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สำนักเลขาธิการคณะกรรมการแห่งชาติว่าด้วยการศึกษา
วิทยาศาสตร์ และวัฒนธรรมแห่งสหประชาชาติ (ยูเนสโก)

DMR-CCOP-TNCU Technical Seminar on

Biostratigraphy and Karst Morphology of Satun Aspiring Geopark

13th-14th July, 2017
The Berkeley Hotel Pratunam
Bangkok, Thailand

Organized by

- Department of Mineral Resources
- Coordinating Committee for Geoscience Programmes in East and Southeast Asia
- Thai National Commission for UNESCO

SATUN
Aspiring Geopark

SATUN
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“GEOPARK FOR PEOPLE”

PREFACE

The Royal Thai Government through the Department of Mineral Resources, Ministry of Natural Resources and Environment, the Coordinating Committee for Geoscience Programmes in East and Southeast Asia (CCOP), and Thai National Commission for UNESCO organize the DMR-CCOP-TNCU Technical Seminar on Biostratigraphy and Karst Morphology of Satun Aspiring Geopark" on 13th -14th July 2017 at the Berkeley Hotel Pratunam, Bangkok, Thailand.

Aim of this Seminar mainly focus on raising up scientific significance of Satun Aspiring Geopark which is one of the most importance part leading to sustainable development of the areas. Four sessions namely Biostratigraphy, Karst morphology, stratigraphy and discussion on Geological Similarities and difference between Langkawi Global Geopark and Satun Aspiring Geopark were included in this Seminar. The Seminar provides an opportunity for more than 100 Geo-scientific participants from Thai Governmental organizations, Universities and Public Organizations as well as Minerals and Geoscience Department Malaysia, National University of Malaysia, University of California, Riverside, USA, University of Hong Kong, University of Tsukuba, Universitas Gadjah Mada, Indonesia and organization in Laos to share the knowledge and discuss technical issues on paleontology, stratigraphy, karst morphology and geological significances of Satun Aspiring Geopark, especially in geological differences from Langkawi Global Geopark. The geological differences between Langkawi Global Geopark and Satun Aspiring Geopark will also be discussed.

The Technical Seminar on Biostratigraphy and Karst Morphology of Satun Aspiring Geopark comprises of 20 abstract papers and 16 Posters titles. All papers will be also oral presentation in this event time.

On behalf of the organizations, we would like to welcome you all to the seminar. We hope that the Session can draw our geoscientist colleagues' attention to the major role that the geosciences can play for society. We wish the seminar all success and wish you all a pleasant time in the beautiful city of Bangkok.

(Dr.Tawsaporn Nuchanong)
Director General,
Department of Mineral Resources, Thailand

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

13th-14th July 2017

The Berkeley Hotel Pratunam, Bangkok, Thailand

Thursday, 13th July 2017

08.30-09.00 Registration (Mayfair Ballroom A, 11th Floor)

09.00-09.30 Video Presentation on Satun Aspiring Geopark
Opening Ceremony
Dr. Tawsaporn Nuchanong, Director General of DMR

09.30-09.50 Keynote address: **Satun Aspiring Geopark: The Challenging Thailand National Geopark for Global Geopark**
Dr. Tawsaporn Nuchanong, Director General of DMR

09.50-10.10 **Role of geoheritage sites in contribution to development of Satun Aspiring Geopark**
Dr. Apsorn Sardsud, Senior Professional Geologist, DMR

10.10-10.30 Coffee break and poster session

Section I: Biostratigraphy of Satun Aspiring Geopark

10.30-10.50 **Tarutao Formation: Globally significant key to late Cambrian space and time**
Prof. Dr. Nigel Hughes, University of California, Riverside, USA

10.50-11.10 **Late Cambrian paleontology of the Tarutao Formation**
Ms. Shelly Wernette, University of California, Riverside, USA

11.10-11.30 **Zircon U-Pb-Hf constraints on Cambrian paleogeography of Asian terranes along in eastern Gondwana**
Dr. Ryan McKenzie, University of Hong Kong

11.30–11.50 **Ordovician-Silurian-Devonian: Significance of fossil assemblages at Tarutao, Khao Noi, and Kuan Tung, Satun Aspiring Geopark.**
Assoc. Prof. Dr. S. Agematsu, the University of Tsukuba, Japan

12.00-13.00 Lunch (The Noth Café, 11th Floor)

13.10-13.30 **The Red Stromatolitic Limestone, the Pa Kae Formation**
Dr. Thanis Wongwanich, Expert Specialist, Thailand

13.30–13.50 **Morphology and ontogeny of an early Devonian trilobite from southern Thailand**
Dr. Catherine Crônier and Prof. Richard Fortey
(Presented by Prof. Dr. Nigel Hughes, University of California, Riverside, USA)

13.50–14.10 **Fossil Faunas and sedimentary sequences in Satun Geopark-regional and global Significance**
Prof. Dr. Clive Burrett & Dr. Pol Chaodumrong, Expert Specialist, Thailand

14.10-14.25 Coffee break and poster session

Section II: Karst morphology of Satun Aspiring Geopark

14.25–14.45 **An Overview of Karst Systems with Reference to Satun Aspiring Geopark**
Dr. Terry Bolger, Cave&Karst Specialist, Lao PDR.

14.45–15.05 **Cave Carrying Capacity: Lesson Learned from Pindul Cave and Baru cave, Gunung Sewu Geopark, Indonesia**
Dr. Eko Haryono, Expert specialist, Indonesia

15.05–15.25 **Kilim Karst Geoforest park: Marine beautiful karst**
Mr. Amir Mizwan bin Mohd Akhir, Geologist, JMG, Malaysia

15.25–15.45 **The Conservation of Tasik Dayang Bunting as one of the geosites of Langkawi UNESCO Global Geopark**
Ms. Nur Susila bt. Md. Saaid, Senior Geologist, JMG, Malaysia

15.45–16.30 Discussion

18.30–20.00 Welcome Dinner hosted by DMR (The Wedding Lounge, 10th Floor)

Friday, 14 July 2017

Section II: Karst morphology of Satun Aspiring Geopark (con't)

09.00–09.20 **Terrestrial karst connect to Nature and People of Satun Aspiring Geopark**
Mr. Chaiporn Siripornpibul, Expert specialist, DMR, Thailand

09.20–09.40 **Thamlay Stegodon, the Longest and Biodiversity cave of Thailand**
Ms. Russarint Siripattarapureenon, Geologist, DMR, Thailand

09.40-10.00 **Mammalian fossils and their depositional processes in the Wang Kuay cave, Thungwa District, Satun Province, Southern Thailand**
Dr. Jaroon Duangkrayom, Nakhon Ratchasima Rajabhat University, Thailand

10.00-10.20 Coffee break and Poster Session

Section III: Stratigraphy of Satun Aspiring Geopark and Langkawi Global Geopark

10.20–10.50 **Langkawi research center: a research arm of Langkawi UNESCO Global Geopark.**
Prof. Dr. Che Aziz bin Ali, Expert, UKM, Malaysia

10.50–11.20 **Geological significances of Langkawi Global Geopark**
Dr. Tanot Unjah, Expert, UKM, Malaysia

11.20–11.40 **Singa Formation and its geological significances**
Mr. Mat Niza Abdul Rahman, Expert Geologist, JMG, Malaysia

11.40–12.00 **Lithostratigraphic Correlation between Langkawi Island and Satun Aspiring Geopark**
Mr. Suvapark Imsamut, Senior Professional Geologist, DMR, Thailand

12.00 - 13.00 Lunch (The Noth Café, 11th Floor)

Section IV: Workshop on Satun Aspiring Geopark

13.00–15.30 **Discussion on Geological Similarities and difference between Langkawi Global Geopark and Satun Aspiring Geopark**
- *Prof. Dr. Nigel Hughes –moderator*
- *Prof. Dr. Clive Burrett*
- *Dr. Eko Haryono*
- *Assoc. Prof. Dr. S. Agematsu*
- *Prof. Dr. Che Aziz bin Ali, UKM,Malaysia.*

15.30-16.00 Closing Ceremony

18.30–20.00 Farewell Dinner hosted by CCOP (The Mulberry Chinese Cuisine Restaurant, 10th Floor)

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ABSTRACT VOLUME

DMR- CCOP- TNCU Technical Seminar on

Biostratigraphy and Karst Morphology of Satun Aspiring Geopark

"GEOPARK FOR PEOPLE"

13th-14th July, 2017

At the Berkeley Hotel Pratunam, Bangkok, Thailand

- Department of Mineral Resources
- Coordinating Committee for Geoscience Programmes in East and Southeast Asia
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SATUN ASPIRING GEOPARK: THE CHALLENGING THAILAND NATIONAL GEOPARK FOR GLOBAL GEOPARK

Dr. Tawsaporn Nuchanong

Department of Mineral Resources (DMR), Thailand

Abstract

The promotion of geoconservation activity in Thailand has long been done by DMR since 2001 by issuing 2 publications related to geo-heritage sites and geotourism sites in order to disseminate the knowledge of geological values to public. In 2010, the pilot project with geopark concepts has been conducted in Satun province, then followed by the subsequent projects in Ubon Ratchathani, Khon Kaen, Nakhon Ratchasima and Tak province. Many criteria are set up to standardize the geopark e.g. the geoconservation evaluation criteria and the geopark establishment criteria. So far, there are three province-geoparks; Ubon Ratchathani, Nakhon Ratchasima and Tak, and one national geopark; Satun which is the most active one.

Satun geopark has run an area of about 2,600 km^2, it is now a quiet, peaceful tourism area and has received status as 'ASEAN Heritage Parks and Reserves' designated by UNESCO in 1982. Geologically, it composed international significances that are 1) the Tarutao Group type stratigraphic section at Tarutao Island, where many Cambrian-Ordovician index fossils and new genus are reported. Furthermore, some of those fossils can indicate the Cambrian-Ordovician boundary. Recently, absolute dating of ash layers found between the index fossil layers at the Cambrian-Ordovician boundary has been studied and may bring to another indication of absolute age of the Global Boundary Stratotype Section and Points (GSSP). 2) The stratigraphic type locality at Khao Noi and the stromatolitic limestone aged Ordovician-Devonian. 3) biostratigraphy and biodiversity where complete periods of the Paleozoic Era are delineated by fossils and/or index fossils. 4) The depositional environment of the Kaeng Krachan Group which was glaciomarine mass flow origin indicated by Bouma sequence and drop stone.

According to those geological importance, Satun local organisations and DMR then work side by side to promote Satun geopark as a new theme of tourism and bring the real and tangible benefits to local communities since 2014. After that year, Satun geopark has recognized by people through TV programmes and 1st- 4th Fossil Festival, consequently, the number of tourists is increasing, also the income of locals. In 2016, Satun geopark then steps forward to apply as a member of UNESCO Global Geopark. This is the big challenge as it is the first time for Thailand. No matter what the outcome will be, the good collaboration among Satun geopark stakeholders will be a good example of bottom up process for other geoparks, many obstacles happening will become the good lessons for other geopark development.

ROLE OF GEOHERITAGE SITES IN CONTRIBUTION TO DEVELOPMENT OF SATUN ASPIRING GEOPARK

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Extended Abstract

Satun Aspiring Geopark is proposed to be a Global Geopark from the reasons of at least 5 international significance; Fossil Diversity of the Paleozoic, International Stratotype Section of Lower to Upper Paleozoic, Upper Ordovician Red Stromatolitic Limestone of the Pa Kae Formation, Terrestrial Karst, and Tarutao National Park. It is including almost 27 geoheritage sites that related to the international significance, such as Mo Lae Bay, type section at Khao Nui (Noi), Khao To Ngai time-bounded, Stegodon cave, Wang Sai Thong waterfall, etc.

Satun Aspiring Geopark is well known as the land of Paleozoic fossils in Thailand and Southeast Asia for its geological sites that yielded abundance, high diversity and oldest succession of fossil including trilobites, brachiopods, stromatolites, conodonts, graptolites, tentaculites, and nautiloids. The Late Cambrian trilobite fossils at Tarutao Island are the oldest recorded in the Thai-Malay Peninsula and the Southeast Asian region, with volcanic ash, allow absolute dating of the well-established Late Cambrian trilobite biostratigraphy. One new genus and five species of Cambrian trilobites are presented, as well as the mysterious red stromatolitic limestones.

Significant evidence provides support for the evolution of the Old World Realm in which Shan Thai formed part of peri-Gondwana terranes. Evolution through geological time has majestically shaped sublime and precious scenery of the Satun Aspiring Geopark. In previous time, even geological sites in Satun area were important and interested to the researchers but they were not connected and related to the people, economy and their life. Recently, people in Satun area realized that the geological sites in their lands are important and be able developed to the geoheritage sites, national geopark, and geotourism as a global geopark, in ascending order. Satun area is a model of the bottom up development that the people in the area realize and try to create their new local products and develop the areas to the Global Geopark for their sustainable economy. The new local products, for example Batik and melon, are also related to the Satun Aspiring Geopark by using the symbol and the raw material from geological related materials. The geoheritage sites role as the tools for geopark, geotourism, and finally will lead to people life as the sustainable economic development.

Introduction

In the previous time, the geologists did only geological surveying, mapping, and research. The results of them are necessary and important for the geological knowledge and scientific value. They are no connect to the people as someone said "Geologists talk to themselves". Satun area is well known among the geologists and paleontologists more than seven decades ago as high paleo-biodiversity especially in Paleozoic era. Many geologists and paleontologists around the world visited, researched, reported, and published many geological evidence from Satun area, such as the new genus and new species of fossils, the paleo-environments and evolution of Shan-Thai terrane and Gondwana. Since Brown *et al.* (1951), Sresthaputra (1951), Kobayashi (1957) surveyed, researched, and reported the Late Cambrian fossils from Mo Lae Bay, Tarutao Island, Satun area, the oldest recorded fossils were recognized. The Mo Lae Bay is one of the important geological site where the geologists around the world have still visit and discover more scientific values. After the pioneer research in Tarutao, the geological studies were increasing until now. The marine deposited during Paleozoic era in Satun area are exposed in widely area with many fossils almost everywhere, such as behind the house, schools, and in the rubber fields. According to the high paleo-biodiversity in Satun area, they are many geological sites in both island and mainland that yielded many kinds of fossils especially of Paleozoic era such as trilobites, brachiopods, conodonts, nautiloids, stromatolites, graptolites, tentaculites, ammonoids and others. Their Regional and international correlation of the rocks, paleoenvironment, and paleoecology have been attempted and reconstructed (Wongwanich et al., 1990; Fortey, 1997; Agematsu et al., 2006; Cock and Fortey, 2006; Ridd, 2011; Wongwanich and Boucot, 2011). Department of Mineral Resources (DMR) realized about our responsibility to do survey, mapping, research, communicate and connect the geological knowledge to people. The small exhibitions, site museums, and geological museums have be established in many fossils areas around Thailand. They may probably be the geoheritage site, such as Sirindhorn Museum in Kalasin province, etc. In Satun, the local people realized about the fossil sites in their area and cooperated with DMR try to promote them to the Global Geopark.

Fig. 1 Department of Mineral Resources has the mission on 1.geological surveying and mapping, 2. research, and 3. conveying the knowledge to people.

The Geoheritage sites of Satun Aspiring Geopark

The geological sites such as the fossil and karst topography sites are developed to be the geoheritage sites for the Satun Aspiring Geopark. They are at least 27 geoheritage sites are proposed to be Satun Aspiring Geopark (Fig.2). The geoheritage sites can be divided the rank of importance into three levels as; International importance (INT) – recognized as of international interests by scientific communities or bodies of international organizations, Importance (NAT) – recognized in the registries of national bodies, and Regional importance (REG) – recognized in the registries on a regional or country level.

Among twenty seven of the proposed geoheritage sites in Satun Aspiring Geopark, six of them are defined the value of importance as the International importance (INT). They are four of them located in Tarutao Island and surrounded islands; Malaka Formation, Mo Lae Bay, Hin Ngam Island, and Khai Islet. The other two international value of geoheritage sites are located in the mainland in La-ngu District, Satun Province, they are Kuan Tung and Khao Nui/Noi sites.

No.	Name of the site	Site type	Value of importance	Scientific	Educational	Touristic	Protection
1	Khao Thanan	G/N	REG		x	x	
2	Stegodon Cave	G/N	NAT	x	x	x	x
3	Tharnplew lapies	G	NAT		x		
4	Khlong Huay Ba stone	G	NAT		x		
5	Taban Island	G/N	REG	x	x	x	x
6	Tharnplew waterfall	G/N	REG		x		
7	To Sam Yot fossils	G/C	REG		x	x	
8	Wang Klang cave	G/N	REG		x	x	
9	Phu Pha Phet cave	G/N/C	NAT	x	x	x	x
10	Phu Pha Phet lapies	G	REG		x	x	
11	Paphon lapies	G	REG		x	x	
12	Chet Khot cave	G/N	REG		x		
13	Malaka Formation	G	INT	x	x	x	x
14	Mo Lae bay	G/N	INT	x	x	x	x
15	Son bay	G/N	REG	x		x	x
16	Pramong beach granite	G/N	REG			x	
17	Hin Ngam Island	G/N	INT		x	x	
18	Khai Islet	G/N	INT		x		
19	Khuan Thang type section	G	INT	x	x		x
20	Khao Noi type section	G	INT	x	x	x	x
21	Thung Samet stromatolite lapies	G	REG	x	x		x
22	Tharae stromatolite lapies	G	REG		x		
23	Khao Daeng nautiloids	G	REG		x	x	
24	Urai cave	G/N/C	REG	x	x	x	x
25	Wang Sai Thong waterfall	G/N	NAT		x	x	
26	Khao To Ngai geological time boundary	G/N	NAT	x	x	x	x
27	Lidi Lek Island fossil	G/N	NAT	x	x		x

Fig. 2 List of the geoheritage sites in the Satun Aspiring Geopark. In terms of their international, national, and regional/local value. (after the Dossier of Satun Geopark, Thailand: Annex 2 Geological Heritage, November 2016, Satun Aspiring Geopark)

International value of Geoheritage sites at Tarutao and surrounded Islands

They are four geoheritage sites as the international significance value at Tarutao and surrounded islands, Tarutao National Park. It is a protected area as Thailand's first marine national park among the eight national parks, having been established on 19 April 1974. It was honored as an ASEAN Heritage Parks and Reserves.

Malaka Formation: geological boundary between Late Cambrian to Ordovician

Malaka Formation located at Malaka Bay, the northern shores of the Malaka river mouth, northwest of Tarutao Island and at the southern side of Ao Talo Dang (Wongwanich *et al.*, 1983). It is a good exposures of the upper part of Tarutao group. The international significance of Malaka Formation site is the biostratigraphy and fossil assemblages. Fossil assemblages such as numerous trilobites, conodonts, and brachiopods in the upper part of the group indicated the boundary of Late Cambrian to Early Ordovician (Kobayashi, 1957; and Shergold *et al.*, 1988; Stait *et al.*, 1984). It is an important geoheritage area that still need more the scientific and educational research especially about the Cambrian and Ordovician geological boundary, and it is also in the conservative tourism area.

Mo Lae Bay: the oldest recorded trilobite (Late Cambrian, 490 ma.)

Mo Lae Bay are presented 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* (Fig.4), and *Coreanocephalus phanulatus*. Brachiopods are *Apheorthis (?)* sp. Shergold *et al.* (1988) studied the trilobites of the Tarutao Group from Tarutao Island and concluded that the oldest trilobites are found at Mo Lae Bay and include *Hoytaspis? thanisi, and Prosaukia ?* aff. *nema*. The oldest recorded trilobites and many new discovered genus and species are the international significance of this geoheritage site. It is a good exposure for the oldest recorded fossil of Late Cambrian (490 ma.) in Thailand and the region. It was also related to another part of the Gondwana. This geoheritage is also important as scientific research and education.

Hin Ngam Island: Gravel beaches

The Hin Ngam Island meaning beautiful rock island, is located between Ra Wee and Li Pe Islands. This geoheritage site is a small island mostly composed of lamination hornfels and quartzitic sandstones and quartzite, the metamorphic rocks of the Kaeng Krachan Group. There are two wave directions striking against the island; west and south that break hornfels into pieces, creating gravel beaches in the north (Fig. 5). This geoheritage site is suitable for education and tourism area.

Khai Islet: Geomorphic landforms and sea wave erosion

The Khai Islet is located between the Adang and Tarutao Islands. The islet is a paired islet connected by a white sand tombolo. The sand is composed of quartz and coral debris with a small patch of tree canopy. The northern side of the islet has a sea arch produced by sea wave erosion (Fig.6). These geomorphologic landforms are spectacular geological features for geotourism and education.

Fig. 3 Late Cambrian to Ordovician rock succession at Malaka bay, Tarutao National Park area.

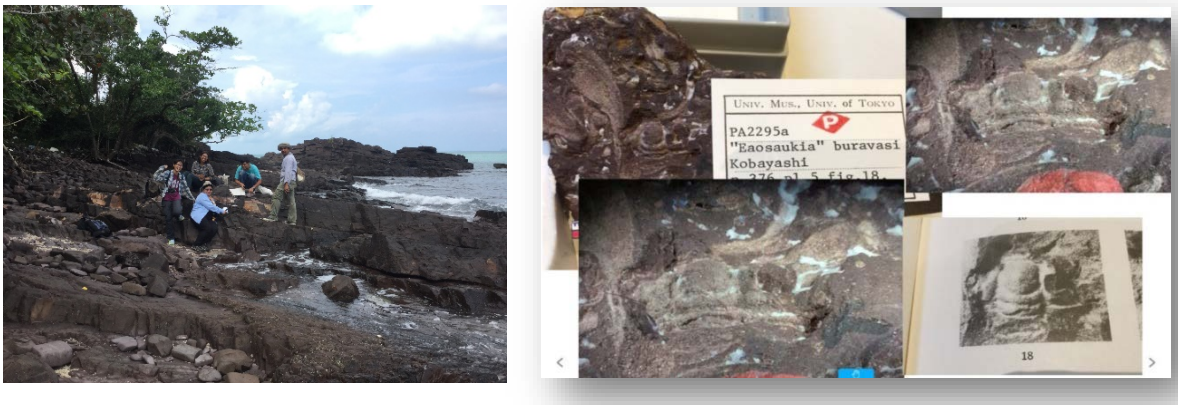

Fig. 4 The view of Mo Lae Bay, the geoheritage site of Satun Aspiring Geopark and the photos of *Eosaukia buravasi* (Paratype), the trilobite samples that were published by Kobayashi and were collected in Tokyo University Museum.

Fig.5 The metamorphic gravel beach of Hin Ngam Island

Fig. 6 The natural sea arch of Khai

The International value of geoheritage sites in the mainland at La-Ngu District, Satun Province.

They are two geoheritage sites as the international significance value at La-ngu District, Satun Aspiring Geopark. Marine sediments were widely deposited during the Paleozoic era at the Satun area. The continuous sequences of Ordovician to Silurian are exposed at Khao Nui (Noi) geoheritage area including the type section of Wang Tong Formation. They was continuously deposited from Devonian

– Carboniferous sediments at the Kuan Tung geoheritage area. Both of them are the international significance of the biostratigraphy and chronostratigraphy that related to both of lithostraigraphy and chronostratigraphy boundaries.

