บรรพชีวินวิทยาของกลุ่มชีวินหอยน้ำจืดยุคครีเตเชียสตอนต้นจากหมวดหินเสาขัวบริเวณ หนองบัวลำภู ภูเวียง และสหัสขันธ์ ภาคตะวันออกเฉียงเหนือของประเทศไทย

นายศักดิ์บวร ตุ้มปี่สุวรรณ

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต

สาขาวิชาธรณีวิทยา ภาควิชาธรณีวิทยา

คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2553

PALAEONTOLOGY OF THE EARLY CRETACEOUS NON-MARINE MOLLUSCAN ASSEMBLAGES FROM THE SAO KHUA FORMATION IN NONG BUA LAMPHU, PHU WIANG AND SAHAT SAKHAN AREAS, NORTHEASTERN THAILAND

Mr. Sakboworn Tumpeesuwan

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Geology
Department of Geology
Faculty of Science
Chulalongkorn University
Academic year 2010

Thesis Title	PALAEONTOLOGY OF THE EARLY CRETACEOUS NON-MARINE MOLLUSCAN ASSEMBLAGES FROM THE SAO KHUA FORMATION IN NONG BUA LAMPHU, PHU WIANG AND SAHAT SAKHAN AREAS, NORTHEASTERN THAILAND
By	Mr. Sakbowom Tumpeesuwan
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ศักดิ์บวร ตุ้มปี่สุวรรณ: บรรพชีวินวิทยาของกลุ่มชีวินหอยน้ำจืดยุคครีเตเชียสตอนต้นจากหมวดหินเสาขัว บริเวณหนองบัวลำภู ภูเวียง และสหัสขันธ์ ภาคตะวันออกเฉียงเหนือของประเทศไทย. (PALAEONTOLOGY OF THE EARLY CRETACEOUS NON-MARINE MOLLUSCAN ASSEMBLAGES FROM THE SAO KHUA FORMATION IN NONG BUA LAMPHU, PHU WIANG AND SAHAT SAKHAN AREAS, NORTHEASTERN THAILAND) อ. ที่ปรึกษาวิทยานิพนธ์หลัก : อ.ดร. โยชิโอะ ซาโต, อ. ที่ปรึกษาวิทยานิพนธ์ร่วม: ผศ. ดร. สมชาย นาคะผดุงรัตน์, 214 หน้า.

ซากดึกดำบรรพ์กลุ่มชีวินหอยน้ำจืด 16 ชนิด จากชั้นซากดึกดำบรรพ์หอย 16 ชั้น ใน 12 แหล่งซากดึกดำบรรพ์ในพื้นที่บริเวณหนองบัวลำภู ภูเวียง และสหัสขันธ์ได้ถูกขุดค้นและนำมาศึกษา ซากดึกดำบรรพ์เหล่านี้สามารถแบ่งได้เป็น 4 กลุ่มชีวินหอยน้ำจืด ได้แก่ กลุ่มชีวิน *Koreanaia (Eokoreanaia)* sp. – *Yunnanoconcha* sp., กลุ่มชีวิน *Yunnanoconcha* sp. cf. *Y. khoratensis*, กลุ่มชีวิน *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* และกลุ่มชีวิน *incertae cedis* (4) กลุ่มชีวิน *Koreanaia (Eokoreanaia)* sp. – *Yunnanoconcha* sp. พบเฉพาะที่แหล่งซากดึกดำบรรพ์ห้วยเหล่ายางเพียงแห่งเดียว บริเวณใกล้กับรอยต่อระหว่างหมวดหินเสาขัวกับหมวดหินพระวิหารที่วางตัวอยู่ตอนล่าง กลุ่มชีวินหอยน้ำจืดนี้มีความสัมพันธ์กับชั้นหินโคลนและหินทรายแป้ง และสามารถเทียบเคียงอายุสัมพัทธ์ได้กับกลุ่มชีวิน *Nippononaia (Eonippononaia) tetoriensis* – *Koreanaia (Eokoreanaia) cheongi* – *Danlengiconcha elongata* จากเอเชียตะวันออกซึ่งมีอายุอยู่ในช่วง Hauterivian-Barremian กลุ่มชีวิน *Yunnanoconcha* sp. cf. *Y. khoratensis* มีความสัมพันธ์กับชั้นหินโคลนและหินทรายแป้ง *Yunnanoconcha* sp. cf. *Y. khoratensis* มีลักษณะสัณฐานวิทยาและขนาดก้ำกึ่งระหว่าง *Yunnanoconcha* sp. และ *Yunnanoconcha khoratensis* จากหมวดหินโคกกรวด กลุ่มชีวิน *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* พบกระจายอย่างกว้างขวางในชั้นหินทรายและหินกรวดมนของหมวดหินเสาขัว *Pseudohyria (Matsumotoina) somanai* Tumpeesuwan, Sato & Nakhapadungrat, 2010 เป็นซากดึกดำบรรพ์หอยสองฝาชนิดใหม่และเป็นรายงานการพบสกุลย่อย *Pseudohyria (Matsumotoina)* ครั้งแรกในประเทศไทย ซึ่งสกุลย่อยนี้พบเฉพาะในช่วงอายุ Barremian ตอนปลายของประเทศญี่ปุ่นและเกาหลี ตอนบนของหมวดหินเสาขัวที่พบกลุ่มชีวิน *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* ควรมีอายุอยู่ในช่วง Barremian ตอนปลาย กลุ่มชีวิน *incertae cedis* (4) พบเฉพาะในชั้นซากดึกดำบรรพ์หอย 3 ชั้น บริเวณภูเวียง กลุ่มชีวินนี้สัมพันธ์กับชั้นหินกรวดมน ซากดึกดำบรรพ์หอยสองฝาชนิด *incertae cedis* (4) ไม่สามารถจัดจำแนกได้เนื่องจากขาดลักษณะสำคัญคือฟันบานพับของเปลือกและรอยมัดกล้ามเนื้อยึดเปลือก จากหลักฐานกลุ่มชีวินหอยน้ำจืดสามารถให้อายุสัมพัทธ์ของหมวดหินเสาขัวตอนล่างอยู่ในช่วง Hauterivian ถึง Barremian ตอนต้น และหมวดหินเสาขัวตอนบนอยู่ในช่วง Barremian ตอนปลาย ตามลำดับ

ภาควิชา ธรณีวิทยา.......................................ลายมือชื่อนิสิต.......ศักดิ์บวร ตุ้มปี่สุวรรณ.......

สาขาวิชา ธรณีวิทยา.....................................ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก.......Sato.......

ปีการศึกษา 2553...ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์ร่วม ....

4873894623 : MAJOR GEOLOGY

KEYWORDS : Non-marine molluscan assemblages/ Trigonioidoidea/ Early Cretaceous/ Sao Khua Formation/ Northeastern Thailand

SAKBOWORN TUMPEESUWAN: PALAEONTOLOGY OF THE EARLY CRETACEOUS NON-MARINE MOLLUSCAN ASSEMBLAGES FROM THE SAO KHUA FORMATION IN NONG BUA LAMPHU, PHU WIANG AND SAHAT SAKHAN AREAS, NORTHEASTERN THAILAND. THESIS ADVISOR: YOSHIO SATO, Ph.D. THESIS CO-ADVISOR: ASST. PROF. SOMCHAI NAKAPADUNGRAT, Ph.D., 214 pp.

Sixteen taxa of freshwater molluscan assemblages from 16 shell beds at 12 localities in Nong Bua Lamphu, Phu Wiang and Sahat Sakhan Areas were studied. They were subdivided into 4 assemblages, including, *Koreanaia (Eokoreanaia)* sp. – *Yunnanoconcha* sp. Assemblage, *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage, *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage and *incertae cedis* (4) Assemblage. *Koreanaia (Eokoreanaia)* sp. – *Yunnanoconcha* sp. Assemblage was discovered only in Huai Lao Yang Fossil Locality, near the boundary between the Sao Khua Formation and the underlying Phra Wihan Formation. The assemblage is related to mudstone and siltstone, and can be related to Hauterivian - Barremian *Nippononaia (Eonippononaia) tetoriensis – Koreanaia (Eokoreanaia) cheongi – Danlengiconcha elongata* Assemblage of East Asia. *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage is related to mudstone and siltstone. *Yunnanoconcha* sp. cf. *Y. khoratensis* possesses their morphology and size as intermediate form between *Yunnanoconcha* sp. and *Yunnanoconcha khoratensis* of the Khok Kruat Formation. *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage is widely distributed in sandstone and conglomeratic sandstone of the Sao Khua Formation. *Pseudohyria (Matsumotoina) somanai* Tumpeesuwan, Sato & Nakhapadungrat, 2010 was proposed as new species and firstly reported of the subgenus *Pseudohyria (Matsumotoina)* in Thailand. This subgenus is restricted to Late Barremian of Japan and Korea. This evidence might be suggested Late Barremain age for the Upper part of the Sao Khua Formation. *incertae cedis* (4) Assemblage was discovered only in 3 shell beds of Phu Wiang Areas. This assemblage is related to conglomeratic sandstone. Hinge teeth and muscle scars of *incertae cedis* (4) are not preserved on the molds; therefore, exact identification is impossible. Based on the evidences of molluscan assemblages, Hauterivian – Early Barremian and Late Barremian Ages were assumed for the lower and upper parts of the Sao Khua Formation, respectively.

Department : Geology	Student's Signature *Sakboworn Tumpeesuwan*
Field of Study : Geology	Advisor's Signature *Sato*
Academic Year : 2010	Co-Advisor's Signature *S. Nakapadungrat*

ACKNOWLEDGEMENTS

I wish to express my sincere gratitude to my thesis advisor, Dr. Yoshio Sato, for his valuable suggestion, guidance, and training me to be a palaeontologist. My grateful thanks to Assistant Professor Dr. Somchai Nakapadungrat, thesis co-advisor and Associated Professor Dr. Visut Pisutha-Arnond, Chairman of thesis committee for his precious advice. I am especially grateful to thesis committee, Dr. Chongpan Chonglakmani, Dr. Pol Chaodumrong, Assistant Professor Dr. Sombat Yumuang and Assistant Professor Dr. Thasinee Charoentitirat for their valuable advices, comments and suggestions.

I am also grateful to Professor Dr.Chen Jia-hua, Dr. Tochifumi Komatsu, Professor Dr. Sha Jin-jeng, Professor Dr. Seong Young Yang, Dr. Assanee Meesook, Dr. Marc Philippe, Mr. Fred Naggs, Dr. Takahiro Asami, Professor Dr. Kenshiro Ogasawara, Dr. Shinji Isaji, Dr. Pitsanupong Kanjanapayont, Mr. Thanakhom Bundhitwongrat, Mr. Sravut Klorvuttimontara, Dr. Chitchai Chantangsi, Dr. Wannasiri Wannarat, Dr. Suravech Suteethorn and Dr. Chirasak Sutcharit for helpful suggestions and sending me many papers, which were difficult to obtain in Thailand.

I would like to express my gratitude to all members of the Phu Wiang National Park and Phu Wiang Dinosaur Museum for their kindness and help, especially Dr. Wikanet Songtham and Mr. Prachaya Bamrungsong. Special thanks to Mr. Terapon Wongprayoon for providing valuable publications of the Sao Khua Formation.

I want to give a very special thank to my wife, Mrs. Chanidaporn Tumpeesuwan for her encouragement, help, etc. during the period of my works. I am indebted to Vorajuk family, Mr. Passakorn Bunchalee, Dr. Komsorn Lauprasert and his students, Athiwat Wattanapitaksakul, Suchada Kamha, Uthumporn Deesri, and Wilailuck Naksri for their help in field investigation and collection. Thanks to Mr.Paladej Srisuk who discovered Huai Lao Yang Shell Bed and provided valuable specimens available for study

I am indebted to the grant from Mahasarakham University for financial support during my study in Doctor of Philosophy Program in Geology Department of Chulalongkorn University. The research was also supported by Graduated Thesis Grant of Chulalongkorn University (3/2551).

The special thanks are also conveyed to my parent for their encouragement. Finally, I would like to express my deep gratitude to all of my teachers, especially Professor Dr. Somsak Panha, Professor Emeritus Dr. Thosaporn Wongratana and Professor Emeritus Phaibul Naiyanetr for their guidance and training me toward this success.

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List of abbreviations

Abbreviation	Terminology
Museum	
CUMZ	Natural History Museum, Chulalongkorn University
PRC	Palaeontology Research and Education centre, Mahasarakham University
PRC-M-M	Palaeontological Collection of Research and Education centre, Mahasarakham University Mesozoic Era, Phylum Mollusca
General	
PW-M	Phu Wiang Molluscan Locality
ar	articulation
disar	disarticulation
l	left valve
r	right valve
mm	millimeter
cm	centimeter
m	meter
km	kilometer
Morphological term	
AA	Anterior adductor scar
APR	Anterior pedal retractor scar
PA	Posterior adductor scar
PL	Pallial line

Latin Abbreviation	Word	Meaning
ca	*circa*	about, approximately
cf.	*confer*	compare
et	*et*	and
gen.	*genus*	genus
inc. ced.	*incertae cedis*	uncertain affinity
sp. indet.	*species indeterminata*	indeterminate species
fam. indet.	*family indeterminata*	indeterminate family

CHAPTER I

INTRODUCTION

1.1 Rationale

The Sao Khua Formation is the third formation from basal of the Khorat Group (Racey and Goodall, 2009). It contains abundant fossils, including dinosaurs, crocodile, fish, turtle, freshwater shark, gastropods, bivalves and pollen (Kobayashi *et al.*, 1963; Hahn, 1982a, b; Buffetaut and Ingavat, 1983a, b; Martin *et al.*, 1994; Wongprayoon and Meesook, 1999; Cuny *et al.*, 2003; Tumpeesuwan, 2005; Racey and Goodall, 2009).

The Sao Khua Formation was interpreted as deposited in meandering river environment and the age was recognized as Early Cretaceous based on fossils assemblages and stratigraphic correlation (Meesook *et al.*, 2002). However, some arguments had occurred, that is some bivalves and reptile teeth were identified as marine species (Kobayashi *et al.*, 1963; Hahn, 1982a, b; Jearanaiwong, 2000). According to these results, some researcher interpreted that marine transgression had occurred (Hahn, 1982a).

The vertebrate specialists re-examined the problematic teeth, and re-identified as freshwater crocodile teeth (Buffetaut and Ingavat, 1983a, b). However, the problematic molluscan fossils are still in question, because the type materials are rather poor preservation for identification.

Nowadays, the good exposures of molluscan fossil localities were discovered in three study areas, namely, Nong Bua Lamphu (type locality of the Sao Khua Formation), Phu Wiang and Sahatsakhan Areas (Figure 1.1). The examination of

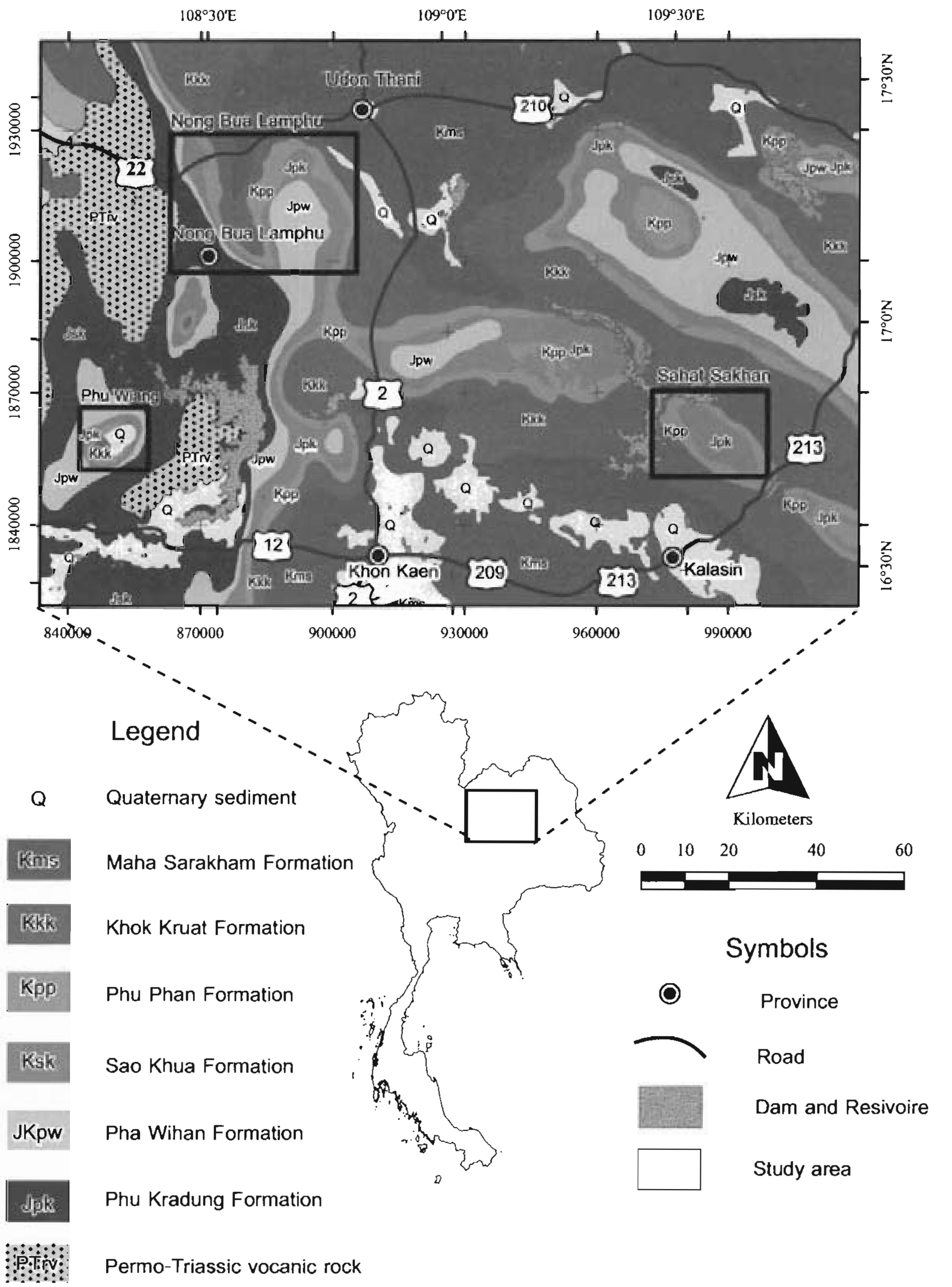


Figure 1.1 Geologic Map of the 3 study areas (Adapted after Department of Mineral Resources, 1999)

better materials of molluscan fossils and sedimentary facies analysis together with the block sampling method could yield better palaeontological information and more precise sub-environments of the Sao Khua Formation in the study areas.

Furthermore, the molluscan assemblages of the study areas can be compared with those trigonioidids from East Asia reported by Sha (2007). This should bring about the narrower age of the Sao Khua Formation.

1.2 Theoritical Framework

Palaeoecology is the study of the interactions of ancient organisms (fossils) with one another and with ancient environments (Goldring, 1999). Thus, to be successful on palaeoenvironment reconstruction, conclusion of depositional environments from sedimentary facies analysis and palaeoecological analysis of fossils are needed (Figure 1.2).

Sedimentary facies analysis

Each sedimentary facies is defined and distinguished from others by its geometry, lithology, sedimentary structures, palaeocurrent pattern, and fossils (Selley, 1980). The method of facies analysis includes the measurement and interpretation of vertical profiles, which has been realized that the vertical sections are inadequate for the description of facies variation in many environments (Miall, 1990). Therefore, the descriptions of large laterally extensive outcrop are important for the development of more quantitatively accurate reconstructions of depositional environments.

Architectural-element analysis was proposed for diagnosis of the three-dimensional variation in composition and geometry (Miall, 1985). This method subdivides the fluvial deposits into local suites consisting of one or more of a set of basic three-dimensional architectural-elements (Figure 1.3 and Tables 1.1-1.4). These methods should be used to determine micro-environment of the fluvial systems and reconstructed the palaeoenvironments of the 3 study areas.

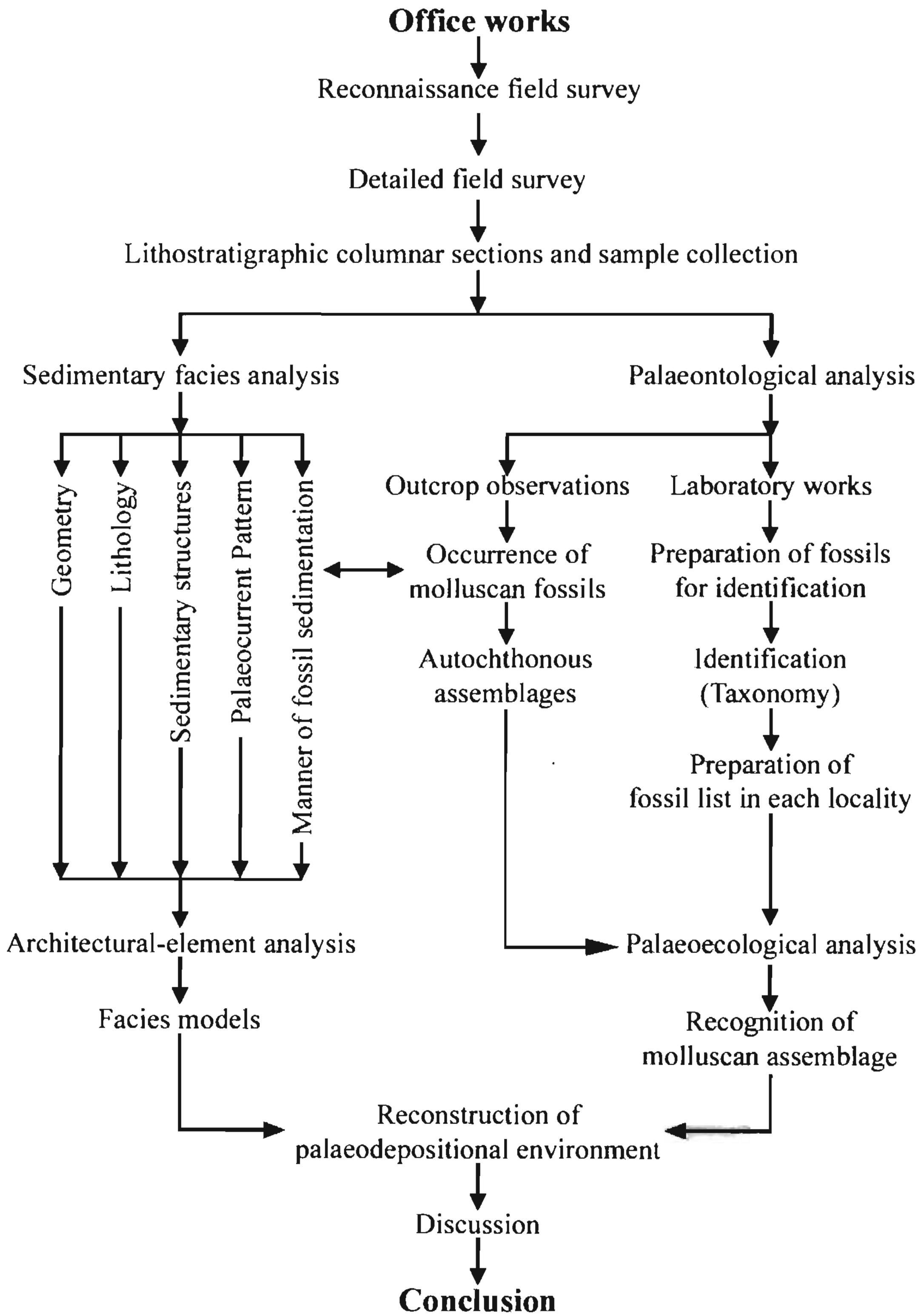


Figure 1.2 Schematic diagrams illustrating the research logic structure.

Table 1.1 Facies classification (After Miall, 1996).

Facies classification (Modified from Miall 1978c)

Facies code		Sedimentary structures	Interpretation
Gmm	Matrix-supported, massive gravel	Weak grading	Plastic debris flow (high-strength, viscous)
Gmg	Matrix-supported gravel	Inverse to normal grading	Pseudoplastic debris flow (low strength, viscous)
Gci	Clast-supported gravel	Inverse grading	Clast-rich debris flow (high strength), or pseudoplastic debris flow (low strength)
Gcm	Clast-supported massive gravel	-	Pseudoplastic debris flow (inertial bedload, turbulent flow)
Gh	Clast-supported, crudely bedded gravel	Horizontal bedding, imbrication	Longitudinal bedforms, lag-deposits, sieve deposits
Gt	Gravel, stratified	Trough cross-beds	Minor channel fills
Gp	Gravel, stratified	Planar cross-beds	Transverse bedforms, deltaic growths from older bar remnants
St	Sand, fine to very coarse, may be pebbly	Solitary or grouped trough cross-beds	Sinuous-crested and linguoid (3-D) dunes
Sp	Sand, fine to very coarse, may be pebbly	Solitary or grouped planar cross-beds	Transverse and linguoid bedforms (2-D dunes)
Sr	Sand, very fine to coarse	Ripple cross-lamination	Ripples (lower flow regime)
Sh	Sand, very fine to coarse, may be pebbly	Horizontal lamination parting or streaming lineation	Plane-bed flow (critical flow)
Sl	Sand, very fine to coarse, may be pebbly	Low-angle (< 15°) cross-beds	Scour fills, humpback or washed-out dunes, antidunes
Ss	Sand, fine to very coarse, may be pebbly	Broad, shallow scours	Scour fill
Sm	Sand, fine to coarse	Massive, or faint lamination	Sediment-gravity flow deposits
Fl	Sand, silt, mud	Fine lamination, very small ripples	Overbank, abandoned channel, or waning flood deposits
Fsm	Silt, mud	Massive	Backswamp or abandoned channel deposits
Fm	Mud, silt	Massive, desiccation cracks	Overbank, abandoned channel, or drape deposits
Fr	Mud, silt	Massive, roots, bioturbation	Root bed, incipient soil
C	Coal, carbon-aceous mud	Plant, mud films	Vegetated swamp deposits
P	Paleosol carbonate (calcite, siderite)	Pedogenic features: nodules, filaments	Soil with chemical precipitation

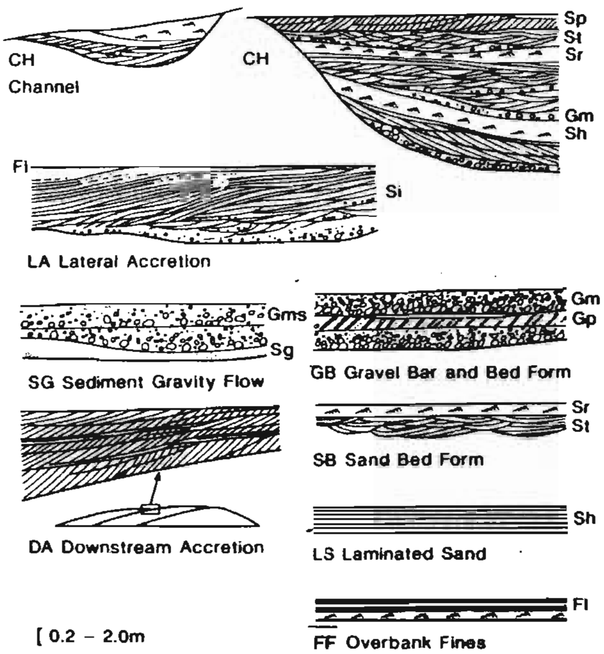


Figure 1.3 Basic architectural-elements in fluvial deposit (After Miall, 1996).

Table 1.2 Architectural elements of fluvial deposits. (After Miall, 1996).

Architectural elements in fluvial deposits. (Modified from Miall 1985)

Element	Symbol	Principal facies assemblage	Geometry and relationships
Channels	CH	Any combination	Finger, lens or sheet; concave-up erosional base; scale and shape highly variable; internal concave-up 3rd-order erosion surfaces common
Gravel bars and bedforms	GB	Gm, Gp, Gt	Lens, blanket; usually tabular bodies; commonly interbedded with SB
Sandy becforms	SB	St, Sp, Sh, Sl, Sr, Se, Ss	Lens, sheet, blanket, wedge, occurs as channel fills, crevasse splays, minor bars
Downstream-accretion macroform	DA	St, Sp, Sh, Sl, Sr, Se, Ss	Lens resting on flat or channeled base, with convex-up 3rd-order internal erosion surfaces and upper 4th-order bounding surface
Lateral-accretion macroform	LA	St, Sp, Sh, Sl, Se, Ss, less commonly Gm, Gt, Gp	Wedge, sheet, lobe; characterized by internal lateral-accretion 3rd-order surfaces
Scour hollows	HO	Gh, Gt, St, Sl	Scoop-shaped hollow with asymmetric fill
Sediment gravity flows	SG	Gmm, Gmg, Gci, Gcm	Lobe, sheet, typically interbedded with GB
Laminated sand sheet	LS	Sh, Sl; minor Sp, Sr	Sheet, blanket
Overbank fines	FF	Fm, Fl	Thin to thick blankets; commonly interbedded with SB; may fill abandoned channels

Table 1.3 Architectural elements of fluvial deposits in the Cutler Formation. (After Miall, 1996).

Architectural elements in the Cutler Formation, New Mexico. (Adapted from Eberth and Miall 1991)

	Symbol	Lithology	Geometry	Interpretation
Major ss. sheet	CHS	Gm, Se, St, Sh, Sl, rare Sp	w/d > 15, with 'wings', storeys 2–5 m thick, units < 1 km wide	Braided fluvial channel
Major ss. ribbon	CHR	Gm, Se, St, Sh, Sl, rare Sp	w/d< 15, with 'wings', storeys <5 m thick	Anastomosed fluvial channel
Minor ss. sheet	CS	Se, Sh, Sl, rare St, Sr	Tabular, flat-based, < 1 m thick, wing of CHS sheet	Sheet splay
Minor ss. lens	CRS	Se, St, Sl, Sh, Sr	w/d< 10, < 1 m thick	Minor crevasse channel
U-shaped mixed fill	CRM	Se, Sr, Fl, P	1–10 m thick 1–30 m wide	Deep, stable crevasse channel
Interlam. mixed sheet	FFP	Sr, Fl, P	Tabular, < 15 m thick	Proximal floodplain deposits
Siltstone-mudstone sheet	FFD	Fl, P	Tabular < 5 m thick	Distal floodplain deposits

Table 1.4 Architectural elements of the overbank environment (After Miall, 1996).

Architectural elements of the overbank environment

Element	Symbol	Lithology	Geometry	Interpretation
Levee	LV	Fl	Wedge up to 10 m thick, 3 km wide	Overbank flooding
Crevasse channel	CR	St, Sr, Ss	Ribbon up to a few hundred m wide, 5 m deep, 10 km long	Break in main channel margin
Crevasse splay	CS	St, Sr, Fl	Lens up to 10 × 10 km across, 2–6 m thick	Delta-like progradation from crevasse channel into floodplain
Floodplain fines	FF	Fsm, Fl, Fm, Fr	Sheet, may be many km in lateral dimensions, 10s of m thick	Deposits of overbank sheet flow, floodplain ponds and swamps
Abandoned channel	CH(FF)	Fsm, Fl, Fm, Fr	Ribbon comparable in scale to active channel	Product of chute or neck cutoff

Palaeoecological analysis

A bivalve fossil is one of an important parameter to identify the depositional environment of the host sediment. The autochthonous occurrence is very important indicators because the fossils were preserved *in situ*, whereas the allochthonous one reflects its transportational history, energy level and process of depositional environment (Goldring, 1999).

The population properties (such as growth rate, size distribution, population size, spatial distribution and morphological variability) are influenced by environmental parameters, thus, it should be able to determine the nature of palaeoenvironments by measuring these properties in fossil populations (Dodd and Stanton, 1981).

The community is an assemblage of co-occurring organisms that are controlled by the environment. They are potentially useful in the reconstruction of ancient environments. The community characteristics such as diversity and abundant have been used in palaeoenvironmental reconstruction (Dodd and Stanton, 1981).

The analysis of population properties and community characteristics in each locality need the systematic sampling of the samples. Block and bulk sampling methods were used to get this delicate information of fossil assemblage and to clarify the microenvironment. Examination of consistency of ecology in each fossil assemblage is evaluated by using the data from both qualitative and quantitative analyses of block samples (Sato, 1991).

1.3 Objectives

1.3.1 To study taxonomy and palaeoecology of the molluscan fossils of the Sao Khua Formation in the study areas.

1.3.2 To study stratigraphy and sedimentary facies of the Sao Khua Formation in the study areas.

1.3.3 To reconstruct palaeoecology of the molluscan assemblages of the Sao Khua Formation in the study areas.

1.4 The scope of the research

The scope of this research will be studied on taxonomy and palaeoecological analysis of the molluscan assemblages from the Sao Khua Formation in the study areas. The palaeoenvironments will be reconstructed by the sedimentary facies analysis and the architectural-element analysis which the fluvial styles will be recognized from the combination of architectural-elements of the fluvial deposit. The association among molluscan assemblages and sedimentary facies are also examined.

1.5 Hypothesis

The molluscan fauna, especially bivalves, which are mostly benthic animals, live in or on the soft sediments. They are well preserved in the sediment as in life position so this can be an important indicator for depositional environments. For instance, species composition and shell articulation of the channel-fill facies are different from the abandoned channel and proximal overbank deposits (Komatsu and Chen, 2000). These characteristics are resembled with those recent river and still water bivalves (Brandt, 1974). Therefore, the molluscan fossil assemblages studied should be significant recognition for sub-environment of the Sao Khua Formation in the study areas.

1.6 Methodology

Methodology can be categorized into 4 main aspects, namely the office work, field work, laboratory work and data interpretation, details are as follows.

1. Office work includes literature review, and topographic and geologic maps study.

1.1. Literatures review on previous works of geology, stratigraphy, and palaeontology of the Khorat Group, and taxonomy and ecology of freshwater bivalve.

1.2. Study on topographic and geologic maps in order to obtain the geologic setting of the study and adjacent areas.

2. Field work has been subdivided into 2 steps, namely the reconnaissance survey and detailed field investigation.

2.1. Reconnaissance survey will be done to get an overview of the geological setting of the study areas for further planning of detailed field investigation.

2.2. Detailed field investigation includes 6 aspects, i.e.

2.2.1. Compilation of geological map in each study areas.

2.2.2. Making lithostratigraphic columnar sections at 12 molluscan fossils localities.

2.2.3. Examination of geometry, lithology, sedimentary structures, palaeocurrent pattern and fossils for sedimentary facies analysis. Furthermore, describe the outcrop with the concept of three-dimensional architectural-elements for accurate reconstruction of palaeoenvironments.

2.2.4. Examination of the fossil characteristics such as shell orientation, articulation, and fragmentation on both bedding surface and vertical section of shell beds.

2.2.5. Sampling rock samples for petrographic study.

2.2.6 Sampling specimens for fossil identification and block sample size 30X30X20 cm, 3 blocks per 1 locality for palaeoecological analysis (or collected approximately same volume of weathering small blocks).

3. Laboratory works include 4 aspects, i.e.

3.1. Petrographic study

3.1.1 Examination of textures, composition, sedimentary structures, and fossil characteristics megascopically by making rock slabs.

3.1.2 Preparation of thin sections for rock identification under the polarizing microscope, and examine composition, textures, microfossils, molluscan fossil characteristics and relationship between mineral grains microscopically.

3.2. Preparation of molluscan fossils for identification by using air pen, sand blaster, and small cutters.

3.3. Preparation of fossil list in each locality

3.4. Block sample analysis

3.4.1 Counting number of individuals in each species per volume after break block sample.

3.4.2 Calculation of Index of species diversity (Shannon-Wiener Function) of each molluscan assemblage (Krebs, 1999).

3.4.3. Examination of shell fragmentation.

4. Results, discussions, and conclusions

4.1. Analysis of sedimentary facies.

4.2. Identification of the taxonomic position of each molluscan species.

4.3. Recognition of molluscan assemblages and age determination of the Sao Khua Formation.

4.4. Interpretation of palaeoecology of each molluscan species, assemblage and their association with sedimentary facies.

5. Report and publication

5.1. Publication of scientific papers and writing thesis.

5.2. Thesis presentation.

1.7. Expected results

1. Palaeontological characteristics of molluscan assemblages of the Sao Khua Formation in study areas.
2. Relationship of molluscan assemblages and palaeoenvironments.
3. Narrower relative age of the Sao Khua Formation by correlation of freshwater molluscan assemblages to the freshwater molluscan assemblages bearing horizons in East Asia.

CHAPTER II

REGIONAL STRATIGRAPHY

2.1 Regional Geology

Mainland Southeast Asia is divided into 4 terranes including Indochina, Sibumasu (Shan-Thai), and some parts of Western Burma and South China (Racey, 2009). Thailand is a part of both Indochina and Sibumasu terranes in eastern and western parts of the country, respectively (Figure 2.1). The study areas are on the Khorat Plateau in northeastern Thailand, which is located in the amalgamated Indochina terrane. Almost areas are covered by the Khorat Group.

The Khorat Group is the thick succession of Mesozoic red bed, which were occupied much of the Khorat Plateau in northeastern Thailand and some part of Laos and Cambodia (Figure 2.2).

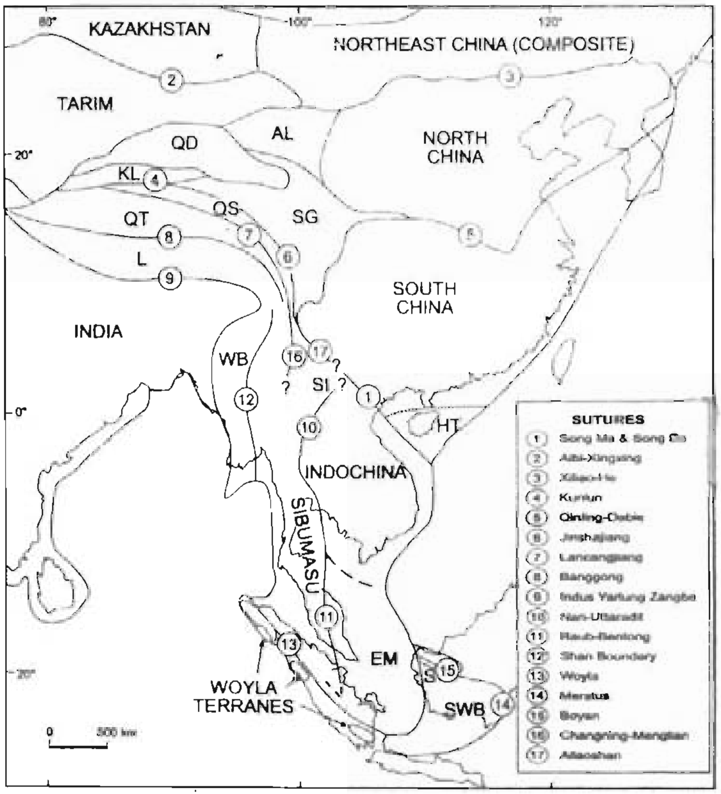


Figure 2.1 Regional Blocks and Sutures of East and Southeast Asia (After Racey, 2009).

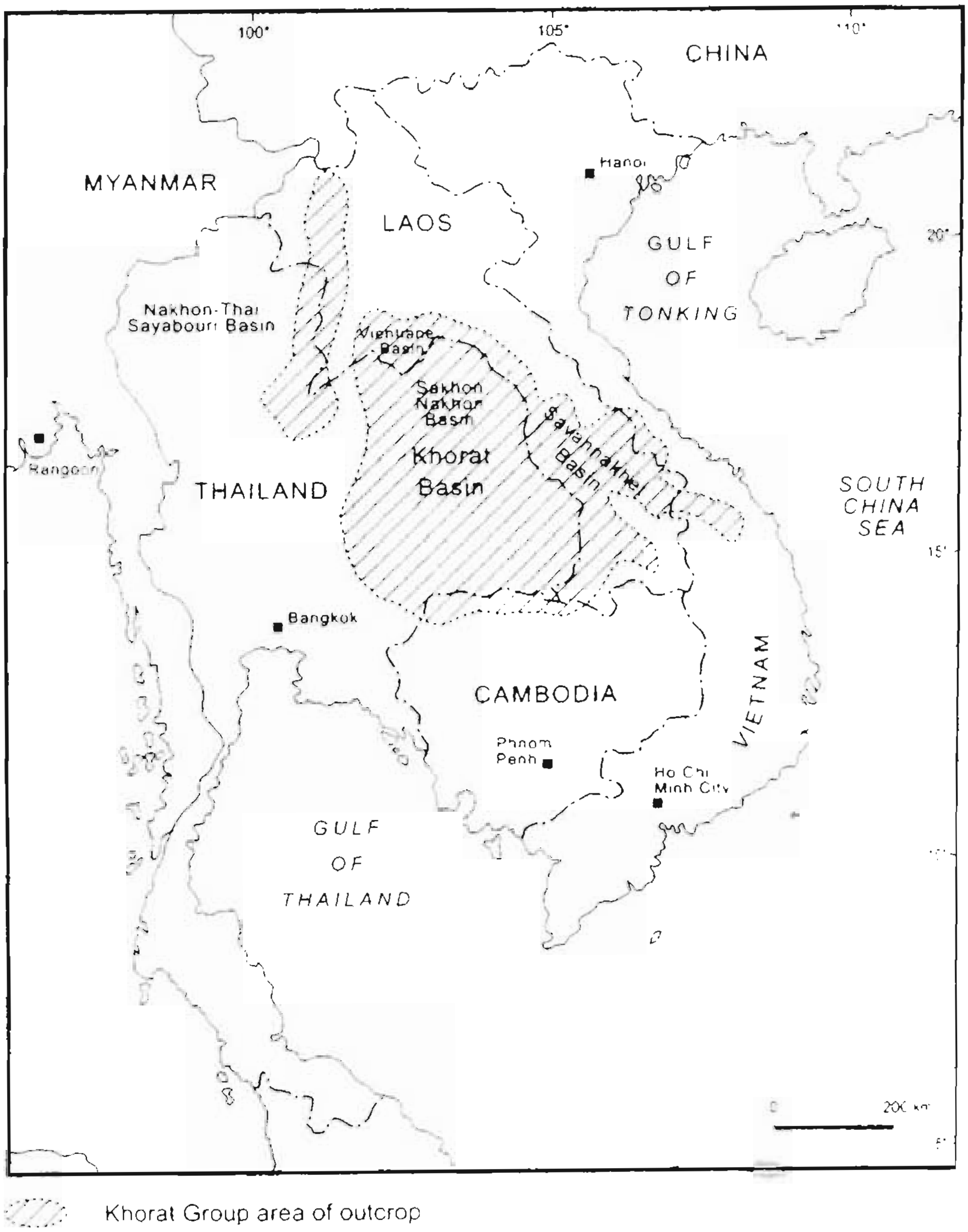


Figure 2.2 Distribution of the Khorat Group (Modified after Racey, 2009)

2.1.1 Terranes and Sutures

Mainland Southeast Asia comprises a complex mosaic of allochthonous terranes that accreted throughout the Late Palaeozoic to Mesozoic. There are 3 major blocks of relevance to the study area, including Indochina, South China and Sibumasu Blocks (Figure 2.1).

The Indochina Block is bounded to the northeast by the Song Ma Suture and to the northwest by the Nan-Uttaradit Suture.

The South China Block is bounded to the north by the Qingling-Dabie Suture, to the west by the Tertiary Long Men Shan Thrust Belt and to the southwest by the sinistral Ailaoshan and Song Ma Sutures.

The Sibumasu Block (Shan-Thai Block) is bounded to the west by the Western Burma Block along the Shan Boundary Fault (Sagaing Fault Zone).

2.1.2 Geological History

The Indochina and South China Blocks collided during the Early Carboniferous, the boundary being marked by the Song Ma Suture (Metcalfe, 1996).

The Sibumasu Block collided the Indochina Block during the Late Permian–Triasic along Nan-Uttaradit Suture, which continues southwards as the Phetchabun Fold Belt and in Peninsular Malaysia as the Bentong-Raub Suture (Racey, 2009).

During the Late Triassic a series of intracontinental rift basin developed across northeast Thailand extending into western Laos. These are filled with fluvial-lacustrine sands, silts and mudstone of the Huai Hin Lat Formation. The major tectonic event is observed on seismic sections separating the Huai Hin Lat Formation from the Lower Nam Phong Formation (Figure 2.3). Based on seismic sections in the Khorat Plateau, the Lower Nam Phong Formation was separated from the Upper Nam Phong Formation by an unconformity (Figure 2.3). This event represents hiatus with subsequence deposition of the overlying Upper Nam Phong, Phu Kradung, Phra

Wihan, Sao Khua, Phu Phan and Khok Kruat Formation, respectively in ascending order (Racey, 2009).

The uppermost part of the Khorat Group is marked by an unconformity between the Aptian Khok Kruat Formation and the Albian-Cenomanian Maha Sarakham Formation. This unconformity represents a mid-Cretaceous inversion, which led to the development of the Phu Phan Uplift in northeast Thailand and to the subsequent formation of a rimmed basin across much of the Khorat Basin into which the Maha Sarakham Formation was deposited. This was followed by the deposition of the Latest Cretaceous-Early Tertiary Phu Thok Formation.

The continuing collision of India with Eurasia during the Tertiary resulted in extensive dextral movement along the Song Da Suture, causing Indochina to move southeastwards along the suture. It also resulted in general uplift and inversion of the Khorat Plateau (Racey, 2009).

2.1.3 Tectonic model for the evolution of the Khorat Group

Metcalfe (1996) concluded that from the Late Permian-Triassic onwards the various blocks that now form much of Southeast Asia began to collide and accrete in the series of 4 events.

The first event is the collision of the South China and Indochina Blocks in early Carboniferous.

The second event is the collision and accretion of the Qiantang and Sibumasu Blocks to the Indochina Block in the Triassic. It associated with the late kinematic granites in northeast Thailand dated at 200 Ma (end Triassic) making the final stage of this collision.

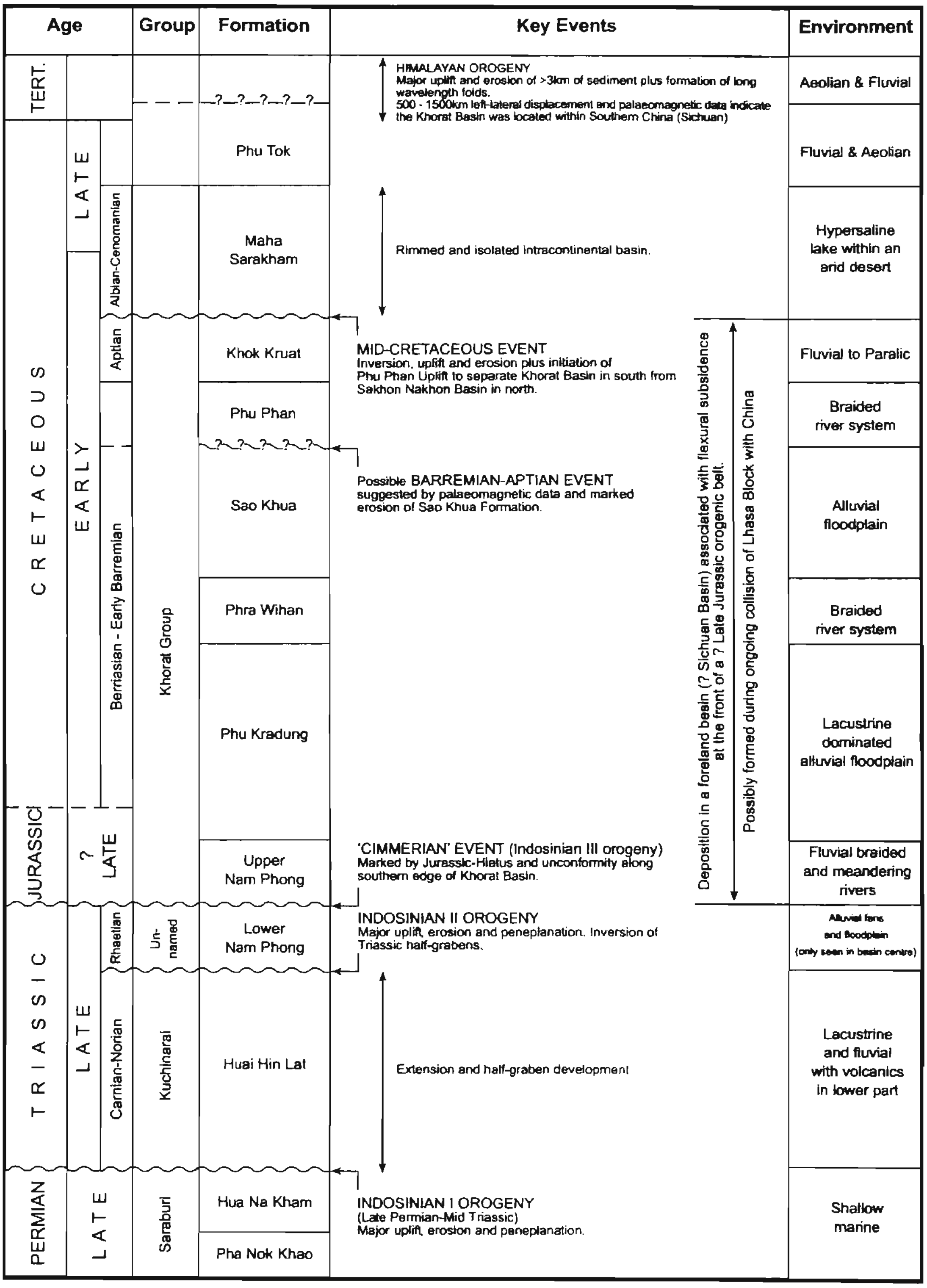


Figure 2.3 Revised stratigraphic column of the Mesozoic of northeast Thailand with the main depositional environments and key tectonic events. (Modified after Racey, 2009)

The third event, the Indochina Block then became sutured to South China in the Northeast along the Song Ma and Song Da Sutures and to the Sibumasu Block in the west along the Nan-Uttaradit Suture.

The final event, in the Early Cretaceous the Lhasa Block, and then in the Late Cretaceous the West Burma Block collided and accreted with the Qiantang-Sibumasu Terrane (Metcalfe, 1996).

2.1.4 Stratigraphy of the Khorat Group

Traditionally, non-marine Mesozoic Khorat Group in Khorat Plateau consists of 8 formations, namely, the Huai Hin Lat, Nam Phong, Phu Kradung, Phra Wihan, Sao Khua, Phu Phan, Khok Kruat and Maha Sarakham Formations, respectively, in ascending order, (Department of Mineral Resources, 1992; Meesook *et al.*, 2002).

Many previous researchers have assumed that the Nam Phong Formation which forms the basal part of the Khorat Group is Uppermost Triassic (Rhaetian), and the overlying Phu Kradung, Phra Wihan and Sao Khua Formations are the Early, Middle and Late Jurassic respectively, whereas, the Phu Phan and Khok Kruat Formations were assigned to Early Cretaceous (Figure 2.4).

These early stratigraphic studies of the Khorat Group, plant fossils were used couple with guesswork to assign ages for each formation. Subsequent age dating has been used mainly on vertebrate fossils from Phu Kradung and Sao Khua Formations (Buffetaut *et al.*, 1993, 2006, 2009) and palynology (Racey *et al.*, 1994, 1996; Racey and Goodall, 2009).

Racey *et al.* (1994, 1996) proposed new palynological evidence that reassigned the Phra Wihan and Sao Khua Formations to Early Cretaceous and the Phu Kradung to Late Jurassic to Early Cretaceous (Figure 2.4).

Several new vertebrate discoveries have also led to a revision of the age of the formations such that they are now more in line with the palynological dating (Buffetaut *et al.*, 2006, 2009).

Racey and Goodall (2009) proposed an updated palynological data that suggest an Early Cretaceous (Berriasian to Aptian age for the Phu Kradung to Khok Kruat Formations, and probably Late Jurassic age for the Upper Nam Phong and the lowermost part of the Phu Kradung Formations (Figure 2.4).

Normally, the traditionally Khorat Group composed of the continental red bed succession deposited in a semi-arid environment. Consequently, the preservation of organic matter is often poor and palynomorph are rare. However, it contained age diagnostic taxa, which the Khorat Group can be dated on the basis of palynology as follows, in ascending order.

Huai Hin Lat Formation

The Huai Hin Lat Formation unconformable overlies the Hua Na Kham Formation of Saraburi Group (Figure 2.3). The type section is located in Huai Hin Lat, Km 108 of Khon Kaen – Loei Highway. The thickness at the type section is 140 m. The formation consists of conglomerate, limestone conglomerate, gray to very dark sandstone, siltstone, shale and marl containing plant fossils. This formation was interpreted as deposited in fluvio-lacustrine depositional environment. The age was proposed to be Carnian to Rhaetian (Late Triassic) by Department of Mineral Resources (2001). Based on palynological studies from the Non Sung-1 well, the formation has yielded *Ovalipollis ovalis, Corollina minor, Corollina* sp., *Polycingulatisporites* spp. and *Staurosaccites* spp. (Racey *et al.*, 1996). Hail (1973) also recorded pollen assemblage, which would indicate a Carnian-Norian age.

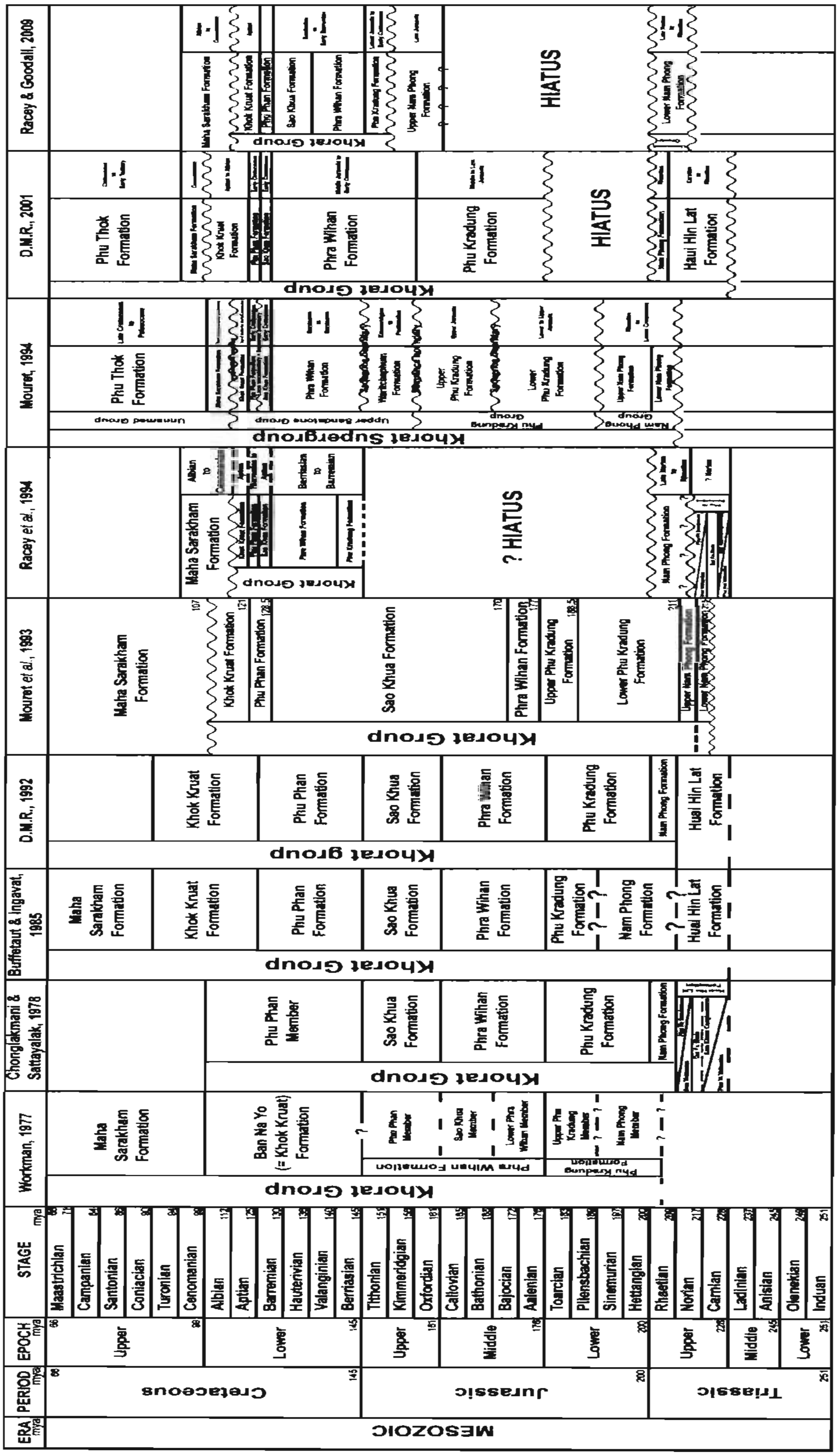


Figure 2.4 Mesozoic stratigraphy of Northeast Thailand (Modified after Racey *et al.*, 1994; Racey and Goodall, 2009)

Nam Phong Formation

The Nam Phong Formation unconformable overlies the Hui Hin Lat Formation (Figure 2.3). The type section is located in Nam Phong, Phu Kradung District, Loei Province. The thickness at the type section is 1,465 m. The formation consists of alternating thick-bedded siltstone, resistant fine-grained sandstone and conglomerate. This formation was interpreted as deposited in fluvio-lacustrine depositional environment. The previous age was proposed to be Rhaetian (Late Triassic) by Department of Mineral Resources (2001).

