MICROFACIES OF ORDOVICIAN LIMESTONE AT WAT MONG KRATAE SECTION, BAN THA KRADAN AREA, SI SAWAT DISTRICT, KANCHANABURI PROVINCE

Thitikan Junrattanamanee

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ชุดลักษณะระดับจุลภาคของหินปูนยุคออร์โดวิเชียนหน้าตัดวัดหม่องกระแทะ พื้นที่บ้านท่ากระดาน อำเภอศรีสวัสดิ์ จังหวัดกาญจนบุรี

นางสาวฐิติกัญ จุลรัตนมณี

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต

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MICROFACIES OF ORDOVICIAN BEDDED LIMESTONE IN BAN THA KRADAN AREA, SI SAWAT DISTRICT, KANCHANABURI PROVINCE

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

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งานวิจัยนี้มีวัตถุประสงค์เพื่อกำหนดชุดลักษณะระดับจุลภาคของหินปูนที่โผล่ด้านตะวันออกของเขื่อนศรีนครินทร์ในอำเภอศรีสวัสดิ์ จังหวัดกาญจนบุรี เพื่อสร้างสภาพแวดล้อมการทับถมของหน้าตัดศึกษาและเทียบเคียงกับหินยุคออร์โดวิเชียนในภูมิภาคอื่นของประเทศ หน้าตัดศึกษาตั้งอยู่ในตำบลท่ากระดาน อำเภอศรีสวัสดิ์ จังหวัดกาญจนบุรี ตัวอย่างหินจำนวน 24 ตัวอย่างถูกเก็บจากลำดับชุดหินคาร์บอเนตบริเวณหน้าตัดศึกษา และถูกจำแนกเป็น 11 ประเภทชุดลักษณะระดับจุลภาค (MF) ได้แก่ MF1 pelletal grainstone MF2 molluscan packstone MF3 molluscan-peloidal packstone MF4 bioclastic packstone (tempestite) MF5 rounded clast grainstone MF6 intraclast-peloidal packstone with microbially coated grains MF7 bio-intraclast packstone MF8 fine packstone with intraclast MF9 coarse packstone with microbially coated grains MF10 peloidal calcisiltite และ MF11 algal-intraclast-peloidal packstone ทั้ง 11 ชุดลักษณะระดับจุลภาคถูกกำหนดให้ทับถมอยู่ใน 5 เขตการทับถม ประกอบด้วย เขตเหนือระดับน้ำขึ้นสูงสุด (peritidal) เขตทะเลเปิด (open marine) สันดอนคาร์บอเนต (carbonate shoal) ที่ลาดส่วนใน (mid ramp) และที่ลาดส่วนนอก (outer ramp) ศิลาวิทยาและรายละเอียดการวิเคราะห์ชุดลักษณะระดับจุลภาคของหน้าตัดศึกษาคล้ายหินยุคออร์โดวิเชียนตอนกลางในพื้นที่ทองผาภูมิ ซากดึกดำบรรพ์ขนาดใหญ่ที่พบในหมวดหินปูนท่ามะนาวถูกพบในลำดับชุดหินนี้ด้วย *Armenoceras chediforme*, *Sibumasuoceras langkawiense*, *Teiichispirina* sp. และ *?Fisherites* sp. ระบุอายุออร์โดวิเชียนตอนกลาง (Dapingian – Darriwilian age) ซากดึกดำบรรพ์เหล่านี้พบในภาคใต้ของไทย และบนเกาะลังกาวีในประเทศมาเลเซีย ดังนั้นหน้าตัดศึกษาเทียบเคียงได้กับหินปูนของกลุ่มหินทุ่งสง บริเวณอำเภอทุ่งหว้า จังหวัดสตูล และหินปูนของหมวดหิน Kakit Bukit บนเกาะลังกาวี ประเทศมาเลเซีย

สาขาวิชาเทคโนโลยีธรณี ลายมือชื่อนักศึกษา________________________

ปีการศึกษา 2562 ลายมือชื่ออาจารย์ที่ปรึกษา___________________

THITIKAN JUNRATTANAMANEE : MICROFACIES OF ORDOVICIAN LIMESTONE AT WAT MONG KRATAE SECTION, BAN THA KRADAN AREA, SI SAWAT DISTRICT, KANCHANABURI PROVINCE. THESIS ADVISOR : ASST. PROF. ANISONG CHITNARIN, Ph.D. 126 PP.

MICROFACIES ANALYSIS/PALEOENVIRONMENT/THA MANAO LIMESTONE/SIBUMASU TERRANE/MIDDLE ORDOVICIAN

This research is aimed to define microfacies of limestones exposed on the east side of the Srinagarind Reservoir in Si Sawat District, Kanchanaburi Province, to reconstruct the depositional environment of the studied section, and to correlate with the Ordovician rocks in other regions of the country. The studied section is located in Tha Kradan Subdistrict, Si Sawat district, Kanchanaburi Province. Twenty four rock samples were collected from the carbonate succession at the studied section. They can be classified into eleven microfacies types: MF1 pelletal grainstone, MF2 molluscan packstone, MF3 molluscan-peloidal packstone, MF4 bioclastic packstone (tempestite), MF5 rounded clast grainstone, MF6 intraclast-peloidal packstone with microbially coated grains, MF7 bio-intraclast packstone, MF8 fine packstone with intraclast, and MF9 coarse packstone with microbially coated grains, MF10 peloidal calcisiltite and MF11 algal-intraclast-peloidal packstone. The eleven microfacies are designated to be deposited in five depositional belts including peritidal, open marine, carbonate shoal, mid ramp and outer ramp facies zones. Lithology and the detailed microfacies analysis of the studied section are similar to the Middle Ordovician sequence of Thong Pha Phum area. Macrofossils recorded from Tha Manao

Limestone Formation are also found in this sequence. *Armenoceras chediforme*, *Sibumasuoceras langkawiense*, *Teiichispirina* sp. and ?*Fisherites* sp. indicate Middle Ordovician (Dapingian – Darriwilian age). These fossils are known from Southern Thailand and on Langkawi Island in Malaysia, therefore; the studied section can be correlated with limestones of Thung Song Group in Thung Wa District, Satun Province and limestones of Kaki Buki Formation on Langkawi Island in Malaysia.

School of Geotechnology Student's Signature_____________________

Academic Year 2019 Advisor's Signature_____________________

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Thitikan Junrattanamanee

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CHAPTER I

INTRODUCTION

The Ordovician rocks of Thailand consist chiefly of marine deposits and are distributed in northern, western, eastern and southern Thailand (Bunopas, 1983; Wongwanich et al., 1983) (Figure 1.1). In Kanchanaburi province, the Chao Nen Group comprised of two formations including the Chao Nen Quartzite Formation and the Tha Manao Limestone Formation was proposed by Bunopas (1981). The Tha Manao Limestone consists mainly of argillaceous limestone sequences and contains abundant cephalopods. Previously, they were referred as the Thung Song Limestone (Brown et al., 1951). The age of the rocks is designated by several fossil faunas e.g., conodonts, brachiopods, trilobites and cephalopods (Baum et al., 1970; Bunopas and Bunjitradulya, 1975; Bunopas, 1976; Hagen and Kemper, 1976 and Ingavat, 1994). The limestones exposed on the east side of Sri Nakharind Reservoir were investigated and their lithology and paleontology were reported which indicated Middle Ordovician period. Although, the Ordovician limestones in Kanchanaburi province have been investigated many times but restricted only in the Thong Pha Phum area (e.g. Hagen and Kemper, 1976; Wolfart, 2001; Agematsu, 2003; Agematsu et al., 2006). Even though there are many new exposures in areas on the east side of the Sri Nakharind Reservoir, the detailed geologic investigation is rare. Thus, this research is aimed to investigate the limestone sequence of the Tha Manao Limestone Formation which exposed on the east side of the Sri Nakharind Reservoir in order to

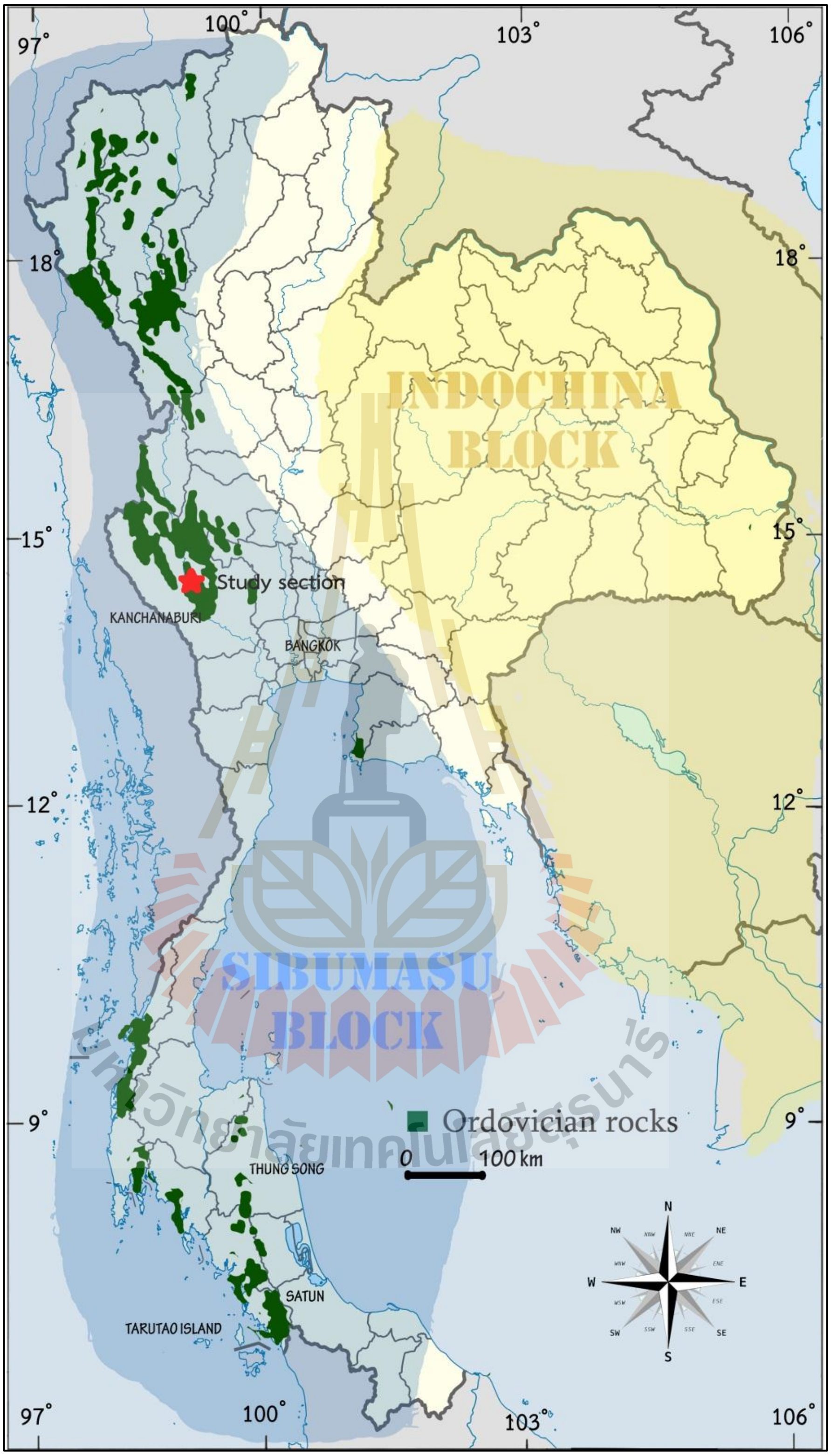

Figure 1.1 Index map of Thailand showing distribution of the Ordovician rocks in Thailand (modified from Wongwanich et al., 1983 and Ridd, 2011)

understand the environment of deposition. The expected result of this research is an attempt to correlate the rocks exposed elsewhere in Thailand and the previous works in order to fulfill knowledge of the Ordovician succession on Sibumasu Terrane.

1.1. Research objective

The objectives of this research are (1) to define microfacies of the limestones exposed on the east side of the Srinagarind Reservoir in Ban Tha Kradan area, Si Sawat district, Kanchanaburi province, and (2) to reconstruct the depositional environment of the studied section and to correlate with the Ordovician rocks in other regions of the country.

1.2. Scope and limitation

The studied section is located in the Tha Kradan subdistrict, Si Sawat district, Kanchanaburi province, western Thailand. Polished slabs and rock thin sections were prepared. Microfacies analysis and interpretation of depositional environment were carried out following (Flügel, 2004). The polished slabs and thin sections were prepared at the Geotechnology Laboratory, Suranaree University of Technology (SUT).

1.3. Research methodology

The methodology is divided into six steps including literature review and planning, field investigation and sampling, laboratory work, data analysis and interpretation, discussion and conclusion and thesis writing and presentation. The summarized flow chart of the methodology is illustrated in Figure 1.2

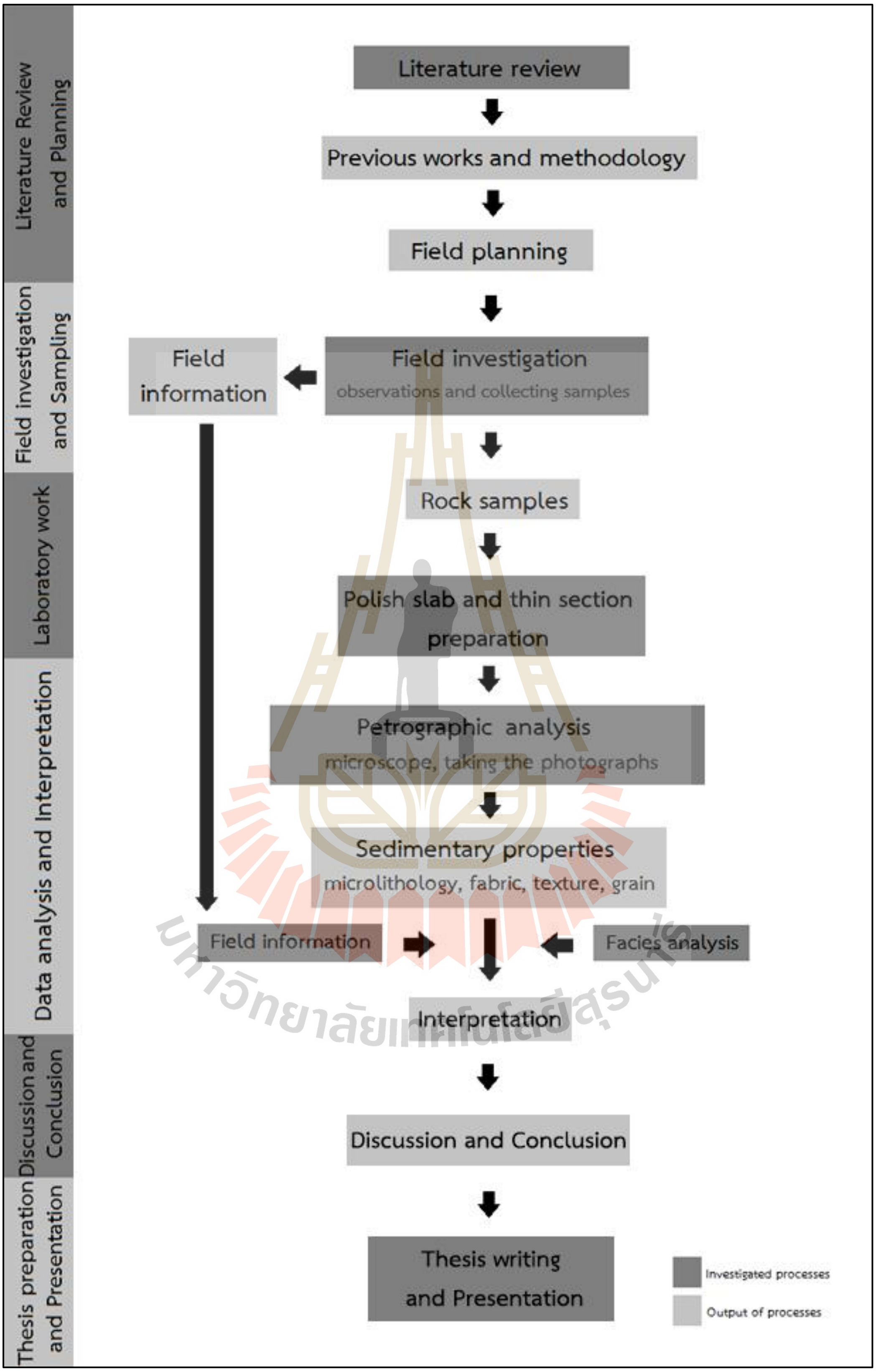

Figure 1.2 Flow chart represents the methodology of this study

1.3.1 Literature review and planning

The literature review including geologic setting, fauna assemblage and microfacies are summarized in chapter II and processes of rock sample preparation in the laboratory are compiled in chapter III.

1.3.2 Field investigation and sampling

Previous works, topographic maps and geologic maps had been reviewed and prepared before field investigation in December 2016. (Figures 1.3 and 1.4). The field equipment such as geologic compass, geologic hammer, measuring tape, water-resistant pens, plastic bags, scale and camera were prepared. The investigation was carried out in Ban Tha Kradan area, several sited were visited and chosen for researched. Lithostratigraphy of the studied section (at approximately Latitude 14° 27´10´´N, Longitude 99° 07´50´´E) was achieved consequently. The rock samples were collected from the studied section. Field investigation is mentioned in chapter III.

1.3.3 Laboratory work

All rock samples were prepared at Geotechnology Laboratory, Facility Building 7 (F7), Suranaree University of Technology. The laboratory works were divided into two parts as described follows: (1) the polished slabs were prepared following Green (2001) to observe sedimentary structures and texture of the rocks. (2) the thin sections were prepared to analyze the microfacies under stereomicroscope and polarized light microscope. The thin section preparation was prepared following Green (2001) and Hill (1999). Laboratory works are described in chapter III

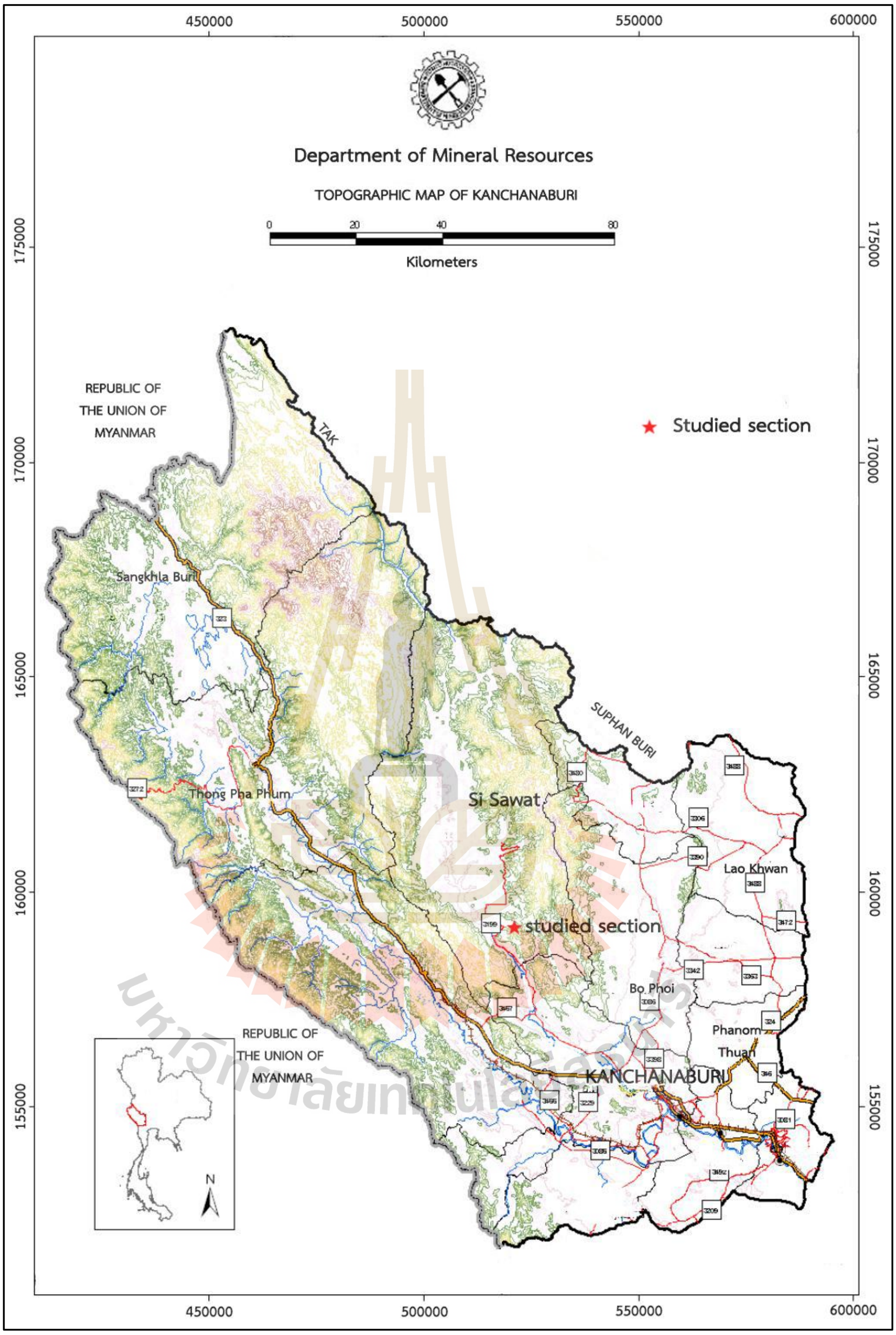

Figure 1.3 Topographic map represents the district boundary in Kanchanaburi province and shows the location of the studied section (modified from RTSD, 2008).

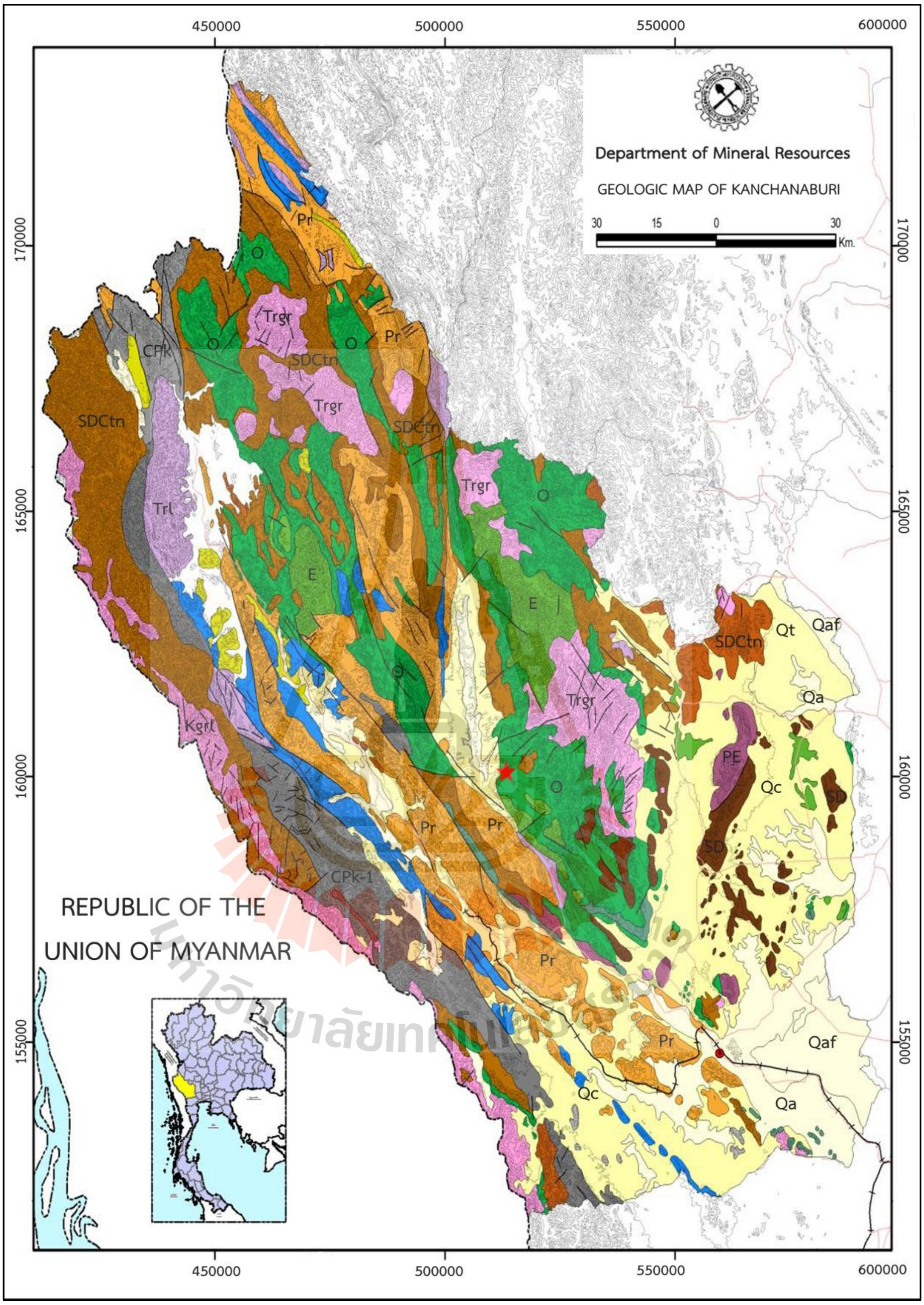

Figure 1.4 Geologic map represents the distribution of rock units in Kanchanaburi province (modified from DMR, 2007)

Figure 1.4 Geologic map represents the distribution of rock units in Kanchanaburi province (modified from DMR, 2007) (cont.)

1.3.4 Data analysis and interpretation

1. Data analysis

The microfacies were analyzed from the polished slabs and thin-sections under the stereomicroscope and the polarized light microscope following (Flügel, 2004). In thin sections, the samples were classified as the depositional texture of carbonate (Dunham, 1962) and the grain characteristic and matrix type (Flügel, 2004). Fossils and fabric were observed.

2. Interpretation

The field and laboratory information were synthesized and analyzed to determine microfacies type, facies zones and facies models. The microfacies associate with the facies zones in the facies models. Characteristics of grain type, matrix type, and depositional texture were considered and used for selecting of facies model. In Flügel (2004), the ramp microfacies were defined from previously studied of microfacies types about Paleozoic and Mesozoic ramp carbonate. The facies zone associated with microfacies types were described in studies with Paleozoic and Mesozoic carbonate ramps. Data analysis and interpretation are showed in chapter IV

1.3.5 Discussion and Conclusion

The microfacies and palaeoenvironment were discussed and correlated with other work of the Ordovician rocks from the Thong Pha Phum area, western Thailand, Satun area, southern Thailand, Ko Si Chang area, eastern Thailand and northern part of Thailand. All results are presented in chapter V.

1.4. Thesis contents

This thesis is presented as follows;

Chapter I introduces the study by describing the background and rationale, research objectives, scope and limitations and methodology.

Chapter II summarizes the results of the literature review.

Chapter III describes the research methodology.

Chapter IV analyzes the microfacies of the studied section and interprets the depositional environment of the studied section and discusses the research results.

Chapter V reports conclusion of the research results.

CHAPTER II

LITERATURE REVIEW

This chapter gives the results of the literature review carried out to provide the brief description of the Ordovician successions, paleontology and microfacies. The topic reviewed here includes the geologic setting, faunal assemblage and microfacies.

