



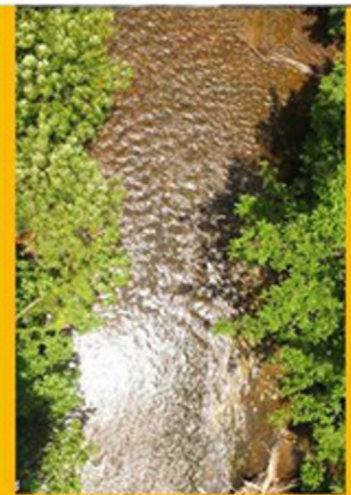
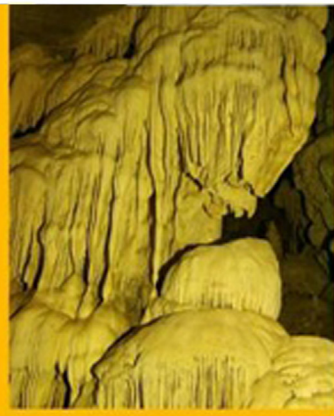
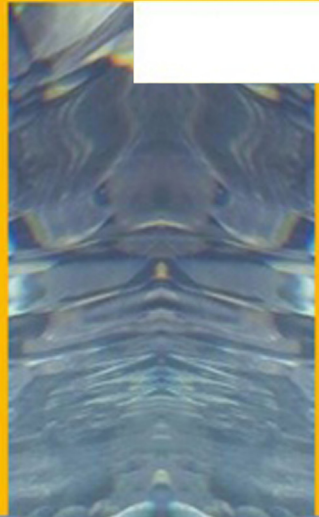
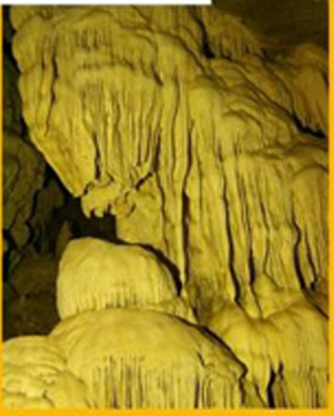
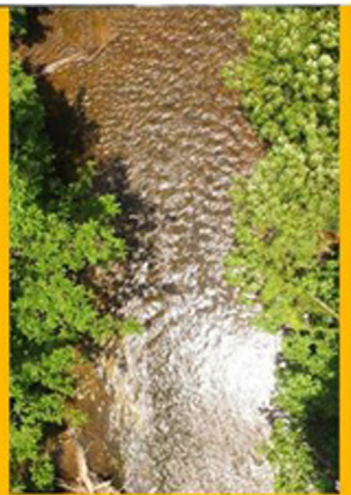
THAI National Commission for UNESCO  
สำนักงานคณะกรรมการแห่งชาติว่าด้วยการศึกษา  
วิทยาศาสตร์ และวัฒนธรรมแห่งสหประชาชาติ (ยูเนสโก)



DMR-CCOP-TNCU Technical Seminar on  
"Biostratigraphy and Karst Morphology of Satun Aspiring Geopark"

**INTERNATIONAL GEOLOGICAL SIGNIFICANCE and GEOLOGICAL**

**DIFFERENCES BETWEEN LANGKAWI AND SATUN GEOPARKS**

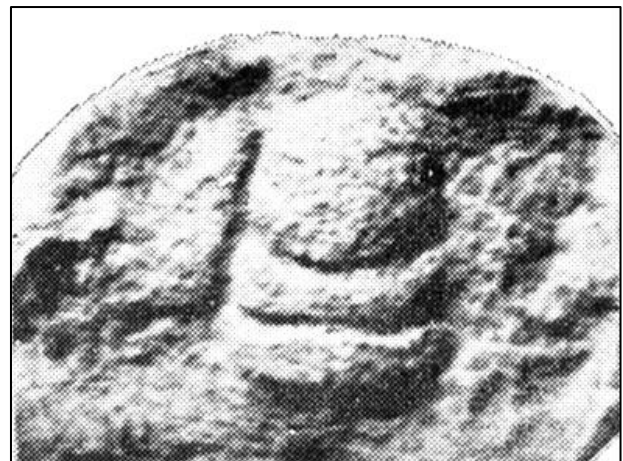
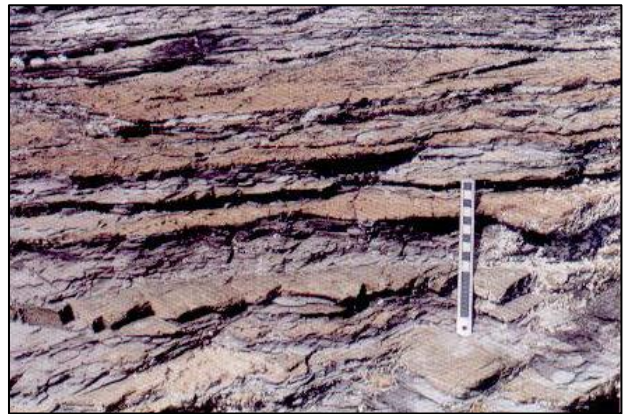


**SATUN**    
Aspiring Geopark

13<sup>th</sup>-14<sup>th</sup> July 2017  
The Berkeley Hotel Pratunam  
Bangkok, Thailand

**SATUN**    
Aspiring Geopark

# INTERNATIONAL GEOLOGICAL SIGNIFICANCE



**SATUN**    
Aspiring Geopark

## TABLE OF CONTENTS

Abstract.....	1
A-International Geological Significance.....	1
A-1. Tarutao Island Type Section.....	1
A-1.1 TaruTao Group.....	1
A-2. Khao Noi Type Locality.....	3
A-2.1 Thung Song Group (Ordovician) .....	3
A-2.2 Thong Pha Phum Group (Silurian-Devonian-Carboniferous).....	4
A-3 Kaeng Krachan Group (Uppermost Carboniferous-Lower Permian).....	4
 Annex	
Annex 1 Stratigraphic Type Section, Tarutao Island.....	5
Annex 2 Khao Noi Stratigraphic Type Area.....	10
Annex 3 Kaeng Krachan Group.....	21
REFERENCES.....	22



- Middle part: Medium beds of brown to brownish pink sandstone, thin shale interbedded  
Thickness; 180 m
- Thick to very thick beds of cross bedded brown quartzitic or orthoquartzite, gray to green shale interbedded  
Thickness; less than 270 m
- Lower part: Thick beds of brown to grayish brown, coarse-grained sandstone with inclusion of some conglomerate and ilmenite mineral.  
Thickness; less than 100 m

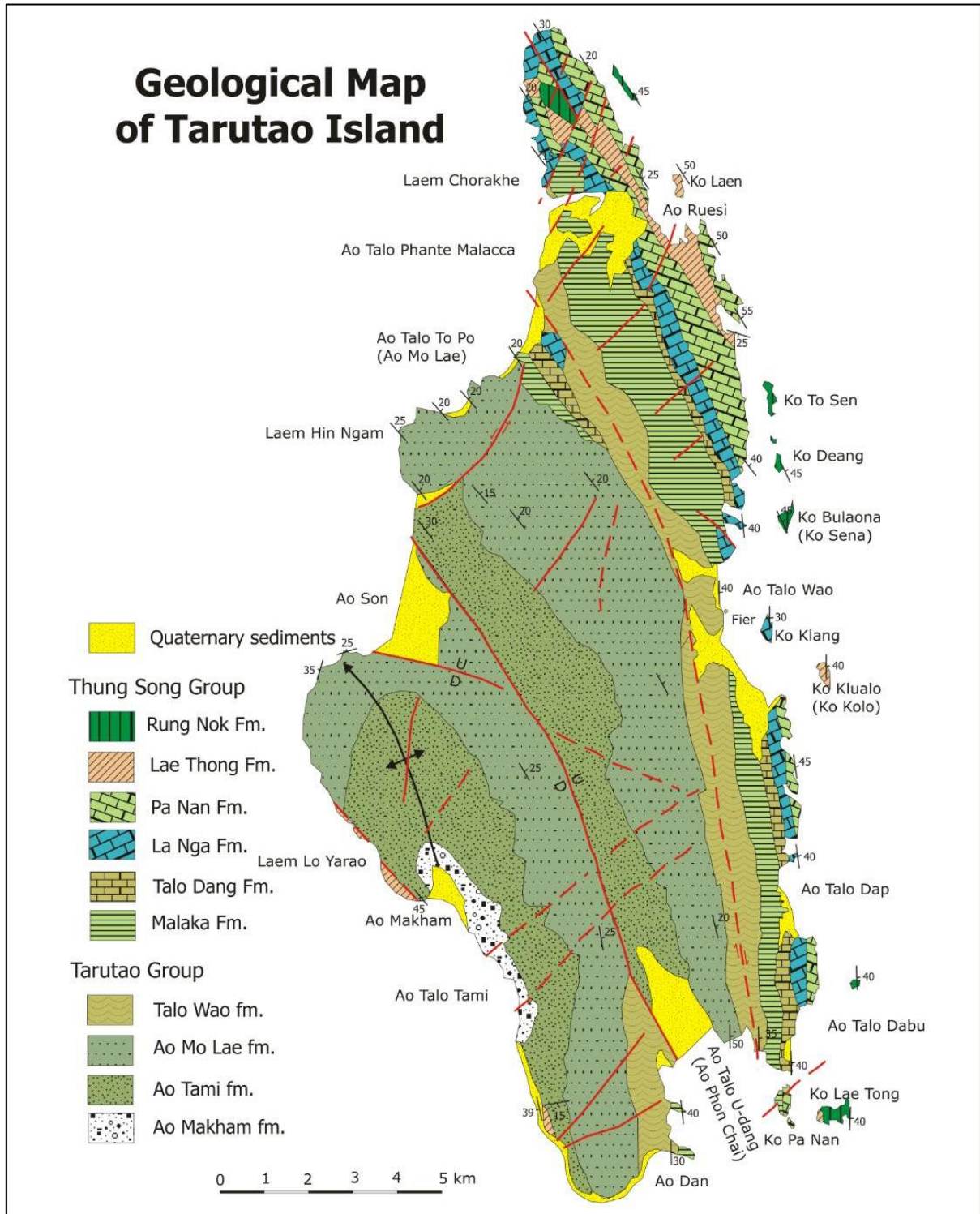


Figure 1 Geologic map of the Tarutao Island (Clive and Chaodamrong, 2017, personnel communication).

Numerous trilobites and brachiopods are present in the west of Tarutao island. Kobayashi (1957) dated a common trilobite fauna yield the Late Cambrian. The best known trilobites are *Pagodia thaiensis*, "*Eosaukia*" *buravasi*, and *Coreanocephalus phanulatus* while brachiopods are *Apheorthis* (?) sp. Shergold *et al.* (1988) studied the trilobites of the Tarutao Group from Tarutao island and concluded that they are Late Cambrian to the boundary between Cambrian and Ordovician. The oldest trilobites are found in the west of Tarutao island and west of Laem Hin Ngam and include *Hoytaspis? thanisi*, and *Prosaukia ? aff. nema*.

The younger trilobite fossils were found in Talo Topo bay consisting of *Lichengia? tarutaoensis* (Kobayashi) (= *Saukiella tarutaoensis*), *Lophosaukia* cf. sp. indet., *Quadratichephalus planulatus* Kobayashi (= *Coreanocephalus planulatus*), *Leiostegiid* gen. et sp. indet., *Shumardiid* gen. et sp. indet., *Szechuanella ? cf. damujingensis*, *Thailandium solum*, *Tsinania (Tsinania)* cf. *jiangnanensis*, *Micragnostus (Micragnostus) nomas*. The trilobite assemblage is closely related to those previously described from the inner detrital environments (rather than platform carbonate) of northern Vietnam, western Yunnan, Sichuan, Gansu and eastern Qinghai and in central Australia (Shergold *et al.*, 1988) and may indicate proximity of these areas in the Late Cambrian to Early Ordovician (Burrett *et al.*, 1990). The youngest Cambrian fossils were found at Talo Udang bay as identified by trilobite; *Parakoldinioidia thaiensis*, (= *Pagodia thaiensis*), which dates closely to the Cambro- Ordovician boundary.

Ordovician fossils are limited to the uppermost part of the Tarutao Group at Malaka bay, northwest of Tarutao island (Wongwanich *et al.*, 1983) and Talo Udang bay in south of Tarutao island (Stait *et al.*, 1984). The fossil strata are the *Pagodia- Eosaukia* fauna beds described by Kobayashi (1957). This Middle to Upper Tremadoc fauna consists of *Pseudokainella malakensis*, *Asaphellus* sp., *Geragnostus*, *Rossaspis bunopasi* and a harpid. *Rossaspis* also occurs in the overlying Thung Song limestone on Tarutao island and in Kanchanaburi province (Wolfart 2001).

In conclusion, **Upper Cambrian** of 19 species of trilobites were described by world expert (John Shergold) with stratigraphic and sedimentological control. Furthermore, brachiopod and conodont fossils identified Cambrian-Ordovician boundary. Recently, absolute dating of ash layers found between index fossil layers at the Cambrian-Ordovician boundary has been studied and this may bring to another indication of absolute age of the Global Boundary Stratotype Section and Points (GSSP).

**Lower Ordovician** trilobite fauna on the Tarutao Island indicates succession of highly fossiliferous limestone. Detailed studied on sedimentology discloses that the layers contains nautiloids\*, conodonts\*, the gastropod *Peelerophon oehlerti* (Gondwana)\* and chiton *Chelodes whitehousei* (Australia) \* and brachiopods *Syntrophina* & *Archaeorthis?*. In Satun mainland, similar faunas to Langkawi. *Spanodonta* – Australian brachiopod and *Aportophyla*\* and nautiloids\*. Characteristics of lithology and fossils of the Tarutao Group in Tarutao island are illustrated in annex 1.

## A-2 Khao Noi Type Locality

### **A-2.1 Thung Song Group (Ordovician)**

Thung Song Group was firstly called Thung Song limestone by Brown *et al.* (1951). It was upgraded to the Thung Song Group by Javanaphet (1969). Later, Burton (1974) called Ordovician limestone in Nakhon Si Thammarat (Thung Song district) that lying over the Cambrian sandstone and quartzite as Nai Tak formation. Bunopas (1981) named this group of rocks found in Tarutao island as Thung Song formation. Recently, most of geologists names Ordovician limestone in the south and other regions in Thailand as the Thung Song Group.

Characteristics of rocks and fossils in the Thung Song Group by Wongwanich (1990) at the tarutao island and are described in annex 2.

Bunopas (1981) reported the continuation of the rock sequence in this group was found in eastern end of Talo Udang bay, south of Tarutao island. Lower to middle part and gradational contact between the Thung Song Group and underlying red sandstone of the Tarutao Group were found. The upper part of the group is exposed at a limestone mountain in northeastern part of the island close to Rusi bay.

Detailed study of the Thung Song Group at Tarutao island has been made by Teraoka *et al.* (1982), Wongwanich *et al.* (1983), and Wongwanich (1990). The study of the Thung Song Group at Tarutao island can be divided rocks into 6 formations. Sequence of rocks conformably lies over the red sandstone of the Tarutao Group. In addition, Wongwanich *et al.*, (1990) found the uppermost part of the Thung Song Group in area north of La-ngu district, Satun province, consists of another formation of red deep marine limestone.

In conclusion on fossil biodiversity, **Middle Ordovician** comprises large, well preserved, fauna of 39 species of Katian to Ashgill, deep and/or cold water trilobites in stratigraphic sequence described by world leading expert on trilobites\*. Brachiopod *Foliomena*\*, large nautiloids also found at this layer. **Upper Ordovician** fossil of conodonts are described\*, Hirnantian *Hirnantia-Mucronaspis*, fauna with graptolite control\*\*.

### **A-2.2 Thong Pha Phum Group (Silurian-Devonian-Carboniferous)**

Silurian-Devonian-Carboniferous rocks in southern region overlie Thung Song Group and underlain the Khuan Klang Formation or the Kaeng Krachan Group. The rocks predominantly consist of black shale, chert, sandstone and limestone. They distribute in western and central region of southern Thailand from Khao Luang, Surat Thani province to Nakhon Si Thammarat province, and Satun province.

Wongwanich *et al.*, (1990) made a detailed study of the rocks at km 10-11 along road between Lang-Thung Wa districts, north of Satun province and mapped four formations. The sequence of these formations, starting from older to younger, comprises the Wang Tong, Kuan Tung, Pa Samed and Khao Chu Nong Formations. They were dated Late Ordovician to Carboniferous. Later, conodonts at the Khao Chu Nong Formation were dated as Ordovician and are denoted fault contact rock with the underlying Pa Samed Formation. Therefore the Thong Pha Phum Group in the southern region consists of only three formations.

**Silurian:** Graptolite fauna described\*.

**Devonian:** Four species of Lower Devonian brachiopod described by world leading expert on Silurian-Devonian brachiopods (Boucot)\*. Furthermore, Lower Devonian conodonts\*, Lower Devonian trilobite and another fauna (5 species) have been described by Fortey. Peri-Gondwanan deep water trilobite *Plagiolaria poothai*\*, and Tentaculitids have been described\*.

**Carboniferous:** Diverse fauna with these trilobites found in Khuan Klang Formation at Satun geopark boundary has not been described yet as well as *Posidonomya* and radiolarian fauna. Namurian B (Lower Pennsylvanian) brachiopod/ goniatite fauna are described by world leading experts on brachiopods and goniatites, (Boucot and House)\*.

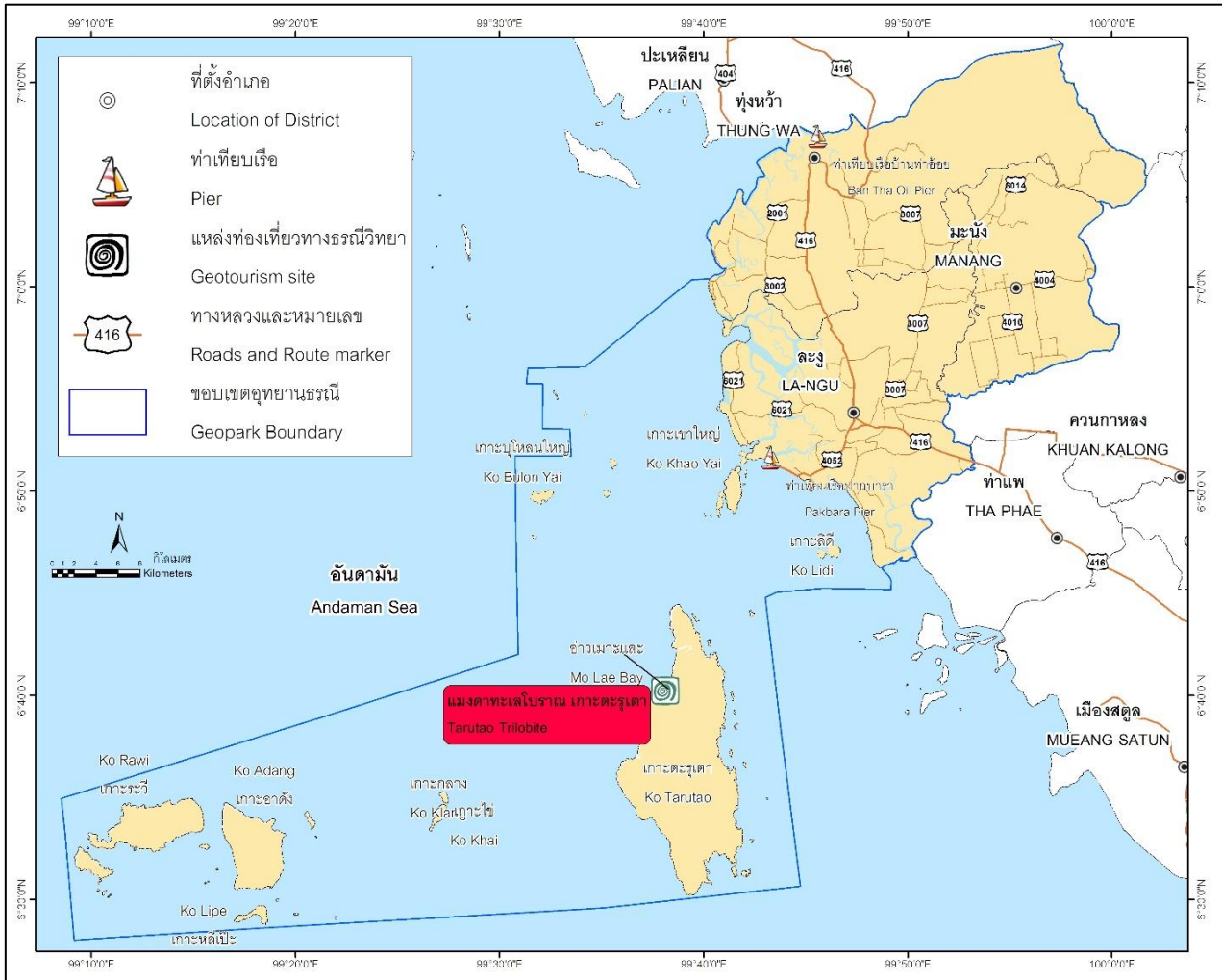
Characteristics and stratigraphy of rocks in Thong Pha Phum Group in Satun Geopark undary are described in annex 2.