Racey *et al.* (1994, 1996) reported *Ovalipollis ovalis* from the Lower part of Nam Phong Formation, which indicated Ladinian-Rhaetian age for the formation. In the Non Sung-1 well, the formation yielded a palynomorph assemblage which was assigned to Norian-Rhaetian age. Mouret (1994) considered the age of the Upper Nam Phong Formation to extend into the Early Jurassic but no supporting dating evidence was presented to support this conclusion.

However, both subsurface and well data permit the identification of the Lower Nam Phong Formation of Late Triassic age and Upper Nam Phong Formation of possible Jurassic age separated by an unconformity.

Phu Kradung Formation

The Phu Kradung Formation contacts with the underlying Nam Phong Formation. It is considered to be unconformable in the subsurface along the southwest margin of the Khorat Plateau, suggesting a possible minor hiatus (Racey and Goodall, 2009). The type section is located in Phu Kradung, Phu Kradung District, Loei Province. The thickness at the type section is 1,001 m. The formation consists of soft siltstone and non-resistant sandstone with greenish gray calcareous conglomerate.

This formation was interpreted as deposited in a mainly lake-dominated floodplain cut by meandering and occasionally braided river channels. Originally, the formation was dated as Early-Middle Jurassic based on bivalve, fish, crocodile and turtles (Buffetaut and Ingavat, 1984, 1985).

Racey *et al.* (1994) firstly reported palynological data from this formation, which all of them are long-ranging palynomorph assemblage. The Huai Sai Samples from the upper part of the Phu Kradung Formation have yielded the Early Cretaceous marker *Dicheiropollis etruscus* and other palynomorphs. A similar assemblage was also recovered from samples collected from the widened road cut just east of Nong Bua Lamphu. The assemblage is dated as Berriasian to Early Barremian based on the occurrence of *D. etruscus* and absence of taxa younger than Early Barremian. The assemblage is dominated by *Corollina,* which suggested that the formation is probably older than Barremian based on the degree of dinosaur evolution.

However, the subsurface palynological data from Phu Horm-1 well also support an Early Cretaceous age for most. The Late Jurassic age cannot as yet be ruled out for it lowermost part.

Phra Wihan Formation

The Phra Wihan Formation shows gradational conformable contact with the underlying Phu Kradung and overlying Sao Khua Formations. The type section is located in the southern slope of Khao Phra Wihan. The thickness is 56-136 m. The Formation consists of white quartz sandstone and thin laminations of red siltstone. This formation was interpreted as deposited in fluvio-lacustrine environment. The age was proposed to Middle Jurassic to Early Cretaceous by Department of Mineral Resources (2001). It was previously assumed as Middle Jurassic based on the vertebrate fossils in the underlying and overlying formations. Both formations were thought to be Early and Late Jurassic, respectively. However, the Middle Jurassic - Early Cretaceous was indicated based on plant, crustacean and insect fossils (Heggeman *et al.*, 1990).

Racey *et al.* (1994) firstly proposed Berriasian to Barremian age for the formation. Based on palynomorph assemblage, it comprised several taxa, however, the most significant taxon is the Berriasian to Early Barremian *D. etruscus*. Therefore, the Berriasian to Early Barremian age was proposed for the Phra Wihan Formation.

Sao Khua Formation

The Sao Khua Formation shows gradational conformable contact at the outcrop with the underlying Phra Wihan and overlying Phu Phan Formations. However, the Phu Phan–Sao Khua contact is locally unconformity (Mouret *et al.* 1993; Mouret, 1994; Trakoolngam, 1999; Imsamut, 2003; Racey and Goodall, 2009). The type section is located at Km 35.2-41.5 of Udon Thani–Nong Bua Lamphu Road, The thickness at the type section is 512 m. The formation consists of non-resistant siltstone and conglomeratic sandstone. The formation was originally considered as Late Jurassic based on the rich of vertebrate fossils (Buffetaut *et al*, 2009). Based on palynological data, it was considered to Late Jurassic – Early Cretaceous (Hahn, 1982a, b). The palynological data of the underlying Phra Wihan Formation was assigned to Berriasian to Barremian (Racey *et al.* 1994). Therefore, the overlying Sao Khua Formation must be of a similar or younger age, which Early Cretaceous age was used by Department of Mineral Resources (2001).

Recently, Racey and Goodall (2009) analyzed the sample from Phu Phan Thong site in Nong Bua Lamphu. It yielded an assemblage dominated by the

Berriasian to Early Barremian *D. etruscus* and other palynomorphs. A second sample set from Huai Sai in Mukdahan yield common *D. etruscus* and *Corollina* sp. Angiosperm pollen are absent in all samples, suggesting an age no younger than Barremian – Aptian. Spores and Pollen that indicate sediment younger than Early Barremian is also absent. Based on the present of *D. etruscus*, the Berriasian to Early Barremian age is proposed for this Formation.

Phu Phan Formation

The Phu Phan Formation contacts with the underlying Sao Khua Formation. It is locally erosive and therefore may be unconformable, whereas the contact with the overlying Khok Kruat Formation is conformable. The type section is located in Phu Pha Phung in Phu Phan Range. The thickness is 183 m. The formation is composed of thick-bedded and cross-bedded conglomeratic sandstone and conglomerate. This formation was interpreted as fluviatile depositional environment.

The absent of the Berriasian to Early Barremian *D. etruscus* may indicate an age younger than Early Barremian. An unconformity between the Phu Phan Formation and the underlying Sao Khua Formation has been suggested by Maranate and Vella (1986) on the basis of palaeomagnetic data. Mouret *et al.* (1993) and Mouret (1994) suggested the presence of a minor unconformity at the base of the Phu Phan Formation, based on changes in lithology, palaeocurrents and seismic stratigraphy. Based on the ages of the over- and underlying formations, the age of the formation must, therefore, fall within the interval Mid-Barremian to Aptian.

Khok Kruat Formation

The Khok Kruat Formation shows unconformable contact with the overlying Maha Sarakham. The type section is located at Km. 207 and Km. 209 of Friendship Highway. The thickness is 709 m. The formation consists of soft siltstone and moderately resistant sandstone and caliche-siltstone pebbles of calcareous conglomerate. This formation was interpreted as fluviatile depositional environment.

The Aptian–Albian hybodont shark *Thaiodus ruchae* were found in this formation (Cappetta *et al.*, 1990). Sattayarak *et al.* (1991) indicated a latest Aptian age for the upper part of the formation based on palynology, although no floral list were provided from subsurface samples. The contact with the overlying Maha Sarakham Formation has yielded Albian–Cenomanian palynomorphs. Buffetaut and Suteethorn (1992) also have recorded Aptian–Albian dinosaurs from this formation. Based on evidences of fauna and flora present above, the age of the formation was proposed as Aptian to Albian (Middle Cretaceous) by Department of Mineral Resources (2001).

The formation is now considered to be Aptian in age but may extend to the Albian based on the palynology and vertebrate fauna (Racey and Goodall, 2009).

Maha Sarakham Formation

The Maha Sarakham Formation locally unconformably overlies the Khok Kruat Formation. Therefore, it was considered to separate from the Khorat Group (Sattayarak *et al.*, 1991; Racey *et al.*, 1994). The type section is located at Borabu District, Maha Sarakham Province. The thickness is 1,000 m. In Bamnet Narong Area, Chaiyaphum Province, the sub-surface lithostratigraphy of the formation was studied. It was subdivided into five members and proposed as marine evaporate deposits

(Yumuang, 1983). This formation comprises a mixed sequence of interbedded salt, anhydrite and red beds, which was deposited in a hypersaline, landlocked lake within an arid continental desert.

Harris (1977) recorded palynomorph assemblage that indicates a broad Early Jurassic–Cenomanian age. The presence of angiosperm pollen *Tricolpites* (middle to late Albian), *Tricolporites* (late Albian to early Cenomanian), and *Triporites* (Cenomanian), therefore, the formation was considered to be Albian–Cenomanian age. The age was proposed as Cenomanian (Late Cretaceous) by Department of Mineral Resources (2001).

2.1.5 Significance of the Khorat Group

Age dating

Revised age dating based on palynomorph indicates that the Phu Kradung to Khok Kruat Formations are mainly Early Cretaceous (Berriasian to Aptian) in age. A Late Jurassic age for the lowermost part of the Phu Kradung Formation can not be completely ruled out, because it lacks the key Early Cretaceous palynomorph *D. etruscus* but also has not yielded any Jurassic restricted palynomorphs (Racey and Goodall, 2009).

The subsurface well and seismic data suggest that the Nam Phong Formation can be subdivided into two formations, which Racey (2009) referred to as the Lower Nam Phong and Upper Nam Phong formations. The Lower Nam Phong formation is separated from the Upper Nam Phong formation by an unconformity. The age of the Lower Nam Phong formation can be constrained to the Late Triassic (Rhaetian) based on palynology and vertebrate data. The age of the Upper Nam Phong formation is more problematic. Palynological data from the Phu Horm-1 well presented by Racey and Goodall (2009) suggest that the Upper Nam Phong formation can not be older than Pliensbachian (middle Early Jurassic) based on the presence of *C. turbatus*, but is unlikely to extend into the Early Cretaceous (based on the absence of the early Cretaceous marker *D. etruscus*). Therefore, the age of the Upper Nam Phong Formation could fall between the Pliensbachian and the end of Jurassic.

Because the Lower Nam Phong Formation is bounded by unconformities it cannot according to the code of lithostratigraphic nomenclature be assigned to the same formation as the Upper Nam Phong Formation (Racey, 2009).

Fossils

All micro- and macrofossils found in the Khorat Group are interpreted as non-marine (Racey *et al.*, 1994, 1996) and would not therefore fit with a marine delta model. Moreover, no evidence of marine diagenesis or marine sedimentary structures or trace fossils has been noted in the Khorat Group (Racey, 2009).

Buffetaut *et al.* (2006) have noted that the vertebrate fauna from the Phu Kradung Formation of northeast Thailand is very similar to that from the Upper Shaximiao Formation of Sichuan in southern China, which is assigned Late Jurassic age. The fauna of the Sao Khua Formation is in part similar to that of the Napai Formation from Guangxi in southern China, whereas, the vertebrate fossils of the Khok Kruat Formation are very similar to the Aptian-Albian forms from China.

Palaeocurrents

Palaeocurrent data for the Khorat Group from outcrops presented by Heggemann *et al.* (1994) and Racey *et al.* (1996) indicate that the Nam Phong Formation had both eastward- and westward-directed palaeocurrents, whereas in the

Phu Kradung to Phu Phan Formations they are mainly directed towards the southwest and west, implying sediment sourcing from the northeast and east (Racey, 2009). The Khok Kruat palaeocurrents tend to be directed towards the west (Racey, 2009).

Mouret *et al.* (1993) and Mouret (1994) have also suggested the presence of a minor unconformity at the base of the Phu Phan Formation based on changes in lithology and palaeocurrents couple with seismic stratigraphy. This evidence also reported in some localities of Phu Phan Area (Trakoolngam, 1999; Imsamut, 2003).

Provenance

Racey *et al.,* (1996) noted that, based on petrographic study, the Hui Hin Lat and Nam Phong Formations contained significant volcanic component unlike the overlying formation (Figure 2.5). The Phu Kradung to Phu Phan Formations are dominated by metamorphic quartz.

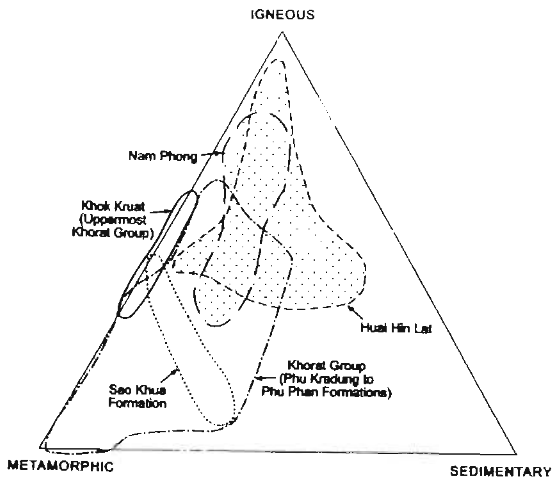


Figure 2.5 Variation in rock fragment types between the formations of the Khorat Group and the Triassic Hui Hin Lat and Nam Phong Formations (after Racey, 2009).

The Mesozoic (Late Triassic to Early Cretaceous) continental red beds expose in the Southeast Asia and Southern China (Figure 2.6). Carter and Bristow (2002) have suggested that the position of the Khorat Basin in Early Cretaceous times was more probably much closer to the Sichuan Foreland Basin in Southern China (Figure 2.7). The Khok Kruat Formation contains a large proportion of detrital feldspar, indicating a possible igneous component (Figure 2.5), and differs from all underlying formation of the Khorat Group in having westerly directed palaeocurrents (Figure 9 in Racey, 2009).

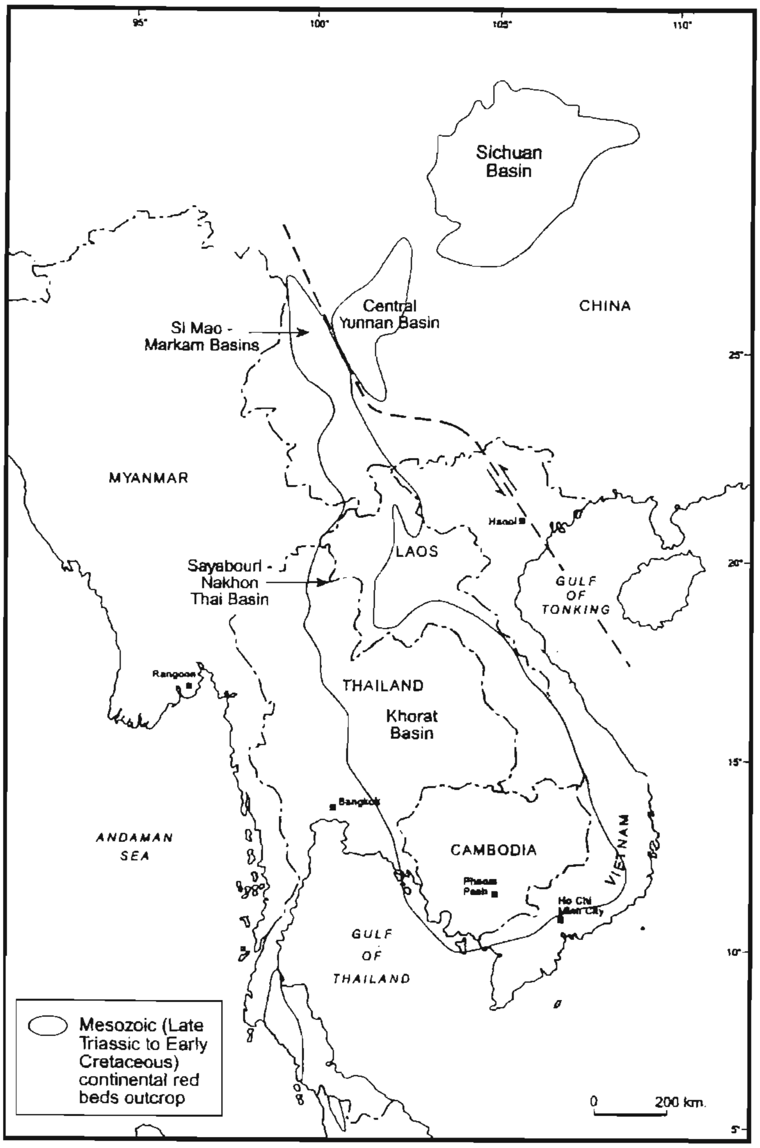


Figure 2.6 Distribution of the Mesozoic red beds of Late Triassic to Early Cretaceous age (Modified after Racey, 2009).

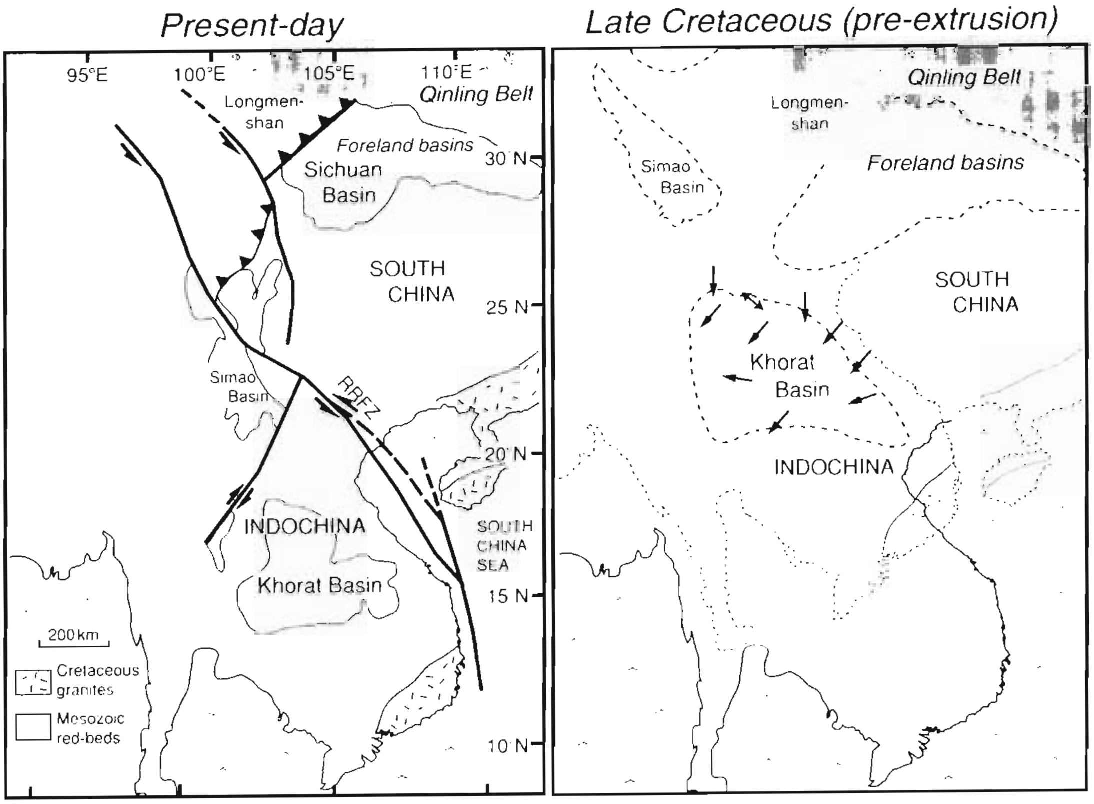


Figure 2.7 Map showing the present-day (left side picture) and restored Cretaceous (dashed lines in right picture) locations of the Khorat basin (After Carter and Bristow, 2002).

<u>Diagenesis</u>

Petrographic studies of the Khorat Group have revealed a complete absence of marine cements, with the calcite and ferroan calcites observed being clear pedogenic origin (Racey, 2009). All diagenetic processes were interpreted as deposition in an arid to semi-arid continental clastic setting (Canham *et al.*, 1996).

CHAPTER III

LITHOSTRATIGRAPHY AND FACIES ANALYSIS OF THE MOLLUSCAN FOSSIL LOCALITIES IN THE STUDY AREAS

3.1 Stratigraphy of the Study Areas

The non-marine Mesozoic Khorat Group in the Khorat Plateau consists of 5 formations, namely, in ascending order, the Phu Kradung, Phra Wihan, Sao Khua, Phu Phan and Khok Kruat Formations (Figure 2.4).

The Sao Khua Formation was proposed for the thick succession of friable siltstones and sandstone that lies between the well cemented Phra Wihan and Phu Phan Formations (Ward and Bunnag, 1964). It was conformably underlain and overlain by the Phra Wihan and Phu Phan Formations, respectively.

Twenty-two molluscan fossil localities were reported from the Sao Khua Formation in the Khorat Plateau (Kobayashi *et al.* 1963; Ward and Bunnag, 1964; Inthuputi and Suwanasing, 1978; Hahn, 1982b; Meesook and Wongprayoon, 1999; Wongprayoon and Meesook, 1999; Jearanaiwong, 2000; Wongprayoon and Meesook, 2002; Imsamut, 2003; Tumpeesuwan, 2005; Tumpeesuwan and Sato, 2005). However, good exposure of twelve molluscan fossil localities in three main areas should be studied in details of sedimentary facies analysis and palaeontological analysis. including, the Nong Bua Lamphu, Phu Wiang, and Sahatsakhan Areas (Figure 1.1). The stratigraphy of these study areas are shown in Table 3.1.

Table 3.1 Stratigraphy of the Khorat Group in the 3 study areas. A synthesis based on Kobayashi *et al.* (1963), Ward and Bunnag (1964), Hahn (1982b), Inthuputi and Pluhar (1982), Buffetaut and Ingavat (1983a, b), Chonglakmani *et al.* (1985a, b), Suteethorn and Jarnyahran (1985), Matin *et al.* (1994), Buffetaut *et al.* (1996), Wongprayoon and Meesook (1999), Jearanaiwong (2000), Meesook *et al.* (2002), Wongprayoon and Meesook (2002), Imsamut (2003), Tumpeesuwan (2005), Tumpeesuwan and Sato (2005), and Tumpeesuwan *et al.* (2010).

Phu Wiang	Nong Bua Lamphu (Type section)	Sahatsakhan
soil and laterite	Soil	Soil and laterite
Khok Kruat Formation sandstone, siltstone, claystone and calcrete horizon		**Khok Kruat Formation** sandstone, siltstone, mudstone and conglomerate **Fossils** vertebrate bones, bivalve
Phu Phan Formation sandstone, conglomeratic sandstone with quartz, volcanic, quartzite and chert pebbles. Siltstone and claystone are intercalated locally	**Phu Phan Formation** conglomeratic sandstone or conglomerate with quartz and chert pebbles Diastem	**Phu Phan Formation** massive sandstone, conglomeratic sandstone with volcanic, chert and quartz pebbles
Sao Khua Formation sandstone, siltstone, claystone, calcrete horizon, calcareous conglomerate **Fossils** Dinosuars:- *Phuwiangosuarus sirindhornae* - *Siamosaurus suteethorni* - *Siamotyranus isanensis* Crocodile :- *Goniopholis phuwiangensis* Bivalve :- *Pseudohyria (Matsumotoina) somanai* - *Unio* sp. - *Plicatounio* sp. - *Nippononaia* sp. - Mytilinae *gen. et sp. indet.* fish, turtle, hybodont shark, ostracod, pollen and plant fragments	**Sao Khua Formation** shale, siltstone, calcareous concretions, arkosic sandstone, conglomerate **Fossils** Dinosuars:- suaropod Crocodile Bivalve :- *Pseudohyria (Matsumotoina) somanai* - *Cardinioides magnus* - *Mytilus (Pachymytilus) rectangularis* Gastropod :- *Natica*-like gastropods fish, turtle, hybodont shark and pollen	**Sao Khua Formation** mudstone, siltstone, sandstone, lime-nodule conglomerate, caliche **Fossils** Dinosuars:- *Phuwiangosuarus sirindhornae* sauropods and theropods Crocodile, fish, turtle Bivalve :- *Pseudohyria (Matsumotoina) somanai*
Phra Wihan Formation quartzitic sandstone, siltstone and claystone are intercalated locally **Fossils** dinosaur footprints	**Phra Wihan Formation** quartzitic or partly arkosic sandstone with intercalation of shale and siltstone **Fossils** worm casts, pollen	
Phu Kradung Formation sandstone, siltstone, claystone, calcrete horizon	**Phu Kradung Formation** shale, siltstone, soft sandstone. **Fossils** Crocodile:- *Sunosuchus thailandicus* worm tubes, pollen	

3.2 Characteristic of the Sao Khua Formation and its stratigraphic relationships

The Sao Khua Formation contains abundant vertebrate and invertebrate fossils, especially molluscs. In searching for molluscan fossil sites ability to distinguish the Sao Khua Formation from its underlying and overlying formations is needed.

3.2.1 Phra Wihan Formation

Sandstones are thick-bedded and cross-bedded. They vary from well cemented to friable, from very fine- to medium-grained. They are less calcareous, silty, and micaceous than sandstone of the underlying and overlying formations. Ward and Bunnag (1964) summarized several characteristics that were not observed in sandstone of the underlying and overlying formations as follows.

1. Some beds are grayish-orange to pale orange in color (Figure 3.1A).
2. Some beds are reddish- or limonitic-brown on weathered surfaces.
3. Some beds are composed of clean quartz sand grains with a few scattered gray to black chert grains (Figure 3.1B).
4. Some beds are conglomeratic sandstone with pebbles of quartz and chert.
5. Some beds are quartzitic.
6. Many sand grains have secondary overgrowth of quartz.

3.2.2 Sao Khua Formation

Sandstones vary from yellowish-gray to yellowish-brown and pale red (Figure 3.1C). They are thin to thick units of siltstone. The sandstone is very fine- to medium-grained, well cemented to friable, and slightly to moderately calcareous in some beds. About half of the beds are moderately to slightly silty, a fourth are moderately to slightly micaceous, and about the third are slightly conglomeratic with pebbles and fragments of siltstones and shale (Figure 3.1D) and rarely of quartz and chert. Cross-bedding was observed in about half of beds.

Siltstone is grayish-red to reddish-brown, usually is slightly mottled with greenish-gray. It is normally soft and easily weathered, but the calcareous beds are more resistant.

Some beds are lenticular, calcareous caliche-siltstone pebble conglomerates. The colors vary from grayish-red and pale red to light olive-gray and greenish-gray.

Normally, the Sao Khua Formation takes the topographic form of the strike valley between the cuestas formed by the Phra Wihan and Phu Phan Formations.

3.2.3 Phu Phan Formation

Sandstones vary from yellowish-gray to pale orange, pinkish-gray and pale red. They are thick bedded and cross-bedded and show wide variation in the degree of cementation (Figure 3.1E). The sandstones are fine- to coarse-grained, some beds are calcareous, silty, or micaceous. Beds are typically conglomeratic to a widely varying degree, with rounded pebbles of quartz and chert and reddish-brown or greenish-gray siltstone (Figure 3.1F).

The cuesta or ridge expressed by the Phu Phan Formation is more or less isolated peaks along the course of its outcrop. This topographic expression is probably due to highly variable cementation of the bed and possibly also to unusually pronounced lenticularity of beds.

Figure 3.1 A, Grayish-orange, fine-grained sandstone of the Phra Wihan Formation overlies on green-gray mudstone-siltstone; B, Sandstone with lenes of quartz and chert granules; C, Yellowish channel sandstone of the Sao Khua Formation overlies on dark brown mudstone-siltstone; D, Yellowish-brown, cross-bedded sandstone with small mud pebbles; E, Conglomeratic sandstone of the Phu Phan Formation overlies on pale orange friable medium-grained sandstone.; F, Yellowish-gray conglomerate with quartz and chert pebbles. (Scale in A and C is 120 cm; Pen in D is 14 cm height; Field of view in B and F is about 30 cm height, in E is about 4 m height)

3.3 Lithostratigraphy and facies analysis of the molluscan localities in the study areas.

Molluscan localities were reported in 3 sections of Nong Bua Lamphu Area nearby the type section, including Phu Lon, Phu Chan, and Ban Huai Dua (Hahn, 1982b). The thick shell bivalves were recognized in all localities as cf. *Cardinioides magnus* Kobayashi and Hayami, 1963 without description and illustration of fossils.

At the type section, Trakoolngam (1999) studied at 3 localities, including Thao To Waterfall, between Km 82 and Km 82.6 of Nong Bua Lamphu-Udon Thani Highway, and Phu Lon. There is no report of molluscan fossil locality.

In the present study, several localities around Nong Bua Lamphu, Phu Wiang, and Sahat Sakhan were examined for searching molluscan localities. These molluscan localities were examined in details of sedimentary facies such as lithology, geometry, sedimentary structure, palaeocurrent pattern and fossils were described as follow.

3.3.1 Nong Bua Lamphu Area

3.3.1.1 Type section of the Sao Khua Formation

The type section is in the drainage area of the Huai Sao Khua, an intermittent stream that flow westward parallel highway between Udon Thani and Nong Bua Lamphu (Figure 3.2). Thickness of the formation at the type section is 512 m. A few fossils were found in thick calcareous, conglomeratic sandstone, and in an overlying conglomerate in the upper part of the type section (Figure 3.3). They include shells, tooth, and silifified bone fragments. The shells were identified as naticoid gastropod and two species of bivalves, *Cardinioides magnus* Kobayashi and Hayami, 1963 and *Mytilus rectangularis* Kobayashi and Hayami, 1963, whereas tooth was identified as ichthyosaur tooth (Kobayashi *et al.,* 1963).

The poorly preserved shells of naticoid gastropod and thick-shelled bivalves of which *Cardinioides magnus* Kobayashi and Hayami, 1963 were found from sandstone unit 21. It is 10.5 m. thick of pale red to light brownish gray, well cemented calcareous, thick-bedded; conglomeratic in zones with fragments of grayish red siltstone up to 1 cm in diameter. Ichthyosaur tooth was also discovered in this unit, which was re-identified as freshwater crocodile by Buffetaut and Ingavat, (1983a, b).

Naticoid gastropod and bivalves *Mytilus rectangularis* Kobayashi and Hayami, 1963 were found from rock unit 22, which overlying on unit 21. It is 2.1 m. thick of conglomerate, pale red, well cemented; contain pebbles of grayish red calcareous caliche in fine- to medium-grained, calcareous, sandy matrix.

However, in the present study, the outcrops of the type section could not be found in the stream, reported by Ward and Bunnag (1964).

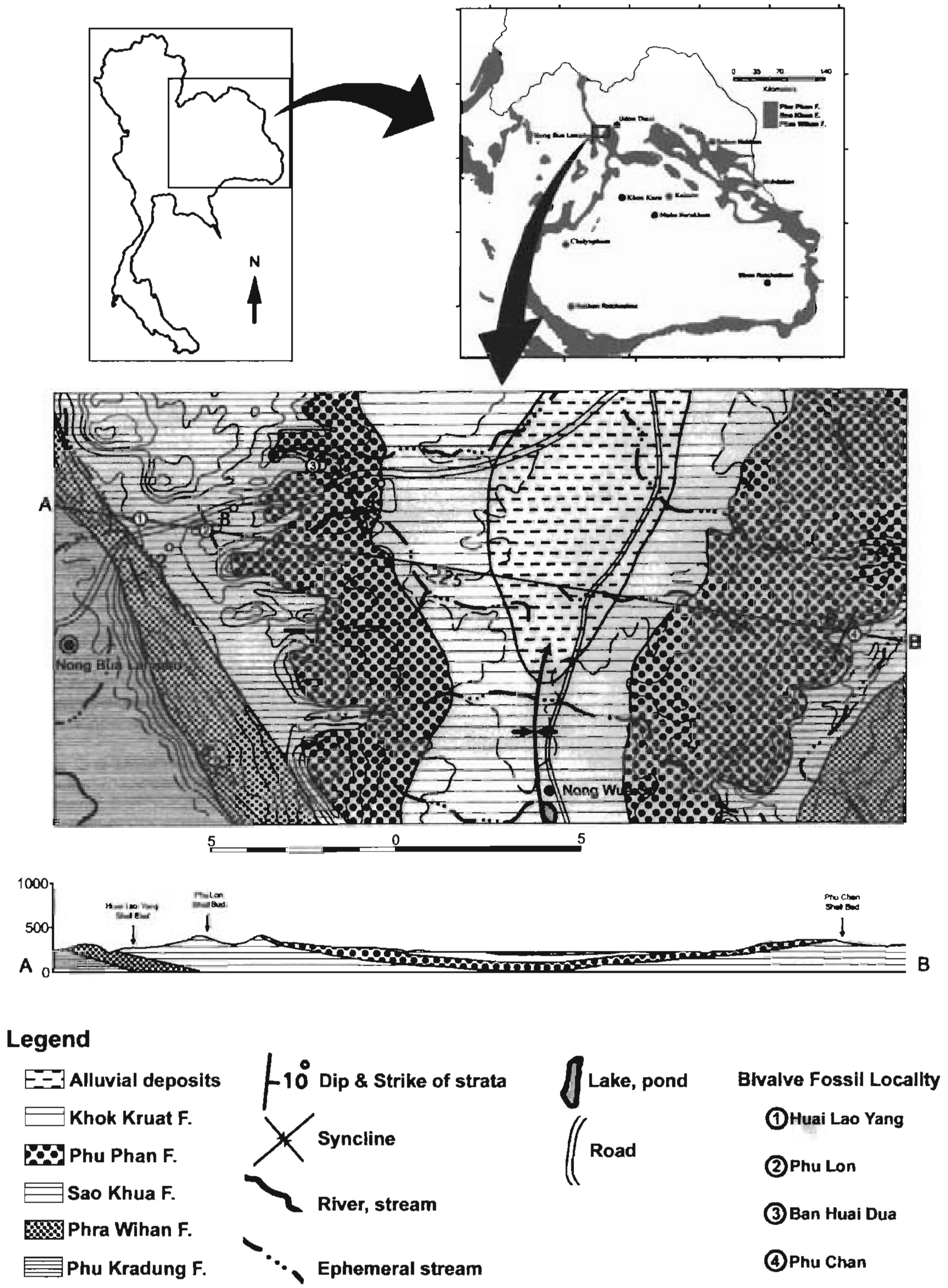


Figure 3.2 Geological Map of Nong Bua Lamphu Area (modified after Geological map of Thailand sheet Changwat Udon Thani and Vang Vieng, NE 48-9, Chonglakmani *et al.,* 1985a) showing Index map of the Huai Lao Yang, Phu Lon, Ban Huai Dua, and Phu Chan Shell Beds.

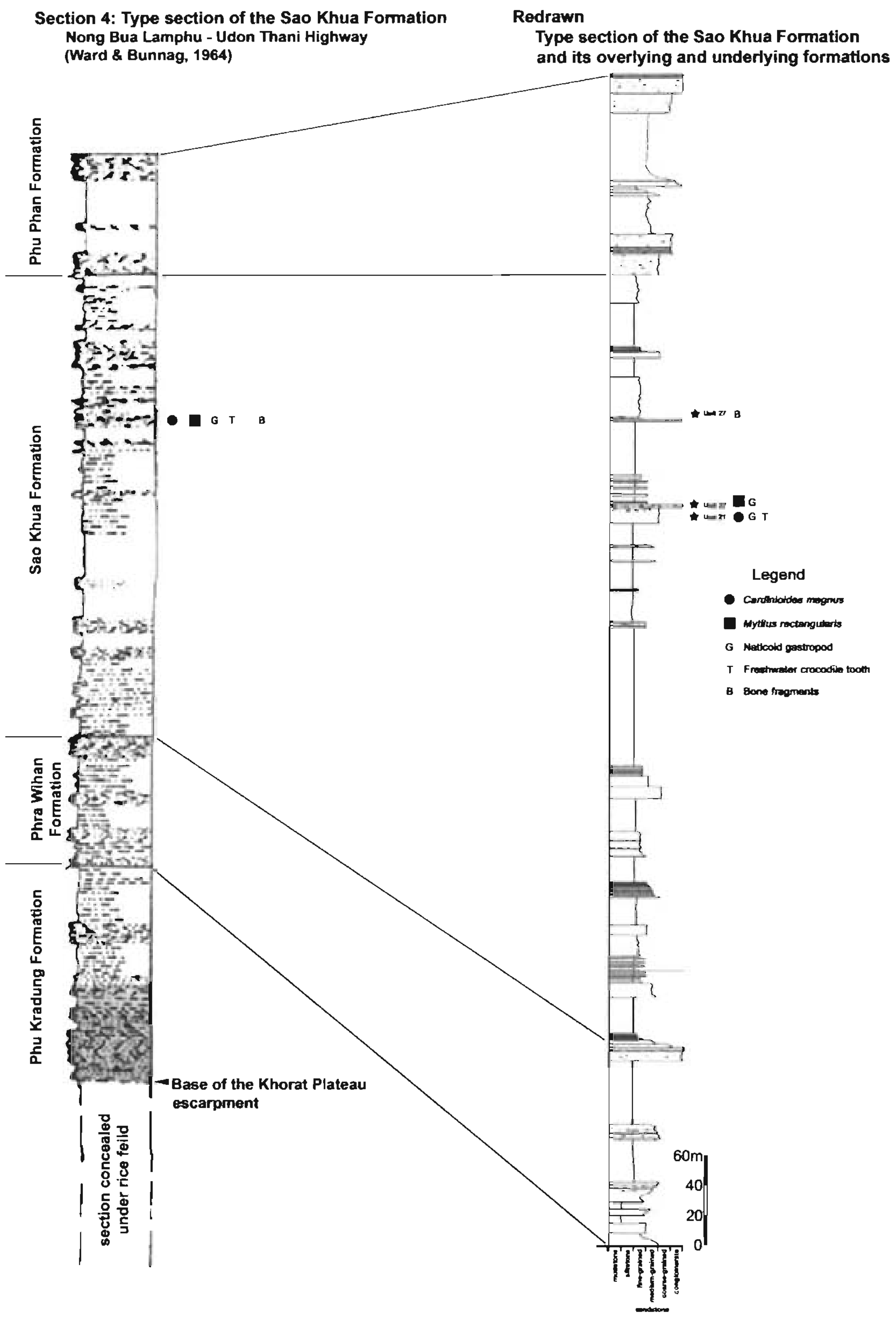


Figure 3.3 Type section of the Sao Khua Formation (left section) and Redrawn type section (right section). (Left section after Ward and Bunnag, 1964).

3.3.1.2 Huai Lao Yang Molluscan Fossil Locality

Map sheet: 5443 II CHANGWAT NONG BUA LAMPHU

UTM grid reference: $^{2}31^{100m}$E $^{19}07^{100m}$N

Location: Soil pit near Huai Lao Yang Water Station (Figure 3.2 and 3.5A).

Accessibility: From Nong Bua Lamphu, between Km 82 to Km 83 of Highway Number 210 before arrive Ban Phu Phan Thong; turn left to Huai Lao Yang Water Station. The locality is about 0.5 km from Ban Phu Phan Thong.

Lithology: The shell bed is red brown mudstone-siltstone with numerous internal molds of bivalve fossils (Figure 3.4 and 3.5A-D).

Geometry: Shell bed is lenticular. The most thickness part is about 0.6 m.

Sedimentary structures: The shell bed is massive with numerous molds of molluscs (Figure 3.5B-D). The lateral extent of shell bed shows gradational contact to laminated, very fine- to medium-grained sandstone with numerous burrows.

Fossils: This molluscan assemblage composes of *Nakamuranaia* sp., *Yunnanoconcha* sp., *Sinonaia* sp., *Koreanaia (Eokoreanaia)* sp., *"Cardinioides" magnus* and gastropods. Other fossils from this locality are bony fish, hybodont shark teeth, pterosaur teeth, crocodile teeth, turtle plates, theropod teeth and coprolites.

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), mudstone-siltstone with freshwater molluscs might be classified as Massive, Mud, Silt Lithofacies (Fm) (Table 1.1 and Figure 3.4) and Overbank fines Element (FF) (Table 1.2, 1.4 and Figure 3.4). Palaeoecology of the shell bed might be interpreted as deposits from standing pools of water during low-stage channel abandonment, overbank, and floodplain swamps (Table 1.2, 1.4 and Figure 3.4).

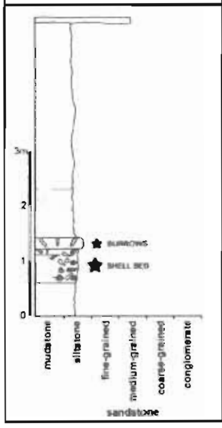
Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	sheet 0.2 m. thick	Horizontal lamination with mud pebbles	-	Sh	LS	Flash flood deposit
	Sheet 4.8 m. thick	Massive or faint lamination	-	Fsm	FF	Backswamp or abandoned channel deposit
	Lenticular < 0.6 m. thick	Lamination Burrows	**Mollusc molds** *Koreanaia (Eokoreanaia) sp.* *Yunnanoconcha sp* *Nakamuranaia sp* *Sinonaia sp.* *'Cardinioides' magnus* *Viviparus sp.* **Bony fish scales, turtles plates** **Shark & crocodile teeth** **Theropod teeth** **Coprolite**	Fm	FF	Overbank, abandoned channel & swamps

Figure 3.4 Lithologic columnar section at Huai Lao Yang Locality. UTM grid reference: $^{2}31^{100m}E$ $^{19}07^{100m}N$

Figure 3.5 A, Outcrop of Huai Lao Yang Shell Bed; B, Mold of *Sinonaia* sp. exposed on the bedding surface of weathering out of red mudstone-siltstone; C and D, Molds of numerous bivalve show no preferred orientation. (Coin diameter is 2 cm).

3.3.1.3 Phu Lon Molluscan Fossils Locality

Map sheet: 5443 II CHANGWAT NONG BUA LAMPHU

UTM grid reference: $^{2}32^{800m}$E $^{19}06^{600m}$N

Location: Phu Lon (Figure 3.2).

Accessibility: Between Km 84 and Km 85 of Highway Number 210. From Nong Bua Lamphu, Phu Lon is on the right side of the Highway.

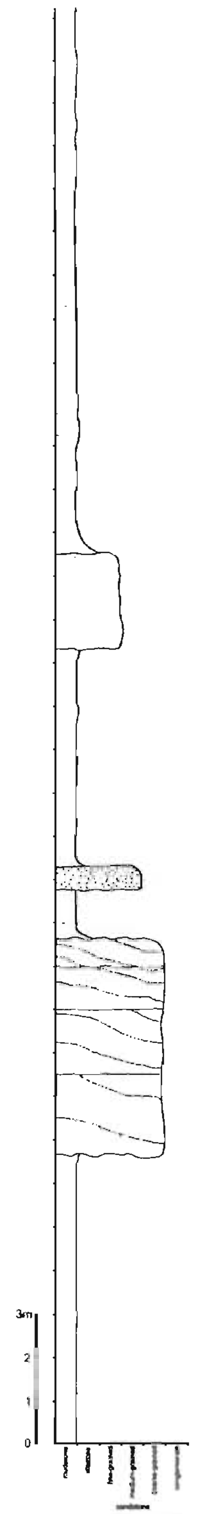
Lithology: Shell bed is green grey, lime-nodule conglomerate (Figure 3.6 and 3.7A-C).

Geometry: Shell bed is lenticular. The most thickness part is approximately 0.65 m. It bounded at the top and bottom by erosion surface.

Sedimentary structures: Shell bed is massive. The overlying bed is cross-bedded medium-grained sandstone with lime and mud pebbles (Figure 3.6).

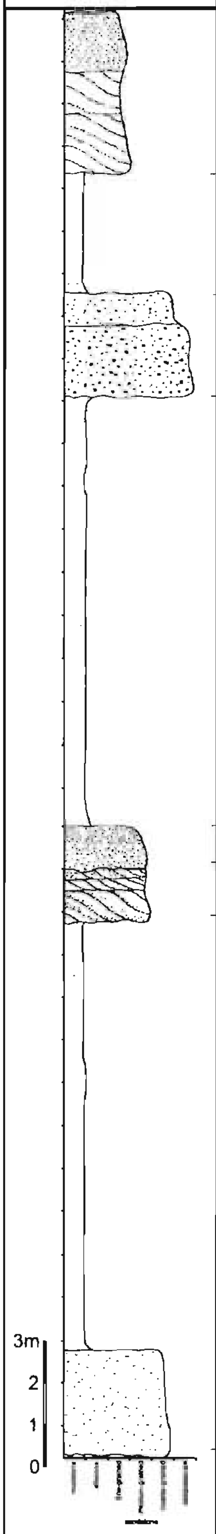
Fossils: Almost fossils are articulated bivalves of *Pseudohyria (Matsumotoina) somanai*, Trigonioidoidea *fam. indet.* and *incertae cedis* (5). Disarticulated valves are very rare. Tooth of *Siamosaurus suteethorni* was also found in the shell bed.

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), lime-nodule conglomerate might be assigned to Matrix-supported Gravel Lithofacies (Gmm) (Table 1.1 and Figure 3.6). Trough cross-bedded pebbly sandstone overlies on this shell bed might be classified as Trough-Cross-Bedded Sand Lithofacies (St) (Table 1.1 and Figure 3.6). Combination of both Gmm and St might be classified the outcrop as Lateral accretion macroform Element (LA) (Table 1.2, Figure 1.3 and 3.6). Palaeoecology was interpreted as point bar deposits, which bivalve fossils in lime-nodule conglomerate were possible buried as channel lag deposit, and then was buried by point bar deposit.



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular ~ 2 m. thick	Massive or faint lamination	-	Sm	LS	Flat flood deposit
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular	Massive or faint lamination	-	Sm	LS	Flat flood deposit
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular ~ 5 m. thick	Planar & trough cross-bedding	-	Sp, St	DA	Mid-channel sand flat
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp

Figure 3.6 Lithologic columnar section at Phu Lon Locality. UTM grid reference: $^{2}32^{800m}E$ $^{19}06^{600m}N$



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular	Massive or faint lamination	-	Fsm	CH(FF)	Abandoned channel
	Lenticular	Planar & trough cross-bedding	-	Sp, St	DA	Mid-channel sand flat
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular	Massive	-	Gmm	SG	Plastic debris flow in channel
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular	Massive or faint lamination	-	Fsm	CH(FF)	Abandoned channel
	Lenticular	Planar & Trough cross bedding	-	Sp, St	DA	Mid-channel sand flat
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular ~ 2.5 m. thick	Massive or faint lamination	-	Sm	LS	Flat flood deposit

Figure 3.6 Lithologic columnar section at Phu Lon Locality (continued).

Lithology	Geometry	Sedimentary structures	Fossils	Interpretation: Facies	Interpretation: Architecture Elements	Interpretation: Palaeoecology
	Lenticular ~2 m. thick	Massive	-	Gmm	SG	Sediment gravity flow deposit Plastic debris flow, high strength viscous
	Lenticular ~3 m. thick	Low-angle cross lamination	-	Gmg	SG	Pseudoplastic debris flow low strength and viscous
	Lenticular ~3 m. thick	Massive	-	Gmm	SG	Sediment gravity flow deposit Plastic debris flow, high strength viscous
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain pond and swamp
	Lenticular	[illegible]	-	Sm	LS	Flat flood deposit
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain pond and swamp
	Lenticular	Massive	-	Sm	LS	Flash flood deposit
	Lenticular	Cross bedding	**Bivalve shells** *P. (M.) somanai* Trigonioidoidea *fam. indet.* **Dinosaur tooth** *Siamosaurus suteethorni*	Sp, St	LA	Point bar deposit shell bed is channel lag deposit
	Lenticular	Massive		Gmm		
	Probably sheet	Massive or faint lamination	-	Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp

Figure 3.6 Lithologic columnar section at Phu Lon Locality (continued).

Figure 3.7 A. Shell bed is lime-nodule conglomerate near the top of Phu Lon (arrows); B. Close up around upper arrow of Figure 3.7A showing 2 articulated valves of *Pseudohyria (Matsumotoina) somanai* on bedding surface of shell beds (arrows); C. Vertical section of the shell bed showing 1 convex-up disarticulated valves of *Ps. (M.) somanai*. (Diameter of coin in C is 2 cm.). UTM grid reference: $^{2}32^{800m}$E $^{19}06^{600m}$N

3.3.1.4 Ban Huai Dua Molluscan Fossils Locality

Map sheet: 5443 III AMPHOE NONG WUA SO

UTM grid reference: $^{2}36^{200m}$E $^{19}07^{800m}$N

Location: Approximately 1.5 km. west of Ban Huai Dua (Figure 3.2).

Accessibility: Take the Highway Number 210, approximately 10 km. from Nong Bua Lamphu, between Km 88 and Km 89. The locality is approximately 0.5 km. from the left side of the Highway. The Shell Bed is on the cliff of the old rock quarry.

Lithology: Shell bed is weathering out of red mud-nodule conglomerate (Figure 3.9C).

Geometry: The Shell Bed is lenticular, approximately 0.5 m in thickness.

Sedimentary structures: The overlying beds are cross bedded sandstone (Figure 3.8). Sandstone-siltstone unit showing load and flame structures (Figure 3.9C).

Fossils: This molluscan assemblage composes of *Pseudohyria (Matsumotoina) somanai*, *Nippononaia* sp. and *incertae cedis* (5).

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), mud-nodule conglomerate might be assigned as Matrix-Supported Gravel Lithofacies (Gmm) (Table 1.1 and Figure 3.8). The overlying beds are lenticular, planar and trough-cross bedding, which might be assigned to Planar-Cross-Bedded Sand Lithofacies (Sp) and Trough-Cross-Bedded Sand Lithofacies (St) (Table 1.1 and Figure 3.8). Combination of both Gmm, Sp and St might be classified the outcrop as Lateral accretion macroform Element (LA) (Table 1.2, Figure 1.3 and 3.8). Palaeoecology was interpreted as point bar deposits, which bivalve fossils in lime-nodule conglomerate were possible buried as channel lag deposit, and then was buried by point bar deposit.

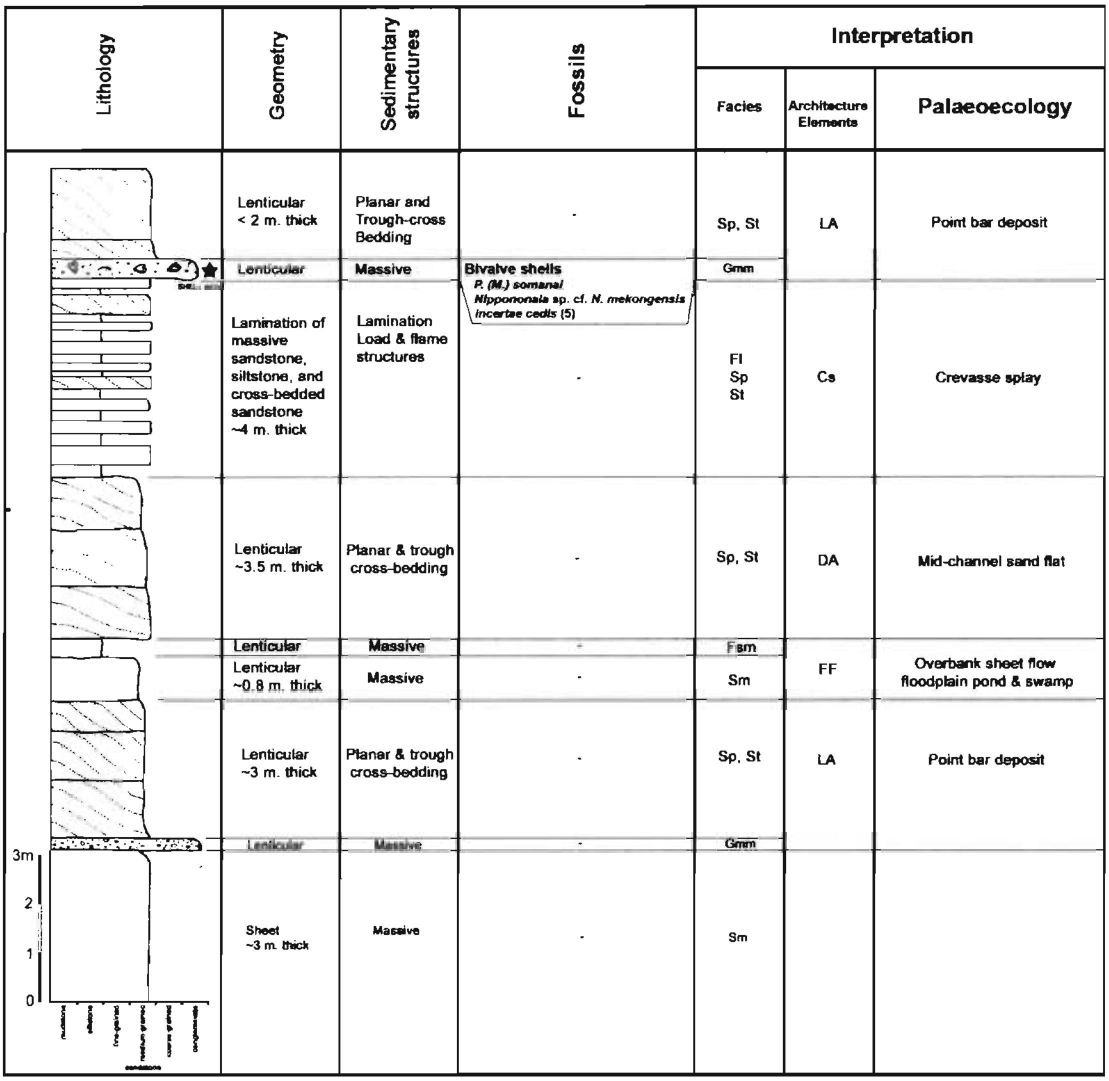


Figure 3.8 Lithologic columnar section at Ban Huai Dua Locality. UTM grid reference: $^{2}36^{200m}E$ $^{19}07^{800m}N$

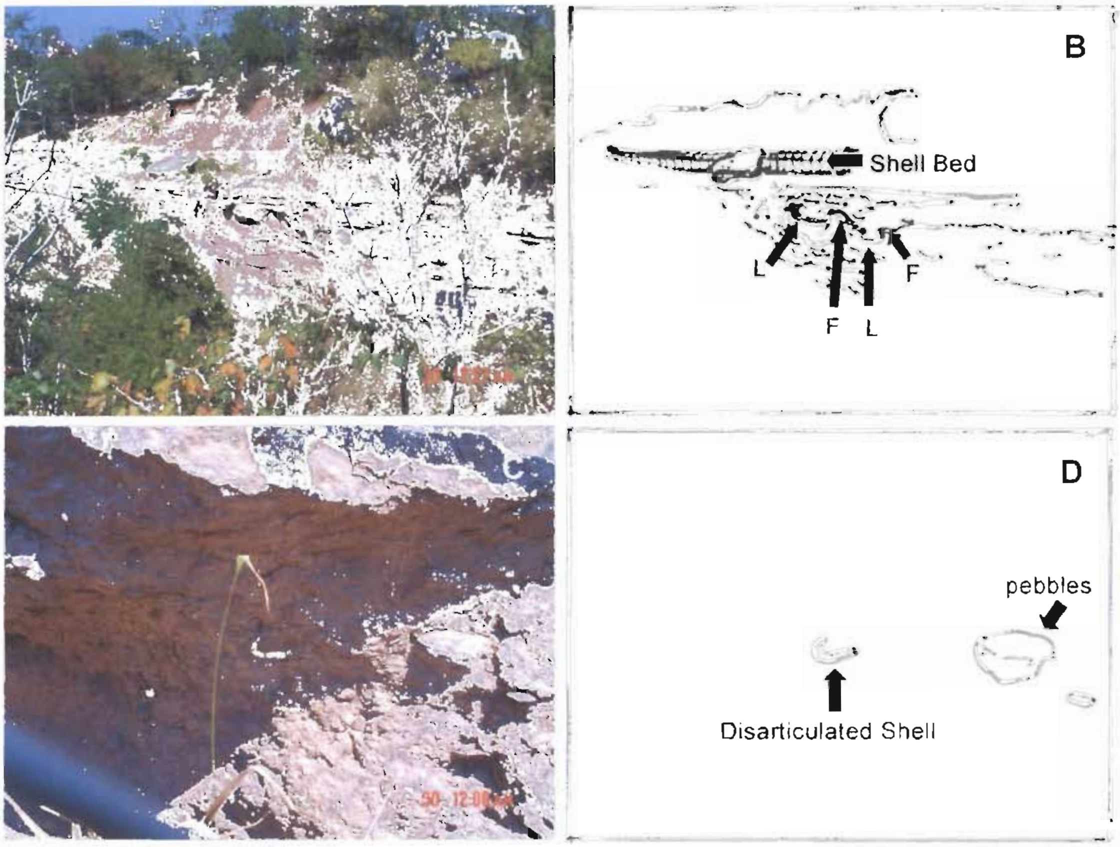


Figure 3.9 A, Ban Huai Dua Shell Bed (behind the fence) exposes on cliff of old quarry; B, Drawing of A. Load (L) and flame (F) structures underlying Shell Bed; C, Close up view showing concave up disarticulated valve; D, Drawing of C. UTM grid reference: $^{2}36^{200m}$E $^{19}07^{800m}$N

3.3.1.5 Phu Chan Molluscan Fossils Locality

Map sheet: 5443 III AMPHOE NONG WUA SO

UTM grid reference: $^{2}49^{800m}$E $^{19}03^{400m}$N

Location: Phu Chan (Figure 3.2).

