STRATIGRAPHY AND PALEOENVIRONMENT OF THONG PHA PHUM GROUP IN KANCHANABURI PROVINCE

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A Thesis Submitted in Partial Fulfillment of the Requirements

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ลำดับชั้นหินและสภาพแวดล้อมบรรพกาลในกลุ่มหินทองผาภูมิ จังหวัดกาญจนบุรี

น.ส.วารุณี มณีรัตน์

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Field of Study	Geology
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วารุณี มณีรัตน์ : ลำดับชั้นหินและสภาพแวดล้อมบรรพกาลในกลุ่มหินทองผาภูมิ จังหวัดกาญจนบุรี. (STRATIGRAPHY AND PALEOENVIRONMENT OF THONG PHA PHUM GROUP IN KANCHANABURI PROVINCE) อ.ที่ปรึกษาหลัก : รศ. ดร.ฐาสิณีย์ เจริญฐิติรัตน์, อ.ที่ปรึกษาร่วม : ดร.สุคนธ์เมธ จิตรมหันตกุล

การศึกษานี้มีวัตถุประสงค์เพื่อศึกษารายละเอียดด้านวิทยาหิน ลำดับชั้นหิน ชุดลักษณ์ของหิน บรรพชีวานุกรมวิธาน (systematic paleontology) ในหินตะกอนทะเลยุคไซลูเรียน-ยุคดีโวเนียนของกลุ่มหินทองผาภูมิ บริเวณบ้านท่ากระดาน อำเภอศรีสวัสดิ์ จังหวัดกาญจนบุรี และเพื่อแปลความหมายและสร้างรูปแบบสภาพแวดล้อมการสะสมตัว

กลุ่มหินทองผาภูมิพบกระจายตัวอย่างกว้างขวางในพื้นที่ศึกษา ส่วนใหญ่ประกอบด้วยหินดินดาน หินทรายแป้ง หินทราย หินปูน หินปูนเนื้อดิน หินดินดานเนื้อปูน หินโคลนเนื้อปูน หินโคลนชั้นบาง และพบซากดึกดำบรรพ์หลายชนิด เช่น แกรปโตไลต์ เทนทาคูไลต์ ออสตราคอด แบรคิโอพอด นอติลอยด์ และไทรโลไบต์ เป็นต้น กลุ่มหินนี้พบวางตัวแบบต่อเนื่องอยู่บนหินปูนของกลุ่มหินทุ่งสงยุคออร์โดวิเชียน และวางตัวอยู่ใต้หมวดหินควนกลางยุคคาร์บอนิเฟอรัสตอนต้นตามลำดับ ชั้นหินของกลุ่มหินทองผาภูมิสามารถกำหนดอายุได้ตั้งแต่ยุคไซลูเรียนถึงยุคดีโวเนียน จากการศึกษาบรรพชีวานุกรมวิธานของซากดึกดำบรรพ์เทนทาคูไลต์ที่พบเป็นจำนวนมากประกอบด้วย 7 ชนิด จาก 3 สกุล ได้แก่ *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, *Styliolina clavulus*, *Styliolina* sp. A, *Homoctenus tikhyi* และ *Homoctenus arctus* ที่บ่งชี้อายุในยุคดีโวเนียนตอนต้นถึงตอนปลาย นอกจากนี้ในพื้นที่ศึกษาพบซากดึกดำบรรพ์แกรปโตไลต์ (*Monograptus* sp. และ *Diplograptus* sp.) ที่บ่งชี้อายุในยุคไซลูเรียน? ถึงยุคดีโวเนียนตอนต้น จากลักษณะของหิน ลำดับชั้นหิน ชุดลักษณ์ของหิน รวมทั้งผลการศึกษาบรรพชีวานุกรมวิธานบ่งชี้ว่ากลุ่มหินทองผาภูมิเกิดการสะสมตัวของตะกอนบริเวณที่ลาดใต้ทะเล (slope environment) ต่อเนื่องไปจนถึงแอ่งทะเลลึก (deep marine basin) ภายใต้พลังงานต่ำ

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Warunee Maneerat : STRATIGRAPHY AND PALEOENVIRONMENT OF THONG PHA PHUM GROUP IN KANCHANABURI PROVINCE. Advisor: Assoc. Prof. THASINEE CHAROENTITIRAT, Ph.D. Co-advisor: SUKONMETH JITMAHANTAKUL, Ph.D.

The purposes of this study are to establish the detail lithology, stratigraphy, lithofacies and systematic paleontology of marine Silurian-Devonian sedimentary rocks of the Thong Pha Phum Group in Ban Tha Kraden, Si Sawat District, Kanchanaburi Province, and to interpret and reconstruct its depositional environment.

The Thong Pha Phum Group is well exposed in the study area. It consists mainly of shale, siltstone, sandstone, limestone, argillaceous limestone, calcareous shale, calcareous mudstone, and laminated mudstone with the many fossils such as graptolites, tentaculites, ostracods, brachiopods, nautiloids and trilobites. These strata are conformably underlain by the Thung Song Group (Ordovician age) and are conformably overlain by the Khuan Klang Formation (Early Carboniferous age). Abundant tentaculites were recognized and they consist of 7 species belonging to 3 genera: *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, *Styliolina clavulus*, *Styliolina* sp. A, *Homoctenus tikhyi*, and *Homoctenus arctus* indicating Early to Late Devonian age. In addition, graptolites (*Monograptus* sp. and *Diplograptus* sp.) were found in this area and they indicate probably Silurian? to Early Devonian. Based on the lithology, lithofacies, sedimentary structure, and fossils contains, they suggest that the Thong Pha Phum Group was deposited on the slope environment to deep marine basin in low energy conditions.

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Student's Signature .....

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Warunee Maneerat

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1
INTRODUCTION

1.1 Rationale

The Silurian-Devonian rocks of Thailand consist of marine sediment facies. They are widely exposed in the northern, western, and peninsular Thailand. In the western Thailand, the Silurian-Devonian sequences are generally known as the Thong Pha Phum Group (Bunopas, 1981) and distributed in Uthai Thani, Suphan Buri, Kanchanaburi and Ratchaburi Provinces. These strata are conformably underlain by carbonate sequences of the Thung Song Group (Ordovician age) and are conformably overlain by clastic sequence of Khuan Klang Formation (Early Carboniferous age) (Bunopas, 1981; Hagen & Kemper, 1976; Meesook, 2013; Polwichai, 2013). Many fossils were found in various rock units of this region for example nautiloids, tentaculites, graptolites, trilobites, conodonts, bivalves, brachiopods, radiolarian and other fossils of lower Paleozoic rocks (Hahn & Siebenhüner, 1982). Although in the past, the Thong Pha Phum Group has been numerous investigations in these regions, the stratigraphy and paleontology of this group have been rarely carried out. There are some difficulties in this area such as the stratigraphy of the sequence and ages of the sedimentary rocks in the sequence are still unclear as well as there is no detail some of fossils found in the sections.

At Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, the Silurian-Devonian rocks are widely distributed and the continuous stratigraphic sections have been recognized in quarries and road-cut outcrops. It consists of mudstone, siltstone, sandstone, limestone, argillaceous limestone, and abundant fossils of graptolite, tentaculate, trilobite and brachiopods. This area is lack of the detailed research dealing with sedimentology and paleontology, especially on the detail petrography, fossils, and depositional environment. This study will propose stratigraphic of the Silurian-Devonian Thong Pha Phum Group in terms of litho- and biostratigraphy, fossils, depositional environment, and paleogeography.

1.2 Objective of the study

The objectives of this study are 1) to study the lithology, lithology, sedimentary structure and fossil contains of Thong Pha Phum Group (marine Silurian-Devonian sedimentary rocks) in Ban Tha Kraden area, Si Sawat District, Kanchanaburi Province, and 2) to interpreted and reconstruct the depositional environment and paleogeography of the study area.

1.3 Scope of work

This study is aimed to clarify the lithology, sedimentary structure and tentaculite fossils that were collected from the isolate localities and measured sections in the study area. The study area covers the Ban Tha Kradan area, Si Sawad District, Kanchanaburi Province, approximately 81 square kilometers. Geological mapping has been conducted on the 1:50,000 scale.

1.4 Methodology

Generally, the detailed methodology for this study can be divided into 5 main stages, as follow (Figure 1.1):

1.4.1 Data preparation

The office work comprises the literature reviews (e.g., general geology, tectonic history, stratigraphy, fossil assemblage, paleoenvironment, and paleoecology, etc.) and planning involves all activities and time-duration of the study. Study on topographic and geologic maps to obtain the geologic setting and general structural geology of the study and adjacent area. This geological map has been carried out to serve as the basis for further planning of detailed field investigation. All data from previous work and geological data of the study area will be based on data for the next steps of work.

1.4.2 Field investigation

Detailed field investigation includes: 1) Compilation of geological map of the study area, 2) Measuring and making lithostratigraphic sections at study area. There section can be measured and collected samples from the bottom to the top of each rock

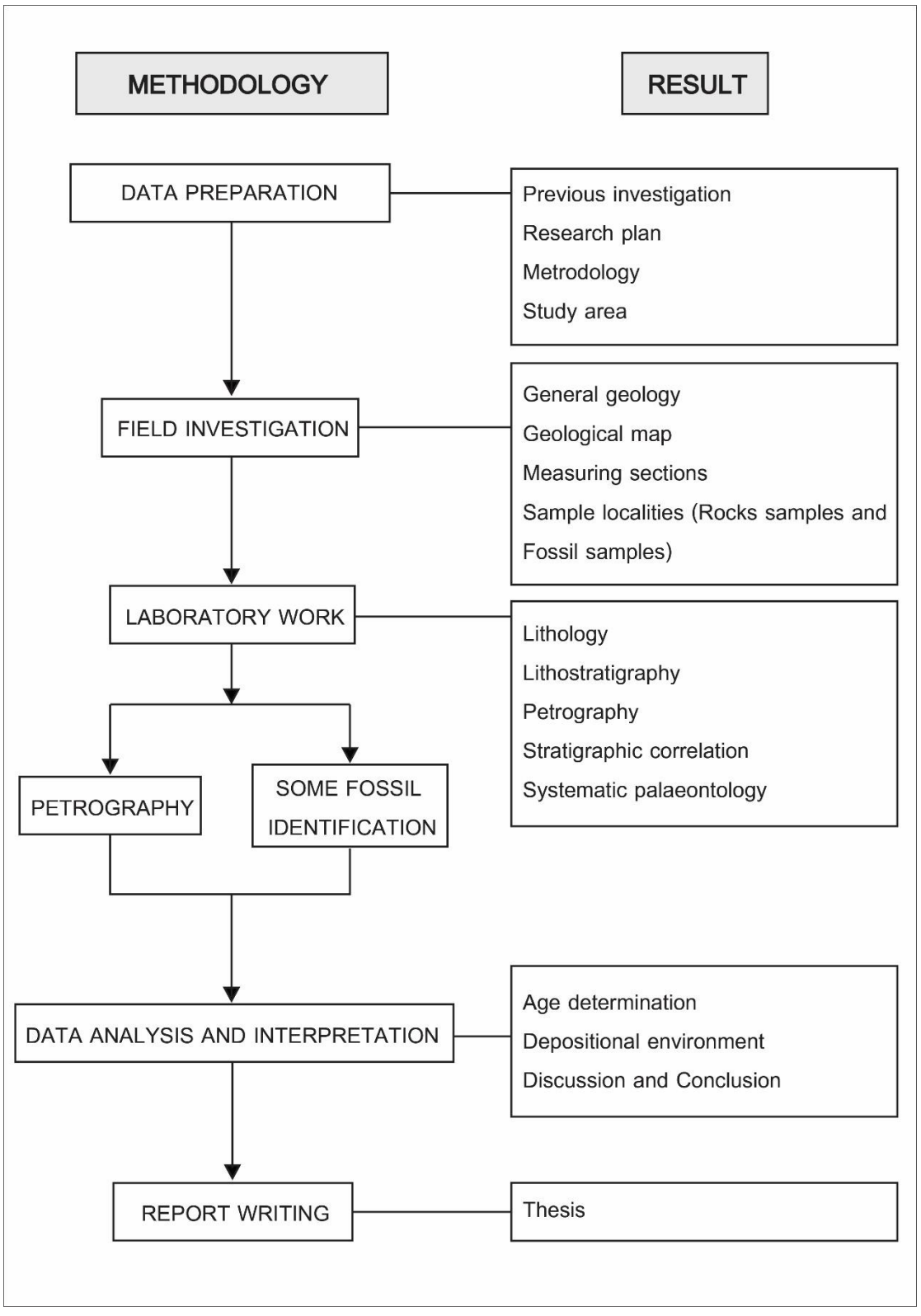

Figure 1.1 Flow chart of methodology of work in the study area.

unit and isolated locations. 3) Investigation of lithology, sedimentary structures, texture, thickness, fossil, and geometry for sedimentary analysis. 4) Sampling rock and fossil samples for laboratory study which carried out at every representative unit. However, some fossil sampling can be identified and determined the age of the rocks.

1.4.3 Laboratory work

Laboratory work focus on details of petrographic observations of rock sample were collected from sturdy area. Rock samples are prepared about 100 thin sections from 22 location then they are examined under microscope. Petrographic observation can be used to identification of composition, texture, cementation, microfossils, and sedimentary structure. For understanding to facies, characteristics of the rock unit and systematic paleontology of tentaculites. In addition, preparation of fossil list in each sample location for analyzing and interpretation.

Petrographic analysis is an arm of this study. The analysis includes classification under polarizing microscope. Terminology of morphological and classification is as followed in several previous works, including, carbonate classification of Wright (1992), sandstone classification and sorting of Pettijohn et al., (1987), visual percentages of Baccelle and Bosellini (1965), and tentaculate morphological classification of Fisher (1962); Larsson (1979); Wei et al., 2019; Wittmer & Miller, 2011).

1.4.4 Data analysis and Interpretation

All results were analyzed of sedimentary rocks and age determination. Their age determination of the Thong Pha Phum Group and other rock units are defined based on their contained fossils and able to correlate each section by their fossil contents. Interpretation of each tentaculate species, paleoenvironment and paleogeography of Thong Pha Phum Group.

1.4.5 Report Writing

Result of this study included the detail of lithology, lithostratigraphic, systematic paleontology, age determination, reconstruction of depositional environment and paleogeography. All data will be writing thesis and thesis presentation.

1.5 Previous investigations

Pitakpaivan et al., (1969) reported the Silurian fossils with *Tentaculites elegans* and *Styliolina clavula* in a pinkish fine sandy shale underlying Permian limestone from Si Sawat district, Kanchanaburi province.

Geological Survey of the Federal Republic of Germany, (1972) published a series of 1:1,000,000 scale geological maps of regions in the North and parts of Kanchanaburi Province, western Thailand. The rock units on this map consists of rocks from Precambrian to Cenozoic. The Silurian-Devonian rocks are composed of shale, grey wacke sandstone, and chert with occasional intercalations of limestone.

Koch (1973) presented the generally stratigraphic column of region Si Sawat - Thong Pha Phum-Sangkhlaburi of Kannchanaburi province. This area was mapped on a scale 1:250,000 by the German Geological Mission from 1968-1971. The stratigraphic sequence is composed of mainly marine sediment and meta-sedimentary rocks, approximately 3,000 meters thick, and is typically ranging in age from Cambrian to Jurassic, some locally covered by Cenozoic sediments.

Hagen and Kemper (1976) described the Ordovician to Permian rocks on the geology of the Thong Pha Phum area, Kanchanaburi province, western Thailand. The sequence 1,000-1,275 meters in thickness, are conformably underlain by Cambrian quartzite and phyllite and are overlain by Permian limestone of the Ratburi Group. The Ordovician rocks are characterized by a sandstone, sandy claystone, and limestone sequence. The age of this rocks was based on the presence of brachiopods, cystoids, trilobites, corals, and conodonts in the siltstone lenses and limestone. The Silurian-Devonian rocks in this area consist of sandy black shale, black shale, dark-gray calcareous siltstone and flaser limestone and the age was based on the fossils of tentaculites, graptolites and brachiopods. The Carboniferous rocks constrain red limestone shale and fossils of cephalopods, ostracods, conodont, and crinoids. In the upper past, the rocks are composed of Permian limestone. Strongly folded were observed. The lower contact of Permian limestone is underlain by olive-gray shale Carboniferous. Brachiopods, corals, fusulinids and foraminiferous were found.

Koch (1978) compiled the geological map of scale 1:250,000 of Thong Pha Phum map sheet, western Thailand.

Bunopas (1981) divided the Thong Pha Phum Group at Thong Pha Phum-Songklaburi area and the type section is exposed along the banks of Huai Thong Phu Phum, north of Thong Pha Phum district. This section was described in some detail by Hagen and Kemper (1976). This group can be divided into three or four formations. The total thickness of this group is approximately more than 1,000 m. Fossil contains in the strata indicate a late Upper Ordovician to Upper Carboniferous.

In 1982, Hahn and Siebenhüner identified the fossil assemblage that appears on the respective geological map of scale 1:250,000 of Thong Pha Phum map sheet. This area consists of various fossils such as trilobite (*Atractopyge* sp.), graptolite (*Climacograptus* vel *Raphidograptus* sp., *Monograptus* sp.), *Dacryoconarida* (*Nowakia holynensis* BOUCEK, *Nowakia sulcate* (ROEMER), *Styliolina* sp. and *Homoctenus hanusi* BOUCEK), brachiopods (*Chonetes* sp.), conodont (*Coelocerodontus variabilis* VAN WAMEL, *Ancyrodella* cf. curvata (BRANSON & MEHL), *Palmatolepis subrecta* MILLER & YOUNGQUIST, *Polygnathus foliates* BRYANT), and Cephalopoda (*Agathiceras* sp.) etc. Age determination for this fossil assemblage is Ordovician to Carboniferous age.

Burrett et al., (1986) studied a Silurian-Devonian carbonate sequence (Mae Ping Formation) at Tat Sador and Ko Luong waterfalls, Mae Ping National, Northern Thailand. Thickness of this formation is 220 m. The lower of this formation, approximately 50 m thick, is composed of thinly to medium-bedded limestone with nautiloids and conodonts. The upper part of this formation, is about 150 m thick, comprises thickly bedded to massive unfossiliferous limestone. This formation is conformably underlain by laminated mudstone with trilobites, tentaculitoids, and crinoids and overlain by weathered grey mudstone. In addition, they identified conodont fauna which refer a Silurian-Mid Devonian age for the Mae Ping Formation.

Sripongpun and Sinpool-anant, (1988) presented the geologic map of scale 1:50,000, Amphoe Si Sawat Quadrangle (4838 III) map sheet and reported Silurian-

Devonian-Carboniferous rocks with fossils of cephalopod as *Eothinoceras* sp. and crinoid stems.

Bunopas (1994) reported the regional stratigraphy, paleogeographic and tectonic events of Thailand and continental Southeast Asia. The Thong Pha Phum Group was presented in the northern and western parts of Thailand and peninsular Thailand which is located on the Shan-Thai Terranes.

According to Wongwanich et al. (1990), reported the Lower to Middle Paleozoic rocks in Satun Province, southern Thailand. The Thong Pha Phum Group is represented by a continuous succession of those deeper water siliciclastic and carbonate rocks in this area. At least three conformably lithostratigraphic units have been recognized in Satun province: The Wang Tong Formation, Kuan Tung Formation and Pa Samed Formation, in ascending order. Graptolites, tentaculites trilobites, brachiopods, ammonites, and conodonts are the main fossils of this group. In addition, Boucot et al., (1999) studied and identified the brachiopods from the Pa Samed Formation. This brachiopod fauna is represented the deep-water benthic assemblage that indicates Early Devonian (probable early Emsian).

Agematsu et al., (2006) reported a Lower Devonian (Emsian) tentaculite from the Satun province, southern peninsular Thailand. Tentaculite fauna (*Nowakia acuaria*) was found in the black shale of siliciclastic sequence. They are widely presented throughout Thailand (e.g., northern, western, and southern parts) and northwestern Malaysia.

Savage et al., (2006) studied the Late Devonian conodonts in Thong Pha Phum District, Kanchanaburi Province. Rock samples were collected from section is exposed in along the road 11 km north of Thong Pha Phum city. Thicknes of this section is about 7 m, and consists of thin- to medium-bedded limestone in the lower part, thick-bedded limestone in the upper part. Conodont *Palmatolepis ultima*, *Palmatolepis thanisi* sp., *Ancyrodella nodosa*, *Palmatolepis hassi*, *Polygnathus aspelundi, Polygnathus* aff. *webbi, Palmatolepis hassi, Ancyrodella nodosa, Polygnathus* aff. *decorosus, Polygnathus decorosus, Palmatolepis* aff. *prominens,* and *Polygnathus* sp. are abundant and indicate the late Devonian (Frasnian and Famennian) age.

Khaowwiset et al., (2010) presented the geological map on scale 1:50,000 of Khuean Srinagarindra Quadrangle (4837 IV) map sheet. General geology is composed of sedimentary and metasedimentary origins ranging in age from Cambrian rock to Quaternary. Major trend of bedding in the area lies approximately in the NW-SE direction with dipping to NE and SW.

In 2013, Meesook reported the lithostratigraphy and marine faunal assemblages of the Ordovician Thong Song Group in Ban Tha Kradan area, Si Sawat districts of Kanchanaburi province. The Ordovician sequence is approximately 66 m thick, consists of thick-bedded limestone, argillaceous limestone, stylolitic limestone, and limestone with stromatolitic structures. Nautiloids *Actinoceras* sp., *Armenoceras* sp., and *Ortlwceras* sp. was found that indicate the middle to late Ordovician in age. The Ordovician limestone can be correlated with those of Southern Thailand such as Satun Province.

Polwichai (2013) reported on Silurian-Devonian stratigraphy, lithostratigraphy and faunal assemblages of Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, Thailand. The sequences in this area are conformably underlain by the thin-bedded, argillaceous limestone of Ordovician age and overlain by the Carboniferous chert beds. The Silurian-Devonian rocks are composed of shale, sandstone, siltstone, mudstone with fossils of *Tentaculites* sp., *Nowakia* sp., and *Styliolina* sp.

1.6 General geology of study area

General geology of Ban Tha Kradan Area (study area), Si Sawat District, Kanchanaburi Province, western Thailand is composed of rock units of sedimentary and metasedimentary origins ranging in age from Cambrian to Quaternary. The mainly structural trend in the area lies approximately in the northwest-southeast direction with dipping to northeast and southwest (dip angle 20° - 70°). According to Meesook (2013) and field measurements, the general structure of the Ban Tha Kradan area consists of two complementary synclinal and anticlinal folds that trend NW-SE and following the tectonic pattern of the entire region. The general fold axis is approximately in the northwest-southeast direction with plunging to the northwest.

Geology of the areas has been described previously by various workers such as Koch (1973); Bunopas (1976); Hagen and Kemper (1976); Bunopas (1981); Khaowwiset et al., (2010) and Meesook (2013). Detail of general geology can be summarized as follows (Figure 1.2):

1.6.1 Cambrian rocks

The Cambrian rocks exposed in the Kanchanaburi area are represented by the Chao Nen quartzite (Bunopas, 1976, 1981). Type section is well exposed at Srinakarin (Chao Nen) Dam and Khao Tha Manao, Kanchanaburi province. In the type of area, the rock consists of well bedded whitish brown, whitish grey and greenish grey, fine-to medium-grained sandstone and quartzite, grade to interbedded shale and phyllite and rare limestone beds, approximately 500-600 m thick in the type section. Fossils of this unit are abundant containing nautiloids, stromatolites, brachiopods, gastropods, and trilobite *Opisthoparian* (Bunopas, 1976, 1981). In the study area, the Cambrian rocks consists of sandstone to meta-sandstone, and calcareous sandstone with rare fossils. This unit is exposed at the Ko Khao Mong Khai and a small hill south of the Ban Mong Krathae.

1.6.2 Ordovician rocks

The Ordovician rocks exposed in the Kanchanaburi province are represented by the Tha Manao limestone (Bunopas, 1981). Its type locality is located along a ridge of low to moderate relief, Khao Tha Manao east of Tha Manao village on the road to Chao Nen Dam, Kanchanaburi province. The formation is approximately 800-1,000 m thick, consists of grey to dark grey limestone, argillaceous limestone showing flaser beds, stromatolitic limestone and flaser-bedded limestone, light or reddish grey, weathering to red and green, soft clayey and sandy. Fossils of this formation are composed of nautiloids *Actinoceras* sp., *Armenoceras* sp., and *Ortlwceras* sp., stromatolite, conodonts, ostracods, bivalve, gastropods, and brachiopods. The Tha Manao limestone has some similarities with the Thung Song Group (Bunopas, 1981 and Wongwanich et al., 2002).

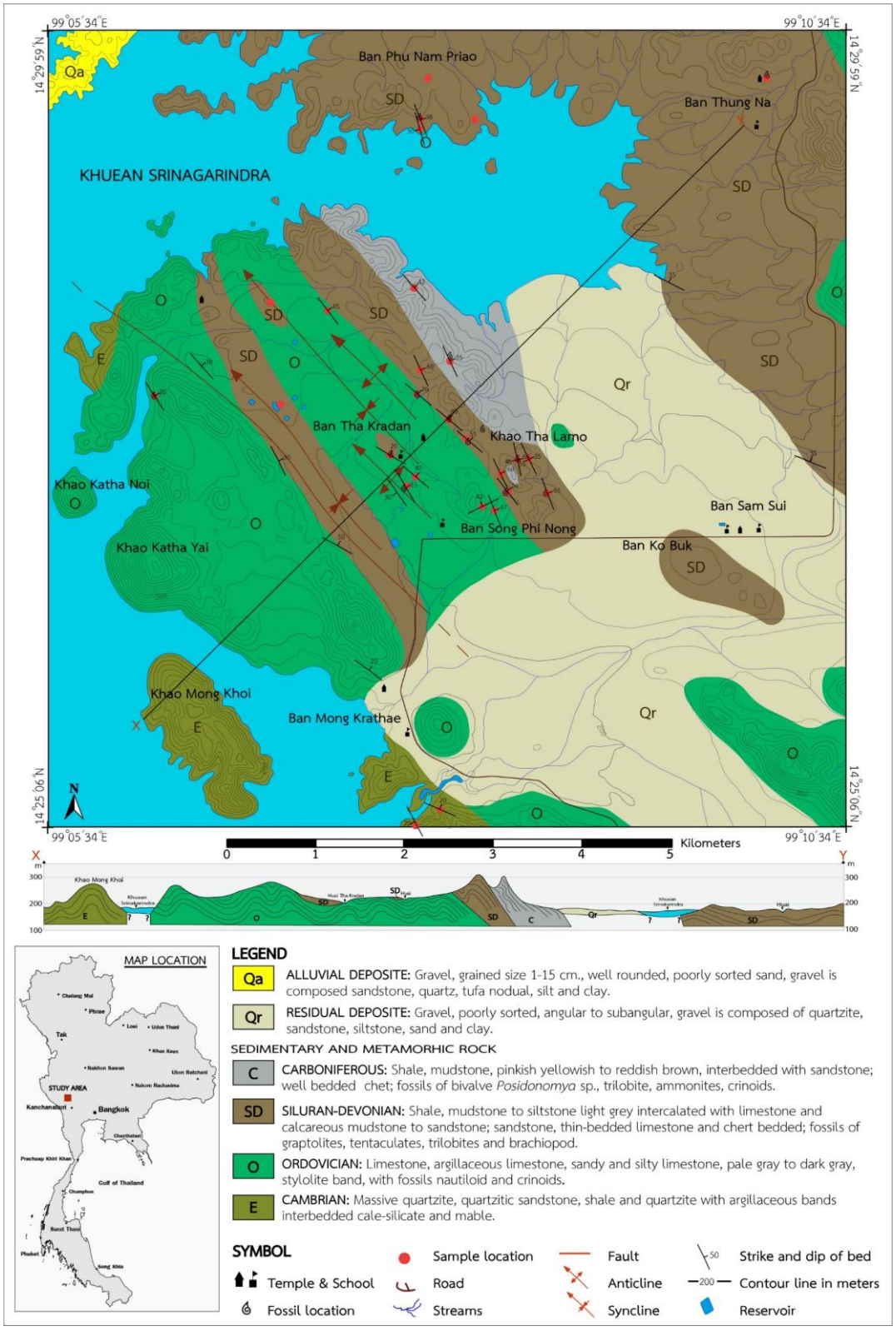

Figure 1.2 Geologic map of the study area at Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand (modified after Khaowwiset et al., 2010 and Meesook, 2013).

In Ban Tha Kradan area, the Ordovician rocks were distributed in Khao Katha Yai, Khao Kratha Noi, Ban Mong Krathae, and Ban Tha Kradan. Generally, the group is characterized by laminated limestone, stylolitic limestone, greenish grey, well bedded, thin- to thick-bedded, stylolite band with fossils of nautiloids *Armenoceras* sp., *Actinoceras* sp. and *Orthoceras* sp. (Meesook, 2013).

1.6.3 Silurian-Devonian rocks

The Silurian-Devonian rocks in the Kanchanaburi Province, western Thailand, have been first proposed into the Bo Phloi Formation (Bunopas & Bunjitradulya, 1975) and later designed under the Thong Pha Phum Group (Bunopas, 1981). The Bo Phloi Formation was shown as a map unit in the geologic map on 1:250,000 scale, sheet Suphanburi (ND 47-7) which was published by the Department of Mineral Resources (1976). The type of location was located at the Khao Yai and Khao Ka, 10 km southeast of Bo Phloi District. The sequence of this formation is about 350 m thick, but it is incomplete and discontinuous exposures.

This rock units consist of quartzite, phyllite, tuffaceous sandstone, shale, chert beds, sandstone, limestone beds, with fossils of tentaculites. The type sections of well expose along the banks of Huai Thong Pha Phum (Huai U-Long) north of Thong Pha Phum District, more than 1,075 m thick. It overlies conformably the Ordovician rock and underlies the Carboniferous rocks, respectively. The group is composed of sandy marl, black shale, calcareous siltstone, thinly limestone, nodular limestone, grey shale with fossils. Fossils of this unit are commonly abundant containing graptolite *Monograptus* sp., tentaculites *Tentaculite* sp., *Nowakia* sp., and *Styliolina* sp., conodonts, nautiloids, trilobite *Proetus* sp. and brachiopods. Based on this fossil assemblage, this group is assigned as the late Ordovician to Carboniferous age (Bunopas, 1981; Hagen & Kemper, 1976). Recently, the Silurian-Devonian sequence is also well exposed in various areas in Kanchanaburi city i.e., Ban Tha Kradan area (study area), Si Sawad District into the eastern of Thong Pha Phum District (Khaowwiset et al., 2010; Meesook, 2013; Polwichai, 2013).

1.6.4 Carboniferous rocks

The carboniferous rocks in the study area are known as the Khuan Klang Formation (Khaowwiset et al., 2010; Meesook, 2013). The formation was named after Khuan Klang, Mueang Satun District, Satun Province where type section is located. Exposed lithology is characterized by shale, reddish brown and gray with bivalves, brachiopods, and fragment of trilobite, interbedded sandstone, siltstone, and chert beds, approximately 120 m thick (Department of Mineral Resources, 2013). This formation contains abundant fossils: bivalves *Posidonomya* sp., brachiopods, trilobites, radiolarians, and crinoids. Based on the fossil assemblage, the Kuan Klang Formation in this area is assigned as the early Carbonifereous (Tournaisian-Visean) age (Tansuwan et al., 1982; DMR, 2007; Ueno and Charoentitirat, 2011; Meesook, 2013). In study area, this formation is conformably overlain by the Silurian-Devonian rocks and covered by Quaternary sediments (Figure 1.2). It is distributed in the small hill northern and northeastern of Ban Tha Kradan area and consists mainly of whitish to reddish brown, red to yellowish brown, micaceous mudstones, sandstones, and well-bedded, yellowish brown chert beds with fossils in some shale and chert beds are comprise of bivalves (*Posidonomya* sp.) brachiopods, trilobites, and radiolarians.

