valve is the pointed beak, which usually curves toward the front (anterior) end of the shell. The rounded and elevated part of each valve directly adjacent to the beak is the umbo (Robert and William, 1953).

The height of a pelecypod shell is measured along a line in the plane of symmetry from umbo to ventral margin (Figure 2.16). The length is the greatest distance between the anterior and posterior margins measured in the plane of symmetry. The thickness is the greatest distance through the shell when it is closed and is measured in a line perpendicular to the plane of symmetry. The thickness of a valve is the distance directly across the valve from inner to outer surface.

The typical pelecypod shell in its complete development is composed of three distinct layers (Figure 2.17) an outer periostracum that is composed of conchiolin; a middle prismatic layer (the ostracum) consisting of an intergrowth of conchiolin and calcareous prisms; and an inner laminated layer (the hypostracum) of closely spaced and alternating lamellae of conchiolin and calcium carbonate (Robert and William, 1953).

2.2.1.7 Surface Sculpture

The exterior of most pelecypod shells is relatively smooth, but in many species it is somewhat sculptured and in a few it is exceedingly rough because of crenulations, ribs, spines, and other surface features. One of the commonest types of sculpture, designated concentric, consists of lines of growth, or growth lines, that are concentric about the umbos. A second type of sculpture is radial and consists of elements that radiate from the beaks. Cancellated sculpture is present on those shells having both concentric and radial elements about equally developed.

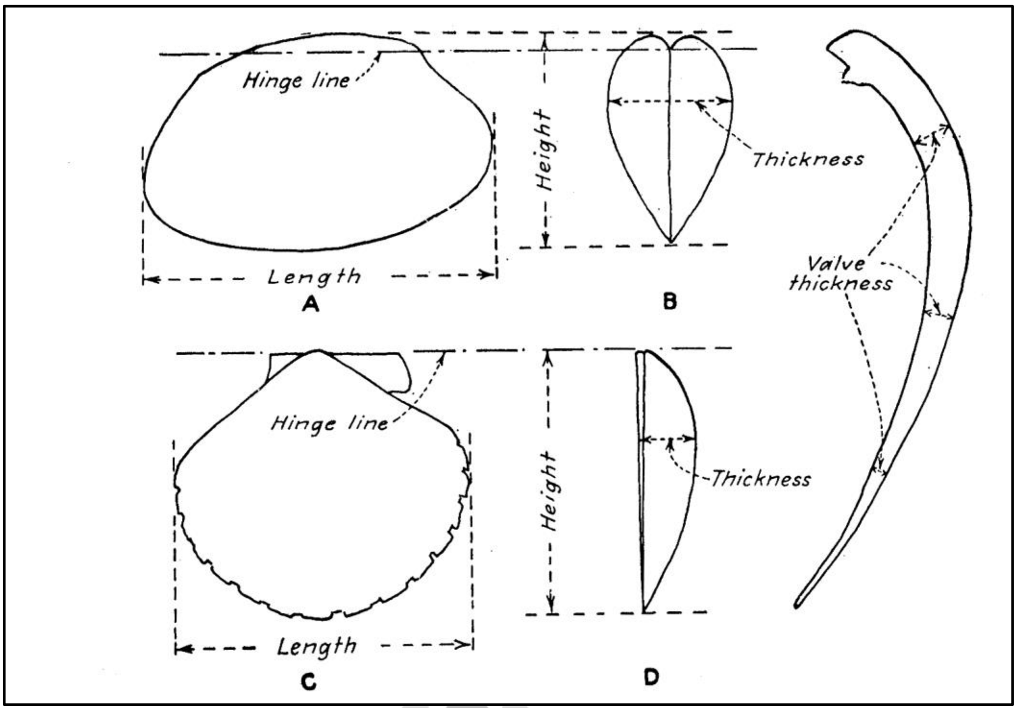


Figure 2.16 Diagrams illustrating how dimensions of pelecypod shells and of the valve such shells are measured (Robert and William, 1953).

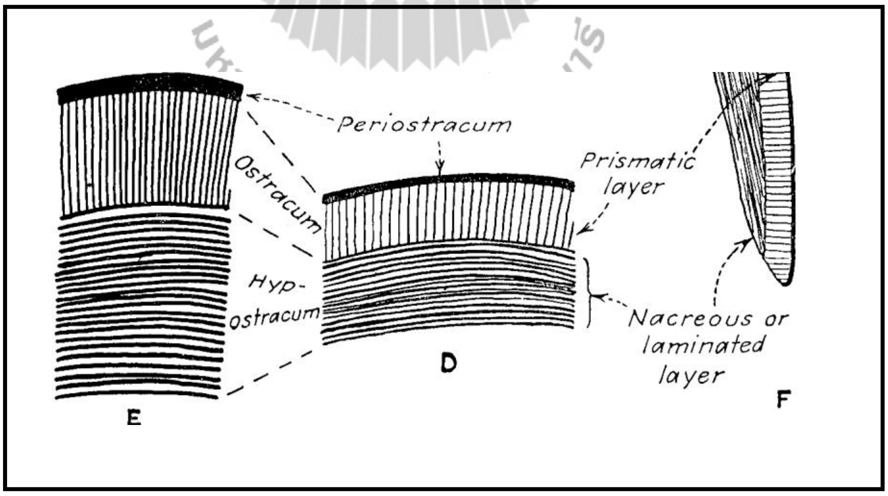


Figure 2.17 Diagrams illustrating the three fundamental shell layers (Robert and William, 1953).

2.2.1.8 Beak

Shells in which the beaks are directed toward one another are described as orthogyre (Figure 2.18) ; those which anteriorly directed beaks, are prosogyre; and those with beaks directed posteriorly are opisthogyre. The obliquity of a shell refers to the inclination of the midumbonal line. Shells with forward obliquity are prosocline; upright, shells, are acline; and shells with backward obliquity are opisthocline. It is known from ontogeny that prosocline shells appeared first and gave rise to acline forms which in turn gave rise to opisthocline types (Robert and William, 1953).

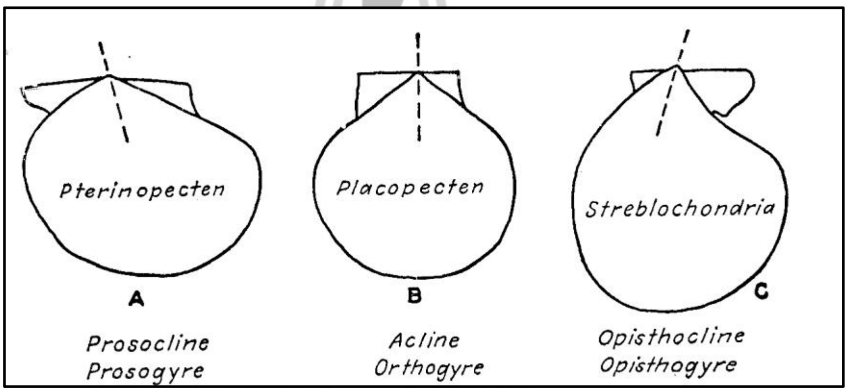


Figure 2.18 Diagrams illustrating shell obliquity and orientation of the beaks. The dashed line approximately bisects the umbonal angle, and its inclination with reference to the hinge line, which is horizontal, indicates the obliquity (Robert and William, 1953).

2.2.1.9 Paleoecology

Living Pelecypoda, are exclusively aquatic and are adapted to life in fresh, brackish and normal marine waters, in any one of which individuals may be exceedingly abundant. They are characteristically bottom dwellers, but within the limits of bottom environments they have acquired a wide range of adaptation. Some move freely over bottom sediments, ploughing through soft mud and sand by means of the foot and leaving a typical furrow as a trail. Most living genera are confined to marine environments, where they exhibit a wide range of adaptation to depth and other conditions. Some live in the ever-changing littoral zone and deep-sea forms have been taken from depths as great as 10,450 meters. Over the continental shelves and slopes, in places where deposition in slow, individuals of some species are widespread and prodigiously numerous (Robert and William, 1953).

The earliest known fossil pelecypods have come from Lower Ordovician rocks. Before the close of the Ordovician many genera and species had appeared and the pelecypods were on the way to establishing themselves as an important component in benthonic faunas, a position that they have held with certain interruptions to the present time. Large pelecypod faunas have been collected from Silurian and Devonian rocks. Some Devonian species lived in fresh water. Brackish-water forms appear in great numbers in later Paleozoic rocks. During the Triassic as many ancient genera became extinct and many new genera, some of which have persisted to the present, made their appearance. Since the Triassic the pelecypod fauna of the world has become increasingly more modern (Robert and William, 1953).

2.2.2 The study of ammonoids

Ammonoidea is an Order of Class Cephalopoda, Phylum Mollusca. This molluscan invertebrates has bilateral symmetry, soft body and undivided in segment. Its body is covered by two fold of tissue (the mantle) which secretes calcium carbonate to form shell and enclose the gill cavity. Mollusca have a muscular "foot" which is used for movement and is modified in various groups. Most of mollusca have an external calcium carbonate shell. The shell may be external univalve, external bivalve, internal or absent. More than 40,000 species have long been extinct but about 80,000 species are survived. Their habitats are usually marine, fresh water or terrestrial.

Cephalopoda is a class of highly organized marine mollusca, characterized by a head with 8, 10 or more tentacles around the mouth. They have a high developed nervous system. They consist of the head and part of foot to form the so call head-foot is characteristic of this class, though its name (Greek word : kephale = head + podos = foot) appendage are used for crawling. The one important organ of this class is the developed siphuncle. Ammonoidea is one of Order of this Class.

Furthermore, Cephalopods are comprised of both living and fossil forms. The living forms are nautiloids, octopus, cuttlefishes, and squids. The fossil form are ammonoids, belemnites and nautiloids. All cepharopods are exclusively marine. They are widely distributed in the present oceans, and from the fossil record, they had a comparable distribution in the past as evidenced. They are most abundant in the shallow sea but occur also in the intermediate and even the abyssal depth of ocean. The fossil form indicated that they were in shallow-water habitat. Many fossil and living forms in Order Ammonoidea have the life habit as nektonic.

Although ammonoids have long been extinct but fossilized shell are common in all continents and many oceanic islands. Ammonoids were widespread and abundant in the past. There are two lines of thought concerning the origin of this group of cephalopods. Some investigators assumed that the ammonoids evolved from some coiled nautiloid genus. Nautiloids range from the Late Cambrian to Recent but the first ammonoids have the record that they were first found in Lower Devonian. Other investigators believed that the ammonoids evolved from the bactritoids by a gradual coiling of the straight shell. It is very difficult to solve this problem. However, the distinguished characters of ammonoids are tightly coiled in planispiral, with a bulbous calcareous protoconch, septa that form angular and curve, suture flexure, and a small marginal siphuncle.

Ammonoids are important as index fossils because of their rapid evolution and wide distribution in shallow marine waters. They became almost extinct at Late of the Permain and again at Late Triassic, then declined slowly during the Upper Cretaceous.

Ammonoid fossils are among the best index fossil because of their rapid and diverse evolution, widespread occurrence, abundance, and easiness of identification even when incomplete and when preserved only as internal mold. They, in particular, are good stratigraphic indices and marine strata of the Late Paleozoic and Mesozoic are zoned with reference to them. According to the rapid evolution, they have much more development in their morphology and ornament. The most important and dominant of them is suture system. They develop from simple suture (goniatitic) in the early form to be ceratitic suture and to the most advanced form in ammonitic suture found in the latter species of ammonoid (Figure 2.19). Goniatitic suture was found in ammonoids that have the age range from the Carboniferous to the Triassic, and ammonitic suture was found in ammonoids that have the age range from the Permian to the Cretaceous (Siritheerasas, 1999).

2.2.2.1 Morphology

A shell is the only fossil record of Ammonoidea; no imprints of the soft body have been found (Orlov, 1962). The shell can be visualized in the uncoiled state as a very long widening tube composed of three totally different parts (Figure 2.20). Posteriorly, the shell begins with a microscopic initial chamber, the protoconch. Next comes the phragmocone, a long tube divided by numerous septa into air chamber. Anteriorly, there is a shorter cavity tube, the living chamber, containing the soft body. Also inside the shell is the siphuncle which extends from the protoconch to the living chamber, traversing all the septa. The protoconch of the regularly coiled Ammonoidea is situated in the center of the planispiral shell and is surrounded by the spiral phragmocone. An important morphology of Ammonoidea are described as followed:

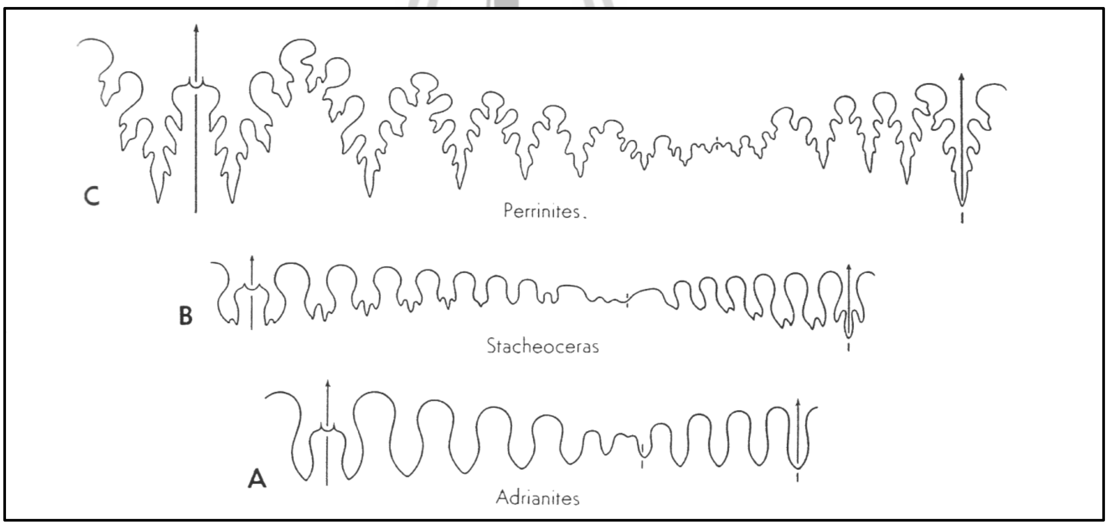


Figure 2.19 Diagram illustrating differences in type of ammonoid suture, all based on Permian species : A, goniatitic suture type, x1.3; B, ceratitic suture type, x2; C, ammonitic suture type, x2.7 (Moore, 1957).

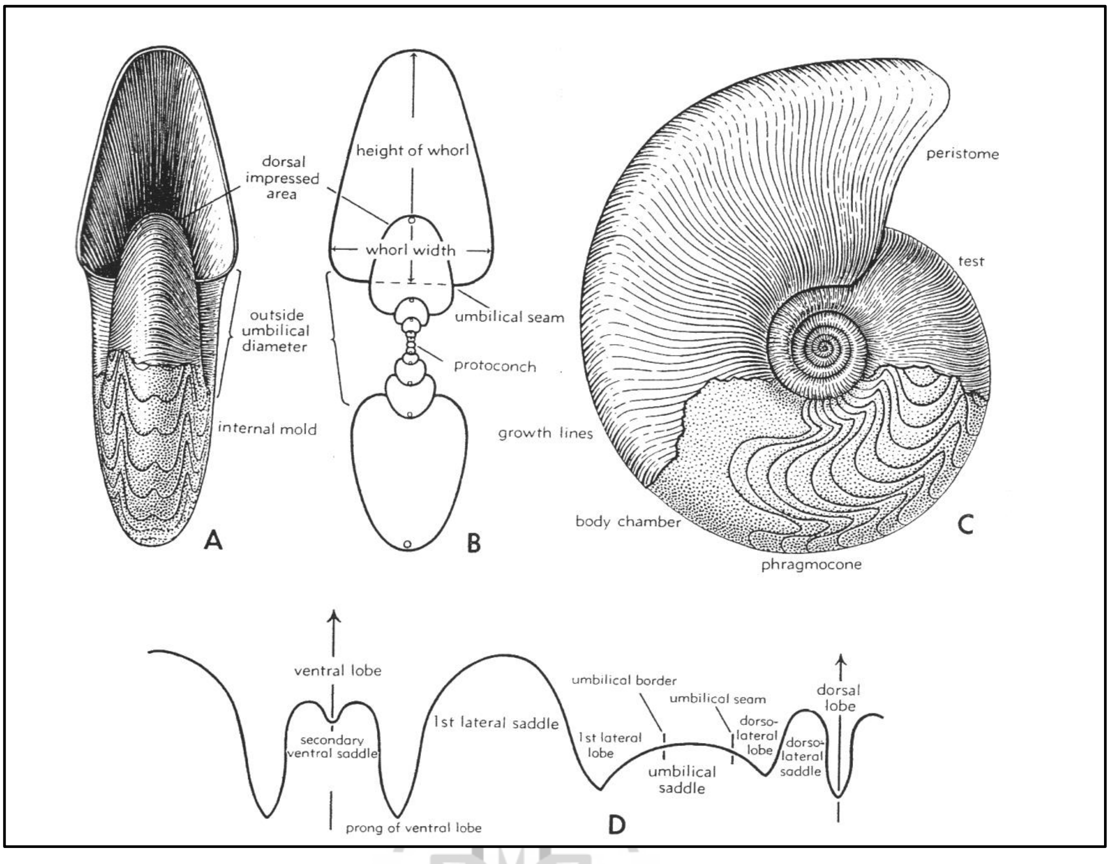


Figure 2.20 Diagrammatic ventral : A, cross-sectional; B, and lateral; C, views of a typical goniatite, *Manticoceras*, about natural size; and D, enlarged representation of a suture of the same. The upper part of A and C portrays the exterior of the test and shows the growth lines, whereas the lower part represents the and internal mold with the sutures (Moore, 1957).

