

**Draft Report**

**MINERAL RESOURCES  
ALONG THE MALAYSIA-THAILAND  
BORDER AREA**



by  
**The Malaysia-Thailand  
Working Group**

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

**The Malaysia-Thailand Border Joint Geological Survey Committee  
(MT-JGSC)  
2016**

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Minerals and Geoscience Department Malaysia

Department of Minerals Resources Thailand

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**(MT-JGSC)**

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## PREFACE

This report is a compilation of the reports on Mineral Resources along the Malaysia-Thailand border area from Langkawi-Tarotao Transect area in the west, to Batu Melintang-Sungai Kolok Transect area in the east. It is accompanied by one simplified Mineral Resources map for the whole Malaysia-Thailand border area.

The report and maps are the result of close joint cooperation in field of geosciences and mineral resources between the geoscientists from the Minerals and Geoscience Department Malaysia, and from the Department of Mineral Resources, Thailand from the year 2000 to 2015.

Most importantly, formal formation names were adopted consensually to describe the rock units in the study area. Stratigraphic succession of rock units is well exposed for detailed studies in terms of stratigraphic correlation, palaeontology, and tectonics. Many geological sites can be studied in detail to be developed as geoparks in the future. The knowledge of historical geology to enhance the value of tourism has been satisfactorily applied. Areas with occurrence of potential mineral deposits has been identified. Future increase in the price of minerals coupled with advances in mining technology may facilitate joint exploitation of these mineral deposits.

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# **MINERAL RESOURCES ALONG THE MALAYSIA-THAILAND BORDER AREA**

by

The Malaysia-Thailand Working Group

## **EXECUTIVE SUMMARY**

The Malaysia-Thailand Border Joint Geological Survey was launched for implementation during the Second Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC) Meeting, held in Hat Yai, Thailand, from 10<sup>th</sup> –13<sup>th</sup> March 2000. Since then, joint geological survey has been carried out to correlate the equivalent rock units along the common border of the two neighbouring countries. Besides geological mapping, joint cooperation in other field of geology including stratigraphy, palaeontology, geological hazard and geological heritage has been carried out.

In carrying out the joint geological survey, the Malaysia-Thailand border area had been divided into six transect areas namely the Gubir-Sadao, Batu Melintang-Sungai Kolok, Pengkalan Hulu-Betong, Bukit Batu Puteh-Satun, Belum-Hala and Langkawi-Tarutao Transect areas. Problems in discontinuity among time rock unit boundaries between the Palaeozoic rocks to Quaternary deposits, and the extension of granitic rocks (including the mineral association), and geological resources have been satisfactorily resolved in these six transect areas.

The mineral resources along the Malaysia and Thailand border are well-developed for the last century. Various types of metallic and non-metallic minerals have been discovered and exploited in both countries to generate and accelerate the economy. The exploration activities are actively conducted to discover more mineral deposits.

The metallic minerals along the Malaysia and Thailand border consist of Gold is the most expensive and important commodity in mining industry in recent years. Studies and reports on gold potential in Transect 1 to Transect 6 area along Malaysia – Thailand border marked an impressive outcome and recommendable for follow-up studies. The commodity is mainly found in Transect 2 area where the northern part of the Gold Belt of Peninsular Malaysia is situated.

In Thailand, the occurrences of various minerals have been recorded in Narathiwat Province. Galena discovered at Ban Khok Ko, Sungai Padi District, kaolin deposits exploited in Sungai Padi District, and silica sand from the weathered granite are good examples. Within the Transect area, the most important mineral resources i.e. gold, chromite, manganese, and their related geology have been revealed. Although the minerals were mined for several years in the past, some potential areas still remained. For example, at the Ban Muno area of Sungai Kolok District, the volcanic alteration is so strongly characterised that it could be a metallic minerals potential area. Abandoned mining areas, quarries and some potential areas are investigated and economically assessed. Unfortunately, in some areas, exploration and exploitation of mineral resources are prohibited due to security reasons.

The occurrence of tin, tungsten, gold and other heavy minerals are common in the Transect area 3 (Betong). On the Thai side, all tin mines have ceased their operation due to low price. It may be re-exploited if both the price and Environmental Impact Assessment permits. In Transect 4 (Satun), The occurrences of mineral resources are reported not so widespread throughout the Transect area. Some metallic minerals such as tin, tungsten, antimony and heavy minerals were produced in the past but most of the mining activities have now being stopped for several years. However, non-metallic minerals, sand, ball clay and limestone are still being investigated in the vicinities.

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## MINERAL RESOURCES ALONG THE MALAYSIA-THAILAND BORDER AREA

### 1.0 INTRODUCTION

Studies on mineral resources in Malaysia – Thailand transect area was conducted and published in reports of Transect 2 to Transect 6 in 2001 until 2016. Based on these reports, the only metallic minerals which were found and potential to exploit are gold, tin, iron, manganese, silver and antimony, while those are non-metallic minerals include dolomite, limestone, granite, ball clays and river sand.

### 1.1 LOCATION

The Malaysia-Thailand border area consists of both a land boundary across the Malay Peninsula from the Straits of Malacca in the west and the Gulf of Thailand/South China Sea in the east. Malaysia and Thailand share maritime borders in those two areas. Malaysia occupies the area in the south of the border, whilst Thailand occupies the area in the north of the border. Most of the border is formed by highlands especially in the central part of the border area. Sungai Golok forms the 95 km stretch in the easternmost part of the land border.

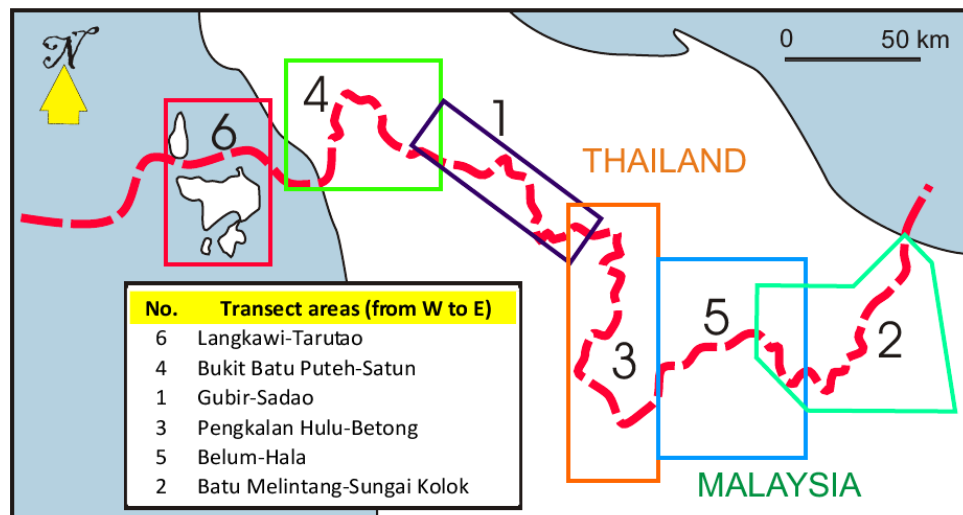


Figure 1: Location map of transect areas along Malaysia-Thailand border area

The Gubir-Sadao Transect area or Transect 1 covers an area of 80 km long and 20 km wide along the Malaysia-Thailand border. The area in Malaysia is geographically confined to the Padang Terap and Sik districts (Kedah state) that partially cover topographic map sheets (scale 1:50,000); Jitra, Padang Sanai, Nami and Bukit Mudin Besar or within three topographic map sheets (scale 1:63,360) of Kuala Nerang, Bukit Debu and Gubir Quadrangles. The area in Thailand covers Na Thawi, Sadao and Saba Yoi Districts (Songkhla Province) and Yaha District (Yala Province) or within five topographic map sheets (scale 1:50,000); Amphoe Sadao, Amphoe Na Thawi, Ban Prakob Tok, Ban Bahoi and Amphoe Yaha Quadrangles.

The Batu Melintang-Sungai Kolok Transect area or Transect 2 covers approximately 3,400 km<sup>2</sup> along the border. The area in Malaysia (1,890 km<sup>2</sup>) is partially covered by eight

topographic map sheets (scale 1:50,000) of Kampung Ipoh (3766), Kampung Batu Melintang (3767), Kampung Lubuk Bungor (3866), Kampung Nibong (3867), Rantau Panjang (3868), Kuala Krai (3966), Tanah Merah (3967) and Kota Bharu (3968). The area in Thailand (1,500 square kilometres), is geographically covered by five topographic map sheets (scale 1:50,000) of Ban Ko Sathon (5421 III), Amphoe Sungai Kolok (5321 II), Amphoe Waeng (5320 I), Ban To Mo (5320 IV), and Amphoe Sisakorn (5321 III) Quadrangles.

The Pengkalan Hulu-Betong Transect area or Transect 3 is bounded by latitude 5° 25' 24" N to 6° 18' 0" N and longitude 100° 57' 24" E to 101° 15' 0" E, covering a total area of 3,411 square kilometres (1,711 km<sup>2</sup> on the Malaysian side and 1,700 km<sup>2</sup> on the Thai side). The Malaysian side of the Transect area is covered by 1:50,000 scale topographic map Sheets 3566 (Gerik), 3567 (Pengkalan Hulu), 3568 (Bukit Mudin Besar) and part of the Sheets 3666 (Tasek Temengor) and 3667 (Belum). On the Thai side, it is geographically covered by four topographic map sheets scale 1:50,000 of Amphoe Yaha (5221 IV), Amphoe Than To (5221 III), Amphoe Betong (5220 IV) and Ban Ai Yoe Boe Chang (5220 III) Quadrangles.

The Bukit Batu Puteh-Satun Transect area or Transect 4 is bounded by Latitude 06° 25' N to 06° 50' N and Longitude 100° 00' E to 100° 30' E. It covers an area of approximately 1,400 km<sup>2</sup> along the Malaysia-Thailand border. In Malaysia, the Transect area covers an area of 829 square kilometres in Perlis and part of Kedah States along the Malaysia-Thailand border. It is bounded by Latitude 06° 25' N to 06° 45' N and Longitude 100° 00' E to 100° 30' E. The Transect area is covered by four 1:50,000 scale Malaysian topographic map sheets; number 3169 (Kuala Perlis), 3269 (Kangar), 3369 (Jitra) and 3270 (Padang Besar). In Thailand, it is geographically covered by five topographic map sheets (scale 1:50,000) of Amphoe Khuan Kalong (5022 IV), Changwat Satun (5022 III), Ban Ko Yao (5021 IV), Ban Khlong Ngae (5022 I), and Amphoe Sadao (5022 II) Quadrangles.

The Belum-Hala Transect area is bounded by latitude 05° 30' N to 06° 00' N and; by longitude 101° 15' E to 101° 35' E covering an area of 2,020 km<sup>2</sup>. On the Malaysian side, the Transect area covers approximately 1,770 km<sup>2</sup> along the Malaysia-Thailand border. It is covered by four topographic map sheets on the scale 1:50,000 i.e. nos. 3666 (Tasek Temengor), 3667 (Belum), 3767 (Kampung Batu Melintang) and 3766 (Kampung Ipoh). On the Thai side, the Belum-Hala Transect area covers approximately 350 km<sup>2</sup> along the border and is geographically covered by two topographic map sheets (scale 1:50,000); Khao Hun Kut (5220 I) and Ban To Mo (5320 IV) Quadrangles.

The Langkawi-Tarutao Transect area or Transect 6 is bounded by latitude 06° 09' N in the south and 06° 45' N in the north, and by longitude 99° 08' E in the west and 99° 57' E in the east. On the Malaysian side, the transect area is covered by topographic map sheet on the scale 1:63,360, No.150 (Pulau Langkawi). On the 1:50,000 scale, the study area is covered by topographic map sheets Nos. 3069 (Pulau Langkawi) and 3169 (Kuala Perlis). The total land area of Langkawi Islands is 478 km<sup>2</sup>. The transect area on the Thai side covers approximately 360 km<sup>2</sup> and is geographically covered by two topographic map sheets (scale 1:50,000); Ko Tarutao (4922 II) and Ban Ko Adang (4822 II) Quadrangles.

## 1.2 PHYSIOGRAPHY

Geomorphologically, the Malaysia-Thailand border area is formed by mountainous terrain and intermontane terrains. It is generally covered by dense tropical rain forest, particularly in the central part of the Malaysia-Thailand border area. Some areas are covered by relatively undulating terrain with rubber and oil palm plantation. The low-lying area in the western and eastern part of the border areas are covered by Quaternary deposits.

In Malaysia, the highest elevation is Gunung Ulu Kebeng (1,403 m above MSL) located in Belum area, and in Thailand is Khao Ta We (1,182 m above MSL) located in Narathiwat Province.

In Pengkalan Hulu Betong area, 80%-85% of the western and eastern sides of the area on the Thai side are of mountainous terrains covered by thick forest especially in the west, near the Malaysia-Thailand border. Rubber trees, oil palm trees and forested terrains cover the southeastern part of the Transect area. Another 15%-20% of the central part of the area is covered by relatively undulating terrains and isolated hills planted with rubber and oil palm trees. The highest elevation on the Thai side is Khao Ku Bang Ba Dak (1,134 m above mean sea level). The low lying residential area in the southwestern part of the Transect area is underlain by Quaternary deposits.

On the Thai side of Bukit Batu Puteh-Satun, the middle part of the area is geomorphologically mountainous terrains (60%-65%) covered by thick forests. Another 15%-20% of the eastern and western parts of the area are covered by relatively undulating terrains cultivated with rubber and oil palm (*Elaeis guineensis*). The low-lying area (15%-25%) in the eastern (Sadao) and western parts (near Andaman Sea) of the area is covered by Quaternary deposits. The highest elevation is Khao Chin (756 m above MSL).

Geomorphologically, the Belum-Hala Transect area which is situated in the Hala-Bala Wildlife Sanctuary on the Thai side covers mostly of mountainous terrain (so-called the Hala mountainous terrain) with dense forest (90%). Another 10% of the eastern part is covered by relatively undulating terrains with rubber and oil palm plantations. In the western part, the mountainous area shows the high elevation (750 m-950 m above MSL) at the Malaysia-Thailand border and decreases in elevation northwardly to 200 m-300 m above MSL at Bang Lang reservoir. The central-eastern part of the area on the Thai side is a plateau of high elevation mountainous terrain (1,000 m-1,400 m above MSL). The highest elevation of this mountain is 1,490 m above MSL. The eastern part of the Transect area consists of the N-S trending elongated mountain range and low-lying areas. General elevation of these terrains is about 200 m-600 m above MSL. The main river on the Thai side is the Hala River originated from the Hun Kut-Bu Lo mountainous area.

The Langkawi-Tarutao Transect is located in the Straits of Melaka, about 50 km to the west of Satun Province. Tarutao Island, the largest island having 26.5 km long and 11 km wide, belongs to the Tarutao National Marine Park. The Adang-Rawi area is located in the Andaman Sea. It is located approximately 90 km west of Satun Province and belongs to the Tarutao National Marine Park. The study area consists of totally twenty eight islands; Rawi and Adang Islands are the largest ones, covering an area of about 2 sq km; Lipe, the southernmost island

of Adang, covers an area of about 2 sq km and is classified as a famous tourist place where large hotels and resorts, and restaurants have been constructed.

Langkawi Islands of the Malaysian side is an archipelago of 99 islands. Pulau Langkawi is the largest island in the archipelago. The other smaller islands including Pulau Dayang Bunting, Pulau Tuba, Pulau Singa Besar, Pulau Timun, Pulau Langgun, Pulau Rebak Besar and Pulau Beras Basah. The higher ground occupies most of the central part of the islands. The highest reliefs reach a maximum height of 881 m (Gunung Raya) and 708 m (Gunung Machinchang) that are located in the central and western part of Pulau Langkawi respectively. Gunung Raya is made up of the Raya Granite, whilst Gunung Machinchang is made up predominantly of metasandstone of the Machinchang Formation. Most of the lower ground and the coastal areas are overlain by unconsolidated marine and terrestrial Quaternary deposits.

Topography of Tarutao Island area is generally high mountainous, undulating and coastal landforms with the maximum elevation of 708 m above MSL. Semi-evergreen rain-forest blankets about 60 percent of the island, and pure mangrove swamps are found near the river mounts in the northern, eastern and southern parts of the island. General landform of the island consists of a rather smooth, but abruptly elevated coast on the western side of the island. The rocky cliffs are abruptly high up above the coast from a few metres to a few hundred metres. Small limestone islands (less than one km long) along the eastern coast are well recognized. A limestone cave and large sink holes occur in the limestone mountain onshore north of the island. Smooth escarpments forming ridges of the sandstone ranges are in contrast with the rough surface topography of limestone cliff displayed in an aerial photograph. Persistent and low-lying escarpments are present along the eastern limbs of the anticlines.

In the Adang-Rawi area, the middle part of Adang, Rawi and Ba Tuang Islands is high slope mountainous terrain with thick forests. Beach sands, white and black colour, are generally found along the bay and coast of islands. The highest mountain peak is above 703 m from mean sea level, located on Adang Island. Flat plateau of shallow coral reef is distributed east and north of Adang, Lipe and Bitsi Islands. The average depth of sea floor surrounding the islands is approximately 40 m below MSL and the deepest sea floor, 75 m below MSL, is situated in the western part of Ba Tuang Island.

The area overlain by Quaternary sediments is generally flat and low-lying, is utilised for paddy (*Oryza sativa*), rubber and palm tree cultivations. Several isolated sand ridges, trending almost parallel to coastline, are located close to the coastal area. At the river mouths where the sediments are dumped into the sea, the coastline builds seaward especially in the Kelantan delta (Bosch, 1988). The old fluvial channel scars can be observed from aerial photographs of the flat and low-lying areas close to the present river systems. Small rivers can be seen surrounded by levees.

In northwestern Kelantan area, exposures at Kampung Bukit Lata, near Bukit Perdah area are generally hilly and are made up of highly to completely weathered volcanic rocks of the Perdah volcanics. The equivalent rock unit is also exposed at Ban Mu No, Thailand.

On the Thai side, the pre-Quaternary areas can be geomorphologically distinguished as high mountain and terrace in the western part, undulating and rolling landforms at the central

part, and flat areas in the eastern part. In Sungai Kolok area, the topography has basically shown remarkable higher level of high mountain range in the western part gradually decreasing to the coastal plain in the east. The highest elevation at Khao Ta We is 1,182 m above MSL, and 1-2 m in the flat areas of Ban Khok Yang, Ban Pa Da Do, and Tak Bai town.

### **1.3 CLIMATE**

Generally, the climate of the mainland of the Malaysia-Thailand border is Tropical Rainforest type (Koppen`s: ‘Af’ climate). The mean annual rainfall for 30 years (1951-1980) was 2,618.8 mm. The hottest month is May (28.4°C in average) and the coldest month is December (25.9°C). The weather is normally warm and dry from January to April, whereas it is wetter from September to December. The annual temperature ranges from 21oC to 32oC and the rainfall ranges from 2,000 mm to 2,500 mm.

Malaysia is having a fair amount of rain year round and it is common to have heavy downpour in the middle of period considered as dry season, so the wet season often seems to just be a slightly wetter dry season. However, the east coast of the Malay Peninsula is having wetter conditions with more rain and flood usually happened during the northeast monsoon.

The Langkawi-Tarutao area in the Straits of Melaka is subjected to monsoon climate. In the summer season, high temperatures in central China cause the air to rise, thus creating a massive low pressure area. This draws wind from the cooler area over the Indian Ocean. The winds coming off the Indian Ocean pick up moisture and dump heavy rains on the west coast of peninsular Thailand from May through October. Normally 250-400 mm. of rain falls in each of these months. The other six months of the year receive little or no rain. Total yearly rainfall averages about 2,500 mm. The monsoon winds make boat travel dangerous from May through October. The mean yearly temperature is between 27-28°C. The high temperatures in April may be 35°C or more. November and December are the coolest months of the year with mean temperatures of about 15°C. The mean yearly humidity is about 80%. It is highest in September, October and November and averages about 85%. Humidity is lowest in February and March, varying from 70-72%.

### **1.4 OBJECTIVE AND ACTIVITIES**

#### **1.4.1 Gubir-Sadao Transect**

The objective of this joint geological mapping project, as adopted by the MT-JGSC, is to resolve the geological boundaries of the Carboniferous–Triassic sedimentary rocks, as well as other younger sediments and granites within the Transect area. A detailed systematic geological mapping of the Gubir-Sadao Transect area in Malaysia and Thailand was carried out in June 2000 by geoscientists of the Minerals and Geoscience Department Malaysia and the Department of Mineral Resources, Thailand. It was later followed by a joint field check in Malaysia (10-14 July 2000) and Thailand (15-19 July 2000) by the geoscientists from both countries. Discussions, exchange of ideas and information on general geology, stratigraphy, palaeontology, and structural geology were conducted. Agreements on mapping units were achieved based on fossil evidences and lithological similarities that enabled the Working Group to delineate the geological boundaries.

### **1.4.2 Batu Melintang-Sungai Kolok Transect**

Detailed systematic geological mapping of the Batu Melintang-Sungai Kolok Transect area in Malaysia was carried out during July-August 2001 and was re-checked during November 2001 by geoscientists from the Minerals and Geoscience Department Malaysia. This was followed by detailed work on Quaternary Geology in January 2002. In Thailand, fieldwork was carried out during September-October 2001 and was re-checked from January to February 2002 by geoscientists from the Geological Survey Division and Economic Geology Division of the Department of Mineral Resources, Thailand. It was later followed by a joint field check along the Transect area in Thailand (5-7 April 2002) and in Malaysia (9-11 April 2002) by geoscientists from both countries. Discussions, exchange of ideas and informations on geology and mineral resources were conducted. Agreement on mapping units were resolved based on lithological similarities that enabled the Working Groups to delineate the geological boundaries. Unfortunately, palaeontological evidence is currently not available because index fossils have not yet been found within the Transect area. Attempts have been made to resolve problems related to geological boundaries within the Malaysia-Thailand border with consideration on economic potential.

### **1.4.3 Pengkalan Hulu-Betong Transect**

On the Thai side, detailed systematic geological mapping in the Transect area was carried out during February 2003 and re-checked during March 2003 by geoscientists of the Bureau of Geological Survey, and Bureau of Mineral Resources of the Department of Mineral Resources, Thailand. Joint field checks were later carried out along the Transect area on the Malaysian side (25th to 28th April 2003) and on the Thai side (29th April to 1st May 2003) by the geoscientists of both countries. Discussions, exchanges of ideas and information on the geology and mineral resources of the Transect area were also conducted by the Malaysia-Thailand Working Group. Agreements on geological mapping units on both sides of the Transect area were resolved based on the lithological, paleontological and structural similarities that enabled the Working Group to delineate the mutually agreeable geological boundaries.

The main objectives of this study are to get a better understanding on the local geology, to solve problems on the geological boundaries of the rock units and to study their correlation within the survey area by using stratigraphic succession, lithologic similarities, and fossils assemblages discovered during the survey or reported by the earlier workers. The occurrences of mineral deposits on both sides of the Transect are also taken into consideration.

### **1.4.4 Batu Puteh-Satun Transect**

In Thailand, detailed systematic geological mapping of the Bukit Batu Puteh-Satun Transect area was carried out in the month of March-April 2004 by the Thai Working Group comprising geologists from the Bureau of Geological Survey and Bureau of Mineral Resources, of the Department of Mineral Resources, Thailand. In 2005, geology of the Transect area has been slightly revised due to the new discoveries of index fossils and exposures in some formations. Rock samples were collected for petrographic, microfossil and geochemistry studies, where applicable.

The study on the Geology of the Bukit Batu Puteh-Satun Transect commenced in 2004 and continued until September 2005. The project stopped for about four years due to the security reason in Southern Thailand and resumed and completed in 2009.

Discussions, exchanges of ideas and information on geology and mineral resources amongs the Malaysian and Thai geoscientists were conducted. Agreements on mapping units were resolved based on lithological, stratigraphical, paleontological and sedimentological points of view that enabled the Malaysia-Thailand Working Group to delineate the geological boundaries. Attempts have been made to resolve problems related to the geological boundaries along the Malaysia-Thailand border with consideration to the economic potential of the area.

#### **1.4.5 Belum-Hala Transect**

On the Thai side, the geological mapping of the Belum-Hala Transect area was carried out based on the remote sensing interpretation and correlation with previous works on the Batu Melintang-Sungai Kolok and Pengkalan Hulu-Betong Transect areas. A geological map based on remote sensing data has been prepared since January 2010. A joint field check had been carried out on the Malaysian side of the Transect area close to the Malaysia-Thailand border in conjunction with the Malaysian-Thai Working Group Meeting on the Belum-Hala Transect area that was held from 9<sup>th</sup> – 14<sup>th</sup> March, 2010 at the Belum Rainforest Resort, Banding Island, Gerik, Malaysia. Then the photogeological map has been improved by using the data and information collected from the joint field check. In addition, raw data from the field works in the Batu Melintang-Sungai Kolok and the Pengkalan Hulu-Betong Transect areas were also included in describing the characteristics of rock units.

Besides geological mapping, photogeological study of the transect area had also been carried out to provide basic and additional information especially in term of structural geology. It will enhance the geological data and information on the mapped area for geological correlation. The objective of the photogeological study is to demarcate the lithology and regional geological structures of the area which were lacking in existing maps and correlation of reported rock units across the border.