Khao Nui (Noi): Type section of Wang Tong Formation and O/S Boundaries

Khao Nui(Noi) geoheritage site is located at Ban Wang Tong 12 km north of La-Ngu District in Satun Aspiring Geopark. This site shows the international significance values of the type section of Wang Tong Formation and the area of two geological boundaries of both lithostratigraphy and chronostratigraphy. The type section of Wang Tong Formation was named after the name of the village (Wongwanich et al., 1990). It consists of shale, chert, greenish gray sandstone and black chert with a brown color when weathered. The Wang Tong Formation lies conformably above the Pa Kae Formation that shows the lithology boundary changed from carbonate (Pa Kae Fm.) to argillaceous (Wang Tong Fm.). Trilobite and brachiopod were found in the middle part of the Wang Tong formation, whereas abundant graptolites were found in the upper part. Total thickness of the formation is 50-110 m. Contact boundary between Ordovician and Silurian rocks is above a sandstone containing the trilobite *Mucronaspis mucronata* and a typical Hirnantian (Late Ashgill) brachiopod fauna consisting of *Onniella ? yichangensis, Hirnantia sagittifera, Mirorthis mira, Cliftonia* sp., *Aegiromena planissima, Paromalomena* sp., and *Eospirigerina* sp. (Cocks and Fortey, 1997). The chronostratigraphy of the Wang Tong formation was indicated that Late Ordovician to Silurian were deposited in deep marine conditions.

Kuan Tung: Type Section of Pa Samed Formation

Kuan Tung geoheritage site is the international significance of the succession of Late Silurian – Middle Devonian gray and red limestones of the Kuan Tung Formation, Middle Devonian - Lower Carboniferous black tentaculitic shale, sandstone, laminated mudstone of the Pa Samed Formation. The richly fossiliferous Lower to Upper Paleozoic beds are packed with graptolites, tentaculites, trilobites, brachiopods, goniatites, etc. Many index fossils provide new insights into their global distribution and the age of the fauna. Several new genera and new species have been described. Some fauna are unlike any known previously from Asia. Regional and international correlation of the rocks, paleoenvironment, and paleoecology have been attempted and reconstructed (Wongwanich et al., 1990; Fortey, 1997; Agematsu et al., 2004, 2006; Cock and Fortey, 2006; Wongwanich and Boucot, 2011).

Geoheritage Sites, Geopark, and Sustainable Development

The Geological or Geoheritage sites of Satun Aspiring Geopark can be able established by the result of the geological survey, mapping, and research since many decades ago. Only the knowledge and geological information in the area is not enough for promote to be the geopark. It must be including another dimentions such as connecting to people, environtments, politics, economy, etc. The 27 propose geoheritage sites are the pioneer sites and role as the tools to approach to the Geopark and Global Geopark. Now a day, local people is realized that the geopark can make them the better life and economy. They may no need to go to another province for working. They can stay at their home town and do their bussiness about the things surrounded them.

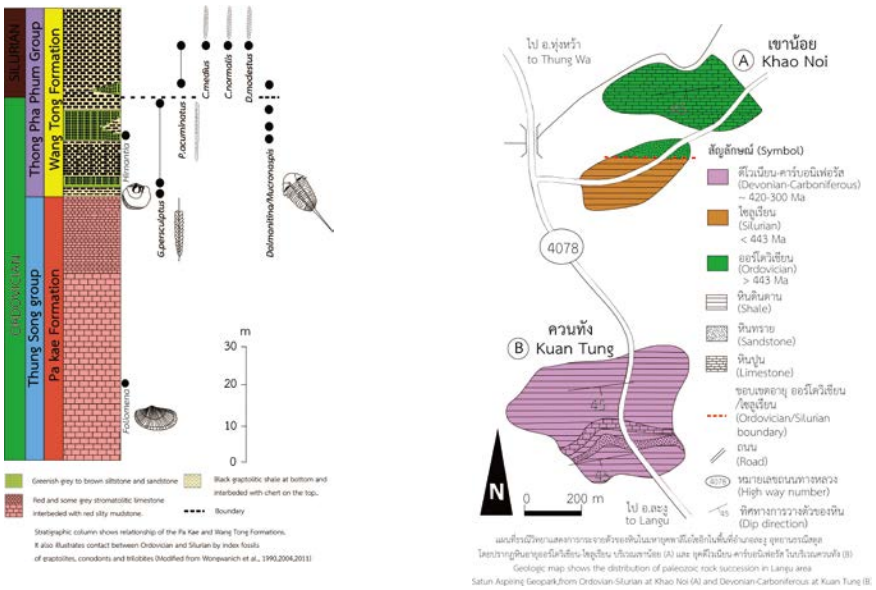

Fig 7. Stratigraphy Section of Khao Nui area (left) and the geogical map (right) shows the distribution of Ordovician to Carboniferous sedimentary rocks at Khao Noi(Nui) and Kuan Tung geoheritage sites, La Ngu district, Satun Aspiring Geopark (modified after Wongwanich et al., 1990,2004,2011; Agematsu et al., 2008)

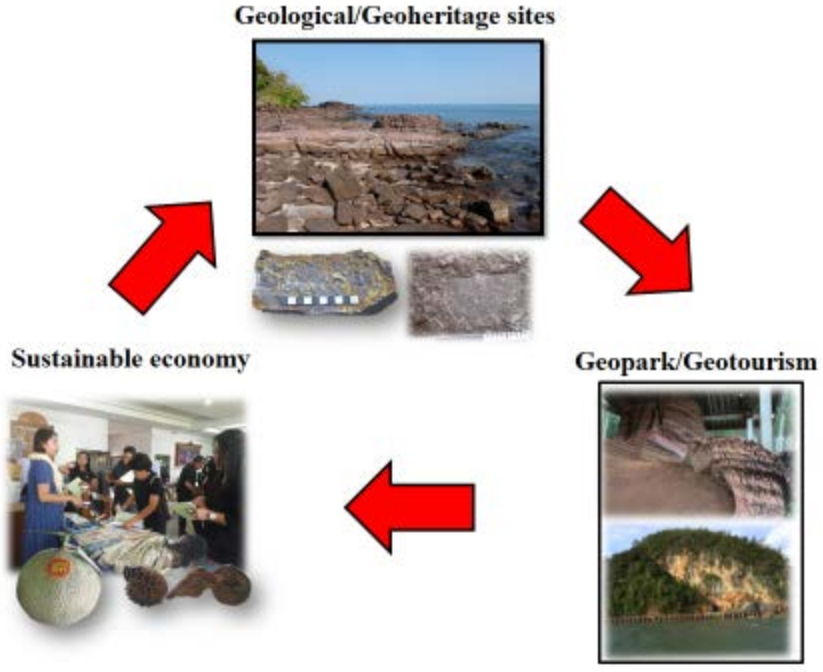

Fig 8. The flow chart shows the connection of many Geological/Geoheritage sites of Satun Aspiring Geopark are promoted to be the Geopark/Geotourism and to develop the business system in the area as the sustainable economy.

In Satun Aspiring Geopark, the new products related to geology and geopark are created. The Batik textile is using the red soils for the color of batik and also painted them with the fossil and geopark symbols. The melon farm create the symbol of Satun Aspiring Geopark on the surface of melon to increasing the price. Khao To Ngai geological time boundary, one of Geoheritage site, is developing to the geotourism area. Deapartment of Mineral Resources (DMR) realize about our duty to support the geological knowledge to the people. Four years ago, DMR associated with Satun Province,Thungwa District, and many organizations established the fossil exbition event namely, "Satun Fossil Festival", at Thungwa District office area and do it every year until this year. The visitors and the accomodation sectors also are increasing. It may be said that the geological sites and fossils may be eatable, that means we can change the geological knowledge and sites to be the sustainble economy for the local people.

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FOSSIL FAUNAS AND SEDIMENTARY SEQUENCES IN SATUN GEOPARK – REGIONAL AND GLOBAL SIGNIFICANCE

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Extended Abstract

The first Cambrian fossils in Satun were found by Mr. Saman Buravas of the Thai DMR on Ko Tarutao and sent to Japan for description by Teiichi Kobayashi 60 years ago. However, it was not until the early 1980's that mapping, detailed sedimentological studies and stratigraphically controlled collection of fossils was initiated on Tarutao and on the Satun mainland by Dr. Sangad Bunopas of the DMR.

Since then a plethora of fossils have been found, identified and described, often by some of the world's leading palaeontologists, and placed generally in stratigraphic and sedimentological context and their local, regional and global significance discussed.
The most significant faunas and associated sedimentary sequences found are:

1. Furongian to Tremadocian trilobites and associated brachiopods, conodonts and zircons in the Tarutao Group sandstones on Ko Tarutao.
2. Tremadoc to Floian, molluscan and conodont faunas from the peritidal carbonates of the Thung Song Group on Ko Tarutao.
3. A diverse trilobite-conodont fauna with brachiopods and ostracodes from the stromatolitic/thrombolitic Pa Kae Formation in Satun mainland.
4. The graptolites, and the Hirnantian Fauna brachiopods and trilobite define the Ordovician-Silurian boundary within the Wang Tong Formation.
5. The Early Devonian trilobite- brachiopod – tentaculitoid -conodont faunas of the Kuan Tung limestone and Pa Samed siliciclastics.
6. The Tournaisian to Early Pennsylvanian (?) trilobite-brachiopod-goniatite faunas of the Pa Samed Formation and Khuan Klang Formations.
7. Pleistocene tetrapod faunas in Stegodon Cave.

Palaeoposition of the Shan-Thai and Chinese terranes

The Lower Palaeozoic faunas of points 1 and 2 and also points 4-6 have played a significant role in discussions concerning the palaeopositions of not only the Shan-Thai (Sibumasu) Terrane but also the Chinese terranes. As palaeomagnetic data are sparse for the Palaeozoic of Shan-Thai, with poles only from the Baoshan Block in western Yunnan for the Devonian and the Early Permian, reliance has been made on the Palaeozoic faunas, especially those from Satun. The Early-Middle Ordovician

nautiloids and conodonts suggest North Chinese and Australian affinities whereas the Late Ordovician trilobites, brachiopods and conodonts show very strong South Chinese affinities. There is clearly a biogeographic switch in the Darriwilian but whether this was due to palaeoclimatic, palaeobathymetric and/or tectonic control is still debated. The well documented stratigraphy and palaeoenvironments of the Lower Ordovician sections on Ko Tarutao provide important evidence in this debate. The Satun Geopark faunas continue to play an important role in discussions concerning the palaeopositions of the North China, South China, Tarim and Tibetan terranes relative to the core-Gondwana terranes.

Detrital zircons from the Tarutao Group sandstones have been used and are being used to suggest placement of the Shan-Thai Terrane relative to core Gondwana. Palaeocurrent and facies patterns in the Lower Palaeozoic siliciclastics of Satun and Baoshan along with palaeomagnetic data support the orientation of Shan-Thai with Baoshan closest to the Himalayan sector of Gondwana and with Sumatra closer to Papua.

Malaysian Palaeozoic successions with Devonian or Tournaisian gaps or paraconformities have been used as evidence to support the idea that the major Chinese terranes rifted from Gondwana in the Devonian. A significant 'paraconformity' representing the Middle Devonian to the Famennian in the Satun succession has also been invoked in this discussion. However, we suspect that this paraconformity will disappear with further work in the Pa Samed and Khuan Klang formations.

Pa Kae – Pagoda Facies – a 'Time Specific Facies'?

Detailed studies of the mainly red, but also grey, Pa Kae Formation by Thanis Wongwanich in 1990, showed that the strange reticulate pattern recorded by many workers was due mainly to microbialites rather than, phacoidal pressure solution, shrinkage cracks, synaeresis or other mechanisms. He demonstrated stromatolitic and thrombolitic textures and estimated water depths of approximately 200 m. Richard Fortey described 39 species of trilobite from the Pa Kae and found that many of the taxa are characteristic of the widespread Pagoda Formation in South China and this fauna has since been used to describe and name faunas from the Pagoda Fm. The Pagoda Formation also has the strange structures found in the Pa Kae and many hypotheses have been advanced for their formation. There have been many discussions as to the palaeobathymetry of the Pagoda Fm with suggestions ranging from a few metres to 400 m. Illustrations of the Pagoda Fm suggest that it is identical sedimentologically and (almost) palaeontologically to the Pa Kae Fm. It appears that the Pa Kae-Pagoda facies is an example of ' the persistence of facies' emphasised by Derek Ager or a 'Time Specific Facies' emphasised by Otto Walliser and Carlton Brett.

However, similarities to other deep-water red limestones on Shan-Thai suggest that the facies is not too 'time specific' and examples are also Silurian (in Langkawi and Myanmar) and Devonian (in the Kuan Tung Fm of Satun) in age. There are obvious similarities to the deep-water, red limestone of the Mediterranean Jurassic - the Rosso Ammonitico Formation. This is a commonly exported, facing stone and its stromatolites and pelagic fauna may be seen on many walls and floors in hotels and shopping malls around the world. Thus detailed studies in Satun provide a global solution to the origins of these enigmatic 'pelagic' limestones.

Pleistocene Faunas and a major biogeographic mystery.

The discovery of Pleistocene and Holocene bones, including the pygmy elephant *Stegodon*, in a cave in Satun Geopark may help solve an important biogeographic problem. The major Neogene biogeographic boundary between the Indochinese and Sundaic faunal and floral realms is drawn either to the north of Satun (Isthmus of Kra) or near or just south of Satun. Mechanisms for this very significant divide, which is comparable in terms of diversity-contrast to the better known Wallace's line further to the south in Indonesia, have included climate-control and marine flooding of the Thai peninsula. Indeed one biologist has criticized geologists for not finding the necessary marine sediments to support this hypothesis. With at least 60 documented caves in Satun, we can expect important discoveries bearing not only on biogeography, but also on evolutionary, palaeoclimatological and archaeological problems.

LATE CAMBRIAN PALEONTOLOGY OF THE TARUTAO FORMATION

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Abstract

The late Cambrian (Furongian) Tarutao Formation of Ko Tarutao in the Satun Province of southern Thailand is a globally significant stratigraphic unit comprised primarily of fossiliferous sandstones interbedded with volcanic ashes and some siltstones. The most abundant fossils are trilobites and orthid brachiopods with a small constituency of echinoderm plates. Some trilobite taxa are endemic to Tarutao (e.g. *Thailandium*) while others are widespread across Gondwana terranes (e.g. *Lophosaukia*). While the works of Shergold (Shergold et al., 1988) and Kobayashi (1957) revealed many Cambrian fossils on Tarutao, more recent excursions have found new taxa not yet described (e.g. a potential genus of Mansuyiinae). The Machinchang Formation of Langkawi is of comparable age with the Tarutao Formation but lacks the latter's extensive faunal record. For this reason, Tarutao is better suited for defining a Furongian biostratigraphic succession for the Shan-Thai Block, a marginal Gondwana terrane consisting of northern Malaysia, western Thailand, eastern Myanmar, and western Yunnan. The tuffaceous units interbedded with the fossiliferous sandstones have already yielded one absolute date with which to constrain this biostratigraphic succession, and work is underway to obtain more. The fauna shared between Tarutao, China, and Australia will allow the age constraints of Tarutao's biostratigraphy to be correlated to other regions across the globe finally bringing resolution to late Cambrian geochronology. The fossils of Tarutao are also essential for reconstructing the paleogeography of Gondwana's late Cambrian northern margin, bringing greater resolution to the early tectonic history of Southeast Asia.

MORPHOLOGY AND ONTOGENY OF AN EARLY DEVONIAN TRILOBITE FROM SOUTHERN THAILAND

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Abstract

A set of *Plagiolaria poothaii* specimens, a late Early Devonian phacopid trilobite, were collected from roadcut B11 in the Pa Samed Formation near Bam Tham Phra. The shales and mudstones also yielded brachiopods and dacryonconarid tentaculitids. The Shan-Thai block is located, according to recent reconstruction, outboard of northwestern Australia at this time, before the Neotethyan rifting in the late Carboniferous. The sedimentology and fossil assemblage is consistent with a deeper water margin setting, and the morphology of the *Plagiolaria* is consistent with this. A modest collection is available, with some diagenetic alteration, but there is a possibility to do some biometrical analyses. These reveal an apparently isometric growth trend in most major characters. One pre-mature, late stage meraspid form is known with 10 thoracic segments, as opposed to the mature number, which is 11 in phacopids. Landmark based morphometric analysis is possible using the best-preserved material only, and shows shortening of the glabella and a small relative decrease in eye size. The pygidium becomes more curved, with the axis extending further posteriorly. The reduced size of the eye and its reduced number of lenses is consistent with evidence of a deeper water setting.

ORDOVICIAN–SILURIAN–DEVONIAN: SIGNIFICANCE OF FOSSIL ASSEMBLAGES AT TARUTAO, KHAO NOI, AND KUAN TUNG, SATUN ASPIRING GEOPARK

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Introduction

The southern area of peninsular Thailand, which has been the subject of geological research for 70 years, is renowned for its abundant early and middle Paleozoic fossils. Since the 1950s, considerable amounts of data on the paleontology and stratigraphy of the area have been reported mainly by Thai, Japanese, Australian, and British researchers. A joint survey team from the Department of Mineral Resources, Thailand, and University of Tsukuba, Japan, has continued research on the biostratigraphy and paleoenvironment in this area for 15 years. In this paper, the authors describe the Ordovician to Devonian stratigraphy of the Satun Group on Tarutao Island and the Satun area on the mainland (including the Khao Noi and Kuan Tung areas), and comment on the geological and paleontological significance of these areas.

Revised lithostratigraphy and conodont biostratigraphy

Ridd (2011) divided the lower and middle Paleozoic rocks on Tarutao Island and the Satun area into the Tarutao Group, the Satun Group (which contains, from oldest to youngest, the Thung Song Limestone, the Pa Kae Formation, the Wang Tong Formation, and the Kuan Tung Formation), and the Nga Chang Supergroup, in stratigraphic ascending order. The authors established a total of six conodont biozones spanning the Thung Song Limestone and Pa Kae Formation (Agematsu et al., 2007, 2008). We also reported two conodont faunas from the Thung Song Limestone (faunas A and B; Agematsu et al., 2006a), and graptolite and tentaculite faunas from the Wang Tong and Kuan Tung formations, respectively (Agematsu et al., 2006b, 2006c). Figure 1 shows the detailed stratigraphy of the lower and middle Paleozoic in this area, including new conodont data (faunas C to E) from the Kuan Tung Formation. Microfossils make it possible to correlate the Satun Group with other successions in detail and to clarify our understanding of the age of the group. The revised stratigraphy is explained below.

The Thung Song Limestone, for which the type locality is on Tarutao Island (Cocks et al., 2005), is widely distributed on both the island and the mainland. Carbonate rocks on Tarutao Island have been subdivided into members S1 to S5 by Teraoka et al. (1982), which approximately correspond to the five formations of Wongwanich et al. (2002; Figure 1). In contrast, rocks on the mainland do not contain abundant macrofossil records and their stratigraphic relationship with the rocks on Tarutao Island has been poorly constrained. Agematsu et al. (2006a) described Early and Middle Ordovician conodont faunas A and B from a carbonate rock sequence exposed along Route 416, about 6 km east

of Thung Wa City (section TUW 2). The section, which has a total thickness of ~80 m, is composed of thickly bedded, argillaceous, dark gray limestones. Based on conodont biostratigraphy, the Thung Song Limestone on Tarutao is assigned to the Tremadocian to Floian stages (Lower Ordovician), whereas the limestone in the TUW 2 section is Floian to Darriwilian (Middle Ordovician; Agematsu et al., 2006a, 2008). Therefore, we define the former as the lower part of the Thung Song Limestone and the latter as the upper part. Conodonts and macrofossils from the S5 member indicate that this member is stratigraphically equivalent to the lowest part of the TUW 2 section. Carbonate rocks in the Satun area on the mainland, which yield Early and Middle Ordovician fossils (localities 5 and 6 in Cocks et al., 2005), probably belong to the upper Thung Song Limestone. These limestones appear to include some shaly limestone or calcareous shale (the "Satun Shale"; see Ridd, 2011).

The upper three formations of the Satun Group were described at Khao Noi and Kuan Tung in the Satun area by Wongwanich et al. (1990). The Pa Kae Formation, which is a fossiliferous carbonate sequence, is divided into lower and upper members (Wongwanich et al., 1990; undulating and nodular limestones in Figure 1). Conodont records show that this formation spans the Darriwilian to Katian (Upper Ordovician) stages. The Wang Tong Formation consists of dark-colored, fine-grained siliciclastic rocks, and is divided into lower, middle, and upper members (Wongwanich et al., 1990). Based on the brachiopod and trilobite assemblages known as the *Hirnantia* fauna (Wongwanich et al., 2002; Cocks et al., 2005), and graptolites (Wongwanich et al., 1990; Agematsu et al., 2006b), the Ordovician–Silurian boundary (OSB) is correlated with the black shale that is the lowest part of the upper member. The age of the upper boundary of this formation is unknown.

The Kuan Tung Formation, which was originally described by Wongwanich et al. (1990), is redefined in this paper and temporarily subdivided into lower, middle, and upper members. The revised lower member is made up of undulating and nodular limestones and is equivalent to the whole of the original "Kuan Tung Formation". The middle member is characterized by interbedded limestone and shale, and a black shale bed containing abundant tentaculites, trilobites, and brachiopods; this shale bed was named "member 1" of the overlying Pa Samed Formation by Wongwanich et al. (1990). The upper member, which is described for the first time here, is seemingly underlain by the middle member with a faulted contact and is composed of nodular limestone that is exposed in the western part of the type locality of the original "Kuan Tung Formation" along Route 416. The latest Silurian to earliest Devonian conodont fauna C and the Lochkovian (Early Devonian) fauna D are present in the lower member. Tentaculites from the middle member and conodont fauna E from the upper member indicate that these rocks were deposited during the Emsian Age (Early Devonian; Agematsu et al., 2006c) and Givetian Age (Middle Devonian), respectively (Figure 1). Therefore, the age of the revised Kuan Tung Formation ranges from Silurian to Middle Devonian. Although few index fossils have been reported from the lowermost part of the formation, its base may be as old as Wenlock in age, by comparison with the Silurian sequence on the Langkawi Islands, northwestern peninsular Malaysia. The Satun Group is conformably overlain by siliciclastic beds of the Pa Samed Formation, which are assigned to "member 2" of Wongwanich et al. (1990), and form the lowermost part of the Nga Chang Supergroup.

Abundant fossils in the Satun Group, including brachiopods, trilobites, orthoceratids, and conodonts, were summarized by Cocks et al. (2005) and Ridd (2011). The ages of these fossil assemblages are consistent with the above-mentioned conodont, graptolite, and tentaculite biostratigraphy.

Significance of the lower and middle Paleozoic succession in the Tarutao, Khao Noi, and Kuan Tung areas

The compiled stratigraphy of the Ordovician to Devonian succession in the Tarutao, Khao Noi, and Kuan Tung areas is approximately continuous without significant hiatuses. The Setul Group and Timah Tasoh Formation in the Langkawi Islands, Malaysia, are partly equivalent to the Satun Group, but the former two sequences differ from the latter in the lack of Cambrian and Early Ordovician fossils, the lithology of Devonian strata, and the presence of a disconformity in the Lower to Middle Devonian strata. The near-complete Satun Group succession is suitable for geological and paleontological studies. Two examples are described below.

Ordovician Paleogeography.—Peninsular Thailand is located on the Sibumasu terrane, an ancient continental block (e.g., Metcalfe, 2013). The paleobiogeographical affinities of conodonts from the Thung Song Limestone show that the Sibumasu terrane was located at low paleolatitudes during the Early Ordovician; in contrast, the faunas from the Pa Kae Formation indicate that the terrane had moved from the tropics to higher latitudes by the Late Ordovician (Agematsu and Sashida, 2009).