Accessibility: Take the Highway Number 210 from Udon Thani, turn left at Nong Wua So Intersection. Then, go strength on to Ban Mak Ya, after pass the village about 1 km turn left and take the road about 5 km to the shell bed on the southwestern side of Phu Chan.

Lithology: Lime-nodule conglomerate (Figures 3.10, 3.11A-F, 3.12A-D).

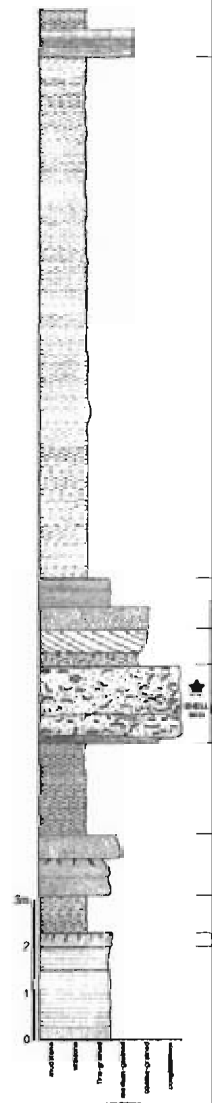
Geometry: Shell Bed is lens of conglomeratic sandstone. The most thickness part is about 1.5 m. It rests on cross bedded sandstone or laminated fine- to medium-grained sandstone by erosion surface (Figures 3.11C, E). Shell Bed was overlaid by cross-bedding medium-grained sandstone by erosion surface.

Sedimentary structures: The underlying shell bed is cross-bedded or laminated sandstone. The shell bed might be subdivided into 2 units by erosion surface (Figures 3.11F, 3.12A-D). The shell bed was overlaid by cross-bedded sandstone, which almost of the incline units dip to northwest.

Fossils: Numerous bivalve fossils are *Pseudohyria (Matsumotoina) somanai.*

Palaeoecology Interpretation: Based on Miall (1996), the underlying shell bed is laminated- or cross-bedded sandstone, which might be interpreted as Horizontally Bedded Sand Lithofacies (Sh) and Low-Angle Cross-Bedded Sand Lithofacies (Sl) (Table 1.1, Figure 3.10, and 3.11C-E). Shell beds in lime-nodule conglomerate might be assigned to Clast-supported, Massive Gravel Lithofacies (Gcm) (Table 1.1, Figure 3.10). The overlying shell bed is planar cross bedding sandstone, which might be assigned to Planar Cross Bedded Sand Lithofacies (Sp) (Table 1.1, Figure 3.10).

Combination of Sh, Sl, Gcm, and Sp might be classified the outcrop as Lateral-Accretion Macroform (LA) (Table 1.2, Figure 1.3, 3.10). Palaeoecology was interpreted as point bar deposits, disarticulated bivalve and shell fragments in lime-nodule conglomerate was possible transported to deposit as channel lag, and then were buried by point bar deposits.



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Sheet	Horizontal lamination	-	Sh	LS	Flash flood deposit
	Sheet	Massive or faint lamination	-	Fsm	FF	Backswamp or abandoned channel
	Lenticular	Horizontal lamination	-	Sh	LA	Point bar deposit
	Lenticular	Planar cross-bedding	-	Sp		
	Lenticular <1.5 m. thick	Massive or locally low-angle cross lamination	Bivalve shells & fragments *P. (M.) somanai*	Gcm Sh Sl		
	Sheet ~2 m. thick	Massive or faint lamination	-	Fsm	FF	Overbank sheet flow floodplain pond and swamp
	Sheet ~1.3 m. thick	Massive or faint lamination with bioturbation	Burrows	Fr		
	Sheet ~0.8 m. thick	Massive or faint lamination	-	Fsm	FF	Overbank sheet flow floodplain pond and swamp
	Sheet, ~0.3 m thick	Bioturbation	Burrows	Fr		
	Sheet ~2 m. Thick	Horizontal lamination	-	Sh	LS	Flash flood deposit

Figure 3.10 Lithologic columnar section at Phu Chan Locality. UTM grid reference: $^{2}49^{800m}E$ $^{19}03^{400m}N$

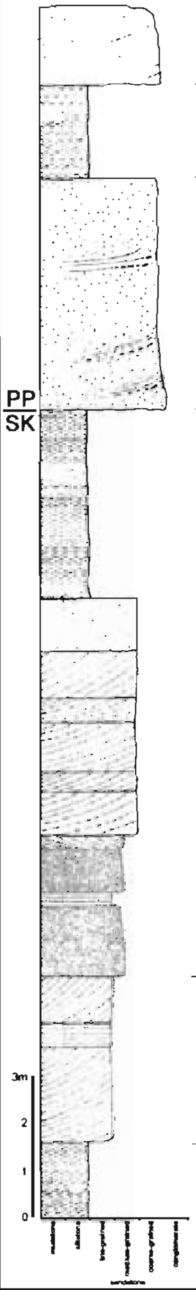
Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular	Low angle cross lamination	-	Gmg	SG	Pseudoplastic debris flow low strength and viscous
	Sheet ~2 m. thick	Massive or faint lamination	-	Fsm	FF	Backswamp or abandoned channels
	Lenticular ~5 m. thick	Low-angle cross lamination	-	Gmg	SG	Pseudoplastic debris flow low strength and vicous
	Sheet	Massive or faint lamination	-	Fsm	FF	Backswamp or abandoned channel
	Lenticular ~5 m. thick	Planar or trough cross bedding	-	St, Sp		
	Lenticular ~3 m. thick	Massive & lamination	-	Sm Sh	DA	Mid-channel sand flat in sand-bed channel
	Lenticular ~3 m thick	Planar or trough cross-bedding	-	St, Sp Sl		
	Sheet ~2 m thick	Massive or faint lamination	-	Fsm	FF	

Figure 3.10 Lithologic columnar section at Phu Chan Locality (continued).

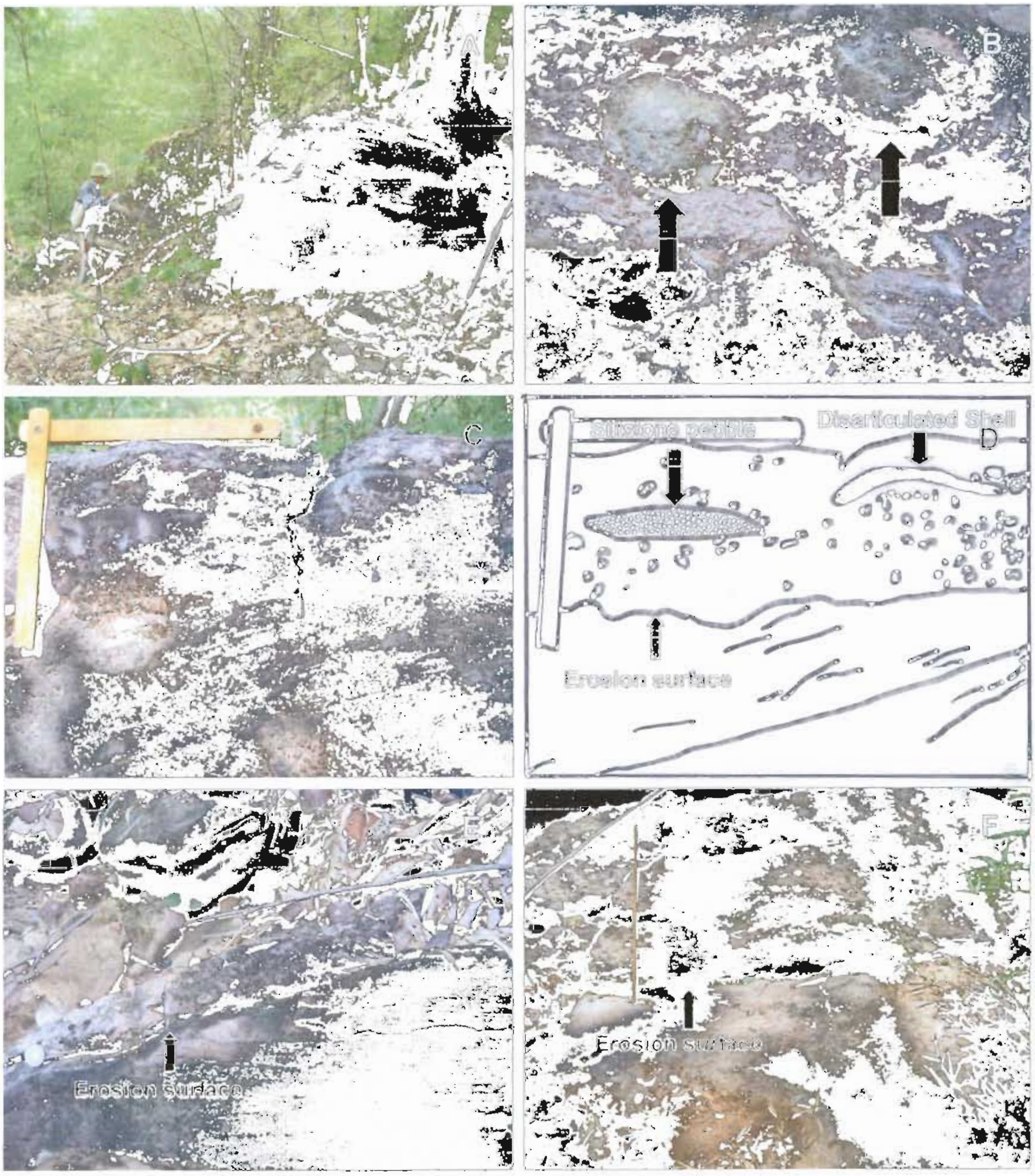


Figure 3.11 A, Phu Chan Shell Bed in sets of cross-bedded lime-nodule conglomerate; B, *Pseudohyria (Matsumotoina) somanai*, exposed on bedding surface of shell bed (arrows); C, Lower part of shell bed contact cross-bedded sandstone with erosion surface (scale in vertical is about 20 cm.); D, Drawing of C; E, In some location, shell bed overlying on horizontal laminated sandstone with erosion surface; F, Two units of shell bed were divided by erosional surface in the center of picture (Scale in left side of F is 1 m. diameter of coin in E is 2 cm.). UTM grid reference: $^{2}49^{800m}E \ \ ^{19}03^{400m}N$

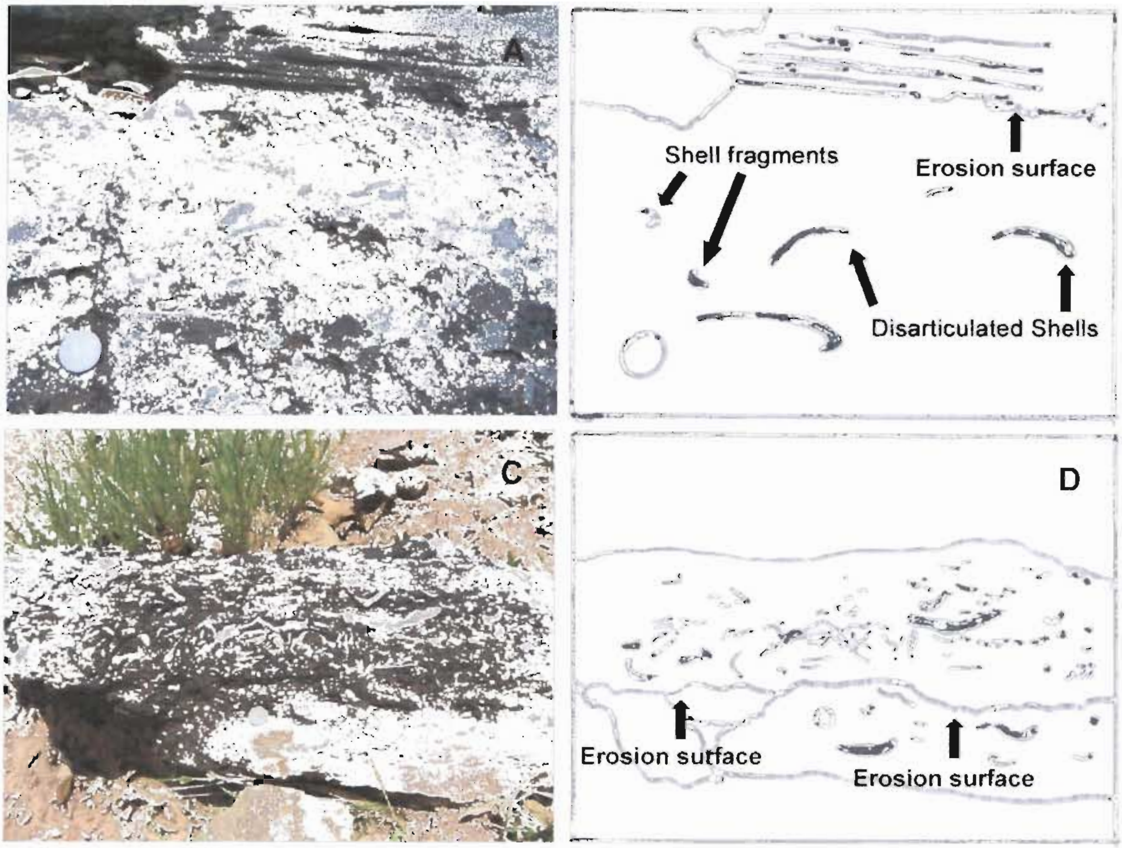


Figure 3.12 A. Close up view of lower left side of Figure 3.11F, showing disarticulated valves; B. Drawing of A; C. Block of shell bed showing 2 units of shell bed, the lower unit yields moderately dense of concave-up disarticulated valves, the upper unit yield dense and no preferred orientation of disarticulated valves; D. Drawing of C (Diameter of coin in both pictures is 2 cm.). UTM grid reference: $^{2}49^{800m}$E $^{19}03^{400m}$N

3.3.2 Phu Wiang Area

According to literature review, abundant vertebrate fossils were found and reported from 8 localities of the inner mountain range of the Phu Wiang mountain range (Suteethorn, 2002). Lithologies of these localities were recognized as the Sao Khua Formation (Inthuputi and Suwanasing, 1978; Inthuputi and Pluhar, 1982; Kroker and Yuthagasemsan (1982); Chonglakmani *et al.*, 1985b; Wongprayoon and Meesook, 2002). In Phu Pratu Tee Ma, Inthuputi and Suwanasing (1978) subdivided the Sao Khua Formation into 4 units. Afterwards, Inthuputi and Pluhar (1982) divided it into 3 units as follows, unit A on the top is siltstone and mudstone, unit B is sandstone, conglomeratic sandstone, unit C is siltstone and mudstone. Petrographic of rock Unit B was studied by Kroker and Yuthagasemsan (1982). The rocks are lithic arenite to subarkose, they yielded 59-76% of monocrystalline and polycrystalline quartz, calcite cementation. The channel's conglomeratic horizons comprise mud pebbles and lime pebbles. The cross bedding directions show unimodal distribution from NE to SW, which indicate a relatively rectilinear flowing river.

For the bivalve fossil, Hahn (1982b) reported bivalve locality from Phu Khrua. Jearanaiwong (2000) reported 2 localities of bivalves from Phu Pratu Tee Ma and Sam Bak Lo in the west of the Phu Wiang area. Both localities also belong to the Sao Khua Formation.

Based on the reasons mentioned above, the outcrops of the inner mountain range were focused to search for new localities of bivalves. Five bivalve fossil localities were found and reported (Tumpeesuwan, 2005; Tumpeesuwan and Sato, 2005; Tumpeesuwan *et al.*, 2010). Columnar sections were made at each bivalve locality (Figure 3.13). Each columnar section and outcrop is shown below.

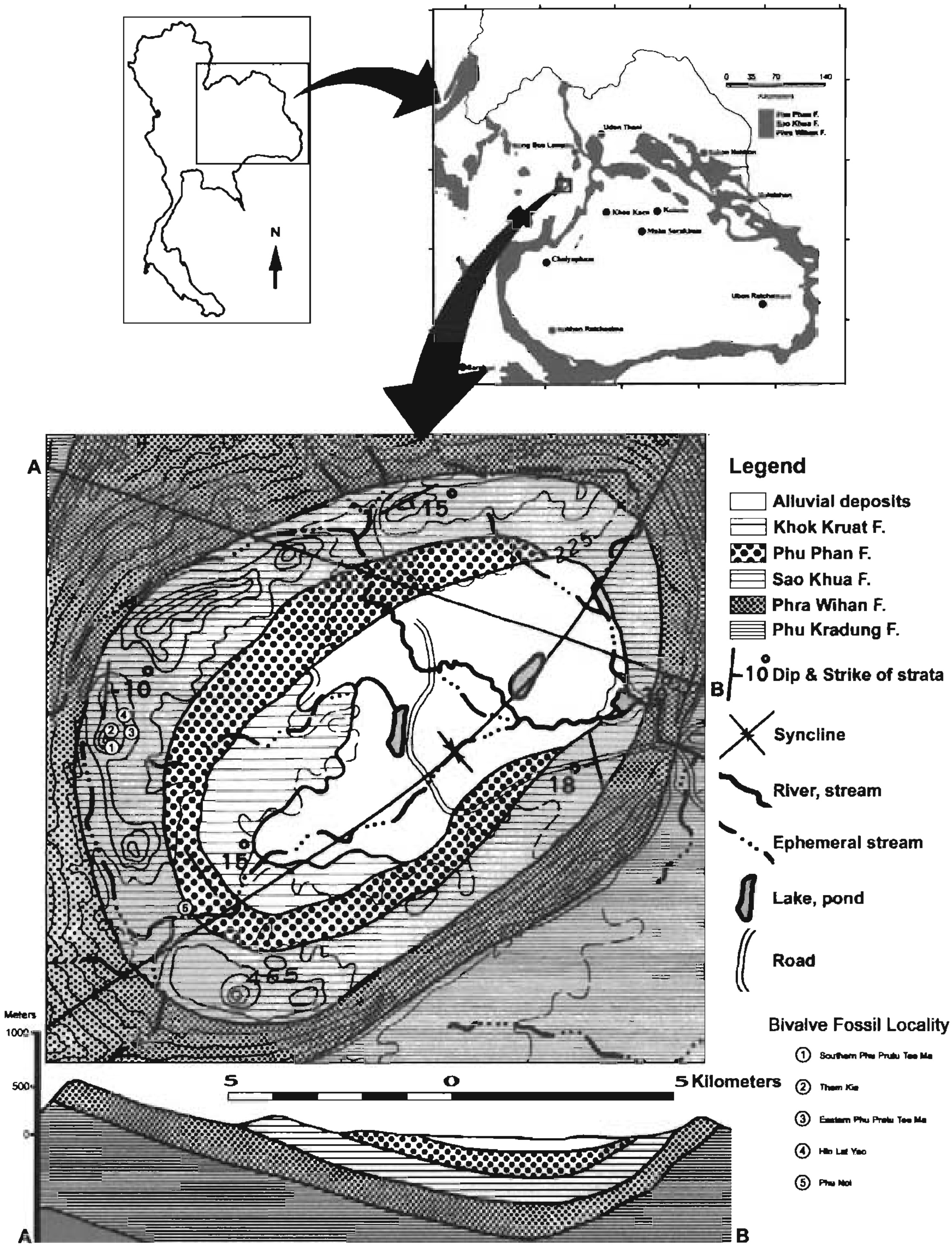


Figure 3.13 Geologic Map of Phu Wiang Area. (Adapted after Tumpeesuwan *et al.*, 2010).

3.3.2.1 Southern Phu Pratu Tee Ma Molluscan Fossils Locality (PW-M-1)

Map sheet: 5442 III AMPHOE CHUM PHAE

Location: Southern Phu Pratu Tee Ma (Figure 3.13)

Accessibility: Take the tourist trail from Phu Wiang National Park Headquarters to Dinosaur site 3, and to view point. This section was made at the outcrop near the trail from Dinosaur Site 3 to view point of Phu Pratu Tee Ma, the thickness of section is about 26.8 m., which comprises 3 shell beds (Figure 3.14).

The Lower Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/1)

UTM grid reference: $^{2}05^{300m}$E $^{18}45^{800m}$N

Lithology: The shell bed is red brown, medium-grained sandstone.

Geometry: The shell bed is regular, sub-parallel thin sandstone bed. The thickness is approximately 0.2 m. The top and the bottom were bounded by erosion surface (Figure 3.15A).

Sedimentary structures: Both underlying and overlying beds of the shell bed are normally trough cross bedding and rather rare planar cross bedding , which most of dip directions of all inclined units are west (Figure 3.15A). The shell bed is laminated, medium-grained sandstone.

Fossils: Numerous fragments of *Pseudohyria (Matsumotoina) somanai* (Figure 3.15A-C).

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), Shell bed is medium-grained sandstone with shell and shell fragments normally are exposed on bedding surface (Figure 3.15B) and on the base of shell bed (Figure 3.15C). This shell bed is classified as Horizontally Bedded Sand Lithofacies (Sh) (Table 1.1 and Figure 3.14). The overlying and underlying beds are several sets of trough cross bedding and planar cross bedding, which is assigned to Trough-Cross-Bedded Sand Lithofacies (St) and Planar-Cross-Bedded Sand Lithofacies (Sp) (Table 1.1 and Figure 3.14). Combination of St, Sp and Sh might be classified the outcrop as Downstream-Accretion Macroforms (DA) (Table 1.2, Figure 1.3 and 3.14). Palaeoecology was interpreted as mid-channel sand flat. Medium-grained sandstone of this shell bed might be occurs in river channel at velocities of around 1m/s and water depths of 0.25 to 0.5 m, or also occurs at lower velocities at shallower depths. Shells and shell fragments are emplaced by being rolled along the sand bed. This shell bed might be deposited during the single flash floods (Miall, 1996).

The Middle Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/2)

UTM grid reference: $^{2}05^{000m}$E $^{18}45^{900m}$N

Lithology: This shell bed is conglomerate, which shows poorly sorted fine- to coarse-grained calcareous sand and contain abundant of shells and shell fragments.

Geometry: The shell bed is lenticular conglomerate in the succession of mudstone, very fine-grained sandstone and calcrete layers (Figure 3.14). Thickness is approximately 1.5 m. It bounded at the top by the convex-up surface and the bottom by an erosion surface.

Sedimentary structures: Massive.

Fossils: Bivalves Trigonioidoidea *fam. indet.*, *incertae cedis* (4) and Ostracod.

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), calcareous conglomerate with abundant bivalve molds and shell fragments might be classified as Scour-Fill Sand Lithofacies (Ss) (Table 1.1 and Figure 3.14). Abundant shells and shell fragments might be assumed as lag materials, which were transported from main channel and rapidly deposited in Crevasse channel (CR) (Table 1.4).

The Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3)

UTM grid reference: $^{2}05^{000m}$E $^{18}45^{900m}$N

Lithology: This shell bed is mud-nodule conglomerate.

Geometry: Shell bed is lenticular, approximately 0.1-0.2 m in thickness. The lower surface of this bed contacts to erosion surface in mudstone. The upper surface contacts laminated fine-grained sandstone by erosion surface (Figure 3.17A).

Sedimentary structures: Shell bed is slightly inverse-grading. Laminated fine-grained sandstone with burrows overlies on the shell bed.

Fossils: Molluscan assemblage in this shell bed composes of *Pseudohyria (Matsumotoina) somanai, Nippononaia* sp., Trigonioidoidea *fam. indet.* and 3 un-identified morphotype. Hybodont shark tooth was also found in this shell bed.

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996**),** mud-nodule conglomerate with abundant disarticulated bivalves and shell fragments. Most of mudstone and siltstone pebbles, shells and shell fragments are mostly oriented around the upper part of the shell bed, which can be assigned to Clast-supported, Inverse-Graded, Gravel Lithofacies (Gci) (Table 1.1 and Figure 3.14). The overlying bed is laminated fine-grained sandstone with burrows, which can be classified as Laminated Sand, Silt and Mud Lithofacies (Fl) (Table 1.1 and Figure 3.14). The shell bed might be assigned to Sediment-Gravity Flow Element (SG) (Table 1.2 and Figure 1.3 and 3.14). and the overlying laminated fine-grained sandstone might be assigned to Overbank Fine Element (FF) (Table 1.2, Figure 1.3, and 3.14). Palaeoecology was interpreted as clast-rich, high strength debris flow or low strength flow with an inertial bed load transported by laminar to turbulent flow. Flow event passively occupy existing erosional channel or the irregular topography formed by earlier sediment-gravity flow and sheet flood events. Overbank Fine Element (FF) of the overlying shell bed normally occurs in overbank areas, and represents deposition from suspension and from weak traction currents. Lamination indicates deposition from suspension or from very low energy underflow.

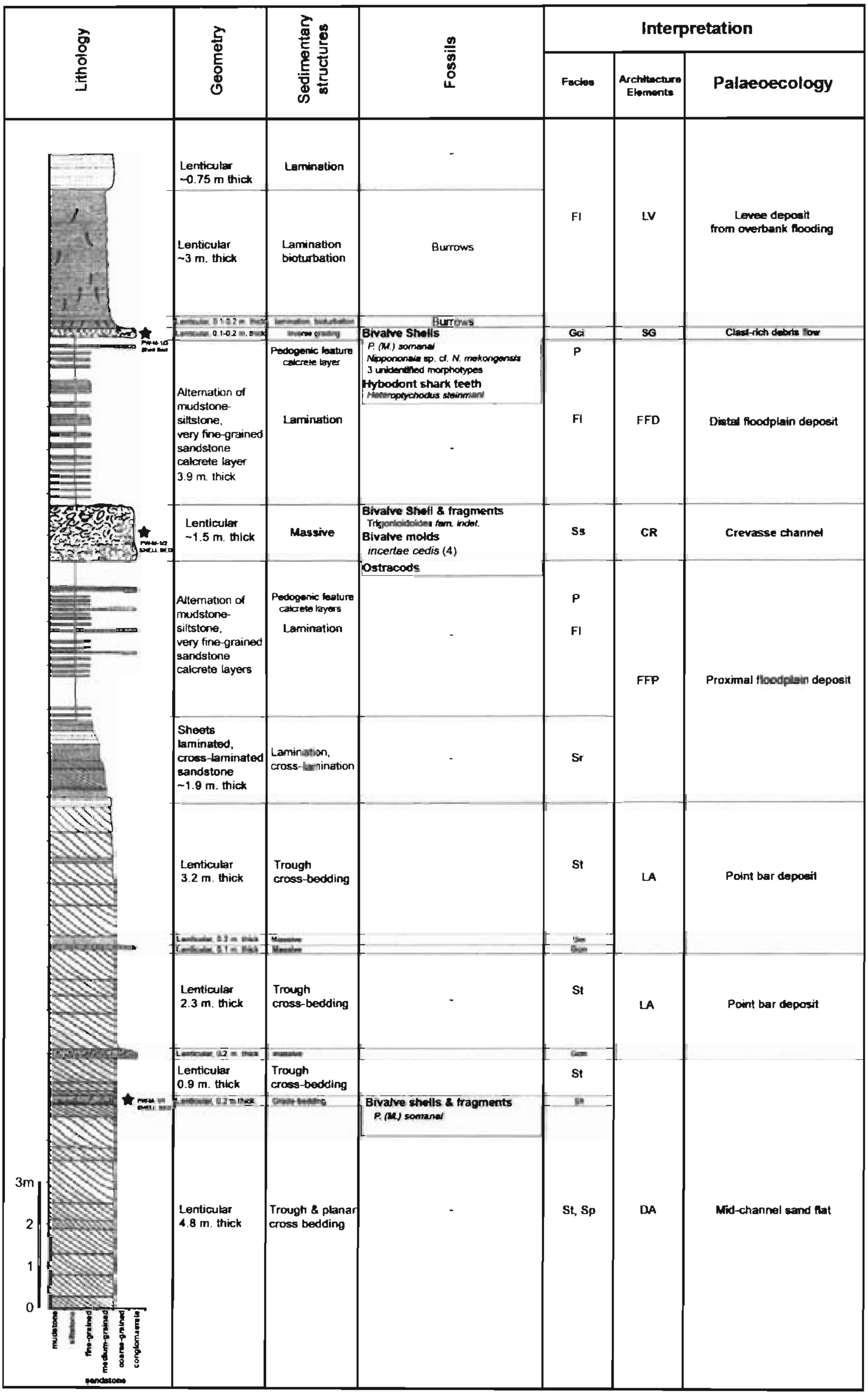


Figure 3.14 Lithologic columnar section of Southern Phu Pratu Tee Ma (PW-M-1)

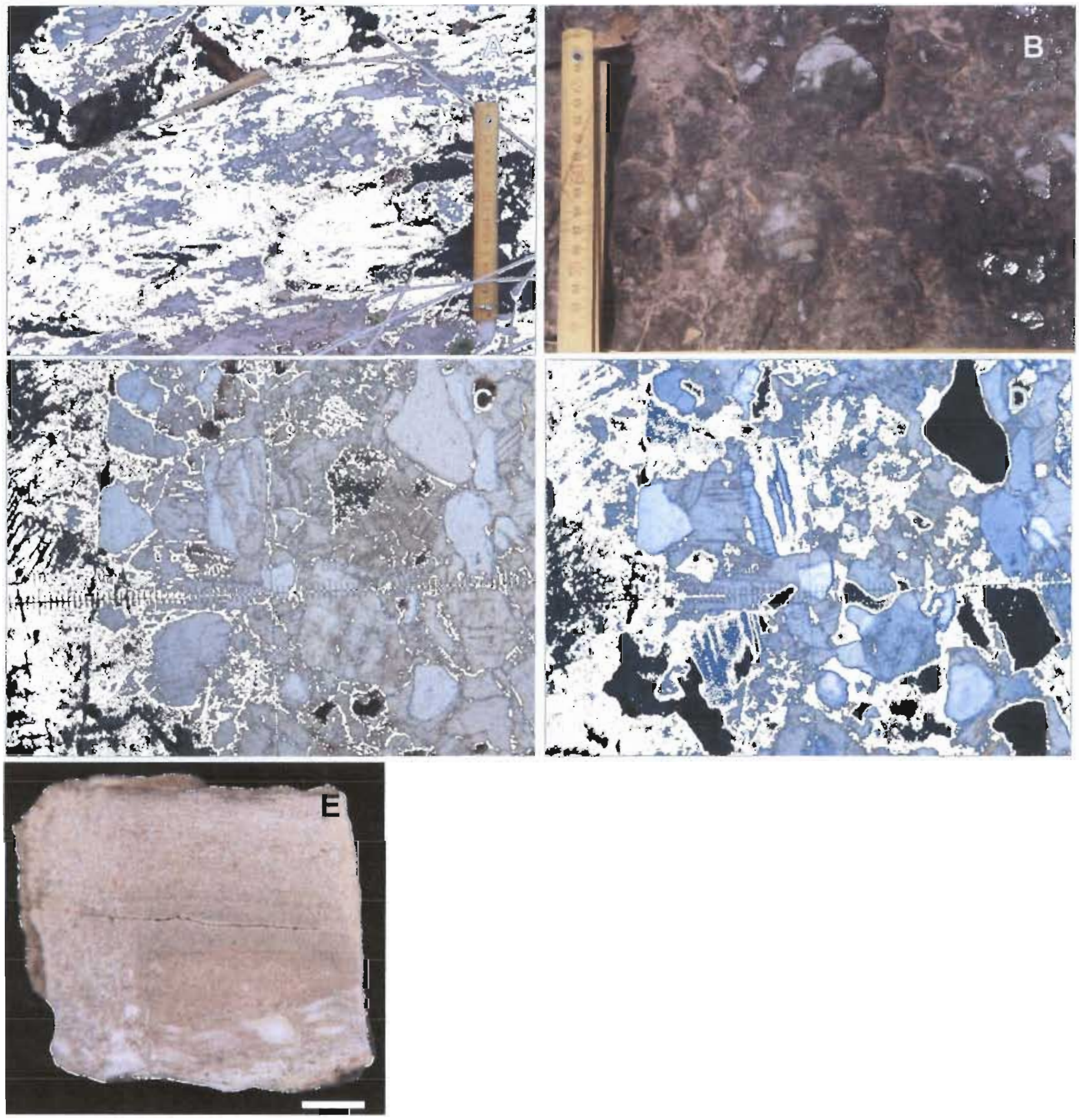


Figure 3.15 A, Lower Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/1), thin layer of shell fragments in sandstone bed overlies on cross-bedded sandstone (scale is about 20 cm.); B, Bedding surface of PW-M-1/1, showing no preferred orientation of bivalve shells; C, Photomicrograph of sandstone from shell bed in plane polarized light; D, in crossed polars. This sandstone contains quartz, feldspar, and rock fragment. Substantial calcite is in form of shell fragment (in whole left side of picture) and as cement between mineral grains; E, A rock slab of PW-M-1/1, showing shell fragments at the base of shell bed (scale bar = 1 cm). UTM grid reference: $^{2}05^{300m}$E $^{18}45^{800m}$N

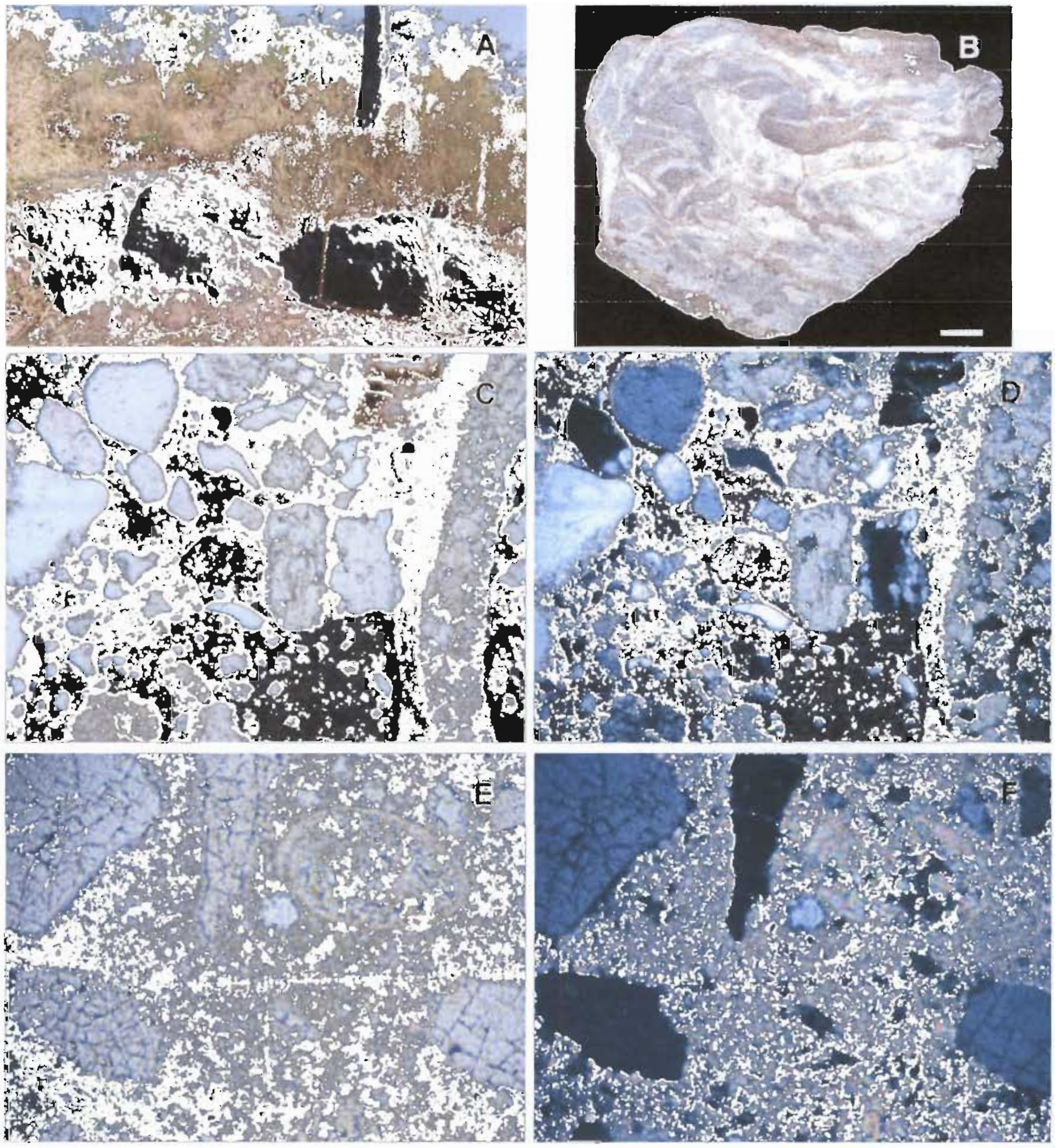


Figure 3.16 A, Middle Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/2); B, Rock slab showing randomly distributed and orientated of disarticulated valve in various sizes (scale bar = 1 cm.); C, Photomicrograph of sandstone from shell bed in plane polarized light and D, in crossed polars. This sandstone contains abundant fine-grained matrix between grained of quartz and rock fragment. Disarticulated valve of ostracod is in the center and disarticulated bivalve is in the right of the picture, which bivalve shell was coat by stromatolite-like lamination; E, Photomicrograph in plane polarized light and F, in crossed polars. This sample showing articulated valve of ostracod (upper right). UTM grid reference: $^{2}05^{000m}$E $^{18}45^{900m}$N

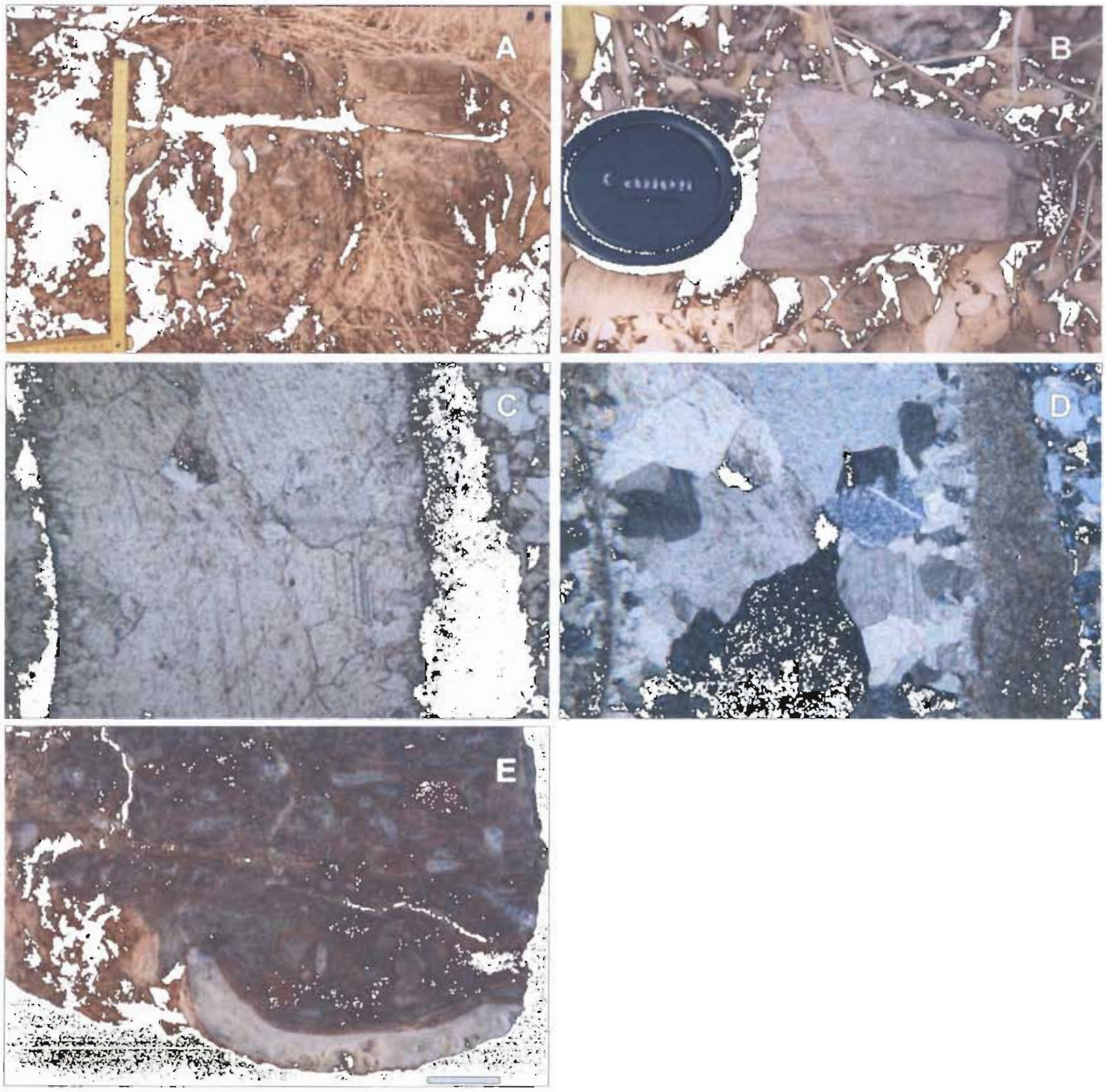


Figure 3.17 A, Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3), the shell bed is mud-nodule conglomerate. (scale bar is about 40 cm.); B, Block of laminated fine-grained sandstone with inclined burrow (diameter of lens cap is about 7 cm); C, Photomicrograph of mud-nodule conglomerate in plane polarized light; D, in crossed polars. This sandstone contains grains of quartz, mud-nodule, siltstone granules and disarticulated bivalve, which bivalve was coat by stromatolite-like lamination (dark brown layers); E, Rock slab of upper shell bed, showing disarticulated valve, many mudstone and siltstone granules, and shell fragments. Most of them were coat by the red brown layers (scale bar = 1 cm). UTM grid reference: $^{2}05^{000m}E$ $^{18}45^{900m}N$

3.3.2.2 Tham Kia Molluscan Fossil Locality (PW-M-2)

Map sheet: 5442 III AMPHOE CHUM PHAE

UTM grid reference: $^{2}05^{000m}$E $^{18}46^{500m}$N

Location: Tham Kia (Figure 3.13).

Accessibility: Take the road from Phu Wiang National Park's tourist center to Dinosaur site 2. This section was made at the shell bed near the top of Phu Pratu Tee Ma, the thickness is about 22 m.

Lithology: Shell bed is lime-nodule conglomerate which yields abundant bivalve fossils (Figure 3.18).

Geometry: Shell bed is lenticular, which the most thickness part is about 2 m. It rests on medium-grained sandstone by erosion surface.

Sedimentary structures: Massive. The underlying set of shell bed is alternation of laminated muddy fine-grained sandstone and fine-grained sandstone.

Fossils: Two species of bivalve fossils were discovered from this shell bed, Trigonioidoidea *fam. indet.* and *incertae cedis* (4). The underlying beds are Dinosaur site 2, bones of *Phuwiangosaurus sirindhornae* were discovered in the alternation of laminated muddy fine-grained sandstone (Suteethorn, 2002).

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), calcareous conglomerate with abundant bivalve molds and shell fragments might be classified as Scour-Fill Sand Lithofacies (Ss) (Table 1.1 and Figure 3.18). Abundant shells and shell fragments might be assumed as lag materials, which were transported from main channel and rapidly deposited in Crevasse channel (CR) (Table 1.4). The dinosaur bed is in the alternation of laminated muddy fine-grained sandstone and fine-grained sandstone. It might be interpreted as

Laminated Sand, Silt and Mud Lithofacies (Fl) (Table 1.1 and Figure 3.18) and might be assigned to Overbank Fine Element (FF) of floodplain deposit.

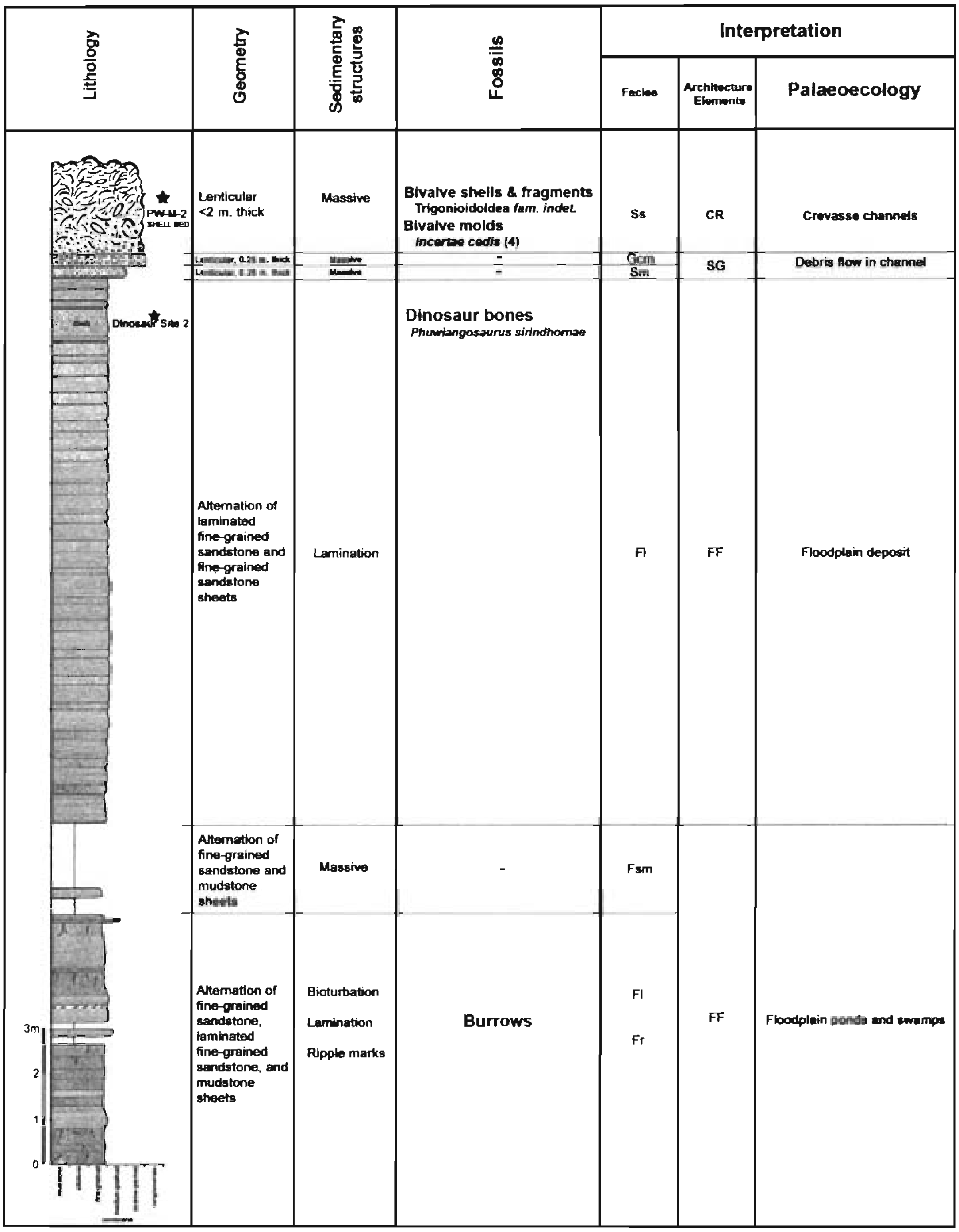


Figure 3.18 Lithologic columnar section of Tham Kia Shell Bed (PW-M-2). UTM grid reference: $^{2}05^{000m}E$ $^{18}46^{500m}N$

Figure 3.19 Tham Kia Shell Bed (PW-M-2). UTM grid reference: $^{2}05^{000m}$E $^{18}46^{500m}$N

3.3.2.3 Eastern Phu Pratu Tee Ma Molluscan Locality (PW-M-3)

UTM grid reference: $^{2}05^{600m}$E $^{18}46^{000m}$N

Map sheet: 5442 III AMPHOE CHUM PHAE

Location: Eastern Phu Pratu Tee Ma (Figure 3.13).

Accessibility: Take the road from Phu Wiang National Park's tourist center to Dinosaur site 2. Section was made at an outcrop exposed at eastern foot of Phu Pratu Tee Ma, near left side of road cut to Dinosaurs Site 2 (Figure 3.20).

Lithology: Shell bed is lime-nodule conglomerate, yields abundant bivalve fossils. It might be assigned as clast-supported conglomerate.

Geometry: Shell bed is lenticular, rests on laminated fine-grained sandstone. It bounded at the bottom erosion surface. The most thickness part is about 0.5 m. (Figure 3.20).

Sedimentary structures: Massive (Figure 3.20).

Fossils: At least 2 species of bivalve fossils were found from this shell bed, including Trigonioidoidea *fam. indet.* and *incertae cedis* (4).

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), calcareous conglomerate with abundant bivalve molds and shell fragments might be classified as Scour-Fill Sand Lithofacies (Ss) (Table 1.1 and Figure 3.20). Abundant shells and shell fragments might be assumed as lag materials, which were transported from main channel and rapidly deposited in Crevasse channel (CR) (Table 1.4).

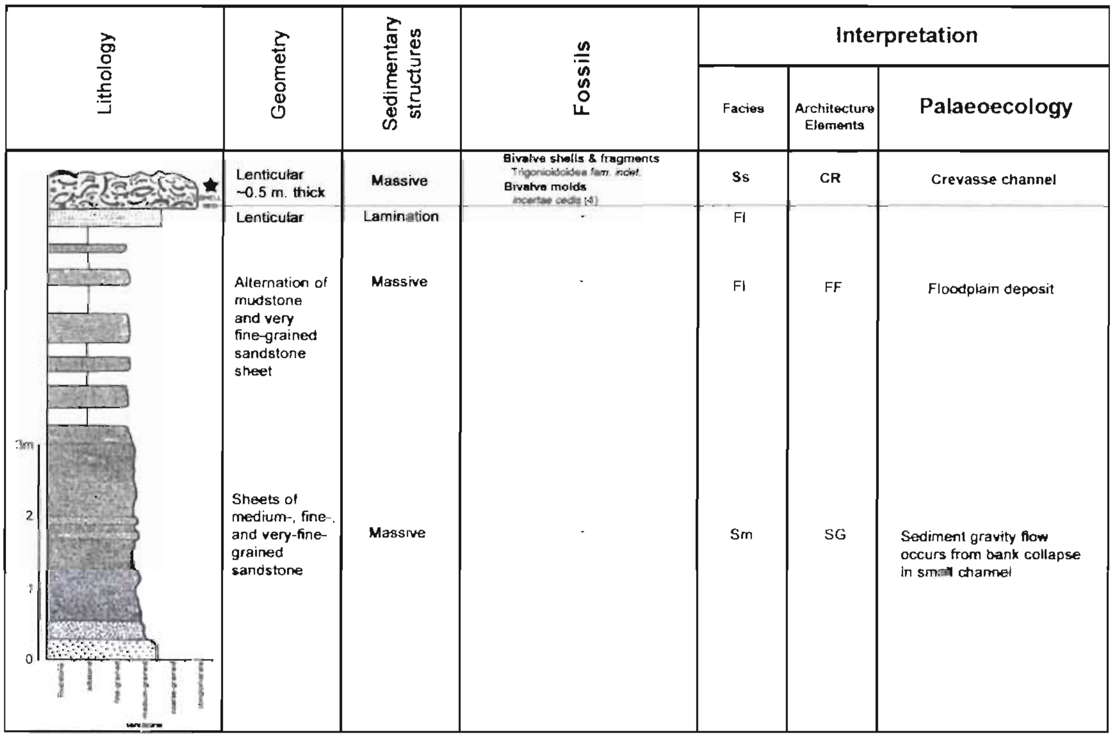


Figure 3.20 Lithologic columnar section of Eastern Phu Pratu Tee Ma Shell Bed (PW-M-3). UTM grid reference: $^{2}05^{000m}$E $^{18}46^{500m}$N

Figure 3.21 A, Outcrop of lower part of the section of Eastern Phu Pratu Tee Ma Locality (PW-M-3); B, Eastern Phu Pratu Tee Ma Shell Bed (PW-M-3). UTM grid reference: $^{2}05^{000m}$E $^{18}46^{500m}$N

3.3.2.4 Hin Lat Yao Molluscan Fossil Locality (PW-M-4)

Map sheet: 5442 III AMPHOE CHUM PHAE

UTM grid reference: $^{2}05^{200\mathrm{m}}$E $^{18}47^{000\mathrm{m}}$N

Location: Hin Lat Yao (Figure 3.13)

Accessibility: Take the road from Phu Wiang National Park's tourist center to parking area, and take the tourist's trail to Dinosaur Site 9. This section was made at the outcrop of shell bed overlying on the red micaceous siltstone of Dinosaur Site 9 bed. Thickness of the section is about 14.5 m. (Figure 3.22)

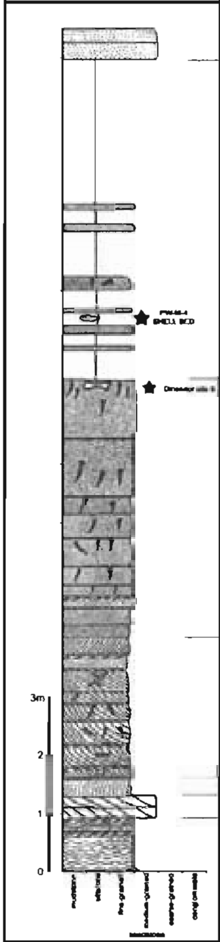
Lithology: Shell bed is poorly cemented, red micaceous mudstone-siltstone.

Geometry: This shell bed is sheet of red mudstone-siltstone interbedded with fine-grained sandstone.

Sedimentary structures: Burrows were found in some fine-grained sandstone beds in the several upper units of shell bed. Bioturbation, ripple mark, cross-bedding, convolute, wavy and cross lamination were found in fine- to medium-grained sandstone in several lower units of the shell bed (Figure 3.22).