#### **1.4.6 Langkawi-Tarutao Transect**

The geology of the Transect area on the Thai side was compiled based on the geological maps on the scale of 1:50,000 covered by topographic map sheet Ko Tarutao (4922 II) and Ban Ko Adang (4822 II) Quadrangles. Detailed geology and mineral resources of those areas had been reviewed. The Thai Working Group has first geological field checks on the scale 1:50,000 at some places in Tarutao Island since March 2011. After the purpose of this joint geological mapping, geological map based on remote sensing data has been prepared since December 2011 and 2012. Subsequently, the Thai Working Group has undertaken geological field checks on the scale 1:50,000 in the Tarutao and Adang Rawi areas during December 2011 - January 2012, March-April 2012 and February-March 2013. A joint field check was carried out in the Tarutao area from 20<sup>th</sup> – 26<sup>th</sup> March 2011 and 22<sup>th</sup> – 28<sup>th</sup> January 2012 by the geoscientists from both Malaysia and Thailand.

## 2.0 GEOLOGIC SETTING

### 2.1 Malaysian side

#### 2.1.1 Stratigraphy

Peninsular Malaysia can be divided into three belts namely the Western, the Middle and the Eastern belts. The belts are trending almost parallel with the elongated orientation of the peninsula. The Western Belt contains the northwestern domain which includes Langkawi, Kedah and Perlis where complete rock sequences of Upper Cambrian to Upper Permian age can be observed.

The Malay Peninsular had been formed after the collision between the Sibumasu and East Malaya Blocks during the Triassic Orogeny. The palaeo-tethys ocean closed during Middle-Late Triassic and is marked by the Bentong-Raub Suture Zone that runs from Kelantan in the north to Melaka-Johor border in the south. The Bentong-Raub Suture Zone forms the boundary between the Western and Central Belts of Peninsular Malaysia.

The rock units along the Malaysia-Thailand border area were deposited in various palaeoenvironmental conditions and have been deformed during the tectonic and magmatic events throughout the geologic time.

The Cambrian Machinchang Formation only exposes in Langkawi Islands and extends northwardly to Tarutao Island of Thailand. It is conformably overlain by the Ordovician-Silurian Setul Formation that occupies the northern and eastern part of Langkawi Islands. In western Perlis it forms a north-south trending Nakawan Range that lies along the Malaysia-Thailand international boundary.

The Devonian Jentik Formation only exposed in small isolated areas in Pulau Langgun at northwestern Langkawi Islands and in Guar Jentik area near Beseri, western Perlis. In both areas, it forms a condensed sequence and is underlain by limestone of the Setul Formation and is overlain by the Carboniferous Rebak Formation.

The Carboniferous rocks along the Malaysia-Thailand border area is represented by the clastic sequence of Rebak and Kubang Pasu Formations. The Rebak Formation is distributed as small bodies in Rebak Islands in Langkawi as well as in Guar Jentik, Hutan Aji and Wang Kelian areas in Perlis. The Kubang Pasu Formation is widely exposed in eastern Perlis in the west up to Belum area in the east.

The Permian-Triassic rocks along the Malaysia-Thailand border comprise the sequence of the carbonate, clastic and pyroclastic rocks. In Langkawi and Perlis, it is represented by the carbonate and clastic sequence of Chuping Formation. Toward the east, in Kedah, it is represented by Cherty unit (formerly considered as part of Semanggol Formation) which is made up of chert sequence. Further east, in Kelantan, it is represented by Telong Formation which comprises argillaceous, arenaceous, calcareous and volcanic sequence.

The Triassic rocks occupy most of the central northern Kedah state. It is represented by Semanggol Formation that can be divided into rhythmic and conglomeratic units. In Padang Terap and Gubir areas, Semanggol Formation is in fault contact with the Carboniferous Kubang

Pasu Formation. The Semanggol Formation also is well exposed in southern Kedah and northern Perak where it is in fault contact with the Ordovician-Silurian sequence.

### 2.1.2 Igneous rocks

The granitic rocks intruded into various rock units, yields contact metamorphic rocks along the contact zones with the pre-existing rocks. In some areas, the intrusion resulted in the formation of mineralized zones such as in Kachi area in Kedah, Kelian Intan area in Perak and Kalai area in Kelantan. On the Malaysian side, the granitic rocks expose in central and southeastern Langkawi Islands, northernmost Perlis, northern and northeastern Kedah, northeastern Perak and northwestern Kelantan.

## 2.2 Thai side

### 2.2.1 Stratigraphy

The continuous sequence of marine Paleozoic succession (Late Cambrian to Late Permian) is distributed as a cratonic area of the Sibumasu terrane (Bunopas, 1981). The oldest rock unit observed is the Late Cambrian- Early Ordovician age Tarutao Group. The Tarutao Group, which exceeds 1,400 m thick, can be separated based on lithostratigraphy and faunal assemblages into 4 units, namely, Ao Makhm Formation, Ao Tami Formation, Ao Mo Lae Formation and Talo Wao Formation. Generally, of this succession consists of well-bedded, brown to reddish brown sandstones and minor interbedded shales. There are a lot of fossils such as trilobites (*Parakoldinioidia thaiensis* and *Eosaukia buravasi*) and brachiopods which indicated Late Cambrian- Early Ordovician age.

The Early to Middle Ordovician Thung Song Group mainly consists of stylolitic limestone succession is exposed extensively in Satun area and Tarutao Island. Thin- to medium-bedded, argillaceous limestones, laminated limestones with intercalations of fine argillaceous bands and medium- to very thick -bedded dolomites, sparitic limestones with stylolitic texture and thin-bedded calcareous shales are typical rocks of this group.

The Silurian-Devonian Pa Samed Formation is exposed only in Thailand. It comprises grey to light grey, massive to thin-bedded mudstone, chert and siliceous mudstone. Fossils of *Tentaculites*, brachiopods, trilobites, and graptolites are abundant within this rock unit. The upper part of the Pa Samed Formation is correlatable with the Devonian Jentik Formation of Malaysia.

The Silurian-Devonian Betong Formation, consist mainly of very thin- to thin-bedded shale, siltstone, lithic sandstone with subordinate chert and argillaceous limestone lenses in the middle to upper part. Thickness of the succession is approximately 100 m. The succession is distributed in N-S trending low relief terrain from Betong area. Local metamorphism by Si Nakhon granite and Chantharat granite to the west resulted in the rocks being metamorphosed to hornfels or slate. Many fossil assemblages, i.e. *Tentaculites elegans*, *Tentaculites* sp. and graptolite that occur in the shale strata and some radiolarian assemblage discovered in the chert beds have been determined.

The Carboniferous rock unit is represented by the Khuan Klang Formation comprises light grey, brown to reddish brown, thick-bedded, laminated, fine- to very coarse-grained,

poorly sorted, subrounded, poorly cemented mudstone intercalated with sandstone, conglomeratic sandstone and pebbly mudstone. This rock unit is assigned as Carboniferous in age by the presence of abundant bivalves, trilobites, brachiopod, gastropod, and crinoid fossils. It is contemporaneous with the Yaha Formation.

The Carboniferous Yaha Formation sequences are distributed to the south of Songkhla and Yala Provinces. It consists predominantly of medium- to thickly-bedded arenite-argillite sequence, consisting of light grey medium- to coarse-grained lithic sandstone and lesser amounts of shale. The sandstone is well sorted, well-cemented, medium- to very thick-bedded, and interbedded with light grey to yellowish brown shale, mudstone and chert. *Posidonomya* (bivalve) commonly occur, followed by trilobites and radiolarians.

The Permian Kaeng Krachan Group, approximately 135 m in thickness, is exposed as roof pendants in the northeastern coast of Adang Island, parts of Rawi Island and some small islands in which the boundaries with the older rock units are unknown. General characteristic of the group is interbeds of dark grey to dark greenish grey slaty shales, mudstones and sandstones in the lower part, and white, medium- to thick-bedded, fine- to medium-grained, quartzitic sandstones with minor mudstones in the upper part.

The Permian sequence in Satun area is represented by Khao Phra Formation. The Khao Phra Formation consists of thick- to very thick-bedded, obviously laminated, sequence of dark grey, mudstone, shale, siltstone and pebbly mudstone; exposed in the central to northern part of the Transect area. It is grading upward into interbedded of thin- to medium-bedded sandstone and black shale, and mudstone. The sandstone usually coarse-grained, poorly sorted, moderately rounded with poorly cemented pebbles of quartz, sandstone and shale. The rock unit consists of abundant bivalves, trilobites, brachiopod, gastropod and crinoid. Dropstone of glacial marine origin are present in parts. The presence of brachiopods i.e. *Spinomartinia* and *Brandoproductus* imply the Sakmarian (Early Permian) age to this rock unit.

In the Suture Zone, the Permian succession is subdivided into two formations, in ascending order: the Ka Lu Bi and Buke Ta formations. The lower part of the Ka Lu Bi formation or the arenaceous facies, is composed mainly of thin- to thick-bedded, tuffaceous sandstones, quartzite, and metaconglomerates. The upper part of the Ka Lu Bi formation or the argillaceous facies is consists of cycles of thin- to medium-bedded shales, sandstones and conglomerates, with quartz veins and dykes at the lower part. At the upper portion, it consists of sharp, even, very thin-bedded or rhythmic sequence of shales and siltstones intercalated with very fine-grained sandstones. Local deformation and low-grade metamorphism took place in the shear and contact zones resulting in the metamorphism of the original rocks to slate, phyllite, phyllitic shale and spotted slate.

The Buke Ta formation is locally distributed at Ban Buke Ta and Mae Nam Kolok. This formation comprises predominantly schists, which are wholly crystalline and generally schistosed. Narrow bands of amphibolite schist and quartz schist occur in mica schists.

The Permian Sri Paen formation is 500 m thick comprising predominantly thin- to medium-bedded argillaceous limestone, shale, siltstone and chert with minor sandstone in the upper to middle part. Some successions are locally deformed and metamorphosed to phyllitic shale, schist and calc-silicate.

The Permian Tham Krachaeng formation is mostly recrystallized and consists of thick bedded to massive recrystallized limestone to marble with chert nodule patches. The thickness of the formation is inconclusive. Based on the occurrences of fossil assemblages, i.e. bivalves and brachiopods in siltstone strata, radiolarian assemblage in siliceous beds and brachiopod fragments, and fusulinids in limestone layers, the age of the Tham Krachaeng formation is assigned as Middle Permian and the Sri Paen formation rock is Early Permian.

The Permian-Triassic succession of the Ai Ba Lo formation is confined to the northwestern part of the Transect area. It consists mainly of sharp, even, thin-bedded cherts with recrystalline radiolarian intercalated with thin shale beds and rare volcanoclastic sediments. The succession obviously exhibits instability of the basin during the time of deposition because of igneous activities. The age of these chert strata can be considered as Permian-Triassic.

The Permian-Triassic Ban Sa formation which are consist mainly of medium- to thick-bedded para-gneiss, augen gneiss with subordinate amphibolites schist, schist and hornfels. The succession is only exposed near the Mae Nam Kolok at the eastern side of the Ba Tu Ta Mong-Jeli granitic belt. The high-grade regional metamorphism (amphibolite facies) is obviously recognised by the prograde of amphibole mineral group in terms of petrography. No fossil assemblages found and the thickness of the succession is indeterminable.

In Satun area, Khao Rub Chang/Chaiburi Formation consists of massive dolomitic limestone and limestone (at the lower part), significant amount of sandstone and shale (middle part), and crystalline limestone (upper part). The grey to dark grey, well-bedded, medium- to thick-bedded dolomitic limestone and limestone; rich in Permian brachiopods and crinoids; exposed in the lower part of the succession is designated as Khao Rub Chang Formation. The Upper limestone member is light grey, well-bedded to massive, crystalline limestone with Triassic conodonts and foraminifera is considered correlatable with the Chaiburi Formation of Thailand. The two Formations can be correlated as the Khao Rub Chang/Chaiburi Formation. The age of unit is designated as Permian-Triassic.

The Triassic sequence in Songkhla area is represented by the Lampang Group. The term Lampang Group was established by Piyasin (1972) as consisting of five formations confined to Lampang Province in northern Thailand. The Triassic Lampang Group in Southern Thailand (Na Thawi, Khuan Chedi and Khlong Kon Formations), studied by many workers such as Grant-Mackie *et al.* (1980) and Sashida *et al.* (1999), is mainly distributed in the Na Thawi and Saba Yoi areas. According to Grant-Mackie *et al.* (1980), the Triassic bivalve *Daonella* sp. can be observed in the Na Thawi area. Recently, Sashida *et al.* (1999) reported that the Khlong Kon Formation in the Saba Yoi area contains Middle to Late Triassic foraminifera.

The Triassic submarine fanglomerate, Bu Yong formation, is unconformably underlain by the Permian and Permian-Triassic rocks. It crops out in the northwestern part of the Transect area, consisting of massive to thick-bedded conglomerates and conglomeratic sandstones, with both matrix- and clast-supported types. Clasts are made up of sandstones, quartz, cherts, and volcanic rocks.

The Cretaceous red beds are represented by the continental deposits of Lam Thap Formation. It comprises reddish brown, thickly bedded, cross-bedded, well sorted, sub rounded, well cemented arkosic and lithic sandstones, siltstone, mudstone and conglomerate beds. The

sandstone is moderately cemented, with ripple marks whilst the conglomerate is poorly sorted, sub rounded, with pebbles of sandstone and quartzite. There is no fossil found in this rock unit.

The Phu Phin Formation occurs as a N-S trending elongated ridge, approximately 1-2 km wide and 17 km long, forming the Malaysia-Thailand border, east of the Pedu Lake area. It is well correlatable with Saiong Formation on the Malaysian side.

The Neogene Sadao formation consists of mudstone, siltstone and sandstone with minor conglomerate and occasional thin coal seams having no economic significance. The rocks are greyish brown to brown, thin- to medium-bedded, with plant fossils and gastropods. Thin coal seams occur occasionally.

The Quaternary deposits are composed of the Pliocene terrestrial deposits, and Holocene terrestrial and marine deposits. The Pleistocene Waeng Formation was a former flood plain/colluvium deposits covering low lying areas of the transect area. It consists of clay, silt and sand with some granules, and pebbles with the presence of iron concretions; red to reddish brown in colour. The Pleistocene Hat Yai formation occupies high undulating terrains. It is made up of semiconsolidated deposits of sand, gravel and boulder; light brown to reddish brown in colour.

In Tarutao Island, Quaternary sediments occupies the coastal area. Sediments originated by stream and long shore current can be divided as three units. The Talo U Dang formation, colluvial and alluvial sediments, were transported by rivers and streams. They cover low-lying lands from seashore up to the base of terraces. The sediments comprise gravel, sand, clay and mud. The Ao Chak formation, beach sediments, were deposited along seashore, consisting of sand, quartz sand, gravel, pebble, shell fragments and corals. Grey and muddy sediments in the Ao Son formation mangrove forests are composed of mud and silt with thickness of 3-7 metres.

In Songkhla-Yala area, unconsolidated sediments were deposited in non-marine environments and can be subdivided into two formations in ascending order: the Ai Yoi Boe Chang gravel beds and Recent fluvial deposit. The Pleistocene gravel beds of Ai Yoi Boe Chang are composed of gravel, sand, silt, and laterite with abundant iron concretions. The size of the pebbles in the gravel beds is decreasing westwards, towards the Betong town. The thickness of this rock unit is interpreted to be more than 20 m. The Holocene fluvial deposit is well deposited as channel fills in the river i.e. Khlong Ka Pae and Pattani rivers. It is mainly made up of sand, silt and clay.

The Holocene Sungai Kolok Formation comprises unconsolidated gravelly, sandy, silty and clayey continental deposits occupying major river valleys. The floodplain clay member is very firm, grey to brown, thick-bedded, interbedded with loose sand beds. Whilst the alluvial sand and clay member are generally consisting of coarse sands, gravelly, poorly sorted, sub-angular, light grey, mottled, very stiff, thin bed, including valley plain deposits.

The Holocene Tak Bai Formation consists of unconsolidated sandy and clayey marine deposits in the vicinity of the present mangrove covered shoreline areas. Clay usually is soft, grey to greenish grey colour, with plant remains and shell fragments; interbedded with loose sand or gravelly sand beds.

### 2.2.2 Igneous rocks

The Triassic Adang Granite that occupies the Adang-Rawi area can be subdivided into two phases of intrusion. The main phase is represented by primary core and outer core phases of pale grey, non-foliated, medium- to very coarse-grained, porphyritic, biotite granite and pale grey to pale brownish grey, fine-grained, heterogeneous texture, sparsely porphyritic tourmaline-biotite granite. The minor phase is represented by two phase variances granite, consisting 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 Triassic Khao Chin granite is exposed along the Malaysia-Thailand border near Wang Kelian/Wang Prachan area. The granite is mainly fine- to coarse-grained biotite-muscovite granite, megacrystic, with K-feldspar phenocrysts. Aplite and pegmatite dykes are normally found in this pluton. Cognate or syngenetic xenoliths comprising mafic minerals accumulation are widespread throughout the pluton in various shapes and sizes.

Pra Kob granite is the only pluton observed in the Gubir-Sadao Transect area on the Thai side. Little research work has been undertaken on this pluton, apart from the work of Zainol Husin and Mohammed Hatta Abd. Karim (in manuscript) along the southern margin of the pluton exposed on the Malaysian side.

Generally, the Paleozoic sequences in Narathiwat area were intruded by two granitic rocks. The N-S trending granitic rocks in the central part of the Transect area consist of equigranular topophyritic biotite-hornblende granite, with muscovite as secondary minerals resulting from the alteration of K-feldspar and/or biotite. Many phases of granitic rock types are also found in the eastern flank of the Ba Tu Ta Mong-Jeli granitic belt. The other belt, trending N-S, is isolated in the western part of the Transect area. It consists of porphyritic biotite-muscovite granite including aplite and pegmatite with associated Sn-deposit.

North-South trending quartz dykes and some other igneous stocks usually intruded the country rocks, especially in the Ka Lu Bi formation in the Suture Zone area. Contact metamorphism and associated late stage mineralisations can be observed in the country rocks.

Triassic granitic rocks intruded the Palaeozoic succession in the Yala-Narathiwat area. The main phase of the Si Nakhon granite is located near the Malaysia-Thailand border. It is characterized by medium- to coarse-grained, porphyritic biotite granite with inequigranular (heterogranular) to good megacrystic texture and K-feldspar megacrysts in various shapes and sizes. It also includes pegmatite, minor phases of aplite or leucocratic granite, barite and base metal sulphide minerals. The minor late stage within the Si Nakhon granite, the Pa Ret Tu granite is mainly composed of fine- to medium-grained (with local two-phase variants texture), equigranular to sparsely porphyritic, tourmaline-biotite-muscovite granite. Biotite is the most abundant mafic mineral. Tin mineralization is commonly associated with this granitoid.

Near the Hala Forest Reserve, Chantharat granite is mainly composed of medium- to coarse-grained, porphyritic biotite granite including aplite, pegmatite and minor phases of chlorite and tourmaline biotite granite. N-S and NE-SW trending quartz dykes usually intruded the country rocks, especially the Carboniferous rocks in the southern and the middle parts of the area. Contact metamorphism and associated late stage mineralizations were observed in the country rocks.

In Narathiwat area, the Permo-Triassic volcanic rocks are subdivided into two sub-units: the Muno Volcanics and the Ku Mung volcanic complex. The intermediate volcanic association of the Muno Volcanics is only represented by a small hill (not mappable) at Ban Mu No, near Mae Nam Kolok in the eastern part of the Transect area. This unit comprises strongly sheared and altered andesite, andesitic tuff and agglomerate. Serpentinite and relicts of ultramafic and mafic rocks, with podiform chromite deposit of the Ku Mung volcanic complex occur as a narrow, NE-SW trending body in the northwestern part of the Transect area. Pillow lava basalt, basaltic andesite and gabbro are well exposed along Mae Nam Sai Buri. The unit is closely related with the Ai Ba Lo formation.

### **2.2.3 Structure and tectonic**

Structurally, the Paleozoic succession on the Thai side is characterised by tightly folded isoclinal folds throughout the area. Generally, the Silurian-Devonian succession deformed into repeated sequence, especially near the igneous pluton. The Triassic sequence generally exhibits open fold. Most of the major faults interpreted from air-photographs and satellite imageries are generally NW-SE and NNE-SSW trending. Beddings are generally N-S striking with dominant eastwardly dipping. Folds can be observed locally. The strike-slip, normal, reverse and thrust faults are conspicuous with three main N-S, NW-SE and NE-SW directions.

Historically, marine sedimentation took place continuously throughout the Silurian-Devonian and Permian Periods. Nevertheless, the large breaks can be observed due to the uplifting of the depositional basins during the Mesozoic Era by Triassic granite intrusions. Palaeozoic succession is mainly composed of shallow to deep continental shelf carbonate and clastic sedimentary rocks with locally low-graded metamorphic rocks. In the central and western parts of this craton, the Palaeozoic succession is intruded by N-S trending of two belts of granitic rocks; Triassic Central belt and Cretaceous Western belt. Deformed structure and contact metamorphism and mineralization are also recognized.

Geological map of the Malaysia-Thailand border area is illustrated in Figure 2

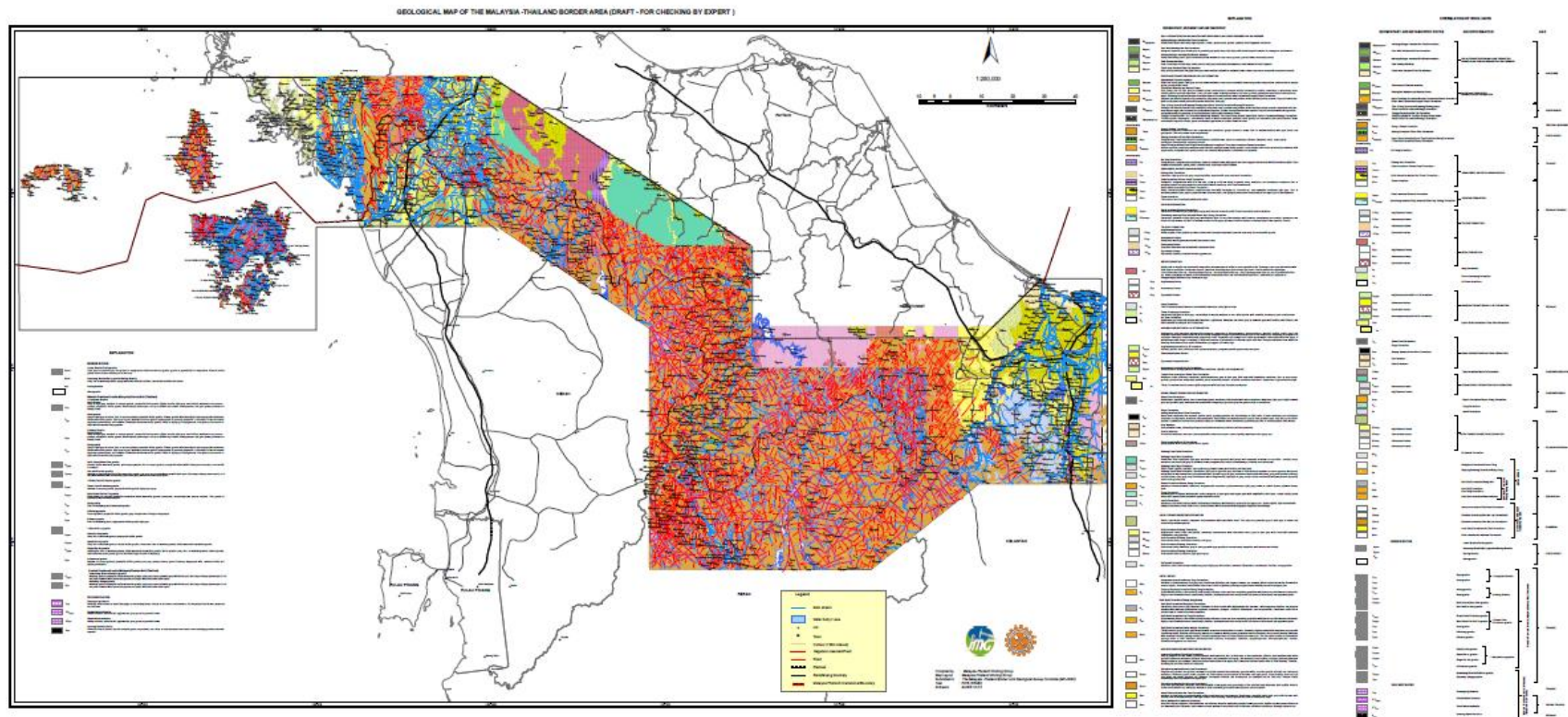


Figure 2 Geological Map along the Malaysia-Thailand border area

### 3.0 METALLIC MINERALS

#### 3.1 Gold

Gold is the most expensive and important commodity in mining industry in recent years. Studies and reports on gold potential in Transect 1 to Transect 6 area along Malaysia – Thailand border marked an impressive outcome and recommendable for follow-up studies. The commodity is mainly found in Transect 2 area where the northern part of the Gold Belt of Peninsular Malaysia is situated.

##### 3.1.1 Gold in Bukit Kuang and Kalai

In Malaysia side, gold is the most important metallic mineral that has been mined for years. The Minerals and Geoscience Department Malaysia identified at least 30 gold anomalies covering a total area of about 2,161 square kilometres in Kelantan State inclusive of Bukit Kuang and Kalai gold areas which are located in the Transect 2.