Ordovician–Silurian boundary.— As mentioned above, the OSB is present in the lowermost part of the upper member of the Wang Tong Formation. This boundary is well known as being the time of the second greatest mass extinction of the Phanerozoic, which was strongly connected with a continental glaciation on Gondwana. In the Khao Noi area, the following paleoenvironment is reconstructed: the Pa Kae Formation accumulated on a carbonate platform on the Sibumasu terrane during the Late Ordovician; a marked cooling of the climate resulted in a temporary halt to the deposition of carbonate rocks by the end of the Katian, and subsequently caused the evolution of the *Hirnantia* fauna and a regression during the Hirnantian (latest Ordovician). Two extinction events are recognized in this area: the first is the disappearance of the abundant shelly fauna and conodonts in the Pa Kae Formation; the second is the disappearance of the *Hirnantia* fauna. Widespread exposures of carbonate rocks and overlying black clastic rocks in the Khao Noi area provide a record this significant geological event.

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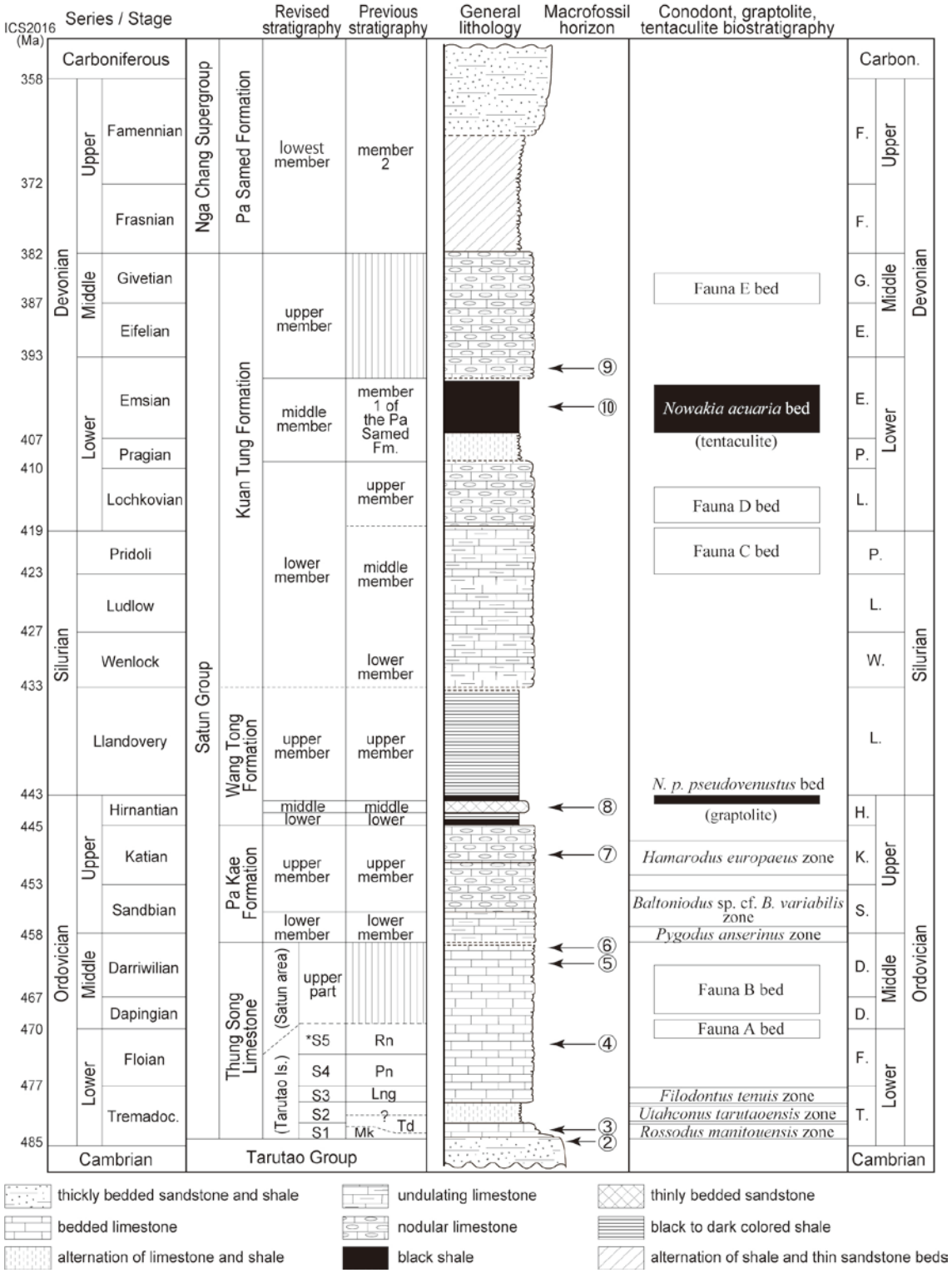

Fig. 1. Columns showing the stratigraphical sequences in southern peninsular Thailand: division of the groups and formations are based on Ridd (2011); previous stratigraphy is after Wongwanich et al. (1990, 2002); macrofossil horizons 2 to 10 are equivalent to those of Cocks et al. (2005); general lithology and biostratigraphy are based on Agematsu et al. (2006a, 2006b, 2006c, 2007, 2008).

TARUTAO FORMATION: GLOBALLY SIGNIFICANT KEY TO LATE CAMBRIAN SPACE AND TIME

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Abstract

The late Cambrian is recognized as a pivotal time in Paleozoic history in which major fluctuations in oceanic chemistry were likely tied to a peak in global magmatism. Although this magmatic interval is widely known from the Gondwana detrital zircon record, knowledge of particular magmatic sources and associated tectonic activity is sparse. A severe consequence of this is that geochronologically the late Cambrian is one of the most poorly resolved intervals of Phanerozoic time. Magnetism was evidently concentrated along the equatorial margin of Gondwana at that time, and a tectonic event associated with this is known regionally as the Kurgiakh orogeny is known in the Himalaya. There, a regional unconformity between the late middle Cambrian and the middle Ordovician corresponds with the ages of local granitic plutons. Cenozoic deformation during collision of India with Asia has obscured many details of the Kurgiakh orogeny. For example, there is almost no record of extrusive volcanism from the Himalaya. The Shan-Thai block, however, presents a different situation. Late Cambrian volcanism and mineralization is known from the Bawdwin area of the Northern Shan State, and Tarutao Island is of unique importance because there felsic ash beds occur interbedded with fossil-bearing strata over an extended stratigraphic interval that approaches and may span the Cambro-Ordovician boundary. This interbedding provides unique potential for calibrating the trilobite biozones of the late Cambrian, which can then be correlated widely across Gondwana and beyond. Our research group (comprising Thai-Burmese-Chinese-US scientists) is now actively integrating geochronological results related to this peak with stratigraphic with paleontological data to allow for a well-resolved calibration of the chronostratigraphy of the late Cambrian, which has a paucity of radiometric dates globally. Our joint project will impact understanding of 1) global Cambrian geochronology, bioevents and evolution, 2) the tectonics of the Himalaya and Southeast Asia, and 3) advance our understanding of igneous activity of the peri-Gondwana realm during and after the last stages of assembly of the supercontinent. Preliminary results are encouraging, including a high-resolution ash date, and the recovery of trilobites spanning a portion of late Cambrian time and approaching very close to the Ordovician boundary. It is clear that the Tarutao section holds the key to the resolution of late Cambrian geochronology across Gondwana, and that the needs for both the academic study of these rocks, and their conservation for future generations is fully appreciated. The scientific merit, along with the immense appeal of the Satun area as an educational and recreational center, fully justifies recognition as UNESCO Geopark status.

THE RED STROMATOLITIC LIMESTONES, THE PA KAE FORMATION

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Extended Abstract

The Upper Ordovician rhythmically bedded sequence of red stromatolitic limestone and dark red silty mudstone, the Pa Kae Formation in the area between Ban Thung Yai (Ban Wang Tong), Ban Pa Samet and Ban Thung Samet (Ban Pa Kae), about 900 m E of km post 7 of a new high way 416 (Formerly 4079) was proposed as the uppermost formation of the Ordovician Thung Song Group in Langu District, Satun Province, southern Thailand by Wongwanich et al, 1990 (Fig. 1). The typical rock and character of this Formation are the alternating beds of the red stromatolitic limestone and red silty mudstones with undulatary or phacoidal bedding and mud crack-like structure but algal polygons on the top of bedding (Fig. 2). In Type area, the rock crops out as the small and large discontinuous bioherms / stromatolitic mounds for a distance of 2.5 kms in NEE-SWW direction along Huai Ba and local road to ban Thung Samet. This extended abstract is condensed from the chapter 7 of the Ph.D. thesis of Tasmania University, Australia (Wongwanich, 1990).

Stratigraphically, the Pa Kae Formation can be subdivided into the lower and upper members at its type section on a small hill grid no. 8583, 7122 in map sheet 4922I, Amphoe Langu. The 34 m thick lower member is poorly laminated to very thin- bedded red stromatolitic limestone with dark red silty mudstone partings in labyrinthine patterns. Many of them are dominated by very thin silty mudstone layers and thin bedded nodular limestone 10-15 cm thick. In general, it looks more massive with large amount of crinoid debris and have smaller algal polygon than those of the upper member. The 32 m upper member is distinguished by clear nodular limestone layers of about 10-25 cm thick and decreasing a number of silty mudstone partings. Dark red algal polygons with concentration of ferrugeneous material are well preserved on bedding surfaces. All of the rocks at type section is red but they change laterally to partly gray limestone at the nearby black shale quarry in the west. The rocks lie conformably in between the middle Ordovician gray limestone of the other Thung Song group at the bottom and the Late Ashgill to the Llandovery black graptolitic shale, chert, siltstone, and sandstone of the Wang Tong Formation on the top. The Ordovician-Silurian boundary lies above the persculptus Biozone and under the acuminatus Biozone, just beneath the upper Dalmanita siltstone, sandstone beds of the Wang Tong Formation (Fig. 3).

The pelagic fauna includes a number of small trilobites, ostracods, nautiloids, bivalves, brachiopods, crinoids, gastropods, stromatoporoids, calcareous algae, sponge spicules and conodonts are well preserved in this rock. The age of the Pa Kae obtained from pelagic trilobites (Fortey 1998) and conodonts (Cantrill 2002, Agemasu et al. 2007) range from Upper Middle Ordovician to Ashgillian (?). The Pa Kae Formation can be correlated through varigated pink nodular limestone in the South to Thong Pha Phum area, Kanchanaburi province, western Thailand, further north to the Liwe Formation,

Nyaungbow Formation in the Shan State of Myanma, and the Pagoda Limestones Formation in central and southwestern China. To the South, a similar rock is exposed on the north-west coast of Pulau Langgon, Langawi Islands, Malaysia.

Petrological studies (Wongwanich, 1990), the red stromatolitic limestone is densely packed biomicrite composing of bioclasts, intraclasts, peloids and minor ferromanganese micronodules, disceminated haematite grains, microdolomites, and glauconites (Fig. 4). Many types of cement have been observed including micrite, isopachous equant spar, microspar, radiaxial fibrous calcite, blocky calcite, haematite cement and ferromanganese crust on submarine hardgrounds. The bioerosion and maceration of bioclasts to micrites are common. The haematite grains and cement gave the red original color to the rock.

The present of abundant pelagic fauna, glauconites, ferromanganese micronodules, hardground and maceration suggests the slow sedimentation in cold and deeps water environment on the well oxygenate sea floor. This gives a good condition for the occurrence of deep water stromatolites on the base of the continental slope and accumulated basin rim by trapping and binding mechanism and calcification process. Four types of stromatolites and trombolites have been recorded (Fig. 5). The stratiform and columnar stromatolites are common whereas the trombolitic stromatolites, oncolitic stromatolites and trombolites are minor and commonly confined to the lower part of the sequence. The development of the Pa Kae stromatolites within a single bed starts from planer at the base and gradually develops upward to the column on the top but in some layers develop further to thrombolitic or oncolitic stromatolites and thrombolites. The fenestral fabric is rare. The small leaf like microbial sheaths, calcified filaments and round coccoid bacteria remains are also observed under SEM.

Geochemical evidences are also confirmed the cold and deep water environment of the red stromatolitic limestone (Wongwanich, 1990). The Mn concentration of 648-4,145 ppm and the Fe concentration of 1,448-12,750 ppm are higher than those of the normal warm and shallow water limstones. The high Sr content up to 546 ppm as well as P2O5 (515 ppm), Ti (2,390 ppm) and Ba (467 ppm) of the Pa Kae were the result of its deep water origin (Fig 6). The excess of Fe and Mn for the precipitation of iron and ferromanganese minerals and their substitution in calcite should be transport to a depositional area by mean of a periodic bottom current from an organic rich reducing environment within the basin further off-shore. The oxygen and carbon isotopic signature of the upper Ordovician Pa Kae ranging from -3.1 to -10.6 ‰oPDB and 3.5-0.5‰oPDB are also different from the other lower Ordovician, shallow water, Thung Song Limestone (Fig 7A).

The heaviest ∂18O value of 3.1‰oPDB is thought to be the original Late Ordovician marine calcite value of the Pa Kae carbonates. It is about 2‰oPDB heavier than the average -5‰oPDB 18O value of the worldwide tropical Late Ordovician shallow marine carbonates. The two difference in ∂18O value indicate 10°C lower temperatures from surface sea water during the depositions of the Pa Kae Formation than those of the normal warm water. These also suggest an open marine and cold-water origin. However, the cold water carbonates of the Pa Kae can be occurred either as deeper water carbonates in warm to hot climates at the low latitudes or a shallow water carbonates in cold climates

at the high latitudes. As mention earlier this rock formed in the deep water, therefore, they should be deposited in the low latitudes in tropical to subtropical climates.

The origin of rhythmically bedded sequence of red stromatolitic limestone and dark red silty mudstone parting were the deposition during the sea level fluctuation in a period of intense Late Ordovician glaciation at the high latitude. The red limestone beds were deposited during regression phases when glaciers growing, exposing a wide continental shelf with high productivity and inducing carbonate to deposit at the deeper zone. As there are abundant well preserved fossils within the biomicritic limestone layers. During the interglacial, the sea level is high during transgression phases allowing only silty mudstone deposition on the very low productivity sea floor.

Attempt to predict their Palaeobathymetry (Wongwanich, 1990), a simple conceptual model based on the drop of temperature from modern sea surface temperature in relation to the temperature gradient profile (Fig 7B) (thermal gradient) from various modern climatic regions has been developed. As from the heaviest ∂18O value of the Pa Kae Stromatolites suggesting 10°C drop of their formational temperature from sea surface temperature during that time and 15°C of glauconite formation, this points to a water depth of 175-290 m for the Pa Kae formation sites in a tropical or subtropical climates.

In conclusion, the Pa Kae Formation is the uppermost formation of the Thung Song Group. They are cold and deep water carbonates, deposited on the oxygenated seafloor at the base of continental slope and basin rim during the Late Ordovician glaciation at high latitude. The paleodepth is 175-290 m depending on the position of Shan-Thai terrane at that time. The most possible position of Shan-Thai Terrane should be tropical climate because 175 m depth is suitable for the Pa Kae stromatolite's photosynthesis.

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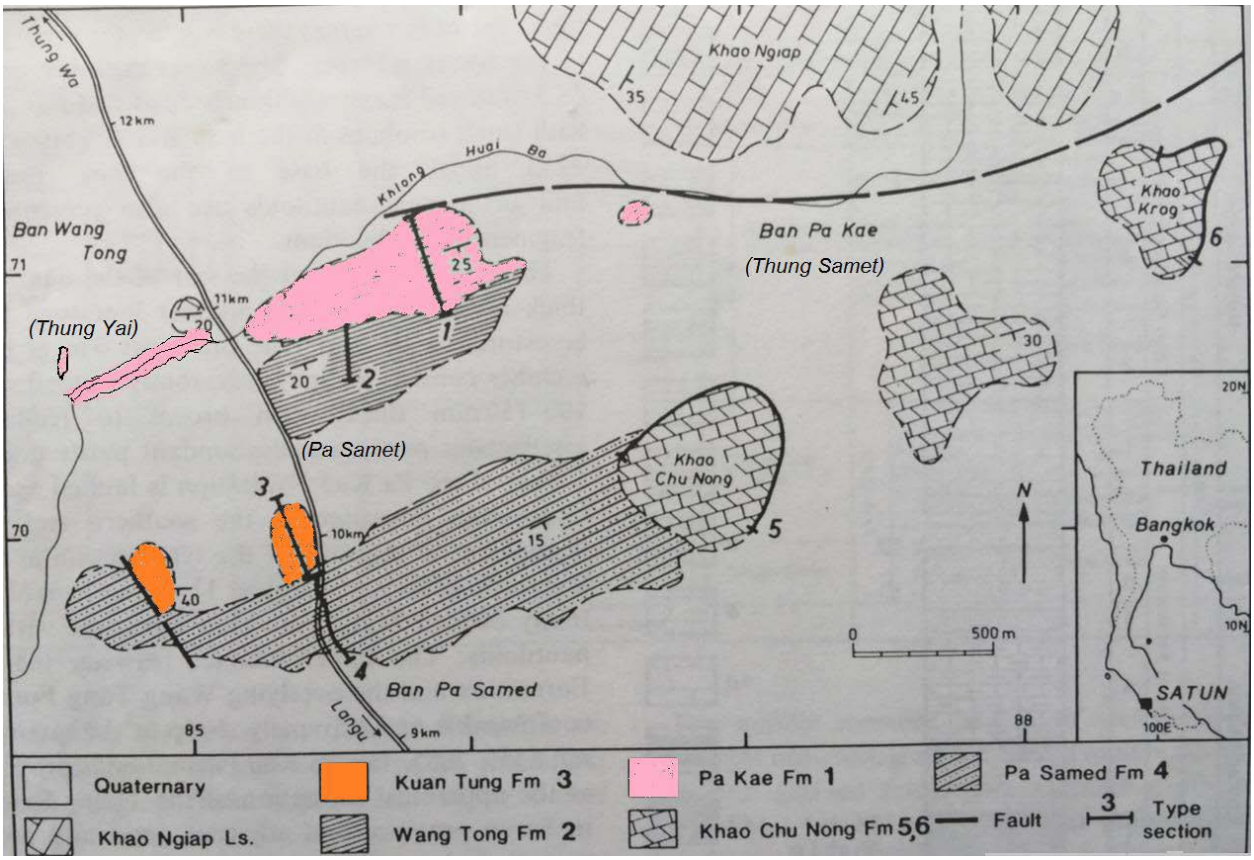

Fig. 1 Map showing type section and distribution of the Pa Kae Formation and the Silurian-Devonian rocks at type area Ban Pa Kae (now Ban Thung Samet), Amphoe Langu, Satun Province. The Khao Chu Nong Formation was moved to the Ordovician Thung Song Group (modified from Wongwanich 1990)

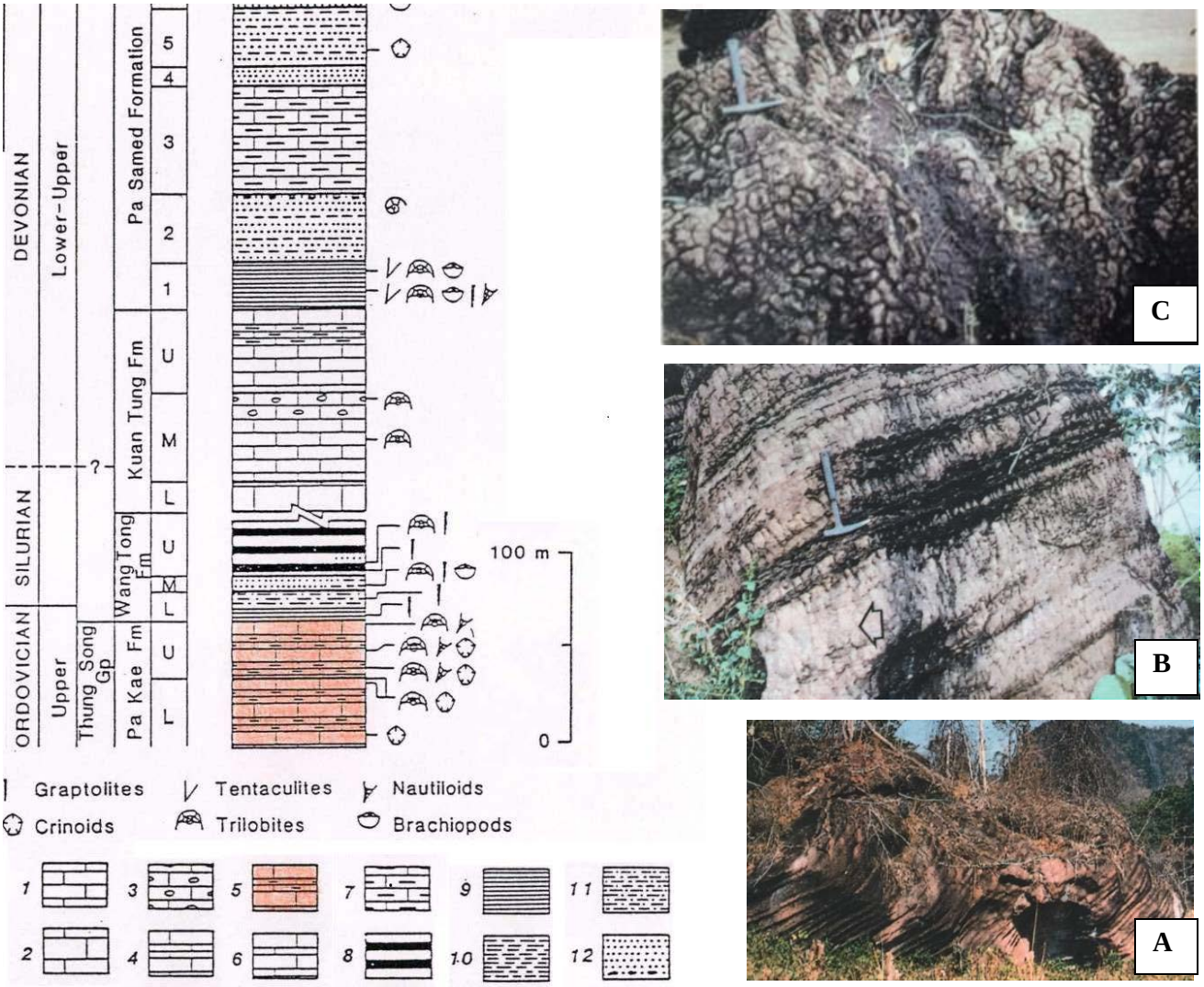

Fig. 2 The Pa Kae Formation in the composite stratigraphic column of Upper Ordovician-Permian rocks. 1) Thin bedded limestone, 2) Massive to thick bedded limestone, 3) Thin bedded limestone with chert nodules, 4) Thin bedded limestone interbedded with laminated limestone, 5) Red stromatolitic limestone, Pa Kae Fm and upper Kuan Thung Fm, 6) Thin bedded limestone with finning-upward sequence, 7) Dark gray silty mudstone with some siliciclastic, 8) Chert and black shale, 9) Black shale, 10) Brown, gray and red shale, 11) Siltstone, 12) Sandstone with in part well rounded pebbles (modified from Wongwanich 1990). Now the Carboniferous and Permian fossils have been found in the upper part of the Pa Samet Formation.

