

GUIDE BOOK

Post-Conference Geological Excursion

*Cross-border Collaboration on Geology and Mineral Resources of
Cambodia-Lao PDR-Myanmar-Thailand-Vietnam
22th – 23th , May 2016*



Cross-border Collaboration on Geology and Mineral Resources of
Cambodia-Lao PDR-Myanmar-Thailand-Vietnam
Excursion Guidebook, 22-23 May 2016

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Reference site

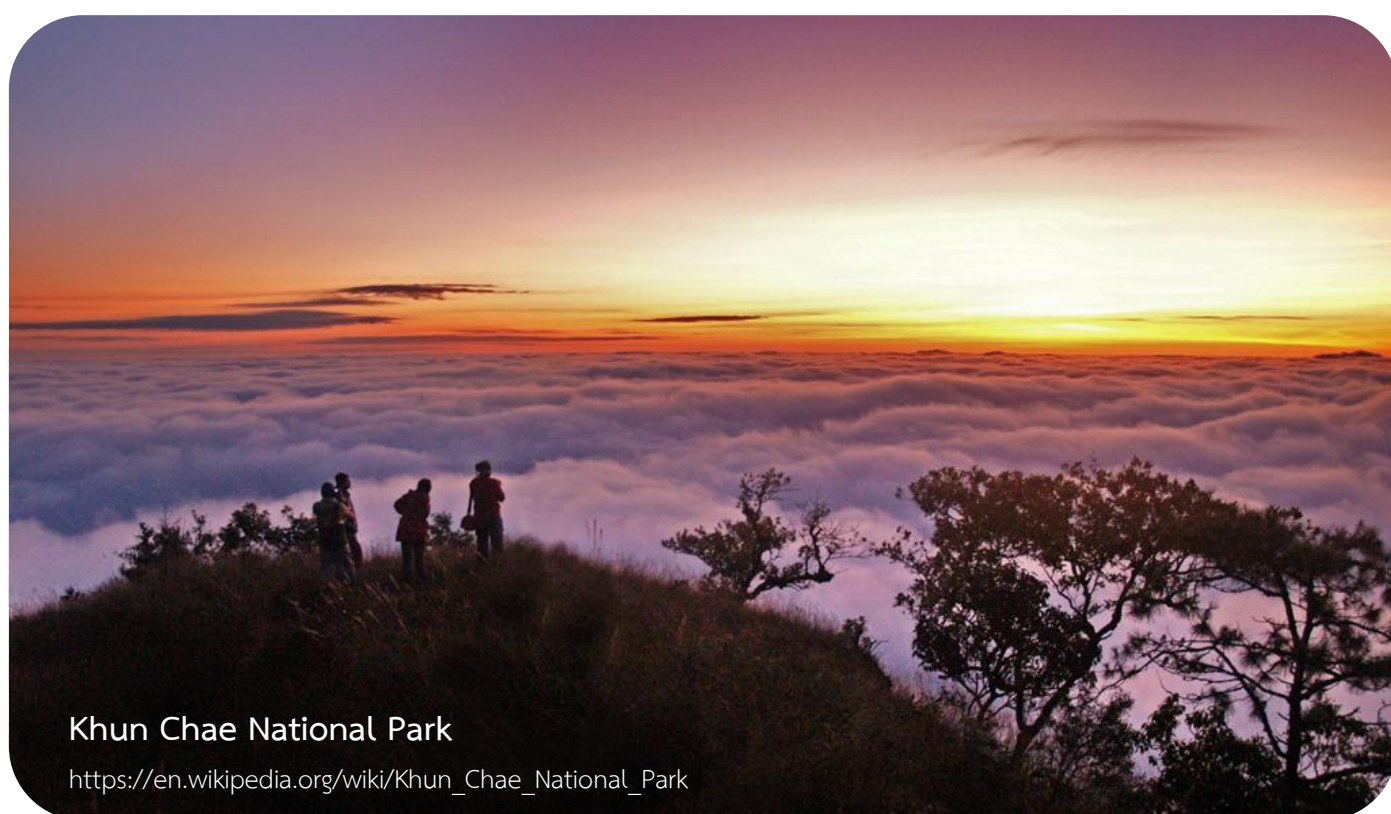
Excursion Guidebook, 22-23 May 2016

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2016, Department of Mineral Resources, Bangkok, Thailand, 46 p.

Preface

A basic, practical understanding of geology is essential for understanding the occurrence of mineral resources and the risk on geologic hazards to accepting and moving beyond them proactively. Due to the continuity of land and abundance of mineral resources of the CLMTV countries, there are advantages and chance for the five countries to study and share geological information together as information network. The technical cooperation projects named “The Cross-border Collaboration on Geology and Mineral Resources of Cambodia-Laos-Myanmar-Thailand-Vietnam” is proposed here. The aims of this project is to correct and updated geological information between boundaries of the five countries and sharing among the members which will be very important basic information for mineral development of member countries in the future. The project will provide member countries with an indispensable tool for the physical knowledge and management (prediction and prevention of natural hazards) of the territory and its resources.

This excursion guidebook is prepared for the field trip held during 22-23 May, 2016 to Chiang Rai province. The 7 sites among routes including geological sites and attractive places for tourists. We do hope that this guidebook will be useful and lead all participants achieve and exchange their knowledge and experiences on geology during the excursion.



Khun Chae National Park

https://en.wikipedia.org/wiki/Khun_Chae_National_Park

Contents

Preface	I
Contents	II
Excursion Programme	III
Introductions	1
• Geography	1
• Boundary	1
• Administration	1
• Climate	1
• Geology of Chiang Rai	3
The excursion stops	10
• Stop 1 Wat Mae Suai Luang	11
• Stop 2 Mae Suai Reservoir	24
• Stop 3 Trench	26
• Stop 4 Wat Rong Khun (White Temple)	30
• Stop 5 Pah Tung Hot Spring	32
• Stop 6 Mae Sai – Tachilek Border	40
• Stop 7 Golden Triangle	41
References	43

Post-Conference Excursion Programme

Geology : Geo-hazard : Geo-conservation

DAY 1 : 22 May 2016

Times	Programme
08.30 - 09.30	Travel from Mueang Chiang Rai district to Mae Suai district
09.30 - 10.30	Stop 1 : Wat Mae Suai Luang, Mae Suai district, Chiang Rai province
10.30 - 10.45	Travel to Stop 2
10.45 - 11.45	Stop 2 : Mae Suai Reservoir, Mae Suai district, Chiang Rai province
11.45 - 12.00	Travel to restaurant
12.00 - 13.00	Lunch
13.00 - 13.15	Travel to Stop 3
13.15 - 14.30	Stop 3 : Trench, Mae Lao district, Chiang Rai province
14.30 - 15.00	Travel from Mae Suai district to Mueang district
15.00 - 16.30	Stop 4 : Wat Rong Khun, buddhist temple, Mueang district, Chiang Rai province
16.30 - 17.00	Travel to Mueang Chiang Rai district

DAY 2 : 23 May 2016

Times	Programme
08.30 - 09.00	Travel from Mueang Chiang Rai district to Mae Chan district
09.00 - 10.00	Stop 5 : Pah Tung Hot Spring, Mae Chan district, Chiang Rai province
10.00 - 10.45	Travel from Mae Chan district to Mae Sai district
10.45 - 11.45	Stop 6 : Mae Sai - Tachilek Border, Mae Sai district, Chiang Rai province
11.45 - 12.15	Travel from Mae Sai district to Chiang Saen district
12.15 - 13.30	Lunch
13.30 - 15.30	Stop 7 : Golden Triangle, Chiang Saen district, Chiang Rai province
15.30 - 17.00	Travel from Chiang Saen district to Mueang Chiang Rai district

INTRODUCTION

GEOGRAPHY

Chiang Rai is Thailand's northernmost province. It is located about 785 kilometers north of Bangkok. Chiang Rai is situated on the Kok River basin with an area of some 11,678 square kilometers situated at about 410 m above sea level. Kok river is a tributary of the Mekong river between the Daen Lao Range in the north and the Phi Pan Nam Range in the south. The Mae Kok River runs along Chiang Rai's north side, flowing eastwards out of Myanmar at Tha Ton town and joining the Mekong River about 40 kilometers in north-east of the city. Chiang Rai has border on both Myanmar and Laos. In addition, the Lao River, a tributary of the Kok, flows in the south of Chiang Rai.



https://en.wikipedia.org/wiki/Chiang_Rai_Province

There are four bridges spanning the Mae Kok river in north-south directions within the town boundaries. The terrain surrounding Chiang Rai town is either flat or moderate hills. The limestone mountains are found in the west and north-west directions as cliff features. These areas are occupied by most of the region's Hill Tribe people.

BOUNDARY

North: Myanmar and People's Democratic Republic of Laos

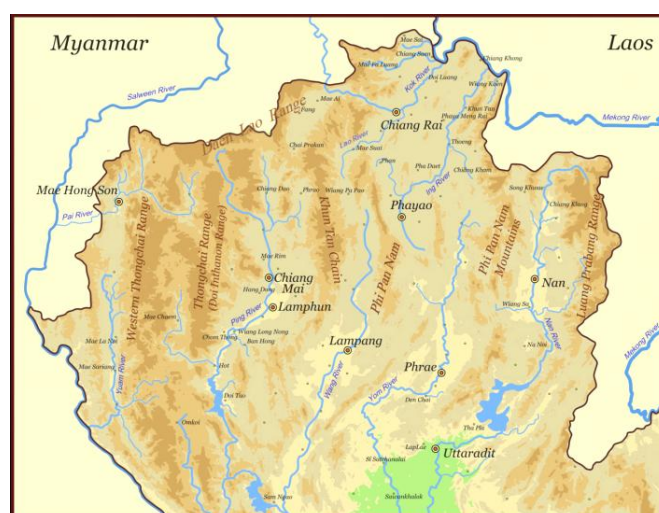
East: Chiang Mai Province

West: People's Democratic Republic of Laos

South: Phayao and Lampang Provinces

ADMINISTRATION

The province is subdivided into 18 districts (Amphoe). These are further subdivided into 124 subdistricts (tambon) and 1,751 villages (muban).



https://en.wikipedia.org/wiki/Kok_River

CLIMATE

Chiang Rai has a tropical wet and dry climate (Köppen climate classification Aw). Winters are fairly dry and cool. In summer, temperatures rise until April, which is hot with the average daily maximum at 34.9 °C (94.8 °F). The monsoon season runs from late April through October, with heavy rain and somewhat cooler temperatures during the daytime.



GEOLOGY OF CHIANG RAI

SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS

SILURIAN-DEVONIAN (SD)

Sukhothai Group : was named from clearly exposed outcrop in Sukhothai province. The sequences consist of low grade metamorphic rocks such as phyllite, Phylitic schist quartzite and chert. This group had deposited in the deep sea at about 438-360 Ma and then was deformed by intensive tectonic process during 220 Ma.

