STRATIGRAPHIC CORRELATION OF THE KUBANG PASU/YAHA FORMATION

By

The Malaysian-Thai Working Group

A joint project carried out by
Minerals and Geoscience Department, Malaysia
and
Department of Mineral Resources, Thailand

The report is submitted to the Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC)

September 2014

PREFACE

This report on the stratigraphic correlation of the Kubang Pasu/Yaha Formation is the result of close co-operation between the Minerals and Geoscience Department Malaysia and the Department of Mineral Resources, Thailand in resolving problems related to cross border geological and stratigraphic correlations between Malaysia and Thailand. This is one of the efforts taken by both parties in resolving problems related to cross border geological and stratigraphical correlation between Malaysia and Thailand. New data obtained from the joint survey carried out by the Malaysia-Thailand Working Group in the Belum-Hala Transect area are also included in this report.

Fieldwork was carried out independently by geoscientists of the Minerals and Geoscience Department Malaysia, and those of the Department of Mineral Resources, Thailand covering the individual territories in the years 2013 and 2014. In Thailand, stratigraphic survey on the Carboniferous rocks was carried out during February-April 2013, and has been slightly revised in July 2013 and February 2014.

After joint field check and discussion by both Malaysian and Thai Working Groups, and reconsidering the occurrence of Lower Carboniferous rock sequence in the transect area no. 1, 3, 4 and 5, both Working Groups have agreed that it can be correlated the Kubang Pasu and the Yaha Formation based on their similarity in stratigraphic and lithologic characteristics as well as fossil content. With the completion of this report, problems on the lithostratigraphic correlation between Carboniferous rock units found on both sides of the common border areas have been satisfactorily resolved. Other than that, with the implementation of this project, the objective of the establishment of the Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC) to foster closer cooperation between both countries in the field of geosciences is successfully achieved.

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ACKNOWLEDGEMENTS

The Malaysian-Thai Working Group would like to express their gratitude to the Director General, officers and staffs of the Minerals and Geoscience Department Malaysia (JMG) and the Director General, officers and staffs of the Department of Mineral Resources, Thailand (DMR) for their encouragement, support and funding of this project.

Thanks are extended to Mr. Mior Sallehhuddin bin Mior Jadid, the Director of Technical Services Division, Minerals and Geoscience Department Malaysia and Mr. Montri Luengingkasoot, the Director of Bureau of Geological Survey, Department of Mineral Resources, Thailand, for their encouragements during the study.

The Malaysian and Thai Working Groups also would like to express their gratitude to Dr. Assanee Meesook for his free consultation and advice especially in stratigraphic correlations as well as identifying fossils discovered along the Malaysia-Thailand border area. Special thanks are extended to Prof. Dr. Katsuo Sashida of Tsukuba University, Ibaraki, Japan for his willingness and efforts to wash, extract, study and identify the radiolarian from the chert samples sent to him by the Working Group.

Thanks are also to all officers and staffs of the Minerals and Geoscience Department Malaysia and Department of Mineral Resources, Thailand for their involvement in this project either directly or indirectly during the meetings and joint field check on both sides of the countries. The Malaysian and Thai military, provincial and border police officials are duly thanked for their assistance in the security matters.

Last but not least to all local residences along the common border of both countries for their support and assistance during the fieldworks.

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By

The Malaysian-Thai Working Group

EXECUTIVE SUMMARY

This report on the Kubang Pasu/Yaha Formation is the result of close co-operation between the Minerals and Geoscience Department Malaysia and the Department of Mineral Resources, Thailand in resolving problems related to cross border geological and stratigraphic correlations between Malaysia and Thailand. Fieldwork was carried out independently by geoscientists of the Minerals and Geoscience Department Malaysia, and those of the Department of Mineral Resources, Thailand covering the individual territories in the years 2013 and 2014. In Thailand, stratigraphic survey on the Carboniferous rocks was carried out during February-April 2013, and has been slightly revised in July 2013 and February 2014.

The Carboniferous rock units along the Malaysia-Thailand border area comprise the Rebak and Kubang Pasu Formations on the Malaysian side, and the Khuan Klang and Yaha Formations on the Thai sides. The correlatable Rebak and Khuan Klang Formations distribute in the western part, whilst the Kubang Pasu and Yaha Formations occupies the central part of the Malaysia-Thailand border area.

On the Malaysian side, the Kubang Pasu Formation is well exposed in eastern Perlis, northwestern, northeastern and central Kedah, and in the Upper Perak areas. Previously, it was considered as lateral equivalent with the Singa Formation in Langkawi and western Perlis. Recently, the Late Devonian to Lower Carboniferous sequence in the lower part of the Late Devonian-Early Permian Singa Formation is taken out and considered as a standalone rock unit named as Rebak Formation. Now, the Rebak Formation in Langkawi and western Perlis is considered as the lateral equivalent of the Kubang Pasu Formation. On the Thai side, the Yaha Formation is widely distributed in Songkhla, Pattani and Yala Provinces. Generally, the sequence are conformably underlain by the Devonian rocks and overlain by the Lower Permian succession. In some places, the contact between the Carboniferous and the overlying Triassic and Neogene succession is also represented by the Permian hiatus particularly in the Chana-Songkhla area. The Yaha Formation is also considered as a lateral facies change with the Khuan Klang Formation.

The Kubang Pasu Formation is proposed to be divided into three members; namely in ascending order: Jelutong, Jenun and Papulut Members representing the lower, middle and upper part of the formation. Generally, the Jelutong Member comprises interbeds of sandstone and shale with occasional well-bedded chert sequence that yields Tournaisian radiolarian in the lower part. Chert occurs as lenticular bodies within the Kubang Pasu Formation. Chert in the Kubang Pasu Formation has thinly bedded, known as ribbon chert; with thickness of individual bed is generally less than 5 cm. Chert of the Kubang Pasu Formation is exposed in several localities in Kedah and Upper Perak. Some of the argillaceous beds are fossiliferous where bivalve *Posidonomya* sp., trilobite pygidiums, brachiopods, and crinoid stems have been found. The Jenun Member comprises very thick sequence of thickly-bedded well-laminated shale, mudstone and siliceous shale with occasional ammonoid *Agathiceras* sp., chonetids, brachiopods and crinoids stems. Minor thin beds of sandstone occur in parts. The Papulut Member comprises very thick sequence of thickly-bedded metasandstone and pellitic schist. The sandstone can be classified as quartz arenite with high quartz content. The Papulut Member expose only in eastern Kedah and Upper Perak. The sequence is metamorphosed throughout due to the intrusion of the S-type Main Range Granite during Indosinian Orogeny in Late Triassic.

The Yaha Formation is lithostratigraphic subdivided into four members; namely in ascending order: Lower member, Middle member, lower Upper member and Upper member. The Lower member is characterized by the presence of interbeds of mudstone and sandstone containing *Posidonomya* sp. and crinoid stems. Plant remains are abundant in argillaceous strata. The Middle member consists of thick sequence of mudstone intercalated with thin- to medium-bedded, laminated sandstone which bivalve *Posidonomya* sp. Pygidium of trilobites, ammonites and crinoids are often found. Chert or siliceous shale yielded Tournaisian radiolarian, tuffaceous and lithic sandstone and mudstone are observed in the upper part of member. The lower Upper member is characterized by thick sequence of thickly bedded to massive quartzitic sandstone intercalated with thin bedded mudstone. The Upper member is characterized by the presences of well-bedded sandstone interbedded with mudstone, shale and siliceous shale containing *Posidonomya* sp., chonetids and pygidium of trilobites. Thickness of the Yaha Formation is about 400-600 m.

Based on current study and after several joint field checks in the Malaysian and Thai sides, the Malaysia-Thailand Working Group agreed that both the Kubang Pasu and Yaha Formation are well correlarable, in term of lithology, stratigraphy and fossils content. The Kubang Pasu/Yaha Formation is now introduced for represent the Carboniferous unit rocks along the north of the central part of Malaysia and south of the central part of Thailand.

According to the fossil evidence and stratigraphic correlation, the age of the Kubang Pasu/Yaha Formation is assigned as Carboniferous. The Kubang Pasu/Yaha Formation was deposited in the intertidal environment to a continental shelf environment. The presence of gritty to pebbly or conglomeratic layers indicates quite strong current that occurred locally from time to time during the depositional episode. The coarsening and thickening upwards, and subsequent fining and thinning upwards sequences at the top part may represent the regressive and transgressive phases, respectively. These phases may have been caused by fluctuation of sea level or tectonic or both during the deposition of the rock unit.

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1. INTRODUCTION

Detailed study and geological research on the Kubang Pasu Formation in Malaysia and Yaha Formation in Thailand was agreed during the Ninth Meeting of the Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC) held in Trang Province, Thailand on 12th September 2012. Both parties also agreed the title of the report is "Stratigraphic correlation on the Kubang Pasu/Yaha Formation" and the joint project is carried out in the Year 2013-2014.

During the joint geological survey carried out by the Minerals and Geoscience Department Malaysia and Department of Mineral Resources Thailand along the Malaysia-Thailand border area, four Carboniferous rock units were identified; Kubang Pasu and the Rebak member of the Singa Formations on the Malaysian side, and Yaha and Khuan Klang Formations on the Thai side. The Kubang Pasu Formation is well correlatable with the Yaha Formation, whilst the Khuan Klang Formation is now well correlatable with the Rebak member of the Singa Formation. Correlation of Carboniferous rock units along the Malaysia-Thailand border area is shown in Table 1.

Table 1: Correlation of the Carboniferous rock units along the Malaysia-Thailand border area (modified after The Malaysia-Thailand Working Group, in manuscript)

Period	Malaysia		Thailand	
	Langkawi/Eastern Perlis	Northwestern, Northeastern and Central Kedah/Upper Perak	West	East
Carboniferous	Rebak Formation	Kubang Pasu Formation	Khuan Klang Formation	Yaha Formation

Kubang Pasu Formation is one of the well known and established rock units in northeastern Peninsular Malaysia. It was originally used to describe the red and grey sequence of Late Palaeozoic rocks exposed in the central and southern Perlis and northern Kedah (Foo, 1983). Jones (1981) considered the formation as the lateral equivalent of the Singa Formation comprising red and grey to black sequence exposed in Langkawi Islands and northern Perlis. However, in this report, the term Kubang Pasu Formation is used for a sequence of well-bedded grey argillaceous and arenaceous rock cropping out in eastern Perlis, northern and western Kedah as well as in Upper Perak. In southern Kedah, the equivalent sequence was referred as Kampong Sena formation by Burton (1965). The red and grey sequence that was referred as part of Kubang Pasu Formation in western Perlis by Jones (1981) and other previous workers is now considered as part of the Rebak Formation which extends into Rebak and Langgun Islands in Langkawi (Mat Niza Abdul Rahman *et al.*, 2014)

The Kubang Pasu Formation is conformably overlying by the Silurian-Devonian Mahang Formation in Kedah and Kroh Formation in eastern Kedah and Upper Perak respectively. It is conformably overlain by the Permian Cherty Unit in eastern Kedah and by the Gerik Formation in Upper Perak.

Lithologically, the Kubang Pasu Formation in the Upper Perak area is different from that exposed in Kedah as a result of metamorphism. The rocks in this area are locally metamorphosed to metasandstone, hornfels, phyllite and schist. Further south, in the west of Kinta Valley in central Perak state, the equivalent areno-argillaceous sequence was named as Kati beds (Foo, 1990). Hutchison (2007) referred the sequence that comprises interbedded phyllite, metaquartzite, sandstone and shale as Kati Formation and interpreted as equivalent to the Kubang Pasu Formation.

The Yaha Formation, one of the main Carboniferous rock units in southern Thailand, is distributed in the N-S direction parallel to the older Paleozoic rocks in the central-eastern regions of southern Thailand such as Songkhla, Yala and Pattani Provinces. The sequence in Yala Province is partly conformably underlain by the Devonian Betong Formation and overlain by the Lower Permian Sri Paen succession. In Na Thawi and Songkhla area, the fault contact between the Carboniferous and the overlying Triassic and Neogene succession is also represented.

The Yaha Formation is represented by the thin- to thick-bedded sandstone intercalated with shale and chert with presence of fossils assemblages i.e. *Posidonomya* sp., trilobites, ammonites, brachiopods, crinoids, gastropods, plant remains, radiolarians and conodonts. Chronologically, the Yaha Formation is generally similar to the Khuan Klang Formation in terms of lithology and age but has more thick sandstone beds and ribbon cherts than the later. This is due to the lateral facies changes of depositional basins between the two formations.

On the Malaysian side, fieldwork was carried out in January 2013 and March 2013 in Perlis, Kedah and Upper Perak. In Thai side, stratigraphic survey on the Yaha Formation was carried out during February-April 2013, and has been rechecked in July 2013 and February 2014. A joint field check was carried out from 21st – 23th March 2014 by the geoscientists from both Malaysia and Thailand.

2. THE KUBANG PASU AND YAHA FORMATIONS

2.1 KUBANG PASU FORMATION

2.1.1 Nomenclature

The term Kubang Pasu Formation was used by Gobbett (1973) for a sequence of grey, red or purple thick-bedded quartz and feldspathic sandstone interbedded with subordinate varies colored mudstone exposed in eastern Perlis and northwestern Kedah. The stratigraphic name was taken after the Kubang Pasu District, Kedah where the good outcrops of this rock unit that can be observed. Subsequently, Jones (1981) used the term Kubang Pasu Formation for a sequence of thick- to very thick-bedded sandstone, mudstone, shale, and a variety of poorly sorted areno-argillaceous deposits varying from muddy siltstone through greywacke to feldspathic sandstone in Kedah area, northwest Peninsular Malaysia.

2.1.2 Distribution and geologic setting

The Kubang Pasu Formation occupies the eastern part of Perlis, covering the Ulu Pauh and Temin areas where it forms N-S trending ridges. Good exposures can be observed along the road-cuts and at earth quarries in south of Bukit Ramera, Kampung Tok Kasim, Kampung Sentang and Temin areas. It is also well exposed along the border security road that runs from Bukit Tangga to Sintok area of the Kubang Pasu District. The Kubang Pasu Formation also can be observed in the vicinity of Sungai Teliang, in the northeastern Kedah State which is located in the remote and forested area which can be accessed by boat via Muda Lake, a man-made lake for the paddy field irrigation in Kedah State. In Pendang area, good exposures can be observed at Bukit Jelutong, Bukit Jambul and Bukit Pinang.

In Upper Perak, good outcrops can be easily observed along the border security road parallel to the Malaysia-Thailand border on the Malaysian side known as Lepang Nenering area, Pengkalan Hulu, Perak. The Kubang Pasu Formation underlies most of the Kerunai Malay Reserve area, extending from the Bukit Kobeh (Khao Ko Be) area along the Malaysia-Thailand border in the north to the Padang Sembai-Kubang Gondang area in the south. It is also well exposed in the vicinity of Sungai Kenerong valley, northeast Perak where this rock

unit is locally metamorphosed to schist, phyllite and metasandstone. Sungai Kenerong located in the remote and forested area which is accessible by boat via Temengor Lake and traverse by foot. The rock exposures can be observed along the tributaries of Sungai Kenarong. Metasandstone and metaconglomerate occurs in the upper reaches of the Sungai Weng valley, at eastern Kedah and in the river mouth of Sungai Tan Hain in the northern part of the Temengor Lake. The succession also occurs in Sungai Lebur and their tributaries at Belum area as roof pendant on top of the Main Range Granite.

The rock unit also can be observed at the twin peaks of Gunung Kenderong and Gunung Kerunai, at the northwest of Gerik area and at Gunung Hulu Titi Basah, in the vicinity of Malaysia-Thailand border. The rock sequence also exposed at FELDA Papulut area as well as along the tributaries of Sungai Piah which is located in the remote and forested area in the southeast of Gerik Township. Distribution map of the Kubang Pasu Formation is shown in Figure 1.

2.1.3 Previous works

Gobbett (1973) reported the Kubang Pasu Formation in eastern Perlis and northwestern Kedah comprises a sequence largely composed of grey, red or purple thick-bedded quartz and feldspathic sandstone interbedded with subordinate mudstone. Jones (1981) described the formation consists of shale, mudstone, siltstone, subgreywacke, greywacke and quartzite. Kobayashi (1964) reported the occurrence of Carboniferous fossil in the areno-argillaceous rocks near Kampung Mak Insun, Kedah that belong to the Kubang Pasu Formation. Burton (1965) used the term Kampong Sena Formation for the areno-argillaceous sequence equivalent with the Kubang Pasu Formation in southern Kedah.

Jones (1973 & 1981) had correlated the Kubang Pasu Formation which was considered as Upper Devonian to Lower Permian in age, with the dark colored argillaceous formation named as the Singa Formation that overlying the transitional units above the Setul Formation in Langkawi Islands. The base of the Singa Formation shows similar characteristics with that of the Kubang Pasu Formation (Jones, 1981). The thickness of the formation was estimated at 1,500 m or more (Foo, 1983). It was considered to be conformably overlying the Setul and Mahang Formations, and overlain conformably by the Permian Chuping Formation. Teoh (1992) has divided the Kubang Pasu Formation into argillaceous facies and arenaceous facies.

Cocks *et al*. (2005) suggested that the Carboniferous Kubang Pasu Formation overlying conformably the Devonian Jentik Formation which is exposed in Guar Sanai at Kampung Guar Jentik, Perlis. Meor Hakif & Lee (2005) proposed new names for the Lower Carboniferous rock units exposed in Perlis and Kedah mainland, i.e. from bottom to top: Binjai Formation, Telaga Jatoh Formation and Wang Kelian Formation. They also divided the Jentik Formation of Cocks *et al.* (2005) into several units and have upgraded them into formation rank: Lower to Middle Devonian Timah Tasoh Formation and Upper Devonian Chepor Formation with Sanai Limestone at the uppermost part of the succession. However, Ong & Basir (2007) disagree with this division and prefer to use the name Jentik Formation. Lee (2009) have combined the Chepor Formation, Binjai Formation, Telaga Jatoh Formation and Wang Kelian Formation of Meor Hakif & Lee (2005) into one unit and named it as the Chepor Formation with age ranging from Upper Devonian to Lower Carboniferous. He assigned the Upper Devonian unit of the Chepor Formation as the Langgun Redbeds and the Lower Carboniferous unit as the Hutan Aji Member.

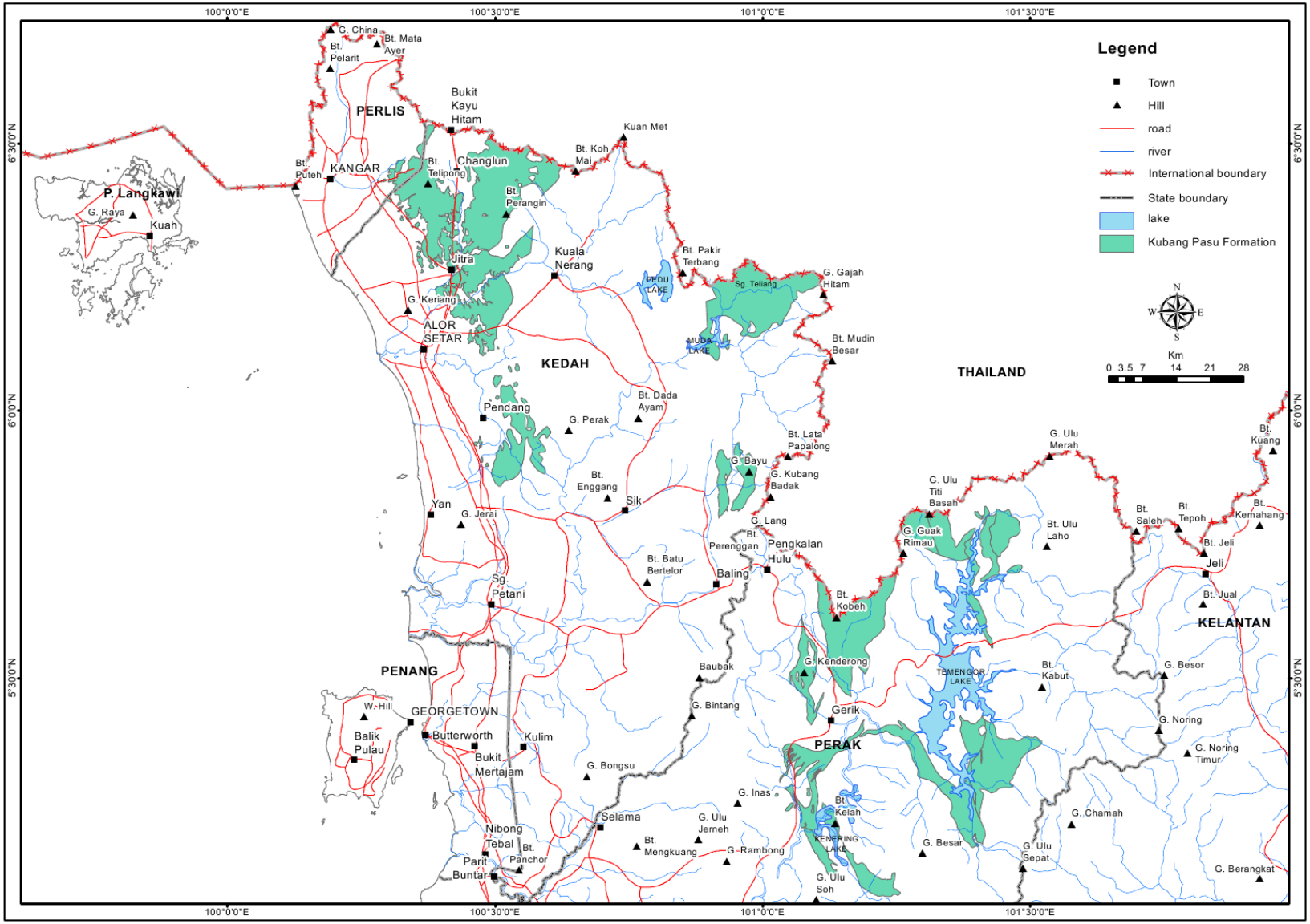

Figure 1: Distribution map of the Kubang Pasu Formation.

The Malaysia-Thailand Working Group (in manuscript) proposed the Upper Devonian to Lower Carboniferous sequence expose at Wang Kelian road, Guar Jentik and Hutan Aji as part of the Rebak member of the Singa Formation. Subsequently, Mat Niza Abdul Rahman *et al.* (2014) proposed the Rebak member to be removed from Singa Formation, upgraded to formation rank and renamed as Rebak Formation. It is well correlatable with Carboniferous Khuan Klang Formation of Thailand.

2.1.4 Lithology

The Kubang Pasu Formation comprises essentially thick interbeds of poorly sorted areno-argillaceous and minor siliceous rock, very thick sequence of argillaceous rock and very thick sequence of thick to massive beds of arenaceous rock with minor conglomerate. The siliceous rocks consist of thin-bedded chert and siliceous shale. It contains minute and rounded texture made up of microcrystalline quartz and chalcedony that may represent traces of replaced radiolarians. Mudstone and shale are the most common argillaceous rock with lesser siltstone. The rocks are essentially dark grey and red in color. The arenaceous rock consists of predominantly grey to white sandstone, greywacke, subordinate grit, and conglomerate. Quarzitic sandstone also occurs. Feldspar is usually present in varying amounts in the sandstone. In some of the sandstone, the feldspar increases to such proportions that the rock may be termed as feldspathic sandstone. Thickness of the individual bed of argillaceous and arenaceous rocks ranges from 10 cm to more than 1 m.

Good exposures can be observed along the security road from Bukit Tangga to Sintok (especially from boundary stone TS26/15 to TS26/75), where radiolarian chert beds are intercalated with red and dark grey mudstone, shale and subordinate sandstone (Figures 2 - 5).

In Sintok area, Kubang Pasu Formation comprises essentially thick interbeds of argillite, sandstone and tuffaceous sandstone and minor siliceous rock. The thickness of the individual beds ranges from 20 cm to 1 m. This rocks comprise thick-bedded sandstone composed of greywacke-subgreywacke intercalated with thick to very thick grey argillite followed by massive, thick-bedded, well-sorted, graded and cross bedded quartz arenite overlain by thin beds of chert or siliceous shale. The argillite consists of shale, mudstone and a variety of poorly sorted argillo-arenaceous deposits varying from muddy siltstone through greywacke and subgreywacke, of dark grey to predominantly light grey, buff and pink to brick red. The succession in the Sintok area represent of the lower and middle part of the Kubang Pasu Formation.

Close to the Koh Mai Granite in northern Kedah, strata of the Kubang Pasu Formation are thermally metamorphosed to either fissile spotted slate or occasionally metaquartzite and quartz-mica schist. Most conspicuously, the spotted rocks contain segregations of quartz-mica spots with incipient chiastolite and cordierite metacrysts.

In Sungai Teliang area, northeastern Kedah, the Kubang Pasu Formation comprises essentially sandstones (Figure 6) interbedded with argillites with intercalation of minor siliceous rocks. The thickness of individual beds ranges from 20 cm to 1 m, forming a complete rock sequence of 300 m to 350 m thick. The siliceous rock consists of thinly-bedded chert and siliceous shale.

At Km. 17 along the border security road near Lepang Nenering in Pengkalan Hulu area, the Kubang Pasu Formation comprises predominantly interbeds of sandstone and shale (Figure 7 & 8). Medium-grained subgreywacke, generally grey to white in color, is the most common arenaceous rock with lesser quartzite (quartz arenite), feldspathic sandstone (arkose) and grit. The siliceous rock consists of thinly-bedded chert and siliceous shale. The chert is thinly-bedded and usually displays tiny white spots or small holes due to the weathering of fossiliferous materials. Characteristic sedimentary features such as graded bedding, cross lamination, fucoidal marking and slump structures are common (Figure 9).

Figure 2: Well-bedded chert overlying red shale along border security road at Bukit Tangga area, northern Kedah, Malaysia. (6° 30.938′ N, 100° 29.471′ E).

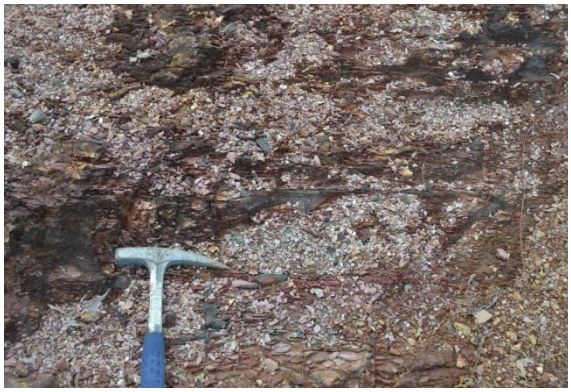

Figure 3: Close-up view of the well-laminated red shale.

Figure 4: Well-bedded radiolarian chert along border security road at Bukit Tangga area, northern Kedah, Malaysia. (6° 30.938′ N, 100° 29.471′ E).

Figure 5: Thin-bedded chert at boundary stone TS26/45 (6° 30.736′ N, 100° 29.626′ E), Malaysia.

Figure 6: Bedded sandstone at Sungai Teliang, near Muda Lake, Kedah

Figure 7: Sandstone interbedded with shale at Km 17 of the border security road near Lepang Nenering, Pengkalan Hulu, Perak.

Figure 8: Sandstone interbedded with shale at Km 17 of the border security road near Lepang Nenering, Pengkalan Hulu, Perak.

Figure 9: Slump structures in the shale at Km 17 of the border security road near Lepang Nenering, Pengkalan Hulu, Perak.

Further east, at Km 18.7 (05° 40′ 32″ N, 101° 06′ 46″ E) along the same border security road, an outcrop of about 5 m thick massive brecciated chert underlying the sequence of sandstone and shale can be observed. The pebble- to cobble-sized chert fragments are cemented by sand and mud. The breccia might be formed by the combination of slumping and tectonic activity. Based on their size and angularity, the breccia has been formed close to its source. There might be a slope failure during the early stage of the formation of the depositional basin from which the brecciated materials were formed. The chert phenoclasts are grey to brownish in color, fine-grained and occasionally finely laminated. Microscopically, the chert is impure and composed of predominantly microcrystalline quartz as well as some micaceous and carbonaceous materials. Patches of recrystalline quartz which may represent the replacement of radiolarian tests also occur. Parallel aligned micaceous materials form irregular fine laminae. Detail studied by Basir Jasin & Zaiton Harun (2006) revealed the chert yields 20 radiolarian taxa indicative of Tournaisian age.

Towards the higher level of the succession, argillaceous and arenaceous rocks are interchangeably predominating. In the Gunung Papulut, Kenderong, Kerunai and Gunung Hulu Titi Basah areas, Upper Perak, the arenaceous facies of the Kubang Pasu Formation is made up of very thick sequence of moderate- to thick-bedded sandstone, quartzite and minor argillite. The sandstone succession is metamorphosed and composed predominantly of medium-grained, pale-colored protoquartzite containing 5% – 15% mica with minor tourmaline, feldspar and carbonaceous material. Orthoquartzite and subgreywacke are also present. The grains are poorly sorted and more often grades into pebbly metasandstone and metaconglomerate or into metasiltstone. The rock unit is commonly thick-bedded to massive, with occasionally observed large-scale cross bedding. Thin interbeds of phyllitic shale occasionally occur within the metasandstone. In the Belum area, the sandstone comprises protoquartzite, orthoquartzite, metagreywacke and some conglomerates.

The argillite consists of shale, mudstone and a variety of poorly sorted argillo-arenaceous sequence varying from muddy siltstone through wacke and subgreywacke, of dark grey to predominantly light grey, buff and pink to brick red. Shale is generally grey to dark grey in color. The shale beds are commonly 0.3 m to 0.6 m thick, occasionally laminated with lamination parallel to the bedding plane. Siltstone occurs commonly as interbeds and intercalations, which are generally less than a few centimeters thick within the shale sequences.

In Belum area, Upper Perak, the whole succession of the Kubang Pasu Formation is metamorphosed metasandstone and schist. Granite intrusion in the country rocks can be

observed along Sungai Terosak and its tributaries where the rocks comprise thick interbeds of pelitic-psammitic sequence.

The pelitic rocks consist of phyllite, schist, hornfels and minor varieties of thinly-bedded, poorly sorted pelitic-psammitic rocks of metamudstone, metasiltstone and metagreywacke. The phyllite and schist consist of very fine- to fine-grained, elongated quartz grains with bands of sericite, chlorite, muscovite, biotite and iron oxide. Hornblende presents as accessory mineral. The phyllite is commonly laminated with the lamination parallel to the original bedding plane and occasionally shows wavy cleavage. Schistosity in the schist is made up of segregation of muscovite and biotite and other flaky and columnar minerals such as hornblende as well as secondary minerals such as sericite and chlorite. Metasiltstone and metagreywacke generally less than a few centimeters thick, occur commonly as interbeds and intercalations within the phyllite or schist sequences. The presence of quartz-mica-chiastolite schist at the right tributary of Sungai Kenarong indicates that it might be the result of both contact and regional metamorphisms. Although granite is not exposed in the surrounding area of quartz-mica-chiastolite schist, it is believed that granite is sub-cropping below the metamorphic rocks.

The psammitic rocks of the Kubang Pasu Formation are made up of very thick sequence of thickly-bedded to massive metasandstone, predominantly quartzite (metaquartzarenite) and minor pelitic rocks such as metasiltstone. At the Gunung Hulu Titi Basah, in the vicinity of Malaysia-Thailand border, the succession is composed predominantly of light grey- to yellowish grey, fine- to medium-grained metaquartzarenite containing more than 95% quartz grains. The rests are muscovite with minor tourmaline, feldspar and iron oxide. Thin interbeds of metasiltstone occasionally occur within the metasandstone.

The upper part of the succession in Upper Perak consists of greywacke and subgreywacke. The rocks are poorly sorted and more often grading up from pebbly sandstone or grit to conglomerate. The metaconglomerate exposures are limited within the vicinity of the river mouth of Sungai Tan Hain (05^{o} 44.884' N, 101^{o} 23.389' E), in the northern part of the Temengor Lake area (Figure 10). The metaconglomerates, grey to yellowish grey when weathered, medium- to thickly-bedded (0.5 m – 1.5 m thick) and coarsening upward sequence. It comprises 20% – 30% clasts of subangular to angular, low sphericity and poorly sorted, various sizes from pebble to cobble; 1 cm – 5 cm in diameter of smoky, pinkish to white vein quartz (95%) (Figure 11), and the rest is light grey sandstones, dark grey siltstone and grey chert (5%) with occasional large mudstone clasts (Figure 12). Orientation of clasts commonly follows the current direction. The matrix is grey, fine- to medium-grained, poorly sorted, dirty sandstones exhibits well-developed graded and cross bedding. In places, cross-bedding can be observed on the top part of the sandstone beds that graded from the conglomerate (Figure 13). The cleavage strikes N-S and NNW-SSE, generally dipping both eastward and westward. The total thickness of the Carboniferous rocks from the representative section in Upper Perak is more than 800 m.

2.1.5 Stratigraphy

The Kubang Pasu Formation can be divided into at least three members; propose to be formally name in ascending order as: the Jelutong, Jenun and Papulut Members.

Jelutong Member

The lower part of Kubang Pasu Formation, Jelutong Member comprises interbeds of thin- to medium-bedded shale and sandstone with occasional fossiliferous beds and intercalated of chert beds. It is named after Bukit Jelutong, Pendang where the sequence of radiolarian chert underlying the interbeds of sandstone and shale sequence can be observed (06^{o} 02.878'N, 100^{o} 30.153'E). It overlies the Mahang Formation in the eastern Perlis and Kedah, and overlies the Kroh Formation in Upper Perak.

Figure 10: The metaconglomerate exposures are limited within the vicinity of river mouth of Sungai Tan Hain (05° 44.884' N, 101°23.389' E)

Figure 11: Various size of quartz clasts within the conglomerate.

Figure 12: Dark grey mudstone clasts that is up to 5 cm in diameter.

Figure 13: Cross-bedding observed on the top part of the sandstone beds grading from the conglomerate.

Jenun Member

The middle part of Kubang Pasu Formation, Jenun Member comprises very thick sequence of shale. It is named after Jenun Sub-district of Pendang District, where good outcrop of thick well-laminated argillaceous sequence can be observed. Some chonetids and ammonoids *Agathiceras* sp. has been discovered in the lower part of the sequence at Bukit Pinang, Jenun, Kedah (5° 56.415' N, 100° 28.089' E). The Jenun member is made up of a very thick sequence of predominantly argillaceous rocks consisting of very well laminated shale and well-bedded shale and mudstone intercalated with minor very thin bed of siltstone and very fine-grained sandstones (Figures 14 & 15). Whenever mudstone and shale are predominating, they usually form low undulating terrains. This feature can be seen in the Bukit Kachi, Padang Siding, Bukit Kayu Hitam, and Bukit Pinang, Bukit Jambul and Sungai Teliang areas.

Papulut Member

The upper part of Kubang Pasu Formation, Papulut Member consist of very thick sequence of thick to massive beds of clean sandstone with some grit and conglomerate. Pellitic schist occurs in the uppermost part of the sequence. Jones (1970) used the term Papulut quartzite for the sequence of quartz or metamorphosed sandstone well-exposed at

Gunung Papulut, Lawin near Gerik area, Upper Perak. He considered the Papulut quartzite as the lowermost part of the Baling Group and interpreted as Cambrian in age and correlated it with the Jerai and Machinchang Formations in western Kedah and Langkawi Islands respectively. Based on their joint studies and correlation with the Carboniferous rock units on the Thai side, The Malaysia-Thailand Working Group (2009a) proposed the Papulut quartzite of Jones (1970) to be taken out from the Baling Group and stratigraphically relocated as the upper part of the Carboniferous Kubang Pasu Formation. It is interpreted as underlies conformably the Permian Gerik Formation and is now proposed to be formally renamed as Papulut Member.

Papulut Member is made up of a very thick sequence of predominantly thick to massive beds of arenaceous rocks consisting of quartz arenite and minor arkosic sandstone interbedded with thin-bedded mudstone or siltstone. The rock is composed of well-bedded sandstones intercalated with mudstone and shale (Figure 16). Various sedimentary structures such as well-sorted quartzitic sandstone with graded bedding and cross lamination can be observed in the sandstones. Thick-bedded sandstone and feldspathic sandstone forms a prominent north-south ridge of Bukit Ramera (6° 30.215′ N, 100° 22.233′ E) and Bukit Telipong (6° 26.068′ N, 100° 23.473′ E; in the south-central part), Bukit Bendang Bongsu (6° 28.437’ N, 100° 27.141′ E), Bukit Buluh Telang (6° 27.319′ N, 100° 27.954′ E; in the eastern part), Ulu Legong, Gunung Bayu, Gunung Papulut, Gunung Kenderong, Gunung Kerunai and Gunung Hulu Titi Basah. The uppermost part consists of psamitic and pellitic schist that can be observed at Sungai Chachor and Sungai Lebur of Belum areas.

Figure 14: Thick sequence of well-bedded shale at Bukit Kachi, Sintok (6° 26.740’N, 100° 31.740’E).

Figure 15: Thick sequence of well-bedded shale at Bukit Pinang, Jenun (5° 56.415’ N, 100° 28.089’ E).

Figure 16: Papulut Member of the Kubang Pasu Formation - quartz-arenite at Ayer Ganda, abandoned quarry, Gerik.

2.1.6 Thickness

The sequence of the Kubang Pasu Formation is estimated up to 1,500 m thick. The thickness of the individual beds ranges from 20 cm to 1 m.

2.1.7 Lower and upper contacts

The Kubang Pasu Formation is underlain by the slate of Mahang Formation as can be observed at Bukit Tuntong in Ulu Pauh, Perlis (6^o 27.900' N, 100^o 19.336' E) as reported by Nur Susila Md. Saaid & Basir Jasin (2014). The underlying Mahang Formation is composed of greenish dark grey sheared slaty mudstone (Figure 17). At this locality, Jelutong Member, the lower part of Kubang Pasu Formation is grading gradually from light grey to grey chert containing Tournaisian radiolarian with yellowish grey siliceous shale, shale, mudstones, siltstone and sandstone (Figure 18). Load structures are common under the sandstone beds. Ripple mark that indicative of shallow water environment also can be observed. The Kubang Pasu Formation is interpreted overlies the Kroh Formation in the Kerunai area. In the Sungai Teliang and Ulu Legong, the Kubang Pasu Formation was intruded by the Late Triassic Main Range Granite. In these areas, the upper part of the succession had been eroded away. In Papulut, Kerunai and Sungai Kenarong areas, the Kubang Pasu Formation is interpreted as overlain by the Gerik Formation.

Figure 17: Slate of the Mahang Formation underlying the Kubang Pasu Formation at Bukit Tuntong (6^o 27.900' N, 100^o 19.336' E).

Figure 18: Interbeds of sandstone, shale and siliceous shale of the Jelutong Member at Bukit Tuntong (6^o 27.900' N, 100^o 19.336' E).

2.2 THE YAHA FORMATION

2.2.1 Nomenclature

The term Yaha Formation, purposed by Muenlek *et al.* (1982), represents a sequence of Carboniferous quartzitic sandstone, shale, mudstone, siltstone and chert in Songkhla, Yala and Pattani Provinces extending northward to Surat Thani Province. It is named after the type section at small hill, located 8 km south of the Yaha district, Yala Province where a good continuously complete sequence of 165 m is exposed. Fossil assemblages *Posidonomya* sp. and plant remains were observed in this sequence, indicating the Early Carboniferous period.