1.6.5 Quaternary sediments

The Quaternary sedimentary deposits are distributed mainly as flat plain and undulating terrains in the study area that corresponding to the weathering of parent rocks under the river processes. The sequences are characterized by loose sediments i.e., clay, silt, sand, and gravel. The study area can be mainly divided into two units as residual deposits (Qr) and alluvial deposits (Qa). Residual deposits are occurred in mainly the undulating terrains in the southeast part of the area. It is products by the rock weathering and consisting of gravel of quartzite, sandstone, siltstone, granite, sand, and clay. The gravel size ranges from pebble to boulders (2 - 10 cm), poorly sorted and angular to subangular. Alluvial deposits, are covered the flat plain near the dam area in the northwestern of study area. It comprises quartz, quartzite, sandstone, siltstone, granite, well rounded and poorly sorted, gravels ranging in size from 0.1-5 cm.

1.7 Criteria used for classification of tentaculites

Tentaculites are small conch and marine invertebrate group, being recorded from Ordovician to Devonian. The conch shell is composed of calcium carbonate. The shell ranges from less than 1 mm to 80 mm in length and approximate 6.5 mm in maximum diameter (Fisher, 1962). Tentaculites have a worldwide distribution (e.g., European, North American, South American, Australia, South China, and Southeast Asia) and they range from the Silurian into Devonian age (Wittmer and Miller, 2011). In Thailand, tentaculite beds were reported mainly from the sedimentary rock of the Thong Pha Phum Group or Silurian-Devonian rocks. It is exposed in Sibumasu Terrance (N-S trending) (Agematsu et al., 2006; Bunopas (1992), and Wongwanich et al., 1990).

The classification of tentaculites is identified generally on morphological criteria such as conch shell, transversal rings, an external mold, maximum length, maximum diameter, conch wall thickness, and initial chamber shape (Fisher (1962); Larsson, (1979); Wei et al., 2012, 2019; Wittmer and Miller, (2011)). The terminology of morphology and classification of the tentaculite is used based on Fisher (1962); Larsson, (1979); Wei et al., (2012); Wei, (2019) and Wittmer & Miller (2011). Four genera (Tentaculite, Nowakia, Homoctenus and Styliolina) have established which differences in the shape of a conch (Figure 1.3) (Larsson, 1979 and Wei, 2019). This study identified using photograph from microscopy studies and it is showing longitudinal and transverse sections with to define the distinguishing characteristics of the fossils. The codes used for tentaculate morphological features is as followed in follows Larsson (1979) and Wei (2019), as shown in Table 1.1.

Table 1.1 The codes used in the tables accompanying the description of the morphological features of a tentaculites (Larsson, 1979 and Wei, 2019)

Code name	Description
DEEC	Distance between ends of conch
DDPE	Distance of deflection of the proximal end from a sagittal plane through the living chamber
ODID	Outer distal diameter
OPRD	Outer proximal diameter
WIC	Width of initial chamber
LIC	Length of initial chamber
CWT	Conch wall thickness
PA	Proximal growth angle
ATR	Amount of transverse ring per mm.
DTR	Distal between of transverse ring (interspace)

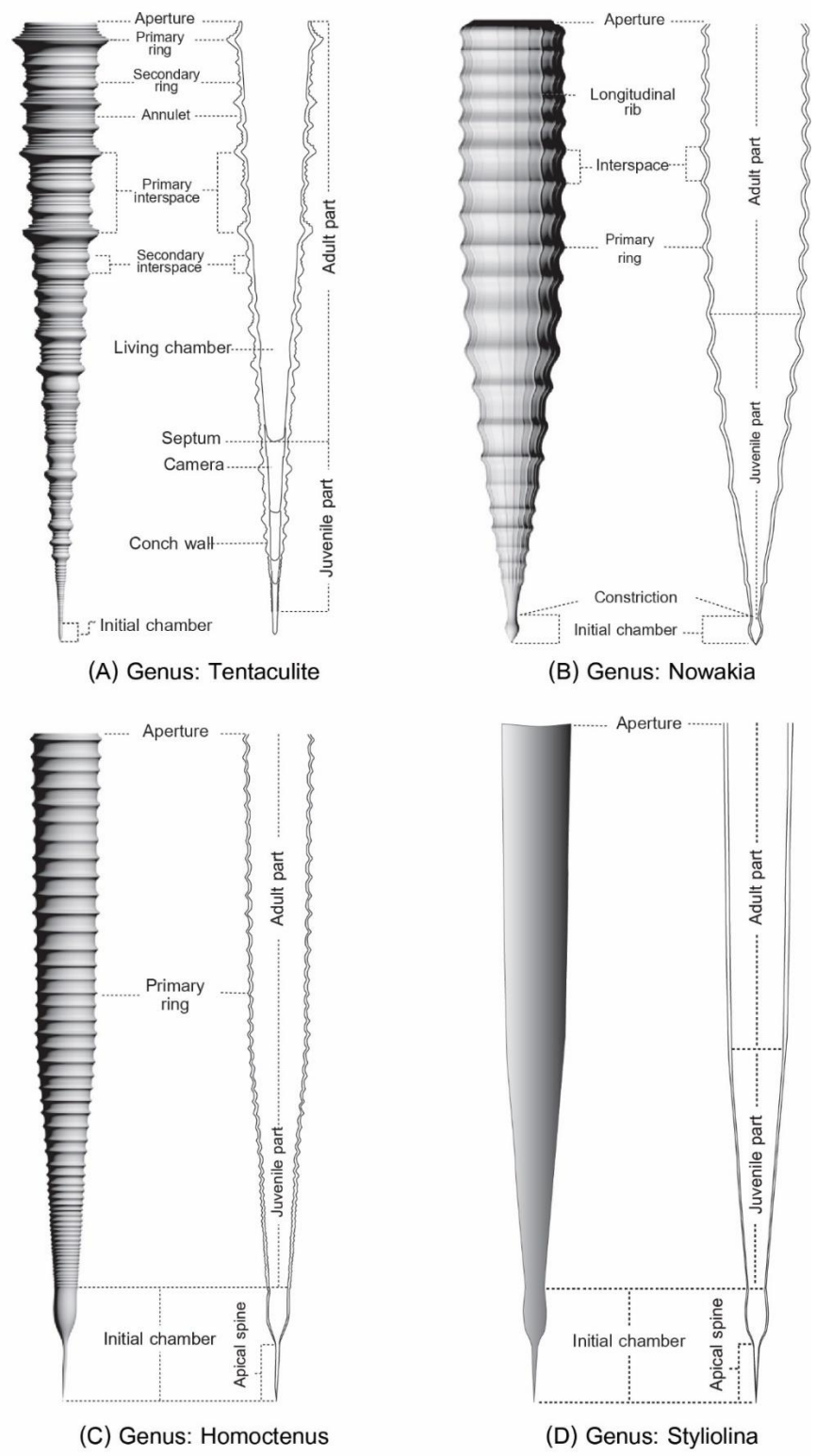

Figure 1.3 Reconstructions of Tentaculite conchs in longitudinal section (4 genera; (A): Tentaculite, (B): Nowakia, (C): Homoctenus and (D): Styliolina) which is characteristics identified. Modified after Fisher (1962); Larsson (1979); Wei et al., (2012); Wei, (2019) and Wittmer and Miller (2011).

CHAPTER 2

RESULTS ON LITHOLOGY AND STRATIGRAPHY

2.1 Results on lithology and stratigraphy

The study area is located in the west of Thailand in Ban Tha Kradan, Si Sawat District, Kanchanaburi province between latitude 14° 25' 06" N to 14° 29' 59" N and longitude 99° 05' 34" E to 99° 10' 34" E. The rocks outcrops are situated within small hills and undulating terrains in the north, northwest central of study area and are well exposed as road cut outcrops and quarries. Lithology of the Ban Tha Kradan area is composed of many rock types: sandstone to meta-sandstone, shale, micritic limestone, argillaceous limestone, calcareous shale, shale to mudstone, with abundant fossils such as tentaculites, graptolites, brachiopods, bivalve, ostracods and nautiloids. During the field investigation, about 95 rock samples (isolate samples and samples in measured sections) and 3 measured sections (sections KCB 09, KCB 12 & KCB 20) have been collected from 22 locality around the Ban Tha Kradan area (Figure 2.1) in order to determine the age and reconstruct the paleoenvironment. Detailed lithology of isolate localities, measured sections and fossil contains in the study area, as follows:

KCB 02: The KCB 02 outcrop is exposed along the road-cut to Sky Lak View 1 Resort at Ban Mong Krathae area that was mapped as the Chao Nen quartzite (Cambrian rocks). The rocks are composed of sandstone to meta-sandstone, pale brown to white, medium- to coarse-grained, rounded to well rounded, well sorted, medium- to thick- bedded, continuous, even, parallel-bed, showing slightly fold and intercalated with siltstone (Figure 2.2). The general attitude of folds is anticline and syncline which fold axis approximately NW-SE direction with dip. Dipping of the western side of the fold is about 20-40° SW and that of the eastern part about 12-30° SW. No fossil is observed.

KCB 03: This outcrop is exposed at slope hill locate in southern part of the study area that also indicated the Cambrian rocks in study area. It consists of calcareous sandstone, pale brown to reddish brown, very fine- to fine-grained, thin- to very thick- bed,

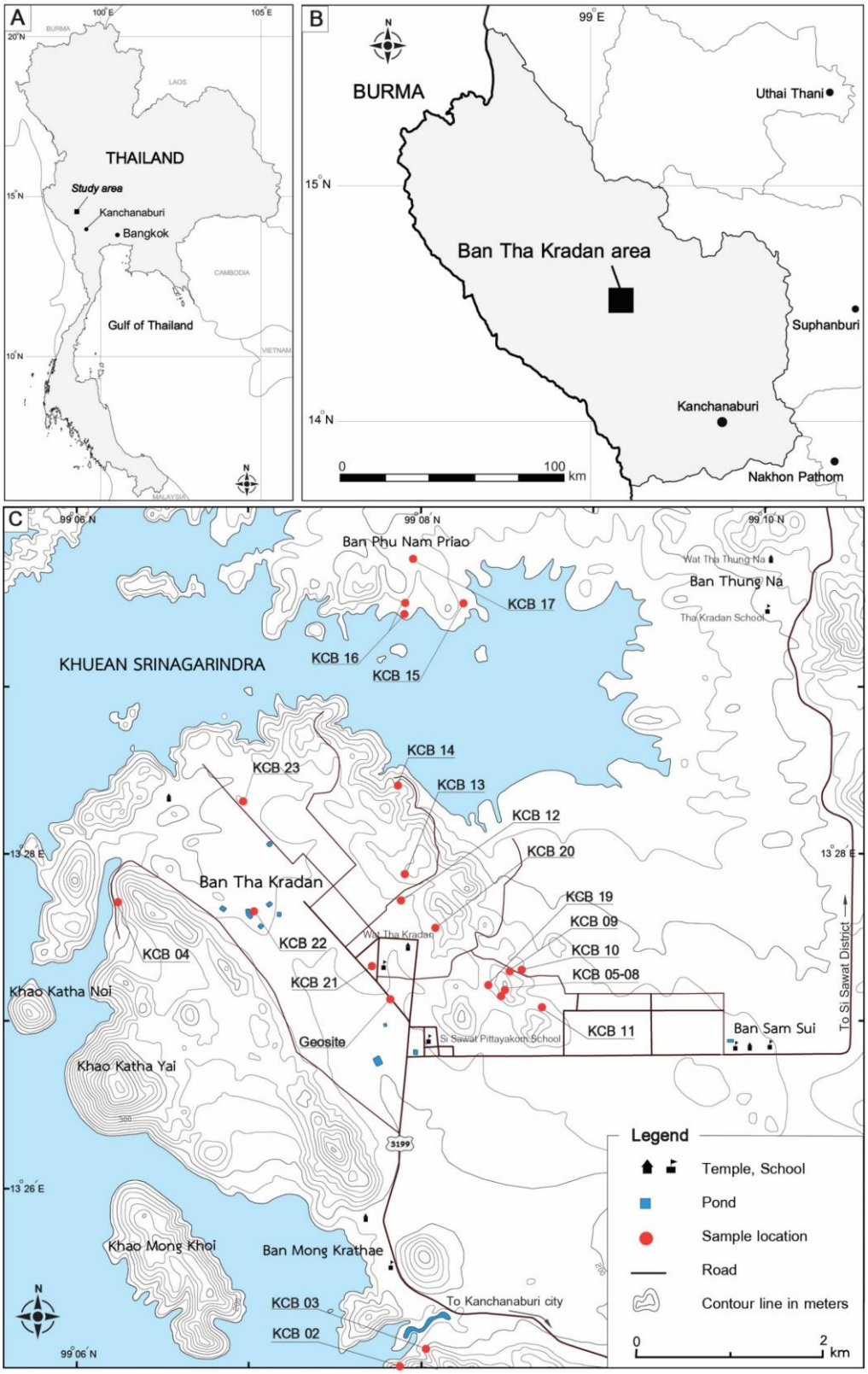

Figure 2.1 (A): Index map showing location of study area in western part of Thailand. (B): Location map shows location of the Ban Tha Kradan section, Si Sawat District, Kanchanaburi Province. (C): Route map showing locations of collected samples around study area.

lamination with calcite vein (Figure 2.3). General strata are approximately NW-SE trending with low angle (15°) to the east. Petrographically, calcareous sandstone (sample no. KCB 03A) consists of dominantly quartz, sparse mica (3%) and rock fragment (5%), subangular-subrounded, well sorted with carbonate cement (Figure 2.3 (C)-(D)).

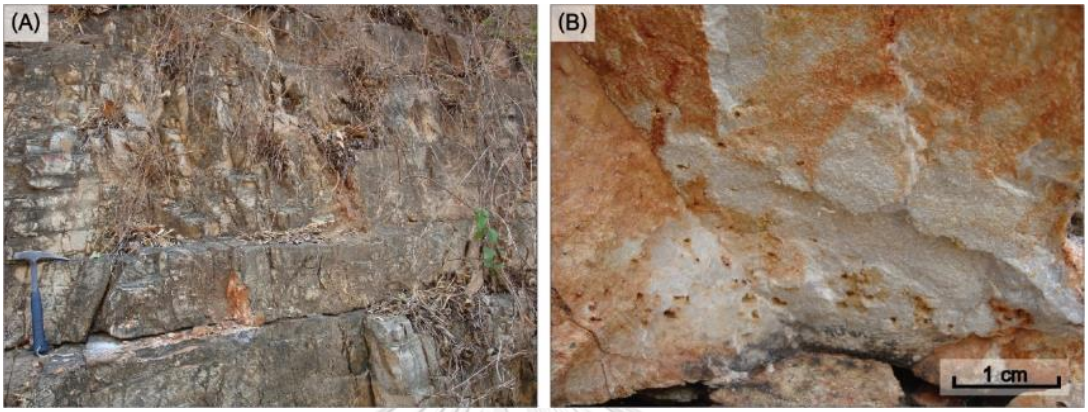

Figure 2.2 Exposure of KCB 02 location. (A): Sandstone to meta-sandstone of the Cambrian rock along the road-cut outcrop of Ban Mong Krathae, (B): Close-up of sandstone of (A).

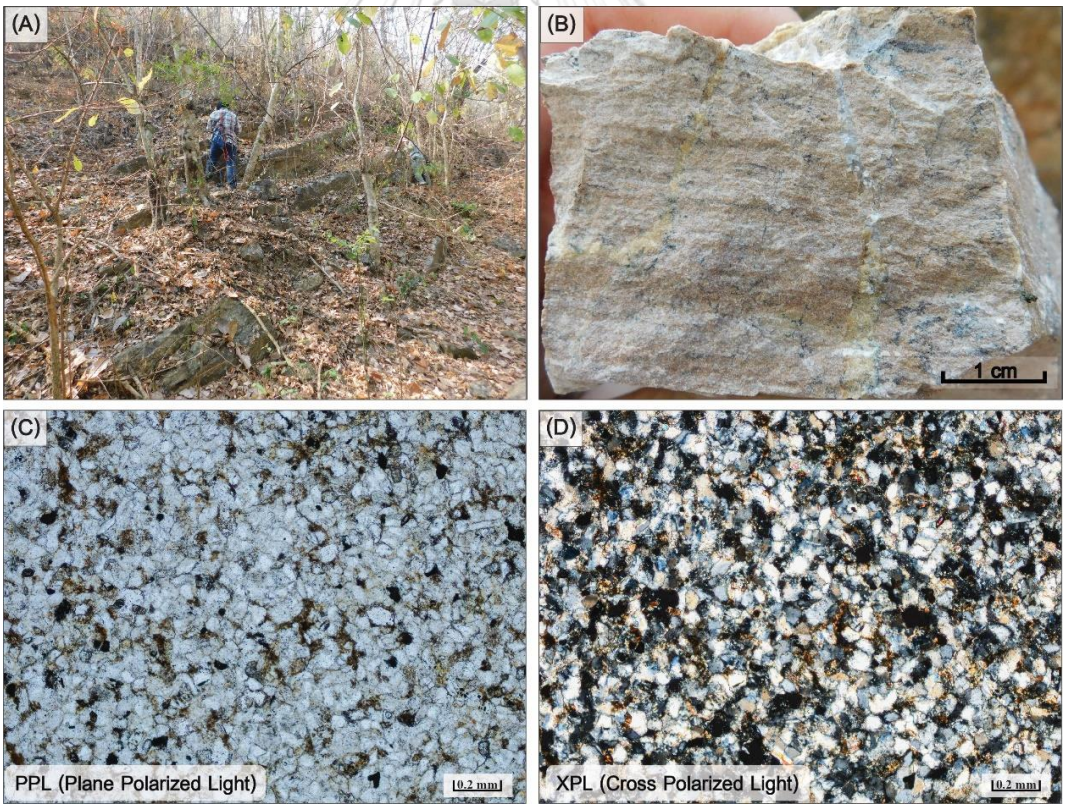

Figure 2.3 Photographs of KCB 03 location. (A): Outcrop of thin- to thick-bedded calcareous sandstone, (B): Close-up photographs of calcareous sandstone, (C) and (D): Photomicrographs of sample no. KCB 03A showing dominantly quartz, sparse mica and rock fragment with carbonate cement.

Geosite: This area is situated at Ban Tha Kradan area which Meesook (2013) studied in detail and proposed of Ordovician sequence and fauna assemblages in this area (Figure 2.1). This sequence is well exposed as an undulating quarry, approximately 66 m thick, can be divide into about 2 portions: the lower part consists mainly of laminated and cross-bedding to thin- to medium-bedded limestone with oriented and rolling nautiloids; the upper portion comprise thin- to medium-bedded, laminated limestone and stylolitic limestone with nautiloids; the uppermost part is dominant by stromatolite beds of limestone, stylolitic band with abundant nautiloids: *Armenoceras* sp., *Actinoceras* sp., and *Orthoceras* sp. (Figure 2.4 - 2.5). Based on these fossil assemblages, unit in study area indicate middle to late Ordovician age.

KCB 04: Its outcrop is Ordovician sequence at along the road cut outcrop west of study area, consist of thin- to thick-bedded, medium grey to pale grey, limestone and stylolitic limestone with of nautiloids and crinoids, approximately 3 m thick (Figure 2.6). Nautiloids are found in some limestone bed and indicate the age in Ordovician age.

KCB 05: This outcrop is exposed at a small hill in southeast of the Ban Tha Kradan area, is composed of stylolitic limestone, greenish grey to light grey, well bedded, stylolitic band with nautiloids and crinoids (Figure 2.7). Fossils of nautiloids indicate late Ordovician age. These rocks dipping succession underlie by the Silurian-Devonian rocks.

Figure 2.4 The nautiloid outcrop of Ordovician rocks. It is known as the geosite of Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand.

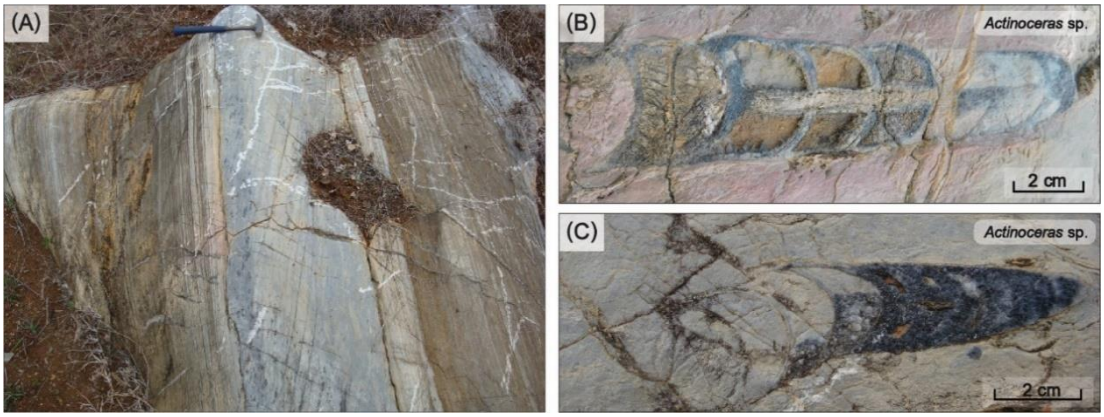

Figure 2.5 Ordovician rocks at the geosite in the Ban Tha Kradan area. (A): Laminated and cross-bedding to thin- to medium-bedded limestone, (B) and (C): Fossils of nautiloids.

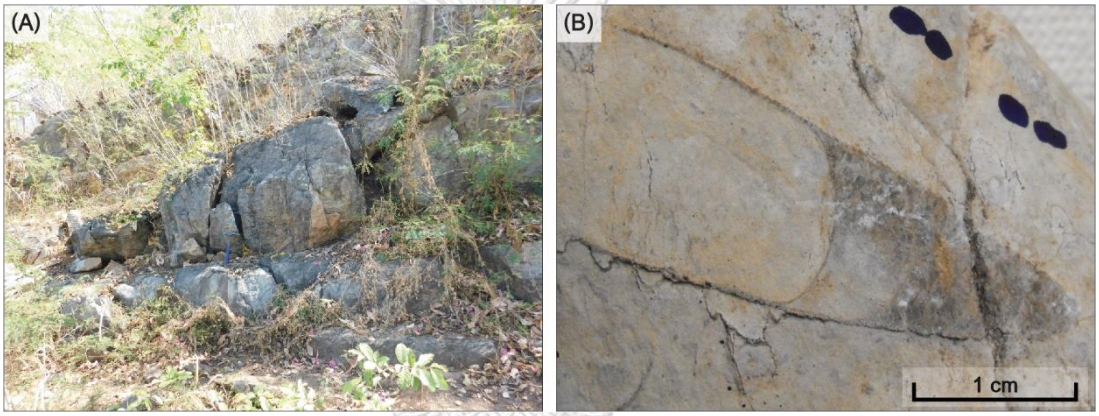

Figure 2.6 Ordovician sequence of KCB 04, approximately 3 m thick, exposed at the along the road-cut outcrop western of Ban Tha Kradan area. (A): Thin- to thick-bedded, limestone and stylolitic limestone, (B): Close up of nautiloids are found in limestone.

Figure 2.7 Ordovician rocks exposed at small hill eastern of Ban Tha Kradan area (KCB 05). (A): Thin- to medium-bedded, stylolitic limestone. General strata are approximately NW-SE trending with medium angle (50°) to the east, (B): Nautiloids are found in this area.

KCB 06-KCB 08: This area is located at small quarry in the east of the Ban Tha Kradan area and is composed of KCB 05 to KCB 08 (Figure 2.1). The lithology is mainly micritric limestone, calcareous shale, mudstone, bedded chert, very thin- to thin-bedded (2-5 cm) with abundant in fossils such as tentaculites, nautiloids, brachiopods, ostracods, and radiolarians (Figure 2.8). Structure geology of this area is very complicated (many faults and folds). The trend of bedding is NW-SE direction and high dip angle (55° - 60°). In micritic limestone, sample KCB 08 containing tentaculites specimens of *Nowakia* (Cepanowakia) *pumilio*, *Styliolina clavulus*. These tentaculites are also commonly found in the micritic limestone (bioclastic mudstone, Figure 2.9) in other areas of study area such as in the KCB09-3, KCB 10, and KCB19-A(1) that indicates the Eifelian to Frasnian (middle to late Devonian) age.

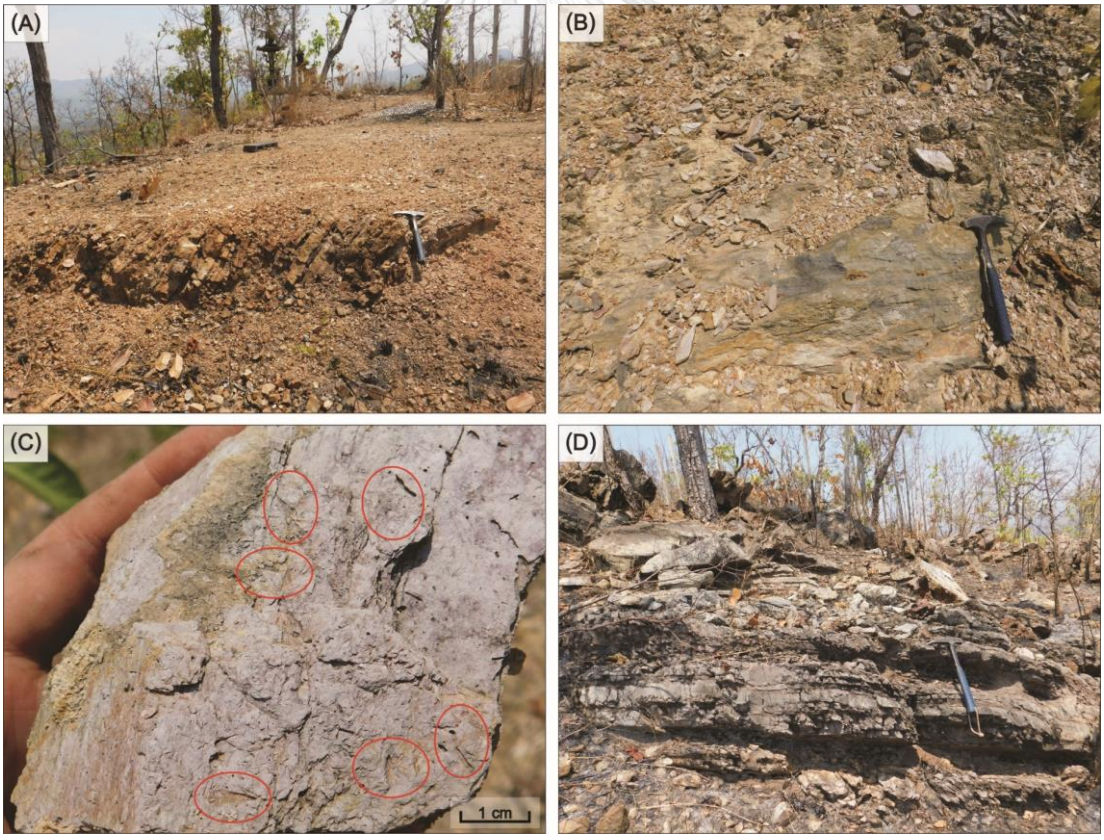

Figure 2.8 Lithologies of KCB 06-KCB 08 of the Thong Pha Phum Group. (A): Outcrop of thin-bed, chert well exposed at top hill (KCB 06), (B): Calcareous cement, laminar to thin-bedded, graded bed, shale to mudstone interbedded with argillaceous limestone (KCB 07), (C): Closed-up of shale containing tentaculites (red circles) in the KCB 07, (D): Thin- to medium-bedded micritic limestone with stylolitic bands (KCB 08).

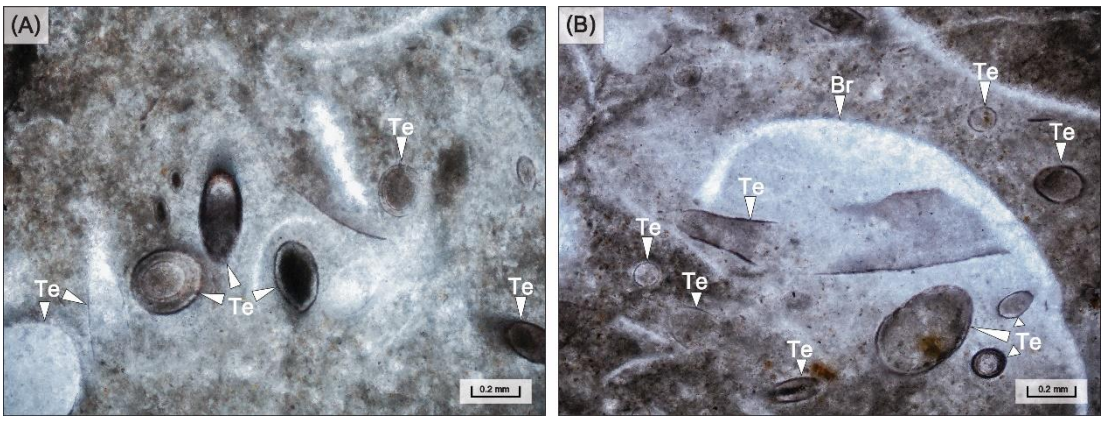

Figure 2.9 Photomicrographs of micritic limestone of sample no KCB 08. Outcrop is illustrated in Figure 2.8 (D). (A) and (B): Bioclast wackestone with fossils of tentaculate (Te) and brachiopods (Br). Plane polarized light and scale bar is 0.2 mm.

KCB 10: This area is located at pond in the northeastern of the Ban Tha Kradan area. It consists of pale grey, thin- to medium-bedded, micritic limestone interbedded with argillite layer and including of nautiloids and tentaculites. The rock of this area is folded (anticline and syncline) which plunging in the NW direction (Figure 2.10). Petrographically, the selected sample no. KCB 10 is micritic limestone. On the basis of limestone classification of Wright (1992), the this sample is bioclastic wackestone. It is shows mainly matrix-supported texture (less than 10 % grains) with consists of carbonate mud matrix and cemented by calcite. The bioclast grains containing tentaculites, few ostracods, and brachiopods (shell fragment). Tentaculites are commonly in bioclastic wackestone (sample no. KCB 10, Figure 2.11 - Figure 2.12) containing *Nowakia* (Cepanowakia) *pumilio*, *Styliolina clavulus*. Base on tentaculites, the age indicated Eifelian to Frasnian (middle to late Devonian) age.

KCB 11: This area is located at small quarry in the east of study area. It consists of grey, thin- to medium-bedded, micritic limestone with argillite bed and lamination, high weathered, calcareous mudstone with many tentaculites (Figure 2.13). General attitude of beds is approximately in the NE-SW direction with high angle (40°) to the NW. Tentaculite specimens are abundant in this area (sample no. KCB 11B) containing *Nowakia acuaria*, *Styliolina fissurella* (Figure 2.14), *Styliolina clavulus* that indicates the middle to late Devonian (Eifelian to Frasnian) age.