### **A—3 Uppermost Carboniferous –Lower Permian**

The Kaeng Krachan Group, aged Uppermost Carboniferous – Lower Permian which does not mention in the dossier but found in the Satun geopark boundary also provides Geological International significant as claimed in the Langkawi UNESCO Global Geopark. Detail and International Geological significant is described in annex 3

## Annex 1: Stratigraphic Type Section, Tarutao Island

Location: Ao (Bay) Mo Lae , Ko (Island) Tarutao, Ko Sarai Subdistrict, Mueang District, Satun Province.



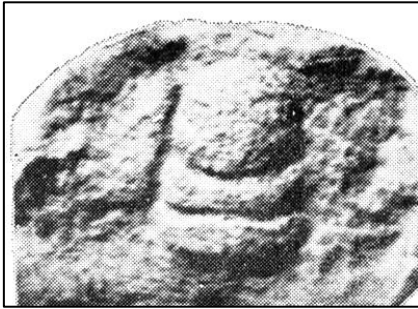
“Tarutao” is a distorted word from the word “Talotrao” in Malay language meaning a lot of gulf. Tarutao is a national park in the Andaman Sea and a center of nature both inland and underwater. Most of the area consists of steep mountains, the highest mountain peak is 708 meters above mean sea level. It was honored as an ASEAN Heritage Parks and Reserves by UNESCO in 1982 (2525). The island is also settlement for the sea gypsies believe in ancestral spirits and natural spirits.

**Highlight:** Complete composite succession of the Stratigraphic type section of the Tarutao Group where enormous and various kind of Paleozoic shallow sea fossils are found. Mo Lae Bay is composed of sandy beach and red sandstone beach.

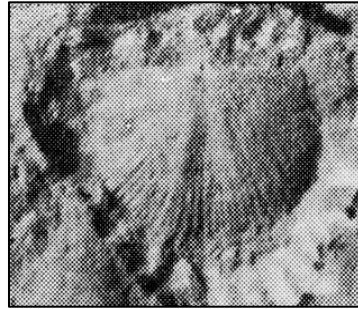
**Geology:** The Tarutao Group stratigraphic type section is situated at the Tarutao Island, referred to all of the quartzose and variegated sandstone, thinly to thickly bedded , poorly developed tabular cross beds where composite thickness is more than 1,000 meters. Tabular cross bedding was found at the upper part of the sequence, revealing eastward paleocurrent flow. The area is rich with diverse tropical plants and the richest Cambrian trilobite fossils in Southeast Asia. One new genus and 5 new species have been found here, including *Thailandium solum*, *Eosaukia buravasi*, *Saukiella tarudaoensis*, *Pagodia thaiensis*, and *Coreanocephalus planulatus*, with *Apheorthis* (?) sp brachiopods indicating shallow marine environment deposition during Upper Cambrian or approximately 500 million years ago. Moreover, the

Tarutao Island is an important area to study the outstanding continuous sequence of Cambrian to Ordovician.

- The oldest trilobite fossil in Thailand approximately 500 million years ago and new specie of the world had been firstly discovered in red sandstone.



The oldest trilobite fossil in Thailand and new specie of the world named *Eosaukia buravasi*.



Brachiopods *Apheorthis* (?) sp. in sandstone aged Upper Cambrian



Fragments of trilobite and other shallow sea fossils commonly found in the Tarutao Group.



Cambrian sandstone exposes at Mo Lae Bay, Tarutao Island.

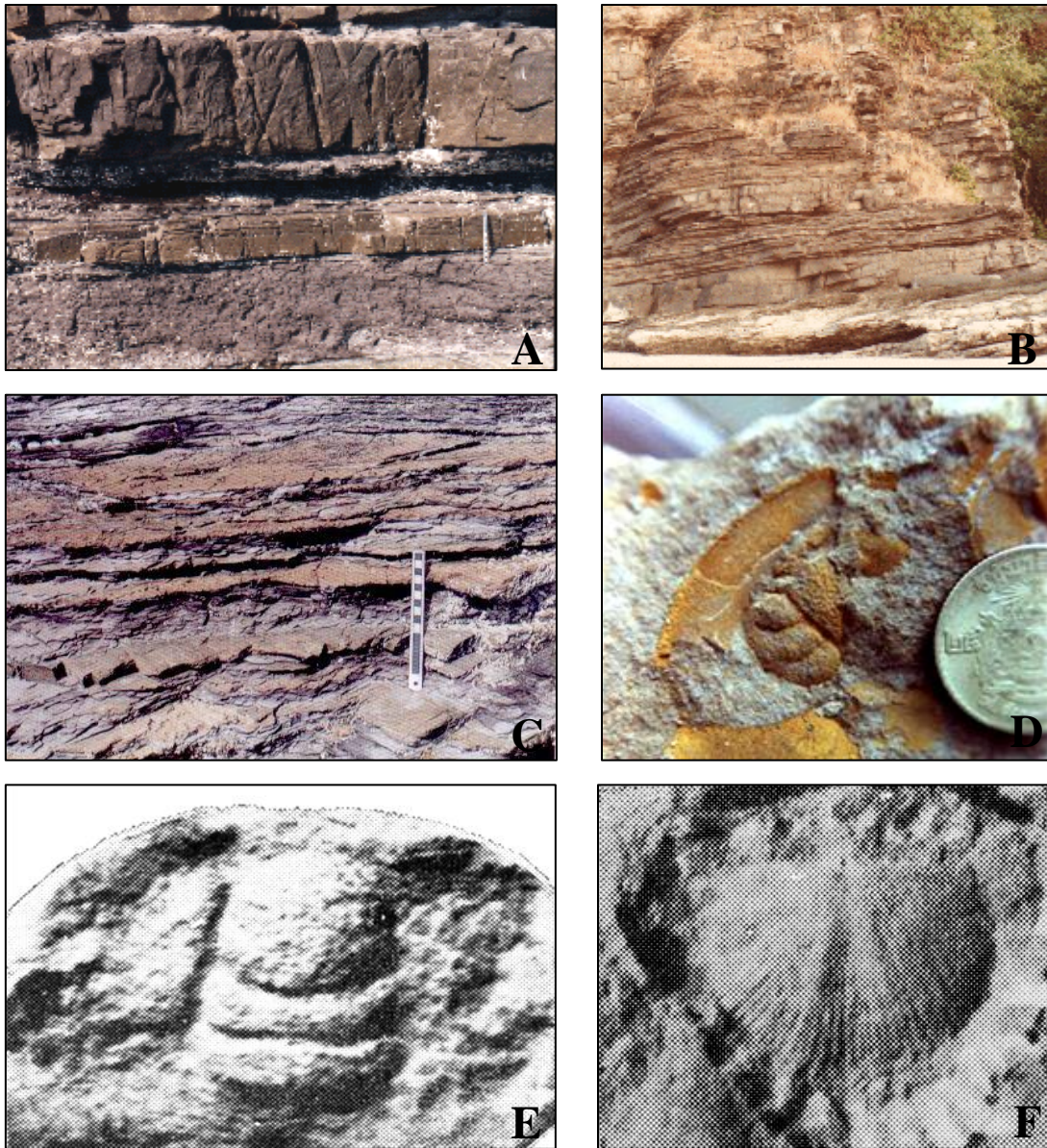
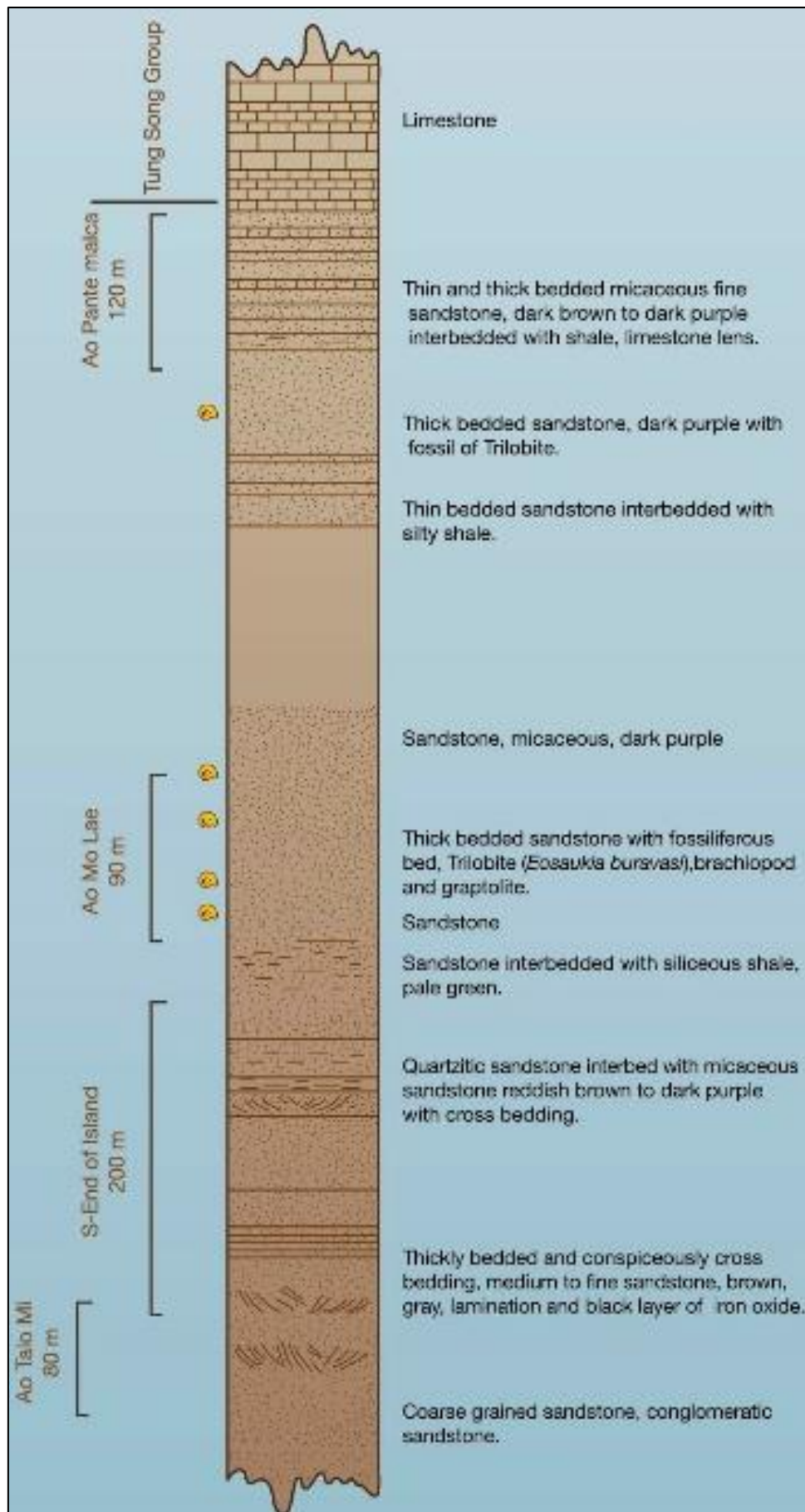


Figure A-1.1 Pictures of rocks and fossils belong to the Tarutao Group, Tarutao island, Satun province.

- A. Interbedding of red sandstone and shale. More resistance to weathering and erosion in sandstone showing thin beds and sharp contacts.
- B. Interbedding of red sandstone and shale in Middle of the Tarutao Group at Talo Topo bay.
- C. Passage beds or translation zone between the Tarutao Group and the Thung Song Group show interbedding of brown limestone, purple gray sandstone and shale in area northern bank of Malaka canal.
- D. Fragment of trilobites fossil commonly found in red sandstone of this group.
- E. *Eosaukia buravasi* in sandstone at mouth of Malaka canal dated Late Cambrian.
- F. Brachiopods *Apheorthis* (?) sp. in sandstone at northwestern coast of Tarutao island (x3 of the size)

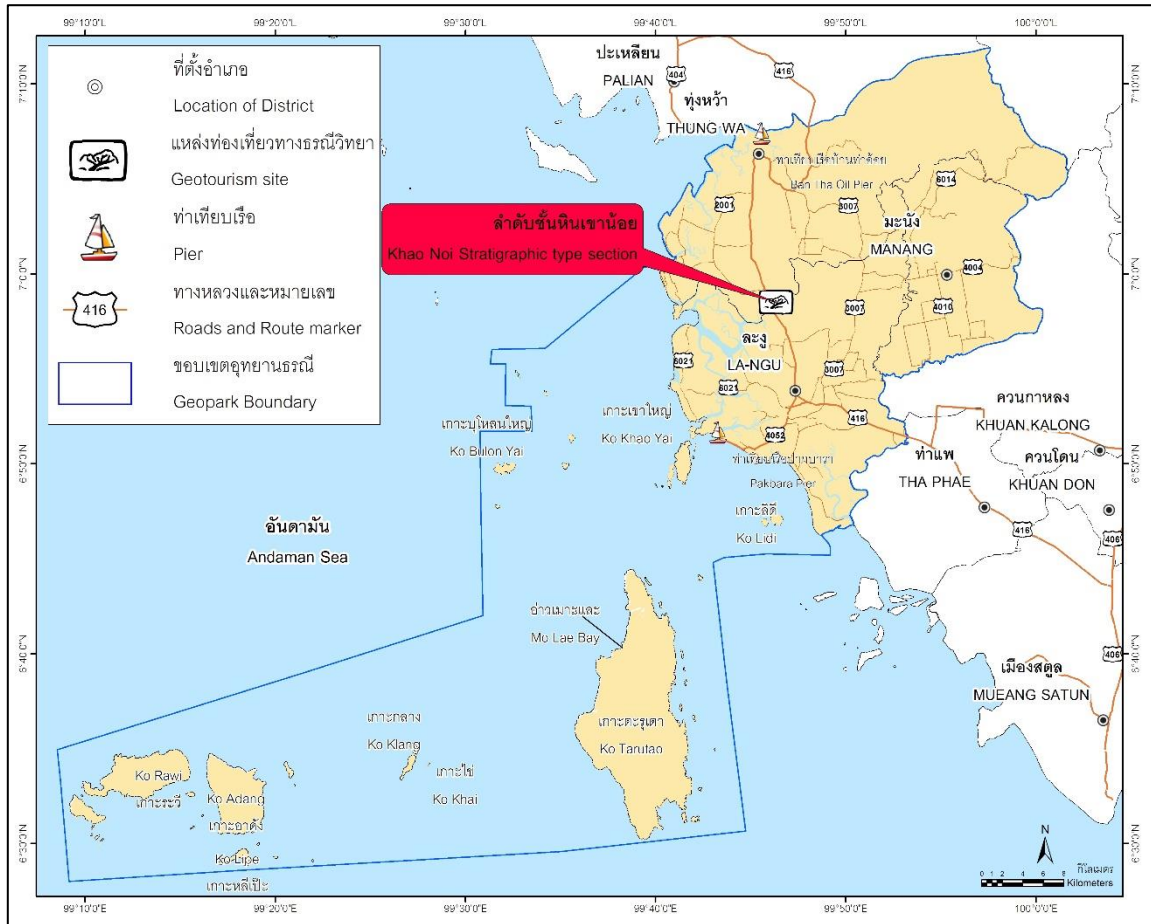


Stratigraphic Type Section, Tarutao Group, Tarutao Island.



## Annex 2: Khao Noi Stratigraphic Type Area

Location: Thung Samed village, Kampong Subdistrict, La-ngu District, Satun Province



**Highlight:** Stratigraphic type section of Pa Kae Formation aged Upper Ordovician (458-443 million years ago) is underlain conformably Wang Tong Formation aged Upper Ordovician to Lower Silurian (443-430 million years ago).

**Geology:** Wongwanich (1983, 1990) studied the Thung Song Group at Tarutao island and at km 10-12 along road between La-ngu-Thung Wa districts and divided rocks into 7 formations.

**1. Malaka Formation** is the lowest unit of Thung Song Group. The formation clearly exposed at mouth of Malaka canal, near the office of Tarutao Marine national park. This formation continuously overlying the Tarutao Group. Rock successions are very thin beds, muddy limestone interbedded with dolomitic limestone. Total thickness of the formation varies in range of 30-410 m. Few volcanic sandstone beds are intercalated in the lower part of the formation. Massive bioturbation including vertical worm burrows are common along with cyanobacterial mats and mud cracks and indicate an intertidal flat environment with some intertidal pools. The polyplacophoran, *Chelodes whitehousei* is abundant, (Stait and Burrett, 1984). The rocks were deposited from sediments in intertidal environment seldom in beach ponds (Fig. A-2.1 – A-2.4)

**2. Talo Dang Formation** is 80-130 m thick and conformably overlies the Malaka Formation. The formation is named after Talo Dang bay in southern Tarutao island. It comprises pink to gray nodular limestone. Thin limestone beds are intercalated with greenish gray to red calcareous shale. Volcanic rocks with cross bedding occurred at lower part of the formation. Fossils and horizontal worm burrows were found in limestone. Rocks in the Talo Dang Formation deposited in coastal marine lake environment.

**3. La Nga Formation** has type section at La Nga bay, northwest of Tarutao island. Thick beds of limestone were intercalated by very thin beds of dolomite. Thickness of this formation is about 75-130 m. Cross beddings were found in all strata of the lower part. Beds became thinner in the upper part and none of cross bedding was recognized. Mass of fossils was generally found together with “U” shape worm burrows. Mud cracks and old small stream channels were also found. Rocks in this formation deposited in coastal environment with shallow tidal channel complex. The widespread peri-Gondwanan gastropod *Peelerophon oehlerti*, indicates an age of Tremadoc-Aranig ( Lower Ordovician)

**4. Pa Nan Formation** was named after Pa Nan island, a small island, situated further south of Tarutao island. Total thickness of this formation is 50-210 m. The formation including thin beds of gray limestone with digitate stromatolites. Most of the stromatolites trending to east-west direction whilst a few trend in a northeast-southwest direction. Small sponge fossils in between clumps of stromatolites were found, characterized by rolling features that can be noticed from the long distance. The rocks were deposited in environment of lower beach or upper part of subtidal flat.

**5. Lae Tong Formation** was named after Lae Tong island, situated further south on Tarutao island. This is a laminated limestone formation, interbedded with mudstone and red to greenish gray shale. This formation is similar to the Talo Dang Formation. Nodular limestone occurs in the lower part of the formation. In the upper part, well continuation of deposition was found with small hummocky cross bedding and shale intercalation. Wave form appeared on top of the beds. Total thickness of the formation is 112-120 m. The Lae Tong Formation was deposited in coastal marine lagoonal environment. Fossils gastropod, brachiopods, trilobites and nautiloids of mostly Middle Arenig age are present.

**6. Rung Nok Formation** is the uppermost unit of the Thung Song Group found on Tarutao island. This formation is named after Rung Nok island, situated to the south of Tarutao island. The lower part of the formation comprises of thin beds of crinoidal sandy limestone. Thickness of the beds increase upwards. Sponges, crinoids, trilobites, corals, nautiloids and receptaculitids are present. Some parts of the upper Rung Nok Formation, has been altered to dolomite. The Rung Nok Formation was deposited in or near a coral reef.

The Thung Song Group at tarutao Island aged Lower to Middle Ordovician while the formation crops out on land aged Upper Ordovician.

