

# Guide Book



Post-Conference Geological Excursion

# THAI-LAO

THE 3<sup>rd</sup> THAI-LAO TECHNICAL CONFERENCE  
ON GEOLOGY AND MINERAL RESOURCES

The 12<sup>th</sup> Anniversary Bilateral Collaboration

*“Thai-Lao Geology  
Beyond the Bounds”*



Organized by

Department of Mineral Resources, Thailand

Department of Geology and Minerals, Lao PDR

Department of Primary Industries and Mines, Thailand

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Bangkok, Thailand





The Third Thai-Lao Technical Conference on  
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Excursion Guidebook, 9<sup>th</sup>-11<sup>th</sup> July 2015  
: Geology of the eastern Thailand 2015

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Reference site

Excursion Guidebook, 9-11 July 2015:  
Geology of the eastern Thailand 2015

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## Preface

The excursion guidebook was prepared for the field trip to the eastern Thailand during July 9-11, 2015. The aim of this excursion is to fulfill the Thai-Lao Technical Conference on Geology and Mineral Resources that has been held at Golden Tulip Sovereign Hotel, Bangkok, Thailand during 9-11 July 2015.

This guidebook was described 8 stops of visit, including not only geological sites but attractive places for tourists also. The authors hope that all participants would achieve and exchange their knowledge and experiences on geology of eastern Thailand during the excursion.

The authors would like to thank you for Mr Montri Luengingkasoot , Director of Bureau of Geological Survey and Mr Suvapak Imsamut, Director of Planning Section for their accommodations. Many thank are also extended to all members that are not mention here for their all valuable supported.



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# POST CONFERENCE EXCURSION PROGRAM

## Nakhon Nayok-Sa Kaeo-Chanthaburi

### DAY 1: 9/7/2015 Bangkok - Sa Kaeo

Times	Programme
08.00	Depart from the Golden Tulip Sovereing Hotel, Bangkok, Thailand
10.00 - 10.15	<b>Relaxing and coffee break</b>
10.15 - 11.40	<u>Stop 01</u> : Pyrophyllite Mining Co. Ltd., Kaeng Khoi district, Saraburi province
12.00 - 13.00	<b>Lunch</b>
13.40 - 14.10	<u>Stop 02</u> : Khun Dan Prakan Chon Dam, Nakhon Nayok province
16.00 - 16.20	<b>Relaxing and coffee break</b>
16.50 - 18.00	<u>Stop 03</u> : Talat Rong Kluea or Talat Chaidae Ban Khlong Luek
18.20	Check in at Aran Mermaid Hotel, Aranyaprathet district, Sa Kaeo province
18.30 - 20.30	Group discussion and dinner

### DAY 2: 10/7/2015 Sa Kaeo - Chanthaburi

Times	Programme
08.00	Depart from the Aran Mermaid Hotel, Aranyaprathet district, Sa Kaeo province
09.00 - 10.00	<u>Stop 04</u> : Chromite Ores at Khao Phlu Hip Forest Park, Sa Kaeo province.
10.00 - 10.10	<b>Relaxing and coffee break</b>
10.30 - 11.10	<u>Stop 05</u> : Sa Kaeo Red Mable at Premier Mable Mine Co., Ltd.
12.00 - 13.00	<b>Lunch</b>
14.20 - 14.30	<b>Relaxing and coffee break</b>
14.30 - 16.30	<u>Stop 06</u> : Chanthaburi Gems & Jewelry Center, Chanthaburi province
17.30	Check in at New Travel Beach Hotel, Chaolao Beach, Tha Mai district, Chanthaburi province
18.30 - 21.30	Group discussion and dinner

## DAY 3: 11/7/2015 Chanthaburi - Bangkok

Times	Programme
08.00	Depart from New Travel Beach Hotel, Chaolao Beach, Tha Mai district, Chanthaburi province
09.00 - 10.00	<u>Stop 07</u> : Silica Sand and Clay of Sainuan Ltd., Tha Mai district, Chanthaburi province
10.00 - 10.10	<b>Relaxing and coffee break</b>
10.10 - 11.30	<u>Stop 08</u> : The Cathedral of The Immaculate Conception Chanthaburi and Chanthaburi's old town.
12.00 - 13.00	<b>Lunch</b>
14.00 - 14.30	<b>Relaxing and coffee break</b>
17.00	Hotel at Bangkok



# Geology of Eastern Thailand

## 1. INTRODUCTION:

The eastern Thailand administratively subdivided into seven provinces, which are Chachoengsao, Prachinburi, Chonburi, Rayong, Chanthaburi, Trat, and Sa Kaeo, respectively. The area is geographically made up of elongated mountain ridges and valleys aligning in the north to northwest directions. These ridges become deviating almost to the east-west as approaching the southern edge of the Khorat Plateau to the north of the area (Salyapongse, *et al.*, 1997).

## 2. TOPOGRAPHY AND GEOMORPHOLOGY

Topography of Thailand has various unique patterns varies in different parts of the country. In this book, description of topography can be divided based on simplified geomorphology, physiography, relief, geological structure, rock types and stratigraphy. Simplified description on geology based on topography and geomorphology can be divided into 8 regions as shown in Figure 1.

The eastern region covers an area from southern rim of the Phetchabun Range and the Khorat plateau down to northern part of the Gulf of Thailand. Bantad mountain range divides Thailand from Cambodia in the east. The Eastern Region consists of Chonburi, Rayong, Chanthaburi, Trat, Chachoengsao, Prachinburi, Nakhon Nayok, and Sa Kaeo provinces.

Landscape of northern part of the region is flat plain and undulating terrain in between mountainous area in connection to the Khorat plateau and the central mountain range within the region. Elevation of undulating terrain is between 50-150 m above mean sea level. Trending of the central flat plains and undulating terrains is in north-south direction. The highest mountain range is Khao Soi Dao mountain range reaching 1,640 m height. Flat plains in this region lie along the major rivers, consisting of fluvial floodplain, lower terrace with elevation between 5-20 m, intermediate terrace with elevation of 20-30 m and higher terrace with elevation of 30-100 m above mean sea level.

Topography of lower part of the region comprises the interchanging of low land and undulating hills. This kind of landscape forms a narrow belt that runs along the sea shore from Chonburi, Rayong, Chanthaburi provinces to Trat province. Elevation of the low relief ranges from 1 to 50 m above mean sea

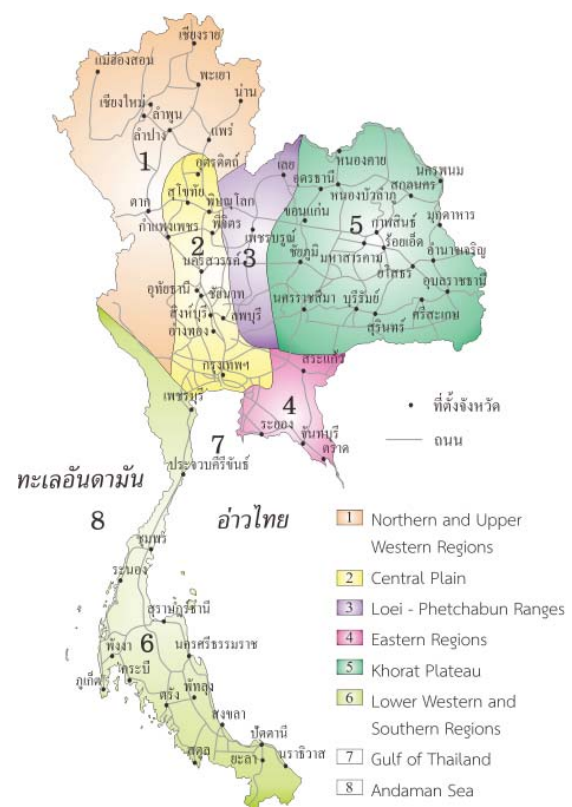


Figure 1 Map shows topographic and geomorphological regions of Thailand, as referred in this book.

level.

Flat area boundary along shoreline of the eastern region restricts between undulating terrain and hill slope and sea shore. Deposition of sediment occurred during transgression of the sea. Width of the area is around 5-10 km, consisting of old and present sand ridges, estuary, lagoon, delta and wave-built terrace. Average elevation of this flat area is 1-10 m above mean sea level.

Estuaries and river deltas were built along the eastern coast of the Gulf of Thailand on the mouths of several rivers in the region such as Bang Pa Kong river, Rayong river, Pra Sae river, Chanthaburi river and Weru river etc. Elevation of this part of the area is 1-5 m height. Most of the area is flooded during high tide period leaving top of old and new sand ridges to be seen as narrow and long tracks exposing over mean sea level with 2-10 m height. Wave cut terrace with 20-25 m height is farther beyond sand ridges and lagoon. It is appeared in Chonburi and Rayong province.

### 3. GENERAL GEOLOGY AND TECTONIC SETTING

(Chaodumrong, et al., 2002)

Geologically, Eastern Thailand appears to be disconnected from the central and the northeastern part of Thailand as a result of flat land surface of Quaternary sediments cover part of Thailand, and on the east by the Cambodia frontier. Generally, the qualities of outcrops are mostly decomposed, except some outcrops along the creeks and where the rocks have been exposed not very long ago.

Tectonically, Eastern Thailand was developed from the wedding of Shan-Thai and Indochina terranes along the Nan-Chanthaburi suture (The suture also named Nan, Nan river, Nan-Uttaradit, Nan-Uttaradit-Sa Kaeo, etc.) during Upper Triassic period. The suture zone passes southeasternward from Chachoengsao to Sa Kae, Chanthaburi and into Cambodia (Salyapongse *et al.*, 1996). Rock confining along these zones are constituted of Upper Triassic greywacke (Fontaine *et al.*, 1996) and conglomerate of submarine sediments (Chaodumrong, 1992), post Triassic I-type granite (Charusiri *et al.*, 1992), Jurassic Cretaceous red bed and Cenozoic basalt. The whole region, away from the suture zone to the west, is classified as Shan-Thai Terrane. The majority of rocks in this part prior to suturing such as submarine-fan conglomerate, oceanic ribbon chert (Sashida *et al.*, 1997) and contemporaneous pillow basalt were accreted to the easternmost margin of the Shan-Thai. This accretion might have been originated before the filling of remnant basin by the Upper Triassic greywacke and conglomerate. Next to the west, follow by the volcanic arc effused through the lower Carboniferous (Fontaine and Salyapongse, 1997). This volcanic terrane was congregated with older and deformed volcanoclastic sequences on which its youngest age part indicates a shallow marine (Fontaine *et al.*, 1999; Fontaine and Vachard, 1991).

Further to the west, fragment of the Precambrian rocks were scattered and juxtaposed with metasedimentary sequence of Silurian-Devonian and apparently unconfirmed sequence of the Upper Carboniferous with possibly graded to the Carboniferous-Permian (Sashida *et al.*, 2000; Bunopas *et al.*, 1983) units. The eastern chert clastic sequence was injected through by the volcanic related mafic intrusion while the western chert, clastic limestone sequence was intruded by the S-type granite batholith. Position of the S-type granite batholith in this area corresponds to the down dip or far on the landward side of the west dipping subduction zone. The closing time of the foreland basin is still needed to unravel, possibly before the S-type granite intrusion. Deposition of molasses red bed is signal the finalization of Late Triassic collision. In the conglomerate contains various kinds of clasts including the infer Precambrian rocks.