2.1. Geologic setting

2.1.1. Tectonic history of the Ordovician in Thailand

Thailand comprises two continental plates including Indochina block or Shan Thai (Sibumasu) block (Figure 2.1). Tectonic evolution of Thailand was studied by paleomagnetic studied data and used to support the plate tectonic theory of South East Asia and also the paleontological data and lithostratigraphic data were used too. These evidences were made to believe both continental plate, Indochina and Sibumasu plate occurred and diverged from the Gondwana margin. Indochina block diverged from North-west part of Australia rimmed plate in Silurian – Devonian age and then Sibumasu block diverged in late Permian and converged in middle Triassic (Metcalfe, 1988a; Metcalfe, 1988b). Bunopas (1981) used plate tectonic theory interpreted geology and divided tectonic province of Thailand into three zones including; western geological province, central geological province and eastern geological province. Ordovician rock was found in western geological province which as Shan Thai or Sibumasu block, the boundary covered in northern, western, eastern and southern Thailand (Figure 2.2).

Figure 2.1 Index map of Thailand showing the continental block of Thailand including; the Indochina and Sibumasu block (modified from Wongwanich et al., 1983 and Ridd, 2011)

Figure 2.2 Index map of Thailand showing the distribution of the Ordovician rocks in Thailand (modified from Wongwanich et al., 1983 and Ridd, 2011)

2.1.2. The Ordovician rock in Thailand

1. Northern Thailand

Baum et al. (1970) investigated geology in the northern Thailand. They described the lower Paleozoic rock in Northern Thailand and concluded that the rocks had been deposited in shallow marine environment. Their study was summarized as follows;

The Cambrian rocks are the oldest of the Paleozoic system which consist of well bedded whitish to violet–red quartzite. The thickness is approximately 500 meters, predominantly fine grained, often cross bedded, with sparse conglomeratic intercalations, e.g. east of Mae Hong Son or northeast of Hod. Some outcrops consist of quartz pebbles. The underlying quartzite is probably upper Cambrian. West of Fang as well as northwest of Hod discovers the Ordovician limestone and the Cambrian quartzite.

The Cambrian quartzite sequence consists of well bedded siltstone and sandstone is intercalating with shaly dolomites beds and thin layered, then nodular and finally massive light to medium grey limestone on East of Mae Hong Son, East Mae Sariang and North of Hod. Algae reefs are discovered near Mae Sariang. The Cambrian quartz phyllites grade successively into dolomite and limestone on Southwest of Fang. Some localities, the limestones are replaced by dark arenaceous and sometimes found the fossiliferous shales as for instance north of Mae Sariang.

Piyasin (1975) described the lower Paleozoic rocks in Northern Thailand. The Cambrian rock is mainly clastic sandstone, well rounded and well sorted which deposits in the stable shelf environment, is conformably overlied by the

Ordovician limestone and he found shallow sea fossils e.g. *Armenoceras* sp. which it is also found in both northern and peninsular Thailand.

Bunopas (1976) investigated the stratigraphy successions from the Precambrian to the Cenozoic, found the lower Paleozoic sandstone and limestone from Mae Hong to Kanchanaburi, the eastern gulf and the southern peninsula. In the northern Thailand, he reported as well bedded quartzite to massive quartzite, whitish to violated color, mostly fine grained, often cross bedded with some conglomerate. The Cambrian and Ordovician rocks were only found at the north in Tak province which two nautiloids in this rock were identified as *Armenoceras* cf. *chediforme* and *Ormoceras* sp. (Kobayashi, 1961). The thickness of the Ordovician limestone in the northern Thailand is approximately 80 to 100 meters and according the conodont faunas represent the lower to the upper Ordovician.

Bunopas (1981) studied paleogeography of Western Thailand; including three sub areas, Western Thailand, Central and Northern Thailand. He proposed the Paleozoic rocks in Northern Thailand which has some similarities with the Paleozoic rocks of west Thailand but different facies. In lower northern Thailand, the Cambro-Ordovician Klong Wang Chao Group consists of two formations, as the Pong Nam Ron Quartzite formation and Suan Mark Limestone formation and the upper northern Thailand consists of the Pha Bong quartzite formation and Hod limestone as describe follows;

The Pong Nam Ron Quartzite Formation has been previously called as Pong Nam Ron Sandstone in Bunopas (1976) which consists of monotonous well bedded quartzite with minor beds of quartz schist and quartz–pelitic schist and without fossil. The age is controlled by the Precambrian basement and the Ordovician fossils in the overlying Suan Mark Limestone. This formation is correlated with the Chao Nen Quartzite formation in western Thailand and the Pha Bong Quartzite formation in upper northern Thailand.

The Suan Mark Limestone Formation has been previously mapped as Thung Song Group in the Phitsanulok Quadrangle (Bunopas, 1976) and Uttaradit Quadrangle (Piyasin, 1975). It closely corresponds to the Tha Manao limestone formation in western Thailand which is chiefly well bedded, argillaceous limestone. In the lower part of the formation, some fragments can be recognized as cephalopods, probably nautiloid. The Ordovician age is inferred from lithological similarity to the Tha Manao Limestone formation of western Thailand and the Hod Limestone.

The Pha Bong Quartzite Formation in upper northern Thailand consists mainly of pinkish brown to whitish brown, thick–bedded, medium–grained orthoquartzite with well–rounded pebbles of quartz, black chert and no fossil. The base of the formation does not expose at the type locality. The Precambrian rock is underlying the Pha Bong quartzite metamorphosed to amphibolite. The Pha Bong quartzite is comformably overlain by the Hod Limestone. The Pha Bong quartzite is correlated with the lower Chao Nen Group or Chao Nen Quartzite Formation in Kanchanaburi, the lower Klong Wang Chao Group or Pong Nam Ron quartzite in Tak, the Ko Lan sandstone in eastern Thailand and Tarutao formation in southern peninsula. The Chao Nen quartzite and the Tarutao formation are correlated by fossils including trilobite probably Upper Cambrian, but possibly in part basal Ordovician in age. The Pha Bong quartzite is regarded as Cambrian period (e.g. Baum et al., 1970; Javanaphet, 1969)

The Hod Limestone Formation is proposed to argillaceous limestone at the limestone mountain, 8 kilometers northwest of Hod district near Ban Mae Pae in south Chiang mai. Fossils are not found at type locality but are found at scattered localities which were mapped as Ordovician by Baum et al. (1970).

Bunopas (1983) compiled the information of the Paleozoic succession in Thailand. The lower Paleozoic rock in northern Thailand cited Bunopas (1981) consisted of the Pong Nam Ron Formation, the Cambrian to early Ordovician age, the Pha Bong Quartzite Formation, the Cambrian age, the Suan Mark Limestone Formation and the Hod Limestone Formation, the Ordovician age.

2. Western Thailand

Brown et al. (1951) studied geology of south peninsular Thailand. They described the geology of Northwest of Kanchanaburi and believed to be of the same age as the limestone of the peninsula.

Bunopas (1976) studied the stratigraphy successions from the Precambrian to the Cenozoic and he found the lower Paleozoic sandstone and limestone from Mae Hong Son to Kanchanaburi, the eastern gulf and the southern peninsula. In the western Thailand, the Ordovician limestone was known to involve with the upper Cambrian sandstone in Kanchanaburi, western mountains up to Mae Sariang, northern most part of the country (Baum et al., 1970; Bunopas, 1974). East of Mae Sariang, Mae Hong Son, north of Hod, south of Tak and Kanchanaburi, there were a transition from the Cambrian quartzite to the Ordovician sequence. In areas west of Kanchanaburi, the Ordovician sequence contains abundant cephalopods.

Hagen and Kemper (1976) investigated the geology of the Thong Pha Phum area, Kanchanaburi province. They divided the stratigraphy in the Thong Pha Phum into seven units including Unit A, B, C, D, E, F, and G which consist of siliciclastic beds which were metamorphosed to quartzite and phyllite and overlain by a carbonate sequence with an Ordovician fauna which is overlain by an argillaceous and carbonate sequence with a Silurian fossils.

Bunopas (1981) studied paleogeography of Thailand and divided into three sub areas, Western Thailand, Central and Northern Thailand. In Western Thailand, the lower Paleozoic rocks as the Chao Nen Group which consists of two formations including; the Chao Nen Quartzite formation and conformably overlying the Tha Manao Limestone formation. The Chao Nen Group age range is the Cambrian to the Ordovician, as describe follows;

The type locality of the Chao Nen Quartzite Formation located at the excavation for the Ban Chao Nen Dam, Khwae Yai, and west of Kanchanaburi. A thickness of 600 meters of Chao Nen Quartzite Formation, the lower part approximately 300 meters consists chiefly of well bedded whitish brown, whitish grey, and green grey fine to medium grained sandstone and quartzite, the middle part about 100 meters composes fine grained sandstone interbedded with thin shale and phyllite and rare limestone beds, the sandstone containing trilobites, and the lower part is 250 meters consists of medium graded sandstone beds containing abundant shell fragments and grading up through finer sandstone to sandy limestone. Near Ban Tha Manao finer clastic layer are metamorphosed to slate, phyllite and biotite schist. Fossils have been found in the middle sandstone of Chao Nen Quartzite, are identified as Opisthoparian trilobite which indicate an upper Cambrian age and in sandy calcareous quartzite, an abundant incomplete fossils are collected by Bunopas (1974), are nautiloids, gastropods, pelecypods and brachiopods. Cephalopods indicate a Llandeilian age and other are brachiopod, *strophomena* sp. and gastropods, *Palaeoinphalus cf. gigantus*, indicate early middle Ordovician age. The lower unfossiliferous sandstone is possibly older than upper Cambrian. The rock are correlated with Tarutao Formation which fossils in the Chao Nen Quartzite Formation are less abundant than in the Tarutao Formation and fossils are also not same but their age ranges are similar, upper Cambrian to early middle Ordovician age.

The Tha Manao Limestone Formation consists chiefly of carbonate, conformably overlying the Chao Nen Quartzite Formation and forming the upper part of the Chao Nen Group. Type section of the Tha Manao Limestone formation at Khao Tha Manao, east of the village Ban Tha Manao on the road to Ban Chao Nen Dam is divided into three parts as; the lower part grade up from the Chao Nen Quartzite Formation, consists of about 200 meters thick limestone at the basal limestone bed about 100 meters abundant chert nodules and occasional fossils nautiloids of Ordovician age. The upper part about 100 meters is thinner bedded grey recrystallized limestone with interbedded thin sandstone, grades up to interbedded quartzite and phyllite 50 meters thick. The highest part consists of dark grey, light grey and brownish grey thin-bedded limestone conformably underlying grey and white shale of the Bo Phloi Formation. The total thickness of the Tha Manao Limestone is about 450 meters.

Bunopas (1983) compiled the information of the Paleozoic succession in Thailand. He described the lower Paleozoic rock in western Thailand, consisted of Chao Nen Quartzite Formation, the Cambrian to early Ordovician age and Tha Manao Limestone Formation, the Ordovician age.

Bunopas (1992) compiled the information and attempted to correlate with the similar stratigraphy. He mentioned the lower Paleozoic rocks distributed in the western belt on Shan Thai terrane. The lower Paleozoic in western Thailand was correlated with the lower Paleozoic in northern, eastern and southern Thailand.

Wolfart (2001) described the geology of the Thong Pha Phum area, Kanchanaburi province which Hagen and Kemper (1976) used to study before. He shows the different succession which in the Unit E, as mudstone and siltstone with limestone lense and he found a conodont assemblage with *Scarbartella altipe* on the upper part of this unit which is of Ashgill age.

Agematsu et al. (2006) studied the Ordovician conodont in the Thong Pha Phum area, Kanchanaburi province. A conodont assemblage has been identified into four zones including; these are the *Juanognathus variaviris* Zone, the *Walliserodus comptus* Zone, the *Juanognathus jaanussoni–Histiodella holodentata* Zone, and the *Plectodina onychodonta* Zone which indicated to Early-Mid Ordovician age.

3. Eastern Thailand

Brown et al. (1951) studied geology of southern peninsular Thailand. They described the geology of Ko Si Chang in the gulf of Thailand which is believed to be of the same age as the limestone of the peninsular.

Bunopas (1976) studied the stratigraphy successions from the Precambrian to the Cenozoic, found the lower Paleozoic sandstone and limestone from Mae Hong Son to Kanchanaburi, the eastern gulf and the southern peninsular. In

Chonburi of eastern gulf of Thailand, the Ko Lan quartzite also occurred underneath the Ordovician limestone of Ko Si Chang, containing fossils overlying the probably Cambrian quartzite.

Bunopas (1981) studied paleogeography of Western Thailand and divided into three sub areas, Western Thailand, Central and Northern Thailand. In Eastern Gulf of Thailand, the lower Paleozoic rocks consists of two formations as; the Ko Lan quartzite formation and the Si Chang limestone formation. Their age ranges are the Cambrian to the Ordovician, as describe below;

The Ko Lan Quartzite Formation is the small island which located about 10 kilometers west of the Pattaya coastal in south Chonburi Province. The rock approximately 500 meters thick consists of reddish brown quartzite, brownish grey shaly slate and black to brown slate. Similar rocks are also found at Bang Lamung, on the coast south of Pattaya.

The Si Chang limestone Formation is probably equivalent to Ordovician limestone known in south peninsular Thailand and western Thailand. The Si Chang Limestone Formation is a small island of Ko Si Chang, about 11 kilometers west of Sriracha district. The thickness approximately 400 meters consists of dark grey well bedded to massive argillaceous limestone with rare Ordovician nautiloid.

Bunopas (1983) compiled the information of the Paleozoic succession in Thailand. The lower Paleozoic rock in eastern gulf of Thailand cited Bunopas, (1981) consists of Ko Lan Quartzite Formation, the Cambrian age and Si Chang Limestone Formation, the Ordovician age.

Bunopas (1992) compiled the information and attempted to correlation with the similar stratigraphy. He mentioned the lower Paleozoic rocks distributed in the western belt on Shan Thai terrene. The lower Paleozoic in eastern Thailand was correlated with the lower Paleozoic in northern, western and southern Thailand.

4. Southern Thailand

Brown et al. (1951) studied geology of south peninsular Thailand. The Paleozoic rocks include clastic sediments which are metamorphosed to schist, slate, argillite and quartzite of the Phuket series. The Thung Song limestone, sandstone, and shale of the Kanchanaburi series which are metamorphosed to slate, phyllite and quartzite.

The Phuket series as the Cambrian age consists of dark colored pebbly shale, shale and fine grained sandstone, in many places metamorphosed to schist, slate, quartzite and argillite. In pebbly shale, pebbles are quartz, quartzite, slate and granite which may be Precambrian age.

The Thung Song Limestone as the Ordovician age consists of dark grey limestone with disseminated crystals of pyrite and thin stringers of brown calcareous material and found bryozoans, crinoid stems, brachiopod fragments, and cephalopod at Ron Phibun. A cephalopod specimen was identified as *Actinoceras* sp. which as the Ordovician age. And it also is believed to be of same age as the limestone of Ko Si Chang in the gulf of Thailand and in northwest of Kanchanaburi.

Bunopas (1976) studied the stratigraphy successions from the Precambrian to the Cenozoic, found the lower Paleozoic sandstone and limestone from Mae Hong to Kanchanaburi, the eastern gulf and the southern peninsula. In the southern peninsular, they were discovered in 1956 from Tarutao Island, peninsular Thailand.

The rocks of the Tarutao Island consist of red thin to thick bedded sandstone with poorly cross beds and sandy shales containing the fossils. Kobayashi (1957) identified the fossils as the trilobites; it is evidence that the Tarutao fauna is upper and may be late upper Cambrian in age. The thickness of the Tarutao sandstone is estimate 200 to 300 meters.

The Ordovician limestone has been known since 1951 (Brown, 1951) from Thung Song between Nakon Si Thamrat and Satun in the Peninsula which contains *Arminoceras chediforme* (Kobayashi, 1958) and also occur on the eastern part of the Tarutao Island and is distributed from Langkawi Islands to perlis on the Malayan side which found gastropod limestone and *Actinocaras* limestone. *Sinuitopis cf. Kochiriensis* and Endoceroid indet. were found respectively on Wanderer Bay on the South coast of Tarutao Island (Kobayashi, 1959).

Bunopas (1981) established paleogeography of Western Thailand and concluded that there were three sub areas, Western Thailand, Central and lower North Thailand and upper north Thailand. He mentioned the south peninsular Thailand that the lower Paleozoic rocks consists of the Cambrian Tarutao Formation and the Ordovician Thung Song Formation as describe follows;

The Cambrian Tarutao Formation consists mainly of thin to thick bed and some cross bed quartzose sandstone and sandy shale which discovered the Cambrian brachiopods and agnostid and opristhoparian free-cheek trilobites on the Tarutao Island. Fossil faunas were described by Kobayashi (1957) as *Apheorthis*? sp. *Pagodia thaiensis, Thailandium solum, "Eosaukia" buravasi, Saukiella tarutaoensis*, and *Coreanocephalus planulatus*. The thickness of sequence is about 800 to 1000 meters. The Tarutao Formation is considered to be the approximate correlative of the lower Chao Nen Group in west Thailand, the lower Khlong Wang Chao Group in central and lower north Thailand and the Pha Bong Quartzite Formation in upper north Thailand.

The Thung Song Formation is overly the Cambrian Tarutao Formation which is chiefly dark crystalline limestone, occasional minor sandstone and shales and rare the Ordovician Fossils which include the nautiloid *Armenoceras chediform*, *Sinuitopsis* cf. *kochiriensis*, and *indeterminant endoceroid* (Kobayashi, 1958, 1959). Javanaphet (1969) applied for the name Thung Song Group to all Ordovician limestone in Thailand but Bunopas and other applied for only in southern peninsular Thailand for the Thung Song Limestone.

Taraoka et al. (1982) investigated the lower Paleozoic strata of the Tarutao Islands in Southern Thailand; they found the lower Paleozoic rock consists of the Tarutao Formation of red clastic facies and the overlying Thung Song Formation of limestone facies. The Tarutao Formation is shallow marine sediments which are predominantly red to reddish brown sandstone, interbedded sandstone and shale and limestone is divided into T1, T2, T3 and T4 members. The T3 and T4 members found brachiopods, trilobites, megafossils, and trace fossils and the T4 member also found the conodont in limestone.

The Thung Song Formation is found in the eastern part of the Tarutao Islands which consists chiefly of limestone interbedded with shale, and is divided into the S1, S2, S3, S4 and S5 members. The Thung Song Formation contains some fossils, trilobites, brachiopods and abundant conodonts.

Stait and Burrett (1984) investigated the Ordovician nautiloids of Thailand and the rock samples were collected from the carbonates of the Thung Song

Formation in Southern Thailand and the Tha Manao Formation in central Thailand. The Ordovician nautiloids were divided into five assemblage base on paleontological data including; (1) the middle Ibexian fauna of indetermined endoceroids from Tarutao Island, (2) *Hardmanoceras chrysanthemum* (Kobayashi) of the upper Ibexian age strata on Tarutao Island, (3) The upper *Ibexian Manchuroceras nakamense* sp. nov. from Ron Phibun, Southern Thailand and (4) *Wutinoceras* sp. *Armenoceras chediforme* Kobayashi and *Georgina* sp. of lower-middle Whiterockian age strata from Kanchanaburi, central Thailand.

Wongwanich (1990) studied lithostratigraphy and sedimentology of the Ordovician carbonates, Southern Thailand. The Ordovician Thung Song Group in Satun Province consists of limestone, dolomites, and calcareous shale. The thickness of this sequence is about 1,400 meters. The age range is the upper Tremadoc to upper Ashgill which indicate by polyphacophoran vales; *Chelodes whitehousei*, conodonts; *Scolopadus quadraplicatus, Acontiodus latus, Drepanodus basiovalis, Drepanodus forceps, Paroistodus parallelius, Baltonigodus oepiki, Prioniodus evae communis, Ptioniodus navis, Drepanoistodus forceps, Baltonioidus triangularis, Acodus longibasis* Orthoconic nautiloids and *Hardmanoceras chrysanthimum* and the small brachiopod; *Chelodes* sp. , Bivalve and Trilobite fauna; *Ovalocephalus, Orthorhachis, Nileus, ?Amphytrion* and *cyclopygidae.* The depositional environment of the Thung Song Carbonate is a homoclinal ramp environment which is a major marine transgression with minor eustatic fluctuation including tidal flat, stromatolite reefs, lagoons, buildup-barrier reefd and deep water carbonates. The microfacies study can be divided into twelve types including stromatolites, micrite to fossiliferous micrite, biomicrite, intramicrite, poorly washed to unsorted biosparite, biopelsparite and pelbiosparite, pelsparite, intrasparite, flat pebble conglomerate oosparite, biolithite and limestone breccia, micro-megadolomite and dolomite breccia which indicate sedimentation in wide range of environments from supratidal, intertidal, subtidal to deeper-water zones.

2.1.3. Regional geology of the studied section

Geology of the Kanchanaburi area has previously been done by many investigations e.g., Koch (1973), Bunopas (1976, 1981), and Meesook (2015) Subsequently, systematic mapping in western Thailand particularly in Kanchanaburi Province and adjacent areas on the scale of 1: 50,000 has been carried out and revised since 2011 by geoscientists from the Bureau of Geological Survey, Department of Mineral Resources of Thailand. This includes the Khuean Srinagarindra Quadrangle (4837 IV) (Figure 2.3) in which Tha Kradan area (study section), Si Sawat District of Kanchanaburi Province is located.

Geomorphologically, the study section and its vicinity of the Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand, shows conspicuous monoclinal features of the Ordovician limestone overlying the Cambrian sandstones to the north. The mountainous areas of the Ordovician limestone are confined to the eastern and southern sides of the area. The geomorphology of the

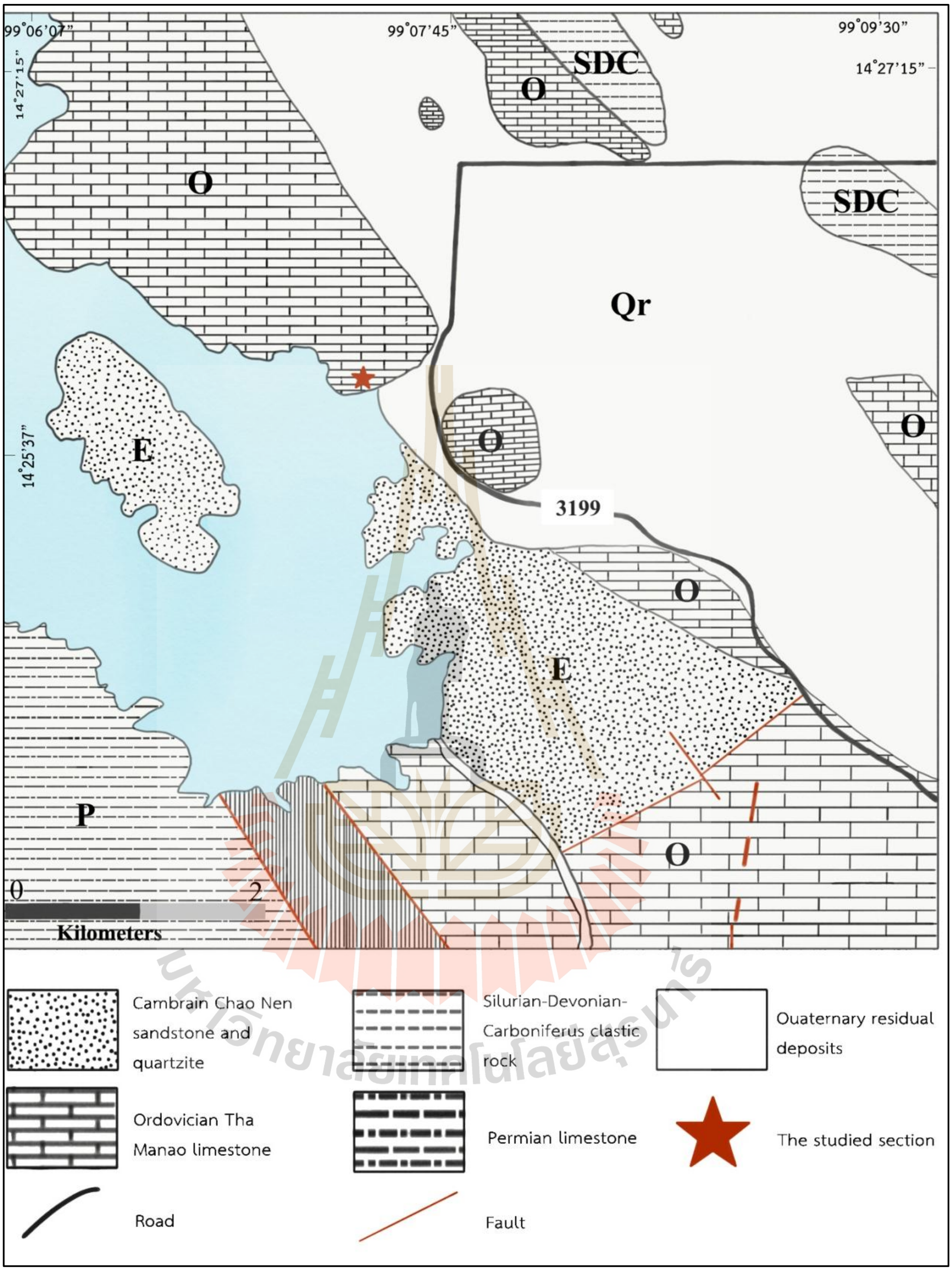

Figure 2.3 Geological map of the Khuean Srinagarindra Quadrangle (4837 IV), scale 1:50,000, Kanchanaburi Province, western Thailand (modified after Khaowiset et al., 2011 and Meesook 2015)

Silurian-Devonian rocks is represented by low-level mountain ranges to the west and east. The gently folded strata of the Ordovician rocks are confined to the undulating terrains where the measured section is located. Some features of the terrains are shown in Figure 2.4 A-B.

The Tha Manao limestone was proposed by Bunopas (1981) to represent the Ordovician rocks in Kanchanaburi Province. Lithologically, the group consists of grey to dark grey limestone, argillaceous limestone showing flaser beds, and stromatolitic limestone. The fossils of nautiloids, brachiopods and crinoid stems are found. Generally, the Ordovician rocks are exposed in many localities in the Ban Tha Kradan area and its vicinities including the measured section at Ban Tha Kradan.

The Ordovician sequence at the nautiloid geo-heritage site in Ban Tha Kradan is well exposed as an undulating quarry. The sequence shows cycle of sedimentation commencing from laminated and cross-bedded to thin- to medium-bedded limestones in the lower part of the sequence. Oriented and rolling nautiloids are found parallel and perpendicular to cross bedding planes. The nautiloids in this part cannot be identified into generic level. In the upper part, the sequence is dominated by thin- to medium-bedded, laminated limestones and stylolitic limestones and the nautiloids can be found. At least 3 genera of nautiloids can be identified. The uppermost part is dominated by stromatolite beds of limestones. Structurally, the sequence in the middle and upper portions is folded and anticline and syncline can be seen with plunging in the NW direction. The rocks and fossils are shown in Figure 2.5 A-B.