2.2.2 Distribution and Geologic setting

The Yaha Formation is distributed as two N-S trending high relief terrains in Songkhla to Surat Thani Provinces or so-called Songkhla belt and Pattani to Yala Provinces or so-called Yala belt (Figure 19). Distribution of rocks in the western part is limited by exposures of main range Triassic granite from Surat Thani Province to the Malaysia-Thailand border. In these

places, the Yaha Formation shows the contact with the Khuan Klang Formation as lateral facies change boundaries. Eastern edge of the Yaha Formation area is approximately parallel to main range granite from Pa Na Rae District, Pattani Province to Sukinrin District, Narathiwat or Bentong-Ruub suture zones. Fault boundary contact of this unit and the Triassic sequence is generally observed in the middle part of their distribution.

Geological structures (i.e., folds) revealed that the Yaha Formation is parallel to the Lower Paleozoic succession structure. They are characterized by N-S trending, complex, asymmetrical folds having moderately to high angle with westward dipping. The N-S and NE-SW normal, strike-slip and trust faults have affected the movement of rock strata.

Stratigraphically, the rock unit is conformably underlain by the Devonian deep sea fine-grained, clastic rock unit of the Betong Formation. The upper contact with the Lower Permian clastic rocks Sri Paen Formations is found especially north of the Betong district, Yala Province, respectively.

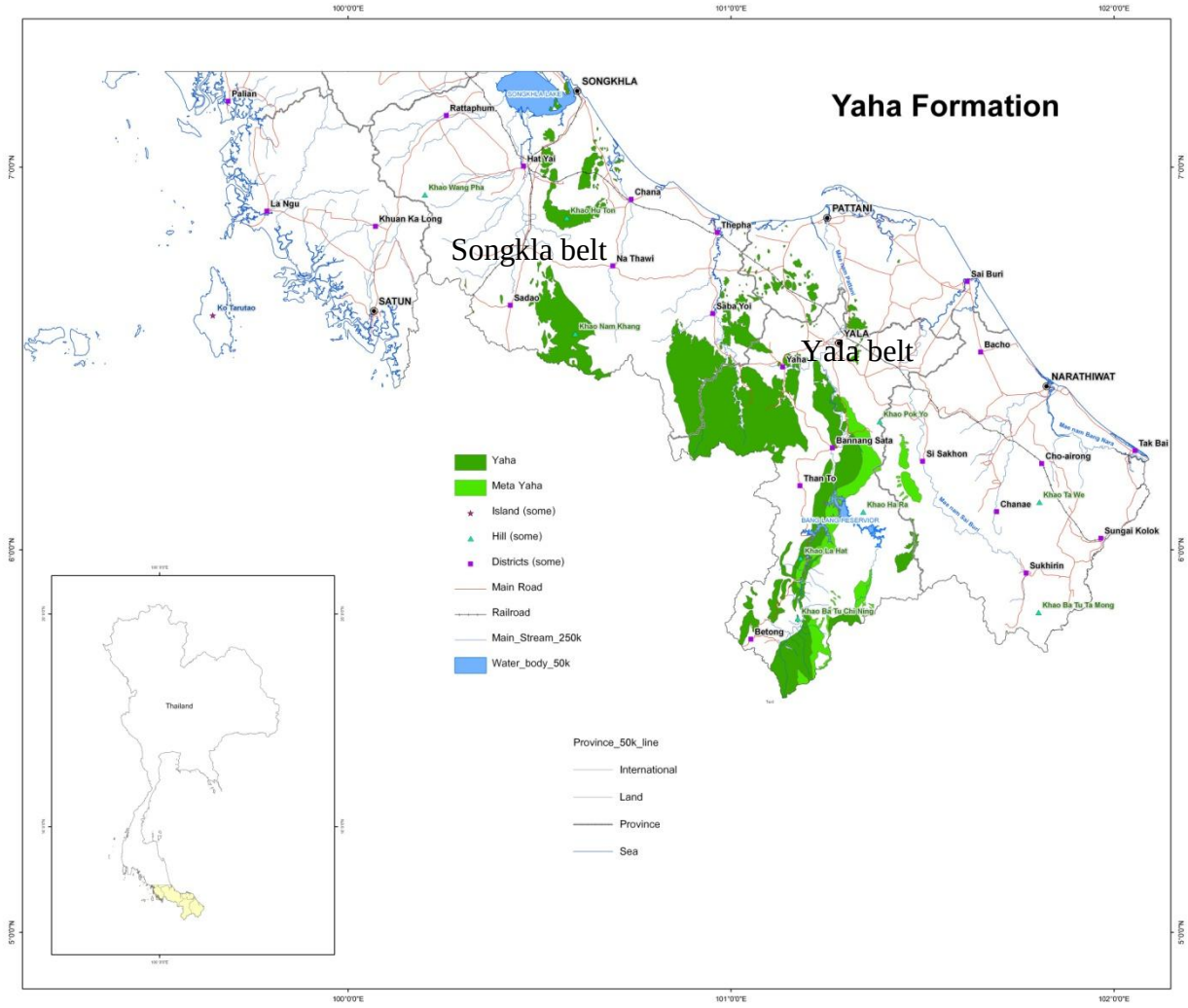

Figure 19: Distribution of the Yaha Formation on the Thai side as two N-S trending i.e. Songkhla belt and Yala belt.

2.2.3 Previous works

The Yaha Formation has been studied by the Thai geological survey mapping teams since 1982-1988 and 2002 but most papers are only reported in Thai. In year 1993-2000, Thai-Japanese geologists studied the microfossil i.e. radiolarian and conodonts at siliciclastic rocks in

the sequence. During year 2003-2006 and 2010-2012, the formation has been systematic studied and revised by the Malaysia-Thailand working Group under the Malaysia-Thailand Border Joint Geological Survey Project. The previous works that explain the characteristic of the Yaha Formation near the Malaysia-Thailand border are summarized as follows:

Muenlek *et al*. (1982) published a regional geological map and report of the Changwat Narathiwat and Takbai (NB47-8,5) and Amphoe Betong sheet (NB47-7) at scale 1:250,000. They introduced the Yaha Formation as the representative of the Carboniferous rocks in their study areas. They purposed the type section of the formation at exposures, 8 km south of Yaha District, Yala Province and mentioned the thickness of them having more than 165 meters.

Chaimanee *et al* (1984) and Chaimanee and Tiyapairat (1983) reported the distribution and attitude of strata of the Carboniferous rocks or Yaha Formation in Amphoe Sting Phra (5023 I), Amphoe Khao Chai Son (5023 IV) and Changwat Songkhla (5123 IV) at scale 1:50,000. They illustrated the characteristic of rock unit is consisted of brown to yellowish brown, quartzite, quartzitic sandstone, bedded chert, sandy shale, siltstone and greyish white, yellowish brown to deep red shale with have fossils of brachiopods, pelecypods, trilobites and conodonts. However, lithostratigraphy and thickness of this formation was not recorded.

Tansuwan *et al*. (1985) published a regional geological map and report of the Changwat Satun (47-7) at scale 1:250,000. They reported that the Carboniferous sequence in the area can be subdivided into 2 Formations, the older Early Carboniferous Khuan Klang Formation and the younger Phru Chaba Formation. However, description on lithology of the Khuan Klang Formation in the eastern part of the area is similar to the Yaha Formation.

Nakapadungrat and Chaisen (1986) reported the Carboniferous rocks or Yaha Formation (DMR, 1999) in Amphoe Cha Na (5122IV) sheet at scale 1:50,000. They described the Formation contains sandstone and shale interbedded with grey siliceous shale and chert bed. Reddish purple shale and minor siliceous shale were also observed. The rock sequence can be subdivided into 3 subunits in ascending order, the lower part; sandstone interbedded with shale, the middle part; siliceous shale and chert and the upper part; shale and minor siliceous shale. Thickness of rock unit exceed to 190m.

Nakapadungrat et al. (1988a) and Nakapadungrat et al. (1988b) reported the Yaha Formation in Amphoe Sabo Yoi (5122II) and Amphoe Kok Pho (5222 III) sheets at scale 1:50,000, respectively. They explained the Formation is characterized by sandstone, light grey, medium-grained, poorly sorted, poorly to moderately cement; shale and mudstone, greenish grey and grey, concoildal fracture; chert, grey to dark grey, thin-bedded; siltstone, light grey; and conglomerate with 1-10 cm clasts of sandstone, quartz, chert and quartzite. Two detailed stratigraphy of the unit i.e. Klong Sanee area and Na Thawi-Yaha road were observed. Thickness of rock unit was estimated to be more than 250m.

Sashida *et al* . (1998) reported the Early Carboniferous radiolarians in chert lens intercalated with sandstone and siltstone-dominated sequence at Ban Wang Yai, 12 km east of the Na Thawi township and Ban Kabang, Kabang District, Yala Province. These radiolarians are *Eutactinia varispina*, *E. vulgaris*, *Astroentactinia multispinosa*, *Spongentactinia* sp., and *Triaenospaera* sp. indicat ive of the Early Carboniferous age (Tournaisian) (Sashida *et al* ., 2000).

Tiyapairat and Maneenai (1988) reported the Carboniferous-Permian Yaha Formation in Changwat Yala (5222II) and Amphoe Raman (5221 I) sheets at scale 1:50,000. The Formation is characterized by interbedded of sandstone, conglomeratic sandstone, shale, mudstone, siltstone, conglomerate with thin bedded of chert and limestone lens, grey to black, locally low grade metamorphic rock. Leaves and crinoids stems in grey to black shale are abundant. Thickness of the sequence was estimated more than 300-400m. General sequence of rock unit from Ban Su A, Muang district to Ban Pa Wang, Bannang Sata district was also explained.

Teeraphan and Teerarungsigul (1988) reported the Carboniferous rocks or Yaha Formation in Changwat Pattani (5222 I) and Amphoe Nong Chik (5222 IV) sheets at scale 1:50,000. They described the Formation is characterized by shale, siliceous shale, chert, sandstone and conglomerate. However, lithostratigraphy and thickness of this formation is not recorded.

Sardsud and Saengseechan (2002) reported the Carboniferous Khuan Klang Formation in Amphoe Had Yai (5023II) sheet at scale 1:50,000. They explained the Formation is characterized by siliceous shale, chert, shale, greenish grey, brown, thin-to medium-bedded. However, lithology of the rock unit in some localities is similar to the Yaha Formation.

The Malaysia-Thailand Working Groups (2006) reported the Geology of the Gubir-Sadao transect area along the Malaysia-Thailand border. They concluded the general characteristics of the Yaha Formation in Na Thawi and Bahoi areas, Sonkhla and Yala Provinces. They also reported the lithostratigraphy, fossil assemblages, thickness and depositional environment of the rock unit.

The Malaysia-Thailand Working Groups (2009) reported the Geology of the Pangolin Hulu-Betong transect area along the Malaysia-Thailand border. They concluded the general characteristics of the Yaha to Betong Districts, Yala Province. They also reported the lithostratigraphy, fossil assemblages, thickness and depositional environment of the rock unit.

The Malaysia-Thailand Working Groups (2010) reported the Geology of the Bukit Batu Puteh-Satun transect area along the Malaysia-Thailand border. They concluded the general characteristics of the Yaha Formation in Sadao District, Songkhla Province and also concluded the geological information of the unit.

2.2.4 Lithology

According to data from the Malaysia-Thailand Joint Geological Survey Project and several previous studies, the Yaha Formation is slightly different in lithology and fossil assemblages from west to east as described below**.**

2.2.4.1 Eastern belt or Yala belt

The Yaha Formation in eastern belt or Yala belt is well exposed at Yala, Pattani Provinces and Saba Yoi District in Songkhla Province. Thickness of the Formation is estimated to 600m. Lithology of the Yaha Formation in subareas can be explained as follow;

a) Betong subarea

The Yaha Formation is largely exposed in N-S trending direction from Betong to Than to Districts, Yala Provinces. Some roof pendants of them are situated in the area between two granitic belts. The sequence is well-exposed along the road from the Suan Som - Sa Ho – Wang Suda (strategic border road) to Ya Rom- Chan Ta Rat village and Bu Su- Lu Po Ta Lo villages. The another locations, in contact with the granite in the west, are the N-S trending high relief from the border - Suan Pae Lim village – Kong Si villages and road cut from Than To-Bannang Sata to Bang Lang Dam site. Generally, the rock displays slightly S1-cleavage developed in the N-S direction with generally dipping eastwardly, especially, in the southward, eastward and the northward of the Betong area. In the central part of the area the rock show generally dipping both eastward and westward with N-S and NE-SW trending with well developed S1-cleavage. Total thickness of the Yaha Formation from the representative section is exceeded 600 m (the Malaysia-Thailand Working Groups, 2009).

In term of lithofacies, the Yaha Formation is this subarea, contains three main types of lithofacies as follows;

- Thin–to thick- bedded, grey to greenish grey mudstone and siltstone intercalated with fine-to medium-grained, thin-to thick-bedded (20-80 cm in general). Sandstone is laminated, pale greenish-grey to yellowish brown, lithic and arkosic which exhibiting diagnostic features of wavy and lenticular beds. Poorly sorted and high rock fragments are common in sandstone texture. Plant remains are observed in mudstone. Some thick-bedded sandstone presents well-sorted and well cement in texture.
- Light brown, well-sorted, fine-to medium-grained, massive to very thick quartzitic , arkosic and lithic sandstone intercalated with very thin bedded, greenish grey dirty mudstone with plant remain and grey, clean, smooth mudstone. Individual sandstone bed is up to 4m. The bottom part of thick-bedded sandstone has small clasts (0.5- 1 mm) of quartz and chert in their texture.
- Thin to very thin (3-7 cm), sharp, parallel, well- bedded, light brown to light grey and white, siltstone, mudstone and siliceous rocks with some light grey to dark grey chert bed with uncompleted radiolarian.

Figures 20 –25 illustrate the exposures of the Yaha Formation in the Betong subarea.

Figure 20: Exposure of thick-bedded sandstone of the Yaha Formation at Bang Lang Dam, Yala Province

Figure 21: Exposure of interbedded sandstone and mudstone of the Yaha Formation at Charo Susu-Wang Suda, Yala Province

Figure 22: Exposure of well-bedded sandstone and mudstone of the Yaha Formation at strategy road, Betong district, Yala Province

Figure 23:Uncompleted *Posidonomya* sp. in mudstone of the Yaha Formation at strategy road, Betong district, Yala Province

Figure 24: Exposure of the Yaha Formation in Than To District, Yala Province

Figure 25: Exposure of ribbon chert of the Yaha Formation in Betong district, Yala Province

The Yaha Formation exposed near the eastern granite pluton, is usually represented by the local deformation and low-grade metamorphism taken place in the shear and contact zones and prograde to metamorphose originated rocks to be phyllite, phyllitic schist, mica schist, quart-schist and quartzite. Example locations of the metamorphosed Yaha Formation can be explained as follows;

- Chan Ta Rat terrain, the rocks consist of strongly folded and sheared, thin banded, dark grey to blueish grey quartz schist alternate with very thin banded, greenish grey phyllitic schist and thin banded, bluelish grey, phyllite. Mica patchs on surface of rock are well developed and the various directions of S1-, S2-cleavage and kink bands are very common. Some secondary pyrite and quartz gash fractures are filled in the rock sequence.
- Sutan Tanun terrain, the rock contains thin layers of blueish grey phyllite and greenish grey schist. The rock display strongly S1-cleavage developed in the N-S direction with generally dipping westward, kink bands and gash fracture are generally recognized.
- At Km 29 to Km 42 village along the Betong-Yala road, the originated Carboniferous succession was affected by NE-SW shear-zone and is progressive metamorphosed by the granitic rocks. It is characterized by the presence of the chevron and recumbent folds, thin to medium banded, yellowish brown to bluelish grey, quartz phyllite, quartz schist and some quartzite. The strongly S1-cleavage developed in NE-SW and NW-SE directions with generally dipping northward, kink band and gash fracture are commonly found in the succession.
- Padeng village, south of Bang Lang Dam are strongly affected by the NE-SW fault zone as well as the granite pluton in the eastern part. It is characterized by the alternated of very thin banded, dark grey to greenish grey, phyllite to mica schist and the thin to medium banded, greenish grey to bluiesh grey, quartz schist with strongly S1- and S2-cleavage developed.
- La Ong Rung waterfall -Ta Pa Yao-Bang Lang Dam range, the facies comprises thick- to very thick-bedded, light greenish grey to grey, fine- to medium-grained, lithic and quartzitic sandstone intercalated with very thin-bedded argillite. The upper portion is composed predominantly of thin-to medium-bedded, grey to greenish grey mudstone and siltstone intercalated with thin- to thick-bedded (20 – 60 cm in general) light greenish grey to yellowish brown, fine- to medium-grained, laminated, lithic, arkosic and quartzitic sandstone exhibiting diagnostic features of wavy and lenticular beds. Strong S1 cleavages are developed in the N-S direction and generally dip westward. Kink bands, quartz dykes and gash fractures are commonly found.

Figures 26-30 shows the exposures of deformation and low-grade metamorphosed the Yaha Formation in Betong subarea.

Figure 26: Exposure of the metamorphosed argillaceous rocks of the Yaha Formation in Betong-Yala Road represent to progressive dynamic metamorphism with kink band developed.

Figure 27: Argillaceous facies with thin- to medium-banded phyllite, phyllitic schist, mica schist and quartz schist of the Yaha Formation in Betong-Yala Road, Betong District, Yala Province

Figure 28: Thin- to medium-banded phyllite and phyllitic schist of the Yaha Formation, west of Bang Lang Dam, Yala Province

Figure 29: Thin- to medium-banded phyllite and phyllitic schist of the Yaha Formation, Sutan Tanun area, Yala Province

Figure 30 The metamorphose Yaha Formation (Left) Medium- to thick-bedded sandstone at Ban Phayao near Bang Lang Dam. (Right) Quartzite at La Ong Rung Waterfall

b) Bahoi-Kabang subarea

The Yaha Formation is well distributed in Yaha Quadrangle and the eastern part of Bahoi Quadrangle. The rocks are trending NE-SW or NNW-SSE with east-dipping strata. In some area, the Yaha Formation is dipping in both east and west directions resulted from intensive folding and faulting. The total thickness of the rocks sequence from the representative section is exceeded 450 m. Good exposures of this Formation are situated in the road cut outcrop from Nam Chieo-Bahoi-Kabang and Yaha-Bannang Sata Roads (the Malaysia-Thailand Working Groups, 2006).

Generally the sequence in this subarea can be subdivided into 6 lithofacies as follows:

- Massive to very thick bedded quartzitic sandstone lithofacies consists mainly of pale brown, well sorted, medium-grained, massive to very thick quartzitic sandstone intercalated with mudstone. Each individual sandstone bed is up to 4 m thick. Plant remains can be recognized in the intercalated mudstone.
- Interbedded mudstone and sandstone lithofacies composes predominantly of mudstone intercalated with sandstone. The pale greenish grey, medium-grained, lithic, arkosic and quartzitic sandstone exhibits diagnostic features of wavy and lenticular beds. The bivalve *Posidonomya* sp. and crinoid stem are occasionally found whereas plant remains are very abundant in argillaceous strata.
- Well-bedded dark grey sandstone lithofacies, consists mainly of dark grey to black, fine- to medium-grained, moderately sorted, well wavy bedded lithic sandstone.
- Tuffaceous sandstone intercalated with mudstone lithofacies, comprises the interbedded of reddish brown, medium-to coarse-grained tuffaceous sandstone, greenish grey, medium-to coarse-grained, uneven-bedded greywacke and thick bedded mudstone and siltstone. The Lower Carboniferous bivalve *Posidonomya* sp. and plant remains are occasionally recognized.
- Chert lithofacies comprises mainly thin-bedded (ribbon), chert and gradually change to siliceous siltstone which often show tight and recumbent folding.
- Even bedded shale interbedded with sandstone lithofacies composes of the interbedded dark grey mudstone and very fine-grained sandstone. The diagnostic sedimentary structures of very thin, even bedded and sharp base bedded exhibiting in the sequence reflect flinch-type or outer fan deposits

Figures 31 –32 illustrate the exposures of the Yaha Formation in Bahoi-Kabang area.

Figure 31: Photographs showing thick bedded sandstone of the Yaha Formation in Nam Chieo area, Songkhla Province

Figure 32: Photographs showing even bedded of sandstone and mudstone of the Yaha Formation in Nam Chieo- Bahoi road, Yala Province

c) Saba Yoi subarea

Nakapadungrat et al. (1988a) and Nakapadungrat et al. (1988b) reported the Yaha Formation in Amphoe Sabo Yoi (5122II) and Amphoe Kok Pho (5222 III) sheets at scale 1:50,000, respectively. They explained the Formation is characterized by sandstone, light grey, medium-grained, poorly sorted, poorly to moderately cement; shale and mudstone, greenish grey and grey, concoildal fracture; chert, grey to dark grey, thin-bedded; siltstone, light grey; and conglomerate with 1-10 cm clasts of sandstone, quartz, chert and quartzite. Two detailed stratigraphy of the unit i.e. Klong Sanee area and between Na Thawi-Yaha road were observed. Thickness of rock unit was estimated to be 250 m (not complete section).

Sashida *et al* (2000) recorded The Early Carboniferous radiolarian-bearing rocks west of Saba Yoi District (Figure 33). They are from lenticular rock bodies embedded in strongly sheared, alternating sandstone and shale. These siliceous shales are thinly bedded, intercalated with siliceous claystone of a few millimeters thick, and are usually dark grey or light grey in color. In contrast to the surrounding alternating beds of sandstone and shale, these radiolarian-bearing siliceous shales have undergone weak shearing. Under microscopic observation, these siliceous shales are composed of abundant radiolarian tests with a clay-size matrix. Scattered, angular detrital quartzs are common. The origin of this siliceous shale is thought to be either an olistostrome or submarine slides from surroundings Lower Carboniferous siliceous shale. The radiolarian fauna consists of *Entactinia variospina* (Won), *Entactinia* cf. *vulgaris* Won, *Entactinia* sp., *Astroentactinia multispinosa* (Won), *Pylentonema* cf. *rachebeaufi* Gourmelon, *Triaenosphaera* cf. *hebes* Won, *Archocytium lagabriellei* Gourmelon, *Polyfistula*? *grantmackiei* Sashida, and *Polyfistula*? sp., among others. Except for the new species and unidentified species, this fauna is quite similar to that in Tournaisian (Early Carboniferous) of France (Gourmelon, 1987), Germany (Braun, 1990), southwestern China (Wang *et al.*, 1998), Thailand (Sashida *et al.*, 1998), and Peninsular Malaysia (Spiller, 1996).

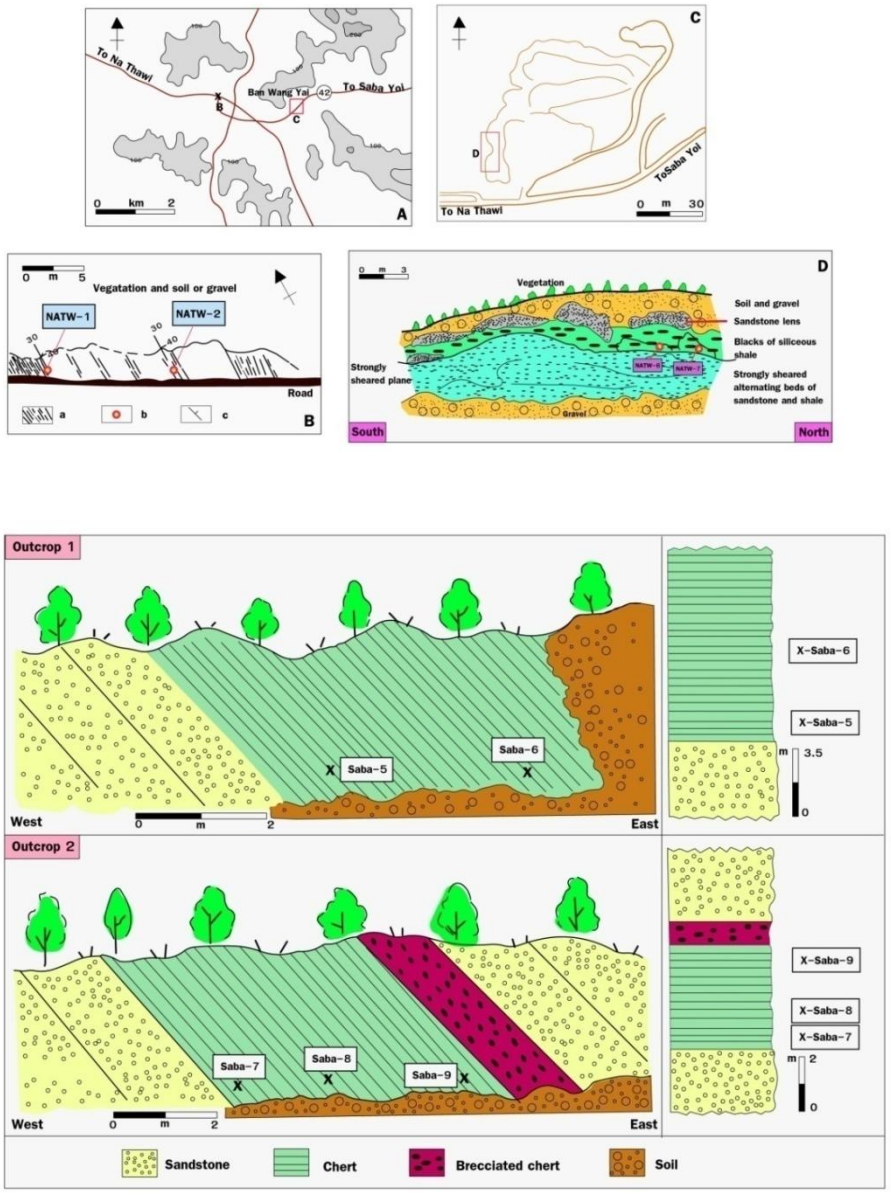

Figure 33 Locality of the Early Carboniferous radiolarian-bearing rocks west of Saba Yoi District, Songkhla Province, consist of siliceous shale by Sashida *et al* (2000)

d) Yala -Raman subarea

Tiyapairat and Maneenai (1988) reported the Carboniferous-Permian Yaha Formation in Changwat Yala (5222II) and Amphoe Raman (5221 I) sheets at scale 1:50,000. The Formation is characterized by interbedded of sandstone, conglomeratic sandstone, shale, mudstone, siltstone, conglomerate with thin bedded of chert and limestone lens, grey to black, locally low grade metamorphic rock. Leaves and crinoid stems in grey to black shale are abundant. Thickness of the sequence was estimated more than 300-400m. General sequence of rock unit from Ban Su A, Muang district to Ban Pa Wang, Bannang Sata district was also explained.

Generally the sequence in this subarea can be subdivided into 4 lithofacies as follows:

- Interbedded of well-bedded, medium- to thick-bedded (30-50cm), mudstone, sandstone, shale and tuff. Sandstone is white to light grey whereas another rock

types are grey to dark grey, greenish grey. Plant remains are generally found in shale. Deformed rock to the phyllite and slate are occasionally found.

- Interbedded of thin-to thick- bedded sandstone, shale, conglomeratic sandstone, siltstone and chert. Typically color of rocks is white, greyish white, brown, greenish grey and black. Sandstone is fine-to very coarse-grained, generally lithic and quartzitic sandstones with minor arkosic sandstone. Conglomeratic sandstone has clasts of quartz, chert, sandstone, and quartzite. Lamination and cross-bedding in sandstone are found.
- Light brown to grey and dark grey chert, ribbon (5-15cm of beds thick) interbedded with sandstone, shale and silicified mudstone. Thickening upward sequence of sandstone strata from 10-30cm to 50-100cm is observed. Conglomeratic sandstones are also intercalated in the upper portion. Monomictic paraconglomerate are recorded.
- Interbedded of sandstone, siltstone, chert and limestone lens

e) Pattani -Nong Chik subarea

Teeraphan and Teerarungsigul (1988) reported the Carboniferous rocks or Yaha Formation in Changwat Pattani (5222I) and Amphoe Nong Chik (5222 IV) sheets at scale 1:50,000. They described the Formation is characterized by shale, siliceous shale, chert, sandstone and conglomerate. However, lithostratigraphy and thickness of this formation is not recorded.

2.2.4.1 Western belt or Songkhla belt

The Yaha Formation in western belt or Songkhla belt is well exposed at Sadao, Na Thawi, Muang, Ko Yo and Sting Phra Districts in Songkhla Province. Thickness of the Yaha Formation is approximately 350-500 m. Lithology of the Yaha Formation in subareas of the Western belt can be explained as follow;

a) Na Thawi-Sadao subarea

The Yaha Formation, is well distributed in the western part of Na Thawi Quadrangle. In the Na Thawi area, the rocks are trending NE-SW or NNW-SSE with east-dipping strata. The succession, approximately 380-450 m thick has good exposures of this Formation are situated in the road cut outcrop from Sadao - Khao Nam Kang- Ban Phakob Road (the Malaysia-Thailand Working Groups, 2006). Generally the sequence in this subarea can be subdivided into 4 lithofacies as follows.

- Brownish white to greenish grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish-grey, thin-bedded shale with plant remains. Grey to greenish-grey, laminated mudstone with the bivalve *Posidonomya* sp., ammonites and crinoids are also observed.
- Brown to greenish-grey, medium- to very thick-bedded mudstone intercalated with thin- to medium-bedded, laminated, medium-grained, well-sorted sandstone with fining-upward sequences and the bivalve *Posidonomya* sp., ammonites trilobite and crinoids. Pebbly sandstone interbedded with mudstones containing various subrounded to subangular clasts of quartzite, sandstone, chert and granite are locally found. These clasts range in size from gravel to boulder.
- Shale and tuffaceous shale intercalated with reddish-brown, fine-grained sandstone followed by thick sequence of dark-grey, well-bedded, thin-bedded chert

- Brown to yellowish-brown, fine- to medium-grained, well-bedded sandstones to siltstone intercalated with mudstone followed by grey, well-bedded cherts. *Posidonomya* sp. and crinoids are also found in this unit.

Figures 34 –37 illustrate the exposures of the Yaha Formation in Na Thawi-Sadao subarea.

Figure 34 Exposure of the well-bedded sandstone interbedded with mudstone of the Yaha Formation Khao Nam Kang, Na Thawi area, Songkhla Province

Figure 35 Photographs showing *Posidonomya* sp. in mudstone of the Yaha Formation, Na Thawi area, Songkhla Province

Figure 36 Exposure of quartzitic sandstone interbedded with mudstone of the Yaha Formation, east of Sadao area, Songkhla Province

Figure 37 Exposure of the well-bedded sandstone to siltstone of the Yaha Formation Khao Nam Kang, Na Thawi area, Songkhla

b) Padang Besar subarea

The formation is distributed on isolated hills near the border line road at Padang Besar, Sadao District, Songkhla Province (the Malaysia-Thailand Working Groups, 2010). The rock sequence consists of predominantly grey to white sandstone, greywacke and conglomerate. Quarzitic sandstone also occurs. Feldspar is usually present in varying amounts in the sandstone. In some of the sandstone, the feldspar increases to such proportions that the rock may be termed as feldspathic sandstone. Mudstone and shale are essentially dark grey and red in color. Thickness of the individual bed of arenaceous and argillaceous rocks ranges from 10 cm to more than 1 m.

Figures 38 illustrate the exposures of the Yaha Formation in Padang Besar area.

Figure 38 Photographs showing the thick- bedded sandstone in the Yaha Formation at Padang Besar area

c) Chana subarea

Nakapadungrat and Chaisen (1986) reported the Carboniferous rocks or Yaha Formation in Amphoe Cha Na (5122IV) sheet at scale 1:50,000. They described the Formation is consisted of sandstone and shale interbedded with siliceous shale, grey and chert beds. Shale and minor siliceous shale, reddish purple were also observed. They also subdivided the rock sequence into 3 subunits in ascending order, the lower part; sandstone interbedded with shale, the middle part; siliceous shale and chert and the upper part; shale and minor siliceous shale. Thickness of rock unit exceed to 190m (not completely section). Strong folding, faulting and partly contact metamorphosed by granites are recorded in some part of this unit.

Generally the sequence in this subarea can be subdivided into 3 lithofacies as follows;

- White to greyish white, fine-to coarse-grained sandstone. Thickness of each bed is 4-6 m. The rock is interbedded with white siltstone, grey and brown shale. *Posidonomya* sp. was found in brown shale.
- Grey to white and purplish grey shale and siliceous shale. Ribbon chert (3-4 cm) is also intercalated. Recumbent and tight folds are found in the upper part. Phyllitic shale is occurred in the fault zone.
- Grey to purplish grey shale with siliceous shale intercalation.

d) Songkhla subarea

Chaimanee *et al* (1984) and Chaimanee and Tiyapairat (1983) reported the distribution and attitude of strata of the Yaha Formation in Amphoe Sting Phra (5023 I), Amphoe Khao Chai Son (5023 IV) and Changwat Songkhla (5123 IV) at scale 1:50,000. They explained the characteristic of rock unit is consisted of quartzite, quartzitic sandstone, bedded chert, brown to yellowish brown, sandy shale siltstone, shale; greyish white, yellowish brown to deep red with fossils of brachiopods, pelecypods, trilobites and conodonts. However, lithostratigraphy and thickness of this formation is not recorded.

In 2013-2014, Thailand Working Groups investigated the Yaha Formation in the Songkhla area. Five reference sections were investigated. Collected radiolaria were also done in these places. Exposures of the Yaha Formation such as Khao Ko Hong, Had Yai District and eastern part of Khao Daeng, Sting Phra District were also investigated. Thickness of the Yaha Formation in this area is estimated not exceed 200 m because of the lower and middle part of the Formation are not observed. Example locations of the Yaha Formation in Songkhla subarea were observed by Thai Working Groups can be illustrated as follows;

At Khao Ko Hong, Had Yai District, the Yaha Formation is well-exposed along the road cut from repeater station (7°02.631´N,100°31.107´E) to Songkhla Observatory (07° 02.372´N,100°30.713´) and at the Cable Car station (07° 02.372´ N,100 °30.713´E). The Formation is generally N-S trending with moderate to high dipping to northeastward. The succession, more than 50m thick sequence, contains quartzitic sandstone intercalated with thin bed of argillite. Quartzitic sandstone is characterized by light grey to yellowish grey, medium-to very thick-bedded (50cm-3m), fine–to medium-grained. Lamination and cross-bedding are occasionally observed. Argillite is light grey to greenish grey, thin-to medium-bedded mudstone. Close-space joints are often found in sandstone beds (Figure 39).

The lower part of the Yaha Formation in this area is represented by road cut outcrops from Cable Car – Guanyinm temple- Songkhla Amusement. General attitude of bedding is 30/120 with cleavage develop 50/060. The sequence is presence by more than 30m thick of greenish grey to reddish brown, mudstone intercalated with light grey, thin-bedded quartzitic sandstone. The sequence is conformably underlain by very thick sequence of mudstone intercalated with sandstone as exposed in current mine, northwestern part of Khao Ko Hong. It is recognized that the contact of the lower part of the Yaha Formation and granitic rocks is located at abandon mine 3 km north of the study area.

The Yaha Formation is also well-exposed along the road cut at eastern coast of Khao Daeng, Sting Phra District. Generally attitude of bedding is NW-SE trending with moderated dipping to northeastward. Repeat sequence of unit by fault movement is very common. The lower succession is white, light grey, thin-to very thick- bedded, fine-grained quartzitic and locally lithic sandstone (Figure 40). Graded bedding and lamination are observed. Clasts of chert and quartz are occasionally found in the bottom part of each bed. Lamination mudstone, white to grey, thin-bedded is intercalated. Total thickness of the succession is more than 80m thick. Above the sequence, the unit is mainly argillite. The unit, more than 70 m thick, contains red, grey, light grey, thin-bedded, well-bedded, siliceous, laminated mudstone and chert. Convoluted and slump beds are often found. Thick sequence of red, medium-to thick-bedded mudstone to siltstone interbedded with red, medium-to thick-bedded mudstone are also observed. Layers of iron hard pans are generally recognized in red bed.

Quarry in Khao Noi in Sting Phra District (7 °12.956´ N,100°33.539´ E) shows the 44.55 m thick sequence of the Yaha Formation. Attitude of bedding of unit is E-W trending with low angle dipping to northward. The rock unit is generally white to light grey, fine-to medium-grained, thick-bedded (1-1.5m) sandstone intercalated with light grey, red, thin-to medium-bedded, laminated mudstone. Load casts and slump structures are observed in bottom part of sandstone beds. Light grey to brownish red, thin-bedded or ribbon chert and siliceous shale is intercalated in the middle sequence (Figure 41). Hard pan is generally observed. Age of rock was determined to Lower Carboniferous by radiolarian assemblages.

Two Quarries of abandon mine in the western part of Khao Daeng, Sting Phra District represent at least 206m thick of the Yaha Formation. Bedding of rock exposure in the quarry 1 (7 °12.143´ N, 100°33.828´ E) is N-S trending with vertical dipping. The lower sequence in this area is characterized by white, light grey fine-to medium-grained, thick-to very thick-bedded (1.5-2m) sandstone interbedded with dark grey, medium-to thick bedded, sandy siltstone. Lamination, flaser beds, bioturbation and carbonaceous materials are occurred in sandy siltstone strata. Siliceous shale, milky, white, well-bedded, sharp, parallel bed, thin-bedded (1-10cm) is also found in the middle portion of this sequence (Figure 42). The upper sequence in this locality is presence by interbedded of sandstone, siltstone and mudstone. Dark red and dark grey, massive, dense, silicified, thin-to thick-bedded mudstone and grey and light grey, thin-bedded silicified mudstone are generally observed.

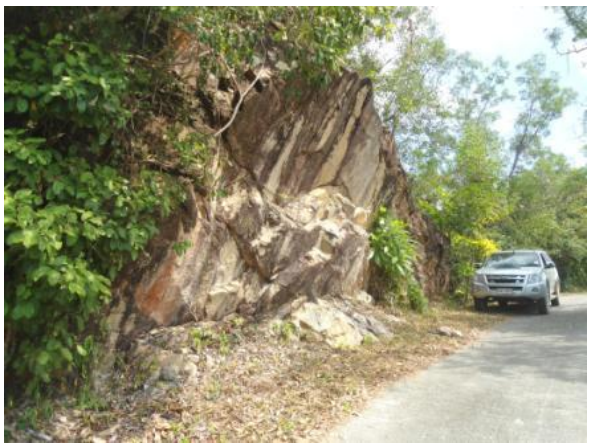

Figure 39 Exposure of thick-bedded sandstone of the Yaha Formation in Khao Ko Hong, Had Yai District, Songkhla Province

Figure 40 Exposure of the Yaha formation at the eastern part of Khao Daeng, Sting Phra District, Songkhla Province

Figure 41 Exposure (left) and closed-up of chert bed in this sequence (right) of the Yaha Formation in Khao Noi, Sting Phra District, Songkhla Province

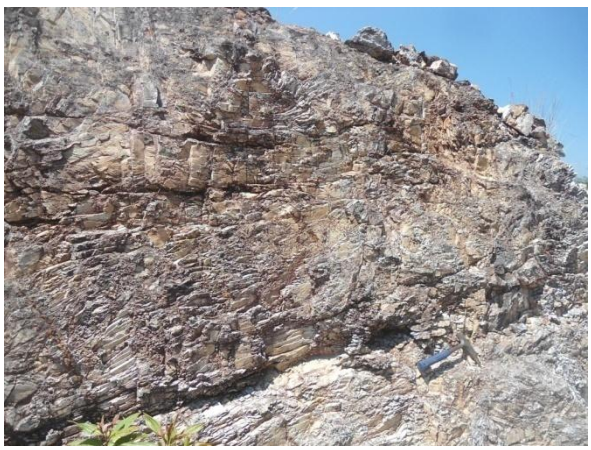

Figure 42 Thick-beds sandstone interbedded with sandy siltstone (left) and siliceous mudstone (right) of the Yaha Formation at quarry1, west of Khao Daeng, Sting Phra, Songkhla Province

In quarry 2 (7 ^{o}12.649´ N, 100 ^{o}34.089´ E), the Yaha Formation is exposed as E-W trending with moderate dipping to northward. The sequence, 86m thick is characterized by thick sequence of red, medium-to thick- bedded mudstone to siltstone interbedded with red, medium-to thick-bedded mudstone. Pale grey to white, thin-to medium- bedded, sandstone is intercalated (Figure 43). Layers of iron hard pans are generally recognized.