2.2.2.2 Protoconch

Protoconch is the first chamber of shell of ammonoids, closed by proseptum (Figure 2.21). It is sometimes called initial chamber or apical chamber. The ammonoid shell consists of a small protoconch and a much larger conch, both of which were calcified and were therefore commonly preserved as fossils. Typically, the conch consists of a circinate spiral tightly coiled about the protoconch, and it is involute, as the whorls are impressed dorsally by the ventral portion of the preceding volution (Figure 2.18) (Moore, 1957).

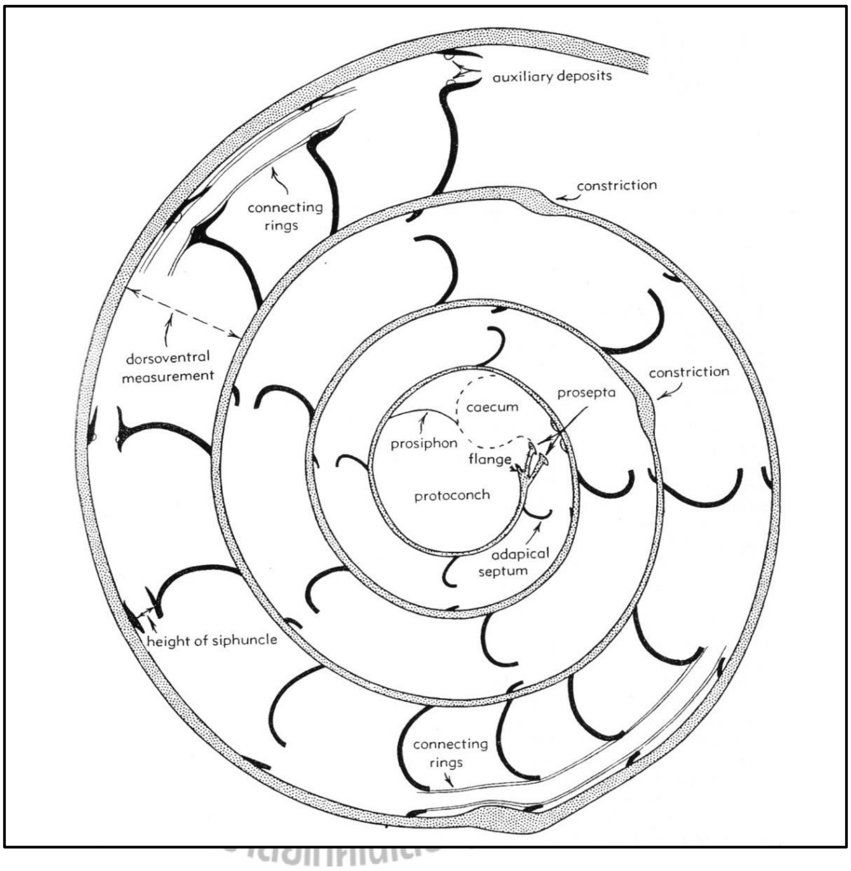


Figure 2.21 Enlarged median dorsoventral section of the adapical portion of the shell of a typical ammonoid, showing diagrammatically the various internal structures (Moore, 1957).

2.2.2.3 Conch

The conch comprises all of the shell except the protoconch. In typical mature in dividuals it has several volutions in length. It consists of a phragmocone and a body chamber. The shells of ammonoids consist of numerous chambers which are separated by septa and communicated with one another solely by means of the siphuncle. The chambers are also called camera. In general, their length increased progressively during development of coiling. The surface of conch tend to be rather smooth and the growth lines are generally fine and not very prominent. Furthermore, in many cases the conch bears transverse constrictions, the depression encircling the whorl which are prominent on the internal mold than on the exterior of the conch and which tend to be more or less parallel to the growth lines and to strengthen the shell. On both sides of ammonoids shell usually show the external depression on each side of shell axis of coiling, it is called umbilicus (Figure 2.20) (Moore, 1957).

2.2.2.4 Body Chamber

The body chamber is not generally preserved in its entirety, for it bears no such internal supports (septa) as does the phragmocone. Typically its length varies from about half a volution to a little more than a full volution, but in some forms at least the outer one and a half whorls are nonseptate. During ontogenetic development there was a tendency for the relative length of the body chamber or decrease. However, the volume ratio of that chamber to the phragmocone remained fairly constant. Furthermore, forms with a relatively large cross-sectional area had a proportionately short body chamber. It seems clear that the length of this chamber is of only secondary taxonomic valve. Traces of the contact areas of the shell muscles and possibly aponeurotic bands, comparable to those of modern Nautilus, have been observed in some specimens (Siritheerasas, 1999).

2.2.2.5 Siphuncle

Siphuncle of ammonoid is a narrow longitudinal tube passing through camerae or septa from protoconch to the base of body chamber. Nevertheless, because at maturity it is marginal in position, it serves to differentiate the ammonoids from the nautiloids (Figure 2.21) (Moore, 1957).

Orlov (1962) reported that the siphon performed an important function during life. It is assumed that it served to alter the gas pressure in the chamber. When the ammonoids diving down into the water, an increase of the intracameral gas pressure, which increased the specific weight of the animal and at the same time counteracted the external water pressure on the hollow shell. When the animal rose, the intracameral pressure was decreased, which lowered the weight of the animal and protected the shell from internal strains resulting from the abrupt reduction of hydrostatic pressure.

2.2.2.6 Septa

The shell of the ammonoid are divided by traverse septa. The first two septa near protoconch, often termed prosepta. The number of septa per volution, though variable, tended to increase during growth. There could be several hundred septa in the adults. All septa have a perforation for the passage of the siphuncle, extends from the protoconch to the body chamber.

Thus, the main function of the septa of ammonoid was to increase the strength of the conch without adding unduly to its weight and to protect any mechanism influences threatening to damage the shell (Siritheerasas, 1999).

2.2.2.7 Suture

The suture is the high taxonomic value of Ammonoidea. Suture line is the line of contact between septum and shell wall. The suture line is invisible to study until the shell wall is scraped off by some instrument. In involuted forms, the portion of the suture that extends across the ventral and lateral area to the umbilical seams is termed the external suture, and its continuation across the dorsal impressed area is called the internal suture. Suture line consists of separate curves directed backward and forward in relation to the position of aperture, and termed respectively lobes and saddles. During evolution, the suture line of ammonoid underwent progressive complication and become extraordinary intricate in some phylogenetic branches (Moore, 1957).

Morphological types of suture line. In the morphological sense the suture line are divided into the following types: goniatitic, ceratitic, and ammonitic (Figure 2.19). These type can be characterized as followed:

1. Goniatitic suture (Figure 2.19A) the elements are more numerous, the lobes and saddles simple, undivided (except the ventral lobe), often peaked.

2. Ceratitic suture (Figure 2.19B) the lobes are serrate at the base and the saddles are simples.

3. Ammonitic suture (Figure 2.19C) the lobes and saddles are strongly and fully divided.

The terms of suture line are still useful in broad way, as well as in a very restricted sense for identification of genera, from which each genera has a specific character of suture system. Goniatites are often appeared in the Early Devonian to Triassic, Ceratites in the Carboniferous to the Triassic and Ammonites in the Permian to the Cretaceous.

2.2.2.8 Size and Measurement

The size of Ammonoidea varied considerably. Shells of definitive size are rare in the collections, but it is evident from a large numbers of observations that the minimum and maximum sizes of ammonoids were one centimeter and two meters. Records of the occurrence of even larger shells, to 3 meter, have not been verified (Siritheerasas, 1999).

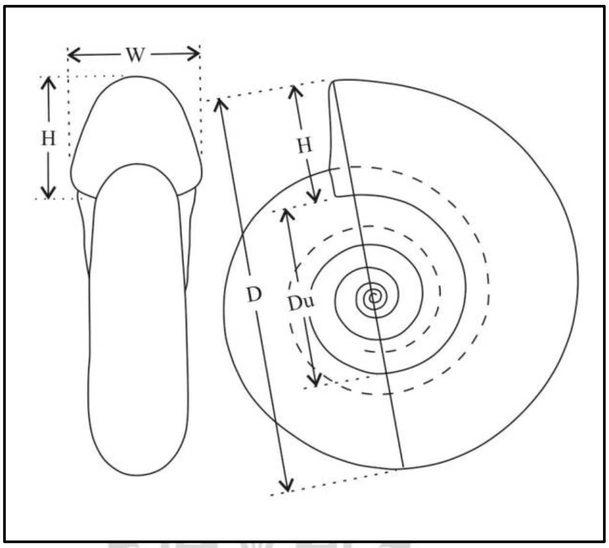


Figure 2.22 Diagram showing the main measurements of the shell in the Ammonoidea: D: shell diameter, H: whorl height, W: whorl width, Du: umbilicus diameter (Siritheerasas, 1999).

2.2.2.9 Paleoecology

The Ammonoidea were exclusively marine animal like all cephalopods. Recent studies show believable evidence that the Paleozoic ammonoids lived in relatively shallow water of normal salinity and were largely confined to the littoral zones (Miller and Furnish, 1936-1937; Teichert, 1943; Maksimova, 1950; Ruzhencev, 1950, 1952, 1956). The Devonian Ammonoidea were particularly abundant in neritic and oceanic zone (Westermann, 1987). They also lived near reefs, sometime on them, if they near sheltered from heavy waves. Bay and inlets with calm water and with a vegetation of algae provided an especially favorable environment for all cephalopods. Ammonoidea also lived in the shelf zone (Siritheerasas, 1999).

All the recent data indicate that ammonoid shells were not transported great distance after the animal's death. For this reason, the sediments which contain these fossils as well as other organic remains buried together with them reflect to some extent their ecology, their mode of life. Ammonoidea are often found in sandstone, limestone, and clay. They are absent in conglomerates and in black shales deposited in conditions of a low oxygen content. In other words, the ammonoids, living mostly in the neritic zone of the sea, require adequate aeration, without abundant sedimentation but could not tolerate such factors as eddy current, abrupt fluctuation of water temperature and salinity.

Invertebrates of other phylum are usually very rare in localities where contain abundant ammonoids. Among the forms which often occur in the group of ammonoids are radiolarians, sponges, bivalve mollusks, and gastropods. Ammonoid and fusulinids are often found in the same formation (Orlov, 1972). As a rule, ammonoids did not live together with such group as corals, bryozoans or brachiopods, although they are buried together (Orlov, 1972).

2.2.3 The study of Fusulinids

Fusulinids are the single-cell invertebrate fossil. They belong to Phylum Protozoa, Class Sarcodina, Order Foraminifera. Fusulinids occurred in upper Mississippian and extinct in late Permian. Many researchers called fusulinids as larger foraminifera. The suitable definition of larger foraminifera is the specimens, which can be identified only by eye without instrument aids or can be observed only by means of the thin-sections under the microscope. The shape of fusulinids shell is varied, although common type has fusiform, lenticular, and discoid. Sizes of fusulinids range from one to 100 millimeters. Most of speciments are between five to 20 millimeters in diameter. Many genera are the excellent index fossil because they have a rapid evolution and they were widely spread in many parts of paleo-marine of the world (Siritheerasas, 1999).

2.2.3.1 Morphology

Fusulinids shell are usually characterized fusiform in shape and coiled around the axis called axis of coiling (Figure 2.23). Even there are various form fusulinids but they have the same important features. Study of fusulinids usually consider on their significance morphologies as followed:

2.2.3.2 Proloculus

The proloculus is the initial chamber of the single-cell animal fusulinids. Proloculus is the original of axis of coiling (Figure 2.23). In most fusulinids the proloculus is spherical to subspherical in shape (Siritheerasas, 1999).

2.2.3.3 Septa, Anthetica, and Spirotheca

The septa of fusulinids are partitions between chambers in the shell (Figure 2.23). For the primitive genera they usually have a plane surface septa, but for the advance genera, the septa become flute. Some genera, the septa may have aperture communication within the shell with numerous small opening; septal pores. The front wall of last chamber septa becomes anthetica, and outer wall of last volution called spirotheca. Furthermore, on the external surface of shell at the position of a septum usually show depression furrow is external furrow (Siritheerasas, 1999).

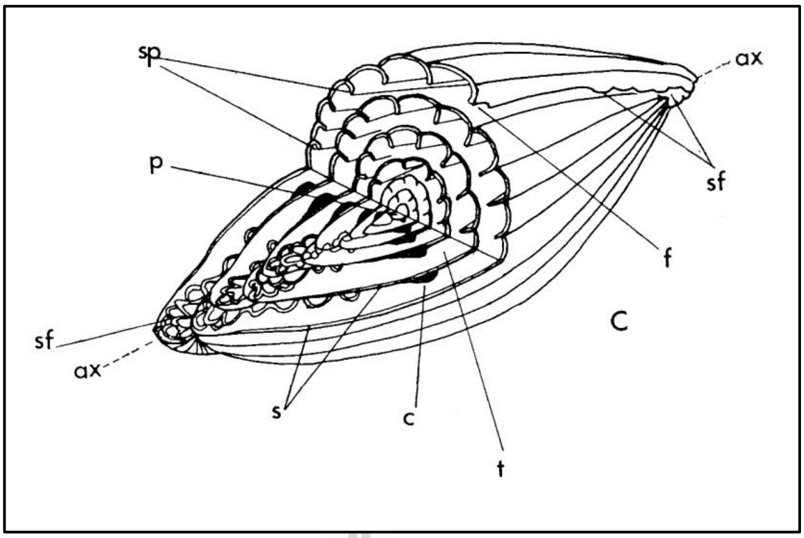


Figure 2.23 Schematic drawing of shell, partly cut to show internal structures. p : proloculus, s : spirotheca, f : foramen, t : tunnel, c : chomata, sp : septa, sf : septal fluting (or folding), ar : axial region, ax : axis of coiling (Siritheerasas, 1999).

2.2.3.4 Tunnel

A central located at lowest part of septum like slit opening is tunnel, penetrates all septum except last septa (Figure 2.23). Opening beside tunnel called foramen (Siritheerasas, 1999).

2.2.3.5 Chomata, Parachomata, and Septula

The chomata is a cumulated calcium carbonate like a ridge between a couple sides of tunnel. Another cumulative calcium carbonate beside chomata throughout the shell termed parachomata. Some fusulinids have a calcium carbonate generated from wall downward at the same direction of parachomata call septula (Figure 2.23) (Siritheerasas, 1999).

2.2.3.6 Axial Filling

Dense deposit calcium carbonate accumulates in the axial region. Some fusulinids group may have heavy axial filling but some are very rare in axial filling (Figure 2.23) (Siritheerasas, 1999).

2.2.3.7 Wall Structure

The wall of fusulinids is composed of micro-granular calcium carbonate crystals. The wall structure of shell is complex. There are two main types; fusulinellid wall type and schwagerinid wall type, each type is well developed (Siritheerasas, 1999).

2.2.3.8 Paleoecology

The environment in which fusulinids survived is interpreted from the study of rock in which they are preserved. Fusulinids usually lived in shallow, clear, and marine water environment, shallow sea on the continental platform far from shoreline (Siritheerasas, 1999).

CHAPTER III

METHODOLOGY

The summarized flow chart showing methods of the study is illustrated in the Figure 3.1. The methodology applied to this study is composed of preparation, field investigation, laboratory investigation and data interpretation.

3.1 Preparation

The previous works on stratigraphy and paleontology were reviewed. The morphology of bivalves, ammonoids and fusulinids were studies. The topographic map scale 1:50,000 (map sheets Amphoe Nong Prue, 4838II) and geologic map of Kanchanaburi province were prepared and used in fieldwork.

3.2 Field investigation

3.2.1 Date of fields

Fieldworks were done during December 2011 to January 2012 and in May 2012.

3.2.2 Equipment

The equipments used for fieldwork are composed of geologic hammer, hand lens, proper scale, knife, measuring tape, notebook, pen, water-resistant pens, pencils, wrapping paper, plastic bags and camera.

3.2.3 Data collections

The measurement of rock sections essentially aims at obtaining the information regarding the sedimentary sequence, lithology, thickness, fossil, sedimentary structure and bedding attitudes. Stratigraphic columns were drawn and the occurrences of fossils were in the columns.

3.2.4 Collecting speciments

Samples were collected from the outcrops for lithologic description. Speciments were labelled before wrapping.

3.3 Laboratory investigation

3.3.1 Bivalves and Ammonoids

Bivalves and ammonoids specimens from rock samples collected from the investigated area were prepared. The photographs were taken for study of morphology and size measurement in detail for classification and identification.

3.3.2 Fusulinids

Thin sections were prepared for microscopic. The photographs were taken for study of morphology and size measurement in detail for classification and identification.

3.4 Data analysis and interpretation

Stratigraphic sections of sedimentary sequences will be complied from field investigation data. The result laboratory study is integrated for interpretation of geological age and depositional environment.