##### Bukit Kuang gold area

In early 1989, former Geological Survey of Malaysia discovered alluvial gold flakes during reconnaissance geochemical survey at the Bukit Kuang area. Subsequently, Ab. Halim Hamzah *et al.* (1991) conducted systematic gold exploration in the area via stream sediment sampling (covering 30 square kilometres) and followed by grid soil sampling (0.6 square kilometres) over Bukit Kecil which could be the source of the gold mineralisation in the area. The stream sediments, concentrate, soil and rock samples were analysed for gold and others elements. Geologically, this area is underlain by Permian volcano-sedimentary rocks such as quartzite, shale and tuff.

The results indicated that the southern half of the area is significant for gold. The weak Au-Pb-Zn-Mn-Fe-Ni-Co anomalous stream sediment values are co relatable with the higher Au anomalous heavy mineral concentrate (stream) results. Based on this result, five anomalous zones were defined, two of which coincide with N75<sup>0</sup> and N290<sup>0</sup> trending aerial photo lineaments. These two zones are classified as Priority 1 and the remaining three are Priority 2 targets.

Stream sediment gold results showed that 20% of the samples are above 50 ppb, and 7% above 100 ppb. The maximum value is 1.55 ppm. Heavy mineral concentrate (stream) gold results showed that 15% of the samples are above 50 mg/m<sup>3</sup> and 5% samples are above 100 mg/m<sup>3</sup>. The maximum value is 805 mg/m<sup>3</sup>.

The grid soil sampling results from the Bukit Kecil area coincided with the results shown by the stream sediment and heavy mineral concentrates. Gold flakes were commonly observed in soil concentrate samples. At the southern half of Bukit Kecil, the idealized correlation between the higher Au tenor results and the more anomalous soil Au value (> 50 ppb Au) is identified. The best Au zones coincide with intersection of lineaments. A few intersections of lineaments show that the Au value in soil is above 200 ppb and the highest gold tenor value in soil concentrate is 359 mg/m<sup>3</sup>.

### **Kalai gold area**

This area is underlain by metasedimentary rocks, which are close to the granite intrusion. The metasediments consist of interbedded metargillites and metarenites of the Mangga formation, Tiang schist and hornfelsic rocks of the Telong formation. Minor intrusion especially quartz veins/stringers and microdiorite veins can be observed in the study area.

Prior to 1923, prospecting and mining in the Kalai area were carried out mainly for gold. After 1923, there was no record of exploration work until 1980's when the former Geological Survey Department of Malaysia and Malaysia Mining Corporation (MMC) separately carried out exploration in the Transect area. From the year 1987 to 1995, 14 Prospecting Permits (PP) and 4 mining certificates (MC) were issued. At present, local people are still working for gold in Kampung Lawar by panning.

Rookewell (1923) reported that the Ulu Pergau area comprised of 2.8 square kilometres of mineral potential land i.e. 1.6 square kilometres (at Berching and Rezorback, 0.4 square kilometres (Tekok) and 0.8 square kilometres (at Chupan and Chinong). Large amounts of Gold in these areas had been mined from the ore bodies and alluvial deposits by Chinese miners from the Chinong and Chupan areas. The ore occurred in hard, grey to yellow ferruginous quartz veins and in many cases the gold could be clearly visible by the naked eye. These veins strike nearly N-S, with dips varying from 70 to 85 degrees towards the East. Their thickness varies from eight to 38 cm at Berching and Razorback, around two meter at Tekuk, which is about 244 m below the Berching outcrops, and 60 – 90 cm at Chinong and Chupan. Rookewell also found 18 old tunnels, which were driven above the water table into the hillside (because they were no pumps to handle the water at that time) where miners had mined on the surface.

Chu *et al.* (1982) carried out reconnaissance geochemical sampling in the Upper Pergau area, covering Kampung Kalai Baru in the north, up to Batu Melintang and Kampung Bendang Lawar in the southern part, with an areal coverage of about 63 square kilometres. Subsequently, Safeen Baharuddin (1987) carried out follow-up geochemical sampling in that area. Stream sediment results showed that the area has mineral potential for gold and lead. The highest tenor of the gold value in heavy mineral concentrate was 1,574.68 mg/m<sup>3</sup>, located at a tributary of Sungai Tadoh. Other elements also showed potentially high values i.e. tin (Sn) and lead (Pb) in the north, nickel (Ni) in the central part and lead (Pb) and uranium (U) in the southern part. The background values of gold from various types of rock samples analysed show that: slate - 0.006 ppm to 0.007 ppm, phyllite - 0.005 ppm to 0.035 ppm, schist - 0.011 ppm, tuff: 0.007 ppm to 0.029 ppm and granodiorite 0.009 ppm.

The stream sediment results obtained from reconnaissance survey for gold carried out by Mohd Azmer Ashaari *et al.* (1995) in the Kampung Kalai and Bukit Berching areas, within the contacts of the sediment and granite bodies showed that maximum gold (Au) value was 132 ppb and the highest grade and tenor in heavy mineral concentrate were 214 ppm and 383 mg/m<sup>3</sup>, respectively.

Mohamad Hussein Jamaluddin *et al.* (in manuscript) also carried out reconnaissance geochemical sampling for 18 elements (including Au) on stream sediments and heavy mineral

concentrates collected in the area close to the granite intrusion underlain by interbedded metargillite and metarenites of the Mangga and the Telong formations. Based on these geochemical data, the Kalai area was interpreted as a geochemical anomalous area and rated as Priority 1, which covers about 14 square kilometres i.e from Kampung Kalai Baru in the southern part to the north close to the Malaysia-Thailand border. An immediate follow-up study was proposed. The geochemical sampling results showed that the area is potential for gold (Au) and Barium (Ba). The highest tenor for gold in heavy mineral concentrate was 391.874 mg/m<sup>3</sup>, located at a tributary of Sungai Tadoh and the lower tenor ranges from 013 ppm to 0.948 ppm. Gold (Au) recovered from the stream sediments ranges from 0.013 ppm to 0.948 ppm.

### 3.1.2 Gold in To Mo area

In Thailand side, gold is the most well-known mineral in the To Mo area, located in the Sukhirin District, Narathiwat Province, which covers Ban To Mo sheet (5320 IV) in a series of topographic map (scale 1:50,000) are located in Transect 2 area. It is a primary deposit and has been exploited since the late 1890s. The first production came out during the year 1936-1940 when a French company called Societe de Mines d' Or de Litcho exploited gold deposits by underground mining. As much as 6,000 ounces (170 kg) of gold were recovered during that period. In 1984, the deposit was back into the limelight with renewal of the mining right by Cholasin Co. Ltd. During 1990–1996, the production was recorded at 230 kilograms (Nuchanong, 1999).

Before the mining operation was stopped, gold was mined along quartz veins 30-50 cm in width; production reduced when the gold reserve was no more economic. Subsequently, in 1994, the Cholasin Company employed the Mineral Resources Office, Region 1 (Songkhla) to explore gold deposits around the To Mo area, especially, along Khlong Ti Moong and its branches covering an area of about 20 square kilometres to the northwestern part of the To Mo mine. The results revealed the presence of some gold in stream sediments with the average grade ranging from 0.057 to 0.106 g/ton. It is interesting to recognise that gold is disseminated in quartz veins, which occurred in the area, the grade is up to 0.42 g/ton (Fuangthong *et al.*, 1994).

The gold potential area in Thailand is confined to Cretaceous granodiorite, granite, andesite and quartz veins/dykes, which intruded the Carboniferous-Permian rocks. Gold mineralisation occurs in N-S trending quartz veins. These veins are 0.1 to 2.2 m thick, and the common associated minerals are pyrite and arsenopyrite, which are usually below 3 %. Mineable reserve calculated by Cholasin at the beginning of the operation was 100,000 tons at 7 g/ton of gold metal.

During the reconnaissance exploration, stream sediment samples were collected along Khlong Ai Ti Moong and its tributaries extending northward from the To Mo area. Generally, gold was recovered by panning in gravel bed, varies from dust up to 3 mm in size (Figure 3). The gold potential area covers about 80 square kilometres.

### 3.1.3 Gold in North Perlis

Gold occurrences have been recorded in stream sediments collected from Sungai Kemian, Sungai Wang Burma, Sungai Gunung Perah and Sungai Benut in the Wang Kelian area which is located in transect 4 area. Mohd Badaruddin Hasan (1990) carried out a systematic geochemical survey with emphasis on the gold occurrences in this area. A total of 60 stream sediment samples were collected. Gold values in the stream sediments are in the range of 6-127 ppb with an average of 74 ppb. Twenty five percent of the samples yielded more than 50 ppb of gold, whilst 8% samples yielded more than 100 ppb gold. A tiny gold flake has been found in heavy mineral concentrates in Sungai Kelong.

Later Mohd Badzran Mat Taib (1998) carried out soil sampling for a follow-up study on the potential of gold in the same area studied by Mohd Badaruddin Hasan (1990) and a total of 250 soil samples were collected. The results of soil analyses revealed that the occurrence of gold in the study area is of no economic significance. Gold values are in the range of 3-157 ppb with an average of 6 ppb. Only 9 out of 250 samples analysed yielded gold value of more than 20 ppb. Based on the previous studies, it can be concluded that the gold occurrence in this area is not significant enough for further investigation. This finding is corresponding to the previous mining records where gold were only collected as by-product of tin mining.

### 3.1.4 Gold in Berusong and Temengor Valley

Scrivenor (1915) was reported that alluvial gold had been mined at Berusong in the Temengor valley which is located in Transect 5 area. He believed that the gold probably came from the basic Pahang Volcanic Series and perhaps from the quartz porphyry in which numerous small quartz veins were seen. The basic Pahang Volcanic Series rocks are now thought to be highly altered basic intrusive and the quartz porphyry is now known to be an acid pyroclastic rock (volcanic rocks of the Gerik formation) rather than an intrusive. The primary gold mineralization may be of similar mode of occurrence to the tin mineralization, which is genetically related to the surrounding granite bodies.



(a)



(b)

**Figure 3:** Gold nuggets discovered by panning (a) and gravel bed with gold deposits (b).

## 3.2 Tin

Tin is an important mineral in the Transect area and it is located within the Western Tin Belt province as delineated by Scrivenor (1928) and up to Thailand side which is located both side in the Transect area.

### 3.2.1 Tin in Kelian Intan Area

In the north Perak state, tin mineralization is concentrated in the Kelian Intan which is located in Transect 3 area. Burton (1970) was reported that there were tin mining activities in the early 1900s in Sungai Pong of the Kelian Intan area. The only tin mine which is still operating until now is the Rahman Hydraulic Tin Berhad, which started its mining activity in the Kelian Intan area earlier than 1903. The tin ore was recovered from alluvium and colluvial material as well as primary tin deposits.

Ismail Iman *et al.* (1989) reported that there were 11 companies operating tin mines in the Kelian Intan area. There were four open cast mines working on the primary tin deposit and seven alluvial tin mines. Up to now, only the Rahman Hydraulic Tin Berhad mine is still working for primary tin deposits in and around the Gunung Paku area (Figure 4). This tin mine is considered as the world's largest open cast primary tin mine currently operating. It survived the world tin crisis in 1985 and the world economic slump in 1997 because of the large production volume of tin ore, average monthly production of more than 100 tones and supplemented by cheap electricity power supply (hydroelectric) owned and maintained by the company. Other tin mines on the Malaysian side had stopped their operation.

Tin fields in the Kelian Intan area are generally underlain by Silurian-Devonian rocks of the Kroh formation ( $SD_{kr}$ ), which consists dominantly of shale, slate with subordinate marble, metasandstone and minor chert. Geological structures within the Transect area shows three major sets of extension joint trending i.e. E-W, ENE-WSW and WNW-ESE directions. However, their relationship with tin mineralization is still not yet studied in detail. In general, tin mineralization and the occurrence of other minerals within the Transect area are genetically related to hydrothermal origin, either directly or indirectly due to intrusions of the nearby granite bodies. The occurrence of tin ores is associated with a stockwork of quartzo-feldspathic veins in the argillaceous and calcareous metasedimentary rocks of the Silurian-Devonian Kroh formation ( $SD_{kr}$ ).

At Gunung Paku (Rahman Hydraulic Tin Berhad area), the mineralized veins are generally trend E-W. The veins vary in width from a few millimeters up to 15 cm or more. Most of these veins exhibit a pinch and swell structures. They have a considerable horizontal extent but their vertical extent is still unknown. The composition of cassiterite lodes (tin ore) varies from mineralogically simple quartz-cassiterite and quartz-tourmaline-cassiterite veins to more complex quartz-cassiterite-polymetallic sulphide lodes in light grey to light brown metaargillite. The veins are believed to constitute a hydrothermal stockwork type of deposit. In the Kota Bunyih area, the bedrock of the mine is also made up of carbonaceous metaargillite with rare metasandstone, marble, hornfels and chert of the Kroh formation ( $SD_{kr}$ ); traversed by numerous mineralized quartz-cassiterite-polymetallic sulphide veins.

### 3.2.2 Tin in Yala Province

In Thailand side, tin mines were widely exploited in the Yala Province. Most of the tin mines are located in four districts i.e. Bannang Sta, Yaha, Than To and Betong Districts which are located in Transect 3 area. However, all the tin mines have ceased their operation due to the low tin price. Currently six deposits are known:

- i. Tham Thalu-Puluan-Balae Deposit
- ii. Dida-Labu Deposit
- iii. Pin Yor Deposit
- iv. Than To Deposit
- v. Ai Yoe Weng Deposit
- vi. Bor Nam Ron-Betong Deposit

#### i. Tham Thalu-Puluan-Balae Deposit

This deposit is situated at Ban Tham Thalu, Bannang Sta District of Yala Province, between Lat.  $6^{\circ} 16' 00''$  N –  $6^{\circ} 16' 30''$  N and Long.  $101^{\circ} 08' 30''$  E –  $101^{\circ} 10' 30''$  E. It is located on the topographic map scale 1: 50,000 of map Sheet 5221 IV (Amphoe Yaha). The deposit occurs at the contact aureole zone of Jurassic-Triassic biotite granite with Carboniferous rocks to the north, and Permian limestone to the east. In this area, five mines had been in operation for several years namely, Tham Thalu, Mai, Bulan, Bayor and Na Sua mines.

Tham Thalu mine was the biggest tin mine in this area (Figure 46). The Yala Mines Co. Ltd. started its operation before the World War II and subsequently it was taken over by many operators until it stopped operating. This mine situated in the contact aureole zone of Jurassic-Triassic porphyritic biotite granite and the Permian limestone. The limestone in the contact zone was metamorphosed to skarn. Generally, this area is covered by gossan, and high grade cassiterite deposits are usually found on higher ground. Associated minerals, such as cerussite (lead carbonate), pyrite, magnetite, goethite, arsenopyrite and grossularite are common. The product obtained from this mine is composed of tin 25% and lead 37%, and the final product was usually refined as mixture of tin and lead.

After the mining activities stopped, the surrounding area was found to have been polluted by toxic materials derived from the tailings, such as lead and arsenic. Due to this impact, the Department of Mineral Resources Thailand was engaged by the government for rehabilitation work to mitigate the impact of toxic materials to the environment since 1999, by using the secure landfill method and reforestation (Figure 5).

Mai mine is located to the west of Tham Thalu mine. Normally, cassiterite and sulphide minerals occur in the contact zone between granite and shale. Cassiterite was transported and accumulated as a placer deposit 50 m to the east of a Permian limestone cliff.

Bulan mine is situated at Ban Bulan, 1.5 km to the northwest of Tham Thalu mine. It is in the contact zone between granite and limestone. Normally, cassiterite occurs in skarn and sulphide mineral veins.

Bayor mine situated in the north of Mai mine and 1 km to the west of Bulan mine. It is also in the contact zone, and quartz veins. Cassiterite commonly occurs in quartz veins and placer deposits.

Na Sua mine is located in the valley of Ban Balae, 1 km to the northwest of Bulan mine. The mine, started operation in 1970, was initially mined for copper (bornite, chalcantite and chalcopyrite). Unfortunately, the intended copper ore were disqualified due to high percentage of cassiterite (>4%) in copper. Consequently, only tin was produced.

The earlier open-cut of Na Sua mine is situated in the contact zone of porphyritic biotite granite and dark grey limestone. Due to metasomatism, the limestone were metamorphosed to marble and skarn, and yielded sulphide minerals, such as chalcopyrite, bornite, chalcantite, sphalerite, galena and cerussite. In addition, pyrite, arsenopyrite, hematite, scheelite and cassiterite also occurred (Sutthakorn, 1970). The later open-cut of the mine, sulphide minerals such as pyrrhotite, galena, sphalerite, occur 40 m in width, cut into the fault in skarn.



A



B

**Figure 4:** The Rahman Hydraulic Tin Berhad, Kelian Intan, Malaysia.

A- Entrance to the mines.

B- Working for primary tin deposits at Gunung Paku.



A



B

**Figure 5:** Tham Thalu mine, Thailand

A- Abandoned open-cut of the mines.

B- Rehabilitated area by reforestation.

Generally, cassiterite is associated with pyrrhotite. To the north, pyrite veins are observed cutting the quartzite with NW-SE strike direction and dipping  $75^{\circ}$  NW. Based on drilling results conducted in 1972, the mineral deposits overlie granite and marble at about 35 – 40 m depth. The regional reserve of lead, zinc, tin and copper was estimated at 400,000 tonnes.

Daily production of tin produced from sulphide mineral veins was about 30 – 40 tonnes and the final product is composed of 70% Sn. After the mining operation ceased, the environmental impacts situation here were critical. The secure landfill and replantation methods were applied by the Department of Primary Industries and Mines to rehabilitate the environmental impact (Figure 6).

## ii. Dida-Labu Deposit

Dida-Labu deposit is located to the northwest of Tham Thalu deposits. It consists of two mines, namely; Labu and Dida mines.

Labu mine situated at Ban Patae, Bannang Sta District, Yala Province. The deposit is located in the contact zone of Jurassic-Triassic biotite granite and sedimentary rocks. This deposit is mainly underlain by blackish quartzite and limestone boulders. Pyrite is oftenly disseminated within the quartzite, especially in the fractures. Cassiterite and other minerals such as galena, chalcopyrite, pyrite and arsenopyrite commonly occurred in quartz veins which generally cut the rock formation in the E-W direction. It was reported that data gathered from drilling conducted by the Strait Consolidated Tin mines company limited in 1940 – 1941, indicated that granite was observed at the depth of about 300 m, and grade of cassiterite in the quartz veins was about 1.2%. Due to the potential of the deposit, drift mining had been conducted for several years.

Dida mine group consists of three mines namely: Dida mine 1, 2 and 3; located to the east of Labu mine, and it is also situated in the contact zone of granite and sedimentary rocks. Cassiterite commonly occurred in greenish skarn and in quartz veins that cut into quartzite. However, tin ore from these mines contained high percentage of iron. The average monthly tin production was 0.9 – 1.2 tonnes.

## iii. Pin Yoh Deposit

Pin Yoh tin deposit is a primary skarn deposit, situated at Tambol Tham Thalu, Bannang Sta District of Yala Province, 3 km from the Malaysia-Thailand border, at  $6^{\circ} 13' 30''$  N,  $101^{\circ} 09' 00''$  E (Figure 7). It is located in the contact zone of granite and limestone. This mine was initially operated by Chinese miners until 1930 and then by the British American Tin Mines Company Limited until World War II. After the War, this mine was controlled by the Thai Tin and Rubber Company under the Royal Thai Government until 1949. Total production of tin since the beginning of operation was 500,000 tonnes. During that period, efficiency of ore dressing was quite low, i.e. only 18% – 36% of tin could be separated. However in 1940 minerals separation was improved by chemical process, called “Cavaet Method”. A total 400,000 tonnes of tailings with  $>1\%$  of tin contents were left around the mine.

Cassiterite in this mine normally occurred in quartz stringers-veins stockworks, in quartzite and shale of the Kanchanaburi Formation. In the mineralized veins, 1% – 2% of cassiterite is commonly associated with garnet and Fe minerals. The mineral assemblage in the contact zone is composed of galena, pyrite, chalcopyrite, arsenopyrite, and magnetite.

#### iv. Than To Deposit

This deposit is situated at Ban Than To, Than To District, 6° 02' 42" N, 101° 12' 42" E on the topographic map Sheet 5221 III of scale 1:50,000. This deposit is in the contact zone of granite and sedimentary rocks. The former mining area has now been completely flooded by water below the Bang Lang Dam.



**Figure 6:** Environmental improvement work by secure landfill at Na Sua mine, Thailand.



**Figure 7:** Open-cut at Pin Yoh mine, Bannang Sta District, Thailand.

## v. Ai Yoe Weng Deposit

This deposit is located in Betong District at Lat. 5° 55' 00" N – 5° 55' 20" N and Long. 101° 07' 30" E – 101° 10' 30" E, on topographic map Sheet 5220 IV (Amphoe Betong). It is within the contact zone of granite and sedimentary rocks of the Kanchanaburi Formation which includes hornfel, quartzite, phyllitic quartzite, slate and phyllite. Generally, pyrite disseminates throughout these rocks, especially, in the fractures. Quartz veins cut the rocks in the E-W direction. Mineral assemblage of the veins is composed of pyrite, arsenopyrite and cassiterite. Cassiterite was also commonly found in the Ai Yoe Weng stream and Ai Yoe Kem stream. This deposit consists of two mines; Prachuab and Ai Yoe Weng mines.

Prachuab mine is situated at Km 98 on the way from Yala to Betong town (28 km north of Betong). The overburden is generally composed of gravels of biotite granite, tourmaline-biotite granite, and quartz. The bedrock is phyllitic quartzite. Gravel pump mining had been carried out to exploit the tin placer deposit.

Ai Yoe Weng mine is located at the Ai Yoe Weng stream, Km 99 on the way from Yala to Betong (27 km northward of Betong downtown). The bedrock is biotite granite and covered by phyllitic quartzite in some parts. Generally, cassiterite and scheelite occur in quartz veins and accumulated in the placers. Three to five tonnes of cassiterite had been produced monthly by gravel pump mining operation.

## vi. Bor Nam Ron-Betong Deposit

This deposit is located at Ban Bor Nam Ron, Betong District, on topographic map Sheet 5220 IV (Amphoe Betong) at Lat. 5° 50' 25" N – 5° 54' 45" N, Long. 101° 04' 00" E – 101° 08' 25" E. It is within the contact zone of granite and sedimentary rocks of the Kanchanaburi Formation. Cassiterite normally occurs in quartz veins and accumulated in the alluvium.

### 3.2.3 Tin in north Perlis

In Malaysia side, the occurrences of alluvial tin deposits in north Perlis (Transect 4 area) are concentrated in limestone caves, alluvium and valley alluvium. This was derived from the contact zone of the granite by weathering and subsequent distribution of the debris by fluvial agent (Jones, 1981). The tin-bearing alluvium is found in valley bottoms, caves and underground-river channels throughout the surrounding limestone hills. The caves rich in alluvial tin ore deposits are mainly distributed in the Kaki Bukit area. Tin ore distribution in cave alluvium is rather erratic of which in some places, tin concentration reached up to 90% cassiterite while in other places it is devoid of tin (Jones, 1981). Abandoned alluvial tin mines can be observed as a lake such as Meranti Lake in Wang Tangga (**Figure 8**).

Wang Kelian and Wang Tangga had served as two main valley alluvial tin ore deposits. Open cast mining started operating in these areas before and after the second World War with average annual production of tin ore was about 18 tonnes (Jones, 1981). Tin ore deposit was also found in the Sungai Burma, Sungai Bahagian Ayer and Sungai Pelarit areas but of less economic potential. Tin mining activities had been stopped for many years ago due to limited deposits and low tin price.

### 3.2.4 Tin in Sadao

In Thailand side, tin deposit covering an area of about 12 square kilometres is confined to Ban Khao Rub Chang, Ban Ta Loh and Ban Si Yaek Patthana, Sadao District, Songkhla Province. This deposit is located near the Malaysia-Thailand border or 5 km to the west of Khao Rub Chang, at the southeastern margin of the Bukit China/Khao Chin granite ( $\text{Trgr}_{bc/kn}$ ) body which is located in Transect 4 area. Tin- and other minerals-bearing quartz veins cut into granite and host rocks (Figure 9). Cassiterite is generally more abundant than wolframite in which wolframite is widely predominant near the contact zone.

In the past, seven tin mines had been operating in this area. However mining operation was stopped during the tin crisis and economic slump. Drilling and blasting had been conducted at Wachirachai Mine, Ban Si Yaek Patthana, Sadao District to exploit the tin from the 50-75 cm thick,  $270^{\circ}/50^{\circ}$  N trending tin-bearing quartz veins. An abandoned open pit at Wachirachai Mine is shown in Figure 10. About 16 tonnes of Tin and 30 tonnes of tungsten had been produced from this mine during 1979-1985. Moreover, three kilometers south of Ban Si Yaek deposit, about five quartz veins trending  $160^{\circ}/50^{\circ}$  SW direction occur in banded form, with one meter separation and approximately 30 cm thick each. The same mining methods had been operated along quartz veins.

Drilling and blasting mining had also been conducted at Ban Ta Loh, along the  $195^{\circ}/30^{\circ}$  NW quartz veins. Generally, each vein is about 15 cm thick associated with minerals such as pyrite, stibnite, chalcopyrite, and arsenopyrite. Abandoned tin ore mine and an adit excavated during mining operation is shown in Figure 11.