The big current mine in Ban Trap, Muang District ($7^{o}01.543'$ N, $100^{o}39.829'$E) illustrates the 168m thick of the Yaha Formation. The unit is generally NE-SW trending with moderate to high angle dipping to southeastward. In the eastern part of the formation have fault boundary contact with the Triassic siliceous shale and chert. General characteristic of the Yaha Formation in Ban Trap area is consisted of four lithofacies as follow;

- Thick sequence of light grey to light brown, thick-bedded, laminated shale with lens of laminated, red mudstone interbedded and the sequence of shale and siliceous shale; thin-to very thin bedded, pale gray in color, well bedded, sharp, parallel bed.
- White, pale grey, fine-to medium grained, thin-to very thick-bedded quartzitic sandstone intercalated with mudstone; white, grey, thin-bedded . Lamination are observed in their strata
- Red and light greenish grey, medium-to thick-bedded mudstone with stringering of sandstone. Bioturbation and hard pans are observed. Pygidium of Trilobite, ammonite and chonetids are often observed. Lamination is common in greenish grey and brown mudstone.
- White and light grey, medium to thick bedded, quartzitic and lithic sandstone interbedded with red and some light grey, medium- to thick- bed mudstone. Hard pans are occasionally found.

Figure 43 The Yaha Formation at Khao Daeng, String Phra District, Songkhla Province (left) and exposure of red mudstone interbedded with siltstone (right)

Figure 44 Thick- bedded sandstone (left) and recumbent siliceous shale or chert (right) of the Yaha Formation at Ban Trap, Muang District, Songkhla Province

In Khuan Bu abandon quarry, Muang District (7 °00.127´ N, 100°39.787´ E), the Yaha Formation is measured to 68.3m in thickness (Figure 45). Attitude of bedding is NE-SW trending with moderate angle dipping to northwestward. General characteristic of rock sequence are described by

- Dark grey, black, light grey, ribbon siliceous shale to chert interbedded with white and pink, very thin- bedded wavy laminated, mudstone
- Interbeds of sandstone and mudstone. Sandstone is white, light grey, medium-to very thick- bedded, quartzitic and lithic in composition. Pebble of chert and quartz grains and load cast structure are often found in the bottom part of sandstone bed. Mudstone, generally red and some light grey, medium to thick- bed and partly lamination. Hard pans are occasionally found.

In Ko Yo (Yo Island), Muang District (7 °00.480´ N, 100°32.649´ E), the Yaha Formation is represent by NW-SE trending with moderate to high angle dipping to northeastward. General characteristic of rock sequence are described by white, pale grey, fine-to medium-grained, thin-to very thick-bedded quartzitic sandstone intercalated with mudstone in the lower part (Figure 46) Mainly siliceous shale and chert, well-bedded, sharp, parallel, light grey to dark grey, thin-bedded are observed in the upper part.

Lower Carboniferous radiolarian assemblages in Khuan Bu abandon quarry and Ko Yo are also observed by Thai Working Group. The result give that the age of the Yaha Formation in both localities is determined to be Early Carboniferous age.

Figure 45 Exposure of siliceous rock sequence of the Yaha Formation, Khuan Bu, Muang District, Songkhla Province

Figure 46 Exposure of thick-bedded quartzitic sandstone of the Yaha Formation, Ko Yo, Songkhla Province

2.2.5 Stratigraphy

Litho- and bio-stratigraphic of the Yaha Formation from several previous studies and current field checking are compiled to introduce the Yaha composited stratigraphic section. Figure 47 illustrates the result of the stratigraphic correlation. In term of stratigraphy, the Yaha Formation can be subdivided into 4 informal members i.e. the Lower member, the Middle member, the lower Upper member and the Upper member. Detailed of each member will be illustrated as follows;

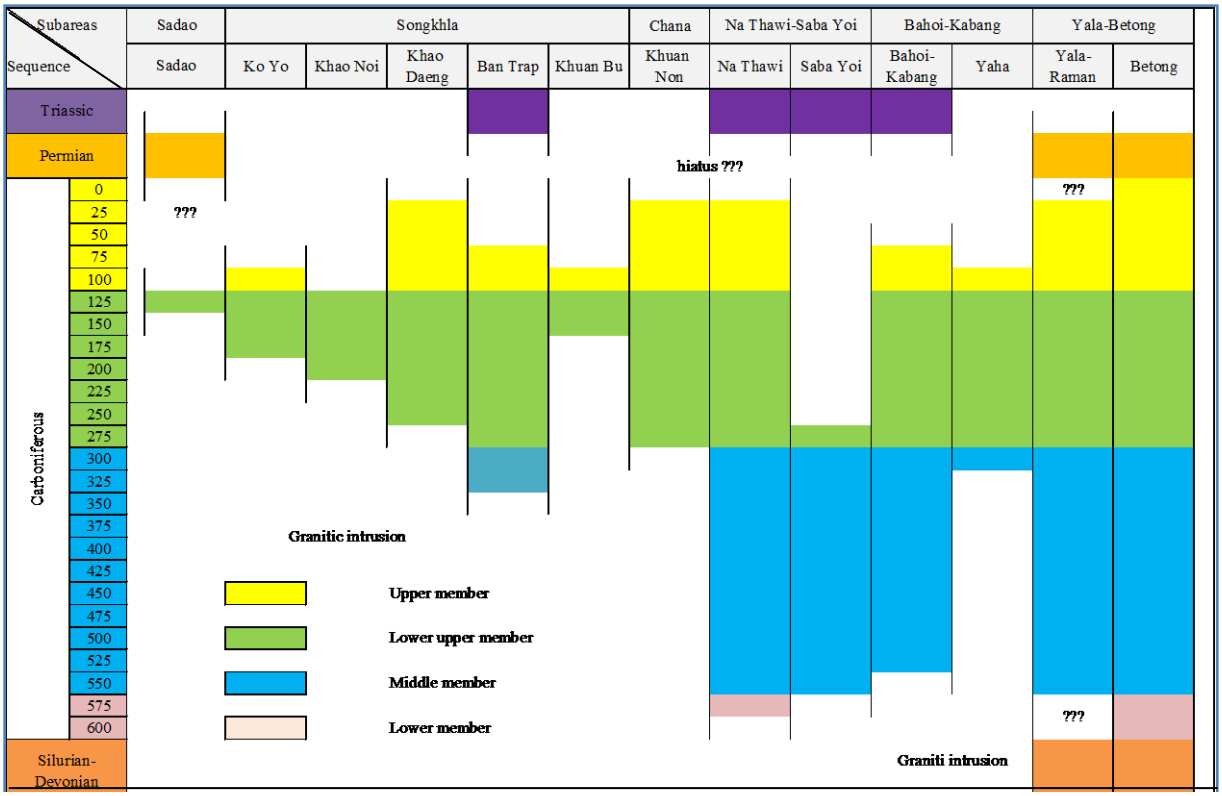

Figure 47 Correlation chart of the Yaha Formation in 13 reference section localities

Lower member

The Lower member is limited exposed at some area of the Yaha Formation because of the interrupt of sequence by Triassic granite region in the western part of Songkhla - Sadao terrains and the area between Bahoi-Kabang and Betong subareas. Stratigraphically, the complete sequence of this member is observed in Betong subarea whereas partly of sequence of the member is found in Na Thawi-Sadao subarea.

The Lower member is generally characterized by interbedded of mudstone and sandstone. *Posidonomya* sp., ammonites and crinoid stems are occasionally found in the upper part whereas plant remains are abundant in argillaceous strata. Sandstone is brownish-white to greenish-grey, thick to very thick-bedded, medium-grained, quartzitic and lithic. Mudstone is grey to greenish-grey and thin-bedded.

In Betong subarea, the Lower member is well -exposed on the strategy border road from Ban Suan Som to Ban Sa Ho, Betong District, Yala Province. The member shows obviously coarsening and thickening -upward sequence from the Devonian Betong Formation. The succession composes predominantly of gray to greenish gray, thin–to medium bedded, mudstone and siltstone intercalated with pale greenish-grey to yellowish brown, fine-to medium-grained, thin-to thick-bedded, laminated, lithic and arkosic sandstone exhibiting diagnostic features of wavy and lenticular beds. Plant remains are generally observed in greenish grey mudstone. Thickness of the member is approximately 50m.

In Na Thawi-Sadao subarea, the Lower member comprises brownish white to greenish grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish-grey, thin-bedded shales with plant remains. The upper part of this unit comprises grey to greenish-grey, laminated mudstones with bivalve *Posidonomya* sp., ammonites and crinoids. Thickness of the member is exceeding 15 m thick.

Middle Member

The member is widely exposed along the Malaysia-Thailand border area. However, thickness of this member is varies because of the interrupts by Triassic granite region. In the eastern belt, complete sequence of the member is observed at Betong, Saba Yoi and Bahoi-Kabang subareas whereas in the western belt, the member is well completely exposed in the Na Thawi-Sadao subarea.

The member is generally characterized by thick sequence of mudstone intercalated with thin- to medium-bedded, laminated sandstone with bivalve of *Posidonomya* sp. Pygidium trilobites and crinoids. Chert and siliceous shale yielded Tournaisian radiolarian, tuffaceous and lithic sandstone and mudstone are observed in the upper sequence of this member.

In the eastern belt, the Middle member is well-exposed at the strategy border road from Ban Suan Som to Ban Sa Ho, Betong District, Yala Province. Rocks sequence are also exposed along the road cut from Ban Nam Chieo to Ban Bahoi, Yaha District, Yala Province and road cut no. 410 Pattani-Yala, Pattani River and along the Tai Rom Yen 3 road from Ban Su A, Muang to Ban Pa Wang, Bannang Sata District. The unit is start from 180-300 m thick of mainly mudstone and siltstone intercalated with fine-to medium-grained, thin to thick-bedded, laminated sandstone. Mudstone is gray color, clean, smoothly, and laminated texture and greenish gray and has dirty texture with feldspar spot and plant remains. The Lower Carboniferous bivalve *Posidonomya* sp. and crinoid stem are occasionally found. Above the sequence, the unit consists of 25-50m sequence of well-bedded dark grey sandstone, tuffaceous sandstone intercalated with mudstone. Above the sequence, the unit is comprised 15-50 m thick sequence of thin- bedded (ribbon), chert and siliceous siltstone which often show tight and recumbent folding.

In Saba Yoi subarea, the Middle member is observed at Klong Sanee, Saba Yoi District, Songkhla Province. The sequence, 250m in thickness, consist of approximately 200m, grey and light brown, medium-grained, sandstone interbedded with greenish grey shale and mudstone followed by siltstone, grey, dense, interbedded with grey sandstone, dark grey shale and greenish grey shale. The upper part, 20m consisted of dark grey ribbon chert overlying by thick- bedded white sandstone.

In Na Thawi-Sadao subarea, the Middle member is observed at Bang Haeng village, Sadao District and the road cut on Sadao-Khao Nam Kang-Ban Prakob, Na Thawi District, Songkhla Province. Thickness of this member is about 250m. The unit start from 40-80 m in thickness of mudstone intercalated with thin- to medium-bedded, laminated, medium-grained, sandstone. Bivalve of *Posidonomya* sp., ammonites, trilobites and crinoids are observed. Pebbly sandstones interbedded with mudstones containing various subrounded to subangular clasts of quartzite, sandstone, chert and granite are also found. Above the sequence, the subunit, 40-120 m thick, is composed of shale and tuffaceous shale intercalated with reddish-brown, fine-grained sandstone followed by 60m sequence of well-bedded cherts or siliceous shale.

Chert bed which record in the middle member can be correlated to the Tournaisian chert lenses within sandstone and siltstone-dominated sequence at Ban Wang Yai, 12 km east of the Na Thawi town and at Ban Kabang, Kabang District, Yala Province. The latter chert was studied by Sashida *et al*. (1998) and Sashida *et al*. (2000). They described that these radiolarians as *Entactinia variospina*, *E. vulgaris*, *Astroentactinia multispinosa*, *Spongentactinia* sp. and *Triaenospaera* sp. indicative of Early Carboniferous age (Tournaisian).

In Songkhla subarea, partly Middle member is located on foothill of Khao Ko Hong, Had Yai District and Ban Trap section, Muang District, Sonkhla Province. Thickness of this

member is not more than 200m. The unit contain interbedded of shale to mudstone; light grey to light brown, laminated, thick-bed with lens of red mudstone and sequence of shale and siliceous shale; thin-to very thin-bedded, pale gray in color, well-bedded, sharp, parallel.

Lower Upper Member

The member is mostly exposed along the mountainous terrains of Malaysia-Thailand border area. Mainly resistant beds have a typical characteristic of this unit. The complete stratigraphy of the member in the eastern belt is observed in the Betong, Bahoi-Kabang, Yala-Raman, Yaha and Saba Yoi subareas whereas in the western belt, complete stratigraphic section of the Middle Member is found in the Na Thawi-Sadao, Chana and most of Songkhla subareas. The member is characterized by thick sequence of predominantly thickly- bedded to massive quartzitic sandstone intercalated with thin- bedded mudstone. Chert and siliceous shale yielded Tournaisian radiolarian are newly observed within the sequence.

In the eastern belt of the Yaha Formation, the lower Upper member is well-exposed on strategy border road and in La Ong Rung waterfall, Betong District, Yala Province. Rock sequence is also found along road cuts from Ban Ba Hoi-Ban Kabang, Yaha District, Yala Province and Ban Tai Rom Yen 3 from Ban Su A, Muang District to Ban Pa Wang, Bannang Sata District. The lower Upper member is subdivided into two parts. The lower part of the sequence, 80-100m in thickness, consist mainly of pale brown, well sorted, medium-grained, massive to very thick-bedded quartzitic sandstone intercalated with mudstone. Each individual sandstone bed is up to 4 m thick. Plant remains can be recognized in the intercalated mudstone. The upper part of the sequence is 30-40 m in thickness of thin- to very thin- (3-7 cm), sharp, parallel, well- bedded, light brown to light gray, siltstone, mudstone and siliceous rocks with some light gray to dark gray chert bed intercalation.

In Na Thawi-Sadao subarea, the lower Upper member is well-exposed at Sadao-Khao Nam Kang-Ban Prakob road. The unit, less than 50m thick, comprises brownish-white to greenish-grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish-grey, thin-bedded mudstone with plant remains. Above the sequence, the rock unit comprises grey to greenish-grey, laminated mudstone which have bivalve *Posidonomya* sp. and crinoids.

At Khuan Non, Had Yai-Khuan Meed road in Chana subarea reveals a good exposure of the lower Upper member of the Yaha Formation. The lower sequence comprises 60m in thickness of white to grayish white, fine-to coarse-grained sandstone. Thickness of each bed is 4-6 m. The rock is interbedded by white siltstone and grey and brown shale. *Posidonomya* sp. was recorded in brown shale. The upper sequence is 50m in thickness of grey to white and purplish grey shale and siliceous shale. Ribbon chert (3-4 cm) is also recorded. Recumbent and tight folds are found in the upper part. Phyllitic shale is recognized in the fault zone.

Part of the lower Upper Member is also observed at the new sections of Ko Yo, Ban Trap, Khuan Bu, Khao Daeng and Khao Noi in Songkhla Subarea. Thickness of the member is approximately 90m thick. The sequence is started by quartzitic sandstone; white, pale grey, fine-to medium grained, thin-to very thick- bedded intercalated with mudstone; white, grey and dark grey, thin-to medium-bedded. Pebble of chert and quartz grains and load cast structure are often found in the bottom part of thick-bedded sandstone. Above the sequence, the unit comprises light grey to light brown, thick-bed, laminated shale with lens of laminated, red mudstone followed by 2-4m sequence of shale and siliceous shale; thin-to very thin-bedded, pale gray in color, well bedded, sharp, parallel bed. Tournaisian radiolarian was observed in chert or siliceous shale beds (Saesaengseerung, in Manuscript)

Upper Member

The complete sequence of the upper member is widely exposed in Chana and most of Songkhla subareas. Partly sequence is also exposed in the Bahoi-Kabang and Na Thawi-Sadao subareas. The Upper Member is characterized by interbeds of well-bedded sandstone intercalated with mudstone, shale and siliceous shale containing *Posidonomya sp*., chonetids and pygidiums of trilobite in the lower part. The upper part is characterized by thick sequence of red mudstone to siltstone intercalated with pale grey to white, thin-to medium- bedded sandstone. Layers of iron hard pans are generally recognized.

In Betong subarea, the member is well-exposed at the La Ong Rung-Ta Pa Yao-Bang Lang Dam site area along the Betong-Yala road. The unit, 50m thick, is consisted of thin- to medium-bedded, grey to greenish grey mudstone and siltstone intercalated with thin- to thick-bedded (20 – 60 cm in general) light greenish grey to yellowish brown, fine- to medium-grained, laminated, lithic, arkosic and quartzitic sandstone exhibiting diagnostic features of wavy and lenticular beds.

In Bahoi- Kabang subarea, the unit is well-exposed at road cut from Ban Bahoi to Yaha District, Yala Province. The sequence, 40-50 m in thickness, is characterized by even bedded shale interbedded with sandstone. The diagnostic sedimentary structures of very thin, even bedded and sharp base bedded exhibiting in the sequence reflect flinch-type or outer fan deposits.

In Na Thawi-Sadao and Chana subareas, the Upper member is well-exposed at Sadao-Khao Nam Kang- Ban Phakob road and at Khuan Non, Had Yai-Khuan Meed, Songkhla, respectively. The unit, 80-100m thick, consists of brown to yellowish-brown, fine- to medium-grained, well-bedded sandstone intercalated with shale. *Posidonomya* sp. and crinoids were also observed in this unit.

In Songkhla subarea, well-exposures of the upper member are occurred at Khao Daeng section, Sting Phra District and Ban Trap section, Muang District, Songkhla Province. The unit, more than 70-100 m thick, contains red and light greenish grey, medium-to thick-bedded mudstone. Bioturbation and hard pans are observed. Stringering of sandstone strata are found. Pygidiums of Trilobite, ammonites and chonetids are often observed. Lamination is common in greenish grey and brown mudstone.

2.2.6 Thickness

Thickness of the Yaha Formation in the type section area purposed by Muenlek *et al*. (1982) is approximately 165 m. Detailed geological mapping during the year 1986-1988 by Nakapadungrat and Chaisen (1986), Nakapadungrat et al. (1988a) and Nakapadungrat et al. (1988b) and Tiyapairat and Maneenai (1988) were reported that the thickness of the succession is between 190-400 m. The Malaysia-Thailand Working Groups (2006, 2009, 2010) were reported that the thickness of the Yaha Formation in the eastern belt is between 400-800 m and in the western belt is between 250-380m. However, in 2013, Thai Working Group has re-checked the raw field data of this rock unit in the Gubir-Sadao, Pengkalan Hulu-Betong and Bukit Batu Puteh-Satun areas. They re-estimated the thickness of the Formation in Betong subarea is not more 600 m in thickness.

In 2014, the upper part of the Yaha Formation in Songkhla subarea is new revised by Thai Working Group. They found a subaerial-shallow marine rocks sequence, 70-100 m thick, of mainly red and grey mudstone with bioturbation and hard pans. Pygidiums of Trilobite, ammonites and chonetids were also observed in the lower part. The sequence is believed that it can be correlated with the upper redbed clastic rocks of the Khuan Klang Formation and the upper grey to greenish grey mudstone and siltstone of the Yaha Formation in previous works.

Therefore, the thickness of the Yaha Formation at the western belt (Songkhla belt) or Na Thawi-Sadao, Chana and Songkhla subareas should be increasing from 250-380m to 350-500m. In the other hand, thickness of the Yaha Formation in eastern belt (Yala belt) or Betong, Bahoi-Kabang, Yala-Raman and Saba Yoi subareas should be not more 600m.

2.1.7 Lower and upper contacts

The Yaha Formation in the Betong subarea is conformably underlain by the Silurian-Devonian succession of the Betong Formation. The contact boundary is situated at the strategy border road from Ban Suan Som to Ban Sa Ho, Betong District, Yala Province. Succession begins from very thin- to thin-bedded siliceous shale, mudstone, siltstone, sandstone with subordinate chert of the Betong Formation. Then, the sequence is gradational changed to thin–to medium bedded, grey to greenish grey mudstone and siltstone intercalated with thin to thick bedded, laminated, pale greenish-grey to yellowish brown, lithic and arkosic sandstone of the Yaha Formation.

The upper contact of the unit is conformably overlied by the Early Permian Sri Paen Formation. Contact boundary is situated at the Betong-Yaha road near the La Ong Rung waterfall. The sequence starts from grey to greenish grey, thin- to medium-bedded mudstone and siltstone intercalated with light greenish grey to yellowish brown, thin- to thick-bedded, fine- to medium-grained, sandstone of the Yaha Formation. Then, the sequence is gradational changed to thin –bedded of brownish grey to brown shale, mudstone and siltstone intercalated with the thin-bedded, very fine-grained sandstone, mudstone and chert strata of the Sri Paen Formation.

In Yala-Raman subarea, Tiyapairat and Maneenai (1988) reported that the lower contact boundary of the Yaha Formation is underlain by the Silurian-Devonian sequence. The upper contact of this unit is overlied by the Permian Ratburi limestone. However, fault boundaries ontact of the Yaha Formation and the Triassic rocks are often found in several areas.

3. REFERENCE SECTIONS OF THE KUBANG PASU/YAHA FORMATION

The term Kubang Pasu Formation and Yaha Formation are already established and well-accepted. However, they have not type section ever proposed for the formations as no complete section of the whole sequence of the formation can be observed at one locality. Based on current study, six reference sections in the Kubang Pasu Formation and eleven reference sections in the Yaha Formation are described representing the various parts of the formation.

3.1 REFERENCE SECTIONS OF THE KUBANG PASU FORMATION

3.1.1. Bukit Jelutong reference section

a. Location

The Bukit Jelutong reference section is located at in Pendang, Kedah (06^{o} 02.878'N, 100^{o} 30.153'E) where the lower part of the formation or Jelutong Member and middle part or Jenun Member can be observed.

b. Exposure

The reference section is located at an earth quarry with about 150 m wide and 8 m height exposure.

c. General geology

Geologically, the reference section comprises sequence of light grey well-bedded chert in the lower part and interbeds of shale and sandstone in the upper part (Figures 48 & 49).

Figure 48: Sequence of light grey well-bedded chert in the lower part and interbeds of shale and sandstone in the upper part exposed at Bukit Jelutong reference section (06^{o} 02.878'N, 100^{o} 30.153'E).

Figure 49: Well-bedded and folded radiolarian chert at Bukit Jelutong reference section (06^{o} 02.878'N, 100^{o} 30.153'E).

d. Lithostratigraphy

Stratigraphic column of the reference section is shown in Figure 50. It can be divided into five subunits as described below:

i. Sequence of carbonaceous shale, highly deformed, highly fractured and pyritized.
ii. Interbeds of grey to black radiolarian chert and shale. Chert beds are 3 cm – 5 cm thick, whilst shale beds are less than 1 cm thick.
iii. Well-bedded grey shale of 5 cm – 20 cm thick with thin beds of sandstone.
iv. Interbeds of grey shale and light grey sandstone of 5 cm – 20 cm thick.
v. Interbeds of red shale of 10 cm – 20 cm thick with thinner beds of sandstone.

The subunit i and ii are considered as Jelutong Member, whilst subunit iii, iv and v are parts of Jenun Member.

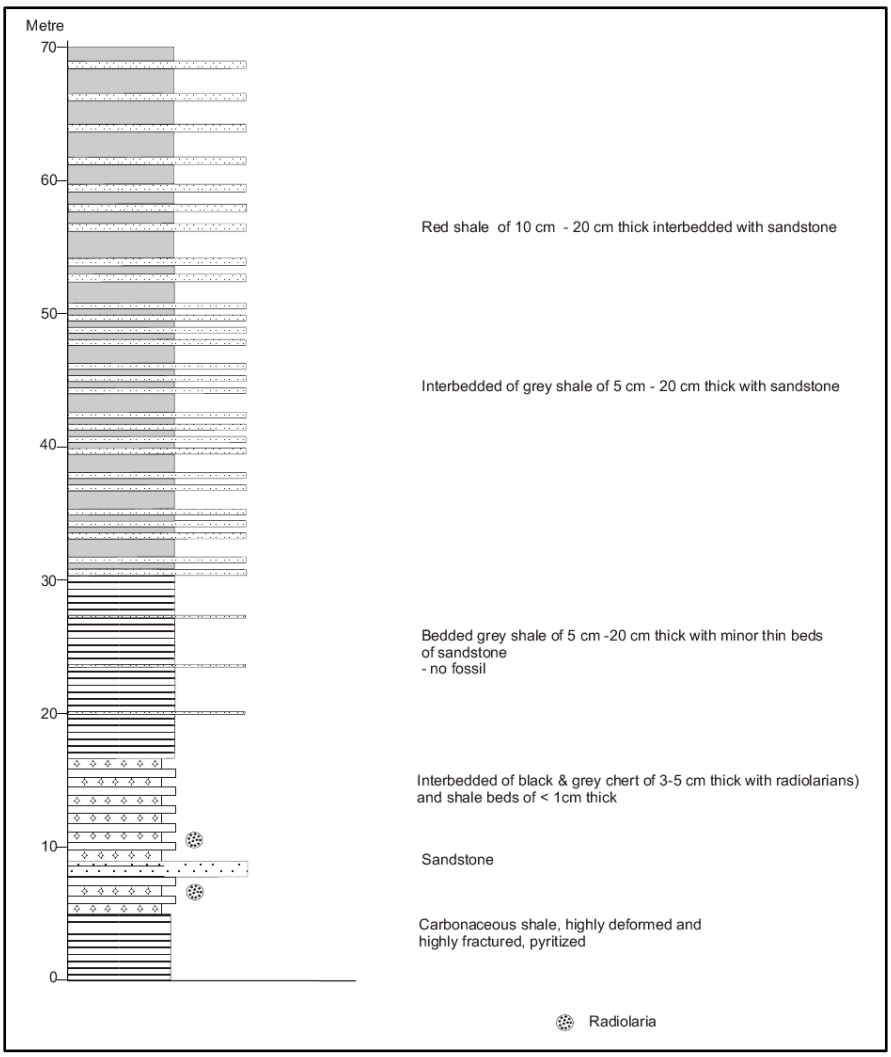

Figure 19: Stratigraphic column of the Bukit Jelutong reference section.

3.1.2 Bukit Tuntong reference section

Bukit Tuntong reference section is representing the Jelutong Member, the lower part of the Kubang Pasu Formation.

a. Location

The reference section is located in an active earth quarry site at Ulu Pauh area, eastern Perlis (06^{o} 27.900'N, 100^{o} 19.336'E).

b. Exposure

The exposure in the quarry area is keep changing with the progress of the earth quarry.

c. General geology

Geologically, the reference section comprises light grey sandstone interbedded with thinner beds of grey shale containing crinoid stems, ammonoids, small brachiopods, trilobite pygidium and gastropods. Well-bedded light grey to grey chert occurs in the lower part of the sequence (Figure 51). The sequence is overlying the dark greenish grey carbonaceous and sheared slate of the Mahang Formation (Figure 52).

Figure 51: Well-bedded chert that yields Tournaisian radiolarian at Bukit Tuntong reference section (06^{o} 27.900'N, 100^{o} 19.336'E).

Figure 52: Bukit Tuntong reference section in an active earth quarry site at Ulu Pauh area, eastern Perlis (06^{o} 27.900'N, 100^{o} 19.336'E). Slate of the Mahang Formation underlying the Kubang Pasu Formation on the right hand side.

d. Lithostratigraphy

Stratigraphic column of the Bukit Tuntong reference section is shown in Figure 53. At this locality, the Jelutong Member of Kubang Pasu Formation is overlying the dark greenish grey sheared slate reported as the upper part of Mahang Formation by Nur Susila Md. Saaid & Basir Jasin (2014). In the field the chert at the lower part of the Jelutong Member is in fault contact with the slate. At this reference section, the sequence can be divided into six subunits as described below:

i. Well bedded radiolarian chert that yields radiolarian indicative of Tournaisian age (Nur Susila Md. Saaid & Basir Jasin, 2014)
ii. Interbeds of sandstone and shale with occasional tuffaceous sandstone beds. Fossils of ammonoids, crinoid stems, trilobite pygidium, brachiopods and gastropods have been found the shale bed. Load cast occur under the sandstone beds. Cross bedding can be observed in the sandstone beds.
iii. Thick beds of shale with minor sandstone beds.
iv. Red fossiliferous shale containing ammonoids, crinoids stems, trilobite pygidium, brachiopods and gastropods.
v. Interbeds of thick shale and sandstone.
vi. Thick sandstone with ripple mark.

3.1.3 Sintok reference section.

Sintok reference section is representing the Jelutong Member, the lower part of the Kubang Pasu Formation.

a. Location

The reference section is located on the road-cut along the new road from Changlun to the Northern University of Malaysia, at 6^{o} 26.950'N, 100^{o} 26.950'E.

b. Exposure

The exposure at the reference section is continuous for about 100 m along the road.

c. General geology

Geologically, the reference section comprises light grey sandstone interbedded with thinner beds of well-laminated grey shale (Figures 54 & 55) containing bivalve *Posidonomya* sp. and trilobite pygidium. The bedding strikes 344^{o} to 360^{o} with dipping 60^{o} -66^{o}.

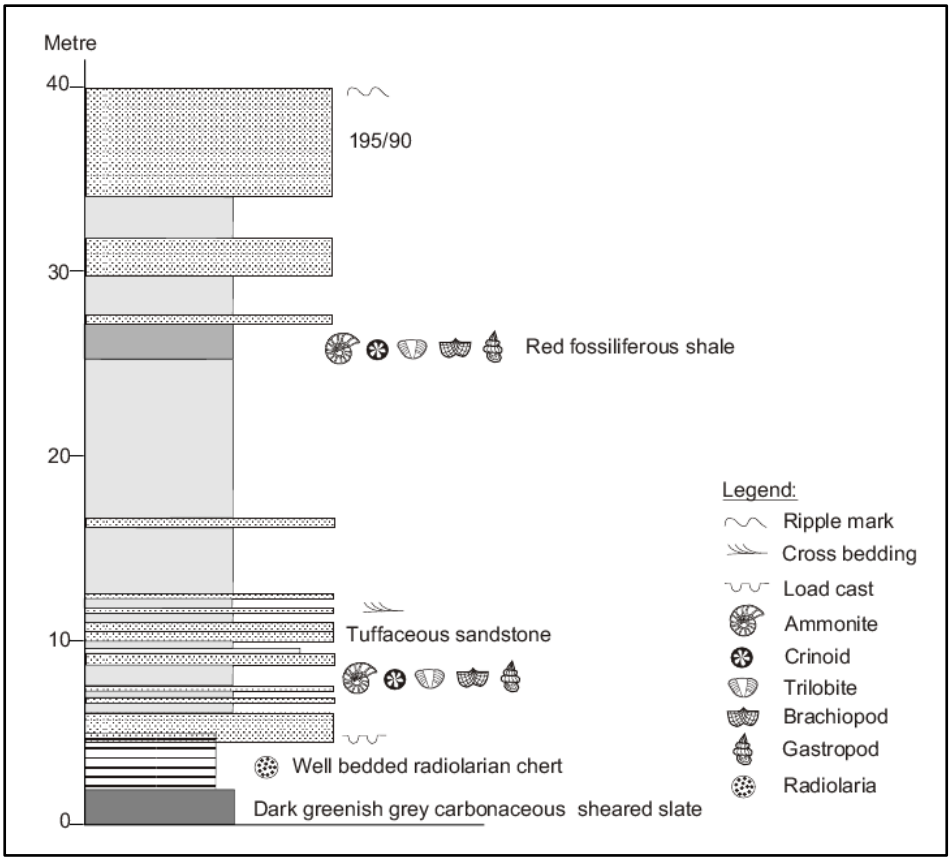

Figure 53: Stratigraphic column of the Bukit Tuntong reference section (after Nur Susila & Basir Jasin, 2014).

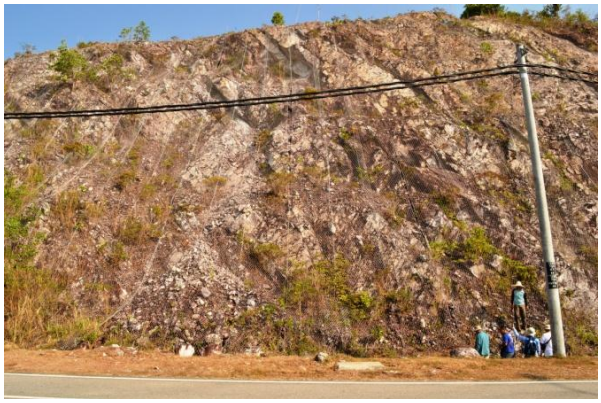

Figure 54: Sintok reference section comprises interbeds of medium- to thickly-bedded sandstone and thinner shale beds.

Figure 55: Well-laminated shale that yields bivalve *Posidonomya* sp. and trilobite pygidium at Sintok reference section.

d. Lithostratigraphy

Sintok reference section is representing the Jelutong Member of Kubang Pasu Formation. Stratigraphic column of the Sintok reference section is shown in Figure 56. It can be divided into four subunits as described below:

i. Thick light grey sandstone bed.
ii. Interbeds of light grey sandstone and light grey shale, bedding thickness around 10 cm – 30 cm.
iii. Thick light grey sandstone interbedded with grey shale beds of 10 cm – 20 cm thick
iv. Interbeds of light grey sandstone and thin beds of light grey shale.

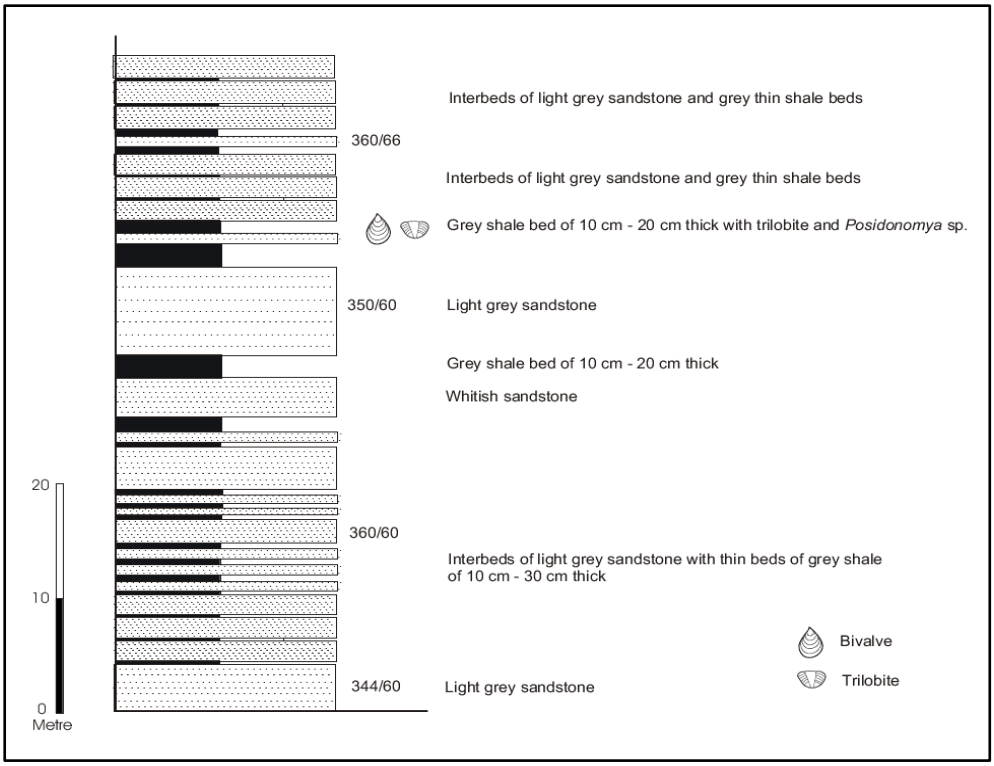

Figure 56: Stratigraphic column of the Sintok reference section.

3.1.4 Bukit Kachi reference section

a. Location

The reference section is located in Bukit Kachi area near Sintok, northern Kedah (6^{o} 26.740'N, 100^{o} 31.740'E).

b. Exposure

The reference section is a small outcrop about 15 m wide and 4 m height expose along the road.

c. General geology

Geologically, the reference section comprises predominantly well-bedded red highly weathered shale (Figures 57 & 58).

Figure 57: Well-bedded red highly weathered shale at Bukit Kachi reference section (6^{o} 26.740'N, 100^{o} 31.740'E).

Figure 58: Close-up of red highly weathered shale at Bukit Kachi reference section (6^{o} 26.740'N, 100^{o} 31.740'E).

d. Lithostratigraphy

Bukit Kachi reference section is representing the Jenun Member, middle part of Kubang Pasu Formation. Stratigraphic column of the Bukit Kachi reference section is shown in Figure 59. It comprises entirely well-bedded and well-laminated shale.

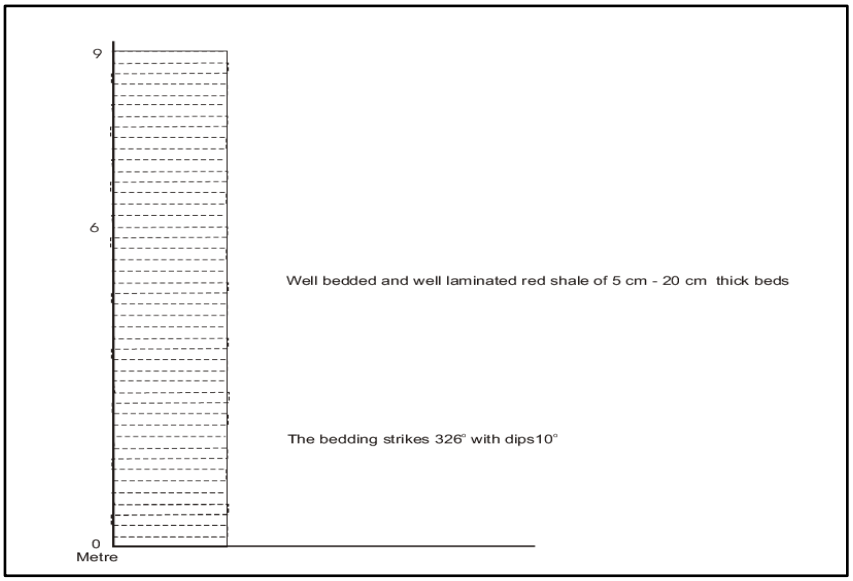

Figure 59: Stratigraphic column of the Bukit Kachi reference section.

3.1.5 Bukit Jambul reference section

a. Location

The reference section is located at Bukit Jambul area in Pendang, Kedah (05^{o} 56.401'N, 100^{o} 28.343'E).

b. Exposure

The reference section is located at huge active earth quarry with estimated continuous 200 m and about 30 m exposure.

c. General geology

In term of geology, the reference section comprises light grey sandstone interbedded with grey shale containing bivalve *Posidonomya* sp. (Figures 60 & 61). The bedding strikes 340^{o} to 330^{o} and dips 50^{o} to 56^{o}.

Figure 20: Lower part of Bukit Jambul reference section with thickly-bedded sandstone and shale. The resistance sandstone bed is about 5 m thick. Lat. & Long.: 05^{o} 56.401'N, 100^{o} 28.343'E.