A. Massively very thin bedded red stromatolitic limestone and dark red silty mudstone parting of the lower member of the Pa Kae Formation.

B. Well rhythmically bedded sequence of red stromatolitic limestone and silty mudstone parting of the upper member showing wavy bedding and stromatolitic columns.

C. Typical stromatolitic polygons on top of bedding.

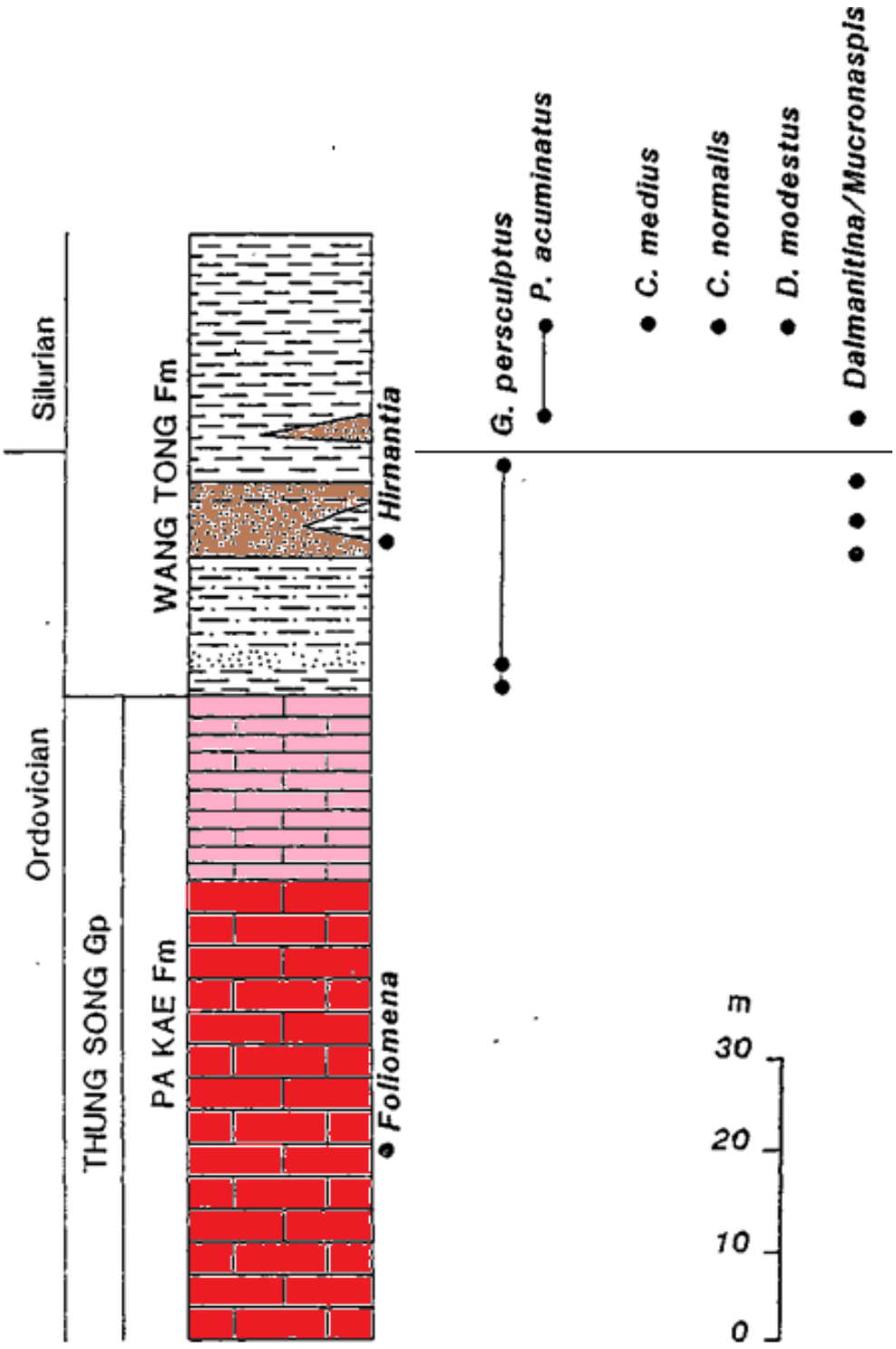

Fig. 3 General stratigraphic column of the Pa Kae Formation and Wang Tong Formation at Khao Nui reference section showing important faunal elements. A position of the Ordovician-Silurian boundary is shown just below the upper Dalmanitina bed (Wongwanich, 1990).

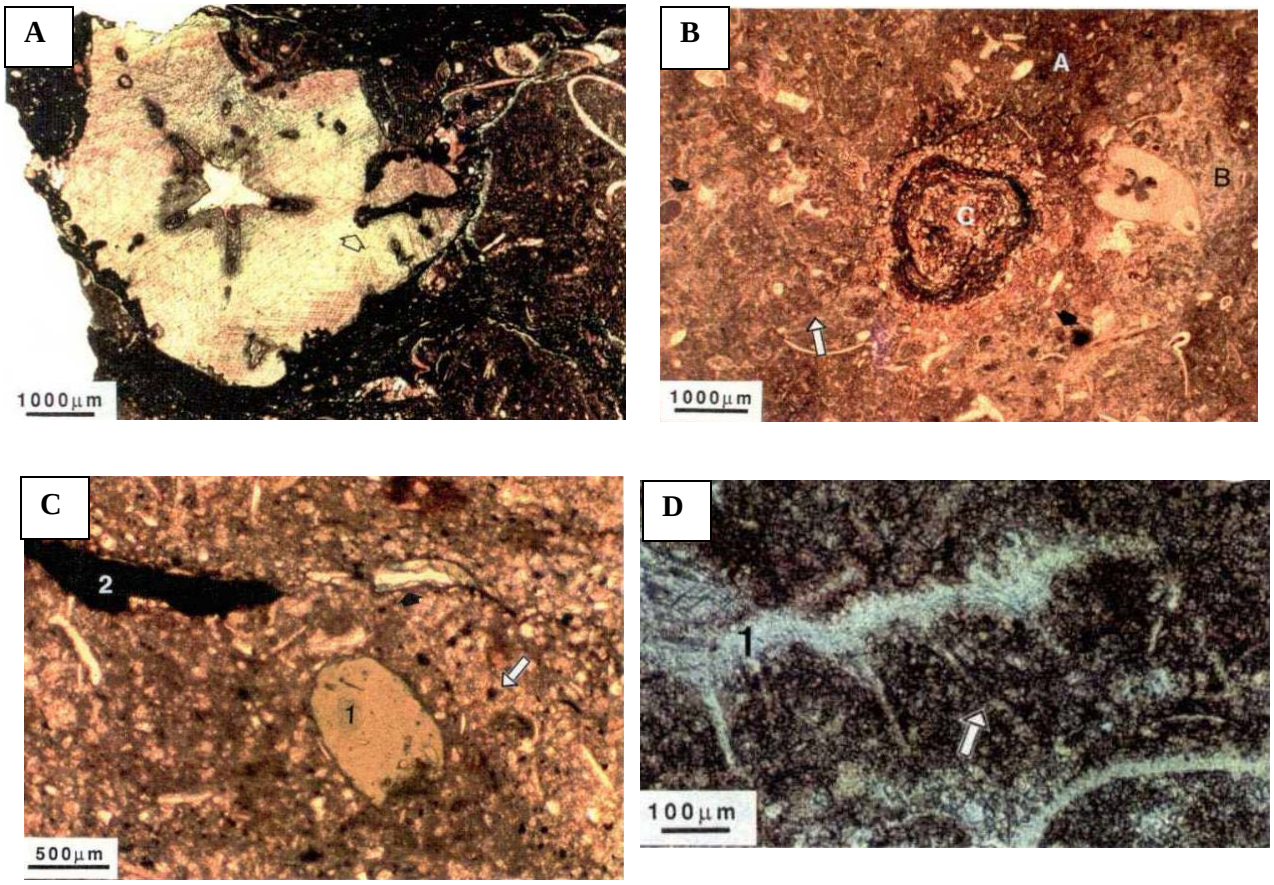

Fig. 4 Thin section photomicrograph of Pa Kae biomicrite showing abundant bioclasts and other allochems within micritic cement (Wongwanich 1990).

A. Heavily bored crinoid ossicle.

B. Allochemical rich layer with multilayering, colloform structure and spar rich laminae of Fe-Mn micronodules.

C. Bored glauconitic pellet and replacement glauconite at bioclast rim, disseminated dark red to black hematite grains and dark red to black amorphous haematite cement filling in skeletal mould.

D. The marceration of bioclasts.

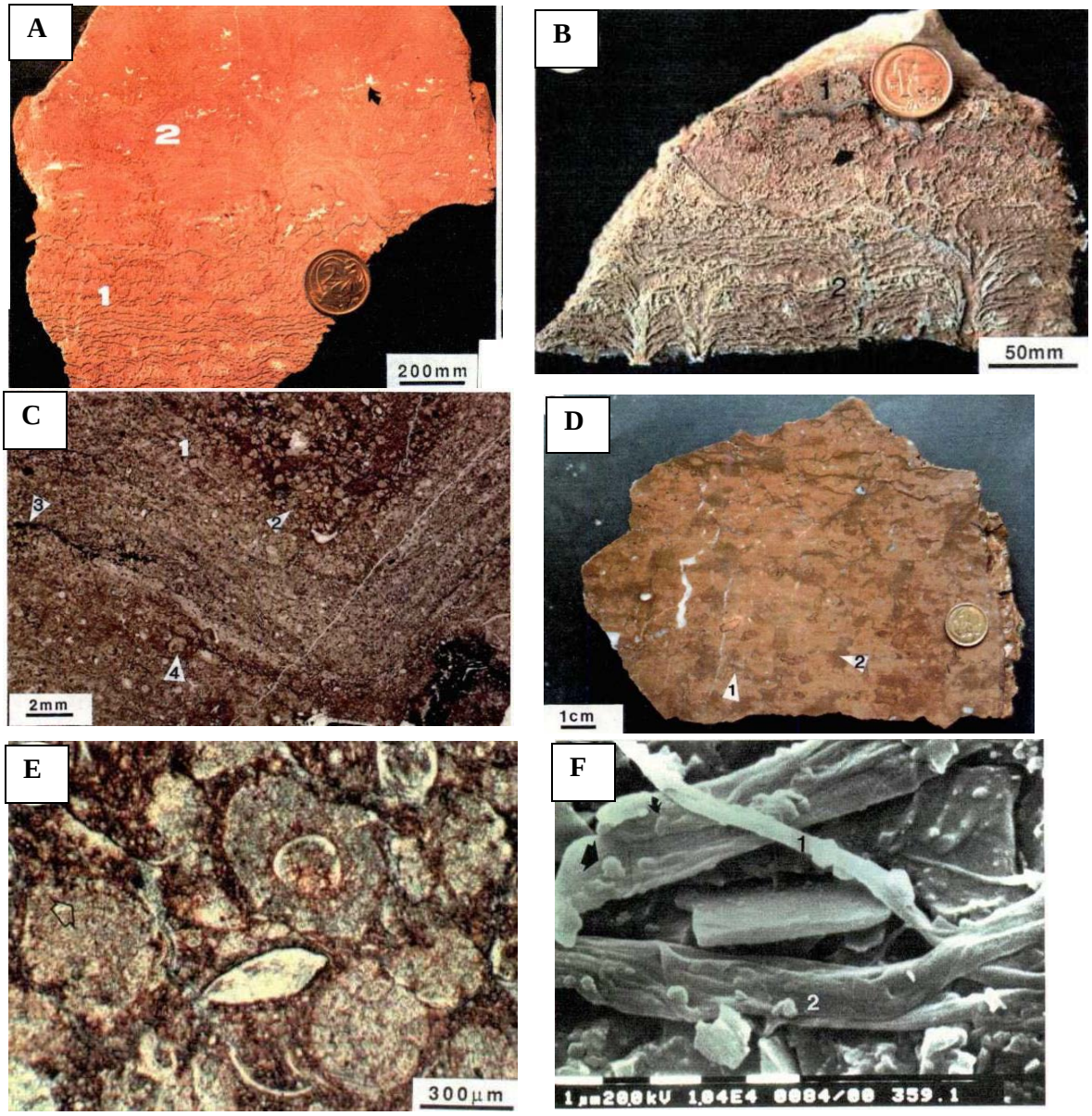

Fig. 5 The Pa Kae Stromatolite Forms (Wongwanich 1990).

A. Etched slabs showing a development from stratiform stromatolites at the bottom to columnar stromatolites on top of bedding. The spar filling fenestrae are rare.

B. Etching slab of reticulate (columnar) stromatolites developing to thrombolite and thrombolytic stromatolites.

C. Oncolitic stromatolites developing upward to normal oncolites.

D. Thrombolitic stromatolite showing link between mesoclotted structures.

E. Thin section photomicrograph of oncolytic stromatolites microfacies.

F. SEM of the well preserved leaf-like calcified microbial sheaths, a filament and rounded coccoid bacteria on their surface, exhibiting trapping (allochems) and binding (clay mineral) mechanism.

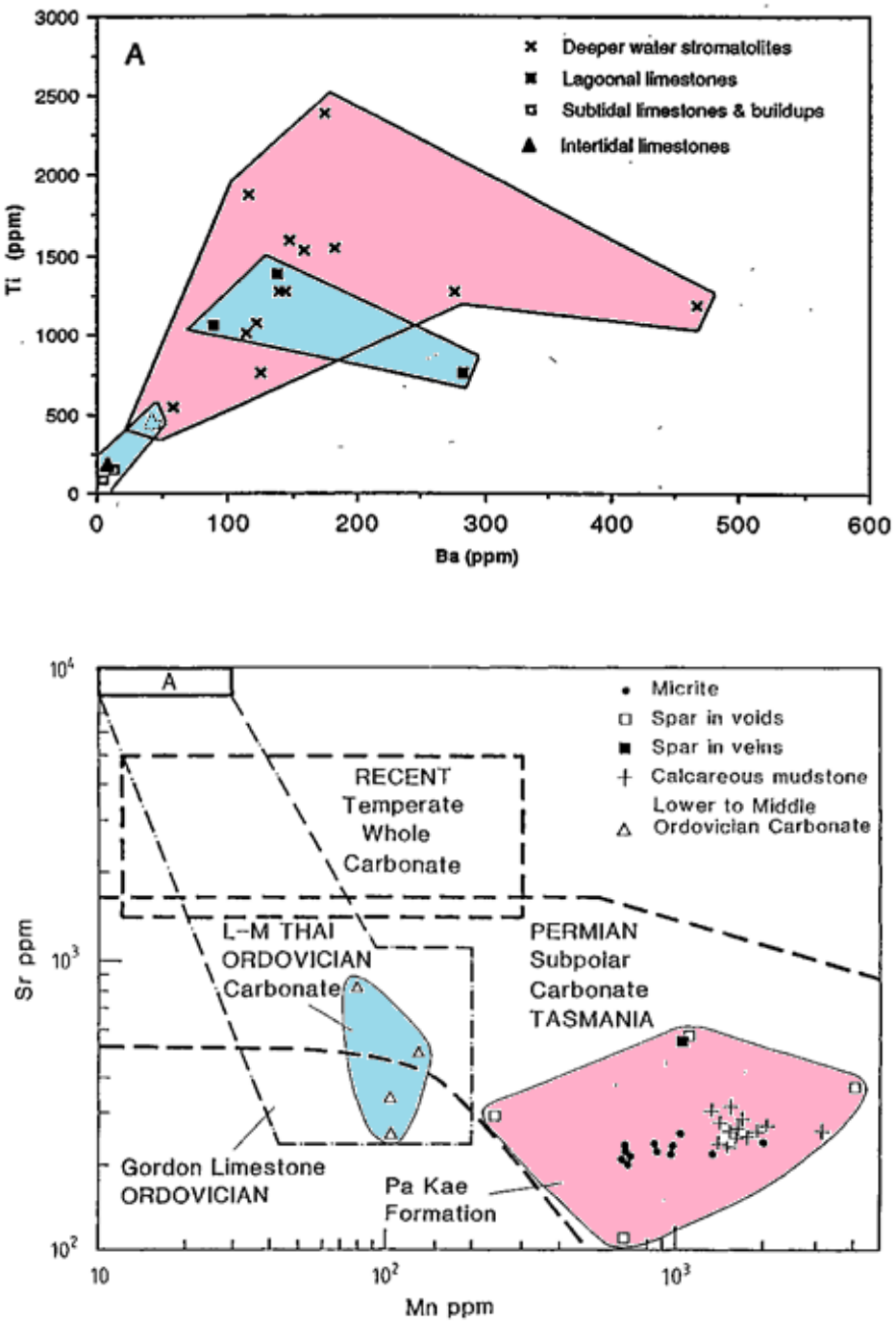

Fig. 6 A. Titanium value for the Pa Kae and other shallow water Thung Song Carbonates plotted against barium value of those rocks. The covariance fields show gradual enrichment in Ti from intertidal and subtidal carbonates to lagoonal and basinal deeper water stromatolitic limestones.

B. Strontium and manganese variation in the Pa Kae deeper water stromatolites and the other Lower to Middle Ordovician Thai shallow water carbonates compared with the field of recent temperate whole carbonates, Permian subpolar carbonates, and Ordovician subtropical Gordon limestone from Tasmania (Rao 1990a). From Wongwanich 1990.

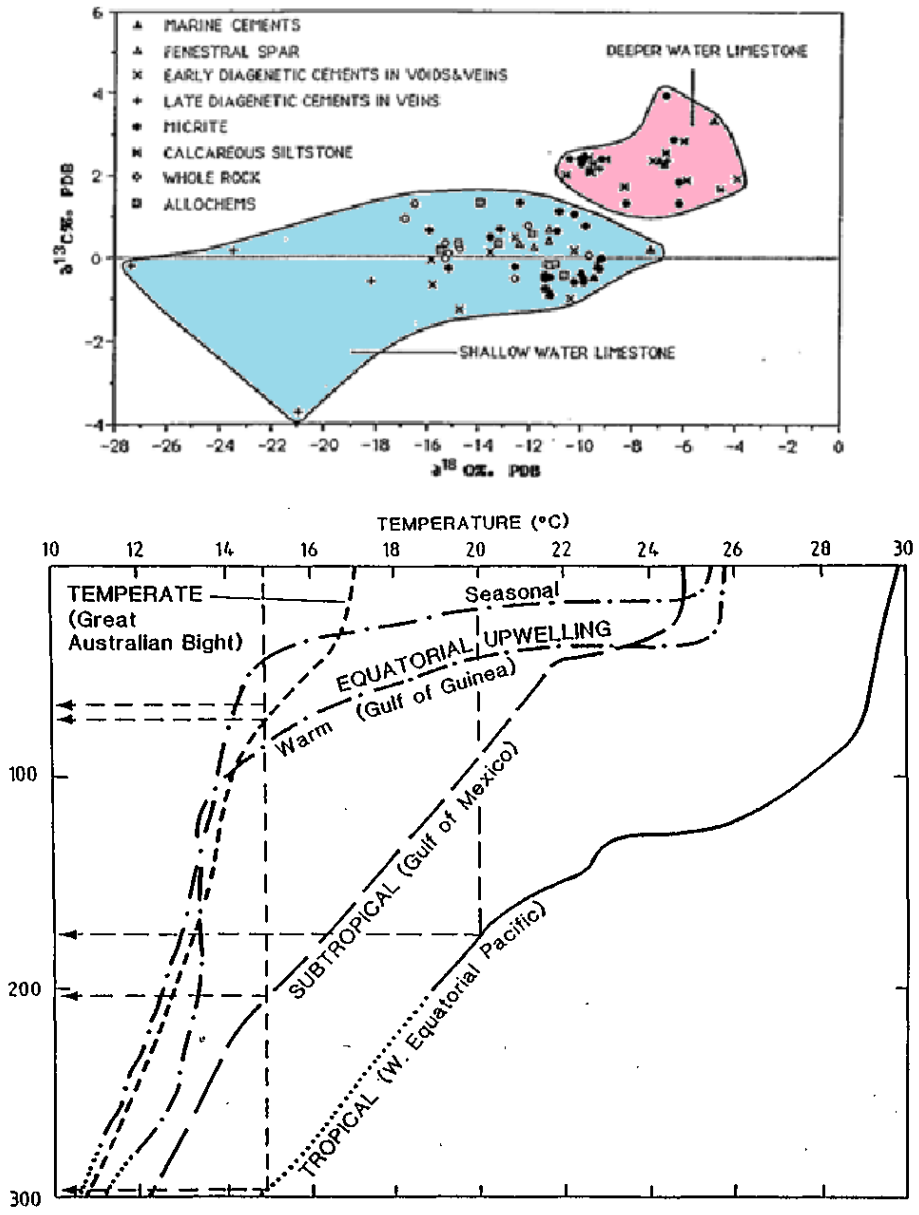

Fig. 7 A. Comparison of $\partial_{18}0$ and $\partial_{13}C$ of separate components from the shallow water limestones of the lower formation and deeper water limestones from the Pa Kae Formation, the Thung Song Group (Wongwanich 1990).

B. Conceptual temperature-depth model for predicting the possible palaeobathymetry of tropical and temperate carbonates based on the drop of temperature from modem sea surface temperature (SST) in relation with the vertical thermal gradient profile in those climatic regions (see text). The vertical axis represents the depths from mean sea level. The horizontal axis represents either SST or the drop of temperatures from SST to the calculated or estimated palaeotemperatures (obtained from the heaviest $\partial_{18}O$ value of the rock) at a predicted depths. This model can be extrapolated to the depths of about 600 m from mean sea level. The arrows point out the water depths of each carbonate setting at specific temperature.