Fossils: Bones of *Siamotyranus isanensis* Buffetaut *et al.*, 1996 was found in red micaceous siltstone underlies mudstone-siltstone and fine-grained sandstone sequence of bivalve bed of *Yunnanoconcha* sp. cf. *Y. khoratensis.* Numerous rootlets and burrows were found in several overlying and underlying red siltstone-sandstone beds (Figure 3.22, 3.23B-C).

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), micaceous mudstone-siltstone with freshwater molluscs might be classified as Massive, Mud, Silt Lithofacies (Fm) (Table 1.1 and Figure 3.22) and Overbank fines Element (FF) (Table 1.2, 1.4 and Figure 3.22). Palaeoecology might be interpreted as deposits from standing pools of water during low-stage channel abandonment, overbank, and floodplain swamps (Table 1.2, 1.4 and Figure 3.22).



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular 0.5 m. thick	Lamination	-	Sh	LS	Flash flood deposit
	Sheets of mudstone-siltstone interbedded with thin beds of fine-grained sandstone	Massive Bioturbation	Bivalve molds *Yunnanoconcha* sp. cf. *Y. Khoratensis*	Fm	FF	Floodplain swamps
	Lenticular sets of red micaceous siltstone 4.5 m. thick	Burrows Ripple marks Cross-lamination	Dinosaur bones *Siamotyrannus isanensis* Rootlets Burrows	Fr Fl	FF	Floodplain ponds and swamps
	Lenticular sets of cross-laminated fine-grained sandstone 2.4 m. thick	Cross-lamination Bioturbation Ripple marks		Fl	LV	Levee
	Lenticular	Lamination		Sh		
	Lenticular	Trough cross-bedding		St	CS	Crevasse splay
	Lenticular 0.9 m. thick	Convolute & wavy lamination Ripple marks		Fl		

Figure 3.22 Lithologic columnar section of Hin Lat Yao (PW-M-4). UTM grid reference: $^{2}05^{200m}$E $^{18}47^{000m}$N

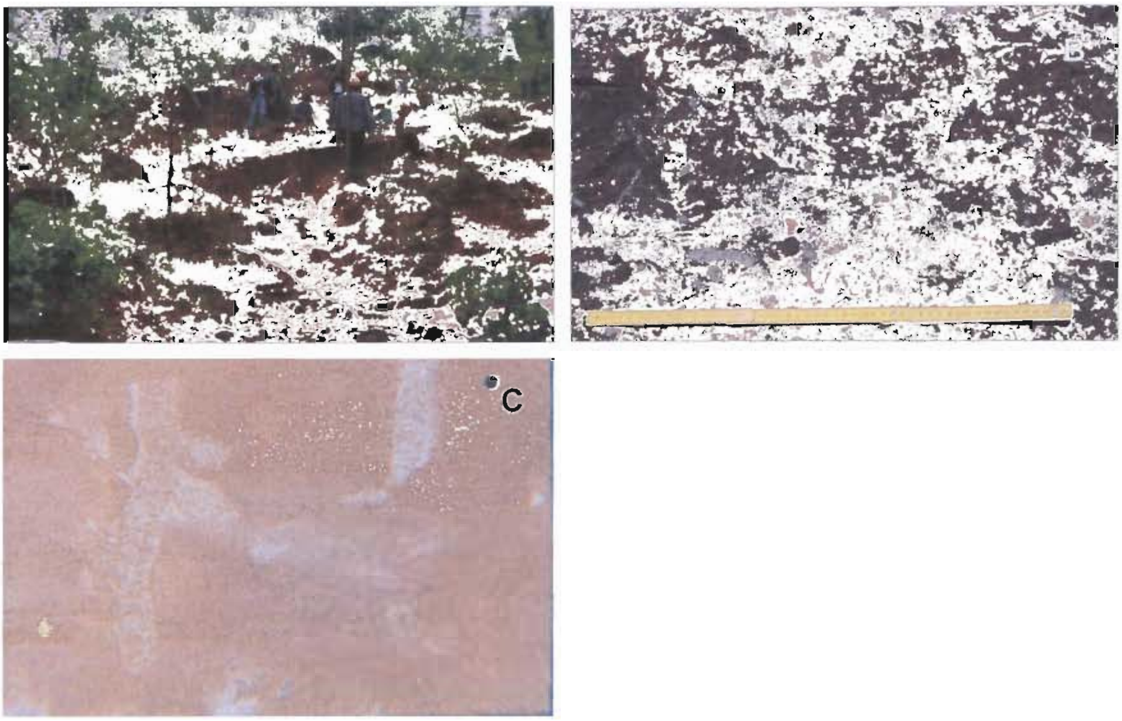


Figure 3.23 A, Hin Lat Yao Shell Bed (PW-M-4) the internal molds of articulated valves were found on the surface of weathering out mudstone at the center of the figure; B, Vertical and horizontal calcareous rootlets on the bedding surface of red brown siltstone bed of Dinosaur Site 9 (*Siamotyranus* Bed), (scale is 60 cm); C, A rock slab of red brown micaceous siltstone showing small scale cross lamination and vertical and horizontal burrows. UTM grid reference: $^{2}05^{200m}E$ $^{18}47^{000m}N$

3.3.2.5 Phu Noi Molluscan Fossils Locality (PW-M-5)

Map sheet: 5442 II AMPHOE PHU WIANG

UTM grid reference: $^{2}06^{700m}$E $^{18}41^{000m}$N

Location: Phu Noi (Figure 3.13)

Accessibility: At Ban Muang Kao, take the road to Huai Bong Weir, and walk across Huai Bong to the locality. Section was made at outcrop exposed from southern foot to the top of Phu Noi. Thickness of the section is about 30 m. (Figure 3.24).

The section reveals 4 cycles of fining-upward sequence; the lower set is the alternation of about 2 m thick of fine-, very fine-, and medium-grained sandstones. The second cycle started with the Lower Shell Bed (PW-M-5/1) in weathering out of mud-nodule conglomerate with numerous of bivalve shells (Figure 3.24; 3.25A, B). The following is about 18.5 m thick of laminated fine-grained sandstone and siltstone beds which some bed contain burrows. The third cycle began with approximately 0.4 m. thick of lime-nodule conglomerate bed (Figure 3.26A) with rare shell fragments of *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* and hybodont shark tooth. This Upper Shell Bed (PW-M-5/2) was overlaid by fine-grained cross-bedded sandstone and approximately 3 m. thick of siltstone. The last cycle started with 0.2 m. thick of mud-nodule conglomerate, which was overlaid by 0.3 m. thick of medium-grained cross bedded sandstone and 1.5 m. thick of red siltstone (Figure 3.26C). The top of the section is approximately 3 m. thick coset of cross-bedded conglomerate, which it yields abundant of quartz and chert pebbles of the Phu Phan Formation (Figure 3.26E).

The Lower Shell Bed of Phu Noi (PW-M-5/1)

UTM grid reference: $^{2}06^{700m}$E $^{18}41^{000m}$N

Lithology: The shell bed is red brown mud-nodule conglomerate (Figure 3.25A-C, E).

Geometry: Almost of this shell bed is weathering out, however, thickness might be estimated from the thickness of some fossil block remains. The shape of this shell bed might be assigned as lenticular, which the most thickness past is about 0.2 m.

Sedimentary structures: burrows present in the overlying sandstone bed.

Fossils: Three species of bivalve were found in this shell bed including, *Pseudohyria (Matsumotoina) somanai, Nippononaia* sp. cf. *N. mekongensis* and *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), red-brown mud-nodule conglomerate might be classified as Clast-Supported, Horizontally Stratified Gravel Lithofacies (Gh) (Table 1.1 and Figure 3.24). It consists of numerous mud-granules, mud-pebbles, and bivalve shells. Some disarticulated valves are in imbrication (Figure 3.25E). It might be assigned to Scour Hollow Element (HO). (Table 1.2, and Figure 3.24). Palaeoecology was interpreted as formed by process of deep scouring at points of channel convergence. Avalanche faces can develop on the upstream end of scours. These scours might be filled by an avalanche deposit in short period during channel swiching or flood event. Because scours result in the deposition of sediment below mean channel depth, they have a high preservation potential (Miall, 1996).

The Upper Shell Bed of Phu Noi (PW-M-5/2)

UTM grid reference: $^{2}06^{700m}E$ $^{18}41^{000m}N$

Lithology: Green to grey lime-nodule conglomerate (Figure 3.26A).

Geometry: This shell bed is lens. The most thickness part is about 0.4 m. It rests on the siltstone unit by erosion surface, and was overlaid by cross-bedded fine-grained sandstone with erosion surface.

Sedimentary structures: The overlying bed is 0.6 m thick of fine-grained cross bedding sandstone, which shows the flow direction to west.

Fossils: *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* and hybodont shark teeth *Heteroptychodus steinmani* were discovered from this shell bed.

Palaeoecology Interpretation: Based on facies classification and architecture elements proposed by Miall (1996), shell bed might be classified as Clast-Supported, Massive Gravel Lithofacies (Gcm) (Table 1.1 and Figure 3.24). The cross-bedded fine-grained sandstone rests on the shell bed might be assigned to Trough-Cross-Bedded Sand Lithofacies (St) (Table 1.1 and Figure 3.24). Combination of Gcm and St might be classified the outcrop as Lateral-Accretion Macroform (LA) (Table 1.2, Figure 1.3 and 3.24). Palaeoecology was interpreted as disarticulated bivalve, shell fragments, and shark teeth in lime-nodule conglomerate was possible transported to deposit as channel lag, and then were buried by point bar deposits.

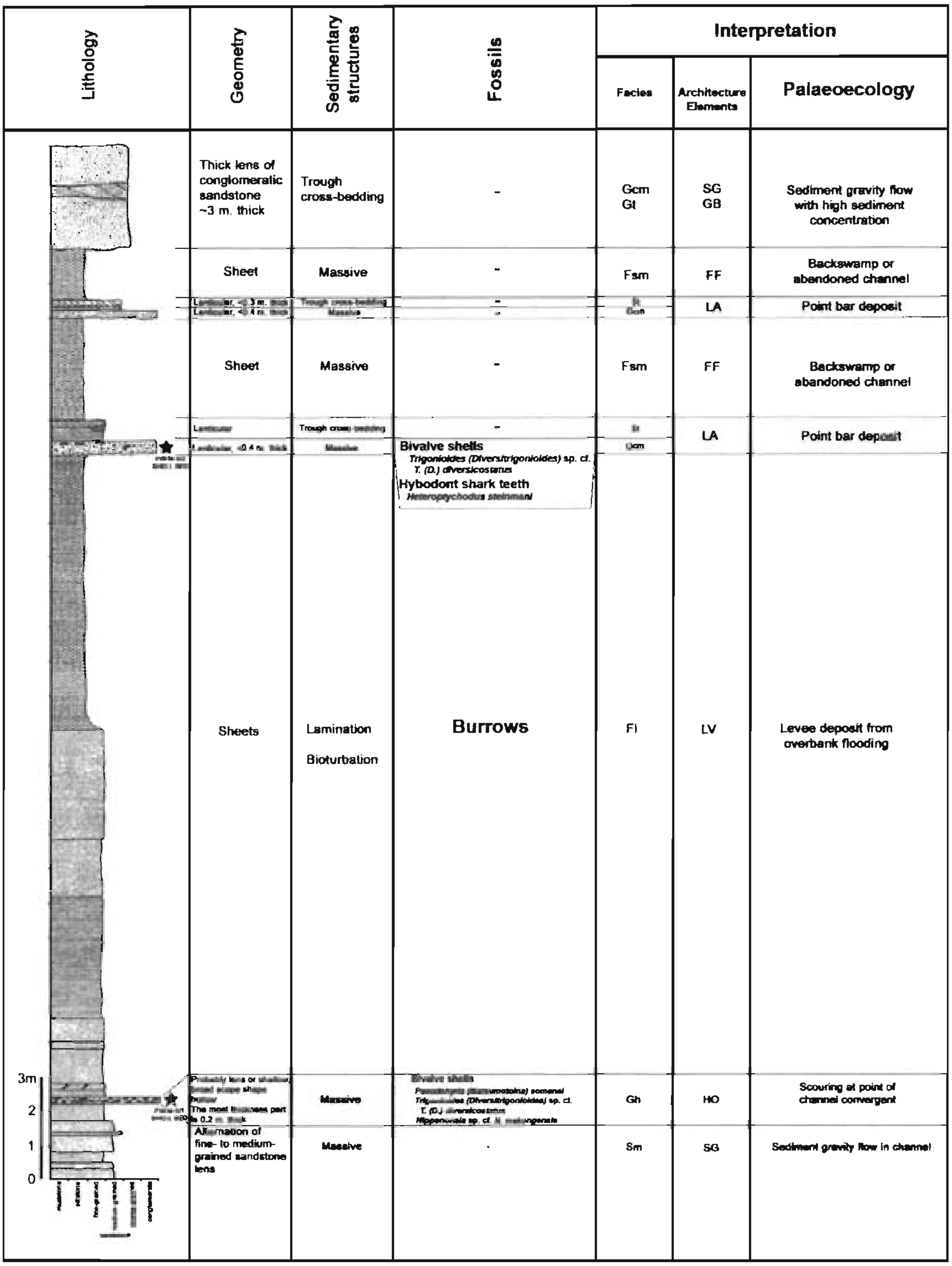


Figure 3.24 Lithologic columnar section of Phu Noi (PW-M-5). UTM grid reference: $^{2}06^{700m}E$ $^{18}41^{000m}N$

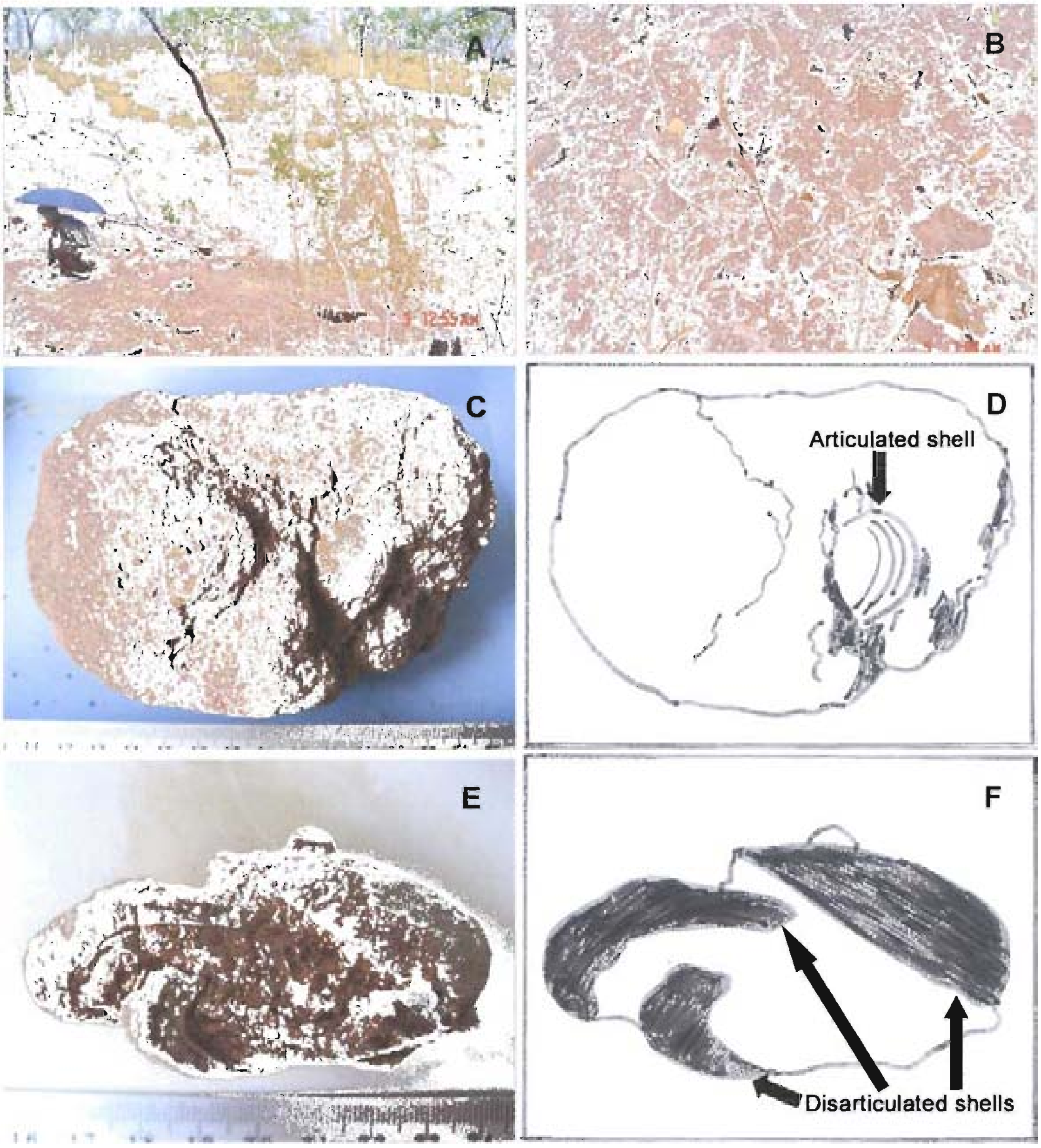


Figure 3.25 A. Lower Shell Bed of Phu Noi (PW-M-5/1), the weathering out of mud-nodule conglomerate bed (red brown color); B. Bedding surface of shell bed with abundant of bivalves (arrows); C. Block of shell bed in bedding surface view showing the convex up of disarticulated valves; D. Drawing of C; E, Vertical section of shell imbrication block; F. Drawing of E. UTM grid reference: $^{2}06^{700m}E$ $^{18}41^{000m}N$

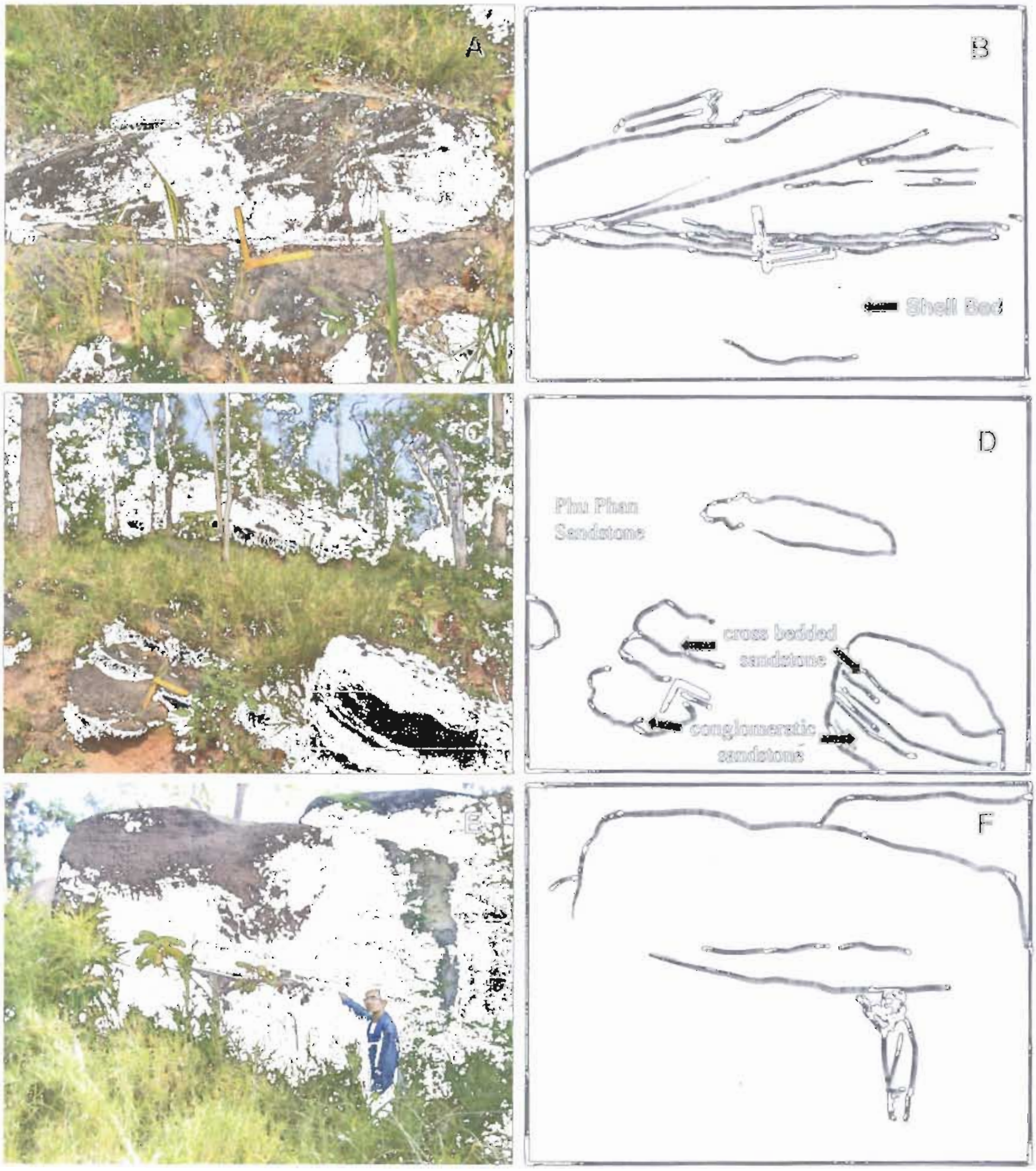


Figure 3.26 A, Upper Shell Bed of Phu Noi (PW-M-5/2), lime-nodule conglomerate bed was overlaid by cross bedded fine-grained sandstone; B, Drawing of A; C, Upper conglomerate bed was overlaid by cross bedded fine-grained sandstone. (scale bar in vertical is about 20 cm.); D, Drawing of C; E, Cross bedded conglomerate of the Phu Phan Formation on the top of the hill; F, Drawing of E. (Scale bar in Figure 3.26A, C in vertical is about 0.2 m; Man in Figure 3.26E is about 165 cm. height). UTM grid reference: $^{2}06^{700m}E$ $^{18}41^{000m}N$

3.3.3 Sahat Sakhan Area

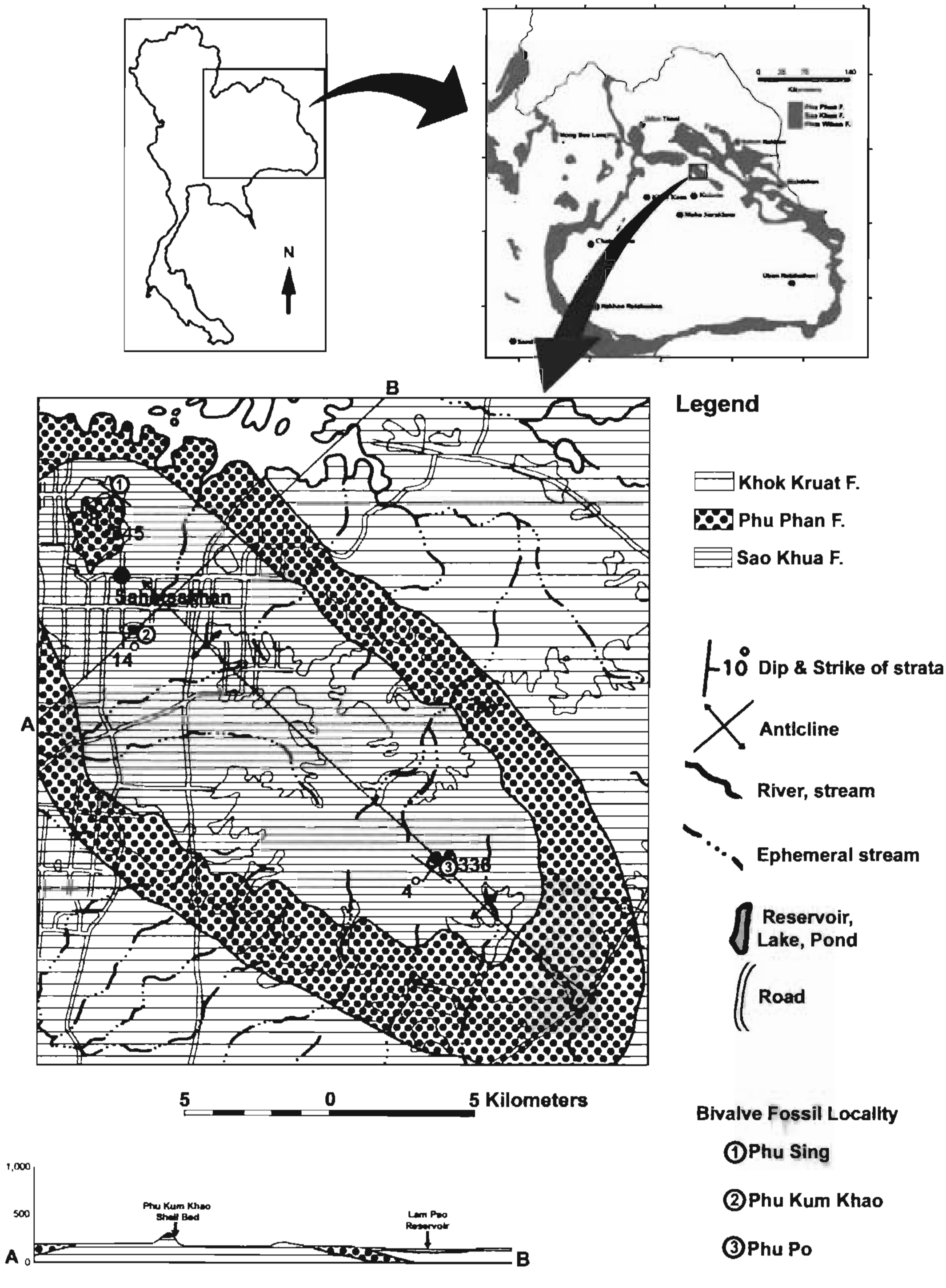


Figure 3.27 Geologic Map of Sahat Sakhan Area (modified after Geological map of Thailand sheet Changwat Roi Et, NE 48-14, Suteethorn and Jarnyahran, 1985)

3.3.3.1 Phu Kum Khao Molluscan Fossils Locality

Map sheet: 5742 III AMPHOE SAHATSAKHAN

UTM grid reference: $^{3}43^{500m}E$ $^{18}46^{200m}N$

Location: Phu Kum Khao (Figure 3.27)

Accessibility: Take the Highway Number 227 from Kalasin City to Sahatsakhan town. Phu Kum Khao is in the right side of the Highway, approximately 1 km before reaching Sahatsakhan town.

Lithology: The shell bed is fine-grained sandstone.

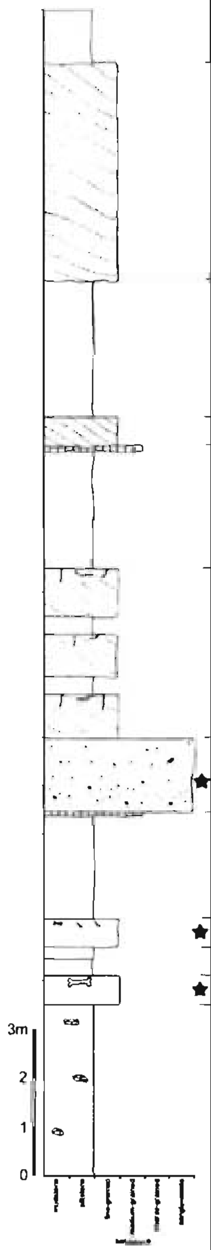
Geometry: The shell bed is lenticular, medium-grained sandstone. The most thickness part is about 2 m. It rest on mudstone-siltstone units by erosion surface (Figure 3.29A).

Sedimentary structures: Rip up clasts of mudstone pebbles in overlying medium- to coarse-grained calcareous sandstone (Figure 3.29B).

Fossils: Trigonal shape fossil of *Pseudohyria (Matsumotoina) somanai*

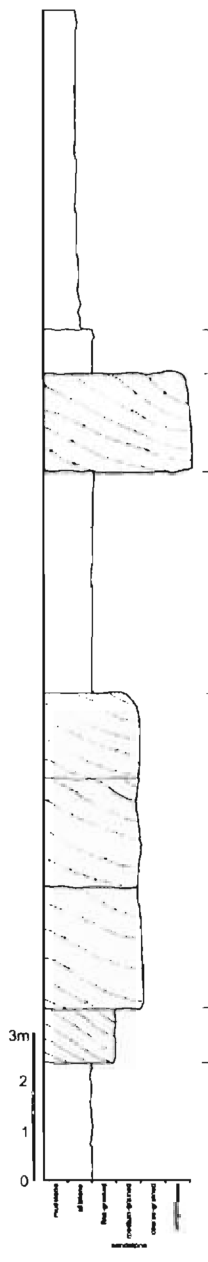
Palaeoecology Interpretation: Based on Miall (1996), fine-grained sandstone of shell bed and the overlying medium- to coarse-grained calcareous sandstone bed reveal massive or very faint cross-lamination, which might be assigned to Massive Sand Lithofacies (Sm)) (Table 1.1 and Figure 3.28). The outcrop might be assigned to Channel Element (CH) (Table 1.2, Figure 1.3 and 3.28). Palaeoecology might be interpreted as minor channel, which normally contains massive sandstone. The rip-up clasts originated from the erosion of the underlying bed, through the passage of an erosive current, or from channel bank collapse into passive flow. The poorly preserved disarticulated valve of *P. (M.) somanai* might be interpreted as they were eroded from channel floor or channel bank somewhere upstream before final burial.

Then they were transported as gravels of sediment gravity flow and deposited in this sandstone bed.



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation: Facies	Interpretation: Architecture Elements	Interpretation: Palaeoecology
	Lenticular Coset of cross-bedded sandstone ~4.5 m. thick	cross-bedding	-	St, Sp	DA	Mid-channel sand flat
	Sheets ~2.8 m. thick	Massive or faint lamination	-	Fsm	FF	Deposit of overbank sheet flow
	Lenticular ~0.6 m. thick	Cross-bedding	-	Sr	CS	Crevasse splay
	Sheets ~2.5 m. thick	Massive with lens of calcrete layer in uppermost part	-	P Fsm	FFP	Proximal floodplain deposit
	Lenticular cross bedded sandstone interbedded with siltstone ~ 3.5 m. thick	Cross-bedded Bioturbation	Vertical & horizontal burrows	St, Sp Fl	LA	Point bar deposit
	Lenticular ~1.5 m. thick	Massive	Dinosaur bones & teeth	Gcm		
	Sheets ~2.2 m. thick	Massive with lens of calcrete layer in uppermost part	-	P Fsm	FFP	Proximal floodplain deposit
	Lenticular	Massive or faint lamination	Dinosaur bones & teeth	Fl	FF	Overbank sheet flow floodplain ponds and swamps
	Lenticular	Massive or faint lamination	-	Fl, Fsm		
	Lenticular ~1.8 m. thick	Massive or faint lamination	Dinosaur bones *Phuwiangosaurus sirindhornae*	Fl		
	Sheet 3.5 m. thick	Pedogenic features calcrete nodules	-	P	FFD	Distal floodplain deposit

Figure 3.28 Lithologic columnar section of Phu Kum Khao Shell Bed. UTM grid reference: $^{3}43^{500m}E$ $^{18}46^{200m}N$



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular 0.8 m. thick	Massive or faint lamination	-	Fsm		
	Lenticular Cosets of cross bedding conglomeratic sandstone ~2 m. thick	Cross-bedding	-	Sp, St	DA	Mid-channel sand flat
	Sheet ~4.5 m. thick	Massive or faint lamination	-	Fsm	FF	Deposit of overbank sheet flow
	Lenticular Cosets of cross bedding conglomeratic sandstone ~6.5 m. thick	Cross-bedding	-	Sp, St	DA	Mid-channel flat
	Lenticular 1.2 m. thick	Cross-bedding	-	Sp, St		
	Sheet ~3.5 m. thick	Massive or faint lamination	-	Fsm	FF	Deposit of overbank sheet flow

Figure 3.28 Lithologic columnar section of Phu Kum Khao Shell Bed (continued).

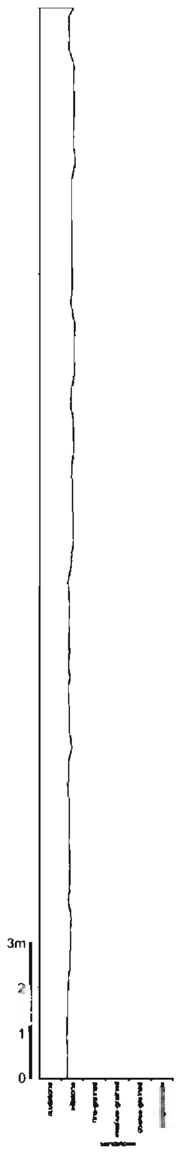
Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Probably alternation of poorly cemented siltstone and mudstone	Probably massive or faint lamination	-	Fsm	FF	Deposit of overbank sheet flow

Figure 3.28 Lithologic columnar section of Phu Kum Khao Shell Bed (continued).

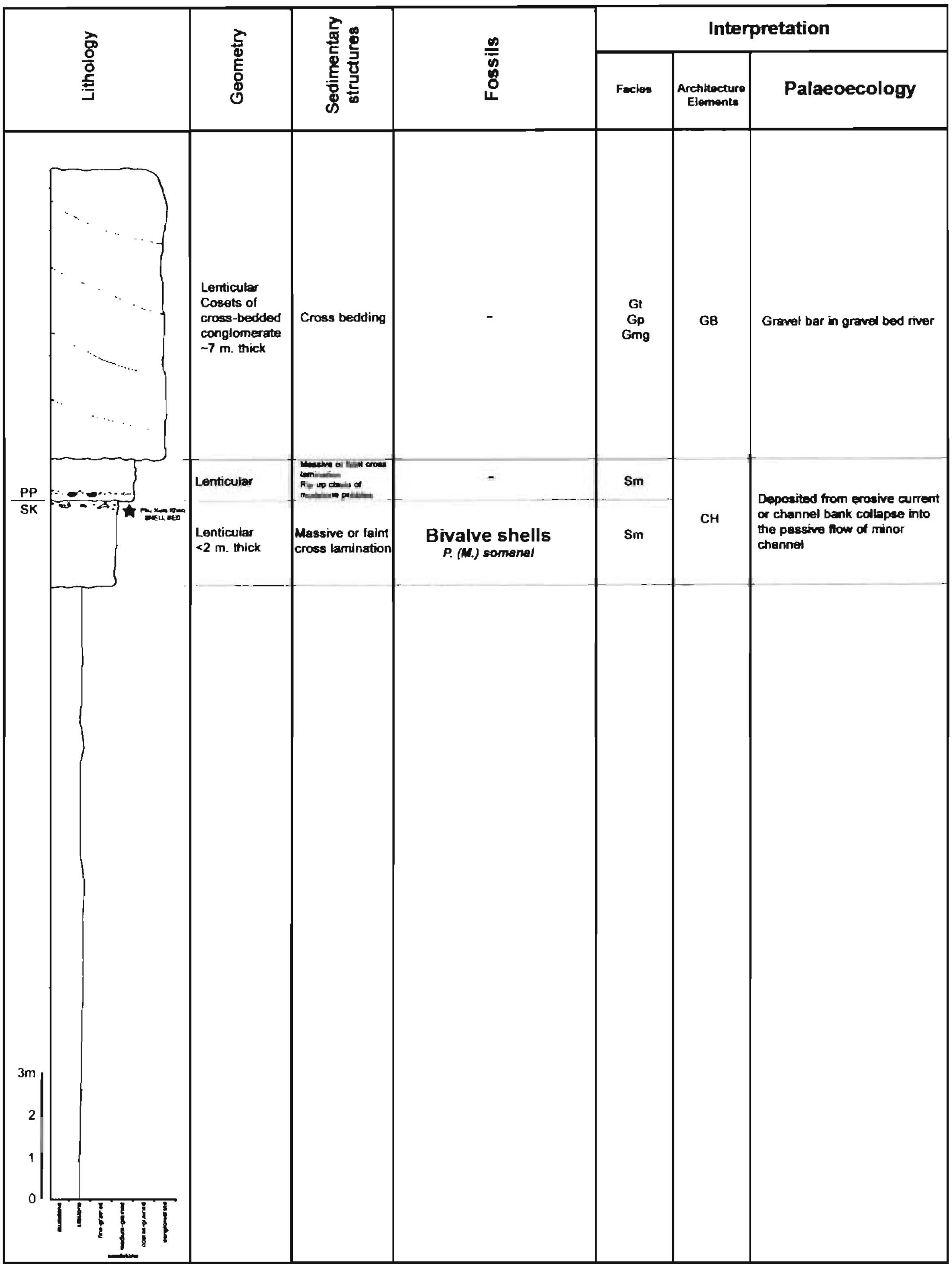


Figure 3.28 Lithologic columnar section of Phu Kum Khao Shell Bed (continued).

Figure 3.29 A, Outcrop of Phu Kum Khao Shell Bed; B, Rip up clasts of mudstone pebbles in the basal of Phu Phan Formation. C, Left valves of *Pseudohyria (Matsumotoina) somanai* on the bedding surface of shell bed. D, Cross section of disarticulated valves of *P. (M.) somanai* on the bedding surface of shell bed (Diameter of coin in Figure 3.29C, D is 2 cm.). UTM grid reference: $^{3}43^{500m}$E $^{18}46^{200m}$N

3.3.3.2 Phu Sing Molluscan Fossils Locality

Map sheet: 5742 III AMPHOE SAHATSAKHAN

UTM grid reference: $^{3}43^{100m}E$ $^{18}50^{900m}N$

Location: Phu Sing (Figure 3.27)

Accessibility: Take the Highway Number 227 from Sahatsakhan town, turn left to Ban Sing Sa-at. Then, take village road to Ban Non Pla Khao and to northern side of Phu Sing. Shell Bed situated near the top of the northern side of Phu Sing.

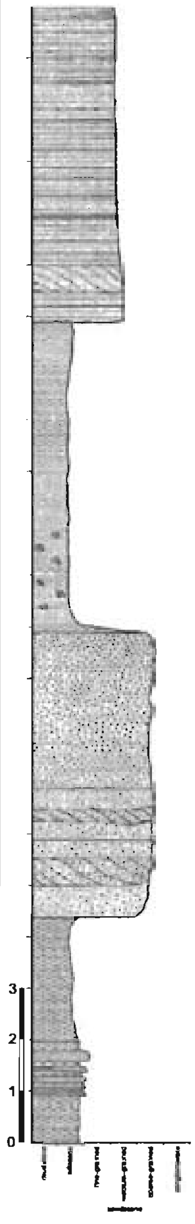
Lithology: Mud- and lime-nodule conglomerate (Figure 3.31A, C, E)

Geometry: This shell bed is lenticular, about 0.3 m in thickness. It gradually decreases in thickness to south. It rests on mudstone-siltstone and was overlaid by laminated and cross-bedded sandstone (Figures 3.32A).

Sedimentary structures: Numerous burrows present on bedding surface of shell bed. The shell bed was overlaid by laminated, planar- and trough-cross bedded, medium-grained sandstone with abundant burrows (Figure 3.31A-D; 3.32A-D). The cross-bedded, medium-grained sandstones show the current direction to the south.

Fossils: Abundant of *Pseudohyria (Matsumotoina) somanai, Nippononaia* sp. cf. *N. mekongensis* (Figure 3.32E) and cementing habit bivalve Trigonioidoidea *fam. indet.* (Figure 3.32F) Burrows are found on the bedding surface of shell bed and in incline units of planar-cross bedding sandstone.

Palaeoecology Interpretation: Based on Miall (1996), Shell bed might be assigned as Matrix-Supported Gravel Lithofacies (Gmm) (Table 1.1 and Figure 3.30). The overlying laminated-, planar-, and trough-cross bedded sandstones might be assigned to Horizontally Bedded Sand Lithofacies (Sh), Ripple Cross-Laminated Sand Lithofacies (Sr) and Planar-Cross-Laminated Sand Lithofacies (Sp) (Table 1.1 and Figure 3.30). The facies assemblage (Gmm, Sh, Sr, Sp), geometry and relationships of the shell bed indicates Lateral-Accretion Macroform (LA) (Table 1.2, Figure 1.3 and 3.30). Palaeoecology might be assigned as deposited in Lateral-Accretion Macroform, which indicates point bar deposit.



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular	Lamination Cross-bedding	-	Fl Sp, St, Sr	CS	Crevasse splays
	Sheet	Massive or faint lamination	-	Fsm	FFD	Distal floodplain deposit
	Sheet ~2 m. thick	Calcrete nodules	-	P		
	Cosets of medium- to coarse-grained sandstone, some interbedded with cross-bedded sandstone	Massive and cross-bedding	-	Sm Sp, St	SB	Crevasse splays and minor bar
	Sheet ~4.3 m. thick	Massive or faint lamination	-	Fl	FF	Floodplain deposit

Figure 3.30 Lithologic columnar section of Phu Sing Shell Bed. UTM grid reference: $^{3}43^{100m}E$ $^{18}50^{900m}N$

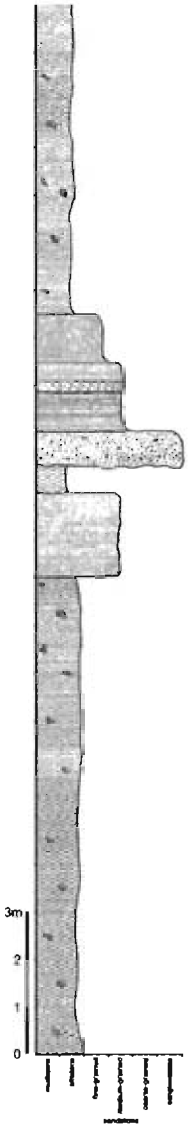
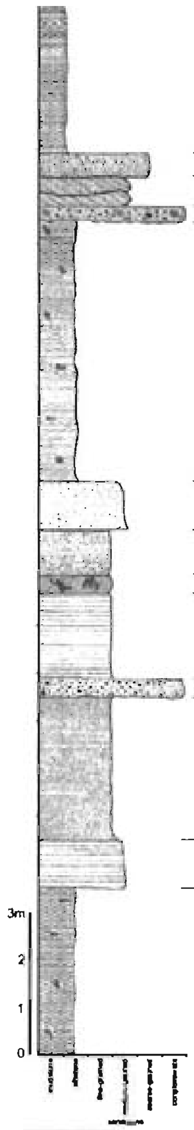
Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Sheet	Calcrete nodules	-	P	FFD	Distal floodplain deposit
	Lenticular	Massive or faint lamination	-	Fsm	CH(FF)	Abandoned channel
	Lenticular	Lamination cross-lamination	-	Sh Sp, St, Sr	LA	Point bar deposit
	Lenticular	Massive	-	Gmm		
	Sheet	Massive	-	Fsm	FF	Deposited of overbank sheet flow
	Sheet	Massive or faint lamination	-	Sm	CH	Deposited from bank collapse in small channel
	Sheet ~10 m. thick	Pedogenic features Calcrete nodules	-	P	FFD	Distal floodplain deposit

Figure 3.30 Lithologic columnar section of Phu Sing Shell Bed (continued).

Lithology



Geometry	Sedimentary structures	Fossils	Interpretation		
			Facies	Architecture Elements	Palaeoecology
Sheet	Massive or faint lamination	-	Fsm	FF	Deposit of overbank sheet flow
Lenticular	Massive	-	Sm	LS	Flash flood deposit
Lenticular	Trough cross-bedding	-	St	LA	Point bar deposit
Lenticular	Massive	-	Gmm		
Sheet	Calcrete nodules	-	P	FFD	Distal floodplain deposit
Sheet	Massive or faint lamination	-	Sm	LS	Flash flood deposit
Sheet	Massive or faint lamination	-	Fsm	CH(FF)	Abandoned channel
Sheet	Massive, bioturbation	-	Fr		
Sheet	Lamination	-	Fl		
Lenticular	Massive	-	Gmm	SG	Plastic debris flow in channel
Sheet	Massive or faint lamination	-	Sm	LS	Flash floods deposit
Sheet	Lamination	-	Sh		

Figure 3.30 Lithologic columnar section of Phu Sing Shell Bed (continued).

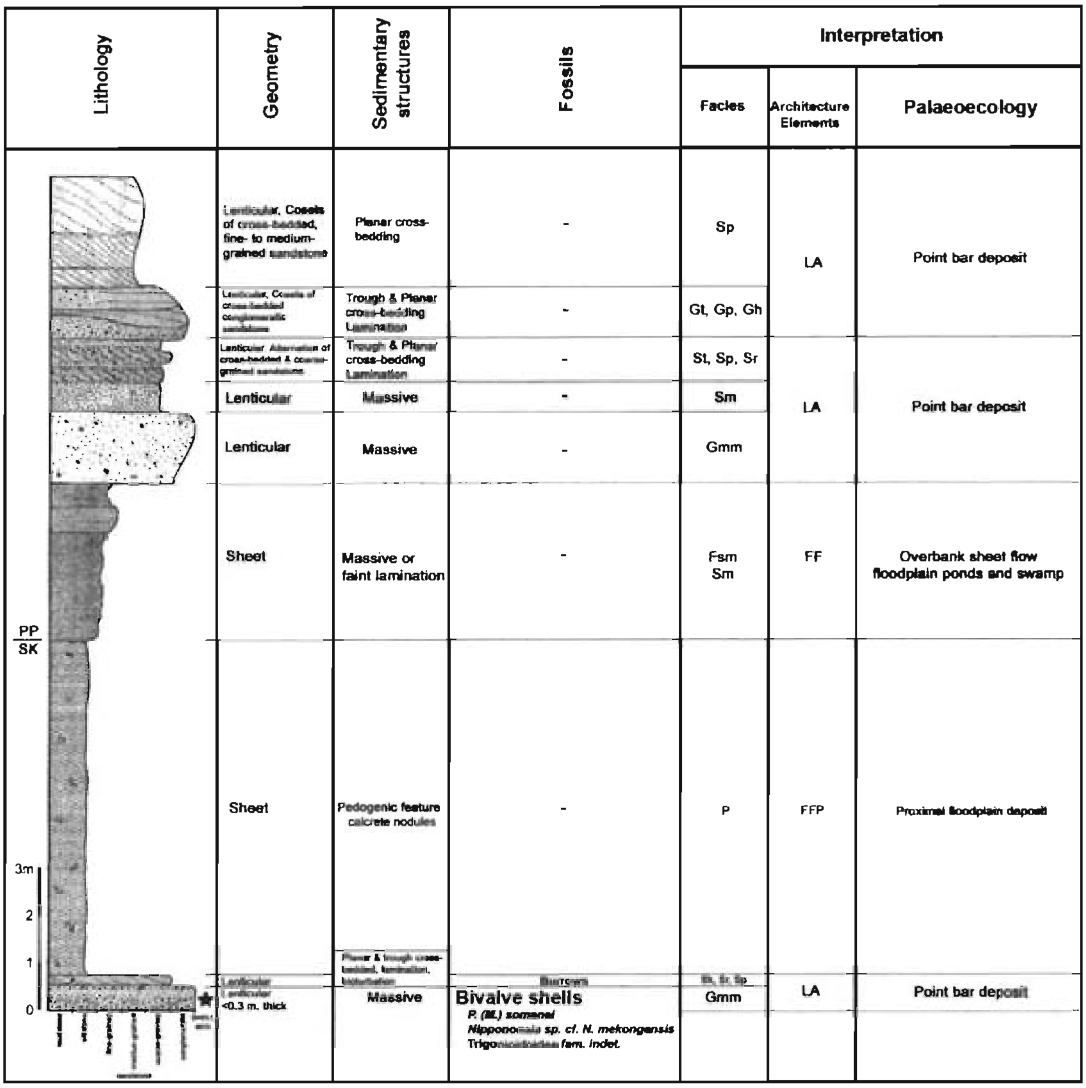


Figure 3.30 Lithologic columnar section of Phu Sing Shell Bed (continued).

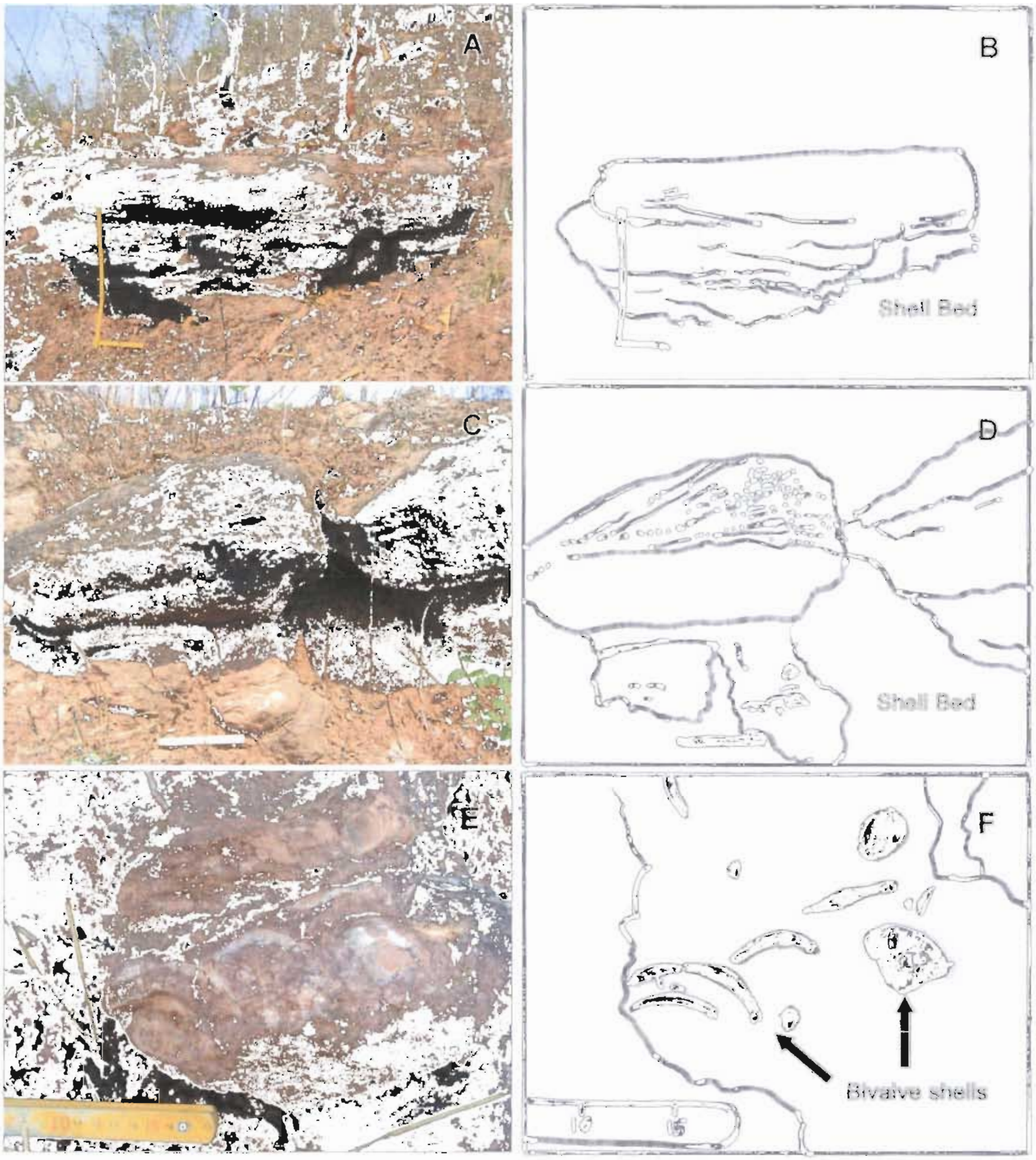


Figure 3.31 A, Phu Sing Shell Bed in conglomerate bed, which was overlaid by laminated sandstone; B, Drawing of A; C, Shell Bed was overlaid by cross bedded sandstone, lower center part of picture is close up in Figure 3.33E (scale bar is 20 cm.); D, Drawing of C; E, Vertical section of shell bed showing shell imbrication of disarticulated valves; F, Drawing of E. UTM grid reference: $^{3}43^{100m}E$ $^{18}50^{900m}N$

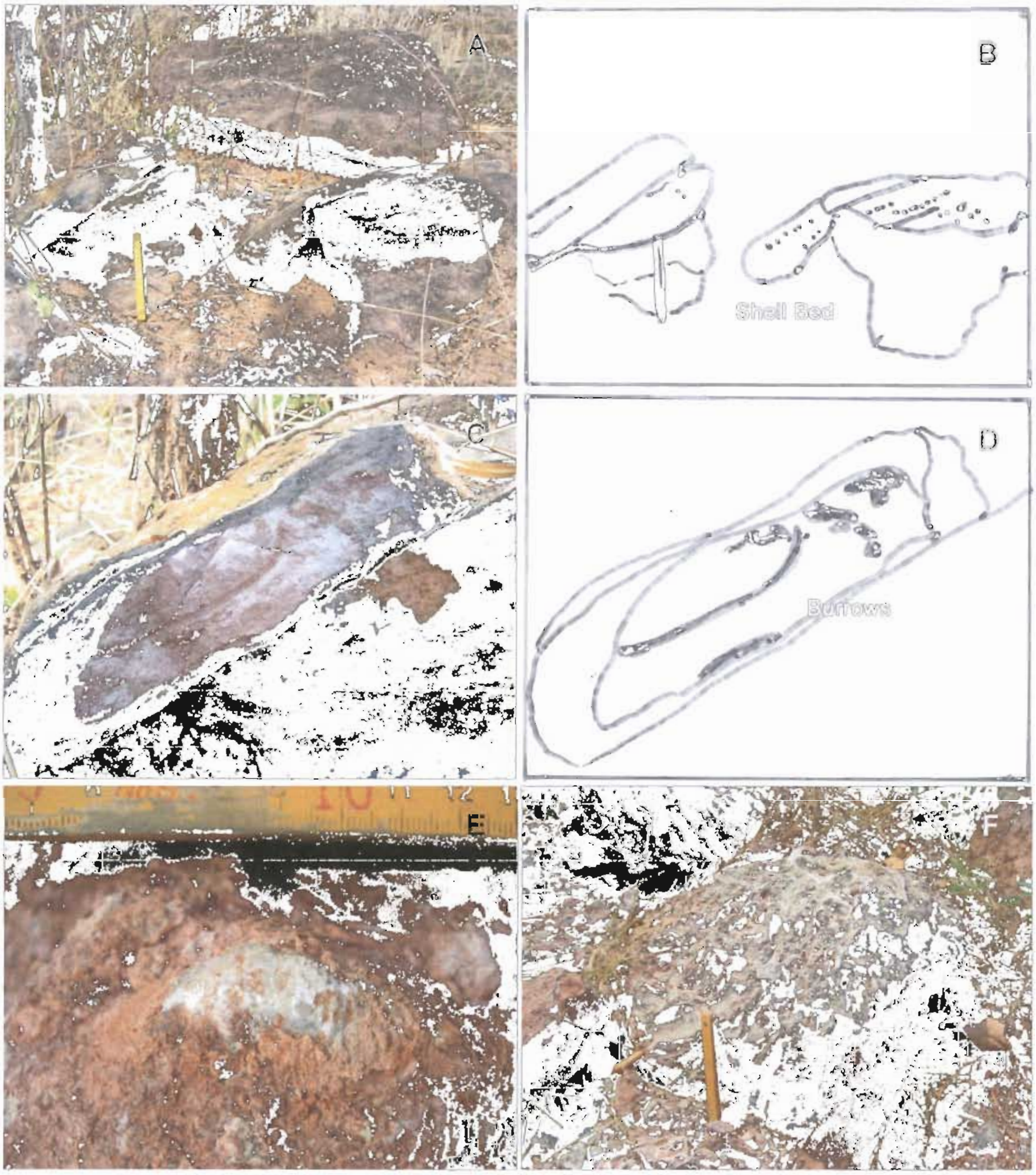


Figure 3.32 A, Erosional surface presents on the boundary between shell bed and the overlying planar cross bedded sandstone, inclined unit on left side of picture is close up in Figure 3.32C; B, Drawing of A; C, Vertical, incline, and horizontal burrows in inclined unit of planar cross bedded sandstone; D, Drawing of C; E, Postero-umbonal region of left valve of *Nippononaia* sp. cf. *N. mekongensis* exposed on the bedding surface of conglomerate; F, Shell accumulation of cementing bivalve in mudstone. (scale bar in Figures 3.32A and F are 0.2 m.) UTM grid reference: $^{3}43^{100m}E$ $^{18}50^{900m}N$

3.3.3.3 Phu Po Molluscan Fossil Locality

Map sheet: 5742 III AMPHOE SAHATSAKHAN

UTM grid reference: $^{3}54^{500m}$E $^{18}37^{800m}$N

Location: Phu Po (Figure 3.27)

Accessibility: Take the Highway Number 227 from Kalasin City to Sahatsakhan town, turn right at Ban Khai Luk Sua, 9 km before reach Sahatsakhan town. Then, take the village road approximately 10 km to the intersection after 2.5 km pass from Ban Huai Saeng. At the intersection turn left go strength on the road to Phu Po about 2 km, turn right at the road to Rong Rian Phu Po Witthaya. The Shell Bed is on the southern side of Phu Po.