Figure 21: Posidonomya sp. within shale bed at Bukit Jambul reference section (05^{o} 56.401'N, 100^{o} 28.343'E).

d. Lithostratigraphy

Bukit Jambul reference section is representing the Jelutong and Jenun Members, lower and middle part of the Kubang Pasu Formation respectively. Stratigraphic column of the Bukit Jambul reference section is shown in Figure 62. It can be divided into two subunits as described below:

i. Interbeds of shale and sandstone, thickly bedded. *Posidonomya* sp discovered in the shale beds. This subunit is representing Jelutong Member.
ii. Thick sequence of well bedded and well laminated grey shale beds, slightly metamorphosed, representing Jenun Member.

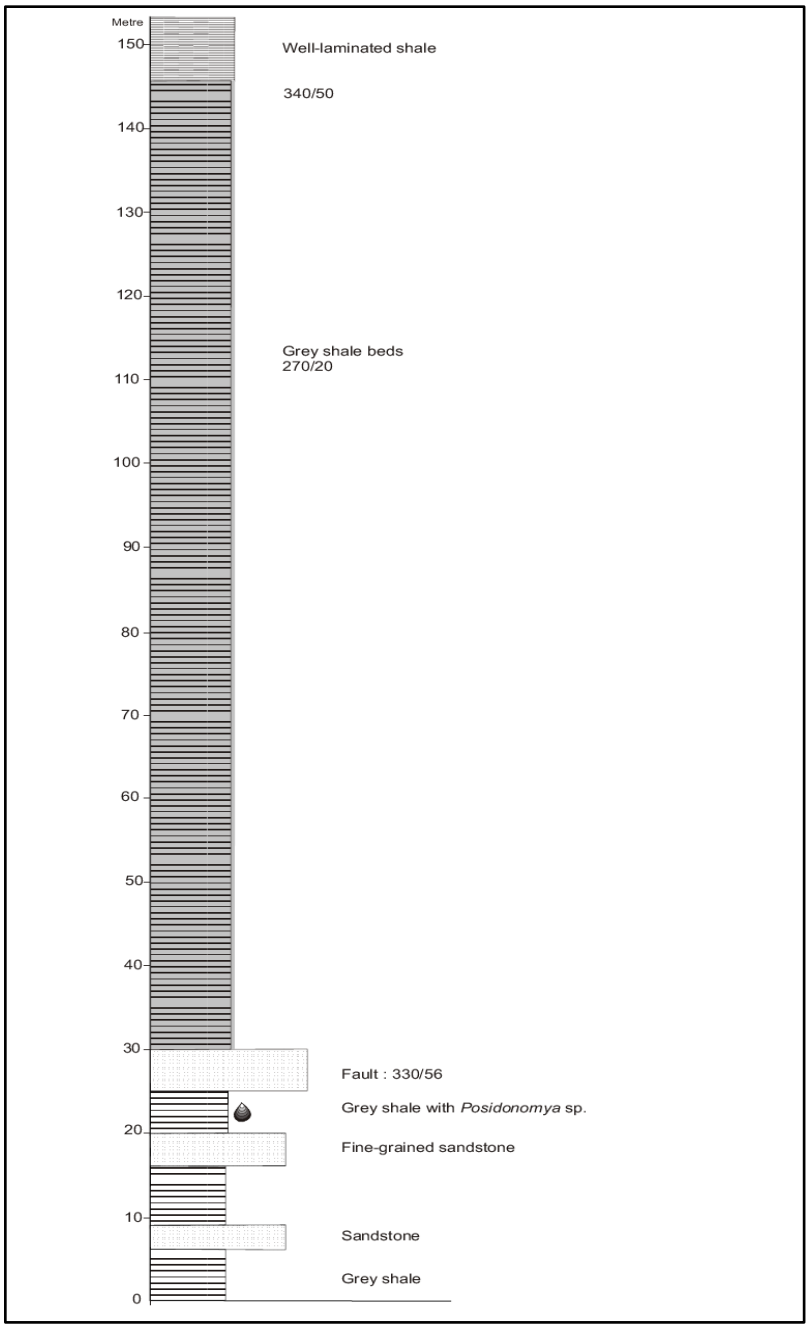

Figure 62: Stratigraphic column of the Bukit Jambul reference section

3.1.6 Ayer Ganda reference section

a. Location

The reference section is located at Ayer Ganda area, to south of Gerik town, upper Perak state.

b. Exposure

The exposure at the reference section is an abandoned quarry face, about 15 m height.

c. General geology

Geologically, the reference section comprises light grey, very thick to massive fine-grained quartz arenite with occasional very thin light grey siltstone partings. The bedding is subhorizontally dipping.

d. Lithostratigraphy

Ayer Ganda reference section is representing the upper member of the Kubang Pasu Formation, named as Papulut Member. The sequence comprises entirely of thickly bedded to massive quartz arenite with occasional thin siltstone partings (Figures 63 & 64).

Figure 63: Thickly-bedded metamorphose sandstone at Air Ganda reference section.

Figure 64: Close-up view of the quartz arenite.

3.2 REFERENCE SECTIONS OF THE YAHA FORMATION

Eleven reference sections of the Yaha Formation are explained in this topic. Distribution of 11 reference section is illustrated in Figure 65. Information of localities, exposures, geology and lithostratigraphy of reference sections will be described as follows;

3.2.1. Betong reference section

a. Location

The Betong reference section is well- exposed along the strategic border road from the Suan Som - Sa Ho, Betong District, Yala Province. Geographic reference of section is 5^{o} 41.102′N, 101 ^{o} 06.245′E to 5^{o} 39.850′N, 101 ^{o} 07.745′E in Ban Ai Yoe Boe Chang 5220 III Sheet on the scale 1:50,000.

b. Exposure

The reference section has continuous exposure 5,000 m long and 10-20 m high along the road cut in the north of Malaysia-Thailand border ridge. Good exposures of fresh rocks having continuous sequence for studying characteristics of the rock units.

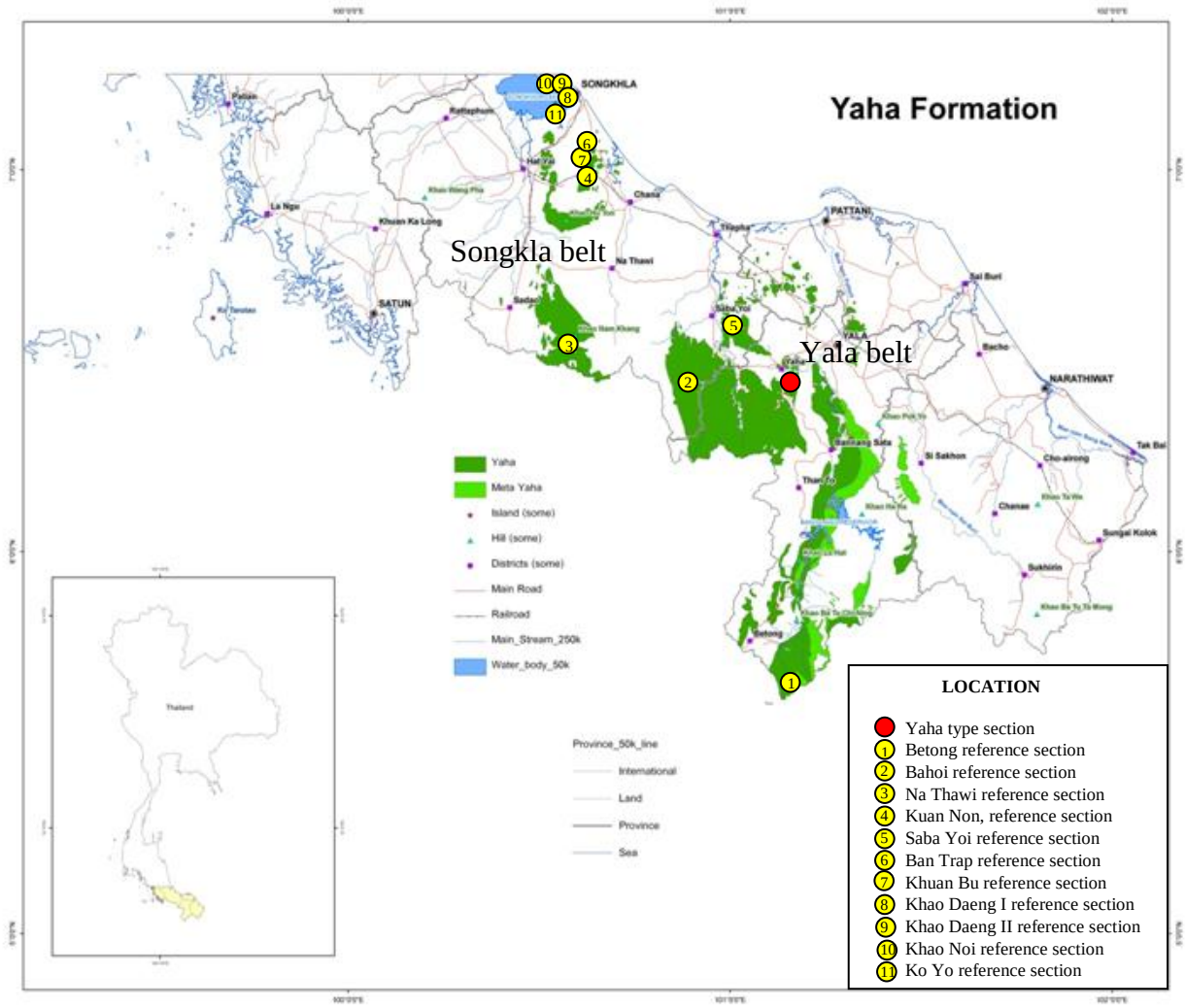

Figure 65: Distribution of the 11 reference sections of the Yaha Formation

c. General geology

Rock units in the reference section have generally N-S trending with eastward dipping. Generally, azimuth of beds varies from 20/090 to 35/090. Main faulting and jointing occurred in the area is characterized by the normal and oblique strike-slip faults trending NW-SE directions.

Two Formations of rock units recognized in this reference section are described in detail, in ascending order, as follows:

1. Devonian Betong Formation is exposed at western part of the Yaha reference section. Characteristic of the Betong Formation in this area is interbedded layers of mudstone and silicified shale and very fine-grained sandstone; dark grey to black, very thin- to thin-bedded, laminated and thin-bedded to ribbon, brown to grey chert with rare radiolarians. The thin-bedded, laminated, friable, porous, light pink shale with *Tentaculites* is partly intercalated in the upper part of the sequence from 2 – 5 m in thickness.

2. Early Carboniferous Yaha Formation is characterized by the presence of very thin to medium-bedded sandstone, siltstone, shale and chert in the lower part and thick to massive bedded sandstone, argillite, and minor ribbon chert in the upper part. The sequence was measured to be more than 500m thick. Fossil assemblages consist of incomplete *Posidonomya* sp. in mudstone and radiolarian and conodont in chert.

d. Lithostratigraphy

The Yaha Formation in the Betong reference section, approximately 500 m thick, comprises three subunits which can be correlated with the lower, middle and lower upper member of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 66) is described in ascending order:

1. Lower Member

The sequence shows obviously coarsening and thickening upward sequence from the Devonian Betong Formation. The succession composes predominantly of thin–to medium bedded, grey to greenish gray mudstone and siltstone (60-80%) intercalated with fine-to medium-grained, thin- to thick- bedded (20-60 cm in general), laminated, pale greenish-grey to yellowish brown, lithic and arkosic sandstone (20-40%) exhibiting diagnostic features of wavy and lenticular beds. Plant remains are generally observed in greenish grey mudstone. Thickness of the member is approximately 50m.

2. Middle member

The member is continuously underlain by the Lower member. The succession, 250 m, thick, consists of medium –to thick-bedded mudstone and siltstone intercalated with fine-to medium-grained, thin to medium-bedded, laminated sandstone. Mudstone is composed of grey color, clean, smoothly and homogeneous texture and greenish grey and has dirty texture with feldspar spot and plant remains. In completed bivalve *Posidonomya* sp. and crinoid stems are rarely found. Sandstone is light greenish-grey, light grey and yellowish brown, lithic, arkosic and quartzitic in composition. General sandstone strata present wavy and lenticular beds. Some sandstone strata have small clasts (0.5- 1 mm) of quartz in their texture.

Above the sequence, the unit is represented by 30-40 m thick sequence of thin to very thin-bedded (3-7 cm), sharp, parallel, well- bedded, light brown to light gray and white, siltstone, mudstone and siliceous rocks with some light gray to dark gray chert bed with radiolarian which often show tight and recumbent folding and become to thick-bedded sandstone sequence.

3. Lower Upper member

The member is continuously underlain by the middle member whereas the overlying unit is fault bound. The succession, 150 m thick, consists of light greenish-grey to yellowish brown, fine-to medium-grained, medium to very thick- bedded (60-200cm thick in general), lithic, arkosic and quartzitic sandstone. Some thick-bedded sandstone (up to 4m) presents well-sorted and well cement in texture. Lamination, cross-lamination and wavy or lenticular beds are common in sandstone strata. The thick-bedded sandstone has small clasts (0.5- 1 mm) of quartz in their texture. Thin- to medium- bedded, greenish gray dirty mudstone with plant remains and gray, clean, smooth mudstone are occasionally intercalated.

Figure 67a-f illustrates the exposures and rock types of the Yaha Formation in the Betong reference section.

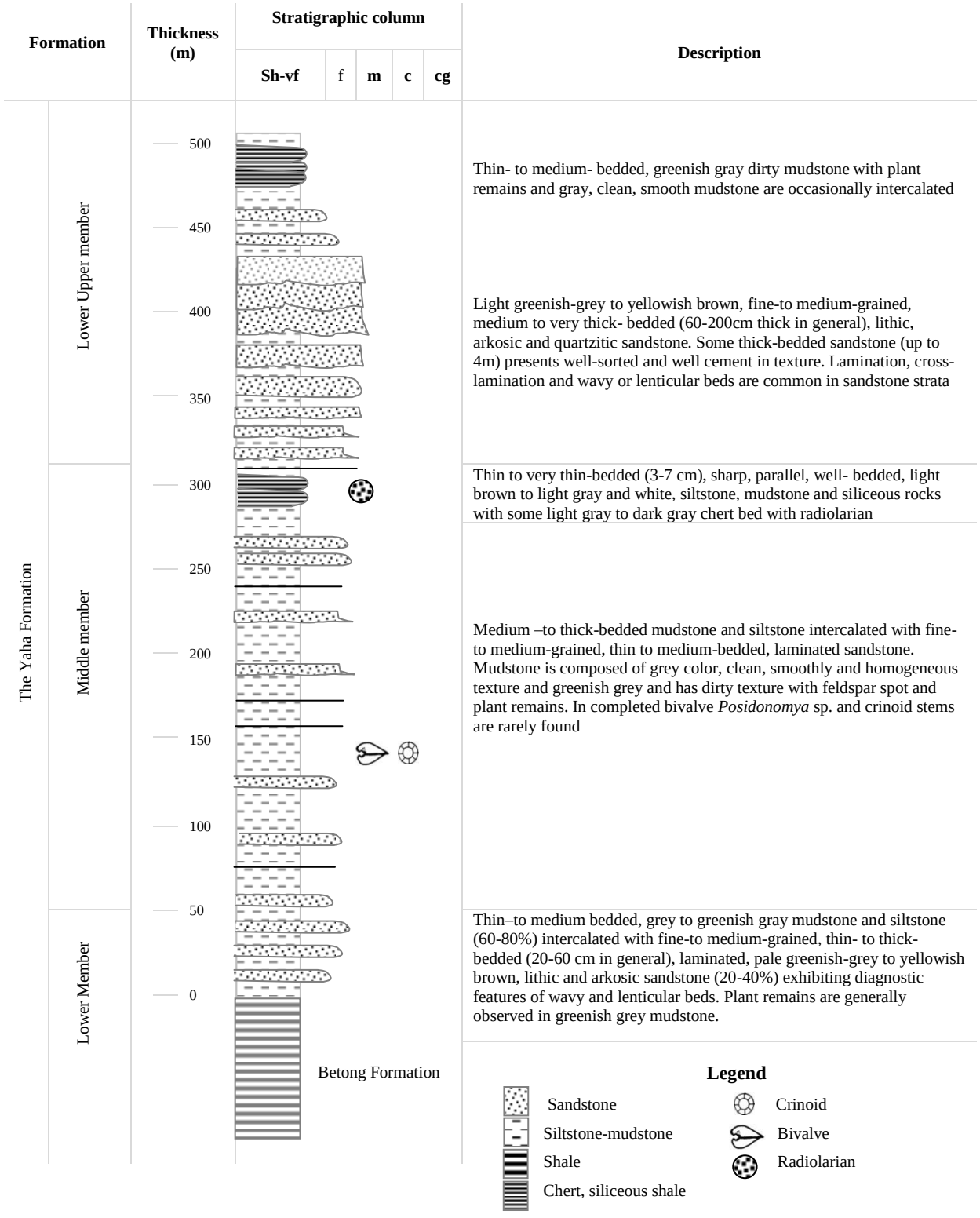

Figure 66: Stratigraphic column of the Yaha Formation in Betong reference section along the strategic border road from the Suan Som - Sa Ho, Betong District, Yala Province

Figure 67 Exposures of the Yaha Formation at strategic border road from the Suan Som - Sa Ho, Betong District, Yala Province (Geographic reference of section is 5° 41.102′N, 101 ° 06.245′E to 5° 39.850′N, 101 ° 07.745′E) a) mainly mudstone in the Lower member b) sandstone and mudstone represent coarsening upward sequence in the Middle member c) medium-to thick-bedded sandstone and thin-bedded mudstone in the Middle member d) lower chert in the Middle member e) thick- bedded sandstone in the lower Upper member f) upper chert in the lower Upper member

3.2.2. Bahoi reference section

a. Location

The Bahoi reference section is well- exposed along the road cut from Ban Nam Chieo-Ban Bahoi- Ban Lubo Bangyang, Yaha District, Yala Province. Geographic reference of section is 6^{o} 26.670′N, 100 ^{o} 51.450′E to 6^{o} 29.160′N, 100 ^{o} 59.005′E in Ban Ba Hoi 5121 I Sheet on the scale 1:50,000.

b. Exposure

The reference section has continuous exposure 25km long and 10-20 m high along the road cut in the mountainous terrain. Good exposures of fresh rocks having 50% continuous sequence are good information for studying characteristics of the rock units.

c. General geology

Rock units in the reference section have generally N-S trending with mainly eastward dipping. Generally, azimuth of beds varies from 35/100 to 65/080. Main faulting and jointing occurred in the area is characterized by the normal, thrust and oblique strike-slip faults trending N-S and NNW-SSE directions. Steep dipping of beds and repeated sequence on the Yaha Formation are locally observed. Two Formations of rock units which are bounded by the N-S thrust fault, is recognized in this reference section. Described rock unit, in detail, can be explained in ascending order:

1. Early Carboniferous Yaha Formation is characterized by the presence of mainly mudstone and siltstone intercalated with fine-to medium-grained, thin- to thick-bedded, laminated sandstone and minor ribbon chert in the lower part, thick to massive bedded sandstone with minor argillite in the middle part and even bedded shale interbedded with sandstone in the upper part. Incompleted bivalve *Posidonomya* sp. and crinoid stems in mudstone and Tournaisian radiolarian in chert were observed. The sequence was measured to be more than 450m thick.

2. Triassic Lampang Group consists of rhythmic alternation of sandstone and shale or mudstone of the Na Thawi Formation, conglomerate, sandstone interbedded with mudstone and shale of the Khuan Chedi Formation and pale grey, massive, oolitic limestone of the Khong Kon Formation.

d. Lithostratigraphy

The Yaha Formation in the Bahoi reference section, approximately 450 m thick comprises three subunits which can be correlated with the Middle, lower Upper and Upper member of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 68) is described in ascending order.

1. Middle member

The member is fault bound by the Triassic succession in the western part. The succession, 250 m in thickness, can be separated into 4 subunits in ascending order as follows;

- Interbedded mudstone and sandstone subunit; the sequence approximately 200 m in thickness which shows obviously fining upward and coarsening upward cycles, composes predominantly of mudstone intercalated with sandstone. Mudstone is grey, greenish grey, thick-bedded and lamination. Sandstone is pale greenish grey, medium-grained, lithic, arkosic and quartzitic in composition exhibits diagnostic features of wavy and lenticular beds. The Lower Carboniferous bivalve *Posidonomya* sp. and crinoid stem are occasionally found whereas plant remains are very abundant in argillaceous strata.

- Well-bedded dark grey sandstone subunit overlies conformably on the previous unit. The sequence, approximately 15-50 m in thickness, consists mainly of dark grey to black, fine- to medium-grained, moderately sorted, lithic sandstone.

- Tuffaceous sandstone intercalated with mudstone subunit overlies conformably on the previous unit. The approximately 10-50 m thick sequence, comprises the intercalation of reddish brown, medium-to coarse-grained tuffaceous sandstone with become red soil when weathered, greenish grey, medium-to coarse-grained, uneven bedded greywacke, thick-bedded mudstone and siltstone. Plant remains are occasionally recognized.

- Chert unit overlies conformably on the previous unit. The 15 m thick sequence comprises mainly thin bedded (ribbon), chert and gradually change to siliceous siltstone which often show tight and recumbent folding. The Lower Carboniferous radiolarian has been reported from the Kabang vicinity (Sashida et al., 2000).

2. Lower Upper member

The member is continuously underlain by the Middle member. Distribution of this unit is located on the area between Ban Bahoi to Ban Lubo Bangyang. The succession, 150 m thick, consists of massive to very thick-bedded quartzitic sandstone intercalated with thin-bedded mudstone. Sandstone is light brown, well- sorted, medium-grained and quartzitic in composition. Each individual sandstone bed is up to 4 m thick. Mudstone is grey and greenish grey and lamination. Plant remains can be recognized in the intercalated mudstone.

3. Upper member

The member is continuously underlain by the Lower Upper member. the unit is well-exposed at road cut from Ban Bahoi to Yaha District, Yala Province. The sequence, 40-50 m thick, is characterized by even bedded shale interbedded with sandstone. The diagnostic sedimentary structures of very thin, even bedded and sharp base bedded exhibiting in the sequence reflect flych-type or outer fan deposits. The unit can be correlated to the upper member of the Na Thawi reference section which preserved abundant fossils of the Early Carboniferous age.

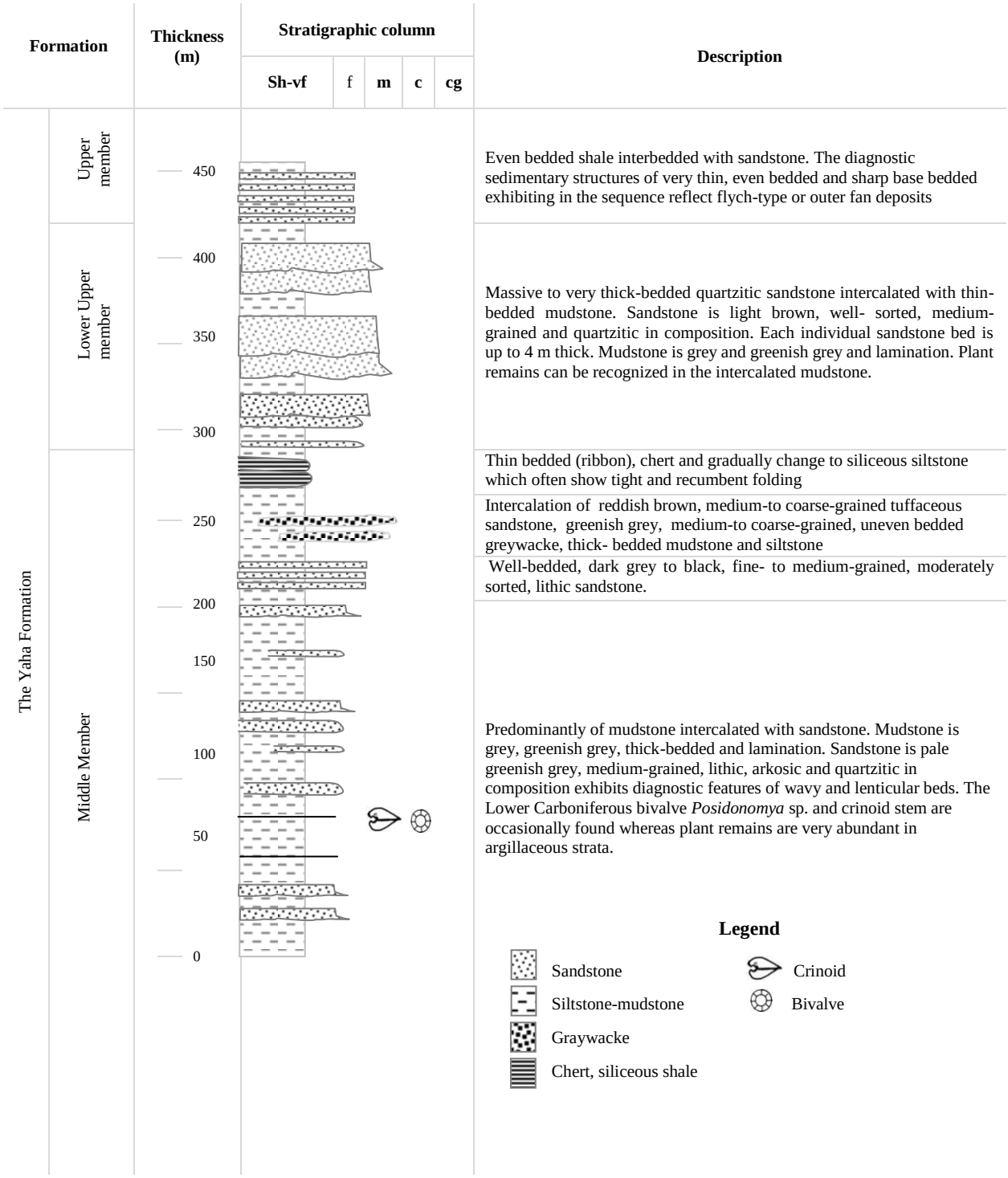

Figure 68: Stratigraphic column of the Yaha Formation in Bahoi reference section along the road cut from Ban Nam Chieo-Ban Bahoi- Ban Lubo Bangyang, Yaha District, Yala Province

3.2.3. Na Thawi reference section

a. Location

The Na Thawi reference section is well- exposed along the road cut from Sadao- Khao Nam Kang road, Na Thawi District, Songkhla Province. Geographic reference of section is 6^{o} 34.580′N, 100 ^{o} 33.752′E to 6^{o} 37.165′N, 100 ^{o} 36.755′E in Amphoe Na Thawi 5122 III Sheet on the scale 1:50,000.

b. Exposure

The reference section has 50% exposure as 7 km long and 5-10 m high along the road cut in the mountainous terrain. Good exposures of rocks with index fossil assemblages having superb for studying characteristics of the rock units.

c. General geology

Rock units in the reference section have generally N-S to NNW-SSE trending with both eastward and westward dipping. Tight and closed folds are commonly found in this area. Generally, azimuth of beds varies from 35/070 to 50/085 and 25/265 to 30/270. Main faulting and jointing occurred in the area is characterized by the normal and oblique strike-slip faults trending NW-SE and NNW-SSE directions. Steep dipping of beds and repeated sequence on the Yaha Formation are locally observed near the fault zone. Two Formations of rock units which bounded by NW-SE oblique strike slip fault are recognized in this reference section. Described rock unit, in detail, can be explained in ascending order:

1. Early Carboniferous Yaha Formation is characterized by the presence of thick sequence of mudstone intercalated with thin- to medium-bedded, laminated, sandstone. Bivalve of *Posidonomya* sp., ammonites, trilobites and crinoids are observed. Above the sequence, unit is consisted of shale and tuffaceous shale intercalated with sandstone followed by well-bedded cherts or siliceous shale and sequence of thick-bedded sandstone. The upper part of the formation comprises grey to greenish-grey, laminated mudstones with the bivalve *Posidonomya* sp. and crinoids. The Yaha Formation in this area was measured to be more than 380m in thickness.
2. Triassic Na Thawi Formation consisting of rhythmic alternation of sandstone and shale or mudstone. The rock is light grey in color, parallel bedded ranges from 10 to 50 cm in thickness. Graded bedding sandstone shows sharp base grading upward to the overlying shale or mudstone. Primary sedimentary structures, such as scour and ripple marks and load structures can be observed at the top part of sandstone beds.

d. Lithostratigraphy

In the Na Thawi reference section, the Yaha Formation approximately 380-450 m thick, comprises three subunits which can be correlated with the middle, lower upper and upper member of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 69) is described in ascending order.

1. Middle member

The member, 250 m, in thickness, consists of thick sequence of mudstone intercalated with thin- to medium-bedded, laminated sandstones with bivalve of *Posidonomya* sp. ammonites and crinoids followed by chert, siliceous shale yielded Tournaisian radiolarian, tuffaceous and lithic sandstone and mudstone. The succession can be separated into 3 units in ascending order as follows;

- Mudstone intercalated with sandstone unit. The sequence, 40-80 m thick, consists of brown to greenish-grey mudstones intercalated with thin- to medium-bedded, laminated, medium - grained, well - sorted sandstone with fining-upward sequences and the bivalve

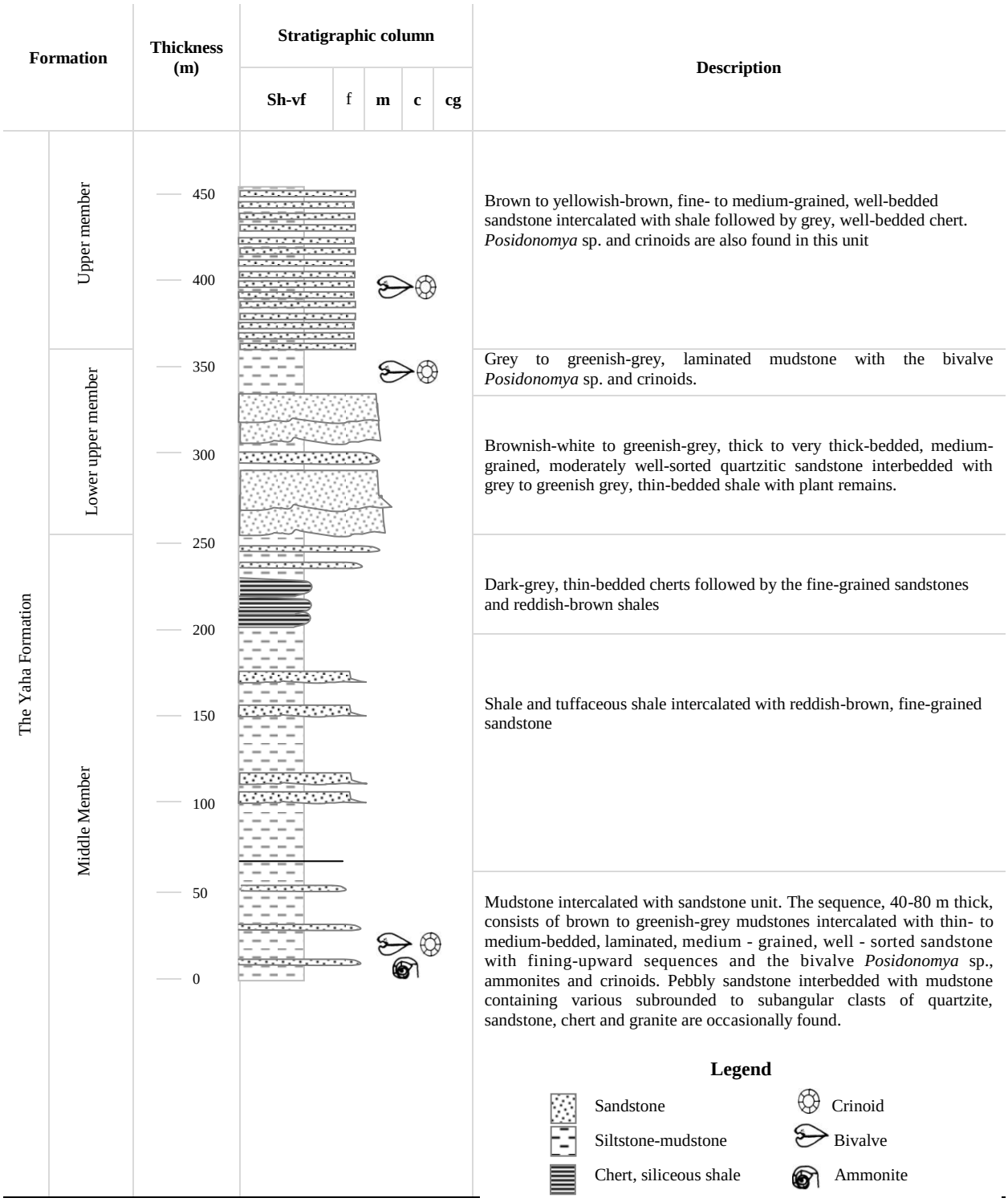

Figure 69: Stratigraphic column of the Yaha Formation in Na Thawi reference section along the road cut from Sadao- Khao Nam Kang road, Na Thawi District, Songkhla Province.

Posidonomya sp., ammonites and crinoids. Pebbly sandstone interbedded with mudstone containing various subrounded to subangular clasts of quartzite, sandstone, chert and granite are occasionally found.

- Shale and tuffaceous shale intercalated with reddish-brown, fine-grained sandstone. The unit is approximately 40-120m in thickness.

- Dark-grey, thin-bedded cherts followed by the fine-grained sandstones and reddish-brown shales unit. The unit is approximately 60m in thickness.

2. Lower Upper member

The member is less than 100m in thickness. The sequence comprises brownish-white to greenish-grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish grey, thin-bedded shale with plant remains. The upper part of this unit comprises grey to greenish-grey, laminated mudstone with the bivalve *Posidonomya* sp. and crinoids.

3. Upper member

The member is continuously underlain by the Lower Upper member. The unit, 80-100 m in thickness, consists of brown to yellowish-brown, fine- to medium-grained, well-bedded sandstone intercalated with shale followed by grey, well-bedded chert. *Posidonomya* sp. and crinoids are also found in this unit. Fossil assemblages indicated that the unit is the sequence of Early Carboniferous rocks.

Figure 70a-d illustrates the exposures and fossil assemblages of the Yaha Formation in the Na Thawi reference section.

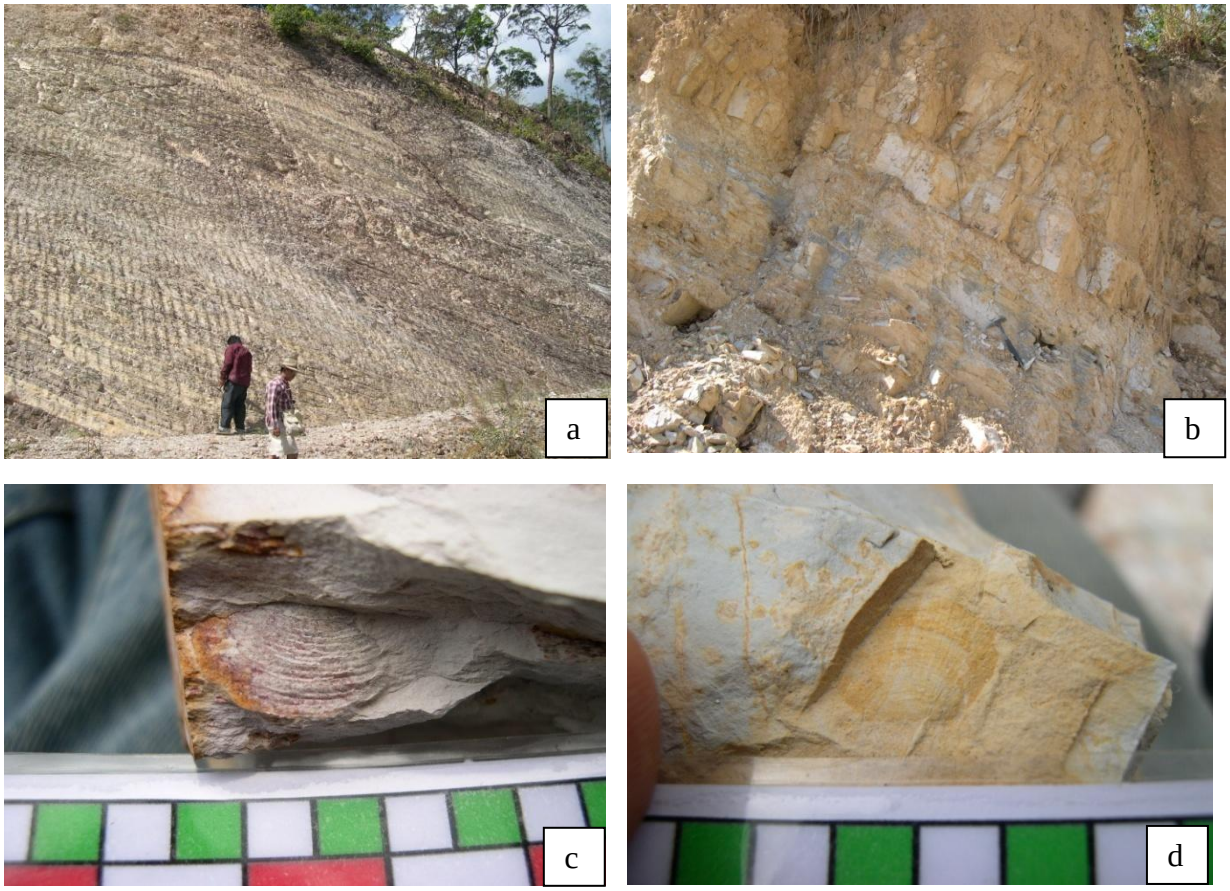

Figure 70 Exposures of the Yaha Formation along the road cut from Sadao- Khao Nam Kang road, Na Thawi District, Songkhla Province a) well-bedded sandstone and mudstone b) medium-thick-bedded sandstone and thin-bedded mudstone c) and d) fossil assemblages at the Upper member

3.2.4. Khuan Non, reference section

a. Location

The Khuan Non reference section is well-exposed along the road cut and quarry of Khuan Non, main road no. 41 between Had Yai - Khuan Meed, Ban Pak Chong, Na Mom District, Songkhla Province. Geographic reference of section is 6° 59.250′N, 100 ° 38.855′E in Amphoe Chana 5122 IV Sheet on the scale 1:50,000.

b. Exposure

The reference section has exposure 500 m long and 5-10 m high along the road cut of isolated hill. Good exposures of fresh rocks with some fossil assemblages having continuous sequence for studying characteristics of the rock units.

c. General geology

Rock units in the reference section have NE-SW trending with high angle dipping to northwestward (70/330). Main faulting and jointing occurred in the section is characterized by the normal and oblique strike-slip faults trending NNE-SSW directions. Only the Yaha Formation is recognized in this reference section. Strong folding, faulting and contact metamorphism with granites are observed in some part of this reference section.

d. Lithostratigraphy

The Yaha Formation in the Khuan Non reference section, approximately 190 m thick, comprises two subunits which can be correlated to the lower upper and upper member of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 71) is described in ascending order.

1. Lower Upper member

The member, more than 110m thick, is generally consisted of mainly resistant sandstone bed. The sequence, in ascending order is explained as follows;

- Brownish-white to greenish-grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish-grey, thin-bedded shale with plant remains in the lower portion. Above the sequence, the unit comprises grey to greenish-grey, laminated mudstone with the bivalve *Posidonomya* sp. and crinoids.
- Grey to white and purplish grey shale and siliceous shale. Ribbon chert (3-4 cm) is also recorded. Recumbent and tight folds are recognized in the upper part. Phyllitic shale is observed near the fault zone.