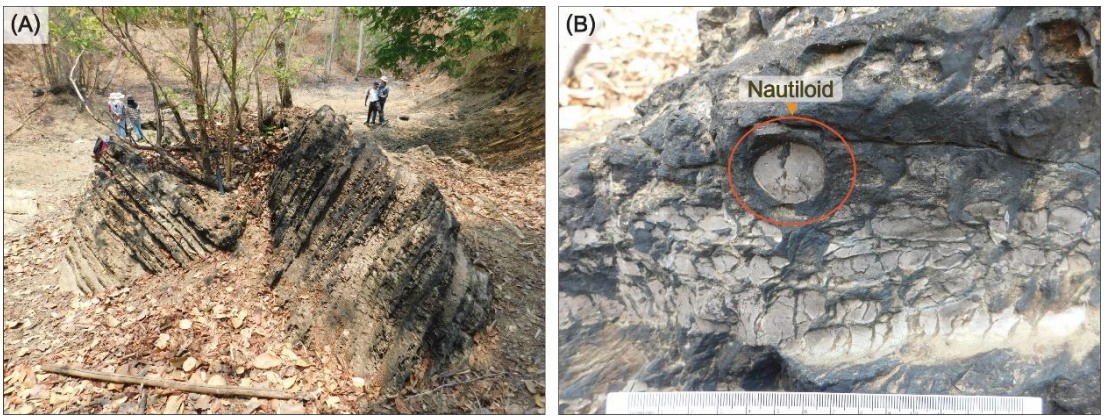

Figure 2.10 Outcrop of pale grey to grey, thin- to medium-bedded, micritic limestone with argillite layer (KCB10 area). (A): Syncline folds plunging in the NW direction, (B): Nautiloids (red circle) are found in this area.

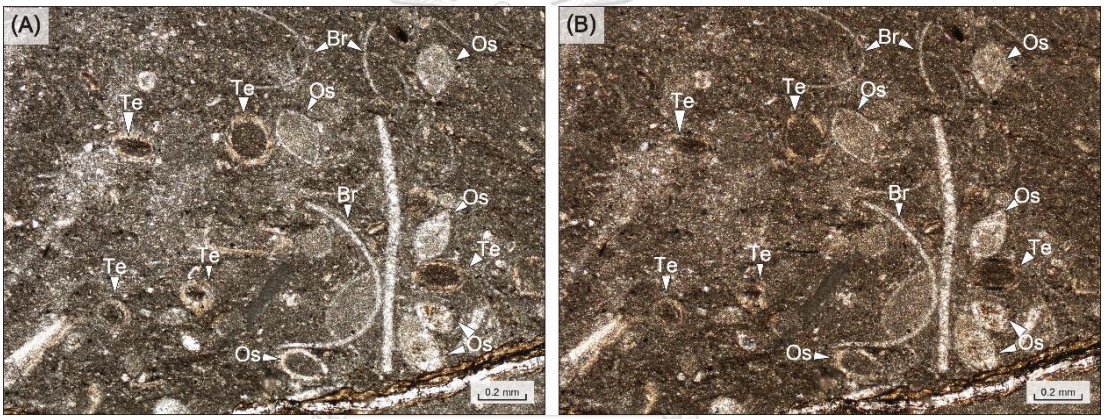

Figure 2.11 Photomicrographs of bioclast wackestone (sample no. KCB 10) showing matrix-supported, containing abundant tentaculites (Te), ostracods (Os) and brachiopods (Br). Scale bar is 0.2 mm. (A): Plane polarized light, (B): Cross polarized light.

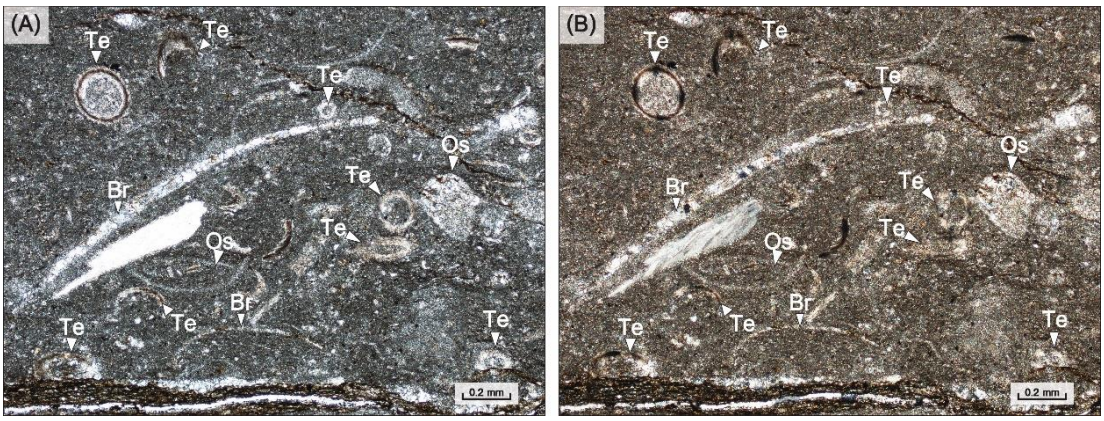

Figure 2.12 Bioclastic wackestone (sample no. KCB 10) showing bioclasts of brachiopods (Br), tentaculites (Te), and few ostracods (Os). (A): Plane polarized light, (B): Cross polarized light. Scale bar is 0.2 mm.

Figure 2.13 Quarry outcrop of KCB11 location (looking SW). (A): Micritic limestone and calcareous mudstone intercalated with argillite bed, (B): Thin- to medium- bedded, micritic limestone with argillite bed and high weathering, mudstone containing abundant tentaculites.

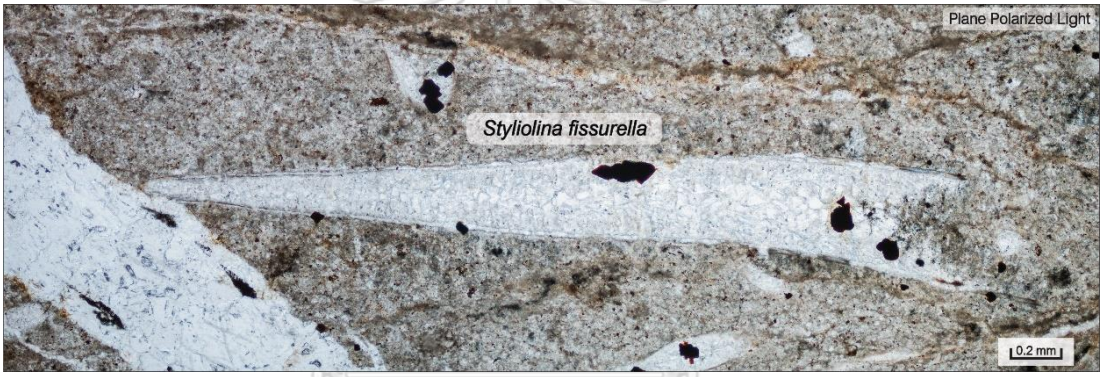

Figure 2.14 *Styliolina fissurella* showing longitudinal section (sample no. KCB 11B).

KCB 13: This area is located at along the road cut in the northern of the Ban Tha Kradan area. This sequence consists mainly of whitish to reddish brown, yellowish brown, micaceous mudstones, siltstone and sandstones. Fossils in some shale beds are comprise of bivalves (*Posidonomya* sp.), brachiopods, trilobites, and crinoids (Figure 2.15). Age of bivalve *Posidonomya* sp. indicated to Carboniferous age (Meesook, 2013).

KCB 14: The outcrop is exposed at quarry approximately 1 km from KCB 13. The rocks consist of well-bedded, yellowish brown to pale grey, high weather, chert beds intercalated with shale layer (Figure 2.16). This outcrop is probably Carboniferous in age (Meesook, 2013).

KCB 15: This area is situated at a natural outcrop in the south of Ban Phu Nam Pria, near Srinagarindra dam. It is characterized by high weathered, gray and dark gray,

lamination, develop cleavage, slaty shale with quartz veins. The fossils are not found. Their lithology can correlate to the shale of the Thong Pha Phum Group.

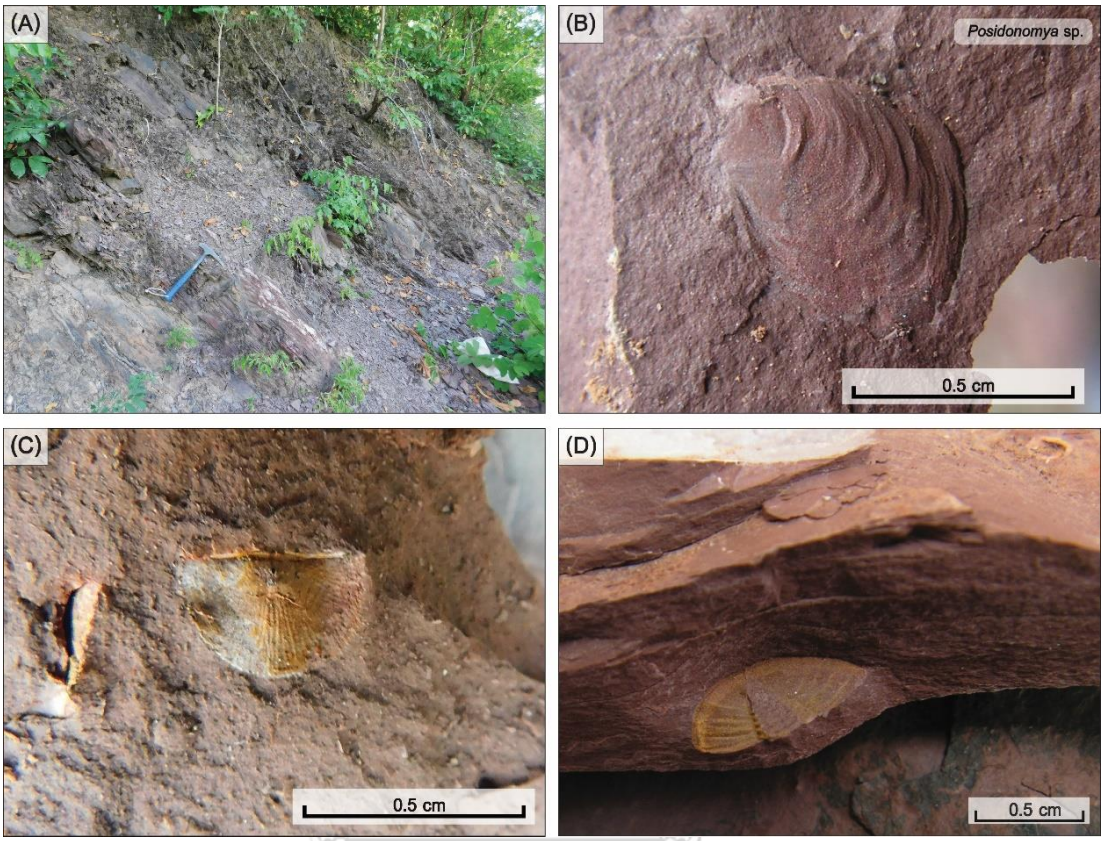

Figure 2.15 Outcrop of the Carboniferous rocks exposed along the road-cut northern part of study area (KCB 13). (A): Reddish brown to reddish purple mudstone intercalated with sandstone. (B): Bivalves (*Posidonomya* sp.). (C): Brachiopods. (D): Pygidium of trilobite.

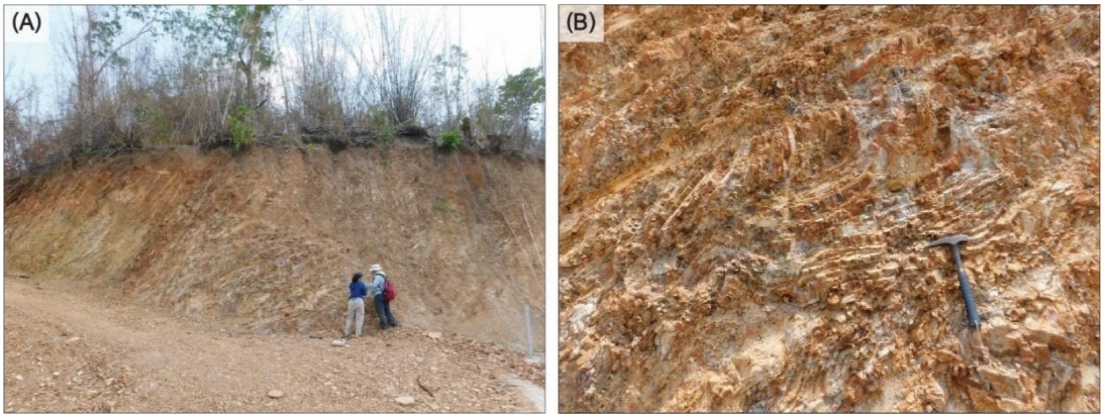

Figure 2.16 Outcrop of the Carboniferous rock exposed along the road-cut northern part of Ban Tha Kradan area. (A): Outcrop of pale grey to greyish brown, very thin- to thin-bedded, chert intercalated with shale. (B): Close-up of chert beds.

KCB 16: In this area, it is located at quarry in southern past of Ban Phu Nam Priao. The lithology in this area, the lower is composed of pale grey, thin- to medium-bedded, recrystallized, limestone and stylolite layer with fossils of nautiloids, ostracods, and crinoids (Figure 2.17 (A)-(B)). The upper part consists mainly of the mudstone to siltstone, light grey and dark gray, lamination interbedded with very fine- to fine-grained, laminated to thin-bedded with fossils of graptolites (*Monograptus* sp.) and trace fossils (Figure 2.17(C)-(D)). Age of graptolites possibly referable to Silurian? to early Devonian.

KCB 17: In this area, it is located at small quarry in southern past of Ban Phu Nam Priao. It is composed of high weathered, yellowish brown to gray, laminated shale to mudstone and very thin- to thin-section, chert that they did not found fossils. It may be equivalent to the upper part of the Thong Pha Phum Group.

Figure 2.17 Ordovician - Silurian? rocks exposed in the Ban Phu Nam Priao area (KCB 16). (A): Thin- to medium-bedded, recrystallized, limestone and stylolite layer, (B): Closed-up of limestone with stylolite band, (C): Laminated, dark gray, thin-bedded, shale with graptolite, (D): Closed-up of graptolite (sample no. KCB 16-4, *Monograptus* sp. (white arrow) in the dark gray shale.

KCB 19: In this area, it is located at quarry in southern past of small mountain. It is characterized by argillaceous limestone with argillaceous band and stylolite band, calcareous mudstone in the lower part. In the upper part, it consists of yellowish brown, thick-bedded mudstone, and greenish grey to brown, well-bedded, very thin- to thin-bedded chert (Figure 2.18). Abundant tentaculites, rare nautiloids, crinoids and radiolarians in chert. The attitude of bedding is approximately in the NW-SE direction with moderately-dipping angle (30°) to the NE. Pethography of sample no. KCB 19-A(1). It is bioclastic wackestone that mainly matrix-supported texture (less than 10 % grains) with consists of carbonate mud matrix and calcite cement. The bioclast grains containing abundant tentaculites and common brachiopods (Figure 2.19). Tentaculites *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, *Styliolina clavulus* indicating middle Devonian. Chert (sample no. KCB19-1& KCB 19-3) with mainly very fine- to fine-grained quartz containing abundant radiolarians (Figure 2.20).

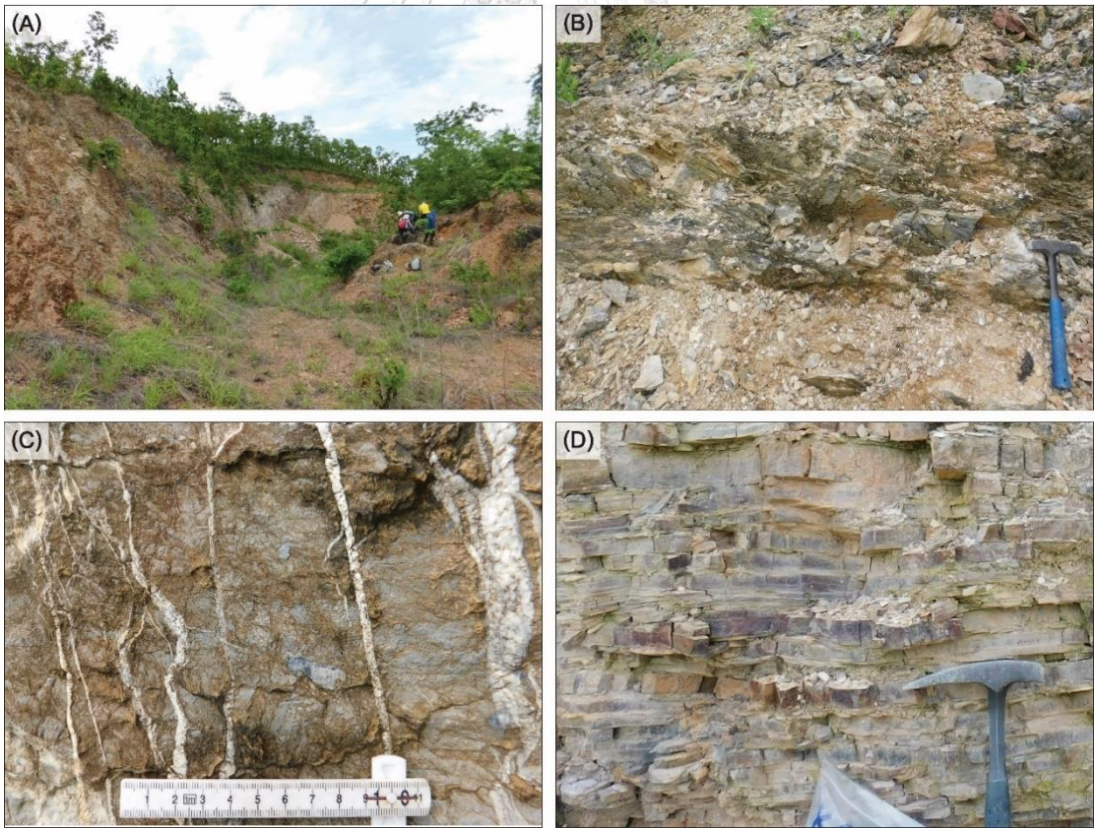

Figure 2.18 Photographs of KCB 19. (A): Quarry outcrop of mudstone, argillaceous limestone and chert, (B): Mudstone with many tentaculites. (C): Argillaceous limestone and calcite vein with nautiloids and tentaculites. (D): Well-bedded, chert.

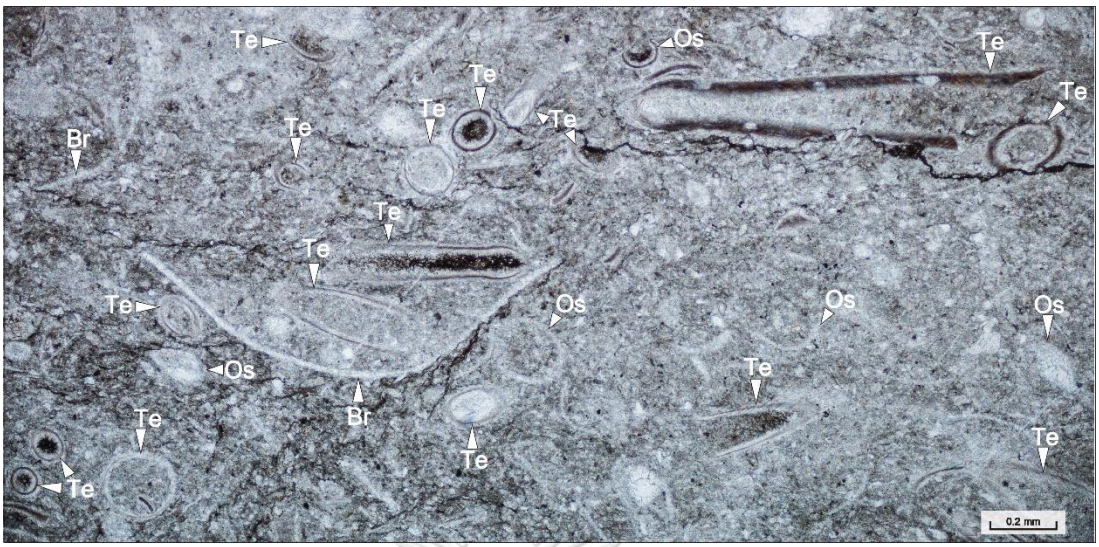

Figure 2.19 Bioclastic wackestone of sample no. KCB 19-A(1) showing matrix-supported, laminated, stylolite layer with abundant tentaculites (Te), common brachiopods (Br) and few ostracods (Os). Plane polarized light, scale bar is 0.2 mm.

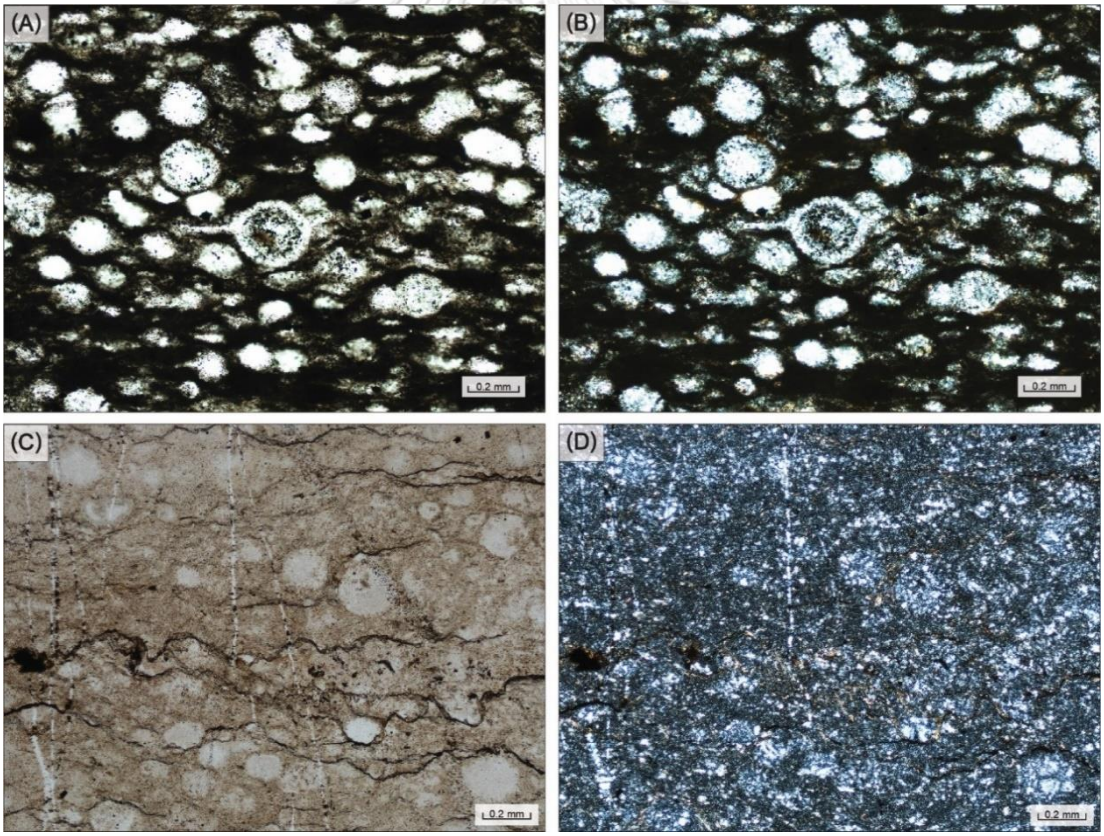

Figure 2.20 Photomicrographs of Chert (KCB19-1 location). (A) and (B): Sample no. KCB19-1 showing good preservation of radiolarians, (C) and (D): Sample no. KCB 19-3 shows very fine-grained, quartz with poorly preservation radiolarian. (A)&(C): Plane polarized light, (B)&(D): Cross polarized light. Scale bar is 0.2 mm.

KCB 21: This area is situated at natural outcrop in the western of the Ban Tha Kradan Community School. The lithology includes argillaceous limestone, sandstone, and mudstone with fossils of graptolite (Figure 2.21 - Figure 2.22). The general dip direction of bedding planes at this measured section northeast (045°) with low dipping angles (20°). Petrographically, on the basis of sandstone classification of Pettijohn et al., (1987), the sample is arkosic wacke (sample no. KCB 21-3) that shows clast supported texture (grains is approximately 60-70%), medium- to coarse-grained with an average grain size of 0.1-0.8 mm (Figure 2.23-Figure 2.24). Tentaculites are not preserved but graptolites (*Monograptus* sp. and *Diplograptus* sp.) are abundant and well preserved. Age of this area is Silurian? to early Devonian age based on the occurrence of graptolite.

KCB 22: This area is located at quarry in western of Ban Tha Kradan. The lithology consits of pale greenish grey to grey, very thin- to thin-bedded (1-3 cm), chert intercalated with siliceous shale (Figure 2.25). Bedding with folds is generally observed and the dip angles is generally about 60º at 80º.

KCB 23: This area is well exposed at small quarry in the northwestern of study area. The lithology of this area, the lower part is composed mainly of yelowish brown to reddish brown, laminated, shale to mudstone. Greenish grey to yellowish brown, very thin- to thin-bedded (1-5 cm), well bedded, high weatered, chert intercalatted with siliceous shale layer at the upper part (Figure 2.26). The fossils are rare in this area.

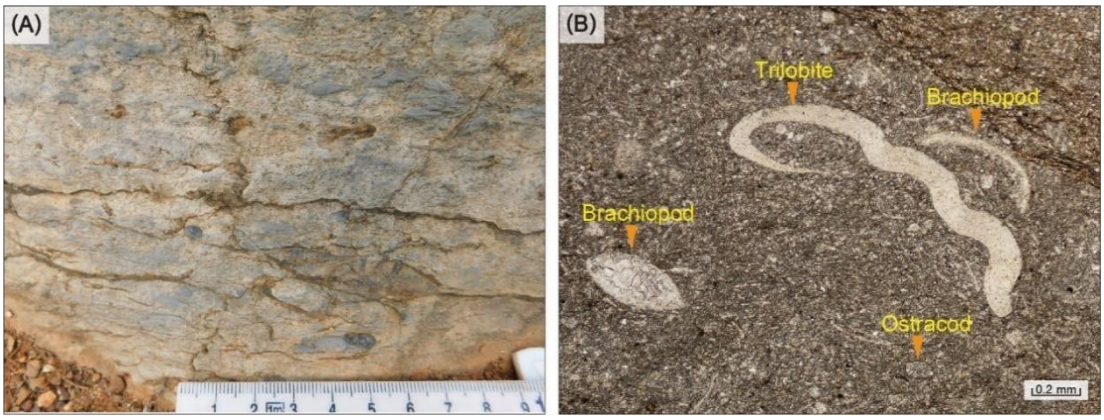

Figure 2.21 Natural outcrop of the lower part of KCB 21 area in Ban Tha Kradan. (A): Argillaceous limestone with stylolite band of Ordovician rock, (B): Thin section of wackestone commonly comprise trilobites, brachiopods, and ostracods (sample no. KCB 23-2).

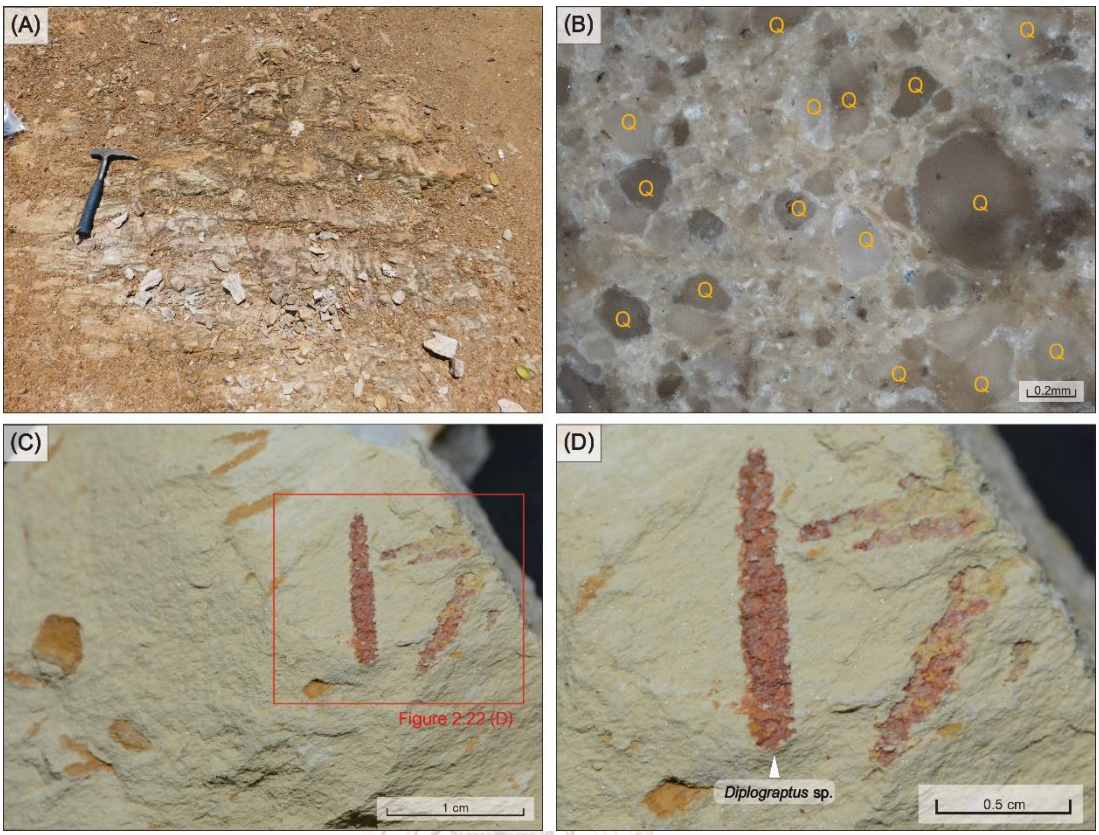

Figure 2.22 Natural outcrop KCB 21 area in Ban Tha Kradan area. (A): Outcrop of sandstone, mudstone, and siltstone. (B): Arkosic sandstone slab, sample no. KCB 21-3 showing mainly fine- to medium-grain quartz, poorly-sorted and subangular to subrounded shape (yellow Q alphabet) of subangular to subrounded, moderately to poorly sorted with minor amounts of feldspar and rock fragment, poorly cement, (C): shale to mudstone containing the gratolite, (D): Close-up of graptolit (*Diplograptus* sp.) of (C).

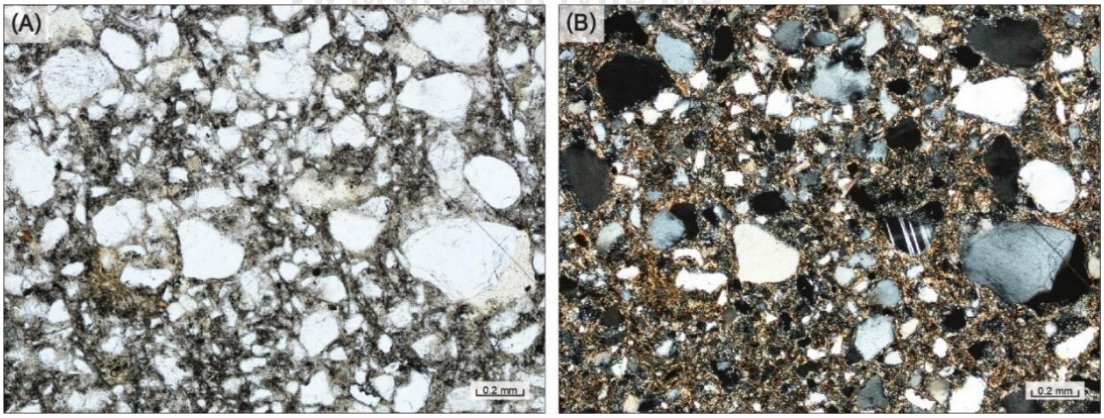

Figure 2.23 Photomicrographs of arkosic wacke (sample no. KCB 21-3) showing mainly fine- to medium-grained of subangular to subrounded, moderated to poorly sorted, graine is composed of quartz, with feldspar, mica and rock fragment. (A): Plane polarized light, (B): Cross polarized light.