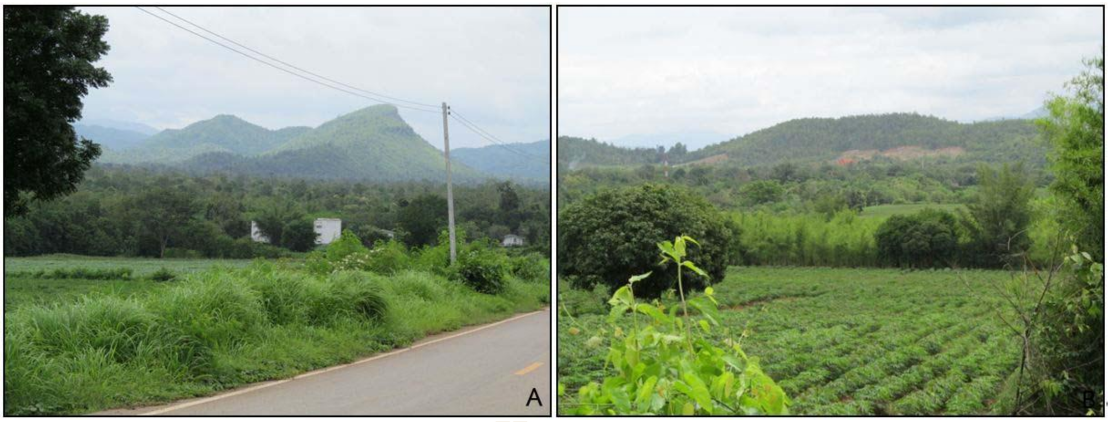

Figure 2.4 Geomorphology of the study area and its vicinity of Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand. A: Monoclinal features of the Ordovician limestones B: Rolling and mountainous areas of the Ordovician limestone (Meesook, 2015)

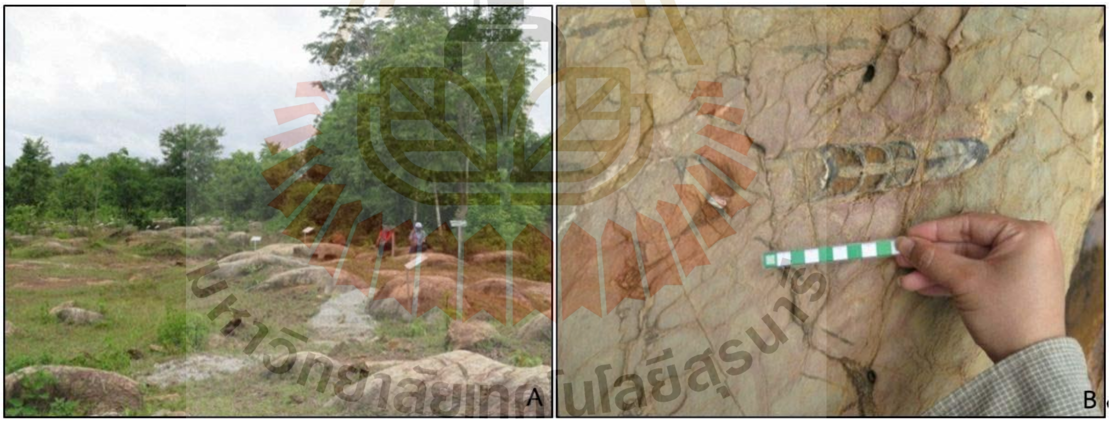

Figure 2.5 Photographs showing the Ordovician sequence at the nautiloid geo-heritage site in Ban Tha Kradan, Si Sawat District, Kanchanaburi Province, and Western Thailand. A: The morphology of this site, B: The fossil of nautiloid

In the northern part of the study area, Ordovician rocks are exposed at the outcrop near Wat Tha Kradan, north of the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand. Greenish grey limestone beds and stylolitic limestones are well exposed as shown in Figure 2.6 A-B.

2.2. Faunal assemblage

The Ordovician fauna was chiefly found in western and southern Thailand and the Ordovician fauna studies in Thailand were briefly summarized following;

Stait and Burrett (1984) studied the Ordovician nautiloid specimen of Thailand which were collected from the carbonates of Thung Song formation (in Southern Thailand) and Tha Manao formation (in Western Thailand) and reviewed previous papers for correlate with nautiloid specimen were found in this study. The nautiloid specimens can be grouped into five assemblages;

The Middle Ibexian fauna of indeterminate endocerids from Tarutao Island.

Hardmanocerus chrysanthemum (Kobayashi) of the Upper Ibexian age strata on Tarutao Island.

The Upper Ibexian *Manchurocerus nakamense* sp. nov. from Ron Phibun, Southern Thailand.

Wutinoceras sp., *Chaohuceras*? sp. of lower to middle Whiterockian age strata from Satun province (Niko and Sone, 2015).

Wutinoceras sp., *Armenoceras chediforme* Kobayashi and *Georgina* sp. of lower middle Whiterockian age strata from Kanchanaburi, western Thailand.

Figure 2.6 Ordovician rocks are exposed at the outcrop near Wat Tha Kradan, north of the Ban Tha Kradan area, Si Sawat District, Kanchanaburi Province, western Thailand. A: Greenish grey limestone beds, B: The stylolitic limestones

Ingavat (1994) reviewed and described the Paleozoic paleontological evidence found in Thailand. Paleozoic fauna covered the range from Cambrian to Late Permian and the Early Paleozoic fauna were mentioned including;

Cambrain: Late Cambrian trilobites species such as *Eosaukia buravasi* and *Thailandium solum* have been reported from the Tarutao sandstone by Kobayashi, (1957).

Ordovician: Ordovician fossils were known from several studies in southern part of Thailand including cephalopods *(Actinoceras*, *Armenocerus*, *Ormocerid*, and *Georgina*), conodonts (*Cordylodus*, *Drepanodus*, *Gothodus*, *Serratognathus*, *Aporthophyla*), trilobites (*Basiliella satunasis*, *Nileus*, *Gertrinodus*, *Arthrorachis* and *Cyclopyge*), graptolites (*Climaeograptus*, *Diplograptus*), polyplacophorous (*Chelodus whitehousi*) and peelerophon snail. In the West, Northwest and North of Thailand, the Ordovician faunas were reported including cepthalopod (*Actinocerus*, *Armenocerus*

Othoceras) and conodonts (*Oelandodus, Panderodus, Ozarkodina, Gnathodus, Scolopodus*, *Scaphelasma* and *Canthodus*).

Fortey and Cock (1988) studied the paleontology of the Ordovician of southern Thailand and adjacent areas of northern Malaysia and these data is important for paleogeographic and paleoecologic interpretation of Ordovician ages.

Tongtherm et al. (2016) discovered new species of nautiloids and ammonoids from peninsular Thailand. Ordovician nautiloids include a sactorthocerid nautiloid (*Sactorthocerus banestanensis*), a ruedemannoceratid nautiloid (*Mediganella magna*) and ammonoid (*Neoglyphiocerus subcirculare*) and two orthocerid nautiloids (*Michelinocerus* sp. A and *Tienocerus* sp. A) and two syringonautilid nautiloids (*Syringocerus barrendei* and *Javavionautilus heterophyllus*) and nautiloids were collected from the same locality (twenty-four species).

Kruse (1989) studied Receptaculitalean specimens which are reported by Wongwanich and Burrett (1983) from the Early Ordovician of Thailand. They are identified as ?*Fisherites* sp. The specimens are from locality 50.18 in the Tha Manao Formation at Khao Tham, Kanchanaburi Province, west-central Thailand.

In the Khao Tham area, they are found some 250 m stratigraphically below an early middle Whiterockian (late Arenig-early Llanvirn) nautiloid assemblage (locality 50.8) of Wutinoceras, Armenoceras and Georgina (Stait & Burrett, 1984).

A receptaculitalean specimen at locality 50.15B is indeterminate due to poor preservation.

From locality KT27 on Ko Sing Ha offshore from Ko Tarutao, Satun Province, southern Thailand, receptaculitalean specimen is similarly indeterminate. It is from the Thung Song Formation, within which it overlies strata yielding conodonts of the Prioniodus evae Zone of probable middle Arenig age and is therefore considered to be of late Arenig age.

Yochelson and Jones (1968) described the characteristic of *Teiichispira* sp slowly expanding hyperstrophic gastropods having a steeply inclined, moderately high outer whorl face, distinct sutures, and an elongate, curved, calcified operculum.

2.3. Microfacies

The microfacies are the petrographic and paleontological study by the thin-sections under the microscope. The microfacies are the total information of sedimentological and paleontological data. They can be described and classified from polished slabs and thin sections.

The concepts of facies analysis depend on the depositional model of sediment. These models are the important tools for identifying the microfacies and the facies zones of the depositional environment from the sedimentological or paleontological data.

The methodology of the microfacies study (Flügel 2004) is the carbonate classification following Dunham (1962) and Folk (1962) the analysis by comparing with standard microfacies which related to the standard facies zones in the facies models.

2.3.1. The carbonate classification under the thin section

Dunham (1962) are used to classify carbonate rocks, in the field and laboratory. The composition is also considered whether the constituent grains are grain-or mud supported. The original classification includes two major groups which can divide into five textural classes as describe follows. (Figure 2.7)

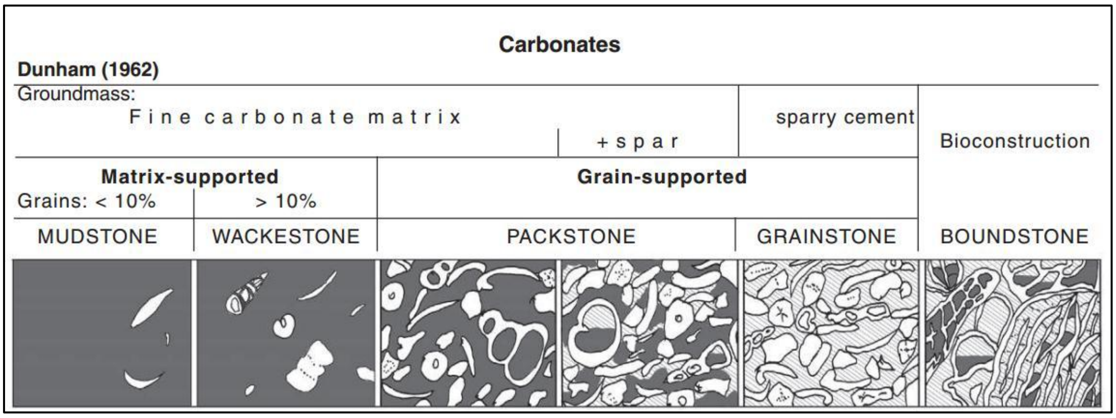

Figure 2.7 The carbonate classification following Dunham (1962) analyze by comparing with standard microfacies which related to the standard facies zones in the facies models

Autochthonous limestones: Carbonates, whose original components were organically bound together during deposition, are called boundstones including reef, stromatolite and travertine.

Allochthonous limestones: Carbonates, whose original components are not organically bound, are divided into two group including; mud-supported (mudstone and wackestone) or grain-supported (packstone and grainstone).

2.3.2. Standard Microfacies Types (SMF)

The microfacies will be studied under the thin-section and divides the facies into units of similar composition that will reflect depositional environments. From the study of Flügel (2004) and the developed by Wilson (1975) found the criteria used in differentiating SMFs can divided into five steps describe as follows; identification of grain types, defining matrix types e.g. micrite, calcisiltite, defining depositional fabrics e.g. lamination, grading, open space structures, burrowing, reworking and redeposition, classification of fossils, determination of depositional texture types follow Dunham (1962)

After considering of the five criteria mentioned the SMF need to be defined from five criteria by consider depositional texture following Table 2.1. There are 26 Standard Microfacies types cite from Flügel (2004) including:

SMF 1: Spiculitic wackestone or packstone, often with calcisiltite matrix.

Criteria: Dark, bedded limestones (mudstone, wackestone), commonly argillaceous and organic–rich. Abundant sponge spicules oriented. Pelagic microfossils (e.g. radiolarians) may found in this SMF.

Occurrence: This microfacies is common in Paleozoic and Mesozoic basinal carbonates (FZ 1), deeper shelf carbonates (FZ 2) as well as in mid ramp and outer ramp settings. Spiculites mainly found in deep cold water settings and somtime found in shallow-marine environments.

SMF 2: Microbioclastic peloidal calcisiltite with fine grainstone and packstone fabrics.

Criteria: Thin to medium bedded limestones and very fine–grained packstones or grainstones are common. Grain types consist of peloids and small litho- and bioclasts. Common bioclasts are echinoderms and mollusks. Small–scale ripple cross-lamination and laminae representing millimeter-scale gradation are common.

Occurrence: Common in deeper basins (FZ 1) and open marine shelf (FZ 2) as well as in deep shelf toe of slope position (FZ 3). Abundant in outer ramp settings

Table 2.1 Common carbonate type and Standard Microfacies Types.

Mudstone	Calcisiltite	Wackestone	Floatstone	Packstone	Grainstone	Rudstone
3 Abundant planktonic microfossils	**2** Micro-bioclastic peloidal fine-grained packstone/grainstone fabric	**1** Sponge spicules, often calcisiltite matrix	**5** Densely packed whole fossils and fragments of fossils, often reef-derived	**1** Sponge spicules, often calcisiltite matrix	**5** Densely packed whole fossils and fragments, often reef- or platform-derived	**4** Microbreccia, small bio- and lithoclasts
23 Micrite or microsparite without fossils		**3** Abundant planktonic microfossils	**8** Whole fossils, fine bioclastic micrite matrix	**4** Microbreccia, small bio- and lithoclasts	**11** Abundant coated skeletal grains	**5** Densely-packed whole fossils, often reef- or platform-derived
		8 Whole fossils, fine bioclastic micrite matrix	**22** Millimeter- to centimeter-sized agglutinated oncoids	**5** Densely packed whole fossils and fragments, often reef- or platform-derived	**13** Millimeter- to centimeter-sized oncoids with tube-like structures	**6** Millimeter- to centimeter-sized reef-derived bioclasts and fossils
		9 Abundant fragments of fossils, bioturbation	**24** Millimeter- to centimeter-sized lithoclasts	**10** Abraded and worn skeletal grains	**15-C** Ooids with concentric structures	**13** Millimeter- to centimeter-sized oncoids with tube-like structures
		10 Abraded and worn skeletal grains		**16-**NON-LAMINATED Very small equally-sized peloids	**15-R** Ooids with radial or radial-concentric structures	**24** Millimeter- to centimeter-sized litho-clasts
		15-M Scattered micritic ooids		**18** Abundant rock-building benthic foraminifera or calcareous algae	**16-**NON-LAMINATED Equally-sized peloids	**26** Pisoids
		22 Millimeter- to centimeter-sized agglutinated oncoids		**21** Spar-filled voids within a micritic or pelmicritic framework	**17** Abundant aggregate grains	
				26 Pisoids	**18** Abundant rock-building benthic foraminifera or calcareous algae	

SMF 3: Pelagic lime mudstone and wackestones with abundant pelagic microfossils.

Criteria: Micrite matrix with common to abundant pelagic microfossils (e.g. radiolarians, foraminifera, calpionellids) or macrofossils (e.g. pelagic crinoids, graptolites).

Occurrence: Basin (FZ 1-B) and open deep shelf (FZ 3).

SMF 4: Microbreccia, bio-and lithoclastic packstone or rudstone.

Criteria: Fine-grained breccias, debrites and turbidites are found in this SMF. Grains are commonly worn and rounded and may consist of both locally derived bioclasts, imported shallow–water material and previously cemented lithoclasts and can be mixed with quartz, cherts and extraclasts Grading textures are common.

Occurrence: Basinal settings (FZ 1) and toe-of-slope settings (FZ 3).

SMF 5: Allochthonous bioclastic grainstone, rudstone, packstone, floatstone, breccia with reef-derived biota.

Criteria: Densely packed whole fossils and fossil fragments with a high percentage of reef–derived organisms. The bioclasts are found in a chaotic order or they show depositional structures with characteristic patterns (e.g.turbidite sequences).

Occurrence: slope (FZ 4). Deposited in fore reef position and reef slopes, or in backreef settings and in lagoons. Inner ramps.

SMF 6: Densely packed reef rudstone.

Criteria: Coarse gravels of biogenic material and lithified sediment deposited in high energy or low energy slope settings by rock fall and various mass flow processes. The size of the clasts is varies. Often with low matrix content. Sorting is poor (debris flows) or good (turbidites).

Occurrence: Slope (FZ 4).

SMF 7: Organic boundstone.

The types of reef limestones have been combined within boundstone characterized by in–situ organic growth of potential reefbuilders. They were subdivided by growth forms and assumed growth patterns (framestone, bafflestone, bindstone). And also the subdivisions are of limited value for microfacies studies.

SMF 8: Wackestones and floatstones with whole fossils and well–preserved endo–and epibiota.

Criteria: Mainly sessile organisms rooted in micrite and some mobile organisms. The micrite contains scattered, very small skeletal debris to a finely bioclastic matrix. Burrowing is common. Fossils are well preserved (e.g. double valved mollusks), but some isolated fragments may originate. Mollusks, sponges, corals and some calcareous algae are found.

Occurrence: Shelf lagoon. Low–energy environments below wave base (FZ 2 and FZ 7). Outer and mid ramp settings. The sediment is formed in quiet water below the fair-weather wave base.

SMF 9: Strongly burrowed bioclastic wackestone.

Criteria: Micrite with common to abundant fragmented fossils that are jumbled through burrowing. Common fossils in Paleozoic limestones are crinoids, brachiopods, bryozoans, and scattered rugose corals.

Occurrence: Shallow lagoon at or just below the fair – weather wave base (FZ 7) and deep shelf (FZ 2); outer and mid ramp settings.

SMF 10: Bioclastic packstone and wackestone with abraded and worn skeletal grains.

Criteria: Worn and coated bioclasts deposited within a fine-grained matrix. Packstones, wackestones and fine – grained grainstones can found. The dominant particles have been transported from high – energy to low – energy environments.

Occurrence: Shelf lagoon lation (FZ 2) and open sea shelf (FZ 7). Common in inner and mid – ramp settings.

SMF 11: Coated bioclastic grainstone.

Criteria: Most grains are coated bioclasts, exhibit micrite envelopes or are completely micritized. Additional grain types may be rounded intraclasts, peloids and some ooids.

Occurrence: FZ 6 (winnowed platform edge sands) and in reefs (FZ 5). Rare in inner ramp and mid-ramp settings. The sediment formed in the constant wave action at or above the fair – weather wave base or between the wave base and the storm wave base. Coating due to micritization by microborers occurs preferentially in very shallow environments

SMF 12: Limestone with shell concentrations.

Criteria: Bioclastic rudstones or densely packed floatstones characterized by accumulations of commonly one – type shells or echinoderm fragments. Shells may be bivalves, brachiopods, gastropods, or crinoids.

Occurrence: Rock – building concentrations of shells occur in various environments, from the coast to the deep sea. Shell concentrations are very common in mid – ramp settings. Accumulations of bivalve shells are caused by various processes including current concentrations, storm wave and tempestite concentrations, transgressive lag and condensation concentrations, or prolonged continuous accumulation of shells, because sedimentation fails to keep up with hard part accumulation

SMF 13: Oncoid rudstone and grainstone.

Criteria: Millimeter – to centimeter – sized oncoids, mianly cyanoids and porostromate oncoids, forming a grain – supported fabric, sometimes in association with ooids and fine – grained bioclasts. Bimodal grain – size distributions are common. Note that this SMF does not categorize oncoid floatstones.

Occurrence: Ancient oncoids were formed, both in high – energy and low – energy environments. Oncoid rudstones and grainstones were common in open – marine winnowed edge sand areas (FZ 6), open shelf lagoons (FZ 7), the environs of platform patch reefs, and in back reef areas behind larger reef complexes. On ramps grain – supported oncoids originated predominantly in shallow inner ramp settings.

SMF 14: Lag deposit.

It characterizes lag deposits originating during periods of reduced sedimentation or non – deposition.

SMF 15: Oolite, commonly grainstone but also wackestone. Subtypes highlight the structure of ooids.

Criteria: Accumulations of carbonate sand with a high percentage of ooids found on or near the seaward edge of platforms, banks and shelves and they form within the platform interiors and in inner and mid – ramps. Ooid – rich limestones consisting of abundant, well – sorted and often over packed ooid, concentric ooids with laminae composed of tangentially arranged crystals, radial ooids characterized by laminae consisting of radially arranged crystals and Micritic ooids.

Occurrence: cross – bedded units formed in high energy environments of oolitic shoals, tidal bars and beaches (FZ 6 and FZ 7; mid – and outer ramp settings). Moderate to low – energy conditions, often in sea – marginal or lacustrine environments with elevated or lowered salinities. Many of these ooids originate in restricted environments (e.g. lagoons, lagoonal ponds; FZ 8). marine environments characterized by reduced sedimentation (e.g. outer ramps), growth within biofilms (FZ 8, FZ 9B), or are the result of pervasive micritization.

SMF 16: Peloid grainstone and packstone.

Criteria: Accumulations of very small, grain-supported, subrounded or subangular peloids. Two subtypes are common: SMF 16-NON-LAMINATED, characterized by tiny, equal-sized peloids associated with benthic foraminifera, ostracods or calcispheres. SMF 16-LAMINATED is characterized by peloids of different size, forming irregularly distributed fine-grained packstone (pelmicrite), grainstone (pelsparite) and sometimes also packstone fabrics. Another criterion is wavy micritic laminations. The peloids of SMF 16 are mud peloids, fine-grained fecal pellets, and microbial peloids (SMF 16-LAMINATED).

Occurrence: SMF 16-NONLAMINATED is common in shallow platform interiors and in inner ramp settings, and may also occur in evaporitic arid platform interiors (FZ 9A). SMF 16-LAMINATED contributes to the formation of mud mounds and the stabilization of platform slopes.

SMF 17: Grainstone with aggregate grains (grapestones).

Criteria: Aggregate-grain grainstone. The grainstones and grainstone-rudstones associated with peloids and some coated and micritized skeletal grains. Fossils are usually rare, except for a few foraminifera and algae.

Occurrence: Characteristic for platforms, very rare in ramp settings. FZ 7 and FZ 8 (open and restricted shallow platforms).

SMF 18: Bioclastic grainstone and packstone with abundant and rock-building benthic foraminifera or calcareous green algae.

Criteria: Benthic foraminifera or calcareous green algae are abundant in this type. Other grains are peloids, cortoids and composite grains. Common textures are grainstones and packstones. Diversity is low to moderate.

Occurrence: Sediments of SMF 18 found as bars and channels, and in sand shoals heaped up by tidal currents in shallow lagoons and bays (restricted platform, FZ 8) and in shelf lagoons (FZ 7). SMF 18 sediments are common in inner ramp settings.

SMF 19: Densely laminated bindstone.

Criteria: Bindstone with a laminated fabric correspond to micrite layers and coarser laminae consist of densely spaced, very small peloids or sparry calcite. Fossils are rare except ostracods and some foraminifera, gastropods and a few algae.

Occurrence: Near – coast platform interior (FZ 8 and FZ 9). Tidal flats of attached and isolated platforms and inner ramps.

SMF 20: Laminated stromatolitic bindstone/boundstone.

Criteria: Planar or variously dome-shaped laminated bindstones composed of fine- or coarse-grained laminae sometimes exhibiting microbial or algal structures.

Occurrence: Very common in the intertidal zone, but also in supratidal and shallow subtidal environments.

SMF 21: Fenestral packstone and bindstone.

Criteria: The fabric exhibits small fenestrae. Ostracods and a few foraminifera may be present.

Occurrence: Platform interior (FZ 8). Common in intertidal pools and very shallow subtidal environments.

SMF 22: Oncoid floatstone and wackestone.

Criteria: Millimeter – to centimeter – sized oncoids which consisting of sedimentary grains (e.g. tiny skeletal grains, terrigenous quartz) trapped and bound together by non – skeletal microbes and algae.

Occurrence: Low – energy environments of shallow lagoons and tidal zones (FZ 8).

SMF 23: Non – laminated homogenous micrite or microsparite without fossils.

Criteria: Lime mudstone without fossils or fine – grained dolomicrite, sometimes with authigenic evaporate minerals.

Occurrence: Tidal flats (FZ 8) and arid evaporitic coasts (FZ 9A). Note: unfossiliferous micrite or other grains may also occur in anoxic deep basins (FZ 1B), and that the 'lack' of fossils can only be a sampling effect.

SMF 24: Lithoclastic floatstone, rudstone or breccia.

Criteria: Coarse, angular carbonate lithoclasts. Elongated micrite clasts are abundant, sometimes cross – bedded, forming an intraformational breccia.

Occurrence: Platform interior (FZ 8). Lag deposits in tidal channels and on tidal flats.

SMF 25: Laminated evaporate – carbonate mudstone.

Criteria: Alternation of fine–crystalline carbonate (limestone, dolomite) which might be microbially induced, and diagenetically deformed layers with evaporite crystals (gypsum).

Occurrence: Upper intertidal to supratidal sabkha facies (FZ 9A) in arid and semiarid coastal plains and evaporitic lacustrine basins.

SMF 26: Pisoid cementstone, rudstone or packstone.

Criteria: Accumulations of pisoids both autochthonous or allochthonous characterize this important facies diagnostic SMF Type. Diagnostic criteria are variously shaped, millimeter- to centimeter-sized, densely packed pisoids, commonly cemented by meteoric cements. The cores of the pisoids are usually broken pisoids or cement crusts.

Occurrence: Terrestrial subaerial, or terrestrial and transitional terrestrial-marine subaquatic settings, formed under meteoric-vadose and marinevadose conditions (FZ 10).

2.3.3. Standard Facies Zones

The Standard Microfacies Types (SMF) can be correlated with Wilson model to identify the Standard Facies Zones (FZ) (Figure 2.8). The zones include:

FZ 1 Deep Sea or Cratonic deep-water basin

FZ 1A Deep Sea

Setting: Below wave base and below the euphotic zone in oceanic deep water. Water depth several hundred to several thousands of meters. Wide facies belt.

Sediments: Entire series of deep – sea sediments including pelagic clay, siliceous and carbonate ooze, hemipelagic muds, turbidites. Close to platforms mixtures of pelagic and platform – derived material (peri – platform oozes and muds). Bedding is variable, often thin – bedded. Rock color: dark, reddish or light depending on differences. The conditons including in oxidizing and reducing conditions.

Biota: mainly plankton, typical oceanic assemblages, sometimes associated with autochthonous benthic fossils. In peri – platform sediments up to 75% shallow – water benthos.

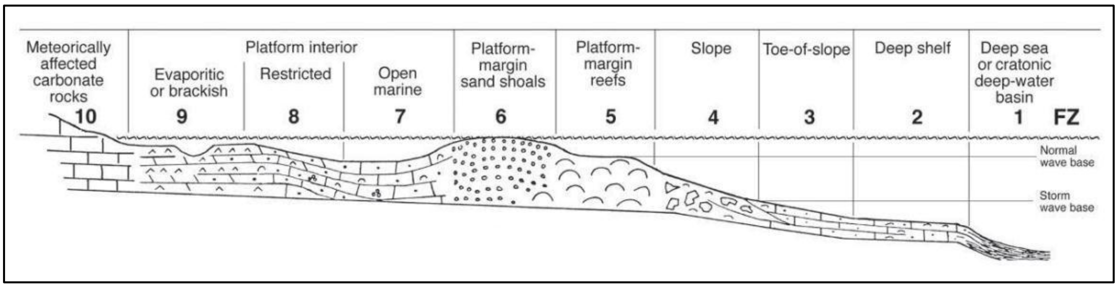

Figure 2.8 Standard Facies Zones (FZ) (Flügel, 2004)

Common lithofacies: Pelagic mudstone and wackestone; marls; allochthonous packstone, grainstone, breccia.