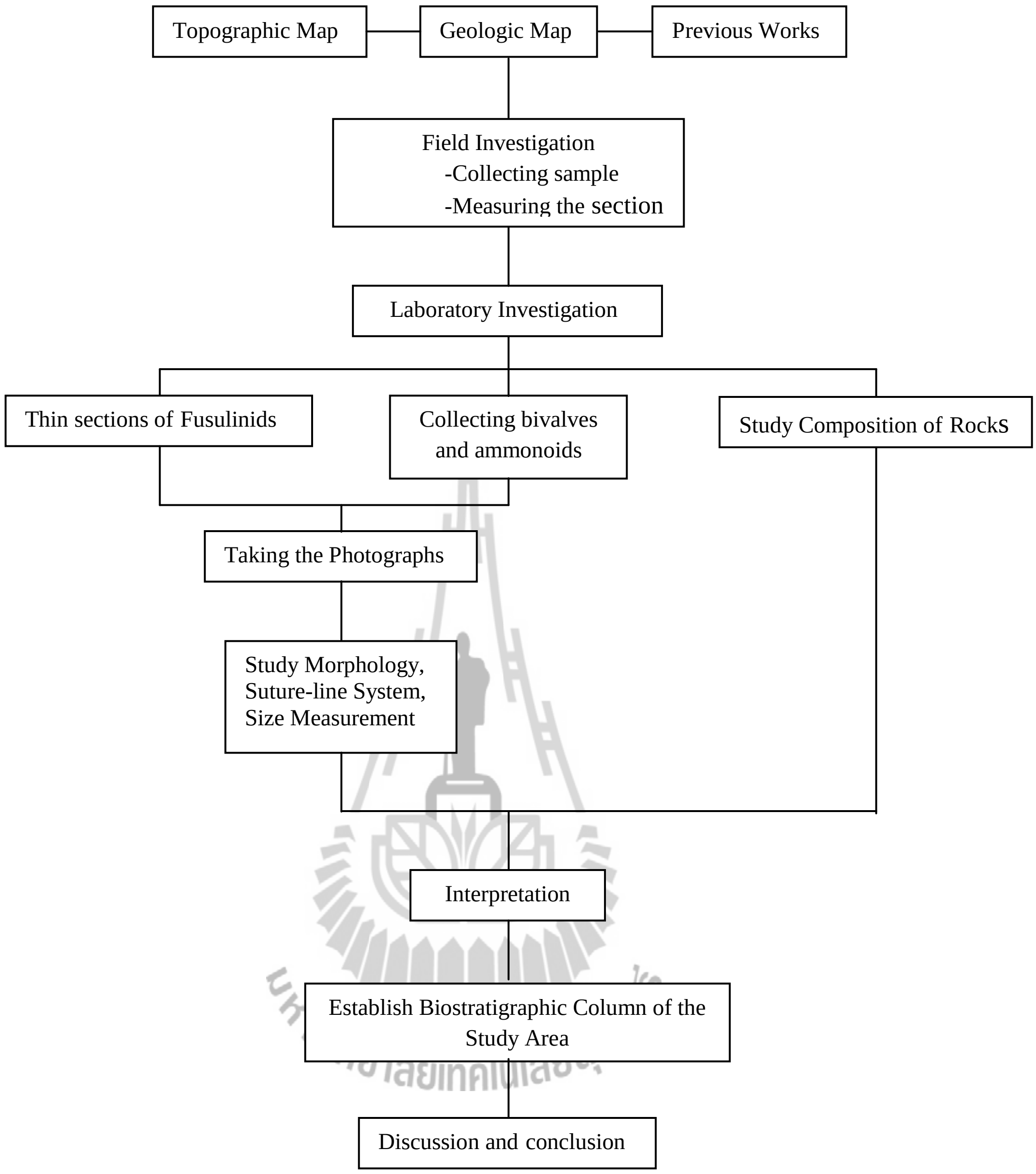


Figure 3.1 Flow chart of methodology.

CHAPTER IV

RESULTS

4.1 Stratigraphy

The study area is located in Nong Prue District, Kanchanaburi Province on the western part of Thailand. The area is approximately 100 Km^2, which covered Ban Pong Chang, Ban Huai Yai, and Ban Nong Makha, of Nong Prue Subdistrict Nong Prue District. The stratigraphy of the study area can be observed from six localities, Ban Pong Chang Locality 1, Ban Pong Chang Locality 2, Ban Pong Chang Locality 3, Ban Huai Yai Locality 1, Ban Huai Yai Locality 2 and Ban Nong Makha. The details stratigraphy of each locality was described in the following sections.

4.1.1 Ban Pong Chang Locality 1 (BPC-1)

Ban Pong Chang Locality 1 is located northwest of Ban Pong Chang and situated at UTM 47P 539505 1622543. The thickness of the section is approximately 20.25 meters. This section can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of a matrix-subported light gray limestone conglomerate. The conglomerate clasts comprise a mixture of clast sizes and are poorly sorted. This conglomerate contains coral, fusulinid and bryozoa in the clasts. It is interbedded with calcareous shale, massive limestones, conglomeratic limestones and flaggy bedded limestones. The Upper Unit was composed of siliceous shale which is four meters in thickness.

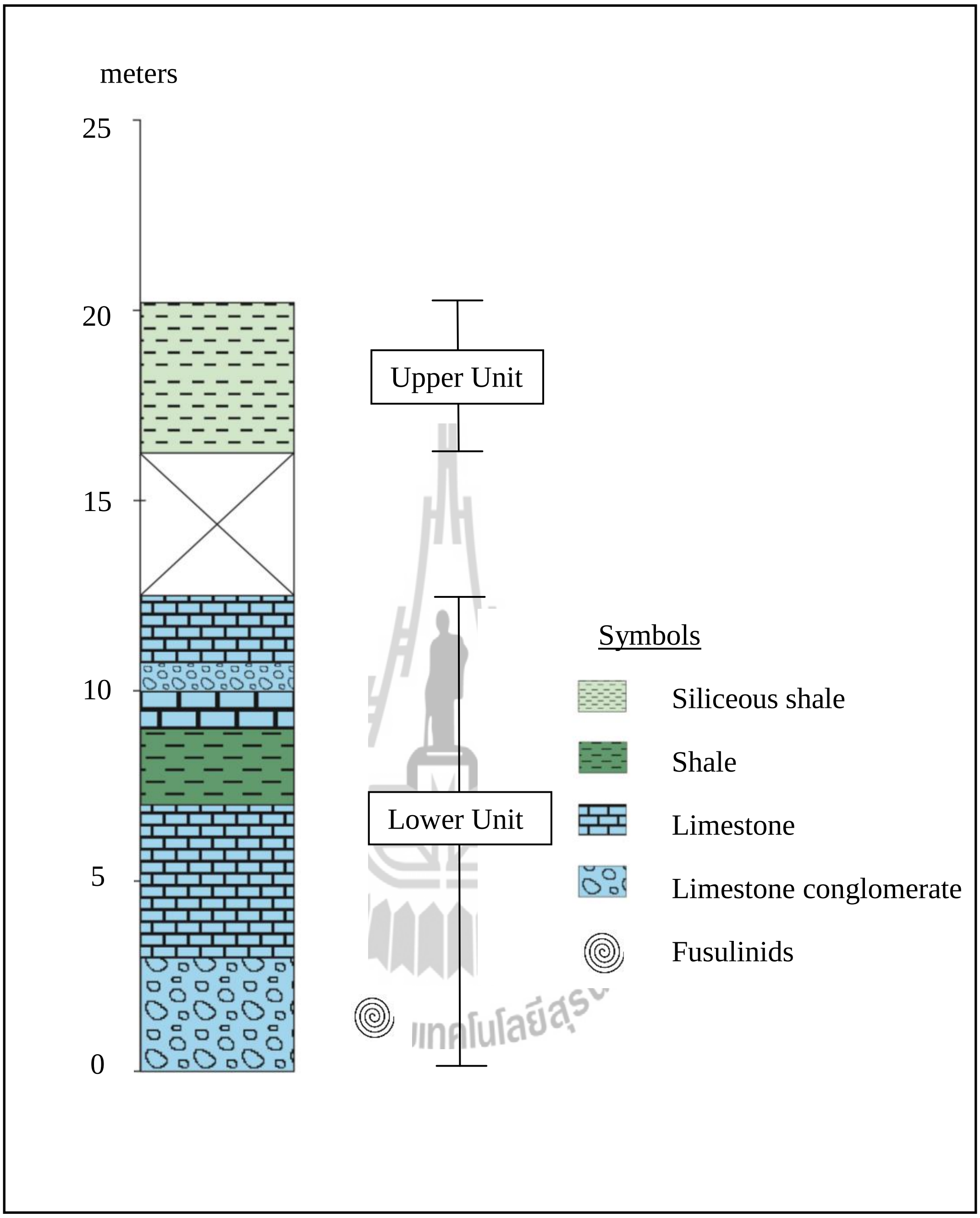


Figure 4.1 Stratigraphic column of Ban Pong Chang Locality 1 (BPC-1).

a)

b)

Figure 4.2 a) Limestone conglomerate and b) Calcite veins of the Lower Unit at Ban Pong Chang Locality 1 at UTM 47P 0539474 1622395.

4.1.2 Ban Pong Chang Locality 2 (BPC-2)

Ban Pong Chang Locality 2 is located North of Ban Pong Chang and situated at UTM 47P 540728 1622560. The thickness of the section is approximately 45.40 meters. This section can be devided into three units, the Lower Unit, the Middle Unit and the Upper Unit. The Lower Unit consists of yellowish gray shale, calcareous shale and limestone. These fossil-bearing shales are composed of abundant ammonoids, which are an index fauna of Middle Permian age. The Middle Unit consists of shale interbedded with limestone. Shale is reddish gray. The attitude of bedding is 105/50. The Upper Unit consists of shale interbedded with siliceous shale. Shale contains bivalves of *Posidonia* sp. and *Daonella* sp., which are an index fauna of the Late Triassic age.

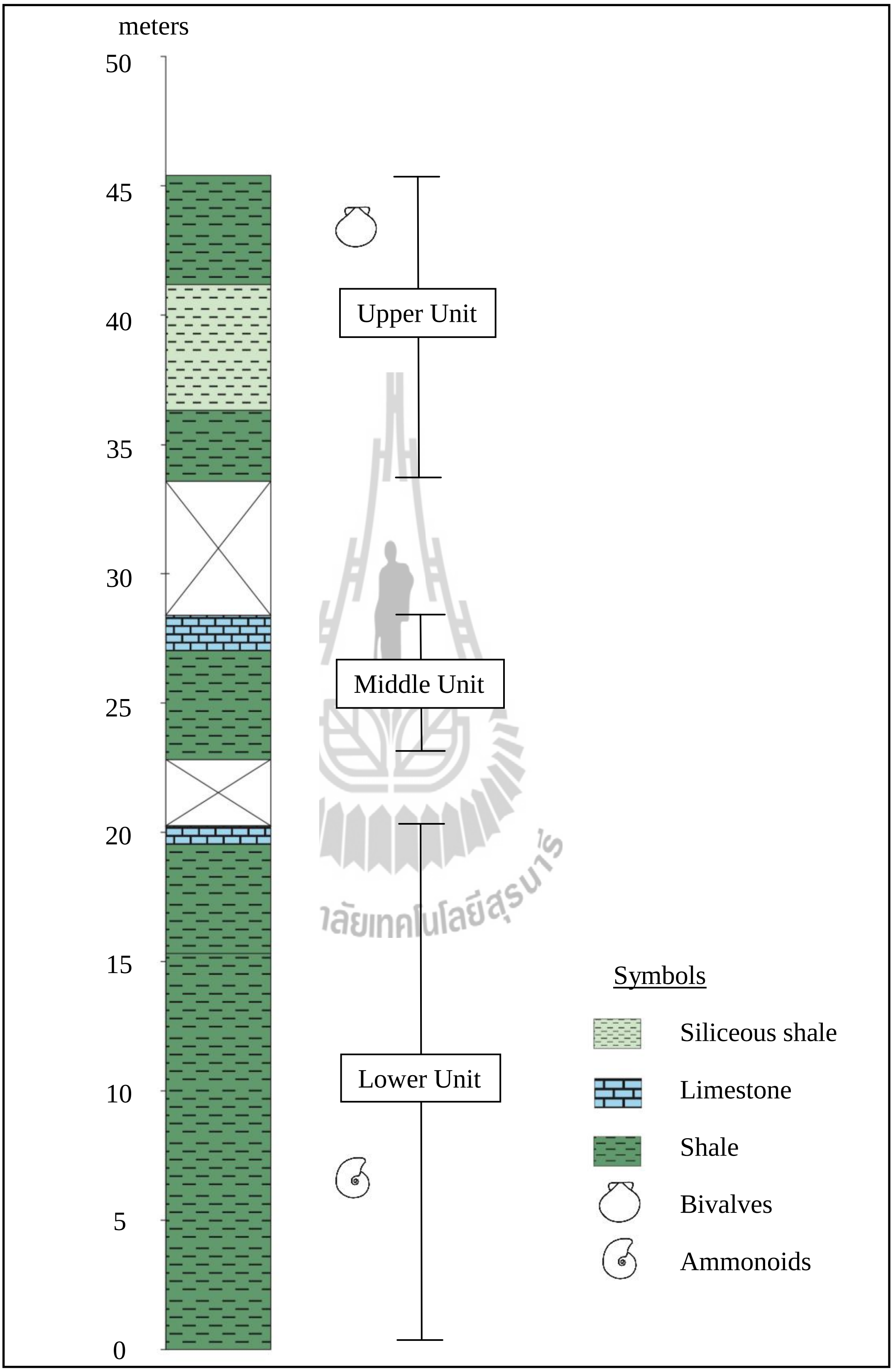


Figure 4.3 Stratigraphic column of Ban Pong Chang Locality 2 (BPC-2).

a)

b)

Figure 4.4 a) *Agathiceras* sp. and b) Ammonoid-bearing shale of Ban Pong Chang Locality 2 at UTM 47P 0540722 1622537.

4.1.3 Ban Pong Chang Locality 3 (BPC-3)

Ban Pong Chang Locality 3 is located east of Ban Pong Chang and situated at UTM 47P 543052 1621573. The thickness of the section is approximately 32 meters. This section can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of dark gray shale. Calcareous shale is interbedded with limestone and siliceous shale. This unit contains bivalves, *Posidonia* sp. and *Daonella* sp., which are an index fauna of Late Triassic age. The attitude of bedding is 113/10. The attitude of siliceous shale bedding is 100/25. The Upper Unit consists of sandstone and shale with limestone lens.

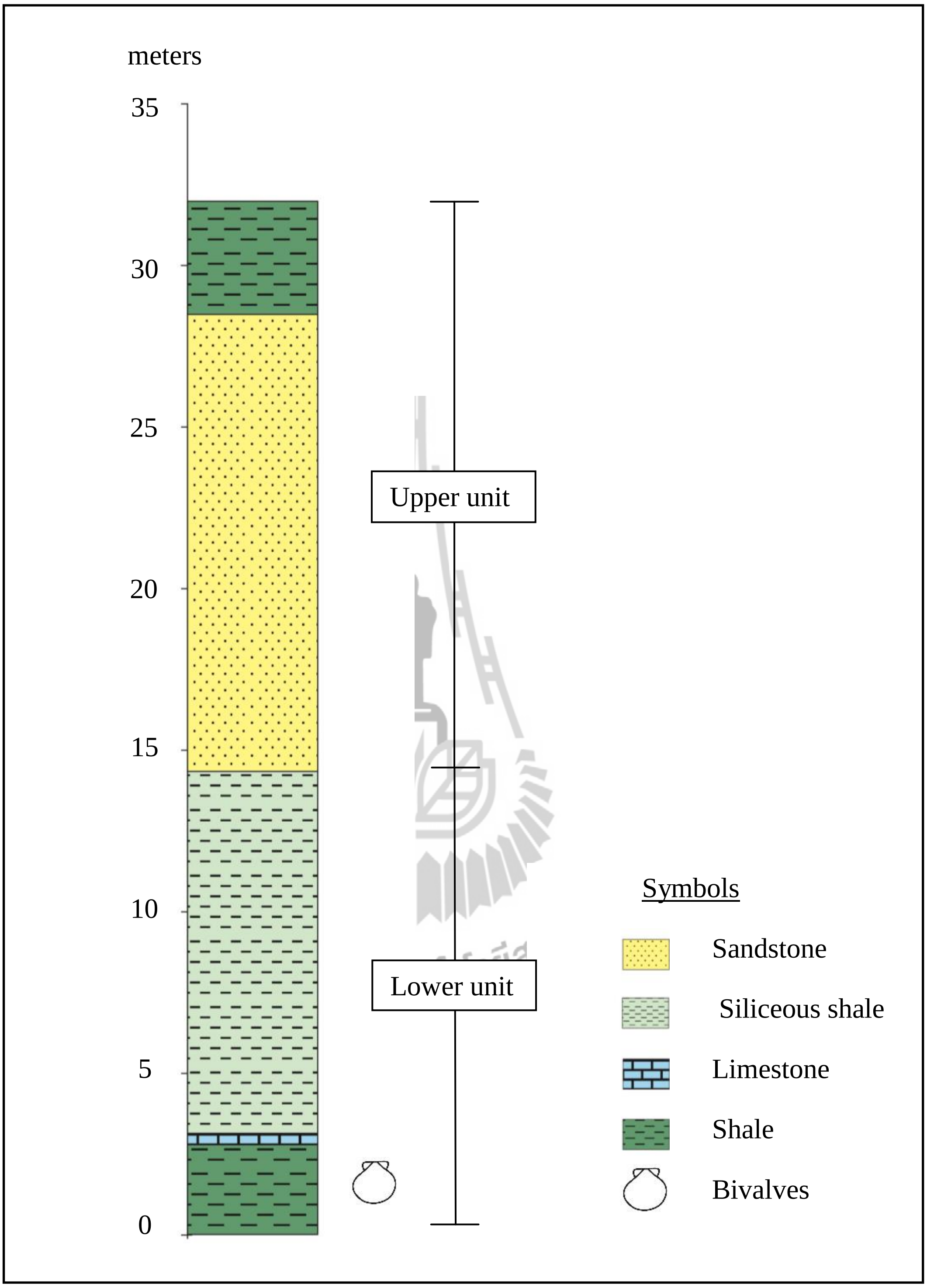


Figure 4.5 Stratigraphic column of Ban Pong Chang Locality 3 (BPC-3).

a)

b)

Figure 4.6 a) Siliceous shale and b) Calcareous shale of Ban Pong Chang Locality 3 at UTM 47P 0543052 162573.

a)

b)

Figure 4.7 a) Shale interbedded with limestone at UTM 47P 0543159 1621452 and b) siliceous shale of the Lower Unit of Ban Pong Chang Locality 3 at UTM 47P 0543184 1621439.

a)

b)

Figure 4.8 a) Conformable contact between sandstone and shale at UTM 47P 0543331 1621216 and b) Calcareous shales with limestone lenses of the Upper Unit at UTM 47P 0543439 1621050.