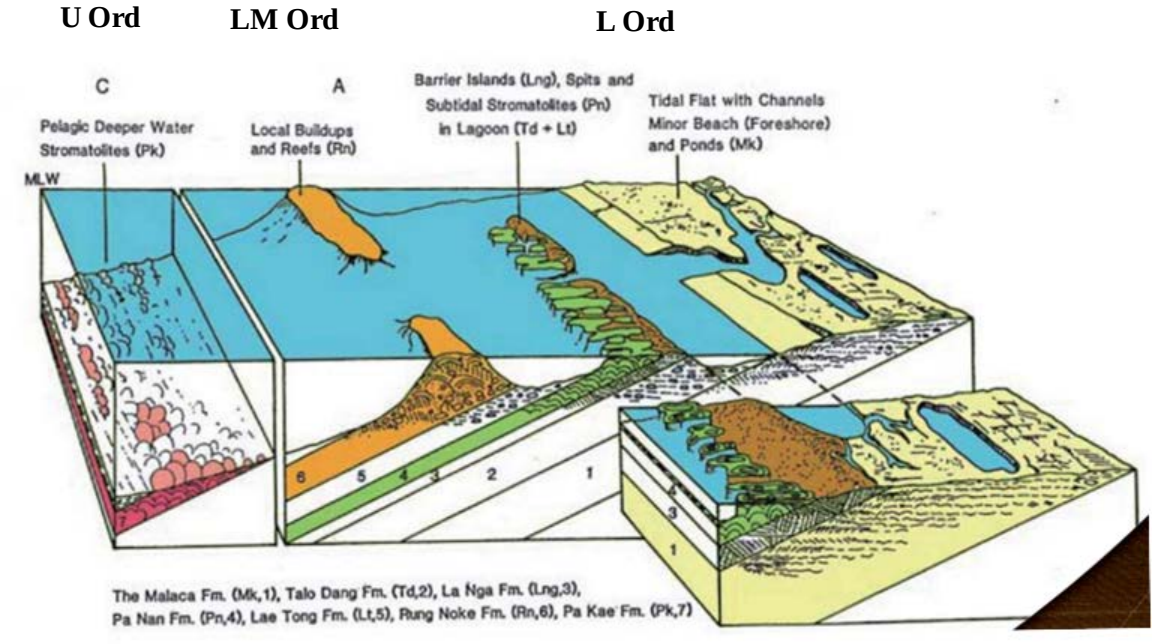

Fig. 8 The diachronous depositional model for transgressive development of the Thung Song ramp carbonates showing environmental setting, distribution and relationship of common rock types through the Ordovician period (modified from Wongwanich 1990).
A. General environmental setting at Ko Tarutao.
B. Spit morphology at La Nga Bay, NE Ko Tarutao, where the La Nga barrier island contacts with the Malaka tidal flat.
C. Deeper water stromatolite, the Pa Kae Formation. Vertical and horizontal scales are exaggerated

ZIRCON U-PB-HF CONSTRAINTS ON CAMBRIAN PALEOGEOGRAPHY OF ASIAN TERRANES ALONG IN EASTERN GONDWANA

Dr. Ryan McKenzie

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Abstract

The Cambrian occupies a time of dramatic climatic and environmental changes, which proudly influenced the early evolutionary trajectory of animals. Changes in atmospheric greenhouse gas concentration and oxygen, as well as nutrient fluxes to the ocean, are intimately linked with volcanism and chemical weathering processes, which are largely driven by plate tectonic processes. The Cambrian is a period characterized by widespread plate re-organization associated with the amalgamation of Gondwana, and understanding the spatial extent and duration of orogenic systems around the various Gondwana terranes is critical to understand the principal mechanisms responsible for changes in Earth's surface environment during this time. Here, I present detrital zircon U-Pb and Hf isotopic data in conjunction with trilobite biogeographical data to assess the paleogeographic configuration of eastern Gondwana, with an emphasis on the relationship between the Shan Thai (Thailand) terrane and other prominent regional terranes. I will further discuss the importance insights to be gained through future studies in the Turatao Formation in Thailand with respect to critical questions of Earth system evolution.

AN OVERVIEW OF KARST SYSTEMS WITH REFERENCE TO SATUN ASPIRING GEOPARK

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Abstract

Karst is a term for landscapes formed by the dissolution of soluble rocks such as limestone, dolomite and gypsum. It is characterized by underground drainage systems with sinking streams, sinkholes, caves and springs. Karst landscapes are often spectacularly scenic areas, especially in the tropics.

In contrast to non-karst areas, karst systems have two primary distinguishing characteristics: First, they have a two-layer structure of surface and subsurface features which has profound influence on the hydrology and biology of these systems. Secondly, karst systems are geochemically a calcium-rich environment of carbonates.

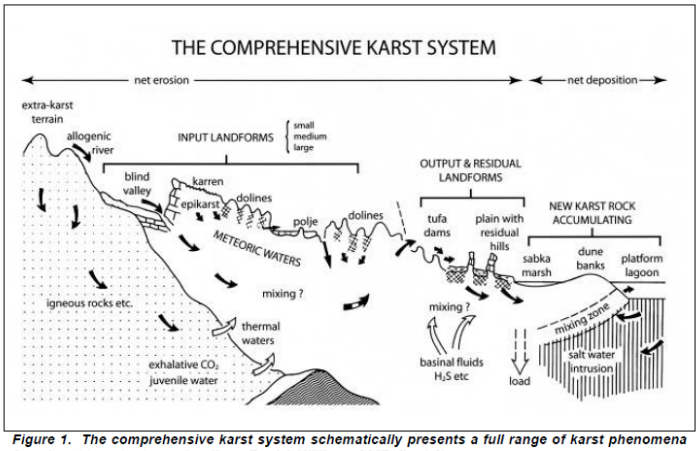

Figure 1. The comprehensive karst system schematically presents a full range of karst phenomena from input to output margins (from Ford & Williams 2007, fig. 1.2).

Karst landform development is closely related to the hydrologic cycle as water passes into, flows through, and emerges from karst terrains. As water flows through a karst system the primary division is into net erosional and net depositional zones, as illustrated in Figure 1.

The net erosion zone contains the input (e.g. blind valley), throughput (e.g. caves, polje), output (e.g. tufa dams) and residual (e.g. karst towers) landforms. It should be noted that most karst geosites represent the net erosion zone, but relatively few include the net deposition zone, with most deposition occurring offshore.

The character of karst landscapes varies around the world as a consequence of lithology, geologic structure and climate. The climatic context under which karst evolves is particularly influential in determining the resulting landscape style, with water availability being a key climatic factor in karst evolution.

Karst systems and their characteristics vary with their climatic context, and can be classified into five types, which differ in their geomorphic and biotic features:

- Humid Tropical Jungle Karst
- Humid Subtropical Stony Karst

- Arid and Semi-arid Karst
- Humid Temperate Karst
- Arctic and Alpine Karst

It is recommended that karst systems be evaluated in the context of four components:

- Climatic context and karst style
- Comprehensiveness of its karst system
- Geology and landscape history
- Surface and subsurface biotic communities

CAVE CARYING CAPACITY: LESSON LEARNED FROM PINDUL CAVE AND BARU CAVE, GUNUNG SEWU GEOPARK-INDONESIA

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[2)] Karst Research Group, Department of Geography and Environment Science, Faculty of Geography, Gadjah Mada University

Introduction

Indonesia is a country that has a many nature landscape and seascape. The rich of natural landscape and seascape make Indonesia have many nature tourism attractions, one of them is a cave. The cave is a natural tourist attraction in a karst landscape. The cave is the most beautiful nature attraction (Cigna and Fortes, 2013 in Lobo et al, 2015). The cave is widely used for tourist destination, research, and education. However, the process of cave formation takes thousands of years. It makes the cave very vulnerable to damage.

Pindul cave area is located in Bejiharjo, Karangmojo, Gunungkidul, and Special Region of Yogyakarta. Pindul cave tourism area have some cave that opened to visitation. The cave is Pindul Cave and Baru Cave. The caves have different characteristics. Pindul Cave is a water-filled cave throughout the year and has two mouths of caves for access to tourism activities. Baru Cave is a dry cave that has one mouth of the cave as in and out.

Tourism in cave requires better management in managing the number of visitors and time of visit in cave, so the cave environment can be maintained properly. This concept is known as the concept of carrying capacity of the cave (De Freitas, 2010; Lobo, 2015). One of the things that influence the carrying capacity of the cave is the characteristics of the cave. Each cave has different characteristics, so the carrying capacity of each cave is different.

The aims of this research are (1) to examine the change of microclimate climate parameters due to tourism activities in Pindul Cave and Baru Cave; (2) to analysis the carrying capacity of tourism in Pindul Cave and Baru Cave.

Methodology

The method used for this research is a direct measurement of microclimate parameters in tow caves. Data collected include the number of visitors entering the cave every half hour for 24 hours, inside and outside cave temperature, inside and outside cave relative humidity,Cave CO_2 concentration, cave daily opening time, route duration, the number of guides, and Recovery time of cave microclimate parameter. The carrying capacity of the cave was calculated using the Lobo (2015) approach.

Result

The results of the measurements in the Baru Cave and Pindul Cave are presented in Table 1.

Table 1. Microclimate average in Baru Cave and Pindul Cave

Cave		Carbon dioxide concentration (ppm)	Temperature (°C)	Relative humidity (%)
Baru Cave	Average	963,168	26.55	97.83
	Average when open to visitation	1042	26.57	97.67
Pindul Cave	Average	625.28	27.06	93.55
	Average when open to visitation	772,08	27.18	93.58

Baru Cave measurements for 5 times (1 low season and 4 peak season) is known that the temperature has an average of 26.55 ° C, an average relative humidity of 97.83%, and an average CO_2 concentration of 963,168 ppm. When there are visitors, the microclimate parameter changes. The average air temperature rises by 26.57 ° C, the average humidity decreased to 97.67%, and the CO_2 concentration rises to 1,042 ppm.

The measurements at Pindul Cave was conducted 7 times measurement (2 times in a low season and five times during peak season). The average temperature is 27.06 ° C, an average relative humidity of 93.55%, and an average CO_2 concentration of 625.28. When there are visitors, the air temperature in Pindul Cave is 27.18 ° C, the relative humidity is an average of 93.58%, and the average CO_2 concentration rises to 772,08 ppm.

The result shows that the mean temperature and CO_2 concentration increase when visitors enter the cave by 0,03° C and 79,773 ppm in Baru Cave. The average cave temperature and CO_2 concentration in Pindul Cave increased by 0,126° C and 146,8 ppm. Based on the results of measurements in the Baru Cave and Pindul Cave, it is known that the average CO_2 concentration has the greatest change when compared with other climate parameters, i.e. temperature or relative humidity.

Discussion

Cave is one place that has different climatic characteristics, so called the cave microclimate. Climatic conditions within the cave differ from one place to another place on the earth's surface (Bogli, 1980). This difference is influenced by the lack of sunlight entering the cave. Cave microclimate is more governed by local factors, namely the relationship between the cave hole and distance to the surface of the earth. The microclimate of the cave is considered stable. Therefore, when visitors enter the cave, it will will affect the microclimate of the cave, especially temperature and CO_2 concentration (Linhua et al, 2000; Lario and Soler, 2010; Sabela et al, 2012; Lobo et al, 2015; Lobo, 2015).

Based on measurements in the Baru Cave and Pindul Cave, it shows that the most affected microclimate parameter is the CO_2 concentration (Fig 1 and Fig 2). The increase of CO_2 concentration results from respiration from visitors (Lario and Soler, 2010; De Freitas, 2010). Human respiration directly influences this increase in CO2 concentration into the cave (De Freitas, 2010). While indirectly, carbon dioxide concentration is governed by the activity of bacteria and microorganisms that feed on organic materials in the skin and human hair.

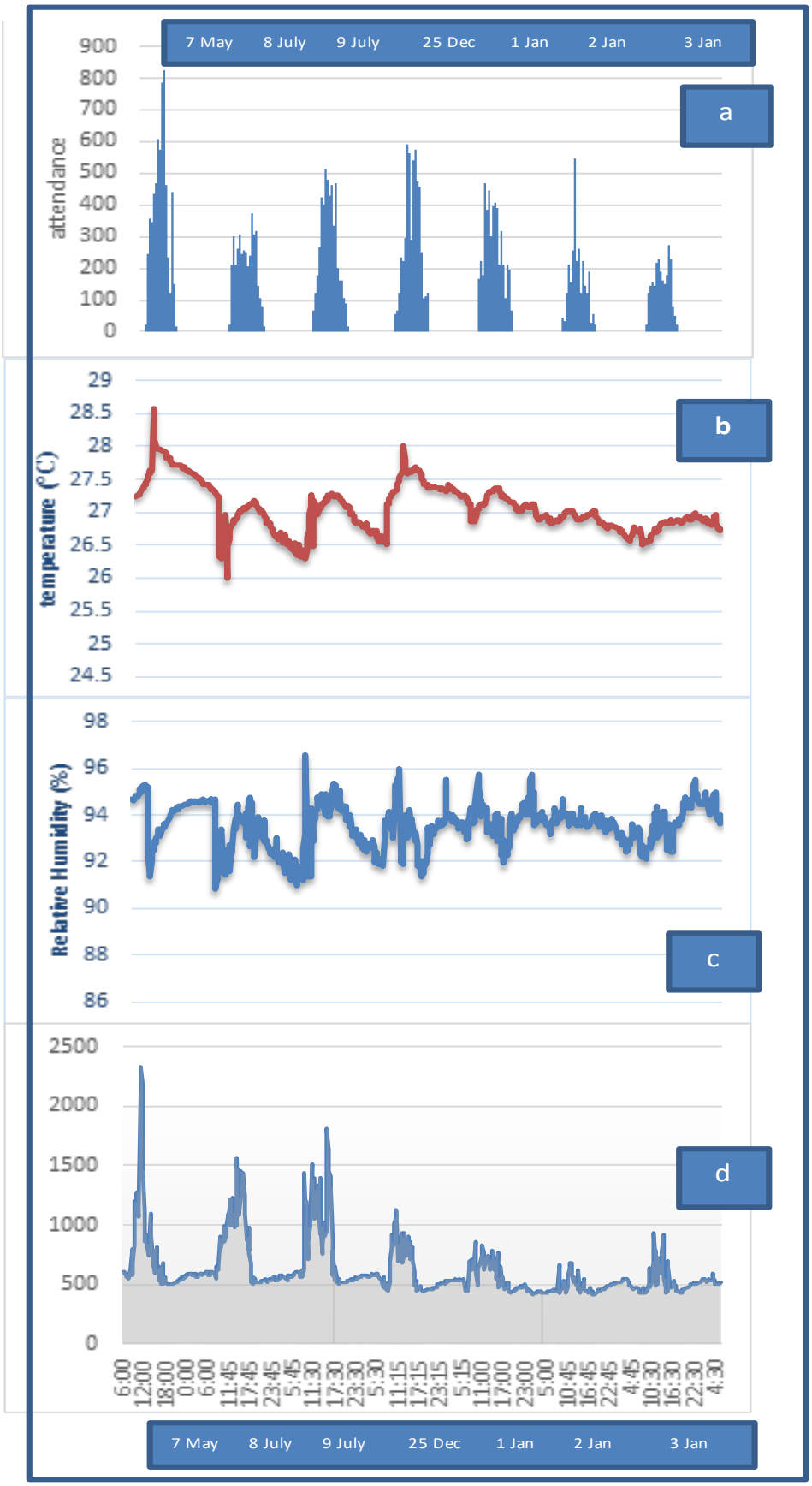

Fig 1. Micro climate and visitors monitoring in Pindul Cave. (a) number of visitors. b) temperature, c) relative humidity, d) CO_2 Concentration

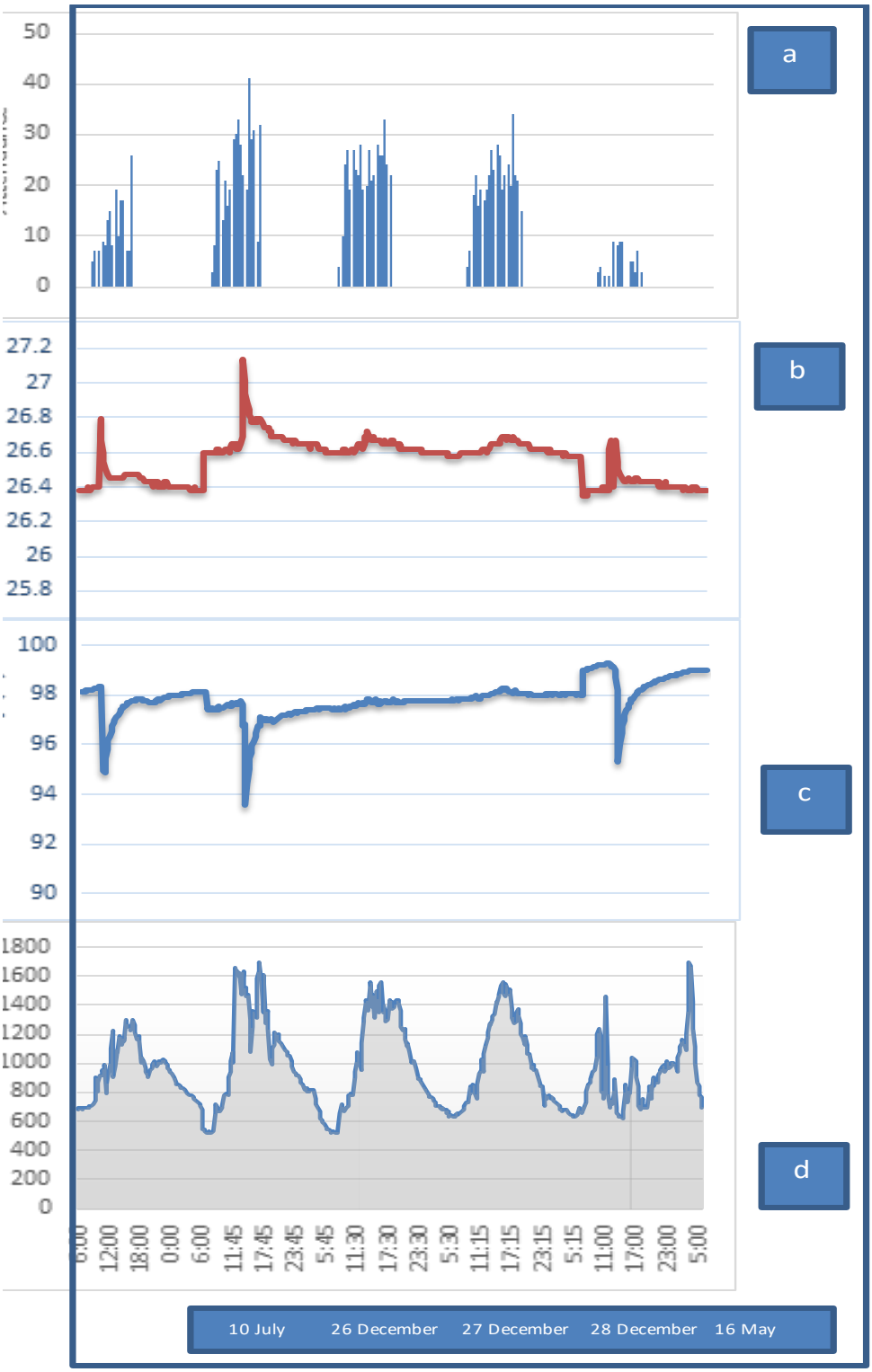

Fig 2. Microclimate and visitors monitoring in Baru Cave. A) visitors number, b) Temperature, c) relative humidity, d) CO_2 concentration

In addition to CO_2 concentration, the microclimate parameter that changes due to tourism activity is the air temperature. This can be seen from Fig 1 and Fig 2, that the air temperatures tend to increase during the visiting hours. Temperatures in the cave grows during the tourist visit. Rising temperatures in this Cave is influenced by the accumulation of body heat from visitors entering the cave (De Freitas, 2010). In addition to the New Cave because using lights for lighting in the cave also affect the temperature inside the cave. This is confirmed by De Freitas (2010) where lighting also affects the air temperature inside the cave.

Therefore, air climate parameters is analyzed for total recovery time (trt). Total recovery time is the time required by microclimate parameters to return to normal state when before being used for tourism. Based on the results of measurements in the Baru Cave and Pindul Cave, it is known that the average CO_2 concentration has the greatest change when compared with other climate parameters, be it temperature or relative humidity.

Table 2. Total recovery time (trt) in Pindul Cave

Date	Type of Visitation	CO_2 before visitation (ppm)	Peak hours	Number of Visitors	Time of visiting closed	Time of recovery	Total recovery time (minutes)
7 May 2016	peak season	585	13:00	6979	17:00	18:30	90
8 July 2016	peak season	570	14:00	4677	17:30	18:15	45
9 July 2016	peak season	574	11:30	5649	18:00	19:00	60
25 December 2016	peak season	528	11:00	5822	17:30	18:30	60
1 January 2016	peak season	527	9:30	5264	17:30	18:30	60
2 January 2016	low season	448	11:00	3031	17:30	18:15	45
3 January 2016	low season	450	14:30	2539	17:00	17:30	30

Total recovery time (trt) in Pindul Cave is presented in Table 2. It shows that total recovery time in Pindul Cave ranged from 30 to 90 minutes. This means that the time required by the Pindul Cave to return to normal conditions when completed for tourist use is an average of 55.71 minutes for CO_2 concentration.

Table 3. Total recovery time (trt) in Baru Cave

Date	Type of Visitation	CO_2 before visitation (ppm)	Peak hours	Number of Visitors	Time of visiting closed	Time of recovery	Total recovery time (minutes)
10 July 2016	peak season	687	16:30	175	17:00	3:00	600
26 December 2016	peak season	657	14:30	431	17:00	3:45	645
27 december 2016	peak season	680	16:00	452	17:00	4:00	660
28 December 2016	peak season	685	16:00	425	17:00	2:45	585
16 May 2017	low season	703	12:00	69	17:00	20:00	180

Total recovery time (trt) in Baru Cave is presented in Table 2. T]It is known that total recovery time in Baru Cave ranged from 180 to 660 minutes. It means that the time required by the Baru Cave to return to normal conditions when completed for tourist use is an average of 534 minutes.

Calculation of total recovery time shows that the Baru Cave has a total recovery time longer than the Pindul Cave. This is governed by the different natural factors of both caves. The natural factor according to (Muvyludov, 1997 in Fandeli and Adji, 2004) is the climate, the morphology that limits the air circulation system, the condition of the cave-forming rocks, and the underground river system.

The Baru Cave is morphologically having only one cave entrance, while the Pindul Cave has two cave entrances. It makes the air circulation in the Baru Cave take longer time compared to Pindul Cave. Therefore the total recovery time in Baru Cave needs longer time. Also, the presence of underground river system affects total recovery time, as the underground river system will accelerate recovery from current climate parameters.

Based on the results of total recovery time, then used to measure the tourism cave carrying capacity. Calculation of tourism cave carrying capacity using Lobo method (2015). The result of the calculation is divided into 3; available time for visitation (atv), number of group (ng), and daily limit visitation (dlv). The Calculation of carrying capacity is divided into 2 when low season and peak season.

Table 4. Carrying capacity of cave in Pindul Cave Tourism Area at peak season

Cave	ttv (min)	rd(min)	atv (min)	tbg(min)	ng (group)	sg (person)	dlv (person)
Pindul	600	45	**555**	10	**55.5**	20	**1110**
Baru	600	30	**570**	15	**38**	12	**456**

Cave carrying capacity during peak season is presented in Table 4. Available time for visitation is 555 minutes for Pindul Cave and 570 minutes for Baru Cave. A number of the group is 56 group for Pindul Cave and 38 group for Baru Cave. Daily limit visitation is 1,110 Pindul Cave and 456 visitors in Baru Cave.

Different cave characteristics influence the difference in carrying capacity of each cave. The more closed a cave, the smaller the carrying capacity will be. This finding ecoes Heaton (1986) theory in Ford and William (2007) of which cave is divided into three categories, namely high energy, intermediate energy, and low energy. The smaller the energy of a cave, the cave will be more fragile, so the carrying capacity will be smaller. This is also appropriate when compared to total recovery time, where caves that have a long recovery total time will have a low carrying capacity.

Conclusion

Cave microclimate in Baru Cave and Pindul Cave is affected by tourism activity. The air temperature and the CO_2 concentration fluctuates during the tourist visit. Baru Cave has a longer recovery time than Pindul Cave. It is governed by air circulation and the existence of underground river system. Total recovery time is then used as a reference in determining the carrying capacity, where Caves with long recovery time will have the less carrying capacity. Baru Cave has daily limitation visit of 456 visitors/day while Pindul Cave has a daily limitation visit 1,110 visitors/day.