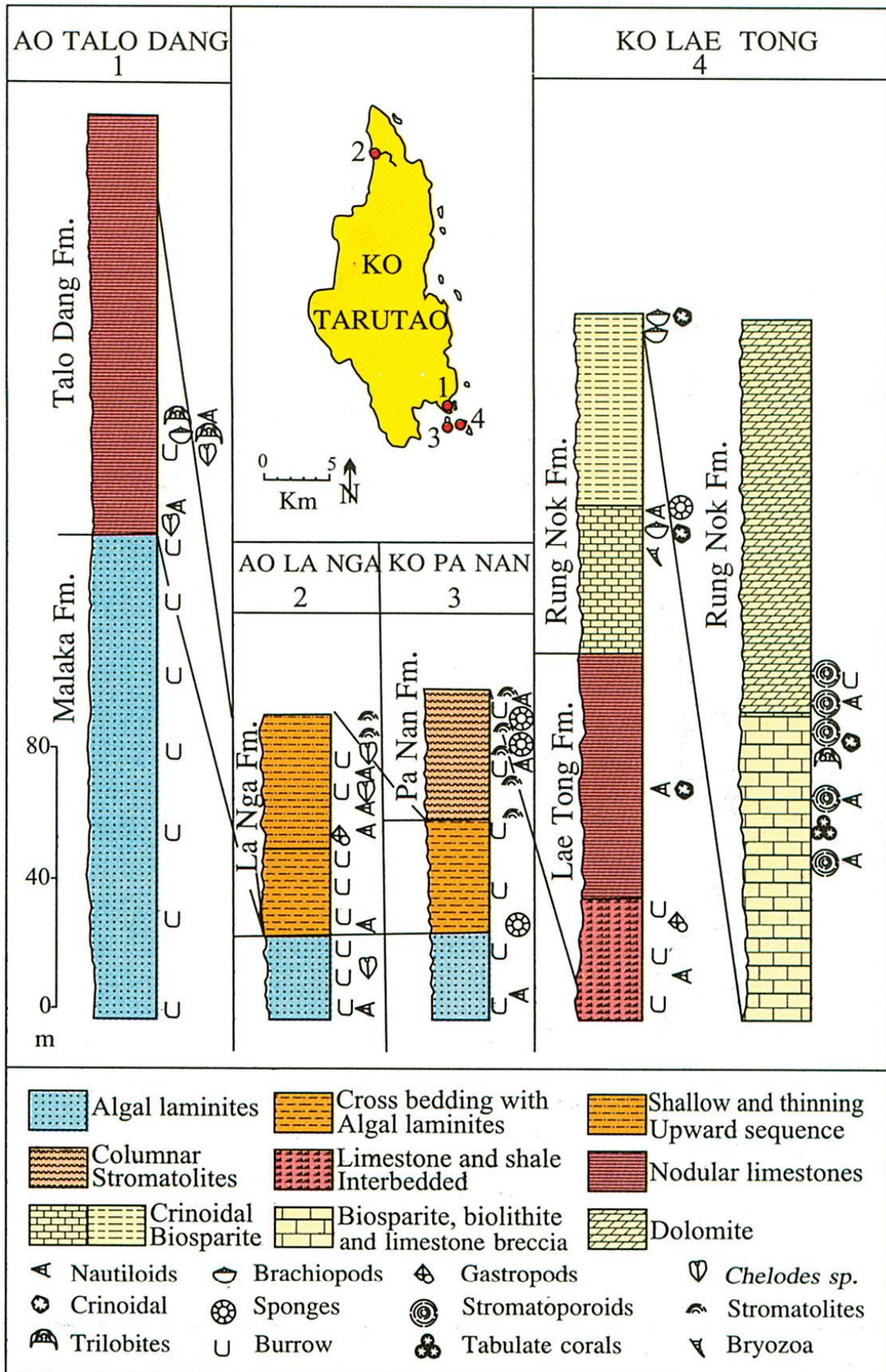


Figure A-2.1 Stratigraphic column of the Thung Song Group in Tarutao island shows location, rock characteristics, fossils and correlation of rocks (modified from Wongwanich *et al.*, 1983).

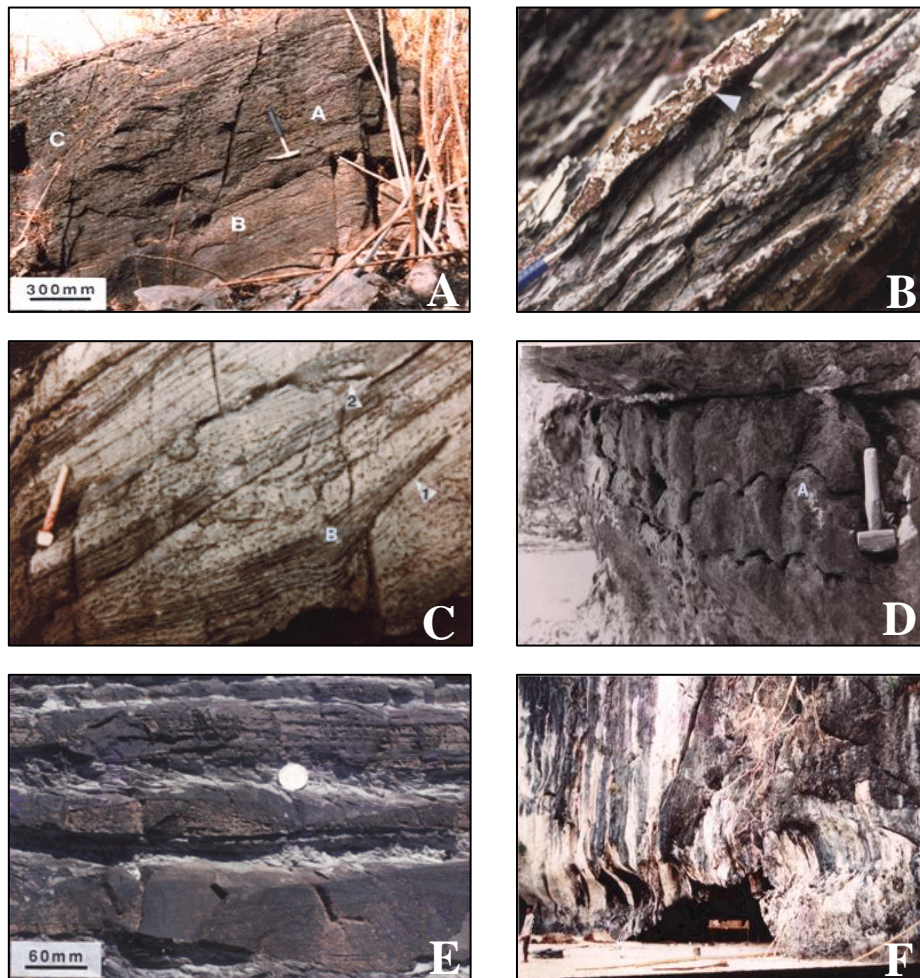


Figure A-2.2 Photo shows rocks and structures of limestone in each formations of Ordovician Thung Song Group on Tarutao island, Satun province.

- A. Very thin beds of limestone including cyanobacterial mats, (A) old stream channel, (B, C) in the Malaka Formation.
- B. Limestone lens and fragments of limestone in shale in the Talo Dang Formation.
- C. Thick beds of limestone show cross bedding (B) and erosional surface underlying sediment redeposition in the La Nga Formation.
- D. Thin beds of limestone curved around stromatolites (A) clumps in the Pa Nan Formation.
- E. Thin limestone beds with hummocky cross bedding interbedded with shale in the Lae Tong Formation, Lae Tong island.
- F. Thick limestone beds contain large structure of sponge stromatoporoid in the Rung Nok Formation.

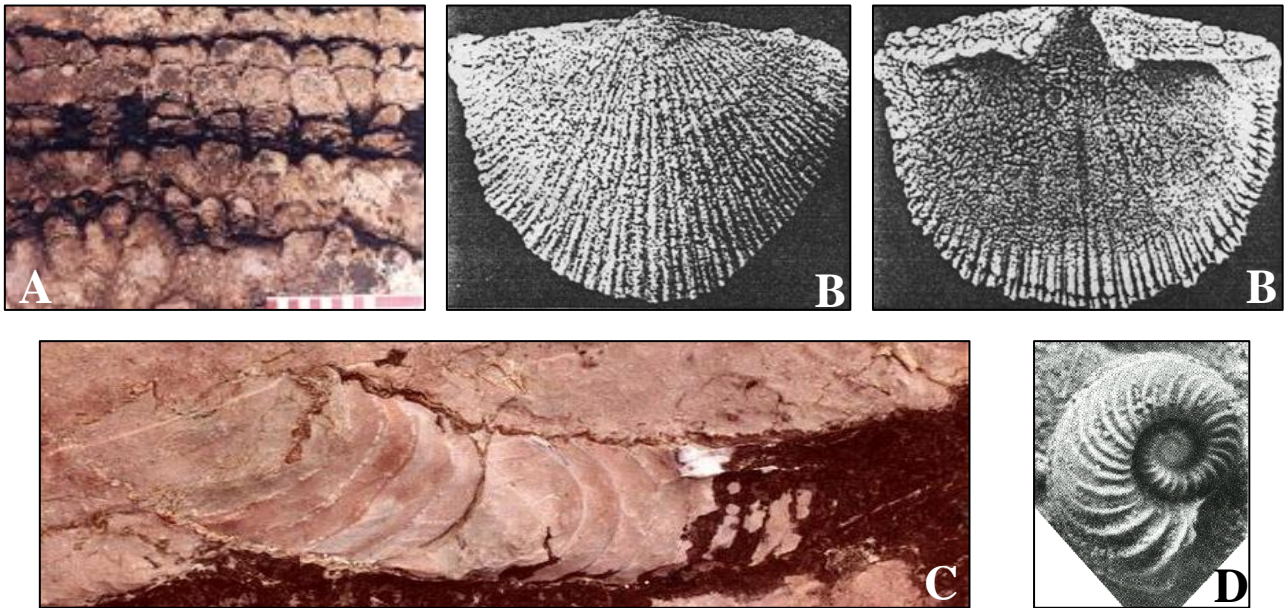


Figure A-2.3 Pictures show Ordovician fossils of each formations in southern region and western region.

- A. Stromatolites in red limestone of Pa Kae Formation, Thung Song Group, Ban Pa Kae, Thung Wa district, Satun province.
- B. *Aporthophyla tienjingshanensis*, Thung Song Group, 4 km southwest of La-ngu district, Satun province.
- C. Curved nautiloids, Lae Tong Formation, Lae Tong island, Satun province.
- D. *Peelerophon oehlerti*, Thung Song Group, southeastern coast of Tarutao island, Satun province.

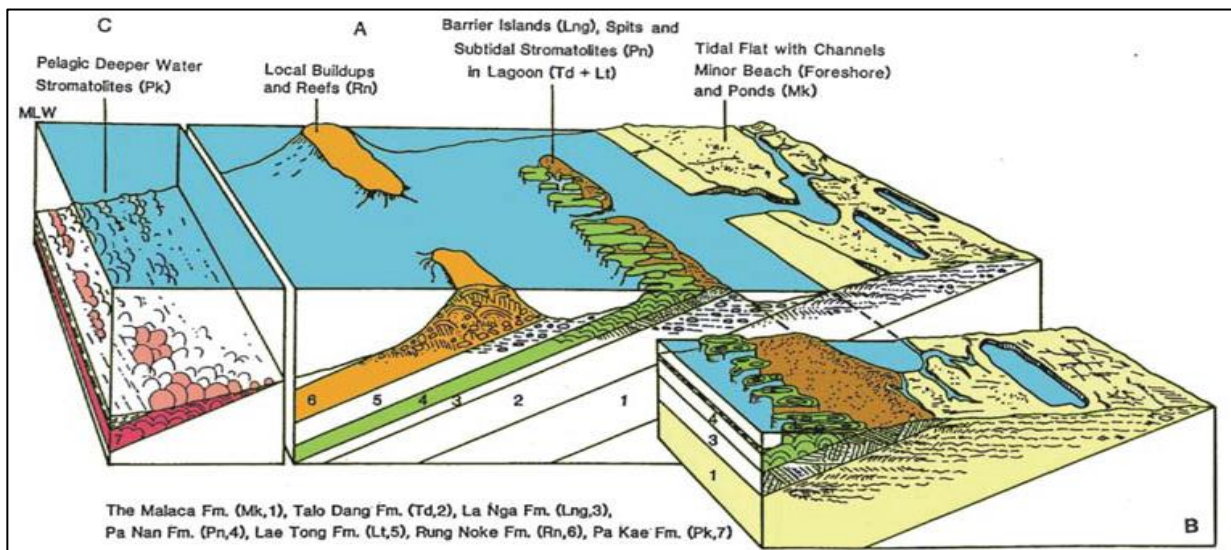


Figure A-2.4 Model of ancient topography and depositional environment of various formations in Thung Song Group during Ordovician Period in southern region, Satun province 1) Malaka Formation deposited in tidal flat 2) Talo Dang Formation deposited in lagoon 3) La Nga Formation deposited in barrier islands and spits 4) Pa Nan Formation deposited in upper part of subtidal flat 5) Lae Tong Formation deposited in lagoon 6) Rung Nok Formation deposited as coral reef. These 6 formations deposited during Lower to Middle Ordovician. 7) Pa Kae Formation deposited as pelagic deeper water stromatolites during Upper Ordovician (Wongwanich, 1990).

**7. Pa Kae Formation** was proposed by Wongwanich *et al.*, (1990) as the uppermost unit of Thung Song Group in southern region. It was named after Ban Pa Kae in the north of La-ngu district, Satun province. The formation comprises thin red limestone beds with very thin red mudstone. It concordantly underlies shale with interbeds of black chert of Wang Tong Formation, Thong Pha Phum Group. All of limestone in Pa Kae Formation was formed from deposition of stromatolites, causing curling surface and cracks along the crest of stromatolites on top of the beds. Approximate thickness of the formation is 66 meters but it is 126 meters at Ao Noon in Petra marine national park south of La-ngu district. Nautiloids and trilobites fossils were found indicating Late Ordovician. The rocks deposited in deep sea environment, probably 175-290 meters deep (Wongwanich, 1990).

Fossils and rock stratum in this formation can be used as index fossils and marker bed indicates the contact between Ordovician and Silurian rocks. The marker bed can clearly recognized by its red color. Rock sequence of the Lower Paleozoic Era found in La-ngu district, Satun province was illustrated in Figure A-2.5 – A-2.7.

An abundant and diverse well preserved fauna of mainly small sized trilobites in the red limestone of the Pa Kae Formation was found by Wongwanich *et al.*, (1990) and Fortey (1997).

They described species belonging to the genera *Ovalocephalus*, *Sphaerexochus*, *Orthorhachis*, *Elegantonileus*, *Arthrorhachis*, *Telephina*, *Rorringtonia*, *Lichas?*, *Microparia*, *Hadromerus*, *Brontocephalina*, *Sculptaspis*, *Hanjiangaspis*, *Panderia*, *Taklamakania*, *Paraphillipsinella*, *Remopleurella*, *Parisoceraurus*, *Oedicybele*, *Cyclopyge*, *Parvigena*, *Currugatagnostus*, *Quyuania*, *Cyamella*, *Miraspis*, *Lonchodoma*, *Hispaniaspis?* and *Nileus*, suggested an age of Late Ordovician from Caradoc to possibly Early Ashgill.

Several genera such as *Nileus* and *Telephina* are typical of deeper /cooler marine conditions. Fortey (1997) shows that the lower fauna has species in common with, or very similar to, the fauna described by Kobayashi and Hamada (1978) from the Langkawi islands including *Nileus malayensis*, *Geragnostus perconvexus* and *Lonchodomas rhombeus*. Neither of the last two named Langkawi species are found in China but Fortey (1997) shows that the remainder of the Pa Kae fauna is remarkably similar, even at the species level, to that of the Pagoda limestone of South China. Cocks and Rong (1988) reported the brachiopod *Foliomena* from the upper part of the Pa Kae Formation. *Foliomena* is an almost cosmopolitan, distal-shelf, deep-water genus (Zhan and Jin, 2005).

Agematsu *et al.*, (2007) described a sequence of deeper or cooler water conodonts of the “North Atlantic” conodont province from the Pa Kae Formation. The lowest fauna belongs to the *Pygodus anserinus* Zone, (Darriwilian to basal Caradoc) followed by the Caradoc *Baltoniodus variabilis* Zone followed by the *Hamarodus europaeus* Zone of Late Caradoc to basal Ashgill age. Thus the trilobites, brachiopods and North Atlantic type conodonts from the Pa Kae Formation all suggest a deeper marine environment possibly of several hundred meters water depth.

Correlation of Stratigraphy applying Fossil assemblages in the Thung Song Group: Fossil assemblages in Thung Song Group are nautiloids, trilobites, brachiopods, gastropods, receptaculitaleans and conodonts and range from the Middle or Upper Tremadoc through to the Ashgill. Faunas in the lower part of the Thung Song Group have mainly North Chinese and Australian affinities (nautiloids, brachiopods and other mollusks) with weaker South Chinese affinities e.g. some of the conodonts such as *Serratognathus* (Metcalf, 1985) and *Panderodus nogamii* (Laurie and Burrett, 1992; Cantrill and Burrett, 2003). A change occurred in middle part of the Thung Song Group (and correlative Setul limestone in Malaysia) with cooler/deeper water faunas (trilobites and North Atlantic conodonts) of strongly South Chinese affinity.

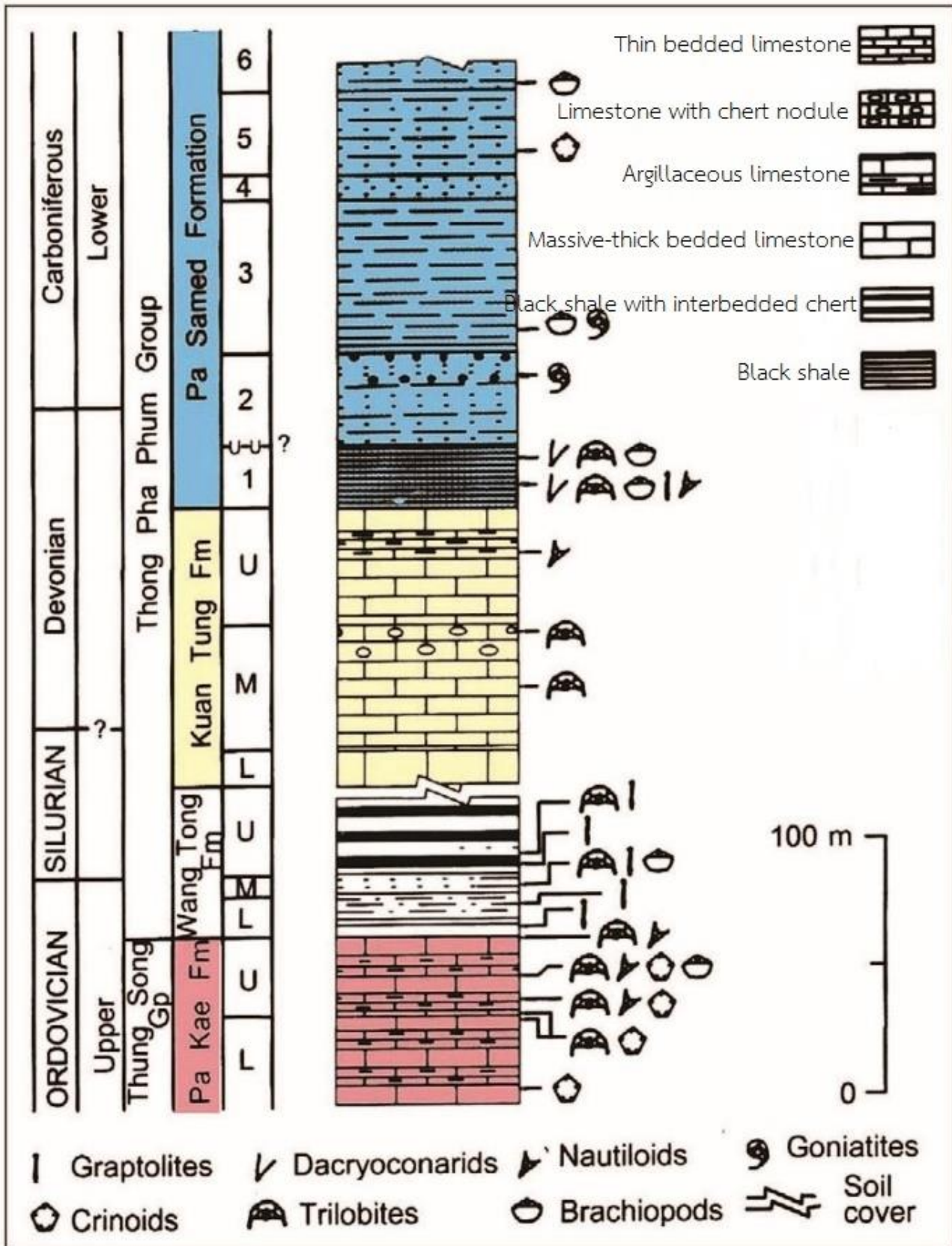


Figure A-2.5 Stratigraphic column of Ordovician to Lower Carboniferous period of the Pa Kae, Wang Tong, Kuan Tung and Pa Samed Formations at km. 11-10 along road between La-ngu - Thung Wa District. 1) Pa Kae Formation, Thung Song Group 2) Wang Tong Formation 3) Pa Samed Formation, Thong Pha Phum Group (Wongwanich *et al.*, 1990). 1.Thin bedded limestone, 2.Limestone with chert nodule, 3.Argillaceous limestone, 4.Massive-thick bedded limestone, 5.Black shale with interbedded chert, 6.Black shale.