DEVONIAN- CARBONIFEROUS (DC)

DC rock units are included quartzite, shale, impure limestone, tuff and black chert, and widely exposed in northeastern of Mae Chan and Mae Fah Luang district.

CARBONIFEROUS (C)

Dan Lan Hoi Group : was named from Dan Lan Hoi district, Sukhothai province. The sequences consist of andesitic agglomerate, red sandstone, siltstone and rhyolitic agglomerate and deposited in the sea close to volcanic arc zone.

CARBONIFEROUS- PERMIAN (CP)

CP rock unit consists of gray sandstone which was intercalated with gray shale, tuffaceous siltstone, reddish brown conglomerate and blackish gray limestone with coral fossils. The rock sequences were partly metamorphosed into phyllite and marble.

PERMIAN (P)

Ngao Group (P) : consists of limestone, recrystallized limestone, gray, shale, phyllitic shale, sandstone, siltstone, tuffaceous shale and conglomerate. This group can be classified into 3 formations from lower to upper part namely: Kui Lom Formation, Pha Huat Formation and Huai Thak Formation. 2 formations have been found in Chaing Rai Province. The details are as follow:

Pha Huat Formation (Pph) : is in the middle formation of Ngao Group and consists of thick-bedded gray limestone showing distinct karst topography, tuffaceous sandstone and shale.

Huai Thak Formation (Pht) : is the upper formation of Ngao Group. This formation consists of dark gray shale and mudstone. Sandstone, limestone and conglomerate may alternated in the sequence.

PERMIAN-TRIASSIC (PTr)

PTr rock unit consists of blackish to greenish gray shale, siltstone, sandstone and was intercalated with thin-bedded chert. The units are widely exposed in eastern part of Chaing Rai province.

TRIASSIC (Tr)

Lampang Group : was represent the marine deposits and consists of mudstone, limestone, sandstone and conglomerate. Lampang Group can be classified into 7 formations from lower to upper part: Phra That Formation, Pha Kan Formation, Hong Hoi Formation Doi Long Formation, Pha Daeng Formation, Kang Pla Formation and Wang Chin Formation.

Lampang Group, Triassic (Trl)

The undifferentiated Lampang Group consists of mudstone, limestone, siltstone and widely distributed in east of Mae Chan district.

In Chaing Rai province, 4 formations which can relate Lampang Group were found. The details are as follow:

Phra That Formation : consists mainly of medium-bedded to massive limestone which partly intercalated with sandstone and mudstone.

Hong Hoi Formation : is a main formation of Lampang Group and extensively widespread. This formation consists of greenish gray mudstone which partly intercalated with thin-bedded greenish gray sandstone and mudstone. Some parts of sandstone maybe thick bed.

Doi Long Formation : consists of massive limestone in gray and light gray color. This formation was formed in the shallow sea.

Kang Pla Formation : consists mainly of fine-to coarse-grained limestone in gray to dark gray color and may be thin bed to massive. In the lower part, this formation consists of sandstone which intercalated with thin-bedded mudstone.

TRIASSIC- JURASSIC (TrJ)

TrJ rock unit consists of red conglomerate, greenish gray sandstone which interbedded with mudstone and is intercalated with volcanic tuff in the lower part.

JURASSIC (J)

J rock unit consists of red conglomerate, brownish red sandstone which interbedded with siltstone, brownish red mudstone and conglomerate with fossils of bivalve.

JURASSIC- CRETACEOUS (JK)

JK rock unit consists of quartzitic sandstone, brown, gray, thick bed, showing high angle cross bedding. The unit may be intercalated with greenish gray siltstone and reddish brown mudstone.

CRETACEOUS (K)

K rock unit consists of brick red arkosic sandstone showing cross bedding. This unit is intercalated with reddish brown mudstone and siltstone. Gypsum nodules were always found in this unit.

TERTIARY (T)

Mae Moh Group : consists of claystone, siltstone, mudstone, diatomite and lignite. These rocks are semi-consolidated with abundant fossils of bivalve, fish and mammal.

QUATERNARY

Terrace deposits (Qt) : consists of gravel, sand, and laterite.

Aluvial deposits (Qa) : consists of clayey sand, sandy clay, lateritic soil, and gravel.

Flood plain deposits (Qf) : consists of clay which intercalated with layer of sandy gravel bulb.

Colluvial deposits (Qc) : consists of clay and rock fragments which has various sizes and show angular shape.

IGNEOUS AND VOLCANIC ROCKS

Devonian-carboniferous volcanic rocks (DCv) consist of thick andesitic basalt, andesite, which interbedded with schist and phyllite.

Permian-triassic volcanic rocks (PTrv) consist of rhyolite, andesite and agglomerate.

Permian-triassic ultrabasic igneous rocks (PTru) consist of serpentinite, gabbro and basalt.

Triassic igneous rocks (Trdi) consist of fine-grained diorite in dark gray color and very coarse-grained hornblende in dark gray to black color.

Triassic igneous rocks (Trgr1) consist of porphyritic biotite granite and porphyritic granite with large phenocryst .

Triassic igneous rocks (Trgr2) consist of biotite granite, hornblende biotite granite with equigranular to small porphyritic texture, fine-to medium-grained leucogranite, and aplite.

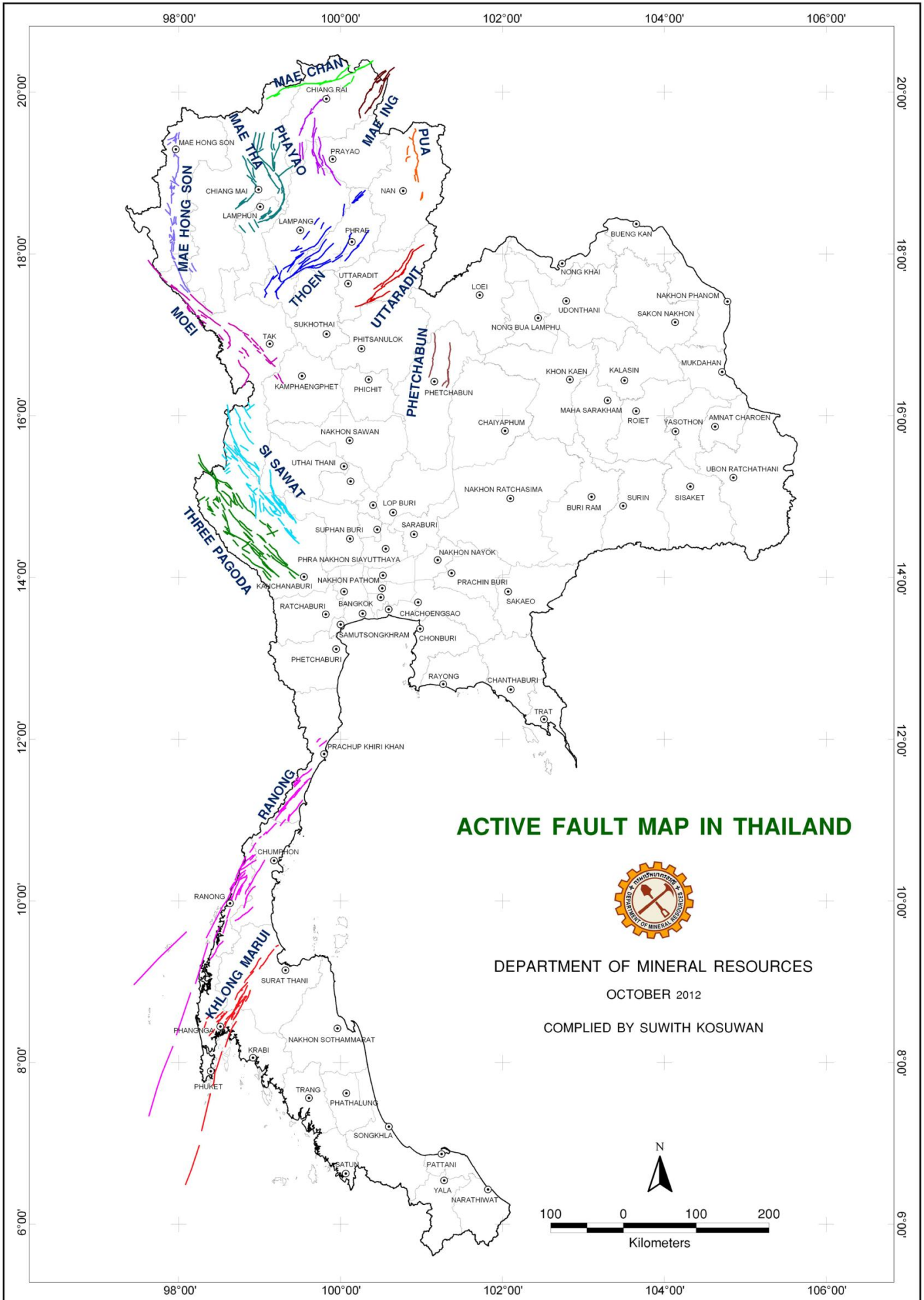
Triassic igneous rocks (Trgr) consist of biotite granite with medium-to coarse-grained and porphyritic texture and fine-grained muscovite granite.

Jurassic volcanic rocks (Jv) consist of rhyolite, andesite and basalt which containing abundant vesicles. The sequence are partly intercalated with shale and feldspathic sandstone.

Tertiary volcanic rocks (bs) consists of blackish gray basalt with vesicular texture and show flow structure (pahoe hoe), volcanic bombs and scoria.