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KARST FEATURES IN SATUN GEOPARK, SATUN PROVINCE

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Abstract

The carbonate rock exposed in Satun Geopark area is the limestones of the Lae Tong Formation and Rung Nok Formation of the Ordovician Thung Song Group which are distributed about 30 percentages based on 1,099.47 sq.km by area. The Lae Tong Formation is characterized by dark to pink argillaceous limestone, thin to very thin bedded with occasional ripple cross -lamination, interbedded with green, black and red shale, thin-bedded. Trilobites and brachiopods are observed in the basal and upper most parts of the unit. The Rung Nok Formation consists of dark grey to grey limestone, medium to thick bedded with stromatolite interbedded with occasional stylolites and massive dolomite with numerous echinoderm fragments, bryozoans, nautiloid, brachiopods, and receptaculitids. Moreover oolitic rich in crinoid stem in limestone is found in the lower sequence.

Karst features in the study area is mostly exokarst – subaerial and their forms generally consist of (1) wall Karst, (2) stromatolitic karst, (3) pinnacle, (4) cone and tower, (5) knob, (6) karren or lapies, (7) stone forest, (8) polje, (9) sinkhole or doline, (10) karst spring or karst seepage, (11) karst waterfall, (12) karst lake and (13) cave. Limestone terrane is associated with the life of the Satun villagers for a long time, such as many Buddhist monks are situated in the cave. The flat land between the mountains are used for agriculture and cultivation. Limestone waterfall is a place to relax and people bring water from karst spring and karst seepage to their daily lives.

Introduction

Department of Mineral Resources, Bangkok, Thailand is planning to develop all geological sites in Thailand in terms of affective management and conservation of geological sites based on the UNESCO's regulations. The main aim is to establish the "Geopark" in the selected, outstanding geological sites throughout the country in order to support tangibly the government policy for enhancing country's economy and sustainable development for local community in geological tourism. This will correspond to the main purpose of UNESCO to encourage each country to establish conservation sites which have outstanding aspects in geological and/or archeological, ecological, and cultural points of view.

"Satun Geopark" is the high potential area which is significant and outstanding in terms of geology, natural science and culture. The significant of Satun Geopark is an ancient sea fossils from 500 to 250 million years ago. One of outstanding points is karst topography. The effective collaboration of communities, local organizations and Department of Mineral Resources result in Satun Geopark was announced as a national geopark in November 2016 and will be assessed by UNESCO for becoming a UNESCO Global Geopark in July 2017

However, this study increases the knowledge and understanding of the Satun Geopark's outstanding which is an important point to encourage Satun Geopark becoming part of UNESCO Global Geopark. It is also an information for disseminating to local people, so they will see the value and cherish their natural resources. This will increase clear understanding and positive attitude of geo-conservation and all of these lead to sustainable development, cooperation and conservation by local people.

Objectives

1 To classify the Karst features in the Satun Geopark.
2 To suppose the academic outstanding data for supporting the Satun national geopark to Satun global geopark.
3 To provide the geological and morphology of karst topography in Satun Geopark, which will be applied in other future works.

Study Area

The study area is located in Satun Province, Peninsular Thailand, covering four districts of the province namely Thung Wa, La-ngu, Manang and part of Mueang Satun District (only including Pethra and Tarutao National Parks). A total area in land is 1,099.47 sq.km. (Fig. 1).

Methodology

4.1 Studying history of previous works and syntheses of all geological data
4.2 Field checking in study area
4.3 identification and analyses of total data in the study area
4.4 Final report preparation and submitting

General Geology

The study area is mostly composed of Paleozoic marine sedimentary rocks comprising limestone, sandstone, mudstone, shale and chert. These rocks represented by a continuous succession of the deeper water siliciclastic and carbonate rocks (Bunopas, 1981). Fossils are abundant and diverse indicating continuous ages from Cambrian to Permian. Triassic granite was exposed in the northeast of the study area and in the islands, namely Adang, Ra Wi, Lipe and other islands. Some metamorphic rocks such as quartzite and hornfel were found in this area.

The carbonate rock exposed in this area is the limestones of the Ordovician Lae Tong Formation and Rung Nok Formation of the Thung Song Group which are distributed about 30 percentages based on 1,099.47 sq.km by area. The Lae Tong Formation is characterized by dark to pink argillaceous limestone, thin to very thin bedded with occasional ripple cross -lamination, interbedded with green, black and red shale, thin-bedded. Trilobites and brachiopods are observed in the basal and upper most parts of the unit. The Rung Nok Formation is conformably overlain by The Lae Tong Formation. It consists of dark grey to grey limestone, medium to thick bedded with stromatolite interbedded with occasional stylolites and massive dolomite with numerous echinoderm fragments, bryozoans, nautiloid, brachiopods, and receptaculitids. Moreover oolitic rich in crinoid stem in limestone is found in the lower sequence (Fig. 2).

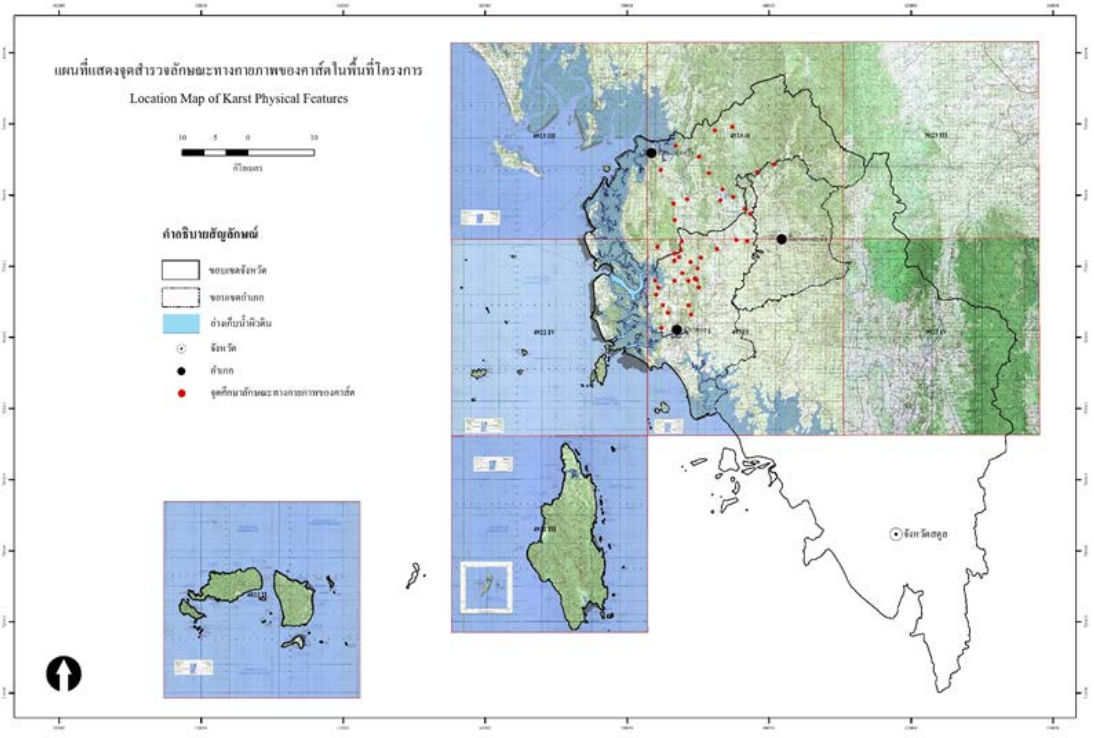

Figure 1 Study area.

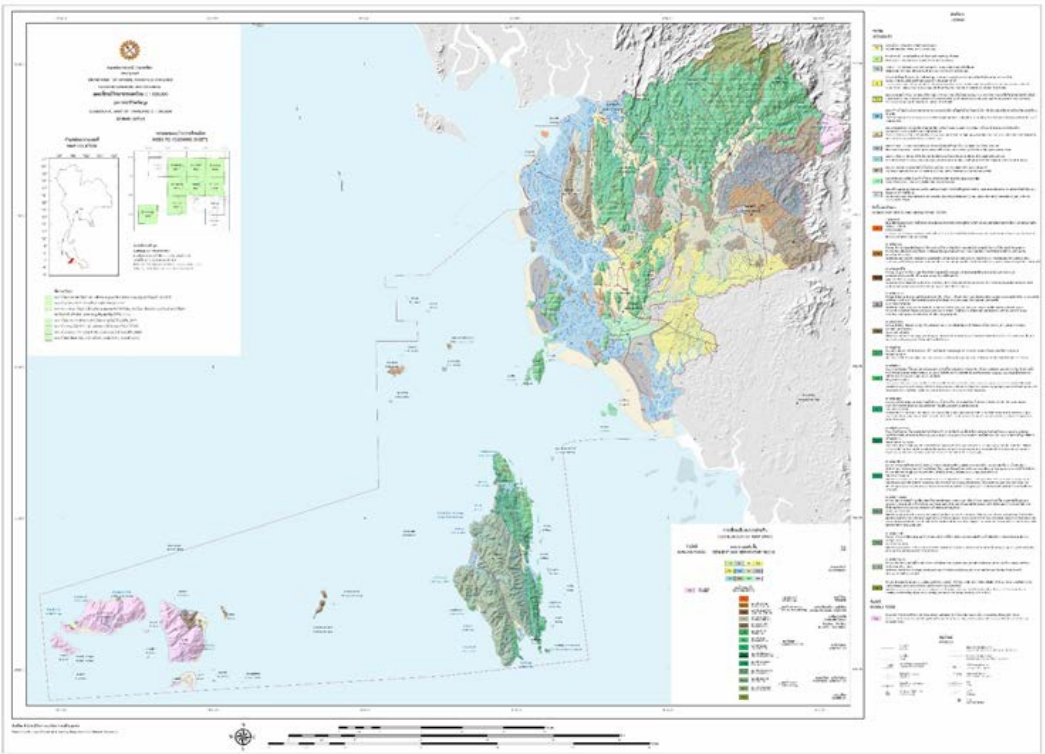

Figure 2 Geologic map of the Study area. (after Sinsakul, 1988; Maranate, 2000; Saengsrichan, 2002; Teerarungsigul *et al.*, 2004; Tiyapairach, 2004; Tiyapairach, 2005; Tiyapairach and Sooksriboonampai, 2005)

Karst features in Satun Geopark

Karst morphology is distributed widely in the world. Different Karst features are dominated by the different of lithology, hydrology, structure, climate and. Karst features in the study area is mostly exokarst – subaerial and their forms generally consist of (1) wall Karst, (2) stromatolitic karst, (3) pinnacle, (4) cone and tower, (5) knob, (6) karren or lapies, (7) stone forest, (8) polje, (9) sinkhole or doline, (10) karst spring or karst seepage, (11) karst waterfall, (12) karst lake and (13) cave. Details of each features are given below

Wall Karst: This pattern is developed by uplift continuously from a sea floor to be a high mountain and controlled by fracture linear in a north-south and northeast-southwest direction. Their character look like a huge wall (Fig. 3).

Stromatolitic Karst: It is characterized by hill or mountain which consisting of thick bedded limestone interbedded with stromatolite (Fig. 4)

Pinnacle: Pinnacle topography in the study area is always found in the top of hill. It is an erosional form created by dissolution. Its characteristic looks like razor-sharp or vertical blades (Fig. 5).

Cone and Tower: Tower Karst is a type of landscape characterized by steep limestone towers and cone karst is characterized by isolate residual hill (Fig. 6).

Knob: Knob are isolated fragment of the plateau, and many retain a fragment of the original caprock that protects them from erosion. They are frequently ringed with vertical shafts that drain off the precipitation that falls on top of the knob. In the later stages of development, the caprock is eroded away and an isolated limestone hill remains standing in relief above the karst plain (Fig. 7).

Karren or Lapies: Direct rainfall, sheet wash, channelized flow, and percolating flow under various kinds of mantle materials produce a myriad of small sculpturings on the bedrock surface of soluble rock. These form, as a class, are called "karren", a German term that has come into general usage in English. The French equivalent is "lapiez" (Fig. 8).

Stone Forest: weathered limestone surface found in karst regions and consisting of etched, fluted, and pitted rock pinnacles separated by deep grooves. This rugged surface is formed by the solution of rock along joints and areas of greater solubility by water containing carbonic and humic acids. Small rock pinnacles of the stone forest may vary in high from a few millimetres to several metres. (Fig 9)

Polje: Polje are large, flat-floored, enclosed depressions in karst terrain. Gams (1978) considered the many geomorphological definitions of polje that have been published and found several elements to be common to most definitions. He identified three criteria that must be met for a depression to be classified as a polje (1) flat floor in rock (which can also be terraced) or in unconsolidated sediments such as alluvium, (2) a closed basin with a steeply rising marginal slope at least on one side and (3) karstic drainage. Moreover, Cvijic´ (1893) also suggested that the flat floor should be at least 1 km wide (Fig. 10)

Sinkhole or Doline is a depression basin or hollow in karstic terrain. These can be up to 20 m in depth and 100 m or more in diameter. Sinkholes develop by a variety of methods such as collapse, suffusion or solution (Fig. 11).

Karst Spring and Karst Seepage is a part of a karst system. That includes the underground drainage of a much larger area, which means that karst springs or karst seepage often have a very large discharge. Karst Spring and Karst Seepage. Groudwater resources within this karst morphology is important for people and ecological system. (Fig. 12).

Karst Waterfall*:* Waterfalls in karst often display the precipitates known as tufa and travertine which formed by the precipitation of carbonate minerals from solution in ground and surface waters. In the study area, waterfalls originate from cave springs that slope down to the perennial streams below. These include Wang Sai Thong, Tharn Plew, Tharn Sawan waterfalls, etc (Fig. 13).

Karst Lake: A large area of standing water in an extensive closed depression in limestone bedrock and commonly is directly connected to and controlled by the subsurface karst drainage network (Fig. 14).

Cave is a natural underground opening in rock that is large enough for human entry. Another definition is a karst cave as an opening enlarged by dissolution to a diameter sufficient for 'breakthrough' kinetic rates to apply if the hydrodynamic setting will permit them. Normally, this means a conduit greater than 5–15mm in diameter or width, the effective minimum aperture required to cross the threshold from laminar to turbulent flow. The study area includes Phu Pha Petch, Urai Thong, Khanti Phon cave, etc. (Fig.15).

Figure 3 Example of *"wall karst"* in the study area. (Left) Khao Wang Kluai, Thung Wa Sub-district, Thung Wa District, it is more than 3 km in length. (Right) Khao Khao, Khao Khao Sub-district, La Ngu District.

Figure 4 Example of *"Stromatolitic Karst"* in the study area at Khao Ped Nam House of Priest, Nam Phud Sub-district, La Ngu District.

Figure 5 Example of *"Pinnacle"* in the study area. (Left) Top of Phu Pha Petch Cave, Palm Phatthana Sub-district, Manang District. (Right) Ban Pa Phon, Palm Phatthana Sub-district, Manang District.

Figure 6 Example of *"Cone Karst"* in the study area. (Left) Kuan Pa Kan, La Ngu District. (Right) Khao Krok, La Ngu District.

Figure 7 Example of *"Knob"* in the study area. (Left) Khao Thanan, Thung Bulang Sub-district, Thung Wa District. (Right) Ko Taban, Na Thon Sub-district, Thung Wa District.

Figure 8 Example of *"Karren or Lapies"* in the study area at Ban Bo Hin, Khao Khao Sub-district, La Ngu District.

Figure 9 Example of *"Stone Forest"* in the study area at Tham Phu Pha Petch House of Priest, Palm Phatthana Sub- district, Manang District.

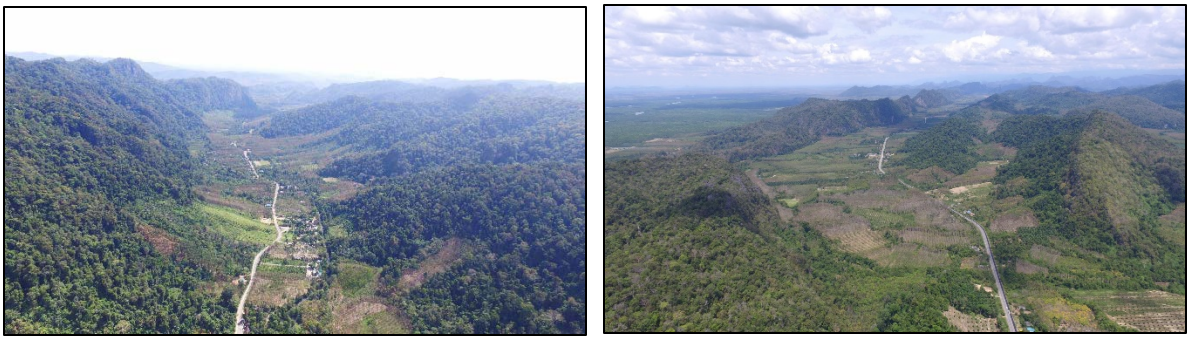

Figure 10 Example of *"Polje"* in the study area. (Left) Wang Sai Thong Kayaking, La Ngu District. (Right) Thung Wa District.

Figure 11 Example of *"collapse Sinkhole or Doline"* in the study area. (Left) Behind Kam Phaeng Wittaya school, Kam Phaeng Sub-district, La Ngu District. (Right) Pannarasa ram temple, Nikhom Phatthana Sub District, Manang District.

Figure 12 Example of *"karst spring"* in the study area. (Left) Ban Rao Pla, Thung Wa Sub-district, Thung Wa District. (Right) Ban Han, Khao Khao Sub District, La Ngu District.

Figure 13 Example of *"karst waterfall"* in the study area at Tharn Pliew Waterfall, Thung Wa Sub-district, Thung Wa District.

Figure 14 Example of *"karst lake"* in the study area. (Left) Pa Nan Rocks, Thung Wa Sub-district, Thung Wa District. (Right) Ban Han, Khao Khao Sub-district, La Ngu District.

Figure 15 Example of *"cave"* in the study area. (Left) Phu Pha Petch Cave, Palm Phatthana Sub-district, Manang District. (Right) Chet Khot Cave, Nam Phud Sub-district, La Ngu District.

Acknowledgements

The authors are grateful to Dr. Tawsaporn Nuchanong, Director General of Department of Mineral Resources and Mr. Anukoon Wongyai, Director of Bureau of Geological Survey for their support and encouragement.

We would like to express our most sincere thanks to Mr. Chaiporn Siripornpibul for his assistance not only in the field trip but also his guidance and teaching in many aspects, encouragement and support during the development of this study, and reading the manuscript. Sincere gratitude to Mr. Santi Leewongchareoun for their support compilation the geologic map.

The authors would also like to thank Mr. Niruth Tangsiri for his support taking photographs by drone. Moreover, we are thankful to all officials of the Thung Wa, Na Thon and Manang sub-district administrative organization for his support, assistance and encouragement during the fieldtrip. Finally, we are most grateful acknowledgement to our family and friends for their support throughout the period of this study.

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KILIM KARST GEOFOREST PARK : MARINE BEAUTIFUL KARST

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Abstract

Kilim Karst Geoforest Park is one of the three main geoforest park areas in Langkawi Geopark. The Kilim area of 82.61 km^2 offers the spectacular features of nearly vertical karstic hills with pinnacles and narrow valleys in between is made of several elongated hills and islands overlain by the untouched mangrove ecosystem. It is predominately underlying by the strata of carbonate rock that form the karst hill with pinnacles, elongated hill with mangrove valley and islands with occurrences of fossil assemblages of the oldest limestone rock in Malaysia (Setul Formation, 490-370 million years ago). The flow of water through the carbonate rock form the unique features such as caves, stalactites, stalagmites, iconic islands and pinnacles. There are number of caves have become the tourist spots with an interesting eco-geotourism attractions such as Gua Kelawar, Gua Cherita, Gua Langsir, Gua Dedap and Gua Buaya. There are also riverine landscape of Kilim River, which form by natural movement of water system at Kilim Karst Geoforest Park. The Kilim River includes the ecosystem (all living things including plants and animals) that being as network to the surrounding land of Kilim area. Kilim Karst Geoforest Park is the only place in Malaysia where the existence of coastal karst and mangrove ecosystems standing together.

Keyword: Kilim Karst Geoforest Park, Setul Formation, geodiversity

MAMMALIAN FOSSILS AND THEIR DEPOSITIONAL PROCESSES IN THE WANG KUAY CAVE, THAUNGWA DISTRICT, SATUN PROVINCE, SOUTHERN THAILAND

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Abstract

In 2008, hemimandible with fragment teeth, m2 and m3, of *Stegodon* was found in Wang Kuay sea cave by Mr. Yutthanun Kaewphitak during finding the crab. This reveal is a first record of proboscidean fossil in Thai-Malay Peninsula. After that, we have collected at least 236 fossil specimens in that cave since 2008 until nowadays. There are two species of proboscidean presented; *Stegodon* cf. *orientalis* and *Elephas* sp. They were found and associated with other vertebrate fossils that consist of *Rhinoceros sondaicus*, *Cervus* sp., cf. *Capricornis* sp., cf. *Nemorhaedus* sp. Bovinae, and turtle. All fossils are fragment and polish that indicate they were transported and reworked several times cause of tidal and channel flow through this cave. Although this area is the most southern part of Thailand that found proboscidean fossils and more close to the Malay-Indonesia archipelagoes, the molar structures of *Stegodon* are more similar to the *S. orientalis* of southern China than the *S. trigonocephalus* of Indonesia. This discovering supports the idea "beast migration from the north" and especially fossil assemblage indicates Pleistocene in age. However, the *S. trigonocephalus* dentary morphotype is also presented in the mainland such as in Tha Chang sandpit, Nakhon Ratchasima, northeastern Thailand. This evidence can indicate the migration route of the magabeast in Southeast Asia. They migrated to the island and sometime moved back to the mainland when the low sea level condition in the Middle Pleistocene.

Key word: *Stegodon*, *Rhinoceros*, *Cervus*, *Capricornis*, *Nemorhaedus*, sea cave, Thungwa, Satun

TERRESTRIAL KARST CONNECT TO NATURE AND PEOPLE OF SATUN ASPIRING GEOPARK

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Abstract

Karst resources in Satun Geopark have played the great roles in the creation of important resources such as landforms, soil, water and vegetation which will provide suitable places for plants, animals and human to live on these available resources. Karst features of both exokarst (surface karst) and endokarst(underground karst or caves) in Satun Geopark are the good examples of the close relationship between nature and people since the ancient time until today . In the past, people have been using caves as the shelters, religious and cultural activities, they also used karst lakes and cave springs as the sources of water for their daily life, soils in the paleokarst areas are very fertile and suitable for many agricultural activities. Under the concept of the Geopark, karst features are the outstanding geosites because of its beauty and astonishing figures, many people would like to join various types of tourism in karst areas such as ecotourism, kayaking, adventure in caves, culture learning, sight-seeing at the seaside, even though the geo-tourism, scientific research and education programs. Karst features in Satun Geopark are very fragile, especially speleothems in caves. The sustainable measures are urgently needed, we needed to have more scientific and systematic study and research works to support. The participation and collaboration from all stakeholders are necessary. And in the scientific point of view, there are many subjects that we should do more research works such as Karst Biodiversity, Paleontology, Paleo-climate, Carbon sink and Neo-Tectonic activities that can be applied in this region. Lastly, International cooperation and networking of international research institutes are also very important.

THAMLAY STEGODON; THE LONGEST AND BIODIVERSITY CAVE OF THAILAND

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Abstract

Stegodon cave, formely named Wang Kluai cave, is characterized by a large horizontal tunnel. The cave is in an elongated mountainous ranges orientated in N-S direction from Ya Ra mountain in the north to Wang Kluai mountain in the south. The cave is a stream cave with two inlets in eastern side of the mountain and one outlet in the western side with two streams flowing from two inlets to join together inside the mountain and flow further to the outlet, totally 3,300 meters long. The stream flow out to the Ya Ra River via a thicket of mangrove forests and finally drained out the Andaman Sea.