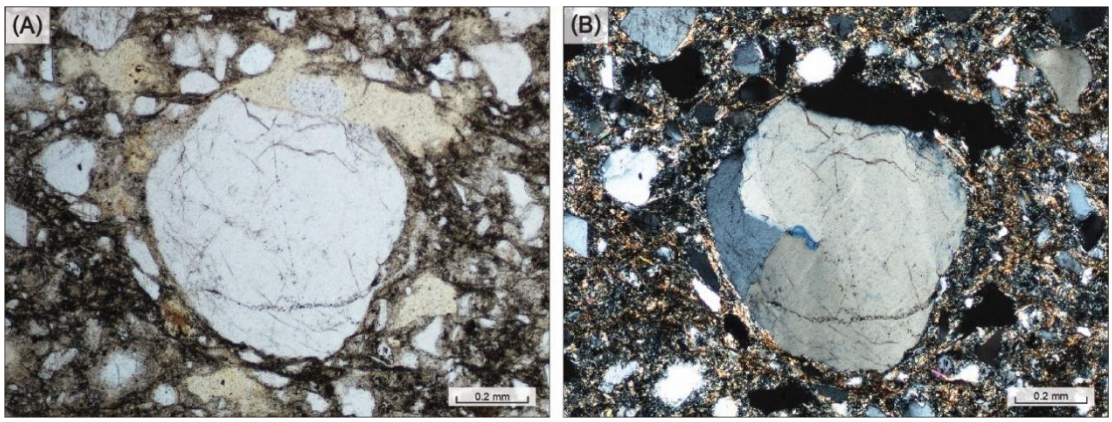

Figure 2.24 Photomicrographs of arkosic wacke showing coarse-grained polycrystalline quartz with undulatory extinction, rounded shape, approximately 0.5 mm across. (A): Plane polarized light, (B): Cross polarized light.

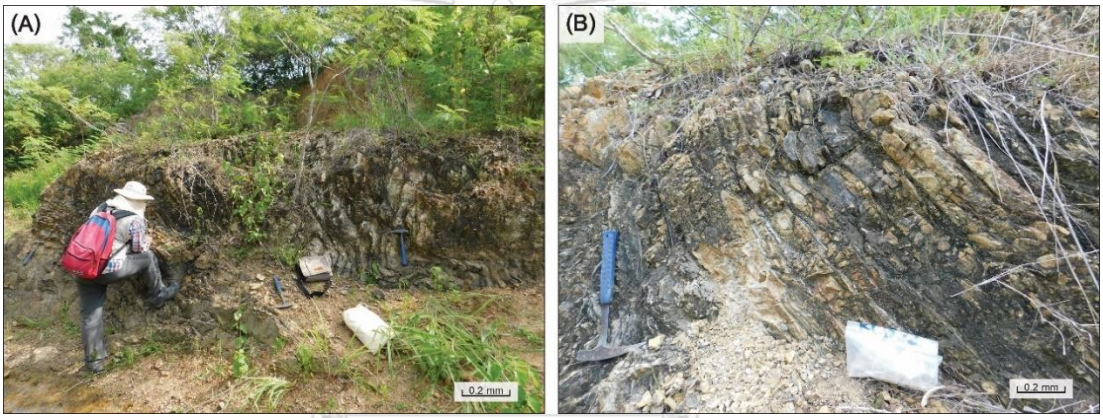

Figure 2.25 Characteristic lithology of bedded chert in KCB 22. (A): Very thin- to thin-bedded chert outcrop at small quarry near Ban Tha Kradan area, (B): Closed-up of thin-bedded chert in this area.

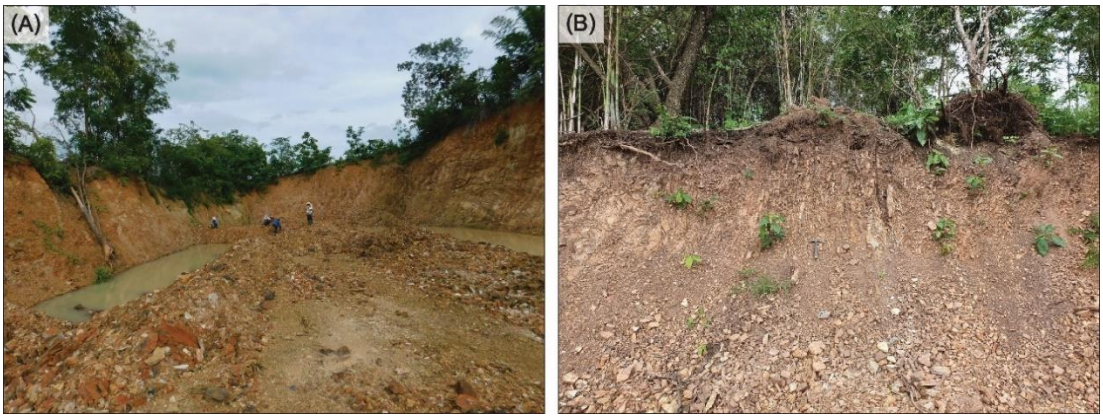

Figure 2.26 Lithological of shale to mudstone and well bedded chert of KCB 23. (A): Laminated shale to mudstone in the lower part, (B): Very thin- to thin-bedded chert intercalated with siliceous shale in upper part of this area.

All data on lithology and fossils of 19 isolate locations (KCB 02 to KCB 23) is shown in Table 2.1.

Table 2.1 Summarize of lithology and fossils of samples were collected from 19 isolate locations in study area.

Sample No.	Lithology	Fossils
KCB 02	Sandstone to meta-sandstone	-
KCB 03A	Pale brown, calcareous sandstone	-
KCB 04A	Medium grey to pale grey, micritic limestone with stylolitic limestone	Nautiloids and crinoids
KCB 05	Greenish grey to light grey, limestone with stylolitic band	Nautiloids and crinoids
KCB 06	Yellowish brown, chert	Radiolarians
KCB 07	Calcareous shale to mudstone (high weathered)	Tentaculite: *Nowakia acuaria*, and brachiopods
KCB 08	Dark grey, micritic limestone with stylolitic bands	Tentaculite: *Nowakia* (Cepanowakia) *pumilio*, *Styliolina clavulus,* brachiopods, and ostracods
KCB 10	Micritic limestone with argillite layer	Tentaculite: *Nowakia* (Cepanowakia) *pumilio*, *Styliolina clavulus,* and nautiloids
KCB 11A	Micritic limestone with argillite bed	Tentaculite: *Nowakia acuaria*, *Styliolina fissurella* and *Styliolina clavulus*
KCB 11B	Micritic limestone with argillite bed	Tentaculite: *Styliolina fissurella*
KCB 13	Reddish brown to yellowish brown, shale to mudstones,	Bivalves (*Posidonomya* sp.), brachiopods, trilobites, and crinoids
KCB 14	Pale yellow to yellowish brown, chert	Radiolarians
KCB 15	Slaty shale with quartz veins	-
KCB 16-1	Pale grey, limestone with stylolite layer	Nautiloids, ostracods and crinoids

Table 2.1 Continued

Sample no.	Lithology	Fossils
KCB 16-2	Pale grey, limestone with stylolite layer	Nautiloids, ostracods and crinoids
KCB 16-3	Pale grey, limestone with stylolite layer	Nautiloids, ostracods and crinoids
KCB 16-4	Dark grey to black, shale	Graptolite: *Monograptus* sp., Diplograptus sp.
KCB 17	Yellowish brown to grey, chert	Radiolarians
KCB 19-A(1)	Pale grey, micritic limestone with calcite vein	Tentaculites *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, *Styliolina clavulus*, and brachiopods
KCB 19-1	Yellowish brown, very thin-thin, chert	Radiolarians
KCB 19-3	Yellowish brown, very thin-thin, chert	Radiolarians
KCB-21-2	Argillaceous Limestone	Nautiloids, trilobite, ostracods, and crinoids
KCB-21-3	Sandstone	-
KCB-21-4	Shale to mudstone	Graptolite: *Monograptus* sp., *Diplograptus* sp.
KCB-22-1	Greenish grey to grey, very thin-thin, chert	Radiolarians
KCB-23-1	Greenish grey to yellowish brown, chert	Radiolarians
KCB-23-2	Yellowish brown to reddish brown, shale to mudstone	-
Geosite	Limestone and stylolitic layer	Nautiloids: *Armenoceras* sp., *Actinoceras* sp., and *Orthoceras* sp.

The lithostratigraphy in study area is composed of 3 short measured sections: KCB 09, KCB 12, and KCB 20 (Figure 2.1). About 16 rock samples were collected from the lower part into the upper of each section for detailed thin section observation. Details of each measured sections in the study area as follows:

Section KCB 09: This section is located at quarry in the eastern of the Ban Tha Kradan area. General attitude of beds is approximately in the NW-SE direction with high angle (70°-80°) to the NE. This sequence is consisting of mudstone, reddish brown to purplish brown, weathering, slightly calcareous, thin- to thick-bedded and lamination to wavy structure interbedded with argillaceous limestone, medium to pale grey, with stylolite, thin-to medium-bedded, abundant fossils of tentaculites and rare brachiopods and some bed show the lateral facies change of calcareous mudstone and argillaceous limestone, total thickness is approximately 6.30 m thick (Figure 2.27 and Figure 2.28). Three rock samples have been collected from calcareous mudstone and argillaceous limestone. Under the microscope study, its lithology shows bioclastic wackestone (sample no. KCB 09-1 & KCB 09-3), matrix-supported texture (less than 10 % grains) with consists of carbonate mud matrix and cemented by calcite. The bioclast grains containing abundant tentaculites, recrystallization ostracods, and shell fragment of brachiopods (Figure 2.29 (A)-(B) and (E)). Laminated shale to mudstone is recognized from laminated shale (sample no. KCB 09-2) that shows graded bedded, calcite veins and parallel-laminated texture with calcite cement. The bioclastic grains containing abundant tentaculites, brachiopods (shell fragment) and rare ostracods (Figure 2.29 (C) - (D)).

In this section, samples: KCB09-1, KCB09-2, and KCB09-3 including many tentaculite specimens e.g., *Nowakia acuaria, Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, and *Styliolina clavulus*. The age of this section in middle to late Devonian (Eifelian-Fransnian) age.

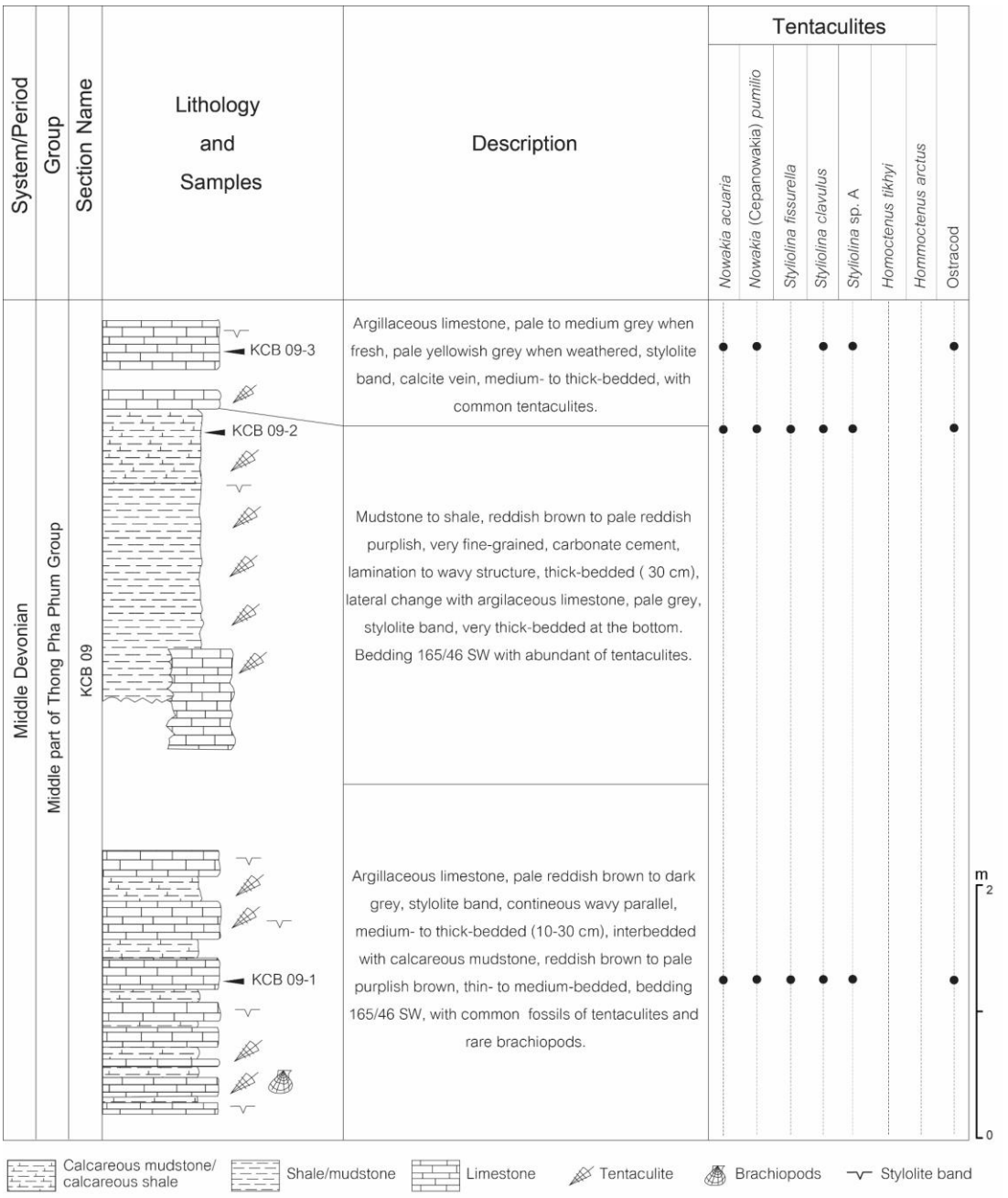

Figure 2.27 Lithostratigraphic column and stratigraphic distributions of tentaculite species and ostracods of the section KCB 09 of the Thong Pha Phum Group in the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province.

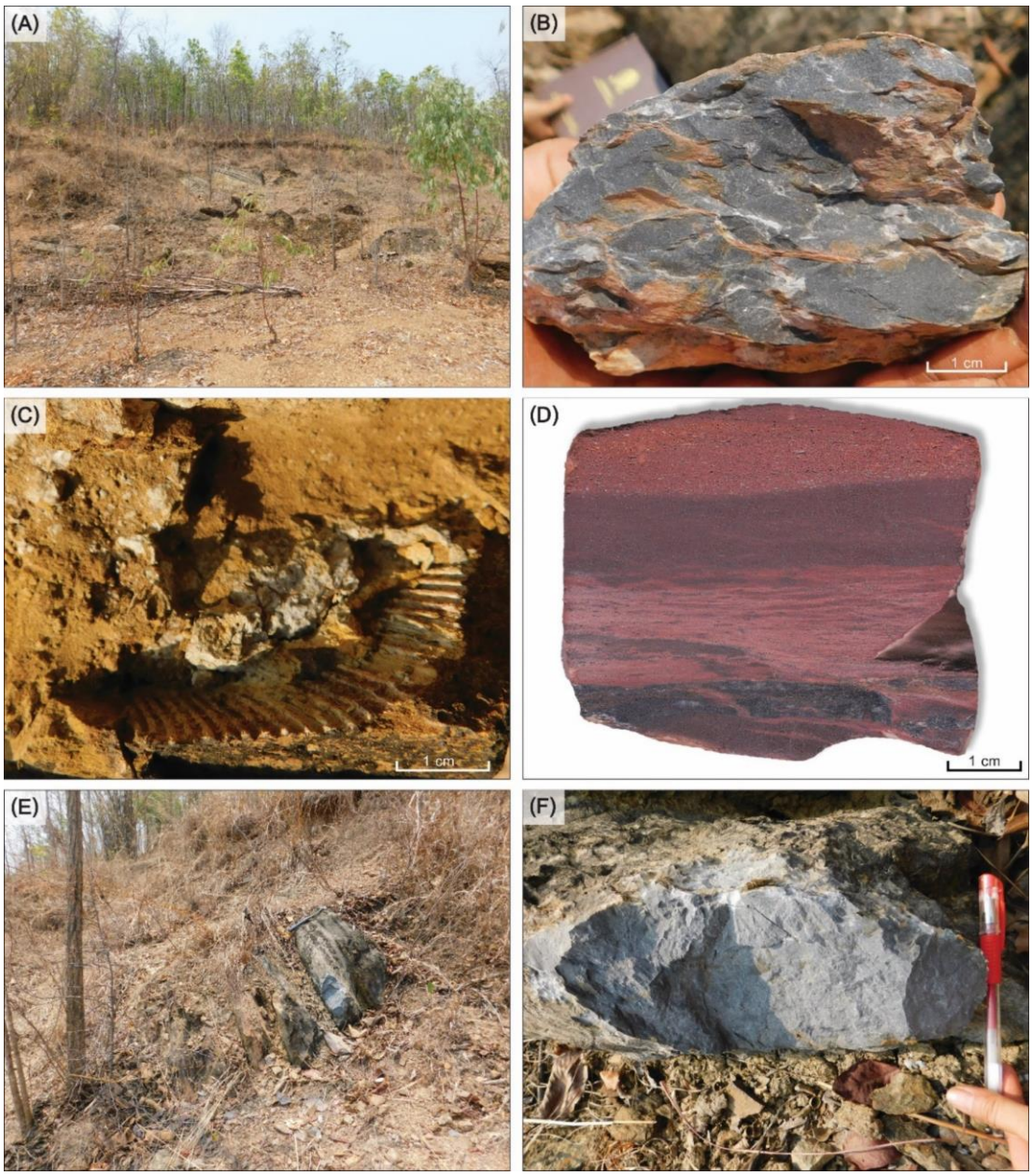

Figure 2.28 Thin- to thick-bedded, limestone with calcareous shale and calcareous mudstone to very fine sandstone (section KCB 09) of the Thong Pha Phum Group in study area. (A): Quarry outcrop of section KCB 09 (looking SE), B: Closed-up of the texture of micritic limestone in the lower part of this section, (C): Brachiopods collected from the lower portion, (D): Vertical cross section of sample number KCB 09-2 slab of laminar to very thin-bedded, calcareous shale and mudstone to very fine-sandstone containing tentaculites with calcite veins, (E): Argillaceous limestone, thin- to medium-bedded interbedded with argillite layer and stylolite bands of the upper part of this sequence, (F): Close-up photograph of texture of micritic limestone of (E).

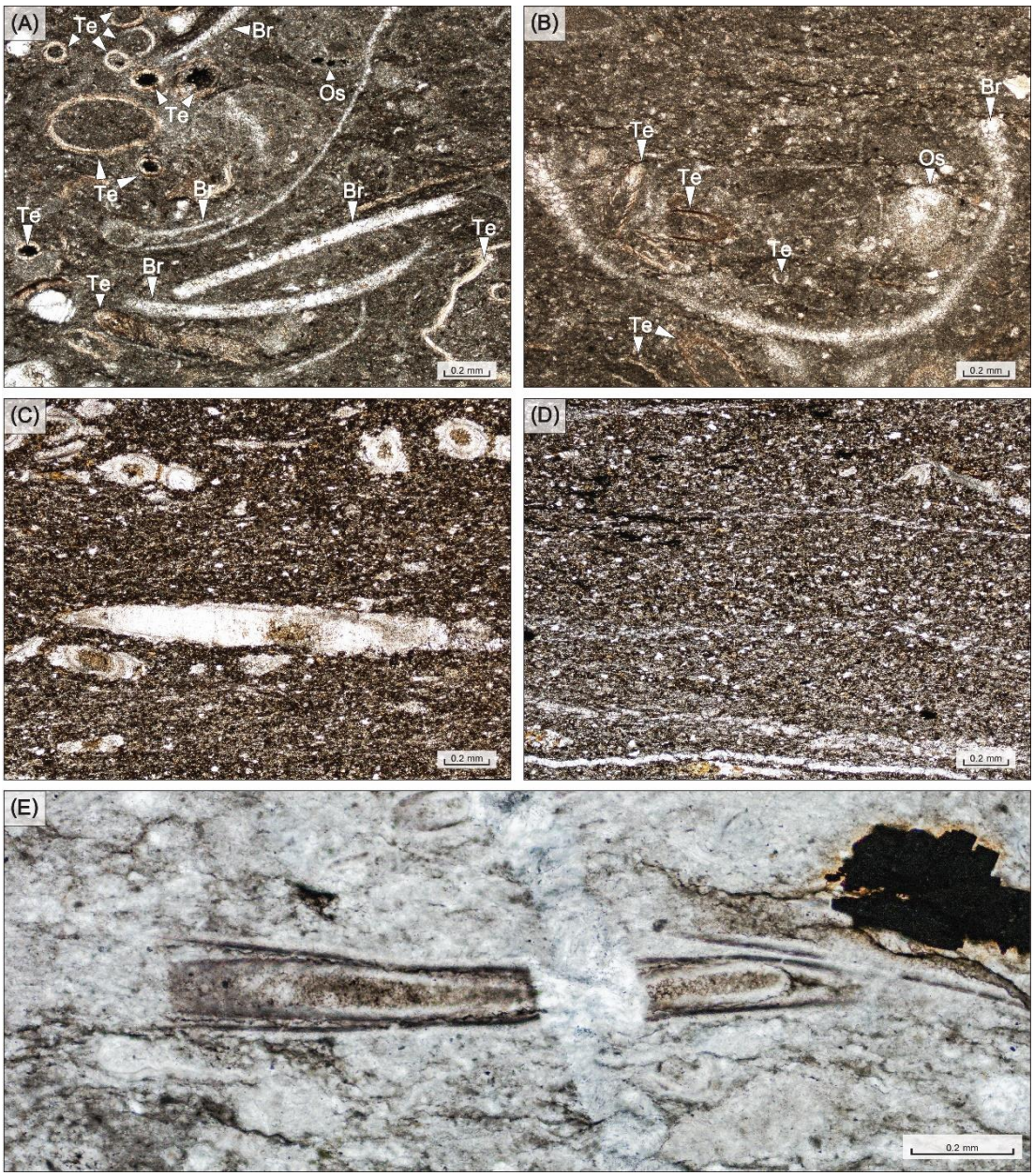

Figure 2.29 Photomicrographs of thin section (section KCB 09). (A) and (B): Bioclastic wackestone (sample no. KCB 09-1) showing mainly matrix-supported, calcite cement with bioclast of tentaculites (Te), brachiopods (Br) and few ostracods (Os), (C)-(D): KCB 09-2 is laminated mudstone showing lamination, graded bedding, cemented by carbonate as well as stylolite layer with tentaculites in the vertical section, (E): Sample no. KCB 09-3 showing, laminated bioclastic wackestone and stylolite layer with tentaculites. (A)-(E): Plane polarized light. Scale bar is 0.2 mm.

Section KCB 12: This section is situated at a natural outcrop in the north of Ban Tha Kradan area. The section, approximately 30 m thick, the lower section is composed of argillaceous limestone, medium to dark grey, with stylolite layer, thin-to medium-bedded and fossils of nautiloids, crinoid and brachiopods. The upper past is consisting of mudstone, reddish brown to yellowish brown, weathering, slightly calcareous, lamination interbedded with thin-bedded, micritic limestone with abundant fossils of tentaculites (Figure 2.30 - Figure 2.31). The attitude of beds is approximately in the NW-SE direction with medium to high angle (50°-70°) to the NE and 8 rock samples (KCB 12-1 to KCB 12-8) collected from argillaceous limestone and micritic limestone. In the lower portion are not found tentaculite specimens but containing nautiloids, crinoids and brachiopods. Accordingly, the lower section can correlate to upper part of the Thong Song Group (Ordovician rocks) and upper past is the Thong Pha Phum Group. Microscopic observations, calci-mudstone are recognized from medium grey to dark grey, thin- to medium-bedded, micritic limestone (KCB 12-7 and KCB 12-8) of this measured section. It shows matrix-supported (less than 10 % grains) with fossils consist of brachiopods, ostracods and tentaculites. The matrix is mud to silt-grained of carbonate micrite as well as stylolite layer with calcite veins are found in the texture (Figure 2.32). The bioclastic packstone is recognized from limestone (sample no. KCB 12-6, float rock). It shows grain-supported texture, laminated, calcite cement with silty matrix (Figure 2.33). Grains are mainly fossils and common grains of pyrite. The bioclast grains consist mainly of tentaculites and rare other bioclast grains. Tentaculite specimens are very rare in the upper section of sample no. KCB12-7 and KCB12-8 but are abundant tentaculites in sample no. KCB12-6 (float rock) collected from this area (Figure 2.34). The tentaculite specimens observed in this section (KCB12-7 and KCB 12-8) are *Nowakia acuaria* and *Nowakia.* (Cepanowakia) *pumilio* that indicates the middle Devonian age. However, sample number KCB 12-6 (float rock) is laminated, bioclastic packstone including many tentaculite *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella, Styliolina clavulus*, *Styliolina* sp. A, *Homoctenus tikhyi* and *Homoctenus arctus.* They indicate middle - late Devonian age.

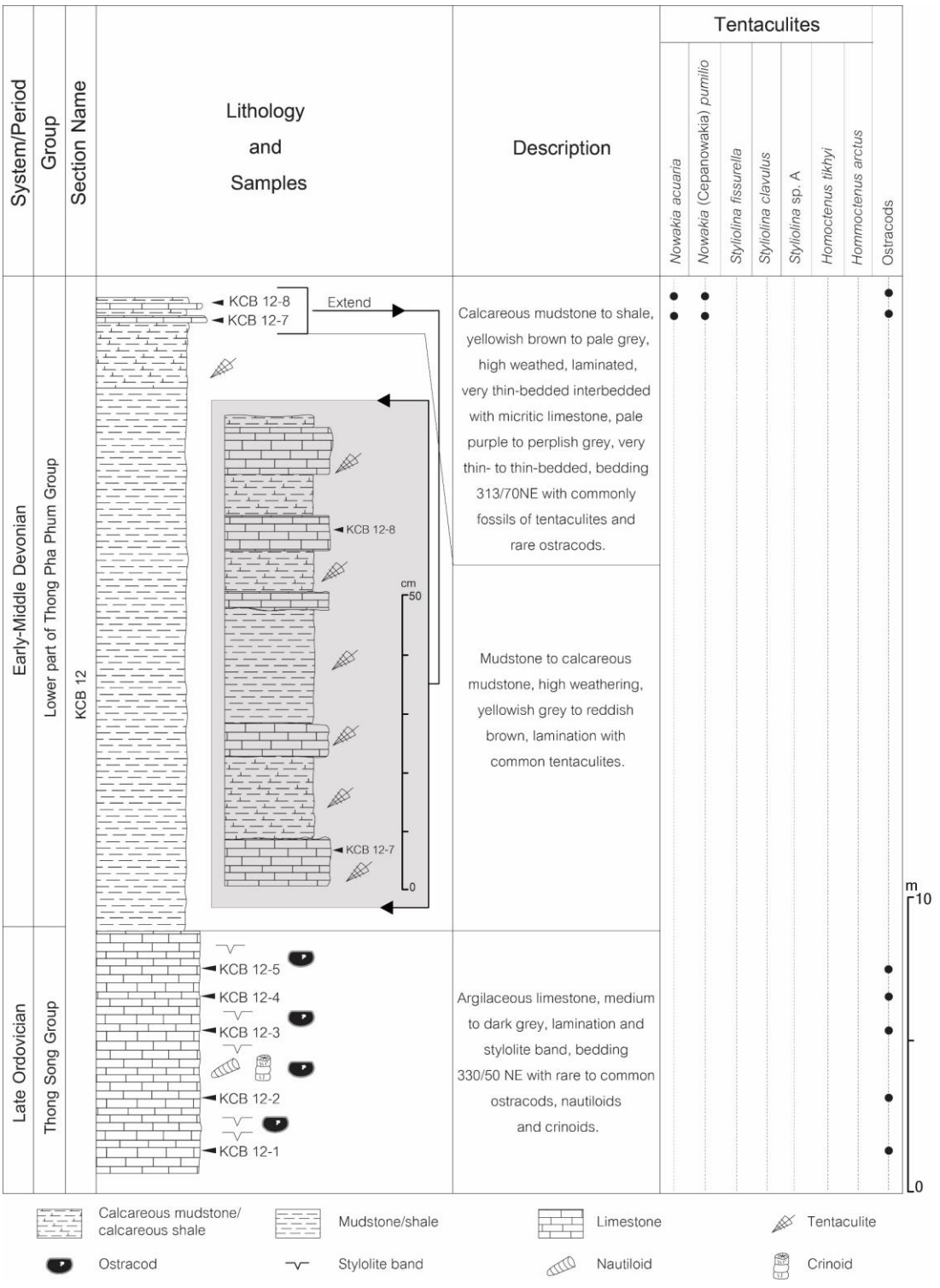

Figure 2.30 Lithostratigraphic column and stratigraphic distributions of tentaculite species and ostracods of the section KCB 12 of the Thong Pha Phum Group in the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province.