FZ 1B Cratonic deep – water basin

Setting: Below wave base, below the euphotic zone. Water depth about 30 m to several 100 m. Wide facies belt.

Sediments: Similar to 1A. Hemipelagic muds very common. Anhydrite and cherts are sometime common. Anoxic conditions fairly common (high organic content; lack of bioturbation). Dark thin limestone beds and dark shale beds. Lime mudstones, calcisiltites. Rock color: dark brown and black (due to organic matter) and reddish (due to slow sedimentation).

Biota: Predominantly nekton (e.g. ammonites) and plankton (radiolarians, pelagic foraminifera, calpionellids, coquinas of thin-shelled bivalves). Occasionally benthos (abundant sponge spicules).

Common lithofacies: Lime mudstone, wackestone, packstones. Marls. Anhydrite.

FZ 2 Deep shelf

Setting: Below fair-weather wave base but within access to the extreme storm waves. Within or just below the euphotic zone. Forming plateaus between active platforms and deeper basins. The plateaus are commonly established on top of drowned platforms. Water depth tens of meters to hundreds of meters. Normal salinity, oxygenated waters with good current circulation. Wide facies belt.

Sediments: Chiefly carbonate (highly fossiliferous limestone) interbedded with marl beds. Skeletal wackestone and whole fossil wackestone; some grainstone and coquinas. Matrix commonly pelmicrite. Some silica. Well bioturbated. Well bedded. Bedding thin to medium, wavy to nodular. Rock color: gray, green, red and brown depending on variable oxidizing and reducing conditions.

Biota: Diverse shelly fauna indicating normal marine conditions.

Common lithofacies: Wackestone. Occasional grainstones. Marls and shales.

FZ 3 Toe-of-slope apron (deep shelf margin)

Setting: Below wave base and nearly at oxygen level. Averagely inclined sea floor (over 1.5°) basinward of steeper slopes. Water depths ten to hundreds of meters and perhaps 200 to 300 m. Narrow facies belt.

Sediments: Generally pure fine-grained carbonates, in some places chertyand intercalations of terrigenous muds are rare. Pelagic material admixed with fine – grained detritus moved off from adjacent shallow shelves. Grain size highly variable. Typical are well – defined graded beds or breccia layers (turbidites, debris-flow deposits) intercalated in finegrained background sediment. Rock color: dark to light.

Biota: Normally redeposited shallow – water benthos; some deep – water benthos and plankton.

Common lithofacies: Lime mudstones; allochthonous packstones and grainstones and shale partings.

FZ 4 Slope

Setting: Obviously inclined sea floor (commonly 5° to nearly vertical) seaward of platform margins. Very narrow facies belt.

Sediments: Mainly reworked platform material and pelagic admixtures. Grain size is varies. Rock color: dark to light.

Biota: Lastly redeposited shallow – water benthos, encrusting slope benthos and some deep – water benthos and plankton. The facies may be very fossiliferous.

Common lithofacies: Mudstone; allochthonous packstone and grainstone; rudstone and floatstone. Breccia.

FZ 5 Platform – margin reefs

Setting: (a) Organically stabilized mud mounds on upper slope; (b) ramps with knoll reefs and sand shoals; (c) wave – resistant barrier reefs rimming the platform. Water depths generally some meters, but some hundred meters for mud mounds. Very narrow facies belt.

Sediments: Almost pure carbonates of variable grain size. Massive limestones and dolomites. Boundstones are various type. Rock color: light.

Biota: Almost exclusively benthos. Colonies of framebuilders, encrusters, and bafflers along with large volumes of loose skeletal rubble and sand containing benthic microfossils (e.g. foraminifera, algae).

Common lithofacies: Framestone, bafflestone, bindstone, wackestone and floatstone, grainstone and rudstone.

FZ 6 Platform – margin sand shoals

Setting: Elongate shoals, tidal bars and beaches, sometimes with eolianite islands. Above fair – weather wave base and within the euphotic zone, strongly influenced by tidal currents. Very narrow facies belt.

Sediments: Clean calcareous, often rounded, coated and well – sorted sands, occasionally with quartz. Sand grains are skeletal grains, or ooids and peloids. Cross – bedding is well preserved and sometimes bioturbated can observe. Rock color: light.

Biota: Worn and abraded biota from reefs and associated environments. Low – diversity infauna adjusted to mobile substrate. Common biota is large bivalves and gastropods and special types of foraminifera and dasyclads.

Common lithofacies: Grainstone, packstone.

FZ 7 Platform interior – normal marine (open marine)

Setting: Flat platform top within euphotic zone, normally above fair – weather wave base. Called lagoon when protected by sand shoals, islands or reefs of the platform margin. Sufficiently connected with the open sea to maintain salinity and temperature close to that of the adjacent ocean. Moderate circulation. Water depths a few meters to tens of meters. Wide facies belt.

Sediment: Lime mud, muddy sand and clean sands, depending on the grain size of local sediment production. Medium to coarse bedded. Locally patch reefs or organic banks. Terrigenous sand and mud may be common in attached platforms, but are generally absent in detached platforms such as oceanic atolls. Rock color: light and dark.

Biota: Shallow – water benthos with algae, foraminifera, and bivalves; gastropods, particularly common. Areas with marine grasses and with patch reefs.

Common lithofacies: Lime mudstone, wackestone and floatstone, packstone, grainstone.

FZ 8 Platform interior – restricted

Setting: Large variations in salinities and temperatures. Within the euphotic zone. Typically strongly differentiated tidal zones with freshwater, saltwater and hypersaline conditions as well as subaerially exposed areas. Shallow, cut – off ponds and lagoons with restricted circulation and hypersaline water. Lagoons behind barrier reefs, within atolls or behind coastal splits. Water depths below one meter and a few meters to a few tens of meters. Wide facies belts.

Sediments: Mostly lime mud and muddy sand; some clean sand. Terrigenous influx common. Early diagenetic cementation common. Limestones and dolomites. Rock color: light.

Biota: Shallow – water biota of reduced diversity, but commonly with high number of individuals. Typical are miliolid foraminifera, ostracods, gastropods, algae and cyanobacteria. Marine and freshwater vegetation.

Common lithofacies: Lime mudstone and dolomite mudstone, wackestone, grainstone, bindstone. Sedimentary breccia.

FZ 9 Arid platform interior – evaporitic and Humid platform interior - brackish (humid)

FZ 9A Arid platform interior - evaporitic

Setting: Gypsum, anhydrite or halite may be deposited beside carbonates, causing episodic influx of normal marine waters and arid climate. Supratidal. Sabkhas, salt marshes, salt ponds. Wide facies belt.

Sediments: Calcareous or dolomitic mud or sands, with nodular, wavy or coarse – crystalline gypsum or anhydrite. Intercalations of red beds and terrigenous eolianites in landattached platforms. Rock color: highly variable; light, yellow, brown, red.

Biota: Little indigenous biota except cyanobacteria; ostracods, mollusks, brine shrimps adapted to high salinities.

Common lithofacies: Laminated lime and dolomitic mudstones and bindstones alternating layers with layers of gypsum or anhydrite.

FZ 9B Humid platform interior – brackish (humid)

Setting: Poor connection with the open sea as in FZ 9A but with a humid climate so that water runoff dilutes small bodies of ponded seawater and marsh vegetation spreads in the supratidal flats. Narrow facies belt.

Sediments: Calcareous marine muds or sand with some freshwater lime mud and peat layers. Rock color: gray, light, brown, dark.

Biota: Shoal water marine organisms washed in with storms plus organisms adapted to brackish – water and freshwater (ostracods; freshwater snails; charophycean algae).

FZ 10 Humid and arid often subaerially exposed, meteorically influenced limestones

Setting: Subaerial or subaquatic, formed under meteoric – vadose and marine – vadose conditions. Abundant in karst settings and pedogenic carbonates, and supratidal and intertidal environments.

Sediments: Limestones affected by early diagenetic meteoric dissolution predominantly during phases of subaerial exposure Common in caliche crusts. Typically occurring in limestones rich in carbonate cement crusts, but also occurring in micritic caliche or as reworked grains in restricted environments.

Biota: Indigenous biota lacking except cyanobacteria and microbes.

The information of the Standard Microfacies Types (SMF) and the Standard Facies Zones (FZ) will be correlated with Figure 2.9 which indicated to the depositional environment.

2.3.4. Common Microfacies Types of Carbonate Ramps

The SMF Types help to describe sediments of tropical rimmed shelves. They can only be sometimes found in carbonate shelves formed in differing latitudinal and climatic settings and developing different geometries. Many microfacies criteria of platform carbonates can also be seen in thin sections of limestones formed in ramp settings. However, there exist differences concerning the distribution and type of the matrix, grains and fabrics. The occurrence of these criteria on inner, mid- and outer ramps is controlled by offshore and onshore transport by storms, the growth of mud mounds and reefs in different parts of the ramps, and the bathymetric dependence of benthic organisms that contribute to carbonate production.

2.3.5. Microfacies Criteria of Carbonate Ramps

The fine-grained matrix is micrite and calcisiltite. Micrite is common in deeper outer ramps and in protected areas of inner ramps. Both allomicrites and

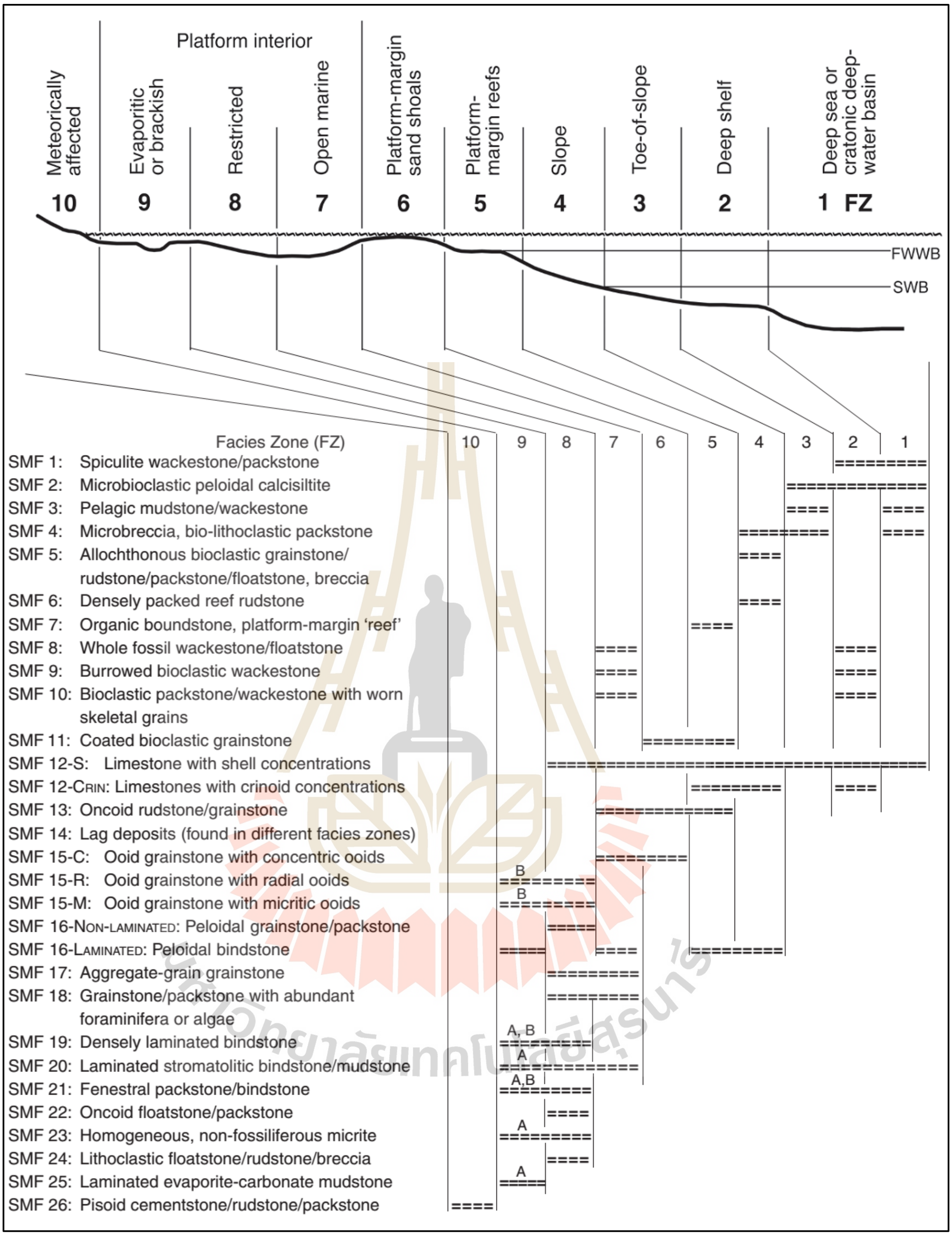

Figure 2.9 The distribution of SMF Types in Facies Zones (FZ) A: evaporitic, B: brackish (Flügel, 2004)

automicrites contribute to carbonate production.

Allomicrites are characterized by poorly sorted matrix exhibiting very fine peloids within a matrix, with small bioclastic debris probably caused by bioerosion, variations in packing and mixed microfossil faunas.

Automicrite matrix is a common constituent of mud mounds. Clues to inplace carbonate production in deeper ramps are down-ramp sequential distribution of depth-sensitive organisms, well preserved and un-abraded fossils, beds and bed sets that are traceable along ramp slopes for tens of kilometers, and that are also traceable through mounds growing on the ramps, geopetals in original position, and lack of sedimentary structures indicative of transport.

Calcisiltite is abundant in outer ramps, characterizing a particular microfacies type (RMF 1). The origin of these calcisiltites is enigmatic. Abrasion in storm-influenced ramp parts and transport to deeper ramp parts may be one of the sources in Paleozoic ramps. Pelagic fallout contributed to the formation of calcisiltite and allomicrite of Mesozoic and Cenozoic ramps.

The dominant grain types of carbonate ramps are skeletal grains and ooids, followed by peloids and intraclasts. Other grain types are quantitatively of minor importance (cortoids, oncoids), or are very rare or totally absent (pisoids, aggregate grains). Abundant aggregate grains are characteristic of carbonate platforms but missing in ramp settings.

Common skeletal grains in outer ramps are calcimicrobes, smaller foraminifera, sponge spicules, bryozoans, brachiopod and mollusk as well as arthropod shells, serpulids and echinoderms.

Shallow inner ramp sediments exhibit similar bioclasts in comparison to the normal marine and restricted platform interior facies of platforms: Calcimicrobes, benthic smaller and larger foraminifera, calcareous green algae, mollusks, serpulids, ostracods and echinoderms. These shells are also major constituents of storm and current induced skeletal shoals in mid-ramp and inner ramp settings.

Organisms taking part in the formation of mud mounds, reef mounds or patch reefs are microbes, some green and red algae, sponges including archaeocyathids, stromatoporoids, coralline and siliceous sponges, tabulate and scleractinian corals, and some pelecypods (rudists).

Taphonomic and preservation criteria including shape, rounding, breakage, and size and sorting of fossils are good indications of transport and allochthonous deposition. Out-of-habitat transport of benthic organisms by bottom currents is indicated by fossils that are uncommon in the depositional environments where they are found (e.g. larger foraminifera in outer ramp settings).

Ooid accumulations originate in three ramp settings: (1) in inner ramps near shorelines and at coasts (here also contributing to eolian sand dunes), (2) in mid-ramp and inner ramp settings forming shoals and thick grainstone sheets; and (3) as grains having been transported from mid-ramps to outer ramps and deposited in thin tempestite beds intercalated with lime mudstones and wackestones, marls or shales. Most of the spherical ooids correspond to concentric or micrite ooids. Parautochthonous spherical and non-spherical radial ooids may occur in inner ramps. Relations between water energy, ooid size and sorting and the thickness of ooid cortices are indicators of transport mechanisms

Peloids occur as fecal pellets in inner ramps and as mud peloids in outer ramps. Cortoids are present in current-washed sand shoals of inner ramps, but appear to have not the same importance as in rimmed platform carbonates.

Oncoids occur in inner and outer ramps. Oncoids from shallow and deep environments differ in nuclei, organisms contributing to the cortices, lamination type, and the composition of the encruster association. Oncoids built by cyanobacteria and algae are present in inner ramps; those built by red algae (rhodoids) in inner ramp, but more frequently in outer ramp settings. Micrite oncoids are common in outer ramps and basins.

Intraclasts may occur in all ramp settings, but are abundant in distally steepened ramps (RMF 9) within debris flows accumulating near to the outer ramp slopes. These intraclasts are micritic, poorly sorted, angular to subrounded grains embedded within a micrite matrix. Important depositional fabrics in differentiating inner, mid- and outer ramps are bioturbation and lamination.

Burrows occur all over the ramps, but are particularly abundant below the wave base and below the storm wave base. Mid-ramp and outer ramp burrows exhibit differences in density, spatial distribution and ichnotaxa association. Depositional lamination is frequent in deep ramp settings with hemipelagic sedimentation. Fenestral fabrics are common in tidal areas in back-ramp regions (RMF 23). Mid-ramp sediments are characterized by biofabrics indicating storm deposits (cross-bedding, imbrication patterns, reverse grading bedding). Good characteristics are disordered fabrics typified by chaotic arrangement of non-sorted, variously sized, commonly fragmented and broken bioclasts whose interspaces are infilled with calcisiltite or bioclastic micrite (RMF 28).

Many ramp carbonates, particularly packstones and grainstones, show low compositional maturity expressed by a mixture of different skeletal grains, peloids, intraclasts and sometimes also ooids. This microfacies is common in packstones and grainstones of mid-ramp- and inner ramp settings. Characteristic microfacies types are RMF 8 and RMF 14

2.3.6. Common microfacies types of Paleozoic and Mesozoic ramp carbonates.

The list starts with microfacies types (Figure 2.10) of the deeper outer ramp zones, and continues with microfacies types of mid-ramps and shallow inner ramp zones. Microfacies types of the bioclastic and oolitic carbonate sand shoals and banks formed in inner and mid-ramp settings are listed following;

Outer ramp

Thin- to medium-bedded, fine-grained, often burrowed limestones and marls. Laminated marls alternate with lime mudstones. Skeletal grains commonly well preserved, not worn. Mudstones, wackestones, packstones. Some tempestite beds (grainstones).

RMF 1: Calcisiltite and mudstone with peloids, very fine skeletal debris, sponge spicules, sometimes fine-laminated (SMF 1).

RMF 2: Argillaceous burrowed mudstone and wackestone; rare agglutinated foraminifera, ostracods, echinoderms.

RMF 3: Burrowed bioclastic wackestone and packstone with diverse, common to abundant fossils (bivalves, brachiopods, echinoderms) and peloids. Skeletal grains not worn; whole fossil preservation common (SMF 8).

RMF 4: Peloidal wackestone and packstone (~ SMF 2).

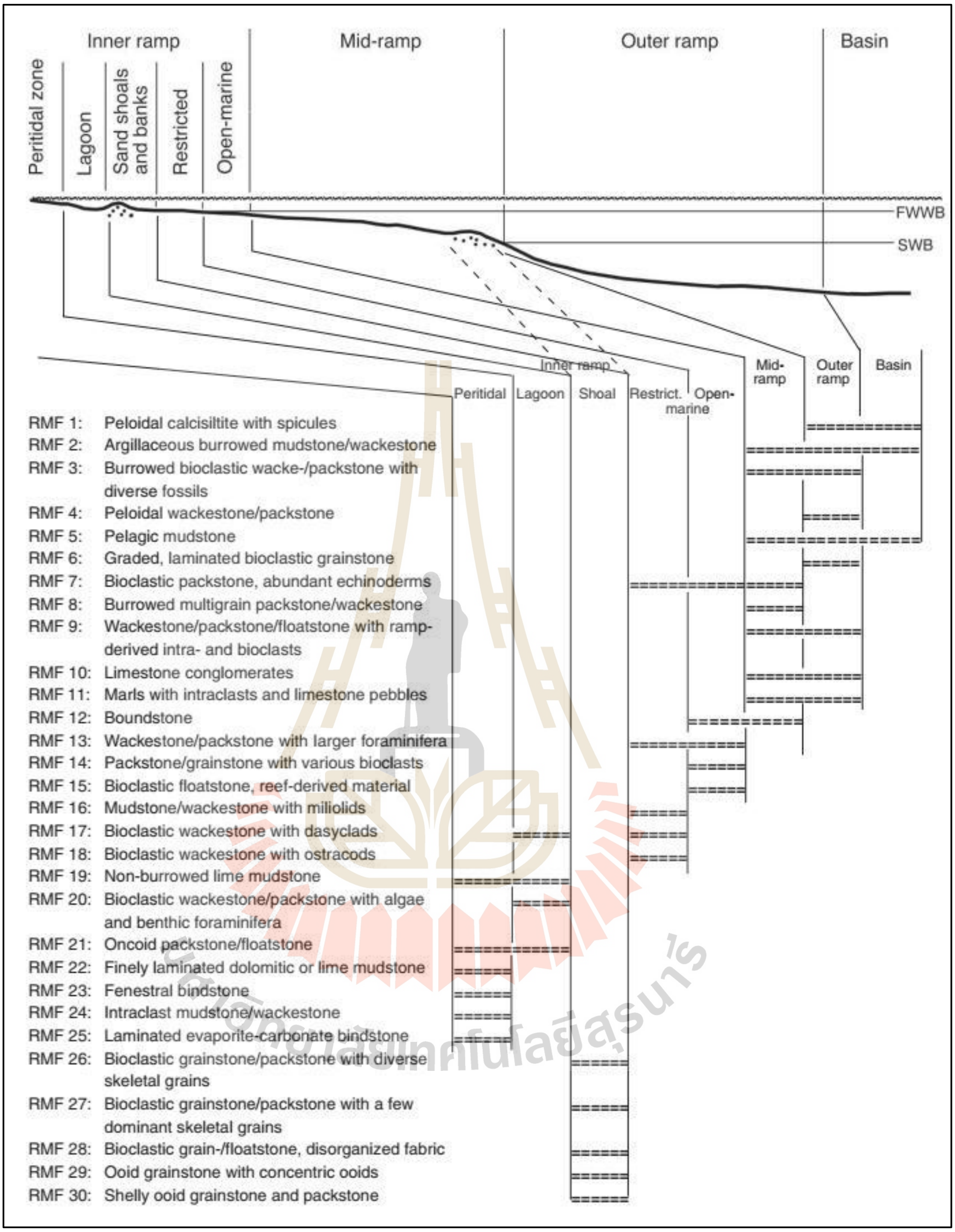

Figure 2.10 Microfacies types frequently described in studies dealing with Paleozoic and Mesozoic carbonate ramps (Flügel, 2004)

RMF 5: Pelagic mudstone with planktonic microfossils and open-marine nektonic fossils (e.g. ammonites) (SMF 3).

RMF 6: Graded, laminated and finely cross-bedded bioclastic and peloidal grainstone (tempestite).

Mid-ramp

Medium-bedded, fine-grained bioclastic limestones and marls, often burrowed. Skeletal grains often worn. Echinoderm is common. Mudstone, wackestone, packstone, some grainstones. Distally steepened ramps exhibit slumps and various signs of reworking and transport of fine-grained ramp material. Distal steepening occurs in outer ramp settings or near the mid-ramp-outer ramp boundary. Calcareous sand shoals and sand banks. Various kinds of reefs occur in mid-ramp and inner ramp settings (e.g. coral patch reefs, coral-red algal reefs). RMF 2, RMF 3, RMF 5 and

RMF 7: Bioclastic packstone with abundant echinoderms and common bivalves and foraminifera. Skeletal grains worn (SMF 10).

RMF 8: Burrowed packstone and grainstone with various skeletal grains, intraclasts, oncoids and peloids.

RMF 9: Wackestone, packstone, floatstone with micritic intraclasts and ramp-derived bioclasts; sometimes microbreccias (distally steepened ramps) (SMF 5).

RMF 10: Limestone conglomerates (distally steepened).

RMF 11: Marls with intraclasts and limestone pebbles (distally steepened).

RMF 12: Boundstones comprising coral and coral-crust framestone, red algal framestone (SMF 7).

Inner ramp

Inner ramp sediments are bedded, microfacially differentiated limestones and dolomites forming relatively thin sequences. Marls are of minor importance. The inner ramp comprises open-marine environments with good water circulation, protected environments with restricted water circulation, sand shoal and bank environments characterized by oolitic and bioclastic grainstones and packstones, lagoonal environments behind shoals or islands and peritidal environments. The latter are separated from other inner ramp parts as back-ramp environments. Common texture types of open and protected inner ramps are bioclastic packstones and wackestones. Coral and and coral-crust framestone, red algal boundstones (RMF 12) and other reef limestones (bivalve reefs) are common in open inner ramps. Other reefs, e.g. serpulid biostromes, occur in protected innerramp settings.

Open inner ramp environments

RMF 13: Bioclastic wackestone and packstone with abundant larger foraminifera (e.g. orbitolinids) (SMF 18-FOR).

RMF 14: Bioclastic packstone and wackestone with skeletal grains, various amounts of intraclasts and some ooids (near-shoal).

RMF 15: Bioclastic floatstone with various reef-derived material (near-reef coral-, algal- or bivalve-debris) (~SMF 6).

Protected and low-energy inner ramp environments

RMF 7 characterized by common to abundant echinoderm fragments. Associate skeletal grains occurring in different quantity are bivalve shells, gastropods, bryozoans, and benthic foraminifera. Other microfacies types are packstones and grainstones with larger foraminifera (RMF 13).

RMF 16: Mudstone, wackestone or packstone with abundant miliolid foraminifera (SMF 18-FOR).

RMF 17: Bioclastic wackestone with dasyclad green algae (SMF 18-DASY).

RMF 18: Bioclastic wackestone with ostracods.

Lagoonal environments

RMF 17 (low-diverse flora) and

RMF 19: Non-burrowed lime mudstone.

RMF 20: Bioclastic wackestone and packstone with calcareous algae and benthic foraminifera.

RMF 21: Oncoid packstone and floatstone (SMF 22).

Peritidal zones

RMF 19 and RMF 21 and

RMF 22: Fine-laminated dolomitic/lime mudstone (SMF 19).

RMF 23: Fenestral bindstone (SMF 21).

RMF 24: Intraclast mudstone and packstone.

RMF 25: Laminated evaporite-carbonate bindstone (SMF 25).

Carbonate sand shoals and banks

Storm-dominated ramps are characterized by accumulations of ooids, skeletal grains and peloids. These grains occurring separately or associate, form grainstone and packstone textures. Bedding and cross bedding are common. These sediments originate in mid-ramp and innerramp settings. Bioclastic banks may be formed by storminduced but also by coast-parallel bottom currents.

RMF 26: Medium- and coarse-grained bioclastic grainstone and packstone with various benthic skeletal grains.

RMF 27: Bioclastic grainstone and packstone composed of few dominant skeletal grains (e.g. predominantly echinoderms, or predominantly foraminifera).

RMF 28: Bioclastic floatstone and rudstone exhibiting a strongly disorganized fabric.

RMF 29: Ooid grainstone with densely packed concentric ooids (common in shoals and banks) (SMF 15-C).