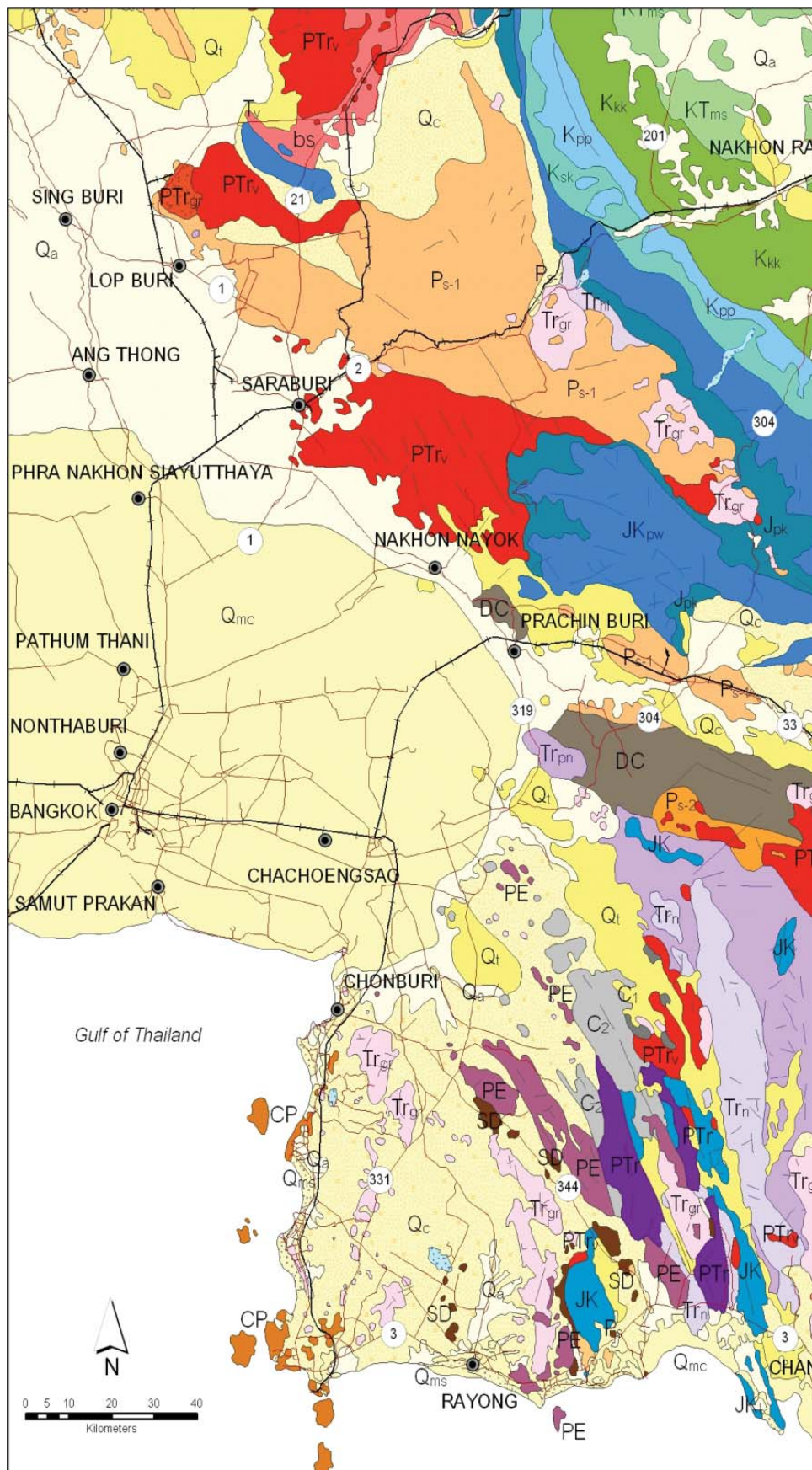


Figure 2 Geological Map of the southwest the Khorat Plateau and the eastern Thailand showing the excursion stops (from geological map of Thailand 1:1,000,000 scale; version 1999)

## EXPLANATION

Sedimentary and Metamorphic Rocks		Age	
Qa	Fluvial deposits; gravel, sand, and clay of channel, river bank, and flood basin.	Quaternary	
Qmc	Coastal tide-dominated deposits; clay, silt, and fine sand of tidal flat, marsh, mangrove swamp and estuary.		
Qms	Coastal wave-dominated deposits; sand, silica sand of beach ridge, barriers, dune, and lagoon.		
Qc	Colluvial deposit; residual sediments, laterite and rock fragments.		
Qt	Terrace deposit ; gravel, sand, and laterite of rejuvenated river.	Cretaceous-Tertiary	
kTms	Maha Sarakham Formation: siltstone,reddish brown to pale red; claystone and sandstone with frequent rock salt and gypsum.		
Kkk	Khok Kruat Formation: siltstone, gray to pale red; sandstone, claystone, and conglomerate with calcrete horizons.		
Kpp	Phu Phan Formation: sandstone,variegated colors (gray, brown, orange, pink), cross bedded, thick-bedded; siltstone and conglomeratic sandstone		
Ksk	Sao Khua Formation: siltstone and sandstone, reddish brown, purple and red, calcareous, with abundant calcrete horizons.		
Jk	Arkosic sandstone, white; conglomerate and intercalated shale.		
Jkpw	Phra Wihan Formation: quartzitic sandstone, white to gray, cross-bedded,thick-bedded; siltstone and claystone.		
Jpk	Phu Kradung Formation: siltstone, red and purple, calcareous and micaceous; sandstone, claystone and conglomerate with calcrete horizons.		
Trhl	Huai Hin Lat Formation: interbedded shale, mudstone siltstone, graywacke, argillaceous limestone, basal limestone conglomerate and local volcanic conglomerate.		Triassic
Trpn	Pong Nam Ron Formation: graywacke , shale , limestone , and conglomerate.		
Trn	Tuffaceous sandstone, bedded chert, and pillow basalt.		
Tr1	Noen Phuyai Yua Formation: tuffaceous sandstone , bedded chert , and intraformational pillow basalt.	Permian-Triassic	
PTr	Sandstone , tuffaceous sanstone , argillaceous limestone, metarhyolitic to metaandesitic tuffs; shale , metalimestone lens, chert , shale , and oncolitic limestone.		
Ps-2	Tuffaceous sandstone , sasndstone , shale , limestone , chert ,local volcanics rocks and hornfls.	Permian	
Ps-1	Limestone , chert , shale , sandstone , tuffaceous sandstone , and volcanics rocks.		
Ps	Saraburi Group: Fossiliferous limestone , chert; pillow basalt , ultramafics , and serpentinite.		
CP	Sandstone , argillaceous limestone , shale , and chert.	Carboniferous-Permian	
C2	Conglomeratic phyllite , phyllite , metatuffaceous sandstone , and slate.		
C1	Quartzitic sandstone,silty shale ,limestone and chert.		
C	Conglomerate , sandstone , shale , slate ,chert , and limestone.		
DC	Metachert , metatuff , marble , metalimestone , metavolcanics , and metasubvolcanics.	Devonian-Carboniferous	
SD	Phyllite , carbonaceous phyllite , and quartzitic phyllite.	Silurian-Devonian	
PE	Lansang gneiss: banded gneiss and augen gneiss , schist , amphibolite-schist , quartzite , calc-silicate , marble , and biotite marble.	Pre Cambrian	
<b>Igneous Rocks</b>			
bs	Gem barren-alkali olivine basalt, hawiite, mugearite and gem barring-nephelinite, bazanite and napheline hawaiiite.	Quaternary	
Trgr	Biotite granite , tourmaline granite , granodiorite , biotite-muscovite granite , muscovite-tourmaline granite , biotite-tourmaline granite.	Triassic	
PTgr	Microgranite , quartzmonzonite , granodiorite , high level , deformed plagiogranite and granophyre.	Permian-Triassic	
PTrv	Rhyolite , andesite , ash flow tuffs , volcanic breccia , rhyolitic tuff and andecitic tuff.		
PTru	Pyroxenite , peridotite serpentinite and hornblendite.		
Pv	Basaltic flow breccia , aquagene tuff and mafic- ultra mafic associates.	Permian	

Figure 3 Explanation of Geological Map of southwest the Khorat Plateau and the eastern Thailand

## 4. REGIONAL STRATIGRAPHY

### The Precambrian rocks

Precambrian rocks in Thailand are thought to consist of various medium to high grade metamorphic rocks underlying Cambrian rocks. The rocks at different locations contain unique characteristics which are easily recognized.

Regional metamorphic rocks in the eastern region, exposing in Chachoengsao, Chonburi and Rayong provinces were called Chonburi Massif by Campbell (1975) and Areesiri (1982). They lie in north-western-southeastern direction. Brief descriptions of these rocks were given by Brown *et al.* (1951) and Nakinbodee *et al.* (1985). Areesiri (1982) has described in detail the rocks in the Khao Chao area, Nong Yai district, Chonburi province as follows.

Khao Chao area, Phanat Nikhom-Nong Yai districts, Chonburi province

Sequence of high grade metamorphic rocks in Chonburi province, arranged in order from younger to older rock, is as follows.

#### Biotite-Microcline Gneiss

This high grade metamorphic unit is fine grained biotite-microcline gneiss in addition with inclusions of hornblende-diopside gneiss, amphibolite and biotite gneiss. Major mineral constituents are diopside, biotite, potash feldspar, plagioclase and quartz, with some apatite and zircon.

#### Biotite-Sillimanite Gneiss

The biotite-sillimanite gneiss unit changes to sillimanite-biotite-potash feldspar augen gneiss in the upper part. It changes to garnet-biotite-sillimanite-quartz schist in the lower part. Some cordierite was found in the lower part of the unit.

#### Hornblende-Diopside Gneiss

The hornblende-diopside gneiss unit is a fine to medium crystalline rock, consisting mainly of hornblende, plagioclase and diopside with some potash feldspar, apatite and sphene. In some area, biotite-hornblende-diopside gneiss, amphibolite, and biotite-sillimanite schist are included.

#### Biotite Gneiss

The biotite gneiss is fine to medium crystalline unit with a continuous contact to the hornblende-diopside gneiss unit. It mainly comprises quartz, potash feldspar, plagioclase and biotite with some zircon, magnetite and apatite.

#### Biotite-Hornblende Gneiss

The biotite-hornblende gneiss is a medium to coarsely crystalline unit, with inclusions of amphibolite, calc-silicate and biotite-sillimanite schist. Major rock forming minerals are biotite, hornblende, plagioclase, quartz, potash feldspar and garnet. Minor minerals are apatite, zircon and magnetite.

#### Biotite-Feldspar-Quartz Gneiss

The biotite-feldspar-quartz gneiss unit is comprised alternations between medium and coarsely crystalline gneiss with interbedded thin bands of amphibolite. Some parts are altered to migmatite with remaining fragments of amphibolite.

Areesiri (1982) separately described other two high grade metamorphic rocks, comprising mar-

ble, calc-silicate and amphibolite as follows.

Marble-calc-silicate unit: Marble occurs as lenses interbedded in biotite-hornblende gneiss. It is consisted of calcite, dolomite and some phlogopites. Calc-silicate is also interbedded in the gneiss. This rock consists of diopside, calcite and sphene.

Amphibolite unit: This unit occurs as subunits ranging from 2 cm to 10 m in thickness. It is interbedded in gneissic rocks and consists of hornblende and plagioclase with some biotite, diopside, quartz, garnet, apatite and sphene. The amphibolite unit can be divided into biotite amphibolite, diopside amphibolite, garnet amphibolite and hornblende amphibolite.

### **Northern Part of Khao Chamao, Klaeng district, Rayong province**

High grade metamorphic rocks in this area are presumably of Precambrian age. This location is considered the farthest east occurrence of the high grade metamorphics. It is in fault contact with younger rocks which gives rise to a long narrow mountain range of mica schist, hornblende schist, and calc-silicates. Biotite-muscovite granite, aplite and pegmatite veins lie parallel to foliation of the schist. Large garnet crystals are disseminated in both the granite and the schist. Gneiss and mica schist are exposed in rolling terrain between Khao Chamao and Klaeng district Office.

### **Structure in Precambrian Metamorphic rocks**

Areesiri (1982) has reported that the high grade metamorphic rocks in the eastern region have experienced at least two periods of metamorphism. The first deformation occurred in the Late Carboniferous at the same time as the Hercynian orogeny in Europe. The second deformation occurred during the Permian and Triassic. The second deformation was superimposed on the first deformation and is demonstrated by amphibolite facies minerals occurring parallel to axial plane cleavage in isoclinal folds in paragneiss (Figure 2.14). Recrystallization after melting formed granite, pegmatite and aplite.

Evidences confirming relationship between Precambrian high grade metamorphic rocks and Lower Paleozoic low grade metamorphic rocks are unclear. This is because stratigraphic contacts between these two types of metamorphic rocks are everywhere covered by Quaternary sediments or the contacts are faulted or granite intrudes along the contact between them. Therefore, the contacts between these high grade and low grade metamorphic rocks are assumed to be an unconformity, indicated by the different degree of metamorphism in the rocks (Braun, 1969; Baum *et al.*, 1970; Nutalaya, 1974; Campbell, 1975; Bunopas, 1976; Dheeradolok and Lumjuan, 1978; and Putthapiban *et al.*, 1987).

Baum *et al.* (1970) and Mantajit (1975) found that upper part of the Precambrian rocks comprise calc-silicates, marble, and quartzite, with interbedded meta-quartzite. The Lower Paleozoic rocks (Cambrian and Ordovician) originated from pre-existing siliciclastic-pelitic-carbonate rocks. These types of pre-existing rocks are the same as those of the Precambrian.

Braun (1969) reported an unconformable contact between high grade and low grade metamorphic rocks in western part of Chiang Mai province where a conglomerate bed occurs between them. Later, Putthapiban *et al.* (1987) disagreed with this interpretation and proposed that the conglomerate is younger and overlays the Ordovician rocks. The conglomerate was dragged down by block faulting and tilted towards the base of the Ordovician limestone. Macdonald *et al.* (1992) described Lower Paleozoic rocks in an area around Doi Inthanon as consisting of biotite schist, with interbedded fine grained marble. These rocks grade into fossiliferous Ordovician limestone nearby. Metamorphic minerals in the Lower Paleozoic rocks are garnet and andalusite. There are no minerals representing amphibolite facies in marble. Biotite schist is classified as a high temperature rock of greenschist facies.

Several geologists agreed that the lowest grade of the Precambrian rocks is limited to the upper amphibolite facies (Mantajit, 1975; Putthapiban *et al.*, 1987; and Macdonald *et al.*, 1992). They found that calc-silicate rock, which is the uppermost unit, contains calcite, dolomite, actinolite-tremolite, phlogopite, epidote, plagioclase, potash feldspar, and diopside. In area around the Bhumibol Dam, andalusite and cordierite are found in the Upper Precambrian rocks (Nutalaya, 1974). These minerals belong to the upper amphibolite facies.