ตะกอน หินชั้น และหินแปร SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	ชื่อหมวด/กลุ่มหิน FORMATION/GROUP	ยุค PERIOD	อายุ (ล้านปี) AGE (my.)
<p>Qf ตะกอนที่ราบน้ำท่วมถึงประกอบด้วย ดินเหนียว มีชั้นทรายปนกรวดเป็นระยะประปราย Flood plain deposits: Clay, intercalated with layer of sandy gravel bulb.</p>	หมวดหินเมมมาะ Mae Moh Formation	ควอเทอร์นารี QUATERNARY	0.01
<p>Qa ตะกอนน้ำพาประกอบด้วย ทรายปนดินเหนียวและดินเหนียวปนทราย มีลูกกริมและกรวด Ahlvial deposits: clayey sand, sandy clay, lateritic soil, and clay.</p>			
<p>Qt ตะกอนบนตะพานประกอบด้วย กรวด ทราย และแม่ริ่ง Terrace deposits: gravel, sand, and laterite.</p>			
<p>Qc ตะกอนตะกอนหินเชิงเขา: ตะกอนดิน เศษหินเชิงเขา มีหลายขนาด ลักษณะเป็นเหลี่ยมและทิวาแลง Colluvial deposits: sediment, colluvium, various size, angular and laterite.</p>			0.01
<p>T หินโคลน หินทรายแป้ง หินทราย หินโคลน ดินเบา และถ่านหินลิกไนต์ Claystone, siltstone, sandstone, mudstone, diatomite and lignite.</p>		เทอร์เชียรี TERTIARY	1.6
<p>K หินทราย เนื้อหยาบ โคน สีแดงอิฐ แสดงชั้นเฉียงระดับ แทรกสลับกับโคลน และหินทรายแป้งสีน้ำตาลแดง มีก้อนหินปูน Arkosic sandstone, brick red, cross-bedding, intercalated with mudstone and siltstone, reddish brown, gypsum nodules.</p>		ครีเทเชียส CRETACEOUS	140
<p>JK หินทรายเนื้อหยาบ สีนํ้าตาล สีเทา ชั้นหินหนา แสดงชั้นเฉียงระดับแบบมุมสูง แทรกสลับกับหินทรายแป้ง สีเทาเขียว และหินโคลนสีน้ำตาลแดง Quartzite sandstone, brown, gray, thick-bedded, high angle cross bedding, intercalated with mudstone, greenish gray and mudstone, reddish brown.</p>			
<p>J หินกรวดมน สีแดง หินทรายสีน้ำตาลแดง แทรกสลับกับหินทรายแป้งและหินโคลนสีน้ำตาลแดง และหินกรวดมนพบซากฟอสซิล Conglomerate, red, sandstone, reddish brown, intercalated with siltstone and mudstone, brownish red; conglomerate with fossils of bivalve.</p>		จูแรสซิก JURASSIC	210
<p>พ หินกรวดมน สีแดง หินทราย สีเทาเขียว แทรกสลับกับหินโคลน หินทรายแป้ง และหินออร์ไรนด์ เนื้อปูน ส่วนล่างพบหินถ่านหิน Conglomerate, red, sandstone, greenish gray, intercalated with mudstone, siltstone and arenite, calcareous; lower part: intercalated with tuff.</p>			
<p>พsp หินปูน สีเทา ชั้นบางถึงชั้นหนา Limestone, gray, thin-to thick-bedded.</p>	หมวดหินกำแพงปลา กลุ่มหินลำปาง Kang Pla Formation, Lampang Group		
<p>พd หินปูน สีเทาอ่อน ไม่แสดงชั้น Limestone, light gray, massive.</p>	หมวดหินดอยสอง กลุ่มหินลำปาง Doi Long Formation, Lampang Group		
<p>พh หินโคลน สีเทาถึงสีเทาเข้ม แทรกสลับกับหินทราย ชั้นบางถึงชั้นหนา Mudstone, gray to dark gray, interbedded with sandstone, thin- to thick-bedded.</p>	หมวดหินสองหอย กลุ่มหินลำปาง Hong Hoi Formation, Lampang Group	ไทรแอสซิก TRIASSIC	
<p>พpk หินปูน สีเทาเข้ม ชั้นหนาปานกลางถึงไม่แสดงชั้น แทรกสลับกับหินทรายและหินโคลน Limestone, dark gray, thick-bedded to massive, locally intercalated with sandstone and mudstone.</p>	หมวดหินผากัน กลุ่มหินลำปาง Pha Kan Formation, Lampang Group		
<p>พl หินโคลน หินปูน หินทราย และหินทรายแป้ง Mudstone, limestone, sandstone and siltstone.</p>	กลุ่มหินลำปาง Lampang Group		
<p>พR หินดินดาน หินทรายแป้ง และหินทราย สีเทาถึงสีเทาเขียว แทรกสลับกับหินเชิร์ต ชั้นบาง Shale, siltstone and sandstone, blackish gray to greenish gray, intercalated with thin-bedded chert.</p>			245
<p>พht หินดินดาน สลับชั้นกับหินโคลน สีเทาเข้ม มีชั้นหินทรายและหินปูนสีเทาแทรกสลับ Shale, interbedded with mudstone, dark gray, intercalated with sandstone and gray limestone.</p>	หมวดหินห้วยทาก กลุ่มหินงาว Huai Thak Formation, Ngoai Group		
<p>พph หินปูน สีเทา ชั้นหนา แสดงลักษณะหน้าตาหินปูนชัดเจน และหินทรายเนื้อหยาบและหินดินดาน Limestone, gray, thick-bedded, distinct karst topography, tuffaceous sandstone and shale.</p>	หมวดหินผาหาว กลุ่มหินงาว Pha Huat Formation, Ngoai Group	เพอร์เมียน PERMIAN	
<p>P หินปูน หินปูนผลึกใหม่ สีเทา หินดินดาน หินดินดานเนื้อฟิลโด หินทราย หินทรายแป้ง หินดินดานเนื้อที่ฟ และหินกรวดมน Limestone, recrystallized limestone, gray, shale, phyllitic shale, sandstone, siltstone, tuffaceous shale and conglomerate.</p>	กลุ่มหินงาว Ngoai Group		
<p>CP หินทราย สีเทา แทรกสลับกับหินดินดาน สีเทา หินทรายแป้งเนื้อหยาบและหินกรวดมน สีนํ้าตาลแดง บางแห่งพบหินปูนสีเทา มีซากปะการัง บางแห่งถูกแปรสภาพกลายเป็นหินฟิลโด และหินอ่อน Sandstone, gray, intercalated with shale, gray, tuffaceous siltstone and conglomerate, reddish brown; partly found limestone with coral fossils; partly metamorphosed into phyllite and marble.</p>			286
<p>C หินทรายเนื้อหยาบ โคน และเนื้อหยาบ สลับกับหินดินดานและหินทรายแป้งถูกแปรสภาพเล็กน้อย แต่ลักษณะชั้นหินถูกเปลี่ยนรูปร่าง Arkosic and quartzite sandstone, interbedded with shale and slightly metamorphosed siltstone, strongly deformed bed.</p>	กลุ่มหินดำนานหอย Dan Lan Hoi Group	คาร์บอนิเฟอรัส CARBONIFEROUS	
<p>DC หินควอร์ตไซต์ หินดินดาน หินปูนเนื้อสปริงก หินถ่านหิน และหินเชิร์ตสีดำ Quartzite, shale, impure limestone, tuff and black chert.</p>		ดีโวเนียน DEVONIAN	360
<p>SD หินแปรชั้นต่ำ หินฟิลโด หินเชิร์ตเนื้อฟิลโด สลับกับหินควอร์ตไซต์ Low grade metamorphic rock: phyllite, Phyllitic schist, interbedded with quartzite.</p>	กลุ่มหินสุโขทัย Sukhothai Group	ไซลูเรียน SILURIAN	408

หินอัคนี IGNEOUS ROCKS	อายุ (ล้านปี) AGE (my.)
<p>bs หินภูเขาไฟชนิดบะซอลต์ สีเทาเข้ม มีโพรงอากาศ แสดงลักษณะการไหล (พวยไฟ) พบออร์บภูเขาไฟ และตะกอนภูเขาไฟ Volcanic rock: basalt, blackish gray, vesicular texture, flow structure (pahoe hoe) with some volcanic bombs and scoria.</p>	< 66.4
<p>Jv หินภูเขาไฟชนิด ไรโอไลต์ แอนดีไซต์ บะซอลต์ที่มีฟองมาก พบหินดินดาน และหินทรายเนื้อฟิลโดสีน้ำตาลแดง แทรกสลับกับ Volcanic rock: rhyolite, andesite, basalt with abundant vesicles; partly intercalated with shale and feldspathic sandstone, reddish brown.</p>	140 - 210
<p>พgr หินอัคนีชนิด หินโอไรต์แกรนิต เนื้อปานกลางถึงหยาบ เนื้อเป็นดอก หินมีสีไลต์แกรนิต เนื้อละเอียด Igneous rock: biotite granite, medium-to coarse-grained, porphyritic texture, muscovite, fine-grained.</p>	
<p>พgr+ หินอัคนีชนิด หินโอไรต์แกรนิต หินออร์บอบนดี โอไรต์แกรนิต เนื้อหยาบถึงปานกลาง หินโอไรต์แกรนิต เนื้อละเอียดถึงปานกลาง และหินโอไรต์ Igneous rock: biotite granite, hornblende biotite granite, equigranular to small porphyritic texture, leucogranite, fine-to medium-grained and aplite.</p>	210 - 245
<p>พgr1 หินอัคนีชนิด หินโอไรต์แกรนิต เนื้อเป็นดอก หินแกรนิต เนื้อเป็นดอก มีแร่คอกซนลาใหญ่ Igneous rock: biotite granite, porphyritic texture; granite, porphyritic texture, large phenocryst.</p>	
<p>พd หินอัคนีชนิด หินไดอไรต์ สีเทาเข้ม เนื้อละเอียด หินออร์บอบนดี สีเทาเข้มถึงดำ เนื้อหยาบมาก Volcanic rock: diorite, dark gray, fine-grained, hornblende, dark gray to black, very coarse-grained.</p>	
<p>พRu หินอัคนีชนิด หินอูว์ราวยลิก เซอร์เพนไทน์ แกบโบร และบะซอลต์ Ultrabasic igneous rock: Serpentinite, gabbro and basalt.</p>	
<p>พRv หินภูเขาไฟชนิด ไรโอไลต์ แอนดีไซต์ และหินกรวดมนเนื้อภูเขาไฟ Volcanic rock: rhyolite, andesite and agglomerate.</p>	210 - 286
<p>DCv หินภูเขาไฟชนิด บะซอลต์ปอนแอนดีไซต์ หินแอนดีไซต์ หนาบาง สลับกับหินเชิร์ตและหินฟิลโด Volcanic rock: andesitic basalt, andesite, very thick, interbedded with schist and phyllite.</p>	286 - 408