4.1.4 Ban Huai Yai Locality 1 (BHY-1)

Ban Huai Yai Locality 1 is located east of Ban Huai Yai and situated at UTM 47P 540809 1623859. The thickness of the section is approximately 33.42 meters. This section can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of thin well-bedded siliceous shale and yellowish gray shale. Shale contains bivalves belonging to *Halobia* sp. and *Posidonia* sp., which are an index fauna of Late Triassic. The Upper Unit consists of sandstone interbedded with shale.

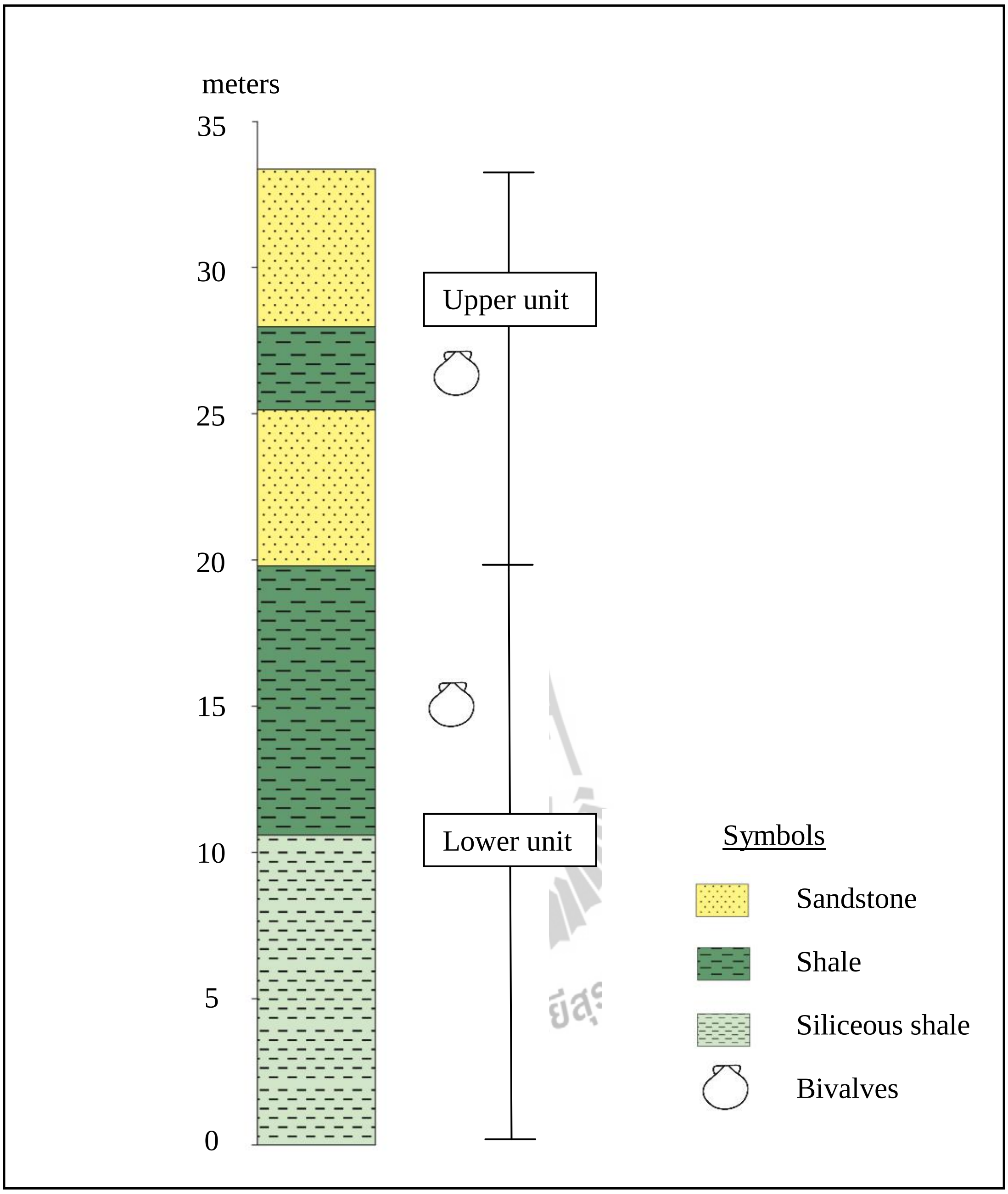


Figure 4.9 Stratigraphic column of Ban Huai Yai Locality 1 (BHY-1).

a)

b)

Figure 4.10 a) Well-bedded Siliceous shale and b) *Halobia* sp. and *Posidonia* sp. bearing shale of Lower Unit of Ban Huai Yai Locality 1 at UTM 47P 0540839 1623831.

4.1.5 Ban Huai Yai Locality 2 (BHY-2)

Ban Huai Yai Locality 2 is located east of Ban Huai Yai and situated at UTM 47P 540851 1623810. The thickness of the section is approximately 24.26 meters. This section consist of thin well-bedded siliceous shale and yellowish gray shale. Shale is intercalated with argillaceous limestone and contains bivalves of *Halobia* sp. and *Posidonia* sp., which are an index fauna of Late Triassic age.

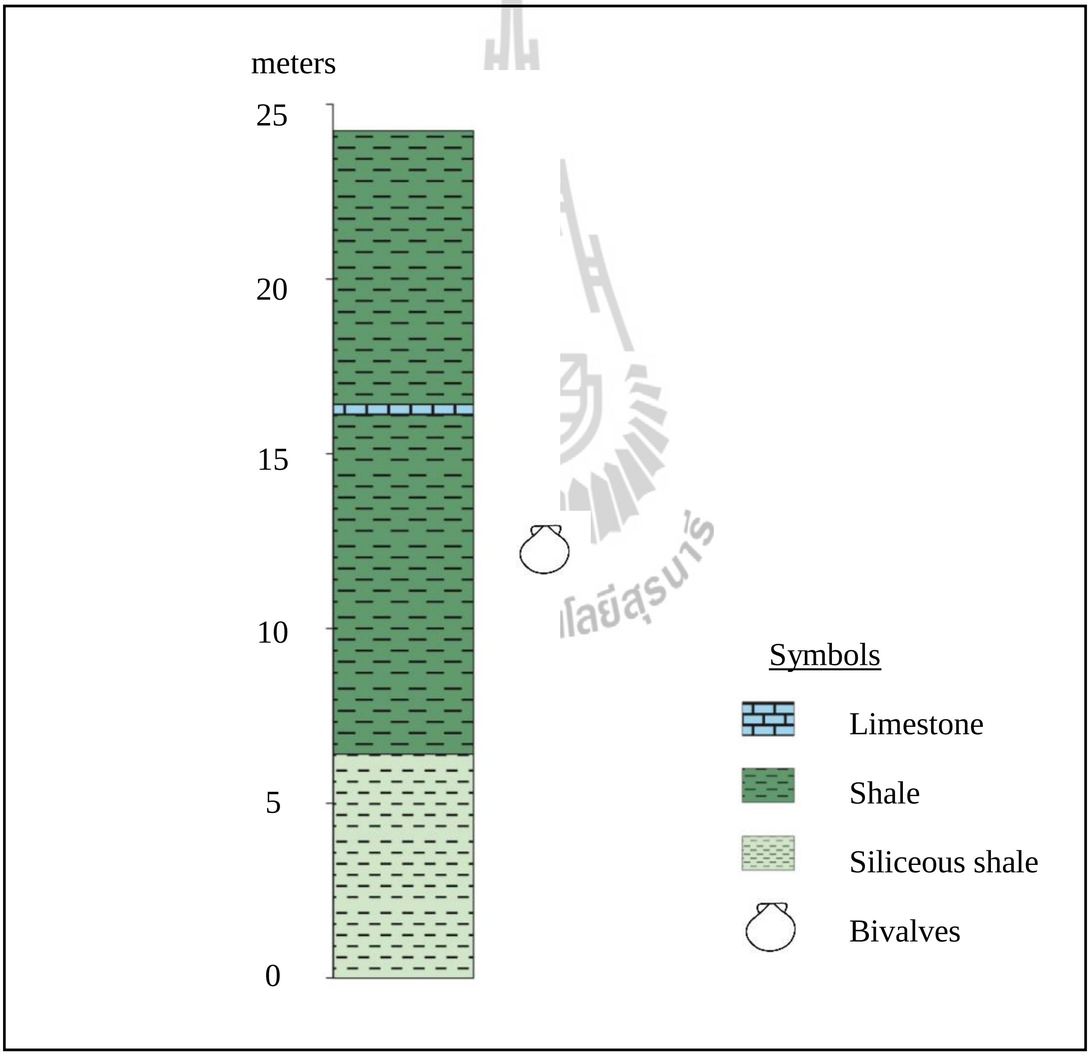


Figure 4.11 Stratigraphic column of Ban Huai Yai Locality 2 (BHY-2).

a)

b)

Figure 4.12 a) Well-bedded siliceous shale and b) Argillaceous limestone interbedded shale of Ban Huai Yai Locality 2 at UTM 47P 0540784 1623911.

4.1.6 Ban Nong Makha (BNM)

Ban Nong Makha is situated at UTM 47P 0546769 1613394. This area is covered by soil. The unit is approximately seven meters in thickness and consists of yellowish gray shale and siliceous shale. Shale contains bivalves of *Posidonia* sp., which is an index fauna of the Late Triassic age.

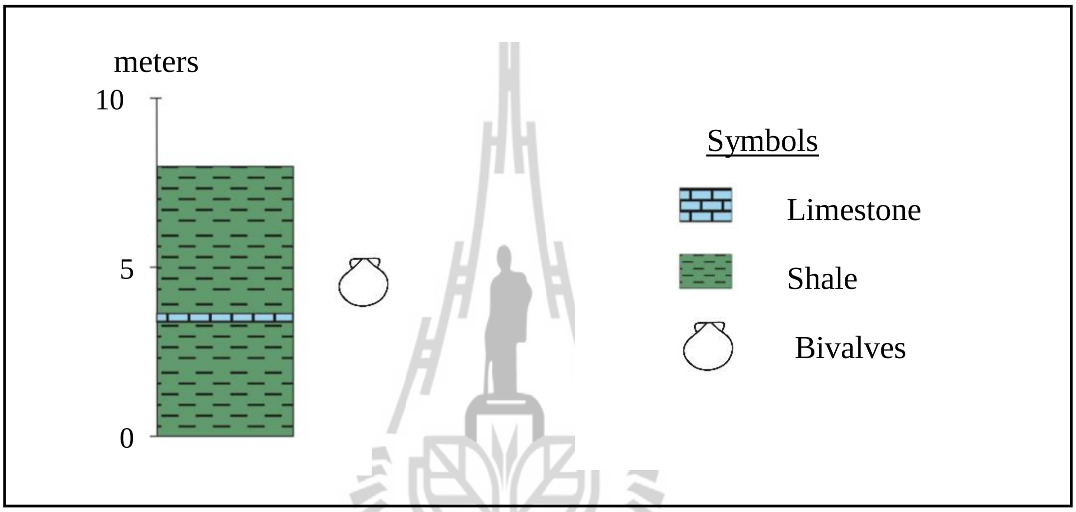


Figure 4.13 Stratigraphic column of Ban Nong Makha (NMK).

a)

b)

Figure 4.14 a) Bedded shale and b) *Posidonia* sp. of Ban Nong Makha at UTM 47P 0546774 1613391.

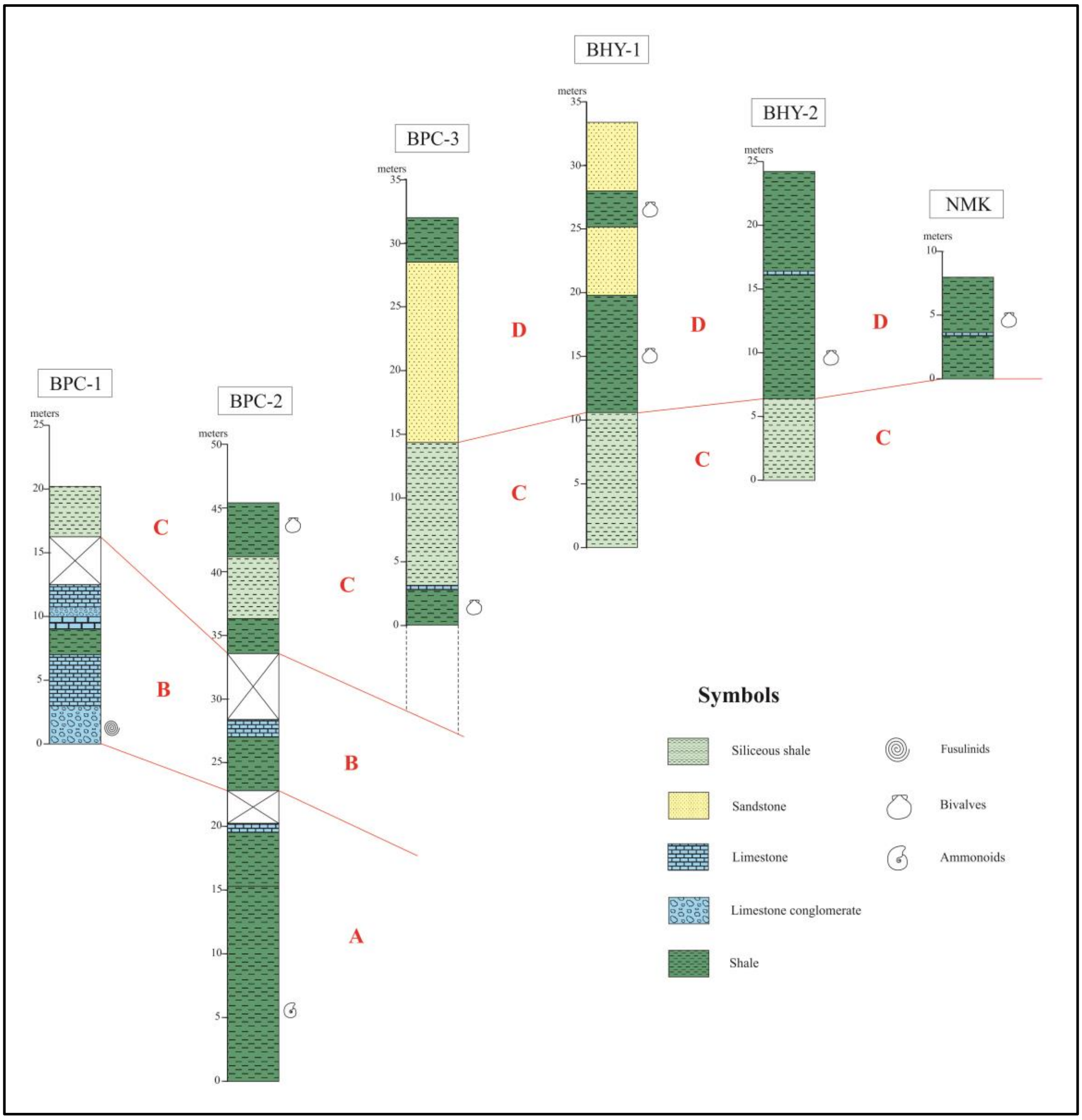


Figure 4.15 Stratigraphic column of six localities in the study area.

Marine sedimentary rocks in the study area can be subdivided into four rock units, A, B, C and D, from older to younger respectively. The unit A consists of shale, calcareous shale and limestone. Ammonoids have been observed in shales. The unit B overlies unconformably on the unit A. It consists of limestone conglomerate, limestone, shale and siliceous shale. Limestone conglomerate contains fusulinid-bearing clasts. The unit C overlies conformably on the unit B and consists of shale and siliceous shale. The unit D overlies conformably on the unit C. It consists of sandstone and shale. A bivalve assemblage has been discovered in shales of units C and D.

4.2 Systematic Paleontology

4.2.1 Class Bivalvia

Bivalves discovered in the study area at Ban Pong Chang Locality 2 (BPC-2), Ban Pong Chang Locality 3 (BPC-3), Ban Huai Yai Locality 1(BHY-1), Ban Huai Yai Locality 2 (BHY-2) and Ban Nong Makha (NMK), Nong Prue Subdistrict, Nong Prue District, Kanchanaburi Province can be identified into three genera, two families and two superfamilies as follow.