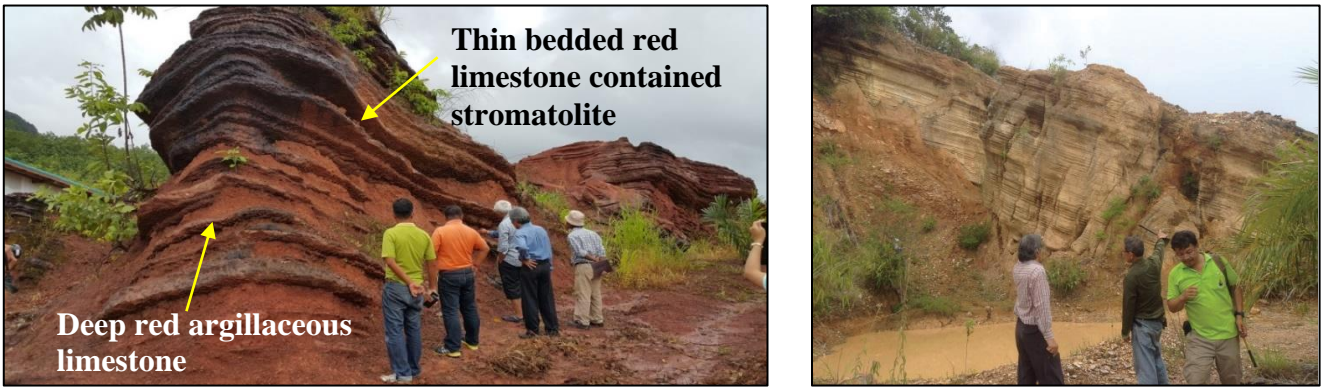


Figure A-2.6 Limestone, red, thin bedded, with darker red argillaceous partings, and abundant stromatolitic polygons of Pa Kae Formation, and thin bedded limestone of the Pa Kae Formation is overlain by black shale of the Wang Tong Formation.

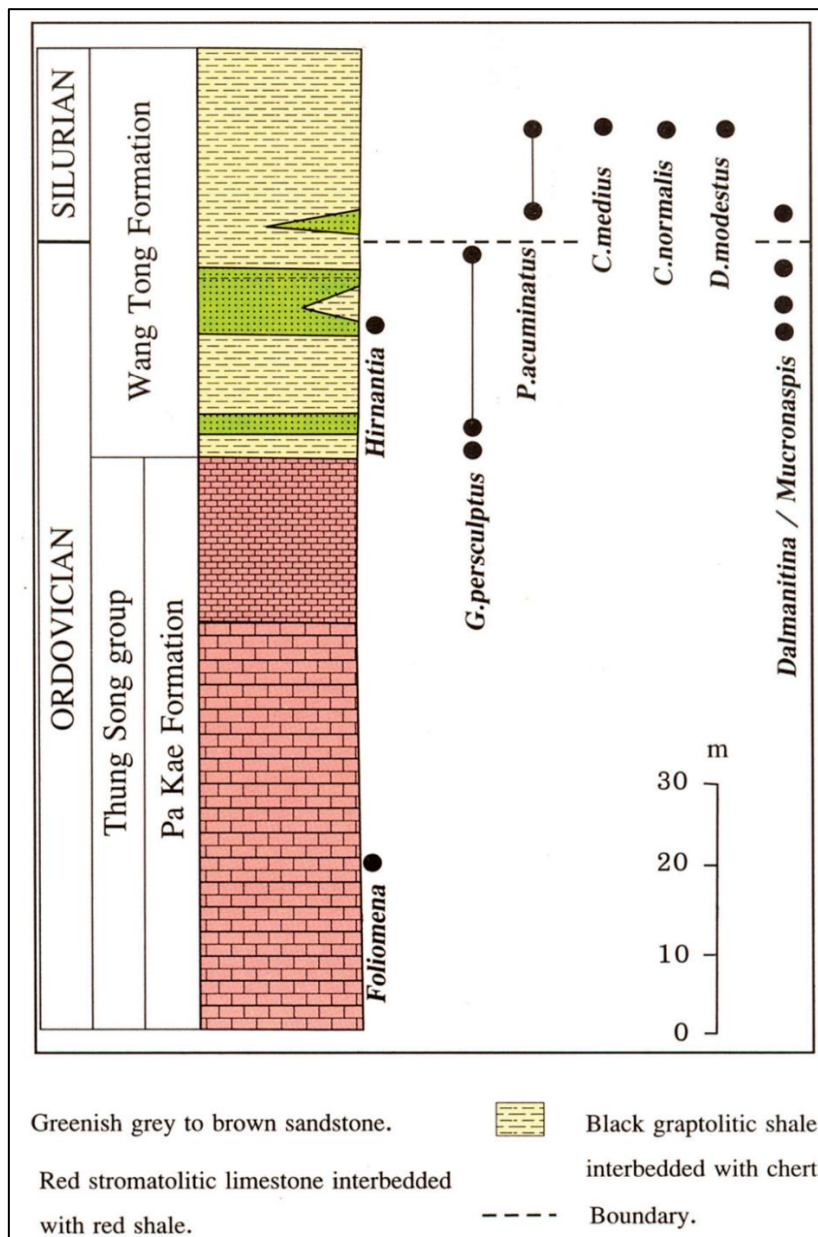


Figure A-2.7 Stratigraphic column shows relationship of the Pa Kae and Wang Tong Formations. It also illustrates contact between Ordovician and Silurian by index fossils of graptolites, conodonts and trilobites.

**Annex-2: Thong Pha Phum Group** : Wongwanich (1983, 1990) studied the Thong Pha Phum Group, lie conformably above the Thung Song Group at km 10-12 along road between La-ngu-Thung Wa districts and divided rocks into 3 formations.

1) **Wang Tong Formation** was named after Ban Wang Tong 12 km north of La-Ngu district (Wongwanich et al., 1990). The type section rocks lie conformably above the Pa Kae Formation. It consists of shale, chert, greenish gray sandstone and black chert with a brown color when weathered. Trilobite and brachiopod were found in chert strata in the middle part of the formation, whereas abundant graptolites were found in the upper part. Total thickness of the formation is 50-110 m. Contact between Ordovician and Silurian rocks is above a sandstone containing the trilobite *Mucronaspis mucronata* and a typical Hirnantian (Late Ashgill), while brachiopod fauna consisting of *Onniella ?yichangensis*, *Hirnantia sagittifera*, *Mirorthis mira*, *Cliftonia* sp., *Aegiromena planissima*, *Paromalomena* sp., and *Eospirigerina* sp. (Cocks and Fortey, 1997). This formation was dated as Late Ordovician to Silurian and deposited in deep marine conditions.

R.B.Rickards in Wongwanich *et al.*, (1990, p.6) identified the Late Ordovician graptolite *Glyptograptus persculptus* beneath the *Mucronaspis* bearing beds in the lower part of the formation and *Glyptograptus* exgr. *persculptus*, *Glyptograptus* sp., *Parakidograptus acuminatus*, *Climacograptus medius*, *Climacograptus normalis*, *Pseudoclimacograptus* sp., *Climacograptus modestus* were found in the upper part and range from the Late Ashgill to Early Silurian. The Ordovician–Silurian boundary therefore lies just above the *Mucronaspis* beds (Figure A-2.8).

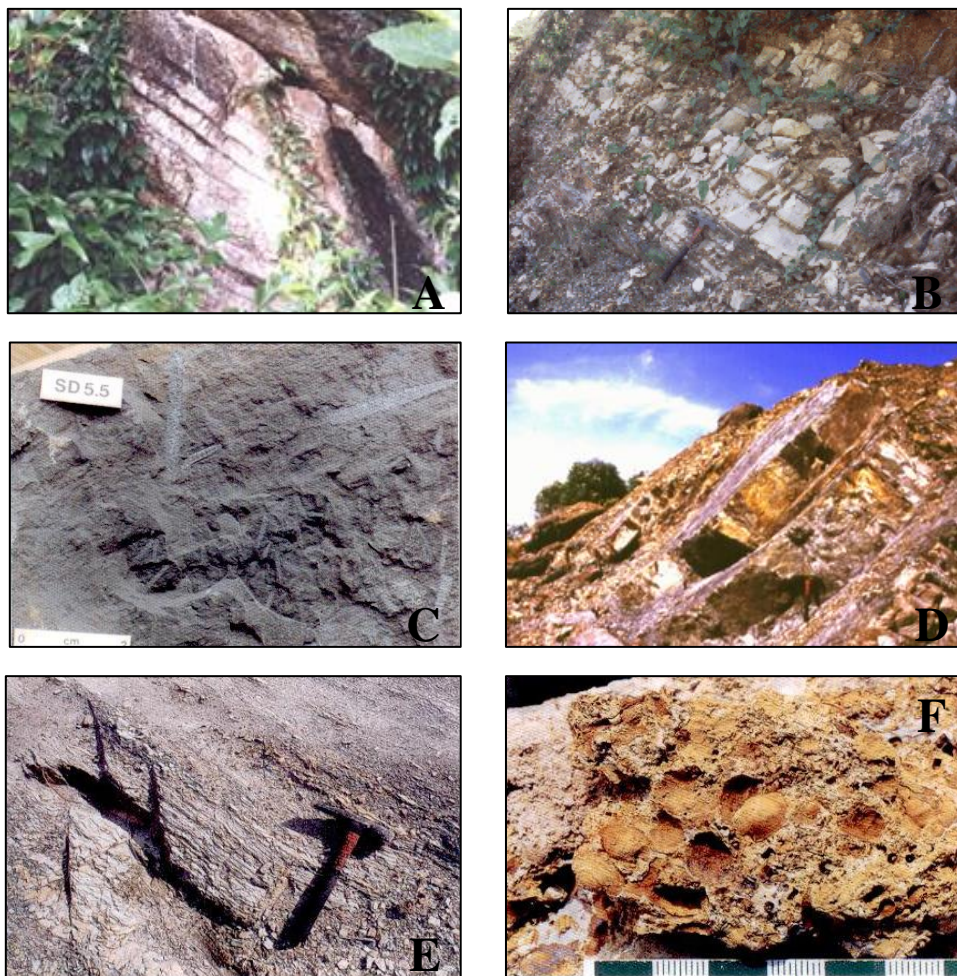


Figure A-2.8 Pictures of Silurian-Devonian-Carboniferous rocks of various formations along La-ngu-Thung Wa road (road number 4078) in Satun Geopark Boundary.

- A. Thin bedded red stromatolitic limestone in Kuan Tung Formation at km 10.
- B. Chert interbedded with black siliceous shale in Wang Tong Formation, at km 10.9.
- C. Thin bedded red stromatolitic limestone Kuan Tung Formation at km 10.
- D. Thick bedded sandstone with partly well sorted and pebbles, Pa Samed Formation at km 10.
- E. Dark gray shale, Pa Samed Formation in area of Ban Pa Samed.
- F. Brachiopod *Quasiprosserella* in dark gray shale, Pa Samed Formation in area of Ban Pa Samed.

2) **Kuan Tang Formation** named after small limestone hill between km 7-10 along road between La-ngu-Thung Wa districts. All rocks in the formation are limestone with gray thin beds in lower part of the formation and thin, red layer of stromatolites. The undulating surface and cracks along stromatolite ridges similar to mud cracks are similar to those in the Pa Kae Formation. Khuan Thang type locality is type sections of the Wang Tong, Kuan Tung and Pa Samed Formations

A trilobite fauna of probable Emsian age has been described by Fortey (1989) from the lower part of the formation and consists of *Reedops megaphacos* and *R. seleniomma*, *Cornuproetus (Sculptoproetus) sculptus*, *Decoroproetus* sp. and *Platyscutellum* sp. These are very similar to trilobites from Turkey, Bohemia, Germany and Morocco and belong to the Hercynian Magnafacies.

A conodont fauna from the middle of the Kuan Tang Formation consists of *Belodella devonica*, *B. resima*, *Pandorinellina steinhornensis steinhornensis*, *Pseudooneotodus kuangtungensis* and *Polygnathus labiosus mawsonae* of Emsian age (Long and Burrett, 1985). Biostratigraphy of this formation is equivalent to Upper Setul limestone in Langkawi island (Igo and Koike, 1968; and Jones, 1980).

3. **Pa Samed Formation** was named by Tansuwan *et al.* (1980) after Ban Pa Samed, approximately 9 km north of La-ngu district, Satun province. Type section of this formation situated at km 9.7-9.8 on the road between La-ngu-Thung Wa districts. The lower part of the formation is black shale with numerous tentaculites. The middle part comprises brown and red sandstone showing bouma sequences and conglomerate with many ammonoid beds. The upper part consists of thin laminations of grayish black shale becoming brown when weathered. Ammonoids and brachiopods were found in lower portion of the upper part of the formation. Thickness of the formation is 105 m. Depositional environment of the lower part of formation was interpreted to be in deep sea environment. The middle part deposited in shallower depth on continental slope. The upper part deposited in deep sea environment but shallower than that of the lower part.

Rucha Ingawat and Benja Songsirikul *in* Wongwanich *et al.*, (1990 p. 7) identified a fauna occurring 10 m above the base of the formation, that includes *Nowakia*, *Metastyliolina*, *Styliolina*, *Echinocoeliopsis*, *Plagiolaria*, *Echinocoelia* and *Monograptus*, indicating an age of Early to Middle Devonian.

Boucot *et al.* (1999) studied the brachiopods from the Pa Samed Formation, and described *Quasiprosserella samedensis*, *Plectodonta (Plectodonta) fortayi*, *Lissatrypa* sp., *Caplinoplia thailandensis*, *Plicanoplites?* and *Clorinda wongwanichi*. These are thought to represent a deep-water benthic assemblage. A trilobite with reduced sight belonging to *Plagiolaria poothaii* originally described by Kobayashi and Hamada (1968) from material collected between Trang and Phatthalung provinces is associated with the brachiopod fauna (Cronier and Fortey, 2006).

Ruan Yi-ping *in* Boucot *et al.* (1999) identified the dacryoconarids in the Pa Samed Formation on the road side near Ban Tham Phra as *Nowakia acuaria*, *Nowakia cf. matlockiensis*, *Nowakia cf. hercyniana*, *Styliolina* sp., *Striasstyliolina* sp., *Viriatellina* sp., assigned them to the *Guerichina* Zone and suggested a Late Pragian age but that they may be as young as Early Emsian.

Late Carboniferous fauna occurs 44 m above the dacryonocarid beds in a siltstone and consists of an abundant but moderate diversity collection of kaolinized, brachiopods and goniatites (Wongwanich *et al.*, 2004). The goniatites include *Stenopronorites* cf., *uralensis*, *Syngastrioceras* sp. and Glaphyritid indet. and are definitely Namurian in age. The brachiopods include *Aseptella satunensis*, *Eileenella elegans*, *Tornquistia orthogona*, *Coledium satuni*, *Plicambocoelia tansathieni*, *Crurithyris* sp., cf. *Martinia* sp., cf. *Reticularia* sp., and *Girtyella* sp. This brachiopod fauna is unlike any previously described fauna from Asia.

The Kuan Tang and Pa Samed Formations both therefore contain Early Devonian faunas but so far, no Late Devonian or definite Early Carboniferous fossils have been found in the Pa Samed Formation. This may suggest a significant paraconformity within the Pa Samed or even a fault within a covered section above the dacryoconarid beds.

Characteristics of fossil assemblages in Wang Tong, Kuan Tang and Pa Samed Formations are illustrated in Figure A-2.9.

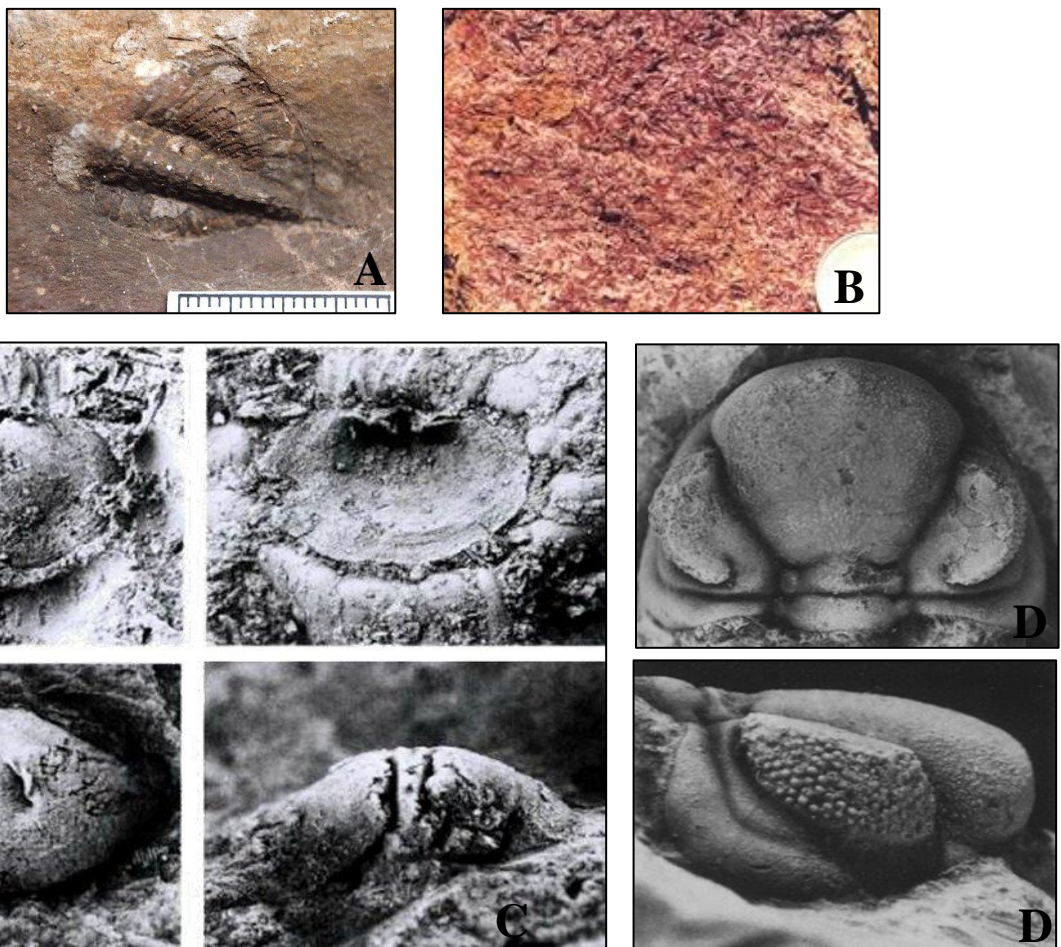


Figure A-2.9 Pictures shows fossils of Silurian-Devonian-Carboniferous ages along La-ngu-Thung Wa road (road number 4078) in Satun Geopark Boundary.

- A. Pygidium of trilobite *Mucronaspis mucronata* in sandstone of the Wang Tong Formation, Thong Pha Phum Group found in west of laterite pit at km 10.9.
- B. *Tentaculites* sp. in shale, Pa Samed Formation, km 9.7-9.8.
- C. Brachiopod *Quasiprosserella samedensis*, Upper Pa Samed Formation.
- D. Trilobite *Reedops seleniomma* in Kuan Tang limestone showing head and composite eyes, Khao Kuan Tang, km 10.

### Annex 3: Kaeng Krachan Group

The Kaeng Krachan Group was named by Piyasin (1975) with type section at the Kaeng Krachan dam, Tha Yang district, Phetchaburi province. The group originally consists of 3 formations as follows.

Laem Mai Phai Formation with type section at Sire island from Laem Mai Phai beach to Pheumsook beach, Phuket Island is more than 120 m thick. In its lower part, there are intercalations of thin, continuous and parallel beds of sandstone and mudstone and bed thickness varies between 10 to 20 cm. Bouma sequence and burrows of the *cruziana* ichnofacies are common. In upper sequence, the rock changes to laminated mudstone where slump structures and dropstones can be observed (Fig. A-3.1). There are at least two depositional cycles of thin bedded sandstone and mudstone upward to laminated mudstone. This formation was deposited under turbiditic current of glaciomarine in outer shelf to basin plain environments.

Spillway Formation was designated for a 120 m thick sequence at its type section in spillway of the Kaeng Krachan dam (Raksaskulwong and Wongwanich, 1993). On the eastern side of the spillway, the formation conformably overlies massive mudstone of the Laem Mai Phai Formation. The formation gradually changes upwards to laminated mudstone with interbedded fine grained graywacke. Load cast structure, burrow, hummocky cross bedding and discontinuous beds indicate deposition in shallow water turbidity currents.