ACTIVE FAULT MAP IN THAILAND

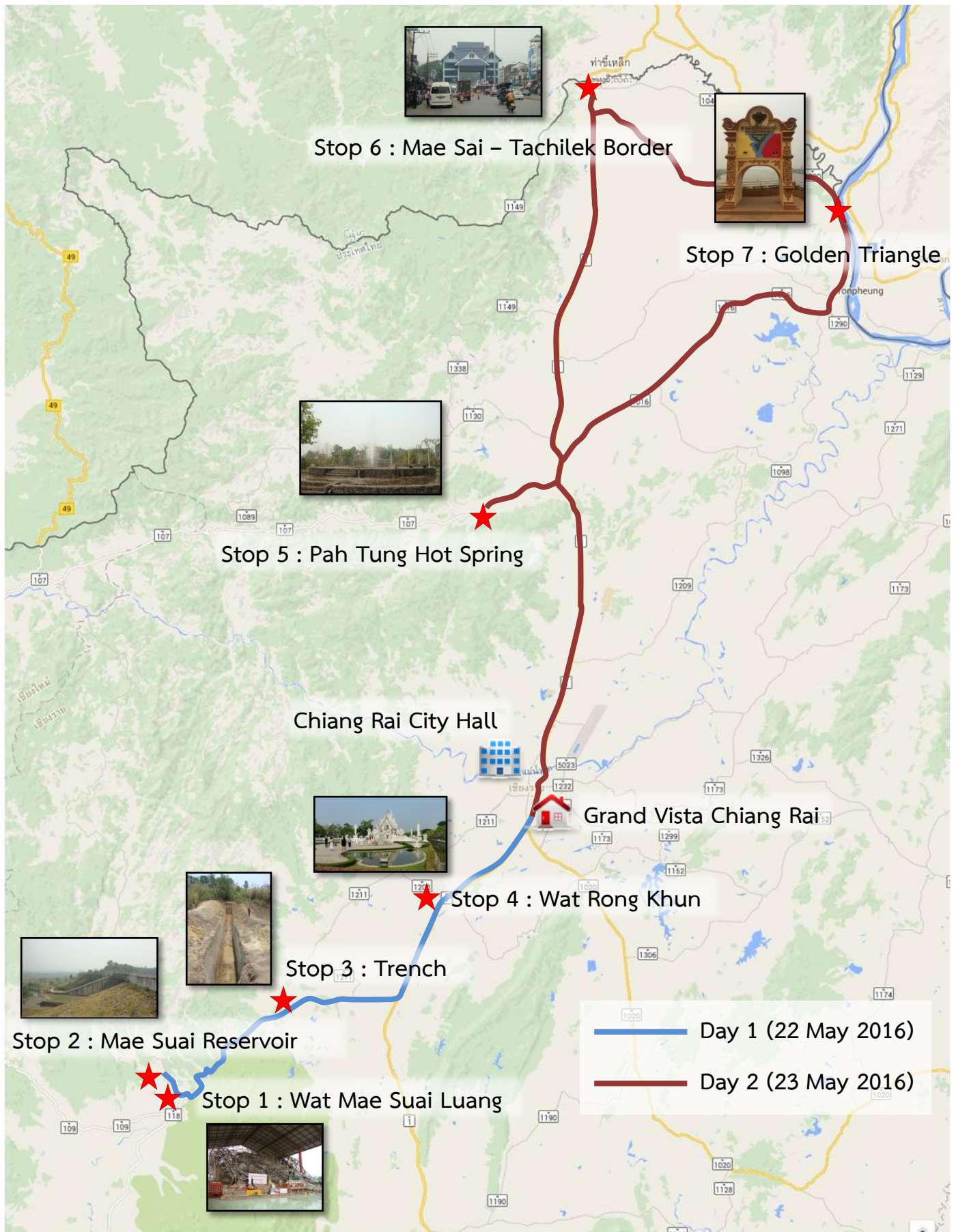


DEPARTMENT OF MINERAL RESOURCES

OCTOBER 2012

COMPILED BY SUWITH KOSUWAN

EXCURSION STOPS

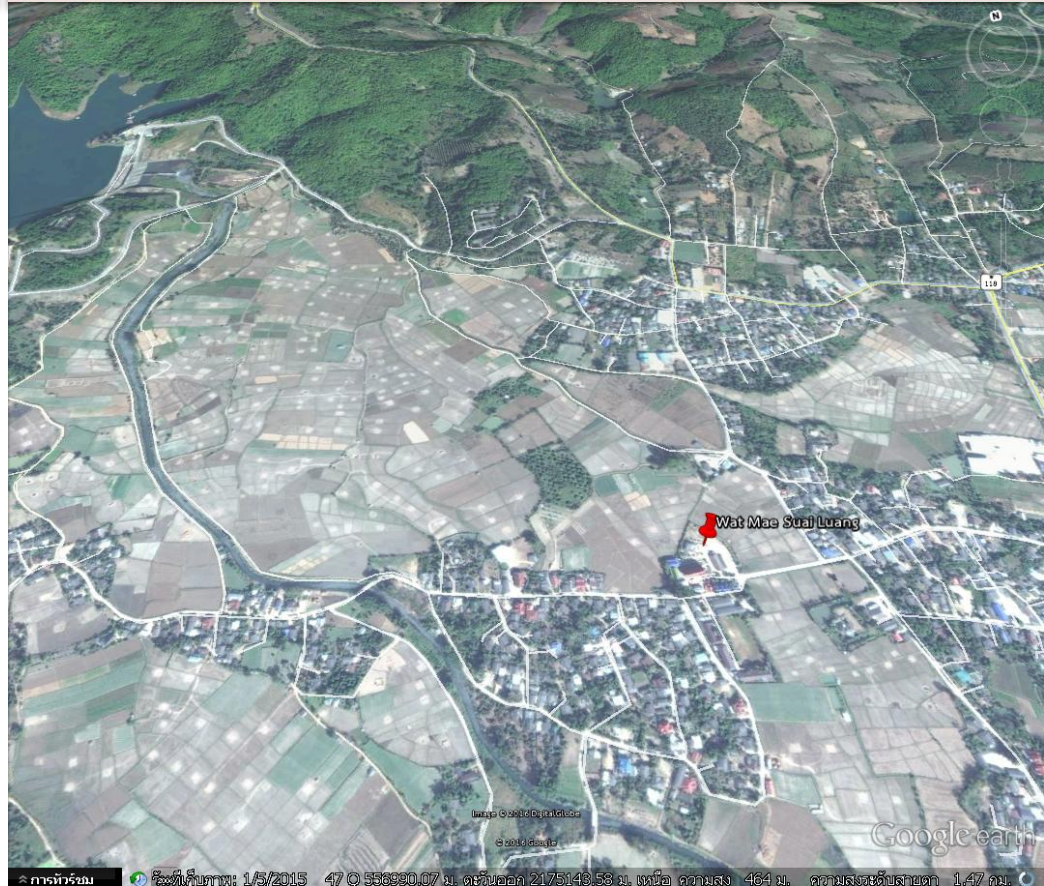


01

Wat Mae Suai Luang

Ban Son Klang, Mae Suai subdistrict, Mae Suai district

Chiang Rai province



Wat Mae Suai Luang is located at Ban Sankang, Moo 2, Mae Suai district, Chiang Rai province, where is approximately 2 kilometers away from Mae Suai district office. Historically, Wat Mae Suai Luang was celebrated for establishment on 15 February, 1678 by Kru Ba Phom Thumma Saro and approximately 50 villagers. Now, the possession includes Buddhist temple, sermon hall in a monastery, pavilion, monk's house, and belfry.





The earthquake, measuring 6.1 magnitude by the Richter scale, had occurred on 5 May 2014. The epicenter was located at Dong Mada tambon, Mae Lao district, Chiang Rai province. Damage ruined the unique construction of Chiang Rai, Wat Rong Khun, that suffered with severe cracks in various supporting structures. Moreover, highway 118 between Mae Lao and Mae Suai districts and Buddha's image at Wat Udom Wari in Phan district were also affected. All damage sites required government support and public participation for renovation. .

The biggest earthquake of the century in Thailand: M_L 6.1 Mae Lao earthquake, Chiang Rai province

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ABSTRACT

According to the Thai Meteorological Department report, the M_L 6.3 Mae Lao earthquake occurred on 5 May 2014 in the Huai Sai Khao subdistrict, Phan district, Chiang Rai province. The magnitude was recalculated using the SEISAN software, and 478 epicenters and hypocenters were also relocated using the double-difference method in the HypoDD software. The magnitude of this earthquake was recalculated to M_L 6.1. After relocation, an epicenter of mainshock was located in the Dong Mada subdistrict, Mae Lao district, Chiang Rai province to the southeast of the NE–SW trending Mae Lao segment of the Phayao Fault. Moreover, the aftershocks were distributed along the NE–SW trending Mae Lao segment. It is concluded that this earthquake event was caused by the left-lateral strike-slip movement of the NE–SW trending Mae Lao segment. The ground cracks and sand boils induced by this earthquake also occurred in the Mae Lao, Mae Suai, and Phan districts, Chiang Rai province. After this earthquake event, macroseismic intensity has been mapped. The maximum intensity of this earthquake event was up to level of VIII of the modified mercalli intensity (MMI) scale. The zone of maximum level of VIII in a radius of 10 km from its source is mainly located in the Mae Lao districts, Chiang Rai province.

Key words: M_L 6.1 Mae Lao earthquake, Mae Lao segment, Phayao Fault, Chiang Rai, northern Thailand

INTRODUCTION

The M_L 6.3 Mae Lao earthquake occurred on 5 May 2014, and the epicenter was located in the Huai Sai Khao subdistrict, Phandistrict, Chiang Rai province (at 19.685°N, 99.687°E), at a shallow depth of 7.0 km (Thai Metrological Department (TMD), 2014). The epicenter was located in a point 9 km south of Mae Lao district and 27 km southwest of Chiang Rai downtown, Thailand (Fig.1). However, according to earthquake reported by the United States Geological Survey (USGS) (2014), the magnitude of this earthquake was M_w 6.1, at 19.656°N, 99.670°E. It was the strongest earthquake ever recorded in Thailand (TMD, 2014; Wiwegwin and Kosuwan, 2014). More than one thousand aftershocks have been recorded by seismograph of the TMD (TMD, 2014). People in northern

Thailand, Myanmar, and Bangkok have been felt. Damage was reported from this event, particularly in the Mae Lao, Mae Suai, and Phan districts, Chiang Rai province. Highway and road were split by serious cracks; e.g., along the highway 118 (Chiang Mai to Chiang Rai) at km 151–152 from Chiang Mai. Ground cracks and sand boils induced by this earthquake also occurred in the Mae Lao, Mae Suai, and Phan districts. Unfortunately, one person died during the earthquake (Department of Disaster Prevention and Mitigation (DDPM), 2014).

In order to understand the characteristics of the Mae Lao earthquake, after this event, we conducted a brief reconnaissance survey along the trace the Mae Lao and Phan segments of the Phayao Fault in the Chiang Rai province. The main propose of this paper is to

clarify the source of the event, and document the ground cracks and sand boils after the earthquake. Then, we discuss the preservation

of coseismic deformation features (i.e., ground cracks) and tectonic significance of these faults.