Class BIVALVIA Linnaeus, 1758

Subclass PTERIOMORPHIA Beurlen, 1944

Order PTERIOIDA Newell, 1965

Suborder PTERIINA Newell, 1965

Superfamily PTERIACEA Gray, 1847

Family POSIDONIIDAE Frech, 1909

Genus *Posidonia* Bronn, 1828

Posidonia sp.

Figure 4.16

Description: A small-sized species of this genus. In this form the umbo is located near but not at the anterior end of the hinge. The surface of the shell is ornamented with several shallow concentric undulation. The dimensions of a moderately large specimen, the maximum convexity could not be measured because of diagenetic compression of the shell.

Measurements: Height= 2.25-5.10 mm, Length=3.5-6.50 mm

Material: BHY20108, BHY20109, BHY20110, NMK21505 and NMK21506

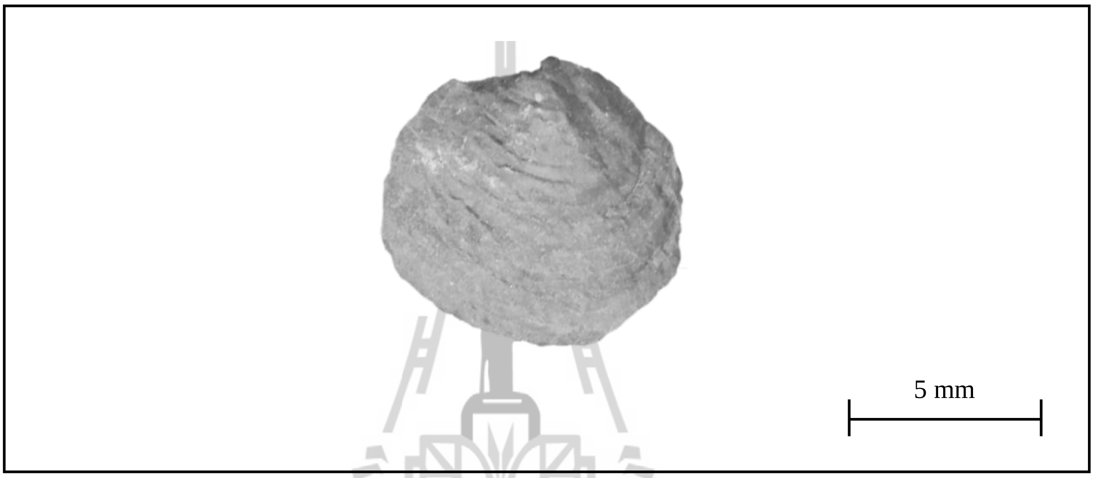


Figure 4.16 *Posidonia* sp., BHY20109.

Superfamily HALOBIOIDEA Campbell, 1994

Family HALOBIIDAE Kittl, 1912

Genus *Halobia* Bronn, 1830

Subgenus *Halobia* Bronn, 1830

Halobia (Halobia) talauana Wanner, 1907

Figure 4.17

Description: Shell small-sized for genus. The shape of shell similar to that of *Daonella* sp. The shell is flat, equivalved, more or less oblique, with straight and elongate dorsal margin. Shells have two valves, equivalve and inequilateral. Radial ribs run straight across shell surface to the ventral margin. In others shell, a distinct initial growth stage is delimited by uniform, anteriorly concave curvature of the ribs which ends with abrupt recurvature at a ruga near the umbo. Beaks are directed toward. Shell surface is smooth near anterior dorsal margin, forming a triangular anterior ear. Sometimes elevated above adjacent ribbed part of shell or separated from it by a groove. Ribbing fades towards posterior dorsal margin forming a poorly defined posterior ear. Surface sculpture is fine radial and consists of elements that radiate from the beaks. Radial ribs is straight and has flat-topped shape. Shells have concentric wrinkles weak and nearly uniform over disc. It height is slightly less than length.

Measurements: Height=16.27-20.54 mm, Length=17.51-21.34 mm

Material: BHY20103-1/1, BHY20103-1/2 and BHY20104

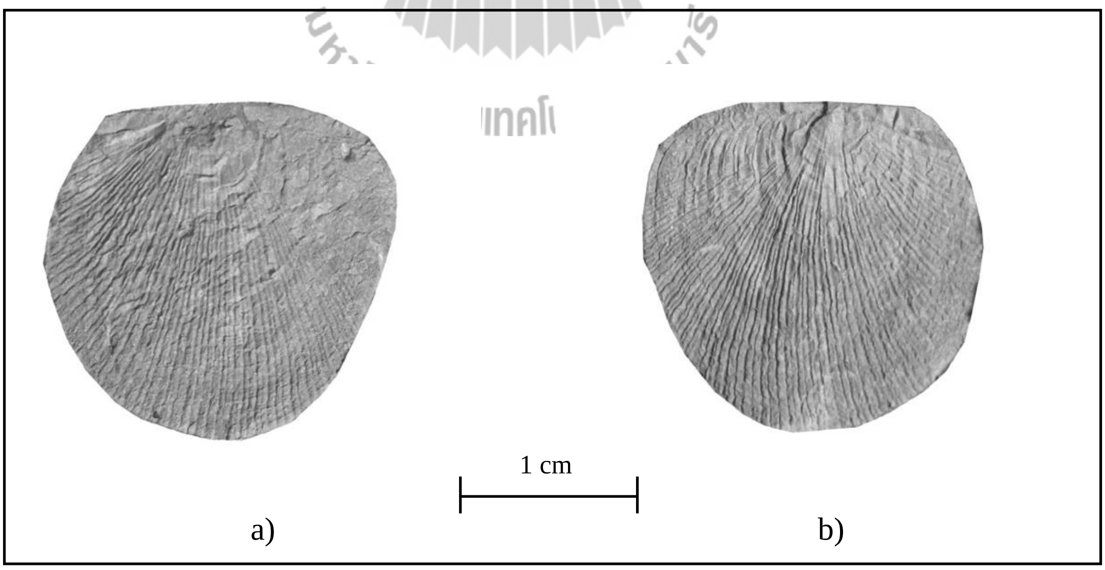


Figure 4.17 *Halobia (Halobia) talauana* Wanner, BHY20103.

Halobia (Halobia) styriaca Mojsisovics, 1874

Figure 4.18

Description: Shell is small-sized for genus. Shape like *Daonella* sp. The shell is flat, equivalved, more or less oblique, with straight and elongate dorsal margin. Shells have two valves, equivalve and inequilateral. Radial ribs run straight across shell surface to the ventral margin In others shell, a distinct initial growth stage is delimited by uniform, anteriorly concave curvature of the ribs which ends with abrupt recurvature at a ruga near the umbo. Beaks are directed toward. Shell surface is smooth near anterior dorsal margin, forming a triangular anterior ear. Sometimes elevated above adjacent ribbed part of shell or separated from it by a groove. Ribbing fades towards posterior dorsal margin forming a poorly defined posterior ear. Surface sculpture is fine radial and consists of elements that radiate from the beaks. Radial ribs is straight and has a few in number. Shells have concentric wrinkles weak and height rather less than length. Posterodorsal unribbed area broad.

Measurements: Height=18.46 mm, Length=21.66 mm

Material: BHY20101

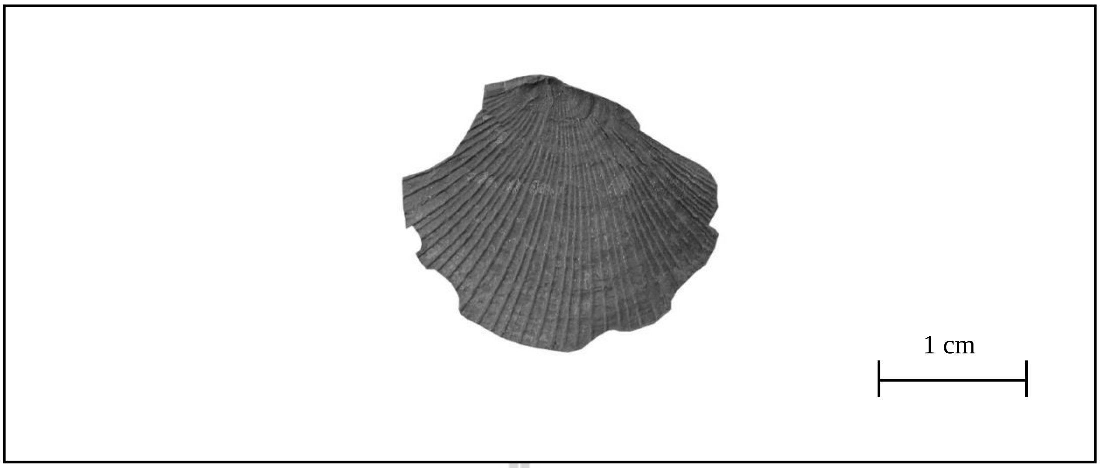


Figure 4.18 *Halobia (Halobia) styriaca* Mojsisovics, BHY20101.

Halobia (Zittelihalobia) Polubotko, 1984

Figure 4.19

Description: Shells have two valves of equivalve and inequilateral. The shell is medium sized and longer than high. Beaks are directed toward. Surface sculpture is fine radial and consists of elements that radiate from the beaks. Radial ribs are undulating which covering the whole shell and a growth-stop.

Measurements: Height=18.08 mm, Length=25.97 mm

Material: BHY20102-1/1, BHY20102-1/2, BHY20106 and BHY20107

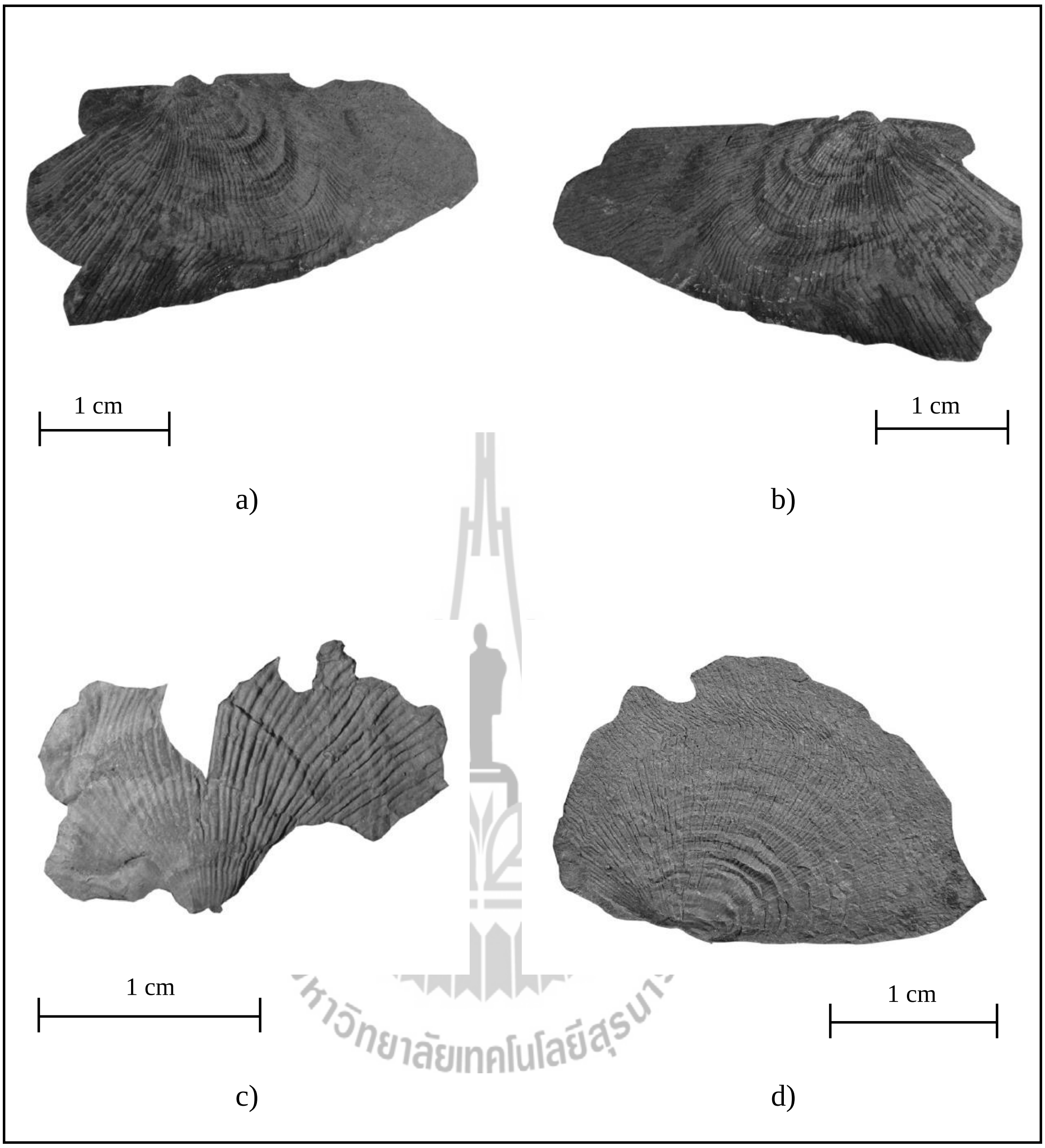


Figure 4.19 *Halobia (Zittelihalobia)* Polubotko, a) BHY20102-1/1 b) BHY20102-1/2 c) BHY20106 and d) BHY20107.

Genus *Daonella* Mojsisovics, 1874

Daonella sp.

Figure 4.20

Description: Halobiidae lacking auricles and any obvious morphological shell structure related to emergence of a byssus. Ligament area alivincular but with no secondary resilifers. Some specimens preservation in butterfly shape.

Measurements: Height=2.24-7.44 mm, Length=3.27-10.71 mm

Material: BPC21202 and BPC21203

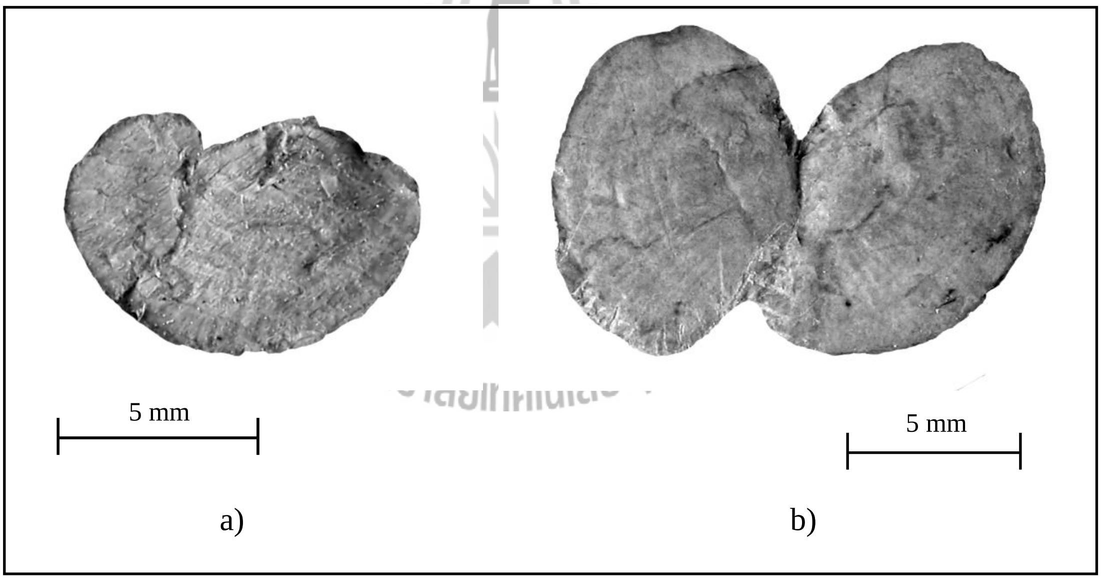


Figure 4.20 a) *Daonella* sp. and b) *Daonella* sp. preserved in butterfly shape.

4.2.2 Class Cephalopoda

Ammonoids were discovered in the investigated area at Ban Pong Chang Locality 2 (BPC-2), Nong Prue Subdistrict, Nong Prue District, Kanchanaburi

Province. They can be identified into five superfamilies, seven families, seven genera as followed.

Class CEPHALOPODA Cuvier, 1797

Subclass AMMONOIDEA Zittel, 1884

Order GONIATITIDA Hyatt, 1884

Suborder GONIATITINA Hyatt, 1884

Superfamily AGATHICERATACEAE Artherber, 1911

Family AGATHICERATIDAE Artherber, 1911

Genus *Agathiceras* Gemmellaro, 1887

Type Species *Agathiceras suessi* Gemmellaro, 1887

Agathiceras sp.

Figure 4.21

Description: The genus *Agathiceras* is characterized by distinctive longitudinal lirae and small umbilicus. The present shells are medium-sized to moderately large for the genus, ranging 20-30 mm in diameter. They are lenticular to ovate in cross-section. The conch is thickly subglobular, involute, with gently convex flanks. Phragmocone constrictions are not preserved. The apertural margin bears an adoral extension. The longitudinal lirae are regular and spiral. A weak, elongate radial depression is present on the flank. The suture is not well preserved. Three subequal lateral saddles present. The corresponding lateral lobes are only faintly recognizable in some specimens.