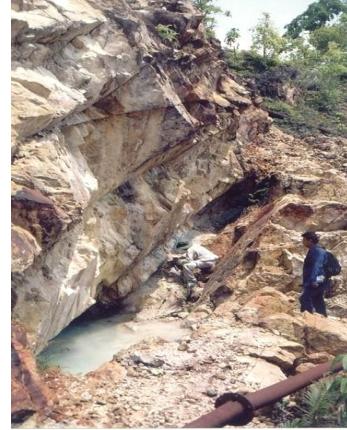
### 3.2.5 Tin in Hat Yai

At Thailand side, there is two deposit of tin ore in Hat Yai District area which is located in Transect 4; i. Ban Cha Lung area, Ban Tung Tum Sao area. At Ban Cha Lung, Hat Yai District of Songkhla Province, tin deposit occurs in the eastern margin of the northern end of Bukit China/Khao Chin granite ( $\text{Trgr}_{bc/kn}$ ). Drilling and blasting mining had been operated in this deposit for a few years. The occurrences of cassiterite- and wolframite-bearing quartz veins can be seen filling the granite fractures of about 1.5 m wide and 47 m long, trending  $310^{\circ}/28^{\circ}$  SW. Generally, associated minerals include beryl, tourmaline, pyrite, scheelite, and arsenopyrite.

At Ban Tung Tum Sao, Hat Yai District of Songkhla Province, an underground mine was operated approximately in the middle part of the eastern margin of the Bukit China/Khao Chin granite ( $\text{Trgr}_{bc/kn}$ ). Tin ores were excavated at three levels; 50, 80, and 120 m above MSL. Mineralized quartz veins cut into the fine- to medium-grained, porphyritic, two-mica granites and hornfels. Greisenisation is a typical alteration found along the wolframite-bearing quartz veins. The Geological Research Project carried out in the year 1979 reported that hundreds of quartz veins occur in this area and extend 3.5 km in the N-S direction. The quartz veins occur less than 300 m from the granite contact, ranges  $180^{\circ}$ - $190^{\circ}$  and dips  $60^{\circ}$ - $90^{\circ}$  NW with veins thickness of 15-100 cm. In general, the veins contain minerals of quartz, muscovite, potassium feldspar, fluorite, chlorite, wolframite, cassiterite, arsenopyrite, and pyrite.



**Figure 8:** Photograph of Meranti lake which is an abandoned mine in Wang Tangga, Perlis.



**Figure 9:** Photograph of tin-bearing quartz veins at Wachirachai Mine, Ban Si Yaek Pattana, Sadao District.



**Figure 10:** Photograph of an open pit at Wachirachai Mine, Ban Si Yaek Patthana, Sadao District.



**Figure 11:** Photograph of an adit excavated during tin mining operation at Ban Ta Loh, Sadao District.

### 3.2.6 Tin in Adang-Rawi Island

On the transect 6 (Tarutao), the 78 sediment samples from drilling wells were analyzed to observe the quantity of Tin and accessory minerals in Adang-Rawi-Tarutao Islands. The 32 sediment samples were collected from 10 drilling wells on sea floor south of Adang-Rawi Islands. Another 46 sediment samples were collected from 17 drilling wells in the other places. Result of geochemical analysis reveals that the 15 minerals were observed in various concentration grades and depths. The maximum concentration of each mineral can be summarized in Table 1.

Results of geochemical analysis indicate that high concentration of Tin and 14 associated minerals i.e. magnetite, garnet, ilmenite, tourmaline and heavy minerals were only recorded on wells in Adang-Rawi Islands. For example, the drilling well no.7 at depth 10.2-13.3 m from sea floor has maximum of tourmaline concentration exceeding  $14 \text{ kg/m}^3$ . Samples

from drilling well no.2 record the maximum of Tin concentration at about 0.74 kg/m<sup>3</sup> at depth 12.9- 16.0 m. from sea floor or 3.1 m thick.

The other 7 from 9 drilling wells in Adang-Rawi Islands also record the occurrence or potential Tin- deposits in sediments at depth 2.3-20.0 m from sea floor. The concentration of Tin is ranging from 0.035 to 0.242 kg/m<sup>3</sup> with averagely 3 to 4 m in thickness.

An offshore near Tarutao Island and sea floor between Tarutao and Adang-Rawi Islands, Tin-deposits and associated minerals are not significant for being potential mineral area. Pyrite, zircon and monazite are observed to be essential minerals occurrence. For example, drilling well no. 19 at depth 1.8-3.8 m from sea floor established the pyrite concentration is 0.12 kg/m<sup>3</sup>. Maximum zircon concentration found in drilling well no. 27 at depth 4.0-7.5 m from sea floor has concentration about 0.1 kg/m<sup>3</sup>.

Table 1: Maximum concentration of 15 minerals from geochemical analysis of sediments in drilling wells of the Adang-Rawi area

No.	Mineral	Maximum grade mineral (kg/m <sup>3</sup> )	No. of drilling hole
1	Tin	0.740	2
2	Tourmaline	14.000	7
3	Ilmenite	0.222	10
4	Hematite	0.175	5
5	Monazite	0.025	27
6	Xenotime	0.005	8
7	Leucosene	0.007	27
8	Zircon	0.285	2
9	Rutile	0.209	2
10	Magnetite	0.227	1
11	Garnet	0.136	2
12	Siderite	0.207	3
13	Limonite	0.007	3
14	Pyrite	0.354	10
15	Anatase	0.008	8

### 3.3 Iron Ore

Iron ore is nonetheless a crucial commodity in metal and steel production industries and regarded as the main products for both Malaysia and Thailand. Geological and mineral resource mapping along Malaysia – Thailand border has shown that iron potential contain in Transect 2, 4 and 6.

In Malaysia, there are two iron ore deposits are found at Temangan (N5° 40', E102° 8') and Bukit Kuang (N5° 55', E101° 57'), Kelantan. Other occurrences in Northern Perlis and Langkawi which is dominantly distributed in Transect 2, 4 and 6.

### 3.3.1 Temangan iron ore deposit

The Temangan deposit is situated within a broad westward curve of Sungai Kelantan. The terrain is below 1,200 m high and expressed as hilly to undulating. The mine is situated along the north-south trending 220 m high ridge. The deposit was probably discovered in 1921. Ishihara Sangyo Koshi initiated prospecting activities, but this company did not consider the deposit to be of economic interest. In 1934, the Southern Mining Company re-prospected the area, and estimated the reserves to be 6 million tonnes. This company commenced production during 1935 but did not export any ore until 1937. All production ceased in 1941 and the mine remained idle throughout the period of Japanese occupation. Ore which had previously been stockpiled, was smelted locally at Temangan Bharu during and after the Japanese occupation, until the supply was exhausted.

There was little interest shown on the iron ore deposit immediately after the war, but in 1955 the deposit was re-prospected by a Malaysian-Japanese group and the result showed the iron ore deposit was still economical for mining. The Oriental Mining Company commenced production in 1958 and exhausted the deposit by the end of 1965. The ore body lies along the north-south line of the rock contact between the Taku schist to the west and shales to the east. Just east of this contact there is a large quartz-porphyry dyke, which follows the regional strike but transgresses the bedding. East of the dyke, interbedded shale, volcanic and pyroclastic rocks are present.

Diamond drill core has shown that beneath the main ore bodies, siderite veins and veinlets cut the shale. The shale in most places is grey or greyish-white in colour and contains some arenaceous and tuffaceous bands. An interesting mineralogical occurrence observed on a schist-tuff contact consists of a sheared and highly altered rock in white and apple green bands, and contains the chrome mica, fuchsite, and a chromium-bearing pyroxene.

The ores are essentially limonite with subordinate hematite and often contain a significant percentage of manganese. Two varieties of limonite were noted, hard brownish black and bluish-banded ore. The banded ore contains large cavities up to 3 m in diameter, and these are lined with hard, black, botryoidal ore. Some of the large cavities contain well-developed stalactites and stalagmites of limonite, and the smaller ones had pseudomorph of psilomelane after manganite. The more massive iron ore contains large cavities, but they are usually much smaller than those in the banded ore.

The main ore bodies were formed as secondary deposits as the result of solution and re-deposition by circulating waters of pre-existing iron-bearing materials, and information as to an adequate source of the iron was found in some of the deeper diamond-drill holes. After the consolidation of the shale a period of crustal disturbance produced shearing and faulting along the shale-schist contact. These showed that shale had been subjected to hydrothermal activity in the form of silicification, pyritisation, and impregnation by veins of siderite and it is thought

the siderite was the parent from which the limonite and hematite were derived. Prolonged weathering produced a secondary limonitic ore from the siderite and country rocks by the process of solution and redeposition. The manganese originally associated with the primary carbonate mineralisation was redeposited in the same manner. Minor crustal movements caused east-west faulting with some displacement of the ore bodies. The hydrothermal solutions produced the quartz-porphyry dyke located east of the Temangan deposit. It appears significant that iron ore occurs at intervals along the length of the dyke and the Temangan deposit is located where the dyke reaches its maximum width.

The ore composition is medium grade and most of it contains a considerable percentage of manganese. Representative analyses are shown in Table 2. Its production is presented in Table 3

### **3.3.2 Bukit Kuang iron ore deposit**

An iron ore deposit in this area appears as boulders of limonite and hematite and their primary body is believed to be at depth. The ore reserve is estimated to be 1.5 million tonnes with a grade of 55% Fe. There is no record of production and detailed description of iron ore from this area.

### **3.3.3. Northern Perlis iron ore deposit**

Hematite and limonite occur in several localities in this area but their economic potential is low. Hematite deposit is reported to occur on top of the limestone hill situated 2 km west of Kampung Kubang Tiga. The deposit is considered to be of limited extent and consists of low to moderate grade iron ore (Jones, 1981).

### **3.3.4 Langkawi and Tarutao Islands iron ore deposit**

Hematite ( $\text{Fe}_2\text{O}_3$ ) and limonite ( $2\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$ ) are known in concentrations from several localities in the Langkawi Islands but all appear to be of limited distribution. Concentration of hematite are known from the limestone-granite contact to the east of Kuah and from the limestone hills between Telok Apau and Kisap area. The iron may be of metasomatic or pyrogenetic origin because of its relationship with the granite intrusion but it could also possibly be associated with faulting. A sample of ore analysed from near the south shore of Telok Apau composed of 49% Fe, 1.42% Mn, 0.08% Sn, 0.60% As, 0.01% S and 0.01% P. Boulders of high grade hematite with 58.2% Fe and 0.03% Mn are conspicuous on a beach on the west coast of Pulau Dayang Bunting. Iron-ore deposit also reported in southwest of Kuah with 19.3% Fe, Pulau Langgun 17.4% Fe and Pulau Rebak Besar 26.9% Fe.

Samples collected from offshore of the Adang-Rawi Islands recorded that the hematite of  $0.175 \text{ kg/m}^3$ , magnetite  $0.227 \text{ kg/m}^3$  and limonite  $0.007 \text{ kg/m}^3$  (refer Table 1).

Table 2: The composition of iron ore discovered in the Temangan area.

Sample	Constituent Percentages						
	Fe	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Mn	P	S	H <sub>2</sub> O
Average 1937	49.86	7.71	4.44	3.00	0.071	0.02	10.42
Average 1941	54.69	4.28	2.71	2.13	0.076	0.04	10.65
Average 1937-41	56.30	4.10	1.55	2.26	0.076	0.04	10.56
Average of 21 samples	56.57	2.47	1.47	3.78	0.037	0.05	4.26
Average of 8 samples from adits	53.07	4.96	-	2.07	-	-	-

Table 3: The annual production of iron ore in the Temangan area.

Year	Production (Long Tonnes)
1935	150,000
1936	127,000
1937	130,000
1938	150,000
1939	180,000
1940	200,000
1941	200,000
1942-57	Nil
1958	293,717
1959	402,751
1960	593,219
1961	617,739
1962	497,823
1963	464,503
1964	476,237
1965	373,225
Total	4,856,214

### 3.4 Chromite

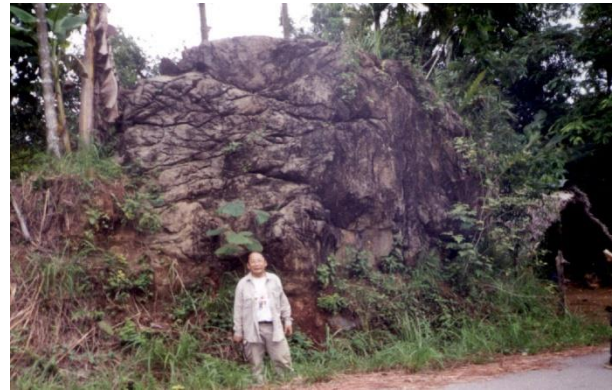
There is no chromite deposit has been reported in any Transect area of Malaysia side.

In Thailand side, chromite has been mined at Bu Yong hill, Ban Ai Sue Rae of Cha Nae District, topographic map Amphoe Si Sakhon sheet (5321 III). The deposit was discovered as podiform in the Permian-Triassic ultrabasic rocks. Ultrabasic rocks intruded the Permian-Carboniferous shale, slaty shale, phyllitic shale and phyllite, along a well defined zone trending NE-SW. Chromite samples collected from the mine are massive, euhedral crystals with brown to dark brown colours and average chemical analysis revealed  $\text{Cr}_2\text{O}_3 = 42.5\%$ ,  $\text{Fe}_2\text{O}_3 = 18.2\%$  and Cr/Fe ratio 2.37/1 (Suwannasing, 1962).

During the joint field checks, ultrabasic rocks were found extending southward at Ban Ai Ba Lo, Ban Chang Phuak and Ban Ai Bue Nae of Cha Nae District (Figure 12).



(a)



(b)



(c)

Figure 12: Chromite mine at Ban Bu Yong (a) and associated ultrabasic rocks at Ban Chang Phuak (b) and Ban Ai Bue Nae (c).

### 3.5 Tungsten

Tungsten was recorded occurred in transect 3 and 4 of Malaysia side and there is no records so far are available in Thailand side.

The occurrence of scheelite (calcium tungstate) is widespread in stream sediments (in trace amount) of the transect area. Wolframite (iron-manganese tungstate) has been recorded on the Malaysian side at the Temengor area by Jones (1969). On the Thai side, scheelite has also been found and it was produced as a by-product at the Ai Yoe Weng tin mine.

Scheelite ( $\text{CaWO}_4$ ) occurs widely though in small amounts along the granite-limestone contact zone in north Perlis (Jones, 1981). The occurrences are not considered to be of economic significance.

### 3.6 Manganese

In Malaysia, manganese ores are located at Gual Periok and Rantau Panjang areas which is located in Transect 2 area. There are four manganese deposits discovered at Bukit Lubuk Itek, Bukit Gharu, Bukit Tandok and Bukit Pak Junus at the Gual Periok area, whereas, Bukit Kuang at Rantau Panjang area (Table 4). MacDonald (1967) reported that the Japanese Company had mined manganese in the year 1953 at the Bukit Tandok area, Bukit Gharu in 1937 and Bukit Lubuk Itek in 1942. Up to 1954, a number of companies investigated the areas and concluded that these mines were no longer economical. In 1959, the Eastern Minerals and Trading continued to mine these deposits.

#### 3.6.1 Manganese in Langkawi Island

Pyrolusite ( $\text{MnO}_2$ ) and psilomelane (hydrated oxides) have been found locally in association with limonite in shale and quartzite. On the south coast of Pulau Rebak Besar, irregular veins of limonite and pyrolusite invaded the disturbed quartzite contains 27% Fe and 0.03% Mn.

#### 3.6.2 Manganese in Chanae area

In Thai side, three manganese mines are located along the mountainous areas, Ban Ai Ba Lo in the Ban To Mo map sheet (5320 IV). Mineral samples were collected from Ban Chang Phuak mine and were identified to be psilomelane and rhodonite (Figure 13). Generally, they occur in quartz veins that cut into phyllitic shale of Permo-Carboniferous age. According to field investigation, the occurrences of manganese are still present in these areas, covering an area of about 6 square kilometres. However, these areas are now being reserved for forestry conservation under the name of “Suan Pa Sirikit”.



Figure 13: The manganese mine at Ban Chang Phuak (left) and close-up outcrop of psilomelane

### 3.7 Antimony

To date, there is no record on the exploitation of antimony on the Malaysian side of the transect area. However, on the Thai side especially in Transect 4, antimony had been mined for several years from the deposit located at Ban Nam Phut, La Ngu District of Satun Province. An open pit of the abandoned mine is shown in Figure 14. Generally, stibnite ( $Sb_2S_3$ ) from this deposit is lead-grey colour, metallic luster, and cryptocrystalline texture. Stibnite occurs as veins of irregular thickness, podiform or lenses in the fractures of argillaceous limestone, and shale intercalated sandstone with limestone lenses. Generally the veins are trending NE-SW and N-S directions, dipping  $50^\circ - 70^\circ$  westwardly, with average thickness of 30 cm and the average length is 150 m. Chemical analyses results show that the ore samples contain 43-54% (by weight) of Sb. From 1988 to 2003; 180 tonnes of antimony has been produced from this deposit.



Figure 14: Photograph of an open pit at Ban Nam Phut, La Ngu District.

Table 4: Summary of manganese deposits in the study area (Malaysian side).

Year investigation		Method of investigation	Area study	Reserve	Grade	Remarks
1955	Solid ore; limonite and manganese boulders.	Pitting holes) (20	60,702.8 m <sup>2</sup> (only 4,046.9 m <sup>2</sup> of potential area)	4,200	Mn 46.5 %	Shale striking to the north and dipping towards the east. A few manganese ore with sizes up to 2.4m in diameters are noted.  Country rock consists of shale. Mined by Japanese company – (Production: 100,000 tonnes Mn ore). The opencast mine: 240 m length, 50 m width and 2.5 m depth.
1955	Residual deposit from shale- Psilomelane with some pyrolusite in the red earth as concretionary masses, solid boulders, limonite-magnetite and maganiferous shale.	Trenching and Pitting holes). (48	64,749.7 m <sup>2</sup>	4,500	Mn 33 %	Country rock of shale; reddish in colour with quartz and calcite veins and a little quartzite. Mined by Japanese company (production: 69,124 tonne)  Country rock of shale.

Has been mined since 1935	Residual deposit from shale (psilomelane with a little pyrolusite occur as reniform, botryoidal and mammillary concretions in the red earth and clay).	Trenching	Not mentioned	Not mentioned	Up to 65 % Mn	
	Secondary deposit of limonite pebbles and psilomelane and small sizes of solid manganese.	Pitting (47 holes)	Not mentioned	42,000	Average: 8.13% Mn (No economic value)	
1960	Secondary deposit with iron boulders: haematite & limonite	Pitting (42 holes)	121,875 m <sup>2</sup>	1,226,145	2.02% Mn 58 % Fe	Country rocks of sandstone and Quartzite.

### 3.8 Silver

In Malaysia, silver was produced from argentiferous galena as a by-product of the refinement of lead from galena. One sample of galena from Wang Batu Mines in north Perlis, which is located in Transect 4 area was reported to have assayed 781 gram of Ag per tonne (Jones, 1981). However, there is no record of silver occurrence on the Thai side of the Transect area.

### 3.9 Mineralization and Alteration zones

#### 3.9.1 Alteration zone in Ban Munno area

Iron deposit has not yet been found in Thailand. However, there is a burrow pit at Ban Munno, 6 km from Sungai Kolok, on the topographic map Ban Ko Sathon sheet (5421 III). The country rocks consist of weathered andesitic tuff, agglomerate of Permo-Triassic age (Figure 15). The geology is related to a strong and very complicated alteration. Generally, clay minerals and pyrite are widespread, and the large number of thin quartz veins cut the country rocks.

Accordingly, it is interesting to note that this area is also potential for base metals and gold deposits. During field checks, 53 soil samples were collected for chemical analysis. Subsequently, the results reveal that Cu = 13-310 ppm, Pb = 4-190 ppm, Zn = 3-94 ppm, Au = 4-59 ppb (detection limit = 3 ppb). The results mentioned above revealed significant mineralization.



(a)



(b)

Figure 15: Photographs of the original country rocks of the Permo-Triassic Volcanic rock in the Ban Munno area (a) and the alteration feature of the country rocks in the Ban Munno area (b).

### 3.9.2 Alteration zone in Bukit Perdah area

The exposure at Kampung Bukit Lata near the Bukit Perdah area extends eastward in Malaysia. They are classified as a part of the Tanah Merah volcanics which are composed of tuffaceous argillite and andesitic tuff. The rocks consist of iron enrichment. Clay minerals altered from feldspar phenocrysts, quartz and also pyrite are widespread in the volcanic rocks. Currently, mineral resources in this area are not considered to be economical

### 3.9.3 Mineralization and alteration in Langkawi Islands

Most of the mineralisation in Langkawi Islands is associated with the granite intrusion and related to the development of skarn along the contact zones between the limestone of the Setul Formation and the granite (Figure 245). These can be seen at Teluk Sambar, Pulau Dayang Bunting, Pulau Tuba and Pulau Bumbun. Diopside, tremolite, idocrase, wollastonite and garnet is commonly developed in the skarn. Fine-grained late phase aplitic veins and tourmaline greisenization is often characterising the granite margin (Jones, 1978).

Among the heavy minerals derived from the granite is ilmenite and tourmaline. Prismatic zircon is commonly abundant in some cases especially on the northern side of the Raya Granite in the Langkawi Islands where a beautiful pink variety is abundant.

In Thailand, Pyrite, zircon and monazite are observed to be essential minerals occurrence especially at the western offshore of Tarutao Island. For example, drilling well no. 19 at depth 1.8-3.8 m from sea floor has the pyrite concentration of 0.12 kg/m<sup>3</sup>. Maximum zircon concentration found in drilling well no. 27 at depth 4.0 m – 7.5 m from sea floor of about 0.1 kg/m<sup>3</sup>.

### 3.10 Heavy minerals and Rare-earth minerals (REE)

On the Malaysian side, Burton (1970) reported that monazite occurred as an accessory mineral in stream sediments and in some cases it occurs together with considerable amounts of xenotime. In a fairly large-scale alluvial tin-mining operation, these minerals could possibly be profitably recovered as by-product.

Thorite and allanite had also been identified. The titanium ore, ilmenite (iron titanate) is a common accessory mineral in granite and is one of the most abundant mineral found in the heavy mineral concentrates. Dumps of heavy minerals (amang) discarded during tin mining operations constitute the main local source of ilmenite.

On the Thai side, heavy minerals such as monazite, xenotime, zircon, rutile, ilmenite and magnetite occur widespread throughout the area, especially near the granite in the Transect area.

#### 3.10.1 Heavy minerals and REE in Malaysia

On the Malaysian side of the Transect area, about 200 stream and beach sands, and gravels were panned in order to identify the heavy mineral contents from these samples (Jones 1981). Semi-quantitative analyses of these samples indicate that ilmenite, iron

oxides, cassiterite, rutile, zircon, topaz, tourmaline and monazite are the most widely distributed minerals. Pyrite, xenotime, amphibole, garnet, scheelite, epidote and andalusite occur in lesser amounts.

### 3.10.2 Heavy minerals and REE in Thailand

On the Thai side, 69 sand-pump drilling holes were sunk along the shore at Ban Pak La Ngu and Ban Pak Bang, La Ngu District of Satun Province. Quantitative analysis results show that average grade of the heavy minerals is 0.48 g/l; consist of zircon, ilmenite, rutile, tourmaline, leucoxene, limonite, garnet, magnetite, siderite, monazite and xenotime. These heavy minerals and rare-earth minerals were determined to be originated from the host rocks occurred on land and were later transported by streams and deposited in the sea. Subsequently, wave action has reworked these minerals onto the present beach (Figure 16).

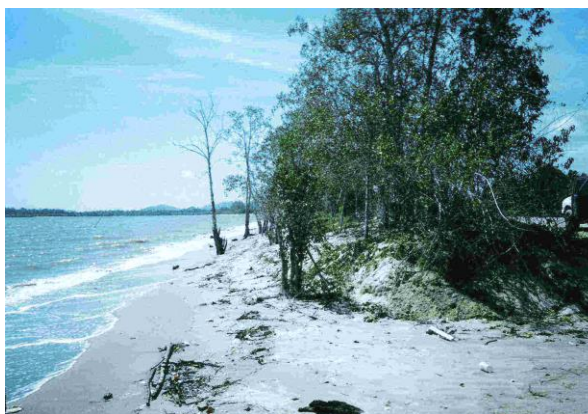


Figure 16: Photograph of a heavy mineral deposit along the beach at Ban Pak Bang, in the Thai side.

## 4.0 NON-METALLIC MINERALS

### 4.1 Granite

Granite resources suitable for construction material is abundant in Malaysia. However, there is only one quarry site, Sebarang Bina Quarry situated near Kemahang currently producing road aggregates and construction materials.

Pink porphyritic Noring granite and fine-grained foliated/non-foliated Kenerong granite has potential sources for dimension stone. Perhaps the Kemahang granite is suitable for feldspar extraction indicated by the high feldspar content. A detailed study should be done for its economic potential.

### 4.2 River sand and gravel

#### 4.2.1 Sand and gravel in Malaysian side

Sand and gravel can be used as basic material in construction industry. Sand is also used as fine aggregates in dry concrete products as well as in cement bricks and filtering materials. However, the deposits are rare in the Transect area and confined to the upper stream of the main rivers.