2. Upper member

The member is thick sequence of grey to purplish grey shale with siliceous shale intercalation. Thickness of this sequence is more than 80m.

3.2.5 Saba Yoi reference section

a. Location

The Saba Yoi reference section is well-exposed along the stream cut of Klong Sani, Saba Yoi District, Songkhla Province. Geographic reference of section is between 6° 30.112′N, 100 ° 53.650′E and 6° 32.088′N, 100 ° 53.850′E in Amphoe Saba Yoi 5122 II Sheet on the scale 1:50,000.

b. Exposure

The reference section has 50% exposures 4 km long along the stream cut in Klong Sani. Good exposures of rocks having continuous sequence for studying characteristics of the rock units.

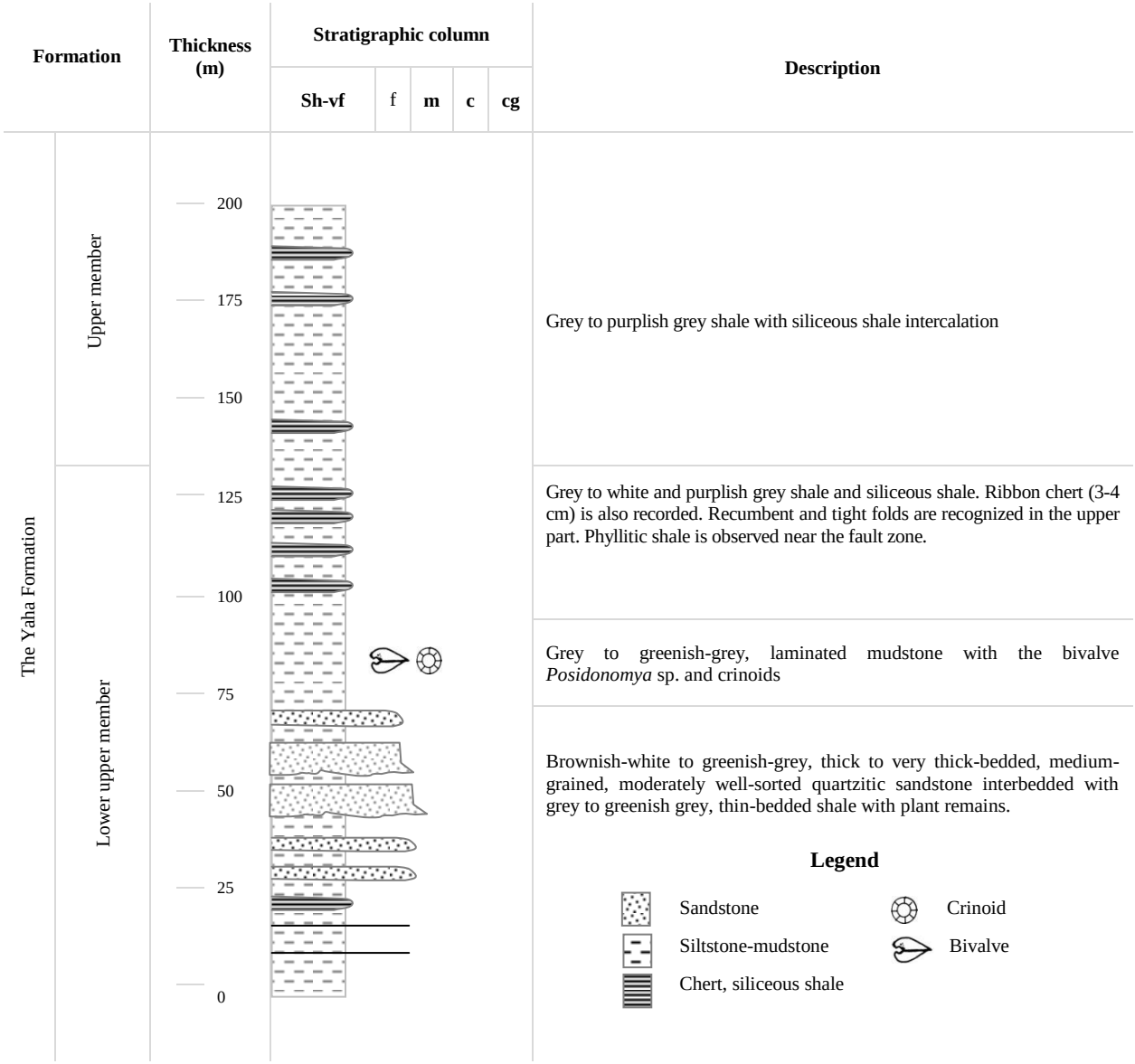

Figure 71: Stratigraphic column of the Yaha Formation in Khuan Non reference section along the road cut and quarry of Khuan Non, main road no. 41 between Had Yai - Khuan Meed, Ban Pak Chong, Na Mom District, Songkhla Province

c. General geology

Rock unit in the reference section has N-S trending with various direction of dipping direction. General azimuths of rock unit are 40/225, 50/300 and 65/090. Main faulting and jointing occurred in the section is characterized by the normal and oblique strike-slip faults trending N-S and NE-SW directions. Only the Yaha Formation is recognized in this reference section. Thickness of the Yaha Formation is approximately 250 m.

d. Lithostratigraphy

In the Saba Yoi reference section, the Yaha Formation can be correlated to the Middle member of the composited section of theYaha Formation. Detailed lithology of the sequence is illustrated in Figure 72. Stratigraphically, The lower part of rock sequence is consisted of

grey and light brown, medium-grained, sandstone interbedded with greenish grey shale and mudstone followed by siltstone, grey, dense, interbedded with grey sandstone, dark grey shale and greenish grey shale. The upper part is consisted of dark grey ribbon chert.

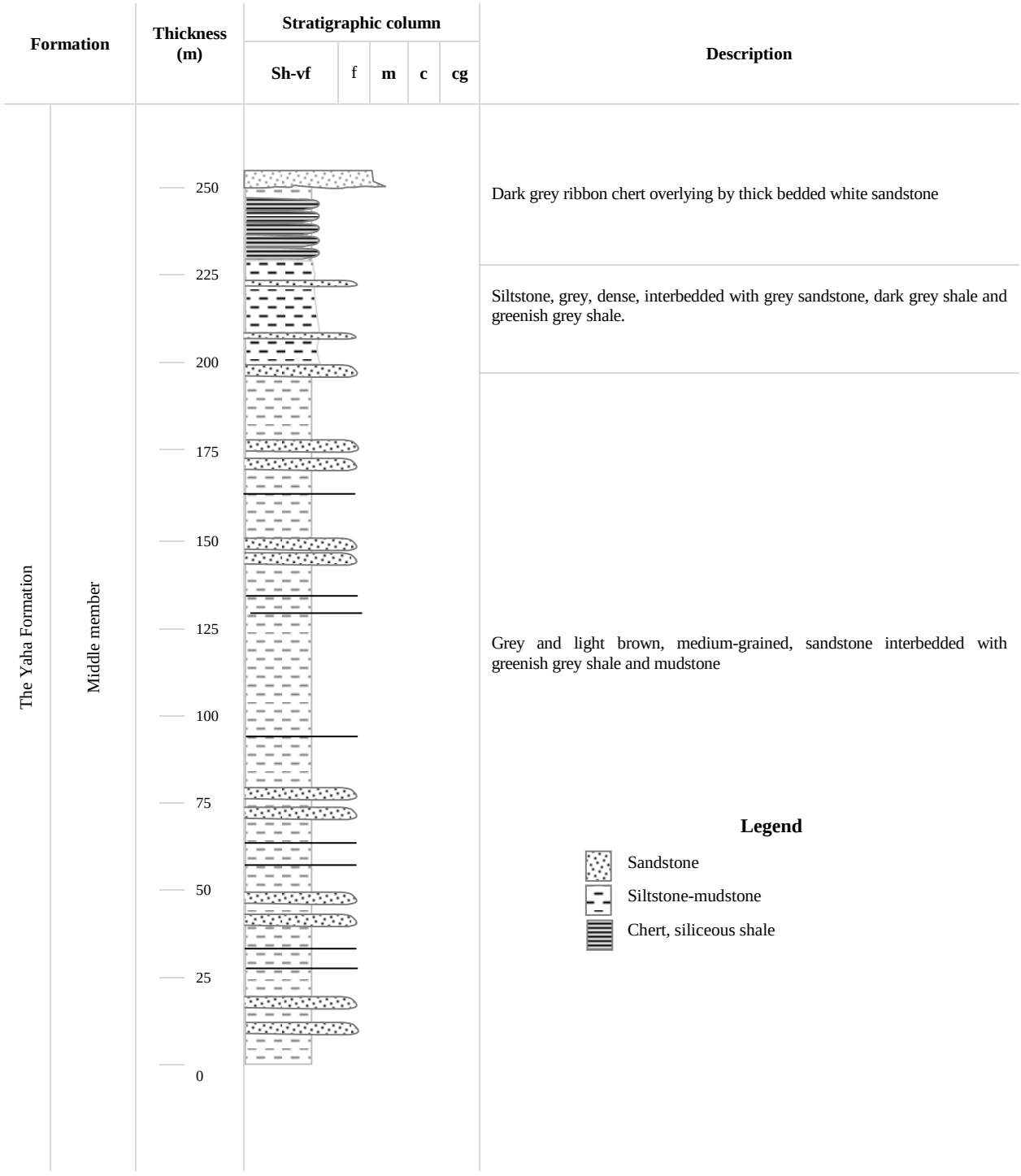

Figure 72: Stratigraphic column of the Yaha Formation in Saba Yoi reference section along the stream cut of Klong Sani, Saba Yoi District, Songkhla Province

3.2.6 Ban Trap reference section

a. Location

Reference section of the Yaha Formation is located on current mine at the southeast of Khao Chom Liam, Ban Tang Khwai, Muang District, Songkhla Province. Geographic reference of section is 7^{o} 01.491′N, 100 ^{o} 39.618′E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section has continuous exposure 350 m long and 100-200 m wide on current mine. The exposures of mine are consisted of three product areas which have approximately NW-SE trending in mining direction. Good exposures of fresh rocks having continuous sequence with minor break are superb for studying characteristics of the rock units.

c. General geology

Rock unit in the reference section has NE-SW trending with various dipping angles to southeastward. The NE-SW thrust fault sets with high angle dipping to southwestward are observed in the central part of the area. In the western part of the thrust fault zone, the rock unit is main azimuths between 80/085 and 75/085 whereas at the eastern part, rock unit has attitude of bedding between 40/120 and 45/120. Minor faulting and jointing system occurred in the section is characterized by the normal and oblique strike-slip faults trending NW-SE and NE-SW directions. Cleavage trending NE-SW direction with high angle dipping is well developed in argillite, especially in the western part.

Two Formations of rock units is recognized in this reference section. The NE-SW oblique strike slip fault contact between both Formations is observed. Described rock unit, in detail, can be explained in ascending order:

1. Early Carboniferous Yaha Formation is characterized by the presence of sequence of shale interbedded siliceous shale and thick-beded quartzitic sandstone intercalated with mudstone in the lower part. The upper part consists of red and light greenish grey, mudstone intercalated with sandstone. Bioturbation and hard pans are observed in the upper part. Pygidiums of Trilobite, ammonites and chonetids are often observed. The sequence was measured to be more than 168m thick.

2. Triassic sequence consisting of well-bedded chert interbedded with siliceous mudstone, thin-bedded, sharp, even, parallel. This sequence exposure in eastern part of the current mine (grid ref. 0683733N, 10776745E), were collected for radiolarian identification. The result of the radiolarian assemblages such as *Triassocampe deweveri* (Nakaseko and Nishimura), *Annulotriassocampe* sp., *Striatotriassocampe laeviannulata* Kozur and Mostler, *Spongstylus* sp., *Pseudostylosphaera longispinosa* Kozur and Mostler, *Pseudostylosphaera* sp., *Eptingium* sp. and others determined that the age of chert (sample no. CN 4A) is assigned to Middle Triassic age (Saesaengseerung, in manuscript).

d. Lithostratigraphy

The Yaha Formation in the Ban Trap reference section, approximately 168m thick, comprises the sequence which can be correlated to the Middle, Lower Upper and Upper members of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 73) is described in ascending order.

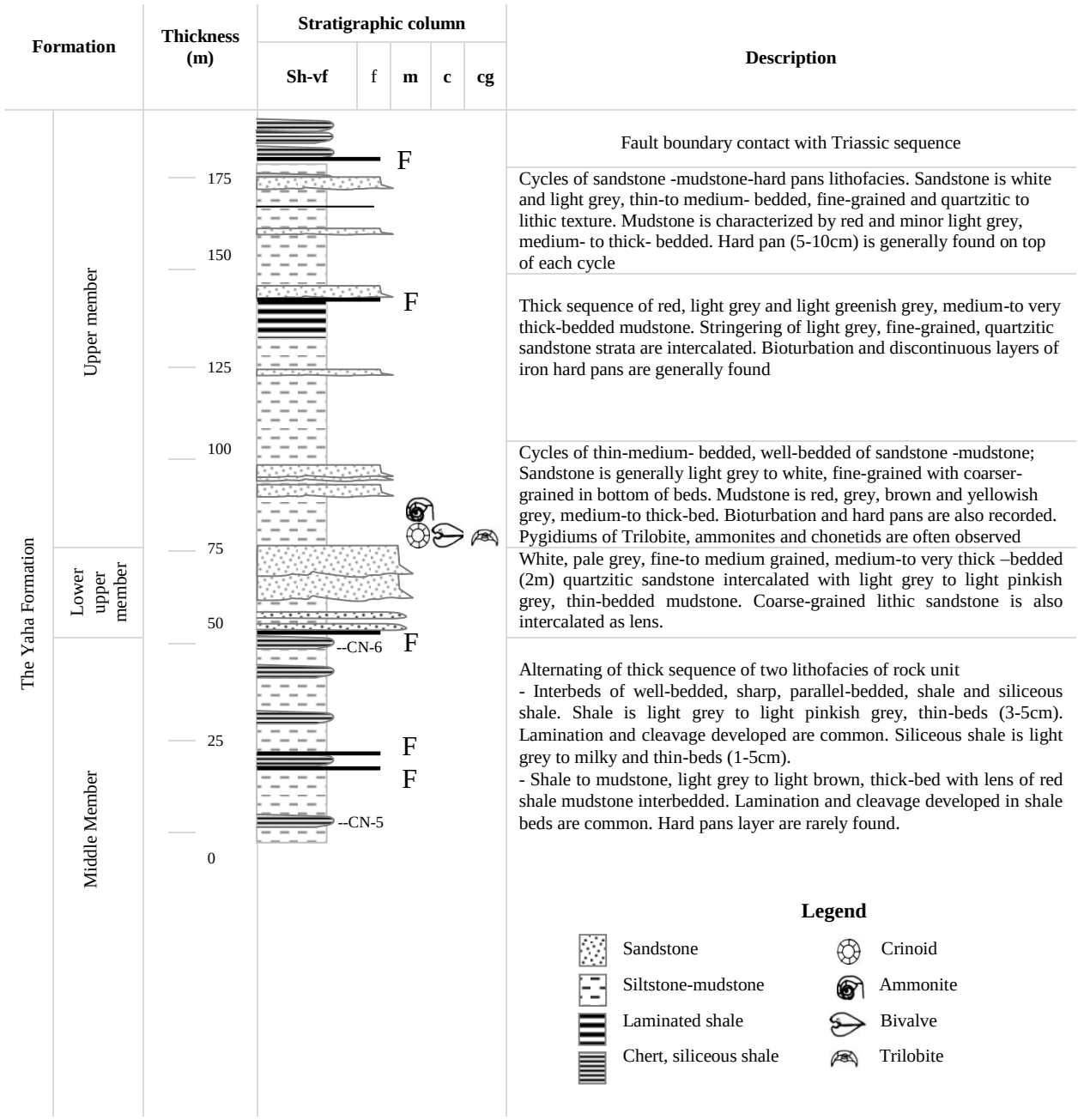

Figure 73: Stratigraphic column of the Yaha Formation in Ban Trap reference section on current mine at the southeast of Khao Chom Liam, Ban Tang Khwai, Muang District, Songkhla Province.

1. Middle member

The member, approximately 63 m in thickness, consists of alternate of 2-4 m thick sequence of two lithofacies of rock unit as follows;

- Interbeds of well-bedded, sharp, parallel-bedded, shale and siliceous shale. Shale is light grey to light pinkish grey, thin-beds (3-5cm). Lamination and cleavage developed are common. Siliceous shale is light grey to milky and thin-beds (1-5cm).
- Shale to mudstone, light grey to light brown, thick-bed with lens of red shale mudstone interbedded. Lamination and cleavage developed in shale beds are common. Hard pans layer are rarely found.

2. Lower Upper member

The member is underlain by the middle member. The sequence, approximately 16m thick, is generally consisted of resistant bed. Fault boundary contact between this sequence and Middle member are observed. The succession is characterized by white, pale grey, fine-to medium grained, medium-to very thick –bedded (2m) quartzitic sandstone intercalated with light grey to light pinkish grey, thin-bedded mudstone. Coarse-grained lithic sandstone is also intercalated as lens. Lamination is observed in their strata. Load cast structure and quartz pebbles of 0.2-0.3mm in diameter are usually observed in bottom part of sandstone bed.

3. Upper member

The member is continuously underlain by the Lower Upper member whereas the overlying unit is not seen. The unit, approximately 87 m in thickness, is characterized by three subunits. The sequence are described in ascending order

- Cycles of thin-medium- bedded, well-bedded of sandstone -mudstone; Sandstone (20%) is generally light grey to white, fine-grained with coarser-grained in bottom of beds. Mudstone (80%) is red, grey, brown and yellowish grey, medium-to thick-bed (30-100cm). Bioturbation and hard pans are also recorded. Pygidiums of Trilobite, ammonites and chonetids are often observed. Lamination is common in grey and brown mudstone.
- Thick sequence of red, light grey and light greenish grey, medium-to very thick-bedded mudstone. Stringering of light grey, fine-grained, quartzitic sandstone strata are intercalated. Bioturbation and discontinuous layers of iron hard pans are generally found. It is noted that thick sequence of dark grey carbonaceous laminated mudstone, thick-bedded is observed as thick sequence in the middle part.
- Cycles of sandstone -mudstone-hard pans lithofacies. Sandstone is white and light grey, thin-to medium- bedded, fine-grained and quartzitic to lithic texture. Mudstone is characterized by red and minor light grey, medium- to thick- bedded. Hard pan (5-10cm) is generally found on top of each cycle.

Figure 74a-k illustrates the exposures and rock types of the Yaha Formation in the Ban Trap reference section.

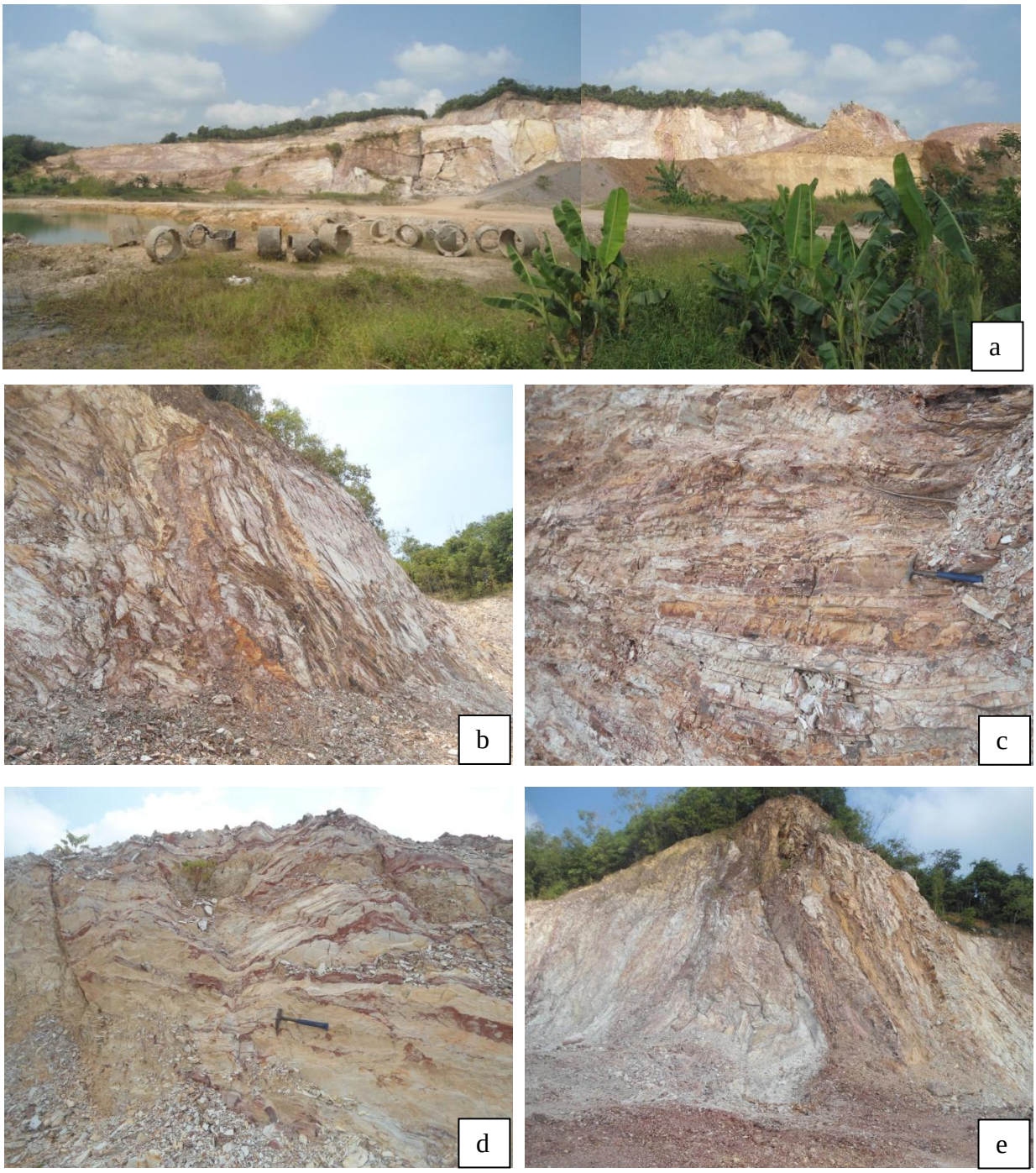

Figure 74 Exposures of the Yaha Formation in Ban Trap reference section, Khao Chom Liam, Ban Tang Khwai, Muang District, Songkhla Province a) general view b) well-bedded mudstone in lower part c) thin-bedded siliceous shale d) thick-bedded mudstone with red mudstone layers e) thrust fault between thick-bedded mudstone and quartzitic sandstone

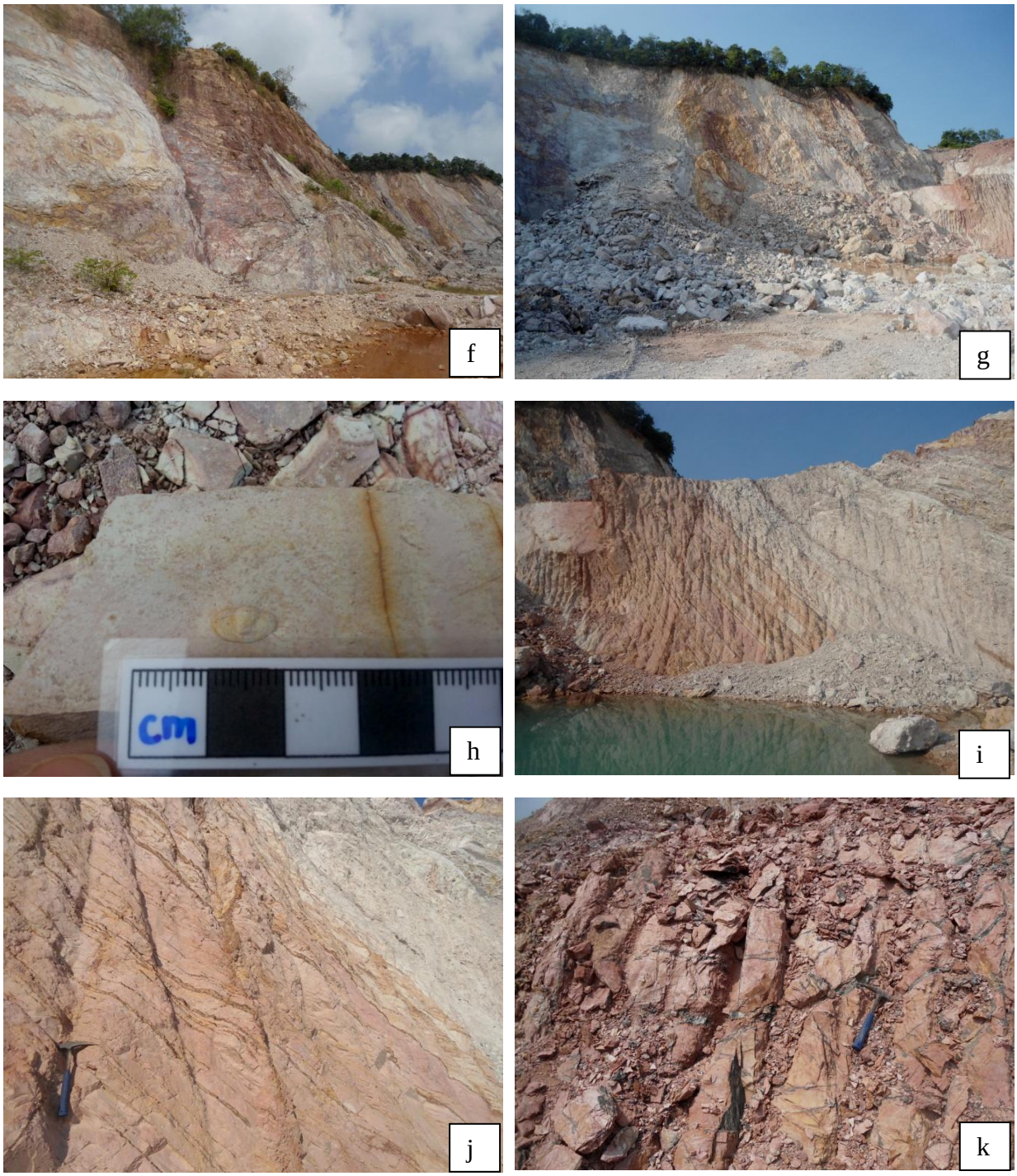

Figure 74 Exposures of the Yaha Formation in Ban Trap reference section, Khao Chom Liam, Ban Tang Khwai, Muang District, Songkhla Province (cont'd) f) thick-bedded sandstone in the middle part g) mainly mudstone in upper part h) pygidium of Trilobite in mudstone i) well-bedded mudstone with layer of hard pans j) closed up mudstone k) red mudstone in the upper part

3.2.7 Khuan Bu reference section

a. Location

Reference section of the Yaha Formation is located in an abandon mine (50x300 m) at the southwestern part of Khuan Bu, near Sansern Isalam School, Ban Hua Khuan, Muang District,

Songkhla Province. Geographic reference of section is 7° 00.127′N, 100 ° 39.787′E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section has continuous exposure 50 m and 5-10m high in quarry part of abandon mine including 50 m exposures at small outcrop in the northwestern part of the quarry. The exposures have approximately NNW-SSE trending. Good exposures of fresh rocks having continuous sequence without break and abundant microfossils are superb for studying characteristics of the rock units.

c. General geology

Rock unit in the reference section has NE-SW trending with moderate dipping angles to northwestward. Azimuth of bedding is 40/300 to 50/300. Main faulting and jointing occurred in the section is characterized by the normal faults trending NE-SW and NW-SW directions. Only the Yaha Formation is recognized in this reference section. Thickness of the Yaha Formation in this section is approximately 68.3 m.

d. Lithostratigraphy

The Yaha Formation in the Khuan Bu reference section, approximately 68.3m thick, comprises the sequence which can be correlated with the Lower Upper and Upper members of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 75) is described in ascending order.

1. Lower Upper member

The member, approximately 33m thick, is consisted of two subunits in ascending order as follow;

- Interbedded of sandstone and mudstone strata. Sandstone is white, light grey, fine-to medium-grained, medium-to very thick- bedded, quartzitic and lithic in composition. Pebble of chert and quartz grains and load cast structure are often found in the bottom part of thick-bedded sandstone. Mudstone, generally white to light grey, pinkish grey and red, thin-to thick- bed and partly lamination. Hard pans are locally intercalated. Lamination in red mudstone is generally observed.
- Light grey to milky, very thin-bedded to ribbon (2-5cm) siliceous shale to chert interbedded with white and pink, very thin- bedded mudstone. Well-bedded, sharp, parallel bedded is typically characteristic. Mudstone reveals the wavy lamination. Strongly tight and recumbent folds are observed in chert strata (Figure 76a-f).

Six rock samples were collected from siliceous shale bed for laboratory work. Sample no. CN7 and CN8 contain poorly preserved radiolarian. The radiolarian includes *Albaillela*sp., *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*sp.,*Trilonche* sp., and *Pylentonema*sp (Figures 77). The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) from Thailand and Malaysia (Sashida and Igo, 1999; Saesaengseerung *et al.*, 2007) and Early carboniferous sequence from several areas, such as France (Spiller, 1996), Germany (Braun, 1990) and Southwestern China (Wang et al., 1998). However, the radiolarian identification is very difficult by poorly preserved (Saesaengseerung, in Manuscript).

2. Upper member

The member is continuously underlain by the Lower Upper member whereas the overlying unit is not seen. The unit approximately more than 35.3 m in thickness is characterized by alternating of 3 lithofacies as follow;

- Mainly mudstone lithofacies. Mudstone is red, and brownish red, thick -bedded intercalate with stringering of lithic sandstone, light grey fine-grained, some micaceous. Layer of iron hard pans are developed.

- Thick sequence of mudstone intercalated with siliceous mudstone. Mudstone is white to pinkish white, medium-to thick-bedded. Laminated and wavy laminated is usually observed. Siliceous mudstone is white to light grey, thin-beds.

- Interbedded of sandstone, siltstone and mudstone. Sandstone is light grey, fine-grained with medium-to coarse-grained in bottom of bed. Pebbles of chert, quartz and flint are also recorded in the bottom strata. Siltstone is white to pinkish white, medium-bedded (20-30cm), laminated, with lens of red mudstone. Mudstone is grey, light grey and red, medium-to thick-bedded with iron hard pan layers.

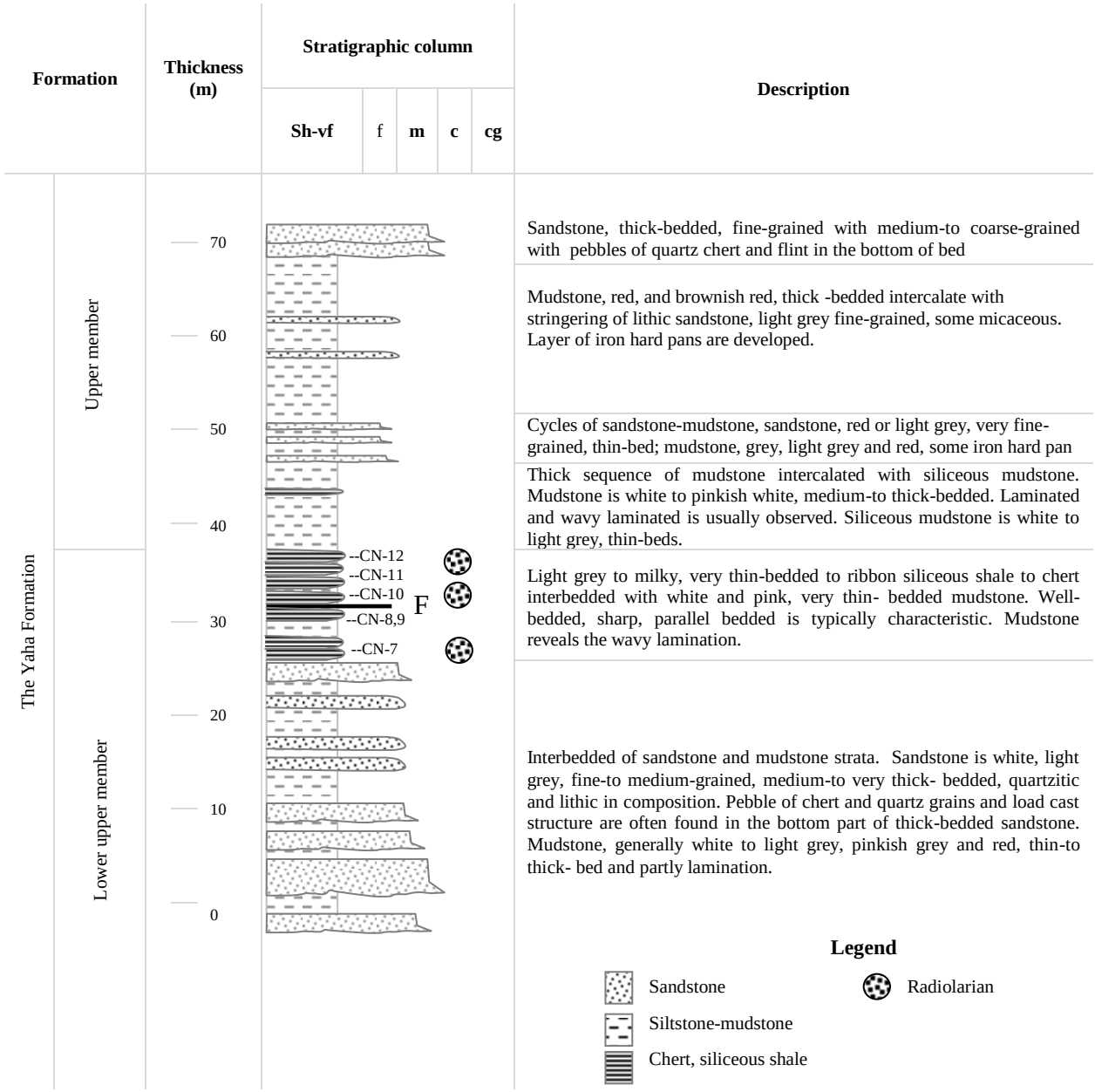

Figure 75: Stratigraphic column of the Yaha Formation in Khuaı Khuan Bu, near Sansern Isalam School, Ban Hua Khuan, Muang District, Songkhla Province.

Figure 76 Exposures of the Yaha Formation in Khuan Bu reference section, southwestern part of Khuan Bu, near Sansern Isalam School, Ban Hua Khuan, Muang District, Songkhla Province a) general exposure b) Pebbly sandstone in the lower part c) laminated mudstone with hard pan layers d) lower chert in the middle part e) upper chert in the middle part f) red mudstone with hard pans layer in the upper part

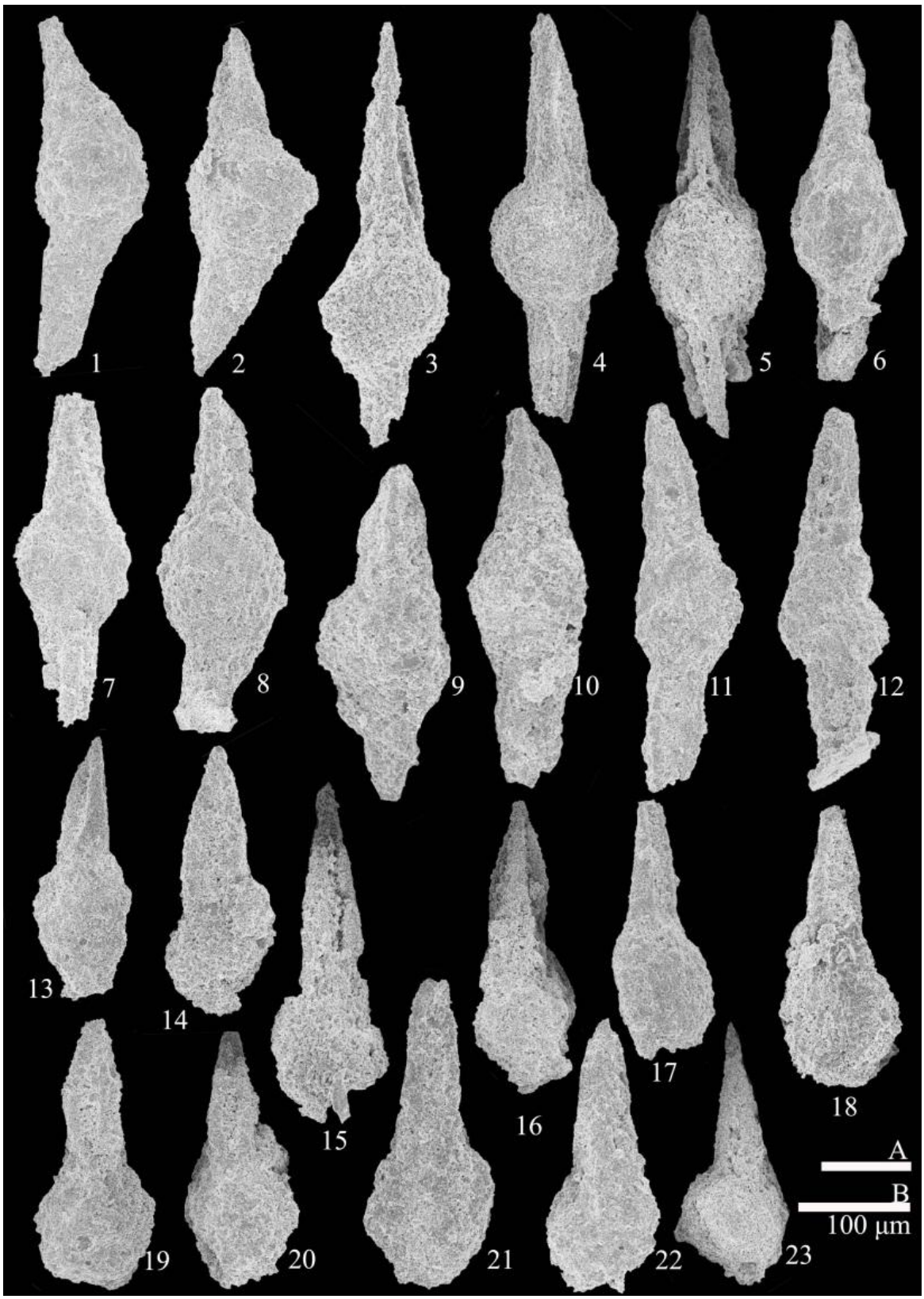

Figure 77 Early Carboniferous radiolarian in Khuan Bu reference section

1,2 *Stigmosphaerostylus variospina* (Won) with two spins
3-12 *S. variospina* (Won) with polar spins
13-23 *S. variospina* (Won)
Scale A: 13-23; B: 1-12

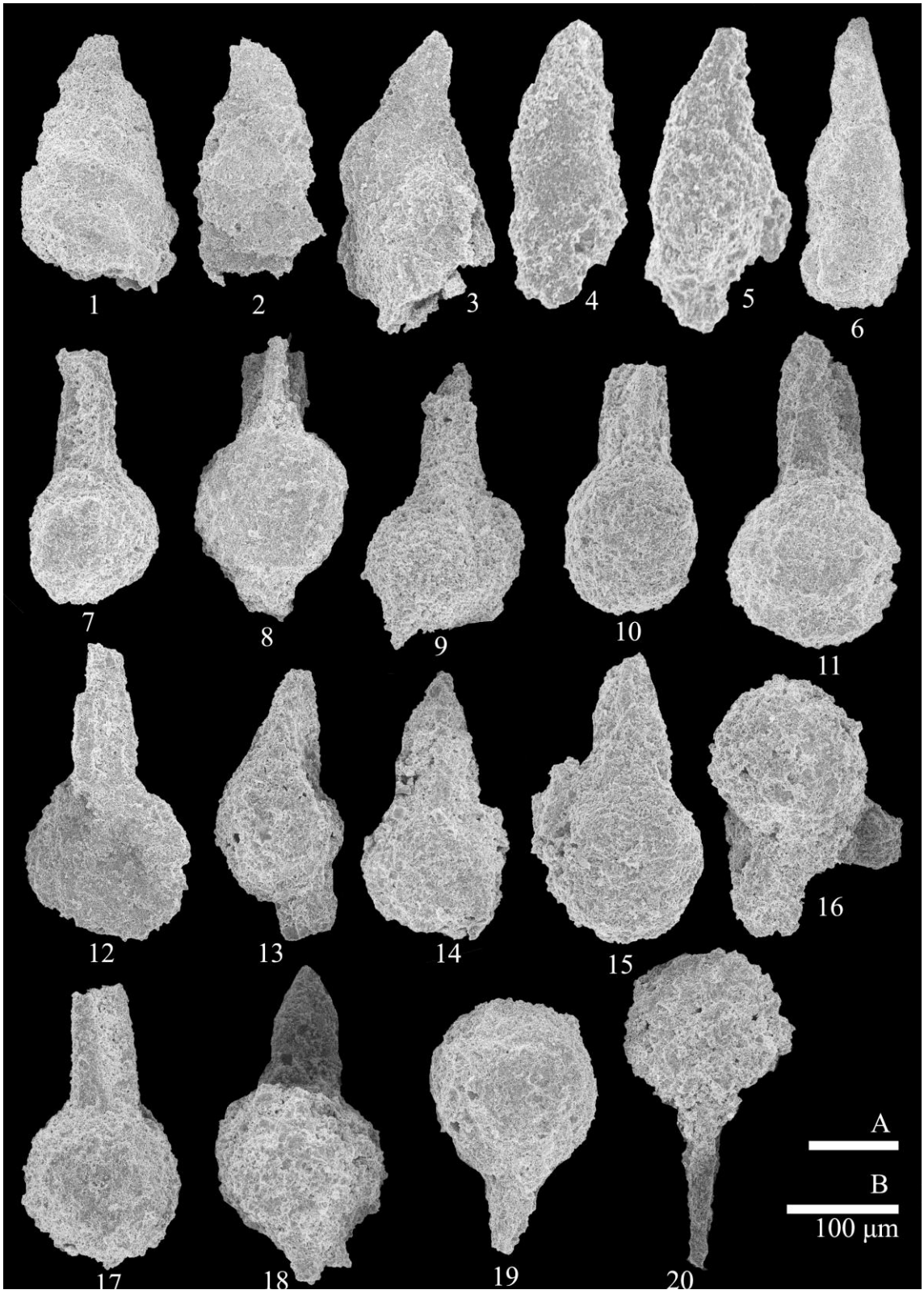

Figure 77 Early Carboniferous radiolarian from Khuan Bu reference section (cont'd)

1-6	*Albillela* sp.
7-15, 17-19	*Stigmosphaerostylus variospina* (Won) with polar spins
16	*Pylentonema* sp.
20	*Trilonche* sp.