Measurements: Umbilicus diameter=2.45 mm, Diameter =32.61-35.7 mm

Material: BPC2030-1/1, BPC2030-1/2 and 50 incomplete specimens

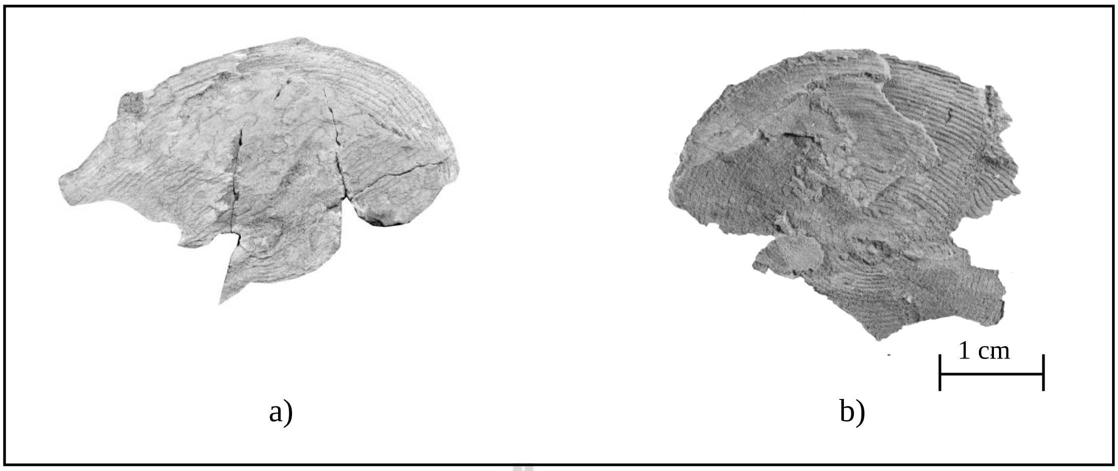


Figure 4.21 *Agathiceras* sp. BPC2030, a) internal views b) external view.

Superfamily ADRIANITACEAE Schindewolf, 1931

Family ADRIANITACEAE Schindewolf, 1931

Genus *Adrianites* Gemmallaro, 1887

Adrianites sp.

Figure 4.22

Description: The conch is subglobular. The width of conch is greater than the diameter. Umbilicus is very small, obliquely deformed fragmental specimen consists of phragmocone and a part of body chamber. Body chamber surface with fine but distinct longitudinal lirae and transverse growth lines forming a regular network. The former slightly prominent than the latter. Poorly preserved suture on lateral side has some U-shaped lobes with somewhat pointed base and rounded saddles. The suture is not well preserved

Measurements: HeightxLength=21.47x11.32 mm, 10.54x9.21 mm, 24.41x21.86 mm, 10.60x14.68 mm, 19.68x8.28 mm, 10.22x6.68 mm

Material: BPC20313, BPC20314, BPC20315, BPC20316 BPC20318 and BPC20319

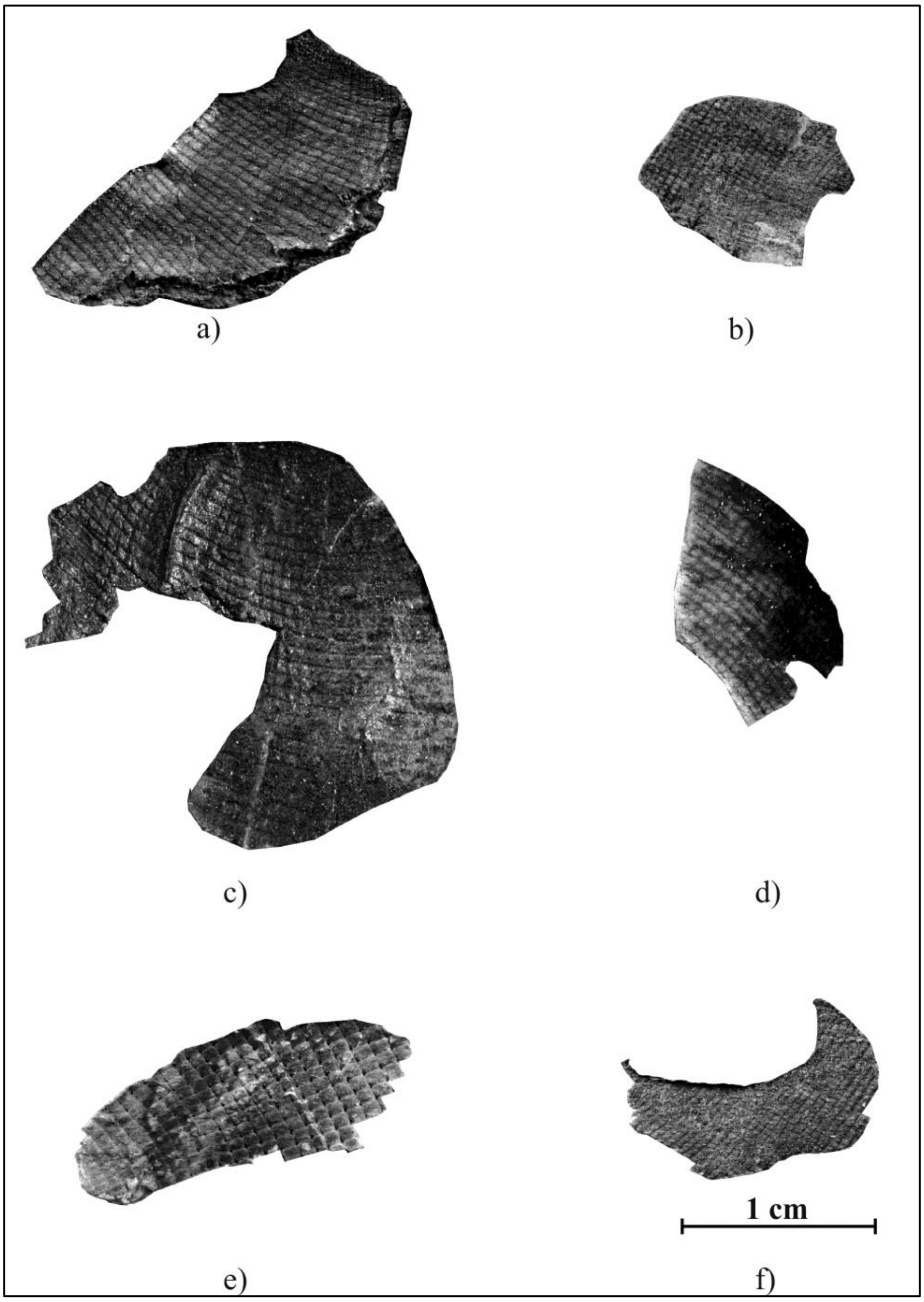


Figure 4.22 *Adrianites* sp., a) BPC20316, external mold b) BPC20319, internal cast c) BPC20313, external mold d) BPC20314, internal cast e) BPC20315, internal cast and f) BPC20318, internal cast.

Superfamily CYCLOLOBACEAE Zittel, 1895

Family POPANOCERATIDAE Hyatt, 1900

Subfamily POPANOCERATINAE Hyatt, 1900

Genus *Popanoceras* Hyatt, 1884

Popanoceras sp.

Figure 4.23

Description: The conch is subglobular. Umbilicus is very small. Shells are medium-sized for the genus, as judged from the size of the ornament. The flanks are almost flat, with a weak longitudinal ventrolateral depression. Growth lamellae are well preserved. They are sinuous and salient. Each lamella is ventrolaterally bifid and occasionally trifid. They are almost identical to those of the Sicilian type species. The suture is not preserved, precluding confident assignment to the type species.

Measurements: Umbilicus diameter=10.03 mm, Diameter=43.58-45.71 mm, HeightxLength=25.10x15.99 mm, 21.52x20.91 mm

Material: BPC20306-1/1, BPC20306-1/2, BPC20305 and BPC20302-1/1

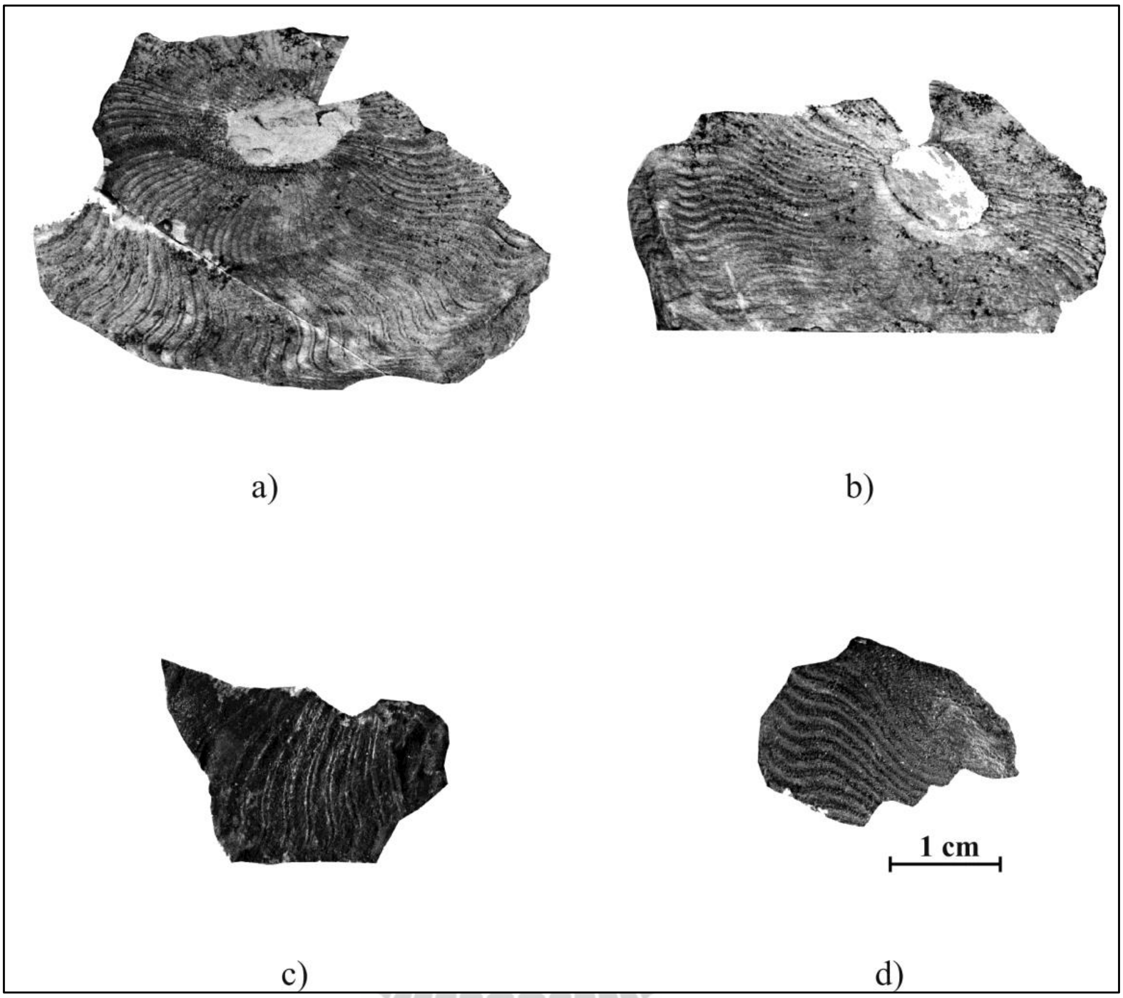


Figure 4.23 *Popanoceras* sp., a) BPC20306-1/2, lateral view of the external mold b) BPC20306-1/2, lateral view of the internal cast c) BPC203065, external mold d) BPC20302-1/1, internal cast.

Superfamily CYCLOLOBACEAE Zittel, 1895

Family CYCLOLOBIDAE Zittel, 1895

Genus *Cyclolobus* Waagen, 1879

Cyclolobus sp.

Figure 4.24

Description: The conch is involute and thickly subdiscoidal in outline with a small umbilicus. Shells are moderately large for the genus. The suture is not well preserved.

Measurement): HeightxLength=40.61x21.34 mm, 41.11x9 mm, 29.02x16.63 mm, 10.5x20.30 mm

Material: BPC20308, BPC20309-1/1, BPC20310-1/1 and BPC20310-1/2

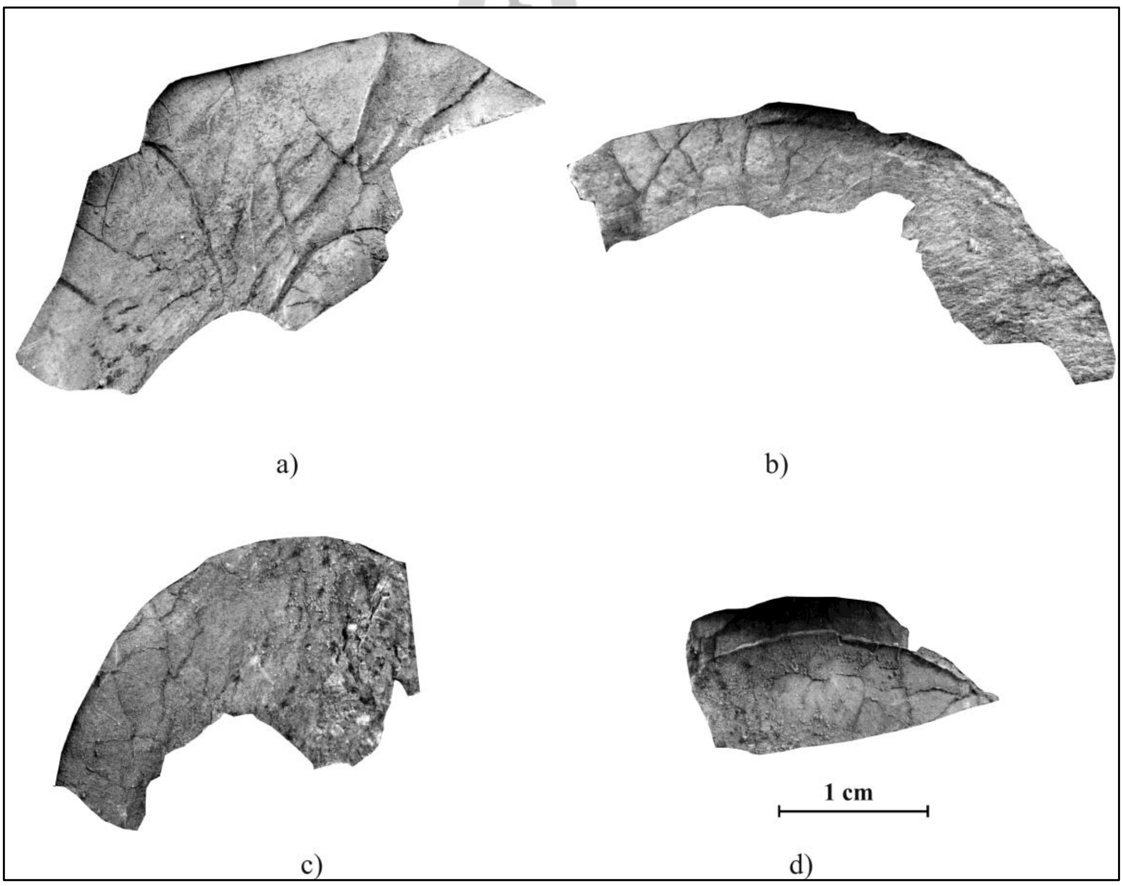


Figure 4.24 *Cyclolobus* sp., a) BPC20308, internal cast b) BPC20309-1/1, internal cast c) BPC20310-1/1, internal cast d) BPC20310-1/2, external mold.

Superfamily GONIATITACEAE De Haan, 1825

Family METALEGOCERATIDAE Plummer&Scott, 1937

Genus *Metalegoceras* Schindewolf, 1931

Metalegoceras sp.

Figure 4.25

Description: The shell is medium-sized for the genus. The conch is thickly subdiscoidal to subglobular, with a suture forming 12 lobes. It indicates the Lower to Middle.Permian.