Depositional environment of the Kaeng Krachan Group has long been interpreted in 2 different origins, mass flow and turbidite origin on a continental slope and continental rise (Mitchell *et al.*, 1970; Garson *et al.*, 1970; Sawata *et al.*, 1975; and Altermann, 1986) or glaciomarine origin with ice rafting (Ridd, 1971; Stauffer and Mantajit, 1981; Bunopas, 1981; Hills, 1989; and Raksakulwong and Wongwanich, 1994). However, there is now no doubt that depositional environment of the group was involved both origins, so called glaciomarine mass flow origin as indicated by Bouma sequence and drop stone (Chaodumrong *et al.*, 2004). There are also remarks as follow.

- The group's age is coincident with widespread covering of glacier in southern hemisphere or Gondwanaland. Although, the age was varied, Lower Permian (Asselian) by Waterhouse (1981); Carboniferous-Permian by Mantajit (1979); and Lower Permian (Chaodumrong *et al.*, 2004).
- A reconnaissance paleomagnetic study by Bunopas and Vella (1983) tentatively showed the position of Thailand in the Carboniferous-Permian to be between latitude 30°-40° south, however no definitive paleomagnetic results have yet been published.
- Granite clasts in the Phuket group of diamictite rock show little weathering indicating rapid sedimentation or deposition under a very dry or cold climate. Faceted pebbles found in Ko He illustrated features of pebbles transported by glacier. Large pebbles, cobbles and boulders in mudstone demonstrated as dropstones may only have been deposited from floating ice.



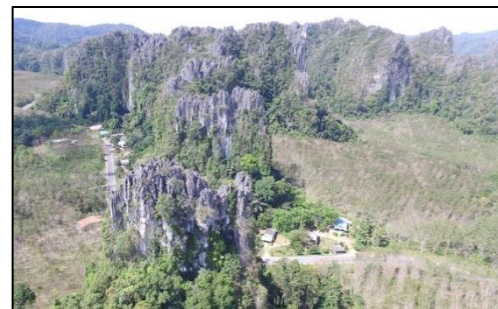
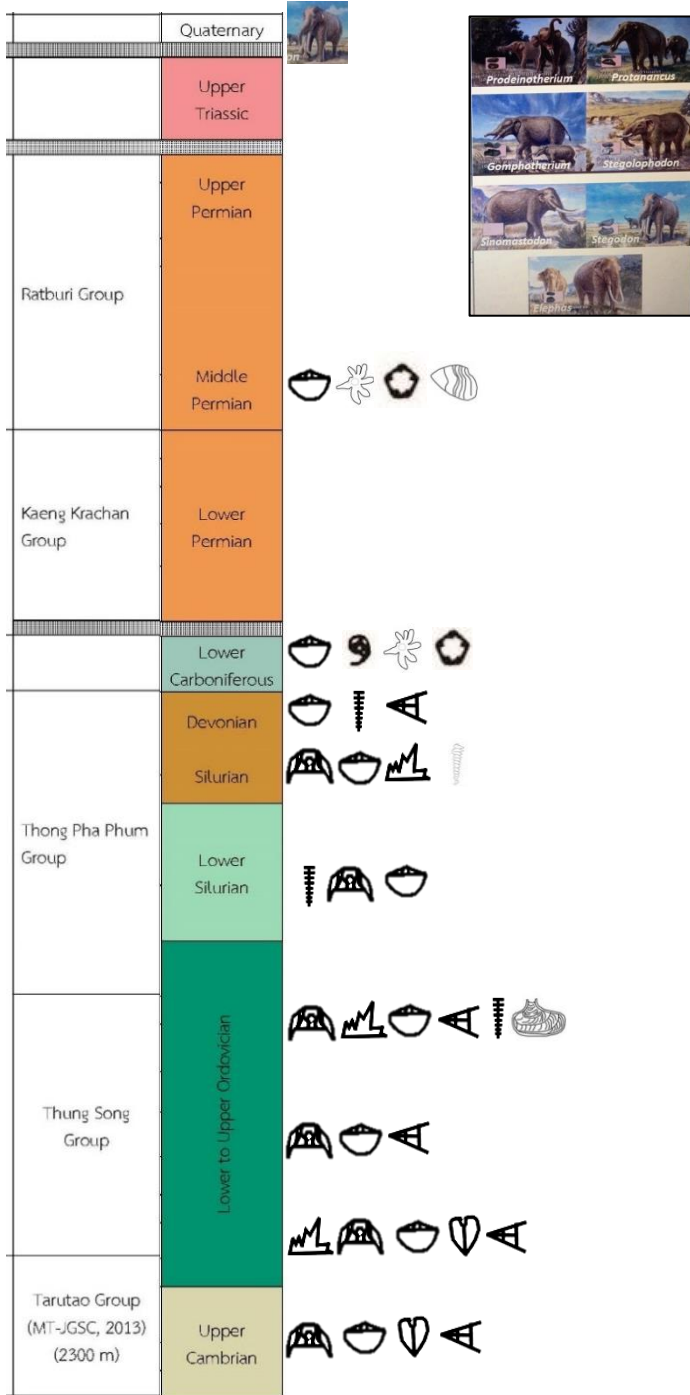
Figure A-3.1 Dropstone of the Laem Mai Phai Formation, Kaeng Krachan Group, in the naval base side of Phanwa bay, Phuket island. Notice that the mudstone was pressed and curved down and cut by the pebble. a) Quartz-schist pebble sizes 5x8 cm, b) Sandstone pebble sizes 5x8 cm.

## References

- กรมทรัพยากรธรณี, 2550, ธรณีวิทยาประเทศไทย, พิมพ์ครั้งที่ 2 ฉบับปรับปรุง, กรมทรัพยากรธรณี กรุงเทพฯ 628 หน้า
- วีระพงษ์ ต้นสุวรรณ, พล เชาวน์ดำรงค์ และ ประวัติ เทียนศิริ, 2523, รายงานการสำรวจธรณีวิทยาบริเวณจังหวัดสตูล (NB 47-7) มาตรฐาน 1:250,000 กรมทรัพยากรธรณี, 60 หน้า และแผนที่ธรณีวิทยา 1 ฉบับสังัด ปิยะศิลป์, 2518, ธรณีวิทยาของแผนที่ระวางจังหวัดอุดรดิตถ์ (NE47-11) มาตรฐาน 1:250,000 กรมทรัพยากรธรณี, รายงานการวิจัย ฉบับที่ 15, 62 หน้า และแผนที่ธรณีวิทยา 1 ฉบับ
- Agematsua, S., Sashida, K., Salyapongse, S., and Sardud, A., 2006, Lower Devonian tentaculite bed in the Satun area, *Journal of Asian Earth Sciences* 26, p. 605–611.
- Agematsu, S., Sashida, K., Salyapongse, S., and Sardud, A., 2008, Early Ordovician Conodonts from Tarutao. *Palaeontology*, Vol.51, Part 6, 2008, pp. 1435–1453.
- Agematsu, S., Sashida, K., Salyapongse, S. and Sardud, A., in press: Ordovician Conodonts from the satun area, southern peninsular Thailand. *Journal of Paleontology*.
- Boucot, A.J., Cocks, L.R.M. and Rachborf, P.R., 1999, Early Devonian brachiopods from Satun Southern Thailand, *Journal of Paleontology*, v.75, no.3, p.850-859.
- Brown, G.F., Buravas, S., Charaljavanaphet, J. Jalichandra, N., Johnson, W.D., Sresthaputra, V., and Taylor, G.C., 1951, Geologic reconnaissance of the mineral deposits of Thailand: USGS Bulletin 984, 183 p., also as Royal Department of Mines Geological Survey, Memoir 1 (1953).
- Bunopas, S., 1981, Paleogeographic history of Western Thailand and adjacent parts of Southeast Asia - A plate tectonics interpretation, Ph.D. thesis, Victoria University of Wellington, New Zealand., 810 p.; reprinted 1982 as Geological Survey Paper no.5, Geological Survey Division, Department of Mineral Resources, Thailand.
- Bunopas, S., 1983, Palaeozoic succession in Thailand, in P. Nutalaya, ed., Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia, Haad Yai, Thailand, September 8-10, v.1, p.39-76.
- Burrett, C., Long, J., and Stait, b., 1990, Early-Middle Paleozoic biogeography of Asia terranes derived from Gondwana, in McKerro W.S. and Scottese C.R., eds., *Palaeogeography and Biogeography: Geological Society Memoir no. 12*, p. 163-174.
- Cocks, L.R.M., Fortey, R.A., Lee, C.P., 2005, A review of Lower and Middle Palaeozoic biostratigraphy in west peninsular Malaysia and southern Thailand in its context within the Sibumasu Terrane. *Journal of Asian Earth Sciences* 24 (2005) p.703–717.
- Fortey, R. A., 1989, An Early Devonian trilobite fauna from Thailand, *Alcheringa* 13, p.257-267.
- Fortey, R. A., 1997, Late Ordovician Trilobites from Southern Thailand, *Palaeontology*, Vol. 40, Part 2, pp. 397-449, 10 pls.
- Grant, E.R., 1976, Permian brachiopods from Southern Thailand, *Journal of Paleontology*, v.50 (Supplement to no. 3), Paleontological Society Memoir 9, 269 p., 71 pl.
- Igo, H., and Koike, T., 1968, Ordovician and Silurian conodonts from the Langawi Islands, Malaysia, Part II: Geology and Palaeontology of Southeast Asia, v. 4, p. 1-21, pl. 1-3
- Igo, H. and Koike, T., 1973, Upper Silurian and Lower Devonian conodonts from the Langkawi Island, Malaysia, with note on conodont fauna of the Thung Song Limestone, Southern Thailand, the Setul Limestone, Perlis, Malaysia, *Geology and Palaeontology of Southeast Asia*, v.13, p.1-22.
- Javanaphet, J.C., 1969, Geological map of Thailand, scale 1:1,000,000: Department of Mineral Resources, Bangkok, Thailand.

- Kobayashi, T., 1957, Upper Cambrian fossils from peninsular Thailand, Jour. Fac. Sci. Univ. Tokyo 2(10) 3, p.367-382.
- Kobayashi, T. and Hamada, T., 1964: On the Middle Ordovician fossils from Satun, The Malaysian frontier of Thailand. In, Kobayashi, T. ed., *Geology and Paleontology of Southeast Asia 1*, p. 269-279. University of Tokyo Press, Tokyo.
- Kobayashi, T. and Hamada, T., 1968, A Devonian phacopid recently discovered by Mr. Charan Poothai in peninsular Thailand, *Geology and Palaeontology of Southeast Asia*, v.4, p.22-28.
- Laurie, J.R., and Burrett, C., 1992, Biogeographic significance of Ordovician brachiopods from Thailand and Malaysia: *Journal of Palaeontology*, v. 66, p. 16-23.
- Long, J.A., and Burrett, C., 1989, Early Devonian conodonts from the Kuan Tung Formation, Thailand: Systematic and biogeographic consideration: *Records of Australian Museum*, v. 41, no. 2, p. 124-130.
- Metcalf, I., 1990, Allochthonous terrane processes in Southeast Asia: *Philosophical Transactions of Royal Society, London*, A331, p. 625-640.
- Shergold, J., Burrett, C., Akerman, T. and Stait, B., 1988, Late Cambrian trilobites from Tarutao Island, Thailand, *New Mexico Bureau of Mine & Mineral Resources Memoir 44*, p.303-320.
- Stait, B. and Burrett, C., 1984, Ordovician nautiloid faunas of Central and Southern Thailand, *Geological Magazine*, v.121, no.2, p.115-124.
- Stait, B., Burrett, C. and Wongwanich, T., 1984, Ordovician trilobites from the Tarutao Formation, Southern Thailand, *Neues Jahrbuch fur Geologie und Palaeontologie, Monatshefte*, p.53-64.
- Teraoka, Y., Sawata, H., Yoshida, T. and Pungrassami, T., 1982, Lower Palaeozoic Formation of the Tarutao Islands, Southern Thailand, Prince of Songkhla University, *Geological Resources Project Publication no.6*, 54 p.
- Wongwanich, T., Stait, B., Burrett, C. and Wyatt, D., 1983, The Ordovician system in Southern Thailand and Northern Malaysia, *Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia*, the Geological Society of Thailand and Geological Society of Malaysia, v.1, p.77-95.
- Wongwanich, T., 1990, Lithostratigraphy, sedimentology, and diagenesis of the Ordovician carbonates, Southern Thailand, unpublished Ph.D. thesis, University of Tasmania., 215 p.
- Wongwanich, T., Tansathien, W., Leevongcharoen, S., Paengkaew, W., Thiamwong, P., Chaeroenmit, J., and Saengsrichan W., 2002, The Lower Paleozoic Rocks of Thailand. *The Symposium on Geology of Thailand 26-31 August 2002, Bangkok, Thailand*, p.16--21
- Wongwanich, T., Boucot, A. J., Brunton, C.H.C., House, M.R., and Racheboeuf, Namurian Fossils (Brachiopods, Goniatites) from Satun Province, Southern Thailand. *Journal of Paleontology*, v.78, no.3, p.1072-1085.
- Wongwanich, T., Burrett, C., Tansathein, W., Chaodumrong, P., 1990. Lower to Mid Palaeozoic stratigraphy of mainland Satun province, southern Thailand. *Journal of Southeast Asian Earth Sciences* 4 (1), 1-9.

# GEOLOGICAL DIFFERENCES BETWEEN LANGKAWI AND SATUN GEOPARKS



















SATUN    
Aspiring Geopark

## TABLE OF CONTENT

Abstract.....	1
A. Geological differences between Langkawi and satun Geoparks.....	3
A-1 Biostratigraphy (Cambriam Fossils and Ash Layer for Absolute Age, Sytromatolite).....	4
A-2 Ordovician Stromatolitic limestone or stromatolite.....	6
A-3 Stegodon Sea and Stream Cave.....	7
A-4 Terrestrial Karsts.....	7
Annex	
Annex 1 SATUN (Thailand) – LANGKAWI (Malaysia) GEOPARKS - SOME by Professor Dr. Clive Burrett, former professor at University of Tasmania.....	11
Annex 2 Early and Middle Paleozoic fossils and strata in Satu by Dr. Agematsu, Japanese expert.....	15
Annex 3 Ordovician Stromatrolitic limestone.....	16
Annex 4 Tham Le Stegodon (Stegodon Cave) .....	18
Annex 5 Phu Pha Phet Cave.....	25

Fossil symbols display on document cover.

 Crinoids	 Dacryoconarids	 Goniatites
 Graptolite	 Receptaculite	 Pelecypod
 Brachiopod	 Coral	 Trilobite
 Nautiloid	 Conodont	 Tentaculite
 Radiolaria	 Graptolite	 Stromatolite
 Fusulinid		

## **Geological Differences between Langkawi and Satun Geoparks**

### **Abstract**

#### **A. Similarity**

In terms of geological setting, Satun Aspiring Geopark and Langkawi Geopark are on the land of same tectonic plate which was a part of Gondwana having moved from the Southern Hemisphere to form a part of Shan-Thai plate as seen in the present time. Both of them possess a complete Paleozoic geological succession ranging from Cambrian to Permian. Some limestone units of both geoparks have formed an outstanding feature of beautiful karst morphology. Although, they are similar in terms of regional geology, there are quite a few differences in local characteristics or identities.

#### **B. Differences**

Although evolution through geological time results in similarity of their regional geology (i.e., stratigraphic sequences of Paleozoic rocks and geological features of limestone karst, etc.), local geological factors (i.e., of the two geoparks) have made differences in characteristics or identities between the two geoparks. The geological factors are such as local land uplift, igneous activity, etc..

Difference in geomorphology between the two geoparks may be explained by different uplifting of lands, higher in the north (Satun) descending to the south (Langkawi) in the present time. Langkawi Geopark is an archipelago that have outstanding marine or island karst, meanwhile Satun Geopark in the higher elevation has various terrestrial karst features such as cone karst, wall karst, tower karst, cave springs, karst lake, polje, collapsed sink holes, etc. Moreover, many caves in the karst areas in Satun Geopark have evidences of mammal fossils (Stegodon cave) and archeological evidence of human settlements (Phu Pha Phet and Uraithong caves). Stegodon cave in Thungwa District, featuring 3.5 km long terrestrial stream cave is one of longest stream caves in the peninsular. Phu Pha Phet in Manang District and Uraithong caves in La-ngu District have giant caves with well preserved paleoclimate and neotectonic evidences. Recent studies of cave (speleology) have shown archeological evidences of human residence and geological evidences of tectonic uplift in this region.

In terms of fossil exposure, some Langkawi's Paleozoic formations (Machinchang) was metamorphosed by the intrusion of Triassic granite that caused rare occurrences of fossils. Meanwhile, those of Satun Geopark further away up north with less effect by the intrusion have abundant and well exposed fossils. In Satun Geopark, there are unique, new discoveries and highly diversified fossils including blind-eye Devonian trilobite fossils, mysterious red stromatolites, well-established late Cambrian trilobite biostratigraphy, Cenozoic mammals fossils along stream Paleozoic caves in which more than 300 Stegodon and other mammal fossils are found, recorded and registered and a further research project has already been planned and proposed for funding. This is obviously a kind of geological identity of Satun Aspiring Geopark which was designated, "Fossil land daen Satun (in Thai words and pronunciation)" in 2013 which means "Satun - a Land of Fossils". Satun Geopark has organized "Satun Geopark Fossil Festival" every year since 2014. The latest event was during 2-11 February 2017.

In summary, Langkawi Global Geopark has an identity of having outstanding beauty of tropical island karst landscape and a complete Paleozoic geological succession. Meanwhile that of Satun Aspiring Geopark has an identity of having outstanding beauty of tropical terrestrial karst and highly abundant, diversified and well exposed fossils.

### **C. Complimentary between the two geoparks**

Based on a discussion between the representatives of Satun and Langkawi Geoparks on the 25th of August 2016 in Satun and on the 6th of February 2017 in Langkawi, both representatives agreed that Satun Aspiring Geopark and Langkawi Global Geopark are different in geological features. Both geoparks have their own identity and characteristics which are complimentary to each other. Such differences are useful to scientists and attractive to overall geotourists. For scientists, a wide range of geological, biological and cultural information can be obtained for further challenging ecological researches starting from Langkawi to Satun or from Satun to Langkawi. Tourists can observe terrestrial karst and caves at Satun Geopark and island karst and caves at Langkawi Geopark. Both sides also agreed that Satun Geopark and Langkawi Geopark are networking. Hopefully, they are future "sister geoparks", and ultimately "transboundary/transnational geopark". They are complimentary to each other. In fact, their representatives have been meeting, having exchanged their visits many times.

## A. GEOLOGICAL DIFFERENCES BETWEEN SATUN GEOPARK AND LANGKAWI UNESCO GEOPARK

Having been discussed between the Langkawi UNESCO Global Geopark experts and Satun Aspiring Geopark colleagues in Langkawi, Malaysia on February 6, 2017, The Satun Geopark colleagues have written minutes of the meeting on February 26, 2017 as stated in the abstract above. The meeting and discussion have been conducted in a friendly atmosphere and photo has been taken.



Photos indicate joint meeting between Langkawi UNESCO Global Geopark experts and Satun Aspiring Geopark colleagues on their Geological International Significances and Geological Differences.

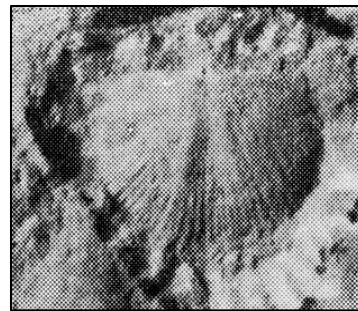
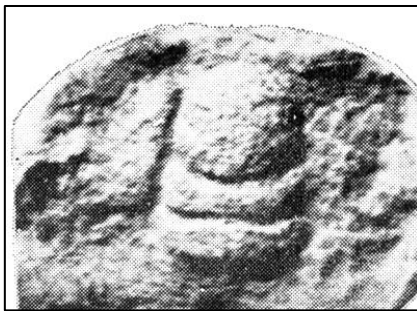
Eventhough Langkawi Island and Satun province are part of the Shan-Thai terrane, comprised flourish fossils and good evidences to support the evolution of old world realm. Later on Sibumasu, extended of Shan-Thai Terrane, formed part of peri-Gondwana during the Paleozoic time. Geological Differences, in terms of geological setting, between Satun Aspiring Geopark and Langkawi UNESCO Global Geopark are on the land of same tectonic plate which was a part of Gondwana having moved from the Southern Hemisphere to form a part of Shan-Thai plate as seen in the present time. Both of them possess a complete Paleozoic geological succession ranging from Cambrian to Permian. Type sections and type localities have been studied and designated to both areas. Some limestone units of both geoparks have formed an outstanding feature of beautiful karst morphology.