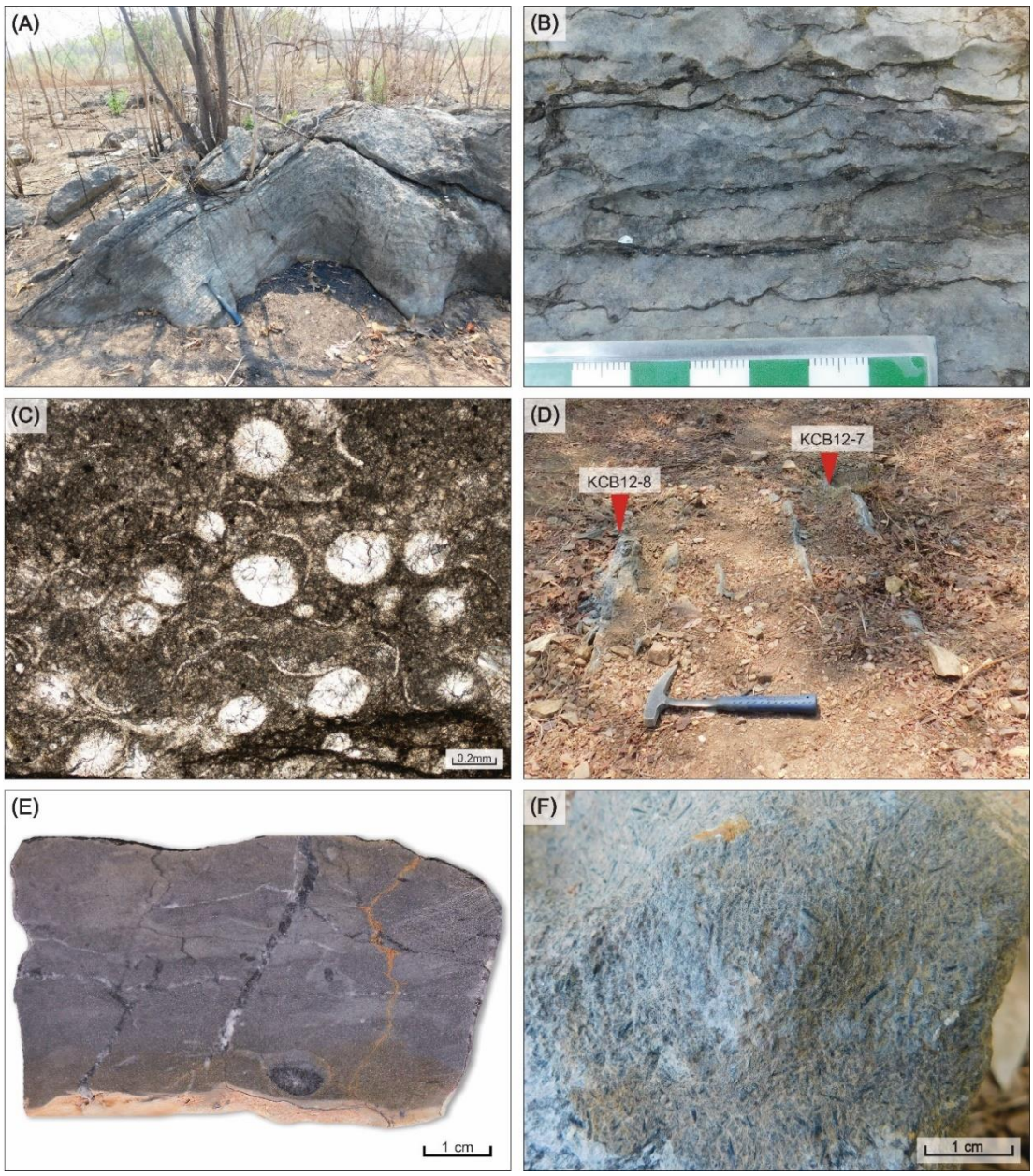

Figure 2.31 Lithologies and fossil associations of section KCB 12 at Ban Tha Kradan area. (A): Outcrop of argillaceous limestone and stylolite band with fold axis trending NW-SE direction in the lower part of this sequence, (B): Closed-up of texture argillaceous limestone in the lower part, (C): Thin section of sample no. KCB 12-1 showing bioclastic wackestone containing ostracods, (D): Lamination, calcareous shale to mudstone interbedded with thin-bedded, micritic limestone in the upper part of section, (E): Micritic limestone slab (sample no. KCB12-7) collected from upper part of this section, (F): Tentaculites are abundant and well preserved in this area (sample no.12-6 (float rock)).

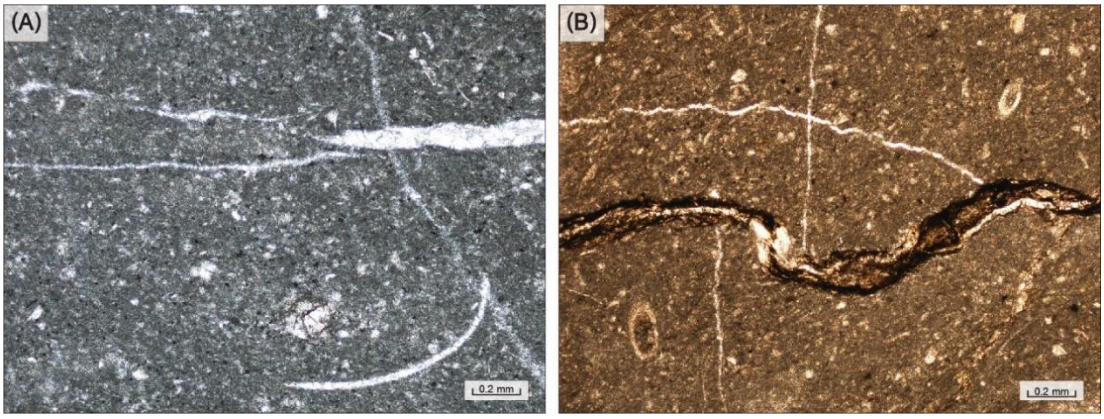

Figure 2.32 Thin section of calci-mudstone (KCB 12). (A): Sample no. KCB 12-7 showing matrix support and calcite vein, (B): Sample no. KCB 12-8 shows matrix support, stylolite band with tentaculites. (A)-(B): Plane polarized light. Scale bar is 0.2 mm.

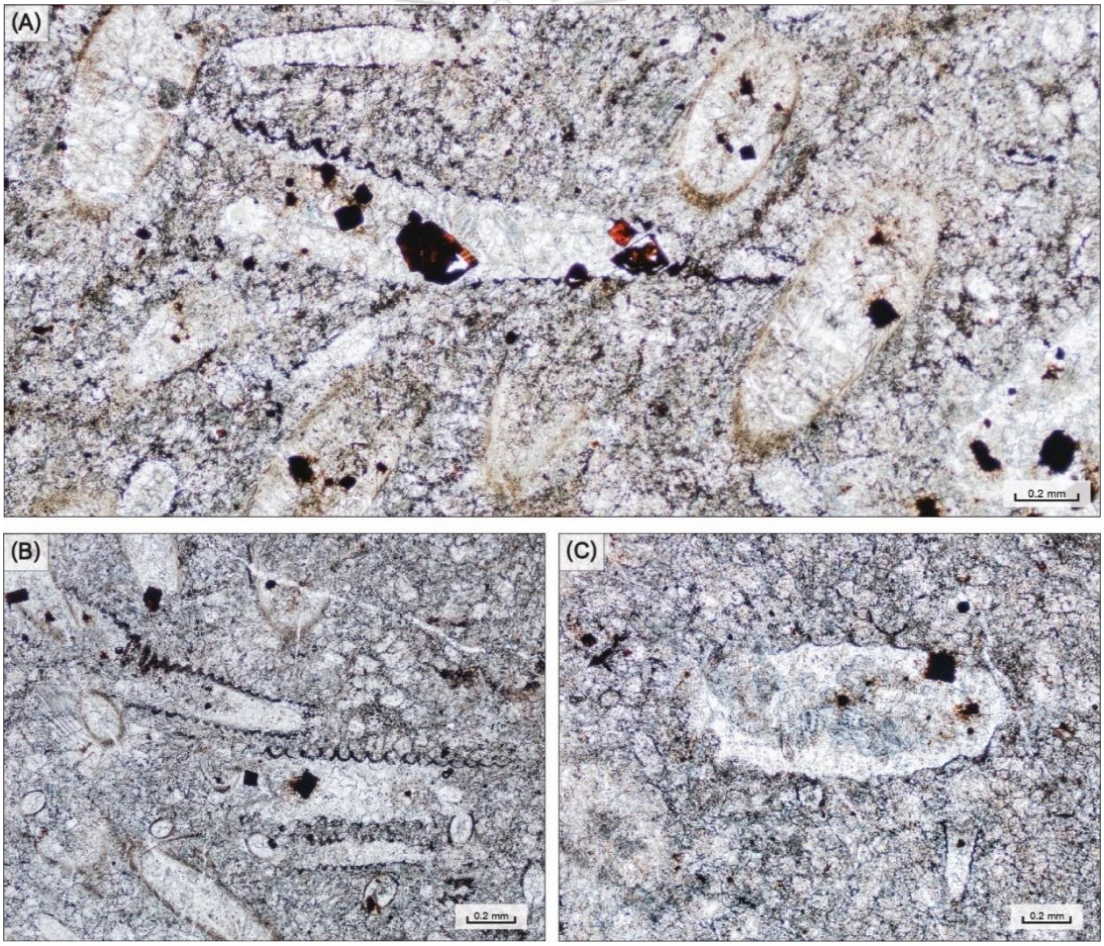

Figure 2.33 Photomicrographs of bioclastic packstone (sample no. 12-6, (A)-(C)) showing grain-supported which grains composed of abundant tentaculites and pyrite. The tentaculites are present and well preserved. (A)-(C): Plane polarized light. Scale bar is 0.2 mm.

Figure 2.34 Thin section of micritic limestone with abundant tentaculites *Styliolina fissurella*, *Homoctenus tikhyi*, and *Homoctenus arctus* of the sample no. KCB 12-6 in Ban Tha Kradan area. Scale bar is 1 mm.

Section KCB 20: This section is exposed at quarry about 200 m northeast of Wat Tha Kradan. The lithology is mudstone and chert with fossils of radiolarian (Figure 2.35 - Figure 2.36). The general dip direction of bedding planes at this measured section northeast (050°) with moderately dipping angles (60°). Besides, this area is composed of calcareous shale to mudstone, micritic limestone, marl, and argillaceous limestone but unclear structure (Figure 2.37 (A) - (C)). Tentaculites are many in this area (Figure 2.37 (D)). The structure is showing anticlinal and synclinal structures are show in Figure 2.37 (E) - (F). The rock sample no. KCB 20-1 study under the microscope which shows recrystallize, very fine-grained, quartz with rare radiolarian. It is poorly preserved and unclear shape of skeletons (Figure 3.38).

According to Polwichai, 2013, the chert bed with radiolarian assemblag (*Albaillella* sp., *Albaillella* sp. cf. A. *pennata*, *Albaillella* sp. cf. A. *paradoxa, Latentifistula*

sp., *Strigmosphaerostylus* sp., *Trilonche* sp., and *Latentifistula concentric*) of in this study area indicates early Carboniferous age and was deposited in the pelagic environment.

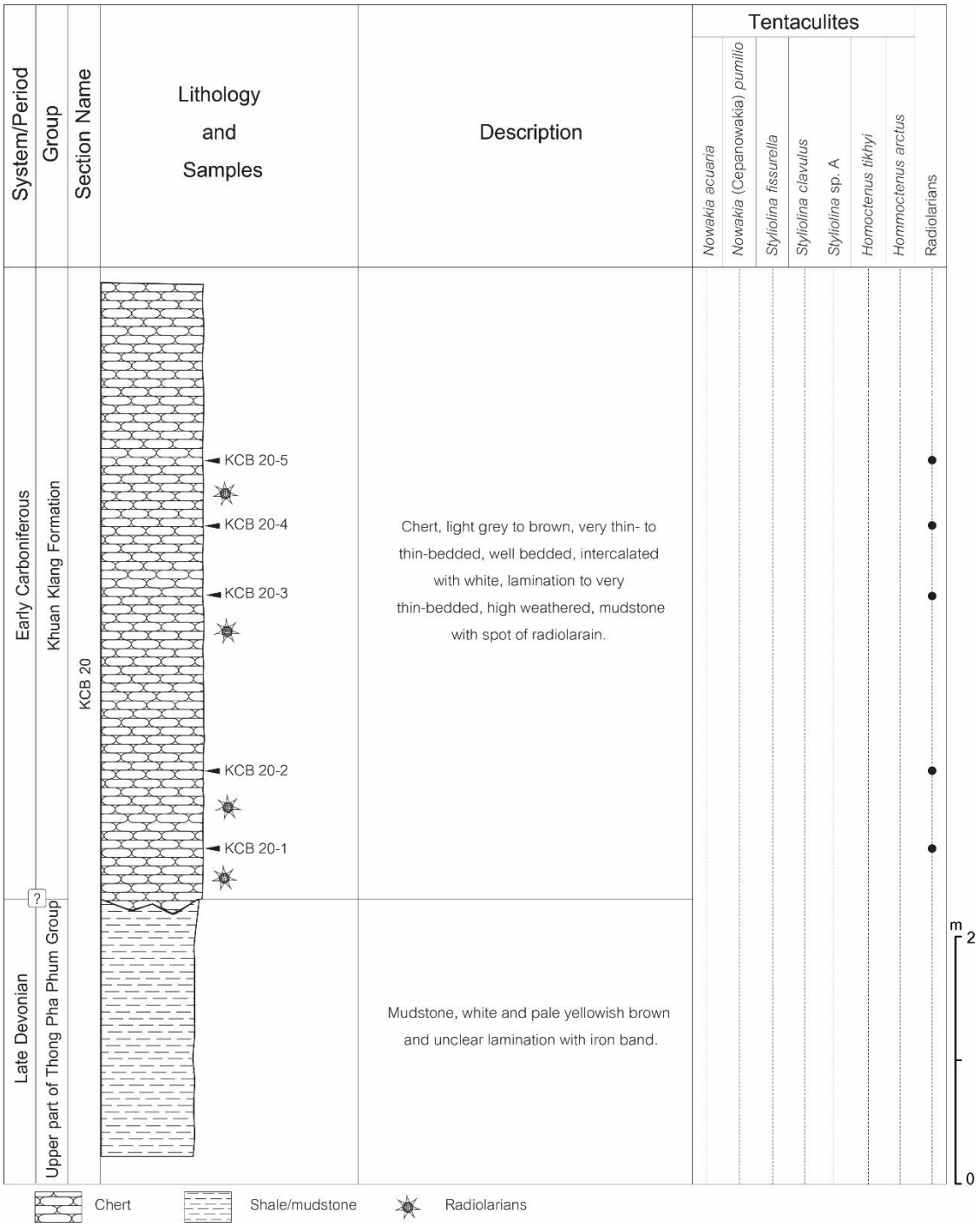

Figure 2.35 Lithostratigraphic column and stratigraphic distributions of fossils of the section KCB20 of the Thong Pha Phum Group in the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province.

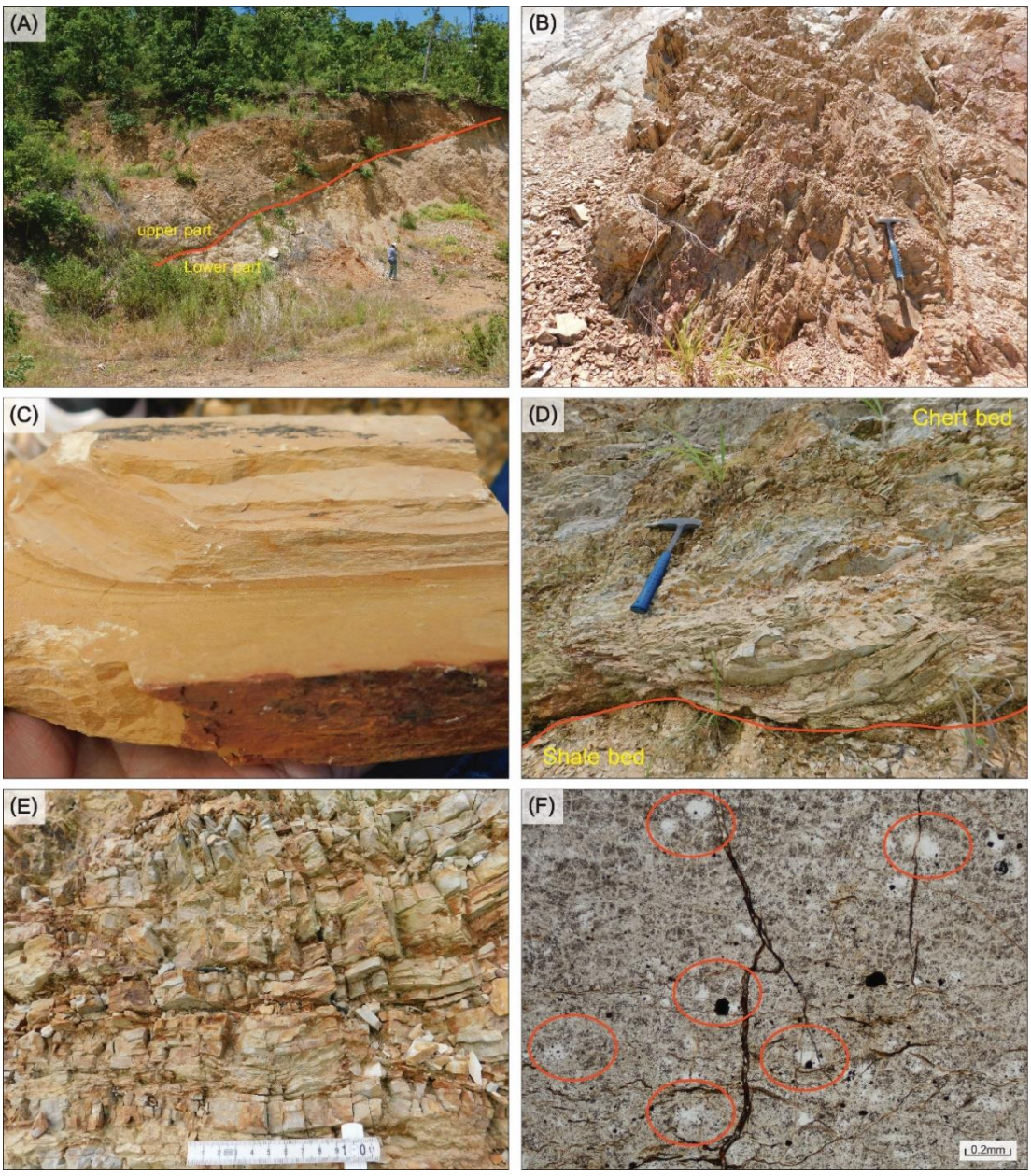

Figure 2.36 Lithologies of section KCB 20 of the Devonian-Carboniferous sequence exposed in the Ban Tha Kradan area. (A): Quarry outcrop of laminated shale (lower part) and thin-bedded chert (upper part), (B): Pale brown to pale yellowish brown, high weatering, laminated shale to mudstone in the lower part of this section, (C): Closed-up photograph of texture surface weathering of laminated shale of (B), (D): Well bedded, chert is overlain on laminated shale to mudstone (red line is boundaries of chert bed and shale bed), (E): Very thin- to thin-bedded, well bedded, chert intecalated with mudstone layer in the upper portion of this sequence, (F): Thin section of chert usually containing radiolarians (red circle) of sample number KCB 20-1.

Figure 2.37 Lithology and structure of the Thong Pha Phum Group in Ban Tha Kradan area southern of section KCB 20. (A): Calcareous shale (high weathered) interbedded with thin-bedded marl that showing the high dip angle (70°-80°), (B): Laminated calcareous shale to mudstone with layer of argilaceous limestone, (C): Outcrop of reddish brown to yellowish brown, lamination, shale with rare fossils, (D): Tentaculites are abundant found in shale bed, (E) Anticlinal structures of argilaceous limestone with fold axis trending NW-SE direction, (F): Very thin- to thin-bedded, micritic limestone interbedded with laminated calcareous shale showing anticline pluging to NW direction.

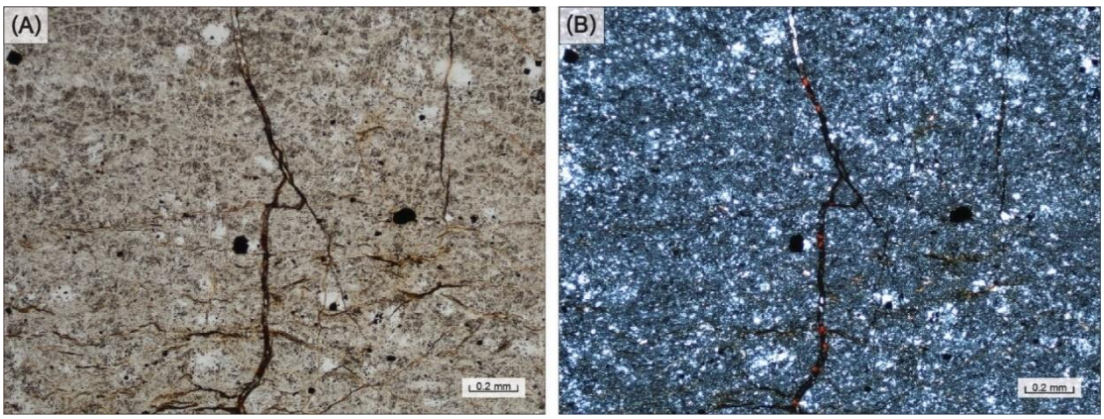

Figure 2.38 Photomicrograph of Chert. (A) and (B): Sample no. KCB 20-1 showing recrystallize, very fine-grained, quartz with rare, poorly preservation radiolarian. (A): Plane polarized light (PPL), (B): Cross polarized light (XPL). Scale bar is 0.2 mm.

2.2 Results on age fossil assemblages

According to previous paleontological studies, the Lower Paleozoic rocks in Kanchanaburi Province contain invertebrate marine fauna such as graptolites, tentaculites, brachiopods, ostracods, crinoids, trilobites, conodont, nautiloids and radiolarians. There fauna indicate the Ordovician-Devonian age (Bunopas, 1981; Hagen & Kemper, 1976; Hahn & Siebenhüner, 1982). However, all fossils found in field investigations and microscopic observations is shown in Table 2.2.

- **Ordovician fauna**: In study area, samples: KCB 04, KCB 05, KCB 16, KCB 12, KCB 21, and geosite area are also studied (Figure 2.1). Lithology is composed of laminated limestone, argillaceous limestone with stylolite facies. These carbonate rocks yield nautiloids ostracods and crinoids. The nautiloids were dominated that nautiloids yield *Armenoceras* sp., *Actinostreon* sp., and *Orthoceras* sp. Age of nautiloids is referred to late Ordovician that can be correlated with the upper Thung Song Group.

- **Silurian? to Devonian Fauna**: Many graptolites *Monograptus* sp., *Diplograptus* sp. bearing grey shale and black shale from KCB16 and KCB 21 (sample nos. KCB 16-3 and KCB 21-4) were examined. A similar graptolite fauna is also known to occur in the Satun Province, southern Thailand (Agematsu et al., 2006a, 2006b; Wongwanich et al., 1990), Thong Pha Phum District (Hagen & Kemper, 1976; Hahn & Siebenhüner, 1982), Si Sawat District, Kanchaburi Province (Pitakpaivan et al., 1969)

Table 2.2 List of all tentaculite specimens and other fossils of the Thong Pha Phum Group in the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province.

Fossil specimens / Sample Number / Sample Locality		Tentaculites								Other fossils								No fossils
		Nowakia acuaria	*Nowakia* (Cepanowakia) *pumilio*	*Styliolina fissurella*	*Styliolina clavulus*	*Styliolina* sp. A	*Homoctenus tikhyi*	*Homoctenus arctus.*	Fragment of tentaculites	Graptolite (*Monograptus* sp. & *Diplograptus* sp.)	Brachipods	Ostracods	Crinoids	Trilobites	Radiolarians	Nautiloids	Bivalves	
KCB 02																		x
KCB 03A																		x
KCB 04																•		
KCB 05A				●								●	•					
KCB 08			●	●								•						
KCB 09	KCB 09-1	•	●		●	●			•		•	●		•				
	KCB 09-2		●	●	●	●			•		•	•						
	KCB 09-3	•	●	●	●	●			•		●	●	•	•				
KCB 10			●	●														
KCB 11A		•																
KCB 11B				●														
KCB12	KCB 12-1										•	●						
	KCB 12-2										•	●						
	KCB 12-3										•	●						
	KCB 12-4										•	●						
	KCB 12-5										•	●						
	KCB 12-6	●		●	●	●	●	●										
	KCB 12-7	•							•	• ?	•							
	KCB 12-8	•	•						•		•	•	•					
KCB 13A											●		●	●			●	
KCB 13B																		x
KCB 14															•			

Remark: • rare (1-5 specimens), ● common (5-15 specimens), ● abundant. (More than 15 specimens)

Table 2.2 Continued

Sample Number/ Sample Locality		Tentaculites								Other fossils							No fossils
		Nowakia acuaria	*Nowakia* (Cepanowakia) *pumilio*	*Styliolina fissurella*	*Styliolina clavulus*	*Styliolina* sp. A	*Homoctenus tikhyi*	*Homoctenus arctus*	Fragment of tentaculites	Graptolite (*Monograptus* sp. & *Diplograptus* sp.)	Brachipods	Ostracods	Crinoids	Trilobites	Radiolarians	Nautiloids	
KCB 16	KCB 16-0											●	●			●	
	KCB 16-1											●	●			•	
	KCB 16-2											●	●			●	
	KCB 16-3									●							
KCB 19	KCB 19-1														●		
	KCB 19-2														●		
	KCB 19-3														●		
	KCB 19-A(1)	•		•	●											•	
	KCB 19-A(2)	•			●												
	KCB 19-B	•	•														
	KCB 19-C	•	•														
KCB 20	KCB 20-1														•		
	KCB 20-2														•		
	KCB 20-3														•		
	KCB 20-4														•		
	KCB 20-5														•		
KCB 21	KCB21-1										•	•	•	•			
	KCB 21-2										•	•		•			
	KCB 21-3																x
	KCB 21-4									●							
KCB22															•		
KCB 23	KCB 23-1														•		
	KCB 23-2																x

Remark: • rare (1-5 specimens), ● common (5-15 specimens), ● abundant. (More than 15 specimens)

and Chiang Dao area, Chiang Mai Province, northern Thailand (Wonganan & Caridroit, 2005). Age of graptolites is possibly referred to Silurian? to early Devonian.

Most of the samples collected in each section and isolate locations (KCB 07, KCB 08, KCB 09, KCB 10, KCB11, KCB12, KCB19, and KCB 20) yielded abundant tentaculites. Seven species within 3 genera (*Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella, Styliolina clavulus*, *Styliolina* sp. A; *Homoctenus tikhy*i and *Homoctenus arctus*) have been systematically studied.

In section KCB 09, all of the rock samples found tentaculite specimens. Bioclastic wackestone facies (sample no. KCB09-1 & KCB 09-3) and laminated, calcareous shale facies (sample no. KCB 09-2) yield abundant tentaculites *Nowakia acuaria, Nowakia* (Cepanowakia) *pumilio, Styliolina fissurella, Styliolina clavulus, Styliolina sp.* A., brachiopods, ostracods, crinoids, and fragment of trilobites (Table 2.1). Sample no. KCB 09-2 was collected from the laminated, calcareous shale facies. It also yields abundant tentaculites *Nowakia* (Cepanowakia) *pumilio, Styliolina fissurella, Styliolina clavulus* and *Styliolina sp.* A. Stratigraphy of this section shown in Figure 2.27. The age of this section is an Emsian to Givetian age that indicated by fossils of tentaculites. In section KCB 12, *Homoctenus tikhyi* and *Homoctenus arctus* were found. They indicate a late Devonian (Frasnian) age.

-**Early Carboniferous fauna**: bivalves *Posidonomya* sp., trilobite, and crinoids were found in the red shale facies (at KCB 13) and radiolarians were presented in well bedded cherts (at KCB 06, KCB 14, KCB 19 and KCB 20) of the Khuan Klang Formation. Age of *Posidonomya* sp. and radiolarians is referred to early Carboniferous (Polwichai, 2013).

2.3 Results on stratigraphic correlation

The details of composite sections in Ban Tha Kradan area and the age of all sequence rocks and isolate outcrops are showed in the Figures 3.29.

Sedimentary sequence of the Thong Pha Phum Group can be divided into 3 part: the lower part, the middle part, and the upper part that contains of sandstone,

siltstone, bioclastic wackestone, bioclastic packstone, calci-mudstone, laminated calcareous shale to mudstone, and laminated mudstone, in ascending order. The lower part is approximately 10-20 m thick and mainly consists of sandstone to siltstone, laminated mudstone, and slaty mudstone with graptolite *Monograptus* sp. and *Diplograptus* sp. This part is situated in the upper part of the KCB 12 section and KCB 15 area, KCB16 and KCB 21 area. The middle portion, the Thong Pha Phum Group are abundant containing faunas of tentaculites *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella*, *Styliolina clavulus*, *Styliolina* sp. A., *Homoctenus tikhyi*, *Homoctenus arctus* and commonly brachiopods, and few nautiloids. The rocks observed in this part including bioclastic wackestone, bioclatioc packstone, calci-mudstone, marl, and calcareous shale to mudstone with pyrite nodule and approximately 30-40 m thick. This portion is observed in the stratigraphic section of KCB 09 and addition area of KCB 07, KCB 08, KCB10, KCB11, KCB 12, and KCB 19. The upper part includes the laminated to massive shale to mudstone with fossils are very rare (trace fossils?). It is approximately 10-20 m thick and observed in the KCB 17, KCB 19, KCB 23 and section KCB 20.

As mentioned above, the Thong Pha Phum Group is continuous marine sedimentary sequence. This group is conformably underlain by argillaceous limestone of the Upper Thung Song Group (Late Ordovician) and conformably overlain by well-bed chert of Khuan Klang Formation (Early Carboniferous). The lower boundary of the Thong Pha Phum and Thung Song Groups is probably defined as the sharp contact of the limestone and siliciclastic rocks. Sharp contact of mudstone with well bedded chert between the Upper Thong Pha Phum Group and Khuan Klang Formation can be observed in some isolate localities and section KCB 20. Total thickness of combined sections base on 3 measured sections is at least approximately 60-80 m.

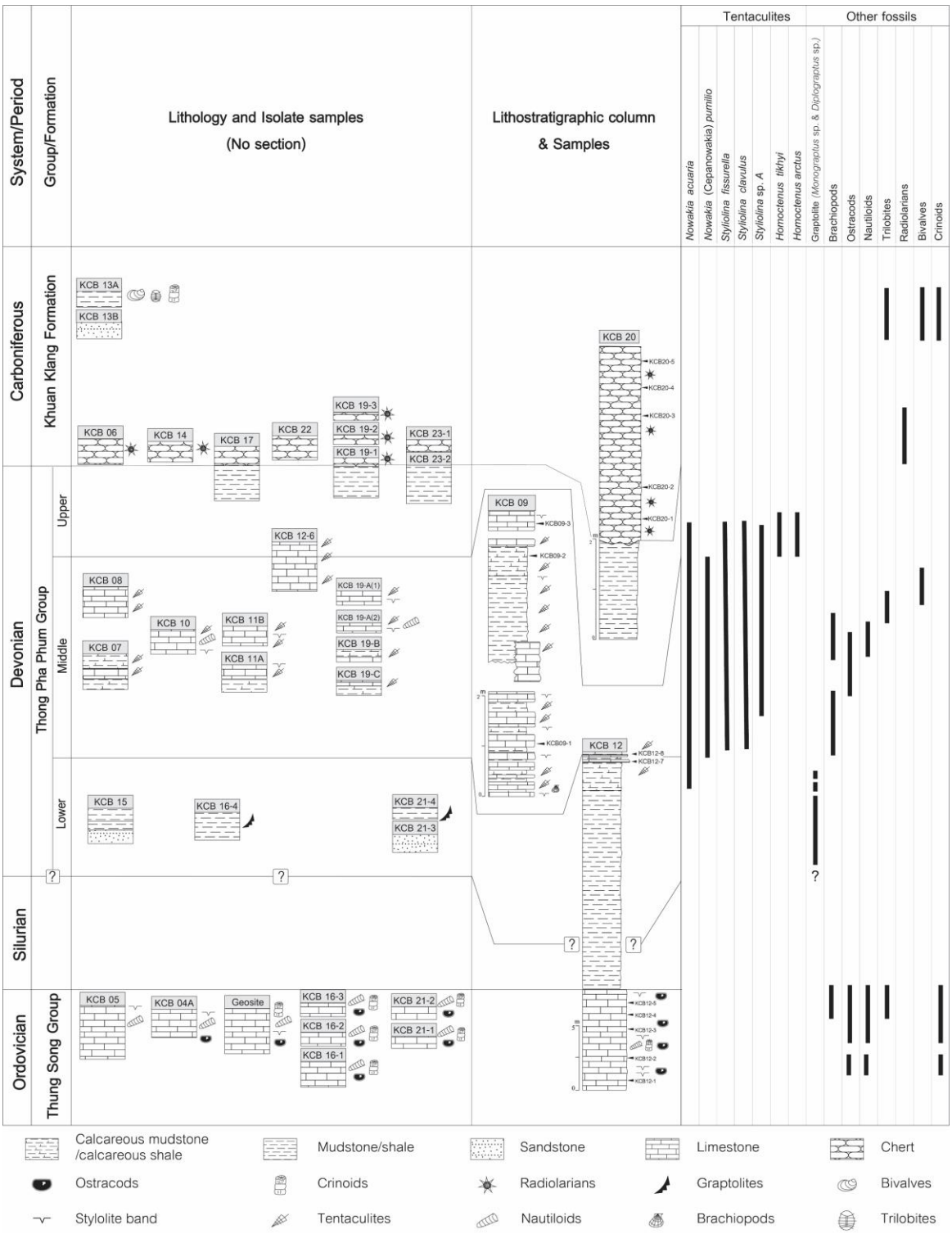

Figure 2.39 Stratigraphic correlation and fauna distribution of the Thong Pha Phum Group at Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province.