Lithology: Medium- to coarse-grained sandstone, conglomerate.

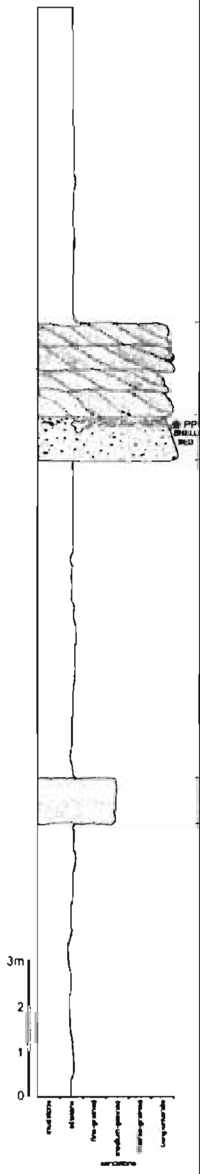
Geometry: The shell bed is lenticular of medium- to coarse-grained sandstone between thick sequences of cross bedded mud-nodule conglomerate (Figure 3.34A).

Sedimentary structures: Trough cross-bedding present in overlying beds, which show the current direction to the west.

Fossils: *Pseudohyria (Matsumotoina) somanai* and vertebrate bone.

Palaeoecology Interpretation: Based on Miall (1996),

Shell bed might be assigned as Matrix-Supported Gravel Lithofacies (Gmm) (Table 1.1 and Figure 3.33). Sets of trough cross-bedding overlie on shell bed might be assigned to Trough-Cross-Bedded Gravel Lithofacies (Gt) (Table 1.1 and Figure 3.33). Lithofacies Gt is normally lying on Lithofacies Gmm, therefore, outcrop of shell bed might be assigned to Gravel Bars and Bedform (GB) (Table 1.2 and Figure 1.3). Palaeoecology might be interpreted as shell bed is gravel-bed river deposits, probably mid-channel bar.



Lithology	Geometry	Sedimentary structures	Fossils	Interpretation: Facies	Interpretation: Architecture Elements	Interpretation: Palaeoecology
	Lenticular	Trough cross bedding	-	Gt	GB	Probably mid-channel bar
	Lenticular <1 m thick	Inverse Grading	Bivalve shells *R (M.) somanai* Vertebrate bones	Gmm		
	Probably sheet	Massive or faint lamination		Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp
	Lenticular	Massive or faint lamination		Sm	LS	Flat flood deposit
	Probably sheet	Massive or faint lamination		Fsm	FF	Deposited of overbank sheet flow floodplain ponds and swamp

Figure 3.33 Lithologic columnar section of Phu Po Shell Bed. UTM grid reference: $^{3}54^{500m}E$ $^{18}37^{800m}N$

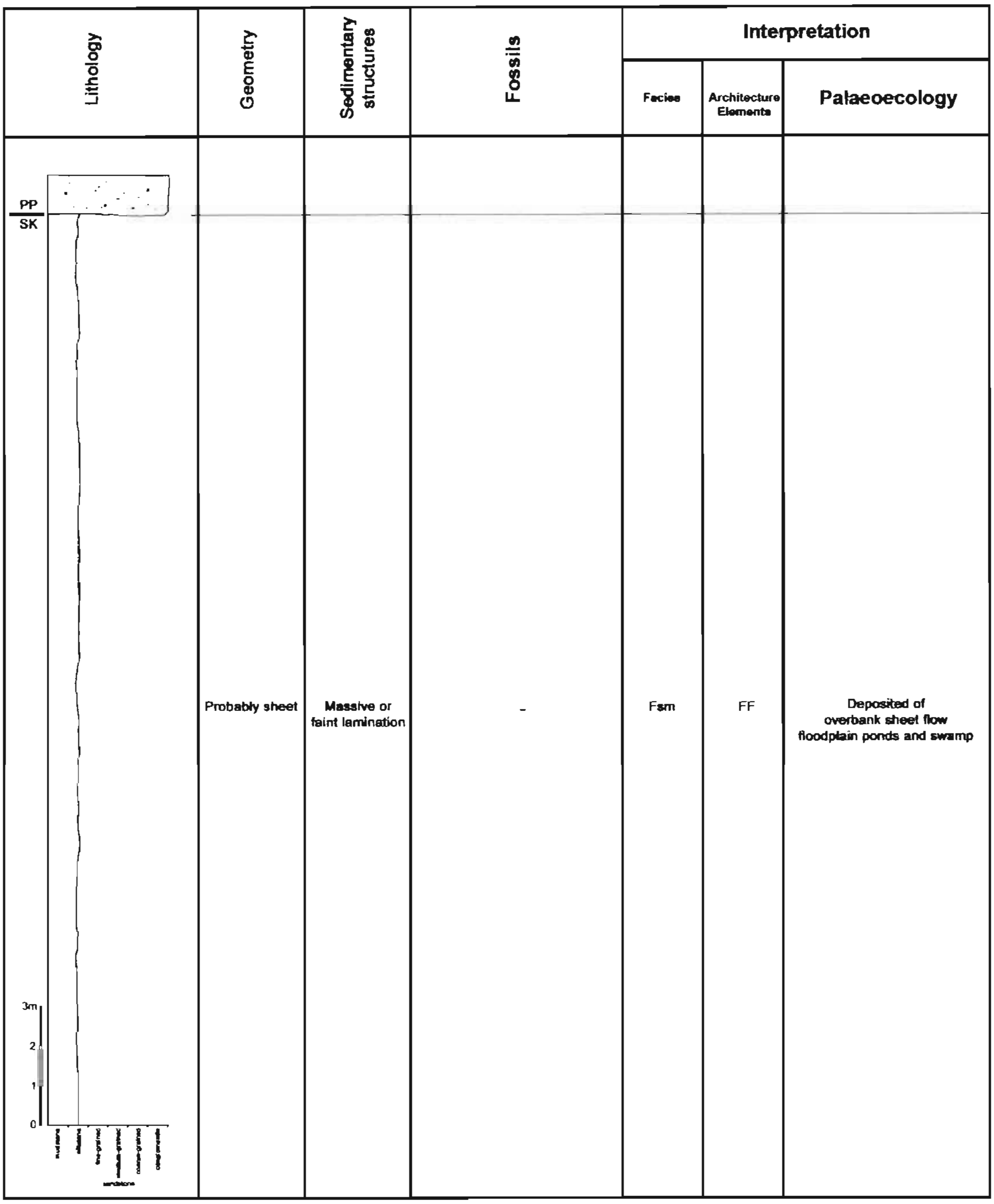


Figure 3.33 Lithologic columnar section of Phu Po Shell Bed (continued).

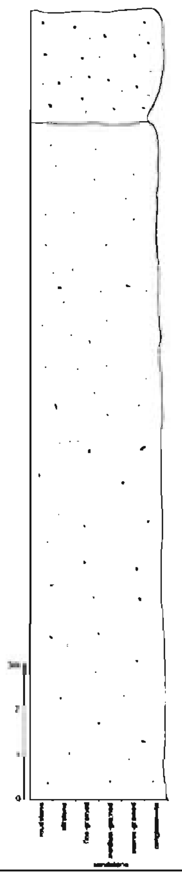
Lithology	Geometry	Sedimentary structures	Fossils	Interpretation		
				Facies	Architecture Elements	Palaeoecology
	Lenticular ~2.5 m. thick	Massive	-	Gmm		
	Thick sheet ~16 m.thick	Massive	-	Gmm	SG	Sediment gravity flow deposit Plastic debris flow, high-strength viscous

Figure 3.33 Lithologic columnar section of Phu Po Shell Bed (continued).

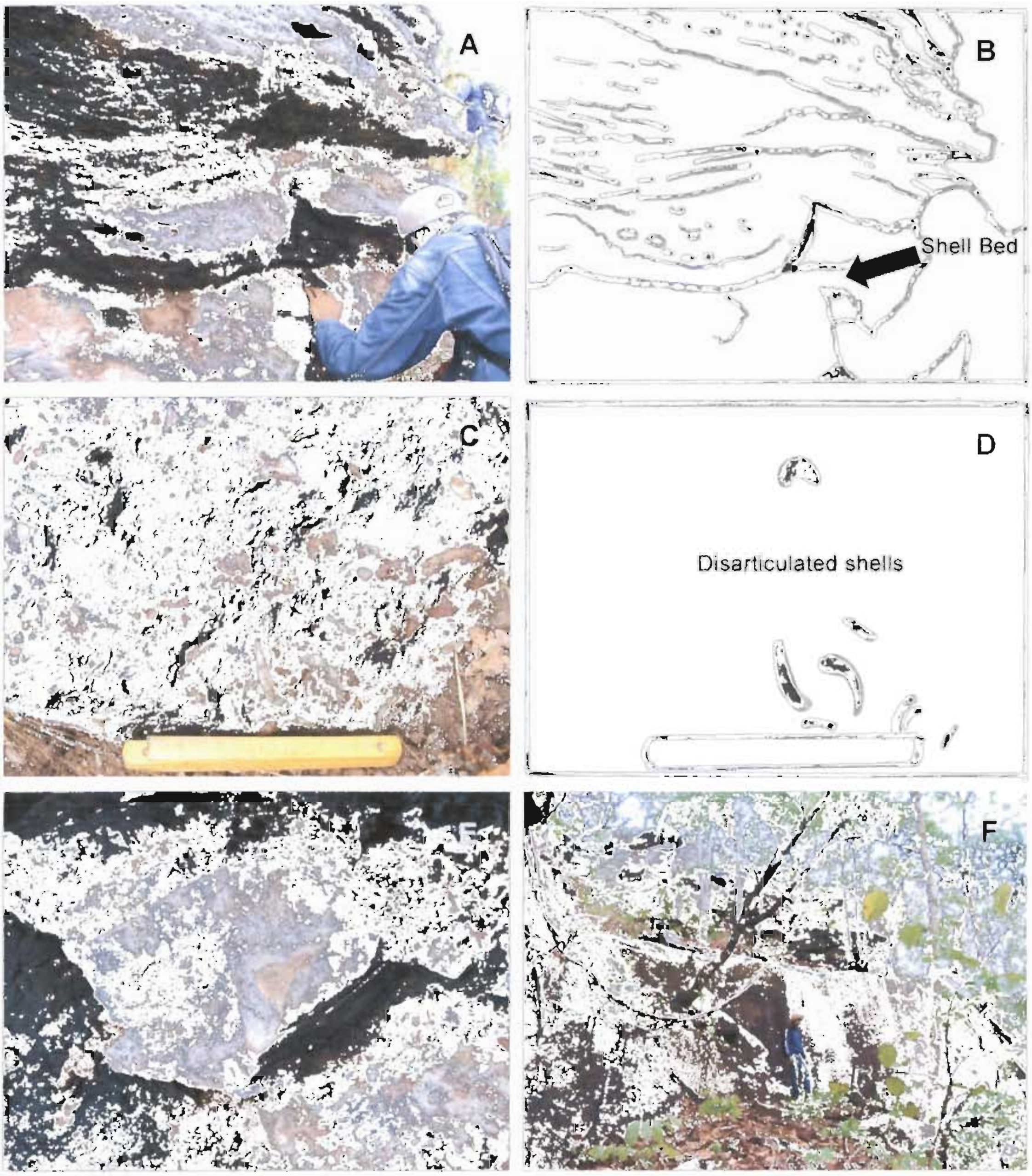


Figure 3.34 A. Outcrop of Phu Po Shell Bed in red cross-bedded conglomerate, most of bivalve fossils were found at upper part of the lower set of conglomerate; B. Drawing of A; C. Shell bed show no preferred orientation of bivalve fossils on bedding plane; D. Drawing of C; E. Vertebrate bone was also found in the same layer with bivalve; F. Very thick massive coarse-grained to conglomerate of the Phu Phan Formation covers the top of Phu Po (Man in the picture is about 1.7 m height). UTM grid reference: $^{3}54^{500m}E$ $^{18}37^{800m}N$

3.4 Correlation of twelve columnar sections of molluscan localities.

Columnar sections of each molluscan fossil localities can be correlated by their similarity of lithology and fossils (Figure 3.35).

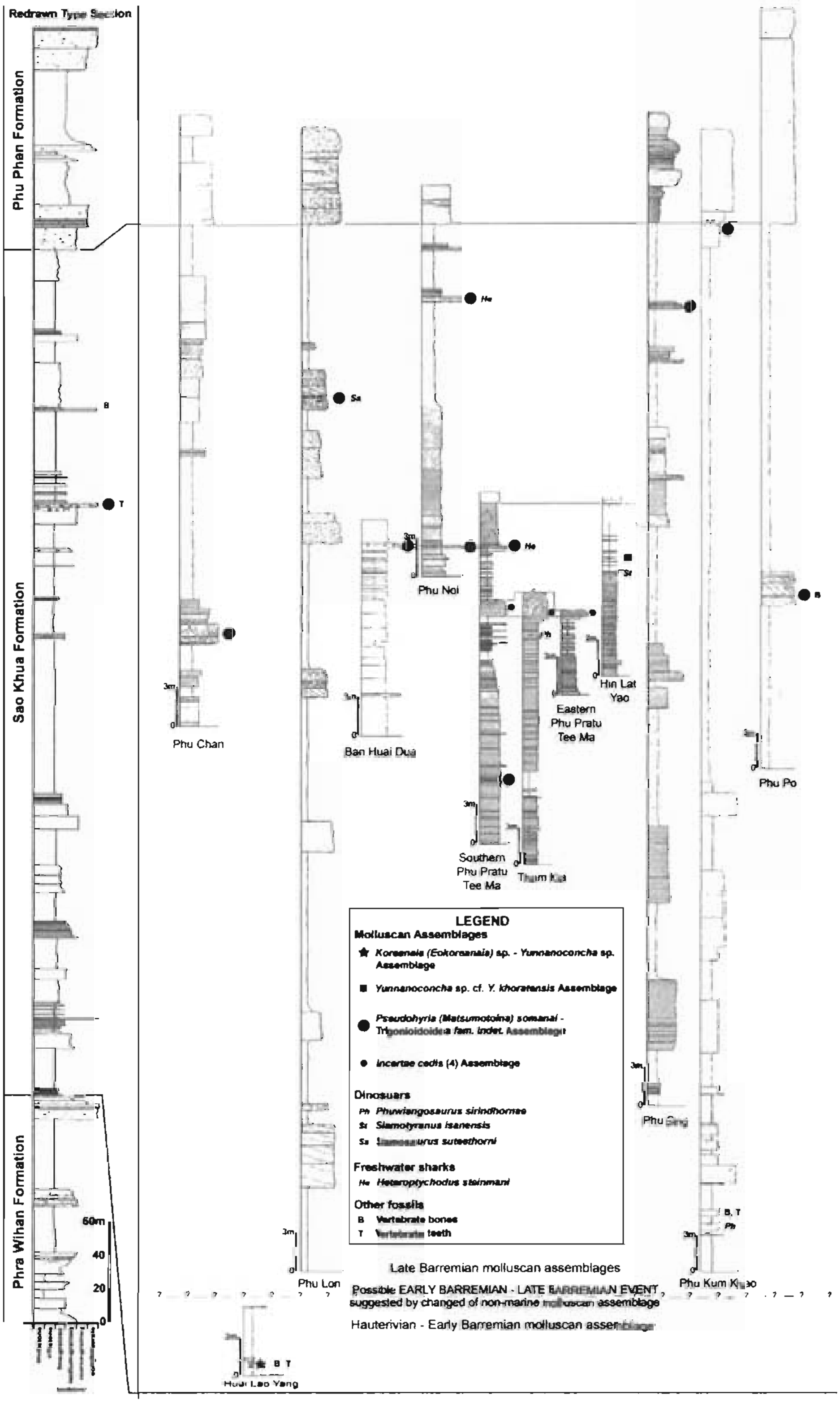


Figure 3.35 Correlation of 12 sections at molluscan localities.

CHAPTER IV

SYSTEMATIC PALAEONTOLOGY OF MOLLUSCAN FOSSILS

4.1 General Information

4.1.1 The Freshwater Molluscs

Molluscs are unsegmented soft-bodied invertebrate animals (Figure 4.1), which their shells are secreted as calcium carbonate, mainly aragonite, from the edge of mantle (Figure 4.2). The Phylum Mollusca comprises 8 classes, including, Aplacophora, Polyplacophora, Tergomya (Monoplacophora), Gastropoda, Bivalvia, Rostroconchia, Scaphopoda, and Cephalopoda.

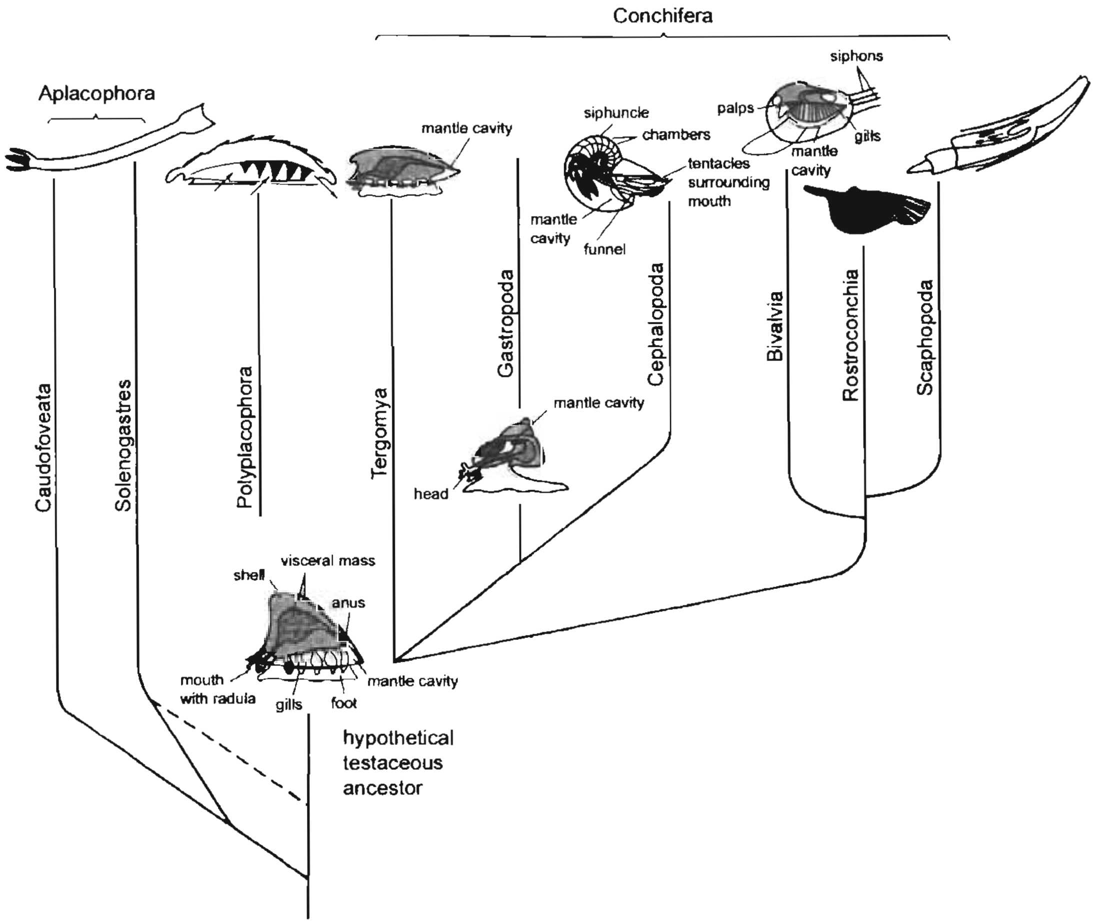


Figure 4.1 Unsegmented soft-bodied invertebrate animals in the Phylum Mollusca and their evolution from the theoretical archimollusc (After Benton and Harper, 1997).

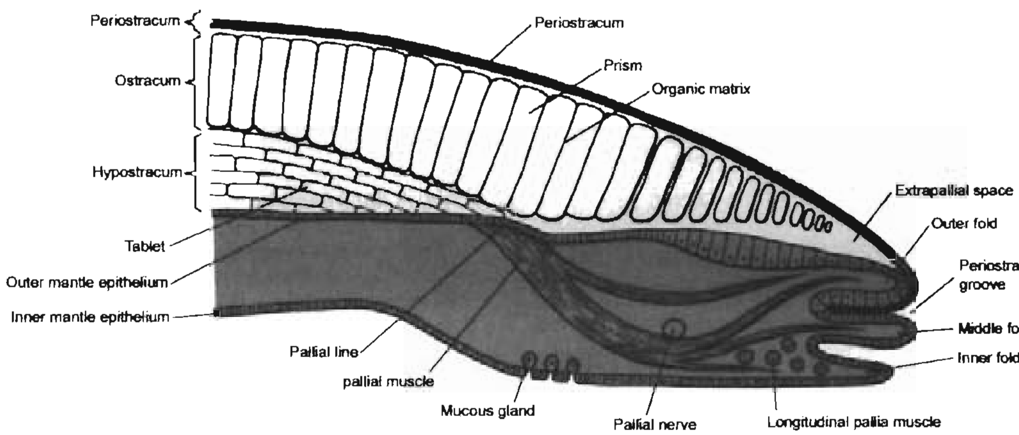


Figure 4.2 Transverse section of the edge of a bivalve valve and mantle margin (After Ruppert *et al.*, 2004).

However, there are only 2 classes live in the freshwater environments, including, Gastropoda and Bivalvia.

Class Gastropoda: Gastropods are univalved, usually coiled shells. Having head with eyes. Internal organs rotated through up to 180° during torsion early in ontogeny. The group originated from Late Cambrian and is alive to Recent (see details in topic 4.2).

Class Bivalvia: Bivalves are twin-valved molluscs, both valves joined along dorsal hinge line with teeth and ligament, lacking head but well-developed muscular foot and often elaborate gill systems. The group originated from Early Cambrian and is alive to Recent (see details in topic 4.3).

In the present study, a few gastropods and numerous bivalves were discovered. The main characters and lifestyles of gastropods and bivalves were described below before systematic description.

4.1.2 Class Gastropoda

Gastropods include snails and slugs, form both with and without a calcareous shell. They evolved into many trophic styles include grazing, suspension-feeding, predatory and parasite. The group is characterized by torsion, the head and the foot remains fixed relative to each other, but all visceral mass and mantle are rotate through 180°. The mantle cavity and anus were open anteriorly and the shell coiled posteriorly in the endogastric position (Figure 4.3).

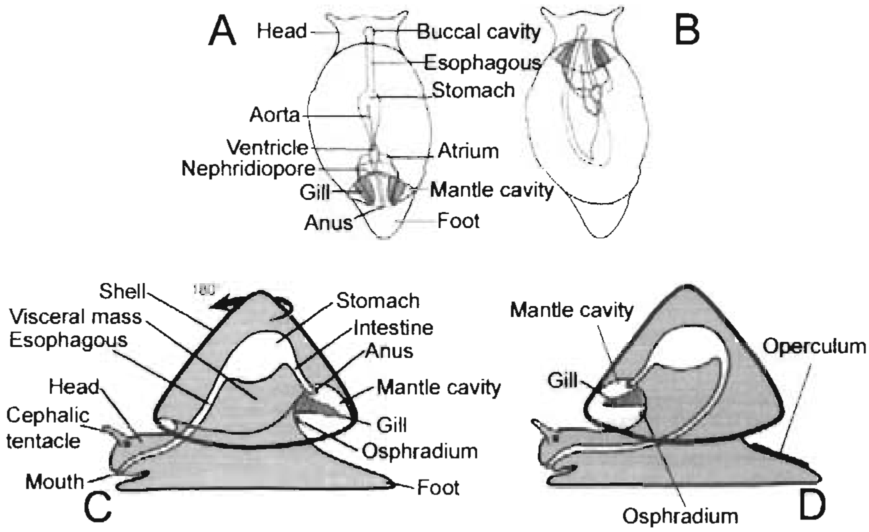


Figure 4.3 The effect of torsion in gastropods. A and B, Dorsal views. C and D, Lateral views from the left. A and C, The monoplacophoran ancestor prior to torsion. B and D, The early gastropods after torsion (After Ruppert *et al.*, 2004).

The gastropod shell is commonly aragonitic or calcitic, usually conical, with closure at the pointed apex and open ventrally at the aperture, when orientated with the aperture facing forward and the apex facing upwards. The head of gastropod emerges at the aperture. Many gastropods have an operculum which partly closes the aperture when the animal withdraws into its shell (Figure 4.3D; 4.4).

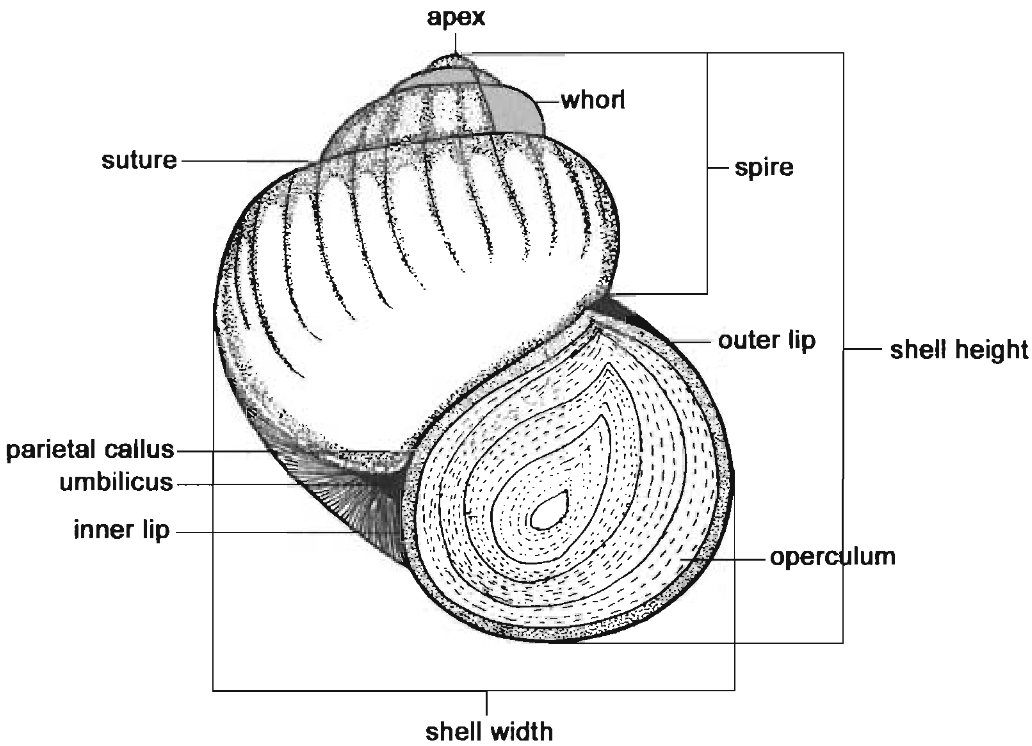


Figure 4.4 Gastropod shell morphology. (Adapted after Subba Rao, 1989).

Three subclasses of gastropods are divided on the basis of respiratory and nervous system, including, Prosobranchia, Opisthobranchia, and Pulmonata. There are only Prosobranchia and Pulmonata live in freshwater environments.

The Prosobranchia is fully torted with one or two gills, anterior mantle cavity and cap-shaped or conispiral shells. This group is mainly part of the marine benthos with a few freshwater and terrestrial taxa.

The Pulmonata is detorted gastropods, such as slugs and snails, with mantle cavity modified to form an air-breathing lung. The group originated from Jurassic and is alive to present.

4.1.3 Class Bivalvia

Bivalves are bilaterally symmetrical and laterally compressed. They are provided with a shell consisting of two wholly or partly calcified valves lying on left and right sides of the body. Typically, the two valves are of equal convexity; but in some forms bilateral symmetry has been lost, usually as the result of cementation of one valve to the substrate, and the valves differ in size to a varying extent.

The valves are united dorsally by an only partially calcified, elastic structure is called ligament, which open and close by hinging along an axis (Figure 4.5). Typically, the hinge axis has an approximately anteroposterior direction. The two valves thus open along their anterior, posterior, and ventral margins.

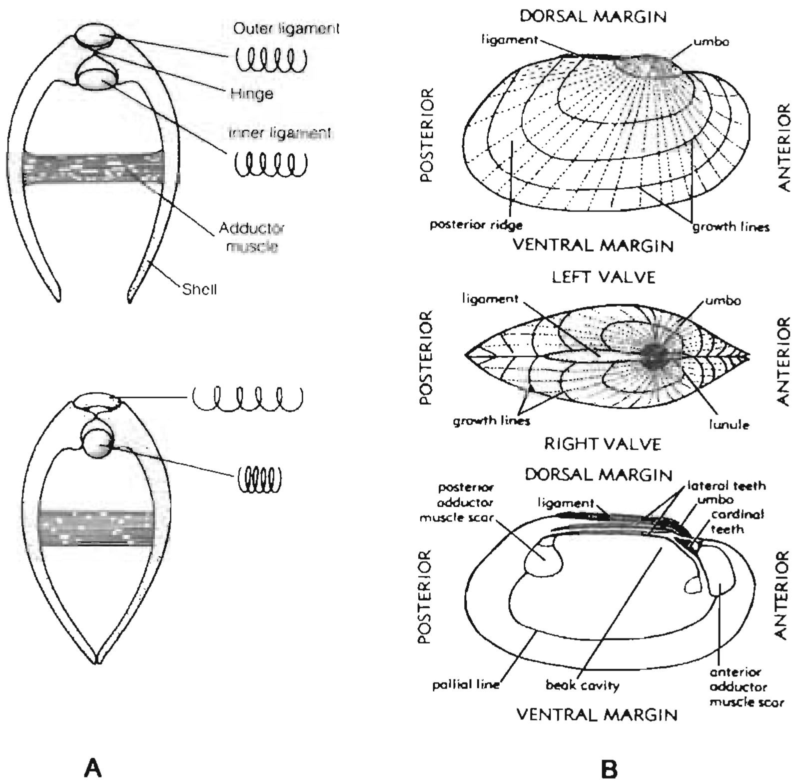


Figure 4.5 A. Transverse section of a bivalve shell, showing antagonistic functions of hinge ligaments and adductor muscles. When the valves are closed by the adductor muscles; the outer hinge ligament is stretched and the inner ligament is compressed (After Ruppert *et al.*, 2004). B. Mophology of freshwater unionacean bivalve (Adapted after Cox *et al.,* 1969).

The valves are closed by the action of adductor muscles (Figure 4.5A), which situated anteriorly and posteriorly. While the shell is closed, the hinge ligament is constrained, when the adductor muscles relax, the ligament expands and the shell spring open (Figure 4.5). The muscle scars may usually be seen as clear shiny and depressed areas inside both valves.

The first bivalves were marine shallow burrowers; epifaunal, deep-burrowing and boring strategies, together with migrations to freshwater habitats were secondary innovation (Benton and Harper, 1997).

The animal lacks a head, radula, jaws, and cephalic sensory organs, which found in other classes of molluscs. Mouth and anus are usually at opposite ends of the body. Foot present in most Bivalvia is an extensile structure which most commonly serves mainly for burrowing.

4.1.3.1 General morphology of bivalve shell

4.1.3.1.1 Hinge teeth There are 8 types of teeth and sockets in bivalves, including, taxodont, actinodont, dysodont, isodont, schizodont, heterodont, pachyodont, and desmodont hinges (Cox *et al.*, 1969; Clarkson, 1998; Hylleberg, 2000). However, most of the freshwater bivalves possess schizodont and heterodont hinges. Cardinal teeth are the teeth which lying just below the beak. Lateral teeth are the teeth which situated close to the dorsal margins at some distance from the beaks (Figure 4.5B). Lateral teeth are described as anterior laterals or posterior laterals according to the end of the shell to which they are the more closely situated.

The term Pseudolateral teeth have been applied to elongate longitudinal teeth which their proximal end is close to the beak. Many authorities on the Unionidae apply the term pseudocardinal to teeth agreeing with the above definition of cardinals but differing from the cardinal teeth of other groups in their very irregular form.

Schizodont (Greek = to split) it was originally applied primarily to the type of dentition found in the Family Trigoniidae, in which the median tooth of the left valve, one of a small number radiating from the beaks, is broad and bifid (Figure 4.5B). Forms belonging to the freshwater Superfamily Unionacea have been described as schizodont, as their dentition shows some similarity to that of the Trigoniacea.

Heterodont (Greek = to different) type of dentition was so termed because of the presence of distinctly differentiated cardinal and lateral teeth (Figure 4.5B). The lateral teeth are obscure in many representative of some heterodont familier. When laterals are present, they may belong to both anterior and posterior categories or only to one.

4.1.3.1.2 Shell shape When describing the outline of bivalve as seen in lateral view, recourse is usually made to such terms as suboval, subtrigonal, *etc.* (Figure 4.6).

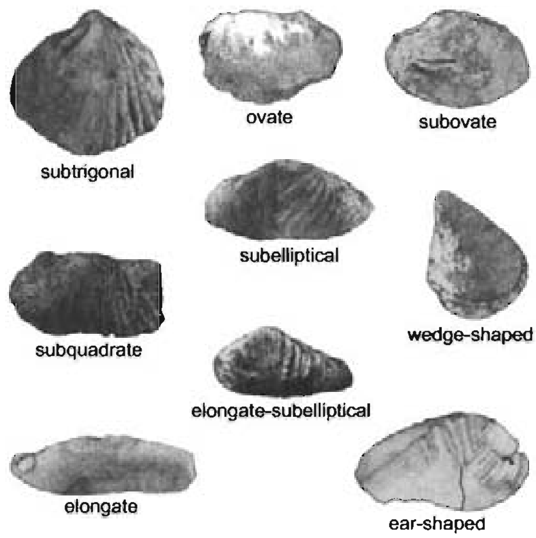


Figure 4.6 Shapes of bivalve shells, illustrating terms commonly used to describe them.

4.1.3.1.3 External features A typical bivalve shell consists of two similar, more or less oval, usually convex valves, which are attached and articulate dorsally with each other. Each valve starting with the larval shell, growth of bivalve shell proceeds by successive increments along the margins of the two valves. It is commonly preserved on each valve of the adult shell, forming a small, nose-like angle termed the beak.

In adult shell, the beak occupies a position close to the middle of the length, the shell is described as equilateral or subequilateral when near to the middle (Figure 4.7A), but if the beak lies closer to one end, the shell is described as inequilateral (Figure 4.7B).

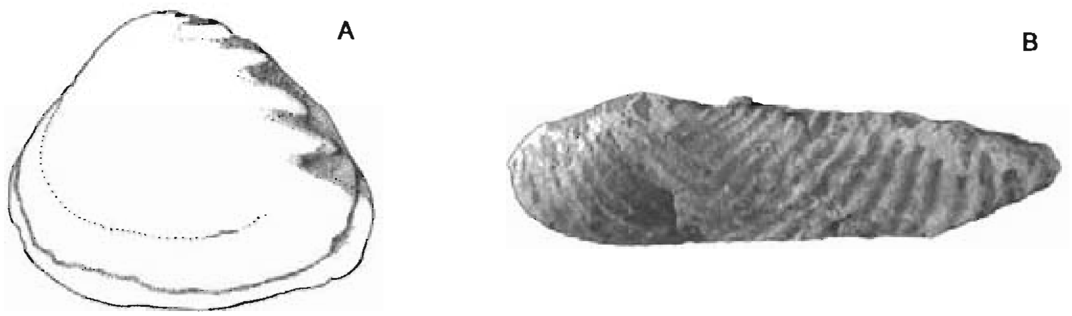


Figure 4.7 Position of beak. A, Subequilateral; B, Inequilateral.

The umbo (plural is umbones) is the point of maximum curvature, a rather indefinite sense to denote the general region of the valve which surrounds this point and extends to the beak. The umbonal cavity is the part of the interior of the valve that lies within the umbo. The umbones are described as prosogyrate if they curve in such a manner that the beaks point in an anterior direction, as opisthogyrate if they point in posterior position, and as orthogyrate if each beak points directly toward the other valves.

4.1.3.2 Lifestyles and morphology of Bivalve

There are seven main ecomorphic groups of bivalves include: infaunal shallow burrowing, infaunal deep burrowing, epifaunal attached by byssus, epifaunal cemented, free lying, swimming and boring and cavity dwelling. Specific assemblages of morphological features are associated with each life mode (Benton and Harper, 1997).

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4.1.3.3 Classification of Bivalvia

Recent Bivalves are subdivided mainly on soft-part morphology, such as features of alimentary canal and the gills together with features of the shell. In bivalve fossils, palaeontologists have attempted to use hinge structures and muscle scars. Five subclasses are recognized including, Protobranchia, Pteriomorphia, Palaeoheterodonta, Heterodonta and Anomalodesmata (Vaught, 1989; Morton *et al.*, 1998).

Most of the freshwater bivalves are belonging to Subclass Palaeoheterodonta, Order Unionoida. Almost of the Asian Cretaceous bivalves are belonging to Superfamily Trigonioidoidea.

4.1.3.3.1 Classification of the Superfamily Trigonioidoidea

The Superfamily Trigonioidoidea possess the hinge structure appears fundamentally unionid in the number and disposition of the principal teeth. It is therefore regarded as a member of the Subclass Heteroconchia, Order Unionoida. It also has no close affinities with trigoniids in the number, form and disposition of hinge teeth (Guo, 1998; Cox, 1952, 1955).

The bivalves in Superfamily Trigonioidoidea were a dominant group of non-marine bivalves in Asia during the Cretaceous (Sha and Fürsich, 1993; Sha, 2007) and Hauterivian-Barremian of Southern England (Baker *et al.,* 1997). They possess unique characters of minute and very depressed anterior pedal retractor scar which separated from the anterior adductor scar (Figure 4.8). The anterior pedal retractor scar is minute and depress. It situates on the postero-dorsal side of the anterior adductor scar (Chen and Jiang, 1990; Sha, 1990, 1992, 1993; Sha and Fürsich, 1993). Trigonioidid bivalves possess some morphological features that are very prominent, and many of them appear to have fairly short ranges. Sha (2007) proposed 7 trigonioidid assemblages in Asia, which some assemblage age are confirmed by marine fossils intercalated in the trigonioidid-bearing formations.

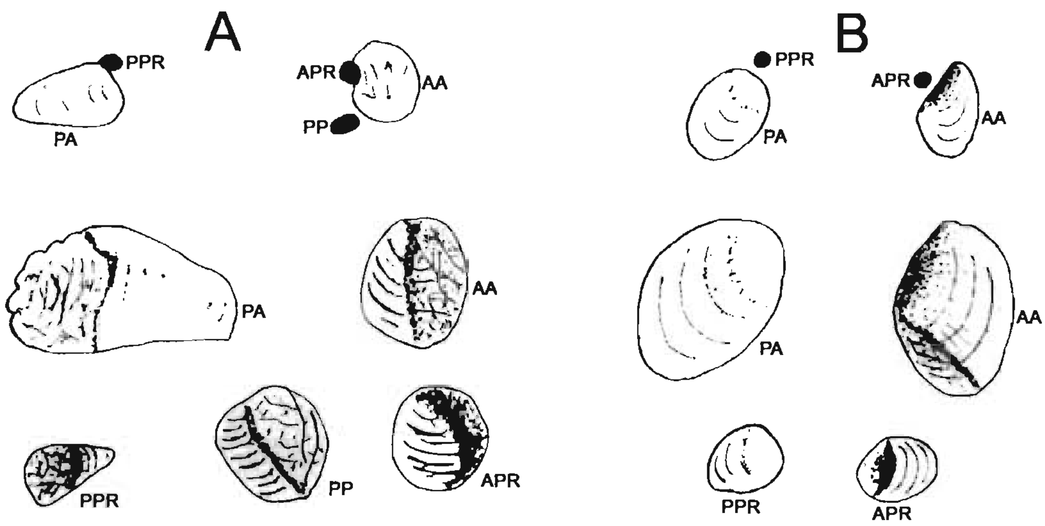


Figure 4.8 Comparative morphology of muscle scars in unionid bivalves (A) and trigonioidid bivalves (B). AA: Anterior adductor muscle; PA: Posterior adductor muscle; APR: Anterior pedal retractor; PPR: Posterior pedal retractor; PP: Pedal protractor (Adapted after Chen and Jiang, 1990).

Sha and Fürsich (1993) subdivided the bivalve fossils in the Superfamily Trigonioidoidea into 4 families, including: Nakamuranaiidae which shell is smooth except for commarginal growth lines; Trigonioididae ornamented with V-shaped ribs; Plicatounionidae covered only with radial ribs; Pseudohyriidae sculptured with chevron-shaped or reverse V-shaped ribs on the posterior area, but either smooth or radially ribbed on flank area (Figure 4.9)

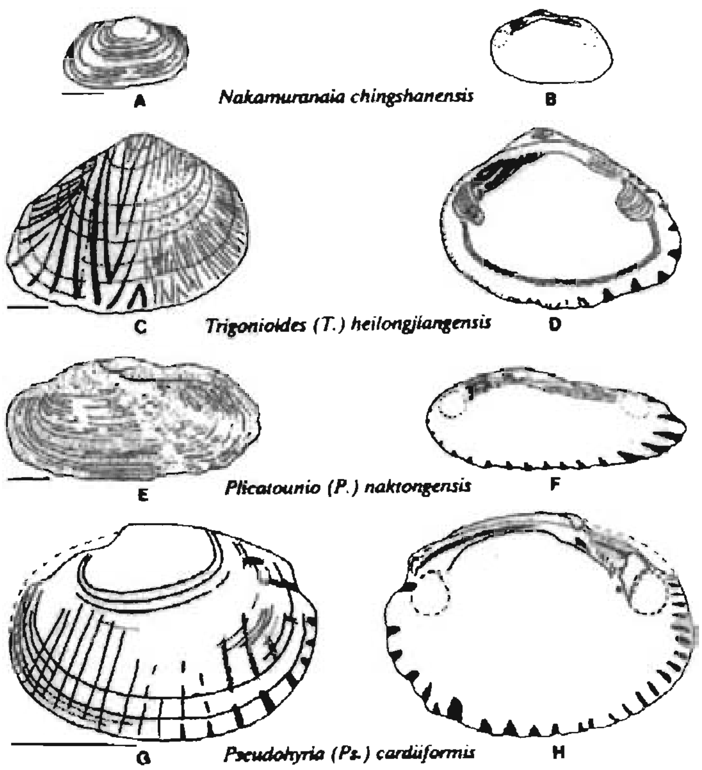


Figure 4.9 Morphological characteristics of 4 families of Trigonioidoidea. A, B: Nakamuranaiidae; C, D: Trigonioididae; E, F: Plicatounionidae; G, H: Pseudohyriidae. Scale bar: 1 cm. (After Sha, 2007).

The external features, such as angle of V-shaped ribs and hinge teeth are diagnostic characters at the generic and subgeneric level. Morphological terms for hinge teeth follow Yang (1979), Guo (1998), and Komatsu *et al.* (2007) (Figure 4.10A). Measurement of bivalve shells follow Good (2004) (Figure 4.10B).

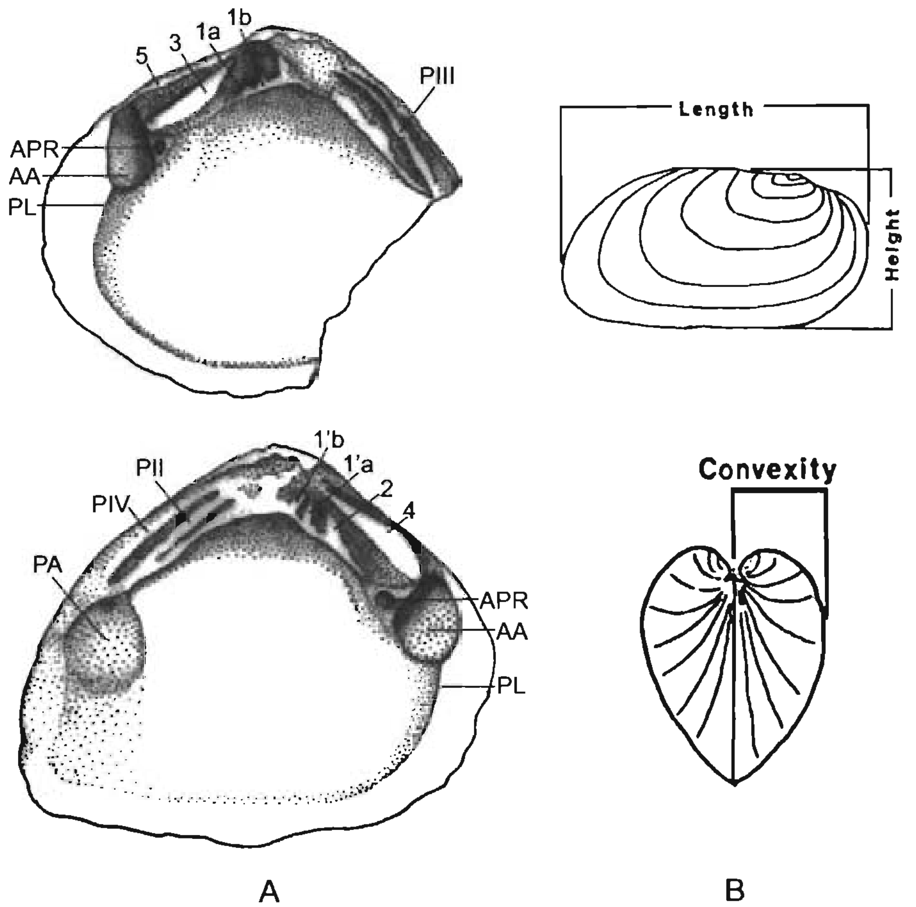
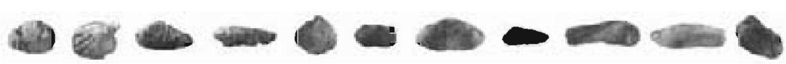


Figure 4.10 A, Morphological terms for the hinge teeth and muscle scars in trigonioidoidean bivalves. Above, internal view of right valve. Below, internal view of left valve. Abbreviations: AA, anterior adductor scar; APR, anterior pedal retractor scar; PA, posterior adductor scar; PL, pallial line; 1a, 1b, 3, 5, pseudocardinal teeth in right valve; 1'a, 1'b, 2, 4, pseudocardinal teeth in left valve; PIII, postero-lateral teeth in right valve; PII, PIV, postero-lateral teeth in left valve (Adapted after Tumpeesuwan *et al.*, 2010); B, Morphometric definition of bivalve shell (Adapted after Good, 2004).

4.2 Systematic description

Eight taxa of bivalve fossils had been reported from the Sao Khua Formation (Table 4.1)

Table 4.1 A summary of the bivalve fossils of the Khorat Group (Modified after Tumpeesuwan *et al.*, 2010; data from Kobayashi (1963, 1968), Kobayashi *et al.* (1963), Hayami (1968), Hahn (1982b), Meesook and Wongprayoon (1999), Jearanaiwong (2000), Imsamut (2003), Tumpeesuwan (2005), Tumpeesuwan and Sato (2005), and Tumpeesuwan *et al.* (2010)).

Formation	Bivalve assemblages
Khok Kruat	
Phu Phan	
Sao Khua	
Phra Wihan	
Phu Kradung	

Trigonioides sp.
Plicatounio sp.
Nippononaia mekongensis
Yunnanoconcha khoratensis
Sainshandia nagnomensis
Nippononaia (Mekongiconcha) subquadrata
Nippononaia (Mekongiconcha) robusta
Nippononaia carinata
Plicatounio namphungensis
Unio sampanoides
Pseudohyria sp.
Cardinioides magnus
Mytilus (Pachymytilus) rectangularis
Goniomya koratensis
Mytilinae *gen. et sp. indet.*
Yunnanoconcha sp. cf. *Y. khoratensis*
Nippononaia sp. cf. *N. mekongensis*
Trigonioides (Diversitrigonioides) sp. cf. *T. (D.) diversicostatus*
Pseudohyria (Matsumotoina) somanai
Unio thailandica
Unio sp.
Neomiodon khoratensis

In this study, 15 morphospecies of bivalve and 1 morphospecies of gastropod fossils were discovered from 15 shell beds in the 3 study areas. Bivalves were classified to 1 order, 3 families; the 8 identified taxa including 6 genera, 8 species; the 7 unidentified taxa including 1 indeterminate family and 6 uncertain affinity. One gastropod species were identified.

The systematic classification used in this study is those of Cox *et al.* (1969), Sha and Fursich (1993) and Sha (2007). All linear measurements of specimens are in millimeters (mm). Morphological terms for trigonioidids follow Chen and Jiang (1990), Sha and Fursich (1993) and Guo (1998). The description of bivalve fossils in this study are shown below

Phulum Mollusca Cuvier, 1975

Class Bivalvia Linnaeus, 1758

Subclass Palaeoheterodonta Newell, 1965

Order Unionoida Stolizka, 1871

Superfamily Trigonioidoidea Cox, 1952

Family Nakamuranaiidae Guo, 1981

Genus *Nakamuranaia* Suzuki, 1943

Diagnosis of the genus: The outer shell surface without ornamentation, except for growth lines. Shell subtrapezoidal in outline, more or less inequilateral. Posterior ridge fairly distinct. Hinge teeth smooth and strongly compress. Pseudocardinal teeth 2 on each valve. Lateral teeth 2 on right valve and 1 on left valve.

***Nakamuranaia* sp.**

Diagnosis: Shell small; subtrigonal, very convex. Well developed escutcheon formed 2 separated part of postero-dorsal margin.

Material: Internal molds of 8 articulated and 9 disarticulated valves of this species were examined (PRC-M-M-293 to PRC-M-M-308; CUMZ 3204).

Locality: Huai Lao Yang, approximately 0.5 km northwest from Phu Phan Thong Locality, Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: Almost fossils are shell dissolution, which they were preserved as molds in red mudstone-siltstone. They are normally scattered in shell bed.

Description: Shell very small, 6.3-14.9 mm in height, 10.0-22.3 mm in length, and 2.6-5.8 mm in convexity, subequilateral and equivalve; subtrigonal or subelliptical in outline. Anterior margin rounded. Posterodorsal and ventral margins slightly arcuated and tapered to the posteroventral end. Outer surface only ornamented with growth lines. Umbo slightly prosogyrate, umbonal cavity slightly deep. Lunule narrow. Escutcheon small. Posterior ridge present. Hinge teeth no preserved in all specimens. Adductor muscle scar circular, ventral side deep. Anterior pedal retractor scar circular, deep, situated on the posterodorsal side of adductor muscle scar. Posterior adductor muscle scar no preserved.

Comparison with fossil species: *Nakamuranaia leei* Yang, 1976 from the Myogog Formation of Korea is similar to this species by size and shape. Postero-dorsal and ventral margins of *Nakamuranaia* sp. are arcuated, forming rounded posterior end at about mid-height or blunt pointed posterior end at about 1/3 to 1/4 of height from ventral end. *N. leei* possesses more arcuated postero-dorsal margin, whereas *Nakamuranaia* sp. possesses well developed escutcheon, which formed 2 separated parts of arcuated postero-dorsal margin.

Discussion: Eight articulated specimens showing various stages of bivalve after dead. They composed of 5 closed valves, 2 slightly opened valves, and 1 slightly moved valves. There are only 3 specimens of articulated valves that muscle scars were preserved. Nine disarticulated specimens composed of 4 left valves, 4 right valves and 1 un-identified valve. This evidence might be revealed no current sorting.

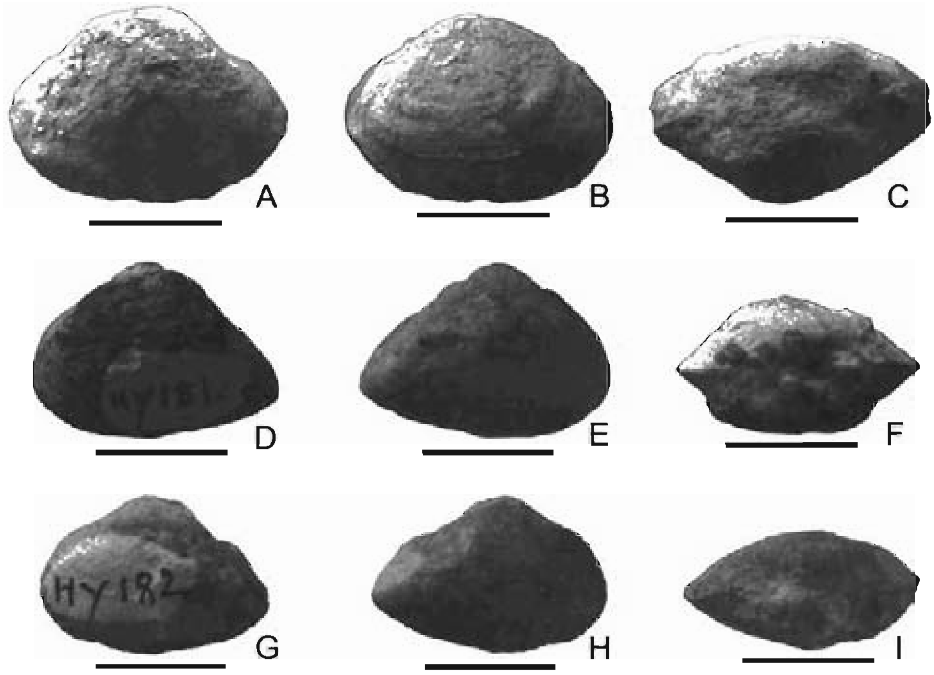


Figure 4.11 Internal molds of *Nakamuranaia* sp. from Haui Lao Yang Shell Bed. A-C, Articulated valves (CUMZ 3204) in A, left side view; B, right side view; C, dorsal view. D-F, Articulated valves (PRC-M-M-293) in D, left side view; E, right side view; F, dorsal view. G-I, Articulated valves (PRC-M-M-294) in G, left side view; H, right side view; I, dorsal view. All scale bars represent 10 mm.

Genus *Yunnanoconcha* Gu and Ma, 1976

Diagnosis of the genus: The outer shell surface without ornamentation, except for growth lines. Shell transversely elongate in outline with well developed escutcheon.

***Yunnanoconcha* sp.**

Diagnosis: Shell elongate. Anterior end slightly rounded. Posterior part tapering. Posterior end lanceolate.

Material: Internal molds of 198 articulated and 29 disarticulated valves of this species were examined (PRC-M-M-314 to PRC-M-M-540).

Locality: Huai Lao Yang Shell Bed, approximately 0.5 km northwest from Phu Phan Thong Locality, Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: Almost fossils are shell dissolution, which they were preserved as molds in red mudstone-siltstone. They are normally scattered in shell bed.

Description: Shell small to medium in size, elongate, gently convex, thin. Length less than three times of height; dorsal margin nearly parallel to ventral. Umbo prosogyrate, located at about one-fourth the length. Lunule short and broad; escutcheon long and broad. Ventral margin slightly arcuate; anterior margin slightly round; posterior margin tapering. Posterior end lanceolate. Pallial line parallel to ventral margin. Pedal retractor scar tiny, deep, and separated from the adductor muscle. Lateral teeth lamelliform. Pseudocardinal teeth no preserved.