The geological differences between Langkawi UNESCO Global Geopark and Satun Aspiring Geopark can be categorized as follow. 1. Lithostratigraphy with biostratigraphy and biodiversity indicated aged of every periods for each formations while Langkawi is Lithostratigraphy without complete fossils indicating every periods. 2. Widespread exposure of Ordovician stromatolitic limestone. 3. Terrestrial Karsts and their continuity of limestone evolution from inland to shore and to offshore and 4. Stegodon stream cave provides 3.4 kilometer long and Cenozoic stegodon fossils found inside the cave.

### A-1 Lithostratigraphy with biostratigraphy and biodiversity

The stratigraphic succession at the Tarutao island, where many index fossils and new genus are found, and every period is delineated by fossils and/or index fossils, will be described.

**Upper Cambrian:** 19 species fossil of trilobites were described by world expert (John Shergold) with stratigraphic and sedimentological control. Numerous trilobites and brachiopods are present in the west of Tarutao island. Kobayashi (1957) dated a common trilobite fauna yield the Late Cambrian. The best known trilobites are *Pagodia thaiensis*, "*Eosaukia*" *buravasi*, and *Coreanocephalus phanulatus* while brachiopods are *Apheorthis* (?) sp. Shergold *et al.* (1988) studied the trilobites of the Tarutao Group from Tarutao island and concluded that they are Late Cambrian to the boundary between Cambrian and Ordovician. The oldest trilobites are found in the west of Tarutao island and west of Laem Hin Ngam and include *Hoytaspis?* *thanisi*, and *Prosaukia* ? aff. *nema*. The younger trilobite fossils were found in Talo Topo bay consisting of *Lichengia?* *tarutaoensis* (Kobayashi) (= *Saukiella tarutaoensis*), *Lophosaukia* cf. sp. indet., *Quadratichephalus planulatus* Kobayashi (= *Coreanocephalus planulatus*), *Leiostegiid* gen. et sp. indet., *Shumardiid* gen. et sp. indet., *Szechuanella* ? cf. *damujingensis*, *Thailandium solum*, *Tsinania* (*Tsinania*) cf. *jiangnanensis*, *Micragnostus* (*Micragnostus*) *nomas*. The youngest Cambrian fossils were found at Talo Udang bay as identified by trilobite; *Parakoldinioidia thaiensis*, (= *Pagodia thaiensis*), which dates closely to the Cambro- Ordovician boundary. Furthermore, brachiopod and conodonts identified Cambrian-Ordovician boundary defined by fossils. Recently, absolute dating of ash layers found between index fossil layers at the Cambrian-Ordovician boundary has been studied and the research may bring to another indication of absolute age of the Global Boundary Stratotype Section and Points (GSSP).

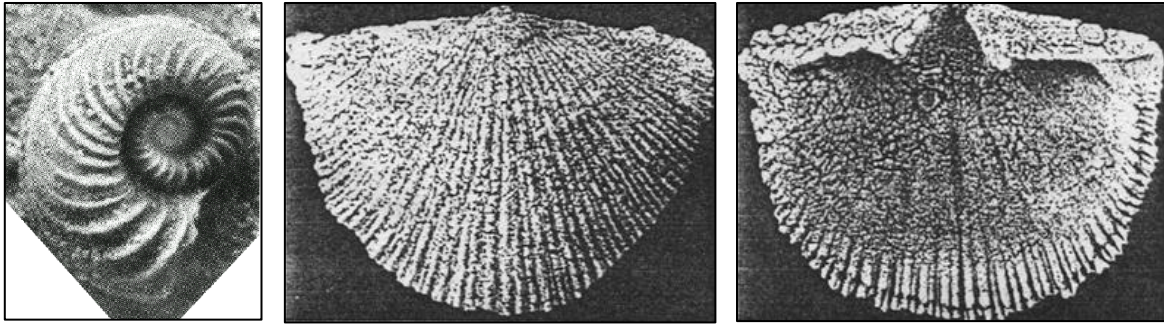


The oldest trilobite fossil in Thailand and new specie of the world named *Eosaukia buravasi*. Aged Upper Cambrian

Brachiopods *Apheorthis* (?) sp. in sandstone

**Lower Ordovician:** Trilobite fauna at the Tarutao Island indicates succession of highly fossiliferous limestone. Detailed studied on sedimentology discloses that the succession contains nautiloids\*, conodonts\*, the gastropod *Peelerophon oehlerti* (Gondwana)\* and chiton *Chelodes whitehousei* (Australia) \* and brachiopods *Syntrophina* & *Archaeorthis?*.

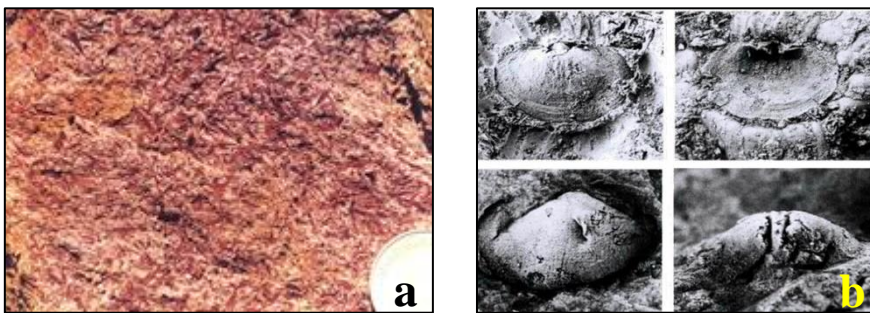
**Middle Ordovician:** Large, well preserved, fauna of Katian to Ashgill, deep and/or cold water trilobites in stratigraphic sequence described by world leading expert on trilobites\*. Brachiopod *Foliomena*\*, large nautiloids also found at this layer.



Lower Ordovician fossils found in the Thung Song Group.

- a) Gastropod named *Peelerophon oehlerti* found at southeastern coast of Tarutao island.
- b) Brachiopod named *Aporthophyla tienjingshanensis* found at 4 km southwest of La-ngu district.

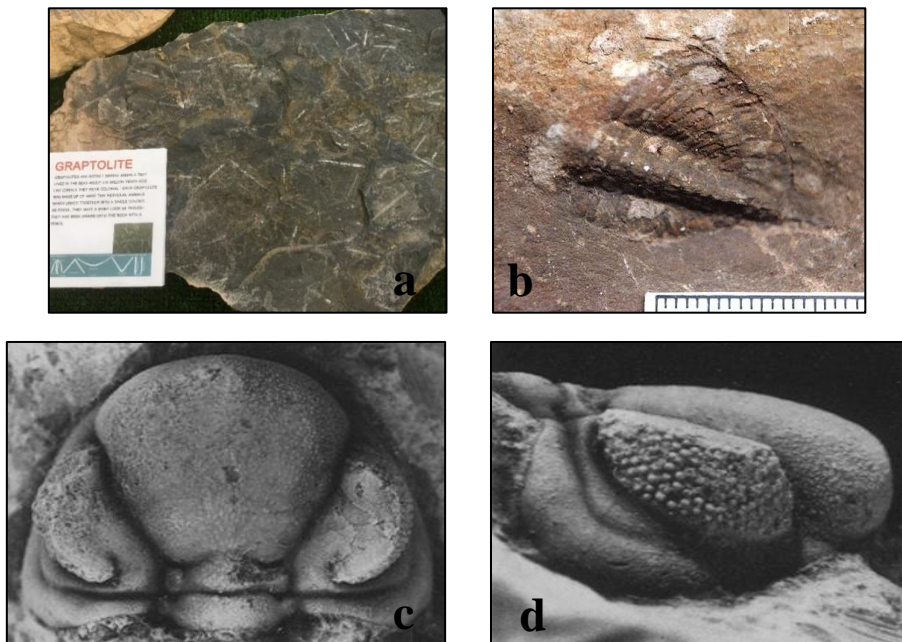
**Upper Ordovician:** Upper Ordovician conodonts are described\* Hirnantian *Hirnantia-Mucronaspis* fauna with graptolite control\*\*.



Pictures show Upper Ordovician fossils along road no. 4078 between La-ngu-Thung Wa districts.

- a) *Tentaculites* sp. found in shale, Pa Samed Formation at km 9.7-9.8.
- b) Brachiopod *Quasiprosserella samedensis* of Upper Pa Samed Formation.

**Silurian :** Graptolite fauna had been described\*.



Pictures show Silurian fossils along road no. 4078 between La-ngu-Thung Wa districts.

- a) Graptolite fossil aged Silurian.
- b) Pygidium of trilobite *Mucronaspis mucronata* found in sandstone of Wang Tong Formation, Thong Pha Phum Group aged Upper Ordovician-Lower Silurian at km 10.9 west of laterite pit.

- c) Trilobite *Reedops seleniomma* in limestone of Kuan Tang Formation aged Lower Devonian shows head and composite eyes, at Khao Kuan Tang, km 10.

**Devonian:** 4 species of Lower Devonian brachiopod described by world leading expert on Silurian-Devonian brachiopods (Boucot)\*. Further more, Lower Devonian conodonts\*, Lower Devonian trilobite and another fauna (5 species) have been described by Fortey. Peri-Gondwanan deep water trilobite *Plagiolaria poothai*\*, and Tentaculitids have been described\*

**Carboniferous:** Diverse fauna with trilobites found in Khuan Klang Formation at Satun geopark boundary has not been described yet as well as *Posidonomya* and radiolarian fauna. Namurian B (Lower Pennsylvanian) brachiopod/ goniatite fauna are described by world leading experts (Boucot and House)\*.

**Permian:** A few Permian fossils present in Kaeng Krachan Group and Ratburi Group have not been described.

**Paleocene-Pleistocene Epoch:** Stegodon and other mammal fossils, found in many caves indicating fauna evolutionary and biogeographic significance, have not yet formally been described.



Posidonomya, Carboniferous Stegodon and other mammal fossils, Paleocene-Pleistocene Epoch

Detail on the biodiversity and index fossil significances is described by international experts on annex 1.

## A-2 Ordovician Stromatolitic limestone or stromatolite

The Pa Kae Formation was proposed by Wongwanich *et al.*, (1990) as the uppermost unit of Thung Song Group in southern region. It was named after Ban (village) Pa Kae located at north of La-ngu district, Satun province. The formation comprises thin red limestone beds with very thin red mudstone. All of limestone in Pa Kae Formation was formed from deposition of stromatolites, causing curling surface and cracks along the crest of stromatolites on top of the beds. It is widespreadly exposed inland with approximate thickness of 66 m at type locality at Khao (hill) Noi but it is 126 m at Ao (bay) Noon in Petra marine national park south of La-ngu district. Nautiloids and trilobites fossils were found indicating Late Ordovician. The rocks deposited in deep sea environment, probably 175-290 m deep.



Fossils and rock stratum in this formation can be used as index fossils and marker bed indicates the contact between Ordovician and Silurian rocks. The marker bed can clearly recognized by its red color. Furthermore, the stromatolitic limestone can predict depth of deposition as well as environment. Detail on the stromatolite is described on annex 2.

### **A-3 Stegodon Sea and Stream Cave**

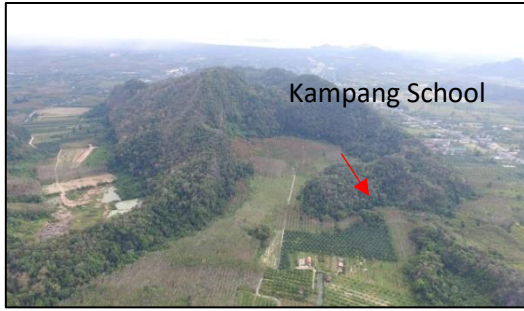
**Karst topography** is a landscape formed from the dissolution of soluble rocks such as limestone, and dolomite. It is characterized by weathering and erosional processes of meteoric water, underground drainage systems and sea wave envisaged as sinkholes and caves. The karstification of a landscape may result in a variety of large or small-scale features both on the surface and beneath.

Erosion of limestone exposed along coastline, notably in the tropical climate, produces karst topography that includes a sharp makatea surface above the normal reach of the sea, and undercuts that are mostly the result of biological activity or bioerosion at or a little above mean sea level. Some of the most dramatic of these formations can be seen in Thailand's Phangnga Bay and at Satun Aspiring Geopark.

Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time. Inside the cave, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals. The cave occurred as evolution of limestone through time under sea and stream weathering and erosional processes. The cave is 3.4 kilometers long where entrance is inland and exit through the mangrove forest and sea. Mammal fossils especially the stegodon fossil has been evacuated at cave floor. Detail on the stegodon cave is described in annex 3.

### **A-4 Terrestrial Karsts**

**Terrestrial Karst topography** is a landscape formed from the dissolution of soluble rocks such as limestone, and dolomite inland. It is characterized by weathering and erosional processes of meteoric water, and underground drainage systems envisaged as sinkholes and caves. The karstification of a landscape may result in a variety of large or small-scale features both on the surface and beneath. On exposed surfaces, small features may include solution flutes (or rillenkarren), runnels, limestone pavement (clints and grikes, a landform consisting of a flat, incised surface of exposed limestone that resembles an artificial pavement), collectively called karren (bands of bare limestone forming a surface) or lapiez (Medium-sized surface features may include sinkholes or cenotes (closed basins), vertical shafts, foibe (inverted funnel shaped sinkholes), disappearing streams, and reappearing springs. Large-scale features may include limestone pavements, poljes (a large flat specifically karstic plain), and karst valleys (Mature karst landscapes, where more bedrock has been removed than remains, may result in karst towers, or haystack/eggbox landscapes. Beneath the surface, complex underground drainage systems (such as karst aquifers) and extensive caves and cavern systems may form.



Sink hole occurs behide Kam Pang school Limestone Lapi finds in front of Phu Pha Phet cave



Polje occurs at Tham Khantiphon

Wang Sai Thong Valley and rapids at the center



Fault scarp along Khao Wang Kloy (stegodon)

Fault scarp at khao kao



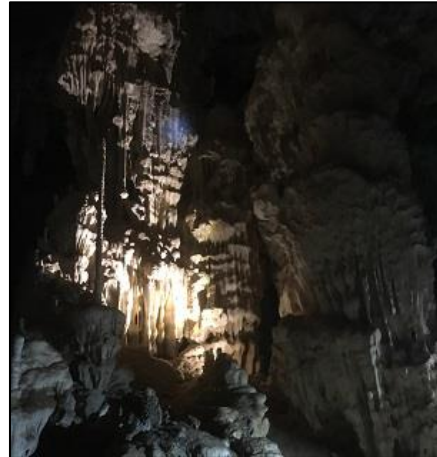
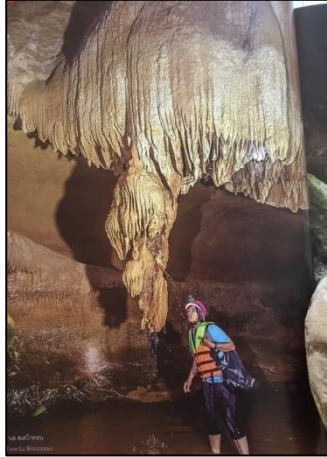
Inland karst at Chet Khot cave shows sinkhole

Inland karst at Phu Pha Phet Cave



Offshore karst at Thousand Peak Rock Palace (Prasat Hin Pan Yod) caused by limestone collapse or sinkholes or cenotes at center.

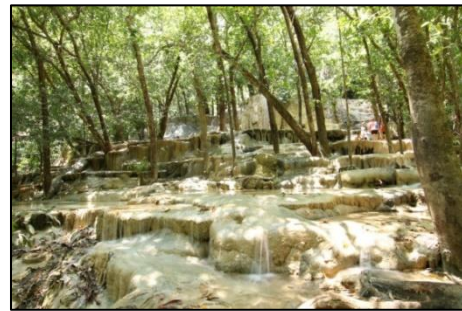
Calcium carbonate dissolved into water may precipitate out where the water discharges some of its dissolved carbon dioxide. Rivers which emerge from springs may produce tufa terraces, consisting of layers of calcite deposited over extended periods of time e.g. at Tharnplew and Wang Sai Thong waterfalls. In caves, a variety of features collectively called speleothems are formed by deposition of calcium carbonate and other dissolved minerals e.g. at Phu Pha Phet, Wang Klang, Chet Khot and Urai caves. Further more, limestone evolution has been developed through time from inland to coastline and offshore. Detail on the terrestrial karst and cave is described on annex 4.



Stalactite and stalagmite at Stegodon cave on left photo and at Phu Pha Phet cave on right photo.



Tharnplew waterfall



Wang Sai Thong waterfall

## Annex 1

### SATUN (Thailand) – LANGKAWI (Malaysia) GEOPARKS - SOME COMPARISONS

This paper is written by Professor Dr. Clive Burrett, University of Tasmania, Australia on March 30, 2017.

### SATUN (Thailand) – LANGKAWI (Malaysia) GEOPARKS - SOME COMPARISONS

Due to intensive studies by several international experts the Palaeozoic history and fossils of Satun is now well known. A record of Palaeozoic sedimentation and life ranges from the Late Cambrian through to the Permian. Both Langkawi and Satun were studied by Kobayashi and Hamada using mainly specimens sent to them from 1958 into the 1980's. Their work lacked structural, stratigraphic and sedimentological context and their descriptions and photography left much to be desired. However, in Satun, studies have been carried out by some of the best palaeontologists using a clearly defined stratigraphy along with related sedimentological studies. This has led to a revision of Kobayashi's (1957) Cambrian trilobite fauna and the addition of many more species (Shergold et al., 1988). By comparison, the Machinchang Formation of Langkawi has no identified Cambrian species. Similarly, Kobayashi's Upper Ordovician fauna from Langkawi contains 7 species (Kobayashi and Hamada, 1978) compared to 39 excellently preserved species described in the Pa Kae Formation of Satun (Fortey, 1997). However, in some systems, Langkawi contains faunas that have not been described, as yet, in Satun. An example is the 8 species Silurian trilobite fauna of Langkawi described by Kobayashi and Hamada (1971),

Comparisons between the Satun and Langkawi Geoparks are shown in the accompanying table with important faunas and geological features in both geoparks highlighted. Obvious differences are the superior diversity of Cambrian and Ordovician faunas, the pelagic red limestone of the Pa Kae Formation and the caves and their Pleistocene faunas in Satun.

<b>Geological features</b>	<b>Satun Aspiring Geopark</b>	<b>Langkawi UNESCO Geopark</b>
<i><b>Fossils</b></i>	(Most fossils published in refereed international journals - *).	(Most studies based on old, unrefereed papers, very few papers published in international refereed journals - *)
<b>Upper Cambrian</b>	19 species of trilobites described by world expert on Upper Cambrian trilobites (John Shergold) with stratigraphic and sedimentological control*. Biogeographically important. Brachiopod and conodonts identified.  Cambrian-Ordovician boundary defined by fossils.	Fragmentary trilobites and brachiopods. None are identifiable.