In conclusion, the grade of metamorphism changed accordingly to the stratigraphy of the rocks. The sequence of the low grade Lower Paleozoic rocks conformably overlying high grade Precambrian can be traced all over the country. This proves that there was only one regional metamorphic event (Chantaramee *et al.*, 1981; Dheeradilok *et al.*, 1985; Macdonald *et al.*, 1992; and Salyapongse *et al.*, 1996). There are several evidences showing that Precambrian rocks were subjected to both regional metamorphism and contact metamorphism.

### Relationship between Age of Rocks and Age of Metamorphism

The age of the Precambrian rocks is the pre-metamorphic age. Evidences used for dating the rocks are grade of metamorphism, stratigraphy, fossils assemblages and isotope dating of minerals. The Precambrian rocks are high grade metamorphic rocks. These high grade metamorphic rocks can be distinguished from adjacent lower grade metamorphic rocks of Paleozoic age by fossils, lithology and possibly discontinuous contacts. The discontinuous contact was considered to be found and/or granite intrusion between the two types of rocks. The rocks were the source of sediments that supplied the Lower Paleozoic rocks (Baum *et al.*, 1970; Nutalaya, 1974; Bunopas, 1983; Pongsapich *et al.*, 1983; and Putthapiban *et al.*, 1987). However, Dheeradilok (1975) and Chantaramee *et al.* (1981) similarly reported that the metamorphic rocks found in Tha Ma Ka and Mueang districts, Kanchanaburi province are greenschist facies rocks showing continuous sedimentation from Cambrian to Ordovician. These low grade metamorphic rocks lie conformably over Precambrian high grade metamorphic rocks. Both low grade and high grade rocks were believed to be metamorphosed at the same period. Lithology of the low grade metamorphic rocks is the same as those found in the other regions of the country.

Dating of rock forming minerals in high grade regional metamorphic rocks clearly demonstrates evolution of the rocks. Macdonald *et al.* (1992) and Dunning *et al.* (1995) have described orthogneiss, age of related granitic rocks, age of metamorphism, and age of cataclastic deformation. They stated that the regional metamorphism occurred only one time in the Late Cretaceous and the high grade amphibolite facies metamorphic rocks lie either unconformably or conformably under the Lower Paleozoic metamorphic rocks. The age of the rocks presumably is in the range of Late Precambrian to Lower Cambrian.

Personnel from the Institute of Geology and Dynamic Lithosphere, Göttingen, Germany, with the support of the Geological Division, Department of Mineral Resource, have studied and dated the regional high grade metamorphic rocks and overlying low grade metamorphic rocks since 1992. Dating of crystalline rocks has been carried out by U/Pb, Sm/Nd, Rb/Sr and K/Ar methods and K/Ar for sedimentary and low grade metamorphic rocks. Mickein (1997) showed that the regional high grade metamorphism occurred twice. The first episode was between Triassic and Jurassic (approximately 200Ma). This metamorphism was the most intensive and caused mineral reorientation in gneiss. This conclusion is contrary to that proposed by Macdonald *et al.* (1992) and Dunning *et al.* (1995) who suggested only one metamorphic episode in the Cretaceous. The second episode occurred in the Cretaceous (approximately 117-72Ma), dated by U/Pb of monazites. The second metamorphism did not change the

pre-existing fabric of the metamorphic rocks. Deformation in the Oligocene-Miocene, detected by dating of rock forming minerals is due to uplift and thrusting of large blocks in the region. Until now, isotope dating of rocks has not indicated any evidence of metamorphism in the Precambrian era (Hansen and Wemmer, 2011).

Dating of pre-existing rocks that were subjected to regional high grade metamorphism in Triassic - Jurassic (approximately 200 Ma) is 1,000-2,000 Ma. This date is the age of the lower section of the pre-existing rocks. The upper part of the sequence is Cambrian-Ordovician age (approximately 500 Ma). The Tarutao and Thung Song Groups occur closely to the group of metamorphic rocks which can be dated as 1,000-500 Ma.

### **Remarks**

The existence of a Precambrian basement within Thailand is still debated among geologists. There are places where foliated high grade metamorphic rocks, that lack of paragneiss but contain the so-called orthogneiss, have been altogether mapped as inferred Precambrian rocks. This is recently proved invalid, at least locally, as exemplified by the originally assigned as Precambrian rocks of the Hua Hin-Pran Buri districts, Prachuab Khiri Khan province. In the same area, a group of third year geology major students from the Mahidol University, Kanchanaburi campus were assigned to practice in mapping the onshore area and discovered sillimanite-mica schist with relict of a pebble at Khao Sawoei Rat, WSW of Hua Hin district around 8 km. This outcrop considered as continuous extension from the Lower Permian pebbly rock sequence of the Kaeng Krachan Group widely distributed to the west which consisted of alternating succession of quartzitic sandstone, shale, limestone, pebbly mudstone, pebbly sandstone and feldspathic sandstone and graded to the Ratburi Group, aged Middle-Upper Permian, in the upper part. Hua Hin-Pran Buri orthogneiss or preferably being called foliated granite which dated as Triassic granite (Kawakami *et al.*, 2014) was thought responsible for the producing of foliated high grade contact metamorphic rocks of the Hua Hin-Pran Buri districts by forceful injection and introducing strongly shearing stress to the rocks of the Kaeng Krachan Group. The evidences of foliated high grade contact metamorphic rocks are clearly and wide spread envisaged at Khao Thung Kratai Kung to Khao Thung Mamao, about 3-4 km north of Prachuab Khirikhan province, abandoned tin mine at Ban Tha Lao, Phetchaburi province and many areas in southern Thailand e.g. Phuket province.

In addition, the foliated granite is generally concordantly intruded parallel through the foliation of this high grade contact metamorphic rocks, altogether covering an elongated area of about 30x10 square kilometers with much more extensive outcrops of the former than the latter. This kind of paragenesis is believed to be quite common in Thailand, particularly in the area of high grade foliated metamorphic rocks that are devoid of paragneiss and associated with foliated S-type granite. Such high grade foliated metamorphic rocks, formerly mapped as inferred Precambrian rocks and appeared paragneiss barren such as in Kanchanaburi province at Khao Chong Insee, Bo Phloi district, Tha Maka district, Kwai Noi-Ban Lin Thin, Thong Pha Phum district; in Suphanburi province at Uthong district; in Rayong province at Northern part of Khao Chamao, Klaeng district; and in Nakhon Si Thammarat province at Khanom-Sichon districts are among the area that needed to clarify, if in fact, they are foliated contact metamorphic rocks or not. Thailand geology will be much better understanding if source rocks and ages before metamorphism of these areas are clearly verified.

The data presented by Hansen, *et al.* (2013) using conventional U/Pb zircon dating method have confirmed the lack of Precambrian rocks within the crystalline basement of Thailand. The obtained data for the high-grade metamorphism show Indosinian ages ranging from 225 - 200 Ma as previously

suggested by Hansen and Wemmer (2011) for the vast majority of outcrops in NW-Thailand, as well as a small group of ages around 445 Ma in the Lampang province. Further, the age of a thermal imprint around 60 Ma was confirmed near Surat Thani province, Peninsular Thailand, and only a few indications of older ages for the unknown source areas were detected in detrital components. They concluded that no evidence of a Precambrian basement in Thailand could be found.

### The Lower Paleozoic rocks

The Lower Paleozoic rocks of Thailand are ranging in age from Cambrian to Devonian and up to the early Carboniferous in some rock units. In Shan-Thai terrane, these rocks are widespread in the western mountain area extending from Kanchanaburi province in the west to Chiang Mai, Mae Hong Son in the north; and to Chonburi in the east. The rocks in the Peninsula are widely distributed in north-south direction alongside of the Khao Luang mountain range, extending from Surat Thani province through Satun province to North Malaysia. In Indochina terrane, only upper part of the Lower Paleozoic rocks are exposed in northeastern part of Loei province extending across Thai-Laos border to Western Laos (Figure 3).

In general, The Lower Paleozoic rocks of Thailand have been subjected to low grade regional metamorphism (greenschist facies) and contact metamorphism in the area nearby granite. The rocks are also strongly folded and faulted. These rocks are closely associated with and overlie unconformable on the Pre-Cambrian high-grade metamorphic rocks in the Shan-Thai terrane.

The Lower Paleozoic rocks of Thailand can be divided into two conformable rock units in ascending order as: a lower siliciclastic, the Tarutao Group and an upper carbonate, the Thung Song Group. The Tarutao Group, type area at the Tarutao island, Satun province, is a thick sequence of red sandstone, siltstone, shale and conglomerate found the Late Cambrian trilobite on upper part of the sequence (Brown *et al.*, 1951; Javanaphet, 1969). However, most of the rocks

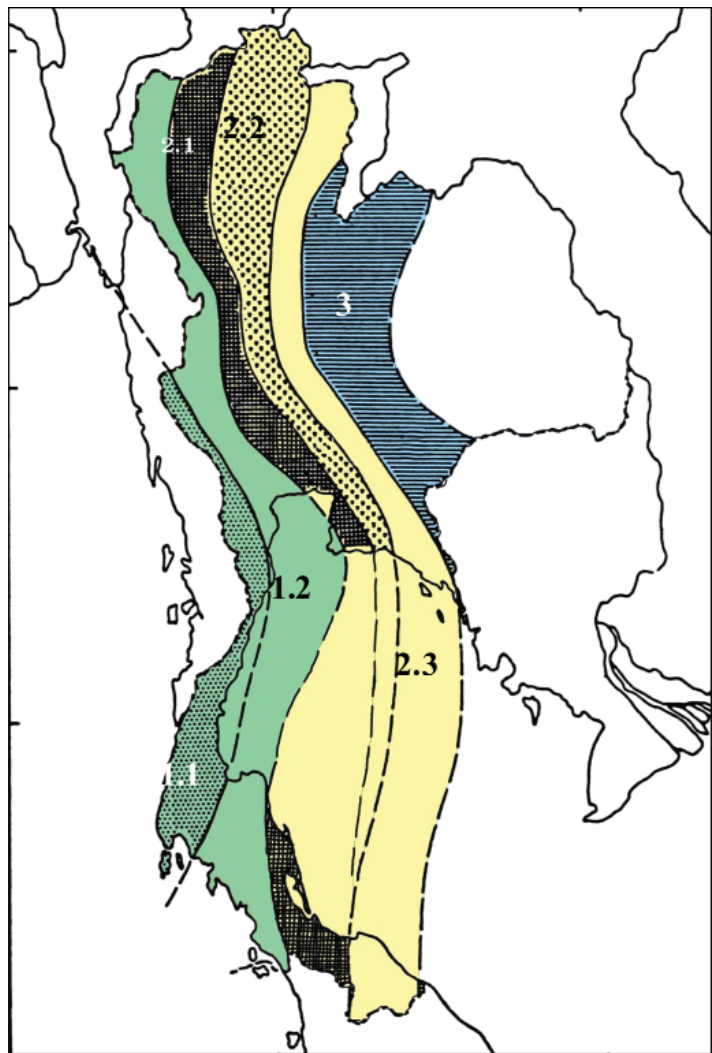


Figure 4 Map shows distribution of the Lower Paleozoic rocks in Thailand, divided into 3 extensive belts, i.e. 1. Western belt, 2. Middle belt, and 3. Eastern belt. Lower Paleozoic rocks are found in Shan-Thai Sub-continent along minor belt nos. 1.1, 1.2, 2.1, 2.2 and 2.3. In Indochina Sub-continent, they were found only in upper part of belt no. 3. (modified from Bunopas, 1994)

on the mainland are quartzite. This group is a shallow shelf sequence periodically subjected to storm. The overlying Ordovician Carbonates, the Thung Song Group, is a thick sequence of tropical limestones, dolomites and calcareous shales. They were deposited in peritidal environment on a homoclinal ramp during a long marine transgression in Early Ordovician, followed by shoaling, reefs, and a deeper subtidal in a Middle and a greater deepening during the Late Ordovician. Lithologically, the carbonate rock of the Thung Song Group is very similar throughout Thailand. However, the age of the similar rock unit in the east (Si Chang island) is still in controversy.

The upper part of the Lower Paleozoic rocks of Thailand, Silurian-Devonian, in the Shan-Thai terrane which overlies conformably on the Cambrian-Ordovician rocks can be differentiated into three major north-south facial belts : the shelf-basin in the west and the Peninsula, the magmatic arc facies in the Sukhothai fold belt and Eastern part of the Peninsula and the eastern belt (Figure 3).

The first belt comprises rocks in the western Thailand from Kanchanaburi to Mae Hong Son provinces and the Peninsula are black graptolitic and tentaculitic shale, chert, sandstone, siltstone and variegated stromatolitic nodular limestone of shelf to back-arc basin facies. These rocks now are defined as the Thong Pha Phum Group. In the Peninsula from Surat Thani to Satun provinces, this rock is represented by a continuous succession of those deeper water siliciclastic and carbonate rocks. Studies on the graptolite, trilobite, brachiopod, ammonite and conodont by many paleontologists revealed that the upper Lower Paleozoic rocks of this shelf-basin facial belt in the Peninsula are ranging in age from Late Ordovician to Early Carboniferous. They seem to be conformably underlied the Upper Paleozoic rocks.