Comparison with fossil species: Shell shape of *Yunnanoconcha* sp. similar to *Y. chuxiongensis* Gu and Ma, 1976 from Puchanghe Formation of Yunnan. Shell length of the former species is longer than the latter one. The dorsal and ventral margins of posterior part of former species are nearly parallel to each other, and form the blunt pointed of posterior end. *Yunnanoconcha* sp. differs from *Yunnanoconcha* sp. cf. *Y. koratensis* by its smaller shell and more slightly rounded anterior end.

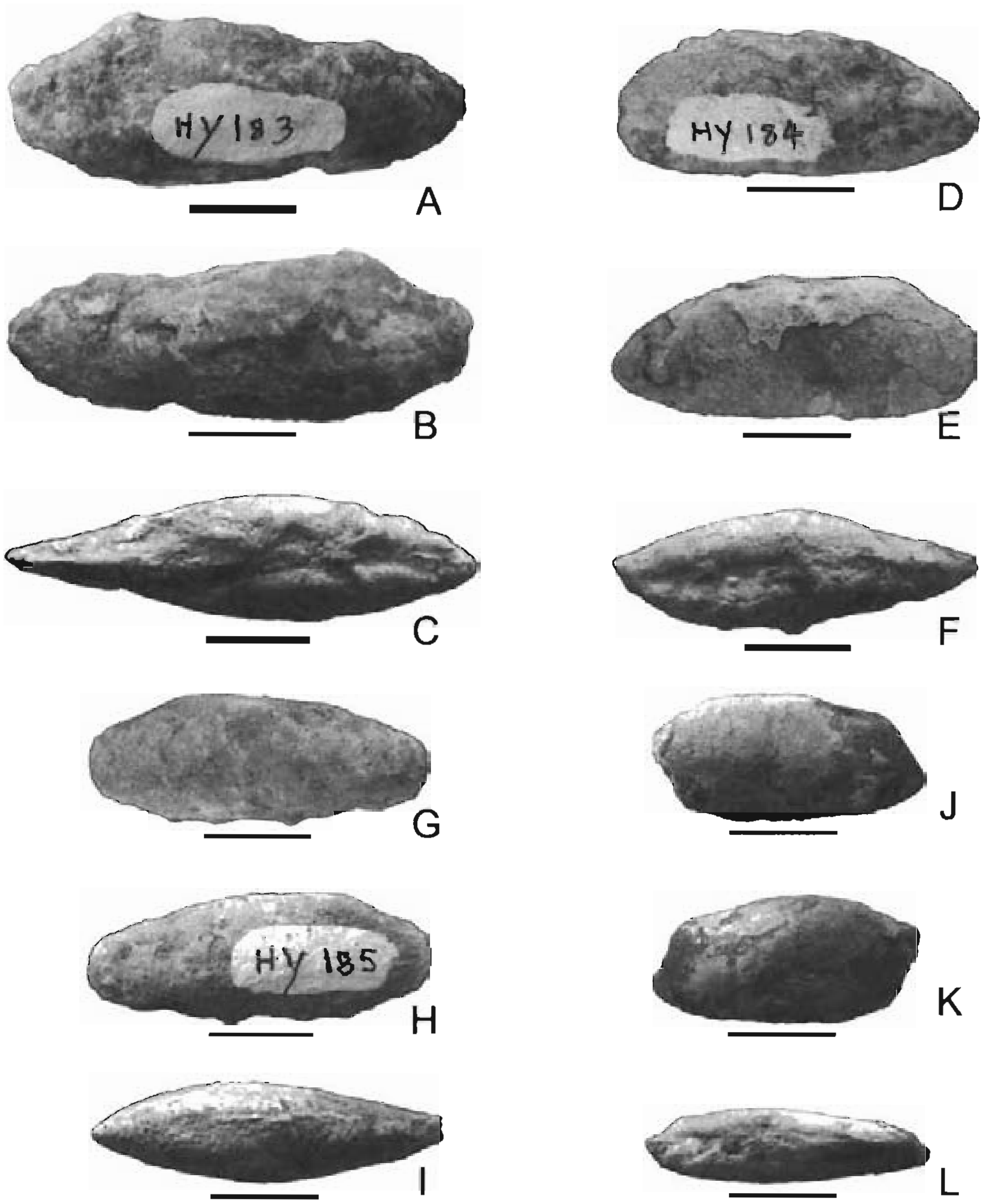


Figure 4.12 Internal molds of *Yunnanoconcha* sp. from Haui Lao Yang Shell Bed. A-C, Articulated valves (PRC-M-M-314) in A, left side view, B, right side view, C, dorsal view. D-F, Articulated valves (PRC-M-M-315) in D, left side view, E, right side view, F, dorsal view. G-I, Articulated valves (PRC-M-M-316) in G, left side view, H, right side view, I, dorsal view. J-L, Articulated valves (PRC-M-M-317) in J, left side view, K, right side view, L, dorsal view. All scale bars represent 10 mm.

Yunnanoconcha sp. cf. _Y. khoratensis_ (Kobayashi, 1963)

2000 *Unio* sp.; Jearanaiwong, p.69-71, pl.1

2005 *Unio* sp. cf. *U. samplanoides*; Tumpeesuwan, p.47, fig. 4.15

Diagnosis: Shell elongate. Anterior end slightly tapering. Posterior end rounded.

Materials: Internal molds of 2 articulated valves (CUMZ 3205 to CUMZ 3206).

Locality: Hin Lat Yao Shell Bed, Phu Wiang District, Khon Kaen Province (Figure 3.13).

Mode of Occurrence: Specimens were found as the weathering debris of red mudstone-siltstone.

Description: Shell large, 27.5 mm in height, 66.5 mm in length, and 17.0 mm in thickness; elongate, gently convex, thin, length less than three times of height; dorsal margin nearly parallel to ventral; umbo located at about one-fourth the length; ventral margin slightly sinuate in the middle part; anterior margin tapering, anterior end pointed, blunt at about mid-height; posterior margin rounded; Hinge teeth, muscle scars, and pallial line are not preserved on the molds.

Comparison with fossil species: The present materials are closely related to *"Unio" samplanoides* Kobayashi, 1968 from the Khok Kruat Formation of Nam Phung Dam site, Sakon Nakhon Province. These materials are slightly different from *"U." samplanoides* in shell length, which the length of *"U." samplanoides* is more than three times the height.

Discussion: Kobayashi (1984) referred *"U." samplanoides* Kobayashi, 1968 as synonym of *"Paranodonta" khoratensis* Kobayashi, 1963 and placed both of them to the genus *Yunnanoconcha.* According to the less number of internal molds, which some characters disappear. The name *Yunnanoconcha* sp. cf. *Y. khoratensis* was used for the Phu Wiang specimens for the time being.

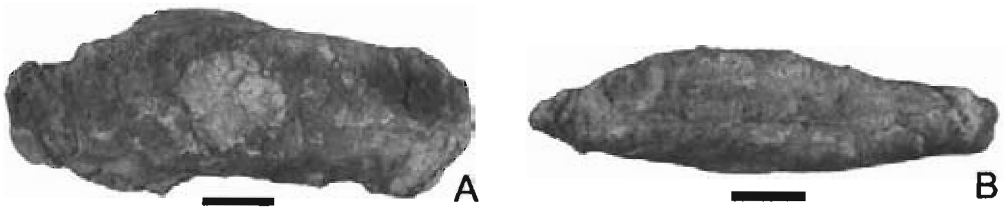


Figure 4.13 Internal mold of *Yunnanoconcha* sp. cf. *Y. khoratensis* (Kobayashi, 1963) (CUMZ 3205) A. left side view, B. dorsal view. All scale bars represent 10 mm.

Family Trigonioididae Cox, 1955

Subfamily Matinsonelliinae Sha, 1993

Diagnosis of the subfamily: The outer surface of shell ornaments with V-shaped ribs only on the median part of shell.

Genus *Sinonaia* Guo, 1981

Diagnosis of the genus: Shell surface ornamented with V-shaped ribs only on the median part of shell. The V-shaped ribs extending to the ventral margin which the angle of V-shaped is more than 90°.

***Sinonaia* sp.**

Material: Internal molds of 2 articulated valves of this species were examined including PRC-M-M-309 and PRC-M-M-310.

Locality: Huai Lao Yang, approximately 0.5 km. northwest from Phu Phan Thong Locality, Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: All fossils were preserved as molds in red mudstone-siltstone, which one of them shows shell remains more than half of shell. They are rare in shell bed.

Description: Shell small, 8.14 mm in height, 27.76 mm in length, and 7.72 mm in thickness; very elongate; less convex, thin. Length more than three times of height; dorsal margin nearly parallel to ventral; inequilateral and equivalve. Umbo located at about one-fourth the length. Anterior margin rounded. Postero-dorsal margin rather straight. Ventral margin straight, truncate at about one-fourth of the length from posterior end. Shell surface ornamented with V-shaped ribs, which the angle of V-shape is 100°-110°. Hinge teeth, muscle scars, and pallial line are not preserved on the molds.

Comparison with fossil species: *Sinonaia* sp. similars to *Sinonaia tenuilonga* Guo, 1981 from the Jingxing Formation of Western Yunnan, Southern China. Both species possess the same very elongate shell shape. However, shell length of the former species is less than four times of height, whereas the latter one is more than four times. The position of the umbo located at about one-fourth of shell length in the former species, but located at about one-fifth of shell length in the latter one. The angle of sub-median V-shaped ribs in the former species (100°-110°) is also smaller than the latter one (125°-140°).

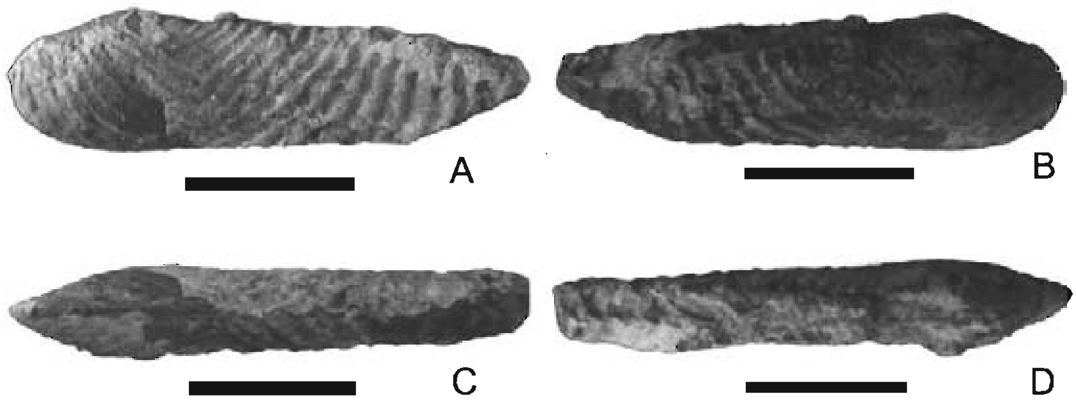


Figure 4.14 Internal mold with some shell remains of *Sinonaia* sp. (PRC-M-M-309) A, left valve, B, right valve, C, ventral view, D, dorsal view. All scale bars represent 10 mm.

Subfamily Trigonioidinae Cox, 1955

Diagnosis of the subfamily: The outer surface of shell ornaments with submedian V-shaped ribs and reverse V-shaped ribs on both anterior and posterior areas.

Genus *Nippononaia* Suzuki, 1941

Diagnosis of the genus: Shell subelliptical, medium sized, with many submedian V-shaped ribs and reverse V-shaped ribs on both anterior and posterior area. Hinge teeth feebly to intensely crenulated with no submedian tooth.

Nippononaia* sp. cf. *N. mekongensis

2005 *Nippononaia mekongensis* Tumpeesuwan, p.48, fig. 4.16

2010 *Nippononaia* sp. cf. *N. mekongensis* Tumpeesuwan *et al.*, p.94, 96

Material: One articulated shell (PRC-M-M-237); and thirteen disarticulated valves (PW-M-1/3.15 to PW-M-1/3.27).

Locality: Lower Shell Bed of Phu Noi and Upper Shell Bed of southern Phu Pratu Tee Ma at Phu Wiang Area, Khon Kaen Province (Figure 3.13); Phu Sing Shell Bed at Sahatsakhan Area, Kalasin Province (Figure 3.27).

Mode of Occurrence: One articulated shell was collected from weathering out of mud-nodule conglomerate bed (Lower Shell Bed of Phu Noi = PW-M-5/1). Thirteen recrystalized disarticulated valves were derived from block sample of mud-nodule conglomerate bed (Upper Shell Bed of southern Phu Pratu Tee Ma = PW-M-1/3). These specimens comprise 9 left valves and 4 right valves, which all of them were encrusted by stomatolite-like layers and could not precisely measured. One shell was found on the bedding surface of Phu Sing Shell Bed (PS) (Figure 3.32E).

Description: Shell medium in size, 19.5 mm in height, 33.8 mm in length, and 13.63 mm in thickness; inequilateral, subelliptical, and strongly convex; maximum length and thickness lying respectively a little below and above the mid-height; umbo small or medium in size, orthogyrous and located at a distance 2/5 to 3/8 the length of the shell; Lunule small and deep; escutcheon broad. Pre-umbonal outline rounded; post-umbonal outline subtriangular, produced posteriorly or posteroventrally and subtruncated diagonally or subvertically in posterior, posterior rostration developed through growth.

Test thick; the tendency for small shells that the umbo is shifted more interiorly in the grown stage, the post-umbonal outline looks slender in the young shell, but later the rostration greatly develops.

Surface ornamented by numerous fine subvertical ribs in middle and anterior parts, and few stout ribs in posterior alternating with equally strong groove, both series of ribs join together, they form acute v-shaped ribs below umbo, pointed ventrally.

Comparison with fossil species: *Nippononaia mekongensis* Kobayashi, 1963 was described from the Aptian-Albian Khok Kruat Formation at Ban Na Yo, Mukdahan Province. *Nippononaia* sp. cf. *N. mekongensis* was discovered from the Sao Khua Formation in 3 localities in this study. Both species differ from other known *Nippononaia* species by very suddenly change of ribs from numerous fine ribs in anterior part to few strong stout ribs in posterior part behind the umbo. *Nippononaia* sp. cf. *N. mekongensis* possesses angle submedian V-shaped ribs (30°-40°) wider than *N. mekongensis* (15°-25°). The post-umbonal part is more slender and slightly truncate end for *N. mekongensis*, whereas more width and rounded posterior end for *Nippononaia* sp. cf. *N. mekongensis*.

Discussion: The presence of *Nippononaia* sp. cf. *N. mekongensis* in the Sao Khua Formation may be indicated that this species is the ancestor of *N. mekongensis* of the Khok Kruat Formation.

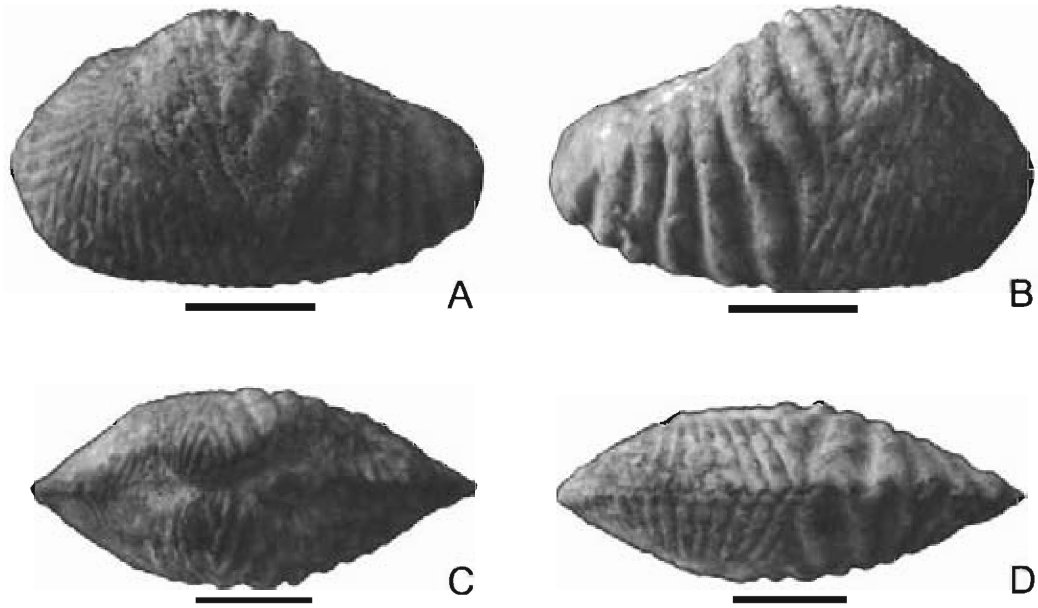


Figure 4.15 A-D, Articulated shell of *Nippononaia* sp. cf. *N. mekongensis* (Kobayashi, 1963) (PRC-M-M-237) in A, left side view; B, right side view; C, dorsal view; D, ventral view. All scale bars represent 10 mm.

Subfamily Peregrinoconchiinae Gu *et al.*, 1976

Diagnosis of the subfamily: The outer surface of shell ornaments with submedian V-shaped ribs and reverse V-shaped ribs on posterior area, but absent or feeble or rare on the anterior area.

Genus *Koreanaia* Yang, 1976

Diagnosis of the genus: Shell surface ornamented with V-shape ribs in the median part of shell. The angle is 35°-60°. The reversed V-shape ribs present on the posterior part. Hinge teeth not crenulated, but rather lamellar.

Subgenus *Eokoreanaia* Sha and Fursich, 1993

Diagnosis of the subgenus: Anterior reversed V-shaped ribs may be absent or feeble, hinge teeth smooth or striae

***Koreanaia (Eokoreanaia)* sp.**

Materials: Internal molds of 186 articulated and 236 disarticulated valves of this species were examined (PRC-M-M-541 to PRC-M-M-962).

Locality: Huai Lao Yang, approximately 0.5 km. northwest from Phu Phan Thong Locality. Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: Almost fossils are shell dissolution, which they were preserved as molds in red mudstone-siltstone. They are normally scattered in shell bed.

Description: Shell medium in size, subtrapezoidal in outline. Anterior margin rather rounded; posterior one straight and truncated. Ventral margin sinuate at the middle part. Umbo slightly prosogyrous, placed about one-third of the shell length from anterior extremity. Lunule narrow; escutcheon wide. Surface ornamented with V-shape ribs in the median part and reversed V-shape ribs on the posterior ridge (Figure 4.20F). The angle of the submedian V-shape ribs is about 60°. The angle of the reversed V-shape ribs on the posterior ridge is about 60°. The ribs and grooves on the posterior half stronger and wider than those on the anterior half. The posterior ridge runs from umbo to postero-ventral corner. Hinge teeth no preserved. Most of the specimens were preserved as composited molds, which the well preserved anterior adductor muscle and minute pedal scar are very rare case (Figure 4.20D).

Comparison with fossil species: *Koreanaia (Eokoreanaia)* sp. possesses submedian V-shape ribs, which its angle is approximately 60°. This is the distinct character among Sao Khua bivalve. The subgenus *Eokoreanaia* has only two preceding species, the first one is *K. (Eo.) cheongi* from the Hauterivian Myogog Formation of Korea, and the second one is *K. (Eo.) fordi* from the Upper Hauterivian to Barremian Wessex Formation of southern England. The second species firstly nominated as *Nippononaia (Subnippononaia) fordi* by Barker *et al.* (1997), but was reclassified to *K. (Eo.) fordi* by Sha (2007) based on the reason that the angle of V-shape rib in the median part of shell is close to that of *Eokoreanaia* (30°-45°), which it is much larger than that of *Nippononaia* (less than 25°).

Discussion: The 3 incomplete internal molds of bivalve were discovered in bore core from Ban Krok Namtao, which is considered as the Sao Khua Formation (= Sao Khua Member in Kobayashi, 1984, p.245). They were identified as *Goniomya* (?) *khoratensis* Kobayashi and Hayami, 1963 (in Kobayashi *et al.*, 1963), which should be considered as *nomina dubia*, because this species was described from three poorly preserved specimens. It possesses only the median V-shape ribs, which its angle is about 60°. Both anterior and posterior parts of all shells are not preserved, therefore, the key characters of the Trigonioidoidean bivalve (the separation of anterior pedal retractor muscle scar from anterior adductor muscle scar) could not observed. However, it should be considered that these problematic materials could belong to different taxon until more well preserved specimens will be discovered.

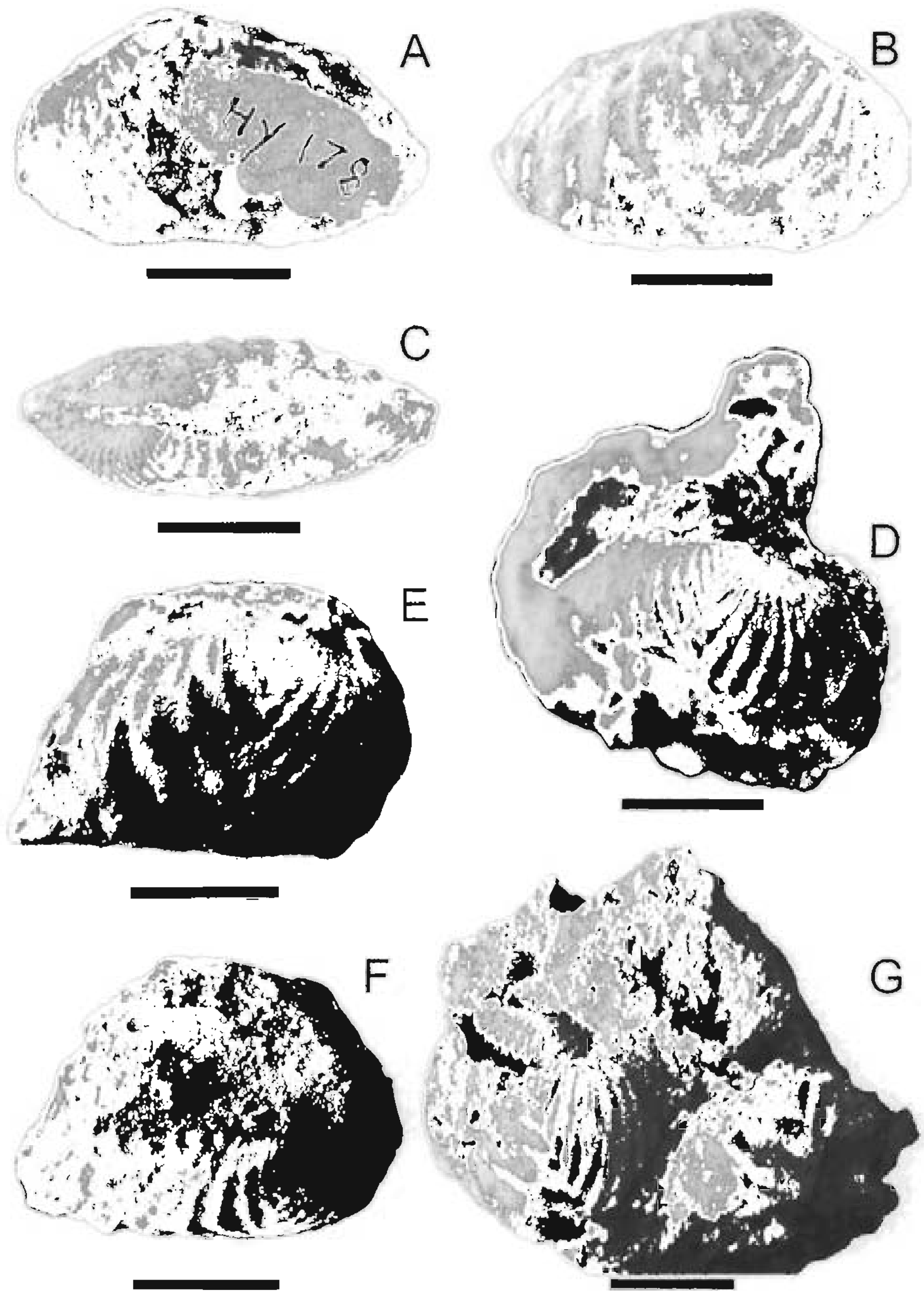


Figure 4.16 Articulated valves of *Koreanaia (Eokoreanaia)* sp. from Haui Lao Yang Shell Bed. A-C, internal mold of articulated valves (PRC-M-M-541) in A, left side view; B, right side view, C, dorsal view; D, composite mold of right valve (PRC-M-M-544), the anterior adductor muscle scar and very small deep pedal retractor muscle scar were preserved at anterior part. E-F, internal mold of right valve (PRC-M-M-545) in E, side view, F, dorsal view showing posterior reversed V-shape ribs; G, three internal molds on the same block (PRC-M-M-546). All scale bars represent 10 mm.

Genus *Trigonioides* Kobayashi and Suzuki, 1936

Diagnosis of the genus: Shell ornamented with submedian V-shape ribs and reversed V-shape ribs on both anterior and posterior parts of shell. Hinge teeth feebly to intensely crenulated, submedian teeth present.

Subgenus *Diversitrigonioides* Gu, 1976

Diagnosis of the subgenus: Posterior branch of submedian V-shaped ribs stout and widely spaced, but anterior branch fine and densely arranged.

***Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* (Hoffet, 1937)**

2005 Unionidae *gen. et sp. indet.* (1) Tumpeesuwan, p.50, fig. 4.18

2010 *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* Tumpeesuwan *et al.*, p.94, 96

Materials: One articulated shell, and 5 disarticulated valves (PW-M-5.2 to PW-M-5.7), including 2 left valves and 3 right valves.

Locality: Lower and Upper Phu Noi Shell Beds (PW-M-5/1 and PW-M-5/2) at Phu Wiang Area, Khon Kaen Province (Figure 3.13).

Mode of Occurrence: These materials were found as weathering debris of mud-nodule conglomerate bed in the southern part of Phu Noi (PW-M-5).

Description: Shell ear-shaped, 33.55-38.67 mm in height, 58.00-69.26 mm. in length, and 12.72-14.50 mm. in thickness; moderately thick, moderately convex and inequilateral; maximum length lying below mid-height. Umbo small, located at a distance about 1/5 the length of the shell; pre-umbonal outline rounded with slightly pointed at the anterior end of shell; post-umbonal outline subtriangular with posterior rostration; ventral margin more sinuated at postero-ventral part. Surface ornamented by numerous incline fine ribs run from pre-umbonal area to centro-ventral area; sharp ridge run from umbo to the posterior end which originated few incline stout ribs from the knob on the ridge run to centro-ventral area; both kinds of ribs join together to form V-shaped ribs in the submedian part, the angles of these sub-median V-shaped ribs is 45°-80°. Umbonal ridge short; present behind the umbo and run parallel to hinge line, small knob present. Hinge plate narrow with tooth-like pseudocardinal tooth; lateral tooth lamelliform; umbonal cavity shallow.

Comparison with fossil species: This species similar to *T. (Div.) diversicostatus* Hoffet, 1937, which it was described from Ban Na Gnôm Bed, North of Muong Phalane in Southern Laos. *T. (Div.) diversicostatus* was also discovered from the Bali Formation in Guangxi, Sothern China (Ma, 1994). The former species differs from the latter one by its angle of submedian V-shaped ribs, which the range of angles is 45°-80° in the former species but 30°-45° in the latter one.

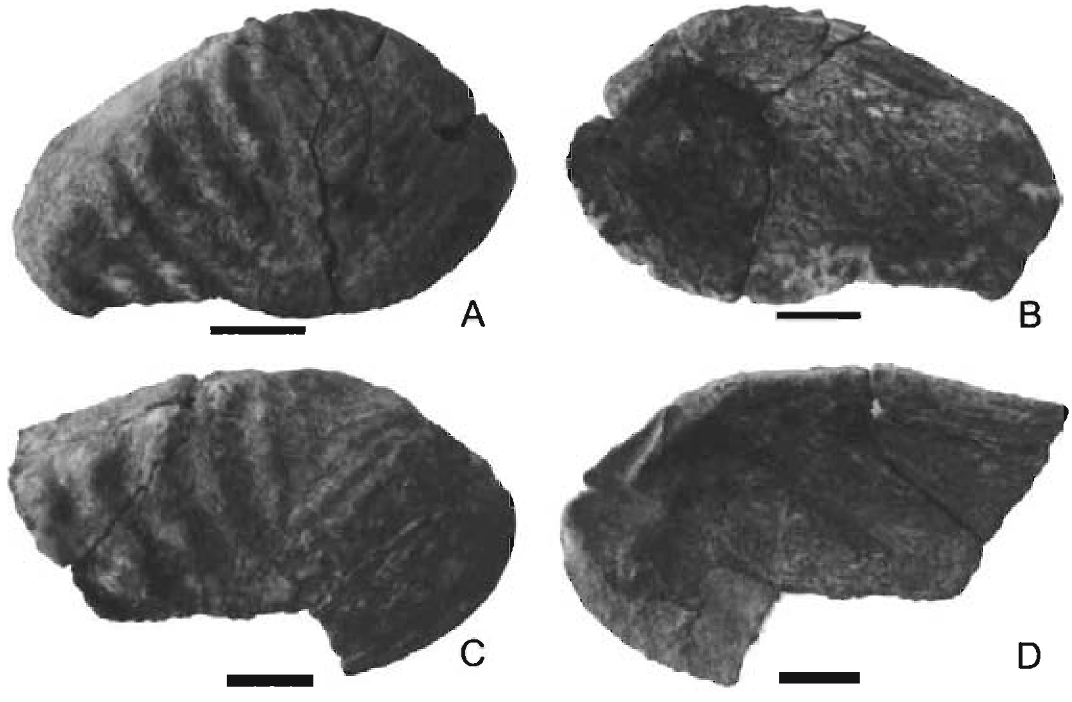


Figure 4.17 *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* (Hoffet, 1937); A-B, shell of disarticulated right valve (PW-M-5.2), A, external view; B, internal view. C-D, broken shell of disarticulated right valve (PW-M-5.3), C, external view; D, internal view. All scale bars represent 10 mm.

Family Pseudohyriidae Kobayashi, 1968

Genus *Pseudohyria* MacNeil, 1936

Diagnosis of the genus: The anterior pedal retractor scar is separated from the anterior adductor scar. The shell surface is ornamented with chevron radial ribs only in the posterior area.

Subgenus *Matsumotoina* Guo, 1982

Diagnosis of the subgenus: Hinge teeth are smooth. The submedian pseudocardinal teeth are present.

***Pseudohyria (Matsumotoina) somanai* Tumpeesuwan, Sato, and Nakhapadungrat, 2010**

1982 cf. *Cardinioides magnus* Hahn, p.22

2000 *Trigonioides* sp. Jearanaiwong, p.72-76, pl.2, figs 1-16

2003 *Trigonioides* sp. Imsamut, p.42

2005 Unionidae *gen. et sp. indet.*(2) Tumpeesuwan, p.51, fig. 4.19

2005 Unionidae *gen. et sp. indet.*(3) Tumpeesuwan, p.52, fig. 4.20

2005 Unionidae *gen. et sp. indet.*(4) Tumpeesuwan, p.53, figs 4.21A-C

2005 Unionids *gen. et sp. indet.* Tumpeesuwan, p.54, fig.4.22

2005 *Trigonioides* sp. Tumpeesuwan & Sato, p.608

2010 *Pseudohyria (Matsumotoina) somanai* Tumpeesuwan *et al.,* p.93-106, figs. 4-5

Material: Two hundred and fifteen specimens were examined (CUMZ 3201 to CUMZ 3203; PRC-M-M-106 to PRC-M-M-236).

Locality: Lower Shell Beds of Phu Noi (PW-M-5/1), Lower and Upper Shell Beds of Southern Phu Pratu Tee Ma (PW-M-1/1 and PW-M-1/3) in Phu Wiang Area (Figure 3.13). Phu Lon, Ban Huai Dua, and Phu Chan in Nong Bua Lamphu Area

(Figure 3.2). Phu Kum Khao, Phu Sing, and Phu Po in Sahat Sakhan Area (Figure 3.27).

Mode of Occurrence: Specimens from Lower Shell Bed of Phu Noi, Ban Huai Dua and Upper Shell Bed of Southern Phu Pratu Tee Ma were collected from red mud nodule conglomerate. All shells in PW-M-1/3 were encrusted by stomatolite-like layers. Specimens from Phu Lon, Phu Chan, Phu Sing, and Phu Po were collected from green-gray lime-nodule conglomerate. Specimens from Phu Khum Khao were collected from medium- to coarse-grained sandstone.

Description: Shell fairly large in size, 19.1-54.0 mm in height and 24.2-56.6 mm in length, trigonally suboval or subelliptical in outline, fairly inflated; subequilateral and equivalve; anterior margin well rounded, postero-dorsal one rather arcuated, postero-ventral corner sharp angulate, ventral margin fairly arcuated. Umbo fairly high and prominent, slightly prosogyrous, situated nearly centrally; lunule short, broad, and slightly deep; escutcheon rather short; narrow and shallow; test thick.

Surface ornamented with concentric growth lines; they are strong and prominent around the umbo which is weakening ventrally. The posterior ridge is fairly prominent with short 5 to 8 chevron ribs on the posterior ridge.

Hinge plate moderate in breadth, provided with smooth pseudocardinal and postero-lateral teeth; pseudocardinal teeth 4 on both valves; postero-lateral teeth 1 on right valve, 2 on left valve, forming the following dental formula:

5, 3, 1a, 1b, PIII / 4, 2, 1'a, 1'b, PII, PIV

where 5: long, narrow, parallel to the antero-dorsal margin.

3: long, stout and high, subparallel to the antero-dorsal margin,

1a: low and short, immediately below the umbo, nearly vertical, 1b: low and short, smallest in the right valve, immediately below the umbo, nearly vertical,

PIII: distinct and elongated, parallel to the postero-dorsal margin,

4: long, stout and prominent, parallel to the antero-dorsal margin,

2: long, rather stout and slightly high, subparallel to the antero-dorsal margin,

1'a: low and short, isosceles triangle shape, nearly vertical.

1'b: low and short, isosceles triangle shape, about 45° of vertical.

PII and PIV: narrow and elongated, parallel to the postero-dorsal margin.

These hinge teeth are neither crenulated nor striated, but rather lamellar.

Anterior adductor semicircular, strongly impressed, postero-dorsal side truncated and steep with slightly straight margin; anterior and postero-ventral side gentle. Anterior pedal retractor scar circular, minute, located at postero-dorsal side of the anterior adductor scar and isolated from it. Posterior adductor scar subcircular, and larger, but not so distinct. Ventral crenulation on the inner side not so distinct. Umbonal cavity moderately deep.

Comparison with fossil species: *Pseudohyria (Matsumotoina) somanai* similar to *P. (M.) matsumotoi* Yang, 1979 in both smooth hinge teeth and the present of submedian pseudocardinal teeth. Shell surface of *P. (M.) matsumotoi* are ornamented with more than 13 radial ribs on the posterior half, whereas this species is ornamented with only 5-8 stout oblique posterior ribs. *P. (M.) matsumotoi* possess 3 or 4 pseudocardinal teeth on the right valve and 3 on the left valve, while the present species possess 4 on both valves.

Discussion: The preceding sole species of the subgenus, *P. (M.) matsumotoi* Yang, 1979 has been reported from the Lower Cretaceous Yeonwhadong Formation in

Korea. The discovery of *P. (M.) somanai* from the Sao Khua Formation of Phu Wiang Area is the first record of this subgenus in Thailand.

Sainshandia nagnomensis (Hoffet, 1937) has a subtrigonal outline with 3 or 4 very strong posterior radial ribs and 4 or 5 oblique posterior ribs which are stouter than radial ribs. The oblique posterior ribs branch off from the first posterior radial rib. This species was originally described by Hoffet (1937) as *"Unio" nagnomensis* Hoffet for the specimens from Ban Na Gnom, Muong Phalane in southern Laos. Later, the generic name was changed by Kobayashi (1968) to *"Plicatotrigonioides" nagnomensis* (Hoffet) on the basis of strong oblique posterior ribs on the shell surface. Ma (1989) reassigned it to *Sainshandia nagnomensis* (Hoffet) and proposed his opinion that *Plicatotrigonioides* (?) *subovalis* (Kobayashi, 1968) from the Khok Kruat Formation at the Nam Phung Dam Site, Sakon Nakhon in northeastern Thailand is the junior synonym of *Sainshandia nagnomensis* (Hoffet, 1937). In addition, Ma (1994) suggested that *Pseudohyria (Matsumotoina) jingguoensis* Guo, 1985 from the Mangang Formation at Yunnan in southern China is identical with *Sainshandia nagnomensis* (Hoffet, 1937). This species was also discovered from the Bali Formation at Guangxi in southern China.

Sainshandia nagnomensis (Hoffet, 1937) from the khok Kruat Formation might be presumed as the descendant of *P. (M.) somanai* Tumpeesuwan *et al.*, 2010 from the Sao Khua Formation. Major morphological changes from *P. (M.) somanai* to *S. nagnomensis* are the formation of radial ribs and the decrease in number of pseudocardinal teeth and oblique posterior ribs.

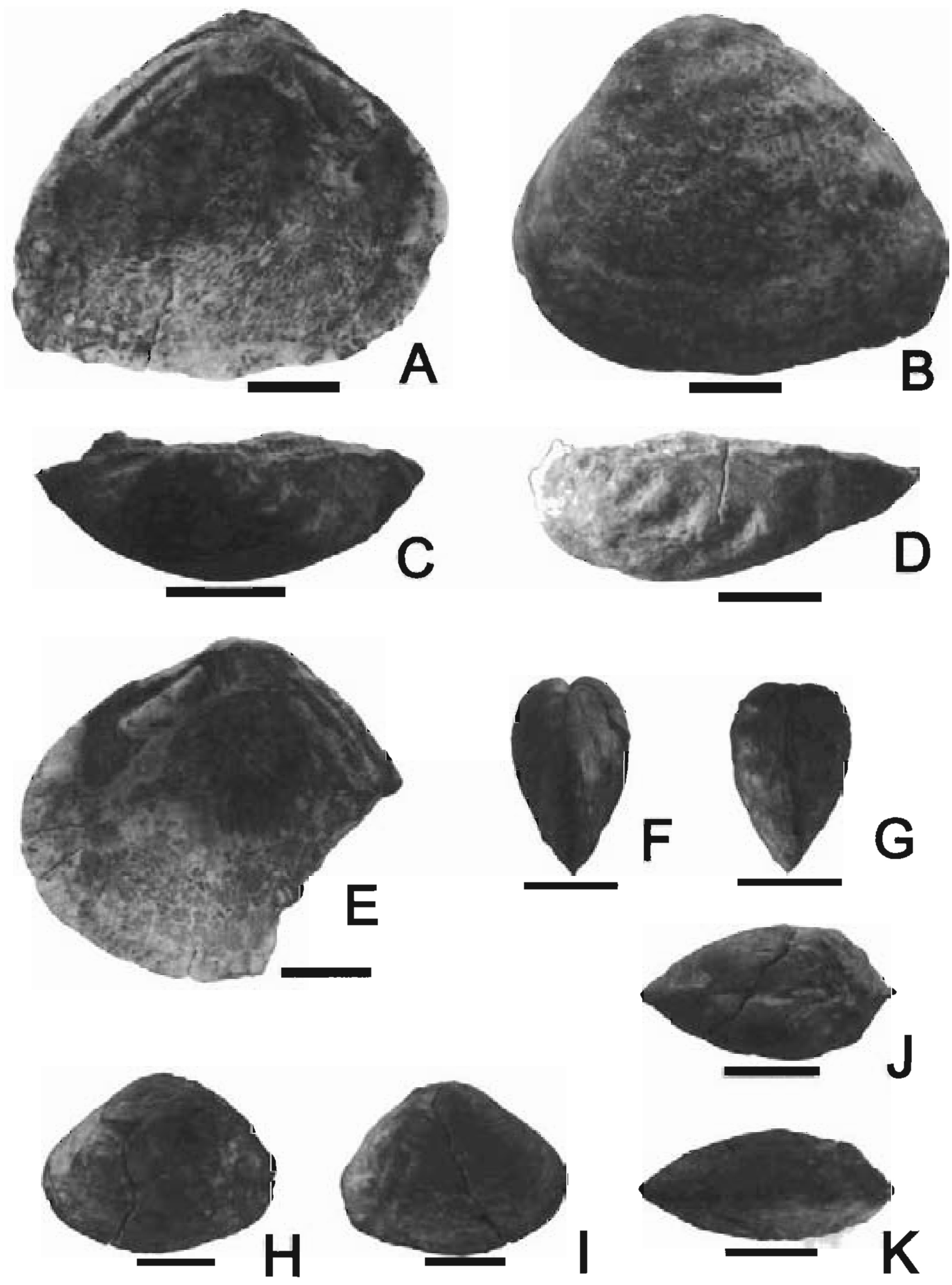


Figure 4.18 *Pseudohyria (Matsumotoina) somanai*. A-D, Left valve, holotype (CUMZ 3201) in A, internal view; B, external view; C, dorsal view; D, posterior view. E. Right valve, paratype (CUMZ 3202) in internal view. F-K, Articulated valve, paratype (CUMZ 3203) in F, anterior view; G, posterior view; H, left side view; I, right side view; J, dorsal view; K, ventral view. All scale bars represent 10 mm.

Family *indeterminata*

Trigonioidoidea *fam. indet.*

2000 *Exogyra* sp.; Jearanaiwong, p.77-78, pl.3.

2002 *Exogyra* sp.; Wongprayoon and Meesook, p.29-30, fig.18.

2005 Mytilinae *gen. et sp. indet.* Tumpeesuwan, p.46, fig. 4.14

Diagnosis of the taxon: Shell outline very variable, mostly elongate-spatulate. Two unequal valves are attached by their right valve. They possess their anterior pedal retractor muscle scar separated from anterior adductor muscle scar, which is the key character of the Superfamily Trigonioidoidea. Therefore, this species is belong to this superfamily.

Material: Eight shells comprise 5 articulated valves and 3 disarticulated valves (PRC-M-M-238 to PRC-M-M-245). Forty shells: PW-M-1/3.1 to PW-M-1/3.14 and PW-M-1/3.121 to PW-M-1/3.126; and seven incomplete internal molds: PW-M-1/2.1 to PW-M-1/2.5; PW-M-2.1; PW-M-3.1.

Localities: Phu Sing Shell Bed in Sahatsakhan Area, Kalasin Province (Figure 3.27). Lower, Middle and Upper Shell Beds of Southern Phu Pratu Tee Ma (PW-M-1/1, PW-M-1/2 and PW-M-1/3), Tham Kia (PW-M-2), and Eastern Phu Pratu Tee Ma (PW-M-3) in Phu Wiang Area (Figure 3.13). Phu Lon (PL) in Nong Bua Lamphu Area (Figure 3.2).

Mode of Occurrence: Five recrystallize shells were found in thick red mudstone mounds in conglomerate bed of Phu Sing. Twenty recrystalized shells were derived from block sample of mud-nodule conglomerate bed (PW-M-1/3). Five internal molds were found from conglomerate bed (PW-M-1/2). One internal mold with some remains of recrystalized shell was found from conglomerate bed (PW-M-2). One internal mold was found from conglomerate bed (PW-M-3).

Description: Shell very thick, wedge-shaped, large shell elongate but small shell spatulate. Right valve tumid, convex, thick, with scars of cementing habit on outside. Left valve flat and concave. Umbo high and strong prominent, slightly prosogyrous, situated nearly centrally; Lunule and escutcheon absent. Shell surface only ornamented with concentric growth lines on ventral part. Hinge plate very broad in breadth, provided with 5 smooth pseudocardinal teeth in right valve; postero-lateral teeth no preserved (Figure 4.19 H-I) , forming the following dental formula: 5, 3, 1a, 1b, 1c

where 5: long, slightly narrow, parallel to antero-dorsal margin,

3: long, stout and very high, subparallel to the antero-dorsal margin,

1a: isosceles triangle shape, low and short, pointed to tooth number 3

1b: isosceles triangle shape, low and short, smaller than tooth number 1a, pointed to tooth number 3

1c: isosceles triangle shape, low and short, smaller than tooth number 1b, pointed to tooth number 3

One disarticulated valve broke pass through the deepest part of anterior adductor muscle scar (Figure 4.19 H-I). Anterior pedal retractor scar sub-circular, rather broad, located at postero-dorsal side of the anterior adductor scar and isolated from it. Posterior adductor muscle scars no preserved. Umbonal cavity moderately deep.

Comparison with fossil species: This species was reported as *Exogyra* sp. from the Sao Khua Formation in the Phu Wiang area (Jearanaiwong, 2000; Wongprayoon and Meesook, 2002). It was re-identified as Mytilinae *gen. et sp. indet.* by Tumpeesuwan (2005) based on the shape of incomplete shells and incomplete internal molds. The name, *Mytilus (Pachymytilus) rectangularis* Kobayashi and Hayami, 1963 was described from the specimen found in calcareous conglomerate of the Sao Khua Formation at Km 39.04 on Highway from Udon Thani to Nong Bua Lamphu. This taxon can be compared to the present materials from Phu Lon, Phu Wiang and Phu Sing, but it could not found in the type locality along the highway in the present study. Based on less contrast published photographs, type material of *M. (P.) rectagularis* cannot be precisely examined in this study and need to examine the type specimen in the future.

Discussion: The well preserved specimens from Phu Sing Shell Bed showing separated anterior pedal retractor muscle scar, which is the key character of Superfamily Trigonioidoidea. However, the number and quality of specimens in hand is not enough to determine this taxon to the lower taxonomic rank. Therefore, the name "Trigonioidoidea *fam. indet.*" is used for this taxon for the time being.

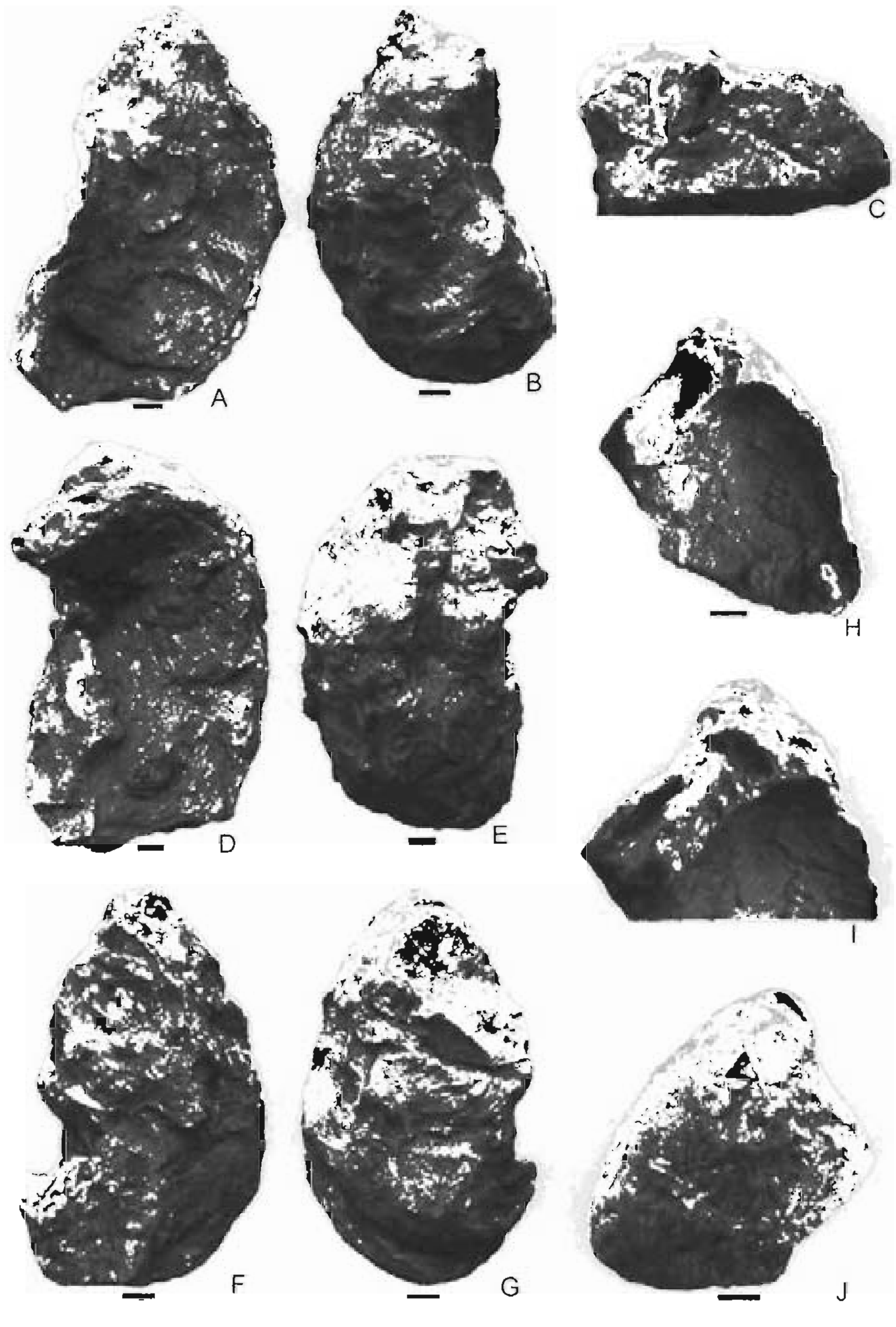


Figure 4.19 Trigonioidoidea *fam. indet.* A-C, articulated valves without umbonal part (PRC-M-M-238) in A, left side view; B, right side view; C, dorsal view showing cross section around hinge plate. D-E, articulated valves (PRC-M-M-239) in D, left side view; E, right side view; F-G, articulated valves (PRC-M-M-240) in F, left side view; G, right side view. H-J, disarticulated right valve (PRC-M-M-243) in H, internal view; I, close up at hinge plate; J, external view. All scale bars are 10 mm.

Subclass *incertae cedis*

***"Cardinioides" magnus* Kobayashi *et al.*, 1963**

Materials: Incomplete internal molds of 1 articulated and 1 disarticulated valves of this taxon were examined including PRC-M-M-963 to PRC-M-M-964 (Figures 4.20B-E).

Locality: Huai Lao Yang, approximately 0.5 km. northwest from Phu Phan Thong Locality. Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: All fossils are shell dissolution, which they were preserved as molds in red mudstone-siltstone. They are rare in shell bed.

Description: Shell large, 34.63-50.52 mm height, ca. 48-68 mm length, 16.78-18.78 mm thick, moderately convex, inequilateral, umbo broad, the angle is about 110°-120°, not very prominent, slightly prosogyrous. Umbonal cavity rather deep. Lunule broad and rather deep. Escutcheon narrow and very deep. Anterior margin rounded, antero-dorsal and postero-dorsal margins slightly sinuated, ventral margin rather arcuated. Posterior end, muscle scars, pallial line and hinge teeth are not preserved on the specimens at hand.

Discussion Based on the poorly preserved specimens, the muscle scars and hinge teeth are not preserved, the precise identification is impossible.

***incertae cedis* (1)**

2005 *incertae cedis* (1), Tumpeesuwan, p.55, fig. 4.23

Materials: Twenty-three disarticulated valves: PW-M-1/3.95 to PW-M-1/3.112. and PW-M-1/3.146 to PW-M-1/3.150.

Locality: Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3) in Phu Wiang Area (Figure 3.13).

Occurrence: Twenty-three recrystalize disarticulated valves were derived from block sample of mud-nodule conglomerate bed. These specimens comprise 10 left valves and 13 right valves.

Description: Shell subtrigonal, quite compressed, beak prominent, prosogyrous, anterior end truncate, postero-dorsal and ventral margins arcuated, forming the postero-ventral end rather point at postero-ventral area (Figure 4.20F).

Discussion: The outline of these shells is similar to *Psoronaias* and *Amblema* (*Psonula*) in subfamily Quadrulinae of family Unionidae. Because of shells in this shell bed were encrust by thick stomatolite-like layers, the details of hinge teeth and muscle scars could not be examined. Therefore the classification and identification below class Bivalvia is impossible for the time being

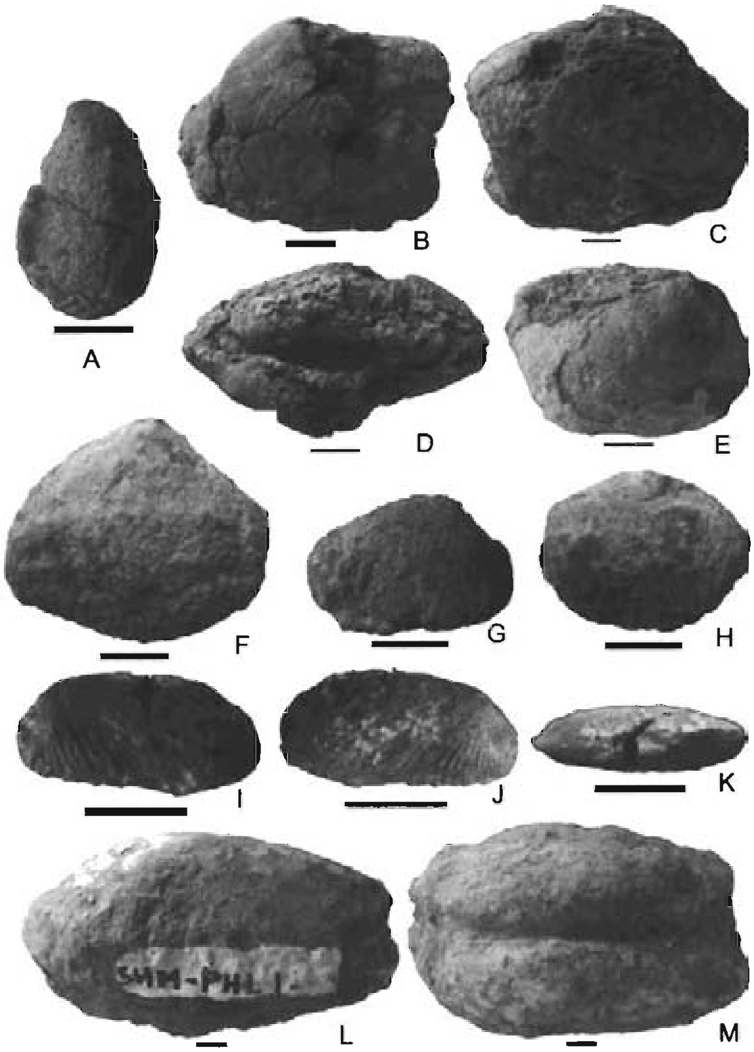


Figure 4.20 A, Trigonioidoidea *fam. indet.* (PW-M-1/3.1). B-E, *"Cardinioides"magnus* Kobayashi *et al.*, 1963 in B-D, articulated valves, (PRC-M-M-963); B, left side view; C, right side view; D, dorsal view; E, side view of disarticulated right valve, (PRC-M-M-964); F, *incertae cedis* (1) (PW-M-1/3.95), external view of right valve; G, *incertae cedis* (2) (PW-M-1/3.113), external view of right valve; H, *incertae cedis* (3) (PW-M-1/3.135), external view. I-K, *incertae cedis* (4) (PW-M-1/2.6) in I, left side view; J, right side view; K, dorsal view. L-M, *incertae cedis* (5) (PRC-M-M-966) in L, left side view; M, dorsal view. All scale bars represent 10 mm.

***incertae cedis* (2)**

2005 *incertae cedis* (2), Tumpeesuwan, p.56, fig. 4.24

Materials: Eight disarticulated incomplete valves: PW-M-1/3.113 to PW-M-1/3.119 and PW-M-1/3.151

Locality: Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3) in Phu Wiang Area (Figure 3.13).

Occurrence: Eight recrystalize disarticulated valves were derived from block sample of mud-nodule conglomerate bed, these specimens comprise 5 left valves and 3 right valves.