RMF 30: Shelly ooid grainstone and packstone (common in banks).

2.3.7. Microfacies study and models reconstruction of carbonates sequence.

Badenas and Aurell (2010) analyzed facies and reconstructed the models which developed from inner to mid ramp areas located south of teruel (northeast Spain).

Emraninasab et al. (2016) studied lithological and microscopic investigation of Sartakht formation. The microscopic examinations have result 2 siliciclastic petrofacies and 12 carbonate microfacies and from field investigation and microscopic results can identified the depositional environments including tidal flat, lagoon, shoal and open marine environment.

Hu et al. (2017) studied the microfacies and interpreted the depositional environment of the carbonate rocks based on field and petrographic observation. Thirteen microfacies of the Ordovician in the Tarim basin, NW China, which are divided into four facies belts including tidal flat, lagoon, shoal, and open marine.

James (1984) studied the carbonate sequence in the shallow shelf sea environment and reconstructed a vertical sequence model of shallowing-upward cycle.

Read (1980) described middle Ordovician rocks in the Virginia Appalachian which were deposited in carbonate ramp. The sequence of ramp to basin were divided into 7 zones including high intertidal to supratidal flat, tidal to restricted subtidal, lime sand flat, shallow to quiet water subtidal ramp, ramp and downslope build ups, subwave-base deep ramp and deep flank downslope build ups and slope and basin.

Ruppel and Walker (1984) investigated middle Ordovician outcrop sections of the Chickamauga group, which can be divided into 10 formations including, Blackford, Five Oaks, Lincolnshire, Rockdell, Holston, Benbolt, Wardell, Bowen, Witten and Moccasin formations. They are deposited in shallow water carbonate platform deposits. The Blackford formation comprises dolostone, lime mudstone and breccia. The depositional environment of the Blackford formation indicates peritidal environment. The Five Oak formation contains dolostone, dolomitic mudstone, pelletal packstones and grainstones. The palaeoenvironment of Five Oak formation is deposited in peritidal, tidal flat environments. The Lincolnshire formation composes of stromatolitic boundstones, pelmatozoan-bryozoan grainstonepackstones, fossiliferous wackestones. The depositional environment is developed in shallow subtidal environments. The Rockdell formation comprises pelmatozoan-bryozoan packstones and grainstones, bryozoan wackestones and deposited in Skeletal sand banks and mud mounds. The Holston formation composes of pelmatozoan grainstones, bryozoan packstones, and bryozoan wackestones and developed in Outer-platform reef complex, skeletal sands and reef boundstones. The Benbolt formation contains pelmatozoan-bryozoan packstonegrainstones, silty trilobite wackestones, pelmatozoan grainstone-packstones and terrigenous claystone-siltstones. The depositional environment indicates Outer platform with pools and channels. The Wardell formation comprises Bryozoan-echinoderm wackestones, pelmatozoan grainstone-packstones, mudstones and claystone-siltstones deposited in restricted subtidal to intertidal with storm deposits. The Bowen formation composed of terrigenous claystones, calcareous siltstones formed in terrigenous tidal flat-marginal deltaic environment. The Witten formation contains pelmatozoan-bryozoan grainstone-packstones, packstone-wackestones, silty mudstones, terrigenous claystones and bryozoan boundstones. The palaeoenvironment of Witten formation is deposited in shallow subtidal-intertidal mudflat with channels and biogenic mounds. The Moccasin formation consists of terrigenous claystones and siltstones, silty packstone-wackestones, pelletal fenestral mudstones. They are deposited in tidal flat environment (supratidal-shallow subtidal).

Sardarabadi et al. (2016) investigated the Qom Formation in Rameh section, northeastern Garmsar. The Qom Formations contain dominant limestone, pebble rich to sandy Limestone and marl Limestone. The Qom Formation rocks in Rameh section are identified the depositional environment and tidal flat, lagoon, shoal and open marine. Open marine facies consists of bioclast wackestone-mudstone and bioclast packstone-roadstone; ooid grainstone, bioclast grainstone and coral boundstone associated with shoal facies; lagoon facies association is intraclast bioclast wackestone, dolomitic mudstone and bioclast packstone; and tidal flat facies association is composed of sandy-dolomudstone and stromatolitic boundstone. They are deposited in a rimmed shelf carbonate ramp.

Shao et al. (2011) studied the carbonate rocks in central Hunan, southern China, which consisted Zimenqiao Formation, Ceshui Formation, Shidengzi Formation, Liujiatang Formation, Menggongao Formation and Shaodong Formation. The Zimenqiao Formation composes of stromatolitic, oolitic and bioclastic limestone, dolomite and evaporites. The Shidengzi Formation consists of thick-bedded to massive bioclastic limestones with intercalation of thin to thick-bedded calcareous shales. The Liujiatang Formation consists of middle to thin-bedded bioclastic limestones, muddy limestones and calcareous shale. The Menggongao Formation consists of massive bioclastic limestones intercalated with middle-bedded alternated bioclastic limestones and calcarenites. The Ceshui Formation consists of quartz arenites, sandy conglomerates, siltstones, mudstones with siderite, stromatolitic and bioclastic limestones. The Shaodong Formation mainly consists of mudstones with marine fossils and intercalated with quartz arenites and siltstones. They recognized 25 lithofacies with can be grouped into: 1. inner ramp peritidal platform, 2. Inner ramp organic bank and mound, 3. mid ramp, 4. outer ramp and 5. shelf basin.

Yao et al. (2016) studied the storm shell beds from the Du'an formation and the upper Shangsi and Baizuo formations in South China. The characteristic of the shell beds are indicated type of tempestites and accumulated feature of shell beds, which are: type A: dominated articulated and convex-down shells in wackestone and packstone. They are developed in distal tempestites (weak water energy around the storm wave-base); type B: mostly disarticulated and convex-up shells in packstone, which occur between distal and proximal tempestites (medium water energy between the storm wave-base and fair-weather wave-base); and type C: highly fragmented shells in grainstone that formed in proximal tempestites (under strong water energy above the fair-weather wave-base). These shell beds types varying from articulated, convex-down and low fragmented shells to disarticulated convex-up and high-breakage shells, they are formed under low and high water energy respectively.

CHAPTER III

RESEARCH METHODOLOGY

This chapter describes methods of this study which can be categorized into three main steps including systematic literature review, field investigation and laboratory work.

3.1. Literature review and planning

The literature review is a basic for research question, research design, data analysis and conclusion. The literature review can help us know and focus the boundary of our research and avoid repeating. The systematic review method is clearly formulated question for systematic and explicit methods to identify, select and critically appraise relevant primary research and extract and analyze data from studies.

3.1.1. Stages of a systematic review

Step1: Planning the review

- Identification of the need for a review
- Preparation of a proposal for a review
- Development of a review protocol

Step2: Conducting the review

- Identification of research terms
- Selection of studies
- Study quality assessment

- Data extraction and monitoring progress
- Data synthesis

Step3: Reporting and Dissemination

- The report and recommendations

The systematic literature review starts with planning the review. In this stage, I clearly defined the research question and boundary from the research question and boundary from the identification of the need for review. And then, the keywords were defined e.g. Lower Paleozoic limestones or carbonate rocks, Ordovician limestones or carbonate rocks, facies analysis (in Thailand). The studies relevant to those keywords were sorted, selected and reviewed. The reviewed literatures include geologic setting (tectonic history of the Ordovician in Thailand, the Ordovician rocks in Thailand, regional geology of the studied section), faunal assemblage, microfacies (the carbonate classification under the thin section, standard microfacies types (SMF), standard facies zones, common microfacies types of carbonate ramps, microfacies criteria of carbonate ramps, common microfacies types of Paleozoic and Mesozoic ramp carbonates, microfacies study and models reconstruction of carbonates sequence). Thesis planning was set up and thesis proposal is prepared as a consequence. They start from field investigation planning in the interested studied section, investigation and collection of rock sampling from the studied section, sample preparation in a laboratory, sample analysis and interpretation.

3.2. Field investigation

The field investigation was carried out in December 2016 at Wat Mong Kratae section, Tha Kradan sub–district, Si Sawat district, Kanchanaburi province (Figure

3.1A). Location of the studied section is approximately located at Latitude 14° 27´10´´N and Longitude 99° 07´50´´E as show on the topographic map sheet Khuean Srinagarindra Quadrangle (4837 IV) (RTSD, 1999) (Figure 3.1B). The 24 rock samples were collected. The section of 157 meters thick is composed of thin to thick bedded stylolitic limestone (Figure 3.1C). Limestones are greenish gray to dark gray and they are mainly classified as wackstone, packstone and some parts of section are classified as grainstone.

3.3. Laboratory works

All rock samples were prepared for the laboratory works. The preparations were divided into two parts as described follows;

3.3.1. Polished slab preparation (Figure 3.2A)

Observation on the polished slabs can help to preliminarily classify limestone type. The polished slab preparation procedure can be divided into three steps as describe below (Green, 2001).

Step1: Select the specimens and draw the line around the interest area where will cut the specimen, especially with rocks that have a fabric.

Step2: Cut the specimen following the section line by the Hillquist SF–8 Trim saw (Figure 3.3A).

Step3: Grind the slab for removing any saw marks by the Hillquist Thin section Grinder (Figure 3.3B) and the silicon carbide powder 240 grits, 400 grits, and 600 grits respectively, they are used to polish the surface of the rock to flat and smooth.

3.3.2. Thin section preparation (Figure 3.2B)

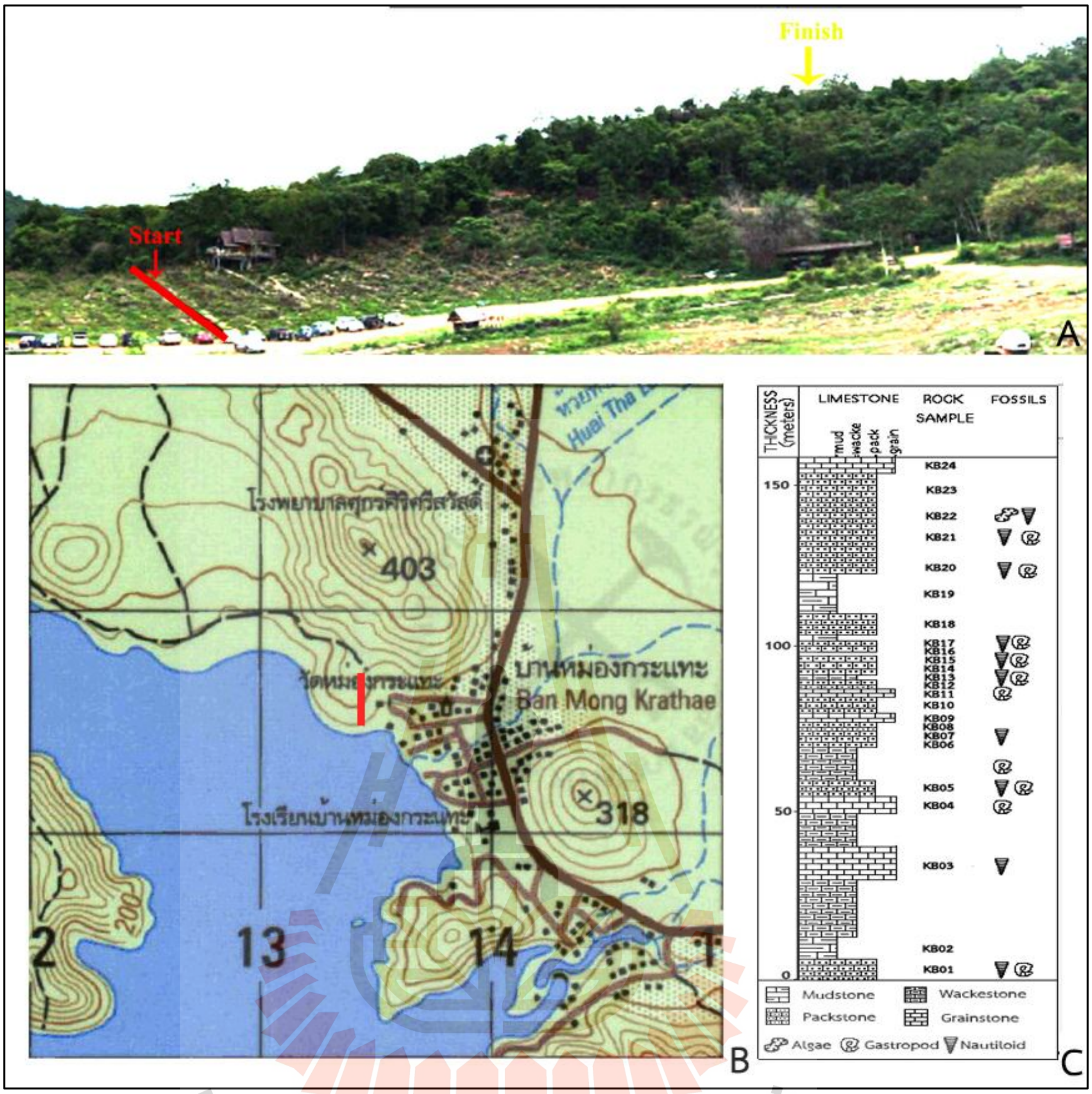

Figure 3.1 The photograph of the studied section (A), the topographic map (B) and the lithostratigraphic column of the studied section (C)

The thin section analysis is a petrographic study under the stereomicroscope and the polarized light microscope for studying mineral composition of the rock. The rock thin section preparation procedure is divided into four steps hereinafter (Green, 2001; Hill, 1999).

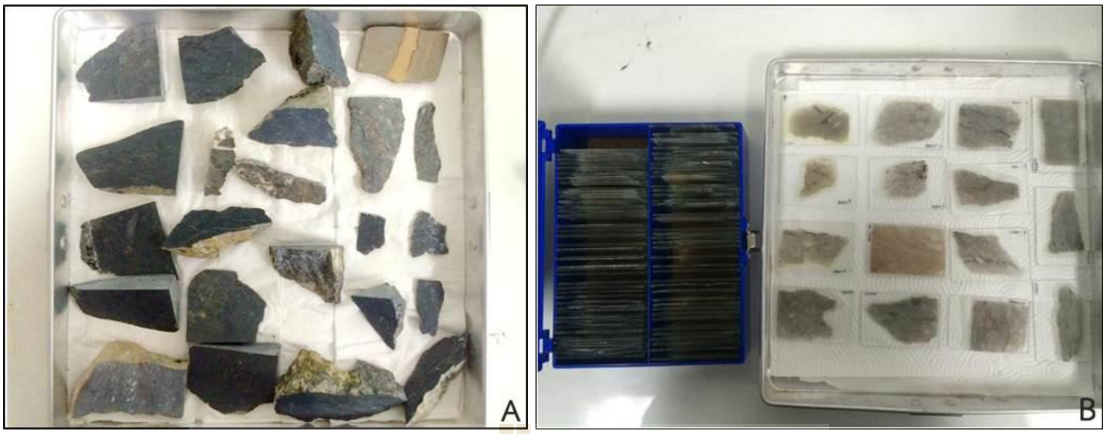

Figure 3.2 The polished slab (A) thin section (B).

Step1: Prepare the first three steps with the same processes as the polished slab preparation. Then slice the specimen to have a dimension at less than 3 cm thick.

Step2: Place a glass slide and the specimen which the suitable size and already polished to flat and smooth on the hot plate.

Step3: Stick a glass slide (either size 7.5 cm. x 5.0 cm. or 4.6 cm. x 2.7 cm) on the surface of the polished specimen with epoxy glue and then leave it to dry for 3 hours.

Step4: Cut-off the rock slab which sticks with a glass slide by the Hillquist Thin section machine (Figure 3.3C). And then reduce the thickness by the thin section grinder (the thickness approximately 0.03 millimeters). Polish the surface of rock to flat and smooth by using the silicon carbide powder.

Figure 3.3 The machine for the preparation of the polish slab and thin section. (A) The Hillquist SF–8 Trim saw machine (B) The Hillquist Thin Section Grinder machine (C) The Hillquist Thin Section machine (Seven republic, www, 2015).

CHAPTER IV

RESULTS AND DISCUSSION

This chapter gives the results of the study and discussion including lithostratigraphy, brief description on paleontology, microfacies analysis, depositional environment and stratigraphic correlation

4.1. Lithostratigraphy

The lithostratigraphy of the studied section observed at Wat Mong Kratae locality in Ban Tha Kradan area, Sri Sawat District, Kanchanaburi Province is described herein. The succession is consisted of gray to greenish grey, well bedded, thin- to thick-bedded limestones which are exposed continuously with bedding sttitude at 330, 30 (strike, dip). The total thickness of the studied section is 157 meters and 24 rock samples are collected from this studied section from bottom to top accordingly (Figure 4.1).

4.1.1. KB01

Their color varies from light olive gray to pale yellowish brown or yellowish gray, thick bedded (30 – 100 centimeters). This sample is collected from the lower part of the measured section and they lie conformably under KB02. They have a thickness of 6.5 meters. The rocks sometimes show argillaceous layers and stylolite. Nautiloid and gastropod are observed.

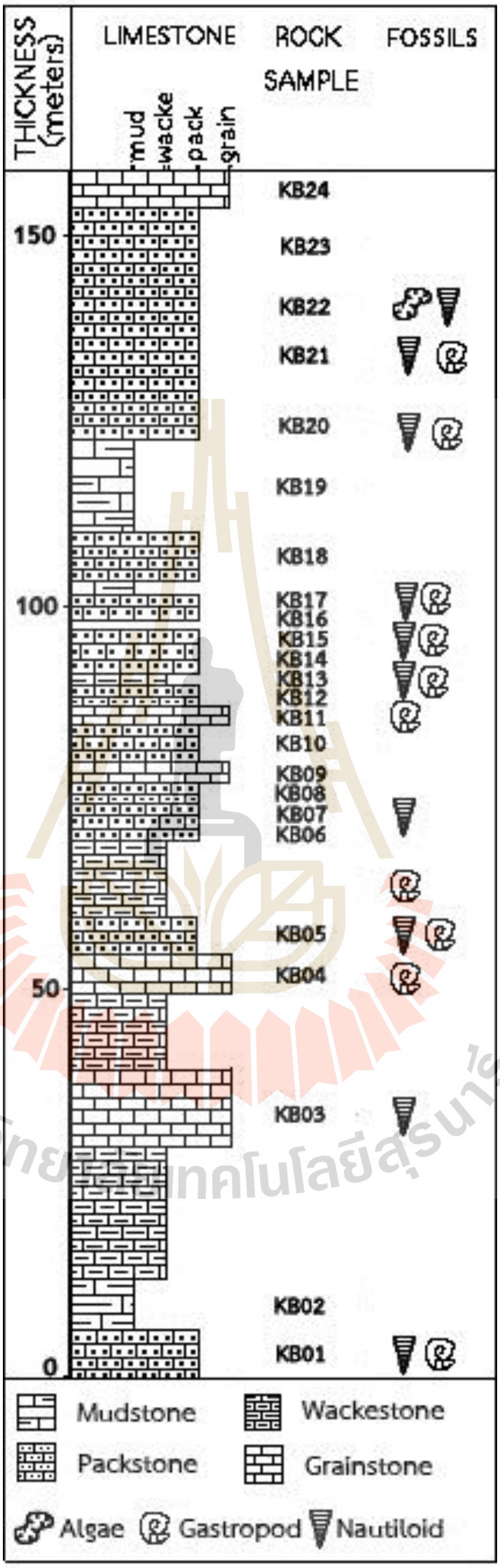

Figure 4.1 The lithostratigraphic column of the Wat Mong Kratae locality

4.1.2. KB02

The rocks are normally thick bedded (30 – 100 centimeters). This sample is collected from the lower part of the measured section and they lie conformably above KB01. They have a thickness of 6.5 meters. Their color ranges from light olive gray to brownish gray and the rocks sometimes show argillaceous layers.

4.1.3. KB03

Their color varies from moderate reddish brown to dark yellowish orange, medium – bedded (10 – 30 centimeters) to thick bedded (30 – 100 centimeters). This sample is collected from the lower part of the measured section. The thickness of them is 10 meters. The rocks sometimes show argillaceous layers and stylolite. Nautiloids are observed.

4.1.4. KB04

Their color varies from brownish gray to dark yellowish orange, medium – bedded (10 – 30 centimeters) to thick bedded (30 – 100 centimeters). This sample is collected from the lower part of the measured section and conformably lies under KB05. They have a thickness of 5 meters. The rocks sometimes show argillaceous layers and stylolite. Gastropods are observed.

4.1.5. KB05

Their color varies from light olive gray to brownish gray, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the lower part of the measured section and lies conformably above KB04. They have a thickness of 5 meters. The rocks sometimes show argillaceous layers. Nautiloid and gastropod are observed.

4.1.6. KB06

Their color varies from light olive gray to brownish gray, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the lower part of the measured section and conformably lies under KB07. The thickness of them is 5 meters. The rocks sometimes show argillaceous layers. Gastropods are observed.

4.1.7. KB07

Their color varies from light olive gray to brownish gray, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section. They have a thickness of 2.5 meters. They lie conformably above KB06 and conformably lie under KB08. The rocks sometimes show argillaceous layers and some part represent stylolite. Nautiloids are observed.

4.1.8. KB08

Their color varies from light olive gray to brownish gray, medium – bedded (10 – 30 centimeters) to thick bedded (30 – 100 centimeters). This sample is collected from the middle part of the measured section. The thickness of them is 2.5 meters. They lie conformably above KB07 and conformably lie under KB09. The rocks sometimes show argillaceous layers and stylolite. Nautiloids are observed.

4.1.9. KB09

Their color varies from light olive gray to brownish gray, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section. The thickness of them is 5 meters. They sit conformably on KB08 and conformably lie under KB10. The rocks sometimes show argillaceous layers and some part represent stylolite.

4.1.10. KB10

Their color varies from brownish gray to moderate reddish brown, medium – bedded (10 – 30 centimeters) to thick bedded (30 – 100 centimeters). This sample is collected from the middle part of the measured section. They have a thickness of 2.5 meters. They sit conformably on KB09 and conformably lie under KB11. The rocks sometimes show argillaceous layers and stylolite. Gastropods are observed.

4.1.11. KB11

The rocks are normally medium – bedded (bed thickness 20 – 25 centimeters) to very thickly bedded. This sample is collected from the middle part of the measured section. A total thickness of them is 2.5 meters. They sit on KB10 and conformably lie under KB12. Their color is pale red – purple and they sometimes represent stylolite and argillaceous layers. Gastropods are observed.

4.1.12. KB12

The rocks are normally thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section. A total thickness of them is 1.25 meters. They sit on KB11 and conformably lie under KB13. Their color ranges from pale yellowish brown to yellowish gray and they sometimes represent argillaceous layers. Nautiloid and gastropod are observed.

4.1.13. KB13

Their color varies from moderate reddish brown to dark yellowish orange, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured sections. They have a thickness of 2 meters. They lie conformably above KB12 and conformably lie under KB14. The rocks sometimes show argillaceous layers and some part represent stylolite. Nautiloid and gastropod are observed.

4.1.14. KB14

Their color varies from moderate reddish brown to dark yellowish orange, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured sections. The thickness of them is 1.5 meters. They lie conformably above KB13 and conformably lie under KB15. The rocks sometimes show argillaceous layers and some part represent stylolite. Nautiloid and gastropod are observed.

4.1.15. KB15

The rocks are normally thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section. A total thickness is 1.75 meters. They lie conformably above KB14 and conformably lie under KB16.Their color is light olive gray and they sometimes represent argillaceous layers. Nautiloid and gastropod are observed.

4.1.16. KB16

Their color varies from grayish pink or pale red, medium – bedded (10 – 30 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section. A thickness is 2.5 meters. They lie conformably on KB15 and sit under KB17. The rocks sometimes show argillaceous layers and stylolite. Nautiloid and gastropod are observed.

4.1.17. KB17

The rocks are normally thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from almost top of the measured section. The thickness of them is 2 meters. They sit conformably on KB16 and conformably lie under KB18.Their color ranges from pale yellowish brown to yellowish gray and sometimes represent argillaceous layers. Nautiloid and gastropod are observed.

4.1.18. KB18

Their color is pale yellowish brown, medium – bedded (10 – 30 centimeters) to very thick bedded. This sample is collected from the middle part of the measured section and is conformable found on KB17. The thickness of them is 6.5 meters. The rocks sometimes show argillaceous layers and stylolite.

4.1.19. KB19

The rocks are normally thick bedded (30 – 100 centimeters). This sample is collected from almost top of the measured section. The thickness of them is 12 meters. They lie conformably above KB18 and conformably lie under KB20. Their color ranges from moderate reddish brown to dark yellowish orange and they sometimes represent argillaceous layers.

4.1.20. KB20

The rocks are normally medium – bedded (10 – 30 centimeters). This sample is collected from in almost top of measuring section and they lie conformably above KB19. They have a thickness of 2 meters. Their color ranges from light olive gray to yellowish gray and some part represent argillaceous layers. Nautiloid and gastropod are observed.

4.1.21. KB21

The rocks are normally medium – bedded (10 – 30 centimeters). This sample is collected from in almost top of the measured section. The thickness of them is 8 meters. They lie conformably above KB20 and conformably lie under KB22.

Their color ranges from light olive gray to pale yellowish brown and some part of rocks represent argillaceous layers. Nautiloid and gastropod are observed.

4.1.22. KB22

The rocks are normally medium – bedded (bed thickness 20 – 25 centimeters) to very thickly bedded. This sample is collected from the almost top of the measured section. The thickness of them is 10 meters. They conformably lie over KB21 and put under KB23. Their color is grayish black and the rocks sometimes represent stylolite and argillaceous layers. Nautiloid and Receptaculitaleans are observed.

4.1.23. KB23

Their color varies from moderate reddish brown to dark yellowish orange, thick bedded (30 – 100 centimeters) to very thick bedded. This sample is collected from the top part of the measured section. The thickness of them is 10 meters. They lie conformably above KB22 and conformably lie under KB24. The rocks sometimes show argillaceous layers.

4.1.24. KB24

Their color varies from dark yellowish orange to dark yellowish brown and grayish brown to grayish yellow, thick to very thick bed of grainstone interbedded thin layer of mudstone. This sample is collected from the topmost of measured section, lies conformably above KB23. The total thickness is approximately 5 meters. Their internal structure represents grain orientation due to compression stress which affected from tectonic activity around this area.