The second belt of the Silurian-Devonian rocks lies along the Sukhothai fold belt of Shan Thai terrane, in Central part of the Northern Highland, the Eastern Gulf and Eastern part of the south can be separated into three sub-facial belts including 1) back-arc-basin facies in the west, 2) volcanic arc facies in the central and the east and 3) fore-arc facies along western edge of the Khorat plateau. The back-arc basin facies are black graptolitic and tentaculitic shale, chert, and occasionally limestone extending from Fang district to Chiang Mai, Lampang provinces, along eastern flank of the Western mountain to Tak, Kanchanaburi provinces, to eastern Gulf of Thailand and eastern part of southern Peninsula to Yala province. Further east of this belt is volcanic arc facies represented by limited outcrops of amphibolites, mica schist, agglomerate and fine-grained meta-tuffs. This belt extends from Chiang Rai to Lampang, and the south at Narathiwat provinces and Rayong and Chanthaburi in the east (Figure 4).

The fore-arc facies deposits in arc trench gap environ, composes of marble and bedded chert. The rocks expose in the north at Sukhothai and Nakhon Sawan provinces, in the east at Rayong and Chanthaburi provinces. The trench facies rocks in Nan province and western part of ultrabasic rocks of the Pha Som Group are sandstone interbedded with thin bedded shale with slightly metamorphosed.

The eastern belt of the Lower Paleozoic rocks of the Indochina terrane form as another N-S belt in the area between Loei and Udon Thani provinces. The rocks are thin bedded chert interbedded with dark gray siliceous shale, quartzite, tuff, conglomerate, and limestone with Silurian-Devonian-Lower Carboniferous fossils. These rocks now are named to be Pak Chom Formation (Charoenprawat and Wongwanich, 1976; Bunopas *et al.*, 1988). They lie unconformably above Silurian quartzite, phyllite and schist of the Na Mo Formation.

Based on stratigraphical and paleontological studies on brachiopod, trilobite, conodont, micro-vertebrate and gastropods of many paleontologists from Australia, England, Japan and USA, it is verified that Thai fauna can be correlated with those of Burma, China, Australia and South America. They sug-

gests that Thailand was a part of the greater Gondwana during the Lower Paleozoic and these terranes were still close to Australia during the Lower Paleozoic (Burrett *et al.*, 1990)

All mentioned formations and groups are standard rock units which are used for correlation of rock strata throughout Thailand and help correlate geographic provinces from the northern region to the southern region (Table 1). These units have been used for geological studies in Thailand and as the basic data for Geological Map of Thailand scale 1:1,000,000 and 1:2,500,000 (Department of Mineral Resources, 1992). However, in each part of the country, names of the rock units are in some places different to those Geological Map of Thailand scales 1:250,000 (Table 2).

Nevertheless, Cambrian age were assumed by the stratigraphic position of the rock unit as it underlies the known age Lower Ordovician rocks and can be stratigraphic correlated to the lower part of Chao Nen quartzite in Kanchanaburi province, the lower part of Khlong Wang Chao Group in Tak province, the sandstone formation at Ko Lan on the eastern coast and the Tarutao Group in the southern peninsula. Fossils of trilobites, found in the Chao Nen Quartzite and the Tarutao Group indicate Upper Cambrian to Lower Ordovician. Therefore, age of the Pha Bong Quartzite can be concluded as from Cambrian to Lower Ordovician (Baum *et al.*, 1970; Javanapetch, 1969; and Wongwanich *et al.*, 1983).

### The Cambrian rocks

*The Ko Lan quartzite:* Ko Lan quartzite was named by Bunopas (1981) using its type section at Ko Lan, an island 10 km west of Pattaya beach or south of Chon Buri province. The Ko Lan quartzite, total thickness of 500 m, comprises variation of massive to well bedded folded, brown quartzite, grayish brown slaty shale and brown to black slate. Age of the rock unit is now unclear. The Cambrian age was based on stratigraphic correlation as the rock possibly underlies the possible Ordovician limestone at Ko Si Chang.

However, many geologists believe that age of the Ko Lan quartzite can be as young as Carboniferous and Permian by comparison with similar quartzite rocks exposed on land from Si Racha district to Sattahip district. This onland quartzite at Bangphra reservoir underlies rocks that found fossil aged Permian (Polprasit and Prasomsap, 1984; Charusiri, 1984; Chaodumrong (a, 1994); Salyapongse, 1997). It may be controversial that there are two similar sets of quartzite yield different age or only one aged quartzite.

### The Ordovician rocks

*The Si Chang limestone, Thung Song Group:* The Si Chang limestone was named by Buravas (1957) for limestone crops out at the Si Chang Island. The limestone is strongly deformed and recumbent isoclinal folds. This formation was later included in the Thung Song Group in the east by Nakinbodee *et al.* (1976). Type section of the rock unit located on the Si Chang island, 11 km west of Si Racha district. Another part of the formation is found along the coast from Si Racha to Bang Lamung, south of Chonburi province.

The Si Chang limestone, approximately 400 m thick, lying over quartzite and quartz schist, consists of dark gray, well-bedded to massive muddy limestone. Its lithological characteristics are similar to the Thung Song Group in Thailand. Nakinbodee *et al.* (1976) found very poorly preserved and deformed nautiloids on Si Chang island which were identified as *Multicameroceras* sp. dated Early to Middle Ordovician. The age of this limestone remains contentious and some geologists believe that the formation may be Permian and are correlate to the limestone at Khao Rewadee on the coast opposite Si Chang Island.

**Table 1** Stratigraphic correlation of the Lower Paleozoic rocks of Thailand designates by the DMR (1992) in comparison with stratigraphic units given by Brown et al. (1951 and Javanaphet (1969).

Region System	Brown et al. (1951)	Javanaphet. (1969)	Western Highland	Northern Highland	Southern Peninsula	Eastern Gulf	The Central Plain	Loei-Petchabun Ranges	The Khorat Plateau
Carboniferous	Kanchanaburi Series	Kaeng Krachan Fm.	Mae Hong Son Fm.	Phrae Fm. Dan Lan Hoi Gr.	Kaeng krachan Fm.	Dan Lan Hoi Gr.(?)	Wang Saphung Fm.		
Devonian		Tanaosi Gr. Kancha-naburi Fm.	Thong Pha Phum Gr.	Thong Pha Phum Gr.	Thong Pha Phum Gr.				
Silurian									
Ordovician	Thung Song Ls.	Thung Song Gr.	Thung Song Gr.(?)	Thung Song Gr.(?)	Thung Song Gr.	Thung Song Gr.(?)			
Cambrian	Phuket Series	Tarutao Gr.	Tarutao Gr.(?)	Tarutao Gr.(?)	Tarutao Gr.	Tarutao Gr.(?)			
Pre-Cambrian			Lan Sang Gneiss Complex	Lan Sang Gneiss Complex	Lan Sang Gneiss Complex	Lan Sang Gneiss Complex (?)			

? = Uncertain    Gr. = Group    Ls. = Limestone    Fm. = Formation    [Grey Box] = No exposure    - - - - - = Unconformity

Table 2 Stratigraphic correlation of the Lower Paleozoic rocks of Thailand designates by the DMR geologic map scale 1:250,000 in comparison with the DMR Lexical (1992) and the DMR geologic map scale 1:1,000,000 (1999).

Udon Thani	Eastern		Lower Western & Southern					
	Bangkok	Rayong	Suphan Buri	Nakhon Pathom	Hua Hin	Surat Thani		
Chonglakmani et al., 1979	Nakinbodee et al., 1976	Nakinbodee et al., 1976	Bunopas et al., 1980	Dheeradilok et al., 1980	Dheeradilok et al., 1976	Nakinbodee et al., 1985	Tansuwan et al., 1980	
Huai Som Fm.	Tanaosi Gr.  Kaeng Krachan Fm.	Tanaosi Gr.  Kaeng Krachan Fm.	Kaeng Krachan Fm.  Carboniferous Shale (Unnamed rock)	Khao Wang Sadung Fm.	Kaeng Krachan Gr.  Kaeng Krachan Fm.	Laem Tap Fm.	Pru Chaba Fm.	
Dok Du Fm.				Khao Phra Fm.			Khao Chao Fm.	Kuan Klang
shale, sandstone, Limestone (Unnamed)				Huai Phu Ron Fm.			Khao Phra Fm.	Fm.
Namo Fm.	Kanchanaburi Fm.	Kanchanaburi Fm.	Kanchanaburi Fm.	Kanchanaburi Gr.  Bo Phloi Fm.	Khao Sawoei Rat Fm.	Tanaosi Gr.	Kanchanaburi Gr.  Pa Sa Med Fm.	
	Thung Song Gr.	Thung Song Gr.	Thung Song Gr.	Thung Song Gr.	Khao Ruak Fm.	Thung Song Gr.	Thung Song Gr.	
			U-Thong Marble	Khao Taphan Gr.	Khao Noi Setthi Fm.	Khao Kralok Fm.	Khwaeng Phao Fm.	
			Chao Nen quartzite	Khao Taptim Fm.	Thung Song Gr.	Thung Song Gr.		
		Thong Tanot Fm.	Tarutao Gr.	Ban Rang Khe Fm.	Thung Song Gr.	Tarutao Gr.	Thung Song Gr.	
	Tarutao Gr.	Tarutao Gr.						

### The Silurian-Devonian-Carboniferous Rocks

*The Sattahip shale:* Sattahip shale was named by Bunopas (1981) represent slaty shale, argillite, fine-grained sandstone and laminated limestone at Chonburi and Rayong provinces. Type section of the formation located on Sattahip naval base, Chon Buri province. General Characteristic of the formation is well- cleavage developed and tight folded. Color of rocks is generally greenish gray and brownish gray shale and sandstone became brownish gray and white when weathered. Fossils were not found in this formation.

#### *Klaeng schist and phyllite:*

Klaeng schist and phyllite was named by Bunopas (1981). Distribution of the rock unit is situated on undulating terrane parallel to the inferred Precambrian rocks in eastern Klaeng district, Rayong province. Klaeng schist and phyllite consists of interbedded of quartz mica schist, tuffaceous quartzite and brown tuffaceous phyllite in the lower part. The upper part consists of interbedded of white to grayish brown quartzite, slaty shale, chert, phyllite and bands of limestone. Most of the rocks are well cleavage developed and medium-tight folded. They were tilted 55o to the northeast. Fossil of small nautiloids, *Michelinoceras michelini* of possibly Silurian age was only found in chert at Laem Thong Lang close to Klaeng district. Klaeng schist and phyllite are equivalent to the Bo Phloi formation and Thong Pha Phum Group in western Thailand (Bunopas, 1981).

### **The Upper Paleozoic rocks**

The Upper Paleozoic covers the Carboniferous Period (approximately 360 Ma to 299 Ma) to the end of Permian Period (approximately 251 Ma). Upper Paleozoic rocks are widespread in Thailand, consisting of limestone, volcanic sediment and siliciclastic deposited in a wide range of paleo-environments. Their lithostratigraphy differs across the country and will be discussed region by region.

### The Carboniferous Rocks

Dating of the Carboniferous rocks in the eastern region was previously problematic since there are too few fossils, a lack of stratigraphic continuity and a complex structure. Recently, more detailed paleontological studies have been carried out and dating is therefore more accurate, especially using microfossils like foraminifera and radiolarian. Structural and tectonic studies and isotope dating have helped to form a more accurate understanding of geological evolution of the area.

On the eastern coast from Mueang district to Sattahip district, Chonburi province, rocks were intensively metamorphosed. Although, nautiloid fossil was found in limestone interbedded with shale on Si Chang island and tentatively determined as *Ellesmeroceras Multicameroceras* (?) dated as Early to Middle Ordovician (Nakinbodee *et al.*, 1976). The fossil was highly deformed thus exact dating was not possible.

Salyapongse and Jungyusuk (1980) determined age of the rocks cropping out along the eastern coast of the Gulf of Thailand from Muang, Laem Chabang, Sattahip districts, Chonburi province to be Carboniferous to Permian. The lower part comprises bedded quartzite, quartz mica schist and quartz schist siliceous shale and thin bedded limestone. The upper part is composed of thick bedded limestone such as at Khao Phu, Khao Choeng Thian, Khao Chee On and Khao Chee Chan.

Limestone is green to brown colored and shows an alternation of thin argillaceous or arenaceous layers with calcareous layers and occasional interbeds of dolomitic limestone. At the base of this sequence, interbeds of chert are also present. The rocks have been subjected to at least two phases of

intensive metamorphism; low grade, greenschist facies in the lower part of the sequence. In some areas they were later affected by contact metamorphism.

In the middle and southern coast, the Carboniferous rocks are found in north of Khao Cha Mun and Khao Yai mountain range, Ban Thammarat Nai area. The rocks strike in northwestern-southeastern direction. They comprise slaty shale, siltstone and sandstone with alignment of black minerals. Some beds are metamorphosed to graphitic schist, especially in areas near faults and in contact with granite (Pholprasithi and Prasomsup, 1984).