Description: Shell subtrapezoidal, quite convex, beak prominent, anterior end truncate, posterior end rounded, postero-dorsal and ventral margin rather straight; one ridge present from umbo to postero-ventral margin (Figure 4.20G).

Discussion: The outline is similar to *Unio (Heterunio)* in Subfamily Unioninae and *Peudodontoides* in Subfamily Anodontinae, both are Family Unionidae. Because of shells in this shell bed were encrust by thick stomatolite-like layers, the details of hinge teeth and muscle scars cannot be examined. Therefore, the small number of incomplete valves in this study is difficult to ascertain in classification and identification below class level.

incertae cedis (3)

2005 *incertae cedis* (6), Tumpeesuwan, p.50, fig. 4.28

Materials: Eleven disarticulated incomplete valves: PW-M-1/3.135-145.

Locality: Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3) in Phu Wiang Area (Figure 3.13).

Occurrence: Eleven recrystalize disrticulated valves were derived from block sample of mud-nodule conglomerate bed.

Description: Shell elliplical in outline, quite compressed, equilateral; beak small, orthogyrous and located about middle of the length of the shells, anterior, posterior, and ventral margin round and slightly round (Figure 4.20H).

Discussion: The outline of these shells is similar to genus *Tutuella* in Family Pseudocardiniidae, Subclass Palaeoheterodonta, and Genus *Heterodon* in Family Tellinidae, Subclass Heterodonta. Because of shells in this shell bed were encrust by thick stomatolite-like layers, the details of hinge teeth and muscle scars cannot be examined. Therefore, these specimens are left in open nomenclature, and wait for the discovery of well preserved specimens.

***incertae cedis* (4)**

2005 *incertae cedis* (7), Tumpeesuwan, p.61, fig. 4.29

Materials: Seven articulated internal molds. : PW-M-1/2.6-9, PW-M-2.2-3. PW-M-3.2.

Locality: Middle Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/2), Tham Kia Shell Bed (PW-M-2), and Eastern Phu Pratu Tee Ma Shell Bed (PW-M-3) in Phu Wiang Area (Figure 3.13).

Occurrence: Four internal molds of articulated shells were found from PW-M-1/2, which only one complete mold can precisely measure. Two internal mold's fragments of articulated valves from PW-M-2 and one specimen from PW-M-3 were discovered.

Description: Shell small, 11.47 mm in height, 23.46 mm in length, and 6.92 mm in thickness; inequilateral, elliptical in outline, quite compressed; beak small, slightly prosogyrous and located near anterior end. Anterior and posterior margins rounded, postero-dorsal margin nearly parallel to ventral one, ventral margin slightly sinuated. Muscle scars and hinge teeth no preserved. Posterior ridge presented. More than 15 small radial ribs run from umbo to ventral margin. Growth line present only on the lowermost part of ventral side.

Comparison with fossil species: These specimens possess radial ribs that showing the same character of the Family Plicatounionidae in Superfamily Trigonioidoidea.

Discussion: All specimens in hand no preserved of muscle scars and hinge teeth. It cannot confirm that the taxon is belonging to the Superfamily Trigonioidoidea. Therefore, these specimens are left in open nomenclature for the time being.

incertae cedis (5)

Materials: Two articulated valves of this taxon was examined (PRC-M-M-966 to PRC-M-M-967)

Locality: Phu Lon Shell Bed, Nong Bua Lamphu Province (Figure 3.2).

Occurrence: Both of two articulated valves are open valves (Figure 4.20L-M). They were collected from the lime-nodule conglomerate bed of Phu Lon.

Description: Shell large in size, slightly elongate, gently convex. Length is approximately two times of height. Dorsal and ventral margins arcuated. Umbo slightly prosogyrous, located at about one-third the length. Lunule and escutcheon not prominent. Anterior margin slightly round; posterior margin in both specimens at hand no preserved. Muscle scars and hinge teeth cannot be observed from both articulated valves.

Comparison with fossil species: This taxon showing similar shell shape with the genus *Yunnanoconcha* of the Family Nakamuranaiidae in Superfamily Trigonioidoidea. Their shell is thick, but all members of the genus *Yunnanoconcha* possess thin shell remains.

Discussion: The detail of muscle scars and hinge teeth cannot be examined for the time being. Therefore, these specimens are left in open nomenclature.

Class Gastropoda Cuvier, 1804

Subclass Streptoneura Spengel, 1881

Order Mesogastropoda Thiele, 1929

Superfamily Viviparacea Gray, 1847

Family Viviparidae Gray, 1847

Genus *Viviparus* Montfort, 1810

Viviparus sp.

1963 Naticoid-like gastropod, Kobayashi *et al.*, p.188, pl. XI, fig 7.

Material: One internal mold of small shell in mudstone blocks (PRC-M-M-965).

Locality: Huai Lao Yang, approximately 0.5 km. northwest from Phu Phan Thong Locality, Nong Bua Lamphu Province (Figure 3.2).

Mode of Occurrence: The specimen is shell dissolution, which it was preserved as molds in red mudstone-siltstone. It is very rare in shell bed.

Description: Shell small, conically ovate in outline; spine conical, low, having more or less outlines; apex bluntly pointed. Whorls 2-3 in number, fairly rapidly increasing in width; suture shallow; last whorl inflated, rounded periphery. Aperture subvertical, ovate in outline, narrow in upper part and rounded in lower part; peristome continuous; lip thin and simple.

Discussion: Based on only 1 specimen at hand, the conically ovate shaped gastropod was roughly identified as *Viviparus* sp. by its similar shell shape for the time being until more well preserved specimens will be discovered.

CHAPTER V

PALAEOECOLOGICAL ANALYSIS OF MOLLUSCAN ASSEMBLAGES

Depositional environments of the Sao Khua Formation have been recognized as part of an extensive floodplain with low energy meandering river system, deposited in semi-arid condition (Mouret *et al.*, 1993; Racey *et al.*, 1996; Meesook, 2000; Meesook *et al.*, 2002).

Molluscan fossils had been reported from the Sao Khua Formation by Kobayashi *et al.* (1963), Ward and Bunnag (1964), Hahn (1982b), Meesook *et al.* (1995), Meesook and Wongprayoon (1999), Jearanaiwong (2000), Wongprayoon and Meesook (2002) and Imsamut (2003). However, these former works had done only identification and description of fossils. Recently, Tumpeesuwan (2005) and Tumpeesuwan and Sato (2005) tried to used palaeoecological methodology to analyze some molluscan assemblage of the Phu Wiang Area.

5.1 Methodology of palaeoecological analysis

In this study, methodology were adapted from Sato (1991), Matsukawa and Ido (1993), and Good (2004). Sixteen shell beds of 12 bivalve fossils localities were described in many features, such as species composition, articulation, size distribution, orientation, diversity, etc. These freshwater molluscan assemblages have been analyzed to identify ecological association that can be used to refine interpretation of depositional environments. This analysis uses the ecological tolerances of recent freshwater bivalves as the guide to the palaeoecologic tolerance of extinct trigonioidoidean bivalve. Molluscan assemblages and their co-occurring taxa such as freshwater hybodont sharks, *Lepidotes* fishes, freshwater crocodiles, non-marine turtles, dinosaurs and trace fossils were analyzed to identify mixing of fossils from disparate ecologic communities that were brought together before burial.

Sixteen shell beds were discovered and studied, including Huai Lao Yang (HLY), Lower and Upper Shell Beds of Phu Lon (PL-1 and PL-2), Ban Huai Dua (BHD), Phu Chan (PC), Lower, Middle and Upper Shell Beds of Southern Phu Pratu Tee Ma (PW-M-1/1, PW-M-1/2 and PW-M-1/3), Tham Kia (PW-M-2), Eastern Phu Pratu Tee Ma (PW-M-3), Hin Lat Yao (PW-M-4), Lower and Upper Shell Beds of Phu Noi (PW-M-5/1 and PW-M-5/2), Phu Sing (PS), Phu Kum Khao (PKK), and Phu Po (PP) (Figure 3.8, 3.13 and 3.27).

5.2 Sample collection

Block sampling method was tried to collect the block sample size 30x30x20 cm^3, 3 blocks/shell bed for paleoecological analysis. In the difficult cases, such as, the shell bed expose on the cliff, or deep in the forest, or near the top of the mountain, or were protected by the national park or local government as the tourist points, which these cases, the following methods were adapted to collect the fossils or data for paleoecological analysis. The shell bed was examined both on bedding surface and in cross-section, or directly collected individual specimens or small blocks of weathering out shell bed in approximately same volume as block samples in each locality, or analyzed on the fossil collection of PRC.

5.3 Recognition of individual

Numbers of individuals were counted from the identifiable bivalves that possess an umbo. In the cases of umbonal region loss, the fossils were recognized as individuals when more than half of the shell remains.

5.4 Recognition of fossil molluscan assemblages

Sixteen molluscan taxa are identified and counted numbers of individuals of each species from 15 shell beds at 12 localities in the 3 study areas (Table 5.1). The degree of modification from the death assemblage of the original population is estimated by using the criteria of Matsukawa and Ido (1993, p.368), as following: (1) higher abundance of articulated valves, (2) little difference in relative frequency between right and left valves, (3) existence of shells of various growth states in a sample, (4) shell without damage, and (5) recognition of life habit.

Among 16 taxa, the dominance species was already described as new species, *Pseudohyria (Matsumotoina) somanai* Tumpeesuwan *et al.*, 2010. This species is normally found from sandstone and conglomeratic sandstone of the Sao Khua Formation.

Four different fossil molluscan assemblages are recognized. These assemblages are strongly related to the sedimentary facies. The similar sedimentary facies yield identical bivalve species. The characteristic species normally form nearly 50 % in compositions of fossil assemblages and shows articulated valves (Table 5.2).

5.4.1 *Koreanaia (Eokoreanaia)* sp. - *Yunnanoconcha* sp. Assemblage

Lithofacies: Massive, Mud, Silt Lithofacies

Locality: Huai Lao Yang Shell Bed (HLY)

Characteristic species: *Koreanaia (Eokoreanaia)* sp. and *Yunnanoconcha* sp.

Associated species: *Nakamuranaia* sp., *Sinonaia* sp., *"Cardinioides" magnus*, and *Viviparus* sp.

Table 5.1 List of the mollusc taxa from the Sao Khua Formation of the 3 study areas. Numbers in each row showing numbers of individuals of each taxon, numbers in bold characters showing numbers of articulated valves.

Taxa	Nong Bua Lamphu Area				Phu Wiang Area								Sahatsakhan Area		
	HLY	PL	BHD	PC	PW-M-1/1	PW-M-1/2	PW-M-1/3	PW-M-2	PW-M-3	PW-M-4	PW-M-5/1	PW-M-5/2	PKK	PS	PP
1. *Nakamuranaia* sp.	17 **8**														
2. *Yunnanoconcha* sp.	227 **198**														
3. *Yunnanoconcha* sp. cf. *Y. khoratensis*										2 **2**					
4. *Sinonaia* sp.	2 **2**														
5. *Nippononaia* sp. cf. *N. mekongensis*			1 **1**				22				1 **1**			1	1
6. *Koreanaia (Eokoreanaia)* sp.	422 **186**														
7. *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*											6 **1**	2			
8. *Pseudohyria (Matsumotoina) somanai*		28 **27**	69 **69**	3	3		139				215 **31**		2	19	7
9. Trigonioidoidea *fam. indet.*		4 **4**			2	5	40	1	1					11 **8**	13 **2**
10. " *Cardinioides*" *magnus*	2 **1**														
11. *incertae cedis* (1)							23								
12. *incertae cedis* (2)							8								
13. *incertae cedis* (3)							11								
14. *incertae cedis* (4)						4 **4**		2 **2**	1 **1**						
15. *incertae cedis* (5)		2 **2**	6 **6**												
16. *Viviparus* sp.	1														
Total species	6	3	3	1	2	2	6	2	2	1	3	1	1	3	3
Total specimens	671	34	76	3	5	9	243	3	2	2	222	2	2	31	21
Dominance Index	0.51	0.69	0.83	1	0.52	0.50	0.37	0.55	0.50	1	0.93	1	1	0.50	0.49
Species diversity Index	0.79	0.57	0.34	0	0.67	0.68	1.30	0.63	0.69	0	0.15	0	0	0.77	0.80

Table 5.2 Fossil molluscan assemblages of the Sao Khua Formation.

Taxa		Molds	Molds	Shells	Shells	Shells	Shells	Shells	Shells	Shells	Shells	Shells	Shells	Molds Shells	Molds Shells	Molds Shells
	Lithology	Red brown mudstone-siltstone	Red brown, micaceous mudstone-siltstone	Purple brown fine-grained sandstone	Red brown medium-grained sandstone	Red brown medium- to coarse-grained sandstone	Green-gray, lime-nodule conglomeratic sandstone	Green-gray, lime-nodule conglomeratic sandstone which was overlaid by cross-bedded sandstone	Green-gray, lime-nodule conglomeratic sandstone which was overlaid by cross-bedded sandstone	Green gray to red brown, lime-nodule conglomeratic sandstone with mudstone mound and overlying by cross-bedded sandstone	Red brown, mud-nodule conglomeratic sandstone which was overlaid by cross-bedded sandstone	Red brown mud-nodule conglomeratic sandstone	Red brown mud-nodule conglomeratic sandstone	Purple brown or green gray, lime-nodule conglomeratic sandstone	Purple brown or green gray, lime-nodule conglomeratic sandstone	Purple brown or green gray, lime-nodule conglomeratic sandstone
	Shell Bed	HLY	PW-M-4	PKK	PW-M-1/1	PP	PL-2	PC	PW-M-5/2	PS	BHD	PW-M-1/3	PW-M-5/1	PW-M-1/2	PW-M-2	PW-M-3
1. *Nakamuranaia* sp.		◑														
2. *Yunnanoconcha* sp.		●														
3. *Sinonaia* sp.		●														
4. *Trigonioides (Koreanaia)* sp.		◑														
5. *"Cardinioides" magnus*		◑														
6. *Viviparus* sp.		■														
7. *Yunnanoconcha* sp. cf. *Y. koratensis*			●													
8. *Pseudohyria (Matsumotoina) somanai*				○	○	○	●	○		○	●	○	◔			
9. Trigonioidoidea *fam. indet.*					○	◔	●			◕		○		○	○	○
10. *Nippononaia* sp. cf. *N. mekongensis*						○				○	●	○	●			
11. *incertae cedis* (5)							●				●					
12. *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*									○				◔			
13. *incertae cedis* (1)												○				
14. *incertae cedis* (2)												○				
15. *incertae cedis* (3)												○				
16. *incertae cedis* (4)														●	●	●

Bivalves 10 > ● 50 > ● ≥ 10 ● ≥ 50 Disarticulated valves ◑ Articulated valves

Gastropods 10 > ■

Mode of occurrence: Almost of bivalve fossils are dissolution and were preserved as composite molds in poorly cemented, red mudstone-siltstone. These species are interpreted as probably representing mixed of autochthonous and paratochthonous occurrences (Table 5.3). This assemblage occurs as shell supported bed, which showing lateral facies change to calcareous burrow beds. Then, both of them were covered by siltstone with abundance calcareous burrow beds.

Palaeoecological analysis

5.4.1.1 Huai Lao Yang Shell Bed

Articulation: Two hundred and twenty seven individuals of *Yunnanoconcha* sp. comprise 198 articulated valves (87.22 %). Two specimens of *Sinonaia* sp. comprise 2 articulated valves (100 %). Two individuals of *"Cardinioides" magnus* comprise 1 articulated valve (50 %). Seventeen individuals of *Nakamuranaia* sp. comprise 8 articulated valves (47.05 %). Four hundred and twenty two individuals of *Koreanaia (Eokoreanaia)* sp. comprise 186 articulated valves (44.07 %) (Table 5.1 and 5.3).

Size distribution: Various stages of *Yunnanoconcha* sp., *Koreanaia (Eokoreanaia)* sp. and *Nakamuranaia* sp. were found.

Fragmentation: Some internal molds of shell fragments of *Yunnanoconcha* sp. and *Koreanaia (Eokoreanaia)* sp. were found.

Orientation: Bivalve fossils on block samples of PRC collection and in front of outcrop of the shell bed reveal no preferred orientation (Figure 3.5C-D; 4.16G).

Diversity Index: Six-hundred and seventy one individuals in PRC collection and the recent field survey collection were examined. This molluscan assemblage comprised 5 species of bivalve and 1 species of gastropod (*Viviparus* sp.). The Dominance Index is 0.51 and Species diversity Index is 0.79.

Density: Highly concentrated internal molds of bivalve fossils were discovered from an approximately 50 cm thick of shell bed.

Associated Fauna: Freshwater hybodont shark teeth *Heteroptychodus steinmanni* was reported from this shell bed (Cuny *et al.,* 2006, 2007). Bony fishes, pterosaur teeth, crocodile teeth, turtle plates, theropod teeth, and coprolites were also discovered in this locality, which all of them are deposited in PRC collection. Vertical and inclined burrows were also found at the rim of the outcrop.

Palaeoecology Interpretation: Bivalve fossils are well preserved, subequal articulated and disarticulated valves. This evidence represents disturbed neighborhood assemblage (species preserved in sediment, where they inhibited during life, but out of life position). The fine-grained matrix and slender morphology of the bivalve indicate floodplain swamp habitat. Abundance of specimens suggests optimum condition for bivalves (clean, well oxygenated, pH greater than 7, lime-rich, and shallow water (less than 7 m depth), perennial aquatic habitat, warm, stable substrate, and abundant plankton food resource (Good, 2004).

Table 5.3 Occurrence of bivalve fossils from Huai Lao Yang Shell Bed.

Taxa	Articulated valves		Disarticulated valves			Total number of individuals
	Unmoved	Slightly moved	Left valves	Right valves	Unidentified valves	
Yunnanoconcha sp.	198 (87.22%)	-	-	-	29	227
Koreanaia (Eokoreanaia) sp.	186 (44.07%)	-	-	-	236	422
Sinonaia sp.	2 (100%)	-	-	-	-	2
"Cardinioides" magnus	1 (50%)	-	-	1	-	2
Nakamuranaia sp.	8 (47.05%)	-	4	4	1	17

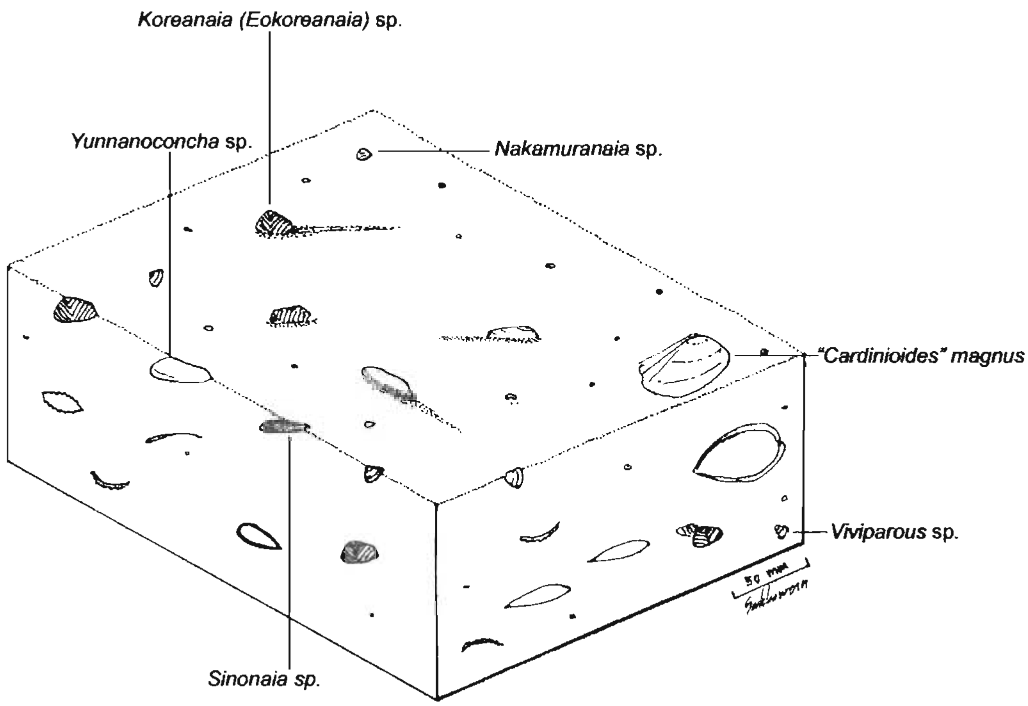


Figure 5.1 Palaeoecology reconstruction of *Koreanaia (Eokoreanaia)* sp. - *Yunnanoconcha* sp. Assemblage in floodplain swamp habitat.

5.4.2 *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage

Lithofacies: Massive, Mud, Silt Lithofacies.

Locality: Hin Lat Yao Shell Bed (PW-M-4).

Characteristic species: *Yunnanoconcha* sp. cf. *Y. khoratensis*

Mode of occurrence: All bivalve fossils are partly dissolution and were preserved as internal molds of articulated bivalve fossils were found in red micaceous mudstone-siltstone. Some shell fragments remain on the middle part of the fossil (Figure 4.13A).

Palaeoecological analysis

5.4.2.1 Hin Lat Yao Shell Bed (PW-M-4)

Articulation: Only two articulated valves were found.

Orientation: In the present study, no evidence of bivalve fossils were found in the outcrop, therefore their orientation can not be examined.

Diversity Index: Two individuals of one bivalve species were found in this locality. Dominance Index is 1 and Species Diversity Index is 0.

Density: It can be implied that bivalve fossils in this shell bed is rare.

Associated Fauna: The underlying red micaceous fine-grained sandstone bed yields dinosaur bones of *Siamotyranus isanensis*, numerous burrows and rootlets.

Palaeoecology Interpretation: The underlying red micaceous fine-grained sandstone showing small scale cross-lamination with numerous calcareous burrows and rootlet. These evidences indicate floodplain swamp. The shell bed is red micaceous mudstone-siltstone. It is in the alternation of red mudstone-siltstone and fine-grained sandstone, which indicate floodplain swamp habitat.

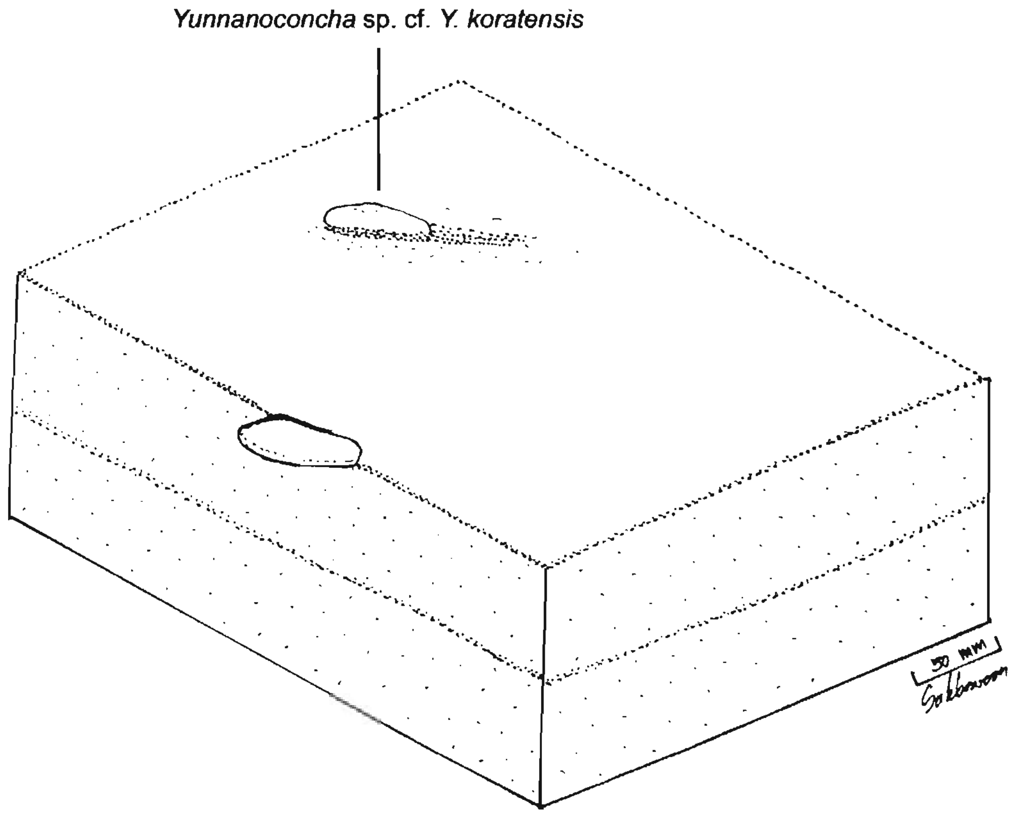


Figure 5.2 Reconstruction of *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage in floodplain swamp habitat.

5.4.3 *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.*

Assemblage

Locality: Ten shell beds are Phu Kum Khao (PKK), Lower and Upper Shell Beds of southern Phu Pratu Tee Ma (PW-M-1/1 and PW-M-1/3), Upper Shell Bed of Phu Lon (PL2), Phu Chan (PC), Upper Shell Bed of Phu Noi (PW-M-5/2), Phu Sing (PS), Phu Po (PP), Ban Huai Dua (BHD).

Characteristic species: *Pseudohyria (Matsumotoina) somanai* and Trigonioidoidea *fam. indet.*

Associated species: *Nippononaia* sp. cf. *N. mekongensis*, *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*, *incertae cedis* (1) – (3) and *incertae cedis* (5)

Mode of occurrence: This assemblage occurs in 5 types of lithology.

1. Red to purple brown, fine- to medium-grained sandstone. It comprises PKK and PW-M-1/1. All bivalves which were found in these shell beds are disarticulated valves and normally are in convex-up position on bedding surfaces. Abundant shell fragments are also present in these 2 shell beds. *Ps. (M.) somanai* presents in both shell beds, whereas, Trigonioidoidea *fam. indet.* presents in medium-grained sandstone of PW-M-1/1.

Palaeoecological analysis

5.4.3.1 Phu Kum Khao Shell Bed

Molluscan species composition: Only *P. (M.) somanai* was discovered (Figure 3.29C-D).

Articulation: Only two identifiable disarticulated valves were found.

Abrasion: Quality of specimens could not be observed the abrasion of shells.

Orientation: No preferred orientation of fossils was found (Figure 3.29C-D).

Diversity Index: Two disarticulated valves of *P. (M.) somanai* were found. Dominance Index is 1 and Species Diversity Index is 0.

Density: Very low density.

Matrix: Fine-grained sandstone.

Preservation: Disarticulated shells were preserved as recrystalized calcite.

Palaeoecology Interpretation: Rare disarticulated valves of *P. (M.) somanai* on the bedding surface of very thick fine-grained sandstone bed indicate that these specimens were transported and deposited in the channel sandstone bed.

5.4.3.2 Lower Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/1)

Molluscan species composition: Two identifiable species are *Pseudohyria (Matsumotoina) somanai* and Trigonioidoidea *fam. indet.*

Articulation: All rather complete shells are disarticulated valves.

Size distribution: Various sizes of disarticulated valves of *P. (M.) somanai*, Trigonioidoidea *fam. indet.* and their fragments were observed on the bedding surface.

Fragmentation: Abundant shell fragments.

Orientation: Fossils and their fragments show no-preferred orientation (Figure 3.15A-C).

Diversity Index: Dominance Index is 0.52 and Species Diversity Index is 0.67.

Density: Very dense bivalve shells and shell fragments can be observed on bedding surface (Figure 3.15B).

Matrix: Medium-grained calcareous sandstone.

Preservation: Both complete shells and shell fragments were preserved as recrytalized calcite.

Associated Fauna: Rootlets of unknown plants were found in this shell beds.

Palaeoecology Interpretation: Various sizes of disarticulated valves and shell fragments represent a death assemblage that has been transported and deposited on cross-bedding sandstone of point bar. Rootlets on the upper part of shell bed represent vegetation succession on the point bar.

2. Red brown, medium- to coarse-grained sandstone. It comprises PP. Bivalve fossils comprise *Pseudohyria (Matsumotoina) somanai*, Trigonioidoidea *fam. indet.* and *Nippononaia* sp. cf. *N. mekongensis.* Almost of shells are disarticulated valves are in no-preferred orientation on the bedding surface. Only two incomplete articulated valves of Trigonioidoidea *fam. indet.* were discovered.

Palaeoecological analysis

5.4.3.3 Phu Po Shell Bed

Molluscan species composition: *P. (M.) somanai*, Trigonioidoidea *fam. indet.* and *Nippononaia* sp. cf. *N. mekongensis*

Articulation: All shells of *P. (M.) somanai* and *Nippononaia* sp. cf. *N. mekongensis* are disarticulated valves. Almost shells of Trigonioidoidea *fam. indet.* are disarticulated valves.

Abrasion: All shells showing shell abrasion.

Fragmentation: Many shell fragments were found in the shell bed.

Orientation: Bivalve fossils showing no preferred orientation (Figure 3.34C).

Diversity Index: Dominance Index is 0.49 and Species Diversity Index is 0.80.

Density: Many shells and shell fragments were found as the layer at the base of second set of conglomeratic sandstone bed.

Matrix: Medium- to coarse-grained sand with pebbles of conglomeratic sandstone.

Preservation: All bivalve fossils were preserved as recrystalized shell.

Associated Fauna: Vertebrate bone was found at the same layer of bivalve fossils (Figure 3.34E).

Palaeoecology Interpretation: Abrasion of disarticulated bivalves and shell fragments represent the dead assemblage. Disarticulated bivalves, shell fragments, Dinosaur's bone, granules and pebbles have been transported in trough between channels.

3. Green gray, lime-nodule conglomerate. They comprise PL, PC, and PW-M-5/2. In Phu Lon Shell Bed, almost bivalve fossils are articulated valves, which indicate they were buried *in situ*. These bivalves are *Pseudohyria (Matsumotoina) somanai*, Trigonioidoidea *fam. indet.* and *incertae cedis* (5). In Phu Chan Shell Bed, only disarticulated valves of *P. (M.) somanai* were found. Upper Shell Bed of Phu Noi, only disarticulated valves of *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* were found.

Palaeoecological analysis

5.4.3.4 Phu Lon Shell Bed

Molluscan species composition: *P. (M.) somanai*, Trigonioidoidea *fam. indet.* and *incertae cedis* (5).

Articulation: Twenty-eight individuals of *P. (M.) somanai* comprise 27 articulated shells (96.42%). Four specimens of Trigonioidoidea *fam. indet.* and two specimens of *incertae cedis* (5) are articulated valves (100%).

Relative frequency between right and left valves: Only 1 convex-up disarticulated valve was discovered on vertical section of shell bed. Therefore, identification of left and right valves is impossible.

Size distribution: Little variation of large size of shells.

Abrasion: Little shell abrasion.

Fragmentation: Little shell fragmentation.

Orientation: In the outcrop, slightly open articulated valve of *P. (M.) somanai* and *incertae cedis* (5) were found. They randomly orientated on bedding surface of the shell bed. Convex-up disarticulated valves of *P. (M.) somanai* were also found on vertical section of the shell bed.

Diversity Index: This molluscan assemblage comprises 3 species of bivalves. The Dominance Index is 0.69 and Species Diversity Index is 0.57.

Density: Moderately dense.

Matrix: Very fined- to medium-grained sandstone and coarse-grained to pebble conglomerate.

Preservation: The bivalve fossils were preserved as recrystalized shells in lime-nodule conglomerate bed.

Associated Fauna: Tooth of spinosaurid dinosaurs, *Siamosaurus suteethorni* was also found in shell bed.

Palaeoecology Interpretation: Large articulated shells represent a dead assemblage that has been transported and deposited in channel bed bedforms. Rare disarticulated valve and minor fragmentation and abrasion suggests that this bivalve were transported not far from their habitat before final burial by rapid sedimentation.

Table 5.4 Occurrence of the mollusc fossils from Upper Shell Bed of Phu Lon.

Taxa	Articulated valves		Disarticulated valves			Total number of individuals
	Unmoved	Slightly moved	Left valves	Right valves	Un-identified valves	
Pseudohyria (Matsumotoina) somanai	27(96.42)	-	-	-	1	28
Trigonioidoidea*fam. indet.*	4 (100%)				-	4
incertae cedis (5)	2 (100%)	-	-	-	-	2

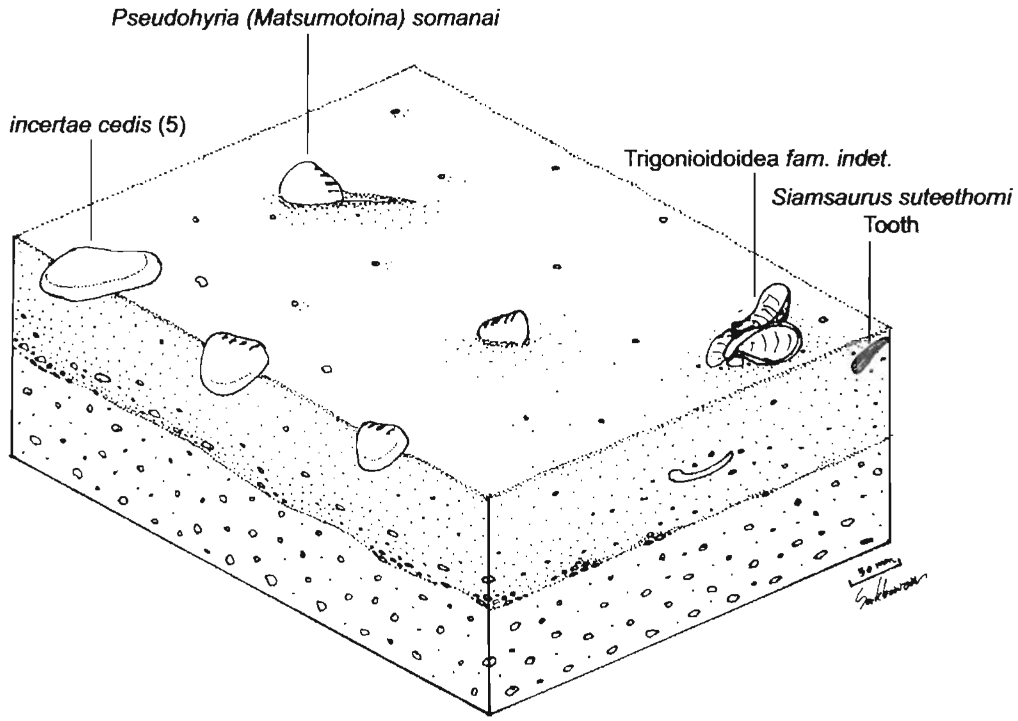


Figure 5.3 Palaeoecology reconstruction of *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage in sand and lime pebbles channel bed habitat.

5.4.3.5 Phu Chan Shell Bed

Molluscan species composition: Only one species of identifiable shells were identified as *Pseudohyria (Matsumotoina) somanai.*

Articulation: Three examined specimens are disarticulated valves.

Size distribution: Various sizes of shell fragments and disarticulated valves were found.

Fragmentation: Numerous shell fragments can be observed on the vertical section and bedding surface of the shell bed in front of the outcrop.

Orientation: Disarticulated shells and shell fragments showing 3 difference types of shell orientation on the vertical section of the shell bed. Convex-up orientation is found in both lower and upper units of shell bed (Figure 3.11B, C; 3.12A). Concave-up orientation is found only in the lower unit (Figure 3.12C) and no preferred orientation is found in the upper unit (Figure 3.12C).

Diversity Index: Identifiable species is *P. (M.) somanai* were discovered. The Dominance Index is 1 and Species Diversity Index is 0.

Density: Low to high density.

Matrix: Fine-grained calcareous sandstone, with abundance of mud- and lime-pebbles.

Preservation: Shells and fragments were preserved as recrytalized calcite.

Palaeoecology Interpretation: Disarticulated valves and shell fragments represent death assemblage that has been transported and deposited in troughs between channels of meandering river. Based on shell orientation as described above, this occurrence represents minimally transported assemblage.

5.4.3.6 Upper Shell Bed of Phu Noi (PW-M-5/2)

Molluscan species composition: *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*

Articulation: The specimens that can be recognized as individuals comprise only 2 disarticulated valves.

Size distribution: Various sizes of bivalve and shell fragments were found.

Abrasion: All shells and fragments showing the evidence of shell abrasion.

Fragmentation: Numerous shell fragments were found in this shell bed.

Orientation: No preferred shell orientation.

Diversity Index: Two disarticulated valves of *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* were found. Dominance Index is 1 and Species Diversity Index is 0.

Density: Bivalve fossils rather rare for this shell bed.

Matrix: Fine-grained calcareous conglomerate.

Preservation: Fossils were preserved as recrystalized shells.

Associated Fauna: Hybodont shark teeth of *Heteroptychodus steinmani*.

Palaeoecology Interpretation: Abrasion of disarticulated shells and shell fragments represented death assemblage that were slightly long way transported and deposited in channel. The shell bed was overlain by cross-bedded medium-grained sandstone and mudstone-siltstone beds, respectively. These evidences indicate point bar deposit of the meandering river system.

4. Green gray to red brown conglomerate with mudstone mould of cementing bivalves. It comprises PS. Bivalve fossils comprise disarticulated valves of *Pseudohyria (Matsumotoina) somanai* and *Nippononaia* sp. cf. *N. mekongensis*, Trigonioidoidea *fam. indet.* comprise 72.72 % of articulated valves and 27.28 % of this disarticulated valves. Most of Trigonioidoidea *fam. indet.* are in mudstone moulds, probably were preserved in life position.

5.4.3.7 Phu Sing Shell Bed

Molluscan species composition: Three species were discovered from this shell bed. The assemblage comprises *Pseudohyria (Matsumotoina) somanai*, Trigonioidoidea *fam. indet.* and *Nippononaia* sp. cf. *N. mekongensis*

Articulation: The specimens from this shell bed comprise 19 disarticulated valves of *P. (M.) somanai*, 11 individuals of Trigonioidoidea *fam. indet.*, which is composed of 8 articulated valves (72.73%), and 1 disarticulated valves of *Nippononaia* sp. cf. *N. mekongensis*

Size distribution: Only medium to large size of bivalves were found.

Abrasion: Most disarticulated valves of *P. (M.) somanai* showing evidence of shell abrasion.

Fragmentation: Many shell fragments of *P. (M.) somanai* were found.

Orientation: Disarticulated valves of *P. (M.) somanai* and *Nippononaia* sp. cf. *N. mekongensis* normally occur in current stable orientation (convex up), occasionally with oblique imbrication (Figure3.31E-F, 3.32E).

Diversity Index: Diversity of this shell bed was examined from bivalve fossils from the weathering conglomerate bed. Total species is 3, and the most abundant species is *P. (M.) somanai*. Dominance Index is 0.50 and Species Diversity Index is 0.77

Density: Shells of Trigonioidoidea *fam. indet.* are clump in red mudstone, whereas, disarticulated valves of *P. (M.) somanai* randomly distributed in shell bed.

Matrix: Fine-grained calcareous sandstone and red mudstone-siltstone.

Preservation: Articulated valves of Trigonioidoidea *fam. indet.* were found in red mudstone, whereas disarticulated shells of *P. (M.) somanai* and *Nippononaia* sp. cf. *N. mekongensis* were found in mud-nodule conglomerate.

Palaeoecology Interpretation: Articulated cementing bivalves occur as clump in mudstone matrix on cross-bedded sandstone. Moderately to largely size of disarticulated valves of *P. (M.) somanai* and *Nippononaia* sp. cf. *N. mekongensis* occur in convex up position, and some case in oblique imbrication. These evidences indicate the shell bed is channel deposit of high velocity fluvial system. The appearance of cementing bivalves in the mudstone mounds within the shell bed might be interpreted as their colony established on the low velocity current part of the channel. The overlying cross-bedded medium-grained sandstone showing numerous burrows, which indicate point bar deposit of meandering river system.

Table 5.5 Occurrence of the mollusc fossils from Phu Sing Shell Bed.

Taxa	Articulated valves		Disarticulated valves			Total number of individuals
	Unmoved	Slightly moved	Left valves	Right valves	Un-identified valves	
Pseudohyria (Matsumotoina) somanai	-	-	10	9	-	19
Trigonioidoidea *fam. indet.*	8	-	2	1	-	11
Nippononaia sp. cf. *N. mekongensis*	-	-	1	-	-	1

5. Red brown mud-nodule conglomerate. It comprises BHD, PW-M-1/3 and PW-M-5/1.

Palaeoecological analysis

5.4.5.8 Ban Huai Dua Shell Bed

Molluscan species composition: *Pseudohyria (Matsumotoina) somanai*, *Nippononaia* sp. cf. *N. mekongensis* and *incertae cedis* (5).

Articulation: Almost specimens are articulated valves.

Size distribution: Uniformly large size.

Orientation: Random

Diversity Index: Dominance Index is 0.83, Species Diversity Index is 0.34.

Density: Moderately dense.

Matrix: Fine- to medium-grained with mud-pebble conglomerate.

Preservation: Same as Phu Lon Shell Bed.

Associated Fauna: Freshwater hybodont shark teeth *Heteroptychodus steinmanni* were reported from this shell bed (Cuny *et al.*, 2006, 2007).

Palaeoecology Interpretation: The large obese of *P. (M.) somanai* is dominance species of this shell bed suggests slow velocity condition. The abundance of specimens indicates optimum condition for bivalve.

5.4.5.9 Upper Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/3)

Molluscan species composition: Six morphospecies were discovered. The assemblage comprises *Pseudohyria (Matsumotoina) somanai* (Figure 4.18), Trigonioidoidea *fam. indet.* (Figures 4.19; 4.20A), *Nippononaia* sp. cf. *N. mekongensis* (Figure 4.15), *incertae cedis* (1), *incertae cedis* (2), *incertae cedis* (3) (Figures 4.20F-H)

Articulation: The vertical section of this shell bed exposed approximately 56.3 m long in the outcrop. It was examined by tracing on the translucent plastic in front of the outcrop; this shell bed contains about 99% of disarticulated valves (Table 5.8). All specimens from block samples are disarticulated valves.

Size distribution: The most abundant species were examined the size frequency distribution by measured shell height, which the result show high mortality in young shells and gradually decreased in older stage (Figure 5.7).

Abrasion and Fragmentation: of shell abrasions and fragments were found.

Orientation: This shell bed was examined in both bedding surface and in cross-section. On the bedding surface, 6 convex-up trigonal shells were measured the direction of umbo, and show as the rose diagram in Figure 5.4. The vertical section shows no preferred orientation and shell normally distributed near to the upper part of shell bed (Table 5.8 and Figure 5.5).

Diversity Index: Total species is 6; the most abundant species is *P. (M.) somanai*, (Figure 5.6). Dominance Index is 0.37 and Species Diversity Index is 1.30.

Density: Moderately to highly concentrated.

Matrix: Fine- to medium-grained calcareous sandstone.

Preservation: The bivalve fossils were preserved as recrystalized shell in mud-nodule conglomerate. Most of shells, shell fragments, and mudstone and siltstone granules were coat by stromatolite-like lamination (Figure 3.17C-F).

Associated Fauna: Hybodont shark tooth of *Heteroptychodus* sp. was found

Palaeoecology Interpretation: Stromatolite-like lamination coat on almost clasts of mudstone and siltstone granules and almost shells and shell fragments. This evidence indicates that these materials were transported from the original habitat that stromatolite-like forming their lamination on the materials. The fragments of some clasts with stromatolite-like lamination suggests these shells and clasts were transported not far from the first place and rapidly deposited in the final place as the channel bed bedforms.

Table 5.6 The occurrence of shell orientation in vertical section of PW-M-1/3 (After Tumpeesuwan, 2005).

Block number	Location in outcrop (meters x to meters y)	Occurrences					total
		Disarticulated shells				Articulated shells	
		Convex-up	Concave-up	Oblique	parpenticular		
1	8.00-8.20	-	-	2	-	-	2
2	8.75-8.95	9	2	1	-	1	13
3	9.30-9.55	9	9	5	-	-	23
4	9.65-9.80	2	2	4	-	-	8
5	10.05-10.25	-	-	-	-	-	0
6	11.25-11.45	1	2	7	3	-	13
7	11.48-11.65	1	1	3	-	-	5
8	12.35-12.50	4	3	11	6	1	25
9	12.65-12.90	3	5	7	-	-	15
10	13.00-13.20	2	2	4	4	-	12
11	13.25-13.37	1	-	2	-	-	3
12	13.65-13.90	1	3	18	-	-	22
13	14.35-14.65	5	5	13	2	-	25
14	14.85-15.05	1	1	9	-	-	11
15	15.45-15.80	6	5	39	4	2	56
16	16.20-16.55	3	5	7	5	-	20
17	16.75-17.00	1	1	21	1	-	24
18	17.60-17.80	3	2	13	3	-	21
19	18.30-18.52	7	3	9	-	-	19
20	18.53-18.65	-	1	1	1	-	3
21	18.70-18.90	4	-	11	-	-	15
22	24.00-24.25	4	5	13	-	-	22
23	24.60-24.75	5	2	20	1	-	28
24	56.20-56.30	-	3	5	-	-	8
Total		72 (18.32%)	62 (15.78%)	225 (57.25%)	30 (7.63%)	4 (1.02%)	393 (100%)
Total		389 (98.98%)					

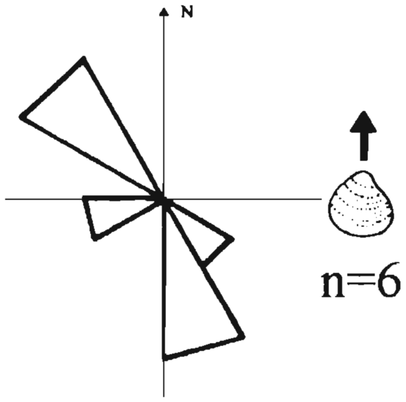
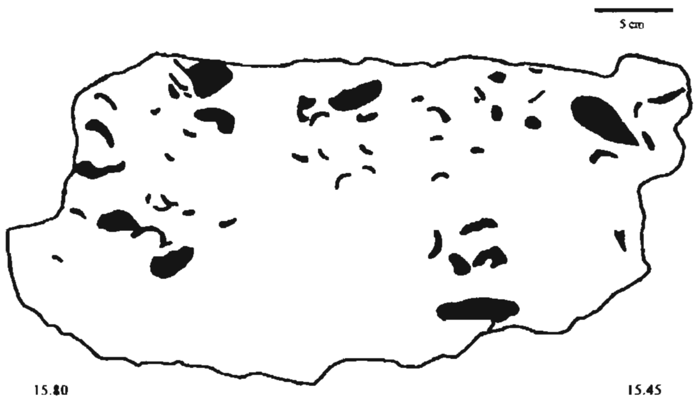


Figure 5.4 Rose diagram of bivalve shell orientation on bedding surface of shell bed PW-M-1/3 (After Tumpeesuwan, 2005).

A



B

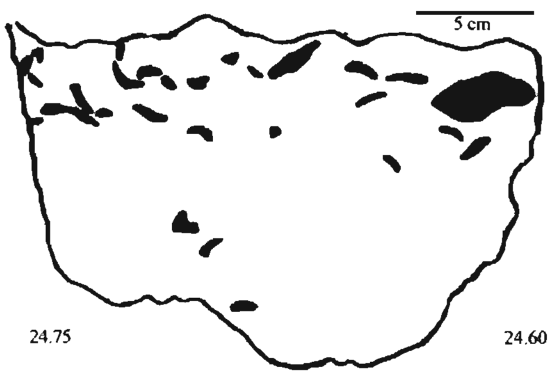


Figure 5.5 The occurrences of shell orientation in vertical section of PW-M-1/3 A. Block number 15 (between meters 15.45 and 15.80); B. Block number 23 (between meters 24.60 and 24.75) (After Tumpeesuwan, 2005).

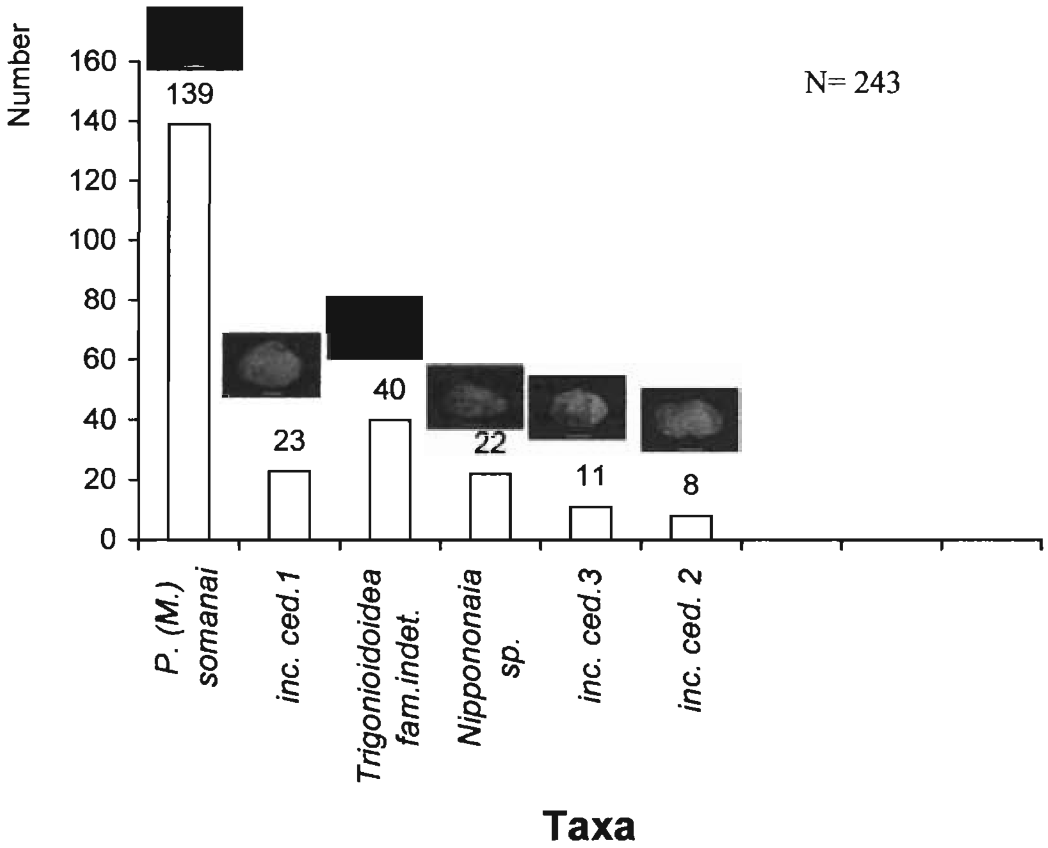


Figure 5.6 Bivalve species composition of PW-M-1/3 (Scale bar = 10 mm)

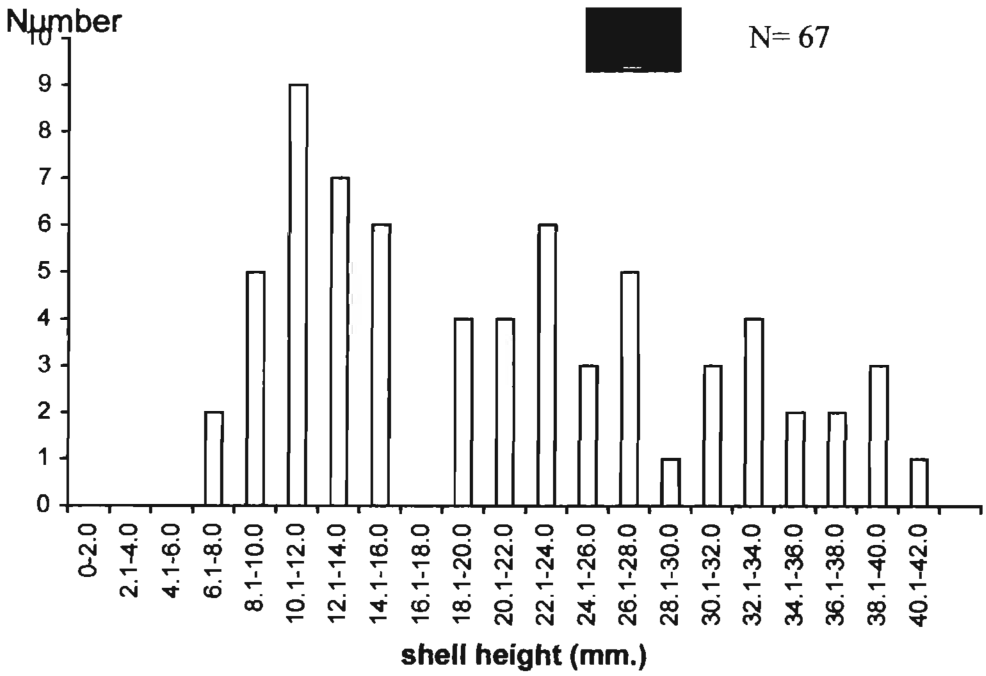


Figure 5.7 Size frequency distribution of *Pseudohyria (Matsumotoina) somanai*

5.4.5.3 Lower Shell Bed of Phu Noi (PW-M-5/1)

Molluscan species composition: *Pseudohyria (Matsumotoina) somanai*, *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* and *Nippononaia* sp. cf. *N. mekongensis*

Articulation: Two hundred and fifteen individuals of *P. (M.) somanai*, comprise 31 articulated valves (14.42%). Six individuals of *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* comprise 1 articulated valve (16.67%). One articulated valves of *Nippononaia* sp. cf. *N. mekongensis* (100%) was found (Table 5.6).

Relative frequency between right and left valves: Based on the identifiable disarticulated valves of *P. (M.) somanai*, 97 left valves (57.39%) and 72 right valves (42.61%) were found (Table 5.5). Five disarticulated valves of *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* comprise 2 left valves (40%) and 3 right valves (60%)

Size distribution: Various sizes of *P. (M.) somanai* were found.

Abrasion: Some shells of *P. (M.) somanai* show evidence of shell abrasion.

Fragmentation: Numerous shell fragments of *P. (M.) somanai* and *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* were found.

Orientation: This shell bed is *in situ* weathering, which can not be directly examined shell orientation in front of the outcrop. One fossil block collected from shell bed showing shell imbrication of *P. (M.) somanai* (Figure 3.25E).

Diversity Index: Bivalve fossils from the weathering conglomeratic sandstone bed were examined. The total species is 3, and the most abundant species is *P. (M.) somanai*. Dominance Index is 0.93 and Species Diversity Index is 0.15.

Density: Based on 222 individuals of 3 species and numerous shell fragments, it can be implied that molluscan fossils in this shell bed is rather dense.

Matrix: The mud-nodule conglomerate with muddy fine-grained sand matrix and numerous mudstone granules.

Preservation: Fossils were preserved as recrystalized shells.

Palaeoecology Interpretation: Well preserved articulated valve of all 3 species were discovered. Large obese shells of the abundance species *P. (M.) somanai*, and many well preserved delicate growth lines on umbonal area of articulated valves of small *P. (M.) somanai* indicate this was a living community of bivalves, that was suddenly buried by rapid influx of mud, sands, granules, dead shells, and shell fragments from upstream.

Table 5.7 Occurrence of the mollusc fossils from Lower Shell Bed of Phu Noi.