4.2. Brief description on Paleontology

The fossils of nautiloids, gastropods, brachiopods and algae are found and they indicate Middle Ordovician (Dapingian – Darriwilian age). Some of these fossils are identical to those reported from the Tha Manao Limestone exposed elsewhere. Nautiloids are cephalopods belonged to phylum Mollusca, subclass Nautiloidea, order Nautilitida. They were abundant during the Lower Paleozoic. The cephalopod characteristic are distinctive and easy to recognize in the field, can found include chambered, coiled or external straight shell. External parts of the shells including chambers and a siphuncle connected with all chambers passing through the septa. They lived in shallow marine to deep marine environment. At the studied section, nautiloid specimens were observed thin connecting rings and long straight shell but they lack a detailed endosiphuncular canal system. The observed specimens are likely to be *Sibumasuoceras langkawiense* (Niko and Sone, 2015), and *Armenoceras chediforme* (Kobayashi, 1958), the feature of specimens are shape like a pagoda and have broadly expanded connecting rings. The siphuncle is exceptionally large for the Orthocerida and occupies approximately 1/3 of the corresponding conch diameter. Gastropods are members of phylum Mollusca, class Gastropoda. They have lived in marine and marginal marine environment. At the studied section, Shells of genus *Teiichispira* (Yochelson and Jones, 1968) were recognized. The shells are characterized by hyperstrophic coiled shell having a steeply inclined, moderately high outer whorl face, distinct sutures, and an elongate, curved, calcified operculum. Apical cavity is deep and smooth walls. Receptaculids were also found at the studied section. Receptaculiteae are characterized by large, discoidal to globular thallus, top of thallus rarely calcified; nucleus at tip; merom shafts, merom heads consist of four ribbed stellate structure (a radiating pattern like that of a star.) and plate, interlocking and fused to form unperforated outer wall; distinct internal structure. Receptaculites and Fisherites are two genera of the tribe with thick, short merom shafts. The distinguishing features of Fisherites are large size; discoidal to globular thallus; uncalcified top of thallus; nucleus situated at tip of conical projection (corniculum) on base of thallus; abaxial tapering of merom shafts; surface morphology and arrangement of merom plate. Receptaculitalean specimens at the studied section are of large size (12-15 cm in diameter); discoidal or sheet-like thallus, the inner wall is preserved, 3-4 mm in thickness, merom shafts only rarely preserved They are similar to those identified as *?Fisherites* sp. (Kruse, 1989) from Khao Phra locality in Kanchanaburi area.

4.3. Microfacies analysis

Lithological and microfacies analysis are studied under the basis of texture/fabrics, grain constituents and fossil contents. And from the data analysis can classify as eleven microfacies types of the Wat Mong Kratae section (Table 4.1). Degree of abundant the microfacies are percents of microfacies found from the studied section which can divide to 3 part include abundant (A): 40 - 50 %, common (C): 20 – 30 % and rare (R): 0 – 10 %.

4.3.1. Microfacies 1 Pelletal grainstone

The microfacies 1, is composed of micritic mud (30 percent) and grains of fecal pellets and small intraclasts (70 percent). Grain orientation and micro-fracture are observed under microscope which may be an evidence of compressive stress caused by tectonic activity in this area. Bioclasts are very rare. Degree of abundance

Table 4.1 Characteristics of the microfacies identified in the studied section DEG: degree of abundant the microfacies (A = abundant (40 -50 %), C = common (20 – 30 %), R = rare (0 – 10 %))

Facies	**Lithological Characteristics**	**Deg**	**Facies zone**
MF1 Pelletal grainstone	-grayish brown to grayish yellow, medium bed limestone -approximated 70% of pellets and some small intraclast	R	Peritidal
MF2 Molluscan packstone	-brownish gray to moderate olive brown, gastropod limestone -up to 50% of carbonate grains including peloid and intraclast -10 – 40% of bioclast (commonly mollusk and gastropod)	C	Open marine
MF3 Molluscan – peloidal packstone	-brownish gray to light gray, medium to thin bed shell limestone -20 – 25% of peloid, intraclast and some coated grains -10 – 40% of skeletal grains (shell, molluscan, bryozoan, crinoid and algae)	C	Open marine
MF4 Bioclastic	-brownish gray to gray, abundant brachiopod limestone	C	Carbonate shoal

Table 4.1 Characteristics of the microfacies identified in the studied section (Cont.)

Facies	**Lithological Characteristics**	**Deg**	**Facies zone**
packstone (tempestite)	-15 – 40% of peloid -30 – 45% of shell (include brachiopod, gastropod and cephalopod)		
MF5 Rounded clast grainstone	-light gray to brownish gray, dense shell limestone -30 – 60% of rounded carbonate grains (peloid, cortoid and some intraclast) -up to 40% of worm skeletal grain (algae, bryozoan, shell fragment)	A	Carbonate shoal
MF6 Intraclast – peloidal packstone with microbially coated grains	-grayish black, medium argillaceous limestone -30 - 50% of intraclast, peloid and microbially coated grains -less than 10% of skeletal grains (abundant microbially coated shell fragment grains, algae and bivalve)	R	Mid ramp
MF7 Bio – intraclast packstone	-light gray to gray, medium to thick bed limestone -50 - 60% of carbonate grains including intraclasts, oncoid, some peloids	A	Mid ramp

Table 4.1 Characteristics of the microfacies identified in the studied section (Cont.)

Facies	**Lithological Characteristics**	**Deg**	**Facies zone**
	-up to 10% of shell		
MF8 Fine packstone with intraclast	-light gray, medium to thick bed shell limestone -15%-45% of carbonate grain (mainly intraclast, peloids, cortoids, and some microbially coated skeletal grain) -15%-35% of fragmented bioclast (bivalve, gastropods, cephalopods, crinoids and algae)	C	Mid ramp
MF9 Coarse packstone with microbially coated grains	-grayish black to brownish gray, coarse limestone -20%-60% of intraclast, microbially coated skeletal grain, and some peloid. -10%-50% of bioclast (commonly shell, bivalve, gastropod , algae, crinoid, bryozoan)	C	Mid ramp
MF10 Peloidal calcisiltite	-dark gray to grayish brown, argillaceous limestone -up to 7% of carbonate grains (mainly peloid)	C	Outer ramp

Table 4.1 Characteristics of the microfacies identified in the studied section (Cont.)

Facies	**Lithological Characteristics**	**Deg**	**Facies zone**
	-less than 3% of micro-sized bioclasts		
MF11 Algal – intraclast-peloidal packstone	-gray, stylolitic shell limestone -55%-70% of Intraclast (include micritic intraclast, sandy micritic intraclast and small intraclast) and peloid. -up to 7% of skeletal grain (mollusk shell fragments, algal, crinoid, trilobite and bryozoans	R	Outer ramp

of the MF 1 is rare. This microfacies is observed in rock sample number KB24.

The depositional texture of the MF 1 is grain supported, well sorted, allochthonous limestone (Dunham, 1962).

The allochems including small intraclasts and fecal pellets are ranged between 0.063 mm – 2 mm in diameter, and dominated by the size smaller than 0.1 mm. The fecal pellets are high sphericity, rounded and dominated in this microfacies (approximately 53.5 percent). The small intraclasts are usually elongated, poorly rounded and comprised 15 percent of the allochems and comprised 15 percent of the allochems. The selective samples of the MF 1 showing grains categories and structural texture are illustrated in Figure 4.2 (A – D).

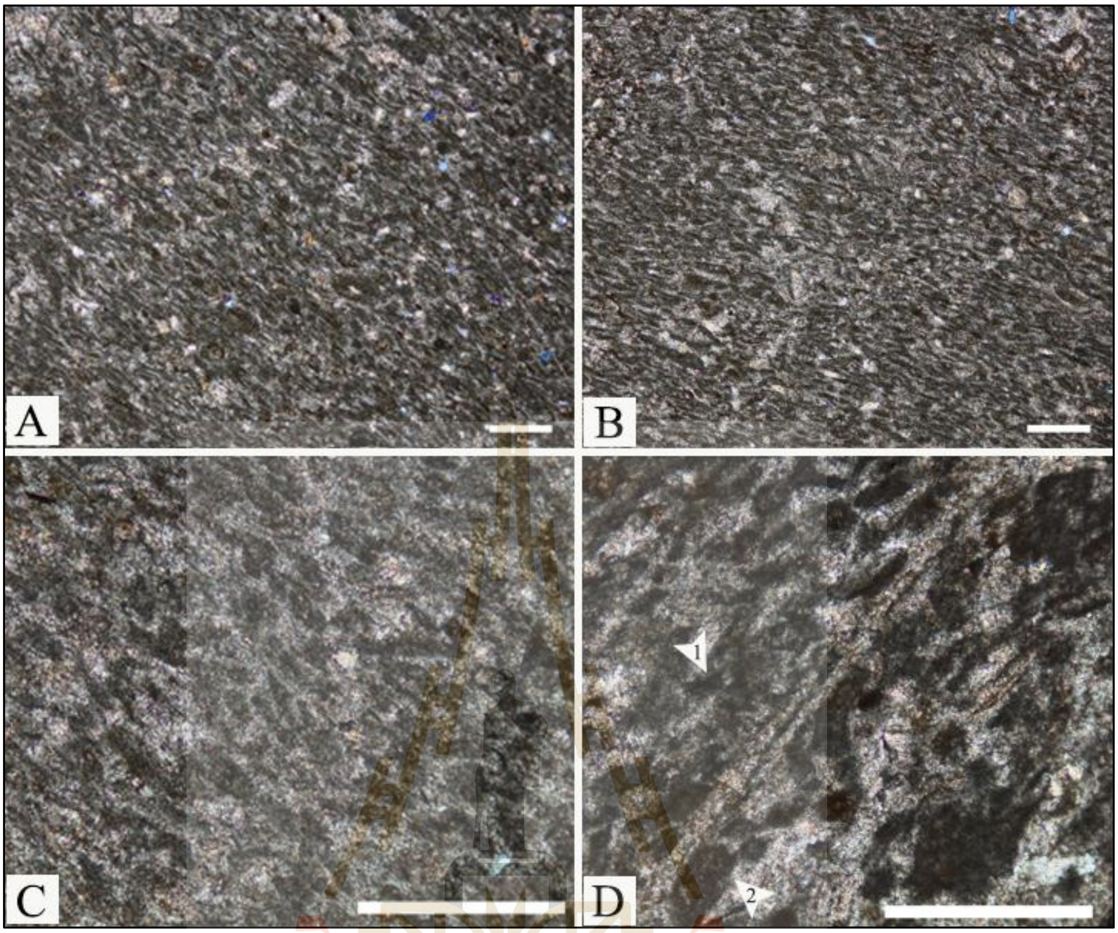

Figure 4.2 Microfacies 1 Pelletal grainstone. (A – D) Sample number KB24 (1) fecal pellet (2) small intraclast. All scale bars are 0.5 mm.

4.3.2. Microfacies 2 Molluscan packstone

This microfacies is composed of 30 percent of carbonate grains (peloids and intraclasts) and 10 – 40 percent of bioclasts mainly consisted of mollusk shell fragments. Stylolite can be observed, they are a result of pressure solution and compression in chemical compaction that associated with fracturing structure. This microfacies is common in this studied section.

Under the microscope, they show the depositional texture of carbonate whose original components were not organically bound (allochthonous limestone).

The association of grain categories, matrix type, and carbonate cement indicates to grain supported and the matrix type is allomicrite or lime mud matrix (packstone). This microfacies consists of the rock sample numbers KB11 and KB22.

The allochems are both skeletal grains and non – skeletal grains. Their grain size is predominantly 0.063 – 2 millimeters. Grain shape of carbonate grains is elongate to moderate sphericity and sub rounded. The sorting of grain is moderate to poorly sorted.

Fecal peloids are most abundant carbonate grains (approximately 21.8 percent) and intraclasts are the second most abundant carbonate grain (12.3 percent).

The distinctive bioclasts, echinoderm fragments are most common (usually more than 15 – 20 percent). A remain appeared only the unidentified echinoderm clasts and they indicate allochthonous origins

The allochems are the second most abundant mollusk shells in common (5 – 20 percent). The mollusk shells consist of incomplete cephalopods and incomplete gastropods. Some gastropods in the studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field which they are identified to *Ormoceras* sp. and *Armenoceras* sp.

Algae remains are quite rare (less than 5 percent) in this facies. Those algal remains are unidentifiable.

The selective examples of the MF 2, showing grain categories and texture are illustrated in Figure 4.3 (A – D).

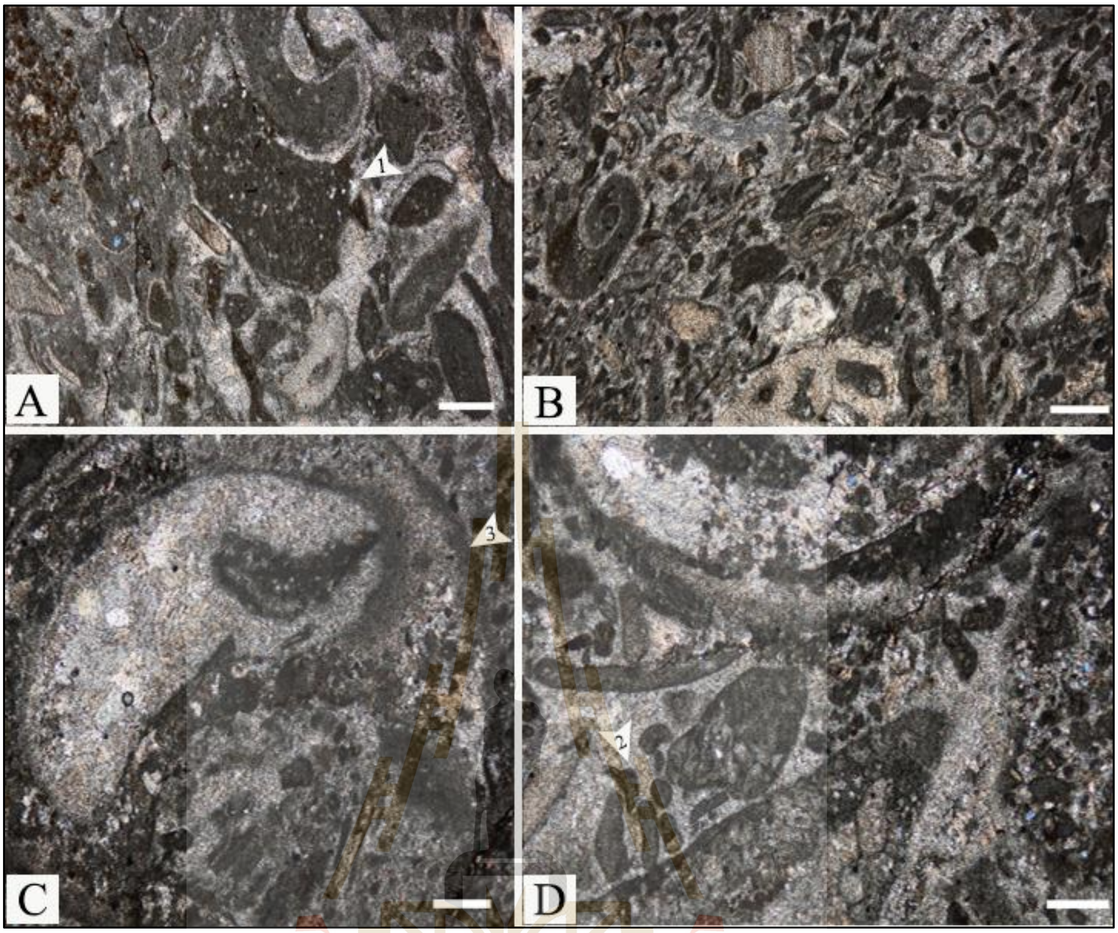

Figure 4.3 Microfacies 2 Molluscan packstone (KB11, KB22). (A – B) Sample number KB22 (C – D) Sample number KB11 (1) intraclast (2) fecal peloid (3) gastropod. All scale bars are 0.5 mm.

4.3.3. Microfacies 3 Molluscan – peloidal packstone

The microfacies 3 is composed of 20 – 25 percents of carbonate grain (peloids and intraclasts) and 10 – 40 percents of skeletal grains (mollusk shell, bryozoans, crinoids and algae). Grain orientation and stylolite are observed. The grain orientation may be affected by compression stress caused by either compaction or tectonic whereas the stylolites are a result of pressure solution and compression in chemical compaction that associated with fracturing structure. This microfacies is common and observed in the rock sample numbers KB16 and KB18.

Under the microscope, they show grain supported texture with micrite matrix cement and the depositional texture of carbonate whose original components were not organically bound (allochthonous limestone). The association of grain type, matrix and carbonate cement indicates to packstone.

The allochems are carbonate grains and skeletal grains. The carbonate grains are of small to medium size (0.1 – 0.5 millimeters in diameter). Grain shape is dominantly found as elongate to low sphericity and sub rounded which are observed from the both carbonate grains and skeletal grains. The sorting grain is poorly sorted.

Small intraclasts are most abundant carbonate grains (approximately 15.5 percent) and usually well rounded and well sorted. Fecal peloids are the second – most abundant carbonate grain (6.55 percent) and microbially coated grains can be found in this facies (about 3.9 percent). Their shape and sorting frequently elongate sphericity and well sorted.

The most abundant bioclasts are found in this facies as shell fragment such as gastropods, and cephalopods and crinoids (approximately 12 percent). Some gastropods in the studied section can identified to *Teiichispira* sp. and cephalopods can be observed in the field which they are identified to *Ormoceras* sp. and *Armenoceras* sp. Crinoid remains appeared as unidentified clasts which indicate allochthonous origins.

Bryozoans are the second most abundant bioclasts (about 7.8 percent). They are incomplete for identification but can indicate the allochthonous origin.

Algae remains are quite rare (less than 5 percent) in this facies. Those algal remains are unidentifiable.

The selective samples showing grain constituents and textures of the MF 3 are shown in Figure 4.4 (A – D).

4.3.4. Microfacies 4 Bioclastic packstone (tempestite)

The microfacies 4, bioclastic packstone composes of 30 – 45 percent of skeletal grains such as brachiopods, gastropods and cephalopods and 15 – 40 percent of carbonate grains (peloids). Stylolite can be observed, they are a result of pressure solution and compression in chemical compaction. This microfacies is common in this studied section. This facies consists of the rock sample numbers KB20 and KB21.

Under the microscope, they show the characteristic of tempestite. The texture is grain supported with lime mud matrix. The association of grain type, matrix and carbonate cement indicates packstone.

The bioclasts consist of brachiopods, gastropods and cephalopods. Their grain size ranges from medium to very coarse (4 – 64 millimeters in diameter). The carbonate grain size ranges from medium to coarse grains (0.2 – 1 millimeter in diameter). Grain shapes are generally elongate to moderate sphericity and angular to sub angular. The sorting of grain is poor to well sorted.

Intraclasts are most abundant carbonate grains (approximate 17.5 percent) and commonly subangular and moderate to well sorting. Peloids are the second most abundant carbonate grains (13.75 percent) and often moderate sphericity and well sorted. Coated grains are occasionally found in this facies (about 2.5 percent).

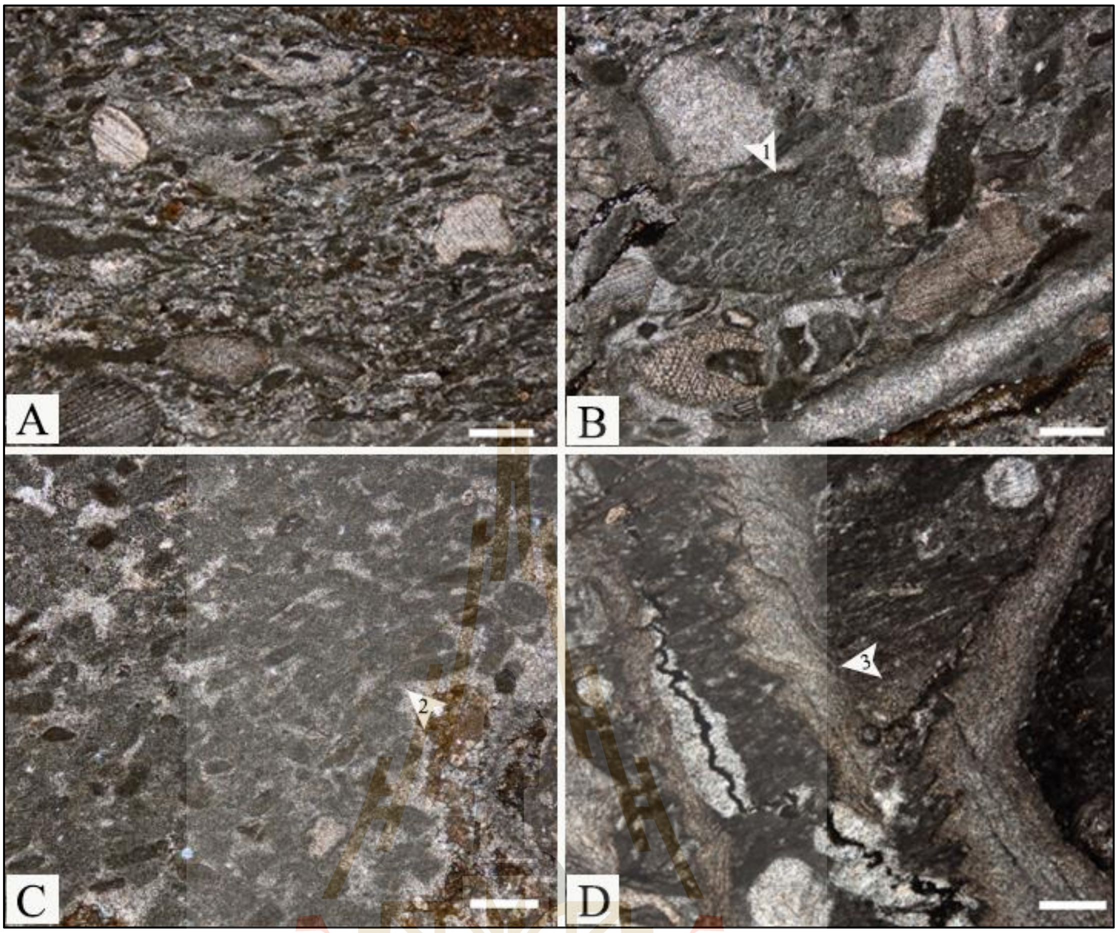

Figure 4.4 Microfacies 3 Molluscan – peloidal packstone (KB16, KB18). (A – B) Sample number KB16 (C – D) Sample number KB18 (1) bryozoan (2) fecal peloid (3) shell fragment. All scale bars are 0.5 mm.

The most abundant bioclasts are found in this facies as shell fragment such as brachiopods, gastropods and cephalopods (36.25 percent). Brachiopods can be observed but they cannot be identified the species. Some gastropods in the studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field. They are identified to *Ormoceras* sp. and *Armenoceras* sp.

The selective examples of the MF 4 representing the grain categories and texture are shown in Figure 4.5 (A – D).

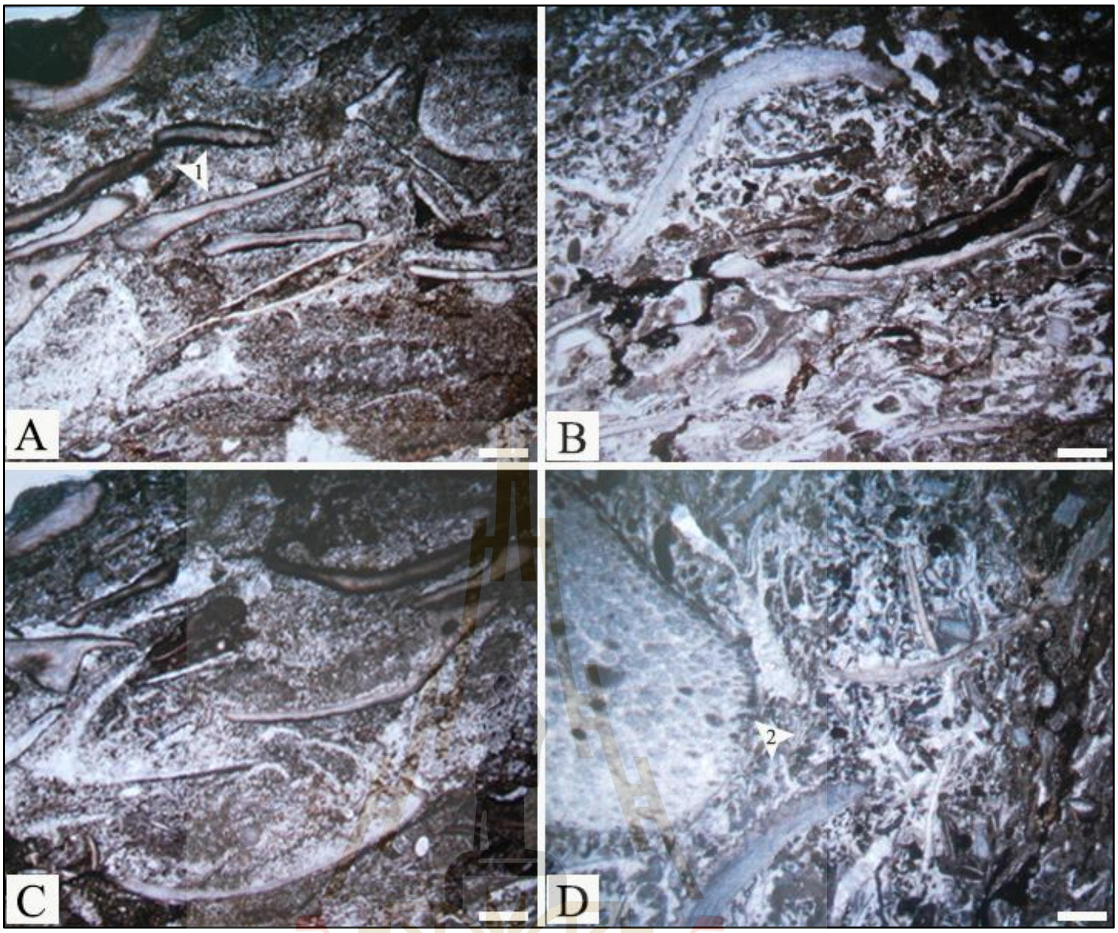

Figure 4.5 Microfacies 4 Bioclastic packstone (tempestite) (KB20, KB21). (A, C) Sample number KB20 (B, D) Sample number KB21 (1) shell fragments (2) gastropods. All scale bars are 0.5 mm.

4.3.5. Microfacies 5 Rounded clast grainstone

This microfacies consist of 30 – 50 percent of carbonate grain (peloids and some intraclasts) and 40 percent of abraded bioclasts are commonly composed of shell fragments (such as bivalves, gastropods, and cephalopods), bryozoans and some algae. Stylolite can be observed, they are result of pressure solution and compression in chemical compaction that associated with fracturing structure. A degree of abundance of the microfacies is abundant in the studied section. This facies consists of the rock sample number KB03, KB04, KB08 and KB10.

Under the microscope, they show the depositional texture of carbonate whose original components were not organically bound (Allochthonous Limestone). The association of grain type, matrix and carbonate cement indicates to grainstone. The texture represents grain supported texture with sparry calcite cement.

The allochems are found both bioclasts and carbonate grains. The bioclasts size is approximately coarse to very coarse grains (4 – 64 millimeters in diameter) and the carbonate grains have the range of grain size from small to medium grains (0.1 – 0.5 millimeters in diameter). Grain shapes are generally highly elongate to high sphericity and angular to sub rounded. They are observed from both the carbonate grain and skeletal grains. The sorting of grain is poorly to well sorted.

Peloids are most abundant carbonate grains (approximate 22.3 percent) and commonly angular and poorly sorted. Intraclasts are the second most abundant carbonate grains (20.1 percent) and often low sphericity and poorly sorted.

The most abundant bioclasts are found in this facies as shell fragment such as brachiopods, gastropods and cephalopods (usually 8.28 percent). Brachiopods can be observed but they cannot be identified the species. Some gastropods in the studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field. They are identified to *Ormoceras* sp. and *Armenoceras* sp.

Crinoids are the second most abundant bioclasts (about 2.09 percent). They are incomplete for identification but can indicate to the allochthonous origins.

Algae and bryozoans are rare (up to 1.5 percent) in this facies. These remains cannot identify the species of them.

The selective texture shows grain constituents and textures of the MF 5 in Figure 4.6 (A – D).