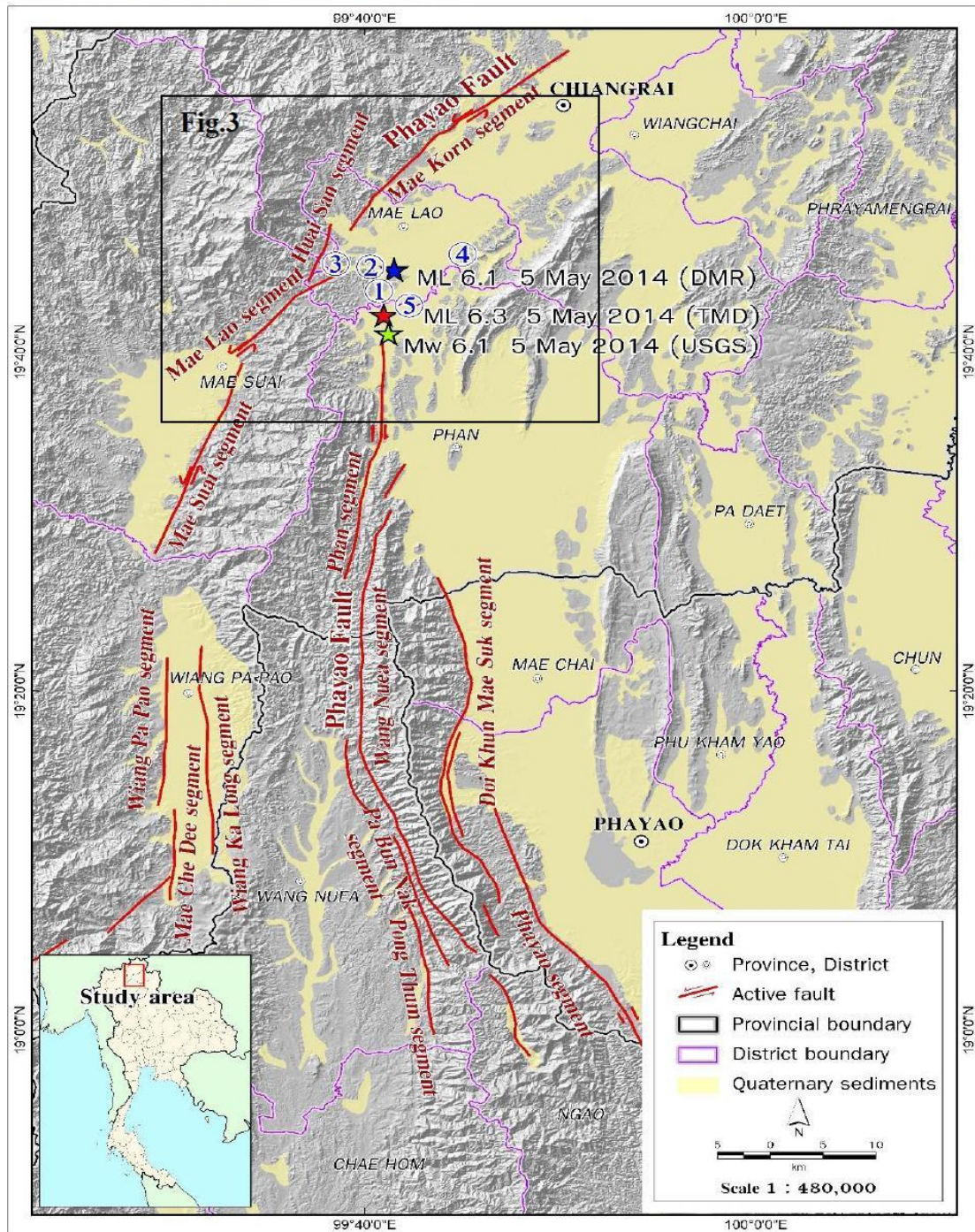


Fig.1 Active fault map of Chiang Rai province and adjacent areas showing the Phayao Fault (Red lines) and the epicenters of the Chiang Rai earthquake reported by TMD (2014) (Red star), USGS (2014) (Green star), and DMR (2014) (Blue star). Locations of ground cracks; 1, Ban Mai Jad San; 2, highway 118 at km 151–152; and 3, Ban Huai San Yao. Locations of sand boils; 4, Ban Nikom Mae Lao; and 5, Ban Tha Ho.

EPICENTER OF MAINSHOCK AND AFTERSHOCKS

An epicenter of mainshock reported by USGS (2014), and TMD (2014) was located in the north of the Phan segment, and south of the Mae Lao segment, both segments belong to the Phayao Fault (Fig.1). Moreover, focal mechanism of this earthquake confirmed the strike-slip motion on the fault. Based on this focal mechanism, the movement of fault is identified as either left-lateral or right-lateral motions (USGS, 2014).

In order to confirm the sources of these earthquake events, the epicenters of mainshock and aftershocks are relocated using HypoDD software; this software implements for relocating earthquakes with the double-difference algorithm of Waldhauser and Ellsworth (2000).

The double-difference technique applies to cluster events and aims to reduce the hypocenter (or focus) scatter of an earthquake event cloud. The basic concept of the double-difference location algorithm considers both P- and S- wave difference travel times, derived from cross-correlation methods, with travel time differences calculated for pair events. The method can be able to determine interevent distances between clusters of correlated events while simultaneously determining the relative locations of other clusters and uncorrelated events.

The residual between observed and calculated differential travel time (or double-difference; equation 1) between events i and j recorded at seismic station k is a possibly related to adjustments in the relative position of the hypocenters and origin times through the partial derivatives of the travel times for each event with respect to the unknown (Waldhauser, 2001). This technique is defined by Waldhauser and Ellsworth (2000) as shown in Fig. 2, and can be described as following;

$$(t_k^i - t_k^j)^{\text{observed}} - (t_k^i - t_k^j)^{\text{calculated}} = dr_k^{ij} \quad (1)$$

$$\left[\frac{\partial t_k^i}{\partial m} \Delta m^i \right] - \left[\frac{\partial t_k^j}{\partial m} \Delta m^j \right] = dr_k^{ij} \quad (2)$$

$$t_k^i, t_k^j = \text{Travel-time from hypocenter } i$$

to seismic station k , and travel-time from hypocenter j to seismic station k , respectively.

m = the components of slowness vector of the ray connecting the sources and receiver measured at the source.

dr_k^{ij} = Residual between observed and calculated differential travel time between the events i and j observed at station k (double-difference residual).

$\Delta m^i, \Delta m^j$ = the change in the relative hypocentral parameters between the events i and j .

After combining these above equations from all event pairs for a station, and for all stations, then we obtain a system of linear equations of the form as following;

$$Gm = d \quad (3)$$

G = matrix of size $M \times 4N$ (M , number of double-difference observation; N , number of events) containing the partial derivatives.

m = a vector of length $4N$

d = data vector containing the double-differences.

Magnitudes of the mainshock and aftershocks were firstly recalculated using SEISAN software; this software implements conveniently to analyze magnitude of local and global earthquakes. Thereafter, 478 earthquake events (mainshock and 477 aftershocks) recorded by DMR and TMD seismographs during 5 May 2014 to 8 July 2014 were relocated using double-difference method in the HypoDD software (i.e., Hypocenter and epicenter). Focal mechanisms of the earthquakes (Magnitude ≥ 4.0) have also been analyzed. The magnitude of mainshock was recalculated to $M_L 6.1$. After relocation, an epicenter of mainshock was located in the Dong Mada subdistrict, Mae Lao district, Chiang Rai province (at 19.7356°N , 99.6992°E), at a shallow

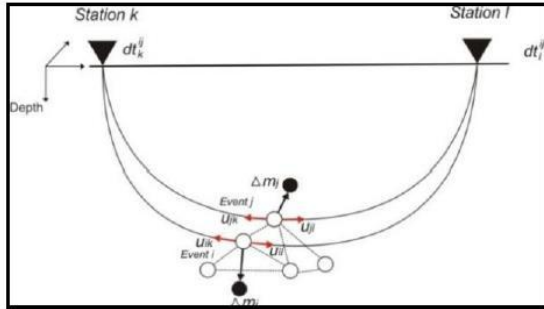


Fig.2 The double-difference earthquake relocation method is proposed by Waldhauser and Ellsworth (2000). Solid and open circles represent trial hypocenters that are linked to neighboring events by cross-correlation (solid lines) or catalog (dashed lines) data. For two events, i and j , the initial locations (open circles) and corresponding slowness vectors, u , with respect to two stations, k and l , are shown above. Ray paths from the sources to the station are indicated. Thick arrows (Δm) indicate the relocation vector for events i and j obtained from the full set of equation 2, and dt is the travel-time difference between the events i and j observed at seismic stations k and l , respectively.

Depth of 3.72 km, to the southeast of the NE–SW trending Mae Lao segment of the Phayao Fault. Moreover, our results showed that the distribution of aftershock epicenters presents more obvious strip-shaped character along the NE–SW trending Mae Lao segment of the Phayao Fault after relocation. Focal mechanisms of the earthquakes (Magnitude ≥ 4.0) indicated that the movement on fault is identified as either left-lateral or right-lateral motions. The results of relocation and focal mechanism analysis are shown in Fig. 3 and table 1.

FIELD OBSERVATION

After earthquake, a lot of damages have been reported in the Mae Lao, Mae Suai, Phan districts and Chiang Rai downtown. Local people houses and buildings of high schools in the Mae Lao and Phan districts were collapsed. Ground cracks and sand boils induced by this earthquake also occurred in the Mae Lao, Mae Suai, and Phan districts (Figs. 4 and 5). Highway and road were split by serious cracks; e.g., along the highway 118 (Chiang Mai to Chiang Rai) at km 151–152 from Chiang Mai (Fig. 4c; see location 2 in Fig. 1). A few days after mainshock event, locations of ground cracks and sand boils were mapped by DMR geologist team. Details of ground deformation mapping are described as following.

Table1. Results of focal mechanism analysis of the earthquake (Magnitude ≥ 4.0) recorded during 5 May 2014 to 8 July 2014.