The Stegodon cave is an Ordovician thin-bedded limestone cave. The cave is zigzag in some directions and some of them are in perpendicular together. Traces of fracture lines. The stream and rainwater can be seeped into the fractures dissolving wider and deeper with time. For long period of time, the limestone with set of fractures has been dissolved and turning into a large cave with long tunnel and stream flows from eastern side to the western seaside of the mountain. Tracing back to thousands of years when the sea-level was about 4-5 meters higher than the present level, some traces of sea notches can be observed along the cave wall around the seaside outlet of the cave, generated by some wave actions. Stegodon sea cave is ready for tourist there are some kayak services.

In this cave, biodiversities of cave animal lives such as bats, spiders, crickets, planarias, centipedes, crabs, shrimps, and fishes were observed.

THE CONSERVATION OF TASIK DAYANG BUNTING AS ONE OF THE GEOSITES OF LANGKAWI UNESCO GLOBAL GEOPARK

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Abstract

Langkawi UNESCO Global Geopark is the first UNESCO Global Geopark in Southeast Asia. Langkawi Geopark are divided into three parts; Kilim Karst Geoforest Park, Machinchang Cambrian Geoforest Park and Dayang Bunting Marble Geoforest Park. The archipelago, which holds the status of a geopark, requires a form of systematic development and conservation in order to maintain its internationally known identity of Naturally Langkawi. One of the most beautiful geosite of Langkawi Geopark is Dayang Bunting Island that consists of limestone of the Setul Formation which is Ordovician-Devonian (490 to 370 million years) in age, and Chuping Formation which is Permian (290-250 million years) in age. Another geosite at Dayang Bunting Island is the natural doline of the Chuping Formation which forms a freshwater lake. The lake is located at the southwestern part of the Dayang Bunting Island and covers an area of about 10 hectares. It is longitudinal shape with 800 m length and 350 m wide. The fresh water lake is separated from the sea by the limestone wall of less than 10 m thick. Based on bathymetric studies using side sonar scan method, the average depth of the lake is 14 m. Many people believe that the fresh water of the lake with high alkali content can help bring the fertility in women. Systematic conservation plans have been carried out in Pulau Dayang Bunting by Langkawi Development Authority (LADA), an agency that manages Langkawi development affairs. Scientific research on Langkawi UNESCO Global Geopark is also conducted periodically and publications are also made by Institute of Environment and Development (LESTARI) of National University of Malaysia (UKM) with the help of various other agencies. There are various facilities available and sustainably developed for the convenience of visitors in the form of small cottage, prayer hall, bathroom, floating platform, souvenir shops, safety pedestrian, bridges, recreational facilities - free water bicycles as well as free therapy facilities - natural spa. Dayang Bunting Lake is a place to better understanding of the Dayang Bunting Marble Geoforest Park in the Langkawi UNESCO Global Geopark.

Fig Dayang Bunting Lake or the Lake of the Pregnant Maiden is the largest freshwater lake at Pulau Dayang Bunting, Langkawi. The area has been conserved as part of Dayang Bunting Marble Geoforest Park.

Fig (Top) among recreational facilities provided for the visitors at Dayang Bunting Lake.
(Bottom) Visitors enjoyed free natural therapies by the cat-fish at Dayang Bunting Lake.

GEOLOGICAL SIGNIFICANCES OF LANGKAWI GLOBAL GEOPARK

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Abstract

Langkawi was recognises as the UNESCO Global Geopark based on three main geological significances and one mixed between geological and biological significance. The first geological significance involved the rocks that formed Langkawi Island which known to be the oldest of the country and surrounding region with evidence of pre Cambrian rock and complete Palaeozoic geological history. Secondly, the island also possesses the most comprehensive evidences supporting the theory that this region originated from Gondwanaland that has experienced various tectonic movements. Such evidences includes presence of various dropstones of glacial origin and cold temperate fossil fauna within the Singa Formation. The granite intrusion early Mesozoic or Triassic cause uplifted in the region and brought most of the deep deposited rock to the surface and later exposed to the weathering. The third geological significance is related to the landscape created by weathering processes, of rain and sea water within limestone area. Since the uplifted, these processes leave various features that known among scholar to be the best place to study tropical island karst landscape in the region. On the other hand all these rock exist in the small area of less than 500 km^2, and the diversity of rock also host various biodiversity of flora and fauna that consider unique to the island ecosystem. These significances are made up of more than 90 geological site, 13 geosites and three geoforest park with integrated importance in geology-biology -culture.

Key words: significance, Langkawi Geopark, geoheritage, integrated

LANGKAWI RESEARCH CENTER: A RESEARCH ARM OF LANGKAWI UNESCO GLOBAL GEOPARK

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Introduction

The rich natural heritage and cultural heritage of Langkawi were not optimally utilised for tourism before the geopark concept were introduced and adopted in 2007. Hence, it was in a dire need of a systematic research and development program in order to sustain its ecotourism niche. During the MOU signing ceremony between Langkawi Development Authority (LADA) and UKM on 5th November, 2001 the idea of establishing a research centre to foster research cooperation on developing Langkawi's natural resources for ecotourism was mooted. In the following year, LRC was established as a research initiative under the Institute for Environment and Development (LESTARI), Universiti Kebangsaan Malaysia (UKM) with the following objectives:

- To become a centre of excellence in research on natural resources and utilization for effective ecotourism development
- To carry out research programs that also highlights policy studies to support ecotourism.
- To coordinate all researches related to natural resources and sustainable development of Langkawi.

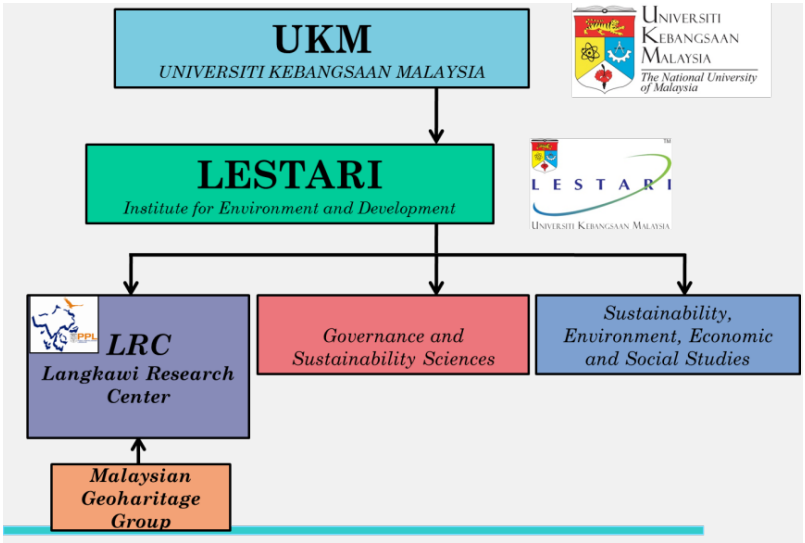
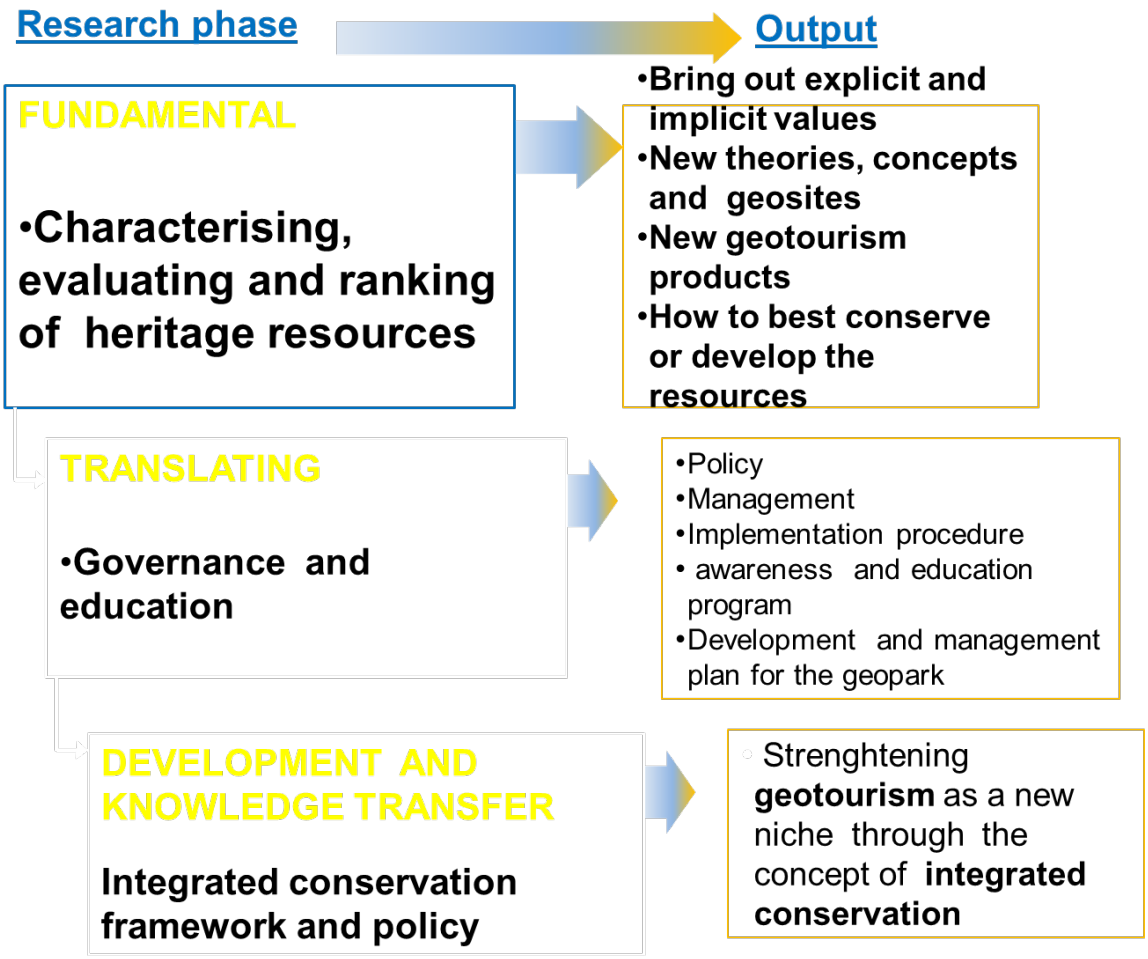


Fig.1. LRC is one of the research entities in UKM

Langkawi Research Centre (LRC) was actually the mover and the force that drives all effort in the establishment of the first geopark in the Southeast Asian Region in 2007 now known as Langkawi UNESCO Global Geopark. Soon after that LRC and LUGG have been working together to make LUGG not only the best geopark but also to become a reference geopark to other new comers.

Research Approach

LRC adopt multi and interdisciplinary approaches to ensure all issues pertaining to geopark and community wellbeing are properly addressed. This involves various phases starting with fundamental studies during which more emphasis are given to characterising, mapping and assessing of all heritage resources in order to know their value and how to best conserve and develop for geotourism. The next phase becomes more difficult where outputs from the fundamental studies need to be translated into actions by the implementers through governance and public education programs. At this stage, policy, management, implementation procedures, as well as development and management plans need to be put in place. Finally, development and knowledge transfer need to be carried out with a clear integrated conservation framework and policy is laid out to strengthen geotourism as a new tourism niche.



Function of Lrc in Geopark Development

After the establishment of Langkawi Geopark, LRC has streamlined its role to support development of the geopark and at the same time to ensure its natural and cultural resources remain intact. Since then LRC has been actively engaging in multidisciplinary and interdisciplinary research and at the same time provides research and consulting experts in sustainable development of natural resources and ecotourism. Identification, characterisation, assessment and ranking of all heritage resources in Langkawi are continuously being carried out and proposed to become knowledge-based tourism products. As awareness and concern about environment became a new agenda lately, LRC has added a new research program known as Environmental Health program to monitor the integrity of environments in Langkawi that might be caused by intense tourism and development activities. LRC also provides expert advice services to policy makers especially in natural heritage conservation and nature based tourism.

Research Programs

There are four research programmes in LRC:

- Geological Resources and Landscape
- Biological Resources and Marine
- Culture Resources and Local Tradition
- Environmental Health

These four programs are intended to address all issues pertaining to heritage conservation, development, geotourism and environmental integrity to ensure that Langkawi UNESCO Global Geopark becomes a sustainable island and its community wellbeing is taken care.

Public Education and Outreach Programs

LRC has been busy organising various public education program to communities and industry players in Langkawi UNESCO Global Geopark. Activities such as Geopark Camp, Geopark to School, Student Mobility and Partnership Programmes, Short courses, Fauna and Flora of Langkawi exhibitions, and Geopark Adopted Schools are being carried out on regularly. With a close cooperation from LADA and Malaysian Geoheritage Group, LRC also has been organising seminar and conference to share and publicise its research findings every year. The outcomes of the seminars and conference are compiled and published in a series of books. We have also prepared a guideline on how to best develop the geopark which is known as Langkawi Geopark Management Plan.

Facilities

LRC is currently housed in a complex located in Tuanku Abdul Halim Mu'adzam Shah Langkawi. It is fully equipped with many facilities to assist research and knowledge based activities. Facilities such as laboratories, a meeting room, a conference hall, an administrative building and two hostels were built in 2012. Currently the facilities are being used not only by researchers but also people from other institutions, agencies and NGOs. LRC has also become Asia Pacific Geopark Network Secretariat where it office is housed in one of the buildings in the complex.

Way Forwards

LRC strives to become a living laboratory that would be able to continuously transfer and disseminate knowledge to stake holders through its Social Innovation. LRC is also moving forwards to become a centre for capacity building that concentrates on heritage and tourism for community wellbeing through Sustainable Development Solution. Last but not least LRC wants to become a reference centre for UNESCO Global Geopark Development in Asia Pacific Region and become a leader of Global Geopark.

LITHOSTRATIGRAPHIC CORRELATION BETWEEN LANGKAWI ISLANDS AND SATUN ASPIRING GEOPARK

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Extended Abstract

In term of geology, Langkawi Islands of Malaysia and Satun Aspiring Geopark of Thailand are having very well-correlatable rock units ranging from the age of Cambrian to Resent. Hence, the Langkawi and Tarutao Islands had been chosen as the study area by the Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC) as part of joint scientific cooperation in the field of minerals and geoscience between both countries. Lithostratigraphic correlation between Langkawi Islands and Satun Aspiring Geopark can be illustrated as follows;

1. Machinchang/Tarutao Group

The Machinchang Group is extensively exposed in the northwestern part of the Langkawi Islands whilst the Tarutao Group is well exposed at the western and central part of Tarutao Island and southwest of mainland in Satun Aspiring Geoparks.

The Machinchang Group is more than 2,000 m thick, comprises grey, brown, purple and red, coarse- to medium-grained quartzite, arkose and subgreywacke with subordinate beds of grit and conglomerate. The conglomerate comprises rounded pebbles of vein quartz and quartzite cemented in the gritty matrix occur on the north coast of Pulau Langkawi (Jones, 1981). The Tarutao Group is more than 1,000 m thick, is mostly comprises interbeds of thin- to thick-bedded, sandstones, conglomerates and red shales bearing common tabular and hummocky cross beddings. These rocks also contain fossils including trilobites and brachiopods. Fossils assemblages consist of trilobites including *Pagodia thaiensis, Thailandium solum, Eosaukia buravasi, Coreanocephalus phanulatus, Hoytaspis? thanisi, Prosaukia aff. nema, Lichengia? tarutaoensis (=Saukiella tarutaoensis), Lophosaukia cf. jiangnanensis, Micragnostus sp., Quadraticephalus planulatus (= Coreanocephalus planulatus), Szechuanella? cf. damujingensis, Leiostegiid,* and *Shumardiid* with reports of a species of brachiopod, Apheorthis sp. This fossil assemblage strongly suggests the fauna was from the Upper Cambrian to Lower Ordovician (Kobayashi, 1957; Shergold *et al.*, 1988; Stait *et al.*, 1984).

Stratigraphically, the Machinchang Group can be well-correlated to the Tarutao Group. The correlatable unit, the Machinchang/Tarutao Group can be divided into four members in ascending order;

- *The Hulor/Ao Makham Formation* comprises dark brown to cream, medium-very thick beds of siltstones and minor sandstones. Strongly fractures and cleavages are well developed on argillite strata. The lower part of this formation is unexposed.

- *The Anak Datai/Ao Tami Formation* is composed of white, pink and reddish brown, well-bedded, medium- to thick-bedded, low angle tabular cross bedded quartzitic sandstones, with partly pebbly sandstones and conglomerates in the lower part.
- *The Chinchin/Ao Mo Lae Formation* comprises brown and brownish red, laminated, medium- to thick-bedded, arkosic sandstones and minor quartzitic sandstones with tabular cross-bedding, and green and brown siltstones in the lower part and resistant beds of purplish red to brown, medium- to very thick-bedded sandstones in the upper part. Incomplete trilobites and brachiopods are abundant. Volcano-clastic sedimentary rocks are also recorded.
- *The Jemuruk/Talo Wow Formation* comprises well laminated, fine-grained sandstones to siltstones rhythmically alternated with mudstones. Cross-bedding, load cast, ball and pillow and slump structures are common. Calcareous sandstone with limestone lenses is recorded in the upper part of the sequence. Trilobites, brachiopods and trace fossils are observed.

2. Kaki Bukit Formation/Thung Song Group

The Ordovician Kaki Bukit Formation/Thung Song Group conformably overlying the Machincang Formation/Tarutao Group. The Kaki Bukit Formation occupies the eastern part of Langkawi Islands, the eastern part of Pulau Dayang Bunting, and the Pulau Langgun. On the Satun Aspiring Geopark, the Thung Song Group is well-exposed at the eastern part of the Tarutao Island and central-eastern parts of Geopark mainland.

The Kaki Bukit Formation (or revised to be Setul Formation) comprises predominantly of grey limestone which is strongly banded, grey to dark grey stylolitic limestone with irregular laminae and is variably dolomitic and massive limestone. Fossil such as *malayaspira rugosa* (Ordovician in age) and Upper Ordovician trilobites (Kobayashi & Hamada, 1978) as well as conodonts are commonly found. Lithostratigraphically, the formation, is more than 800 m in thick, consisted of three units ascending order;

- *Lower member* consists of thin bedded of grey argillaceous and stromatolites limestone. Intercalated with finely laminated shale and continuous wavy layer of stromatolites are common. The stromatolites layer is distinct gradation of high to less in limestone. Grey to dark grey of thin bedded argillaceous and stromatolites limestone and grey, well thin-bedded laminated limestone
- *Middle member* consist of siliceous unit such as interbedded of sandstone/shale and shale/siltstone. The grey limestone in this member is strongly banded due to the present of abundant siliceous parting at the lower part and changes to limestone-shale dominated and the upper part.
- *Upper member* consists of laminated to thinly bed dark grey limestone interbedded with shale. It progressively changes into massively bedded limestone. Thin to medium-bedded dark grey limestone with abundant stromatolites are common. Some fossils such as brachiopods (*Malayspira rugosa sp.*) and Cephalopods (*Nautiloidea sp., Orthoceras sp.*) and brachiopods (*Malayspira rugosa sp.*) are present. Bioturbation by bivalves (Chitons) are generally found.

The Thung Song Group is more than 900 m in thickness. The unit is mostly composed of limestone, thin-bedded to thick bedded and stromatolitic, all containing abundant and diversified fossils

including nautiloids, trilobites, mollusks, algal remains and worm burrows. Lithologically, the Group can be subdivided into 4 Formations (mapped units) as ascending order;

- *Pante Malaka formation* (or Malaka, Talo Dang, La Nga and Panan Formations of Wongwanich, 1990), consist of very thin-bedded, muddy dolomitic limestone with dense bioturbations and algalmats with general mudcracks. The presence of the polyplacophoran mollusk, *Chelodes* sp., was also reported. The rock succession changes onwards into a purple to grey very thin-bedded, nodular limestone intercalated with greenish grey to red calcareous shale. The overlying rock, is dominated by limestone with intercalations of very thin-bedded dolomite. Then, the formation is characterized by abundant through cross beddings, unlike the upper portion. Dense bioturbations are present with general U-shaped worm burrows, mud cracks and shallow tidal channels. The presence of gastropod, *Peelerophon oehlerti,* is an indicator of Lower Ordovician age. The onward rock succession is characterized by the presence of branching digitate stromatolites.
- *Lae Tong Formation* It is dominated by thin bedded, 1-3 cm thick, argillaceous limestone intercalated with red and green shale. Nodular limestone is common in the sections. The upper part is well bedded containing small hummocky cross beddings with ripple marks on the top of the rock beds. The fossils found in this rock formation are gastropods, brachiopods, trilobites and nautiloids also suggesting the Lower Ordovician.
- *Rung Nok Formation* is fossiliferous limestone and dolomitic increasing in thickness from thin bedded towards the top and containing fossil sponges, crinoids, bryozoans, trilobites, corals and nautiloids. The upper part of the rock formation is dolomite.
- *Pa Kae Formation* is characterized by red thin bedded siliceous, stromatolitic limestone, with stomatolitic polygons on top of the bedding rhythmically interbedded. With dark red very thin-bedded brown siliceous limestone mudstone. Four genera of deep water trilobites were reported including *Ovalocephalus, Orthorhachis, Nileus* and *Amphytrion* suggesting Upper Ordovician

3. Tanjong Dendang/Wang Tong Formation

The Ordovician-Silurian Tanjong Dendang/WangTong Formation conformably overlying the Kaki Bukit Formation/Thung Song Group. The Tanjong Dendang Formation is well- exposed at Teluk Mempelam, in the northwestern coast of Pulau Langgun. It also can be observed at Pulau Tanjung Dendang, Pulau Timun and Pulau Tuba. In Satun Aspiring Geopark, the Wang Tong Formation is well-exposed on abandon mine in Khao Nui area, Langu district of Satun Province.

The Tanjong Dendang Formation, is not more than 100 m in thickness, is characterized by interbeds of dark grey to pink, very thin- to thin-bedded black greenish grey, black and red shales. The presence of trilobite *Dalmanitina malayensis* that is now identified as *Mucronaspis mucronata* (Cocks *et al.*, 2005) indicates latest Ordovician age. The occurrence of graptolites vesiculosus, cyphus, gregarious, convolutes and sedgwickii Zones indicate that the thin black shale of the Tanjong Dendang Formation extend from the Ordovician Hirnatian to the top of the Aeronian Stage of the Silurian Llandovery series (Cocks *et al.*, 2005). Wong (1974) reported the discovery of graptolites *Climacograptus* sp. in the black shale of the Lower Detrital Member (now Tanjong Dendang Formation) near Teluk China Mati, Pulau Tanjung Dendang indicatives of Llandovery (Early Silurian)

age. Mohd Shafeea Leman *et al.* (2007) and Che Aziz Ali *et al.* (2008) reported the occurrence of graptolite and trilobite in the Tanjung Dendang Setul Fomation in Pulau Langgun.

The Wang Tong Formation, generally 50 m thick, consisting of the succession of shale, chert and sandstone intercalations. A large variety of fossils were reported from these rock formations including trilobites *Dalmanitina sp.*, graphtolites *Glyptograptus persculptus, Parakidograptus acuminatus, Climacograptus medius, Climacograptus normalis, Climacograptus modestus, Pseudoclimacograptus sp.* and brachiopods. The fossil assemblage is suggested to be that of the Late Ordovician to the Early Silurian in age.