CHAPTER 3

RESULTS ON SYSTEMATIC PALEONTOLOGY

At Ban Tha Kradan area, 5 sample localities (KCB 07, KCB 08, KCB 10, KCB 11, and KCB 19) and 3 measured sections (KCB 09, KCB 12, and KCB 20) were collected samples and about 100 polished thin sections were prepared for tentaculites study. This tentaculite specimens were well preserved in bioclastic wackestone, bioclastic packstone, calci-mudstone, and calcareous shale to mudstone (Figure 3.1). Many longitudinal sections of tentaculite specimens can be found in each thin section. All thin sections were photographed by transmitted light microscope (Figure 3.2). Morphological terminology, classification, and description for study of tentaculites here follow as Boucek (1967); Fisher, (1962); Larsson, (1979); Wei (2019); Wei et al., (2012, 2019) and Wittmer & Miller (2011). In this study, three genera: Nowakia, Homoctenus and Styliolina which contains 7 species: *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio, Styliolina fissurella, Styliolina clavulus, Styliolina sp. A, Homoctenus tikhyi,* and *Homoctenus arctus*. They indicate early to late Devonian age. In size, most tentaculites within the small to medium size, from 0.2 - 3 mm. However juvenile body can be smaller than 0.2 mm, and the largest conch are as large as more than 2 cm. However, thin section photomicrographs of each genus/species are included in Plates 1-13.

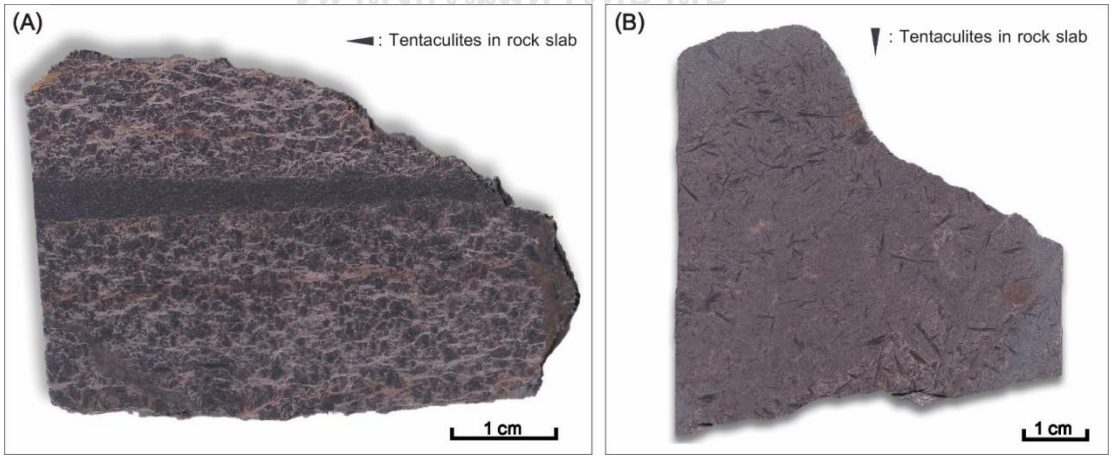

Figure 3.1 Laminated, calcareous shale to mudstone slabs with tentaculites. A: Vertical cross-section of calcareous shale with tentaculate, B: Bedding plane of calcareous shale that shows many tentaculite specimens.

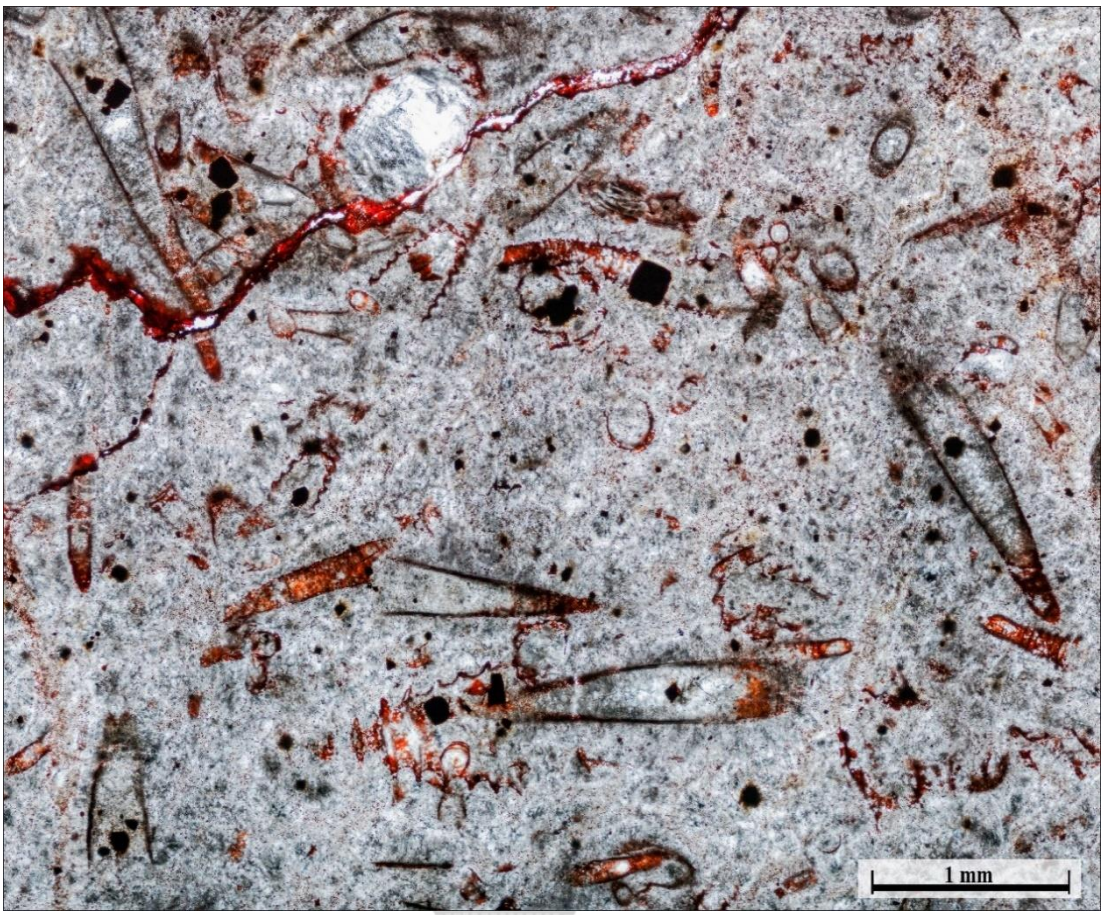

Figure 3.2 Photomicrographs of thin section shows abundant tentaculites on bedding surface of calcareous shale in the study area. Scale bar is 1 mm.

Class TENTACULITOIDAE Ljaschenko, 1955

Order DACRYOCONARIDA Fisher, 1962

Family NOWAKIDAIDAE Bouček and Prantl, 1960

Genus Nowakia (Gürich, 1896)

Nowakia acuaria

Figs. 3.3 and Figs. 3.4 (A)-(D)

1854 *Nowakia acuaria*; Richter, 1854

1962 *Nowakia acuaria*; Fisher, 1962, p. W112, Fig.55-3

1964 *Nowakia acuaria*; Bouček, 1964, p.60-69, pl.1, figs. 1-7.

1967 *Nowakia* aff. *Acuaria* (Richter); Sherrard, 1967, pl.38, figs.14-15.

1970 *Nowakia acuaria* (Richter); Churkin and Carter,1970, pl.16, figs 1-8.

1980 *Nowakia acuaria* (Richter); Zhi-wen, 1980, pl.1, figs. 15-16.

2006 *Nowakia acuaria*; Agematsu et al., 2006, p. 608, figs. 4.1-4.15.

2007 *Nowakia acuaria*; Theng and Jasin, 2007, p. 5. pl. 1, figs. 1-4.

Material: 5 specimens from the dark gray, micritic limestone (KCB12-6) on the thin section.

Description: The conch is conical-sharp and straight, medium to large size. It is about 3.5 - 5.6 mm in length and approximate 0.5 - 1.5 mm in distal width. Initial chamber is not preserved. The density of transverse rings is 8-12/mm and well-distributed. Interspaces are concave and smooth. Growth angle varies between 8º - 13º. The conch wall thickness is 10 - 22 µm. The internal surface of the wall is wavy.

Measurements: Show in the table 3.1

Occurrences: Lower to Upper Devonian (Emsian - Frasnian), section of Thong Pha Phum Group, Ban Tha Kradan area, Kanchanaburi Province, western Thailand.

Table 3.1 List of measurements for *Nowakia acuaria*

Figure of specimen	Sample no.	DEEC (mm)	ODID (mm)	WIC (mm)	LIC (mm)	CWT (mm)	PA	ATR	DTR (mm)
Fig. 3.3	KCB 12-6	5.813	1.232	-	-	0.026	-	5/1 mm	0.29-0.3
Fig. 3.4(A)	KCB 12-6	5.600	0.600	-	-	0.023	-	6/1mm	0.2-0.24
Fig. 3.4(B)	KCB 12-6	3.070	0.923	-	-	0.021	-	7/1mm	0.194
Fig. 3.4(C)	KCB 12-6	3.157	-	-	-	0.020	-	6/1mm	0.200
Fig. 3.4(D)	KCB 12-6	1.124	-	-	-	0.020	-	6/1mm	0.245

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

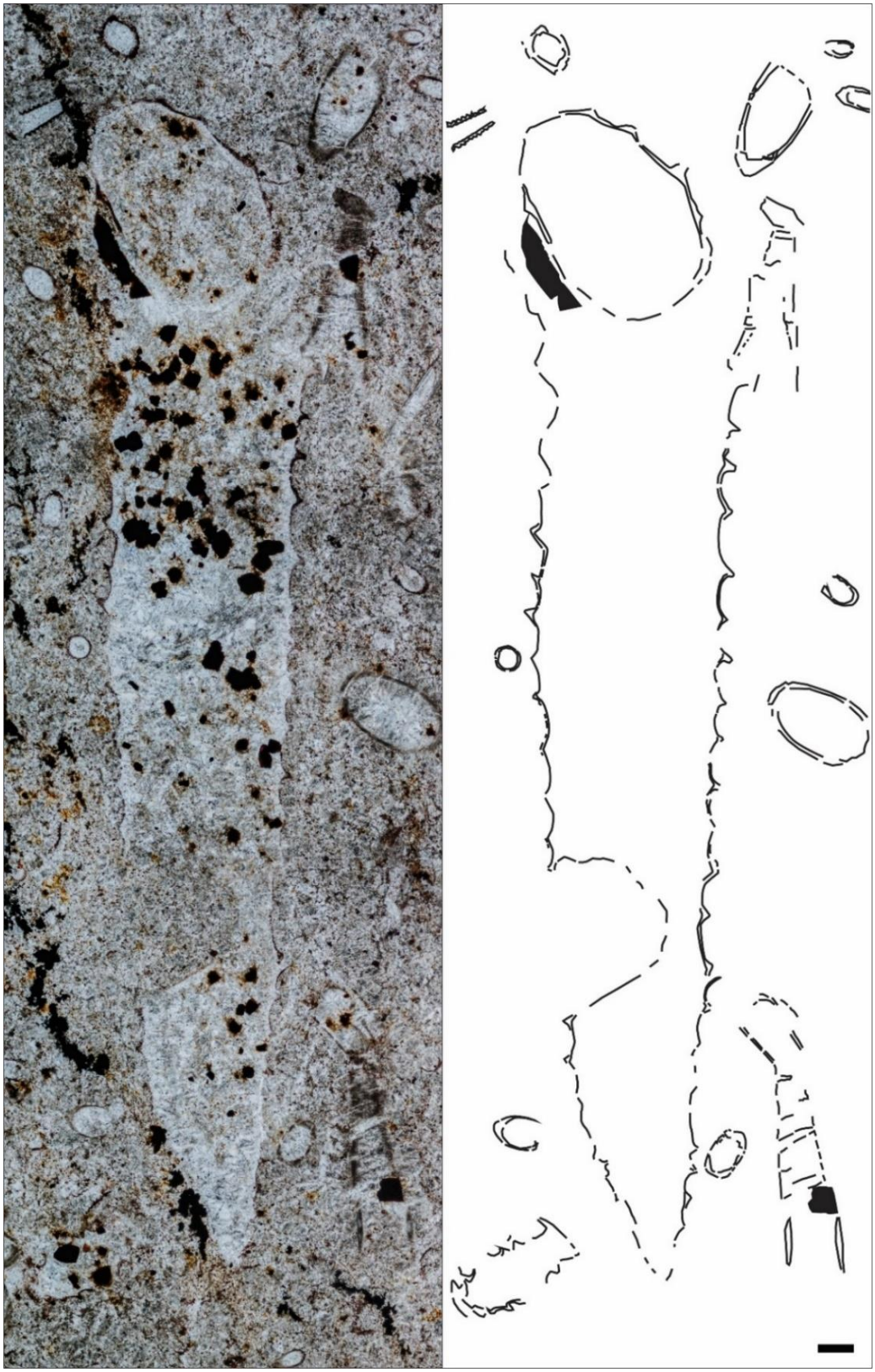

Figure 3.3 Photomicrographs and drawings of *Nowakia acuaria* (sample no. KCB 12-6) showing longitudinal section and internal ornamentation of middle distal part. Scale bar is 0.2 mm.

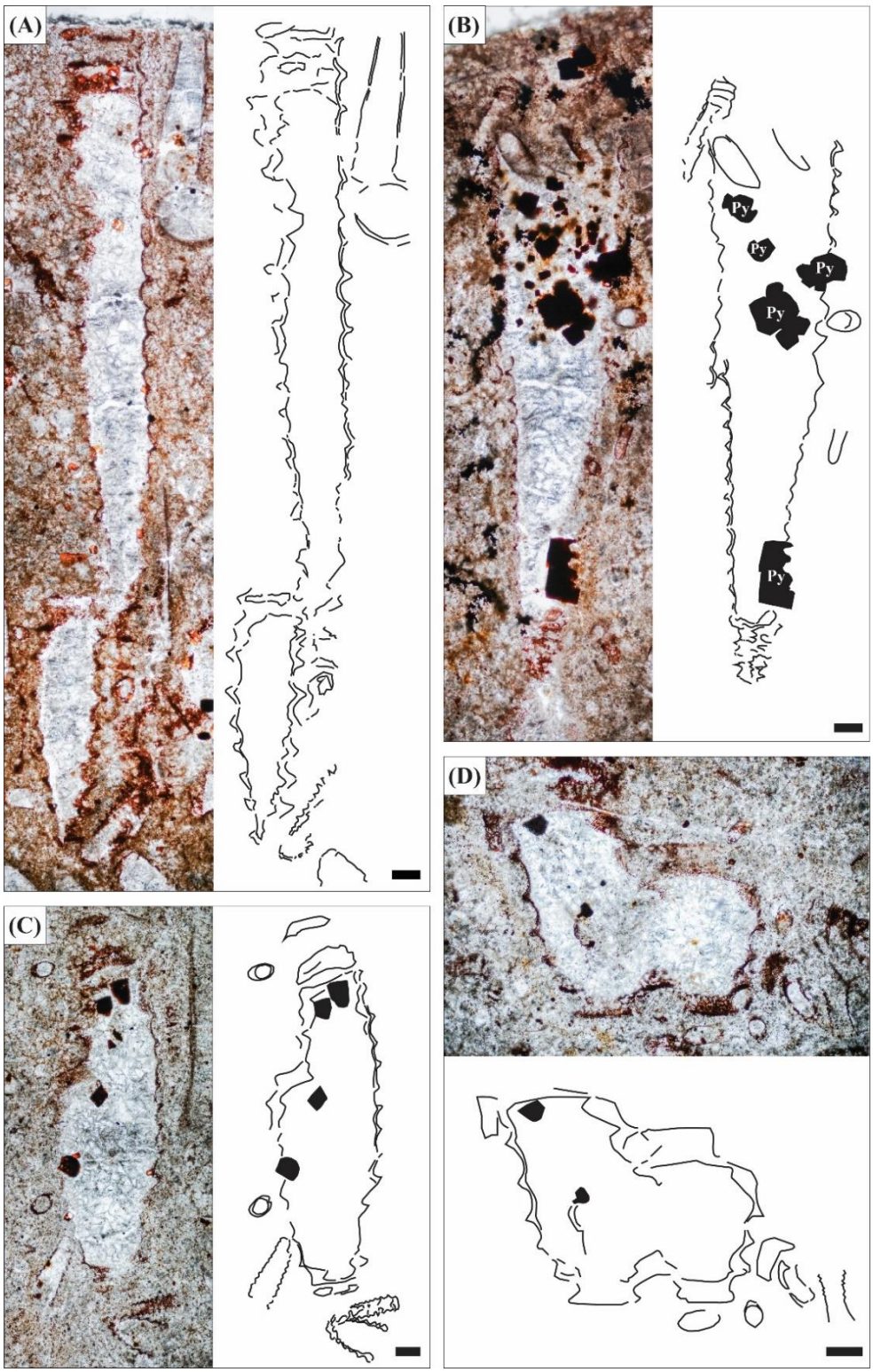

Figure 3.4 Photomicrogrphs of *Nowakia acuaria* (sample no. KCB 12-6). (A): Longitudinal section of distal part, (B): Internal of distal part and pyrite nodule (Py), (C): Distal part and internal ornamentation, (D): Internal section and transverse ring of distal part. All figures are transmitted light photomicrographs and drawings. Scale bar is 0.2 mm.

Nowakia (Cepanowakia) *pumilio*

Figs. 3.5 (A)-(F) and Figs. 3.6 (A)-(F)

2004 *Nowakia* (Cepanowakia) *pumilio* Alberti,1987; Berkyova, 2004, p.149, figs. 3, A-C.

Material: 12 specimens from KCB 09-1, KCB 09-3, and KCB19-A(1) on the thin section.

Description: Conch is a small and conical shape which slightly curved in the proximal part and straight in the middle part to distal part. Estimated length is approximate 0.5 - 0.8 mm and maximum outer distal diameter is 0.1 mm. The initial chamber is well-preserved and having a cone shape. Density of transverse ring is 10 - 12/0.5 mm and well-distributed. Growth angle varies between 7º - 15º. Interspaces are smooth and rounded concave. The conch wall thickness is 10 - 20 µm. the internal surface of the conch wall is wavy.

Measurements: Show in the table 3.2.

Occurrences: Middle Devonian (Eifelian-Givetian), middle part of section of The Thong Pha Phum Group, Kanchanaburi Province, western Thailand.

Table 3.2 List of measurements for *Nowakia* (Cepanowakia) *pumilio*

Figure of specimen	Sample no.	DEEC (mm)	ODID (mm)	WIC (mm)	LIC (mm)	CWT (mm)	PA	ATR	DTR (mm)
Fig. 3.5(A)	KCB09-3	0.750	0.110	0.070	0.083	0.013	7º	9/0.5 mm	0.065
Fig. 3.5(B)	KCB09-3	0.560	0.089	0.060	0.097	0.012	8º	10/0.5 mm	0.043
Fig. 3.5(C)	KCB09-3	0.522	-	-	-	0.019	-	5/0.5 mm	0.113
Fig. 3.5(D)	KCB09-3	0.519	0.166	-	-	0.013	-	6/0.5mm	0.115
Fig. 3.5(E)	KCB19-A(1)	0.553	0.212	-	-	0.015	-	8/0.5 mm	0.060
Fig. 3.5(F)	KCB09-3	0.346	0.121	0.116	0.199	0.018	13º	-	-
Fig. 3.6(A)	KCB09-3	0.821	0.134	0.073	0.090	0.016	10º	9/0.5mm	0.063
Fig. 3.6(B)	KCB09-3	0.556	0.089	0.080	-	0.012	9º	9/0.5mm	0.044
Fig. 3.6(C)	KCB09-3	0.594	0.134	0.076	0.091	0.01	10º	12/0.5mm	0.050
Fig. 3.6(D)	KCB09-3	0.470	0.116	0.081	0.049	0.014	13º	-	0.054
Fig. 3.6(E)	KCB09-3	0.225	-	0.081	0.093	0.014	-	-	0.046
Fig. 3.6(F)	KCB09-3	0.215	-	0.083	-	0.019	-	-	0.041

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

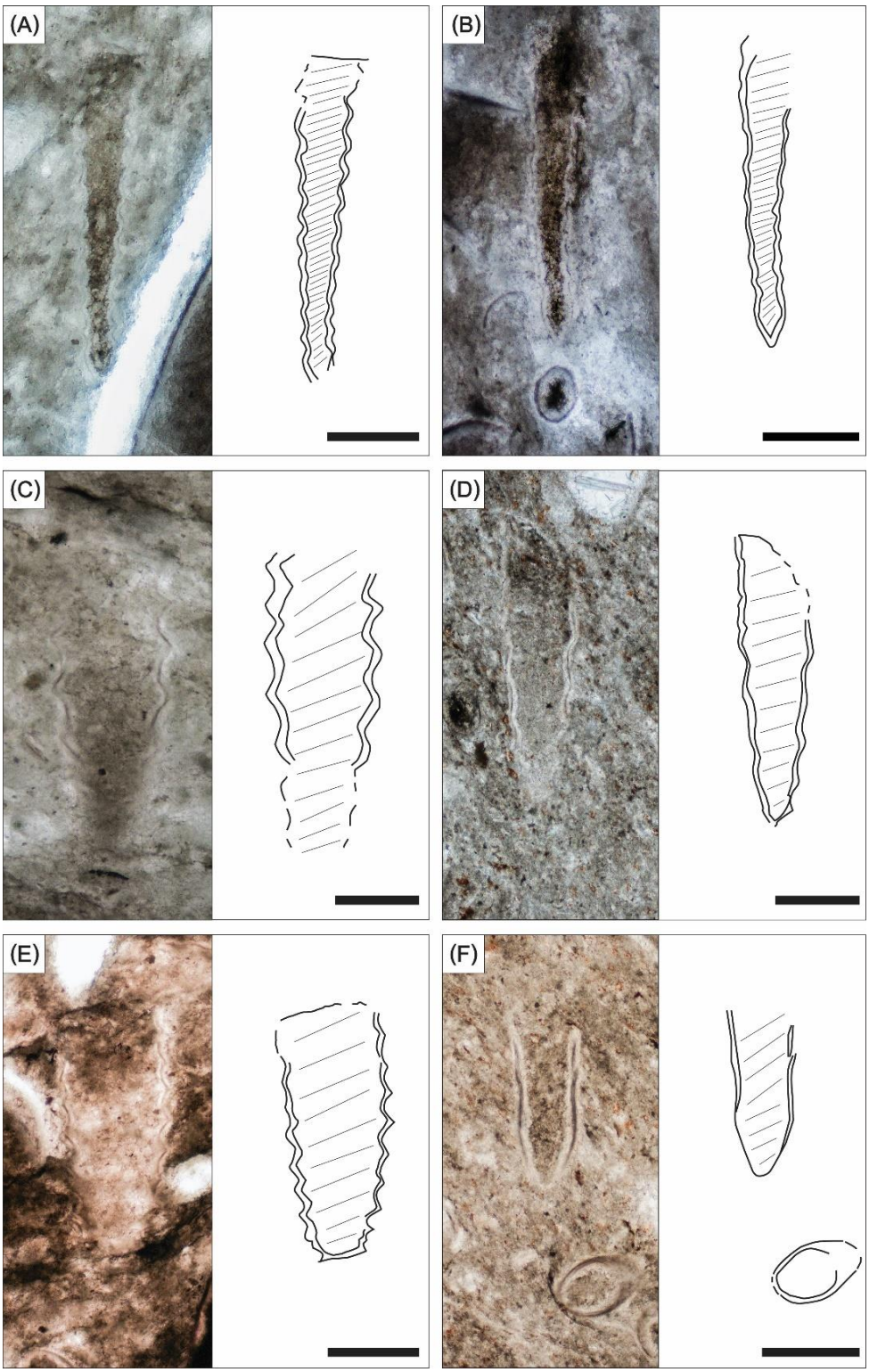

Figure 3.5 *Nowakia* (Cepanowakia) *pumilio.* (A)-(B): Longitudinal section and external ornamentation, (sample no. KCB 09-3), (C)-(D): Distal part and internal ornamentation (sample no. KCB 09-3), (E): Distal part and transverse ring (sample no. KCB 19-A (1)), (F): Proximal part and initial chamber (sample no. KCB 09-1). All figures are transmitted light photomicrographs and drawings. Scale bar is 0.2 mm.

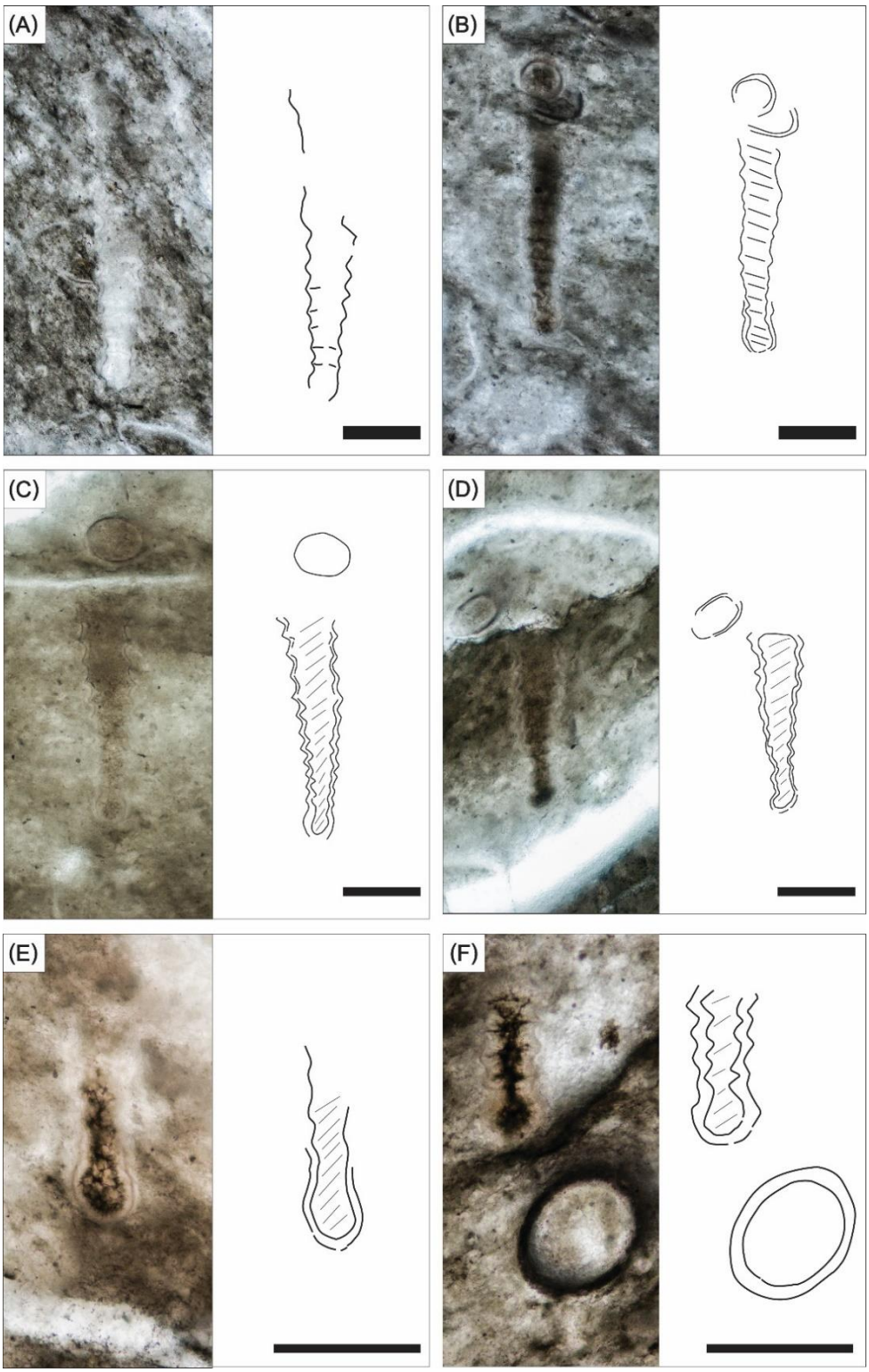

Figure 3.6 *Nowakia* (Cepanowakia) *pumilio*. (A)-(B): Longitudinal section of conch (sample no. KCB 09-3), (C)-(D): Proximal part of longitudinal section (sample no. KCB 09-3), (E)-(F): Proximal part and initial chamber (sample no. KCB 09-3). All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

Family STYLIOLINIDAE Grabau, 1912 / Gabrau & Shimer, 1910

Genus STYLIOLINA Karpinsky, 1884

Styliolina fissurella

Figs. 3.7(A)-(E) and Figs. 3.8(A)-(D)

1843 *Tentaculite fissurella* Hall, 1843, p.182. fig.71/10.

1964 *Styliolina fissurella* (Hall); Bouček, 1964, p. 127-131. pl.31. fig 1 e 2.

1970 *Styliolina* sp. cf. *Styliolina fissurella* (Hall); Churkin and Carter,1970, pl.16, figs 1-8.

1972 *Styliolina sp.* cf. *Styliolina fissurella* (Hall); Ludvigsen, 1972, p.308, pl.2, figs. 24-26, p.310, pl.3, fig. 6.

2004 *Styliolina fissurella* (Hall); Berkyová, 2004, p.152. fig.4a.

2007 *Styliolina sp*; Theng and Jasin (2007), p. 5. Pl. 1, Figs. 5-7.

2016 *Styliolina* cf. *Styliolina fissurella* (Hall); Corrigida, 2016, P. 152. Fig.26.

Material: 10 specimens preserved from KCB 12-6 and KCB 11B on the thin section.

Description: Conch is conical, straight and has medium to large size. Estimated maximum length is 3.70 mm and maximum distal diameter is 0.6 mm. Apical angle is 9º - 11º and growth angle varies between 5º - 8º. The initial chamber is well preserved, slightly elongate, and drop-shaped that 0.08 - 0.1 mm in width and 0.10 - 0.15 mm in length and merges with proximal part of conch. A small apical spine extends from the initial chamber. The conch wall thickness is about 10 - 20 µm. The surface of external and internal conch wall is flat and smooth.

Measurements: Show in the table 3.3.

Occurrences: Middle to late Devonian (Eifelian-Frasnian), section of Thong Pha Phum Group, Ban Tha Kradan area, Kanchanaburi Province, western Thailand.