No.	Timing of earthquake		Lat	Long	Depth (km)	M_L	Strike	Dip	Rake
	Date	Time							
1	5/5/2014	18.08	19.726	99.727	3.72	6.1	76	77	-17
2	5/5/2014	18.19	19.745	99.703	2.2	4.9	337	62	-142
3	5/5/2014	18.22	19.755	99.608	2.5	4.6	73	38	18
4	5/5/2014	19.06	19.785	99.706	2.1	4.2	146	80	118
5	5/5/2014	19.2	19.811	99.673	2.1	4.4	0	58	-179
6	5/5/2014	20.18	19.705	99.724	2.1	4	77	88	-41
7	5/5/2014	20.34	19.77	99.63	2.1	4.2	70	68	-41
8	5/5/2014	23.07	19.746	99.589	2.1	4.2	168	60	-166
9	5/5/2014	23.2	19.781	99.68	2.1	4	156	88	169
10	5/5/2014	0.35	19.766	99.617	2.1	4	15	68	-155
11	5/5/2014	2.12	19.771	99.691	2.1	4.2	321	90	115
12	5/5/2014	3.05	19.742	99.611	2.1	4.1	319	62	-168
13	5/5/2014	4.17	19.748	99.658	2.1	4.6	173	74	-156
14	5/5/2014	6.04	19.671	99.62	6.6	4.6	339	90	-162
15	6/5/2014	7.5	19.783	99.711	2.1	5.2	273	53	7
16	6/5/2014	7.58	19.702	99.533	2.1	5.2	331	57	-160
17	6/5/2014	19.42	19.744	99.608	2.1	4.2	333	59	-172
18	6/5/2014	20.47	19.739	99.683	2.1	4.2	161	86	167
19	6/5/2014	21.5	19.736	99.621	2.1	4.4	319	81	169
20	6/5/2014	22.57	19.739	99.683	2.1	4.3	160	85	173
21	6/5/2014	3.52	19.734	99.594	6.5	4.3	168	86	148
22	8/5/2014	3.43	19.767	99.625	3.3	4.5	61	8	126
23	12/5/2014	18.05	19.795	99.723	2.1	4.5	274	31	65
24	14/5/2014	0.23	19.742	99.708	2.1	4.4	84	82	-10

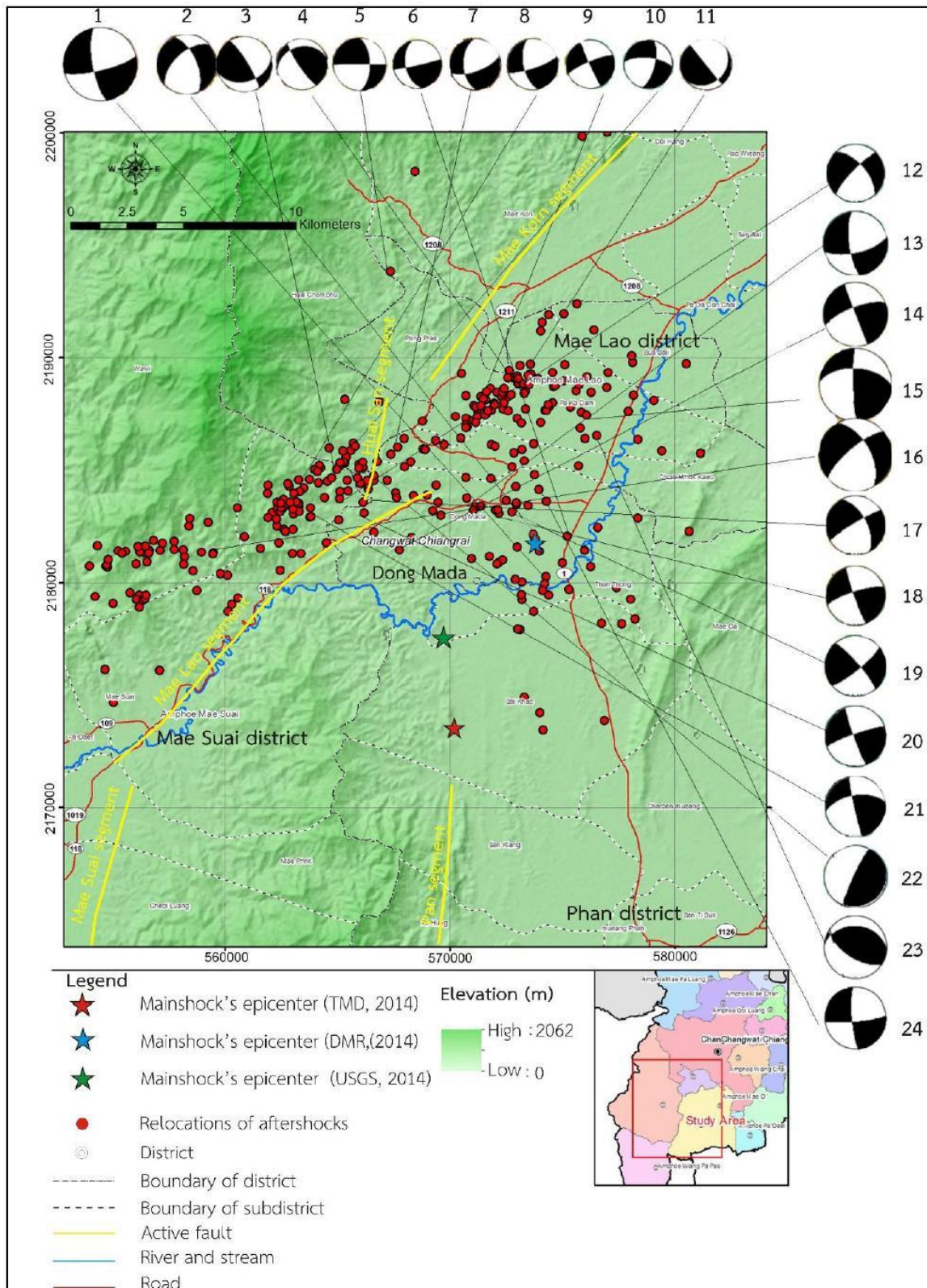


Fig.3 Distribution of mainshock (blue star) and aftershock epicenters (red circles) after relocation, red and green stars indicated the epicenters of mainshock reported by TMD (2014) and USGS (2014), respectively. The focal mechanisms of the earthquake nos. 1-24 in table 1 are also shown on the figure. Location of this figure is shown in Fig.

GROUND CRACKS

We used a tape for measuring the offset of cracks. 183 locations of ground cracks and their orientations were measured. These ground cracks can be classified into three major directions based on rose diagram analysis, mainly trend NE–SW, with a set of conjugate ground cracks of NW–SW and NNW–SSE directions (Fig.4e).

We also observed coseismic left-lateral offsets ranging from approximately 6–10 cm on the NE–SW trending ground cracks (Fig.4b). The major NE–SW trending ground cracks and the coseismic left-lateral offsets are consistent with the sense of fault movement on the NE–SW trending Mae Lao segment of the Phayao Fault.



Fig.4 Ground crack was observed at Ban Mai Jad San, Dong Mada district, Mae Lao district, Chiang Rai province (a and b; see location 1 in Fig. 1). Highway and road were split by serious cracks on the highway 118 (Chiang Mai to Chiang Rai) at km 151–152(c; see location 2 in Fig. 1). Ground crack was also observed at Ban Huai San Yao, Dong Mada district, Mae Lao district, Chiang Rai province (d; see location 3 in Fig. 1). Principle orientation of ground cracks shown as a rose diagram (e, inset in a)

SAND BOIL (LIQUEFACTION)

Sand boil or liquefaction is the loss of strength and stiffness of saturated loose sand caused by increased pore-water pressure during strong earthquake-shaking. This increased

pore-water pressure attempts to flow out from the soil to zones of low pressure (usually upward towards the ground surface). It finally makes a large sandy deposit on the ground surface.

It is commonly occurred during the earthquakes with moment magnitudes (M_w) greater than 6 and frequently causes damage, but it is rarely associated with earthquakes of $M_w \leq 5.2$ (Holzer et al., 2010; Sims and Gravin, 1995). Atkinson et al., (1984) proposed that the earthquakes with moment magnitudes (M_w) greater than 5 can cause liquefaction. Audemard and Santis (1991) confirmed Atkinson et al., (1984)'s ideas and presented evidence of liquefaction caused by moderate shallow earthquakes (M_b 5.7 and 5.0) located within the areas covering approximately 25 km from its source. They also proposed that the earthquake with ground acceleration values ranging between 0.1 and 0.3 g can trigger liquefaction.

After the M_L 6.1 Mae Lao earthquake, sand boils have occurred in the Mae Lao, Mae Suai, and Phan districts, Chiang Rai province. We mapped the locations of these sand boils; the distribution of sand boils is located within the areas covering approximately 40 km from the epicenter of mainshock. 53 sand boils can be observed there, and are mainly located on the saturated Quaternary sediments (Fig.5).

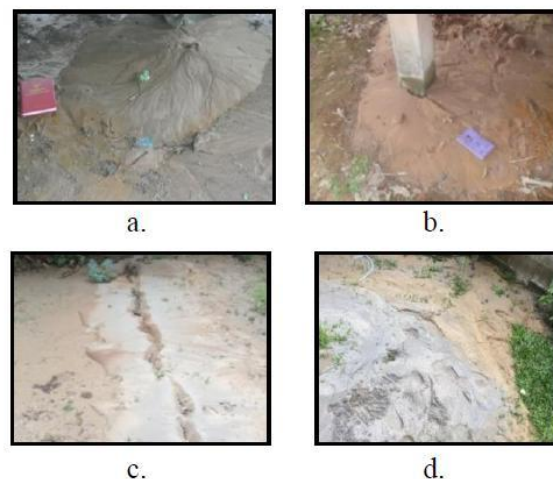


Fig.5 Sand boils or liquefactions induced by the earthquake in Chiang Rai province were mapped; sand boils occurred at Ban Nikom Mae Lao, Than Thong subdistrict, Pan district (a and b; see location 4 in Fig. 1), and Ban Tha Ho, Sai/Khao/subdistrict, Phan district, Chiang Rai province(c and d; see location 5 in Fig. 1)

IMPACT OF THE M_L 6.1 MAELAO EARTHQUAKE

A few days after the M_L 6.1 Mae Lao earthquake, we assessed the impact of this earthquake (i.e., ground cracks, sand boils, and earthquake-damaged buildings). 235 locations of damages reported by DDPM (2014) were also used for evaluating the impact zone of this earthquake. We have produced the isoseismal map, which generally represents the spatial distribution of macroseismic intensity data, and shows lines of equal felt seismic intensity. Our isoseismal map was depicted based on the impact of the earthquake in the Chiang Rai province and adjacent areas with respect to the Modified Mercalli intensities (MMI) scale. The M_L 6.1 Mae Lao earthquake generated MMI values in the range IV-VIII levels spreading out more than 320 km from the epicenter in Mae Lao district, Chiang Rai province (Fig.6).

The maximum intensity of this earthquake was up to level of VIII of the modified mercalli intensity (MMI) scale. The zone of maximum level of VIII in a radius of 10 km from its source is located in Mae Lao district, Chiang Rai province.