On the Malaysian side, the deposits are only available in substantial quantity in the main river valleys such as along the valleys of Sungai Rui and Sungai Pong (Figure 17). Alternative supplies of sand and gravels may be exploited from thick sequence of semi-consolidated sand, grit and gravel of the Nenering beds ( $Q_{nn}$ ). Tailing from the tin mines such as gravel and sand also can be used for construction material. Siti Faridah *et al.* (2002) mentioned that there are five river sand producers in the Gerik area and three mine tailing sand producers at the Kelian Intan area.

#### **4.2.2. Sand and gravel in Yala area**

There are at least two localities of sand and gravel deposits. They are confined along the Pattani river i.e., at Ban Kor Mor 32 and at Ban Bor Nam Ron Betong District. At Ban Bor Nam Ron, the sand and gravels are exploited from tailing of tin mines. Generally, most of sand and gravel have been produced for construction material.

#### **4.2.3. Sand and gravel in Satun area**

on the Thai side of the Transect area, sand has been exploited from the rivers, canals, and terrace deposits. Most of sand produced is for construction materials. In Satun Province, sand has been investigated from two streams in Muang and Khuan Don Districts.

Sand deposit in Khlong Bam Bang is noted to originate from the Triassic biotite-muscovite granite to the east; transported downstream to deposit along Khlong Mam Bang. The sand is generally white in colour, angular to rounded shape and composed of translucent-transparent quartz (93%), feldspar (5%), iron concretion and granite fragments (2%), and small amount of tourmaline.

Along the Khlong Du Son and Khlong Chiow, it is noted that four sand deposits had been exploited. The sand deposit is transported downstream from the same source as mentioned earlier, but its grain size is angular to rounded shape and has coarser grain as compared to that of Khlong Bam Bang, due to its closer sources. Chemical analysis results indicate that the sand is composed of translucent-transparent quartz (90%), feldspar (7%), iron concretion and some granite fragments (3%), and small amount of tourmaline and muscovite. Sand mound in this deposit is shown in Figure 18.

#### **4.2.4. Sand and gravel in Songkhla area**

In Songkhla Province, sand has been exploited in four deposits in Sadao District, along Khlong U Ta Phao, Ban Pang La and Khlong Ram, Ban Thung Mor and Ban Thung Pho. The sand is characterized by yellowish brown colour and angular to rounded shape. It is composed of translucent yellowish brown quartz (95%), feldspar (3%), iron concretion and some granite fragments (2%), and small amount of tourmaline.

#### 4.2.5 Black sand in Langkawi

The main occurrence of black sand in Langkawi Islands is at Pantai Pasir Hitam, Mukim Padang Mat Sirat (Figure 243) where the beach got its name from. The black sand may contain as much as 40% ilmenite (Jones, 1978) and the other half is tourmaline (borosilicate of aluminium). Tourmaline is widely distributed in the Raya Granite and appears to be concentrated in the beach sands together with ilmenite at many places. Monazite and zircon also occur associated with the ilmenite and tourmaline but the reserves or quantity is relatively small (Figure 19).

Mineralogy of the black sand at Pantai Pasir Hitam has been studied in detailed by Wan Fuad Wan Hassan (1987) and Mohamad Sari Hasan (2011). The minerals content of the black sand as reported by Wan Fuad Wan Hassan (1987) is shown in Table 5.



Figure17 : Sand mining in Sungai Pong, Kelian Intan area, Malaysia  
 A- The sand dredging pump  
 B- The sand stockpile



Figure 18: Photograph of sand mound at Khlong Du Son, Khuan Don District.

Figure 19:Thinly interbedded of black sand and quartz at Pantai Pasir Hitam

Table 5: Mineralogical composition of the black sand at Pantai Pasir Hitam, Langkawi (after Wan Fuad Wan Hassan, 1987)

Magnetic fraction	Weight percent	Mineralogical composition
0.2 Amp.	0.15	magnetites
0.2.Amp.	0.92	ilmenites; rounded and polished
0.4 Amp.	10.76	mainly ilmenites; well rounded
0.6 Amp.	86.09	> 95% tourmalines; rounded, few grains of monazite and xenotime
0.8 Amp.	0.14	middlings and composite grains
1.0 Amp.	0.11	middlings and composite grains
1.0 Amp.	1.85	zircon, allanite, rutile, quartz etc.

Mohamad Sari Hasan (2011) has carried out quantitative mineral estimation analysis on the black sand samples from Pantai Pasir Hitam. He discovered that the black sand comprises predominantly quartz mixed with dark coloured heavy minerals. The dark coloured minerals consist predominantly of ilmenite and tourmaline with minor accessory minerals such as rutile, zircon, garnet, hydroilmenite, leucoxene, xenotime, monazite, epidote, magnetite and iron oxide. Based on the field evident and supported by the quantitative mineral estimation analysis, he concluded that the heavy minerals in the black sand is originated from the weathering of the granite which is abundantly occurred in Sungai Nyior valley. Reserve of the black sand deposit in Pantai Pasir Hitam coastal area is estimated at 5,120 metric tonnes. Ilmenite in the black sand is suitable for paint industries.

Alluvial ilmenite was recovered and mined for a short period prior to the Second World War from beach sands at Pantai Pasir Hitam along the north coast of Pulau Langkawi. The ore reserves were quickly exhausted and operations were brought to a close after a few months only.

### 4.3 Clay

In Malaysia, there are five clay deposits with an estimated reserve of 20.3 million tonnes of ball clay and 51.5 million tonnes of mottled clay found in the Pengkalan Kubur area (Mohd Suhaili Ismail *et al.*, 1993), Bukit Pak Junos (Zainol Abidin *et al.*, 1994) and Kampung Bakong Kechik, Kampung Gertak 3 and Padang Lichin, Gual Lensa and Kampung Cherang H Angus (Zainol Abidin *et al.*, 1995a). Summary of their reserves is shown in Table 6.

#### 4.3.1 Gual Lensa and Kampung Cherang H Angus ball clay

Follow-up ball clay investigation in these areas leads to discovery of a deposit covering 823 hectares in the Gual Lensa and Kampung Cherang H Angus areas, Pasir Mas.

Two types of ball clay, namely, mottled ball clay and unmottled ball clay were identified. The ball clays occur as lenses (Zainol Abidin *et al.*, 1995a).

Table 6: Summary of clay reserves in the study area.

No.	Potential area	Type of clay	Measured reserved (million metric tonne)
1.	Kampung Geretak Tiga and Kampung Padang Lichin.	Ball clay	1.8
		Mottled clay	3.9
2.	Gual Lemsu and Cherang Hangus	Ball clay	10.3
		Mottled clay	23.2
3.	Kampung Bakong Kechik	Ball clay	2.4
		Mottled clay	14.4
4.	Pengkalan Kubur	Ball clay	1.2
5.	Bukit Pak Junus	Ball clay	4.6
		Mottled clay	10.0
Total:		Ball clay	20.3
		Mottled clay	51.5

The mottled ball clay occurs mainly at the upper part of the deposit. Its thickness ranges from 0.2 to 8.0 m with an average of 2.3 m. This red clay has medium plasticity and medium to good green strength. The fired colour at 1,100°C is light pink to light red. The clay is comparable with some of the ball clays used for local tile, vitrified clay pipe, art ware and brick industries.

The unmottled ball clay layers have an average thickness of 1.2 m. The clay, light grey in colour, has generally medium to good green strength and medium to good plasticity. Its SiO<sub>2</sub> content ranges from 48.0 to 62.2%. The Al<sub>2</sub>O<sub>3</sub> content ranges from 24.5 to 33.6% and the Fe<sub>2</sub>O<sub>3</sub> content ranges from 1.14 to 2.6%. The fired colour at 1,100°C is predominantly off-white. The clay is comparable with some ball clays currently being used by the local tile, sanitary ware, tableware and artware industries.

The minimum reserve of the clay deposit based on a 200 m grid bore hole spacing is estimated at 33.5 million tonnes, comprising 23.2 million tonnes of mottled ball clay and 10.3 million tonnes of unmottled ball clay. The overburden is estimated to be 44 million tonnes.

#### 4.3.2 Kampung Geretak Tiga and Kampung Padang Lichin ball clays

Result of a follow-up clay investigation in these areas, a deposit covering 77 hectares has been discovered. Two types of ball clay, namely mottled ball clay and unmottled ball clay were identified. The ball clays occur as lenses (Zainol Abidin *et al.*, 1995b).

The mottled ball clay occurs mainly at the upper part of the deposit. The thickness of the clay ranges from 0.1 to 6.5 m with an average of 2.3 m. The clay, largely red in colour, has medium plasticity and good green strength. The fired colour at 1,100°C is light pink. The clay is comparable with those used for the local tile, vitrified clay pipe, art ware and brick industries.

The unmottled ball clay layers have a thickness of up to 4.0 m. The clay, light grey in colour, has medium to good green strength and medium plasticity. Its SiO<sub>2</sub> content ranges from 46.5 to 56.5%. The Al<sub>2</sub>O<sub>3</sub> content ranges from 27.9 to 35.0% and the Fe<sub>2</sub>O<sub>3</sub> content ranges from 1.23 to 2.26%. The fired colour at 1,100°C is predominantly off-white. The clay is comparable with those currently being used for the local tile, sanitary ware, table and art ware industries.

The minimum measured reserve of the deposit is estimated at 5.7 million tonnes comprising 3.9 million tonnes of mottled ball clay and 1.8 million tonnes of unmottled ball clay. The overburden is estimated to be 8.7 million tonnes.

### **4.3.3 Kampung Bakong Kechik ball clays**

Follow-up ball clay investigation in this area has resulted in the delineation of a deposit covering 292 hectares in the Kampung Bakong Kechik area, Pasir Mas. Two types of ball clay, namely mottled ball clay and unmottled ball clay were identified. The ball clays occur as lenses.

The mottled ball clay occurs mainly at the upper part of the deposit. The thickness of the clay ranges from 0.5 to 8.0 m with an average of 3.3 m. The clay, largely red in colour, has medium to high plasticity and medium to good green strength. The fired colour at 1,100°C ranges from light brown to red. The clay is comparable with those used for the local tile, vitrified clay pipe, art ware and brick industries.

The unmottled ball clay layers have an average thickness of 1.9 m. The clay, light grey in colour; has generally good green strength and medium plasticity. Its SiO<sub>2</sub> content ranges from 51.6 to 69.6%. The Al<sub>2</sub>O<sub>3</sub> content ranges from 21.3 to 30.7% and the Fe<sub>2</sub>O<sub>3</sub> content ranges from 1.15 to 2.37%. The fired colour at 1,100°C is predominantly off white. The clay is comparable with those currently being used for the local tile, sanitary ware, tableware and art ware industries.

The minimum measured clay reserve of the deposit based on a 200 m grid borehole spacing is estimated at 16.8 million tonnes comprising 14.4 million tonnes of mottled ball clay and 2.4 million tonnes of unmottled ball clay. The overburden is estimated to be 3.6 million tonnes (Zainol Abidin *et al.*, 1995c).

### **4.3.4 Pengkalan Kubur area ball clay**

A reconnaissance survey revealed two potential areas (on the basis of quality, thickness and extent of the unmottled ball clay deposit) at Kampong Kajang Sebidang–Kampong Kubang Sawa–Kampong Palas Merah and Kampong Ninchang in Tumpat

District. The unmottled ball clays occur as lenses. The total reserve is 1.2 million tonnes (Mohd Suhaili Ismail *et al.*, 1993).

At the Kampong Kajang Sebidang–Kampong Kubang Sawa–Kampong Palas Merah area, the unmottled ball clay layers have thicknesses ranging from 1.3 m to 2.1 m and the colour is light grey. Its SiO<sub>2</sub> content ranges from 53.0 to 56.8 %. The Fe<sub>2</sub>O<sub>3</sub> content ranges from 1.32 - 1.79 % and the TiO<sub>2</sub> content ranges from 0.58 - 0.89 %. The fired colour at 1,100 °C is off-white.

At the Kampong Ninchang area, the ball clay layers have an average thickness of 1.1 m and are light grey in colour. Its SiO<sub>2</sub> content is high (65.2 %). The Fe<sub>2</sub>O<sub>3</sub> and TiO<sub>2</sub> contents are 1.64 % and 0.74 % respectively. The fired colour at 900 °C, 1,000 °C and 1,100 °C is off-white.

#### **4.3.5 Bukit Pak Junus area ball clay**

Follow-up ball clay investigation in this area has resulted in the delineation of a deposit covering 362 hectares in the Bukit Pak Junus area, Pasir Mas (Zainol Abidin *et al.*, 1994). Two types of ball clay, namely, mottled ball clay and unmottled ball clay were identified. The ball clays occur as lenses.

The mottled ball clay occurs mainly at the upper part of the deposit. The thickness of the clay ranges from 0.2 to 6.4 m with an average of 1.9 m. The clay, largely red in colour, has medium to high plasticity and medium to good green strength. The fired colour at 1,100°C ranges from pink to mainly orange and reddish brown. The clay is comparable with those used for the local tile, vitrified clay pipes, art ware and brick industries.

The unmottled ball clay layers have an average thickness of 1.32 m. The clay, light grey in colour, has generally good green strength and medium plasticity. Its SiO<sub>2</sub> content ranges from 53.0 to 70.7%. The Al<sub>2</sub>O<sub>3</sub> content ranges from 17.5 to 31.0% and the Fe<sub>2</sub>O<sub>3</sub> content ranges from 0.96 to 2.46%. The fired colour at 1,100°C is predominantly off-white. The clay is comparable with those already used for the local tile, sanitary ware, tablewares and art ware industries.

The measured reserve of the clay deposit is estimated at 14.6 million tonnes comprising 10 million tonnes of mottled ball clay and 4.6 million tonnes of unmottled ball clay. The overburden is estimated to be 15 million tonnes.

#### **4.3.6 Clay deposit in North Perlis**

To date, there is no detailed clay investigation carried out on the Malaysian side of the Transect area. Clay deposits are found widely distributed in the alluvial plain on the low-lying areas such as at Kampung Darat, Kampung Beseri, Kampung Salang, Kampung Hutan Kandis, Bukit Nasi Sa Bungkus, Kampung Wai and Kampung Wang Besar. It is generally composed of light to dark grey clay containing variable amounts of fine sand. Forty four clay samples from shallow auger holes carried out for Quaternary geology

study have been selected for firing test. The result shows that only 10 samples are suitable for bricks manufacturing.

#### **4.3.7 Clay deposit in Song Khla area**

On the Thai side of the Transect area, ball clay had been exploited in several locations. In Songkhla Province, approximately three deposits have been mined for primary industrial materials such as bricks for construction, jar, bowl (latex container), porcelains etc.

Ban Khao Wang Ching deposit is confined to the plain in Ban Thung Lung, Hat Yai District. Generally, the clay are commonly characterized by its brown to red colour, with slightly sandy.

### **4.4 Crystalline limestone**

#### **4.4.1 Gunung Reng**

Outcrops of crystalline limestone are observed at Gunung Reng, close to Sungai Tadoh which is located in Transect 2 area. It occurs as lenses trending N-S and continuing near the border area. In the southern part, these rocks can also be observed at the Gua Setir area. The rock is light grey to grey, thin bedded to massive. Sometimes it shows light- and dark-banded layers. Detailed study is recommended in the near future to determine the potential of this rock for dimension stone and others such as cement, calcium carbonate powder, quick lime and hydrated lime industries. The Gunung Reng area may have the potential to be developed for the tourism industry due to its beautiful panoramic scene.

#### **4.4.2 Perlis state**

In Malaysia, limestone occurs widespreadly in the western and central parts of the Transect 4 area as represented by the Setul Formation /Thung Song ( $O_{st/ts}$ ) and Chuping/Khao Rub Chang/Chaiburi Formation ( $PTr_{ch/kc/cb}$ ). The limestone resources are sufficient enough to support quarry operation supplying the rock aggregates and various industrial products. Aw (1981) investigated 13 limestone hills in Perlis State and estimated the limestone reserve of about 500 million tonnes. Most of the limestones investigated contain high amount of CaO but in some places it is high in MgO content. Limestone resources in Perlis are being exploited for rock aggregates, cement industries, lime products, hydrated lime as well as for chemical and agricultural products. There are numbers of limestone quarries currently operating in Perlis in which about 3.8 million tonnes of limestone products were produced (Nursusila Md. Said, 2003). Photograph one of the limestone quarries is shown in Figure 20.

#### **4.4.3 Langu area**

In Thailand, the majority of limestone is produced from the Ordovician limestone, Silurian-Devonian sedimentary sequences containing sizeable limestone lenses, and Permian limestone. Three limestone quarries have been investigated for aggregates in Satun Province i.e. at Ban Thung Nui, Khuan Kalong District and Ban Nam Phut of La Ngu

District (Figure 21). Limestone aggregates produced from these quarries during the year 2000-2004 were about 1.5 million tonnes.

In Songkhla Province, limestone quarry has been operating at Khao Nui, Ban Thung Tam Sao, Khlong Hoi Khong District for construction materials production.

#### 4.4.4 Langkawi Island

In Langkawi Islands, limestone is quarried for rock aggregates and cement industries. At Kampung Kilim, Hosna Realty (Quarry) Sendirian Berhad is producing limestone aggregates for constructional purposes. At Telok Ewa, Malayan Cement Industries Sendirian Berhad is exploiting limestone for cement industries. Previously, white marble or better known as Royal White Marble was quarried for dimension stone at the northern part of Pulau Dayang Bunting. However, since a few years ago, the dimension stone quarry was abandoned due to the environment issues.

### 4.5 Barite

#### 4.5.1 Tanah Merah

In Malaysian side, barite deposit was discovered only at Bukit Pencuri in the District of Tanah Merah within the Transect 2 area which is associated with hematite. The percentage of BaSO<sub>4</sub> analysed from three samples collected is shown below:

	BaSO <sub>4</sub> (%)	Fe <sub>2</sub> O (%)	Specific Gravity
Sample 1	57.6	38.1	4.5
Sample 2	64.6	32.5	4.6
Sample 3	79.2	7.11	4.0

The barite ore can be used as a weighting agent in drilling fluid for oil-well exploration. Currently, this mine is closed. There was no production recorded from this abandoned mine.

#### 4.5.2 Klian Intan

In Sg Pong, Klian Intan in Transect 3 area there are occurrences of barite float in the form of boulders was initially reported by Oh (1974) in the vicinity of Sungai Pong. Later Ismail *et al.* (1989) reported that a few barite boulders were found along the lower reaches of Sungai Pong. They occur as subrounded, white translucent gravel sized float material along the valley floor.

During the current study, barite floats were noted in Sungai Pong, and a few primary barite veins that associated with quartz were observed along the timber track cut parallel to Sungai Pong at Kampung Pong, Pengkalan Hulu (5° 33' 11" N, 100° 59' 53" E to 5° 32' 54" N, 100° 59' 31" E). Analysis carried out by the Minerals and Geoscience Department Malaysia indicated that the chemical composition of the barite float is as follows: BaSO<sub>4</sub> (95.65%), Fe<sub>2</sub>O<sub>3</sub> (0.03%) and other components (0.27%). The primary barite veins cut the argillaceous rock of the Kroh formation (SD<sub>Kr</sub>) in the NW-SE direction, not far from the limestone and granite bodies. The largest veins were observed at 5° 32' 46" N,

100° 59' 24" E. Each of the veins is 20 cm wide, trending 40° with dip angle 55° towards SE. Coarsely laminated and rose forms of barite crystal can be observed. The BaSO<sub>4</sub> content varies from 0.04% to 94.67%. Further detail study is recommended in order to trace the extension and to determine the grade of the barite (Figure 22).

#### 4.5.3 Betong area

On the Thai side, the barite deposit was first found during the last fieldwork carried out in the Transect area. The deposit is located along the road-cut at km 5 from Betong town to the Malaysia-Thailand border. Its veins generally occur in shale bed, limestone lenses and chert, and trending N-S. It is mainly found in coarsely laminated form and some of barites in rose form can be observed (Figure 23). Two samples were analysed and indicated its composition is as follows: BaSO<sub>4</sub> (95%), SiO<sub>2</sub> (2%), Al<sub>2</sub>O<sub>3</sub> (0.7%), Fe<sub>2</sub>O<sub>3</sub> (0.3%), MgO (0.03%), CaO (0.25%) and SrSO<sub>4</sub> (1.72%). Therefore, it is recommended that further detailed exploration should be conducted at this locality and adjacent area, in order to evaluate the barite potential.



Figure 20: Photograph of a limestone quarry at Bukit Chuping, Malaysia.



Figure 21: Photograph of a limestone quarry at Ban Nam Put, Thailand



Figure 22: Quartz vein associated with minor amount of barite exposed near Kampung Pong, Pengkalan Hulu, Malaysia



Figure 23: Barite crystal found at Ban Ka Pae Hulu, Betong District, Thailand

## 4.6 Dolomite

### 4.6.1 Perlis

Dolomite deposits are located in the central part of the Transect 2 area which is underlain as part of the Chuping/Khao Rub Chang/Chaiburi Formation (PTr<sub>ch/kc/cb</sub>). Eighteen limestone samples collected from the Chuping/Chaiburi Formation (PTr<sub>ch2/cb</sub>) were analyzed by the Technical Services Division Laboratory, Minerals and Geoscience Department Malaysia to determine the MgO content. Chemical analysis results show that 11 samples have yielded MgO content of more than 18% by weight; indicating the limestone at those locations is dolomite. The size of dolomite area is estimated to be about 8 square kilometres which includes Felda Rimba Mas Quarry, Kampung Belukar Imam and Bukit Ngolang. Highly fractured, pink limestone at Felda Rimba Mas Quarry are quarried to supply dolomite to the Kangar Dolomite Factory, one of the dolomite powder suppliers for the Malaysia Sheet Glass Factory in Johor Bahru (Figure 24).

### 4.6.2 Khao Rub Chang area

On the Thai side, limestone samples collected in the Khao Rub Chang area, Sadao District are pink in colour and highly fractured. Calcite veins can be observed in this area. The analysis results reveal that all of the samples have yielded MgO content of more than 18% by weight. This indicates that the limestone at those locations is dolomite. However, a part of that area has been mined for construction materials whilst some of them are waiting for dolomite mining lease approval (Figure 25).

### 4.6.3 Dolomitic limestone in Langkawi Island

There is some demand for dolomitic limestone rich in magnesia that is used as soil conditioning. The limestone from Pulau Dayang Bunting shows appreciable dolomitization containing almost pure dolomite carrying 21.79% MgO. However the limestone reserve is not yet to be exploited due to the geopark conservation constraints.



**Figure 24:** Photograph of a dolomite open pit at Felda Rimba Mas Quarry, Perlis.



**Figure 25:** Photograph of a dolomite open pit at Khao Rub Chang Quarry, Sadao District.

## 4.7 Rock aggregates

These resources are widespread in the Transect 3. The reserves are sufficient enough to be quarried for construction materials and also to supply the raw material for various industrial products i.e. dimension stone, Precipitated Calcium Carbonate (PCC), Grinded Calcium Carbonate (GCC), filler and etc. However detailed study on the quality, their economic potential and environmental impact is needed.

### 4.7.1 Pengalun Hulu area

On the Malaysian side, the granite supplies are available mainly from the Bintang granite ( $Tr_{grbt}$ ) in the west and from Rimba Telui granite ( $Tr_{grrt}$ ) in the north of Gerik town. Abundant supplies of metasandstone and quartzite are available from the arenaceous facies of the Keroh formation ( $SD_{kr}$ ) and the Kubang Pasu Formation ( $C_{kp}$ ). Crystalline limestones are available from the calcareous member of the Silurian-Devonian Keroh formation ( $SD_{kr}$ ) and in the Gerik formation ( $P_{gk}$ ). There are two abandoned quarries, which supplied rocks aggregate for the Temengor and Bersia Dam construction project. The quarries are metatuff quarry at Bersia and quartzite quarry at Jalan Ayer Ganda, south of Gerik. Currently there is only one quarry still operating due to the low demand from the construction projects in the study area. There is only one limestone quarry still operating at Bukit Jagor, near Gerik town which supply rock aggregates to the surrounding areas. However, the quarry operation is temporal and entirely dependent on local demand i.e. the quarry normally closed temporarily when there is no order received (Figure 26).

### 4.7.2 Yala area

On the Thai side, most of limestone products have been exploited in Yala Province. Almost all of them are produced for construction materials and a few for dimension stone (Figure 27). Based on the year 2001 record, approximately 698,000 tonnes of limestone were produced from eight quarries.

### 4.7.3 Merah area

Other potential geological resources in the Transect 5 are rock aggregates and dimension stone. The reserves are sufficient enough to be quarried for construction materials. The granite supplies are available mainly from the Merah and Kabut Granites. There are three abandoned quarries, which previously supplied rocks aggregate for the construction of the East-West Highway, such as at Km 61.6 ( $05^{\circ} 36.057' N$ ,  $101^{\circ} 30.532' E$ ) and at Km 63.3 ( $05^{\circ} 36.345' N$ ,  $101^{\circ} 31.181' E$ ) as shown in Figures 28 respectively.

### 4.7.4 Langkawi Island

At present, granite is quarried for constructional purposes at three localities in Pulau Langkawi; namely Bukit Lembu in Mukim Kedawang, Jalan Ulu Melaka in Mukim Ulu Melaka and Padang Ragut also in Mukim Ulu Melaka. The rock aggregate is produced for local used only.