Scale A: 7-15, 17-20; B: 1-6, 16

3.2.8 Khao Daeng I reference section

a. Location

Reference section of the Yaha Formation is located in an abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province. Geographic reference of section in quarry is 7 ^{o} 12.143´ N, 100 ^{o} 33.828´ E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section in this quarry has continuous exposure 250 m long and 200 m wide along the abandon quarry. The exposures have approximately N-S trending. Good exposures of fresh rocks having continuous sequence without break are superb for studying characteristics of the rock units.

c. General geology

Rock unit in the reference section has N-S trending with high dipping angles to vertical dipping to eastward and westward. Azimuth of bedding of rock unit is 85/090 to 70/100. Main faulting and jointing occurred in the section is characterized by the normal faults trending N-S direction. Only the Yaha Formation is recognized in this reference section. Thickness of the Formation in this section is approximately 119 m.

d. Lithostratigraphy

The Yaha Formation in the Khao Daeng I reference section, approximately 119m thick, comprises the sequence which can be correlated with the Lower Upper and Upper members of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 78) is described in ascending order.

1. Lower Upper member

The member, approximately 67.45m thick, is consisted of two subunits in ascending order as follow;

- White, light grey, fine-to medium-grained, thick-to very thick-bedded (1.5-2m) sandstone interbedded with dark grey medium-to thick bedded, sandy siltstone. Lamination, flaser beds, bioturbation and carbonaceous materials are preserved in sandy siltstone.
- Siliceous shale and chert, milky, white, well-bedded, sharp, parallel beds, thin-to very-thin bedded (1-10cm) interbedded with thin- bedded shale. Sandstone, light grey to grey, thick-bedded, fine-grained, laminated are occasionally intercalated. Strongly fold and recumbent fold are well-observed in siliceous shale. The upper sequence of this subunit composes of sandstone interbedded with siliceous shale; Sandstone is light grey, fine-grained, thin-to medium-bedded. Siliceous shale, grey to dark grey, thin-bedded.

2. Upper member

The member is continuously underlain by the Lower Upper member whereas the overlying unit is not seen. The unit approximately more than 51.5 m in thickness is characterized by alternating of 3 lithofacies as follow;

- Mudstone and shale is red, grey, and greyish red, thick -bedded with stringering of lithic sandstone, light grey fine-grained, some micaceous. Layer of iron hard pans are developed.

. - Thick sequence of mudstone intercalated with siliceous mudstone. Mudstone is consisted of white to pinkish-white, medium-to thick-bedded and grey, greyish red, dark grey, thin-bedded. Flaser lamination and wavy laminated is usually observed. Siliceous mudstone is light grey to colorless, thin-beds. Discontinuous iron hard pans are sometime found.

- Cycles of sandstone-siltstone-mudstone (70-100cm/cycle). Sandstone (25%) is light grey, medium-bed (20-40cm), fine-grained. Lamination is common. Siltstone-mudstone

(70%) is characterized by grey to reddish grey, thick-bedded with discontinuous lamination. Mudstone (5%) is brownish grey to light grey, thin –bedded and siliceous cement.

Figure 79a-f illustrates the exposures and rock types of the Yaha Formation in the Khao Daeng I reference section.

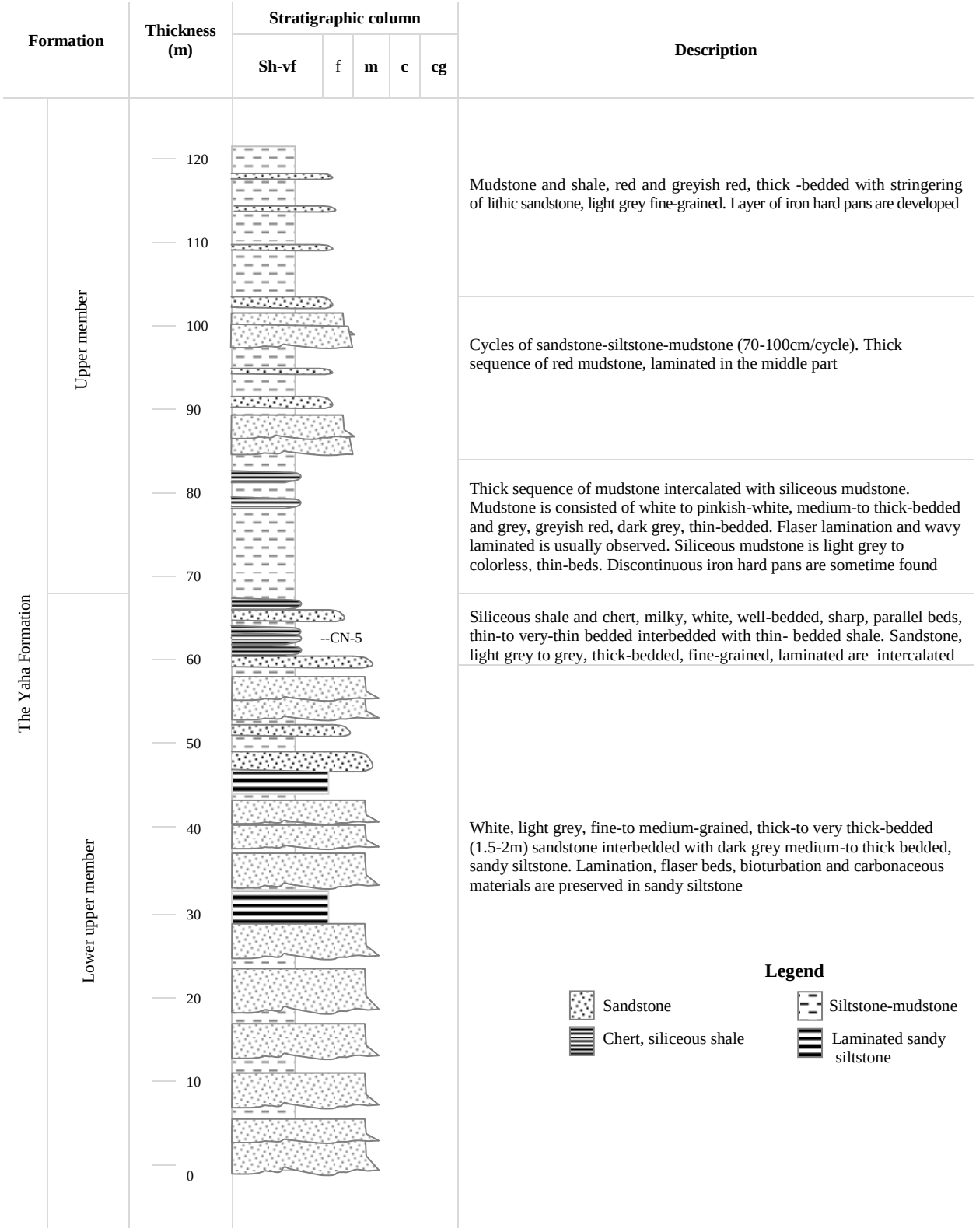

Figure 78: Stratigraphic column of the Yaha Formation in Khao Daeng I reference section, an abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province.

Figure 79 Exposures of the Yaha Formation in Khao Daeng I reference section, an abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province a) general exposure in the western part of the section b) general exposure in the eastern part of the section c) thick-bedded sandstone interbedded with sandy siltstone in the lower part d) siliceous shale in the middle part e) mainly mudstone with hard pans in the upper part f) cycle of sandstone - mudstone in the upper part

3.2.9 Khao Daeng II reference section

a. Location

Reference section of the Yaha Formation is located on abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province. Geographic reference of section in quarry is 7 ^{o} 12.649´ N 100 ^{o} 34.089´ E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section in this quarry has continuous exposure 250 m long and 150 m wide along the abandon quarry mine. The exposures have approximately E-W trending. Good exposures of fresh rocks are superb for studying characteristics of the rock units. However, the repeated sequence is usually occurred because of intensive fault movement in this area.

c. General geology

Rock unit in the reference section has E-W trending with moderate dipping angle to northward. Azimuth of bedding is 30/355 to 50/000. Main faulting and jointing occurred in the section is characterized by the strike- slip faults trending NE-SW and NW-SE directions. Only the Yaha Formation is recognized in this reference section. Thickness of the Yaha Formation in this section is approximately 86 m.

d. Lithostratigraphy

The Yaha Formation in the Khao Daeng II reference section, approximately 86m thick, comprises the sequence which can be correlated to the Upper members of the composited section of the Yaha Formation. Detailed lithology of the sequence is illustrated in Figure 80.

1. Upper member

The member is characterized by two subunits in ascending order as follow;

- Thick sequence of mudstone to siltstone, red, thick-bedded, dense, homogeneous interbedded with mudstone, red, lamination, thick-bedded. The unit is approximately 29m in thickness.
- Interbedded or cycle of siltstone and mudstone (2-3m/cycle). Siltstone to mudstone (50%) is red, dense, thick-bed and homogeneous in texture. Mudstone (40%) is red and thin-to medium bed. Discontinuous lamination is usually found in texture. Another mudstone (10%) is light grey to white, smooth, soft, thin-to medium-bedded. This rock types is generally observed in the upper part of each episode. Cleavage is well- developed in argillite strata. Pale grey to white, thin-to medium- bedded, sandstone is rarely intercalated. Layers of iron hard pans are generally recognized in thick-bedded red mudstone. The unit is approximately 57m in thickness.

Figure 81 illustrates the exposures and rock types of the Yaha Formation in the Khao Daeng II reference section.

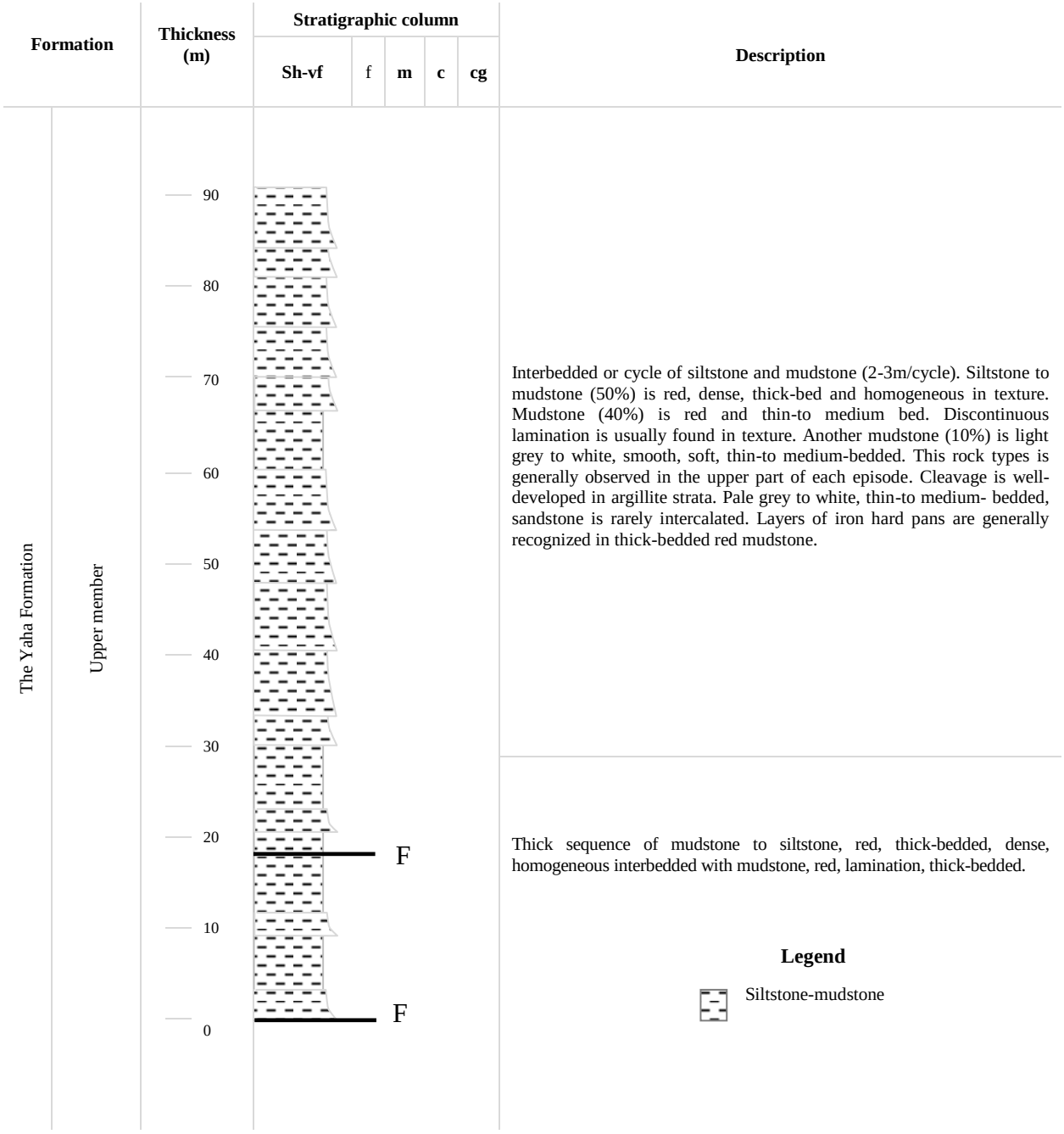

Figure 80: Stratigraphic column of the Yaha Formation in Khao Daeng II reference section, an abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province.

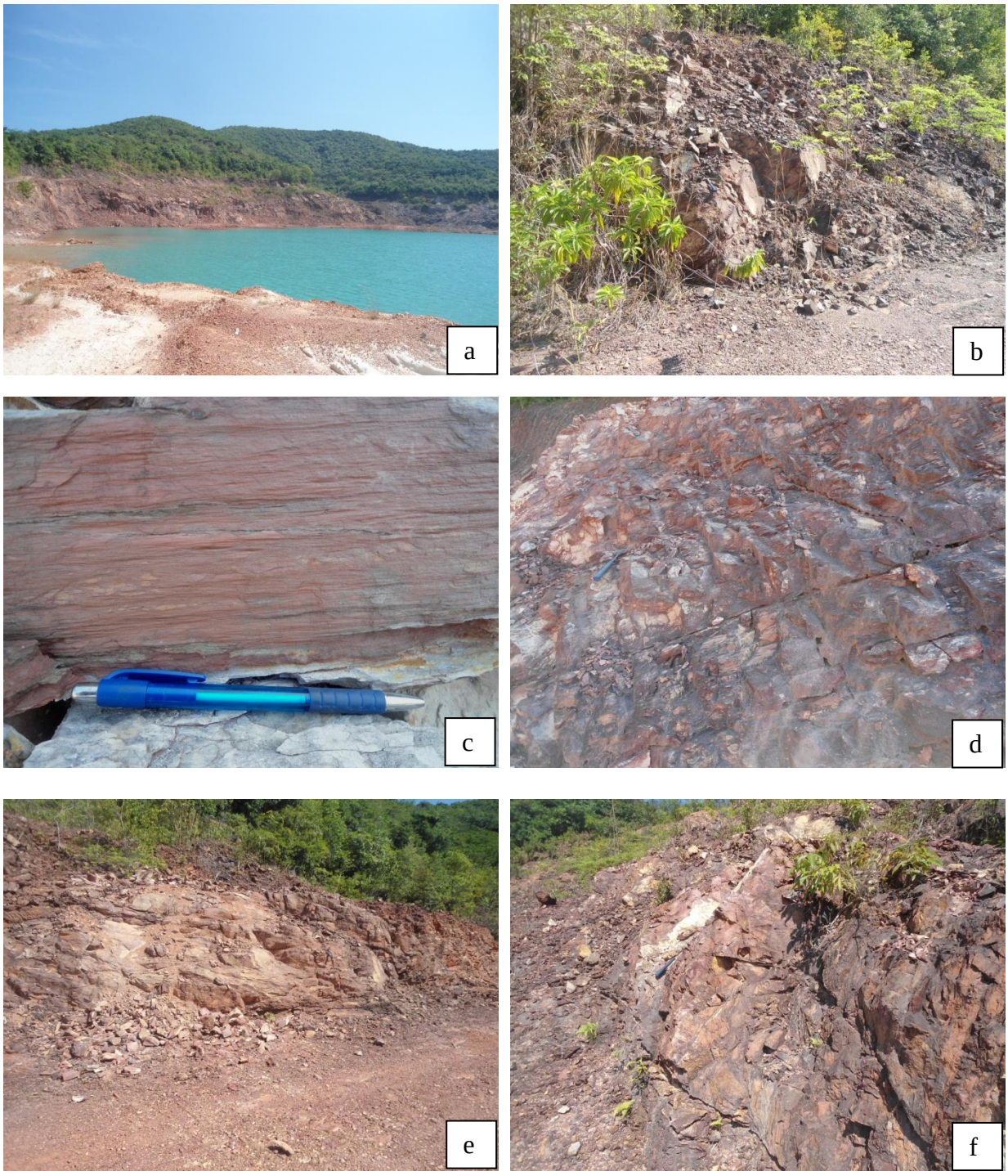

Figure 81 Exposures of the Yaha Formation in Khao Daeng II reference section, an abandon mine in the western part of Khao Daeng, Sting Phra District, Songkhla Province a) general exposure b) red mudstone interbedded with laminated mudstone in the lower part c) discontinuous laminar in mudstone d) massive red mudstone e) exposure of siltstone interbedded with mudstone in the upper part f) Thick-bedded siltstone and stringering of sandstone in the upper part

3.2.10 Khao Noi reference section

a. Location

Reference section of the Yaha Formation is located on quarry in southern part of Khao Noi, Sting Phra District, Songkhla Province. Geographic reference of section in the quarry is 7 °12.956´ N, 100°33.539´ E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section in this quarry has continuous exposure 70 m long and 50 m wide. The exposures have approximately E-W trending. Good exposures of fresh rocks having continuous sequence without break and abundant microfossils are superb for studying characteristics of the rock units.

c. General geology

Rock unit in the reference section has E-W trending with low-moderate angle dipping to northward. Azimuth of bedding in this rock unit is 30/020 to 40/020. Main faulting and jointing occurred in the section is characterized by the minor faults trending NE-SW direction. Only the Yaha Formation is recognized in this reference section. Thickness of the Formation in this section is approximately 44.5 m

d. Lithostratigraphy

The Yaha Formation in the Khao Noi reference section, approximately 44.5m thick, comprises the sequence which can be correlated with the Lower Upper members of the composited Yaha Formation. Detailed lithology of the sequence is illustrated in Figure 82 as follows.

1. Lower Upper member

The member is characterized by three subunits (Figure 83a-h) in ascending order as follow;

- White to light grey, fine-to medium-grained, thick-bedded (1-1.5m) sandstone intercalated by light grey, red, thin-to medium-bedded, laminated mudstone. Load casts and slump structures are well observed in bottom part of sandstone. Mudstone, light grey, thick-bed, lamination with strongly folds is generally observed in the upper part.

- Siliceous mudstone interbedded with mudstone, thin-to medium-bedded, grey, lamination. Stringering of thin-medium-bedded of quartzitic sandstone are found. Light grey to dark grey, very thin- to thin-bedded (1-5cm) sharp, uneven, parallel of chert and siliceous shale are represented in the middle part. Hard pan is generally observed as layers and nodules. Lowest and Uppermost of this unit is thick sequence of mudstone, white, light grey, lamination, well-bedded, thin-medium bedding, powder and clean, lamination, some graded bedding, Hard pan nodules is also found in the sequence near siliceous rock beds.

- Interbedded of sandstone and mudstone. Sandstone is light grey, fine-to medium-grained, very thick-bedded and quartzitic in texture. Load cast, graded-bedding, lamination and small pelloid of dark grey to black minerals are generally observed within sandstone bed. Mudstone is red and light grey, thin-to thick-bed. Lamination is common.

Radiolarian assemblages in siliceous shale in this reference section were also investigated. Two rock samples (SN 3 and SN 4) were collected from siliceous shale bed for laboratory work. Poorly preserved radiolarian and sponge spicules were discovered. The radiolarian includes, *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*cf. *Vulgaris* (Won), *Stigmosphaerostylus*sp., *Archocyrtium* sp. and *Pylentonema*sp (Figure 84). The occurrence of *Stigmosphaerostylusvariospina*(Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) from Thailand and Malaysia (Sashida and Igo, 1999; Saesaengseerung et al., 2007) (Saesaengseerung, in manuscript).

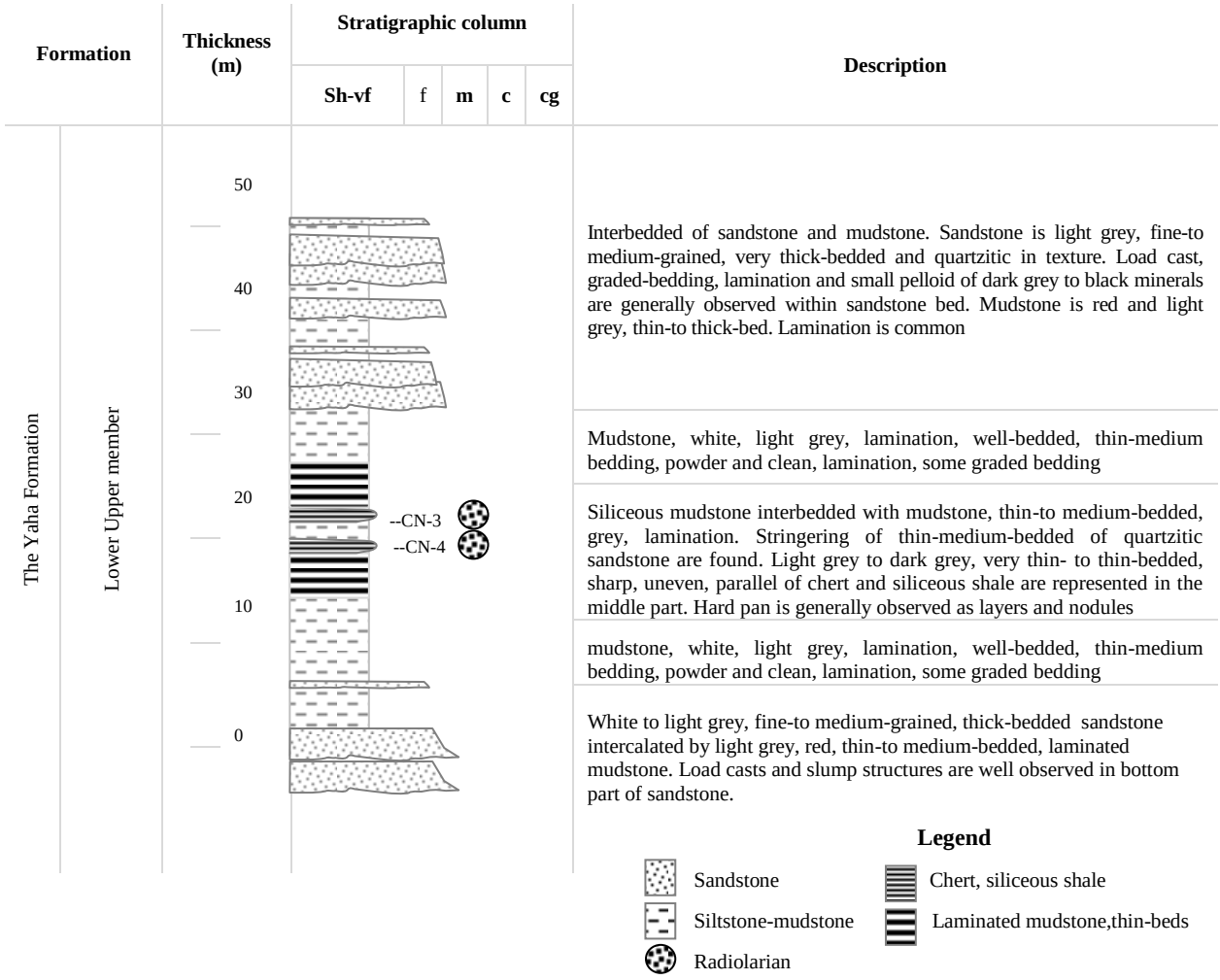

Figure 82: Stratigraphic column of the Yaha Formation in Khao Noi reference section, southern part of Khao Noi, Sting Phra District, Songkhla Province.

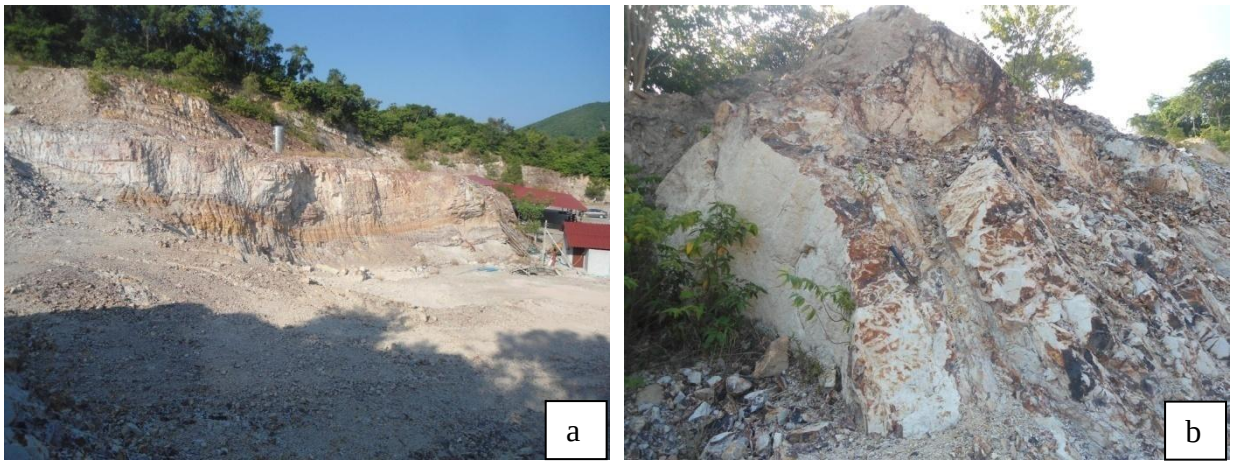

Figure 83 Exposures of the Yaha Formation in Khao Noi reference section, southern part of Khao Noi, Sting Phra District, Songkhla Province a) general exposure b) thick bedded sandstone in the lower sequence

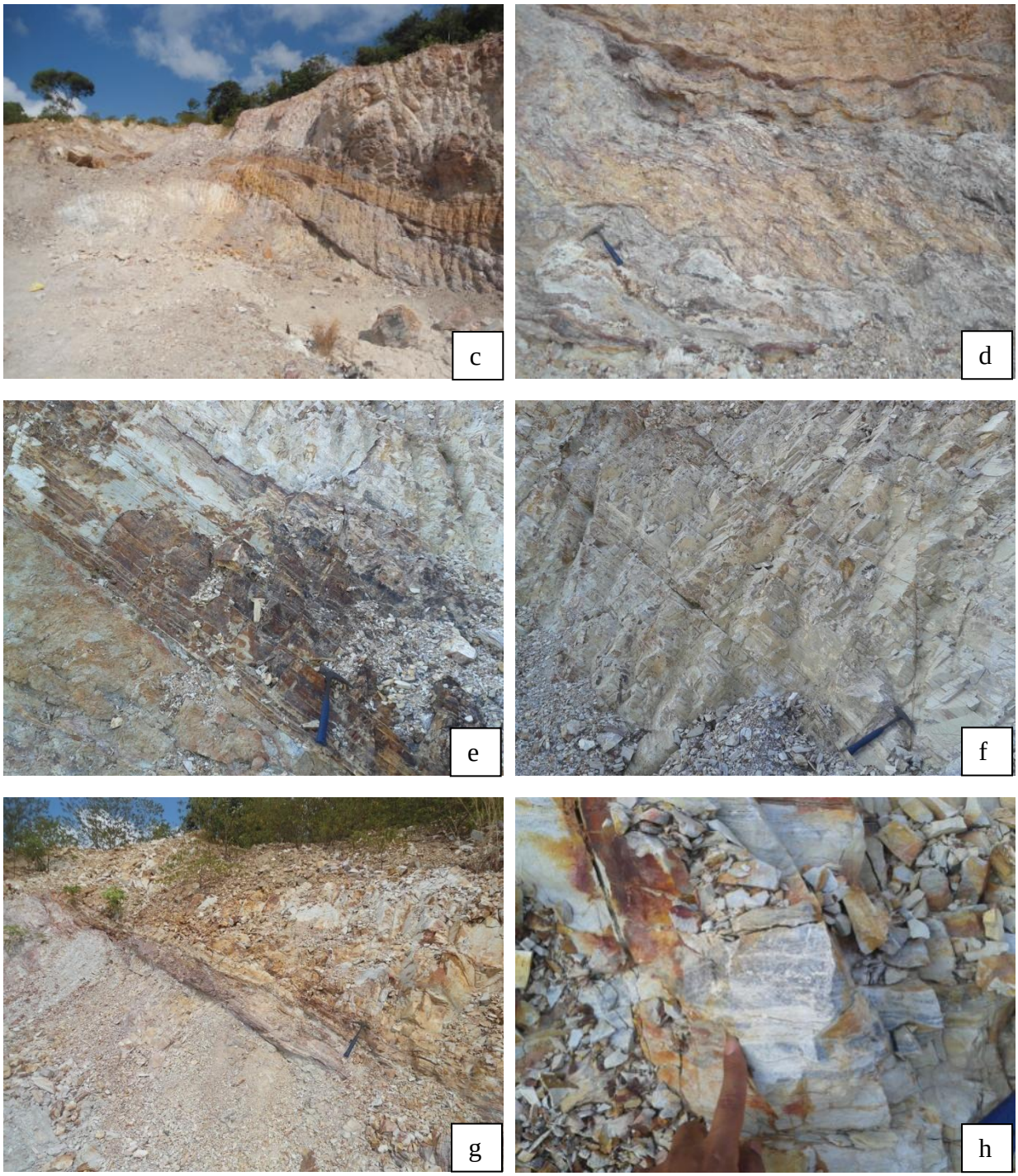

Figure 83 Exposures of the Yaha Formation in Khao Noi reference section, southern part of Khao Noi, Sting Phra District, Songkhla Province (cont'd) c) thick-bedded mudstone followed by siliceous shale d) siliceous shale and chert bed in the middle part e) siliceous shale and hard pans strata f) thick sequence of well-bedded mudstone in the middle part g) cycle of sandstone-siltstone-mudstone in the upper part h) dark mineral bands in sandstone

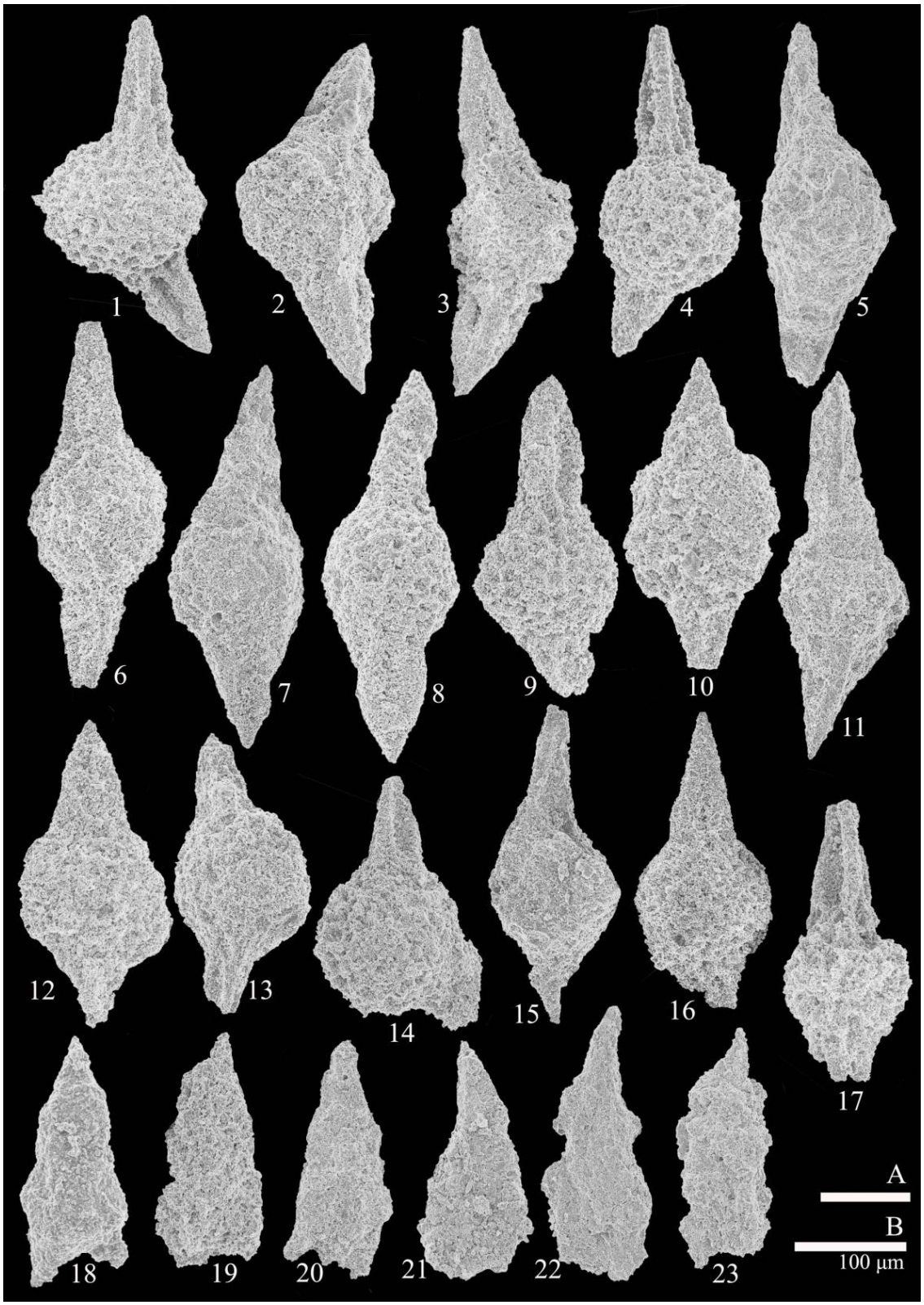

Figure 84 Early Carboniferous radiolarian in Khao Noi reference section

1-4 *Stigmosphaerostylus variospina* (Won) with two spins
5-21 *S. variospina* (Won) with polar spins
11-17 *S. variospina* (Won)
18 *Archocyrtium* sp.
19-23 *Albillela* sp.
Scale A: 1-17, B: 18-23

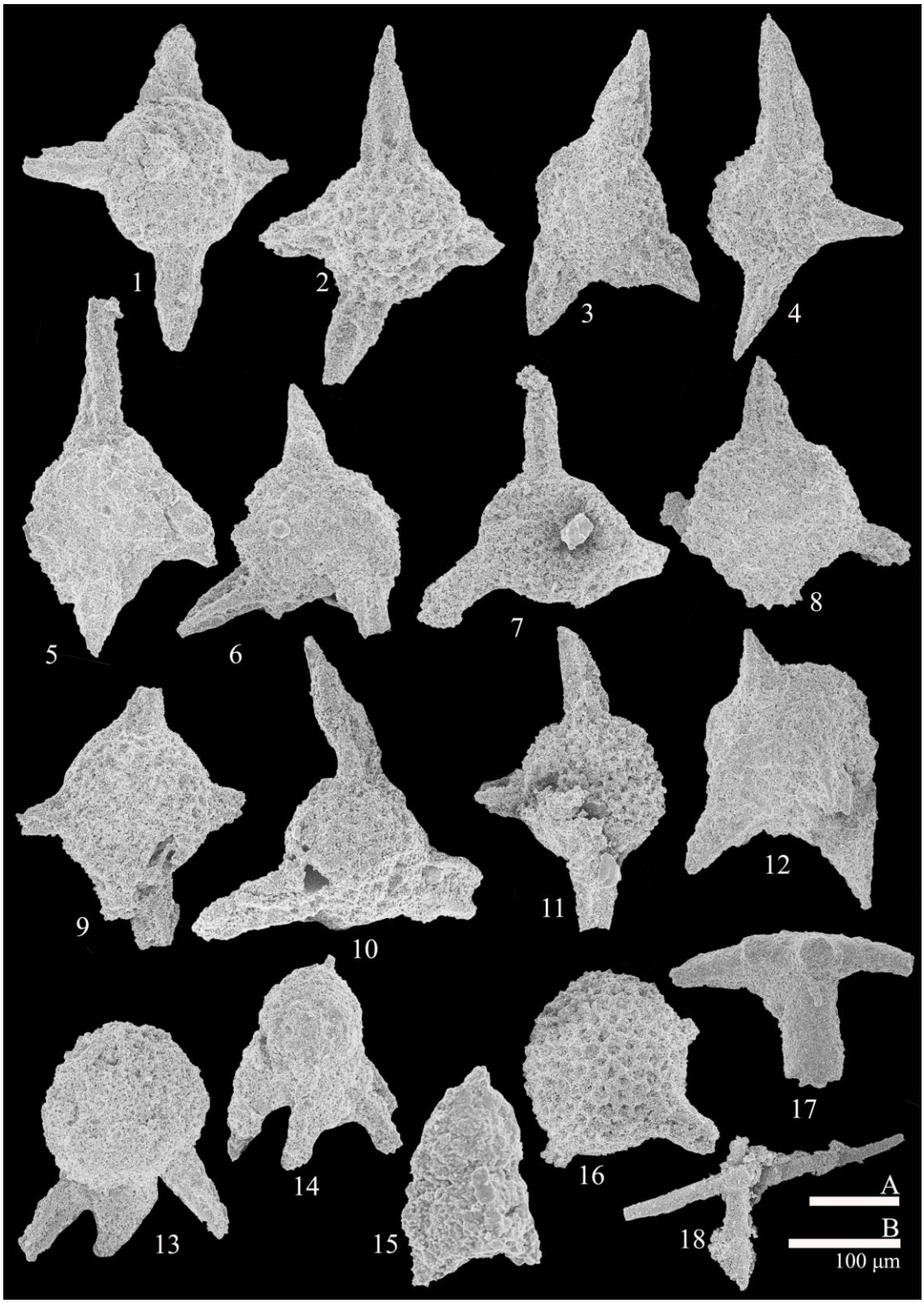

Figure 84 Early Carboniferous radiolarian in Khao Noi reference section (cont'd)

1	*Stigmosphaerostylus*cf. *vulgaris* (Won)
2, 9	*Stigmosphaerostylus variospina* (Won) with four spins
3, 4, 7, 8, 10, 11	*S. variospina* (Won) with three spins
5, 6, 9, 12,13, 14	*Pylentonema* sp.
15	*Archocyrtium* sp.
16	*Stigmosphaerostylus* sp.
17, 18	sponge spicules

Scale A: 1-13, 16, 18; B: 14, 15, 17

3.2.11 Ko Yo reference section

a. Location

Reference section of the Yaha Formation is located on road cut at small hill which are beside the foot of the Tinsulanonda Bridge, northern part of Ko Yo (Yo Island), Sting Phra District, Songkhla Province. Geographic reference of section in quarry is 7 ^{o}00.480´ N, 100^{o}32.649´ E in Changwat Songkhla 5123II Sheet on the scale 1:50,000.

b. Exposure

The reference section has continuous exposure 70 m long and 30 m wide along the road no. 408 at km 6. The exposures have approximately N-S trending. Good exposures of fresh rocks having continuous sequence without break and abundant microfossils are superb for studying characteristics of the rock units.

c. General geology

Rock unit in the reference section has NW-SE trending with moderate to high angle dipping to northeastward. Azimuth of bedding is between 55/053 to 70/065. Main jointing occurred in the section is E-W direction. Only the Yaha Formation is recognized in this reference section. Thickness of the Formation in this section is approximately 89 m

d. Lithostratigraphy

The Yaha Formation in Ko Yo reference section, approximately 89m thick, comprises the sequence which can be correlated with the Lower Upper and Upper members of the composited section of the Yaha Formation. Detailed lithology of the sequence (Figure 85) is described in ascending order.