Nakinbodee *et al.* (1976) divided the Carboniferous into formations named Cp1 and Cp2. The rocks are distributed in areas of Phanom Sarakham district and Sanam Chai Khet district, Chachoengsao province; Bo Thong district, Chon Buri province; Tha Mai district, Chanthaburi province; and Klaeng district, Rayong province and consist of micaceous siltstone, shale, limestone, quartzite, chert and conglomerate. Cp1, yields the bryozoa *Penniretepora* sp., *Fenestella* cf. *F. triserialis*, *Fenestella* sp., *Polypora* sp., and brachiopod *Cleiothyridina* sp. which indicate a Lower Visean to Upper Tournaisian age (Lower Carboniferous).

Kittisarn and Assavapachara (1987) divided the Carboniferous into two formations named C1 and C2. These formations are distributed in areas of Ban Tha Kloei, Ban Thammarat Nai, Ban Khlong Taklao, west of Ban Nong Khok, Khlong Taklao subdistrict and Khao Phai, Khao Ying of Ban Thammarat Nai in Sanam Chai Khet district, Chachoengsao province. This belt of occurrences extends southwesterly along rim of volcanic belt at Khao Yai-Khao Ang Rue Nai.

The lower part of C1 formation often overlies Triassic granite and Permian-Triassic volcanic rocks. In the eastern part, the formation is unconformably overlain by Triassic sedimentary rocks. In the western area, the C1 formation conformably underlies low grade metamorphic rocks of the C2 formation in an area west of Ban Thammarat Nai. Thickness of the C1 formation is 1,500 m.

The C1 formation comprises sedimentary rocks that were slightly metamorphosed. In general, it consists of alternations of sandstone, micaceous siltstone, shale, slaty shale, slate, chert, quartzite, limestone and conglomerate. The rocks near contact with igneous rocks are harder as result of silicification by hydrothermal fluids as at Lum Manao Temple, northeast of Khao Yai, and pale green to gray silicified siltstone in area west of Khao Phrik. Fossils of the bryozoan *Fenestella* sp. and foraminifera were found along the eastern and northern rim of Khao Yai. Light gray to dark gray limestone was found in two areas. The first area occurs as a belt extending from the eastern rim of Khao Yai to south of Ban Thammarat Nai-Khao Phai-Khao Ying, is 30-50 m thick and occurs as lenses in sandstone, micaceous siltstone and shale. The foraminiferans *Endothyra* sp., *Pseudoendothyra* sp., and *Plectogyranopsis* sp., an echinoid spine and fragments of bryozoa are present in limestone. The second area is around Tham Rat Temple, northeast of Ban Nong Khok, Sanam Chai Khet district, Chachoengsao province. Here, dense crystalline limestone occurs as lenses in light gray quartzitic sandstone with a thickness of 50 m and at Ban Thammarat Nai are the smaller foraminifera *Plectogyranopsis* cf. *dendrei*, *Endothyra* sp., *Paraforaminifera* sp., *Tetrataxis* sp., *Mediocris* sp. (?), *Glomospira* sp., echinoid spine and fragments of bryozoa which indicate a Carboniferous age.

A 3 m thick dark gray limestone is also found west of Khao Yai Mo Noi showing recrystallization and cross-cutting calcite veins. Corals indicate a Carboniferous age (Fontaine and Salyapongse, 1997), 150 m south of the previous location, dark gray to brown chert crops out on flat terrain. Dark gray limestone with quartzitic sandstone also crops out northeast of Khao Ang Rue Nai, south of Ban Soi 16, in the area around the Office of Khao Ang Rue Nai forest reserve, Khlong Ta Klao subdistrict, Sanam Chai

Khet district, Chachoengsao province.

*The C2 formation* mostly comprises low grade metamorphic rocks and sub-metamorphosed sedimentary rocks. The formation consists of interbedded black slate, phyllite, slaty shale, graphitic schist, amphibolite and quartz schist. Quartz veins cut across the formation. Sequence of rocks in this formation is clearly seen to the east of Ban Khlong Yang, northwest of Khao Thammarat Nai.

The Carboniferous rocks of the C2 formation can be divided into the C1-2 formation and the C3 formation. The C1-2 formation consists of sandstone, shale, mudstone and limestone and is dated as Lower to 'Middle' Carboniferous. The corals *Kueichouphyllum?*, *Siphonodendron* sp., *Solenodendron* sp. and *Hexaphyllia* sp. indicate a Late Visean-Serpukhovian age. The foraminifera *Eostaffella* sp., *Millerella* sp., *Endothyra* sp. indicate the Bashkirian. The C3 formation consists of metasediments comprising conglomeratic phyllite, graphitic phyllite, meta-pyroclastic sandstone and slate.

### **The Permian Rocks**

Permian sequences in Thailand are often thick limestones and intercalated clastics. The former usually display spectacular tower karst topography. These karsted terrains are regions of scenic beauty such as the group of small islands in Phangnga bay, the Angthong Archipelago in Surat Thani province, Tham Lod in Kanchanaburi province and Doi Chiang Dao in Chiang Mai province. Outcrops of the Permian rocks distributed in all regions of Thailand except the northeastern region, where they, however, occur in the subsurface.

*Eastern Region:* Limestone, clastic rocks, pyroclastic rocks, low grade metamorphic rocks and mélange of Permian are distributed over the eastern region. Based on stratigraphy, rock types and fossil assemblages, the Permian rocks in this region can be divided into three areas, i.e. western coast, central part and an area near the Thai-Cambodia border.

*Western Coast of Eastern Region:* Permian rocks at Khao Rewadee near Bang Phra water reservoir, Si Racha district, Chon Buri province, are dated as Late Carboniferous to Early Permian by *Pseudofusulina* sp. in limestone lens, interbedded in shale (Nakinbodee *et al.*, 1976). Polprasit and Prasomsap (1984) described the rocks as containing arkosic sandstone, graywacke, interbedded with siltstone, shale, mudstone, thick bedded chert and dark gray to black limestone. Fossils of foraminifera, algae, and bryozoa at Khao Rewadee indicate Middle Permian. These Permian rocks unconformably overlie Carboniferous rocks. The rocks are fractured and secondary dolomitic limestone was found within fracture and fault zones (Chaodumrong, 1992).

*Central Part of Eastern Region:* The Permian rocks consist mainly of metatuff. The lower part is metamorphosed conglomerate. The ascending sequence comprises volcanics, chert, shale and siltstone with some interbedded limestone. These rocks lie unconformably over Carboniferous rocks and have a fault contact with Triassic rocks (Polprasit and Prasomsap, 1984). The brachiopods *Leptodus* sp. productid sp., and a bivalve in pyroclastic shales, at Khao E-Prink, 18 km east of Klaeng district, Rayong province indicates Middle to Upper Permian (Bunopas *et al.*, 1983).

*Area near Thai-Cambodia Border:* Sivaborvorn *et al.* (1976) named the limestone interbedded with shale near the Thai-Cambodia border as the Ratburi Group. It contains the fusulinid *Verbeekina verbeeki* dated as Kazanian or Upper Permian. Bunopas (1981) named the Chanthaburi Group consisting of two formations: the Sra Kaew formation and Khao Chakan Formation.

*The Sra Kaew formation* consists of radiolarian chert, limestone and a composite mélange assemblage of ultra-mafic rocks which may be regarded as a dismembered ophiolite. It contains Middle to

Upper Permian fossils.

*The Khao Chakan formation* is mostly composed of limestone in Sa Kaeo province and along the Thai-Cambodian border.

Chaodumrong (1992) divided the Permian rocks into two formations as Wang Nam Yen formation and Khao Taa Ngog Formation.

*The Wang Nam Yen formation* occurs in a narrow belt in Wang Nam Yen district, Chantaburi province, starting between km 83-94 on the road Chantaburi-Sa Kaeo, Khao Laem, Khlong Yai-In, Khao Poon, and Khao Wai. This formation is presumably a thrust sheet complex, comprising red and gray chert with Middle Permian radiolaria.

The Khao Taa Ngog Formation exposed along the Thai-Cambodian border from Khao Taa Ngog limestone mountain, Khao Chong Kaeb, Khao Pha Phung, Khao Prik to Khao Chakan. The formation mostly consists of massive bedded limestone interbedded with shale. The limestone contains numerous Middle-Late Permian fusulinids and crinoids originating in a barrier reef. Fragmentary fossils found at Khao Prik and Khao Chakan indicated breaking and transportation of the fragments before deposition.

### The Mesozoic rocks

Study of Mesozoic rocks in Thailand was originally based on the facies of the rocks. All of red beds of the Mesozoic Era were originally called Khorat Series, named after the Khorat plateau, where the rocks were widely distributed. Later the name was changed to Khorat Group. Continental rocks occur sporadically in the southern and the western regions where they are called the Thung Yai Group. Marine deposits are mainly found in the northern, the western and the southern region and are assigned to the Lampang Group and Umphang Group.

#### The Triassic rocks

The Triassic rocks in the eastern region can be divided into four formations, two informal and two formal, (Chaodumrong, 1992a), from older to younger: the Sukpaiwan and Noen Po formations; Pong Nam Ron and Noen Phu Yai Yua Formations.

*The Sukpaiwan formation* has restricted distribution in area northeast of Klaeng district, Rayong province, especially at Khao Sukpaiwan, Khao Wong, Khao Chong Lom and Khao Cha-ang On. These small hills locate at eastern side of Khao Chamao. This formation is more than 100 m thick (Fontaine and Salyapongse, 1997a), comprising gray to dark gray, purplish brown limestone. The beds are fine to medium bedded (3-30 cm thick). Oncoids with diameters less than 0.5 cm, peloids and bioclasts are present in the limestone. The lithology varies from grainstone to lime-mudstone. Shale is interbedded with limestone in the lower part of the formation. Clasts of volcanic rocks are found. This formation has not experienced strong deformation. It unconformably overlies Late Permian rocks. Fossils of foraminifera *Meandrospira pusilla* Ho, *Glomospira tenuifistula* Ho, and algae *Aeolissacus tintinniformis* Misik indicate an Early-Middle Triassic (Scythian-Ladinian) age.

*The Noen Po formation* distributed from northern Chantaburi province southeastward to Laem Ngop district, Trat province. It is well exposed at Ban Noen Po, Khao Cham-Han and Ban Nong Chim. This formation consists of dark gray to black mudstone and shale with some coal. Locally, layers of gray chert occur in 3-5 cm thick beds. Fossils of radiolaria *Triassocampe*, *Syringocapsa*, *Archaeospongoprunum* indicate Middle to Late Triassic age (Hada *et al.*, 1997). Color of the rock changes to be light color when weathered. Large amount of feldspar and interbedded volcanic horizons occur within the formation.

*The Pong Nam Ron Formation* was named after the Pong Nam Ron district by Sivaborvorn *et al.* (1976), has been widely used but in a different sense (Tansathien *et al.*, 1975; Chaodumrong, 1992a; and Tansuwan, 1997). Outcrops of this formation are clearly visualised in area east of Chanta Buri province, especially on eastern side of the Chanthaburi-Sa Kaeo road and in the Pong Nam Ron and Wang Nam Yen districts along border with Cambodia. Thickness of this formation is more than 200 m, consisting of thick to massive dark gray feldspathic sandstones which became greenish gray when weathered. This sandstone is poorly sorted with clasts and grains of volcanic rock fragments, feldspar, with minor quartz, sedimentary and metamorphic rock fragments. Graded bedding was also found. Interbeds of mudstone and conglomerate were found in sandstone locally. Clasts in the conglomerates are well rounded and consist of volcanic rocks and fossiliferous limestone containing fusulinids. Clasts in conglomerate are both well and poorly sorted.

*The Noen Phu Yai Yua Formation* is well exposed in the Noen Phu Yai Yua Buddhist sanctuary (Figure 5.16), Khao Ploy Waen, Mueang district, Chantha Buri province, Pong Nam Ron Canal and Ban Nong Bon. This formation is more than 300 m thick, conformably overlying the Pong Nam Ron Formation. It consists of medium grained dark gray sandstone, becoming light gray when weathered, with interbedded mudstone. Thickness of sandstone and mudstone beds is similar, varying between 10 and 20 cm. The thickness is constant over a considerable area. Bouma sequence and graded bedding are found in the sandstone. Contacts between sandstone and the overlying mudstone are sharp and planar. Ratio between sandstone to mudstone varies from 2:1 to 1:1. Mudstone increases in upper part of the formation. These sediments indicate deposition in submarine fans in a deep marine basin (Chaodumrong, 1994).

### **The Jurassic Rocks**

Terrestrial rocks in the eastern part of the country were distributed in quite a limited area, covering the south of Chantha Buri province, along Khao Banthat mountain range running along the border with Kampuchea, and on Ko Kut Island, Trat province. Formations of Jurassic age are as follows :

*The Laem Sing formation* unconformably overlies marine Triassic rocks seen in Laem Sing, Khao Tha Le Sai, Khao Takrup, and Khlong Rabom dam (Sivaborvorn, *et al.*, 1976). Its type section is at Laem Sing, Chanthaburi province. It is composed of red sandstone and siltstone, reddish purple, light gray, light brown, claystone and some conglomerate. Detrital grains in the sandstone are mostly composed of quartz. Cross bedding, well sorted, and graded bedding are found in these sediments. The beds are steeply dipping and locally overturned. By stratigraphic correlation with the lower part of the Khorat Group, this formation was dated as Jurassic.