4.3.6. Microfacies 6 Intraclast – peloidal packstone with microbially coated grains

The microfacies 6 is composed 30 – 50 percent of carbonate grains such as intraclast, pelloid and microbially coated grains and less than 10 percent of skeletal grains (shell fragment, algae and bivalve). Grain orientation and microfracture can be observed, they may be affected by compression stress caused compaction or tectonic activity in this adjacent area. This microfacies is rare in this studied section. This facies consists of the rock sample number KB12.

Under the microscope, they show the depositional texture of carbonate whose original components were not organically bound (Allochthonous Limestone). Texture is dominantly micrite matrix and grain supported allochems. The association of grain type, matrix and carbonate cements indicates to packstone.

The allochems are found both bioclasts and carbonate grains. The bioclasts size is approximately coarse to very coarse grains (4 – 64 millimeters in diameter) and the grain size of carbonate grains ranges from small to medium grains (0.1 – 0.5 millimeters in diameter). Grain shapes are generally elongate to low sphericity and sub rounded observed from the carbonate grain. The sorting of grain is poorly sorted.

Peloids are most abundant carbonate grains (approximate 26.15 percent) and commonly moderate sphericity and poorly sorted. Intraclasts and microbially coated grains are the second most abundant carbonate grains (about 10 percent) and often elongate to low sphericity and poorly sorted.

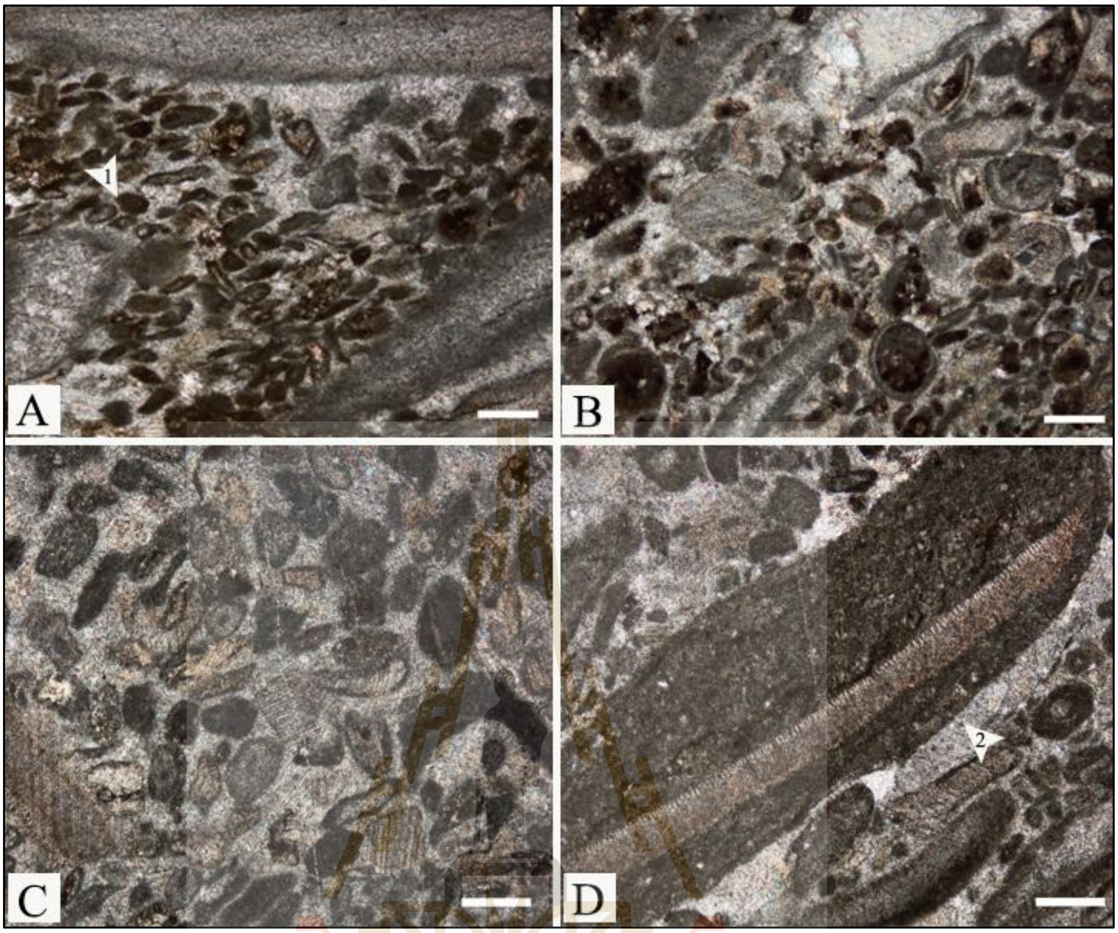

Figure 4.6 Microfacies 5 Rounded clast grainstone (KB03, KB04, KB08, KB10). (A – B) Sample number KB08 (C – D) Sample number KB03 (1) rounded grain (2) microbially coated grains. All scale bars are 0.5 mm.

The most abundant bioclasts found in this facies as microbially coated shell fragment, bivalve and cephalopod shell (usually 8 percent). Bivalves can be observed but they cannot be identified the species. They can indicate to the allochthonous origins. Cephalopods can be observed in the field. They are identified to *Ormoceras* sp. and *Armenoceras* sp.

Algae (3 percent) and crinoids are rare (less than 2 percent) in this facies. These remains cannot identify the species of them.

The selective examples of the MF 6 represent the grain categories and texture in Figure 4.7 (A – D)

4.3.7. Microfacies 7 Bio–intraclast packstone

This microfacies is composed of more than 50 percent of carbonate grains (intraclasts, microbially coated grains and some peloids) and up to 10 percent of bioclasts component mollusk shell fragment. Grain orientation, microfrature and stylolite can be observed, grain orientation may be affected by compression stress caused compaction or tectonic activity in this adjacent area and stylolite are result of pressure solution and compression in chemical compaction that associated with fracturing structure. A degree of abundance of the microfacies is abundant in this studied section. This facies consists of the rock sample number KB07, KB09, KB13 and KB14.

Under the microscope, they show the depositional texture of carbonate whose original components were not or organically bound (Allochthonous Limestone). Texturally, they are predominantly observed as grain supported allochems with lime mud matrix. The association of grain type, matrix and carbonate cement indicates to packstone.

The allochems are found both bioclast and carbonate grains. The bioclasts size is approximately coarse to very coarse grains (4 – 64 millimeters in diameter) and the grain size of carbonate grains ranges from small to medium grains (0.1 – 0.5 millimeters in diameter). Grain shapes are generally highly elongate to moderate sphericity and angular to sub angular. The sorting of grains is poorly to well sorted.

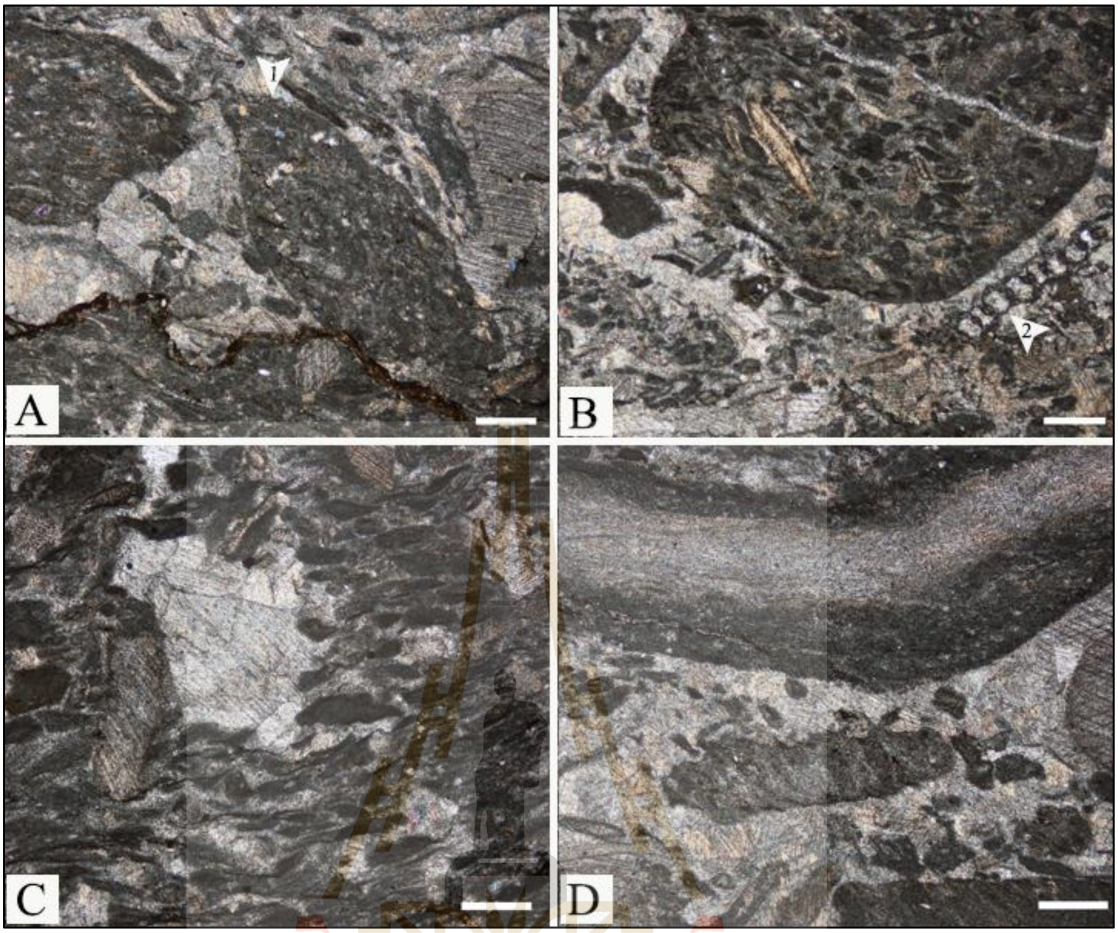

Figure 4.7 Microfacies 6 Intraclast – peloidal packstone with microbially coated grains (KB12). (A – D) sample number KB12 (1) intraclast (2) algae. All scale bars are 0.5 mm.

Peloids are most abundant carbonate grains (approximate 20.91 percent) and intraclasts are the second most abundant carbonate grains (16.25 percent). They commonly elongate to low sphericity and sub angular, well sorted. Microbially coated grains are found (8.89 percent) in this facies.

The most abundant bioclasts are found in this facies as shell fragments such as brachiopods, gastropods and cephalopods (usually 12.32 percent). Brachiopods can be observed but they cannot be identified the species. They can indicate to the allochthonous origins. Some gastropods in this studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field, they are identified to *Ormoceras* sp. and *Armenoceras* sp.

The MF 7, the selective texture show grain constituents and textures in Figure 4.8 (A – D).

4.3.8. Microfacies 8 Fine packstone with intraclast

The microfacies 8 is composed 15 – 45 percent of carbonate grains (intraclasts, peloids, cortoids, and some microbially coated skeletal grains) and 15 – 35 percent of bioclasts compose of bivalves, gastropods, cephalopods, crinoids and algae. Grain orientation can be observed, they may be affected by compression stress caused compaction or tectonic activity in this adjacent area. This microfacies is common in this studied section. This facies consists of the rock sample number KB15 and KB17.

Under the microscope, they show the depositional texture of carbonate whose original components were not or organically bound (Allochthonous Limestone). The texture is dominantly micrite matrix and grain supported allochems. The association of grain type, matrix and carbonate cement indicates to packstone.

The allochems are found both bioclast and carbonate grains. The range of grain size is from small to medium grains (0.1 – 0.5 millimeters in diameter). Grain shapes are generally highly elongate to moderate sphericity and angular to sub rounded. The sorting of grain is poorly to well sorted.

Intraclasts are most abundant carbonate grains (approximate 16.25 percent), microbially coated grains are the second most abundant carbonate grain

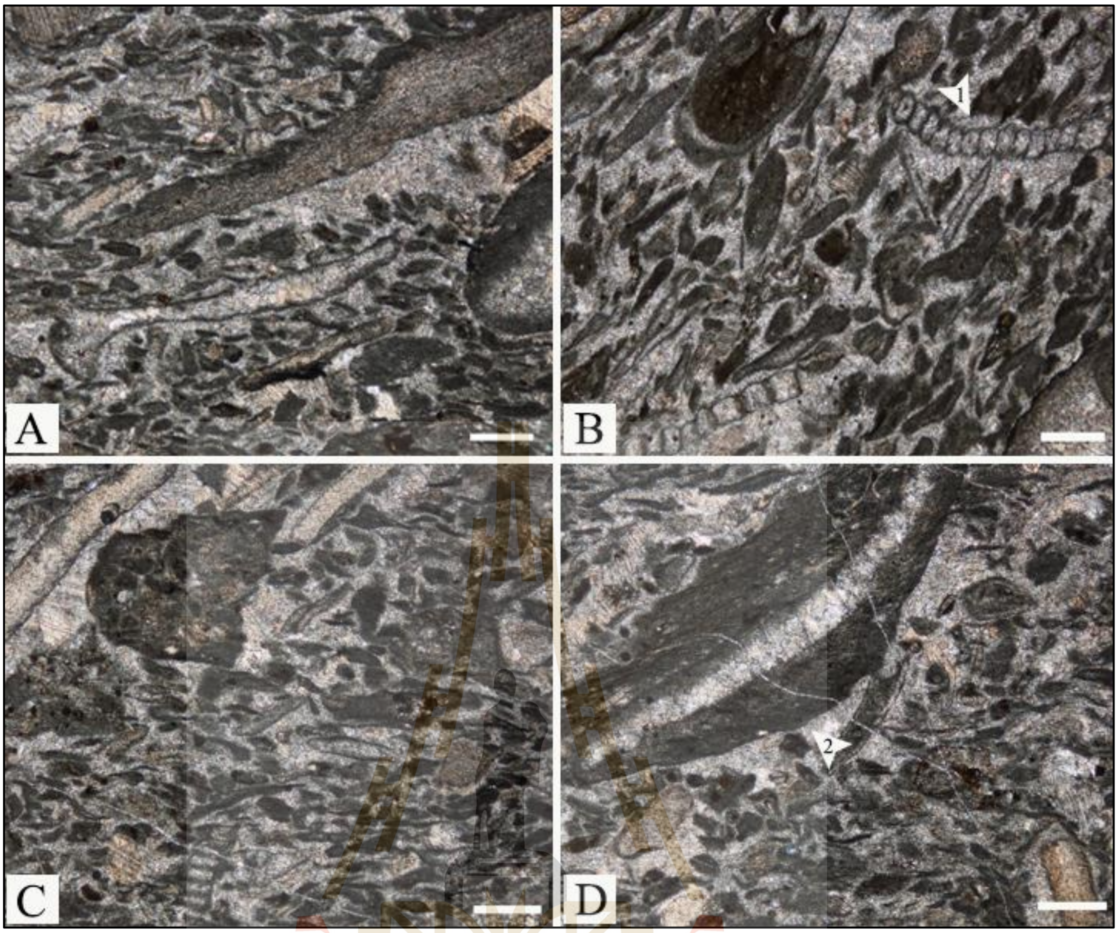

Figure 4.8 Microfacies 7 Bio – intraclast packstone (KB07, KB09, KB13, KB14). (A – B) Sample number KB07 (C – D) Sample number KB09 (1) algae (2) microbially coated grain. All scale bars are 0.5 mm.

(11.88 percent) and peloids are observed in this facies (3.38 percent). They are often low to moderate sphericity and well sorted.

The most abundant bioclasts are found in this facies as shell fragments such as brachiopods, bivalves, gastropods and cephalopods (usually 9.5 percent). Brachiopods can be observed but they cannot be identified the species. They can indicate to the allochthonous origins. Some gastropods in this studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field, they are identified to *Ormoceras* sp. and *Armenoceras* sp.

Crinoids are the second most abundant bioclasts (about 8.75 percent). They are incomplete for identification but can indicate to the allochthonous origins.

Algae and bryozoans are rare (less than 4 percent) in this facies. These remains cannot identify the species of them.

The selective examples of the MF 8 represent the grain categories and texture in Figure 4.9 (A – D).

4.3.9. Microfacies 9 Coarse packstone with microbially coated grains

The microfacies 9 is composed 10 – 50 percent of bioclasts (bivalves, gastropods, algae, crinoids, bryozoans) and 20 – 60 percent of carbonate grains compose of intraclasts, microbially coated skeletal grains, and some peloids. Stylolite can be observed, they are result of pressure solution and compression in chemical compaction that associated with fracturing structure. A degree of abundance of the microfacies is abundant in this measured section. This facies consists of the rock sample number KB05, KB06 and KB23.

Under the microscope, they show the depositional texture of carbonate whose original components were not or organically bound (Allochthonous Limestone). The texture is grain supported allochems with lime mud matrix. The association of grain type, matrix and carbonate cements indicates to packstone.

The allochems are found both bioclast and carbonate grains. The bioclasts size is approximately fine to medium grains (1 – 16 millimeters in diameter) and the grain size of carbonate grains ranges from coarse to very coarse grains (0.5 –1 millimeter in diameter). Grain shapes are generally highly elongate to low sphericity

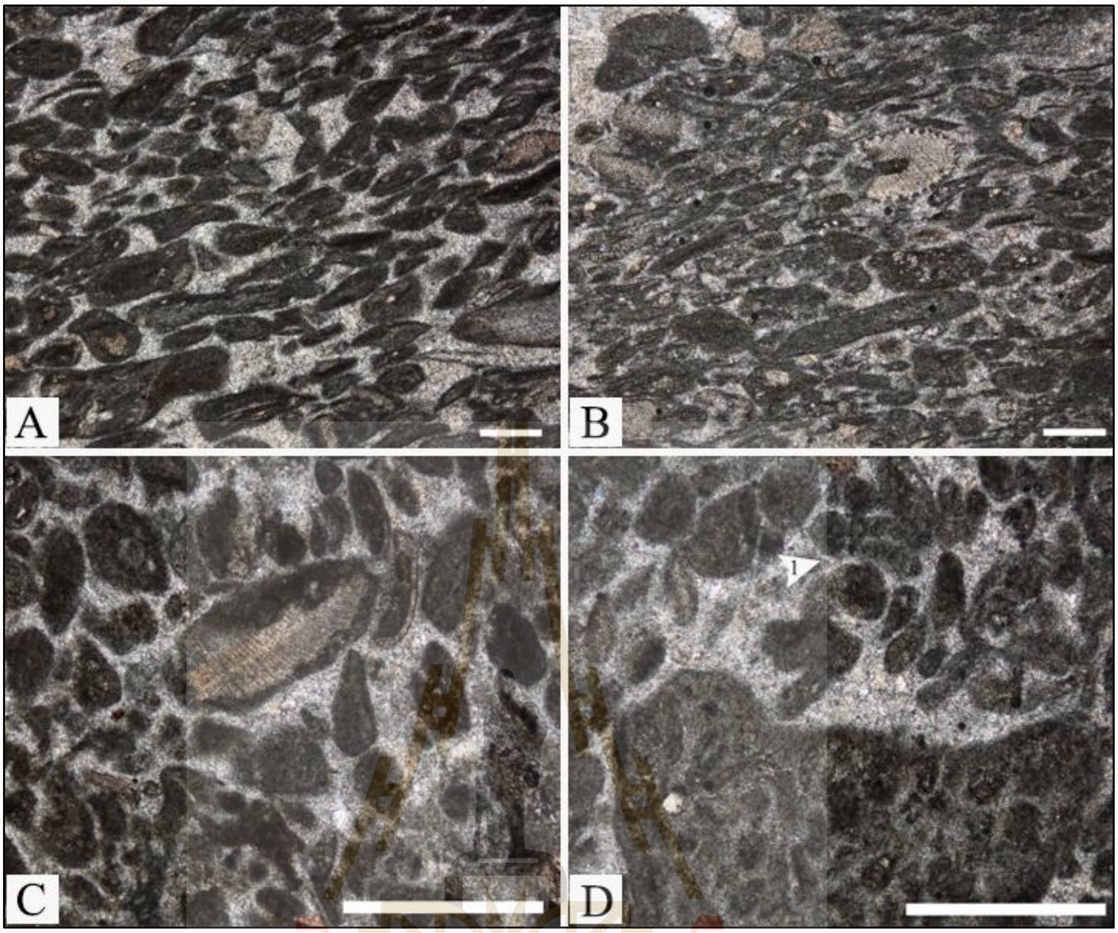

Figure 4.9 Microfacies8 Fine packstone with intraclast (KB15, KB17). (A, C – D) Sample number KB15 (B) Sample number KB17 (1) subrounded to rounded intraclast. All scale bars are 0.5 mm.

and angular to sub rounded. The sorting of grain is poorly to moderately sorted.

Peloids and intraclasts are most abundant carbonate grains (approximate 14.6 percent) and moderate sphericity and poorly sorted. Microbially coated grains are the second most abundant carbonate grains (12.6 percent) and highly elongate to low sphericity and poorly sorted.

The most abundant bioclasts are found in this facies such as brachiopods, bivalves, gastropods and cephalopods (usually 31.54 percent).

Brachiopod and bivalve can be observed but they cannot be identified the species. They can indicate to the allochthonous origins. Some gastropods in this studied section can be identified to *Teiichispira* sp. and cephalopods can be observed in the field, they are identified to *Ormoceras* sp. and *Armenoceras* sp.

Crinoids (about 5.25 percent) and Bryozoans (about 1.7 percent) can found in this facies they are incomplete for identification but can indicate to the allochthonous origins.

Algae are rare (less than 1 percent) in this facies. These remains cannot identify the species of them.

The MF 9, the selective texture shows grain constituents and textures in Figure 4.10 (A – D).

4.3.10. Microfacies 10 Peloidal calcisiltite

This microfacies consists of carbonate grains (7 percent) and less than 3 percent of micro – sized bioclasts. Grain orientation microfracture and stylolite can be observed, grain orientation may be affected by compression stress caused compaction or tectonic activity in this adjacent area and stylolite are result of pressure solution and compression in chemical compaction that associated with fracturing structure. This microfacies is common in this studied section. This facies consists of the rock sample number KB02 and KB19.

Under the microscope, they show the depositional texture of carbonate whose original components were not organically bound (Allochthonous Limestone). This facies contains a fine-grained matrix which is composed of detrital silt-size calcite particle called calcisiltite.

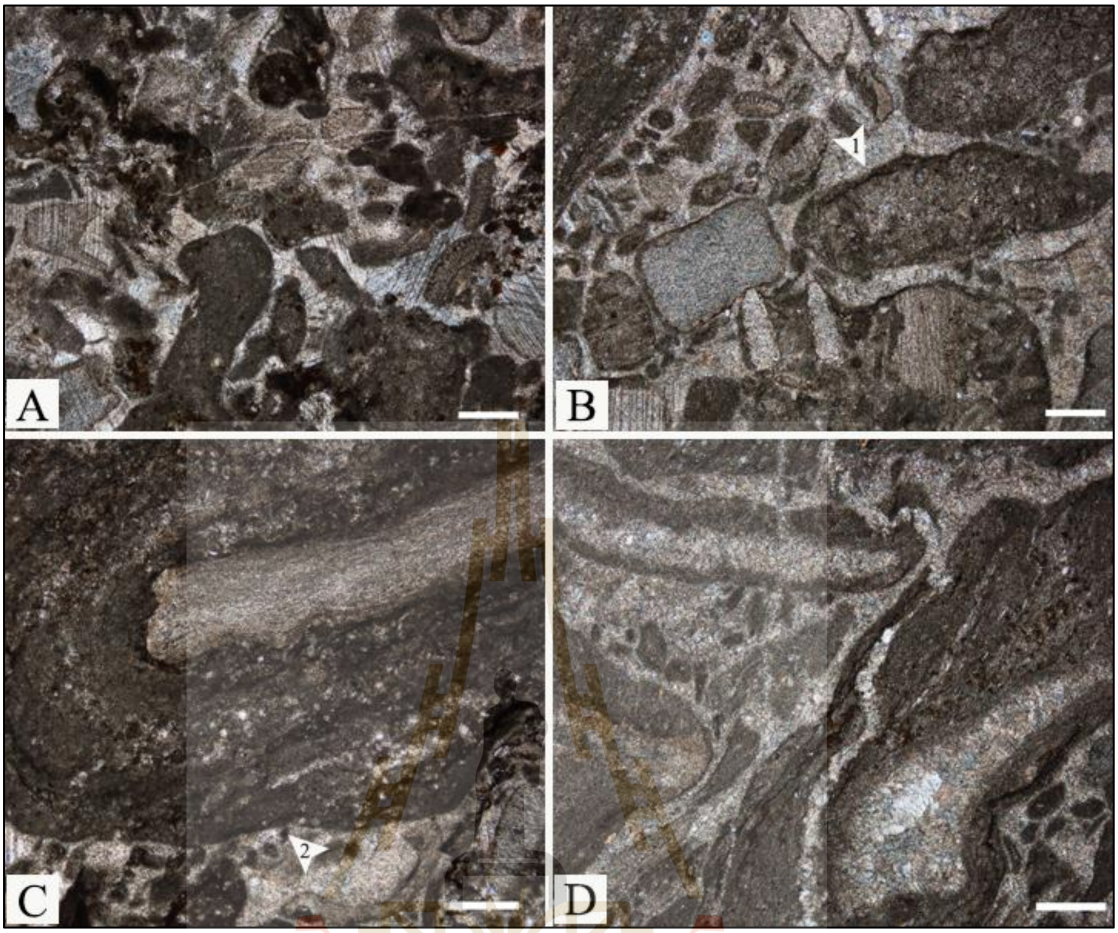

Figure 4.10 Microfacies 9 Coarse packstone with microbially coated grains (KB05, KB06, KB23). (A) Sample number KB23 (B) Sample number KB06 (C – D) Sample number KB09 (1) intraclast (2) microbially coated grain. All scale bars are 0.5 mm.

The allochems are found both bioclasts and carbonate grains. The bioclasts size is mainly very fine to fine grains (approximately 0.062 – 0.125 millimeters in diameter) and the size of carbonate grains ranges from fine to medium grains (0.125 – 0.5 millimeters in diameter). Grain shapes are generally elongate to moderate sphericity and angular to sub rounded. The sorting of grain is moderately sorted.

Peloids are most abundant carbonate grains (approximate 17.4 percent) and intraclasts are found in this facies (approximate 14.9 percent). They are commonly low to moderate sphericity and well sorted.

The most abundant bioclasts are found in this facies as micro – sized bioclasts (about 12.75 percent). They are incomplete for identification but can indicate to the allochthonous origins.

The selective examples of the MF 10 represent the grain categories and texture in Figure 4.11 (A – D).

4.3.11. Microfacies 11 Algal–intraclast–peloidal packstone

The microfacies 11 compose of 55 – 70 percent of carbonate grain including intraclasts (i.g. micritic intraclast, sandy micritic intraclast and small intraclast) and peloid. 7 percent of skeletal grains compose mainly of mollusk shells, algae, crinoids and bryozoans. A degree of abundance of the microfacies is rare in this measured section. This facies consists of the rock sample number KB01.

Under the microscope, they show the depositional texture of carbonate whose original components were not or organically bound (Allochthonous Limestone). The texture is predominantly grain supported allochems with lime mud matrix. The association of grain type, matrix and carbonate cement indicates to packstone.