1. Lower Upper member

The member is characterized by two subunits in ascending order as follow;

- Thick-bedded sandstone intercalated with mudstone, Sandstone is white, pale grey, fine-to medium grained, medium-to very thick-bedded (1-2m) and quartzitic in texture. Mudstone is grey, light pinkish grey and purplish grey and thin-to medium-bedded. Lamination is observed in mudstone.
- Mainly siliceous shale, well-bedded, sharp, parallel, light grey to dark grey, thin-bedded intercalated with light grey to dark grey, thin-bedded chert and siliceous mudstone. Lamination is commonly found (Figure 86).

2. Upper member

The member is continuously underlain by the Lower Upper member. The member, 11 m in thickness consists of thick-bedded red and dark grey mudstone. Sandstone, fine-grained, lithic are also found. The upper most of this sequence is siliceous shale, dark grey, thin-bedded).

Three rock samples in siliceous shale of the Lower Upper member were collected for laboratory work (Figure 87). These samples contain microfossils such as radiolarian, conodont and sponge spicule. The conodont includes *Polygnathus*genera which were reported from Early Devonian to Early Carboniferous sequence worldwide. Conodont elements are white color. Based on the Conodont Alteration Index (CAI), these conodont and rocks were deformed by high temperature about 360˚-550˚C . The identification of this conodont would be re-checking for further study. Poorly preserved radiolarians were discovered from KoYo area (Figure 88).

The radiolarian (Figure 89) consists of *Albaillela*sp. *Stigmosphaerostylusvariospina* (Won), *Trilonche* sp., *Stigmosphaerostylus*sp and *Ruzhencevispongus*sp. The occurrence of

Stigmosphaerostylusvariospina (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) from Thailand and Malaysia (Sashida and Igo, 1999; Saesaengseerung et al., 2007). However, the radiolarian identification is very difficult by poorly preserved (Saesaengseerung, in manuscript).

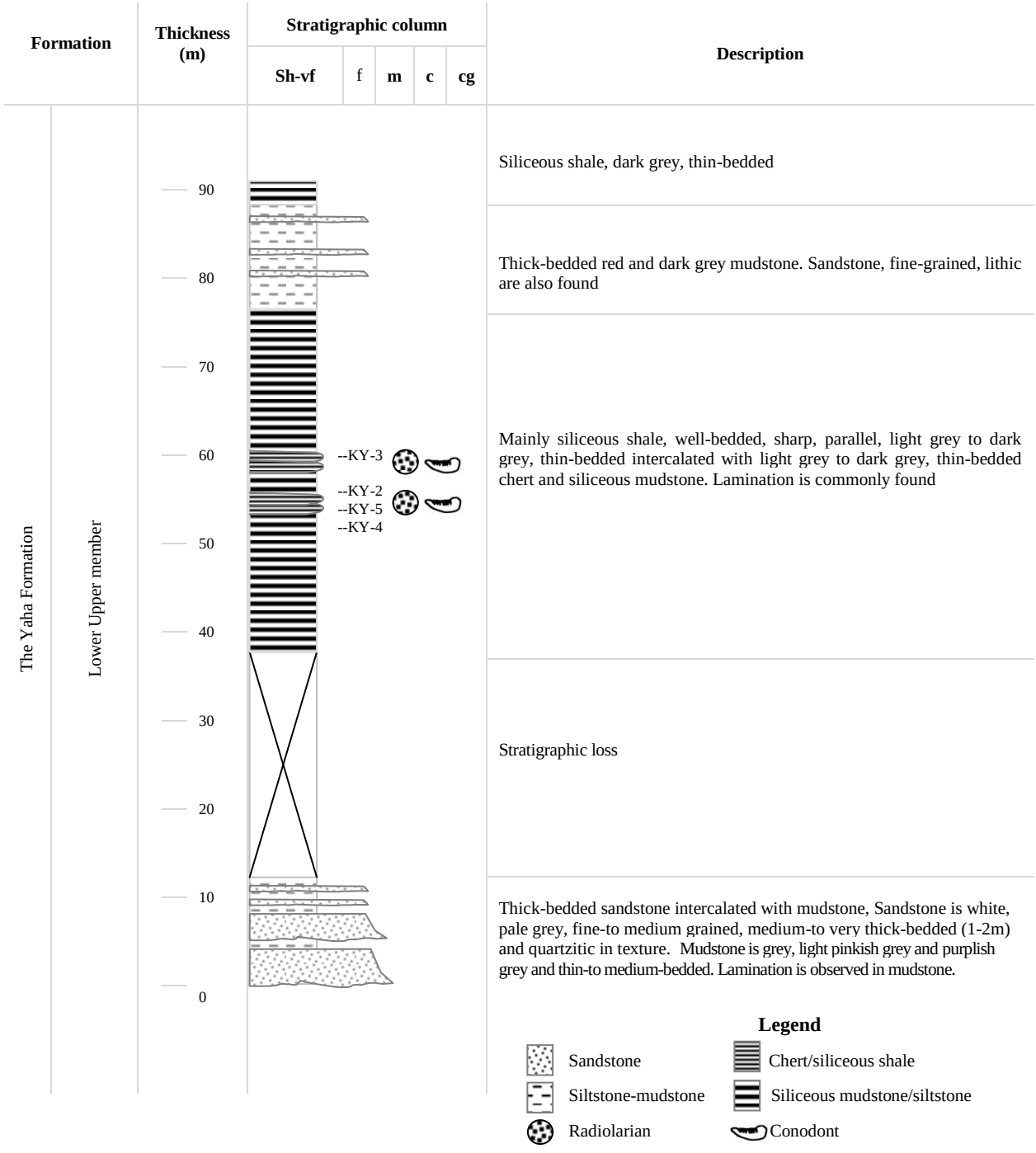

Figure 85: Stratigraphic column of the Yaha Formation in Ko Yo reference section, the foot of the Tinsulanonda Bridge, northern part of Ko Yo (Yo Island), Sting Phra District, Songkhla Province

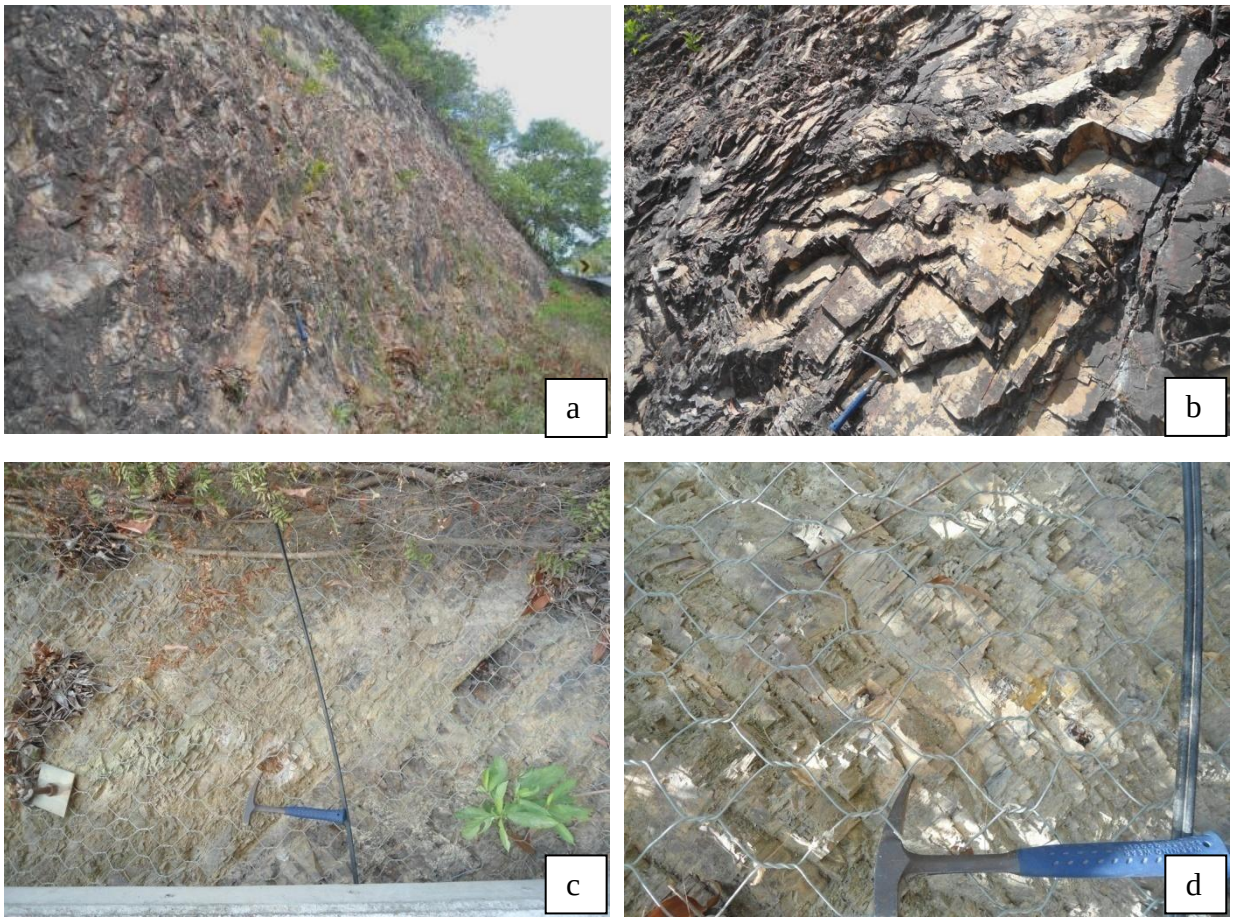

Figure 86 Exposures of the Yaha Formation in Ko Yo reference section, foot of the Tinsulanonda Bridge, northern part of Ko Yo , Sting Phra District, Songkhla Province a) general exposure of thick-bedded sandstone in the lower part b) thick bedded sandstone showing closed space joint c) Thin-bedded siliceous shale and chert d) closed-up of siliceous shale

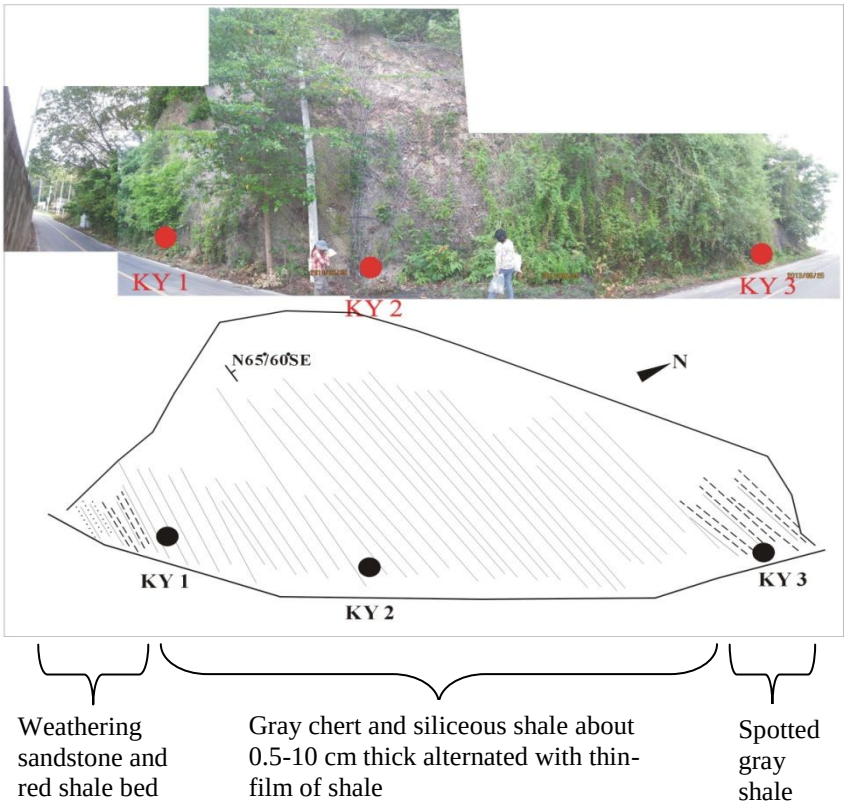

Figure 87 Outcrop photograph and sketch of the study section shows sample locations.

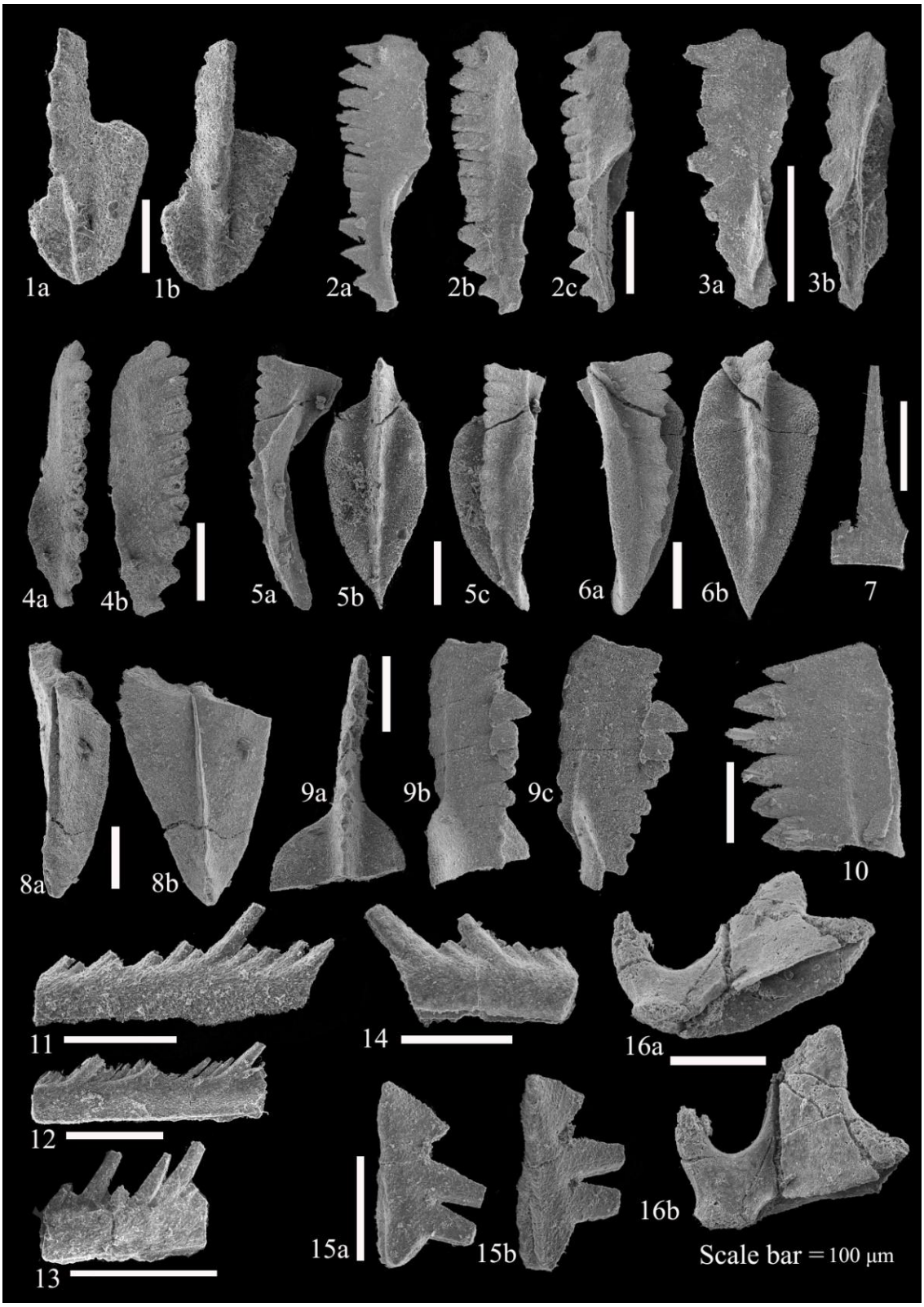

Figure 88 *Polygnathus* Conodont from KoYo.1-10.Pa element (pectiniform), 11-14.Sb element (ramiform), 14-16.Sa element (ramiform).

Oral views: 1b, 5b, 6b, 9a
Oblique oral views: 1a, 2b, 4a, 5c, 6a, 9b
Lateral views: 2a, 3a, 5a, 9c
Lower views: 2c, 3b, 8a, 8b, 16a

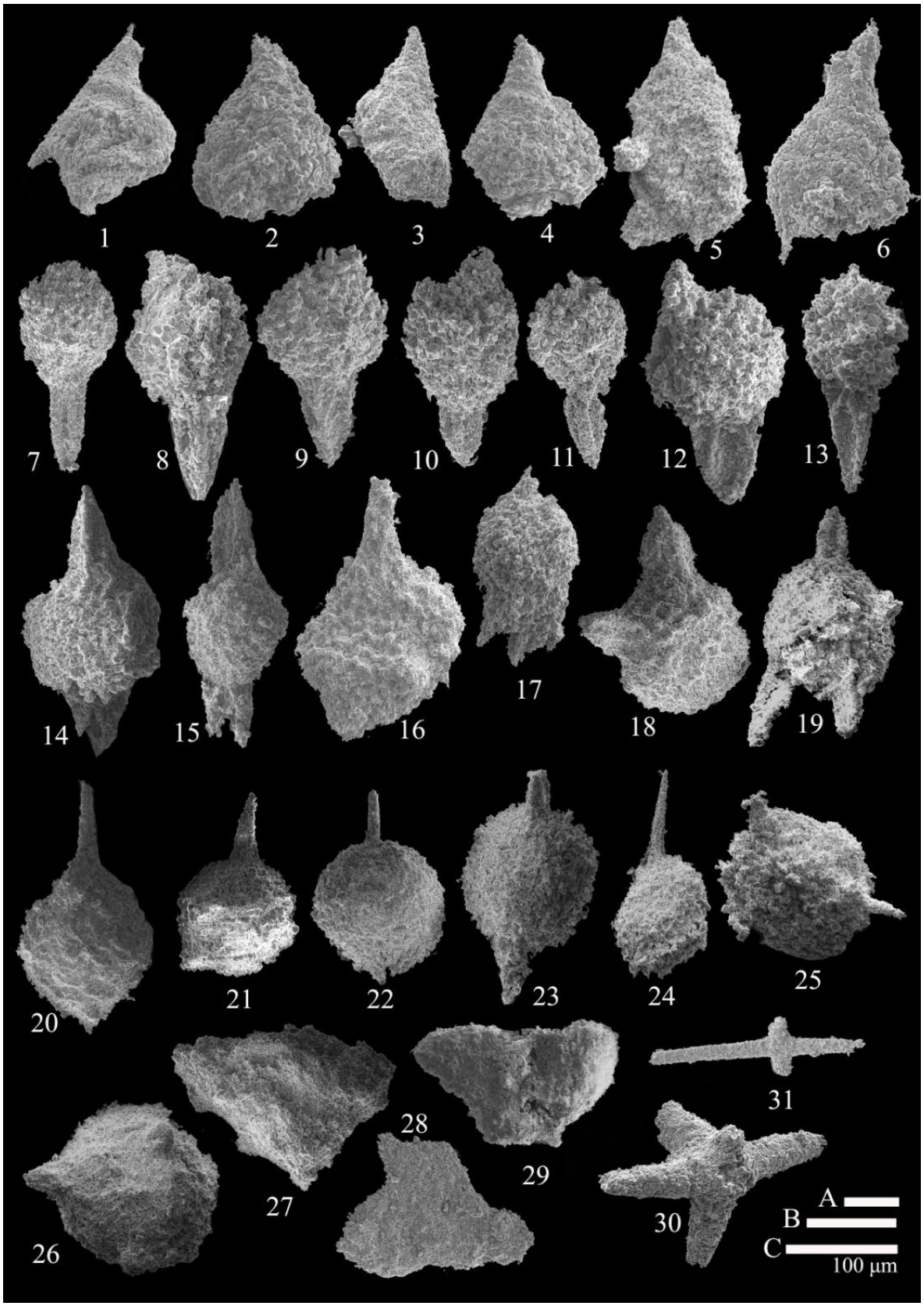

Figure 89 Carboniferous radiolarian from KoYo.1-6. *Albaillela*sp.,, 7-19., *Stigmosphaerostylusvariospina* (Won), 20-25. *Trilonche* sp., 26.*Stigmosphaerostylus*sp., 27-29. *Ruzhencevispongus*sp., 30, 31.Sponge spicule. Scale A: 27-29, 31; B: 7-26, C: 1-6, 30

4. LITHOSTRATIGRAPHIC CORRELATION

4.1 SUMMARY ON LITHOSTRATIGRAPHY OF SECTIONS

4.1.1 Malaysian side

Stratigraphically, the reference sections of the Kubang Pasu Formation from west to east along the Malaysia-Thailand border area can be described as follows:

a. Eastern Perlis

One reference section, i.e. Bukit Tuntong reference section is located in this area. It contains six subunits and is reported overlying the carbonaceous sequence of the Mahang Formation by Nur Susila Md. Saaid & Basir Jasin (2014). This sequence is considered as part of Jelutong Member, the lowermost part of Kubang Pasu Formation. The upper portion of this sequence is eroded away.

Fossils of ammonoids, crinoid stems, trilobite pygidium, brachiopods and gastropods have been found in the shale beds. The chert at the lower part of the succession yields Tournaisian radiolarian (Nur Susila Md. Saaid & Basir Jasin, 2014).

b. Northwestern and central Kedah

Three reference sections are selected in northwestern Kedah representing the Jelutong and Jenun Members of Kubang Pasu Formation. The sections are Sintok, Bukit Kachi and Bukit Jambul reference sections.

Sintok reference section comprises interbeds of medium- to thickly bedded light grey sandstone and thinly- to medium bedded grey shale representing the Jelutong Members. Bivalve *Posidonomya* sp. and trilobite pygidium were found in the upper part of the sequence.

Bukit Kachi reference section comprises thick sequence of well-bedded and well-laminated shale. It represents the Jenun Member of Kubang Pasu Formation. No fossil found in this reference section.

Bukit Jambul reference section comprises thickly-bedded sandstone alternating with thickly-bedded shale with *Posidonomya* sp., representing the Jelutong Member, and thick sequence of well-bedded and well-laminated shale representing the Jenun Member.

c. Northern Perak

One reference section is selected in northern Perak area i.e. Ayer Ganda reference section, representing Papulut Member, the upper part of Kubang Pasu Formation. The section comprises thick sequence of thickly-bedded, white to light grey sandstone with thin grey shale partings. The succession is metamorphosed throughout as it is not far from the granite intrusion. Petrographically, the sandstone can be classified as quartz arenite.

4.1.2 Thai side

Stratigraphically, the reference sections of the Yaha Formation from west to east along the Malaysia-Thailand border area are introduced the composited section of the Yaha Formation (Figure 90). Described information of summarized on Lithostratigraphy of each subarea can be explained as follows;

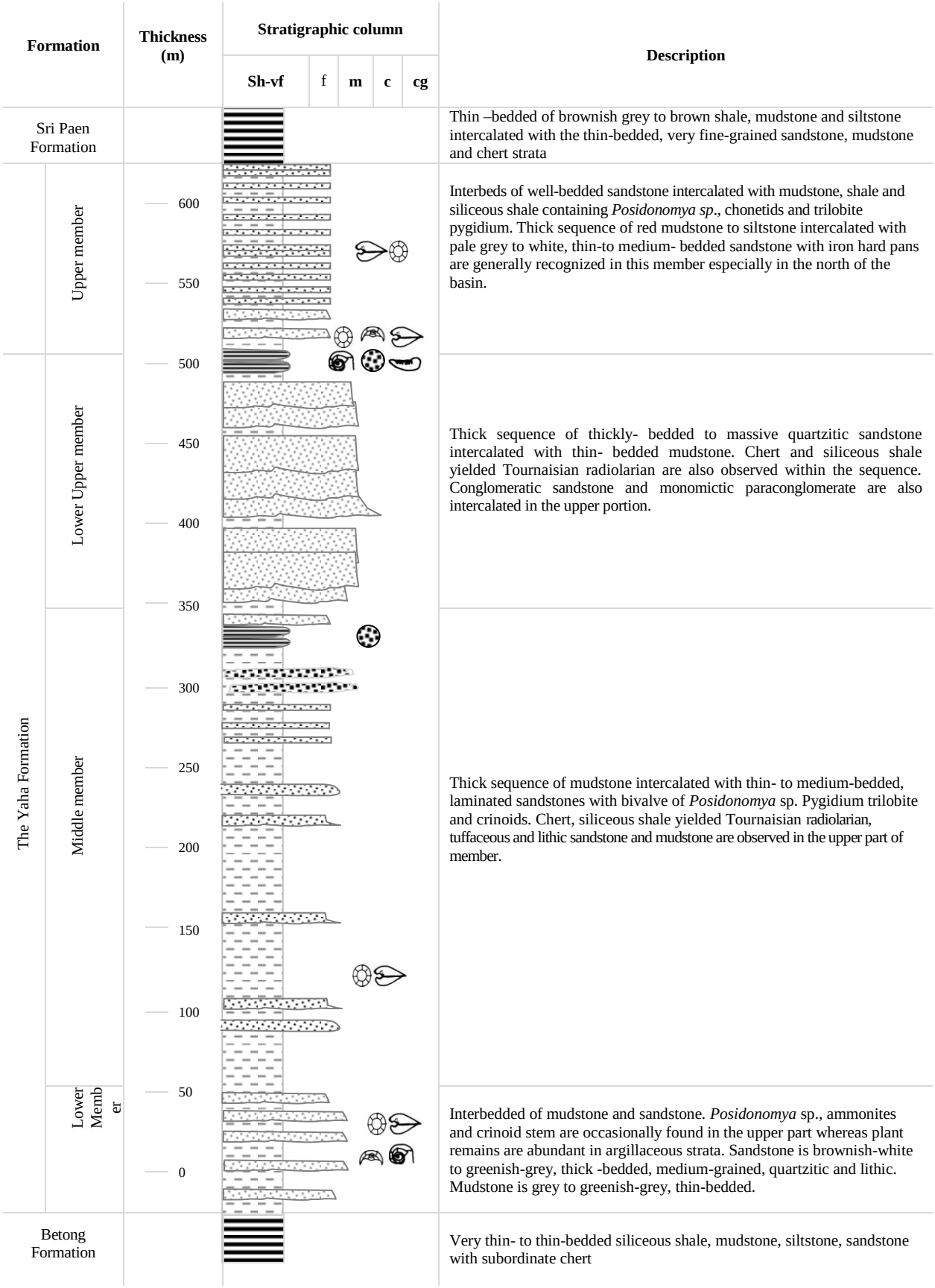

Figure 90: Composited section of the Yaha Formation

a. Padang Besar subarea

No reference section was studied in this subarea. The rock sequence is consisted of predominantly grey to white sandstone, greywacke and conglomerate. Quarzitic sandstone also occurs. Mudstone and shale are essentially dark grey and red in color. Thickness of the individual bed of rocks ranges from 10 cm to more than 1 m. This sequence is considered as part of the Lower Upper member. No fossil found in the Yaha Formation in this subarea. The age of this formation is assigned as Carboniferous on the basis of its stratigraphic and lithologic correlation with the Yaha Formation in several reference sections.

b. Sonkhla subarea

Six reference sections of the Yaha Formation i.e. Ko Yo, Khao Noi, Khao Daeng I, Khao Daeng II, Ban Trap and Khuan Bu reference sections were observed in the Songkhla subarea. They represent the Middle, Lower Upper and Upper members of the Yaha Formation.

Ko Yo reference section, 89 m in thickness, is subdivided into two subunits. The lower subunit is white, pale grey, fine-to medium grained, thin-to very thick-bedded quartzitic sandstone intercalated with mudstone follow by mainly siliceous shale and chert, well-bedded, sharp, parallel, light grey to dark grey, thin-bedded. The conodont includes *Polygnathus*genera which were reported from Early Devonian to Early Carboniferous sequence and radiolarian includes, *Albaillela*sp. *Stigmosphaerostylusvariospina* (Won), *Trilonche* sp., *Stigmosphaerostylus*sp., and *Ruzhencevispongus*sp. The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) (Saesaengseerung, in manuscript). The upper subunit is characterized by thick-bedded red and dark grey mudstone. Fine-grained, lithic sandstone are also found. The reference section is referred to the Lower Upper and Upper members of the Yaha Formation.

Khao Noi reference section, 44.55 m in thickness, consists of white to light grey, fine-to medium-grained, thick-bedded sandstone intercalated by light grey, red, thin-to medium-bedded, laminated mudstone. Load casts and slump structures are observed in bottom part of sandstones. Light grey to brownish red, thin-bedded or ribbon chert and siliceous shale are intercalated. The reference section is referred to the Lower Upper member of the Yaha Formation. Radiolarian assemblages in siliceous shale including *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*cf. *Vulgaris* (Won), *Stigmosphaerostylus*sp. , *Archocyrtium* sp. and *Pylentonema*sp. The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) from Thailand and Malaysia.

Khao Daeng I reference section, 119 m thick, is subdivided into two subunits. The lower subunit is characterized by white, light grey fine-to medium-grained, thick-to very thick-bedded sandstone interbedded with dark grey medium-to thick- bedded, sandy siltstone. Lamination, flaser beds, bioturbation and carbonaceous materials are recognized in sandy siltstone. Siliceous shale, milky, white, well-bedded, sharp, parallel beds, thin-bedded is also intercalated. The upper sequence is presence by interbedded of sandstone, siltstone and mudstone. Dark red and dark grey, massive, dense, silicified, thin-to thick-bedded mudstone and grey and light grey, thin-bedded silicified mudstone are generally observed. The reference section is referred to the Lower Upper and Upper Members of the Yaha Formation.

Khao Daeng II reference section, 86m thick is characterized by thick sequence of red, medium-to thick- bedded mudstone to siltstone interbedded with red, medium-to thick-bedded mudstone. Pale grey to white, thin-to medium- bedded, sandstone is intercalated. Layers of iron hard pans are generally recognized. The reference section is referred to the Upper Member of the Yaha Formation.

Ban Trap reference section, 168m thick is subdivided into three subunits. The lower subunit consist of light grey to light brown, thick-bed, laminated shale with lens of laminated, red mudstone interbedded and the sequence of shale interbedded with siliceous shale. The middle subunit consists of white, pale grey, fine-to medium grained, thin-to very thick bedded quartzitic sandstone intercalated with white, grey, thin-bedded mudstone. The upper subunit composes of red and light greenish grey, medium-to thick-bedded mudstone with stringering of sandstone strata. Pygidiums of Trilobite, ammonite and chonetids are often observed. Above the sequence, the subunit is characterized by white and light grey, medium to thick-bedded, quartzitic and lithic sandstone interbedded with red and some light grey, medium to thick bed mudstone. Hard pans are generally found. The reference section is referred to the Middle, Lower Upper and Upper Members of the Yaha Formation.

Khuan Bu reference section, 68.3m thick are divided into two subunits. The lower subunit is described by Interbeds of sandstone and mudstone strata. Sandstone is white, light grey, medium-to very thick- bedded, quartzitic and lithic in composition. Mudstone is red and some light grey in color, medium to thick- bed and partly lamination. Hard pans are generally found. Pebble of chert and quartz grains and load cast structure are often found in the bottom part of sandstone. Dark grey, black, light grey, ribbon siliceous shale to chert interbedded with white and pink, very thin- bedded mudstone are found in the upper portion. The upper subunit is consisted of interbedded of sandstone, siltstone and mudstone. The reference section is referred to the Lower Upper and Upper members of the Yaha Formation.

The radiolarian from siliceous shale bed in this area includes *Albaillela*sp., *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*sp.,*Trilonche* sp., and *Pylentonema*sp. The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian) from Thailand and Malaysia.

c. Chana subarea

One reference section of the Yaha Formation, Khuan Non reference section is observed in the Chana subarea. The sequence, 190m thick, consists of two subunits. The lower subunit is characterized by white to grayish white, fine-to coarse-grained sandstone. Thickness of each sandstone bed is 4-6 m. the rocks are interbedded with white siltstone, grey and brown shale. *Posidonomya* sp. was recorded in brown shale. Above the sequence, the rock is composed of thick of grey to white and purplish grey shale and siliceous shale. Ribbon chert (3-4 cm) is also recorded. The upper subunit is consisted of thick sequence of grey to purplish grey shale with siliceous shale intercalation. The reference section is referred to the Lower Upper and Upper Members of the Yaha Formation.

d. Na Thawi-Sadao subarea

Only Na Thawi reference section is observed in the Na Thawi-Sadao subarea. The sequence, 380 m thick, consists of three subunits. The lower unit is composed of thick sequence of mudstone intercalated with thin- to medium-bedded, laminated, medium-grained, sandstone. Bivalve of *Posidonomya* sp., ammonites, trilobites and crinoids were observed. Above the unit, it is composed of shale and tuffaceous shale intercalated with reddish-brown, fine-grained sandstone followed by sequence of well-bedded cherts or siliceous shale. The middle subunit comprises brownish-white to greenish-grey, thick to very thick-bedded, medium-grained, moderately well-sorted quartzitic sandstone interbedded with grey to greenish-grey, thin-bedded shale with plant remains followed by grey to greenish-grey, laminated mudstone with the bivalve *Posidonomya* sp. and crinoids. The Upper subunit is consists of brown to yellowish-brown, fine- to medium-grained, well-bedded sandstone intercalated with shale. *Posidonomya* sp. and crinoids were also found in this unit. The reference section is referred to the Middle, Lower Upper and Upper Members of the Yaha Formation.

e. Saba Yoi subarea

The rock sequence, 250 m in thickness, consist of two subunits. The lower subunit, 200m in thickness, is consisted of grey and light brown, medium-grained, sandstone interbedded with greenish grey shale and mudstone followed by siltstone, grey, dense, interbedded with grey sandstone, dark grey shale and greenish grey shale. The upper part, 20m in thickness, consisted of dark grey ribbon chert overlying by thick bedded white sandstone. No fossil found in the Yaha Formation in this subarea. The age of this formation is assigned as Carboniferous on the basis of its stratigraphic and lithologic correlation with the Yaha Formation in several reference sections.

f. Bahoi-Kabang subarea

Only Bahoi reference section is observed in the Bahoi-Kabang subarea. The sequence, 450 m in thickness, can be subdivided into three subunits. The lower subunit is characterized by mainly mudstone and siltstone intercalated with fine-to medium-grained, thin to thick-bedded, laminated sandstone. Lower Carboniferous bivalve *Posidonomya* sp. and crinoid stem are occasionally found. Above the sequence, the unit is sequence of well-bedded dark grey sandstone/tuffaceous sandstone intercalated with mudstone member followed by thick sequence of thin- bedded (ribbon), chert and siliceous siltstone which often show tight and recumbent folding.

The middle subunit consists of massive to very thick- bedded quartzitic sandstone intercalated with mudstone. Each individual sandstone bed is up to 4 m thick. Plant remains can be recognized in the intercalated mudstone. Above the sequence, the unit is thin to very thin, well- bedded, light brown to light gray and white, siltstone, mudstone and siliceous rocks with some light gray to dark gray chert bed. The upper subunit is characterized by even bedded shale interbedded with sandstone.

Sashida *et al*. (1998) reported the occurrence of Early Carboniferous radiolarians in chert lenses intercalated with sandstone and siltstone-dominated sequence at Ban Wang Yai, 12 km east of the Na Thawi town and at Ban Kabang, Kabang District, Yala Province. Sashida *et al*. (2000) later described that these radiolarians as *Entactinia variospina*, *E. vulgaris*, *Astroentactinia multispinosa*, *Spongentactinia* sp. and *Triaenospaera* sp. indicative of Early Carboniferous age (Tournaisian). *Posidonomya* sp., crinoids and plant remains had been occasionally found at Ban Nam Chieo and Ban Bahoi (Thailand). Based on the faunal assemblages, the Yaha Formation in this subarea is assigned to Early Carboniferous in age.

The reference section is referred to the Middle, Lower Upper and Upper members of the Yaha Formation

g. Yala-Raman subarea

No reference section was studied in this subarea. The Formation, 300-400m in thickness, is subdivided into three subunits. The lower subunit is interbedded of well-bedded, medium- to thick-bedded mudstone, sandstone, shale and tuff. The middle subunit is interbedded of thin-to thick- bedded sandstone, shale, conglomeratic sandstone, siltstone and chert. Conglomeratic sandstone and monomictic paraconglomerate are intercalated in the upper portion. The upper subunit is consisted of interbedded of sandstone, siltstone, chert and limestone lens. The reference section is referred to the Middle, Lower Upper and Upper members of the Yaha Formation.

h. Betong subarea

One reference section of the Yaha Formation, Betong reference section is observed in the Betong subarea. The sequence, 500m thick, is subdivided into three subunits.