DISCUSSION EPICENTER OF THE M_L 6.1 MAE LAO EARTHQUAKE

The epicenter of mainshock reported by TMD (2014) was located in the north of the NNW–SSE trending Phan segment, and south of the NE-SW trending Mae Lao segment, both segments belong to the Phayao Fault (Fig.1). This earthquake epicenter was also reported by the USGS (2014), and located to the south of the TMD (2014)'s epicenter (Fig.1). Two locations of an epicenter of this earthquake reported by TMD (2014) and USGS (2014) are different. However, an epicenter reported by TMD (2014) was located using the Regional Crustal Velocity Model (IASPEI91 Velocity Model) in the SEISCOMP3 software; this software is a fully featured automated real-time earthquake monitoring software, and was originally developed for rapid monitoring of potentially tsunamigenic earthquakes at the regional and global scale (Hanka et al., 2010; Clinton et al., 2011; Olivieri and Clinton, 2012). Recently, an ability to monitor local seismicity of this software is rapidly being

improved. An obvious advantage of this technique is the ability to quickly locate an epicenter. However, this IASPEI91 Velocity Model has some unpleasant features as, for example the absences of any low velocity zone in the upper mantle (Firbas, 1994). It seems that this technique is suitable to locate an epicenter of regional or global earthquakes. Moreover, an epicenter of the Mae Lao earthquake reported by TMD (2014) was located using seismic wave forms obtained from seismic stations that are located far from Chiang Rai area. From these reasons as mentioned above, it is concluded that an epicenter of the Mae Lao earthquake reported by TMD (2014) will be less accuracy.

Thus, the epicenters of mainshock and aftershocks recorded by DMR and TMD seismographs during 5 May 2014 to 8 July 2014 were relocated using the double-difference method in the HypoDD software. The double-difference method has some advantages over other methods as following; the travel time differences can be related with high accuracy to the offsets between hypocenters (Details in Waldhauser and Ellsworth, 2000). After relocation, an epicenter of mainshock was located in the Dong Mada subdistrict, Mae Lao district, Chiang Rai province (at 19.7356°N, 99.6992°E), at a shallow depth of 3.72 km, to the southeast of the NE-SW trending Mae Lao segment of the Phayao Fault. Moreover, the aftershocks were distributed along the NE-SW trending Mae Lao segment.

The Department of Mineral Resources (DMR) (2009) has studied paleoearthquakes along the NE-SW trending Mae Lao segment. Remote sensing techniques were firstly applied to interpret the fault trace, morphotectonic landforms, and its sense of movement. DMR (2009) suggested that the NE-SW trending Mae Lao segment was a sinistral fault using the results on morphotectonic landform observation along the fault traces in the Mae Lao area. Recent trench investigations across this fault segment have confirmed that the last movement on the fault occurred a few thousand years ago (DMR, 2009).

Focal mechanism reported by USGS (2014) showed that this earthquake event can be generated by either the left-lateral displacement of the NE–SW trending Mae Lao segment or the right-lateral displacement of the NNW–SSE trending Phan segment. We also proposed that

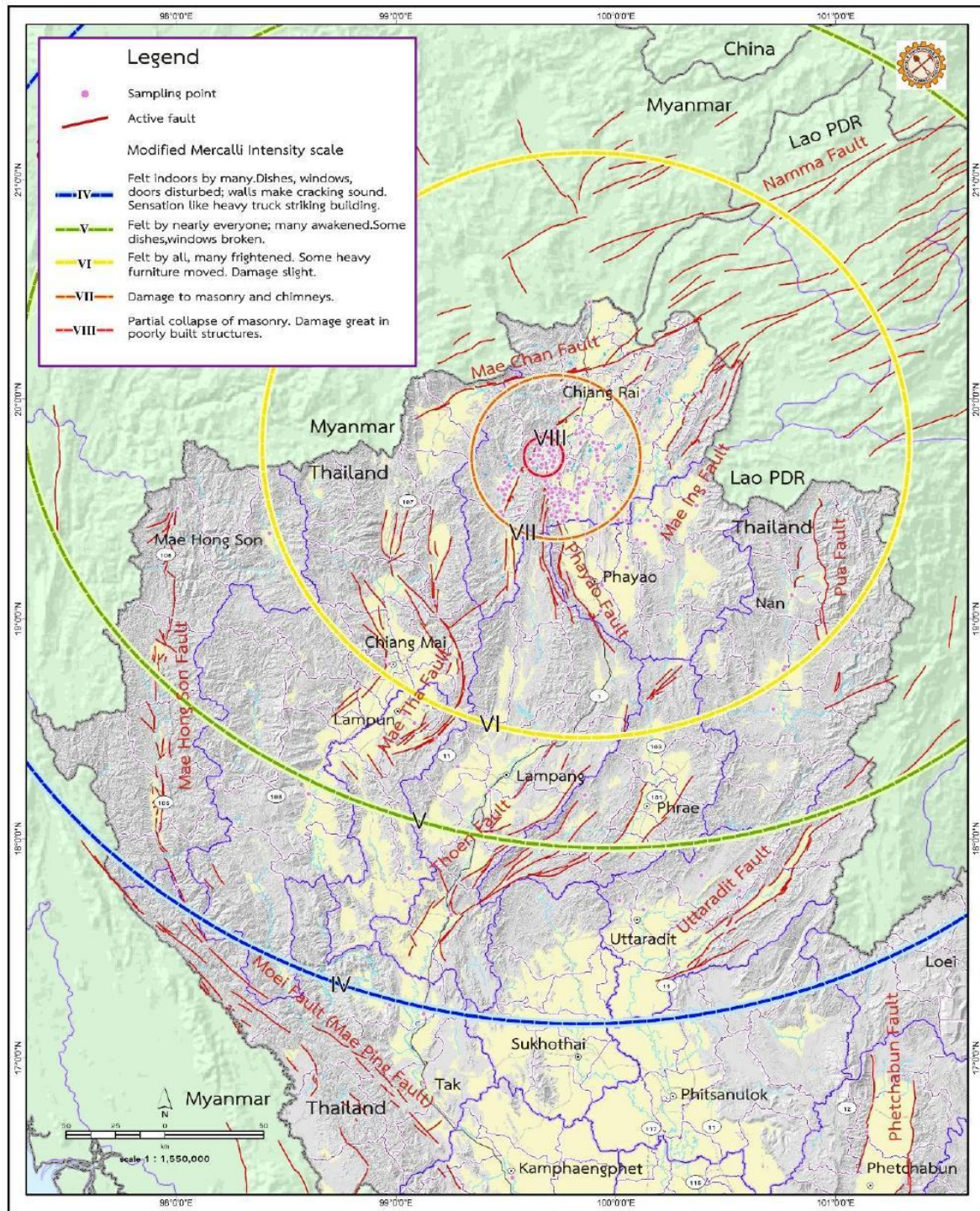


Fig.6 Isoseismal map of the $M_L6.1$ Mae Lao earthquake. The circles labeled IV-VIII indicate the ground shaking intensities in terms of the MMI scale

the focal mechanism of this earthquake is similar to those of USGS (2014)'s report.

Based on epicenter distribution and focal mechanism identified from our study (i.e., left-lateral or right-lateral motions), and sense of fault movement of the Mae Lao segment identified by DMR (2009), it is concluded that the movement on the NE-SW trending Mae Lao segment has ruptured and generated the seismic events in the Mae Lao district, Chiang Rai province (Fig.3).

NEOTECTONIC ACTIVITY OF SE ASIA AND GROUND CRACKS

The Eocene–Oligocene collision of the Indian and Eurasian plates resulted in N–S compressive stresses in the Indochina region. It is likely that the N–S compressive stresses caused dextral motion on major NW–SE trending faults and sinistral motion on the NE–SW faults in Yunnan region, China, and northern Thailand (Fig. 7). The movement on faults accompanying regional E–W extension during the late Oligocene–Miocene initiated the formation of Neogene basins. It is possible that strike-slip fault movements and E–W extensional tectonics in the Neogene played a critical role in the generation of neotectonic patterns and active faulting. Based on Global Position System (GPS) data, Yunnan is experiencing SSW–WSW motions relative to Sundaland (including Thailand) that are associated with clockwise rotation of blocks immediately south of the eastern Himalayan syntaxis (Simons *et al.*, 2007). Block motion diminishes from *ca.* 12–13 mm/yr SSW in the east of Yunnan, to *ca.* 6 mm/yr WSW in the west of Yunnan, while displacements in northern Thailand are *ca.* 2–3 mm/yr to ENE (Simons *et al.*, 2007). The ENE–WSW and NE–SW trending faults (i.e., Mae Chan, Uttaradit, and Mae Lao segment of the Phayao Faults) have been displaced in northern Thailand, and these displacements are consistent with the displacement of northern Thailand as measured from GPS data.

Our results showed that the ground cracks induced by the M_L 6.1 Mae Lao earthquake are mainly trend NE–SW, with a set of conjugate ground cracks of NW–SW and NNW–SSE directions (Fig.4e). Moreover, we observed coseismic left-lateral offsets ranging from approximately 6–10 cm on the NE–SW

trending ground cracks (Fig.4a and b). The major NE–SW trending ground cracks and the coseismic left-lateral offsets are consistent with the sense of fault movement on the NE–SW trending Mae Lao segment. It is inferred that major NE-SW trending ground cracks are caused by the movement of the NE–SW trending Mae Lao segment of the active Phayao Fault, and the movement of the NE–SW trending active faults in Indochina are controlled by neotectonic activity in this region.

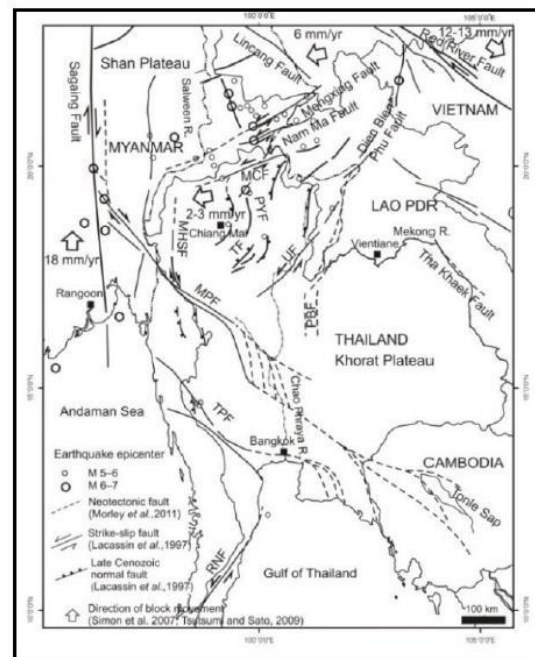


Fig.7 Map of Thailand and adjacent areas showing major active and neotectonic faults [modified from Lacassin *et al.*, 1997, 1998; Morley *et al.*, 2011; DMR, 2006] and the epicenters of large earthquakes. MPF, Mae Ping Fault; MCF, Mae Chan Fault; PYF, Phayao Fault; MHSF, Mae Hong Son Fault; RNF, Ranong Fault; TPF, Three Pagoda Fault; UF, Uttaradit Fault; TF, Thoen Fault; PBF, Phetchabun Fault. Arrows show direction of block movement.