Table 3.3 List of measurements for *Styliolina fissurella*,

Figure of specimen	Sample no.	DEEC (mm)	DDPE (mm)	ODID (mm)	WIC (mm)	LIC (mm)	CWT (μm)	PA
Fig. 3.7(A)-1	KCB 12-6 (A-1)	2.799	-	0.423	0.080	0.117	0.019	8.5º
Fig. 3.7(A)-2	KCB 12-6 (A-2)	1.033	-	0.278	0.100	0.150	0.018	6.6º
Fig. 3.7(B)	KCB 12-6	2.620	-	0.407	0.094	0.172	0.018	8.2º
Fig. 3.7(C)	KCB 12-6	2.620	-	0.409	0.080	0.106	0.020	8.1º
Fig. 3.7(D)	KCB 12-6	1.246	-	0.194	0.103	0.151	0.015	5.6º
Fig. 3.7(E)	KCB 12-6	0.504	-	0.123	0.089	0.129	0.011	5.9º
Fig. 3.8(A)	KCB 11B	3.447	-	0.437	0.087	0.154	0.025	7.0º
Fig. 3.8(B)	KCB 11B	3.781	-	0.512	0.117	0.183	0.018	7.6º
Fig. 3.8(C)	KCB 11B	0.988	-	0.171	0.095	0.135	0.015	6.3º
Fig. 3.8(D)	KCB 11B	0.940	-	0.295	-	-	0.012	-

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

Styliolina clavulus

Figs. 3.9(A)-(E) and Figs. 3.10(A)-(H)

1962 *Styliolina clavulus*; Fisher 1962, P.W 112, fig. 55-2.

1970 *Styliolina* sp.; Churkin and Carter,1970, pl.16, figs. 8-10.

2016 *Styliolina clavulus* Barrande, 1867; Comniskey, 2016, p.83, figs. 27(A-D).

Material: 13 specimens, KCB09-1, KCB09-2, KCB09-3, KCB12-6, KCB19-A (1) on the thin section.

Description: Conch is 0.5 - 2 mm in length and 0.1 - 0.4 mm in distal width. It is small to medium size and conical shape. Slightly curvature in the proximal part and straight in the distal part. The initial chamber is drop-like but a little different from the proximal part of the conch. Apex of initial chamber extended into a small apical spine. The conch wall

(internal and external) is flat surface and approximate 10 - 20 μm in thickness (the relatively thick-walled conch).

Measurements: Show in the table 3.4.

Occurrences: Middle-late Devonian (Eifelian-Frasnian), section of Thong Pha Phum Group, Ban Tha Kradan area, Kanchanaburi Province, western Thailand.

Table 3.4 List of measurements for *Styliolina clavulus*.

Figure of specimen	Sample no.	DEEC (mm)	DDPE (mm)	ODID (mm)	WIC (mm)	LIC (mm)	CWT (μm)	PA
Fig. 3.9(A)	KCB 12-6	1.740	-	0.335	0.100	0.147	0.014	8.1°
Fig. 3.9(B)	KCB 12-6	1.034	-	0.140	0.107	0.136	0.019	6.7
Fig. 3.9(C)	KCB 12-6	1.222	-	0.204	0.097	0.168	0.015	8.6°
Fig. 3.9(D)	KCB 12-6	0.839	-	0.191	0.103	0.133	0.014	6.4°
Fig. 3.9(E)	KCB 12-6	0.440	-	0.159	0.111	0.137	0.016	9.2°
Fig. 3.10(A)	KCB 09-1	0.663	-	0.139	0.067	0.111	0.010	9.8°
Fig. 3.10(B)	KCB 09-2	1.273	-	0.192	0.106	0.140	0.017	10°
Fig. 3.10(C)	KCB 19-A(1)	1.284	-	0.227	0.156	0.246	0.360	7.2°
Fig. 3.10(D)	KCB 19-A(1)	1.035	-	0.179	0.076	0.104	0.014	7.3°
Fig. 3.10(E)	KCB 12-6	1.046	-	0.173	0.088	0.200	0.015	7.7 °
Fig. 3.10(F)	KCB 12-6	0.475	-	0.103	0.107	0.138	0.014	4.2°
Fig. 3.10G)	KCB 19-A(1)	0.652	-	0.203	0.166	0.195	0.018	5.4°
Fig. 3.10(H)	KCB 19-A(1)	0.312	-	-	0.104	0.159	0.010	4.8°

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

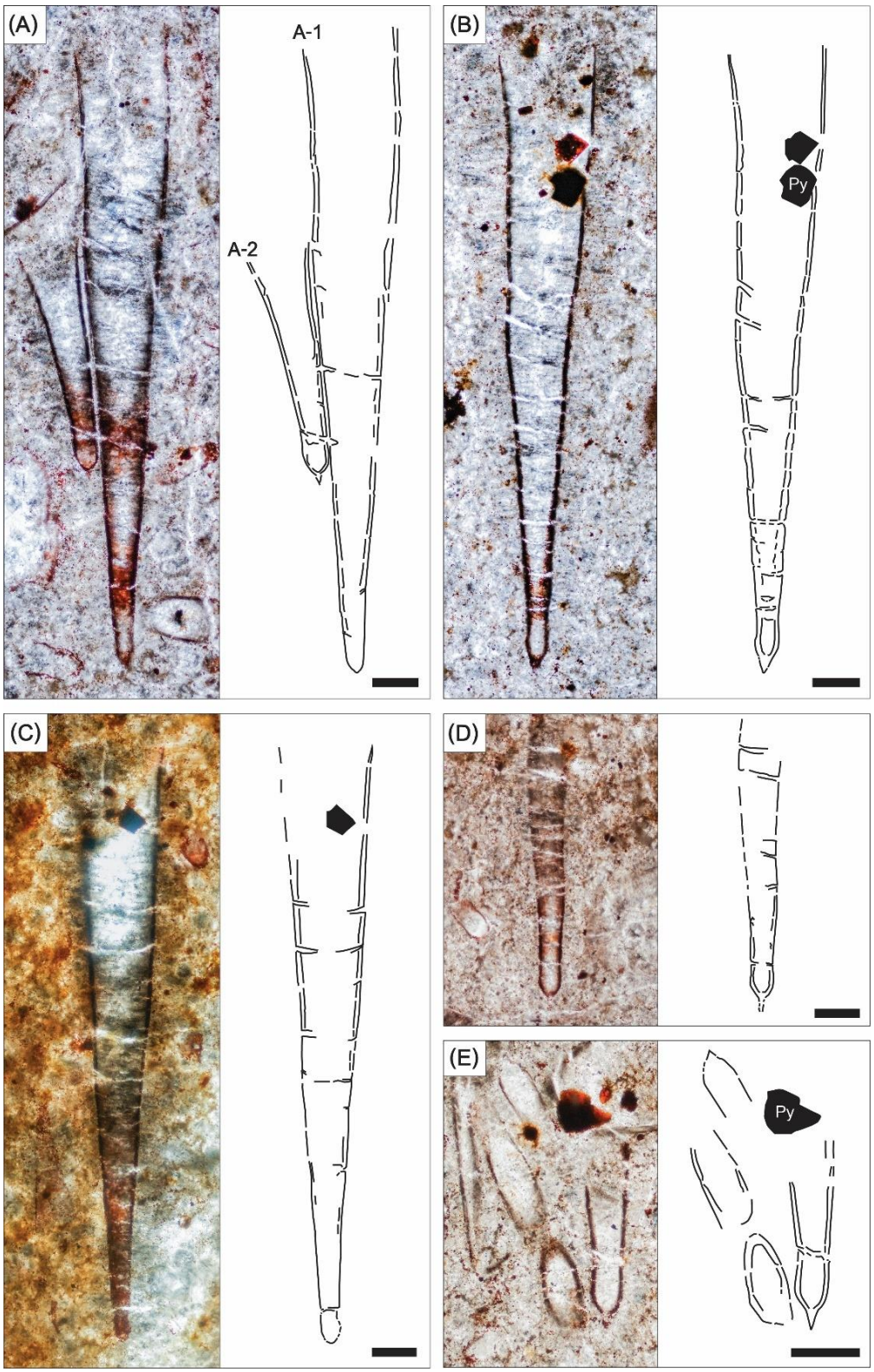

Figure 3.7 *Styliolina fissurella* of sample no. KCB 12-6, (A): Longitudinal section, (B)-(C): Internal ornamentation of longitudinal section, (D): External ornamentation with initial chamber, (E): Initial chamber and small apical spine with pyrite nodule. All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

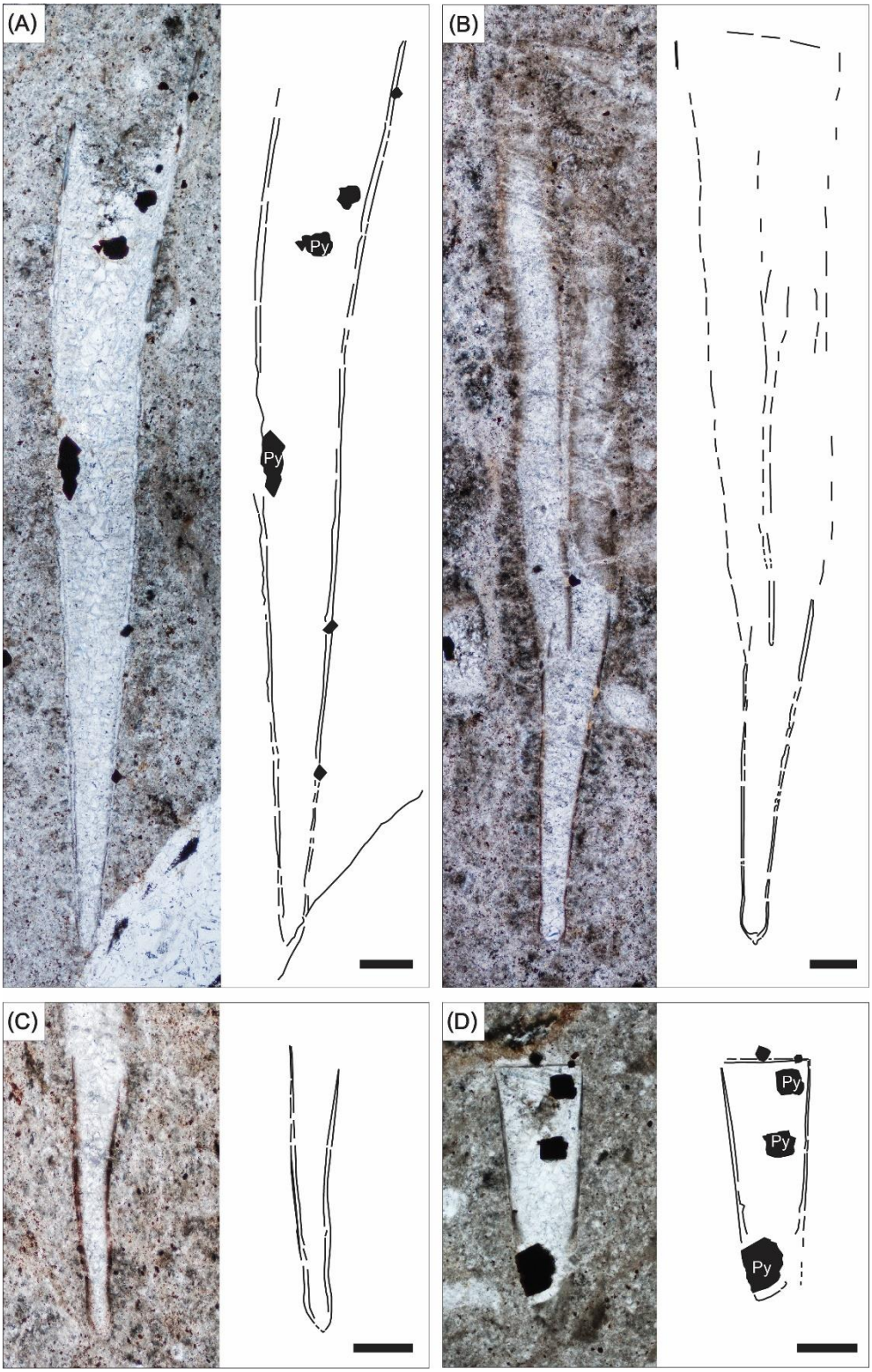

Figure 3.8 *Styliolina clavulus* of sample no. KCB 11B, (A): Longitudinal section with pyrite nodule (Py), (B): Longitudinal section and initial chamber, (C): Proximal part with initial chamber, (C): Distal part of conch with pyrite nodule (Py). All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

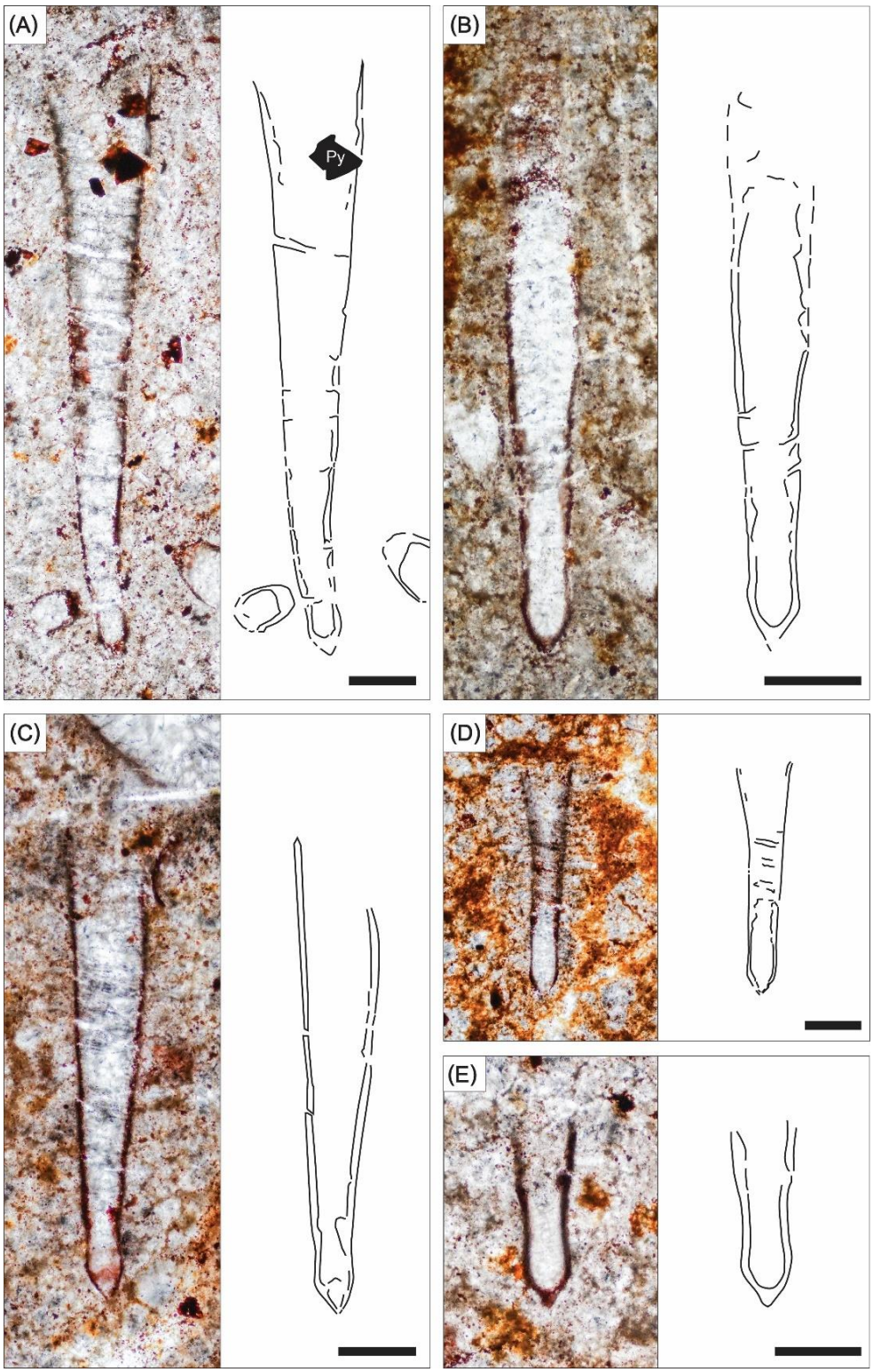

Figure 3.9 *Styliolina clavulus* of sample no. KCB 12-6, (A): Longitudinal section of conch with pyrite nodule (Py), (B): Internal section with initial chamber, (C): Internal of longitudinal section and initial chamber, (D): Early proximal part of conch, (E): Juvenile part and initial chamber with apical spine. All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

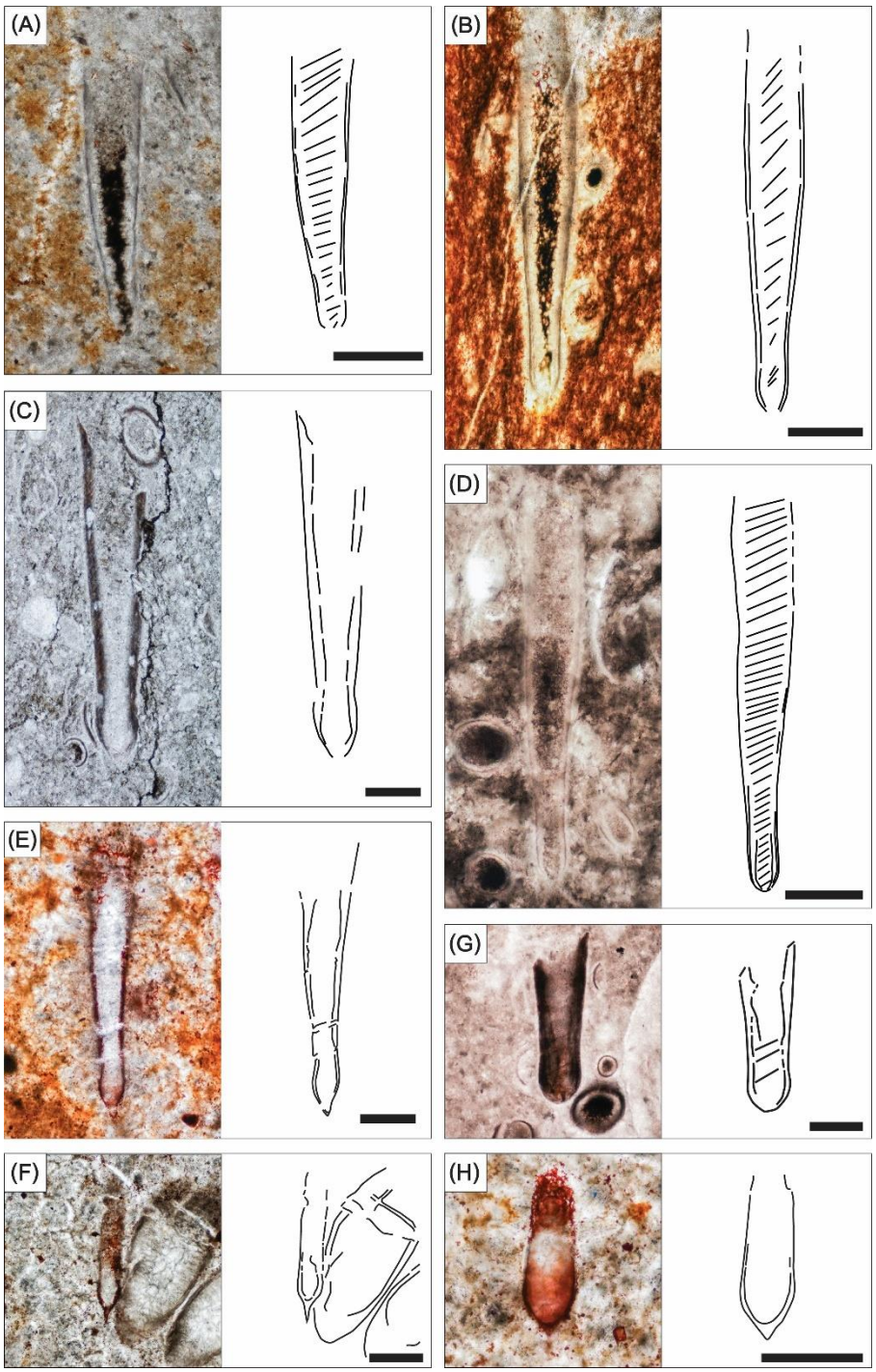

Figure 3.10 *Styliolina clavulus,* (A): Longitudinal section of proximal part (sample no. KCB 09-1), (B): Longitudinal section with initial chamber (sample no. KCB 09-2), (C)-(D): Longitudinal section with initial chamber (sample no. KCB 19-A(1)), (E): Juvenile part and initial chamber with apical spine (sample no. KCB 12-6), (F): Initial chamber with apical spine (sample no. KCB 12-6), (G)-(H): Initial chamber of juvenile part and small apical spine (sample no. KCB 19-A(1)). All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

Styliolina sp. A

Figs. 3.11(A)-(F)

Material: 6 specimens, KCB09-1 and KCB12-6 on the thin section.

Description: The conch has small size and curve conch that curved in the proximal part and slightly curved in the distal part. It is about 1 - 2.7 mm in length and 0.1 - 0.33 mm in distal width. The external and internal of wall surface are flat and smooth. Conch wall thickness is approximately 10 - 19 μm. The initial chamber is complete and well-preserved. The apex of the initial chamber has a short spine that extended from this part.

Measurements: Show in the table 3.5.

Occurrences: Middle to late Devonian, section of Thong Pha Phum Group in Ban Tha Kradan area, Kanchanaburi Province.

Table 3.5 List of measurements for *Styliolina* sp. A

Figure of specimen	Sample no.	DEEC (mm)	DDPE (mm)	ODID (mm)	WIC (mm)	LIC (mm)	CWT (μm)	PA
Fig. 3.11(A)	KCB 12-6	1.500	0.058	0.249	0.087	0.114	0.016	11º
Fig. 3.11(B)	KCB 12-6	2.747	-	0.377	-	-	0.019	-
Fig. 3.11(C)	KCB 12-6	0.923	0.053	0.203	0.083	0.101	0.110	6.7º
Fig. 3.11(D)	KCB 12-6	1.109	-	0.245	-	-	0.017	-
Fig. 3.11(E)	KCB 09-1	0.713	0.076	0.143	0.065	0.083	0.010	10º
Fig. 3.11(F)	KCB 12-6	0.562	0.033	0.151	0.087	0.132	0.010	-

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

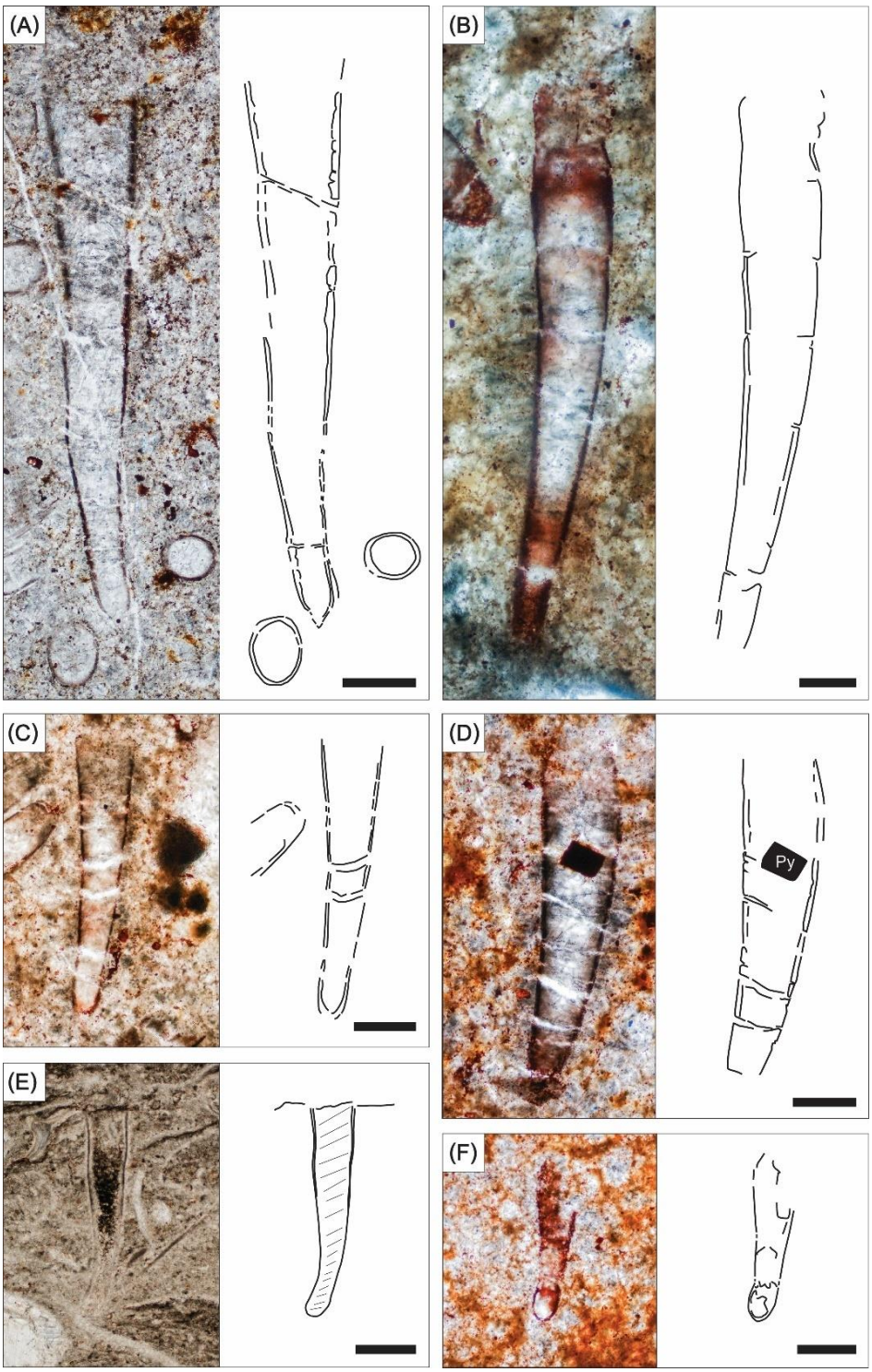

Figure 3.11 *Styliolina* sp. A., (A): Longitudinal section (sample no. KCB 12-6), (B): External ornamentation of proximal to distal part (sample no. KCB 12-6), (C): Proximal part of longitudinal section (sample no. KCB 12-6), (D): External ornamentation of distal part with pyrite nodule(Py) (sample no. KCB 12-6), (E): Internal section of conch (sample no. KCB 09-1), (F): Juvenile part with initial chamber (sample no. KCB 12-6). All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

Order HOMOCTENIDA Boucek, 1964

Family HOMOCTENIDAE Lyashenko, 1955

Genus Homoctenus Lyashenko, 1955

Homoctenus tikhyi

Figs. 3.12(A)-(F) and Figs. 3.13(A)-(E)

1959 *Homoctenus tikhyi*; Lyaschenko, 1959, p. 98, pl.17, figs. 1-4.

2000 *Homoctenus* sp. cf. *Homoctenus tikhyi* (Lyaschenko, 1959); Li, 2000, p. 972, fig. 4.2.

2015 *Homoctenus* sp. cf. *Homoctenus tenuicinctus* Roemer, 1985; Hansan et al., 2015: p. 555, Figs. 4 and p. 556, Figs. 5.

Material: 11 specimen, KCB12-6 on the thin section.

Description: The conch is straight to slightly curved. It is in is small - medium size and conical shape that approximately 1 - 3 mm in length and 0.2 mm in distal width. Transverse rings decrease into the distal part. Density of transverse rings is 18 - 22/1 mm. Interspaces are concave and smooth surface. The internal and external conch wall is wavy in the proximal part to distal part. Conch wall thickness is 10 - 15 μm. The initial chamber is well-preserved and elongated shape or like-conical that flat surface. This part is about 0.1 mm in width and approximately 0.1 - 0.2 mm in long.

Measurements: Show in the table 3.6.

Occurrences: late Devonian (Frasnian), section on Thong Pha Phum Group in Ban Tha Kradan area, Kanchanaburi Province.

Table 3.6 List of measurements for *Homoctenus tikhyi*

Figure of specimen	Sample no.	DEEC (mm)	DDPE (mm)	ODID (mm)	OPRD (mm)	WIC (mm)	LIC (mm)	CWT (mm)	PA	ATR	DTR (mm)
Fig. 3.12(A)	KCB12-6	2.371	-	0.591	-	-	-	0.019	6.1°	17/1mm	0.077
Fig. 3.12(B)	KCB12-6	1.709	-	-	-	-	-	0.010	5.7°	21/1mm	0.050
Fig. 3.12(C)	KCB12-6	0.705	-	0.182	0.097	0.113	0.161	0.010	12°	12/0.5mm	0.044
Fig. 3.12(D)	KCB12-6	0.825	-	0.210	-	-	-	0.013	10°	9/0.5mm	0.056
Fig. 3.12(E)	KCB12-6	0.844	-	0.222	-	-	-	0.012	10 °	11/0.5mm	0.052
Fig. 3.12(F)	KCB12-6	0.536	-	-	0.110	0.131	0.196	0.011	7.2°	-	0.034
Fig. 3.13(A)	KCB12-6	2.097	-	0.395	-	-	-	0.016	10°	20/1mm	0.073
Fig. 3.13(B)	KCB12-6	1.894	-	0.400	-	0.114	0.194	0.012	11°	16/1mm	0.086
Fig. 3.13(C)	KCB12-6	1.841	-	0.384	-	-	-	0.013	11°	15/1mm	0.088
Fig. 3.13(D)	KCB12-6	1.030	-	-	-	-	-	0.013	-	18/1mm	0.047
Fig. 3.13(E)	KCB12-6	0.538	-	0.147	-	-	-	0.009	-	12/1mm	0.055

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

Homoctenus arctus

Figs. 3.14 (A)-(E) and Figs. 3.15(A)-(F)

1995 *Homoctenus arctus*; Li, 1995, p. 164-165, figs. 6-7.

2000 *Homoctenus arctus*; Li, 2000, p. 972, figs. 4.5-4.6.

2018 *Homoctenus* sp. A; Komatsu et al., 2018, p. 9, figs. 6 (e-l).

Material: 10 specimen, KCB12-6 on the thin section.

Description: The conch has small sized as well as conical shape in the proximal part and slightly cylindrical in the distal part. It is curved in initial chamber to the proximal part. Maximum length is approximately 1.4 - 1.5 mm with outer distal width is 0.1 - 0.3 mm. Transverse ring is wavy and density is 20 - 23 mm/1mm. Interspaces are concave

and smooth. Initial chamber is drop-shape and flat surface. The conch wall is thin with is about 8 - 10 μm in thickness. The internal surface of conch wall is wavy.

Measurements: Show in the table 3.7.

Occurrences: Late Devonian (Frasnian), middle part of section of Thong Pha Phum Group in Ban Tha Kradan area, Kanchanaburi Province, western Thailand.

Table 3.7 List of measurements for *Homoctenus arctus*

Figure of specimen	Sample no.	DEEC (mm)	DDPE (mm)	ODID (mm)	OPRD (mm)	WIC (mm)	LIC (mm)	CWT (mm)	PA	ATR	DTR (mm)
Fig. 3.14(A)	KCB12-6	3.240	-	0.458	-	-	-	0.016	10º	16/1mm	0.076
Fig. 3.14(B)	KCB12-6	1.284	0.080	0.287	0.091	0.113	0.170	0.013	10º	20/1mm	0.053
Fig. 3.14(D)	KCB12-6	0.397	-	0.225	-	-	-	0.010	-	13/0.4mm	0.037
Fig. 3.14(E)	KCB12-6	1.397	-	0.280	-	-	-	0.015	-	15/1mm	0.070
Fig. 3.15(A)	KCB12-6	1.628	0.088	0.343	0.087	0.107	0.150	0.016	11º	19/1mm	0.062
Fig. 3.15(B)	KCB12-6	1.547	0.069	0.289	0.074	0.105	0.195	0.013	10º	24/1mm	0.048
Fig. 3.15(C)	KCB12-6	1.229	-	-	-	-	-	0.016	-	-	0.086
Fig. 3.15(D)	KCB12-6	0.463	0.038	0.157	0.100	0.130	0.188	0.012	11º	-	0.040
Fig. 3.15(E)	KCB12-6	0.713	-	0.185	-	-	-	0.12	-	12/0.5mm	0.049
Fig. 3.15(F)	KCB12-6	0.463	0.038	0.157	0.100	0.130	0.188	0.012	11º	-	0.040

Remark: **DEEC** (Distance between ends of conch), **DDPE** (Distance of deflection of the proximal end from a sagittal plane through the living chamber), **ODID** (Outer distal diameter), **OPRD** (Outer proximal diameter), **WIC** (Width of initial chamber), **LIC** (Length of initial chamber), **CWT** (Conch wall thickness), **PA** (Proximal growth angle), **ATR** (Amount of transverse ring per mm.) and **DTR** (Distal between of transverse ring (interspace)).