Measurements: Umbilicus diameter=4.36-15.25 mm, Diameter=9.74-28.64 mm, HeightxLength=16.82x6.01 mm, 16.99x6.04 mm, 19.42x12.38 mm

Material: BPC20323, BPC20325-1/1, BPC20325-1/2 and BPC20327

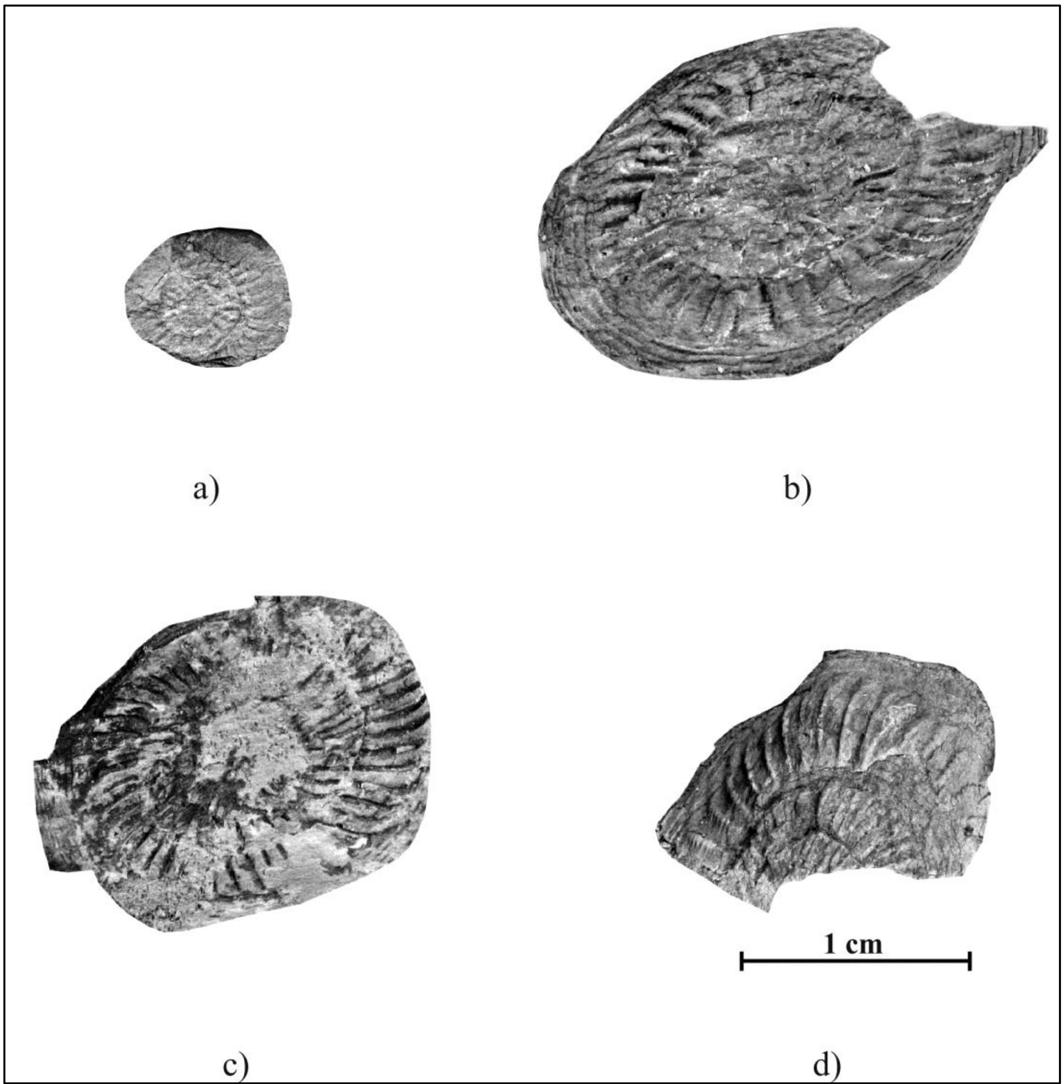


Figure 4.25 *Metalegoceras* sp., a) BPC20323, external mold b) BPC20325-1/1, internal cast c) BPC20327, internal cast d) BPC20325-1/2, external mold.

Superfamily MEDLICOTTIACEAE Karpinsky, 1889

Family PRONORITIDAE Frech, 1901

Genus *Parapronorites* Gemmellaro, 1887

Parapronorites sp.

Figure 4.26

Description: The conch is subdiscoidal, involute to intermediate involute with flattened flanks and evenly rounded venter. The umbilicus is small. The suture is characterized by irregular serration in prongs of mature external lateral lobe and one to three adjacent umbilical lobes. The dorsal and adjacent internal lobe is bidentate. Seven or eight pairs of umbilically derived lobes in external suture, one-half as many internally.

Measurements: HeightxLength=13.70x8.27 mm, 10.35x22.30 mm

Material: BPC20307 and BPC20328

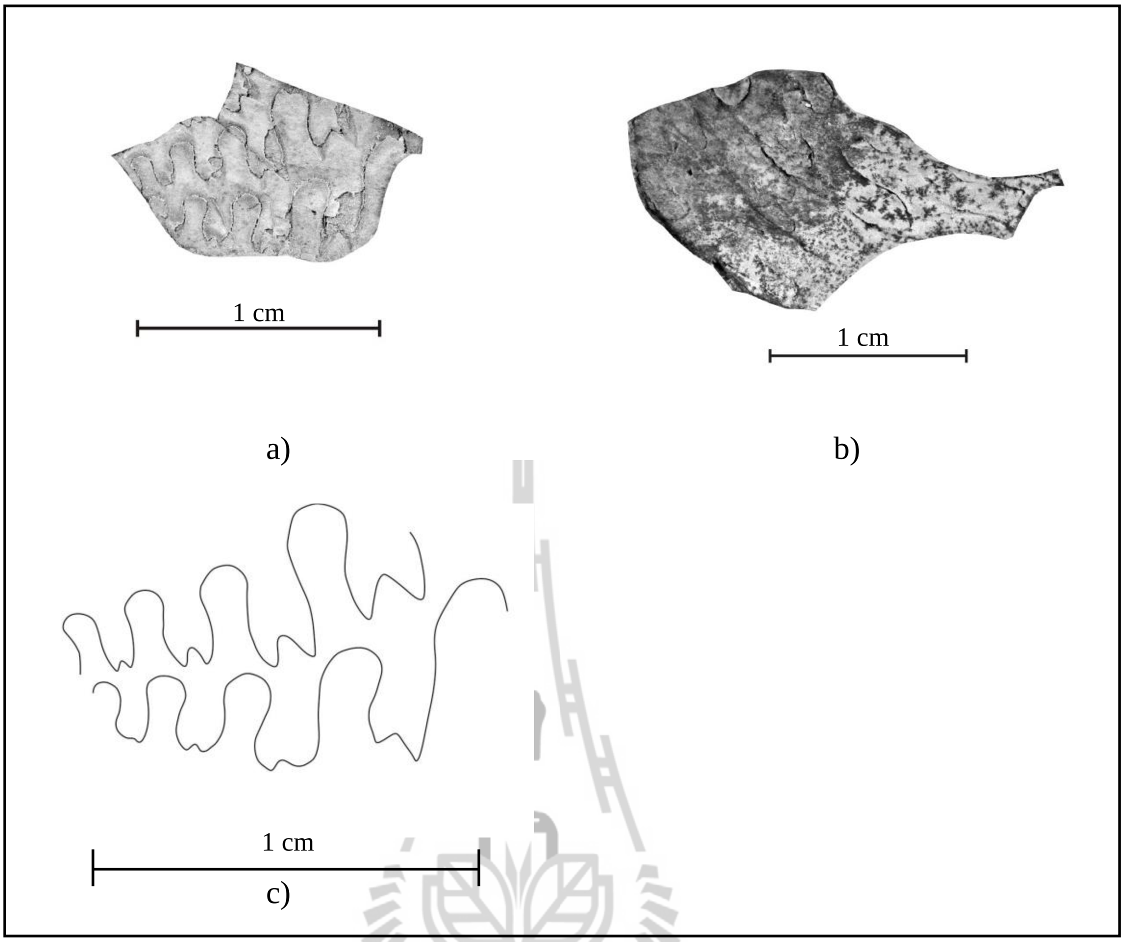


Figure 4.26 *Parapronorites* sp., a) BPC20307, suture line b) BPC20328, suture line c) ceratitic suture type.

Superfamily MEDLICOTTIACEAE Karpinsky, 1889

Family MEDLICOTTIIDAE Karpinsky, 1889

Subfamily MEDLICOTTIINAE Karpinsky, 1889

Genus *Propinacoceras* Gemmellaro, 1887

Propinacoceras sp.

Figure 4.27

Description: The shell is medium-sized for the genus. The conch is involute, with a small umbilicus. The flattened venter bears two rows of prominent transversely elongate nodes, which are separated by a moderately rounded. The sides are flat. The suture is only poorly preserved in some specimens and its details cannot be observed.

Measurements: HeightxLength=12.19x4.69 mm, 16.32x4.27 mm, 15.43x3.52 mm, 11.85x3.70 mm

Material: BPC20329-1/1, BPC20329-1/2, BPC20330-1/1 and BPC20330-1/2

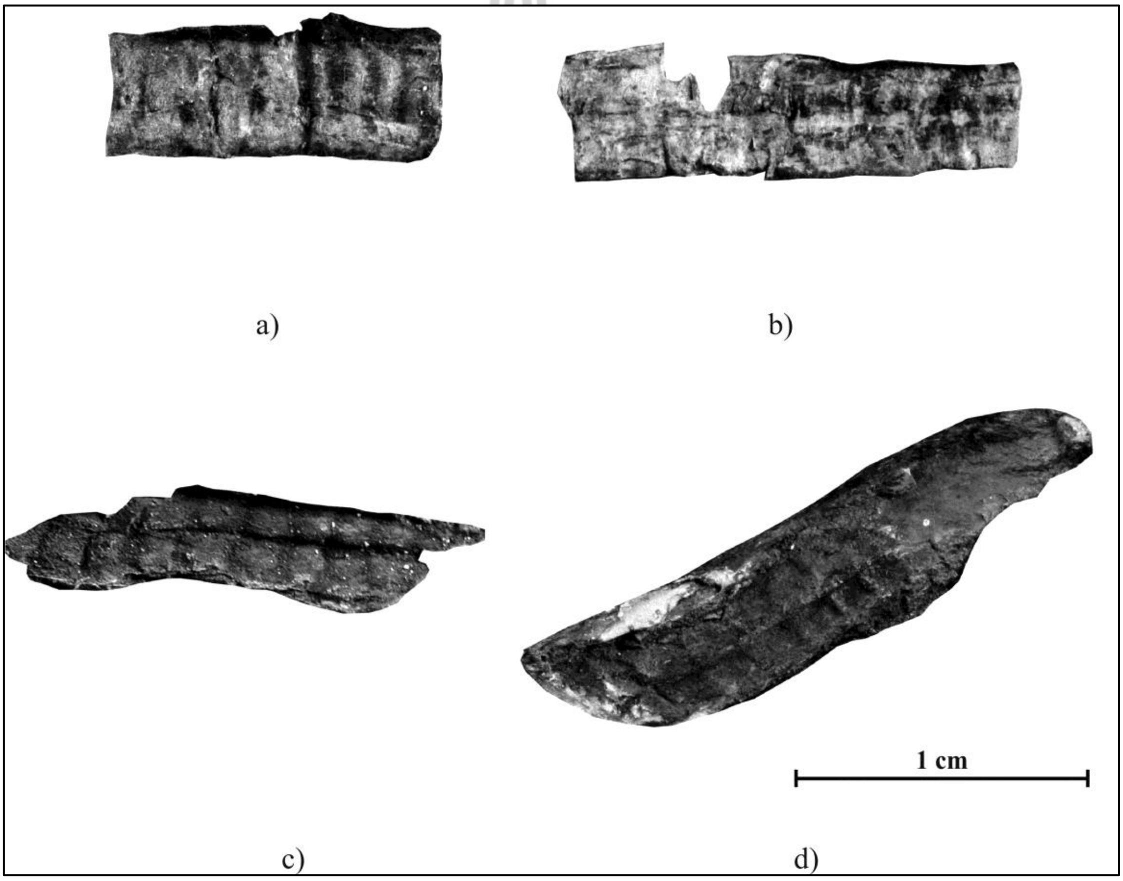


Figure 4.27 *Propinacoceras* sp., a) BPC20329-1/1, ventral mold b) BPC20329-1/2, ventral cast c) BPC20330-1/1, ventral cast d) BPC20330-1/2, ventral mold.

4.2.3 Class Foraminifera

Microscopically, the conglomeratic limestone from Ban Pong Chang Locality 1 (BPC-1), Nong Prue Subdistrict, Nong Prue District, Kanchanaburi Province consists of fusulinid fauna, *Veebegena* sp., which is the characteristic fauna in Middle Permian.

Order FORAMINIFERIDA Eichwald, 1830

Suborder FUSULININA Wedekind 1937

Superfamily FUSULINACEA von Moeller, 1878

Family VERBEEKINIDAE Staff and Wedekind, 1910

Subfamily VERBEEKININAE Staff and Wedekind, 1910

Genus *Verbeekina* staff, 1909

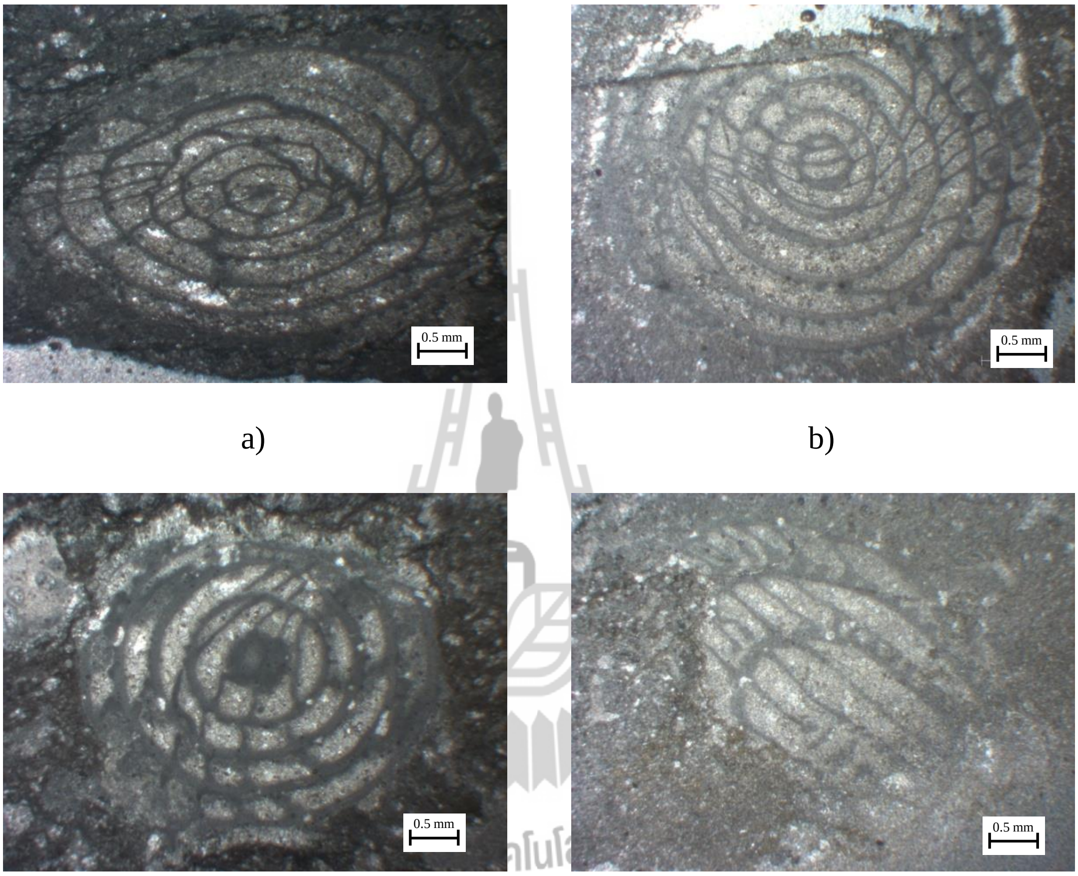
Verbeekina sp.

Figure 4.28

Description: Test ellipsoidal with a gently vaulted median zone and rounded poles. Shell medium to large and spherical. Shell composed of 10-20 volutions, 5-7 mm long and wide, provided with slightly umbilicated axial regions. Proloculus minute, inner 2-4 volutions coiled tightly, following expanded rapidly. Parachomata small, half-circular. The axial length and the median width of a para-axial section which is cut close to the proloculum, parachoma present, primary transverse septula absent, keriotheca present. Parachomata very rarely developed or entirely absent in the inner whorls, and those built in the outermost volutions are widely-spaced and varying in breadth and height.

Measurements: HeightxLength=3.18x5.11 mm, 3.96x4.57 mm, 3.87x3.24 mm, 3.04x4.15 mm

Material: FSL02, FSL03, FSL04 and FSL05



a) b)

c) d)

Figure 4.28 Photomicrographs of *Verbeekina* sp. a) FSL02, cross-sectional view b) FSL03, tangential view c) FSL04, tangential view and d) FSL05, longitudinal view

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this study are to define the lithostratigraphy of marine Permian and Triassic sedimentary sequences, to identify the bivalve, ammonoid and fusulinid fauna, and to clarify the geological age and the depositional environment. The area of study is located in the Nong Prue District, Kanchanaburi Province, western Thailand.

5.1.1 Results of stratigraphy

The stratigraphy of the study area can be observed from six localities and detail of each locality was described in the following sections.

- Ban Pong Chang Locality 1 (BPC-1) can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of a matrix-subported light gray limestone conglomerate. Clasts of conglomerate contain coral fusulinid and bryozoa. The Upper Unit was composed of siliceous shale.

- Ban Pong Chang Locality 2 (BPC-2) can be devided into three units, the Lower Unit, the Middle Unit and the Upper Unit. The Lower Unit consists of yellowish gray shale, calcareous shale and limestone. These fossil-bearing shales are composed of abundant ammonoids. The Middle Unit consists of shale interbedded with limestone. The Upper Unit consists of shale interbedded with siliceous shale. Bivalves have been observed in shales.

- Ban Pong Chang Locality 3 (BPC-3) can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of dark gray shale. Calcareous shale is interbedded with limestone and siliceous shale. Bivalves have been observed in shales. The Upper Unit consists of sandstone and shale with limestone lens.

- Ban Huai Yai Locality 1 (BHY-1) can be devided into two units, the Lower Unit and the Upper Unit. The Lower Unit consists of thin-bedded siliceous shale and yellowish gray shale. Bivalves have been observed in shales. The Upper Unit consists of sandstone interbedded with shale.

- Ban Huai Yai Locality 2 (BHY-2) consist of thin well-bedded siliceous shale and yellowish gray shale. Shale is intercalated with argillaceous limestone. Bivalves have been observed in shales.

- Ban Nong Makha (NMK) consists of yellowish gray shale and siliceous shale. Bivalves have been observed in shales.

The six studied sections can be correlated and subdivided into four rock units, A, B, C and D, from older to younger respectively. The unit A consists of shale, calcareous shale and limestone. Ammonoids have been observed in shales. The unit B overlies unconformably on the unit A. It consists of limestone conglomerate, limestone, shale and siliceous shale. Limestone conglomerate contains fusulinid-bearing clasts. The unit C overlies conformably on the unit B and consists of shale and siliceous shale. The unit D overlies conformably on the unit C. It consists of sandstone and shale. A bivalve assemblage has been discovered in shales of units C and D.