Geological features	Satun Aspiring Geopark	Langkawi UNESCO Geopark
<b>Lower Ordovician</b>	<p>Lower Ordovician trilobite fauna described*. Tarutao Island succession of highly fossiliferous limestone studied sedimentologically in great detail. Contains nautiloids*, conodonts* the gastropod <i>Peelerophon oehlerti</i> (Gondwana)* and chiton <i>Chelodes whitehousei</i> (Australia) * and brachiopods <i>Syntrophina &amp; Archaeorthis?</i>*</p> <p>In Satun mainland similar faunas to Langkawi. <i>Spanodonta</i> – Australian brachiopod and <i>Aportophyla</i>* and nautiloids*. Conodonts described*</p>	<p>No identifiable fauna described in Machinchang Fm</p> <p>In part, metamorphosed by granite. No trilobites. Nautiloids described * gastropods, conodonts* described</p>
<b>Middle Ordovician</b>	<p>Large, well preserved, fauna of 39 species of Katian to Ashgill, deep and/or cold water trilobites in stratigraphic sequence described by world leading expert on trilobites*. Brachiopod <i>Foliomena</i>. *</p> <p>Large nautiloids</p>	<p>In Langkawi similar faunas to Satun mainland. <i>Spanodonta</i> - Australian brachiopod* and nautiloids*. Stromatoporoids described* Conodonts described*</p> <p>7 species of Katian -Ashgill trilobites described 40 years ago.</p>
<b>Upper Ordovician</b>	<p>Upper Ordovician conodonts described*</p> <p>Hirnantian <i>Hirnantia-Mucronaspis</i> fauna with graptolite control**</p>	<p>Hirnantian trilobite- brachiopod fauna with graptolite control**</p>
<b>Silurian</b>	<p>Graptolite fauna described*</p>	<p>Graptolite fauna described*</p> <p>Upper Llandovery to Lower Wenlock trilobite fauna from basal Upper Setul Limestone 8 named species not found in Thailand. Crinoid loboliths</p>

Geological features	Satun Aspiring Geopark	Langkawi UNESCO Geopark
<b>Devonian</b>	<p>4 species of Lower Devonian brachiopod described by world leading expert on Sil.-Devonian brachiopods- Boucot)*</p> <p>Lower Devonian conodonts*.</p> <p>Lower Devonian trilobite fauna (5 species) described by Fortey.*</p> <p>Peri-Gondwanan deep water trilobite <i>Plagiolaria poothai</i>.*</p> <p>Tentaculitids described*</p>	<p>One Satun species: <i>Plectodonta forteyi</i> found in Langkawi*.</p> <p>This trilobite fauna not present.</p> <p>Tentaculitid fauna present</p>
<b>Carboniferous</b>	<p>Diverse fauna with these trilobites found in Khuan Klang Fm of Satun – not described yet and <i>Posidonomya</i></p> <p>Includes radiolarian fauna.</p> <p>Namurian B (Lower Pennsylvanian) brachiopod/ goniatite fauna (described by world leading experts on brachiopods and goniatites, Boucot and House)*</p>	<p>Rebak Formation with trilobites <i>Lanngonbole vulgaris</i> &amp; <i>Waribole perlisensis</i> with thin shelled bivalve <i>Posidonomya</i></p> <p>This fauna not found in Langkawi.</p>
<b>Permian</b>	<p>A few Permian fossils present in Kaeng Krachan Group of Satun: not described</p>	<p>Lower Permian fossils described in well studied glacial marine sequence of Singa Fm. (Leman &amp; Yop, 2002)</p>
<b>Paleocene-Pleistocene</b>	<p><i>Stegodon</i> and other mammals in caves: fauna of evolutionary and biogeographic significance. Not yet formally described.</p>	<p>No Paleocene - Pleistocene mammal fauna</p>

<b>Geological features</b>	<b>Satun Aspiring Geopark</b>	<b>Langkawi UNESCO Geopark</b>
<i>Geological features</i>	<p>Upper Ordovician Red pelagic stromatolitic limestone Pa Kae Fm, Satun mainland. Easy access.</p> <p>Lower - Middle Ordovician stromatolitic limestones and peritidal carbonates – well studied with classic sedimentological features. Ko Tarutao</p> <p>Terrestrial and offshore karsted limestone including sea and inland caves. Numerous karst features.</p> <p>Picturesque beaches derived from granites.</p> <p>Close association with abundant terrestrial and marine faunas and floras in protected national parks including coral reefs.</p>	<p>Present but limited and little studied.</p> <p>Not so well studied and documented.</p> <p>Sea karsted limestone. Numerous karst features.</p> <p>Beaches derived from granites</p> <p>Close association with abundant terrestrial and marine faunas and floras in protected national parks including coral reefs.</p>

Langkawi UNESCO Global Geopark			Satun Geopark		
	Member	Formation	Group	Formation	
Quaternary		Beruas fm*		Talo U dang fm*	Quaternary
Upper Triassic		Kuah Granite Raya granite		Rawi Granite Adang Granite	Upper Triassic
Upper Permian	Chuping Formation (Jones, 1961) (750-900 m)		Ratburi Group	Um Luk Formation	Upper Permian
Middle Permian				Phanom Wang Formation	
Lower Permian				Phap Pha Formation	
	Singa Formation (Jones, 1981) (2100 m)		Kaeng Krachan Group	Khao Muang Khrut Sandstone	Middle Permian
				Thung Nang Ling Formation	
Carboniferous				Khao Chao Formation	Lower Permian
				Khao Phra Formation	
				Ko He Formation	
			Spillway Formation		
			Laem Mai Phai Formation		
Upper Devonian		Rebak Formation		Khuan Klang Formation	Lower Carboniferous
L-M Devonian	Jentik Formation*/ upper detrital member*	Setul Formation (Jones, 1981) (1550 m)	Thong Pha Phum Group	Pa Samed Formation	Devonian
	Mempelam member*/ upper limestone member*			Kuan Tung Formation	Silurian
Lower Silurian	Tanjung Dendang member*/ lower detrital member* (25 m)			Wang Tong Formation	Lower Silurian
Ordovician	Kaki Bukit member*/ lower limestone member*		Thung Song Group	Pa Kae Formation	Lower to Upper Ordovician
				Rung Nok Formation	
				Lae Tong Formation	
				Pa Nan Formation	
				La Nga Formation	
				Talo dang Formation	
			Malaka Formation		
U Cambrian	Jemuruk member*	Machinchang Formation (Lee, 1983; MT-JGSC, 2013) (2830 m)	Tarutao Group (MT-JGSC, 2013) (2300 m)	Talo Wow Formation*	Upper Cambrian
M Cambrian?	Chinchin member*			Ao Mo Lae Formation*	
	Anak Datai member*			Ao Tami Formation*	
	Hulor member*			Ao Makham Formation*	

Remark: \*informal name

## **Annex 2**

### **Early and Middle Paleozoic fossils and strata in Satun**

This paper is written by Dr. S. Agematsu from Japan on April, 2017.

#### **Early and Middle Paleozoic fossils and strata in Satun**

The Lower and Middle Paleozoic strata in the Satun area are preserved continuously, with little omissions. The Carbonate and siliciclastic rocks yield many kinds of fossils, for example trilobites, brachiopods, orthoceras, conodonts, graptolites, and tentaculites, which are important for studies on biostratigraphy, biogeography, and evolution of these taxa. Endemic species of trilobites, brachiopods, and conodonts have been also described.

One of the most notable points on geology in Satun is the fossiliferous Cambrian and Lower Ordovician strata, which are not found in the Langkawi Islands (Although the Cambrian and Lower Ordovician are distributed in Langkawi, these rocks do not contain fossils due to metamorphism). Biostratigraphy and biogeography of the Cambrian trilobites and Ordovician conodonts provide significant data on the Paleozoic history. Particularly, the lower and middle Ordovician boundary beds distributed in this area must record the “Early Ordovician diversification event” which is similar to the “Cambrian explosion” and is drawing attention in the world recently.

#### **Significant geological events**

These strata cover from Cambrian through Devonian in age and include significant beds for evolutionary events, that is, the lower and middle Ordovician boundary, the Ordovician-Silurian boundary (OSB), the Lower Devonian beds, and probably the Frasnian-Fammenian boundary (FFB). The first one is recognized as the “Early Ordovician diversification event” bed, as mentioned above, and distributed in Thung Wa district and Tarutao island. The OSB is famous for the second biggest mass extinction and found in Thung Wa (?Satun?). The Lower Devonian strata, exposed in Thung Wa and Satun, also seem to record some global catastrophes. In addition, we expect that the FFB bed will be found in Satun near future. These event beds in this area are preserved in black mudstone sequences, yielding graptolites, tentaculites, and trilobites, and provide good teaching materials for evolution and environmental changes. Satun is a really attractive area for paleontology and geology, because we can easily look around all these localities within the area.

Satun is different from Langkawi in that the Lower and Middle Paleozoic rocks are preserved without essential lacks and distributed in much wider area. In the Langkawi Islands, Cambrian and Early Ordovician fossils have not been reported, and most of Devonian strata appear to be lost. The outcrops in Satun are kept in excellent conditions and we can see dry and wide outcrops on the mainland.

### Annex 3

#### Ordovician Stromatrolitic limestone

The following document is taken from [www.wikipedia.com](http://www.wikipedia.com), but photo is taken by the satun geopark team.

**Stromatolites or stromatoliths** are layered bio-chemical accretionary structures formed in shallow water by the trapping, binding and cementation of sedimentary grains by biofilms (microbial mats) of microorganisms, especially cyanobacteria. Fossilized stromatolites provide ancient records of life on Earth by these remains, some of which may date from 3.7 billion years ago.

Stromatolites exhibit a variety of forms and structures, or morphologies, including conical, stratiform, branching, domal, and columnar types. Stromatolites occur widely in the fossil record of the Precambrian, but are rare today.



Limestone, red, thin bedded, with darker red argillaceous partings, and abundant stromatolitic polygons of Pa Kae Formation.

#### Formation

Biddanda et al. (2015) found that cyanobacteria exposed to localized beams of light moved towards the light, or expressed phototaxis, and increased their photosynthetic yield, which is necessary for survival. In a novel experiment, the scientists projected a school logo onto a petri dish containing the organisms, which accreted beneath the lighted region, forming the logo in bacteria. The authors speculate that such motility allows the cyanobacteria to seek light sources to support the colony. In both light and dark conditions, the cyanobacteria form clumps that then expand outwards, with individual members remaining connected to the colony via long tendrils. This may be a protective mechanism that affords evolutionary benefit to the colony in harsh environments where mechanical forces act to tear apart the microbial mats. Thus these sometimes elaborate structures, constructed by microscopic organisms working somewhat in unison, are a means of providing shelter and protection from a harsh environment.

#### Fossil record

Some Archean rock formations show macroscopic similarity to modern microbial structures, leading to the inference that these structures represent evidence of ancient life, namely stromatolites. However, others regard these patterns as being due to natural material deposition or some other abiogenic mechanism. Scientists have argued for a biological origin of stromatolites due to the presence of organic globule clusters within the thin layers of the stromatolites, of aragonite nanocrystals (both features of current stromatolites), and because of the persistence of an inferred biological signal through changing environmental circumstances.

Stromatolites are a major constituent of the fossil record of the first forms of life on earth. The earliest fossils date to 3.7 billion years ago. They peaked about 1.25 billion years ago and subsequently declined in abundance and diversity, so that by the start of the Cambrian they had fallen to 20% of their peak. The most widely supported explanation is that stromatolite builders fell victim to grazing creatures (the Cambrian substrate revolution); this theory implies that sufficiently complex organisms were common over 1 billion years ago.

Proterozoic stromatolite microfossils (preserved by permineralization in silica) include cyanobacteria and possibly some forms of the eukaryotechlorophytes (that is, green algae). One genus of stromatolite very common in the geologic record is *Collenia*.

The connection between grazer and stromatolite abundance is well documented in the younger Ordovician evolutionary radiation; stromatolite abundance also increased after the end-Ordovician and end-Permian extinctions decimated marine animals, falling back to earlier levels as marine animals recovered. Fluctuations in metazoan population and diversity may not have been the only factor in the reduction in stromatolite abundance. Factors such as the chemistry of the environment may have been responsible for changes.

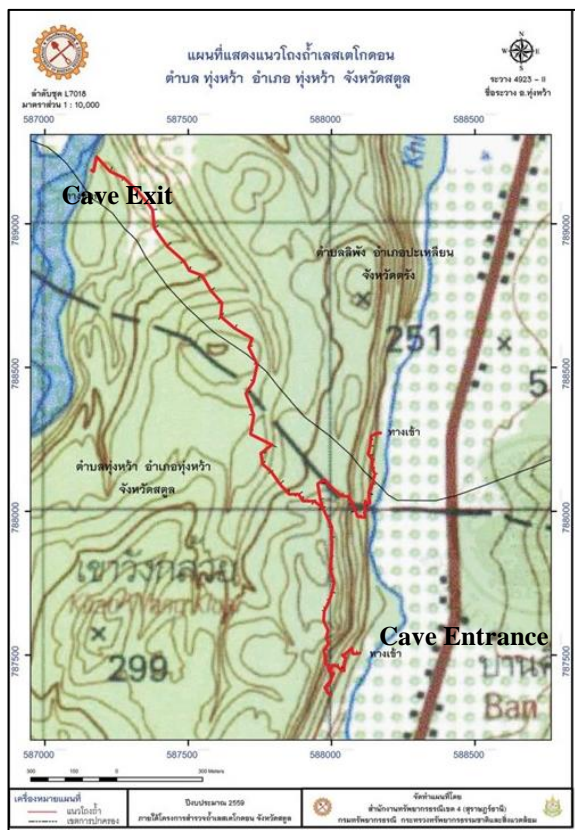
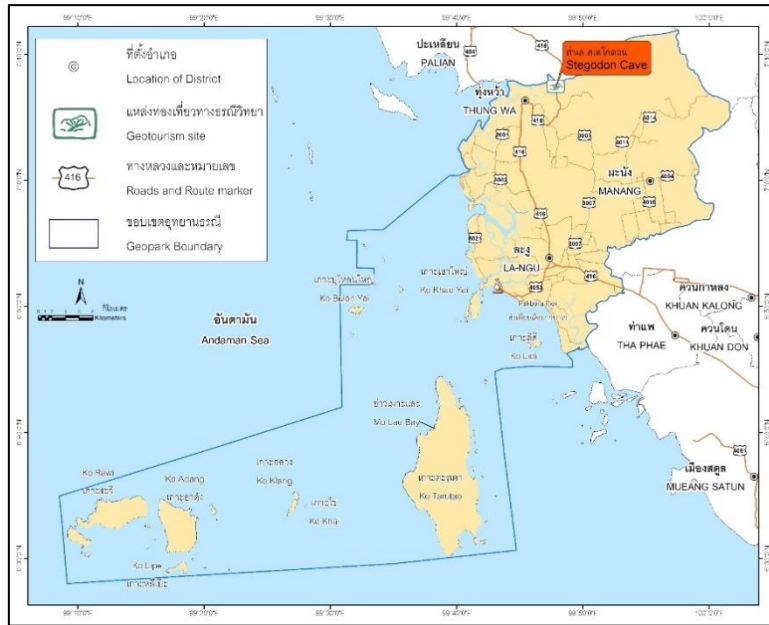
While prokaryotic cyanobacteria reproduce asexually through cell division, they were instrumental in priming the environment for the evolutionary development of more complex eukaryotic organisms. Cyanobacteria (as well as extremophile Gammaproteobacteria) are thought to be largely responsible for increasing the amount of oxygen in the primeval earth's atmosphere through their continuing photosynthesis. Cyanobacteria use water, carbon dioxide, and sunlight to create their food. In modern microbial mats, debris from the surrounding habitat can become trapped within the mucus, which can be cemented together by the calcium carbonate to grow thin laminations of limestone. These laminations can accrete over time, resulting in the banded pattern common to stromatolites. The domal morphology of biological stromatolites is the result of the vertical growth necessary for the continued infiltration of sunlight to the organisms for photosynthesis. Layered spherical growth structures termed oncolites are similar to stromatolites and are also known from the fossil record. Thrombolites are poorly laminated or non-laminated clotted structures formed by cyanobacteria, common in the fossil record and in modern sediments.

Modern stromatolites are mostly found in hypersaline lakes and marine lagoons where extreme conditions due to high saline levels prevent animal grazing. One such location is Hamelin Pool Marine Nature Reserve, Shark Bay in Western Australia where excellent specimens are observed today, and another is Lagoa Salgada ("Salty Lake"), in the state of Rio Grande do Norte, Brazil, where modern stromatolites can be observed as bioherm (domal type) and beds. Inland stromatolites can also be found in saline waters in Cuatro Ciénegas, a unique ecosystem in the Mexican desert, and in Lake Alchichica, a maar lake in Mexico's Oriental Basin. The only open marine environment where modern stromatolites are known to prosper is the Exuma Cays in the Bahamas.

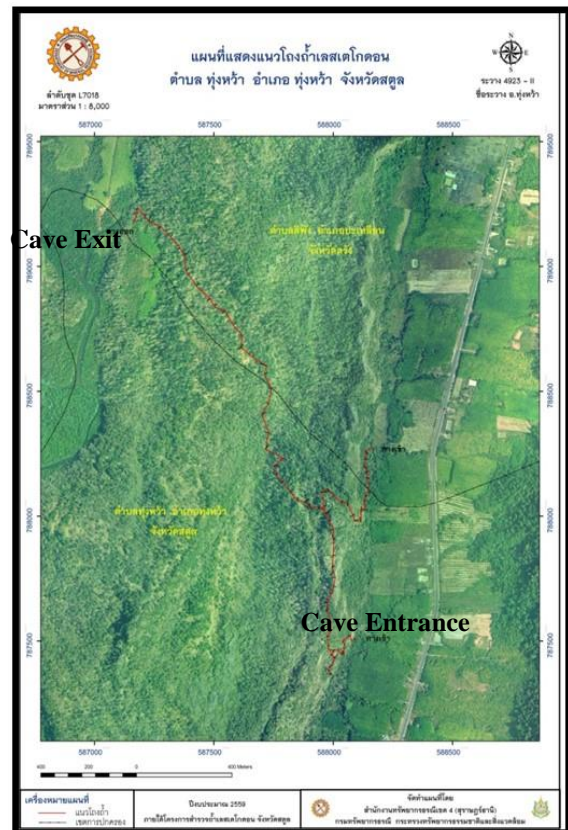
Annex 4

Tham Le Stegodon (Stegodon Cave)

Location: Thung Wa Subdistrict, Thung Wa District, Satun Province.



Stegodon cave route map, red solid line, delineates on base topographic map scale 1:50,000



Stegodon cave route map, red solid line, delineates on satellite map.



Drone photo takes at Khao Wang Kluay where Stegodon cave lie underneath.

**Highlight:** The longest stream cave in the Thai-Malay Peninsula is 3, 389meters. The cave entrance is brackish stream while the cave exit is mangrove forest. Ancient elephant named Stegodon was discovered in the cave and firstly discovered in southern Thailand, aged Pleistocene (2.6 – 0.01 million years ago).



Spectacular and lively stalactite can be seen inside the cave.



Right mandible (lower jaw) with the second and third molars of an ancient elephant Stegodon found inside the cave floor.



Stegodon elephant replica (photo courtesy from Petrified wood Museum, Nakhon ratchasima province).



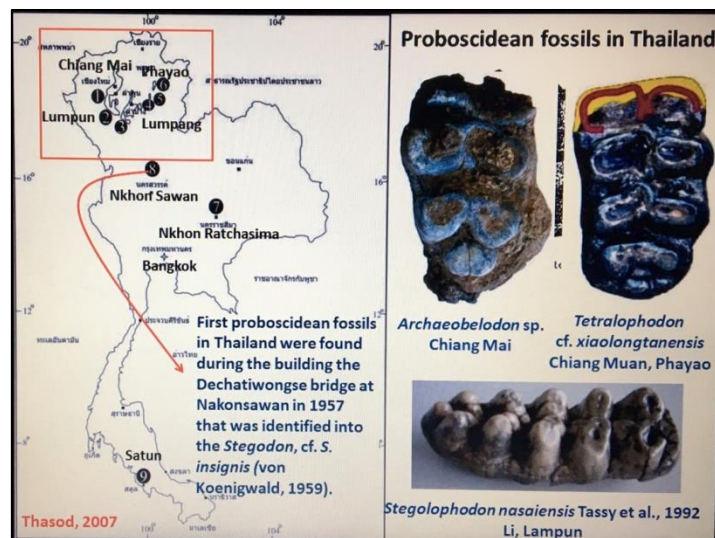
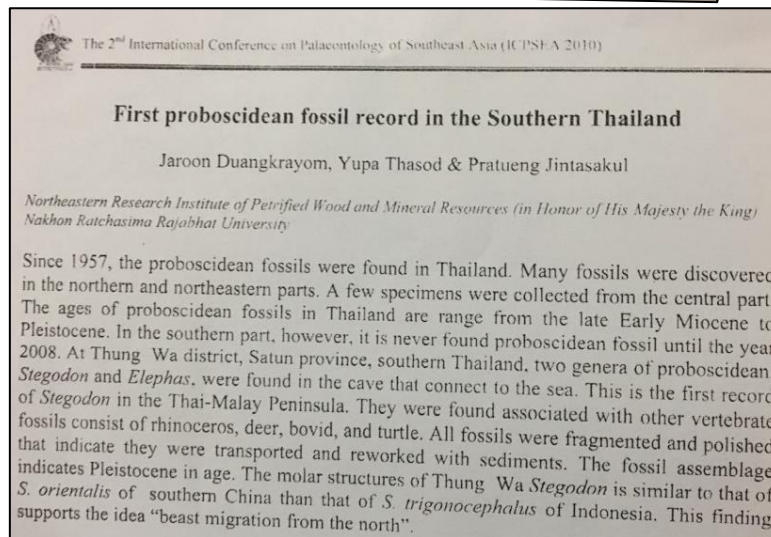
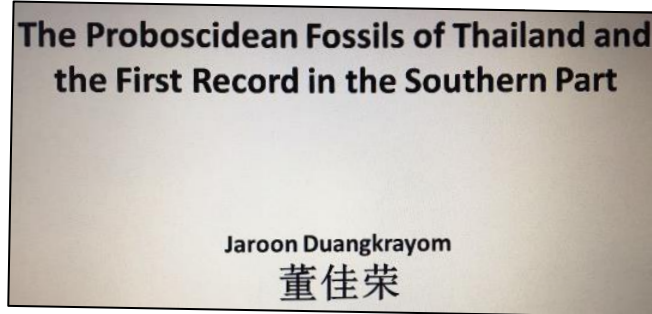
Stegodon cave is stream cave geomorphology providing adventure kayaking.