*The Phu Kradung Formation* comprises reddish, light gray shale with interbedded sandstone and siltstone. It is found in Banthat mountain range along the border with Cambodia. The beds have moderate dips. Volcanic ash occurs in the basal parts of shale beds. Plant remains are found in gray shale. The reddish purple to gray, fine to medium grained, well sorted, and well cemented arkosic sandstones were deposited in a meandering river system. By stratigraphic correlation with the lower part of the Khorat Group, this formation was dated as Jurassic.

*The Phu Kradung Formation* in Ko Kut comprises red, brown sandstone, siltstone and conglomeratic sandstone. Plant remains and vertebrate bones were found in conglomeratic sandstone. This formation was formed in a meandering river system in a coastal environment. It was dated as Jurassic, on the evidence of sharks teeth, teeth of the fish *Lepidotes*, freshwater turtle plates and freshwater

crocodile and plesiosaur teeth (Buffetaut and Ingavat, 1983). The plesiosaur is similar to one found in Tchepone, Lao PDR (Hoffet and Le Maitre, 1939).

### The Jurassic-Cretaceous rocks

*The Phra Wihan Formation* conformably overlies the Phu Kradung Formation at Khao Banthat Mountain, comprising sandstone with interbedded shale. Thick bedded, well cemented sandstone is composed mostly of light gray to white gray, brown, coarse grained quartz. Cross bedding is evident. The rocks were deposited in a braided river system. The formation was dated as Jurassic by stratigraphic correlation with the lower part of the Khorat Group.

### **The Cenozoic rocks**

Cenozoic is an era for mammal prosperity. This era in Thailand contains several geologic resources including fossil fuels exploited today such as natural gas, crude oil and coal, associated with oil shale, diatomite and ball clay. In this chapter, the Cenozoic Era consists of the Paleogene, Neogene and Quaternary Periods. The name Tertiary has been omitted following the Geologic Time Scale of the International Commission on Stratigraphy published in 2004 and 2009. However, their Epochs are still valid and have the same meaning. Therefore, the name ‘Tertiary’ in some instances, for the sake of convenience and continuity, will be used. The term Quaternary (or the “ice age”) has been expanded to range from 2.59 Ma to the present.

### The Paleogene and Neogene rocks

Rocks in these periods accumulated in many isolated intermontane basins widely distributed from the north to the south as well as in the Gulf of Thailand and Andaman Sea. In the northeast or the Khorat plateau, Miocene elephants and other mammals have been discovered but the Miocene outcrops have not been discovered. These basins vary in size from small to large and the large basins normally consist of many small sub-basins.

### The Quaternary rocks and sediments

Quaternary is the last period in geological time scale from 2.6 Ma to the present. This period is further divided into two epochs namely the Pleistocene from 2.6 Ma to 10,000 years B.P. and the Holocene from 10,000 years B.P. to the present. The fossils in this period are mostly comparable to modern taxa. Sedimentation has taken place from the lower layers to the upper layers in successions where many sedimentary horizons are hidden below the ground surface. Studying the Quaternary geology is thus mainly available from drilling, sedimentary profiles in cliffs, road cuts, quarries and along river banks. Quaternary rocks and sediments in Thailand are observable in various regions of the country as follows:

Geomorphologic features of the eastern region vary from high mountainous areas in the north to undulating terrains and foot hill terraces in the central and coastal plains closed to the Gulf of Thailand in the south. In general, the eastern sea shores are mainly composed of cliffs alternating with small barrier beaches for example the areas in Bang Lamung district of Chonburi province. The tidal flats and mangrove swamp plains are around the large estuaries such as in the Bang Pa Kong, Chanthaburi, and Trat estuaries.

*The Quaternary sedimentary* successions in the eastern region is not very thick averaging about 20-50 m and overlying igneous and metamorphic bedrocks. The detailed geologic mapping scale

1: 50,000 by the Department of Mineral Resources (Sinsakul and Chaimanee, 1982; Kaewyana and Phuanta, 1984; Tiypairat and Mahaphum, 1994; Raksaskulwong and Prakobchart, 1994; Chaimanee, 1995) enables the classification of the Quaternary stratigraphy of the eastern region on the basis of geomorphologic features, depositional environments and sediment types. Detail deposits from the older to the younger are as following:

*The residual deposits* are found as the foot hill terraces in the north and cliff coasts in the south of the region. The sedimentary succession consists of gravel, sand and clay layers on the igneous rocks or silt with sand layers on the metamorphic or sedimentary rocks. The sand and gravel are slightly angular and unsorted. The sedimentary succession might be intercalated by a laterite layer. This sedimentary unit is about 10-20 m thick and is believed that it is the weathering product from the mountain retaining the flat area or peneplaination and from erosion by the wave cut during the last marine transgression (Late Pleistocene to Early Holocene).

*The colluvial deposits* are found near the mountains in the north and parts of the undulating terrain in the central of the region. The sedimentary succession consists of slightly angular gravel and coarse sand mixed with clay and is poorly sorted. This coarse sedimentary layer is overlain by a layer of silt or fine sand with clay without any sedimentary structures. Sedimentation of this sedimentary unit is derived from weathered rocks accumulated around the foot hills by gravity and stream flows on the hard rocks or on the residual sedimentary unit.

*The flood plain deposits* are found around the plains along various rivers that flow from the mountains in the north to the sea in the south. The sedimentary succession is consisted of gravel and sand layers intercalated with fine sand or silt layers mixed with clay transported and deposited by stream flows. The types of sediments vary in relation with types of the hard rocks and geomorphologic features in each area. The hard rocks in Chonburi and Rayong provinces are mainly igneous rocks with steep geomorphologic landforms yielding mainly gravel and sand. Whereas the areas of Chanthaburi and Trat provinces are mainly composed of metamorphic and fine grain sedimentary rocks with gentle slope terrains yielding mainly fine sand and silt with clay.

*The coastal wave-dominated deposits* are found in Chonburi and Rayong provinces along the cliff coasts alternated with barrier beaches. Sedimentary succession is mainly consisted of loose sand of the barrier beaches, berms and sand dunes. The sediments are subrounded to rounded with well sorting in association with mollusk shells in the sedimentary deposits. Some decayed plant remains may be found in lagoonal sand deposits. The sediments are influenced by wave action during the Early Holocene marine transgression. The sea later regressed in the Middle Holocene to the present. This sedi-

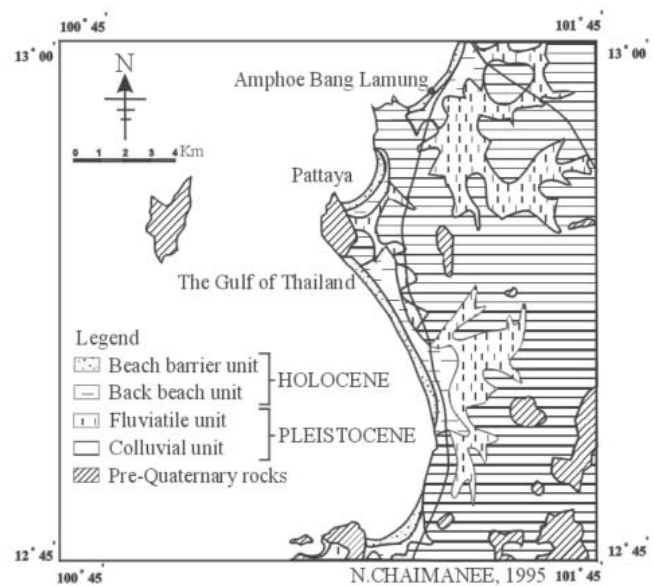


Figure 5 Geological map sheet Amphoe Bang Lamung shows alternations between small barrier beaches and cliff coasts (Chaimanee, 1995),

mentary unit is laterally related to the inland flood plain sedimentary unit and overlying older inland sedimentary units previously mentioned.

*Coastal tide-dominated deposits* are found in the tidal flat and mangrove swamps in Chanthaburi and Trat provinces. Sedimentary succession is consisted of soft marine clay and clay alternating with silt layers. Plant remains and mollusk shells are present. This sedimentary unit was deposited under the influence of tides during the marine transgression the same as the coastal wave-dominated deposits and laterally related with the flood plain deposits overlying the older inland sedimentary units.

Depositional environments of the Quaternary sediments in the eastern region are clearly related with the types of the sourced rocks, paleo-geomorphologic features, and climatic conditions in each period of time. Long period of erosion in the Early Quaternary shaped a steep slope physiographic feature near the high resistive-igneous rock mountains. Whereas, the gentle slope areas near the mountains are composed of fine texture metamorphic and sedimentary rocks. Transportations and deposition were taking place by the inland stream flows alternated with erosion through the Pleistocene.

The global climatic condition has changed to be a moist tropic since the Late Pleistocene to Early Holocene. The ice sheets at the poles melted leading to global sea level rises and marine transgressions. From the results of a peat palynological study from the coastal sediments in Chanthaburi province, the area gradually changed from the fluvial terrestrial sediments into a freshwater swamp near the sea and a mangrove swamp environment (Pramojanee and Hastings, 1983). The sea water encroached inland about 3-5 km from the present shoreline at about 6,000 years B.P. After that the sea gradually regressed to the present level. During the regression, the coastal sediments have accumulated forming the various coastal geomorphologies.

## 5. MINERAL DEPOSITS OF EASTERN THAILAND

Mineral deposits of eastern Thailand are relatively scarce comparing with those of other regions. Some of know mineral resources within the Shan-Thai Terrane is composed of silimanite and iron ore in the Precambrian rock unit. Gold bearing quartz loades were found in rock of Silurian-Devonian with has been intruded by the S-type granites. The sources of iron ore in the Permian-Triassic metatuff sequence is unknown, it can be either volcanogenic or the granitic rock from Khao Chamao. Stibnite occurs in various host rocks and is located with an equal distance from the Khao Chamao granite and the Permo-Triassic volcanic. The stibnite ore concentrates appear to be localized and has been mined out not very long ago. Not like the S-type granites in the western mountain range and the peninsular, the S-type granites are hardly carry tin-tungsten, only some heavy mineral deposits and the pegmatite bearing

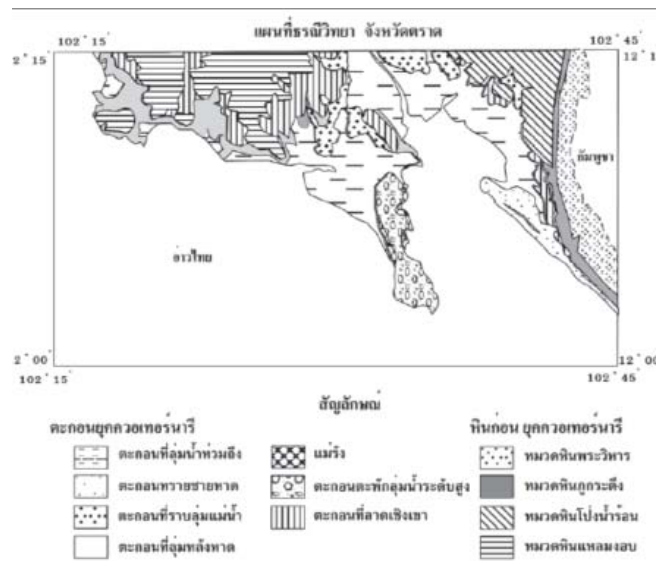


Figure 6 Geological map around the areas of Trat province shows Quaternary sedimentary units around Trat estuary that composed of the tidal flat and beach sand deposits (Tiyapairat and Mahaphum, 1994).

feldspar are presented. Other minerals found in minor amounts are galena, fluorite, manganese and molybdenum.

Along the contiguous area between the Shan-Thai and the Indoshinian terranes, here is only the gem-bearing Cenozoic basalt that strikes across the terranes. Within the Indoshinian terrane, there are only gold and sedimentary manganese which had been mined. Iron ore, chromite, magnesite, stibnite and fluorite are considered minor occurrences. Silica sand in Rayong and Trat appears to derive from the Red beds and the Khorat rocks.

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# EXCURSION STOPS



## 01

## Pyrophyllite Mining Co. Ltd.

Khao Mai Nean, Ban Cha-om, Kaeng Khoi district  
Saraburi province



Pyrophyllite Mine is a subsidiary of SCG Cement Co.,Ltd. (Public). The mine is located at Khao Mai Nean, Ban Cha-om, Kaeng Khoi district, Saraburi province and covers the area of 0.14 km<sup>2</sup>. The pyrophyllite and dickite occur as a hydrothermal origin that associated with volcanic host rocks e.g. rhyolite, andesite, ash flow tuffs, volcanic breccia, rhyolitic tuff and andesitic tuff which occurred during Permo-Triassic (PTrv). The host rocks have been altered by the tectonic and resulting in the dominant NW-SE fault set. Hydrothermal solutions traversing through fractured rocks/fault sets, the solution reacts with the wall rocks causing changes in mineral composition and are prone to be weathered. Pyrophyllite and dickite minerals can be formed by these processes. From the mine owner data, pyrophyllite and dickite has Al<sub>2</sub>O<sub>3</sub> ranging from 15% - 30% with SiO<sub>2</sub> < 76-78% and Fe<sub>2</sub>O<sub>3</sub> < 0.2-3%





Dickite ( $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ): Usually referred to as “soft rock” or “soap rock”, the pale green to pale brown, is the fact one of the kaolinite group formed under the influence of hydrothermal water that seeped through fractures in parent rocks, e.g. rhyolite and tuff. Dickite usually contains a considerable amount of alumina (28-32 %) and always used as carving materials or ceramics.