The allochems are found both bioclasts and carbonate grains. The bioclasts size is mainly coarse to very coarse (approximately 4 – 64 millimeters in diameter) and the grain size of carbonate grains ranges from fine to medium (0.1 – 0.5 millimeters in diameter). Grain shapes are generally highly elongate to moderate sphericity and sub rounded. The sorting of grain is poorly to moderately sorted.

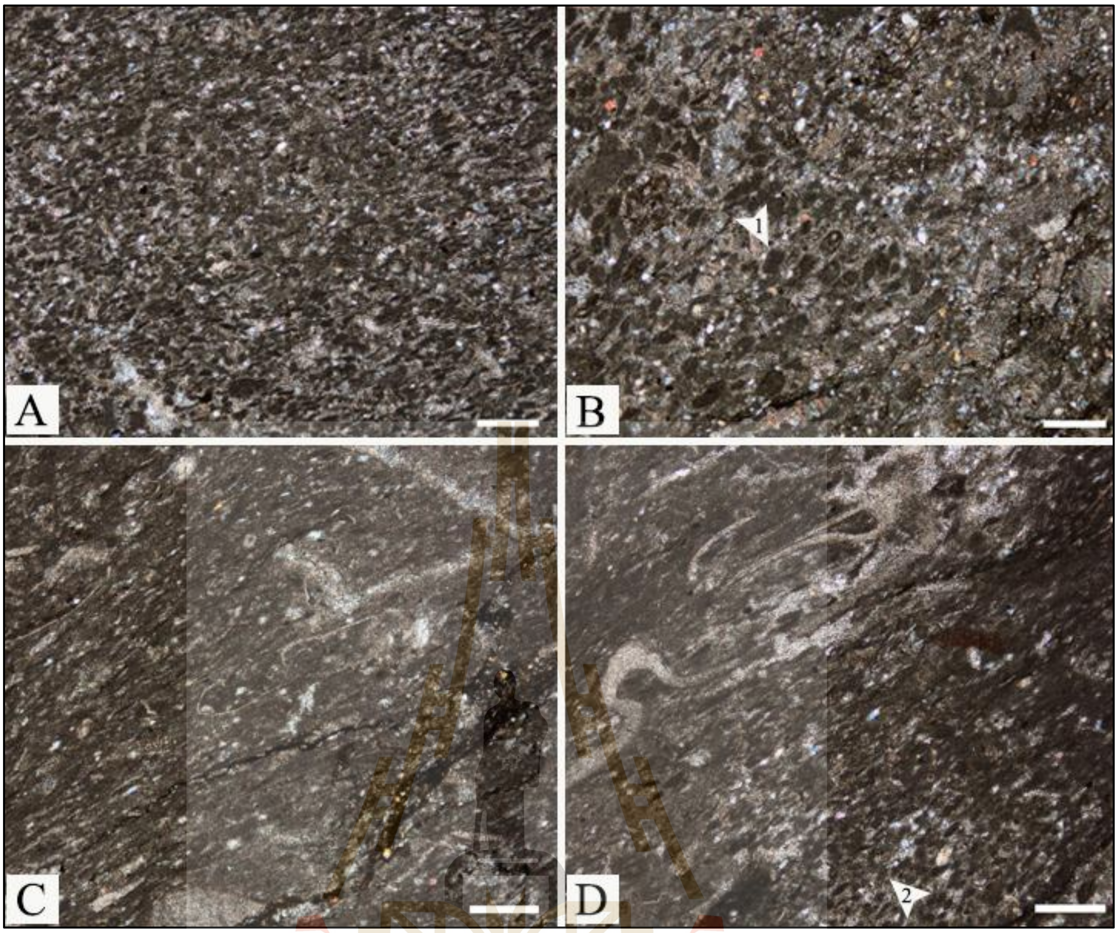

Figure 4.11 Microfacies 10 Peloidal calcisiltite (KB02, KB19). (A – B) Sample number KB02 (C – D) Sample number KB19 (1) small intraclast (2) mud peloid. All scale bars are 0.5 mm.

Peloids are most abundant carbonate grains (approximate 33.7 percent) and commonly moderate to high sphericity. Intraclasts are the second most abundant carbonate grains (22.44 percent) and elongate to low sphericity and poorly sorted.

The most abundant bioclasts are found in this facies as crinoids (about 1.54 percent). They are incomplete for identification but can indicate to the allochthonous origins.

Cephalopod shell fragment (usually 1.38 percent) can observe in the field which is identified to *Ormoceras* sp. and *Armenoceras* sp.

Algae and bryozoans are rare (about 0.5 percent) in this facies. They are incomplete for identification but can indicate to the allochthonous origins.

The MF 11, the selective texture shows grain constituents and textures in Figure 4.12 (A – D).

4.4. Depositional Environment

According to facies analysis, vertical facies distribution represents a change of depositional environment from deep to shallow water environments. The studied rock samples are lake of texture, fractures or characters of depositions on the slopes. The dominant grain types are skeletal grains, peloids and intraclasts. Cortoids and oncoids are minor found and aggregate grains are absent in this sequence. So, the studied carbonate succession is interpreted to be deposited on carbonate ramp model. The depositional environment of each facies is discussed as follows.

The microfacies 1, the presence of abundant allomicrite and exhibiting pellets and small intraclasts within a matrix indicates the low energy depositional environment. Fecal pellets usually occur in areas of the inner ramp. Thus, this microfacies should be deposited in inner ramp environment (Flügel, 2004) which can be compared with RMF 24. The microfacies 1 can be compared with limestones of the Five Oaks Formation which characterized by constitution of pelletal grainstone – packstone (Ruppel and Walker 1984). The rocks were considered as peritidal

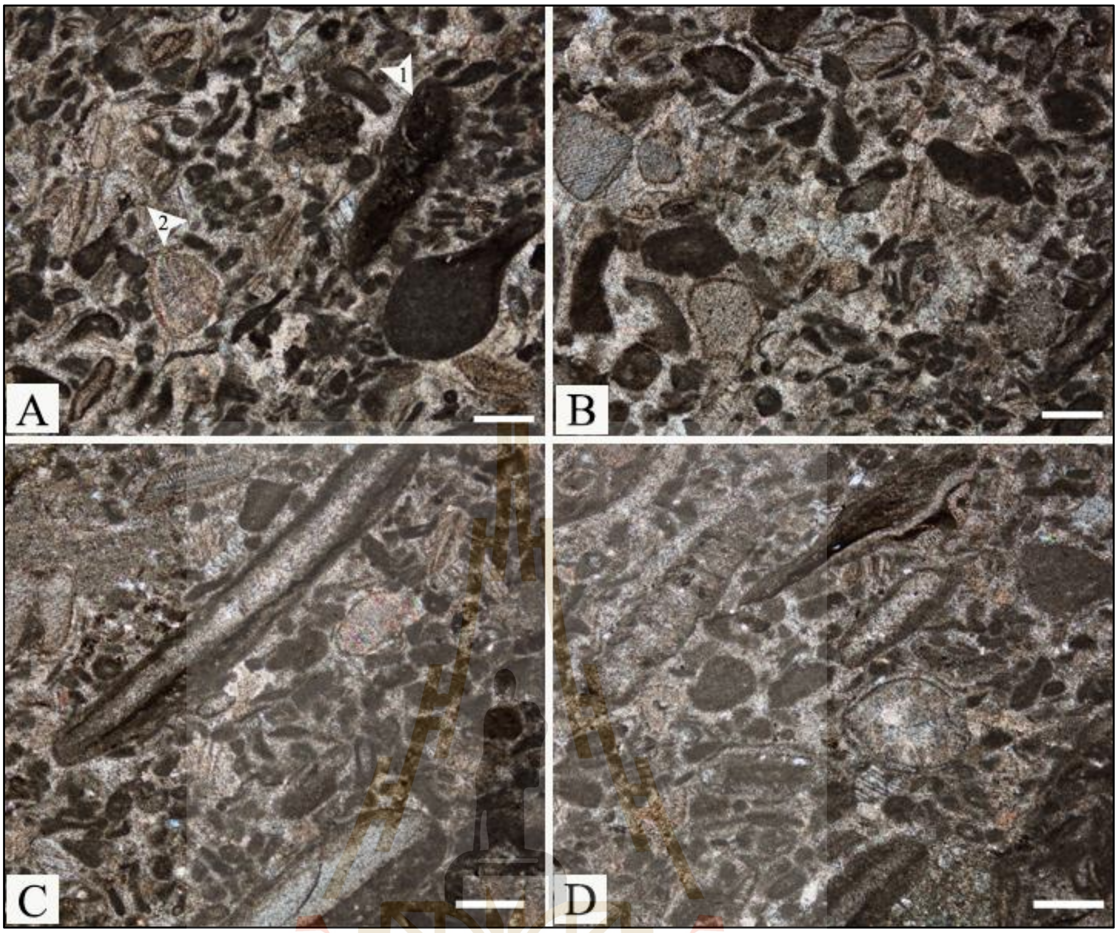

Figure 4.12 Microfacies 11 Algal – intraclast – peloidal packstone. (A – D) Sample number KB01 (1) intraclast (2) crinoid. All scale bars are 0.5 mm.

sediment which deposited during Middle Ordovician transgression in peritidal zone of the inner ramp.

The microfacies 2 contains abundant allomicrite and well preserved and completed skeletal grains indicating the low wave energy depositional environment. Fecal peloids are normally found in inner ramp. Therefore, this microfacies can be compare with RMF 7 which should be deposited in restricted marine to open marine environments in the inner ramp setting.

The microfacies 3, the occurrences of abundant micrite and fecal peloid are the feature of this facies which indicate low energy to moderate shallow water. Fecal peloid usually occur in inner ramp. This microfacies can be compared to RMF 14 which were deposited in open marine environment on the inner ramp setting.

The microfacies 2 and microfacies 3 can be compared with open marine facies of the Qom Formation at Rameh section, northeastern Garmsar (Sardarabadi et al. 2016).

The microfacies 4, the presences of abundant micrite and abundant complete skeletal grains indicated the deposition in low to moderate wave energy. The storm deposits are frequently observed in this facies which are represented by shell-bioclastic packstone or tempesite. The tempestite normally occur between distal and proximal parts of mid ramp and carbonate shoals between fair-weather wave base and storm weather wave base (Yao et al. 2016; Shao et al. 2011). This microfacies compared with RMF 26 which should be deposited in carbonate shoal facies.

The microfacies 5, the grainstone texture represents deposition in moderate to high energy shallow subtidal. Dominant grainstone and texture and the variety of skeletal grains indicated active carbonate shoal in open marine, high energy area, above the fair – weather wave base (Hu et al. 2017; Emraninasab et al. 2016; Badenas and Aurell 2010). From the constituent, this facies cannot indicate clearly for the facies zone but from ramp microfacies type, they are interpreted as RMF 26 which they are originated in the carbonate shoal facies zone.

The microfacies 6, the presence of abundant allomicrite and microbially coated grain indicate the low wave energy or quiet water deposition to moderate wave energy and the presence of mixture of different grains and incomplete grains can be a normality of mid ramp setting. From the constituent, this microfacies can be compare with RMF 9 which was deposited in mid ramp to outer ramp settings.

The microfacies 7, this facies is mainly composed of shells which are major constituents of storm and current induced skeletal shoals in mid-ramp setting. The presence of packstone can normally be found in mid ramp setting. Thus, this microfacies can be compared with RMF 9 which was deposited in mid ramp to outer ramp settings.

The microfacies 8, this facies is dominated by packstone and contains whole body fossils and fossil fragments, thus, it indicates moderate wave energy environment. Mixture of allochems is found in mid ramp settings. Therefore, this microfacies can be comparable with RMF 9 which was deposited in mid ramp to outer ramp settings.

The microfacies 9, this facies is dominated by packstone and contains whole body fossils and fossil fragments such as shells, bryozoans, algae and gastropods which indicates low to moderate wave energy environment. A mixture of different grain is common in mid ramp setting. This facies can be compared with RMF 9 which was originated in mid ramp to outer ramp settings.

The microfacies 6, microfacies 7, microfacies 8, and microfacies 9 can compare with pelletal, fossiliferous wackestone – packstone contain coated grains and skeletal grainstone – packstone of the Lincolnshire Formation in Virginia (Ruppel and Walker 1984). They indicate low energy under wave base conditions (Read, 1980).

The microfacies 10, the presences of calcisiltite and micro-bioclastic grain indicate the abrasion in storm influenced ramp parts and transportation to deeper water ramp parts. The mud peloids normally occur in the outer ramps. This facies association represents the deposits in the outer ramp which is developed below the storm weather wave base. Thus, this microfacies can be compared with RMF 4 which was deposited in outer ramp setting.

The microfacies 11, the presences of abundant micrite and completed skeletal grains indicate the low energy depositional environment, and the mud peloids are generally found in the outer ramps. This facies association represents the deposits in the outer ramp which is developed below the storm weather wave base. Therefore, this microfacies can be compared with RMF 9 which was deposited in mid ramp to outer ramp settings.

The lithology, bedding characteristics and fossil assemblages at the studied section were analyzed along the succession. They are chiefly composed of thin – to thick bedded stylolitic limestone, greenish gray to dark gray, and dominanted by packstone and grainstone, less of wackestone. These microfacies analysis shows the depositional environment from the outer ramp to inner ramp. The environmental conditions and depositional characteristics of each facies belts are summarized in Figure 4.13.

The depositional environment of the studied section is interpreted to be the subtidal offshore open marine environment of carbonate succession by comparing with hypothetical shoaling – upward carbonate sequence (James, 1984). The succession is designates to Middle Ordovician (Dapingian – Darriwilian age) from fossil assemblages found at the studied section. The vertical facies distribution shows three shallowing – upward parasequences (Figure 4.14). The lower sequence (0-55 meters from the base), the sequence is dominated by intraclast and peloid-rich packstone-grainstone facies. Grain categories and bed thickness indicate low energy

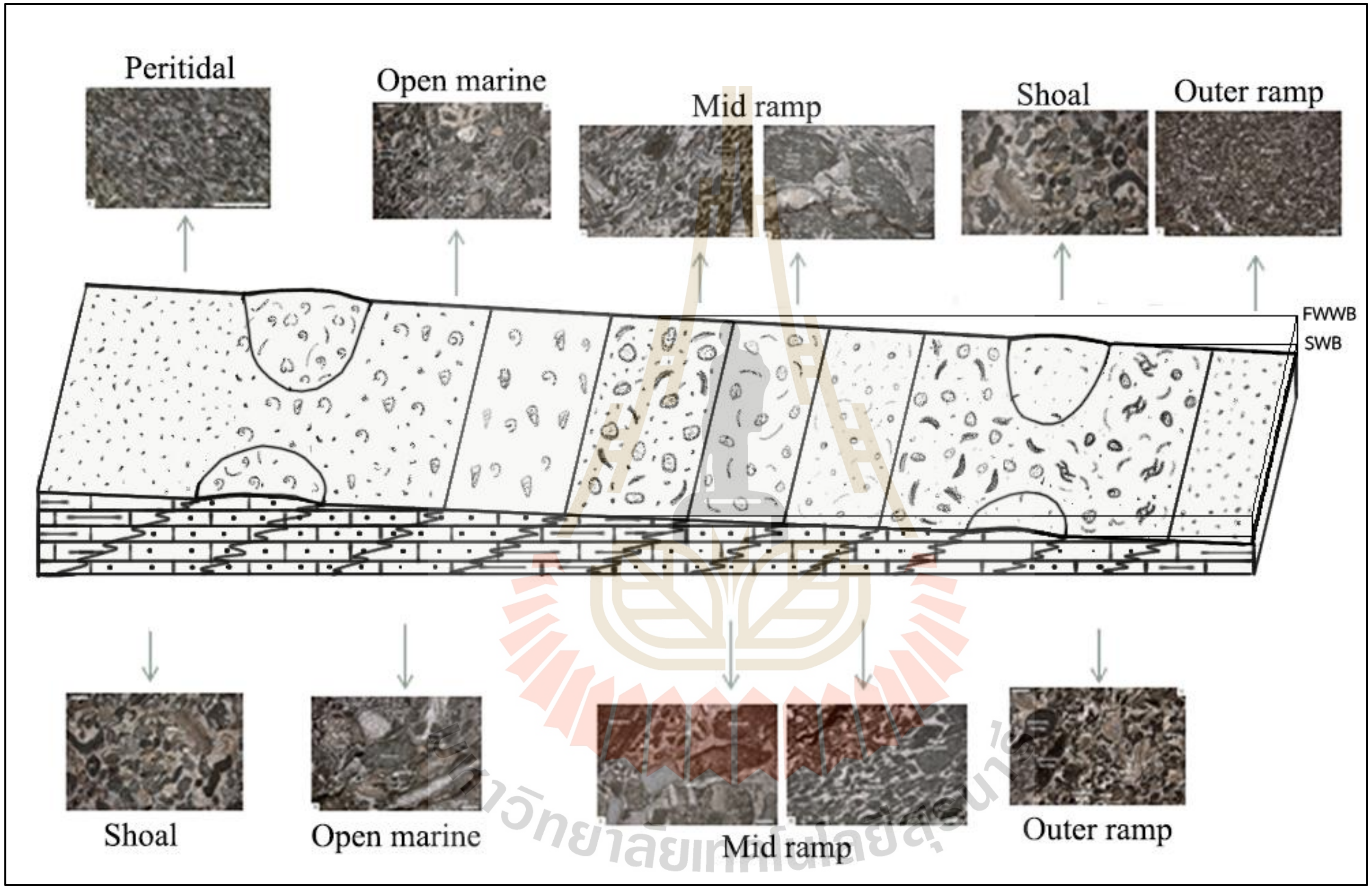

Figure 4.13 Depositional model of carbonate ramp system proposed from the study of facies analysis in Wat Mong Krathae locality.

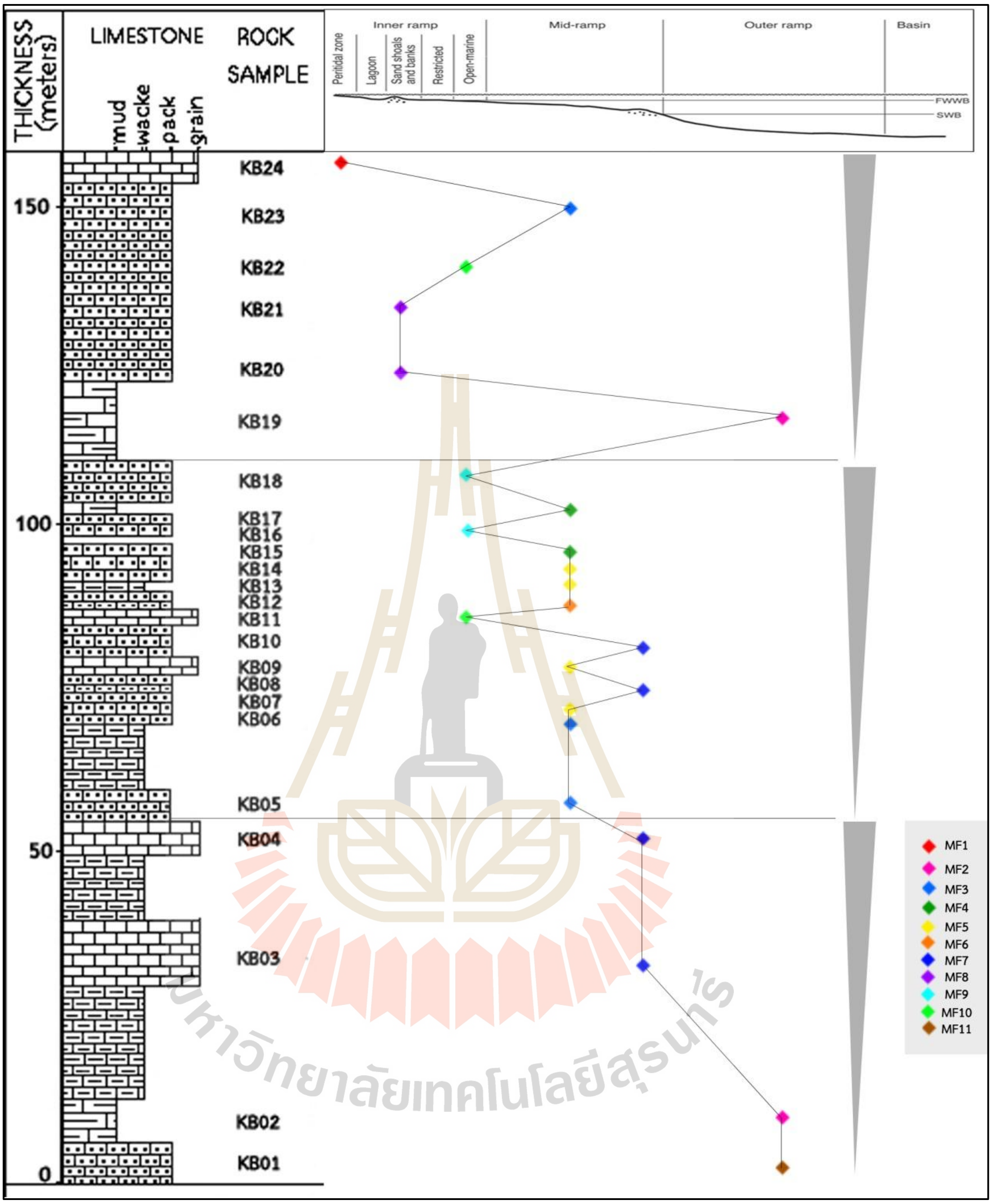

Figure 4.14 The vertical facies distribution showing three shallowing – upward parasequences

condition and the microfacies analysis suggests the outer ramp to inner ramp settings.

The middle sequence (55-110 meters from the base), grain categories and bed thickness indicate moderate to high wave energy condition. The sequence represents mid ramp to inner ramp settings evidenced by the larger and mixed grains. The upper sequence (110-157 meters from the base), grain categories and bed thickness indicate moderate to high energy condition. This sequence shows abundant shells and mollusks which are normally deposited in the outer ramp to the inner ramp setting. Base on field observations and facies analysis, the lower parasequence is deeper than the middle and upper parasequences.

4.5. Stratigraphic Correlation

From detailed investigation, lithology and microfacies analysis the studied section is composed mainly of argillaceous limestone is similar to upper part of the Thong Pha Phum section of Agematsu (2003) and Agematsu et al (2006). Macrofossils recorded from Tha Manao Limestone Formation exposed elsewhere are also found at the studied section including *Armenoceras chediforme* (Kobayashi, 1958), *Sibumasuoceras langkawiense* (Niko and Sone, 2015), *Teiichispirina* sp. (Yochelson and Jones, 1968) and *?Fisherites* sp. (Kruse, 1989). These fossils fossils are known from Southern Thailand and on Langkawi island in Malaysia, therefore, the studied section may be correlated with the Thung Wa section, Thung Song Formation in Satun, southern Thailand and Langkawi section, Kaki Buki Formation in Malaysia (Wongwanich et al., 1990; Bunopas, 1981; Agematsu et al., 2006). The similar fossil records provide information of fossil distribution in the Ordovician rocks among these regions and suggest the continuous oceanic pathway during Middle Ordovician (Dapingian – Darriwilian age).

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The objectives of the study are to define microfacies of limestone exposed on the East side of the Srinagarind Reservoir in Ban Tha Kradan area, Sri Sawat district, Kanchanaburi province, to reconstruct the depositional environment of the studied section, and to correlate with the Ordovician rocks in other regions of the country. The study section is located in Tha Kradan sub-district, Si Sawat district, Kanchanaburi province, Western Thailand.

5.1.1. Lithostratigraphy

The lithostratigraphy at Wat Mong Kratae section consists of gray to greenish gray stylolitic limestone sequence showing well bedded, thin to thick beds. Twenty four rock samples are collected from this studied section from bottom to top and the total thickness is 157 meters.

5.1.2. Brief description on paleontology

Macrofossils are recorded in Tha Manao limestone formation and are also found in this sequence. Nautiloid specimens are found as *Armenoceras chediforme* and *Sibumasuoceras langkawiense*. The feature of gastropods specimens is identified as *Teiichispirina* sp. and receptaculids were also found at the studied section which they are similar to *?Fisherites* sp. The fossils of nautiloids, gastropods and algae are found and they indicate Middle Ordovician (Dapingian – Darriwilian age).

5.1.3. Microfacies analysis

The microfacies analysis can be divided into eleven facies types in this studied section including MF1 pelletal grainstone, MF2 molluscan packstone, MF3 molluscan – peloidal packstone, MF4 bioclast packstone, MF5 rounded – clast grainstone, MF6 intraclast-peloidal packstone with microbially coated grains, MF7 bio-intraclast packstone, MF8 fine packstone with intraclast, MF9 coarse packstone with microbially coated grains, MF10 peloidal calcisiltite, MF11 algal – intraclast-peloidal packstone. Five depositional facies belts comprising peritidal inner ramp, open marine, carbonate shoal, mid ramp, outer ramp were recognized in this studied section. MF1 is classified in the peritidal facies. MF2 and MF3 are referred to open marine. MF4 and MF5 are classified into the carbonate shoal facies. MF6, MF7, MF8 and MF9 belong to mid ramp facies. MF10, MF11 are categorized into outer ramp facies.

5.1.4. Depositional Environment

According to the environmental interpretation on the basis of the detailed microfacies analysis and the studied succession, the depositional models were reconstructed to understand the concepts of the studied facies deposition. The microfacies (MF) were analyzed and can be divided into five types of facies zones including peritidal inner ramp, open marine, carbonate shoal, mid ramp, outer ramp facies associations. The depositional environment of the study section is interpreted to be the subtidal offshore open marine environment of carbonate succession and the succession are indicated to Middle Ordovician (Dapingian – Darriwilian age) from fossil assemblages found in the studied section. The vertical facies distribution shows three shallowing – upward parasequences. The lower sequence (0-55 meters from the base), the sequence dominated by intraclast and peloid-rich packstone-grainstone facies (the outer ramp to inner ramp settings). The middle sequence (55-110 meters from the base) represents mid ramp to inner ramp settings evidenced by larger and mixed grains. The upper sequence (110-157 meters from the base) shows abundant shells and mollusks, which are normally deposited in the outer ramp to the inner ramp setting. Base on field observations and facies analysis, the lower parasequence deeper than the middle and upper parasequence.

5.1.5. Stratigraphic Correlation

The lithology, the detailed microfacies analysis and depositional environment are quite similar and can be correlated to upper part of Thong Pha Phum section. Macrofossils recorded from Tha Manao Limestone Formation are also found in this sequence including *Armenoceras chediforme*, *Sibumasuoceras langkawiense*, *Teiichispirina* sp. and *?Fisherites* sp. Nautiloid fossils were found along the studied section and compared with the previously studied and give the age of Middle Ordovician (Dapingian – Darriwilian age).

5.2. Recommendations

This study of microfacies is a new data and this helps us to more understand of depositional environment Ordovician rocks in the western part of Thailand. The information of these microfacies can also be useful for the interpretation of the depositional environment in the future's other study.

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APPENDIX

PUBLICATION

Publication

Junrattanamanee, T., Noipow, N., and Chitnarin, A. (2018). Facies analysis and paleoenvironmental interpretation of Tha Manao Limestone (Middle Ordovician) in Sri Sawat district, Kanchanaburi province. **In proceeding of The 2nd International Symposium on Geoscience Resources And Environments of Asian Terranes (GREAT2018) at Chulalongkorn University, Bangkok.** (pp. 171-188).

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