5.1.2 Results of Systematic Paleontology

The collected fossils are systematically identified and described. They consist of two Phyla, the Mollusca and the Protozoa. The Mollusca consists of two Classes, the Bivalvia and the Cephalopoda (Ammonoidea). The Protozoa consists of one Class, the Foraminifera.

- The Bivalvia comprises three genera: *Halobia*, *Posidonia* and *Daonella*. *Halobia* consists of three species; *Halobia (Halobia) talauana* Wanner, *Halobia (Halobia) styriaca* Mojsisovics, and *Halobia (Zittelihalobia)* sp.
- The Cephalopoda (Ammonoidea) comprises seven species, i.e., *Agathiceras* sp., *Adrianites* sp., *Popanoceras* sp., *Cyclolobus* sp., *Metalegoceras* sp., *Parapronorites* sp. and *Propinacoceras* sp.
- The Foraminifera comprises one species: *Verbeekina* sp.

5.1.3 Depositional environments and age

Based on the lithological and paleontological evidences, the depositional environments of the studied rock units can be inferred. The unit A consists predominantly of laminated shales which indicate a low-energy environment. These shales contain ammonoids but without associated marine benthic fauna suggesting that they were accumulated far from shore on a deep marine (abyssal plain) environment in the Middle Permian time. The limestone conglomerate in the unit B indicates the main tectonic event of the basin with considerable uplift and erosion which is represented by a strong unconformity after the late Middle Permian time. Shales of units C and D also represent a low-energy environment. They contain only pelagic bivalves (Halobiids) suggesting that they were accumulated on a deep marine (abyssal plain) environment in the Late Triassic time.

The age of the unit A is assigned to the Middle Permian (Roadian-Wordian) age based on the ammonoid fauna. Unit C and D contain the Halobiid bivalve which indicates a Late Triassic (Carnian-Norian) age. The basal conglomerate of the unit B contains fusulinid-bearing clasts suggesting that the unit is younger than a late Middle Permian age and is most likely the Triassic based on the stratigraphic ground.

5.2 Recommendations

This study of stratigraphy and paleontology is a new data and this would significantly improve the understanding of geology of marine Triassic rocks in the western part of Thailand. The information of these invertebrate fossils can also be useful for the correlation in the future study.

REFERENCES

Ampornmaha, A. (1995). Triassic carbonate rocks in the Phattalung area, Peninsular Thailand. **Journal of Southeast Asian Earth Science**. 11: 225-236.

Braun, E., Von, and Jordan, R. (1976). The Stratigraphy and Paleontology of the Mesozoic Sequence in The Mae Sot Area in Western Thailand. **Geologisches Jahrbuch**. 21: 5-51.

Bunopas, S. (1961). Stratigraphy of Thailand. In **Proceedings of the 9th Pacific Science Congress**. 12: 301-305.

Bunopas, S. (1976). Stratigraphic succession in Thailand-a preliminary summary. **Journal of the Geological Society of Thailand**. 2: 31-58.

Bunopas, S. (1981). **Paleogeographic history of western Thailand and adjacent parts South-East Asia – A plate tectonics interpretation**. Ph.D. Thesis. Victoria University.

Bunopas, S. (1992). Regional stratigraphic correlation in Thailand. In **C**. Piancharoen and others (eds.). In **Proceedings of the National Conference on Geological Resources of Thailand: Potential for Future Development** (pp. 189-288).

Bunopas, S. and Vella, P. (1983). Tectonic and geologic evolution of Thailand. In **P. Nutalaya: Proceedings of the workshop on Stratigraphic correlation between Thailand and Malaysia** (pp. 307-322). Hadd Yai : Geological Society of Thailand and Malaysia.

Campbell, H.J. (1994). The Triassic bivalves Daonella and Halobia in New Zealand, New

Caledonia and Svalbard. **Institute of Geological & Nuclear Sciences**. 166 p.

Caridroit, M., Bohlke, D., Lumjuan, A., Helmcke, D. and Wever., P. D. (1993). A mixed radiolarian fauna (Permian/Triassic) from clastics of the Mae Sriang area, northwestern Thailand. In T. Thanasuthipitak (ed.). In **Proceedings of the International Symposium on Biostratigraphy of Mainland Southeast Asia** (pp. 401-413).

Chaodumrong, P. (1992). **Stratigraphy, Sedimentology and Tectonic setting of Lampang Group, central north Thailand**. Ph.D. Thesis. University of Tasmania.

Chaodumrong, P. and Burrett, C. (1997). Stratigraphy of the Lampang Group in Central North Thailand. **CCOP Technical Bulletin**. 26: 65-80.

Chaodumrong, P. and Rao, P. (1992). Depositional environments of Triassic carbonates, Lampang Group, central north Thailand. In C. Piencharoen (ed.). In **Proceedings of a conference on Geological Resources of Thailand** (pp. 355-367).

Charusiri, P., Chonglakmani, C., Daorerk, V., Supananthi, S. and Imsamut, S. (1994). Detailed stratigraphy of the Ban Tha Si area, Lampang, northern Thailand: Implications for paleoenvironments and tectonic history. In P. Angsuwathana, T. Wongwanich, W. Tansathien, S. Wongsomsak, and J. Tulyatid. (eds.). In **Proceedings of the International Symposium on Stratigraphic Correlation of SE Asia** (pp. 306-321).

Chonglakmani, C. (1972). Stratigraphy of the Triassic Lampang Group in Northern Thailand. **Newsletter of the Geological Society of Thailand**. 5: 33-36.

Chonglakmani, C. (1981). **The Systematics and Biostratigraphy of Triassic bivalves**

and ammonoids of Thailand. Ph.D. thesis, University of Auckland.

Chonglakmani, C. (1982). The Mesozoic marine faunas of Thailand and their paleogeographic implications. **Bollettino della Societo Paleontologica Italiana**. 21: 255-266.

Chonglakmani, C. (1983). The marine Mesozoic stratigraphy of Thailand. In P. Nutalaya (ed.). In **Proceedings of the workshop on stratigraphic correlation of Thailand and Malaysia** (pp. 105-126).

Chonglakmani, C. (1999). The Triassic system of Thailand; implication for the paleogeography of Southeast Asia. In B. Rattanasthien (ed.). In **Proceedings of the International Symposium on Shallow Tethys 5th** (pp. 486-495).

Chonglakmani, C. (2002). Current status of Triassic stratigraphic of Thailand and its implication for geotectonic evolution. In N. Mantajit (ed.). In **Proceedings of the Symposium on Geology of Thailand** (pp. 1-3).

Chonglakmani, C. (2011). Triassic. In M.F. Ridd, A.J. Barber, and M.J. Crow (eds.). **The Geology of Thailand**. Geological Society of London (pp. 137-150).

Chonglakmani, C. and Grant-Mackie, J.A. (1993). Biostratigraphy and facies variation of marine Triassic sequences in Thailand. In T. Thanasuthipitak (ed.). In **Proceedings of the International Symposium on Biostratigraphy of Mainland Southeast Asia** (pp. 97-123).

Feng, Q., Malila, K., Wonganan, N., Chonglakmani, C., Helmcke, D., Ingavat-Helmcke, R. and Caridroit, M. (2005). Permian and Triassic Radiolaria from Northwest Thailand. **Revue de micropaleontology**. 48: 237.

Grant-Mackie, J.A., Sawata, H., Arpornsuwan, S., Arrykul, S., Chutais, V. and Pungrassami, T. (1980). Some Triassic and associated strata of southern

Thailand. **Prince of Songkla University Geological Research Project Publication**. 5: 1-85.

Hagen, D., and Kemper, E. (1976). Geology of the Thong Pha Phum area (Kanchanaburi province, western Thailand). **Geologisches Jahrbuch**. 21: 53-91.

Jenjitpaiboon, K. and Chonglakmani, C. (2014). Stratigraphy and Paleontology of Marine Permian and Triassic Sequences in Nong Prue district, Kanchanaburi province, Thailand. **International Workshop on Tethyan Orogenesis and Metallogeny in Asia and Cooperation among Institutions of Higher Education** (pp. 25-26).

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

Kobayashi, T., and Tokuyama, A. (1959). The Halobiidae from Thailand. **Journal of the Faculty of science, University of Tokyo Sect. 2**. 1291: 27-30.

Koch, K. E. (1973). Geology of the Region Sri Sawat-Thong Pha Phum-Sangkhlaburi (Kanchanaburi province, Thailand). In B. K., Tan (ed.). In **Proceedings of the Regional Conference on the Geology of SE Asia** (pp. 177-185).

Kummel, B. (1960). Triassic ammonoids from Thailand. **Journal of Paleontology**. 34: 682-694.

Meesook, A., Teerarungsigul, N. and Saengsrichan, W. (2005). Mesozoic stratigraphy and faunal aspects of Thailand. **Bureau of Geological Survey**. Department of Mineral Resources.

Meesook, A., Kozai, T., Ishida, K. and Hirsch, F. (2006). The welding of Shan-Thai. **Geosciences Journal**. 10:195-204.

Meesook, A., Suteethorn, V., Chaodumrong, P., Teerarungsigul, N., Sardsud, A. and Wongprayoon, T. (2002). Mesozoic Rocks of Thailand: A Summary. In **Proceedings of the Symposium on the Geology of Thailand** (pp. 82-94).

Metcalfe, I. (1988). Origin and assembly of South-East Asian continental terrance. In M. G. Audley-Charles, and A. Hallam (eds.). **Gondwana and Tethys** (pp. 101-118). New York: Geological Society of London Special Publication, 37 Oxford University Press.

Miller, A. K., and Furnish, W. M. (1954). The Classification of the Paleozoic ammonoids. **Journal of Paleontology**. 28(5): 685-692.

Moore, R. C. (1957). **Treatise on Invertebrate Paleontology, Part L, Mollusca 4**, Geol. Soc. America, Univ. Lawrence: Kansas Press.

Moore, R. C. (1969). **Treatise on Invertebrate Paleontology, Part N Volume 1(of 3), Mollusca 6**, Geol. Soc. America, Univ. Lawrence: Kansas Press.

Orlov, Y.A. (1962). **Fundamental of Geology**. Jerusalem: Keter Press.

Pitakpaivan, K. (1955). **Occurrences of Triassic formation at Mae Moh.** Department of Mineral Resources. Report of investigation no. 1 (pp. 47-57).

Piyasin, S. (1971). Marine Triassic sediments of Northern Thailand. **Newsletter of the Geological Society of Thailand**. 4: 12-20.

Piyasin, S. (1972). **Exploration for the Geological Map of Thailand 1:250,000 sheet Changwat Lampang (NE 47-7).** Bangkok. Department of Mineral Resources.

Robert, R. S. and William, H. T. (1953). **Principles of Invertebrate Paleontology**. 2nd ed. of Invertebrate Paleontology. New York-London: McGraw-Hill. 816 pp.

Ruzhencev, V.E. (1950) Upper Carboniferous ammonites of the Ural. **Akademiia Nauk SSSR, Paleontologicheskogo Instituta Trudy**. 29: 1-223.

Sashida, K., Ueno, K., Nakornsri, N. and Sardsud, A. (1998). Early Carboniferous radiolarians from Na Thawi, southern peninsular Thailand. **Palaeontological Society of Japan Meeting**. 147: 1-24.

Sashida, K., Ueno, K., Nakornsri, N. and Sardsud, A. (1999). Lithofacies and biofacies of the Klong Kon Limestone, southern Peninsular Thailand. In B. Ratanasthin, and S.L. Ried (eds.). In **Proceedings of the International Symposium on Shallow Tethys 5th** (pp. 228-241).

Siritheerasas, K. (1999). **Biostratigraphy of Permian rocks at Khao Nong Hoi, Changwat Nakhon Ratchasima, with reference to fossil ammonoids and fusulinids in rock strata**. Master's Thesis. Chulalongkorn University.

Srinak, N. (2002). **Lithostratigraphy of Triassic Clastic Rocks in Southern Part of Amphoe Muang Mae Hong Son, Changwat Mae Hong Son, Northwest Thailand.** Master's Thesis. Chulalongkorn University.

Sudasna, P. and Pitakpaivan, K. (1976). **Geological map of Thailand on 1:250,000 scale: Sheet Changwat Suphan Buri (NE47-7)**. Bangkok: Department of Mineral Resources.

Tofke, T., Lumjuan, A. and Kelmcke, D. (1993). Triassic syn-orogenic siliciclastics from the area of Mae Sariang (northwestern Thailand). In T. Thanasuthipitak (ed.). In **Proceedings of the International Symposium on Biostratigraphy of Mainland Southeast Asia** (pp. 391-400).

Ueno, K. (1999). Gondwana/Tethys divide in East Asia: solution from Late Paleozoic foraminiferal paleobiogeography. In B. Ratanasthin, and S.L. Ried (eds.). In **Proceedings of the International Symposium on Shallow Tethys 5th** (pp. 45-54).

APPENDIX

PUBLICATION

Publication

Jenjitpaiboon, K. and Chonglakmani, C. (2014). Stratigraphy and Paleontology of Marine Permian and Triassic Sequences in Nong Prue district, Kanchanaburi province, Thailand. **International Workshop on Tethyan Orogenesis and Metallogeny in Asia and Cooperation among Institutions of Higher Education** (pp. 25-26).

Stratigraphy and paleontology of marine Permian and Triassic sequences in the Nong Prue district, Kanchanaburi Province, Thailand

Krongkaew Jenjitpaiboon[1,2*], Chongpan Chonglakmani[1]

1. School of Geotechnology, Institute of Engineering, Suranaree University of Technology, Nakhon Ratchasima, 30000, Thailand.

2. Northeastern Research Institute of Petrified Wood and Mineral Resources, Nakhon Ratchasima Rajabhat University, Nakhon Ratchasima, 30000, Thailand.

*Corresponding author's e-mail address: kaew2912@hotmail.com

Abstract

The aims of this study are to define the lithostratigraphy of marine Permian and Triassic sedimentary sequences, to identify the bivalve, ammonoid and fusulinid fauna in them, and to clarify the geological age and the depositional environment of these rocks. The area of study is located in the Nong Prue District, Kanchanaburi Province, western Thailand. Marine sedimentary sequences in the study area can be subdivided into four rock units, A, B, C and D, from oldest to youngest, respectively. Unit A consists of shale, calcareous shale and limestone and contains an ammonoid assemblage in the shales. Unit B unconformably overlies unit A and consists of limestone conglomerate, limestone, shale and siliceous shale. The limestone conglomerate contains fusulinid-bearing clasts. Unit C conformably overlies unit B and consists of shale and siliceous shale. Unit D conformably overlies unit C and consists of sandstone and shale. A bivalve assemblage has been discovered in the shales of units C and D.

The collected fossils were systematically identified and described. They consist of two Phyla, the Mollusca and the Protozoa. The Mollusca consists of two Classes, the Bivalvia and the Cephalopoda (Ammonoidea). The Bivalvia comprises three genera: Halobia, Posidonia and Daonella. Halobia consists of three species; Halobia (Halobia) talauana Wanner, Halobia (Halobia) styriaca Mojsisovics, and Halobia (Zittelihalobia) sp. The Cephalopoda (Ammonoidea) comprises seven species, i.e., Agathiceras sp., Adrianites sp., Popanoceras sp., Cyclolobus sp., Metalegoceras sp., Parapronorites sp. and Propinacoceras sp. The Protozoa consists of one Class, the Foraminifera which comprises one species: Verbeekina sp.

Unit A is assigned to the Middle Permian (Roadian-Wordian) based on the ammonoid faun; units C and D contain the Halobiid bivalve, which indicates a Late Triassic (Carnian-Norian) age; and the basal conglomerate of unit B contains fusulinid-bearing clasts suggesting that it is younger than late Middle Permian and is most likely Triassic based on stratigraphic grounds. Based on the lithological and paleontological evidence, the depositional environments of the studied rock units can be inferred. Unit A consists predominantly of laminated shales which indicate a low-energy environment. These shales contain ammonoids but without associated marine benthic fauna *suggesting that they were accumulated far from shore on a deep marine (abyssal plain) environment in the Middle Permian. The limestone conglomerate in unit B indicates a major tectonic event of the basin with considerable uplift and erosion which is represented by a strong unconformity after the late Middle Permian. Shales of units C and D also represent a low-energy environment. They contain only pelagic bivalves (Halobiids) suggesting that they accumulated in a deep marine (abyssal plain) environment in the Late Triassic.*

***Keywords**: Marine Triassic, Permian, Bivalve, Ammonoid, Fusulinid, Stratigraphy, Paleontology*

BIOGRAPHY

Miss Krongkaew Jenjitpaiboon was born on the 29th of December 1980. She earned her high school diploma in Science-Math Program from Chonkunyanukoon School in 1999. She graduated with a bachelor's degree in geology, Faculty of Science, Chiang Mai University in 2003. After graduation, she worked as researcher assistant (Geologist) in the project of spectacular geological features related to Agro - Geo - Eco Tourism Project, Phrae province at Kasetsart University until the year 2006. During the year 2006-2008, she had worked as a scientist (Geoscience) at Mahidol University. Since the year 2008, she has been working as a geologist at the Northeastern Research Institute of Petrified Wood and Mineral Resources (In Honour of His Majesty the King), Nakhon Ratchasima Rajabhat University. She studied for master's degree at Suranaree University of Technology.