Pyrophyllite ( $\text{Al}_2\text{Si}_4\text{O}_{10}(\text{OH})_2$ ): containing 28.3%  $\text{Al}_2\text{O}_3$ , 66.7%  $\text{SiO}_2$  and 5%  $\text{H}_2\text{O}$ , is usually white to colorless, greasy to dull, but pearly on cleavage surfaces. In appearance it looks like talc and has physical properties similar talc. However, it differs in chemical composition, as talc is a hydrous magnesium silicate whereas pyrophyllite is hydrous aluminium silicate. The Pyrophyllite is also chemical inertness, high dielectric strength, high melting point, and low electric conductivity make it useful for ceramic and refractory applications.



## 2

## Khun Dan Prakan Chon Dam

Ban Tha Dan, Hin Tang subdistrict, Mueang district  
Nakhon Nayok province



The Khun Dan Prakan Chon Dam was originally named the Khlong Tha Dan Dam. The Thai authorities subsequently changed the name to the Khun Dan Prakan Chon Dam, which is the stream that flows from Heaw Narok Waterfall. You may still see some road signs pointing to Khlong Tha Dan Dam but most now call it the Khun Dan Prakan Chon Dam. They are the same place.





His Majesty King Bhumipol initiated the dam project. Nakhon Nayok province had long suffered from a cycle of floods and drought. The resulting poor acidic soil caused the farmers great hardship and occasional flash floods had claimed many lives. His Majesty the King, highly revered by Thai people, was aware of the suffering this cycle was causing to the people of Nakhon Nayok. He personally came to inspect the area in 1993. He spoke to local people about their problems, inspected the area on foot and by air. He concluded that a water management and irrigation system could solve many of Nakhon Nayok's problems and initiated the Tha Dan Dam project. Construction of the dam commenced in 1999.

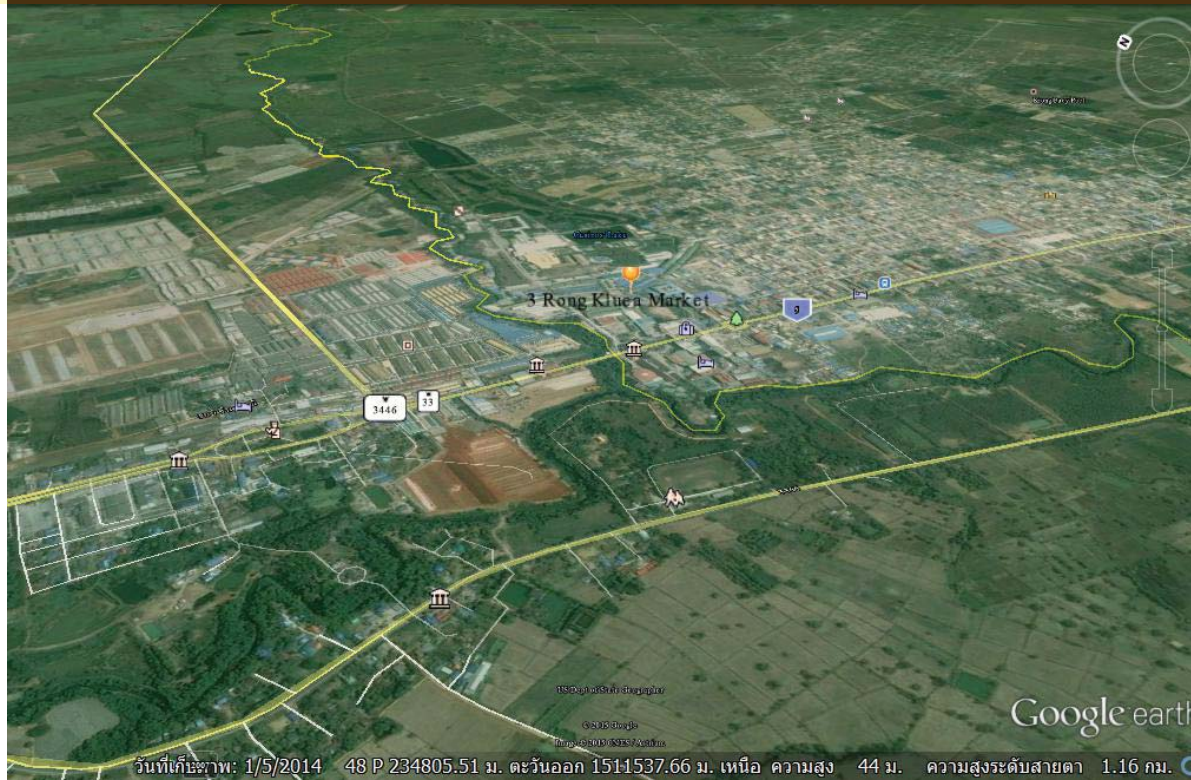
The Khun Dan Prakan Chon Dam was completed in 2005. It is 93 m high and 2,720 m long of which an incredible 5.5 million cubic meters of concrete. It has a storage capacity of 224 million cubic meters of water. It is the biggest dam in Thailand. It is also the largest and longest roller compacted concrete (RCC) dam in the world. The benefits for Nakhon Nayok including reduce damage from flooding, constant water supply for agricultural irrigation, water supply for local community, fish stocks in reservoir, tourism and natural scenery ([http://www.nakhon-nayok.com/khlong\\_tha\\_dan\\_dam.htm](http://www.nakhon-nayok.com/khlong_tha_dan_dam.htm))



## 3

## Rong Kluea Market

Ban Khlong Luek, Aranyaprathet district  
Sa Kaeo province



Talat Rong Kluea or Talat Chaidan Ban Khlong Luek is located at Ban Khlong Luek, Tha Kham Sub-district, 6 kilometres from Aranyaprathet district to the east, bordering with the Thailand – Cambodia frontier. It can be reached by taking Highway No.33 (Sa Kaeo-Aranyaprathet).

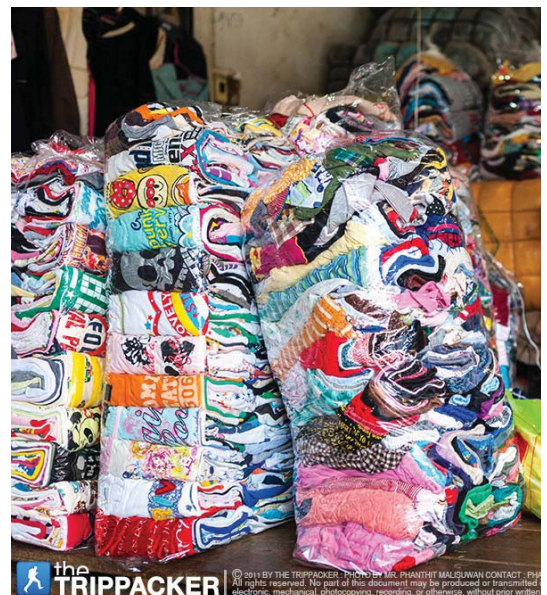




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Talat Rong Kluea is an important border market on the Thai side. The word “RongKluea” has originally been called because this location was once a place to reserve salt-Kluea-for further sale to the Cambodians as an ingredient to preserve fishes. Then, the necessity to use salt decreased, together with the fighting inside Cambodia from 1979-1993, causing the Cambodians to face famine. Therefore, Thailand came to help to solve the problem. Shops in the market are constructed in the style of school buildings, divided into rooms.

Most products are from the Cambodian border such as brass products, glazed products, ceramics, crockery, clothes, curtains, electronic appliances from Russia, woven products, dried fish, etc. ( <http://www.tourismthailand.org> )

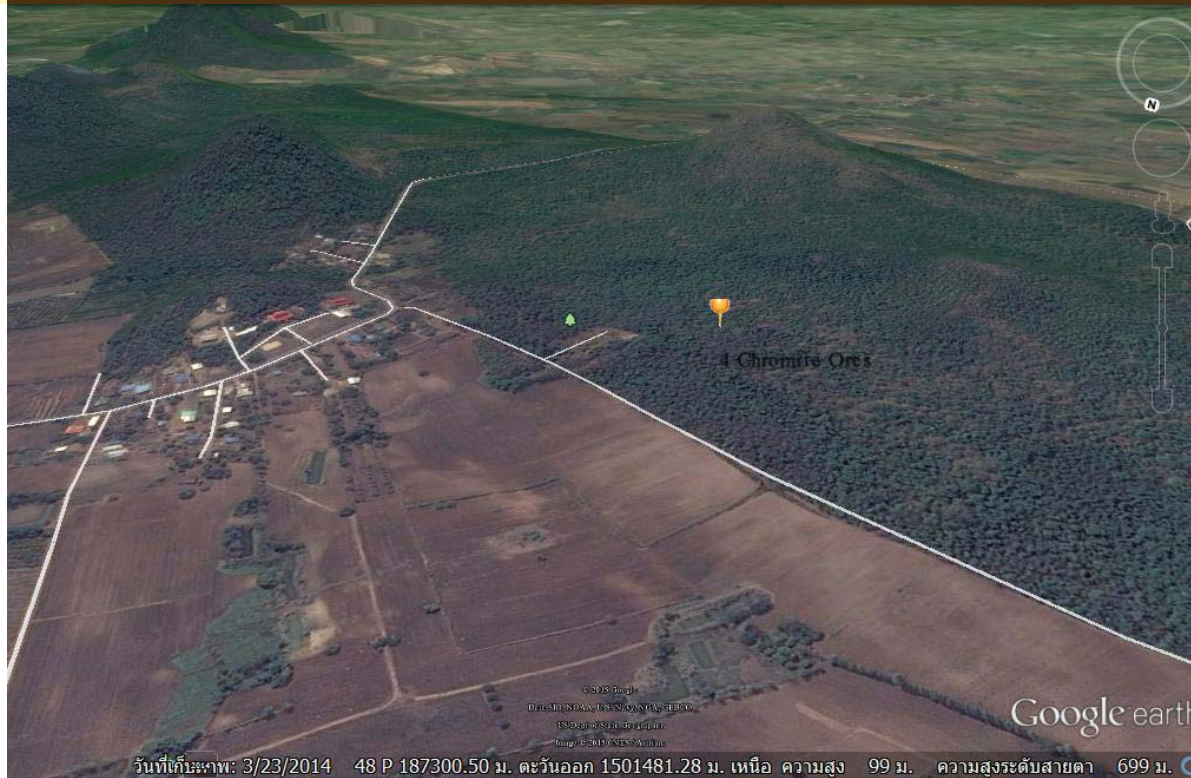


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## 4

## Chromite Ores

Khao Phlu Hip Forest Park, Ban Bo Luk Rang, Ta Lang Nai  
Wang Nam Yen district, Sa Kaeo province



Chromite ( $\text{FeCr}_2\text{O}_4$ ) is a major chromite ore for chromium metal producing. It is normally found as dense pisolite mass, brown to black color, hardness of 5.5, and specific gravity of 4.6. Two types of chromite ore are defined as chemical grade and refractory grade. In Thailand, chromite was precipitated and settled from ultramafic magma chamber. Shape of orebody was found as podiform, veinlet, dense mass, and lense. Dissemination was discovered in peridotite, pyroxenite, and amphibolite.





At Khao Phlu Hip Forest Park, serpentinite peridotite is the main rock type with minor peridotite. The rock shows olive green to dark green (color on weathered surface) but pale green to rather white tint (decomposed). On fresh surface, peridotite is dark green to black, dominant olivine and pyroxene, minor serpentine and enveloped opalization are in association with podiform-chromite and secondary altered magnesite.

Chromium from chromite is mainly used in metal alloy manufacturing. It makes the metal alloy to be higher strength, rust-proof, heat resistant, galvanic corrosive resistant and chemical corrosive resistant. Nichrome is used as glazing material to make metal shining, refractory brick etc.