Figure 26: Limestone quarry at Bukit Jagor, Gerik, Malaysia.



Figure 27: Quarries in Yala Province, Thailand.

A- Limestone aggregates quarry, Betong District.

B- Abandoned marble quarry in the Tham Thalu mining area.



Figure 28: A: Abandoned granite quarry at Km 61.6 of the East-West Highway

B: Abandoned granite quarries at Km 63.3 of the East-West Highway

#### 4.8 Volcanic rocks with high flux content

Large amounts of feldspar are available in the tuff of the Gerik formation in Malaysia and they may be potential sources for feldspar extraction. Feldspar mineral is an important raw material for industrial product such as in glass making industries, ceramic etc. Results from XRD and geochemistry analyses for a number of volcanic rocks samples collected during the survey indicated high flux content but a follow-up detailed survey is recommended to obtain more accurate volume estimate and its economic potential.

On the Thai side, there is so far no record of feldspar deposits.

#### 4.9 Guano

On the Malaysian side of the Transect area, most of the limestone hills contain valuable deposits of bat guano, which is used for fertilizer. Bukit Chuping, Bukit Mata Ayer and Bukit Jerneh are the major hills which serve as the main source of guano in the Transect area. The guano-bearing caves are confined to the Chuping/Khao Rub Chang/Chaiburi Formation (PTr<sub>ch/kc/cb</sub>), where the massive nature and purity of the carbonate contribute to the development of the enormous caves, which form place for the bats (Figure 29). On the Thai side, studies on guano have not yet been recorded.



Figure 29: Guano at Bukit Mata Ayer, Perlis.

### 5.0 GEOCHEMICAL EXPLORATION

On the Malaysian side, regional geochemical survey had been carried out by Geological Survey Department in 1991 – 1993 covering Topographical Map Sheets 11 (Gunung Ulu Merah), 19 (Kerunai) and 20 (Belum) areas. Stream sediment and rock samples were collected for geochemical study. As a result, several multi-elements anomalous areas were identified; of which seven of them are situated in the Belum-Hala Transect area (Figures 30-31). Pertinent information on these anomalies including element associations, area extent, underlying geology, the number of anomalous samples and the range of values is summarized in Table 7. Anomalies are ranked from 1 – 4 in descending order of follow-up priority. Follow-up work is not recommended for anomalies with a rating of four.

### 5.1 Anomaly 1901 [Sn, W, U (As, Ag, Zn, Pb)]

Anomaly 1901 is situated in the upper reaches of Sungai Kenarong, close to the Malaysia-Thailand border. The area covers approximately 20 km<sup>2</sup> and is underlain by arenaceous rocks of the Carboniferous Kubang Pasu Formation, intruded by small granitic stock. Anomalous elements are Sn, W and U as well as As, Ag, Pb and Zn. Sn value ranging from 40 ppm – 160 ppm whereas W ranging from 3 ppm – 20 ppm and U ranges from 2 ppm – 19.8 ppm. This anomaly is rated as Priority 3 which requires possible follow-up for Sn, W and U.

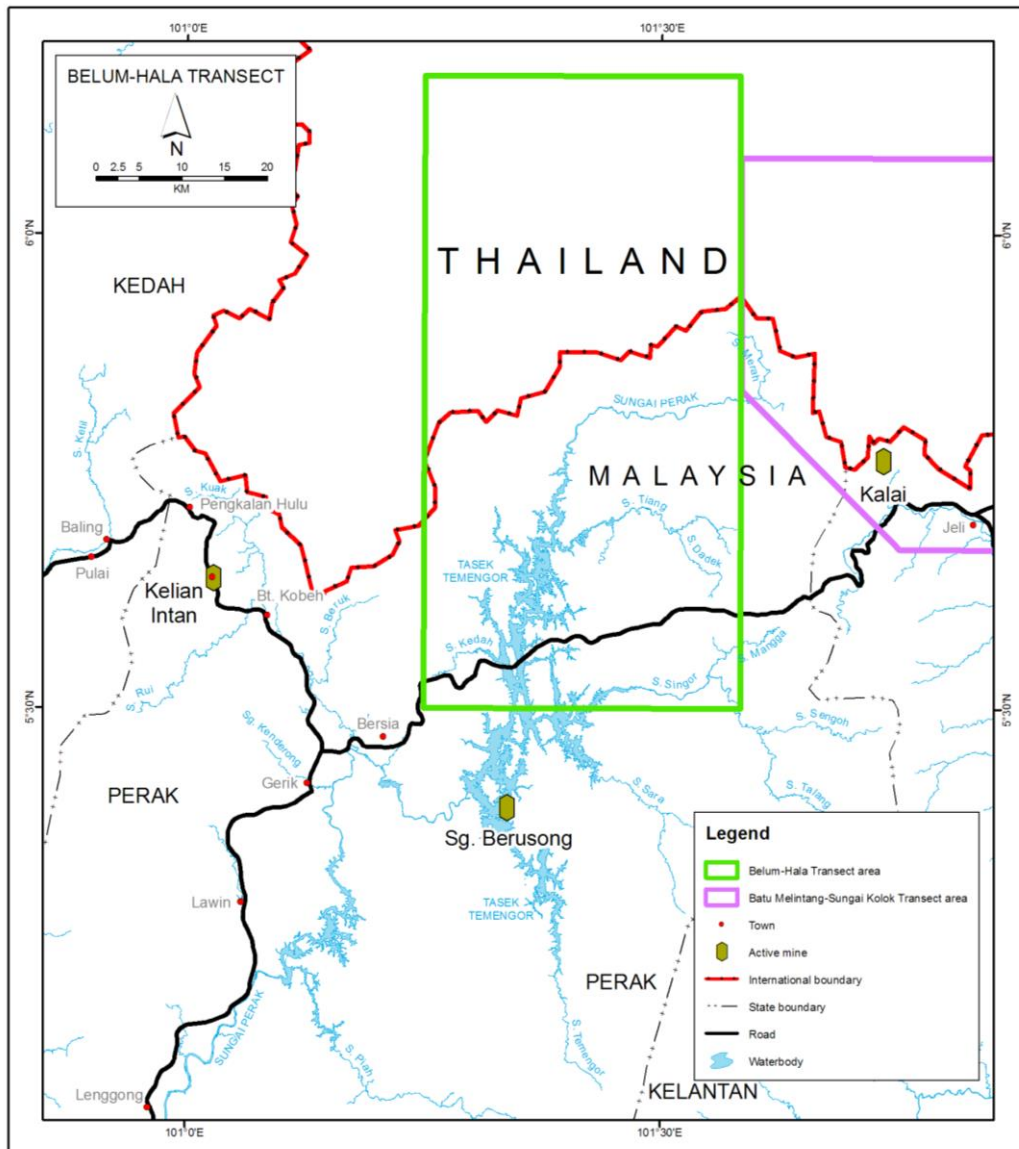


Figure 30: Mining activities in the adjacent areas (Malaysian side)

## 5.2 Anomaly 1903 [Au, Cu, Co (Mn, Ni, Hg)]

Anomaly 1903 is situated on the western part of the Transect area. It covers approximately 27 km<sup>2</sup> in the headwaters of Sungai Kedah and Sungai Cermin. The area is underlain by arenaceous and argillaceous rocks of the Permian Gerik formation, intruded by small dolerite dyke. This is essentially an Au-Cu-Co anomaly with less extensive anomalies for Mn, Ni and Hg. Gold value in stream sediment is 0.05 ppm – 10.049 ppm whereas in heavy mineral concentrate it gives maximum tenor value 3.2 mg/m<sup>3</sup>. Anomalous Cu and Co are found in Sungai Cermin. Their values in stream sediment are ranging from 60 ppm – 300 ppm and 22 ppm – 103 ppm respectively. This anomaly was rated as Priority 2 that requires eventual follow-up for Au, Cu and Co.

## 5.3 Anomaly 2001 [Sn, As, W (Zn, Au)]

This is predominantly Sn-As-W anomaly, located in the Sungai Palai drainage. It covers an area of at least 43 km<sup>2</sup>. The rocks underlying this anomaly are predominantly quartz-mica schist of the Tiang schist that intruded by small stocks of Singor Granite. The area is cut by NE-SW fault that runs parallel to the Laho Fault. Tin and tungsten show high anomalous geochemical values in the stream sediment where anomalous Sn values range from 20 ppm – 40 ppm and W from 4 ppm – 12 ppm. Anomalous Sn values are randomly distributed over the area whereas As and W exhibit good association. This anomaly is given Priority 3 which requires possible follow-up.

## 5.4 Anomaly 2002 [Sn, Ag, W, As (Pb, Ni, U)]

This multi-element anomaly, located in the upper reaches of Sungai Dadek and tributaries of Sungai Mangga with an areal extent of 51 km<sup>2</sup>. High geochemical values are centred over the NE-SW Jakal Fault and unnamed NW-SE fault which demarcates the contact between the Triassic Kabut Granite and the Carboniferous Tiang schist. This anomaly is highlighted by Sn associated with Ag, W and As. It is defined by thirteen anomalous stream sediment samples containing Sn values ranging from 20 ppm – 30 ppm and also anomalous values of Ag (39 samples), W (15 samples) and As (19 samples). Anomalous values of Pb, Ni and U also occur. This anomaly is given a Priority 2 and should be followed up to assess the tin and tungsten potential.



Table 7: Summary of anomalies on the Malaysian side of the Transect area

Anomaly No.	Element(s)	Area (km <sup>2</sup> )	Range in ppm (No. of anomalous samples)	Geology	Priority Rating
1901	Sn, W, U (As, Ag, Zn, Pb)	20	Sn 40 – 160 (11) W 3 – 20 (10) U 2 – 19 (10) As 8 – 120 (4) Ag 0.08 – 0.4 (12) Zn 110 – 260 (10) Pb 6 – 60 (4)	Arenaceous rocks of Carboniferous Kubang Pasu Formation, intruded by small granitic stock	3
1903	Au, Cu, Co (Mn, Ni, Hg)	27	Au 0.015 – 10.049 (9) Cu 60 – 300 (5) Co 22 – 103 (5) Mn 5,000 – 6,130 (2) Ni 16 – 83 (3) Hg 0.05 – 0.16 (2) *Gold tenor: 3.2 mg/m <sup>3</sup>	Arenaceous and argillaceous rocks of Permian Gerik formation, intruded by small dolerite dyke	2
2001	Sn, As, W (Zn, Au)	43	Sn 20 – 40 (31) As 10 – 200 (22) W 4 – 12 (8) Zn 127 – 142 (2) Au 0.083 – 0.324 (2)	Predominantly quartz-mica schist of the Tiang schist intruded by small stocks of Singor Granite, microgranite, lamprophyre as well as quartz veins.	3
2002	Sn, Ag, W, As (Pb, Ni, U)	51	Sn 20 – 30 (13) Ag 0.6 – 1.0 (39) W 8 – 40 (15) As 10 – 60 (19) Pb 51 – 96 (5) Ni 49 – 55 (3) U 6.2 – 14.2 (8)	Contact aureole between the Kabut Granite and Tiang schist. Fault zone strikes NE-SW and NW-SE	2
<p>Note:                      Priority 1 indicates high priority rating - warrants immediate follow-up                      Priority 2 indicates moderate priority - requires follow-up                      Priority 3 indicates low priority - possible follow-up</p>					

## **6.0 OTHER GEOLOGICAL RESOURCES**

### **6.1 Hot springs**

#### **6.1.1 Hot Spring in Malaysian Side**

Hot spring discharging water rich in dissolved minerals are known at many localities in and around the Transect area. The water is related to the final cooling phase of magmatic activity.

On the Malaysian side, hot springs are located at, Pengkalan Hulu and along the Lebey fault (after Sungai Lebey). The hot springs cut through the metasedimentary rocks of the Kroh formation ( $SD_{kr}$ ) close to the granite bodies. The water temperature at Kampung Ayer Panas hot spring is up to 91 °C. The other three are located outside of the study area:

- a) In the valley of Sungai Kenering emerged from the Bintang granite ( $Tr_{grbt}$ ) at Kampung Ayer Panas,
- b) At 4 km South of Gerik from bedded tuff and
- c) At Kampung Ulu Legong, Baling from granite (49 °C).

The hot springs at Kampung Ayer Panas, Pengkalan Hulu and at Kampung Ulu Legong, Baling have already been developed for tourist attraction (Figure 32).

#### **6.1.2 Hot Spring in Betong area**

The first site is one of the famous tourist attractions for Betong District which is located at Ban Bor Nam Ron, 9 km north of Betong town (Figure 33). The hot spring occurs along the N-S trending fault located on the contact between the Betong Formation ( $SD_{bt}$ ) and Pa Ret Tu granite ( $Tr_{grpr}$ ). The water temperature is up to 60 ° – 70 °C. The second site is at Ban Na Kor, 38 km northeast of Betong town. It is originated from the NW-SE trending fault located on the contact between the Yaha Formation ( $C_{yh}$ ) and Chantharat granite ( $Tr_{grch}$ ). The water temperature is approximately 40 ° – 50 °C. It is now being developed into a tourist attraction.

Due to its rich content in dissolved minerals and high temperature, the hot spring water is believed to have some therapeutic value. The high temperature hot spring might be developed for thermal power. However, its development is subjected to further detailed studies.

#### **6.1.3 Hot Spring in Satun area**

Another hot spring was discovered in Thai side is at Khlong Nam Ron and Ban Bor Nam Ron, Khuan Kalong District of Satun Province (Figure 34). This area is confined to the contact zone of coarse-grained granite and argillaceous limestone. Water temperature is about 50<sup>0</sup> C and the rate of water flow is about 140 cubic meters per hour. However, this area has not yet been developed for tourist attraction.



Figure 32: Hot springs in Malaysia.

A- Hot spring at Ulu Legong, Baling District, Kedah.

B- Hot spring at Kampung Ayer Panas, Pengkalan Hulu, Perak.



Figure 33: Hot springs in Thailand.

A- Hot spring at Ban Bor Nam Ron, Betong District.

B- Hot spring at Ban Na Kor, Betong District.



Figure 34: Photograph of a hot spring at Ban Bor Nam Ron, Khaun Kalong District of Satun Province.

## 6.2 Coal

On the Malaysian side of the Transect area, the occurrence of coal in the Bukit Arang Beds was first reported by Scrivenor (1913). He mentioned that the coal-bearing strata were exposed in the pits on the slopes of Bukit Arang located on the Malaysia-Thailand border. Its quality is comparable to the coal at Batu Arang in Selangor. Deep boring by the Railway Department in the year 1919 and 1921, revealed that very small amount of coal deposits exist in this area and considered as of no economic significance (Jones, 1981).

In 1982, Geological Survey Department Malaysia carried out coal investigation in this area. During the exercise, four deep boreholes (to the depth of 135–180 m) and numerous shallow holes (< 100 m) were sunk. A few coal seams of not more than 30 cm thick had been observed and evaluated (Aw, 1982).

On the Thai side, drillings was done at Ban Kaun Lak, Sadao District, Songkhla Province. However, the results revealed that lignite potential is in the Pleistocene terrace deposits.

## 6.3 Geological Heritage

All 20 geosites and geoconservation sites in Tarutao Island (see table 8) are significant geological evidences which indicate the geological history of the islands including fossil diversity. According geological survey, there are still many important geosites in Tarutao have not been reported, and these geosites are well protected by National Park Act.1961 to ensure that natural resources are free from harm. However, to conserve the geosites, Thailand has followed some Langkawi geopark's practices such as specify geo-conservation areas, present their importance and develop and promote geotourism.

The geosites in Tarutao are now defined into 4 areas depending the geological value and geomorphology (Figure 35), some sites need the urgent protection. The followings are details of each area;

### 6.3.1 Ao Pante Malaka-Ao Son bio-diversity area

The protected Geosites is the fossiliferous diversity area of the oldest rock unit in Thailand known as Tarutao Group. The correlated unit in Langkawi Islands is known as The Machinchang Formation. The area is covered along the coast of sandstones from Ao Pante Malaka- Ao Chak- Ao Moe Lae – Laem Hin Ngam – Ao Son, in the western part of Tarutao.

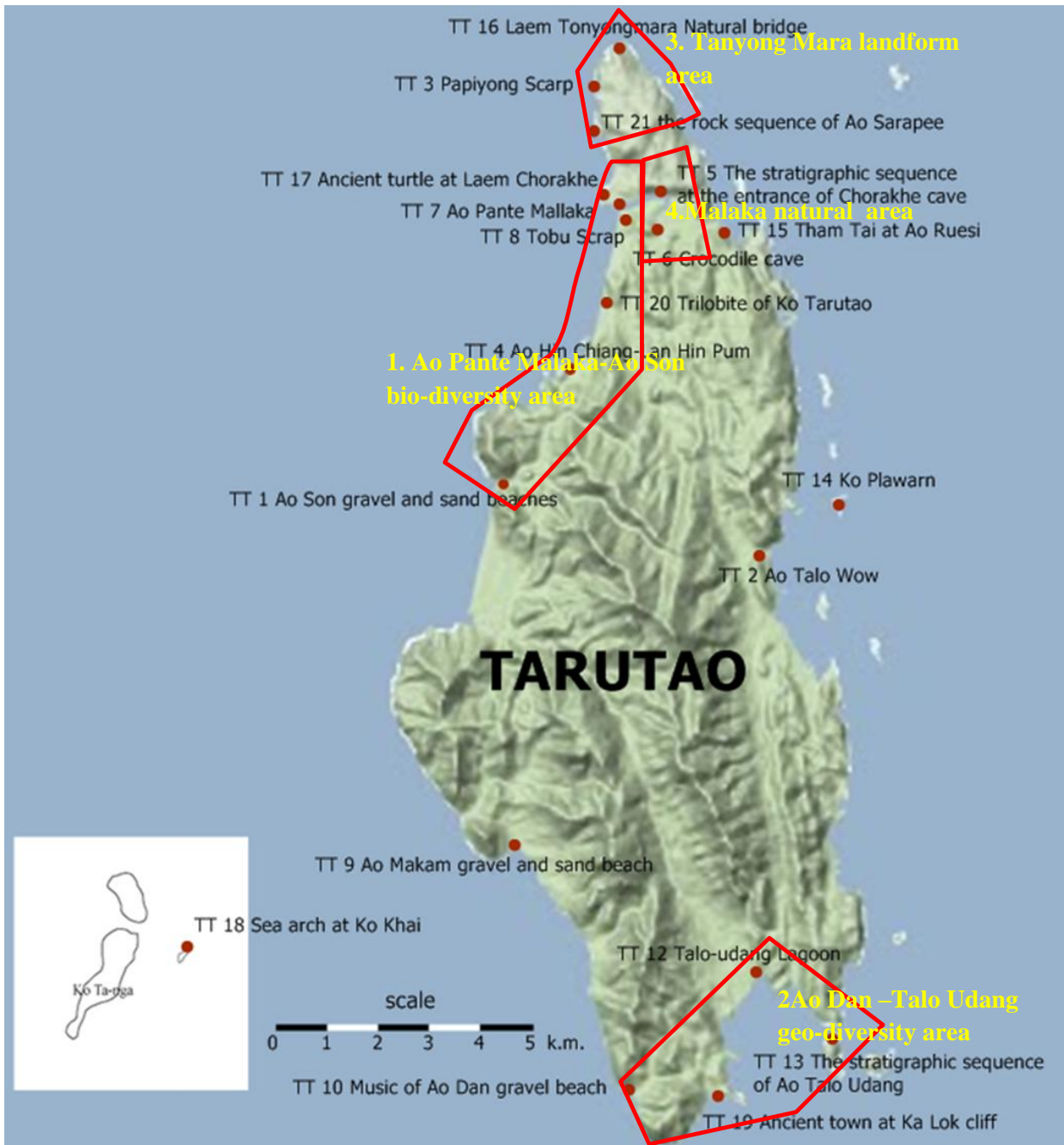


Figure 35: The location of four protected geosites in Tarutao Island

Table 8 Simplified list of geological site based on geodiversity and significance of Talutao Islands

No.	GEOLOGICAL SITES	SIGNIFICANT	GEODIVERSITY							Protection Status
			Typical Mineral	Typical Rocks	Geological Structure	Geomorphology	Hot Spring	Type Section	Fossil	
1	Ao Pante Mallaka (TT 7)	The oldest rocks in Thailand are well exposed.			✓	✓			✓	Tarutao National Park
2	Laem Tonyongmara Natural bridge (TT 16)	A beautiful scenic morphology represented by cape and sea knock.			✓	✓				Tarutao National Park
3	Ao Son gravel and sand beaches (TT 1)	The site is characterised by 4 km long white sand and gravel beaches.				✓				Tarutao National Park
4	Ao Makam gravel and sand beach (TT 9)	It is characterised by 2 km long white sand and gravel beaches.				✓				Tarutao National Park
5	Music of Ao Dan gravel beach (TT 10)	It is represented by the 1 km long gravel beach during deposition having music and transportation.				✓			✓	Tarutao National Park
6	Talo-udang Lagoon (TT 12)	It is represented by the lagoon deposits close to the sand barrier.				✓				Tarutao National Park
7	Ao Talo Wao (TT 2)	It is characterised by the karst topography of the Ordovician limestone with faults and fractures.			✓	✓		✓		Tarutao National Park
8	Papiyong Scarp (TT 3)	It is characterised by the karst topography and a fault scarp in the Ordovician limestone resulting from Normal faults and fractures.			✓	✓				Tarutao National Park
9	Crocodile cave (TT 6)	It is characterised by the karst topography and a cave in the Ordovician limestone with beautiful stalagmites and stalactites.			✓	✓				Tarutao National Park
10	Tobu Scrap (TT 8)	It is characterised by the karst topography and fault scarp in the Ordovician limestone with beautiful scenery.			✓	✓				Tarutao National Park

Table 8 Simplified list of geological site based on geodiversity and significance of Talutao Islands (con't)

No.	GEOLOGICAL SITES	SIGNIFICANT	GEODIVERSITY						Protection Status	
11	Ko Plawarn (Islands of Whales) (TT 14)	The islands are caused by weathering and erosion processes. Stunning natural sculptures look like a whale that pops up from the sea.			✓	✓			✓	Tarutao National Park
12	Tham Tai (inactive cave) at Ao Ruesi (TT 15)	A small cave with stalactites on the ceiling. Nearby, there is a beach surrounded by limestone cliffs.			✓	✓				Tarutao National Park
13	Ancient turtle at Laem Chorakhe (TT 17)	This site has a beautiful morphology shaped like “green turtle”. This stunning natural sculpture is caused by the processes of weathering and erosion.			✓	✓				Tarutao National Park
14	Sea arch at Ko Khai (TT 18)	This site has a beautiful morphology by weathering and erosion processes. The sea arch shape looks like wedding arch.			✓	✓				Tarutao National Park
15	Ancient town at Ka Lok cliff (TT 19)	This site has a beautiful morphology by weathering and erosion processes. The steep cliffs look like a beautiful painting of the ancient town.			✓	✓				Tarutao National Park
16	Ao Hin Chiang-Lan Hin Pum (TT 4)	This site is a bay located east of Ko Tarutao and presents the type section of the Tarutao Group.			✓	✓		✓		Tarutao National Park
17	The stratigraphic sequence at the entrance of Chorakhe cave (TT 5)	This site is located east of Ko Tarutao where the type section of the Malaka Formation of the Ordovician Thung Song Group is indicated. These limestones have been eroded until there are a lot of amazing looks such as a craggy rock, cavity, caves etc.			✓	✓		✓		Tarutao National Park

Table 8 Simplified list of geological site based on geodiversity and significance of Talutao Islands (con't)

No.	GEOLOGICAL SITES	SIGNIFICANT	GEODIVERSITY						Protection Status
18	The stratigraphic sequence of Ao Talo Udang (TT 13)	This site has a good section for study the rock sequence of the Thung Song Group. Beautiful cliffs can be observed from this area caused by folding and erosion processes.			✓	✓		✓	Tarutao National Park
19	the rock sequence of Ao Sarapee (TT 21)	This site is in the northwestern part of Ko Tarutao consisting of the type section of the La Nga Formation, Thung Song Group (Ordovician). A beautiful dark grey, thick-bedded limestone is exposed with eastward dipping. There are rough surfaces of a sharp edge.			✓	✓		✓	Tarutao National Park
20	The site along the road from Pante Malaka to Ao Talo Wao, at the crossroad to Ao Son. (TT 20)	Oldest trilobite fossils and rock sequences in Thailand are present. The trilobite was identified as the new species of the world i.e. Easaukia buravasi.			✓	✓		✓	Tarutao National Park

Geological Heritage Sites of Ao Pante Malaka-Ao Son bio-diversity area;

i. Ao Pante Malaka is located at the mouth of canals Northwest of the Tarutao Island with very clearly primary sedimentary structures such as ball and pillow structures, cross bedding, load casts, convolute bedding, and hummocky cross stratification. The rock exposures consist of reddish brown sandstone intercalated with siltstone containing invertebrate fossils. It is exposed about 400 m in length from Laem Jorake (crocodile cape) to the mouth of canals near the Tarutao national park. Geologically, it is represented by reddish brown sandstone, and siltstone interbedded with micaceous sandstone of the Cambrian Tarutao Group. This unit is conformably overlain by argillaceous limestones of the Ordovician Thung Song Group. The geological structures in this area consist mainly of cross bedding, ball and pillow structures, load casts, and slump structures.

ii. Ao Son gravel and sand beaches is located at Ao Son, Tarutao Island. This geomorphology site is represented by white sand and gravel beaches, namely, Ao Son gravel and sand beaches. The sand and gravel beaches, about 4 km long, are exposed along the shoreline. The site is situated approximately 8 km west of the Tarutao National Park's headquarter and can be accessed by boat and car. Geologically, Quaternary sediments at this site are represented by white and reddish brown, fine- to medium-grained sand with local deposits of well rounded, high sphericity pebbles and boulders

iii. Tobu Scrap is located at Tobu Scarp, Tarutao Island. The site can be accessed by walking tract from the park office with the distance of about 400 m. This site is characterised by the karst topography and fault scarp in the Ordovician limestone with beautiful scenery. At the top of scarp is the view point area where Laem Hin Ngom (south), Adang Island (west) and Laem Chorakhe (north) can be seen. Geologically, the rocks consist of grey, thin- to medium-bedded limestone belonging to the Pante malaka Formation of the Ordovician Thung Song Group. The scarp is resulted from NNW-SSE direction fault (Figure 36).

iv. Ancient turtle at Laem Chorakhe This site has a beautiful morphology shaped like "green turtle". This stunning natural sculpture is caused by the processes of weathering and erosion. It is located on Malaka creek, Tarutao Island. Size of the turtle island is about 100X150 m which can be accessible by boat from the Tarutao national park office, the distance about 500 m. Laem Chorakhe is composed of 440 million years old limestone. Scour of cracks is caused by erosion and weathering processes of wave actions. This island looks like the green turtle facing the sea when viewed from the sea towards the coast. However, the island looks like a crocodile lying down facing the sea. This can be seen from the view point of the To Bu cliff.

v. Ao Hin Chiang-Lan Hin Pum This site is a bay located east of Tarutao Island and presents the type section of the Tarutao Group. Bay width is about 800 m, accessible by boat from the Tarutao national park office about 3.5 km or by road about 4 km. Ao Mo Lae or Ao Hin Chiang-Lan Hin Pum consists of the delicate white sand beach (about 1 km long) extending along the western coastal line of Tarutao Island. The southern part of the beach comprises the oldest rock of Thailand (500 million years old) containing abundant fossils. The rocks have brown or purple brown colour with dipping seaward. In some areas, rocky crevices are filled with cracks and eroded forming nodes, holes, and porous (honeycomb) shapes. The gravels have angular shape.