The lower subunit composes predominantly of thin–to medium bedded, gray to greenish gray mudstone and siltstone intercalated with fine-to medium-grained, thin to thick bedded, laminated, pale greenish-grey to yellowish brown, lithic and arkosic sandstone exhibiting diagnostic features of wavy and lenticular beds.

The middle subunit is mainly mudstone and siltstone intercalated with fine-to medium-grained, thin- to thick-bedded, laminated sandstone. Lower Carboniferous bivalve *Posidonomya* sp. and crinoid stem are rarely found. Above the sequence, the unit represents thick sequence of thin- bedded (ribbon), chert and siliceous siltstone which often show tight and recumbent folding and become to thick-bedded sandstone sequence.

The upper subunit consists of massive to very thick- bedded quartzitic sandstone followed by thin to very thin (3-7 cm), sharp, parallel, well- bedded, light brown to light gray and white, siltstone, mudstone and siliceous rocks with some light gray to dark gray chert bed. Each individual sandstone bed is up to 4 m thick. The reference section is referred to the Lower, Middle and Lower Upper Members of the Yaha Formation.

4.2 CORRELATION OF THE KUBANG PASU/YAHA FORMATION

Based on field observation in the Malaysian and Thai sides, and after lengthy discussions by the Malaysia-Thailand Working Group, in term of stratigraphy and paleontology, both parties agree that the Kubang Pasu Formation can be well correlated with the Yaha Formation.

4.2.1 Lithology

On the Malaysian side, lithologically the Kubang Pasu Formation comprises sequence of sandstone and shale interbeds with the occurrence of Tournaisian chert in the lower part. Thickly-bedded shale with minor sandstone beds occurs in the middle part. Thickly-bedded metamorphosed sandstone with occasional conglomerate occurs in the upper part.

On the Thai side, lithology of the Yaha Formation is generally classified to 7 main lithofacies as follows;

a. Massive to very thick-bedded quartzitic sandstone lithofaices, consisting mainly of pale brown, well-sorted, medium-grained, massive to very thick-bedded quartzitic sandstone intercalated with mudstone. Individual sandstone beds are up to 4 m thick with a total thickness in general of 50-100 m. This unit usually observed in the middle-upper part of the Formation in both eastern and western Yaha belts.
b. Interbedded mudstone and sandstone lithofacies, approximately 50-300 m thick, is composed of mainly mudstone intercalated with sandstone. Mudstone is composed of grey color, clean, smoothly and homogeneous texture and greenish grey and has dirty texture with feldspar spot and plant remains. Sandstone is pale greenish grey, medium-grained, lithic, arkosic and quartzitic in composition exhibit diagnostic features of wavy and lenticular beds. *Posidonomya* sp. Pygidium trilobites, ammonoids, chonetids and crinoids are occasionally found in this lithofacies. The unit is generally found in lower to middle part and upper part of the Formation in both eastern and western Yaha belts.
c. Well-bedded, dark grey sandstone lithofacies, approximately 15-50 m thick, consists mainly of dark grey to black, fine- to medium-grained, moderately sorted, well wavy-bedded lithic sandstone. The unit generally observes in the upper portion of the middle part of the Yaha Formation in the area between Na Thawi-Sadao and Bahoi-Kabang subareas.
d. Tuffaceous sandstone intercalated with mudstone lithofacies, approximately 10-50 m thick. The sequence comprises intercalations of reddish-brown, medium- to

coarse-grained tuffaceous sandstone, greenish-grey, medium - to coarse-grained, unevenly bedded greywacke and thick-bedded mudstone to siltstone. The unit generally observes in the upper portion of the middle part of the Yaha Formation in the area between Na Thawi-Sadao and Bahoi-Kabang subareas.

e. Chert lithofacies comprises mainly thin-bedded (ribbon) chert, changing gradually to siliceous shale, mudstone and siltstone, which often show tight and recumbent folding. The Early Carboniferous radiolarians had been reported in this chert sequence. Stratigraphically, the unit is generally intercalated within the middle to upper part of the Formation in both eastern and western Yaha belts especially, closed to the thick-bedded sandstone unit.
f. Even bedded dark grey mudstone interbedded with very fine-grained sandstone reflects flysch-type or outer fan deposits lithofacies is approximately 100 m in thickness. *Posidonomya* sp. and crinoids are also found in this unit. The lithofacies is found in the upper part of the Formation in both eastern and western belts of the Yaha Formation except in Songkhla area.
g. The red argillite lithofacies, 100m in thickness, comprise thick sequence of red, medium-to thick- bedded mudstone to siltstone interbedded with red, medium-to thick-bedded mudstone. Pale grey to white, thin-to medium- bedded, sandstone is intercalated. Layers of iron hard pans are generally recognized. The unit generally found in the upper part of the Songkhla area. Lateral facies change with the even bedded dark grey mudstone interbedded with very fine-grained sandstone lithofacies should be recognized.

It is remarkable that the Yaha Formation in the eastern belt especially at the Betong subarea is strongly affected by granite intrusion and fault movements. The metamorphism of rocks to fissile spotted slate, phyllite, metaquartzite and quartz-mica schist are very common.

The similarity in lithofacies of both rock units i.e. the representative of interbedded mudstone and sandstone sequence in the lower-middle part of sequence, massive to very thick-bedded quartzitic sandstone sequence in the middle-upper sequence. The occurrences of Tournaisian chert in several localities and tuffaceous sandstone intercalated with mudstone in some place are two typical characteristics of both Formations. Moreover, the presence of the similar fossiliferous argillite unit in the lower and middle parts represents that the Kubang Pasu Formation in Malaysia are correlatable to the Yaha Formation in Thailand.

4.2.2 Stratigraphy

On the Malaysian side, at Bukit Tuntong in eastern Perlis, Nur Susila Md. Saaid & Basir Jasin (2014) reported the Kubang Pasu Formation is underlain by the Silurian-Devonian Mahang Formation. The upper part of the succession in this area is eroded away.

In northeastern Kedah, the formation is overlain by the Permian Cherty unit and underlain by the Silurian-Devonian Mahang Formation, whilst in upper Perak it is overlain by the Permian Gerik Formation and underlain by the Silurian-Devonian Kroh Formation. Nur Susila Md. Saaid & Basir Jasin (2014) reported direct contact between the Kubang Pasu Formation and the underlying Mahang Formation can be observed at an active earth quarry at Bukit Tuntong, Ulu Pauh, Perlis state. However, direct contact between the Kubang Pasu Formation and the overlying younger sequence is nowhere exposed in the field.

On the Thai side, the Yaha Formation in the Betong subarea is only recorded conformably underlain by the Silurian-Devonian succession of the Betong Formation. The contact boundary is situated at the strategy border road from Ban Suan Som to Ban Sa Ho, Betong District, Yala Province. The upper contact of the unit is conformably overlied by the Early Permian Sri Paen Formation. Contact boundary is situated at the Betong-Yaha road near the La Ong Rung waterfall. In Yala-Raman subarea, the lower contact boundary of the Yaha

Formation is underlain by the Silurian-Devonian sequence. The upper contact of this unit is overlied by the Permian Ratburi limestone. However, in general, fault boundaries contact of the Yaha Formation and the Triassic sequences are usually observed i.e. Bahoi-Kabang, Na Thawi-Sadao, Saba Yoi and Songkhla subareas.

Stratigraphically, the Kubang Pasu Formation generally divisible into three members; namely in ascending order: Jelutong, Jenun and Papulut Members. The Yaha Formation generally subdivided into four informal members; namely in ascending order: Lower, Middle, lower Upper and Upper members.

The descriptions of each member of the Kubang Pasu Formation are as follows:

i. The lower part, Jelutong Member comprises interbeds of sandstone and shale with occasional chert sequence that yields Tournaisian radiolarian. Occasionally, bivalve *Posidonomya* sp. and trilobite pygidium has been found in the shale beds.
ii. The middle part, Jenun Member generally comprises very thick sequence of thickly-bedded well-laminated shale. Ammonoid *Agathiceras* sp. occasionally occurred in the lower portion of the middle part.
iii. The upper part, Papulut Member comprises very thick sequence of thickly-bedded sandstone of quartz arenite with thin shale partings. Metaconglomerate occurs in the higher level of the sequence. In Belum area, towards the upper part, it forms the fining upward sequence where pelitic rocks of schist and pelitic hornfels are predominant. As it is metamorphosed throughout, no fossil found within this member.

The descriptions of each member of the Yaha Formation are as follows:

i. The Lower member consists of interbedded of mudstone and sandstone. *Posidonomya* sp., ammonites and crinoid stem are occasionally found in the upper part whereas plant remains are abundant in argillaceous strata. Sandstone is brownish-white to greenish-grey, thick -bedded, medium-grained, quartzitic and lithic. Mudstone is grey to greenish-grey, thin-bedded.
ii. The Middle member consists of thick sequence of mudstone intercalated with thin- to medium-bedded, laminated sandstones with bivalve of *Posidonomya* sp. Pygidium trilobite and crinoids. Chert, siliceous shale yielded Tournaisian radiolarian, tuffaceous and lithic sandstone and mudstone are observed in the upper part of member.
iii. The Lower Upper member consists of thick sequence of thickly- bedded to massive quartzitic sandstone intercalated with thin- bedded mudstone. Chert and siliceous shale yielded Tournaisian radiolarian are also observed within the sequence. Conglomeratic sandstone and monomictic paraconglomerate are also intercalated in the upper portion.
iv. The Upper member consists of interbeds of well-bedded sandstone intercalated with mudstone, shale and siliceous shale containing *Posidonomya sp*., chonetids and trilobite pygidium. Thick sequence of red mudstone to siltstone intercalated with pale grey to white, thin-to medium- bedded sandstone with iron hard pans are generally recognized in this member especially in the north of the basin.

In term of stratigraphic boundaries, The Kubang Pasu is quite similar to the Yaha Formation i.e. the representative of the conformably underlain by the Silurian-Devonian succession of the Mahang Formation (in Malaysia) and the Betong Formation (in Thailand) and the conformably overlied by the Early Permian succession of the Gerik Formation (in Malaysia) and the Sri Paen Formation (in Thailand).

In term of stratigraphy, Jelutong and Jenun Members of The Kubang Pasu is quite similar to Lower and Middle member of the Yaha Formation. The representative of units compose of interbeds of sandstone and shale with occasional chert sequence that yields Tournaisian radiolarian and followed by thick sequence of mudstone intercalated with thin- to

medium-bedded, laminated sandstones with bivalve of *Posidonomya* sp. Pygidiums trilobite, ammonoids *Agathiceras* sp. and crinoids.

The Papulut Member of the Kubang Pasu Formation in Malaysia is quite similar to the lower Upper member of the Yaha Formation in Thailand. In general, both units recognize thick sequence of thickly- bedded to massive quartzitic sandstone intercalated with thin-bedded mudstone and conglomeratic sandstone in this sequence.

The Upper portion of Papulut Member of the Kubang Pasu Formation in Malaysia is recorded by the fining upward sequence of schist and pelitic hornfels dominant. The originate rock sequence should be quite similar to the interbeds of well-bedded sandstone intercalated with mudstone unit of the Upper member of the Yaha Formation in Thailand. However, because of the upper part of the Kubang Pasu was recorded to be mostly eroded. Therefore, the correlation of the redbeds in the upper part of the Yaha Formation in Songkhla area and the uppermost part of the Yaha Formation should be further studied.

Based on the similarity in stratigraphy and the stratigraphic boundaries of both rock units, the Kubang Pasu Formation is well correlatable to the Yaha Formation. Summary of lithostratigraphic correlation of the Kubang Pasu/Yaha Formation along the Malaysia-Thailand border is shown in Table 2 and distribution of the Kubang Pasu/Yaha Formation is compiled in Figure 91.

Table 2: Summary of lithostratigraphic correlation of Kubang Pasu/Yaha Formation along the Malaysia-Thailand border area.

<table>
<tr><th>Period</th><th colspan="2">Malaysian side</th><th>Description</th><th colspan="2">Thai side</th><th>Description</th></tr>
<tr><td rowspan="4">Carboniferous</td><td rowspan="4">Kubang Pasu Formation</td><td rowspan="2">Papulut Member</td><td rowspan="2">Thick sequence of predominantly thickly bedded to massive quartz arenite with occasional paraconglomerate beds. Pelitic rock with schistose and gneissic textures occur in the upper part of the sequence.</td><td rowspan="4">Yaha Formation</td><td>Upper member</td><td>Interbeds of well-bedded sandstone intercalated with mudstone, shale and siliceous shale containing Posidonomya sp., chonetids and trilobite pygidium</td></tr>
<tr><td>Lower upper member</td><td>Thick sequence of predominantly thickly bedded to massive quartzitic sandstone intercalated with thin bedded mudstone Chert, siliceous shale yielded Tournaisian radiolaria, are observed.</td></tr>
<tr><td>Jenun Member</td><td>Thick sequence of predominantly shale and mudstone with minor thin sandstone and siliceous shale beds, well-bedded and well-laminated. Ammonoid Agathiceras sp. occasionally occur at the lower part of the succession.</td><td>Middle member</td><td>Thick sequence of mudstone intercalated with thin- to medium-bedded, laminated sandstones with bivalve Posidonomya sp. Pygidium trilobite and crinoids. Chert, siliceous shale yielded Tournaisian radiolaria, tuffaceous and lithic sandstone and mudstone are observed in the upper part of member.</td></tr>
<tr><td>Jelutong Member</td><td>Interbeds of sandstone and shale containing Posidonomya sp. and trilobite pygidium with occasional chert sequence yielded Tournaisian radiolaria</td><td>Lower member</td><td>Interbeds of mudstone and sandstone containing Posidonomya sp., and crinoid stem are occasionally found whereas plant remains are abundant in argillaceous strata.</td></tr>
</table>

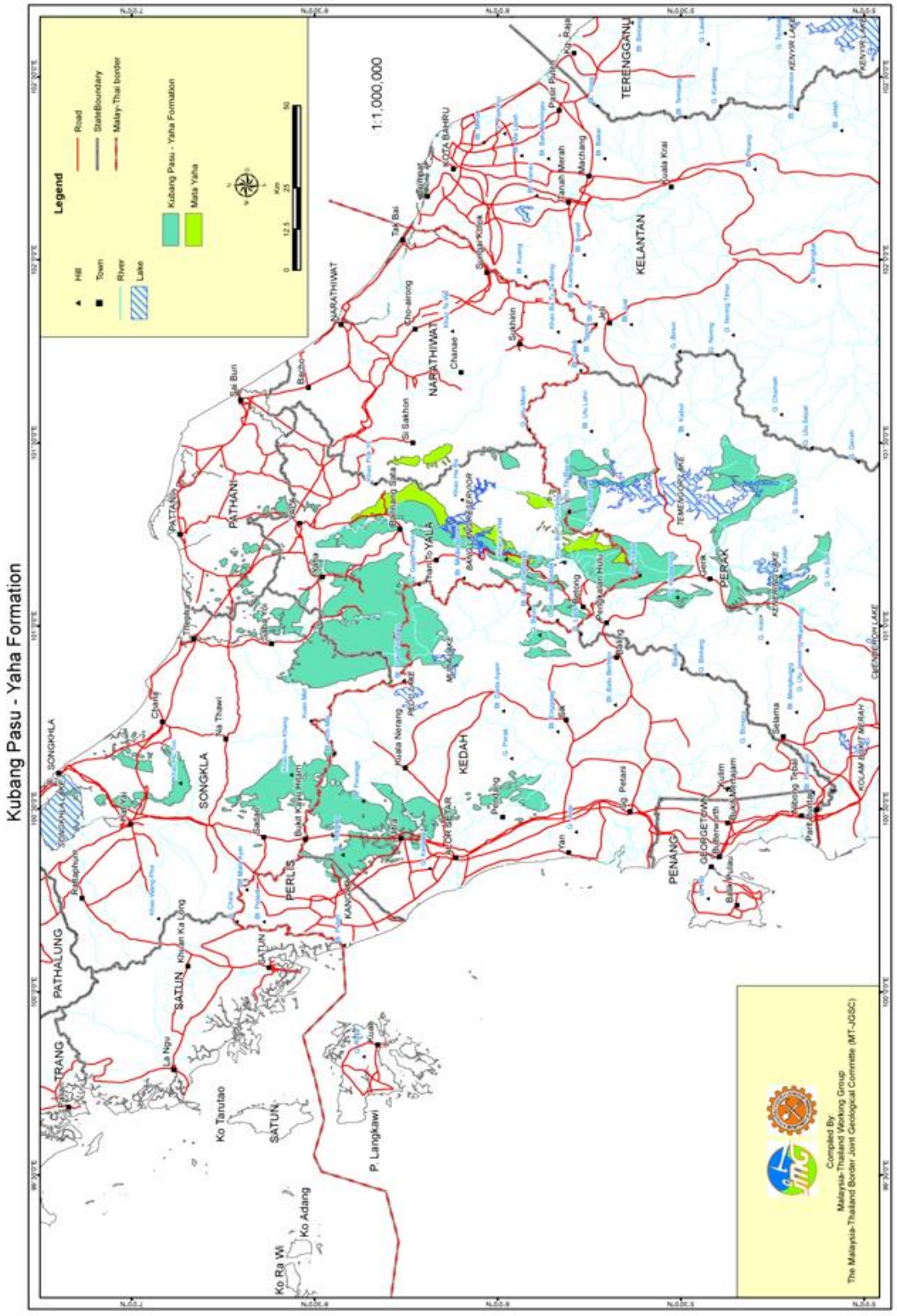

Figure 91 Map showing the distribution of the Kubang Pasu/Yaha Formation

5. AGE, TECTONIC AND DEPOSITIONAL ENVIRONMENTS

5.1 AGE

The lower limit of the Kubang Pasu/Yaha Formation in Malaysia side is exposed at Bukit Tuntong, Ulu Pauh area in Perlis where it rests conformably on the Silurian-Devonian Mahang Formation (Nur Susila Md. Saaid & Basir Jasin, 2014). At this locality, a rock sequence consists of red and grey mudstone and subordinate sandstone, and chert forms the basal part of the Kubang Pasu/Yaha Formation. At the strategy border road from Ban Suan Som to Ban Sa Ho, Betong District, Yala Province, Kubang Pasu/Yaha Formation is recorded conformably underlain by the Silurian-Devonian succession of the Betong Formation (The Malaysia-Thailand Working Groups, 2009)

Jones (1981) reported that the Upper Carboniferous strata do exist by the occurrence of a goniatite-brachiopod-gastropod fauna at Milestone 11 Alor Setar-Kuala Nerang road. Among the fossils, Gobbett identified the Upper Carboniferous genera *Agathiceras?* and *Paralegoceras?*

Sashida *et al*. (1998) reported the occurrence of Early Carboniferous radiolarians in chert lenses intercalated with sandstone and siltstone-dominated sequence at Ban Wang Yai, 12 km east of the Na Thawi town and at Ban Kabang, Kabang District, Yala Province. Sashida *et al*. (2000) later described that these radiolarians as *Entactinia variospina*, *E. vulgaris*, *Astroentactinia multispinosa*, *Spongentactinia* sp. and *Triaenospaera* sp. indicative of Early Carboniferous age (Tournaisian). *Posidonomya* sp., crinoids and plant remains had been occasionally found at Ban Nam Chieo and Ban Bahoi (Thailand).

Two species of radiolarian faunas had been identified from the chert exposed at Bukit Telaga Jatoh; *Entactinia variospina* (Won) and *Callela* sp. (Basir Jasin, 1995). *Entactinia variospina* indicates the age of Early Carboniferous, probably Tournaisian age (Braun & Schmidt-Effing, 1993).

Basir Jasin & Zaiton Harun (2001) reported the discovery of radiolarian *Entactinia variospina* in the chert from Guar Kepayang, in northern Kedah. Meanwhile eight radiolarian faunas discovered at Bukit Binjal contain *Entactinia variospina* (Won), *Entactinia unispina* (Won), *Entactinia* (?) *inaequoporosa* (Won), *Callela hexatinia* (Won), *Callela* cf. *parvispinosa* (Won), *Treanosphaera herbes* (Won), *Cubaxonium*? *octaedrospongiosum* (Won), *Duplexia*? *foremanae* (Ormiston and Lane), and *Duplexia parviperforata* (Won).

In the Kuala Nerang and Sintok areas, fossil assemblages of Bivalve *Posidonomya* sp., trilobites, ammonites, brachiopods, crinoids, gastropods and plant remains had been found at Bukit Tunjang, Sintok, Kedah, to the west outside of the Transect area. Further to the west of Sintok, Basir Jasin & Zaiton Harun (2001) reported the occurrence of *Albailella indensis-rota* Assemblage Zone (radiolarian) in chert representing the lower part of Kubang Pasu Formation at Bukit Binjal, Kedah. This confirms that the age of the lower part of Kubang Pasu Formation is Late Tournaisian (Early Carboniferous).

The Malaysian-Thai Working Group (2006) has found ammonoids of genus together with *Posidonomya* sp. and trilobite pygidium on a road-cut at Kampung Tok Kasim, near Sintok (6^o 26.947′ N, 100^o 27.060′ E) as shown in Figures 92 & 93. *Agathiceras* sp. also has been found in front of the Northern University of Malaysia campus at Sintok, Kedah (6^o 26.871′ N, 100^o 30.633′ E) as shown in Figure 94, also has been discovered at Kampung Tok Kasim outcrop. In Thailand, Fossil assemblages of the bivalve *Posidonomya* sp., trilobites, ammonites, brachiopods, crinoids, gastropods and plant remains had been found at Ban Bang Haeng, Khao Nam Kang, Na Thawi district.

The Kubang Pasu/Yaha Formation exposed along the border security road near Lepang Nenering in Pengkalan Hulu, Upper Perak is lithologically similar to the succession exposed in the Kuala Nerang area, north Kedah. However, the former is poor in fossils as compared to the later. Bedded chert and intraformational chert conglomerate occur in the lower part of the succession. Besides radiolarian in the chert, undeterminable plant fragments were found in the sequence of shale interbedded with sandstone. Basir Jasin & Zaiton Harun (2006) reported the discovery of Early Carboniferous radiolarian in the chert sequence. They have identified 20 radiolarian taxa of *Albaillella* cf. *perforata* Won, *Archocyrtium lagabriellei* Gourmelon, *Archocyrtium pulchrum* Braun, *Archocyrtium venustum* Cheng, *Astroentactinia biaciculata* Nazarov, *Astroentactinia digitosa* Braun, *Astroentactinia mirousi* Gourmelon, *Astroentactinia multispinosa* Won, *Astroentactinia stellaesimilis* Won, *Belowea hexaculeata* Won, *Belowea variabilis* Ormiston and Lane, *Ceratoikiscum berrgreni* Gourmelon, *Palaeoscenidium cladophorum* Deflandre, *Pylentonema antiqua* Deflandre, *Stigmosphaerostylus brilonensis* Won, *Stigmosphaerostylus tostispina* Ormiston and Lane, *Stigmosphaerostylus variospina* Won, *Stigmosphaerostylus vulgaris* Won, *Trilonche altasulcata* Won and *Triaenosphaera* sp. The radiolarian indicates Tournaisian age.

Figure 92: Posidonomya sp. in shale on a road-cut at Kampung Tok Kasim, near Sintok (6° 26.947′ N, 100° 27.060′ E)

Figure22: Trilobite pygidium in shale on a road-cut at Kampung Tok Kasim, near Sintok (6° 26.947′ N, 100° 27.060′ E)

Figure 94: Ammonoids genus *Agathiceras* discovered near the front gate of the Northern University of Malaysia campus, Sintok, Kedah, Malaysia (6° 26.871 N′, 100° 30.633 E ′),

Fossil assemblages of the bivalve *Posidonomya* sp., trilobites, ammonites, brachiopods, crinoids, gastropods and plant remains had been found at Bukit Tunjang and Kampung Baru, Sintok.

The Malaysia-Thailand Working Groups (2009) reported the discovery of well-preserved radiolarian probably indicative of Tournaisian age (Early Carboniferous) in seven chert samples collected along the border security road near Bukit Tangga, Kedah. The identification of the radiolarian had been done by Professor Katsuo Sashida of the Tsukuba University, Japan. The radiolarian faunas identified are *Stigmosphaerostylus* sp., *Archocyrtium riedeli* Deflandre. *Stigmosphaerostylus tortispina* (Ormiston and Lane), *Triaenospahera? Bareillensis* Gourmelon, *Astroentactinia multispinosa* (Won), *Helioentactinia polycanthina* (Foreman), *Stigmosphaerostylus* cfr. *palimbola* (Foreman), *Archocyrtium* sp., *Palaeoscenidium cladophorum* Deflandre, and *Pylentonema* sp.

Nur Susila Md. Saaid & Basir Jasin (2014) reported the occurrence of chert sequence in the lower part of Kubang Pasu/Yaha Formation that yields *Stigmosphaerostylus variospina* (Won), *Stigmosphaerostylus vulgaris* (Won), *Astroentactinia multispinosa* (Won) and *Belowea* sp. They propose the term Pala Member for the chert sequence as lowermost part of the Kubang Pasu succession

In 2014, Thai working Group observed fossil assemblages of the bivalve chonetids.and pygidium of trilobites in Ban Trap, Muang District, Songkhla Province.

In 2014, Saesaengseerung (in manuscript) recorded the radiolarian assemblages in three locations of the Kubang Pasu/Yaha Formation in Songkhla Province as follows;

1) Khao Noi, Sting Phra District, Radiolarian assemblages in siliceous shale includes, *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*cf. *Vulgaris* (Won), *Stigmosphaerostylus*sp., *Archocyrtium* sp. and *Pylentonema*sp . The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian)
2) Khuan Bu, Muang District, Radiolarian assemblages in siliceous shale to chert includes *Albaillela*sp., *Stigmosphaerostylusvariospina* (Won), *Stigmosphaerostylus*sp.,*Trilonche* sp., and *Pylentonema*sp. The occurrence of *Stigmosphaerostylusvariospina* (Won) is characteristic species of *Stigmosphaerostylusvariospina* assemblage in Early Carboniferous (Tournaisian).
3) Ko Yo Muang District, Radiolarian assemblages in siliceous shale to chert includes, *Albaillela*sp. *Stigmosphaerostylusvariospina* (Won), *Trilonche* sp., *Stigmosphaerostylus*sp., and *Ruzhencevispongus*sp. The conodont in this area was also investigated. They include *Polygnathus*genera which were reported from Early Devonian to Early Carboniferous sequence worldwide.

On the basis of the faunal assemblages, the Kubang Pasu/Yaha Formation is assigned as Early to Late? Carboniferous age.

5.2 TECTONICS

The Early Carboniferous was a time of important changes in plate tectonic and tethyan plate tectonics. Bunopas (1981) proposed that Gondwana moved rapidly in a clockwise rotation and the Australian continent moved rapidly towards the south. During the rotation of Gondwana, rifting began along its northern margin from Sibumasu to Turkey observable as a rift basin in the north of the continent. The Late Ordovician or Early Silurian rocks deposited along the eastern margin of the continent (with respect to the present) as well as some parts of Precambrian rocks were rifted away from Gondwana.

The Kubang Pasu/Yaha Formation had been deposited in the depositional basin located on Sibumasu block or Gondwanaland to the west of Bentong-Raub Suture Zone. During the Carboniferous, Sibumasu block have lain 43^{o} south, adjacent to, or part of northwest Australia (Huang & Opdyke, 1991). No major tectonic events occurred during the deposition of the Kubang Pasu Formation. The relatively quite environment allows the deposition of that thick areno-argillaceous sequence throughout the Carboniferous period.

After the deposition of Kubang Pasu/Yaha Formation, during Late Permian to Early Triassic, the Sibumasu block travelled northwards nearer to the palaeo-equator (Sasajima *et al*., 1978) and (Bunopas *et al*., 1989). Sibumasu collided with Cathaysialand or Indochina microcontinent in the Triassic to form the Bentong-Raub Suture with the elimination of Palaeo-Tethys Ocean. This resulted in the major mountain building events known as the Indosinian Orogeny (Hutchison, 1989).

The final suturing during the Indosinian Orogeny created crustal thickening resulting in the intrusion of the S-type tin-bearing Main Range Granite (Hutchison, 2009). The granitic intrusion has resulted in the major metamorphism episode to the existing rocks including the Kubang Pasu/Yaha Formation that distributed in vicinity of the intrusion belt including in eastern Kedah and Upper Perak areas in Malaysia and Pattani, Yala and Songkhla Provinces in Thailand.

5.3 DEPOSITIONAL ENVIRONMENT

Terrigeneous sediments as source supply for the Kubang Pasu /Yaha Formation should derived from the older rock units. Based on paleoslope and paleo-current studies, the detrital materials probably transported from the west as well as from northwest, derived from a landmass somewhere in the west (Ahmad Jantan, 1973).

The lower part of the Kubang Pasu/Yaha Formation, Jelutong/Lower Member is dominantly observed in Malaysia. The unit characterized by interbeds of sandstone, mudstone and shale with occasional occurrence of chert and siliceous shale. The color of the rocks is dominantly in the shade of red. This indicates that the rocks have been affected by oxidation process, which usually takes place in shallow water. Fossils found in this unit are usually broken and they include *Posidonomya* sp., *Macrobole* sp., gastropod and crinoid, which also indicates shallow water environment. According to lithological characteristics and fossil assemblages, it is interpreted that the lower part of the Kubang Pasu/Yaha Formation was probably deposited in a shallow marine in continental shelf environment. The presence of chert and siliceous shale in the lower part of the Kubang Pasu/Yaha Formation in Malaysia may be due to the increase in supply of silica derived from the siliceous rocks of the Mahang/Kroh/Betong Formation, or radiolarians activity, or both aspects. The presence of lenticular sandstone and thick-bedded mudstone indicates the deposition in the sand flat and mix flat zones near the low tide. However, the wave actions were then low energy due to the presence of complete forms of fossils particularly bivalves.

The middle part of the Kubang Pasu/Yaha Formation, Jenun/Middle Member is represented by very thick sequence of shale and minor thin-bedded sandstone, with ammonoid *Agatheceras* sp., chonetid brachiopods and crinoids assemblages in Malaysia side. In Thai side, bivalve of *Posidonomya* sp. Pygidium trilobite and crinoids are found. Chert, siliceous shale yielded Tournaisian radiolarian, tuffaceous and lithic sandstone and mudstone are observed.

Thick sequence of shale and minor thin-bedded sandstone sequence may be interpreted as having been deposited in the outer shelves below low tide-mean tide level, where winnowing process may have led to the deposition of finer-grained sediments. The upper sequence of Jenun/Middle Member in Thailand is represented by shale and tuffaceous shale intercalated with reddish-brown, fine-grained sandstones followed by dark-grey, well-bedded, thin-bedded chert. The sequence may be interpreted as having been deposited in outer shelves where winnowing process may bring about the deposition of cherts and finer-grained sediments. The coarsening and thickening upward, and fining and thinning upward sequences at the top part may represent the regressive and transgressive phases respectively, caused by fluctuation of either sea level or tectonism or both in Early Carboniferous.

The upper part of the Kubang Pasu/Yaha Formation, Papulut/Lower Upper/Upper Member may represent a near shore environment of deposition, probably in either intertidal or upper subtidal zones with partly subaeriel environment. The rock is composed of very thick sequence of thickly-bedded sandstones intercalated with mudstone, shale and conglomerate beds. Thick-bedded to massive, well-sorted quartzitic sandstone with graded bedding and cross lamination may represent a near shore environment of deposition, probably in either intertidal or upper subtidal zones. The occurrence of plant fossil fragments within the shale and fine-grained sandstone indicates that the environment of deposition may be a shallow marine environment. Poorly sorted metaconglomerate in Malaysia is interpreted as reworked conglomerate previously deposited in the shelf environment and then redeposited in the deeper environment together with the arenaceous and argillaceous materials. The coarsening and thickening upwards, and subsequent fining and thinning upwards sequences at the top part may represent the regressive and transgressive phases, respectively.

The topmost part of the Papulut Member comprises interbeds of argillites and minor arenite sequence. In Songkhla area, red color of argillaceous sequence is also recorded.The presence of red argillite with iron hard pans in the top most of the Formation in Thailand together with marine fossils may indicate the maximum regressive phrase. The basin of deposition subsequently became salt marsh or flood plain in which oxidization subaerial condition may be occurred at the maximum high tide where complete forms of fossils without influences from wave and tide can be found. The occurrence of various hard pans indicates the hiatus and may be criteria to support this interpretation. These phases may have been caused by fluctuation of sea level or tectonic or both in the Late Carboniferous to probably Early Permian.

According to the litholgy and fossil evidence, The Kubang Pasu/Yaha Formation was deposited in the intertidal environment to a continental shelf environment. The presence of gritty to pebbly or conglomeratic layers indicates quite strong current that occurred locally from time to time during the depositional episode. The coarsening and thickening upwards, and subsequent fining and thinning upwards sequences at the top part may represent the regressive and transgressive phases, respectively. These phases may have been caused by fluctuation of sea level or tectonic or both during the deposition of the rock unit.

The schematic model of the depositional environment of the Kubang Pasu/Yaha Formation is illustrated in Figure 95

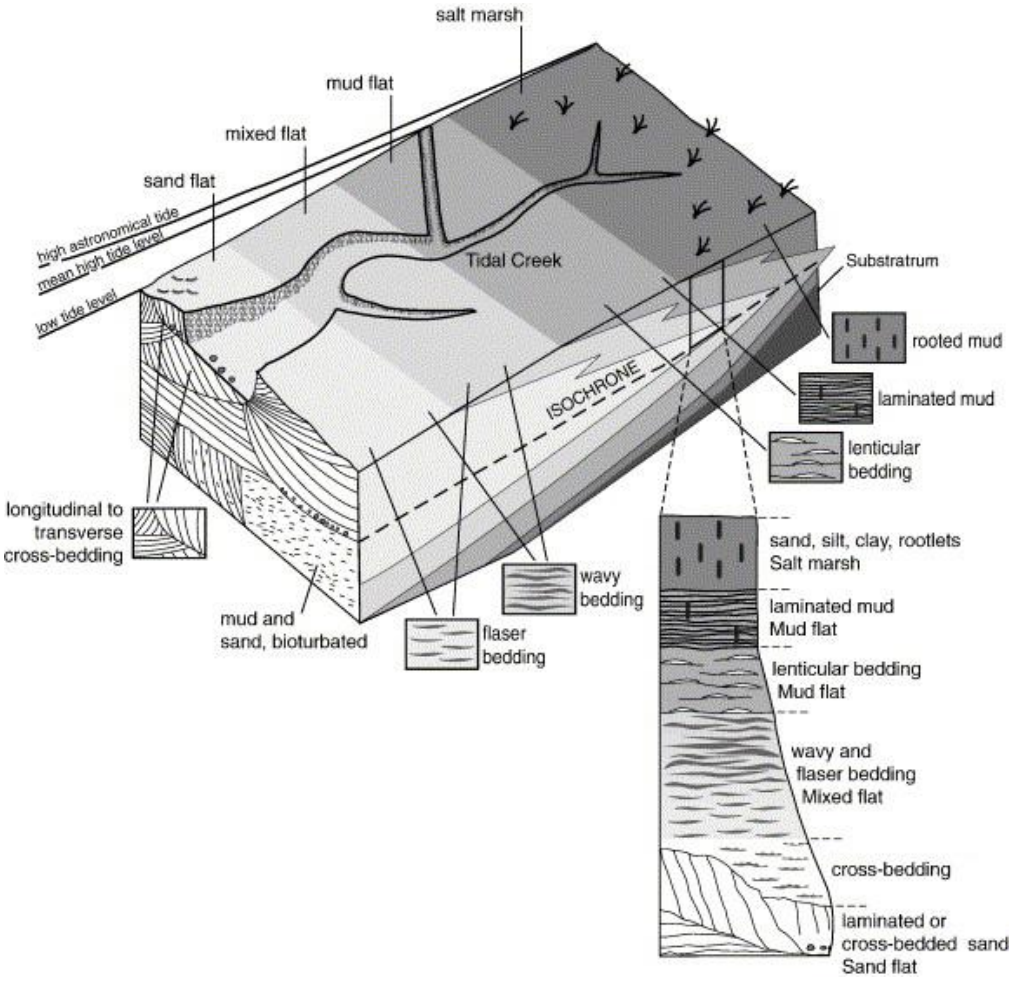

Figure 95: Schmatic model of the depositional environment of the Kubang Pasu/Yaha Formation (www.sciencedirect.com/science/article/pii/S0025322706003483)

6. DISCUSSION AND CONCLUSION

6.1 DISCUSSION

a. On the Malaysian side, the Kubang Pasu Formation is divisible into three members; in ascending order; Jelutong, Jenun and Papulut Members. It is ranging in age from Upper Devonian to Lower Carboniferous.
b. On the Malaysian side, the Kubang Pasu Formation is mainly distributed in Ulu Pauh, Perlis; Sintok, Pendang, Sungai Teliang, Ulu Legong and Gunung Bayu in Kedah; and Papulut, Kerunai and Belum areas in Perak.
c. In eastern Perlis and western Kedah, the Kubang Pasu Formation is interpreted overlain by the Permian Chuping Formation. In eastern Kedah, Kubang Pasu Formation is interpreted overlain by the Permian Cherty Unit, whilst in Upper Perak area, it is interpreted overlain by the Permian Gerik Formation. However, no direct contact between Kubang Pasu Formation and the overlying younger sequence being observed in the field.
d. On the Thai side, the term Yaha Formation is used for sandstone, mudstone, shale and chert of the Carboniferous age located at the western flank of the main range granite belt, covering Pattani, Yala and Songkhla Provinces. The Yaha Formation can be divided into four informal members, namely in ascending order: Lower, Middle, Lower Upper and Upper members. It is ranging in age from Lower Carboniferous to Upper? Carboniferous.
e. The Yaha Formation is conformably underlain by the Devonian Betong Formation and conformably overlain by the Early Permian Sri Paen Formation.
f. The thick sequence of redbed unit of the Yaha Formation in Songkhla subarea is new discovered. Sequence of mainly red and grey mudstone with bioturbation and hard pans are abundant. Pygidium of Trilobite, ammonite and chonetids are observed in this unit. The sequence is believed that it can be lateral facies change with the red clastic rocks of the upper grey to greenish grey mudstone and siltstone of the Yaha Formation in southwardly area.
g. In term of stratigraphic correlation, the Jelutong Member of the Malaysian side can be correlated with the lower member on the Thai side, the Jenun Member can be correlated with the middle member, and the Papulut Member can be correlated with the combined lower upper and upper members.
h. The Kubang Pasu Formation/Yaha Formation has been deposited in the intertidal to continental shelf of the cratonic area in the Sibumasu terrain.

6.2 CONCLUSION

Based on lithological characteristics and faunal assemblages, the Kubang Pasu Formation on the Malaysian side is correlatable with the Yaha Formation on the Thai side. Age of the Kubang Pasu/Yaha Formation is assigned based on the discovery of the radiolarian and other fossils to be Carboniferous period. Based on lithological characteristics and fossil assemblages, it is interpreted that the Kubang Pasu Formation/Yaha Formation was probably deposited on intertidal environment to a continental shelf environment. The presence of gritty to pebbly or conglomeratic layers indicates quite strong current that occurred locally from time to time during the depositional episode. The coarsening and thickening upwards, and subsequent fining and thinning upwards sequences at the top part may represent the regressive and transgressive phases, respectively. These phases may have been caused by fluctuation of sea level or tectonic or both aspects.

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APPENDICES