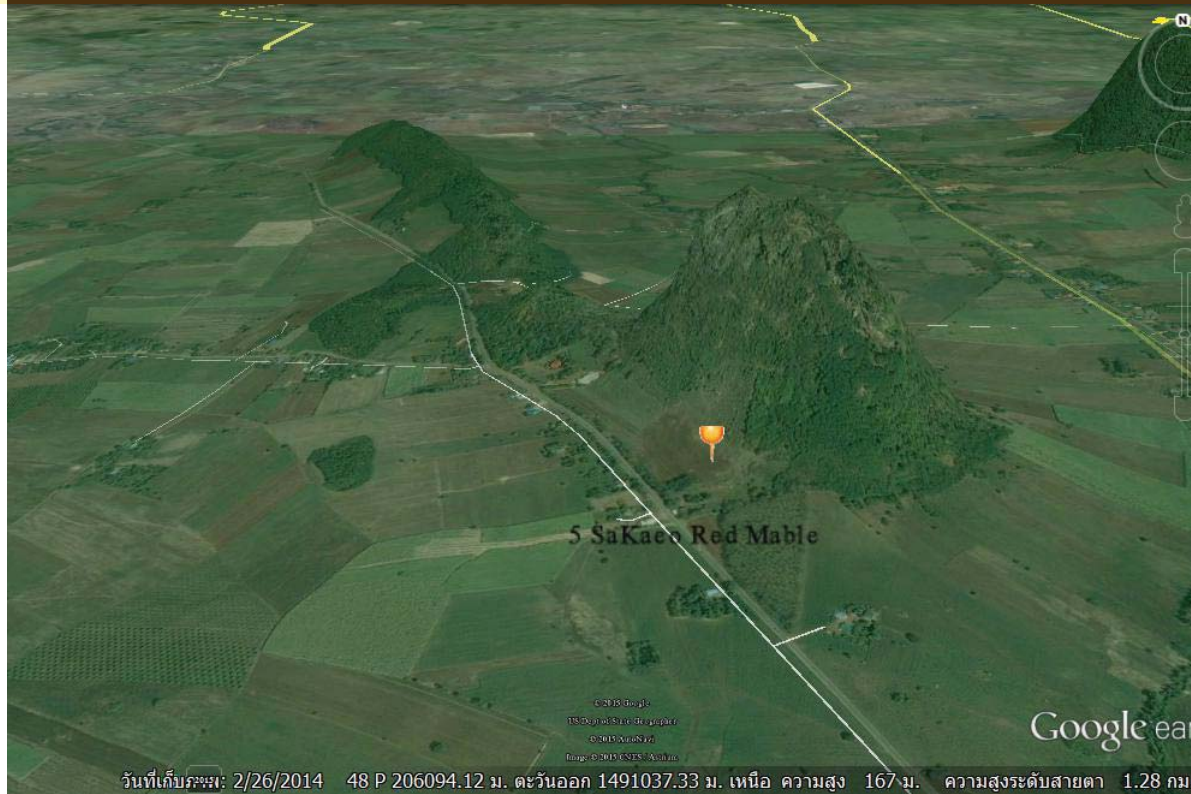


## 5

## Sa Kaeo Red Marble

Ban Khao Pha Phueng, Khlong Hat subdistrict

Khlong Hat district, Sa Kaeo province



Marble is a rock resulting from metamorphism of sedimentary carbonate rocks, most commonly limestone or dolomite rock. Metamorphism causes variable recrystallization of the original carbonate mineral grains. The resulting marble rock is typically composed of an interlocking mosaic of carbonate crystals. Primary sedimentary textures and structures of the original carbonate rock (protolith) have typically been modified or destroyed.



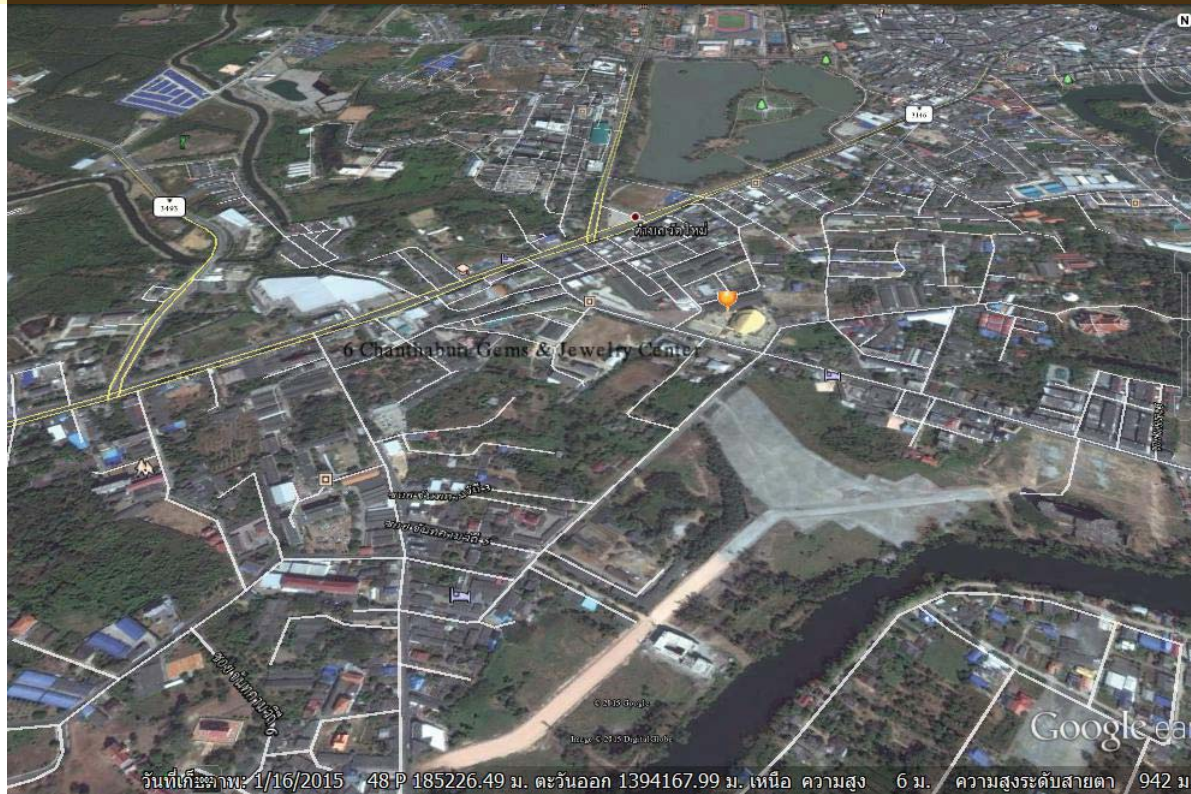


The Sa Kaeo red marble has become a popular construction material with higher price than marble of other colors. They are only a few red marble mines in Thailand, e.g. the Premier Marble Mine Co., Ltd. at Khao Pha Phueng, Khlong Hat district. Marble of Khao Pha Phueng is fine- to medium-grained, red to reddish brown and result of iron impurity within the rock mass. Sa kaeo red merble is classified as Khao Taa Ngok Formation deposited during the middle Permian period or around 270 million years ago. Fossils of crinoids, bryozoans, gastropods, and brachiopods are presented.

## 6

## Chanthaburi Gems & Jewelry Center

Muang district, Chanthaburi province



Gemstone and Jewelry Industry earns hundreds of billion baht of income for Thailand from exports. Eighty percent of exported gemstone are cut and given value added in Chanthaburi. Chanthaburi Province has therefore been famous for gem cutting has treatise enhancing and burning from the past until today.





Chanthaburi province is also the biggest gems trade and production center in Thailand and Southeast Asia. This means that we were ahead in the competition and have the potential to make Thailand the gem center of the region and, finally, of the world in the future. In order to establish Chanthaburi as “city of Gems,” the Gem and Jewelry Center was built with the support of fund and land from Chanthaburi. It is an important gemstone trade and information center of Thailand.

The Chanthaburi Gem and Jewelry Center is an all-around gem center which comprises a gem museum, a multimedia room (modern 3D videos introducing stone processing) gem exhibition hall, and gem cutting and inlay demonstration room. Chanthaburi Gems and Jewelry Center is open for visitors every day from 9.00 a.m.-5.00 p.m.



## 7

## Silica Sand and Clay of Sainuan Ltd.

Ban Nong Chawi, Khao Baisi subdistrict  
Tha Mai district, Chanthaburi province



The Silica Sand and Clay of Sainuan Ltd. is covered the area of 0.12 km<sup>2</sup> and is located at Ban Nong Chawi, Khao Baisi subdistrict, Tha Mai district, Chanthaburi province. It is operated by both opened mine and ground sticking. The average about 12 meters thick of this weathering layer is the deposit weathering product of Triassic granite. The granite rock is light gray to white in color, medium- to coarse-grained, equi-granular texture with small patch of mica and tourmaline. In general volumes of the raw materials consist of silica sand 70% and clay 30%.





Silica sand contains more than 95% quartz ( $\text{SiO}_2$ ) with low percentage of iron oxides and other impurities. Silica sand is a weathering product of granitic rock containing quartz crystals. Quartz is colorless to light gray, transparent and glassy luster, 8-250 mesh of diameter grain size, very angular to angular and high sphericity. Large pure and clear crystals are used to make optical lens, prism, digital quartz, and electronic parts. Impure quartz is used as abrasive, sand paper and iron smelting flux in substitution of fluorite. Silica sand is main raw material in glasses in-

dustry, ceramics, making mound in cast iron industry and abrasive material to polish iron steel.

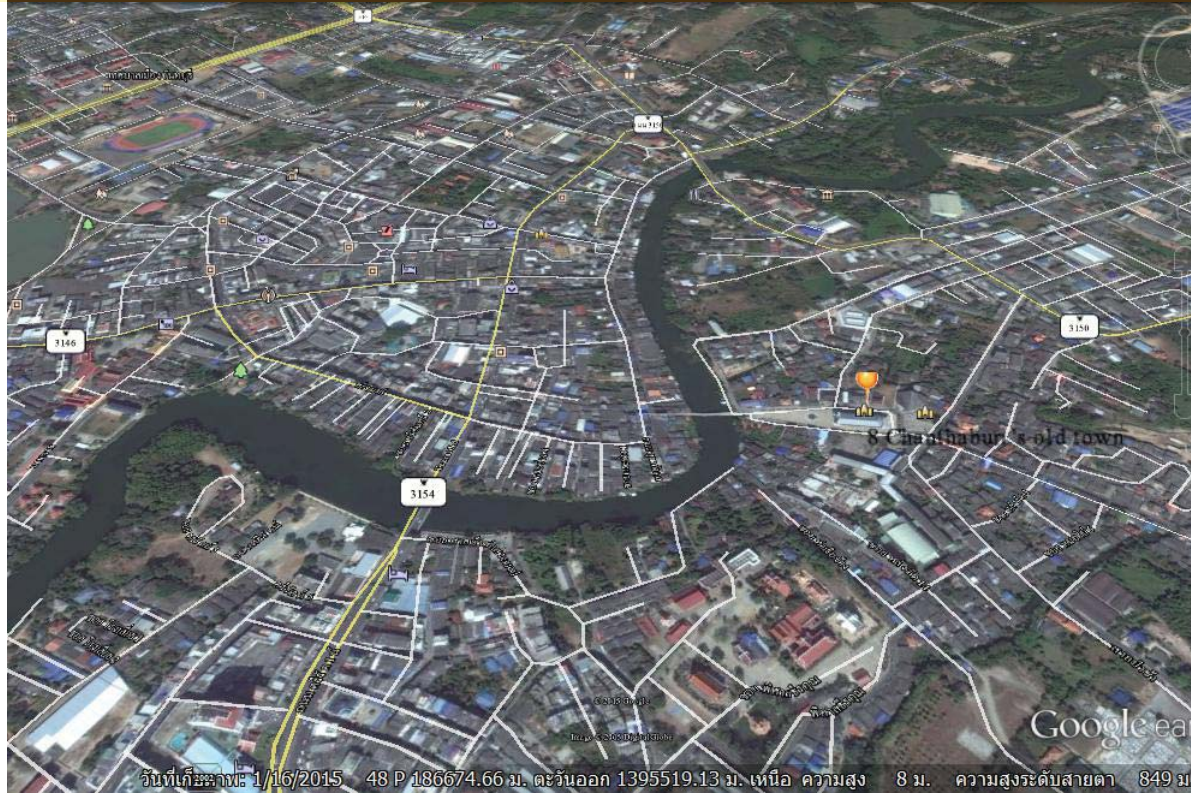
Clay mineral in mine is kaolinite ( $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$ ) because the main composition of high ratio of alumina. The 250-325 mesh kaolin processing has 25-30% of Al content while altered granite white clay 16-22%. The  $\text{Fe}_2\text{O}_3$  content is less than 4%. This clay is major raw material for ceramic manufacturing.



## 8

## Chanthaburi's Cathedral

Santisook Road, Chantanimit subdistrict,  
Muang district, Chanthaburi province



Chanthaburi's Cathedral of the Immaculate Conception is the largest Catholic building in Thailand. With its two towers, it became the symbol of the city. It is the the fifth church built there. Inaugurated in 1909 with the installation of a huge bell in one of its towers, it was built during the nearly 10 years of French occupation of Chanthabun (now Chanthaburi). It has quite classic Gothic style.





The cathedral stands on a small plaza where a statue of the Virgin Mary stands a few meters in front of the main entrance of the building. Open daily from 9 a.m to 4 p.m. One of the unique features of Chanthaburi Cathedral is the statue of the Virgin Mary located on a golden dais in front of the altar. Chanthaburi is famous for its gem trade and the glittering, jewel-encrusted statue showcases the workmanship of the local people.

Chanthaburi's old town is pervaded by an artsy, and at times quirky, atmosphere. Many old homes and shops are decorated with colorful lanterns, flags, signs and paintings, and a number of striking blue-yellow-purple murals depicting Chanthaburi night scenes are found throughout town. Our favorite of the art we saw in the old town was an old advertisement that depicts a woman's smiling face, which now beams from a crumbling brick wall down an alley.





# Excursion Route Map 2015