Figure 36: Scenic view point at Tobu Scarp; Laem Chorakhe (top left), Laem Hin Ngom (bottom left), bedding along the way to Tobu Scarp (right).

v. Ao Hin Chiang-Lan Hin Pum This site is a bay located east of Tarutao Island and presents the type section of the Tarutao Group. Bay width is about 800 m, accessible by boat from the Tarutao national park office about 3.5 km or by road about 4 km. Ao Mo Lae or Ao Hin Chiang-Lan Hin Pum consists of the delicate white sand beach (about 1 km long) extending along the western coastal line of Tarutao Island. The southern part of the beach comprises the oldest rock of Thailand (500 million years old) containing abundant fossils. The rocks have brown or purple brown colour with dipping seaward. In some areas, rocky crevices are filled with cracks and eroded forming nodes, holes, and porous (honeycomb) shapes. The gravels have angular shape.

Numerous trilobites and brachiopod are present west of Tarutao Island. Kobayashi (1957) dated a common trilobite fauna to the Late Cambrian. The best known trilobites are *Pagodia thaiensis*, "*Eosaukia*" *buravasi*, and *Coreanocephalus phanulatus*. Brachiopod is *Apheorthis* (?) sp. Other trilobites fossils were found in Talo Topo Bay (Ao Mo Lae) consisting of *Lichengia?* *tarutaoensis* Kobayashi (= *Saukiella tarutaoensis*), *Lophosaukia* cf. *jiangnanensis*, *Micragnostus* (*Micragnostus*) sp. indet., *Quadraticephalus planulatus* Kobayashi (= *Coreanocephalus planulatus*), *Leiostegiid* gen. et sp. indet., *Shumardiid* gen. et sp. indet., *Szechuanella* ? cf. *damujingensis*, *Thailandium solum*, *Tsinania* (*Tsinania*) cf. *nomas* (Figure 37-42).



Figure 37: Closed- up view of fossil assemblages in sandstones of the Mo Lae Formation. Most of them are rather incomplete consisting of broken pieces, Ao Mo Lae, Tarutao Group



Figure 38: Closed- up view of giant spines of trilobites in the Ao Mo Lae Formation at Ao Mo Lae



Figure 39: Closed- up view of several types of trilobite in the Ao Mo Lae Formation. The trilobites have been identified as *Thailandium solum* Kobayashi, *Eosaukia buravasi* Kobayashi and *Coreanocephalus planulatum*



Figure 40: Closed- up view of perfect bodies of brachiopod in the Mo Lae Formation at Ao Mo Lae, Tarutao Island



Figure 41: Closed-up view of *Eosaukia buravasi* , Tarutao Island.



Figure 42: Closed-up view of brachiopods in the Tarutao Group, Tarutao Island

vi. The rock sequence of Ao Sarapee This site is in the northwestern part of Tarutao Island consisting of the type section of the La Nga Formation or the middle part of the Pante Malaka Formation, Thung Song Group (Ordovician). This bay, 100 m long, can be accessible by boat from the Tarutao national park office about 1 km. The rock sequence is represented by dark grey, massive limestones alternated with thin-bedded dolomitic limestone. These limestones have sandy texture containing, trace fossils (U-shaped borrows of worm), mud cracks and bivalves. Therefore, this indicates a shallow coastal deposition environment

vii. Trilobites of Tarutao Island This site is along the road from Pante Malaka to Ao Talo Wao, at the crossroad to Ao Son. This site is accessible by car from the Tarutao national park office about 3 km. The oldest trilobite fossils and rock sequences in Thailand are present. The trilobite was identified as the new species of the world, i.e. *Easaukia buravasi*. Geologically, Glabella and genal spines of trilobites (Late Cambrian) and brachiopods were discovered from sandstones alternated with red shale of the Tarutao Group. This rock sequence shows high weathering with southeastward dipping.

### **6.3.2 Ao Dan –Talo U Dang geo-diversity area**

Geodiversity in this area is remarkable such as stratigraphy and rock age which are perfectly continued. This can indicate the evolution of area which composes of Tarutao Group (incomplete) and complete Thung Song Group. The latter unit can be correlated with part of Setul Formation in Langkawi Islands. The area is covered along the coast of sandstones and limestones from Ao Dan- Ao Talo U Dang – Pana Island- Lae Tong Island, in the southern part of the Tarutao Island. Geological Heritage Sites of Ao Dan –Talo U Dang geo-diversity area is represented by

i. Music of Ao Dan gravel beach. The site is represented by the typical beautiful gravel beach, namely, the Music of Ao Dan gravel beach. The site is situated at Ao Dan, Tarutao Island. The site can be accessed only by boat from the park office with distance of about 29 km. Geologically, Quaternary deposits at this site are characterised by reddish brown, well rounded, high sphericity pebbles and boulders. These gravels are weathered and eroded from the reddish brown sandstone of the Cambrian Tarutao Group. Trilobites and brachiopods are found in the outcrops east of the site. Gravels beach, approximately 1 km long, is exposed along the shoreline.

ii. Talo-udang Lagoon The site is located at Ao Talo-udang, Tarutao Island. The lagoon covers approximately 200 m long along the shoreline. The site can be accessed by boat 33 km from the park office. Geologically, Quaternary sediments are characterised by grey to greenish grey, clayey sand of lagoonal deposits with fragments of shells. The sediments are interpreted as having been deposited in lagoonal environment under the fluvio-lacustrine and occasional marine influxes.

iii. Ancient town at Ka Lok cliff The site has a beautiful morphology by weathering and erosion processes. The steep cliffs look like a beautiful painting of the ancient town. The site can be accessed by boat from the Tarutao national park office about 27 km. Cliffs are composed of yellowish brown rocks that look like a castle in the ancient city of Cambodia. This geomorphology is resulted from the nature of the rocks having thin beds, the processes of weathering and erosion along the beds, and wave actions perpendicular to the cracks (Figure 43).



Figure 43: Ancient town at Ka Lok cliff, Ao Tami, Tarutao Island

iv. The stratigraphic sequence of Ao Talo udang The site is located in Ao Talo U Dang, southern part of Tarutao Island where the complete sequences of the Malaka Formation, Thung Song Group (Ordovician) are exposed. The site can be accessible by boat from the Tarutao national park office about 33 km. Geomorphologically, this site has a good section for study the rock sequence of the Thung Song Group. Three lithostratigraphic units of the Thung Song Group have been recognized as the Pante Malaka, Lae Tong and Rung Nok Formations in ascending order. In addition, beautiful cliffs can be observed from this area caused by folding and erosion processes (Figure 44).



Figure 44 : Exposure of the Pante Malaka Formation, Thung Song Group along the coast of Ao Talo U Dang, Tarutao Island

### 6.3.3 Tanyong Mara Landform area

This protected area composes of various kinds of geological features i.e. beautiful karst topography, geodiversity and stratigraphy which are continuous sequence. These sequences can indicate the evolution of the area where some part of Thung Song Group is exposed. The area is covered along the coast of limestone landforms from Laem Tayong Mara to Rusi Cave, in the northern part of the Tarutao Island.

Karst topography of this rock cliff landscape is largely shaped by the dissolving action of water on limestone of the Thung Song Group, and is also developed by fracture and fault in limestone as shown in the pictures below (Figure 45).

Geological Heritage Sites of Tanyong Mara Landform area consist of

i. Laem Tonyongmara Natural bridge This site, namely Laem Tonyongmara Natural bridge, is represented by the clearly folded structures. The area is situated at Laem Tonyongmara, Tarutao Island, It is exposed at about 300 m along the shoreline, 5 km from the Tarutao National Park's headquarter which can only be accessed by boat. A beautiful scenic morphology represented by cape and sea knock in grey to greenish grey, limestones. Geologically, the rocks at this site are represented by grey to dark grey, well bedded, medium- to thick-bedded limestones and argillaceous limestones belonging to the Ordovician Thung Song Group. Faults, folds, and fractures in various directions are the main structural features which have affected the limestones. The cape, sea knock, and erosional surfaces are caused by wave actions, particularly during high tide.

ii. Papiyong Scarp This site shows a fault scarp in the limestone of Ordovician age. The name of this scarp is derived from a movie called "Papiyong". The site is located at Papiyong Scarp, the northernmost part of Tarutao Island. The exposure of this scarp along the shoreline is approximately 100 m long. The site can be accessed only by boat from the park office about 2.5 km. It is characterised by the karst topography and a fault scarp in the Ordovician limestone resulting from Normal faults and fractures (Figure 46).

iii. Tham Tai (inactive cave) at Ao Ru si is located on Rusi cave, eastern part of the Tarutao Island. The cave is about 50 m wide and 10 m deep. This cave is accessible by boat from the Tarutao national park office about 11 km. The beach is surrounded by limestone cliffs in this bay. Sand beach is along the coast, about 500 m long. The Northwest - southeast part of this bay is blocked by the limestone cliff. The central part has a small cave with stalactites on the ceiling of the cave, but not sparkling calcite crystals i.e. No accumulation of calcite. This cave is similar to the "inactive cave." Geologically, This area consists of grey to dark grey, thin- to medium-bedded limestone, argillaceous limestone and dolomitic limestone. The structures are commonly found such as folds, faults, cleavages and fractures. Calcite can be found in many fractures. This area has a fault line having strong weathering and erosion along the surface of faults and cleavages (Figure 47).



Figure 45: General view of the Ordovician limestone at Laem Tanyong Mara, Tarutao Island.



Figure 46: Papiyong Scarp at Laem Tanyong Mara, Tarutao Island



Figure 47: Tham Tai (inactive cave) at Ao Ru si , Tarutao Island.

#### 6.2.4 Malaka Natural area

This protected area shows the gorgeous karst topography where some part of the Thung Song Group is exposed. The area is located along the mouth of Malaka canale to Crocodile cave, in the northern part of Tarutao Island. Geological Heritage Sites of Malaka Natural area is illustrated by

i. Crocodile cave The site displays a cave in the limestone of the Ordovician age, namely, Crocodile cave. The site is located at Crocodile cave, Tarutao Island. The site can be accessed only by boat from the park office with the distance of about 7 km. Geomorphologically, It is characterised by the karst topography and a cave in the Ordovician limestone with beautiful stalagmites and stalactites.

ii. Stratigraphic sequence at the entrance of Chorakhe cave The site is located east of Ko Tarutao where the type section of the Malaka Formation of the Ordovician Thung Song Group is indicated. Along the banks of Phante Malaka canal the wonderful limestones (about 440 million years old) are present. These limestones have been eroded until there are a lot of amazing looks such as a craggy rock, cavity, caves etc. Geologically, the Ordovician limestones belonging to the Malaka Formation can be seen along the banks of Phante Mallaka canal. This formation is the lowest unit of the Thung Song Group consisting of argillaceous limestone alternated with dolomitic limestone. However, these strata were interfered with bioturbation and commonly show mud cracks and some fossils (algalmat and shipworm) (Figure 48-49).



Figure 48: Exposure of limestone along Malaka canal showing discontinuous laminar, thin-medium bedded. The rocks are represented to the lower part of the formation.



Figure 49: Well-bedded, medium-bedded limestones of the middle part of the formation represent good exposures of paleo-sea cave

## 7. REFERENCES

- Abdullah Sulaiman and Mat Niza Abdul Rahman, in manuscript.** Geology and mineral resources of the Pengkalan Hulu-Baling area, Kedah, part of Sheet 18. *Geological Survey Department Malaysia* (in Malay).
- Ab. Halim Hamzah and Mohd Azmer Ashaari, 1991.** Gold exploration in Bukit Kuang, Kelantan. *Geological Survey Malaysia, Report No: EMR 2/1991.* (in Malay).
- Abdul Rahim Samsudin, Basir Jasin, Ahmad Jantan and Uyob Said, 1991.** Some geological aspects of the Triassic clastic rocks along western zone of Peninsular Malaysia. *Sains Malaysiana*, **20**(1), 55-74 (in Malay).
- Ahmad Jantan, Basir Jasin, Abdul Rahim Samsudin and Uyop Said, 1987.** Note on the Occurrence of Limestone in the Semanggol Formation, Kedah, Peninsular Malaysia. *Warta Geologi*, **13**(14), 151-159.
- Alexander, J.B., 1959.** Pre-Tertiary Stratigraphic Succession in Malaya. *Nature*, London, **183**, 203 – 232.
- Aranyakanon, P., 1969.** Tin deposits in Thailand, A Second Technical Conference on Tin, Bangkok, in Fox, W., *International Tin Council*, London, V. I, 83 – 102.
- Aw, P.C., 1967.** Ignimbrite in the Central Kelantan, Malaya. *Geological Magazine*, 104, 13-17.
- Aw, P.C., 1978.** An Evaluation of the Barite Resources of Peninsular Malaysia. *Geological Survey Malaysia, Report No: MX(N)1/1978.*
- Aw, P.C., 1990.** Geology and Mineral Resources of the Sungai Aring Area, Kelantan. *Geological Survey Malaysia Memoir*, 12. 116 p.
- Basir Jasin, 1994.** Middle Triassic radiolaria from the Semanggol Formation, Northwest Peninsular Malaysia. *Warta Geologi*, **20**(4), 279 – 284.
- Basir Jasin, 1995.** Occurrence of bedded radiolarian chert in the Kubang Pasu Formation, north Kedah, Peninsular Malaysia. *Warta Geologi*, **21**(2), 73-79.
- Basir Jasin, 1996.** Discovery of Early Permian Radiolaria from the Semanggol Formation, Northwest Peninsular Malaysia. *Warta Geologi*, **22**(4), 283 – 287.
- Basir Jasin and Zaiton Harun, 2001.** Some radiolarians from the bedded chert of the Kubang Pasu Formation. *Proceedings Geological Society of Malaysia Annual Geological Conference 2001*, 111 – 114.
- Bignell, J.D., 1972.** The Geochronology of the Malayan granites. *PhD. Thesis, University of Oxford.* pp. 174, 175, 291 (unpublished).
- Bignell, J.D. and Snelling, N.J., 1977.** Geochronology of Malayan granites. Overseas Geological and Mineral Resources, 47. Institute of Geological Sciences, London. 77 p.
- Biswas, B., 1973.** Quaternary changes in sea-level in the South China Sea. In *Proceedings of Regional Conference SE Asia, Geology Society Malaysia Bulletin*, No. 6, 229-256.
- Bosch, J.H.A., 1986.** Young Quaternary Sediments in the coastal plain of Kelantan, Peninsular Malaysia. *Geological Survey Malaysia. Quaternary Geology Section Report No. QG/2 of 1986*, 42 p.
- Bosch, J.H.A., 1988.** The Quaternary Deposits in the Coastal Plains of Peninsular Malaysia, *Geological Survey Malaysia. Quaternary Geology Section Report No. QG/1 of 1988*, 87 p.
- Bradford, E.F., 1972.** The geology and mineral resources of the Gunung Jerai area, Kedah. *Geological Survey Department West Malaysia Memoir*, **8**, 242pp.
- Burton, C.K., 1965.** Wrench faulting in Malaya. *Journal of Geology*, **73**, 781 – 798.
- Burton, C.K., 1967.** The Mahang Formation: A Mid-Palaeozoic euxinic facies from Malaya-with notes on its condition of deposition and palaeogeography. *Geologie en Mijnbouw*, **46**, 167 – 187.
- Burton, C.K., 1970.** The geology and mineral resources of the Baling area, Kedah and Perak. *Geological Survey Department West Malaysia Memoir*, **12**, 150pp.
- Burton, C.K., 1972.** Outline of the geological evolution of Malaya. *Journal of Geology*, **80**, 293 – 309.
- Burton, C.K., 1973.** Mesozoic, in: **Gobbet, D.J. and Hutchison, C.S., (Eds.).** *Geology of the Malay Peninsula.*

Wiley Interscience, 97 – 142.

- Burton, C.K., 1986.** The Baling Group/Bannang Sata Group of the Malay/Thai Peninsula. *Journal of Southeast Asian Earth Sciences*, **1**(2), 93 – 106, Tokyo University Press.
- Chaimanee, N. and Tiypairat, S., 1983.** Quaternary Geology and Silica Sand Deposits in Songkhla; *Geological Survey Division, DMR, Bangkok*, 67 p. (in Thai).
- Chaimanee, N., 1999.** The Lowland Peat of Thailand: Evolution and Human-Induce hazards, *In Proceedings of the CCOP 35, part-II Technical Reports, Subic Bay, Zambales, The Pilippines*, 251-263.
- Chakapag, P., 1985.** Geological Map of Thailand: Amphoe Betong (scale 1:250,000). *Geological Survey Division, Department of Mineral Resources, Thailand*.
- Chaodumrong, P., 1992.** Stratigraphy, sedimentology and tectonic setting of the Lampang Group, Central North Thailand. *Ph.D thesis*, University of Tasmania, 230p.
- Charusiri, B., 1989.** Lithopile Metallogenetic Epochs of Thailand: A Geological and Geochronological Investigation. *Ph.D. thesis, Queen's University, Kingston, Canada*, 891p. (unpublished).
- Charusiri, B. and Charusiri, P., 1990.** Geology and Sn-mineralization at Pinyok mine, Yala, Southern Thailand. *Development Geology for Thailand into Year 2000, Chulalongkorn University, Bangkok, Thailand*. pp. 170 – 187.
- Che Aziz Ali, Ahmad Jantan, Ibrahim Abdullah and Juhari Mat Akhir, 1995.** Depositional environment and the occurrence of paleosol in the Nenering bed in Grik, Perak. *Bulletin of the Geological Society Malaysia*, **38**, 91 – 108 (in Malay).
- Chu, L.H., Muntanion, H., Sidik, A., Chand, F. and Troup, A., 1982.** Regional geochemistry of South Kelantan. *Geological Survey Malaysia. Geochemical Report 1.*, 59 p.
- Cobbing, E.J., Mallick, D.I.J., Pitfield, F.E.J. and Teoh, L.H., 1986.** The granites of the South East Asian Tin Belt. *Journal of the Geological Society, London*, **143**, 537 – 550.
- Cobbing, E.J., Pitfield, P.E.J., Darbyshire, D.P.F. and Mallick, D.I.J., 1992.** The granites of the Southeast Asian tin belt. *British Geological Survey, Overseas Memoir*, **10**, London HMSO, 369 p.
- Corpel, J., and Pebeglia, N., 1987.** Malaysia-Airborne Magnetic Survey, Central Belt Project. *A reinterpretation report. French-Malaysia Technical Cooperation*.
- Courtier, D.B., 1974.** Geology and mineral resources of the neighbourhood of Kulim, Kedah. *Geological Survey Malaysia Map Bulletin*, **3**, 50p.
- Darbyshire, D.P.F., 1988.** Southeast Asian granite project: Geochronology of Malaysian Granite. *Report of the Isotope Geology Centre, Natural Environment Research Centre*, No. 88/3, 56pp.
- Dheeradilok, P., Tiyanan, S. and Teerarungsigul, N., 1991.** The coastal deposits of Pattani area, southern Thailand, *The Inqua International Symposium on Stratigraphy and Correlation of Quaternary deposits of the Asian and Pacific Regions, CCOP/TP.22*, 87-106.
- Fontaine, H. and Ibrahim Amnan, 1994.** The limestone of Sungai Rui and Sungai Kuak Valleys, (Upper Perak). *Geological Survey Department Malaysia Report SP/02/1994* (unpublished).
- Foo, K.Y., 1983.** The Palaeozoic sedimentary rocks of Peninsular Malaysia-Stratigraphy and correlation. *Proceedings of the workshop on Stratigraphic Correlation of Thailand and Malaysia*. Geological Society of Thailand & Geological Society Malaysia, Volume 1- Technical Papers, 1 – 19.
- Foo, K.Y., 1990.** Geology and Mineral Resources of the Taiping-Kuala Kangsar area Perak Darul Ridzuan. *Geological Survey Department Malaysia Map Report*, **1**, 145pp.
- Fuangthong, S., Maneeprapan, K., Chaiyasen, S. and Sukkhwon, N., 1994.** Report on General Geological and Geochemical Surveys in the area of Khlong Ti Moong, Sukhirin District, Narathiwat Province, Thailand, *technical report submitted to Cholasin Co. Ltd.*, 31 p. (in Thai).
- Geological Society of Malaysia, 1997.** *Malaysian Stratigraphic Guide*, 30p.
- GMT, 1995.** The Geotechnological Investigation Report, Pigul Thong Project, Narathiwat, 53 p. (in Thai).

- Hamada, T., 1968.** Ambocoeliids from red beds in the Malayan Peninsula. *Geology and Palaeontology of Southeast Asia*, **5**, 13 – 25, Tokyo University Press.
- Hamada, T., 1969.** Late Palaeozoic brachiopods from red beds in the Malayan Peninsula. *Geology and Palaeontology of Southeast Asia*, **6**, 251 – 267, Tokyo University Press.
- Hamada, T., 1970.** Devonian brachiopods from Kroh, Upper Perak in Malaysia. *Geology and Palaeontology of Southeast Asia*, **7**, 1 – 13, Tokyo University Press.
- Hamada, T., Igo, H., Kobayashi, T. and Koike, T., 1975.** Older and Middle Palaeozoic formations and fossils of Thailand and Malaysia. *Geology and Palaeontology of Southeast Asia*, **15**, 1 – 38, Tokyo University Press.
- Hastings, P., 1983.** Polynology and the Vegetation Development of a lowland peat swamp in Narathiwat, Thailand, In *Proceedings of the Annual Technical Meeting 1992*, edited; Thanasuthipitak T., Publication Department of Geological Sciences, Chaing Mai University, Chiang Mai, Thailand, 121-131.
- Hutchison, C.S., 1977.** Granite emplacement and tectonic subdivision of Peninsular Malaysia. *Bulletin of the Geological Society of Malaysia*, **9**, Special Circum-Pacific Volume, 187 – 207.
- Hutchison, C.S., 1989.** *Geological Evolution of South-east Asia*. Clarendon Press, Oxford, 368p.
- Hutchison, C.S., 1996.** *Geological Evolution of South-east Asia*. Second Edition. Geological Society of Malaysia. 368 p.
- Hutchison, C.S. and Taylor, D., 1978.** Metallogenesis in S.E. Asia. *Journal of Geological Society of London*, **135**, 407 – 428.
- Ibrahim Abdullah, Juhari Mat Akhir, Abd. Rasid Jaapar and Nor Azian Hamzah, 1991.** The Tertiary Basin in Felda Nenering, Pengkalan Hulu (Keroh), Perak. *Warta Geologi*, **17**(4), 181 – 186.
- Ismail Iman, Zakaria Mohamad and Khoo, K.K., 1989.** Geochemistry of southwest Klian Intan, Upper Perak, Malaysia. *Geological Survey Department Malaysia Report NM 01/1989* (unpublished).
- Javanaphet, C., 1969.** Geological map of Thailand, scale 1:1,000,000. *Department of Mineral Resources*, Bangkok, Thailand.
- Jones, C.R., 1968a.** Lower Palaeozoic Rocks of Malay Peninsula. *Bulletin American Association of Petroleum Geology*, **52**(7), 1259 – 1278.
- Jones, C.R., 1968b.** Malayan Early to Mid-Palaeozoic Stratigraphy and the Siluro-Devonian Graptolite Faunas of the Malay Peninsula. *University of Birmingham PhD. thesis*, (unpublished).
- Jones, C.R., 1970.** The geology and mineral resources of the Grik area. Upper Perak. *Geological Survey Department Malaysia Memoir*, **11**, 144pp.
- Jones, C.R., 1973a.** Lower Palaeozoic In: *Geology of Malay Peninsula* (Edited by **Gobett, D.J & Hutchison, C.S.**), 25 – 60. Wiley International, New York.
- Jones, C.R., 1973b.** The Siluro-Devonian graptolite faunas of the Malay Peninsula. *Overseas Geology and Mineral Resources*, **44**, Institute of Geological Sciences, London.
- Jones, C.R., 1981.** Geology and mineral resources of the Perlis, north Kedah and the Langkawi Islands. *Geological Survey Department West Malaysia Memoir*, **17**, 257pp.
- Jones, C.R., 1981.** Geology and mineral resources of Perlis, North Kedah and the Langkawi Islands. *Geological Survey of Malaysia Memoir*, **10**, 457p.
- Jones, C.R., Gobett, D.J. and Kobayashi, T., 1966.** Summary of fossil record in Malaya and Singapore 1900 – 1965 in Kobayashi and Toriyama. *Geology and Palaeontology of Southeast Asia*, **2**, 309 – 359, Tokyo University Press.
- Kaewyana, W. and Kruse, G.A.M., 1987.** On the Muddy Coast Deposits of an Area North of Songkhla, Southern Thailand, CCOP/ROPEA-R. , 17 p.
- Kamal Roslan Mohamed, 1989.** Stratigraphy and sedimentology of the Triassic rocks of Peninsular Malaysia. *Ph.D thesis*, University College, London, 293p. (unpublished).