Figure 3.12 Photomicrographs of *Homoctenus tikhyi* (sample no. KCB 12-6), (A): External ornamentation in the juvenile part and internal ornamentation in the adult part, (B): External ornamentation of proximal part, (C): Proximal part and initial chamber, (D): Internal ornamentation of proximal part with pyrite nodule (Py), (E): Internal ornamentation of proximal part, (F): Initial chamber with small apical spine. All figures are transmitted light photomicrographs and drawings. Scale bar is 0.2 mm.

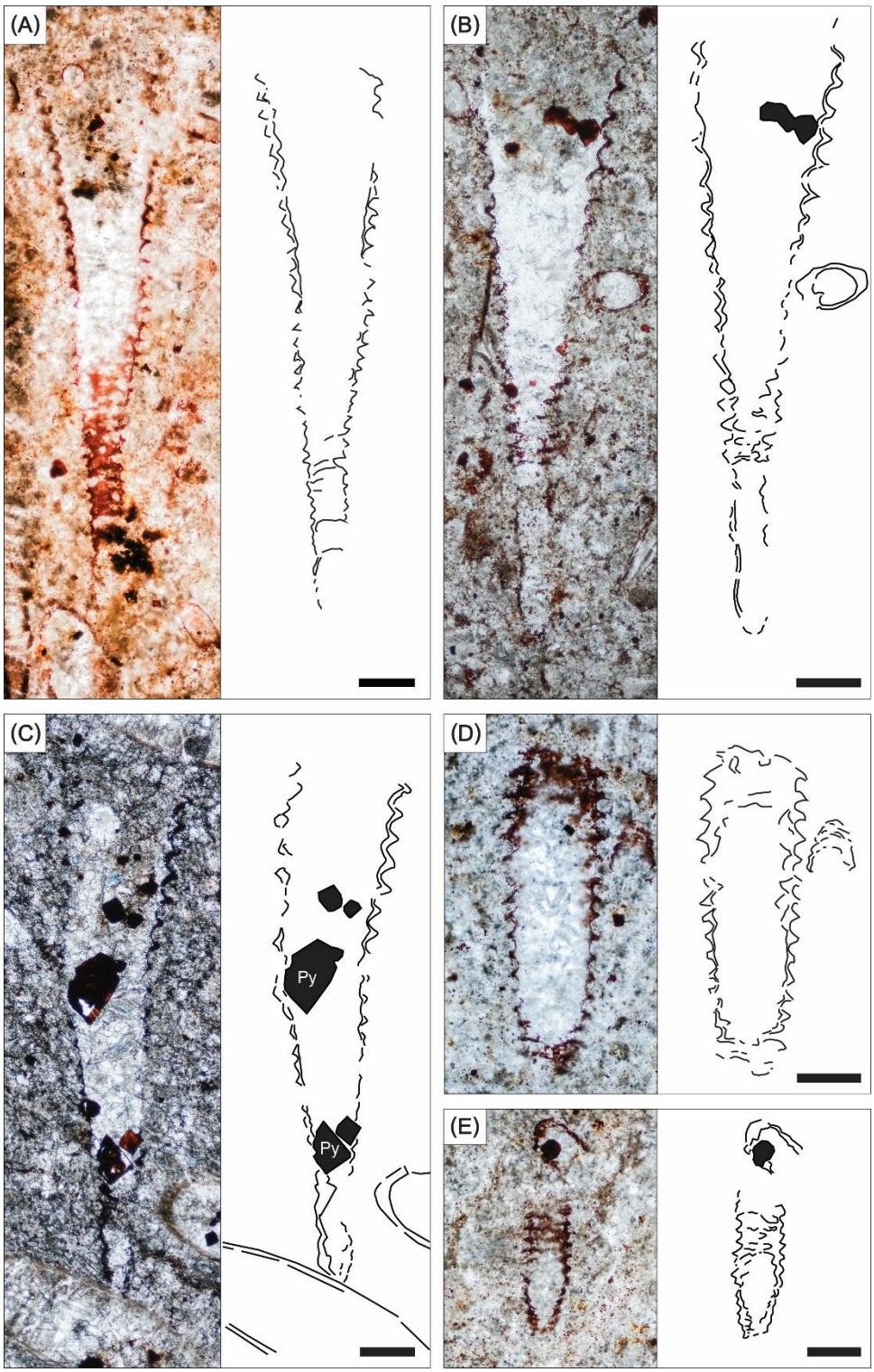

Figure 3.13 *Homoctenus tikhyi* of sample no. KCB 12-6, (A): Longitudinal section, (B): Internal longitudinal section and poorly preserved, (C): Internal ornamentation of proximal to distal part with pyrite nodule (Py), (D): Internal ornamentation and transverse ring of middle distal part, (E): Externa ornamentation of proximal part. All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

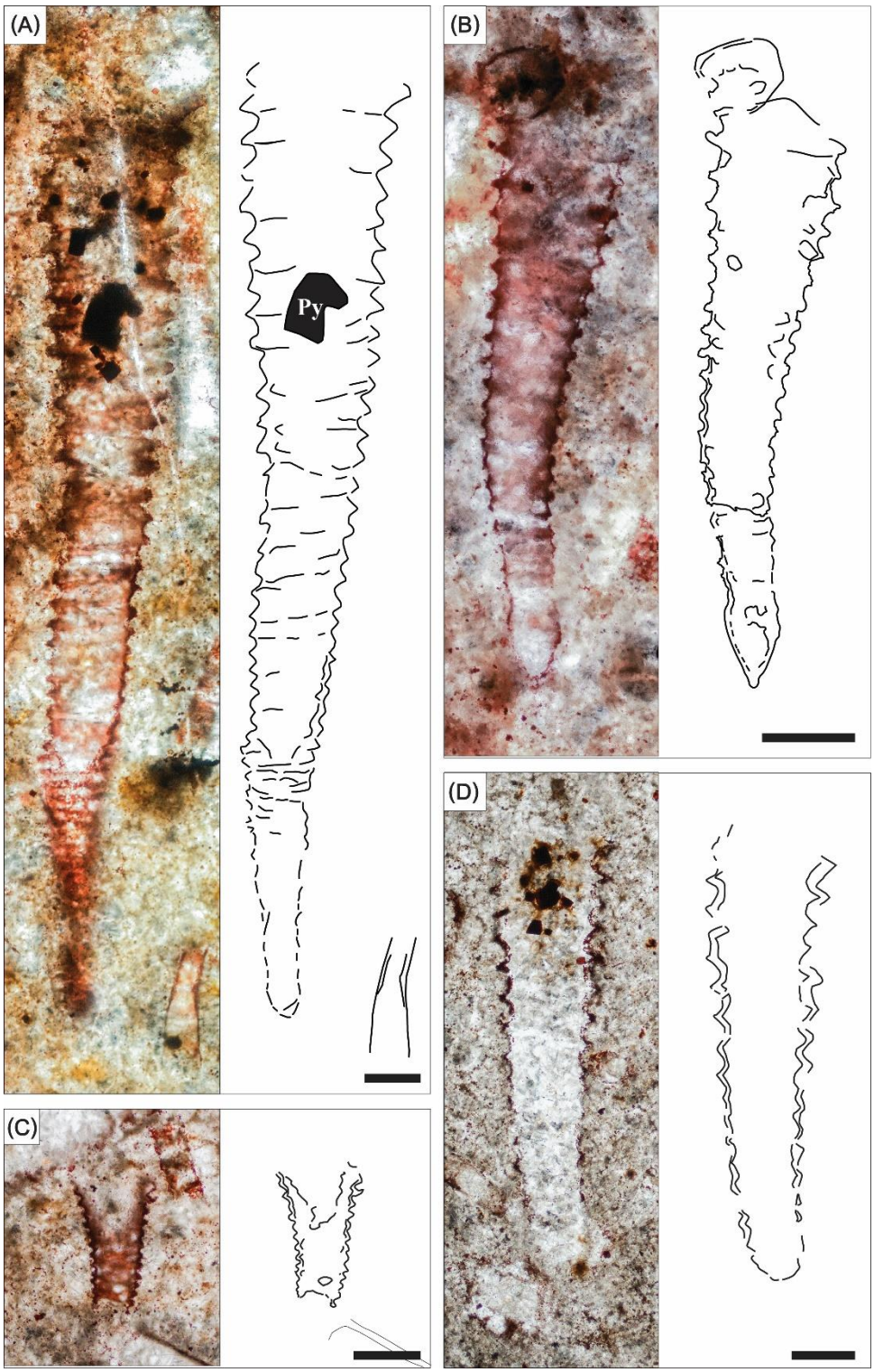

Figure 3.14 *Homoctenus arctus* of sample no. KCB 12-6, (A): External ornamentation of longitudinal section with pyrite nodule (Py), (B): External ornamentation of longitudinal section with initial chamber, (C): External ornamentation with transverse ring, (D): Internal ornamentation of proximal part. All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

Figure 3.15 *Homoctenus arctus* of sample no. KCB 12-6, (A): Longitudinal section, (B): External ornamentation of proximal part with initial chamber, (C): External ornamentation of distal part, (D): External ornamentation with initial chamber, (E): Internal ornamentation of proximal part, (F): Initial chamber and small apical spine. All figures are transmitted light photomicrographs of thin section and drawings. Scale bar is 0.2 mm.

CHAPTER 4

AGE DETERMINATION AND PALEOENVIRONMENT ANALYSIS

4.1 Age determination

In the study area, the Thong Pha Phum group has been dated paleontologically to be Silurian to Devonian age based on graptolites and tentaculites (Khaowwiset et al., 2010; Meesook, 2013; Polwichai, 2013). Siliciclastic beds in the KCB 16 and KCB 21 consist mainly shale, siltstone and fine-grained sandstone. Grey shale to black shale samples containing graptolites were collected from shale beds of the KCB 16 and KCB 21. This graptolite fauna consists at least two species, *Monograptus* sp. and *Diplograptus* sp. Wongwanich et al., (1990) reported many kinds of fossils assemblage, including tentaculite, graptolite and trilobite from Silurian-Devonian rocks in Satun Province, southern Thailand. Wonganan and Caridroit (2005) also reported graptolite faunas which is Emsian graptolite from black siliceous shale in Chiang Dao district, Chiang Mai, northern Thailand. In addition, Hassan et al., 2013 reported an occurrence of Early Devonian graptolites from black carbonaceous shales in the northwest Peninsular Malaysia. The age of these graptolite faunas is probably Silurian? to early Devonian (Emsian). However, more detailed study of the graptolites will be able to determine the age of the siliciclastic beds

According to previous works on tentaculites by Fisher (1962), Boucek (1967), Hagen and Kemper (1976); Larsson (1979), Li (2000), Agematsu et al. (2006), Wittmer and Miller (2011), and Wei et al. (2012, 2019) are assigned as the Silurian-Devonian age. On the basis of tentaculite faunas-bearing rocks succession examined in this study had been assigned to the Devonian rocks. Several rock samples, collected from the measured sections (KCB 09, KCB 12, and KCB 20) and sample localities (KCB 07, KCB 08, KCB 10, KCB 11, and KCB 19) of this study, yield numerous tentaculite (Table 2.1). These faunas are found from bioclastic wackstone, bioclastic packstone, calci-mudstone, calcareous shale to mudstone and siltstone. Seven species belonging to 3 genera could be identified herein, *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*,

Styliolina fissurella, Styliolina clavulus, *Styliolina* sp. A., *Homoctenus tikhyi* and *Homoctenus arctus* (see also Table 2.1). As mentioned above, tentaculite fauna (*Nowakia* sp. and *Styliolina* sp.) similar to those of the Ban Tha Kradan area have been reported from several localities in Thailand and Malaysia: Thong Pha Phum area (Hahn & Siebenhüner, 1982; Savage et al., 2006), Si Sawat area (e.g., Kobayashi, 1958, Pitakpaivan et al., 1969) Satun area (e.g., Agematsu et al., 2006b; Wongwanich et al., 1990) and Kampung Guar Jentik and Perlis areas of northwester Malaysia (e.g., Hassan et al., 2013; Ong & Jasin, 2007). *Nowakia acuaria,* is an Emsian tentaculite, that has been reported from the Satun province, southern Thailand and northwest Peninsula Malaysia (Agematsu et al., 2006b; Hassan et al., 2013; Ong & Jasin, 2007). *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella, Styliolina clavulus* and *Styliolina* sp. A. indicate middle Devonian age. *Homoctenus tikhyi* and *Homoctenus arctus* indicate a late Devonian (Frasnian) age. The uppermost of the Thong Pha Phum group, this part is underlain by well-bedded, Carboniferous chert. But fossil was rarely found in mudstone. The chert sample was collected from the bottom of chert bed of KCB19 area (sample no. KCB19-1) showing good preservation of Carboniferous radiolarians.

The ages of the rock sequences of the Thong Pha Phum Group in the study area are as follows (Table 4.1). Siliciclastic beds in the KCB 16 and KCB 21 are the probably Silurian? to early Devonian (Emsian). The age of the carbonate and siliciclastic sequences of the KCB 09 and KCB 12 sections are younger than early Devonian (Emsian). The bottom of siliciclastic sequences of the KCB 20 section is late Devonian, respectively.

Table 4.1 Age determination of tentacultes and graptolites of the Thong Pha Phum Group.

Period	Epoch	Age	Group	Tentaculites							
				Nowakia acuaria	*Nowakia* (Cepanowakia) *pumilio*	*Styliolina fissurella*	*Styliolina clavulus*	*Styliolina* sp. A	*Homoctenus tikhyi*	*Homoctenus arctus*	Graptolite (*Monograptus* sp. & *Diplograptus* sp.)
Devonian	Late	Famennian	Thong Pha Phum	▮		▮	▮	▮	▮	▮	
		Frasnian			▮						
	Middle	Givetian									
		Eifelian									
	Early	Emsian									
		Pragian									▮
		Lochkovian									?
Silurian											

4.2 Depositional environments

The interpretation of the depositional environments of the Thong Pha Phum Group is essentially based on lithostratigraphy, sedimentary structure, petrography, and fossil contains. The reconstruction of possible depositional environment as summarized is shown in Table 4.2.

The lowest unit of the Thong Pha Phum group within the study area is mainly siliciclastic facies, overlying the Ordovician limestone strata. These facies are characterized by grey to black siliceous shale, siltstone and sandstone. The sandstone is pale brown to white, fine- to course-grained, subangular to subrounded, feldspar rich and poorly cement. The sedimentary structure is present by the lamination and very thin-bedded. It distributed in some area in the northern and central parts of Ban Tha Kradan area. Petrographically, arkosic wacke (sample no. KCB 21-3) which shows clast

supported texture, medium- to coarse-grained. Fossils are abundant in KCB 16 and KCB 21 localities, consisting of graptolites such as *Monograptus* sp. and *Diplograptus* sp. On the basis of the lithology and graptolites, the depositional environment of this portion was relative on slope to basin that low energy during the Silurian? to early Devonian time. The middle unit of the Thong Pha Phum Group, the characteristic lithology of this group is mainly composed of limestone (micritic limestone and argillaceous limestone) interbedded with calcareous shale to mudstone and intercalated with marl and siltstone. Sedimentary structure: lamination, very thin- to thick-bedded, well- bedded, graded bedding and stylolite band are found in the limestone and siliciclastic rocks (sample: KCB 07, KCB 08, KCB 09, KCB 10, KCB 11, KCB 12, KCB 19, and KCB 20). The petrography is predominantly presented by bioclastic wackestone, bioclastic packstone, calci-mudstone, mudstone and siltstone with pyrite dissemination. Fossils include abundant tentaculites *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella, Styliolina clavulus*, *Styliolina* sp. A. *Homoctenus tikhyi* and *Homoctenus arctus*. Ostracods, nautiloids, trilobite and brachiopods are also found. The uppermost of this group is medium to thick sequence of siliciclastic rocks which underlies by the well-bedded, Carboniferous chert with sharp contact. It is composed of yellowish brown to light grey, laminar, siliceous, shale to mudstone with pyrite dissemination. Fossils are rare in siliceous shale. Based on the lithostratigraphy, sedimentary structure and fossil assemblages, depositional environment of Thong Pha Phum Group is deposited in the slope to basin environments in low energy condition during the Silurian? -Devonian time (Flügel & Munnecke, 2010).

Table 4.2 Summarized interpretation of depositional environments of the Thong Pha Phum Group in study area.

Group		Lithology	Thickness (m)	Sedimentary structure	Petrography	Fossil	Depositional environment
Thong Pha Phum Group	Upper part	Shale and mudstone with pyrite disseminations	10-20	Lamination	-	Trace fossils? (very rare)	Deep marine in low energy condition
	Middle part	Limestone (micritic limestone and argillaceous limestone) interbedded with calcareous shale to mudstone and intercated with marl and siltstone.	30-40	Lamination, very thin- to thick-bedded, well-bedded, graded bedding, stylolite band	Bioclatic wackestone, bioclastic packstone, calci-mudstone, calcite vein with pyrite nodule	Tentaculites (*Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio, Styliolina fissurella, Styliolina clavulus, Styliolina* sp. A, *Homoctenus tikhyi* and *Homoctenus arctus*), ostracods, nautiloids, trilobites, and brachiopods	Lower slope to deep marine
	Lower part	Siliceous shale, mudstone siltstone and sandstone	10-20	Lamination and very thin-bedded	Arkosic wacke	Graptolite (*Monograptus* sp. and *Diplograptus* sp.)	Lower slope to deep marine

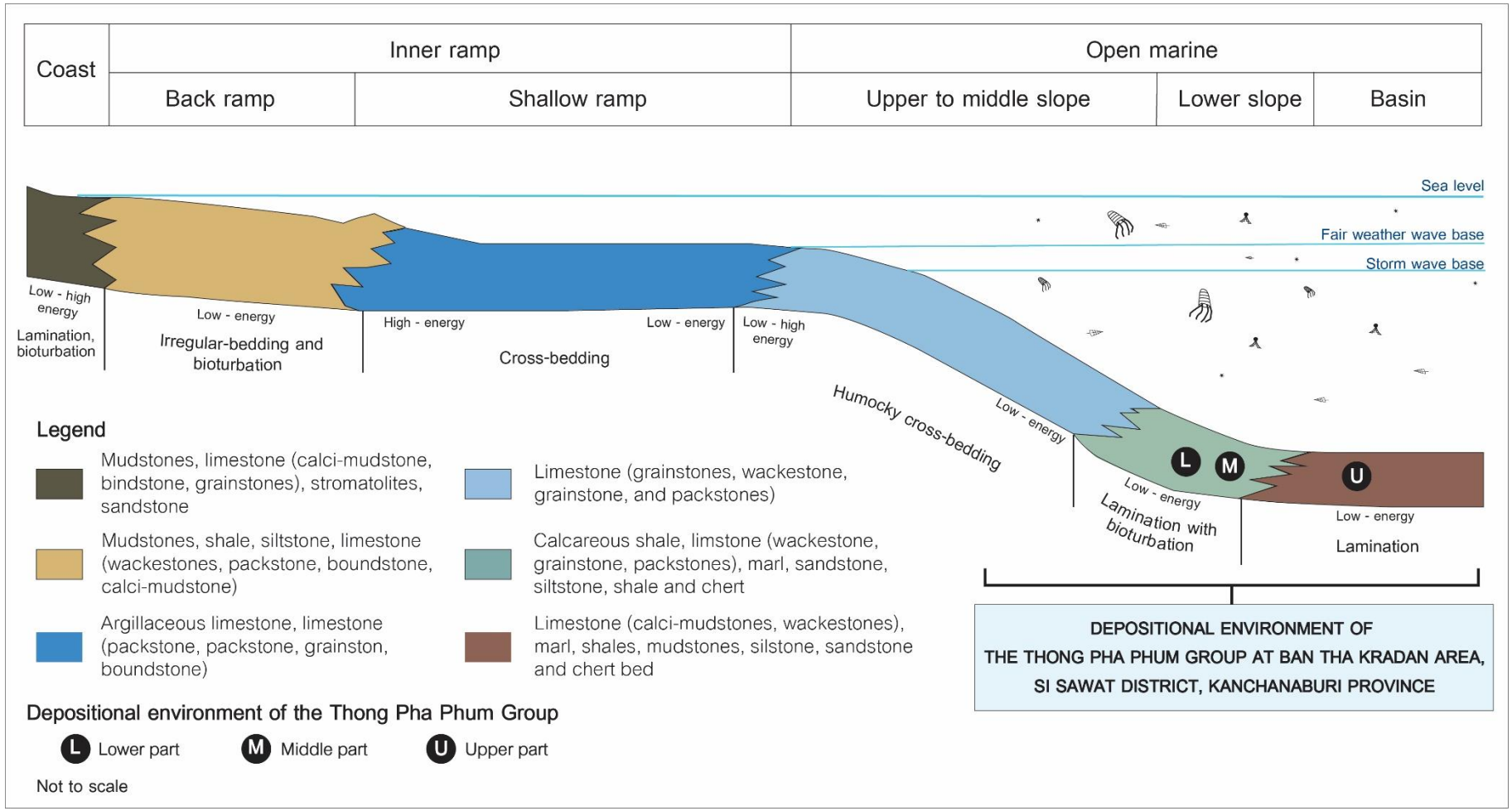

Figure 4.1 Schematic models illustrating of depositionnal environment of the Thong Pha Phum Group at Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province (modified after Flügel & Munnecke, 2010)).

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

1) The paleogeography and the depositional environments of the study area are presented as follows. The study area has been located on the eastern margin of the Sibumasu terrane (Bunopas, 1981). The Silurian-Devonian rocks have been a similarity in lithology and fossil contains such as tentaculites, graptolites, brachiopods, and ostracods (Hahn & Siebenhüner, 1982) which were found in many areas in north, west, and peninsular Thailand. According to Wei et al., 2012 proposed paleogeographic distribution of tentaculite occurrences in the Silurian-Devonian. These faunas that situated at latitude about 35°S to 35°N in the Paleo-Tethys Ocean. However, the tentaculites-bearing rocks succession examined in this study has been assigned to the Thong Pha Phum Group indicating Emsian to Frasnian. This tentaculite fauna can be correlated to Devonian tentaculites in Satun Province, peninsular Thailand (Agematsu et al., 2006b) and northwest Malaysia (Hassan et al., 2013) such as *Nowakia acuaria*, *Styliolina fissurella, Homoctenus tikhyi* and *Homoctenus arctus* in ascending order. As a result, the western and southern Thailand including the study area belong to slope to deep marine of Sibumasu terrane during Silurian? to Devonian time. Moreover, there is no evidence of rifting from Gondwana during this time (Figure 5.1).

2) As mentioned, the Thong Pha Phum Group is the Lower Paleozoic rocks (Silurian-Devonian age). It can be correlated to other marine Lower Paleozoic sedimentary rocks in Thailand such as in the northern, and Peninsular Thailand and northwest Malaysia. In northern Thailand, the Fang Chert is a conformable marine sequence which its thickness is no thicker than 200 m (Bunopas, 1981; Department of Mineral Resources, 2013; Wonganan & Caridroit, 2005). In Peninsular Thailand, the Thong Pha Phum Group is divided into three conformable rocks units in ascending order as Wang Tong Formation, Kuan Tung Formation, and Pa Samed Formation (Wongwanich et al., 1990, 2002). Most marine Silurian-Devonian strata in Thailand are

composed of shale, mudstone, siltstone, sandstone, limestone, calcareous mudstone and siliceous mudstone, and have been correlated by several faunas such as graptolites, tentaculites, trilobite, and brachiopods. They are also reported from Thailand (e.g., northern, western, southern Thailand, and Khorat Plateau) and northwest Malaysia as shown in Table 5.1.

3) At the Thong Pha Phum Group's type section, the total thickness measured by Hagen and Kemper (1976) is approximately 1000-1200 m and this group is also well exposed in Thong Pha Phum creek in Thong Pha Phum, Songkhlaburi, and Si Sawat Districts. In this study, the total thickness of this group is less than 100 m. That is because structural complexes have been recognized in the study areas which is the cause of thickness or stratigraphic repetition.

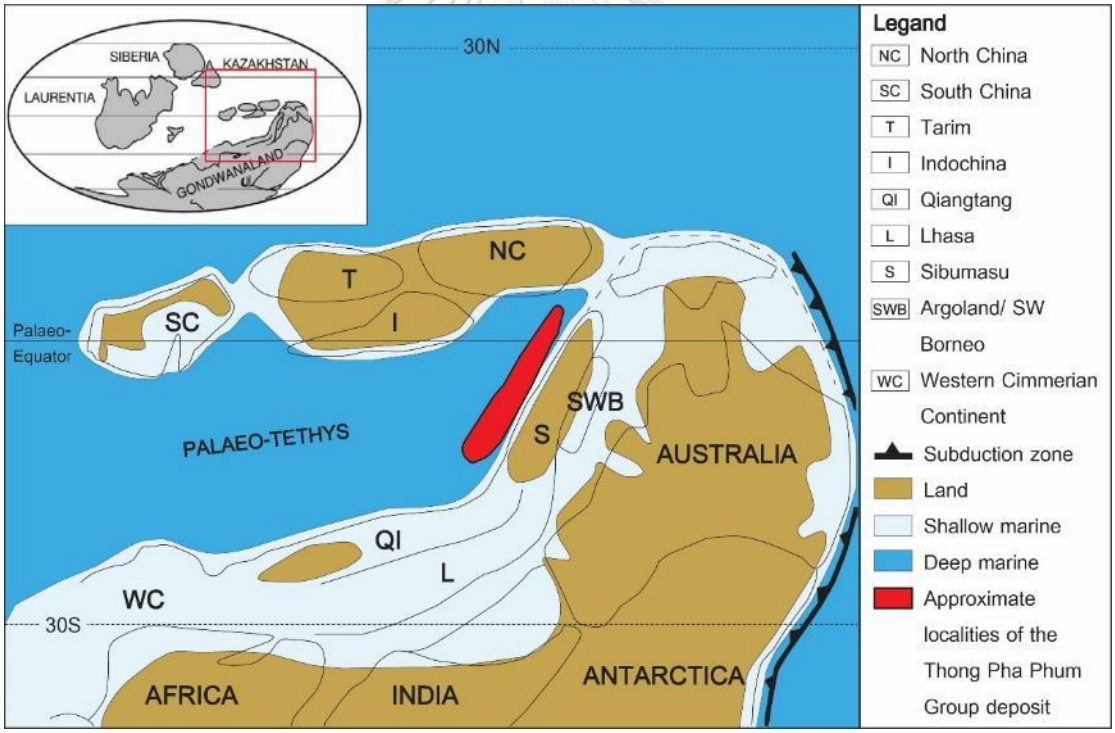

Figure 5.1 Paleogeographical reconstruction of the Paleo-Tethys and showing the approximate localities of the Thong Pha Phum Group deposit (Modified after Metcalfe, 2011).

Table 5.1 The correlation of the Silurian-Devonian marine sedimentary rocks in Thailand and northwest Malaysia (modified after Wongwanich et al., 1990, 2002; Department of Mineral Resources, 2013; Ridd, 2011; The Malaysia-Thailand Working Group, 2016)

Area	Peninsular Thailand (Satun Province)			Northern			Western	Peninsular Thailand	Khorat Plateau	Thailand (Satun Province)		Malaysia (Perlies)	Study area	
Carboniferous	Kaeng Krachan Fm.		Kaeng Krachan Group	Fang Chert	Mae Tha Group (Dan Lan Hoi Group)		Mae Hong Son Fm.	Khuan Klang Fm. /Yaha Fm.	Wang Saphung Fm.	Khuan Klang Fm.		Rebak Fm.	Khuan Klang Fm.	
	Kuan Klang Fm.	Nga Chang Supergroup	Khuan Klang Fm.											
Devonian Upper	Khao Chu Nong Fm.		Pa Samed Fm.		Donchai Group	Thong Pha Phum Group	Thong Pha Phum Group	Thong Pha Phum Group	Nong Dok Bua fm.	Kuan Tung fm.	Pa Samed Fm.	Jentik Fm.	Thong Pha Phum Group	Upper Part
Devonian Middle	Thong Pha Phum Group: Pa Samed Fm.				Mae Ping Fm.									Middle Part
Devonian Lower	Thong Pha Phum Group: Kuan Tung Fm.	Satun Group	Kuan Tung Fm.						Pak Chom fm.			Setul Group		Lower Part ?
Silurian	Thong Pha Phum Group: Wang Tong Fm.		Wang Tong Fm.							Wang Tong fm.				
Ordovician	Thung Song Group: Pa Kae Fm., Ruang Nok Fm., Lae Tong Fm., Pa Nam Fm., La Nga Fm., Talo Dang Fm., Malaka Fm.		Pa Kae Fm. / Thung Song Limestone	Thung Song Group						Thung Song Group			Thung Song Group	
Ref.	Wongwanich et al. (1990, 2002)		Ridd (2011)	Department of Mineral Resources (2013)						The Malaysia-Thailand Border Joint Geological Survey Committee (2016)			This study	

5.2 Conclusion

1) The Thong Pha Phum Group in Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand, is the carbonate and siliciclastic Silurian-Devonian sequence. This group is conformably underlain and overlain by Ordovician Thung Song Group as well as Carboniferous rocks (Khuan Klang Formation), respectively. The lower sequence, approximately 10-20 m thick, is characterized by grey to black siliceous shale, siltstone and sandstone facies containing abundant graptolites (*Monograptus* sp. and *Diplograptus* sp.). Petrographically, this lower sequence is composed of arkosic wacke. The middle sequence, approximately 30-40 m thick, consists mainly of micritic limestone and argillaceous limestone, calcareous shale to mudstone, marl and intercalated with siltstone facies with abundant tentaculites, ostacods, brachiopods, and trilobites. Petrographically, this middle sequence is composed mainly bioclastic wackestone, bioclastic packstone, calci-mudstone, mudstone and siltstone with pyrite dissemination. The upper most part of the group, approximately 10-20 m thick, consists predominantly of siliceous shale to mudstone with pyrite dissemination.

2) Seven species belonging to 3 genera: *Nowakia acuaria*, *Nowakia* (Cepanowakia) *pumilio*, *Styliolina fissurella, Styliolina clavulus*, *Styliolina* sp. A; *Homoctenus tikhyi*, *Homoctenus arctus* are systematically investigated and indicate Emsian to Frasnian (Early to Late Devonian) age. Two species of graptolites (*Monograptus* sp. and *Diplograptus* sp.) are also found in study area, which indicate Silurian? to early Devonian age. On the basis of the tentaculites and graptolite, the age of the Thong Pha Phum Group suggests that the Silurian? to late Devonian age.

3) Depositional environments of sedimentary sequence of the Thong Pha Phum Group were analyzed in terms of lithostratigraphy, lithofacies association and sedimentary structure representing the slope to deep marine environment since Silurian? to late Devonian time.

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