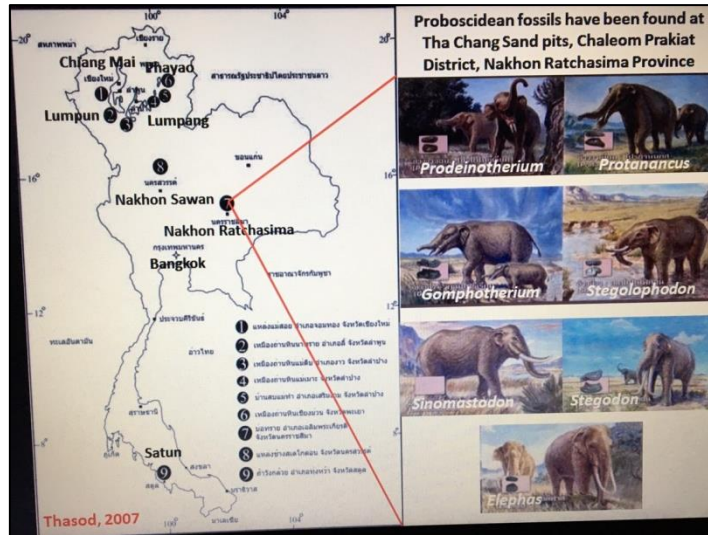
Kayaking towards the cave exit, similar to heart shape, as slogan “In search for the heart at the cave exit”.

**Geology:** The stegodon cave is a limestone cave of Rung Nok and Pa Kae Formations aged Ordovician or 480- 460 million years ago. The cave provides excellent examples of Ordovician limestone tropical karst topography and miracle cave shapes such as mountain cliffs, towers, sinkholes, karst lapies, springs, stalactite, stalagmite, column, curtain etc. Several vertebrate fossils have been discovered, especially the ancient elephant “Stegodon” lived during Late Miocene to Pleistocene epoch or during 11 Ma to 10,000 Ya.

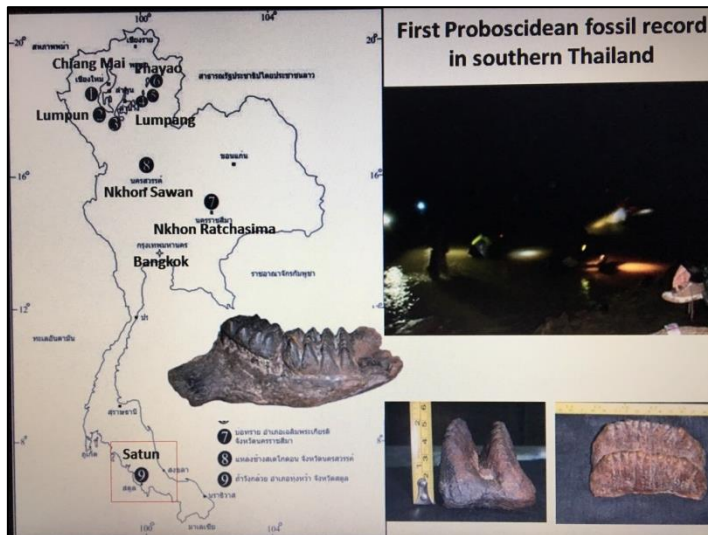
**Publication on first discovery of Stegodon fossils in Southern Thailand.**



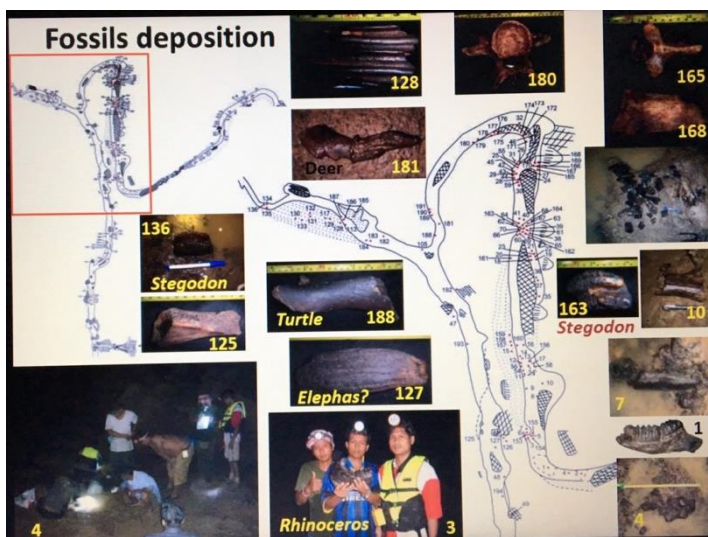
Proboscidean fossils in Nakhon Sawan, Lam Phun, Chiang Mai and Phayai provinces, northern Thailand.



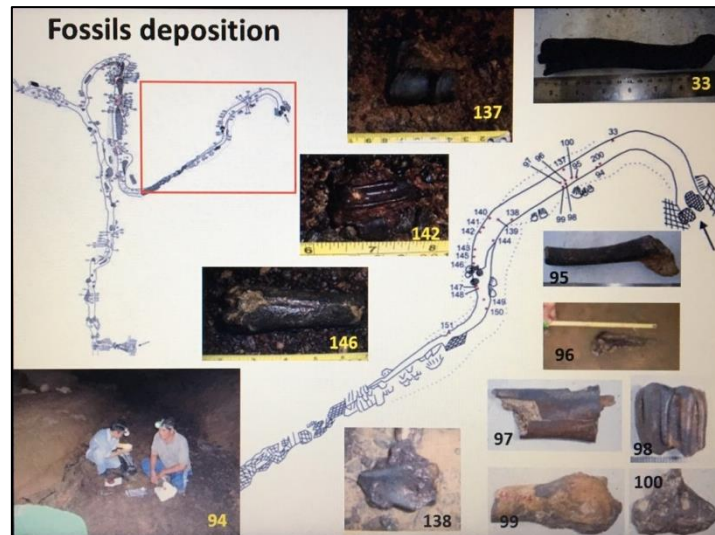
Proboscidean fossils in Nakhon Ratchasima province, northeastern Thailand.



First Proboscidean fossil records in Satun province, Southern Thailand.



Fossil excavation sites, number and type of fossils found in the Stegodon cave in red rectangular.



Fossil excavation sites, number and type of fossils found in the Stegodon cave in red rectangular.

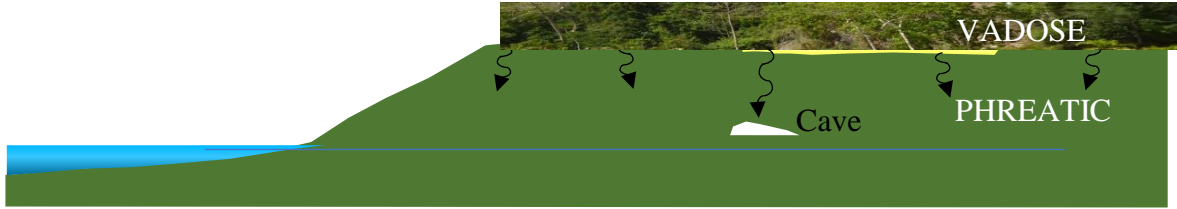
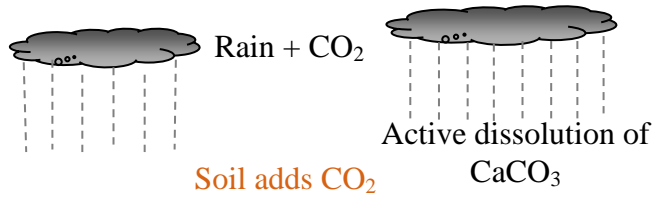


Fossil excavation site indicates insitu fossil found in the Stegodon cave.

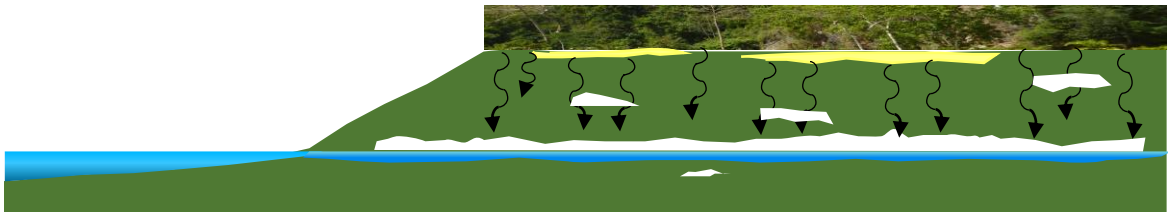
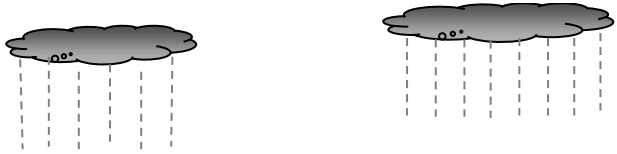
**Stegodon Cave Formation:** Three main criteria for subsurface cave of the stegodon cave formation are water flow, vadose zone above water table where physiochemical and biological dissolution is dominated and water table where intense chemical activity occur and fluctuate in accord with tidal activity.

Mixing and activity among meteoric water, biological and carbonate at the vadose zone infiltrate and dissolve limestone along passages, channels, and shafts walls and ceilings can be smooth, pockmarked with corrosion pockets, dimples, and pits, or textured with rills and grooves. Water movement in the Stegodon cave are mostly vertical in the vadose zone and subhorizontal in the phreatic zone.

**1. CAVE FORMATION VIA DISSOLUTION THROUGH MIXING (close to atmosphere)**



**2. CAVE FORMATION VIA DISSOLUTION THROUGH MIXING (close to atmosphere)**



**3. CAVE PRECIPITATES VIA DEGASSING (open to atmosphere)**



# STEGODON STREAM CAVE

General Information

Inside the Stegodon Sea Cave, there is one main passage with two sub passages. The passage along the main passage is designed for the tourist route while the two passages are reserved for the research paths.

Inside the cave, there are water passage and dry passage with the total length of 3,389.01 meters:

- Tourist route 2,569.62 meters.
- Water passage 706.66 meters.
- Dry passage 112.73 meters.

Geological features

Based on the DMR data, the Stegodon sea cave is situated in the limestone mountainous area. It consists of Ordovician and Quaternary ages.

- **Ordovician (O)**

Ordovician (O) is mainly found in the area of Thing Wa District, Satun Province. Generally, it characterized in Karst Topography. Limestone is composed of various textures. Various fossils of marine species, including Nautiloids, Crinoids stem are generally found. The ages of rock is varied from 505-438 Million years.

- **Quaternary (Q)**

Quaternary (Q) consists of sediment types 1.6 - 0.01 million years in age such as limestone fragments, gravels lateritic soil and clay.

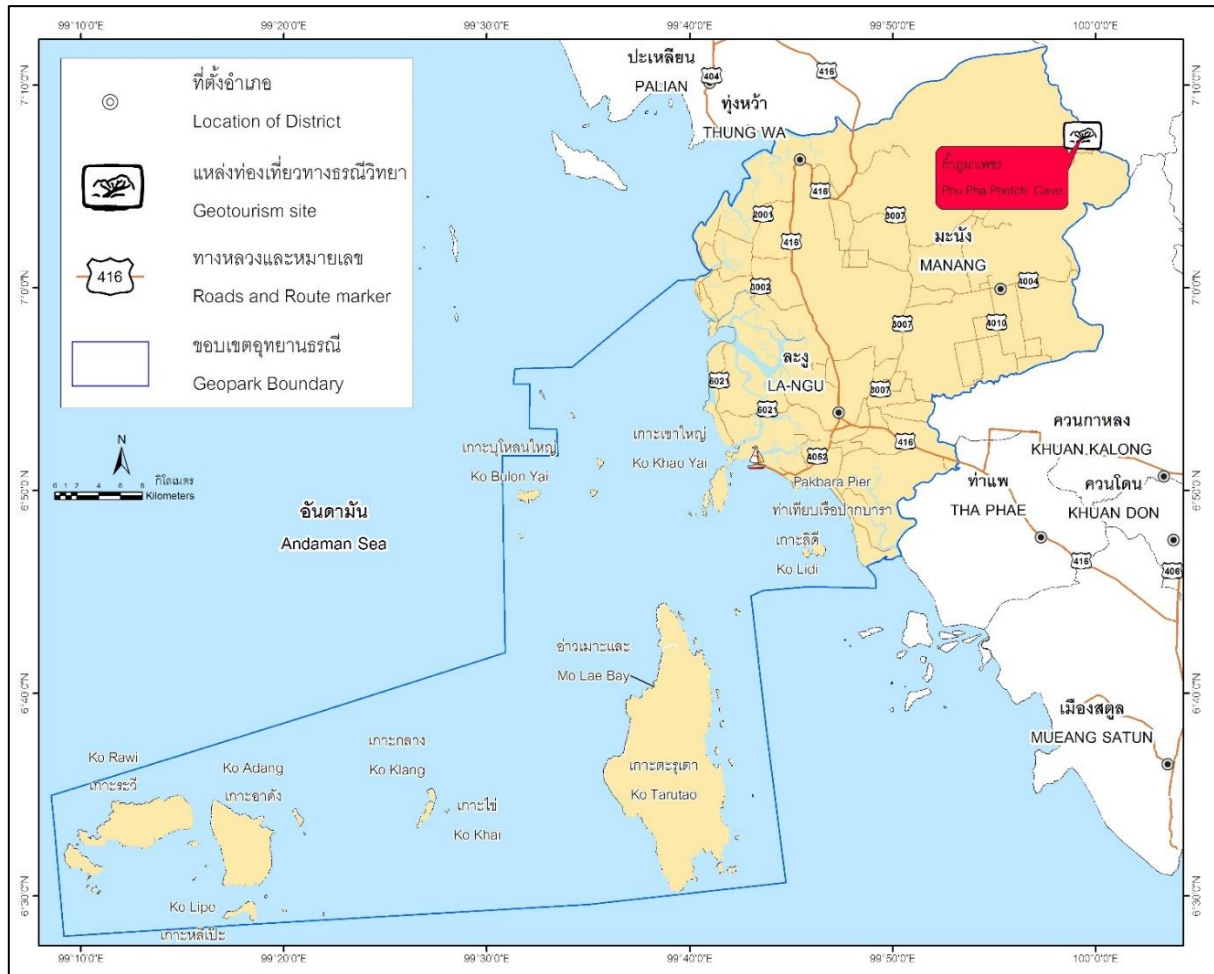
Remarkable features

- Flowstone
- Stalagmite
- Flowstone
- Dissolve Limestone
- Bedding and Flowstone
- Rock fall and Flowstone
- Soda straw
- Rimstone pool
- Flowstone
- Flowstone
- Columnar and Bat
- Hollow shaft of light
- Exit
- Hollow shaft of light
- Tension crack
- Bedding

## Annex 5

### Phu Pha Phet Cave

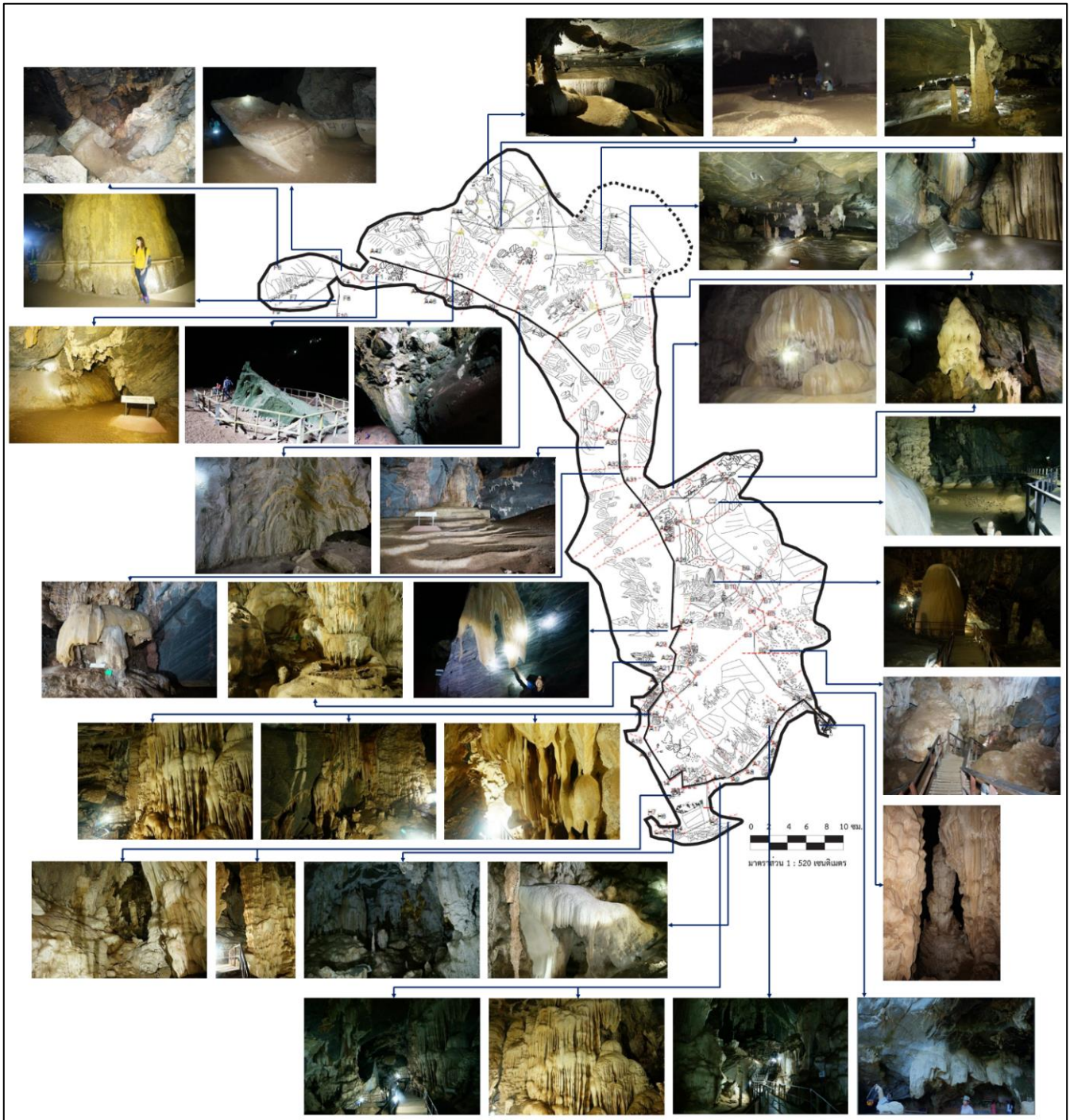
**Location:** Palm Pattana Subdistrict, Manang District, Satun Province.



**Highlight:** One of the largest solution caves in the Thai-Malay Peninsula, covered area roughly 80,000 square meters. The cave shows astonishing shapes of stalagmite, stalactite as cave column, cave curtain and natural arch. There are human skeletons, earthen wares disclosed as a prehistoric human living site more than 3,000 years ago. Mammal fossils also found inside the cave.

**Geology:** It is consisted of dark gray argillaceous limestone and stromatolitic limestone interbedded with shale where nautiloid, brachiopod, crinoid, trilobite and sponge fossils of the Thung Song Group aged Ordovician period (480-445 million years ago) were found. There are several kinds of speleothems and more than 20 cave halls with miracle calcium carbonate precipitation shapes of stalagmites, stalactites imagined as columns, shawls, curtains, corals, straws, sparkling diamonds, pearl, pagoda head, mushroom, monk image, dragon skeleton, and alien etc. Stream cave erosional and depositional processes occurred from previous time and continue until present. The stream process can create speleothems of various types e.g rim stone pool, flow stone, Emerald courtyard. and rock falls etc.

There are spectacular halls and view point inside the caves of at least 7 halls namely Sun Supporting Pillar, Garuda Head, Diamond curtain, Mushroom, Bat, and Small Stone Basin. The last hall is the most spectacular hall named “emerald hall”.



Phu Pha Phet cave map indicates cave hall names and tourist visiting points. (Office of the Natural Resources and Environmental Policy and Planning, 2016, Preparation and Protection Project on climate change impacts affected to the ecology and environmental of natural conservation sites : cased study on caves, Ministry of Natural resources and Environment, Bangkok (in Thai)).



Lighting inside the Phu Pha Phet Cave.



Lively stalagmite with calcium carbonate continuing growth.



Spectacular emerald hall where the sun shines through fern ground, looks similar to emerald sparkling.