- Khoo, K.K., 1989.** Geology and mineralisation of the Rahman Hydraulic tin and adjacent mines, Klian Intan, Upper Perak, Malaysia. *Geological Survey Department Malaysia Report NM/03/1989* (unpublished).
- Khoo, T.T., 1983.** Nature of the contact between the Taku schist and adjacent rocks in the Manik Urai area, Kelantan and its implications. *Bulletin of the Geological Society of Malaysia*, **16**, 139-158.
- Kobayashi, T., 1958.** Some Ordovician fossils from the Thailand-Malayan Borderland. *Japanese Journal of Geology and Geography*, **29**, 224 – 231.
- Kobayashi, T., 1964.** *Halobia* and some other fossils from Kedah, northwest Malaya. *Geology and Palaeontology of Southeast Asia*, **1**, 69-88.
- Kobayashi, T., Burton, C.K., Tokuyama, A. and Yin, E.H., 1967.** The *Daonella* and *Halobia* Facies of the Malay Peninsula compared with those of Japan. *Geology and Palaeontology of southeast Asia*, **3**, 98-122.
- Kobayashi, T. and Hamada, T., 1968.** A Devonian phacops recently discovered by Mr. Charan Poothai in Peninsular Thailand. *Geology and Palaeontology of Southeast Asia*, **4**, Tokyo University Press.
- Kobayashi, T. and Hamada, T., 1971.** Agnostoid trilobites in a Devonian Formation in West Malaysia. *Proceeding of Japan Academy*, **47**(4).
- Kobayashi, T. and Hamada, T., 1972.** A unique trilobite assemblage of the Devonian Kroh fauna in West Malaysia with notes on the tentaculites facies and the older Palaeozoic faunal sequence in Thailand-Malaya, *Geology and Palaeontology of Southeast Asia*, **10**, 1 – 34, Tokyo University Press.
- Liew, T.C. and Page, R.W., 1985.** U-Pb Zircon dating of granitoid plutons from the West Coast Province of Peninsular Malaysia. *Journal of the Geological Society*, London, **142**, 515 – 526.
- Loh, C.H., 1992.** Quaternary Geology of the Teluk Intan Area, Perak Darul Ridzuan. Geological Survey Malaysia, *Quaternary Geology Bulletin III*, 52 p.
- MacDonald, S., 1955.** Brief notes on the geology of the valleys of the Pergau and Lebir, Kelantan. *Geological Survey, Federation of Malaya* (unpublished).
- MacDonald, S., 1963.** Field notes volume I, Geologist Kelantan. *Geological Survey Malaysia* (unpublished).
- MacDonald, S. 1967.** Geology and mineral resources of North Kelantan and North Terengganu. *Geological Survey Malaysia Memoir*, Vol. 10, 202 p.
- Mat Niza Abdul Rahman, Abdullah Sulaiman and Yunus Abd. Razak, 2008.** Geology and mineral resources of the Hulu Muda and Pedu areas, Kedah Darul Aman, Geological Survey of Malaysia (in Malay).
- Mat Niza Abdul Rahman and Mohamad Hussein bin Jamaluddin, 2014.** Lithostratigraphic correlation of the Rebak/Khuan Klang Formation along the Malaysia-Thailand border area, Proceedings National Geoscience Conference 2014, Geological Society of Malaysia, 199-201.
- Metcalf, I., 1990.** Stratigraphic and tectonic implications of Triassic conodonts from northwest Peninsular Malaysia. *Geological Magazine*, **127**, 567-578.
- Mohamad Hussein Jamaluddin, Mohamad Sari Hasan, Mohd Badzran Mat Taib, Selvarajah, M., Askury Abd Kadir and Mohd Asbi Mohd Zin, 1994.** Geology and mineral resources of the Belum and Gunung Ulu Merah (Sheet 20 and part of Sheet 11), Upper Perak. *Proceeding of the 25<sup>th</sup>. Annual Geological Conference, 1994, Technical papers*, **6**, 11 – 25 (in Malay).
- Mohamad Hussein Jamaluddin, Mohamad Sari Hasan, Mohd Badzran Mat Taib, Selvarajah, M., Askury Abd Kadir and Mohd Asbi Mohd Zin, in manuscript.** Geology and mineral resources of the Belum and Gunung Ulu Merah (Sheet 20 and part of Sheet 11), Upper Perak. *Geological Survey Department Malaysia* (in Malay).
- Mohamad Hussein Jamaluddin, Mohd Badzran Mat Taib, Mohd Sari Hasan, Selvarajah, M., Askury Abd. Kadir and Mohd Asbi Mohd Zin (in manuscript).** Geology and mineral resources of the Belum area (Sheet 20 and Sheet 11), Perak. *Geological Survey Malaysia* (in Malay).
- Mohamad Hussein Jamaluddin, Mohd. Badzran Mat Taib and Mohd Sari Hasan (in manuscript).** Geology and mineral resources of the Batu Melintang area (Sheet 21 and Sheet 12), Kelantan. *Geological Survey Malaysia* (in Malay).

- Mohamad Hussein bin Jamaluddin and Mat Niza Abdul Rahman, 2014.** Lithology and stratigraphy of the Panau formation, Proceedings National Geoscience Conference 2014, Geological Society of Malaysia, 202-203.
- Mohd Asbi Mohd Zin, Mohd Badzran Mat Taib, Mohamad Hussein Jamaluddin and Askury Abd Kadir, in manuscript.** Geology and mineral resources of Gerik area, Perak, Sheet 31. *Geological Survey Department*
- Mohd Azmer Ashari, Che Abdul Rahman Jaafar and Ong, W.S., 1995.** Reconnaissance Geochemical Exploration for Gold in Kelantan. *Geological Survey Malaysia*, Report No: **EMR 03/95**. (in Malay). *Malaysia* (in Malay).
- Mohd Badzran Mat Taib, Mohd Asbi Mohd Zin and Selvarajah, M., 1993.** Geology and mineral resources of the Kerunai area (Sheet 19), Perak Darul Ridzuan. *Proceeding of the 24<sup>th</sup> Annual Geological Conference, 1993, Technical papers*, **5**, 92 – 106 (in Malay).
- Mohd Badzran Mat Taib, Mohd Asbi Mohd Zin and Selvarajah, M., in manuscript.** Geology and mineral resources of the Kerunai area (Sheet 19), Perak Darul Ridzuan. *Geological Survey Department Malaysia* (in Malay).
- Mohd Nazan Awang, 1985.** Groundwater investigation at Bukit Bunga, Tanah Merah, Kelantan. *Geological Survey Malaysia Annual Report 1985*. pp. 264-291 (in Malay).
- Mohd Pauzi Abdullah, 1992.** The Occurrence of the Nening Beds in Pengkalan Hulu Area. *Proceeding of the 23rd. Annual Geological Conference, 1992, Technical papers*, **4**, 92 – 106 (in Malay).
- Mohd Suhaili Ismail, Mohd Pauzi Abdullah, Loh, C.H. and Teoh, L.H., 1993.** Reconnaissance Ball Clay Investigation in Kelantan. *Geological Survey Malaysia*, Report No: IM 11/93. (in Malay).
- Morris, 1978.....**
- Muenlek, S., Meesook, A. and Tongchit, P., 1979.** Geological map of Changwat Narathiwat-Kolabaharn, Amphoe Betong, scale 1:250,000, *Geological Survey Division, DMR, Bangkok, Thailand*.
- Muenlek, S., Meesook, A. and Thongchit, P., 1982.** Geology and mineral resources of Sheet Narathiwat and Betong, southern Thailand. *Geological Survey Division Report, Department of Mineral Resources, Bangkok, Thailand*, 56p. (in Thai).
- Muenlek, S., Meesook, A. and Tongchit, P., 1979.** Geological map of Changwat Narathiwat-Kolabaharn, Amphoe Betong, scale 1:250,000, Geological Survey Division, *Department of Mineral Resources*, Bangkok, Thailand.
- Muenlek, S., Meesook, A. and Thongchit, P., 1982.** Geology and mineral resources of Sheet Narathiwat and Betong, southern Thailand. Geological Survey Division, *Department of Mineral Resources*, Bangkok, Thailand, 1 – 56: (in Thai).
- Muenlek, S., Udomratn, C. and Wongwanich, T., 1981.** Geological Survey of Southern Region, Preliminary Report on Stratigraphy of Southern Thailand, Geological Survey Division, *Department of Mineral Resources*, Bangkok, Thailand, 60pp.
- Nakapadungrat, S., Boonkanphai, N., Chinakul, A., Tiyapairat, S. and Maneenai, D., 1988.** Geology of Saba Yoi Quadrangle. *Geological Survey Division Report No. 109, Department of Mineral Resources, Bangkok, Thailand*, 47p.
- Nuchanong, T., 1999.** Gold Exploration and Discovery in Thailand; *Economic Geology Technical Report, DMR, Bangkok*, 106 p.
- Nutalaya, P., Campbell, K.V., MacDonald, A.S., Aranyakanon, P. and Suthakorn, P., 1979.** Review of the geology of Thai Tin Fields. *Bulletin of the Geological Society Malaysia*, **11**, 137 – 159
- Ong. S.S., 1968.** Geology of the Muda Dam Area. *B.Sc(Hons.) Thesis*, University of Malaya (unpublished).
- Pettijohn, E.J., 1975.** *Sedimentary Rocks*. Harper International Edition, Harper & Row, Publishers New York, Evanston, San Francisco & London, 628pp.
- Piyasin, S., 1972.** Geology of the Lampang quadrangle sheet NE 47-7, scale 1:250,000. *Report of Investigation, No. 14, Department of Mineral Resources, Bangkok*, 86p.

- Qalam Azad Rosle and Teh, G.H., 1995.** Stratigraphy, sedimentology and structural geology of the Betong-Lepang Nenering border area, Pengkalan Hulu (Keroh), Hulu Perak. *Geological Society of Malaysia Geological Conference 1995* (abstract).
- Qalam Azad Rosle and Teh, G.H., 1998.** The stratigraphy, structure and significance of the Nenering Tertiary beds, Pengkalan Hulu (Keroh), Upper Perak. *Bulletin of the Geological Society Malaysia*, **42**, 161 – 177.
- Rohayu Che Omar, 1994.** Petrochemistry of the Palaeozoic rocks along the East-West Highway, Gerik-Jeli, Perak/Kelantan. *National University of Malaysia MSc. Thesis*, 381p. (in Malay).
- Rookewell, J., 1923.** Kelantan Gold-Report of the consulting Engineer. *Straits Times*, February 12, 1923.
- Safeen Baharudin, 1987.** Gold Investigation in Batu Melintang area, Kelantan. *Geological Survey Malaysia*. (in Malay).
- Sashida, K., Adachi S., Koike, T. and Ibrahim Amnan, 1992.** Permian radiolarians from the Semanggol Formation, Northwest Peninsular Malaysia. *Second International Symposium on Gondwana Dispersion and Asian Accretion IGCP 321*. Abstract 44.
- Sashida, K., Igo, H., Adaci, S., Koike, T., Nakornsri, N. and Ibrahim Amnan, 1993.** Occurrence of Paleozoic and Mesozoic radiolarians from Thailand and Peninsular Malaysia. *Third International Symposium on Gondwana Dispersion and Asian Accretion IGCP 321*. Abstract, 59.
- Sashida, K., Adachi S., Igo, H., Koike, T. and Ibrahim Amnan, 1995.** Middle and Late Permian radiolarians from the Semanggol Formation, Northwest Peninsular Malaysia. *Transactions and Proceedings of the Palaeontological Society of Japan, New Series*, **177**, 43 – 58.
- Sashida, K., Ueno. K., Nakornsri, N. and Sardsud, A., 1998.** Early Carboniferous radiolarians from Na Thawi, southern peninsular Thailand. In: *Palaeontological Society of Japan Meeting, 147<sup>th</sup>*, Abstract, 24 (in Japanese).
- Sashida, K., Ueno, K., Nakornsri, N. and Sardsud, A., 1998.** Early Carboniferous radiolarians from Na Thawi, Southern peninsular Thailand, Palaeontological Society of Japan Meeting, 147<sup>th</sup>, Abstracts p. 24 (in Japanese).
- Sashida, K., Ueno. K., Nakornsri, N. and Sardsud, A., 1999.** Lithofacies and biofacies of the Khlong Kon Limestone, southern peninsular Thailand. In: *Proceedings of International Symposium: Shallow Tethys (ST) 5*, 1-5 February, 1999, Chiang Mai, Thailand, 228-240.
- Sashida, K., Nakornsri, N., Ueno. K. and Sardsud, A., 2000.** Carboniferous and radiolarian faunas from the Saba Yoi area, southernmost part of peninsular Thailand and their palaeogeographic significances. *Scientific Report*, Institute of Geoscience, University of Tsukuba, Section B. **21**, 71-99.
- Savage, H.E., 1925.** A preliminary account of the geology of Kelantan. *Journal Malayan Branch Royal Asiatic Society*, Vol. 3, part 1, pp. 61-73.
- Sawata, H., 1991.** Note on fossil locality of crabs and cuttlefish bone in Pleistocene marine sandy clay at Sungai Kolok, southeast-most Thailand, Geological Research Project, Prince of Songkhla University, Thailand, *Warta Geologi*, Vol. 17, No. 1, pp. 1-10.
- Schwartz, M.O., Rajah, S.S., Askury, A.K., Putthapiban, P. and Djaswadi, S., 1995.** The Southeast Asian tin belt, *Earth Science Review*. **38**(2-4), 95-293.
- Scrivenor, J.B., 1915.** Geologist's Annual Report for 1914. *Federated Malay States and Straits Settlements*.
- Scrivenor, J.B., 1928.** *The geology of Malayan ore-depoits*. Macmillan, London, 206pp, 47 figures, 3 plates.
- Scrivenor, J.B., 1931.** *The Geology of Malaya*. MacMillan, London, 217pp.
- Sia, S.G., 1989.** Geology of the Grik-Lawin area. *University of Malaya B.Sc. (Hons.) thesis* (unpublished).
- Siti Faridah Yusup, Mohamad Yusuf Che Sulaiman, Hamadi Che Harun, Ooi Inn Eng and Zamri Abu Samah, 2002.** Industrial mineral production statistics and directory of producers in Malaysia 2001. *Minerals and Geoscience Department Malaysia*.
- Snelling, B.J., 1965.** Age determination unit. Summary of results from Malaysia. *Annual Report Overseas Geological Surveys for 1964*, 32 – 33.
- Spiller, F.C.P. and Metcalfe, I., 1995.** Palaeozoic and Mesozoic radiolarian biostratigraphy of Peninsular Malaysia. Proceeding of IGCP Symposium on Geology of SE Asia, Hanoi. *Journal of Geology Series B 5/6*,

- Suntharalingam, T., 1987.** The geology of the Quaternary sediments in the coastal plain of Beruas, *Geological Survey Malaysia Quaternary Geology Bulletin* 2, 70 p.
- Suntharalingam, T. and Teoh, L.H., 1985.** Quaternary Geology of the Coastal Plain of Taiping, Perak. *Geological Survey Malaysia, Quaternary Geology Bulletin* I, 64 p.
- Suthakon, P., 1970.** Report on tin exploration in the Southern Border Area, Narathiwat-Yala-Pattani-Sonkhla Province. *Mineral Resources Division, Department of Mineral Resources, Thailand*, 14pp (in Thai)
- Suwannasing, A., 1962.** Chromite Deposits of Thailand, *Economic Geology Division DMR*, Bangkok, 19 p. (in Thai).
- Tamura, M., Hashimoto, W., Igo, H., Ishibashi, T., Iwai, J., Kobayashi, T., Koike, T., Pitakpaivan, K., Sato, T. and Yin, E.H., 1975.** The Triassic system of Malaysia, Thailand and some adjacent areas. *Geology and Palaeontology of Southeast Asia*, 15, 103 – 149.
- Teh, G.H. and Azhar Hussin, 1994.** Field relationships of rock units along the Malaysia-Thai border area, Nenering, Hulu Perak. *Geological Society of Malaysia Geological Conference 1994* (abstract).
- Teh, G.H. and Sia, S.G., 1991.** The Nenering Tertiary deposits, Keroh, north Perak-A preliminary study. *Warta Geologi*, 17(2), 49 – 58.
- Teoh, L.H., 1992.** Geology and mineral resources of Sungai Tiang area, Kedah Darul Aman, *Geological Survey Department Malaysia Map Report*, 5, 93pp.
- The MacDonald Encyclopedia of Rocks and Minerals, 1990.** MacDonald & Co. (Publishers) Ltd., London and Sydney.
- The Malaysian and Thai Working Groups, 2006.** Geology of the Gubir-Sadao Transect Area along the Malaysia-Thailand Border, *The Malaysia-Thailand Border Joint Geological Survey Committee (MT-JGSC)*, 32pp.
- Tjia, H.D., 1989.** Tectonic History of the Bentong-Bengkalis Suture. *Geologi Indonesia*. 12(1): pp.89-111.
- Tjia, H.D., Fujii, S. and Kogoshi, K., 1977.** Changes of sea-level in the southern South China Sea area during Quaternary times, *CCOP Technical Publication*, 5, pp. 11-36.
- Tonnayopas, D., 1994.** Geology and Stratigraphy of Bang Lang Dam area. *Proceeding of the international symposium on: Stratigraphic Correlation of Southeast Asia, Bangkok, Thailand*. 115 – 121.
- Utha-aroon, C., Khuenkong, P. and Saisuttichai, D., 2000.** Review on mineral resources near the Thai-Malaysian border, Economic Geology Division, *Department of Mineral Resources*, Bangkok, Thailand, 14pp.
- Uyop Said and Che Aziz Ali, 1997.** Nenering continental deposits; its age based on palynological evidence (abstract). *Warta Geologi*, 23(3), 170 – 171.
- Vijarnsorn, P. and Liengsakul, M., 1986.** Formation and Characterization of the Peat Swamps in Narathiwat Province, peninsular Thailand, *In Proc. of the workshop on Economic Geology, Tectonics sedimentary Processes and Environment of the Quaternary in Southeast Asia, Thiramongkol N. (editor)*, pp. 87-100.
- Willbourn, E.S., 1926.** The geology and mining industries of Kedah and Perlis. *Journal of the Malayan Branch of the Royal Asiatic Society*, 4(3), 288-322.
- Zainol Abidin Sulaiman, Loh, C. H. and Teoh, L.H., 1994.** Follow up study of ball clay in Bukit Pak Junus, Pasir Mas, Kelantan. *Geological Survey Malaysia, Industrial Mineral Project, Peninsular Malaysia*. Report no. IM 2/94 (in Malay).
- Zainol Abidin Sulaiman and Loh, C. H., 1995a.** Follow up study of ball clay in Kampung Cherang Hangus, Pasir Mas, Kelantan. *Geological Survey Malaysia, Industrial Mineral Project, Peninsular Malaysia*. Report no. IM 2/95 (in Malay).
- Zainol Abidin Sulaiman and Loh, C. H., 1995b.** Follow up study of ball clay in Kampung Padang Lichin, Pasir Mas, Kelantan. *Geological Survey Malaysia, Industrial Mineral Project, Peninsular Malaysia*. Report no. IM 1/95 (in Malay).

**Zainol Abidin Sulaiman and Loh, C. H., 1995c.** Follow up study of ball clay in Kampung Bakong Kechik, Pasir Mas, Kelantan. *Geological Survey Malaysia, Industrial Mineral Project, Peninsular Malaysia*. Report no. IM 4/95 (in Malay).

**Zainol Husin and Mohammed Hatta Abd. Karim** (in manuscript), Geology and mineral resources of the Kuala Nerang area, Kedah, Malaysia. *Geological Survey of Malaysia* (in Malay).

## 7. APPENDICES

### Appendix 1: List of the Malaysian Working Group

#### Consultant Field Geologists

Mr. P. Loganathan	Mr. Lai Kok Hoong
Dato' Yunus bin Abdul Razak	Mr. Ibrahim bin Amnan
Mr. Mohammed Hatta bin Abdul Karim	Mr. Askury bin Abdul Kadir
Dr. Chow Weng Sum	Mr. Noor Bakri bin Endut
Mr. Loh Chiok Hoong	

#### Field Geologists

Mr. Mohamad Hussein bin Hj. Jamaluddin	Mr. Hamlee bin Ismail
Mr. Mohd Badzran bin Mat Taib	Dr. Mohamad bin Abd. Manap
Mr. Mat Niza bin Abdul Rahman	Mrs. Nur Susila binti Md.Saaid
Mr. Ab. Rashid bin Ahmad	Mr. Amir Mizwan bin Mohd Akhir
Mr. Azmi bin Ismail	Mr. Saiful bin Abdullah
Mr. Nurzaidi bin Abdullah	Mrs. Nurul Amalina binti Md. Nor
Mr. Zamri bin Ramli	
Mr. Hamdan bin Ariffin	

#### Geological Assistants

Mr. Nai Pian a/l Nai Wan	Mr. Engah bin Mamat
Mr. Khalid bin Mat Hashim	Mr. Rashid bin Ismail
Mr. Johari bin Omar	
Mr. Ku Zulhairi bin Ku Yahya	

#### GIS

Mrs. Norsham binti Samsudin	Mrs. Norazmah binti Bahari
Mr. Hamid bin Ariffin	
Mr. Mohd Anuar bin Ishak	

#### Drivers

Mr. Nanjon a/l Rajoo	Mr. Md Razuki bin Hanapi
Mr. Zamberi bin Dollah	Mr. Abdul Hamid bin Ahmad
Mr. Vetrivel a/l Govindasamy	Mr. Razman bin Ismail
Mr. Selim bin Sulaiman	Mr. Zarbani bin Mat Junos
Mr. Mohd. Shaperi bin Kamarudin	Mr. Ramli bin Awang

## Appendix 2: List of the Thai Working Group

### Consultant Field Geologists

Mr. Chaiyan Hinthong	Dr. Thanis Wongwanich
Mr. Somkiat Maranate	Dr. Assanee Meesook
Mr. Lertsin Raksaskulwong	Dr. Sunya Sarapirome
Dr. Adichat Surinkum	Dr. Pol Chaodumrong
Mr. Kumpon Maneeprapun	

### Field Geologists

Dr. Somboon Khositanont	Head of Igneous Sector
Mr. Naramase Teerarungsigul	Head of Quaternary Sectors
Mr. Suvapak Imsamut	Head of Geology and Stratigraphic Sector
Mr. Tawatchai Tepsuwan	Head of Mineral Resources Sector
Dr. Suree Teerarungsigul	
Mr. Nimit Sornklang	
Dr. Apsorn Sardud	
Mr. Adoon Wunapeera	
Mr. Surachet Bumpun	
Mr. Decha Maneenai	
Mr. Sutee Jongautchariyakul	
Mr. Sathaporn Kavinat	
Mr. Wirote Saengsrichan	
Ms. Chotima Yamee	
Ms. Piyathida Buani	
Ms. Duangruthai Saesaengseerung	
Mr. Kitti Khaowiset	
Mr. Surached Rumtham	

### Technical Assistants

Mr. Chanapol Lengboon	Mr. Santi Srichum
Mr. Mana Rakbamrung	Ms. Bareeya Ketpuk

### GIS

Dr. Sunya Sarapirome	Ms. Piya-orn Assavapatchara
Ms. Wanida Romruen	

### Drivers

Mr. Kasem Lek-ngarm	Mr. Chalermpong Nardee
Mr. Wichian Boonchu	Mr. Charn Sapyuyen
Mr. Narong Uma	Mr. Chanlong Ketsatit