4. Mempelam/Kuan Tung Formation

The Silurian-Devonian Mempelam/Kuan Tung Formation conformably overlying the Tanjong Dendang/WangTong Formation. The Mempelam Formation is well- exposed at Teluk Mempelam, in the northwestern coast of Pulau Langgun where the type section had been proposed by Lee (2009). In Satun Aspiring Geopark, the Kuan Tung Formation is well-exposed in small hills -abandon mine near Langu- Thung Wa district road, Satun Province.

Lithologically, the Mempelam Formation is characterised by thickly-bedded, dark grey limestone, less fossiliferous. Stylolites and irregular laminae are common. Black vertical burrow-like thrombolites occurs in parts. Conodonts and trilobites also occur. Fossils of globular plate-type scyphocrinoid lobolith present in the upper part. Lee (2001) reported the occurrence of loboliths that are bladder-like roots of a floating crinoids genus *Scyphocrinites* in the Upper Setul Limestone (now Mempelam Member) at Teluk Mempelam in Pulau Langgun. It occurred in the 30 m thick limestone bed and is Late Silurian to Early Devonian in age.

The Kuan Tung Formation, at about 75-100m in thickness, consisting of grey limestone at the bottom and changing upward to grey and red stromatolitic limestone with dark red mudstone parting and stromatolitic polygons on top of bedding. This formation is, clearly exposed at Kuan Tung with trilobites including Reedops megaphacos, Reedopsseleniomma, Cornuproetus sculptus, *Decoroproetus sp. and Platyscultellum* sp. Conodonts were also reported such as Polygnathus labiosus, Polygnathus dehiscens, Latericriodus beckmanni. These fossils indicate the Silurian- Devonian boundary up to the Middle Devonian

5. Jentik /Pa Samed Formation

The Devonian Jentik/Pa Samed Formation conformably overlying the Devonian Mempelam/Kuan Tung Formation. In Langkawi Islands, the Jentik Formation forms a condense sequence comprises Tenculitids bearing black shale that is only exposed at Teluk Mempelam in the northwestern coast of Pulau Langgun, Langkawi. In Satun Aspiring Geopark, the Pa Samed Formation is well-exposed in small hills -abandon mine near Langu- Thung Wa district road, Satun Province.

The Jentik Formation in Pulau Langgun comprises red-brown fine-grained sandstone, grey to dark grey mudstone and tentaculitids bearing shale. In Pulau Tuba, the rocks were metamorphosed to slate, phyllite, hornfels and platy quartzite due to folding and granite intrusion (Jones, 1981). Jones

(1968b) reported the discovery of *Monograptus* cfr. *uniformis*, *Tentaculites matlokianus* and *Styliolina fisurella* in the Upper Detrital Member (now Jentik Formation). Graptolites *Monograpthus sedgwickii* (Portlock), and dacryoconarids *Nowakia* sp. and *Styliolina* sp. had been discovered in the Jentik Formation at Pulau Langgun. These fossils indicate Early Devonian age. The Tenculitids bearing dark grey shale and the Tentaculitids discovered at Teluk Mempelam in the northwestern coast of Pulau Langgun.

The Pa Samed Formation 50 m thick, is subdivided by two subunits. The lower part is characterized by black shale with abundant tentaculites and further changes to red and brown sandstone showing Bouma sequence and conglomerates. Ammonites are found from many horizons within the rock formations. The upper part is weathered dark shale and mudstone, showing laminations with ammonites and brachiopods from tentaculitic shale at the bottom. Fossils have been identified as: *Nowakia acuaria, Nawokia cf. matlockiensis, Nawokia cf. hercyniana, Metastyliolina sp., Echinocoeliopsis sp., Plagiolaria sp., Echinocoelia sp. and Monograptus sp.* Middle Devonian deep sea benthic brachiopods from an estimated depth of approximately 150-200 m deep were described such as *Quasiposserella samedensis, Plectodonta forteyi, Caplinoplia thailandensis and Clorinda wongwanichi.*

6. Rebak /Khuan Klang Formation

The Carboniferous Rebak /Khuan Klang Formation conformably overlying the Jentik/Pa Samed Formation. In Langkawi Islands, the Rebak Formation, about 200 m thick, is well-exposed in Pulau Rebak Besar, Pulau Rebak Kechil and Pulau Selat Senari in Langkawi archipelago. It also can be observed at Teluk Mempelam, in the northwestern coast of Pulau Langgun. On Satun Aspiring Geopark, the Khuan Klang Formation, approximately 120 m thick, is distributed as the low relief terrains in abandon mine between Langu - Thung Wa area.

The Rebak Formation comprises predominantly red and grey shale and mudstone with minor sandstone beds and some pebbly or conglomeratic layer with parts of the chert and cherty mudstone. Sarkar (1972) reported that several species of *Posidonomya* (previously known as *Posidonia*) had been discovered in Pulau Rebak Besar. The species reported are *Posidonomya elongata sp. nov*., *Posidonomya dilatata sp. nov*., *Posidonomya conspicua sp. nov*. Yancey (1972) reported the discovery of fossils in the mudstone sequence in the eastern end of Pulau Rebak Besar. Yancey (1972) reported that one of the specimens resembles a chonetid *Chonetes* cf. *rectispina* found in Thailand.

The Khuan Klang Formation is characterized by the presence of light grey, red, reddish brown, thin- to very thick- bedded, mudstones, claystones and siltstones with often smooth and powder textures. Ripple mark, lamination, graded bedding and flaser bed are commonly recorded. The argillte is interbedded with lithic and quartzitic sandstones, sandy siltstones and siliceous mudstones or chert. The fossils contain the bivalves *Posidonomya* sp., *Edmondia* sp., *Pterinopecten* sp., *Aviculopecten* sp., and *Allorisma* sp., trilobites *Langgonbole vulgaris* and *Dalmanites* sp.?, brachiopods *Chonetes* sp. and *Echinoconchus* sp., ammonites *Agathiceras* sp. and *Euomphalus* sp., gastropod *Pronorite* sp.?, ostracods and crinoids.were recorded in this Formation, indicating Early Carboniferous period.

7. Singa Formation/Kaeng Krachan Group

The Lower Permian clastic rock unit is represented the Singa Formation /Kaeng Krachan Group. On the Langkawi Islands, the Singa Formation comprises three members in ascending order, namely; Kentut, Ular and Selang Members. The rock units are well exposed at Pulau Intan (Kentut), Pulau Ular, Pulau Selang, Langkawi. A more extensive outcrop of the Selang Member is well exposed at the eastern part of Gunung Raya. On the Satun Aspiring Geopark, the Kaeng Krachan Group is exposed as roof pendants in the northeastern coast of Adang Island, parts of Rawi Island and some small islands. In mainland, the unit is also observed at small hills in Langu District, Satun.

Lithologically, Kentut member comprises hard black mudstone and shale, intercalated with sandstone in parts, zone of pebbly mudstone occurs in the upper part. Ular member comprises soft yellowish brown, alternating slumped and bedded mudstones, siltstone and fine sandstone with burrows trace fossils. Selang members comprises basal black mudstone that contains pebble clasts, grading upward into interbeds of black, thick-bedded mudstone and sandstone. The uppermost part of the Selang member is made up of calcareous sandstone and shale interbeds that grading upwards into the Jong Formation which composed mostly of limestone. Dropstones or megaclasts occurred within the dark grey siltstone beds scattered throughout the Singa Formation. The dropstones range in size from pebble to boulder, mainly blocky, subangular, often facetted and sometimes show clear dropstone characteristics. Early Permian bryozoa, brachiopods and ammonoids fauna had been discovered in the upper part of the Singa Formation. The presence of ammonoid *Metalegoceras* sp. confirms the Sakmarian (Early Permian) age for the upper part of Singa Formation (Mohd Shafeea Leman & Shi, 1998).

The Khao Phra Formation, Kaeng Krachan Group is characterized by interbeds of slaty shales, mudstones and sandstones. Generally, beds of rock are well-bedded, sharp, wavy, and non-parallel. Slaty shales are dark grey to dark greenish grey, very thin- to very thick-bedded. Lamination, load cast and graded bedding are commonly found. Sandstones are greenish grey, fine- to coarse-grained, lithic, wacke and thin- to thick-bedded. Discontinuous lamination and graded bedding are very common. Hornfelsic rocks are usually found near the contact zone. *Spinomartinia* sp., trilobites, ammonites are well observed in several strata of the La Ngu area, indicating Early Permian period.

The Khao Chao Formation, Kaeng Krachan Group is characterized by light grey to light brownish grey and greenish grey, laminated mudstones intercalated with stringering of greenish grey fine-grained beds of sandstones in the lower part and white, medium- to thick-bedded, fine- to medium-grained, quartzitic sandstones with minor mudstones and red siltstones with bioturbation in the upper part.

8. Jong formation/Ratburi Group

The Middle Permian carbonate rock unit is represented the Jong formation/Ratburi Group. On the Langkawi Islands, the Jong formation is exposed at Kisap area in the eastern part of Pulau Langkawi and in the western and northern sides of Pulau Dayang Bunting. It also forms the small islands to the

west and southwest of Pulau Dayang Bunting. On the Satun Aspiring Geopark, the Ratburi Group are exposed as small isolated mountains (Khao Tanan) in the mainland and islands and islets in the sea.

Generally, the Jong formation is made up of massive or thickly bedded, white to grey crystalline limestone. Chert nodules also occurs where the limestone is dark grey in colour. It is metamorphosed throughout might be as the result of both regional and contact metamorphisms during the Triassic tectonic activities along and at the adjacent of the Kisap trust Fault and the granite emplacement.

The Ratburi Group is mostly composed of massive limestone with diversified fossils such as bivalves, crinoids and fusulinids.

9. Beruas Formation/Talo U Dang formation

The unconsolidated Pleistocene terrestrial sediments covers the coastal areas as well as most of the low lying areas especially along the main river valleys as well as foot of terraces. The terrestrial Beruas Formation/Talo U Dang formation or colluvial and alluvial sediments were transported by river stream. Based on lithology, heavy minerals content, grain size, characteristics and colour, this formation is mainly of fluvial deposits related to the existing river system. The deposits comprise predominantly sandy clay, clay and sand with minor gravels and peat.

Age of the unit are Pleistocence to Holocene as indicated by the presence of plant remains and peat deposited in the clay. Carbon-14 radiometric dating results of the sediment collected from a tin mine in Phuket province determined the absoluted age of the sediments as about 31,050±280 years B.P. (Kruse, 1983) and from peat deposited in clay with red and orange mottles in the Phang Nga Bay, gave the absoluted age of the sediments is about 30,430±1,160 years B.P.

10. Gula Formation/Tam Malang formation

On the Langkawi Islands, the Holocene marine deposits is represented by the Gula Formation which is distributed along the coastal areas. On the Satun Aspiring Geopark, the marine deposits Tam Malang formation are cover the coastal areas of Tarutao, Adang, Rawi and small Islands as well as the coastal areas in mainland.

Stratigraphically, the Gula Formation can be well-correlated to the Tam Malang formation. The correlatable unit, the Gula/Tam Malang can be divided into two members in ascending order;

- The Port Weld/Ao Son member comprises brown to grey clays or sandy silts intercalated by thin layers of small debris of plant and mollusk shells as intertidal sediments. Some sands and gravels are intercalated as an indication of the river channel sediments. Age of the mangrove sediments is assigned by correlation of the tidal flat area with the other place that has been dated from peat and mollusk shells in the sediments. There are many ranges of ages from 9,000 years B.P to hundreds of years depending on the depth of of the sediments.
- The Matang Gelugor Member/Ao Chak formation or Beach deposits consisting of sands, quartz sands, gravels, pebbles, shell fragments and corals. The age of the corals and rock-clinging oysters that were determined by carbon dating method indicates the age of 9,500 – 6,500 years B.P. (Early Holocene). Nakamura & Tjia (2002) suggest that the anomalous position of the shells deposit is either due

to drastic geoidal change or rebound of the land surface following impacts by two recent (6,500 – 5,000 years B.P.).

11. Granite

The Langkawi igneous bodies exposed in the central part of Pulau Langkawi, Pulau Dayang Bunting and Pulau Tuba. On the Satun Aspiring Geopark, the granitic rocks only exposed in the Adang-Rawi Archipelago and mountainous range at the eastern part of the Geopak.

The main phase of the Granite is predominantly made up of porphyritic biotite granite with some coarse- and fine-grained equigranular biotite granite. The granites are scattered as large and small igneous stocks and bosses that intruded into several types of host rocks. The intrusions transformed the host rocks into various types of metamorphic rocks, and bringing along with them some minerals such as tourmaline, ilmenite, zircon and garnet. The minor phase of granite is represented as two phase variences granite which derived from Adang granite. They consist of the primary granite with subordinate late stage granite intrusions, which occur as dykes and veins including aplite, or tourmaline granite, pegmatite and tourmaline veinlets. The oldest granite phase is represented by cognate-like form within the younger granite phase.

Two granite samples from Kuah were analysed by both the K-Ar and Rb-Sr methods which give the age of 217+8 Ma and 209+8Ma respectively indicating Late Triassic age (Bignell & Snelling, 1977).

Lithostratigraphic Correlation Chart between Langkawi Islands and Satun Aspiring Geopark is illustrated in Table 1

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Table 1: Correlation of rock unit in the Langkawi Island and Satun Aspiring Geopark

SEDIMENT,SEDIMENTARY AND METAMORPHIC ROCKS

Age	Rock units				
	Langkawi Islands			Satun Aspiring Geopark	
Holocene	Gula Formation	Matang Gelugor Member	Beruas Formation	Tam Malang formation	Ao Chak member
		Port Weld Member			Ao Son member
Pleistocene				Talo U Dang formation	
Permian	Jong formation			Ratburi Group	
	Singa Formation		Selang Member	Kaeng Krachan Group	Khao Chao Formation
			Ular Member		Khao Phra Formation
			Kentut Member		
Carboniferous	Rebak Formation			Thong Pha Phum Group	Khun Klang Formation
Devonian	Jentik Formation				Pa Samed Formation
Silurian	Satul Group	Mempelam Formation			Kuan Tung Formation
Ordovician		Tanjing Densang Formation			Wang Tong Formation
		Kaki Bukit Formation	Upper (Langgun member)	Thung Song Group	Pa Kae Formation
					Rung Nok Formation
			Middle (Teluk Ewa member)		Lae Tong Formation
			Lower (Tanjung Pesak Seluar member)		Pante Malaka Formation (Malaka/Talo Dang/La Nga/ Panan)
Cambrian	Machinchang Group	Jemuruk Formation		Tarutao Group	Talo Wow Formation
		Chinchin Formation	Tengkorak Member		Ao Mo Lae Formation: Upper Sandstones
			Temurun member		Ao Mo Lae Formation: Lower Sandstones
		Anak Datai Formation			Ao Tami Formation
		Hulor Formation			Ao Makham formation

IGNEOUS ROCKS

Age	Rock units	
	Langkawi Islands	Satun Aspiring Geopark
Triassic	Kuah Granite	Rawi Granite
	Raya Granite	Adang Granite

SINGA FORMATION AND ITS GEOLOGICAL SIGNIFICANCES

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Extended Abstract

Introduction

The Singa Formation is well expose in Langkawi Islands, on the northwest of Peninsular Malaysia. The term Singa Formation was used by Jones (1981) for the well bedded dark grey shale and siltstone exposed in Langkawi Islands. It was considered as ranges from Early Carboniferous to Early Permian in age. Initially, the Singa Formation was divided into four members in ascending order; Rebak, Kentut, Ular and Selang members (Ahmad Jantan, 1973). The Early Carboniferous fauna had been discovered in the Rebak member, whilst Early Permian cold water fauna had been discovered in the Selang member. To date, no fossil discovered in the Kentut and Ular members except some trace fossils. Based on lithological and palaeontological characteristics, the Rebak member was taken out from the Singa Formation, upgraded to formation rank, and renamed as the Rebak Formation (Malaysia-Thailand Working Group, in manuscript). The other three members was retained as the members of the Singa Formation. The location map of Langkawi Islands and the distribution of Singa Formation is shown in Figure 1.

Stratigraphy and lithology

Stratigraphically the Singa Formation is divisible into Kentut, Ular and Selang members. Kentut member comprises hard black mudstone and shale, intercalated with sandstone in parts, zone of pebbly mudstone occurs in the upper part. Barrows trace fossil occur within the silt beds. Ular member comprises soft yellowish brown, alternating slumped and bedded mudstones, siltstone and fine sandstone with burrows trace fossils. Selang members comprises basal black mudstone that contains pebble clasts, grading upward into interbeds of black, thick-bedded mudstone and sandstone. The uppermost part of the Selang member is made up of calcareous sandstone and shale interbeds that grading upwards into the Chuping Formation which composed mostly of limestone.

Dropstones or megaclasts occurred within the dark grey siltstone beds scattered throughout the Singa Formation. The dropstones range in size from pebble to boulder, mainly blocky, subangular, often facetted and sometimes show clear dropstone characteristics (Stauffer & Lee, 1986). They are embedded within the laminated, well-bedded, dark grey siltstone. Stauffer & Lee (1986) concluded that these dropstones are of glacial marine origin.

Fossils and age

The Early Permian bryozoa, brachiopods and ammonoids fauna had been discovered in the upper part of the Singa Formation. The bryozoa genera comprises *Fenestella*, *Polypora*, *Ryscritella* and *Streblascopora* (Basir Jasin *et al.*, 1992). Among the brachiopods fauna includes *Spinomartinia profilica* and *Spirelytha petaliformis* (Pavlova), *Bandoproductus monticulus* (Waterhouse), *Arctitreta percostata* Waterhouse and *Spirelytha buravasi* (Hamada) (Shi *et al.*, 1997), highly spinosed brachiopod genus *Spirelytha* and *Suciplica* (Mohd Shafeea Leman, 2003). The silty shale of the formation yields an Early Permian (Asselian-Sakmarian) brachiopod assemblage of strong Gondwanan affinity (Mohd Shafeea Leman, 2002). The presence of ammonoid *Metalegoceras* sp. confirms the Sakmarian (Early Permian) age for the upper part of Singa Formation (Mohd Shafeea Leman & Shi, 1998).

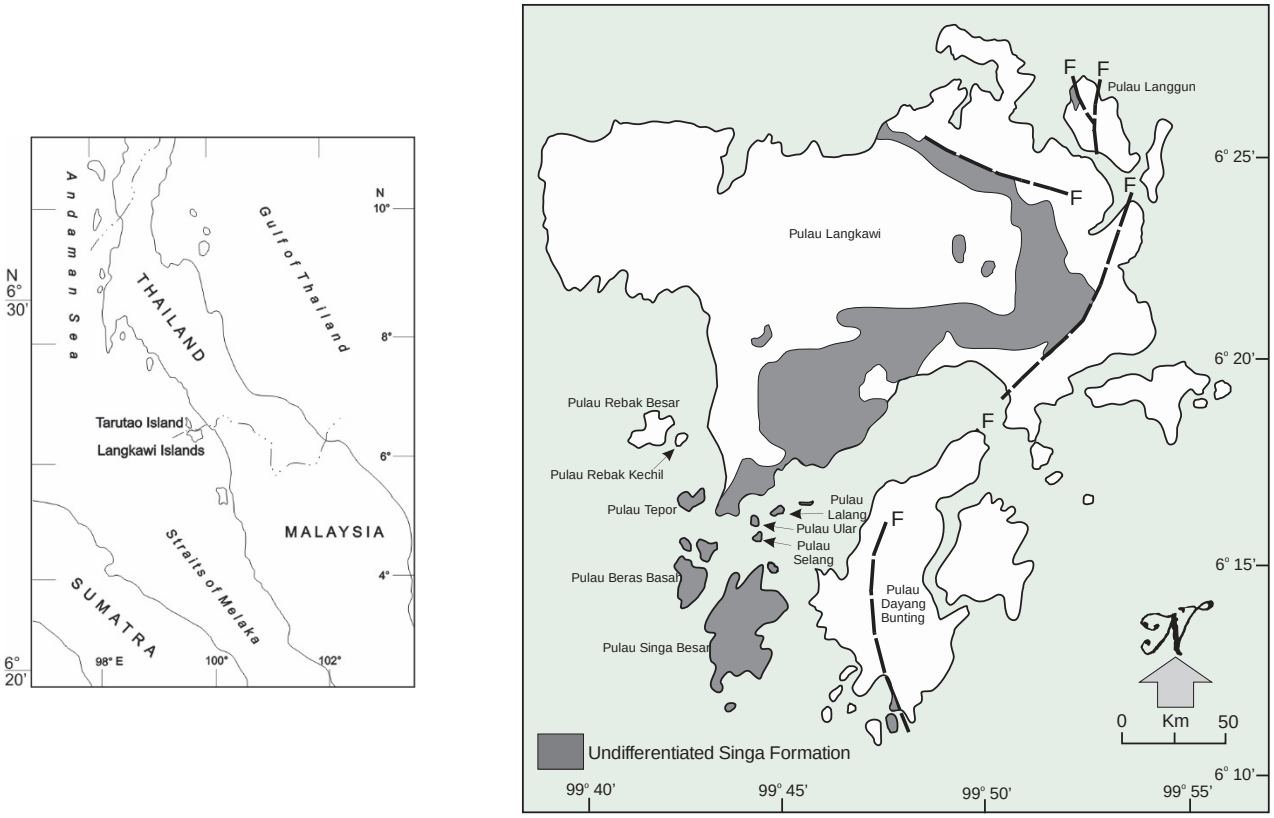

Figure 1: Location map of Langkawi Islands and the distribution of Singa Formation

Geological significance

The presence of dropstones also had been reported in the Late-Paleozoic sequence of south Myanmar (Tenasserim), south Thailand (Phuket area) and in Langkawi Islands. The great extent of this deposit implies that these sediments are related to the activity of a large continental ice sheet, not only local mountain glaciers. The only large continent known to have been glaciated during the Late Paleozoic was Gondwana. Therefore, the belt of sedimentary rocks with dropstones was most probably

formed originally in the marine environment marginal to the Gondwana continent (Stauffer & Lee, 1986).

The presence of cold-water fauna in the Singa Formation supports the interpretation that the deposition took place in a marine environment of relatively shallow water marginal to a glaciated continent.

Conclusion

The Singa Formation is divisible into three members in ascending order; Kentut, Ular and Selang members. The upper part of the formation yields bryozoan, brachiopods and ammonoids assemblages which indicate Early Permian (Asselian-Artinskian) age. The presence of dropstones indicate the rock unit was deposited in the marginal to the glaciated continent where the Gondwana was located during the Early Permian. The presence of cold-water fauna also indicates that the Singa Formation was deposited within the cold climate region. The discovery of bryozoan, brachiopods and ammonoids indicate that the deposition took place in the relatively shallow water environment.

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POSTER TITLE

1. Satun Geopark
2. Satun Geopark Map
3. From a sea 500 million years ago to a great mountain closely knit with the local way of life
4. From 450 million years to present: A way of life tightly linked to nature
5. Chim Melon Farm
6. Khao Noi type section
7. Thung Samet stromatolite lapies
8. Seven water wells
9. Khao To Ngai geological time boundary
10. Panya Batik Handmade Center
11. Satun Inland Aquaculture Research and Development Center
12. Phuphaphet cave