Taxa	Articulated valves		Disarticulated valves			Total number of individuals
	Unmoved	Slightly moved	Left valves	Right valves	Un-identified valves	
Pseudohyria (Matsumotoina) somanai	26	5	97	72	15	215
Trigonioides (Diversitrigonioides) sp. cf. *T. (D.) diversicostatus*	-	1	2	3	-	6
Nippononaia sp. cf. *N. mekongensis*	1	-	-	-	-	1

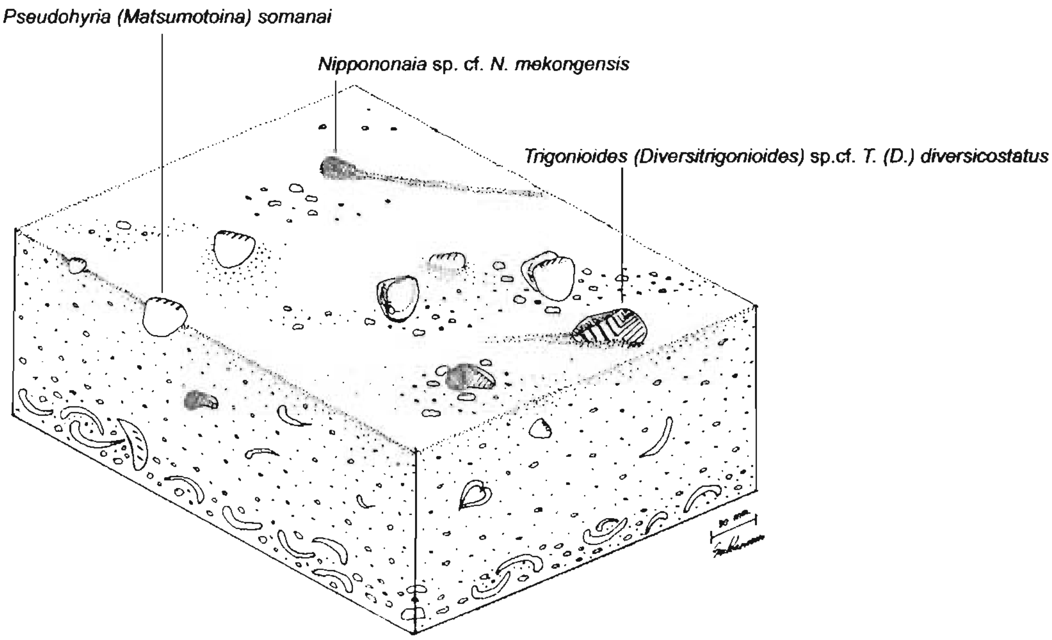


Figure 5.8 Palaeoecology reconstruction of *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage in muddy sand and granules channel bed habitat.

5.4.4 *incertae cedis* (4) Assemblage

Lithofacies: Clast-supported, Massive Gravel Lithofacies.

Locality: Middle Shell Bed of southern Phu Pratu Tee Ma (PW-M-1/2), Tham Kia Shell Bed (PW-M-2) and eastern Phu Pratu Tee Ma Shell Bed (PW-M-3).

Characteristic species: *incertae cedis* (4)

Associated species: Trigonioidoidea *fam. indet.*

Mode of occurrence: This assemblage occurs as shell-supported shell beds. These shell bed are lenticular, they lying on mudstone or fine- to medium-grained sandstone beds usually on erosional surfaces. This assemblage composed mainly of articulated molds of *incertae cedis* (4) and disarticulated shells and shells fragments of Trigonioidoidea *fam. indet.* The former taxon occurs only from these 3 localities in the study area.

Palaeoecological Analysis

5.4.5.1 Middle Shell Bed of Southern Phu Pratu Tee Ma (PW-M-1/2)

Molluscan species composition: Trigonioidoidea *fam. indet.* (Figure 4.19, 4.20A) and *incertae cedis* (4) (Figure 4.20I-K)

Articulation: All specimens of *incertae cedis* (4) are articulated valves (100 %), whereas, none specimens of Trigonioidoidea *fam. indet.* are articulated valves.

Size distribution: Various sizes of disarticulated valves of Trigonioidoidea *fam. indet.* and articulated valves of *incertae cedis* (4) were examined.

Abrasion: No evidence of shell abrasion, some disarticulated shells were encrusted by stomatolite-like layers (Figure 3.16C-D).

Fragmentation: Abundant shell fragments were found.

Orientation: Bivalve fossils show no preferred orientation (Figure 3.16B).

Diversity Index: Two species of bivalves were discovered. Dominance Index is 0.50 and Species Diversity Index is 0.68.

Density: Very dense shell fragments can be observed in the shell bed, internal or composite molds of articulated valves were discovered.

Matrix: Fine-grained calcareous sandstone.

Preservation: Articulated valves of *incertae cedis* (4) were preserved as composite molds, whereas disarticulated valves of Trigonioidoidea *fam. indet.* were preserved as recrytalized calcite.

Associated Fauna: Ostracods (Figure 3.16C-F).

Palaeoecology Interpretation: Articulated valves of *incertae cedis* (4) and ostracod probably preserved in sediments inhabited during life, but out of life position.

The fine-grained matrix and small and slender size of composite molds indicate swamp habitat. Disarticulated valves of Trigonioidoidea *fam. indet.* and abundance shell fragments might be transported from other habitats to deposit in the floodplain swamps.

5.4.5.2 Tham Kia Shell Bed (PW-M-2)

Molluscan species composition: Trigonioidoidea *fam. indet.* and *incertae cedis* (4).

Articulation: The specimens that can be recognized as individuals comprise 1 disarticulated shell of Trigonioidoidea *fam. indet.* and 2 articulated valve of internal molds of *incertae cedis* (4).

Size distribution: Various sizes of both species were discovered.

Fragmentation: Numerous shell fragments were discovered.

Orientation: Bivalve fossils show no preferred orientation.

Diversity Index: Dominance Index is 0.55 and Species Diversity Index is 0.63.

Density: Very dense shell fragments distributed in the shell bed.

Matrix: Fine- to medium-grained calcareous sandstone.

Preservation: Shells of Trigonioidoidea *fam. indet.* were preserved as recrystalized shells, which this recrystalized calcite is very fragile to break off and the internal molds were leaved behind, whereas, *incertae cedis* (4) were preserved as composite molds. This characteristic is similar to PW-M-1/2 and PW-M-3

Associated Fauna: The bones of *Phuwiangosaurus sirindhornae* were discovered from the alternation of laminated muddy fine-grained sandstone and fine-grained sandstone underlain the shell bed.

Palaeoecology Interpretation: Internal molds of articulated valves of *incertae cedis* (4) are small and slender shape. The molds are fine-grained matrix, which this evidence indicate swamps habitat. Medium to large sizes of Trigonioidoidea *fam. indet.* were transported and deposited in the same shell bed in rapid sedimentation by stream to floodplain swamps.

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5.4.5.3 Eastern Phu Pratu Tee Ma (PW-M-3)

Molluscan species composition: Trigonioidoidea *fam. indet.* and *incertae cedis* (4).

Articulation: The specimens that can be recognized as individuals comprise 1 articulated valves of *incertae cedis* (4) and 1 disarticulated valves of Trigonioidoidea *fam. indet.*

Fragmentation: Numerous shell fragments were discovered.

Orientation: Bivalve fossils show no preferred orientation.

Diversity Index: One individual of both species were found. Dominance Index is 0.50 and Species Diversity Index is 0.69.

Density: Very dense shell fragments.

Matrix: Fine- to medium-grained calcareous sandstone.

Preservation: Same as PW-M-1/2 and PW-M-2 Shell Bed.

Palaeoecology Interpretation: Same as Tham Kia Shell Bed.

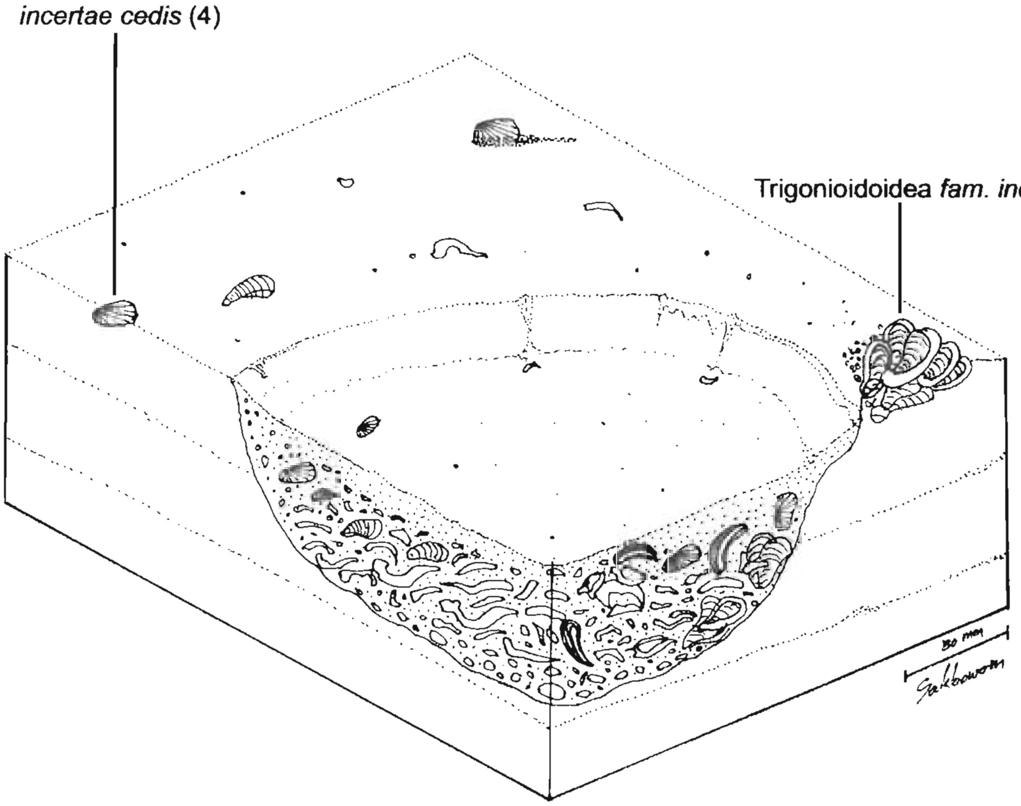

Figure 5.9 Palaeoecology reconstruction of *incertae cedis* (4) Assemblage.

CHAPTER VI

DISCUSSION

6.1 Molluscan assemblages of the Sao Khua Formation

Sixteen molluscan taxa from 15 shell beds at 12 localities in 3 study areas were subdivided into 4 assemblages. These assemblages are related to different kinds of sedimentary facies. These 4 molluscan assemblages are described as following.

6.1.1 *Koreanaia (Eokoreanaia)* sp. – *Yunnanoconcha* sp. Assemblage. This assemblage is related to mudstone - siltstone. This assemblage was only discovered from Huai Lao Yang Shell Bed, which is near to the boundary between the underlying Phra Wihan Formation and the Sao Khua Formation (Figure 3.2 and 3.35). The associated species are *Nakamuranaia* sp., *Sinonaia* sp., *"Cardinioides" magnus* and *Viviparus* sp. Based on the genus level, this assemblage can be related to Hauterivian - Barremian *Nippononaia (Eonippononaia) tetoriensis – Koreanaia (Eokoreanaia) cheongi – Danlengiconcha elongata* Assemblage from East Asia proposed by Sha (2007).

6.1.2 *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage. This assemblage is related to mudstone - siltstone. This assemblage was only discovered from Hin Lat Yao Shell Bed overlying on red micaceous siltstone bed, which pteropod dinosaur, *Siamotyranus isanensis* was found (Figure 3.13 and 3.35). This taxon possesses their morphology and size as intermediate form between *Yunnanoconcha* sp. from Huai Lao Yang Shell Bed of Lower part of the Sao Khua Formation and *Y. khoratensis* from Ban Na Yo Shell Bed and Nam Phung Dam Site of the Khok Kruat Formation.

6.1.3 *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage. This assemblage is widely distributed in sandstone and conglomeratic sandstone of the Sao Khua Formation (Figure 3.2, 3.13, 3.27 and 3.35). The associated species are *Nippononaia* sp. cf. *N. mekongensis*, *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*, *incertae cedis* (1), *incertae cedis* (2), *incertae cedis* (3) and *incertae cedis* (5).

This assemblage might be compared to the assemblage 6 of Ma (1994) and assemblage 2 of Sha (2007).

The assemblage 6 of Ma (1994) is *Pseudohyria – Sainshandia – Limnocyrena* Assemblage, which was firstly proposed as Campanian – Maastrichian age.

The assemblage 2 of Sha (2007) is *Nippononaia (Nippononaia) ryosekiana - Koreanaia (Koreanaia) bongkyuni -Trigonioides (Wakinoa) wakinoensis - Trigonioides (Trigonioides) kodairai, Trigonioides (Trigonioides) quadratus - Plicatounio (Plicatounio) naktongensis - Pseudohyria (Matsumotoina) matsumotoi* Assemblage.

Pseudohyria – Sainshandia – Limnocyrena Assemblage was discovered in the Bali Formation of Guangxi in southern China. It comprises *Sainshandia nagnomensis*, *Trigonioides* sp., *Nakamuranaia* aff. *chingshanensis*, *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus* and *Plicatounio (Acclinoplicatounio) nananensis*. The age of the Bali Formation is currently used as Late Barremian - Early Albian, and the assemblage was grouped in the assemblage 2 of Sha (2007).

Trigonioides (Diversitrigonioides) diversicostatus - Pseudohyria (Pseudohyria) subovalis Assemblage has been reported from Southern China, Southern Laos and Northeastern Thailand (Ban Na Yo Shell Bed and Nam Phung Dam Site, both of them belong to the Khok Kruat Formation). Sha (2007) proposed Aptian age for this assemblage, and might be extended down into the Barremian and up into Aptian. The assemblage in the present study possesses more primitive characters than *Trigonioides (diversitrigonioides) diversicostatus - Pseudohyria (Pseudohyria) subovalis* Assemblage. Therefore, their age might be older than *Trigonioides (diversitrigonioides) diversicostatus - Pseudohyria (Pseudohyria) subovalis* Assemblage, probably, Barremian.

6.1.4 *incertae cedis* (4) Assemblage. This assemblage is related to lime-nodule conglomeratic sandstone. The assemblage was discovered from PW-M-1/2, PW-M-2 and PW-M-3 (Figure 3.13 and 3.35). Based on stratigraphic position from this study, this assemblage occurs between PW-M-1/1 and PW-M-1/3. It might be indicated the same age as *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage.

6.2 Age of some Fauna and Flora in the Sao Khua Formation

6.2.1 Bivalves

6.2.1.1 *Koreanaia (Eokoreanaia)*: This subgenus comprises two preceding species, including *Koreanaia (Eokoreanaia) cheongi* Yang, 1976 and *K. (E.) fordi* (Baker *et al.,* 1997).

The former species was discovered from the Myogog Formation of Korea (Yang, 1976), which Hauterivian age was suggested for the formation (Kozai *et al.,* 2005).

The latter species was discovered from the Upper Hauterivian to Barremian Wessex Formation of southern England (Baker *et al.,* 1997).

According to the appearance of these two preceding species, it might be suggested that the subgenus *Eokoreanaia* is restricted to Hauterivian – Barremian Age (Figure 6.1).

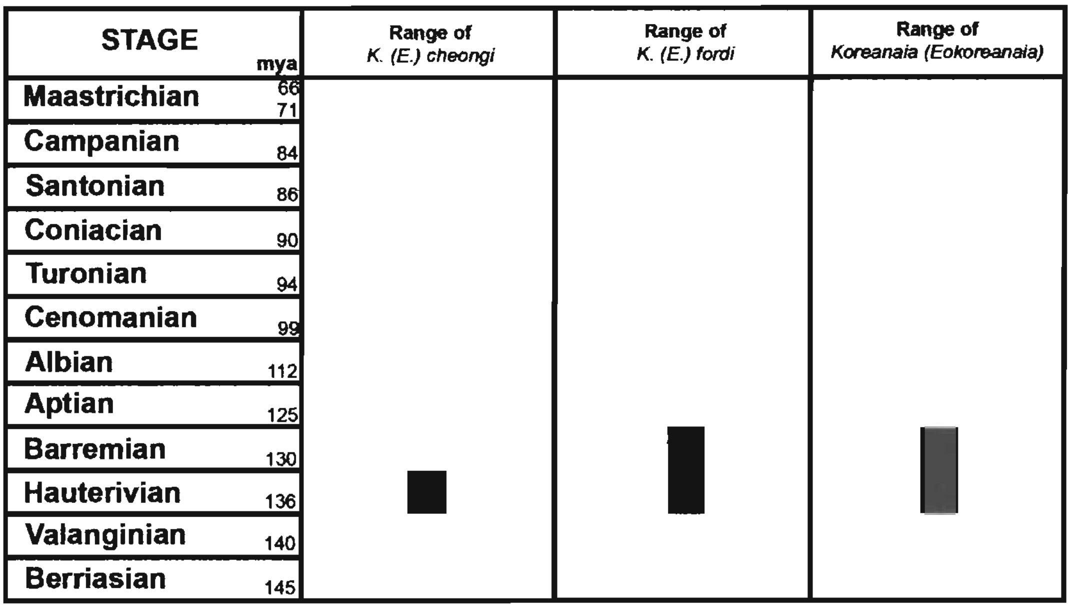

Figure 6.1 Geological range of *Koreanaia (Eokoreanaia).*

6.2.1.2 ***Yunnanoconcha*:** This genus comprises two preceding species, including *Yunnanoconcha chuxiongensis* Gu and Ma, 1976 and *Y. khoratensis* (Kobayashi, 1963).

The former species was discovered from the Puchanghe Formation of Central Yunnan, Southern China (Ma, 1994), which the age might be suggested as Hauterivian – Barremian (Ma, 1994; Guo, 1984; Sha, 2007).

The latter species was discovered from the Khok Kruat Formation of Northeastern Thailand (Kobayashi, 1984). The age of the Khok Kruat Formation was suggested as Aptian by the evidences of Aptian –Albian Hybodont Shark (Cappetta *et al.,* 1990) and Aptian palynomorph (Sattayarak *et al.,* 1991; Racey *et al.,* 1994, 1996; Racey and Goodall, 2009).

Therefore, the range of this genus might be assigned to Hauterivian – Aptian (Figure 6.2).

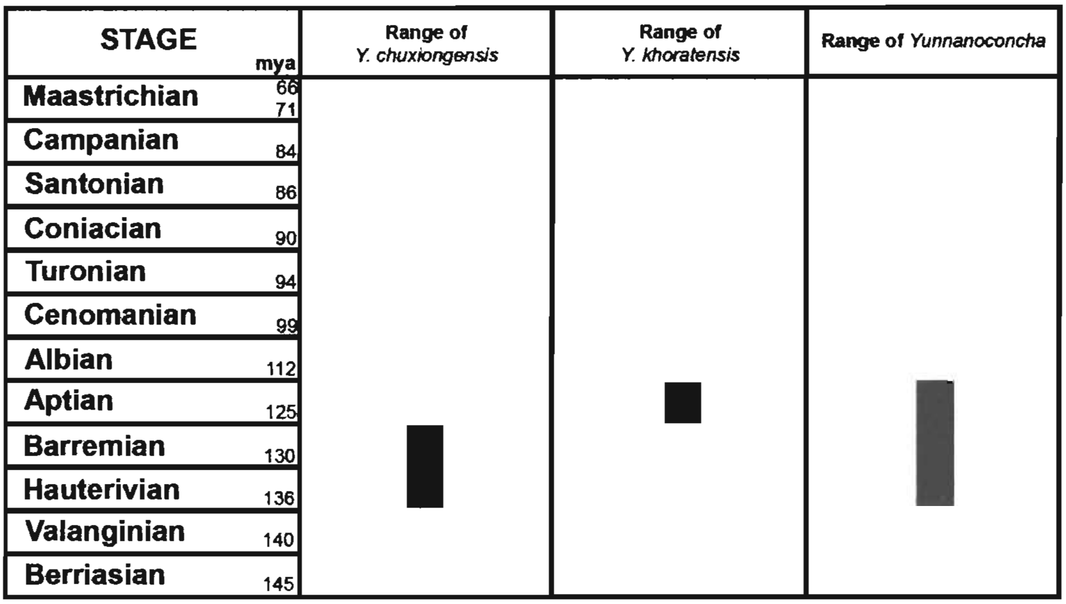

Figure 6.2 Geological range of *Yunnanoconcha.*

6.2.1.3 ***Nakamuranaia*****:** This genus comprises eight preceding species, including *Nakamuranaia soni* (Yang, 1975), *N. leei* (Yang, 1976), *N. mojiangensis* Guo, 1981, *N. elongata* Guo, 1981, *N. chingshanensis* (Grabau, 1923), *N. subrotunda* (Gu and Ma), *N. yongkangensis* (Gu and Ma), and *N.* aff. *chingshanensis* (Grabau, 1923).

N. soni was discovered from the Hauterivian Okurodani Formation of Inner Zone of Japan, the Late Barremian Kitadani Formation of Inner Zone of Japan, and the Nakdong and Hasandon Formations of Korea (Kozai *et al.,* 2005).

N. leei was found from Hauterivian Myogog Formation (Kozai *et al.,* 2005).

N. mojiangensis and *N. elongata* were discovered from the Jingxing Formation of Western Yunnan, southern China (Guo, 1981), which age of the formation was suggested as Hauterivian – Barremian Age, based on its trigonioidid assemblages (Sha, 2007).

N. chingshanensis was discovered from the Qinshan Formation in Shandong and Hanyangpu Formation in Sichuan, Southern China, which age of both formations was suggested as Berriasian? – Barremian (Ma, 1994). Based on trigonioidid assemblages of Sha (2007), Qinshan Formation was suggested as Aptian age and Hanyangpu Formation was assumed as Hauterivian – Barremian Age.

N. subrotunda and *N. yongkangensis* were discovered from the Guantou Formation in Zhejiang, China which age of the formation was suggested as Aptian – Albian (Ma, 1994).

N. aff. *chingshanensis* was discovered from the Bali Formation in Guangxi, Southern China, which age was suggested as Campanian – Maastrichtian (Ma, 1994). The age of the Bali Formation, recently, was changed to Aptian – Cenomanian, but mainly Albian, based on its trigonioidid assemblages (Sha, 2007).

Therefore, based on the most update data, the geological range of the genus *Nakamuranaia* is assumed as Hauterivian – Cenomanian Age (Figure 6.3).

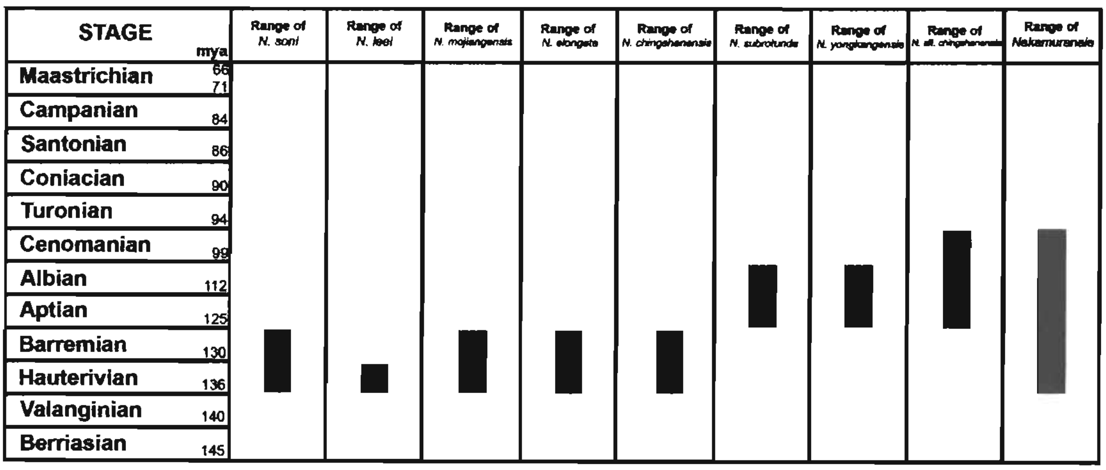

Figure 6.3 Geological range of *Nakamuranaia*.

6.2.1.4 *Sinonaia*: This genus comprises two preceding species, including, *Sinonaia tenuilonga* Guo, 1981 and *S. chuxiongensis* (Gu and Ma). The former species was discovered from the Jingxing Formation of Western Yunnan (Guo, 1981). The later one was discovered from the Upper Member of the same formation (Guo, 1984).

Guo (1984) proposed trigonioidacean zonation, which this genus was found only in subzone 1b of the Upper Member of Jingxing Formation. The age of the formation was suggested as Hauterivian – Barremian Age (Figure 6.4).

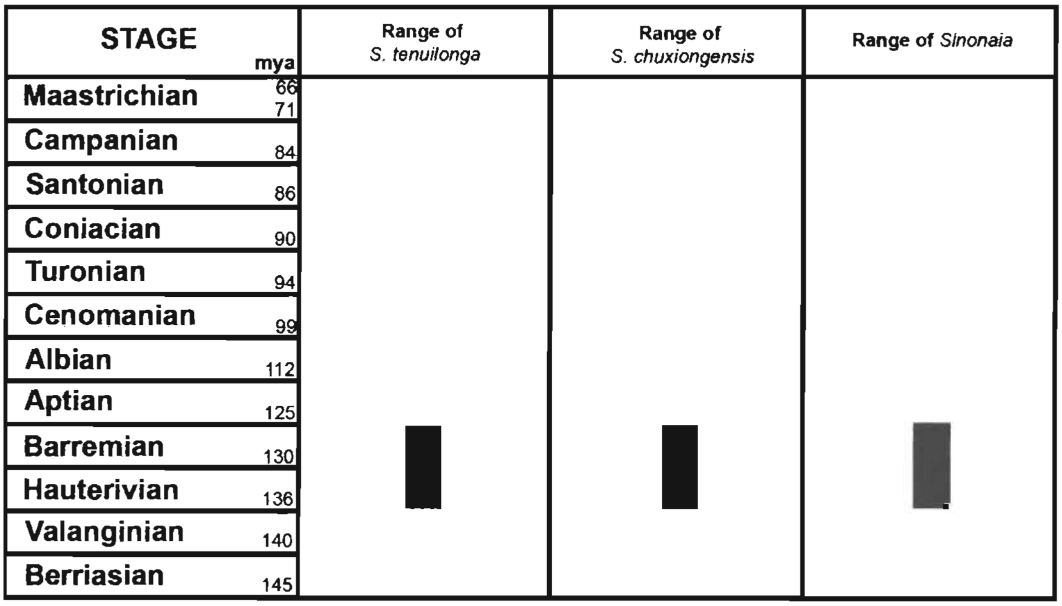

Figure 6.4 Geological range of *Sinonaia*.

6.2.1.5 *Pseudohyria (Matsumotoina)*: The preceding sole species of this subgenus is *Pseudohyria (Matsumotoina) matsumotoi* Yang, 1979 which it was discovered in Korea and Japan. It was first discovered from the Yeonwhadong Formation, Geongsang Group in Korea. The formation also contains other bivalve species, such as, *Nippononaia ryosekiana, Nakamuranaia soni, Koreanaia*

(Koreanaia) bongkyuni, Viviparus sp., and *Micromelania katoensis*. The occurrence of *N. ryosekiana* can be considered to be correlated to the Aptian-Albian Sebayashi Formation in Japan (Yang, 1978), which has been reassigned to the Late Barremian to Early Aptian in age based on the analysis of ammonite assemblages of the underlying Ishido Formation and overlying Sanyama Formation (Matsukawa, 1983).

Ogasawara (1988) discovered *P. (M.) matsumotoi* in association with *Plicatounio* sp. and *Na. soni* from the Monomiyama Formation in northeastern Japan. The age of the formation is assigned to Hauterivian-Barremian.

Tamura (1990) reported the discovery of *P. (M.) matsumotoi* from the Kitadani and Sengoku formations in southwest Japan

Isaji (1993) discovered *N. ryosekiana* from Kitadani Formation of the Tetori Group in Japan, where *N. ryosekiana* is associated with *Trigonioides (Wakinoa) tetoriensis, Plicatounio kobayashii, N. tetoriensis, Na. soni* and *Viviparus* sp. Fujita (2003) assigned this formation to the Barremian on the basis of the occurrences of *N. ryosekiana* and TPN fauna.

Kozai *et al.* (2005) proposed a Sebayashi faunal association which is characterized by the *Hayamina matsukawai - Nippononaia ryosekiana* Assemblage. It comprises freshwater bivalve *N. ryosekiana* and 5 of other species of brackish water bivalves which are restricted to the Late Barremian. The Nagdong fauna of Korea, being characterized by *N. ryosekiana, P. (M.) matsumotoi,* and *Na. soni* are correlated with Kitadani, Sengoku, and Sebayashi faunas and belong to the Sebayashi faunal association (Kozai *et al.*, 2005, p.107, Table 3).

Sha (2007) subdivided the trigonioidid bivalve assemblages in Asia into seven assemblages, and *P. (M.) matsumotoi* is in the second assemblage. He suggested a Late Barremian-Early Albian, but mainly Aptian Age for the assemblage.

Therefore, it should be assumed that the taxon *Pseudohyria (Matsumotoina)* is restricted to Late Barremian (Figure 6.5).

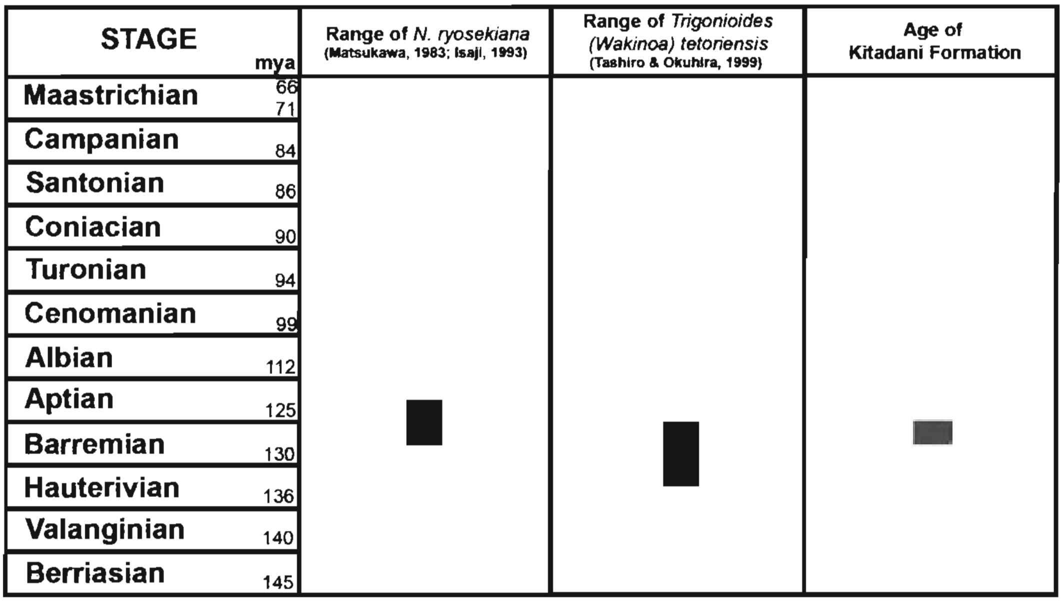

Figure 6.5 Geological range of *Pseudohyria (Matsumotoina)* in the Kitadani Formation.

6.2.1.6 *Nippononaia*: *Nippononaia ryosekiana* was discovered from Late Barremian to Early Aptian Sebayashi Formation in Japan (Yang, 1978 and Matsukawa, 1983). This species was also discovered from Yeonwhadong Formation, Geongsang Group in Korea (Yang, 1978) and Kitadani Formation of the Tetori Group in Japan (Isaji, 1993).

N. tetoriensis was discovered from Late Barremian Kitadani Formation

N. mekongensis Kobayashi, 1963; *N. carinata* Kobayashi, 1968; *N. subquadrata* Kobayashi, 1968 and *N. robusta* Kobayashi, 1968; was discovered from the Aptian Khok Kruat Formation.

Therefore, this taxon might be assigned as Hauterivian to Aptian age (Figure 6.6).

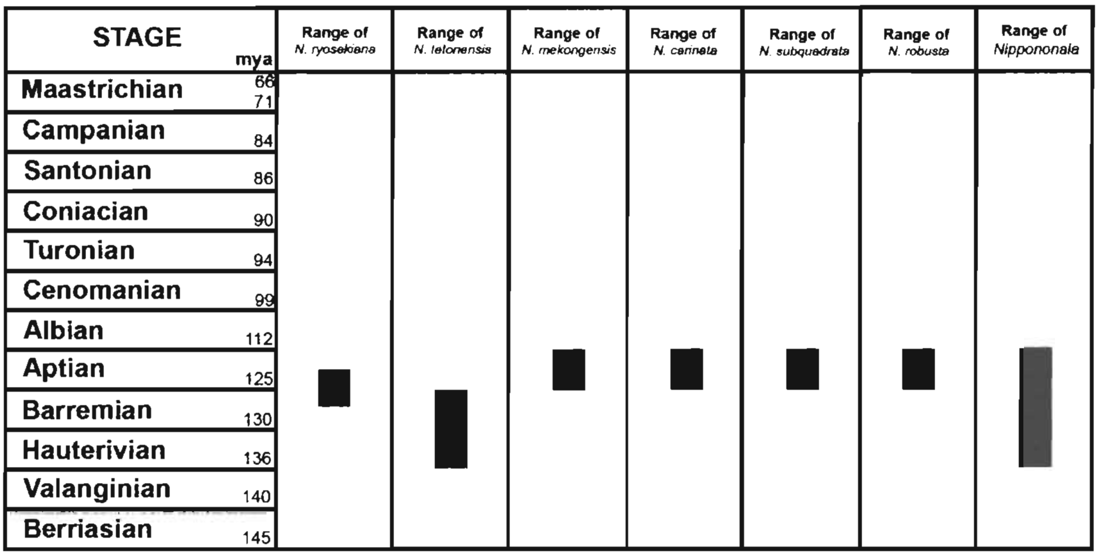

Figure 6.6 Geological range of *Nippononaia*.

6.2.1.7 ***Trigonioides (Diversitrigonioides)*:** One preceding species is *Trigonioides (Diversitrigonioides) diversicostatus*. This species was described from Ban Na Gnom Bed of Northern Muong Phalane, Southern Laos (Hoffet, 1937). It was also discovered from the Bali Formation of Guangxi, Southern China (Ma, 1994).

Based on the trigonioidid assemblages proposed by Sha (2007), the *Trigonioides (Diversitrigonioides) diversicostatus* – *Pseudohyria (Pseudohyria) subovalis* assemblage is mainly Albian and probably extends up into Cenomanain and down into Aptian.

Trigonioides (Diversitrigonioides) sp. cf. *T. (D.) diversicostatus* was discovered from the Sao Khua Formation in the same shell bed with *Pseudohyria (Matsumotoina) somanai* and *Nippononaia* sp. cf. *N. mekongensis*. According to the age of *Pseudohyria (Matsumotoina)*, the age of *Trigonioides (Diversitrigonioides)* might be extends down into Late Barremian Age.

Therefore, the spatial distribution of this subgenus might be assigned as Late Barremian to Cenomanain Age (Figure 6.7).

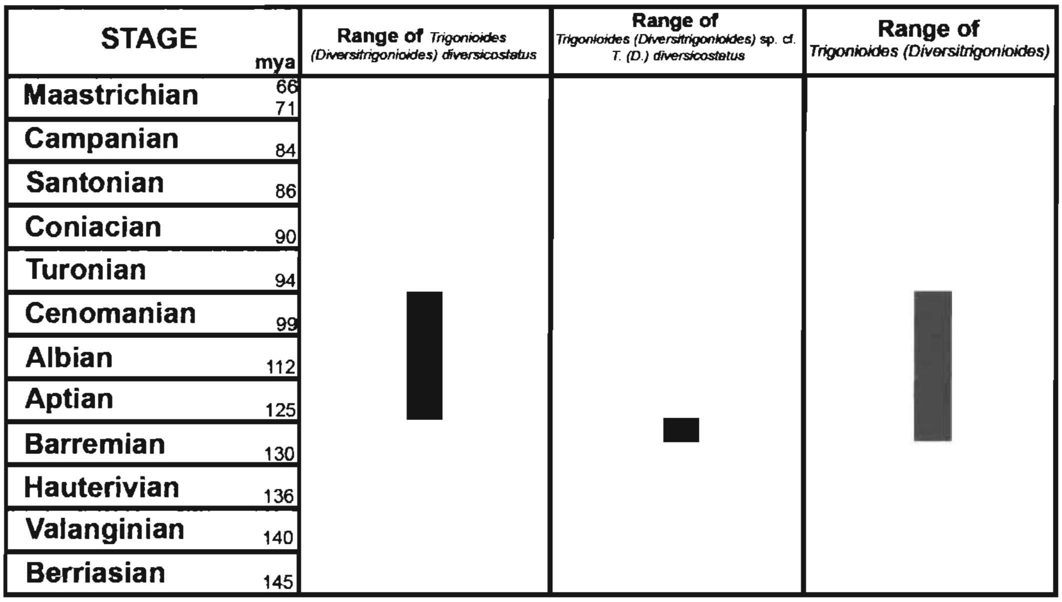

Figure 6.7 Geological range of *Trigonioides (Diversitrigonioides).*

6.2.2 Palynomorph assemblages

Racey and Goodall (2009) analyzed the samples from Phu Phan Thong Locality in Nong Bua Lamphu Province (probably equivalence to Huai Lao Yang Shell Bed). The assemblage dominated by *Dicheiropollis etruscus, Cicatricosisporites* spp., *Corollina* spp., *Appendicisporites* spp., and *Concavissimisporites punctatus.*

The dyad pollen of *D. etruscus* was also discovered in the Phu Kradung, Pra Wihan and Sao Khua Formations (see chapter 2). This palynomorph has worldwide stratigraphic significance and become extinct in the Lower Barremian, and occurs over a broad area, including West Africa, North and South America, Southern Europe, China and Yemen (Racey and Goodall, 2009). The range of *D. etruscus* was assumed that its presence indicates a Berriasian to Early Barremian Age.

6.3 Relative age of the Sao Khua Formation

The presence of the dyad pollen of *Dicheiropollis etruscus* from Phu Phan Thong Bed indicates Berriasian to Early Barremian age for the Sao Khua Formation (Racey and Goodall, 2009).

Huai Lao Yang Shell Bed is equivalent to Phu Phan Thong Bed. Both beds are near to the boundary between the lowermost horizon of the Sao Khua Formation and the uppermost horizon of the underlying Phra Wihan Formation (Figure 3.2 and 3.35).

Koreanaia (Eokoreanaia) sp. – *Yunnanoconcha* sp. Assemblage was discovered from Huai Lao Yang Shell Bed. Some species of the assemblage are belonging to short range taxa, including, *Koreanaia (Eokoreanaia)* sp., *Yunnanoconcha* sp., *Nakamuranaia* sp. and *Sinonaia* sp. The first appearance of all these taxa is Hauterivian and the last appearance of *Koreanaia (Eokoreanaia)* sp. and *Sinonaia* sp. is the end of Barremian. Based on the presence of these short range taxa of pollen and freshwater bivalves, it might be suggested Hauterivian - Early Barremian Age for the Huai Lao Yang – Phu Phan Thong Fossil Horizons at the lower part of the Sao Khua Formation (Figure 6.6).

The discovery of *Pseudohyria (Matsumotoina) somanai* from the upper part of Sao Khua Formation is very important for age determination (Figure 3.35). The preceding sole species of this subgenus *P. (M.) matsumotoi* is restricted to the Sebayashi faunal association suggesting Late Barremian Age (Kozai *et al.*, 2005). Thus, it is likely that the occurrence of the subgenus *Pseudohyria (Matsumotoina)* in the Sao Khua Formation roughly assigns the upper part of Sao Khua Formation to Late Barremian Age based on the geological range of the subgenus (Figure 6.6).

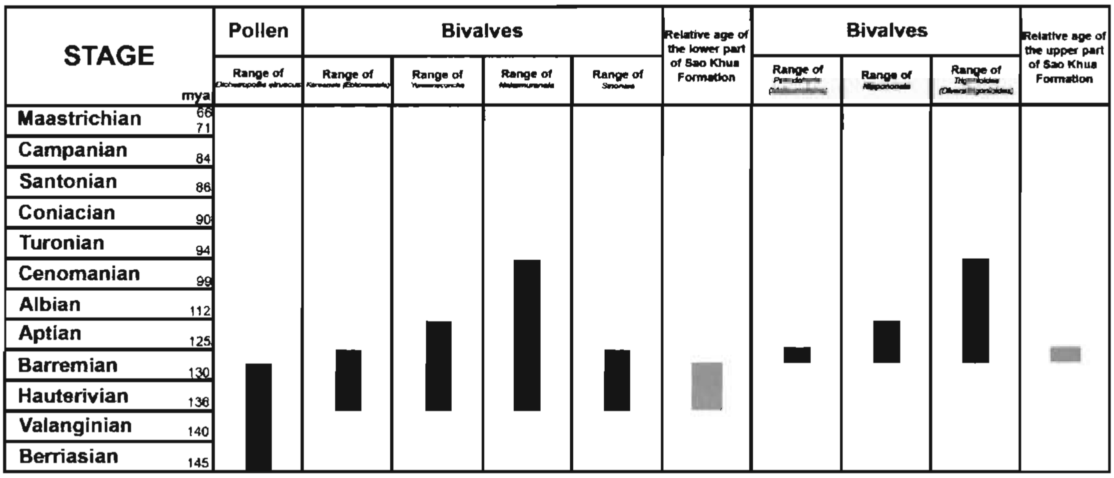

Figure 6.8 Age of some Fauna and Flora, and relative age of the Sao Khua Formation.

6.4 Association among molluscan assemblages and palaeoecology.

Four molluscan assemblages of the Sao Khua Formation were examined, which they can be associated with palaeoecology as following:

Koreanaia (Eokoreanaia) sp. – *Yunnanoconcha* sp. Assemblage is associated with red-brown mudstone-siltstone of floodplain swamps. Most of the shells discovered in this shell bed are articulated valves. Almost species are small, slender shape and thin shell.

Yunnanoconcha sp. cf. *Y. khoratensis* Assemblage is associated with red micaceous mudstone-siltstone of floodplain swamps. Bivalves are bigger and less slender than the previous assemblage. Shells are also thin.

Pseudohyria (Matsumotoina) somanai – Trigonioidoidea *fam. indet.* Assemblage is associated with fine-grained sandstone to pebbly sandstone, the details are shown as following:

- Allochthonous occurrence associated with purple brown fine-grained sandstone, red brown medium-grained sandstone, medium- to coarse-grained sandstone, conglomerate, cross-bedded conglomerate, green gray lime-nodule conglomerate and red brown mud-nodule conglomerate.

- Mixed of Allochthonous and autochthonous occurrences associated with green gray to red brown conglomerate with mudstone mound of cementing bivalves and red brown mud-nodule conglomerate.

- Autochthonous occurrences associated with green gray, lime-nodule conglomerate and red mud-nodule conglomerate.

incertae cedis (4) Assemblage is associated with lime-nodule conglomerate. Articulated valves of internal molds of *incertae cedis* (4) and disarticulated valves of Trigonioidoidea *fam. indet.* show mixed assemblage. Small size and slender shape of articulated valves of *incertae cedis* (4) were preserved in fine-grained matrix indicate swamp habitat. Large and thick disarticulated shells and shell fragments of Trigonioidoidea *fam. indet.* might be transported from other habitats to deposit in the floodplain swamps.

6.5 Palaeoautoecology of bivalves of the Sao Khua Formation

The Sao Khua Formation was interpreted as meandering river system (Meesook, 2000) deposited in semiarid to arid climatic condition (Hahn, 1982a, b; Meesook, 2000).

Palaeoecological studies were performed using a block sample of 30x30x20 cm^3 or bulk sample with approximately same volume as block sample. The most abundant species of the Sao Khua Formation is *Pseudohyria (Matsumotoina) somanai*. However, in this study, palaeoecology can be concluded from palaeoautoecology of some taxa as following:

6.5.1 Palaeoautoecology of *Pseudohyria (Matsumotoina) somanai.* This species was described from specimens discovered from Lower Phu Noi Shell Bed.

The shell bed is red mud-nodule conglomerate (Figures 3.25A-C, E). Conglomerate is thought to have been deposited in a river channel (Meesook, 2000; Meesook and Wongprayoon, 1999; Imsamut, 2003; Tumpeesuwan, 2005; Tumpeesuwan and Sato, 2005). Almost shell beds weathered out and exact shell orientation could not be determined. Articulated valves of small shells are well preserved without abrasion of the delicate growth lines around the umbo (Figures 4.18F-K). This evidence possibly reflects the absence of post-mortem transportation and it can be assumed that the valves were buried *in situ* by rapid sedimentation of flooding. This species may have lived in a muddy sand substratum which contained numerous granules to small pebbles.

6.5.2 Palaeoautoecology of *Yunnanoconcha* sp. and *Yunnanoconcha* sp. cf. *Y. khoratensis.* Both species of the genus *Yunnanoconcha* were found only in mudstone-siltstone of flood plain deposit. It indicated that this species was still water habitat such as swamps, lakes, ditch *etc.* The similarity of shell shape and habitation of the genus *Yunnanoconcha* with the recent Thai bivalve *Pilsbryoconcha exilis* is very interesting point. The recent species live in all kinds of still water (Brandt, 1974). Therefore, the recent freshwater bivalve should be studied concentrating particularly on their different environments.

6.5.3 Palaeoautoecology of *Sinonaia* sp., *Koreanaia (Eokoreanaia)* sp., *Nippononaia* sp. cf. *N. mekongensis*, and *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus.* The fascinating sculpture of v-shape ribs in these genera

Sinonaia, *Koreanaia (Eokoreanaia)*, *Nippononaia*, and *Trigonioides (Diversitrigonioides)* may have function for its livelihood, which no answer for this sculpture. However, the recent Thai freshwater bivalve genus *Scabies* shows zigzag lines in v- or w- pattern, which is slightly similar to *Nippononaia.* Thus, *Scabies* may be used as the modern analog to test the function of v-shape sculpture in Early Cretaceous Bivalves.

CHAPTER VII

CONCLUSIONS

1. Fifteen shell beds from 12 localities were discovered and examined. Nong Bua Lamphu Area comprises 4 Shell Beds, including Huai Lao Yang, Phu Lon, Ban Huai Dua and Phu Chan Shell Beds. Phu Wiang Area comprises 8 Shell Beds, including Lower, Middle, and Upper Shell Beds of Southern Phu Pratu Tee Ma, Tham Kia, Eastern Phu Pratu Tee Ma, Hin Lat Yao, and Lower and Upper Phu Noi. Sahat Sakhan Area comprises 3 Shell Beds including Phu Kum Khao, Phu Sing, and Phu Po Shell Beds.

2. Sixteen taxa of molluscan fossils were recognized from the Sao Khua Formation of Nong Bua Lamphu, Phu Wiang, and Sahat Sakhan Areas. There are 15 taxa of Bivalves, including *Nakamuranaia* sp., *Yunnanoconcha* sp., *Yunnanoconcha* sp. cf. *Y. khoratensis*, *Sinonaia* sp., *Nippononaia* sp. cf. *N. mekongensis*, *Koreanaia (Eokoreanaia)* sp., *Trigonioides (Diversitrigonioides)* sp. cf. *T. (D.) diversicostatus*, *Pseudohyria (Matsumotoina) somanai,* Trigonioidoidea *fam. indet.,* so-called *"Cardinioides" magnus*, and 5 uncertain affinity. There is only 1 taxon of Gastropods, which is *Viviparus* sp.

3. Molluscan assemblages of the Sao Khua Formation in this study can be subdivided into 4 assemblages, i.e., *Koreanaia (Eokoreanaia)* sp. - *Yunnanoconcha* sp. Assemblage, *Yunnanoconcha* sp. cf. *Y. khoratensis* Assemblage, *Pseudohyria (Matsumotoina) somanai* – Trigonioidoidea *fam. indet.* Assemblage, and *incertae cedis* (4) Assemblage.

4. Based on the evidences of Berriasian - Early Barremian Age of palynomorph, *Dicheiropollis etruscus* and Hauterivian – Barremian age of *Koreanaia*

(Eokoreanaia) sp. - *Yunnanoconcha* sp. Assemblage, the lower part of the Sao Khua Formation might be assumed as Hauterivian to Early Barremian Age.

5. *Pseudohyria (Matsumotoina) somanai* from the upper part of the Sao Khua Formation may indicate a Late Barremian age based on the only described species *P. (M.) matsumotoi* being restricted to Late Barremian horizons in Japan and Korea.

6. Autochthonous occurrences of internal molds of small sizes, slender shapes and thin shells associated with red brown mudstone-siltstone of floodplain swamps deposits.

7. Medium to large sizes, robust shape, and thick shells associated with fine- to coarse-grained sandstone and conglomeratic sandstone. Autochthonous occurrences associated with green gray, lime-nodule conglomerate and red mud-nodule conglomerate represent channel or point bar deposits.

8. The most abundant species of the upper part of Sao Khua Formation is *Pseudohyria (Matsumotoina) somanai*. This species may have lived in muddy sand substratum of river which contained numerous granules to small pebbles channel.

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APPENDICES

APPENDIX A

Calculation of Index of species diversity

Index of species diversity (Krebs, 1999)

Shannon-Wiener Function $H' = \sum (p_i)(\log_2 p_i)$

where H' =Information content of sample (bits/individual)

p_i =Proportion of total sample belonging to i species

		pi	lnpi	pipi	pilnpi
HLY	17	0.025335	-3.67556	0.0006419	-0.0931214
	227	0.338301	-1.08382	0.1144476	-0.3666571
	2	0.002981	-5.81562	8.884E-06	-0.0173342
	422	0.628912	-0.46376	0.3955304	-0.2916667
	2	0.002981	-5.81562	8.884E-06	-0.0173342
	1	0.00149	-6.50877	2.221E-06	-0.0097001
	671			0.5106399	-0.7958137
		pi	lnpi	pipi	pilnpi
PL	28	0.823529	-0.19416	0.6782007	-0.1598932
	4	0.117647	-2.14007	0.0138408	-0.2517725
	2	0.058824	-2.83321	0.0034602	-0.1666596
	34			0.6955017	-0.5783253
BHD	1	0.013158	-4.33073	0.0001731	-0.0569833
	69	0.907895	-0.09663	0.8242729	-0.087727
	6	0.078947	-2.53897	0.0062327	-0.2004453
	76			0.8306787	-0.3451556
		pi	lnpi	pipi	pilnpi
PC	3	1	0	1	0
	3			1	0
		pi	lnpi	pipi	pilnpi
PW-M-1/1	3	0.6	-0.51083	0.36	-0.3064954
	2	0.4	-0.91629	0.16	-0.3665163
	5			0.52	-0.6730117
		pi	lnpi	pipi	pilnpi
PW-M-1/2	5	0.555556	-	0.308642	-

			0.58779		0.3265481
	4	0.444444	-0.81093	0.1975309	-0.3604134
	9			0.5061728	-0.6869616
		pi	lnpi	pipi	pilnpi
PW-M-1/3	22	0.090535	-2.40202	0.0081966	-0.2174667
	139	0.572016	-0.55859	0.3272028	-0.3195213
	40	0.164609	-1.80418	0.0270961	-0.2969847
	23	0.09465	-2.35757	0.0089587	-0.2231442
	8	0.032922	-3.41362	0.0010838	-0.1123825
	11	0.045267	-3.09517	0.0020491	-0.1401104
	243			0.3745872	-1.3096099
		pi	lnpi	pipi	pilnpi
PW-M-2	1	0.333333	-1.09861	0.1111111	-0.3662041
	2	0.666667	-0.40547	0.4444444	-0.2703101
	3			0.5555556	-0.6365142
		pi	lnpi	pipi	pilnpi
PW-M-3	1	0.5	-0.69315	0.25	-0.3465736
	1	0.5	-0.69315	0.25	-0.3465736
	2			0.5	-0.6931472
		pi	lnpi	pipi	pilnpi
PW-M-4	2	1	0	1	0
	2			1	0
		pi	lnpi	pipi	pilnpi
PW-M-5/1	1	0.004505	-5.40268	2.029E-05	-0.0243364
	6	0.027027	-3.61092	0.0007305	-0.0975924
	215	0.968468	-0.03204	0.9379312	-0.0310291
	222			0.9386819	0.1529579
		pi	lnpi	pipi	pilnpi

PW-M-5/2	2	1	0	1	0
	2			1	0
		pi	lnpi	pipi	pilnpi
PKK	2	1	0	1	0
	2			1	0
PS	1	0.032258	-3.43399	0.0010406	-0.1107738
	19	0.612903	-0.48955	0.3756504	-0.3000457
	11	0.354839	-1.03609	0.1259105	-0.3676455
	31			0.5026015	-0.778465
PP	1	0.047619	-3.04452	0.0022676	-0.1449773
	7	0.333333	-1.09861	0.1111111	-0.3662041
	13	0.619048	-0.47957	0.38322	-0.2968786
	21			0.4965986	-0.8080599

APPENDIX B

Specimens Collection

Collection Number	Scientific Name	Number of specimens	Locality
PRC-M-M-106 to 236	*Pseudohyria (Matsumotoina) somanai*	131	Phu Noi, Khon Kaen
PRC-M-M-237	*Nippononaia* sp.cf. *N. mekongensis*	1	Phu Noi, Khon Kaen
PRC-M-M-236 to 245	Trigonioidoidea *fam. indet.*	8	Phu Sing, Kalasin
PRC-M-M-293 to 308	*Nakamuranaia* sp.	16	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-309 to 310	*Sinonaia* sp.	2	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-314 to 540	*Yunnanoconcha* sp.	227	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-541 to 962	*Koreanaia (Eokoreanaia)* sp.	422	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-963 to 964	*"Cardinioides" magnus*	2	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-965	*Viviparus* sp.	1	Huai Lao Yang, Nomg Bua Lam Phu
PRC-M-M-966 to 967	*incertae cedis* (5)	2	Phu Lon, Nomg Bua Lam Phu
CUMZ 3201 to 3202	*Pseudohyria (Matsumotoina) somanai*	3	Phu Noi, Khon Kaen
CUMZ 3204	*Nakamuranaia* sp.	1	Huai Lao Yang, Nomg Bua Lam Phu
CUMZ 3205 to 3206	*Yunnanoconcha* sp. cf. *Y. khoratensis*	2	Hin Lat Yao, Khon Kaen
PW-M-3.1	Trigonioidoidea *fam. indet.*	1	Eastern Phu Pratu Tee Ma, Khon Kaen
PW-M-2.1	Trigonioidoidea *fam. indet.*	1	Tham Kia, Khon Kaen
PW-M-1/2.1 to 5	Trigonioidoidea *fam. indet.*	5	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.1 to 14	Trigonioidoidea *fam. indet.*	14	Southern Phu Pratu Tee Ma, Khou Kaen
PW-M-1/3.121 to 126	Trigonioidoidea *fam. indet.*	6	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.15 to 27	*Nippononaia* sp.cf. *N. mekongensis*	13	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-5.2 to 7	*Trigonioides (Diversitrigonioides)* sp. cf. *T. mekongensis*	5	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.95 to 112	*incertae cedis* (1)	18	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.146 to 150	*incertae cedis* (1)	5	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.113 to 119	*incertae cedis* (2)	7	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.151	*incertae cedis* (2)	1	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/3.135 to 145	*incertae cedis* (3)	11	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-1/2.6 to 9	*incertae cedis* (4)	4	Southern Phu Pratu Tee Ma, Khon Kaen
PW-M-2.2 to 3	*incertae cedis* (4)	2	Tham Kia, Khon Kaen
PW-M-3.2	*incertae cedis* (4)	1	Eastern Phu Pratu Tee Ma, Khon Kaen

Biography

Mr. Sakboworn Tumpeesuwan was born on the 6th September 1976 in Mueang District, Ratburi Province. He obtains his bachelor's degree of science in 1999 from the Department of Biology, Faculty of Science, Chulalongkorn University. He also graduated Master degree in zoology at the same place in 2002. After, he got the job at Palaeontology Research and Education Center, Department of Biology, Faculty of Science, Mahasarakham University. He started to study Palaeontology in Earth Science Program, Department of Geology, Faculty of Science, Chulalongkorn University by grant supports from Mahasarakham University since June 2002. He received the research grant from Chulalongkorn University in 2004 and graduated Master degree in Earth Science in October 2005. In the same year, he continued to study Early Mesozoic freshwater bivalves of the Sao Khau Formation in Doctor of Philosophy Program in Geology in the same department. Financial supports for his study from Mahasarakham University and Graduated Thesis Grant of Chulalongkorn University (3/2551).