CONCLUSIONS

According to the Thai Meteorological Department report, the M_L 6.3 Mae Lao earthquake occurred on 5 May 2014, and an epicenter was located in the Huai Sai Khao

subdistrict, Phan district, Chiang Rai province. The magnitude was firstly recalculated using SEISAN software, and 378 epicenters and hypocenters were relocated using the double-difference method. The magnitude (M_L 6.3) was recalculated to 6.1 on the Richter scale. After relocation, an epicenter of mainshock was located in the Dong Mada subdistrict, Mae Lao district, Chiang Rai province (at 19.7356°N, 99.6992°E), at a shallow depth of 3.72 km, to the southeast of the NE–SW trending Mae Lao segment of the Phayao Fault. Moreover, the aftershocks were distributed along the NE–SW trending Mae Lao segment. It is concluded that this earthquake event was caused by the left-lateral strike-slip movement of the NE–SW trending Mae Lao segment.

The ground cracks and sand boils induced by this earthquake event also occurred in the Mae Lao, Mae Suai and Phan districts, Chiang Rai province. 183 locations of ground crack were observed, and their orientations were also measured. These ground cracks can be classified into three major directions based on rose diagram analysis, mainly trend NE–SW, with a set of conjugate ground cracks of NW–SW and NNW–SSE directions. We also observed coseismic left-lateral offsets ranging from approximately 6–10 cm on the NE–SW trending ground cracks. The major NE–SW trending ground cracks and the coseismic left-lateral offsets are consistent with the sense of fault movement on the NE–SW trending Mae Lao segment of the Phayao Fault as reported by DMR (2009).

After this earthquake event, macroseismic intensity has been mapped based on the impact of the earthquake in the Chiang Rai province and adjacent areas. The maximum intensity of this earthquake event was up to level of VIII of the modified mercalli intensity (MMI) scale. The zone of maximum level of VIII in a radius of 10 km from its source is located in the Mae Lao district, Chiang Rai province.

ACKNOWLEDGEMENTS

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REFERENCES

- Atkinson, G.M., Finn, W. D. L., and Charlwood, R. G. (1984) Simple Computation of Liquefaction Probability for seismic Hazard Applications: *Earthquake Spectra*, 1:107-123.
- Audemard, F.A., and Santis, F.D.(1991) Survey of Liquefaction structure induced by recent moderate earthquakes: *Bulletin of the International Association of Engineering Geology*, 44 :5-16.
- Clinton, J. F., Diehl, T., Cauzzi, C., and Kaestli, P.(2011)Earthquake Monitoring: SeisComp3 at the Swiss National Seismic Network:American Geophysical Union, Fall Meeting 2011.
- Department of Disaster Prevention and Mitigation (DDPM, Chiang Rai province office) (2014) The report of the damage from the M 6.3 Chiang Rai earthquake, available at <http://www.dmpccr.wordpress.com> (in Thai).
- Department of Mineral Resources (2006) Active fault map of Thailand, (Online Article, October 2006), available at <http://www.dmr.go.th>.
- Department of Mineral Resources (2009) Investigation on recurrence interval in areas showing trace of movement along the faults in the Chiang Rai, Chiang Mai and Phayao provinces (Mae Chan and Phayao Faults), Technical Report, Environmental Geology Division, Department of Mineral Resources, Thailand (in Thai).
- Holzer, T. L., Jayko, A.S., Hauksson, E., Fletcher, J.P.B., Noce, T.E., Bennett, M.J., Dietel, C.M., and Hudnut, K.W.(2010) Liquefaction caused by the 2009 Olancho, California (USA), M5.2 earthquake: *Engineering Geology*, 116 :184–188
- Hanka, W., Saul, J., Weber, B., Becker, J., Harjadi, P., Fauzi, and GITEWS Seismology Group (2010) Real-time earthquake monitoring for tsunami warning in the Indian Ocean and beyond: *Natural Hazards and Earth System Sciences*, 10: 2611–2622.
- Firbas, P. (1994) Ray Synthetic seismograms: a useful tool in the International Data Center Environment: *Annali Di Geofisica*, XXXVII, N.3.
- Lacassin, R., Hinthong, C., Siribhakdi, K., Chauviroj, S., Charoenravit, A., Maluski, H., Leloup, P.H., and Tapponnier, P. (1997) Tertiary diachronic extrusion and deformation of western Indochina: Structure and $^{40}\text{Ar}/^{39}\text{Ar}$ evidence from NW Thailand: *Journal of Geophysical Research*, 102(5): 10013–10037.
- Lacassin, R., Replumaz, A., and Leloup, P.H. (1998) Hairpin river loops and slip-sense inversion on

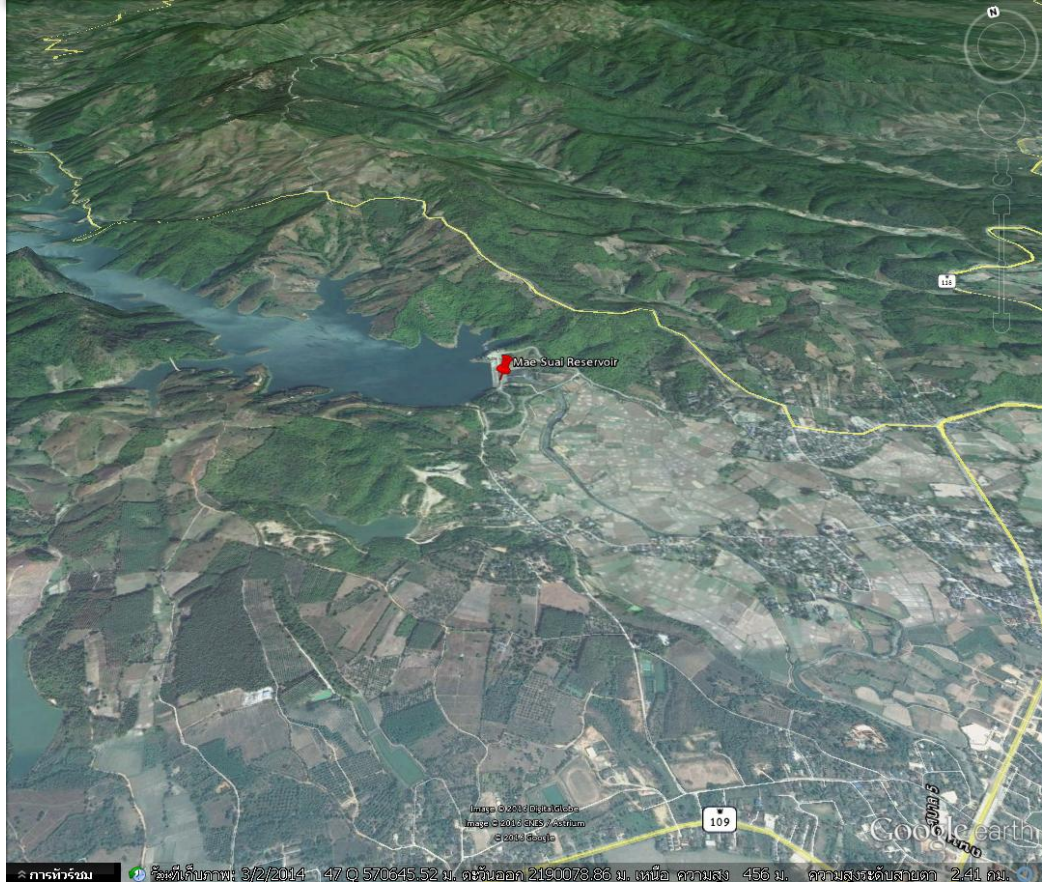
- Southeast Asia strike-slip faults: *Geology*.26: 703–706.
- Morley, C. K., Charusiri, P., and Watkinson, I.K. (2011) Structural geology of Thailand during the Cenozoic. In: Ridd, M.F., Barber, A.J. and Crow, M.J. (Eds.), *The Geology of Thailand: The Geological Society, London*. 273–334.
- Olivieri, M., and Clinton, J. (2012) An almost fair comparison between Earthworm and SeisComp3: *Seismological Research Letters*.83 (4): 720-727, doi: 10.1785/0220110111.
- Simons, W.J.F., Socquet, A., Vigny, C., Ambrosius, B.A.C., Abu, S.H., Promthong, C., SubaryaSarsito, D.A., Matheussen, S., Morgan, P., and Spakman, W. (2007) A decade of GPS in Southeast Asia: resolving Sundaland motion and boundaries: *Journal of Geophysical Research*.112 (B06420): doi:10.1029/2005JB003868.
- Sims, J.D., and Garvin, C.D. (1995) Recurrent liquefaction at Soda Lake, California, induced by the 1989 Loma Prieta earthquake, and 1990 and 1991 aftershocks: Implications for paleoseismicity studies: *Seismological Society of America Bulletin*. 85: 51-65.
- Thailand Meteorological Department (2014) Earthquake statistics of Thailand, available at http://www.seismology.tmd.go.th/inside.html?pageNum_thaievent=35&totalRows_thaievent=2615
- Tsutsumi, H., and Sato, T. (2009) Tectonic geomorphology of the southernmost Sagaing Fault and surface rupture associated with the May 1930 Pego (Bago) earthquake, Myanmar: *Bulletin of the Seismological Society of America*. 99: 2155–2168.
- United States Geological Survey (USGS) (2014) M 6.1-13NNW of Phan, Thailand on 5 May 2014, Available at <http://comcat.cr.usgs.gov/earthquakes/eventpage/usb000qack#scientific>
- Waldhauser, F., and Ellsworth, W.L. (2000) A Double-Difference Earthquake Location Algorithm: Method and Application to the Northern Hayward Fault, California: *Bulletin of the Seismological Society of America*. 90 (6): 1353–1368.
- Waldhauser, F. (2001) HypoDD -A Program to Compute Double-Difference Hypocenter Locations, Open File Report 01-113, United States Geological Survey (USGS), 25.
- Wiwegwin, W., and Kosuwan, S. (2014) The 5.5.57 Chiang Rai Earthquake, Geological annual meeting of Department of Mineral Resources 2014, 9-10 September 2014: Bangkok, Thailand. 363-377 (in Thai).

02

Mae Suai Reservoir

Mae Suai subdistrict, Mae Suai district

Chiang Rai province



Mae Suai reservoir is constructed on Mae Suai river. It is located between Ban San Klang and Ban Den Phu Wiang of Mae Suai subdistrict, Mae Suai district, Chiang Rai province , which is 3 kilometers away from Mae Suai downtowns.

Mae Suai reservoir structure is the combination between Earth-fill Dam and Roller Compacted Concrete dam (RCC Dam) possessing 400 meters long, 59 meters high and 10 meters wide. The middle RCC dam functions as a non-gate-spillway which provides maximum discharge of 1,160 cms. covering 434 sq.km. of catchment area, 73 mcm. of retention capacity and 3 mcm. of dead storage.

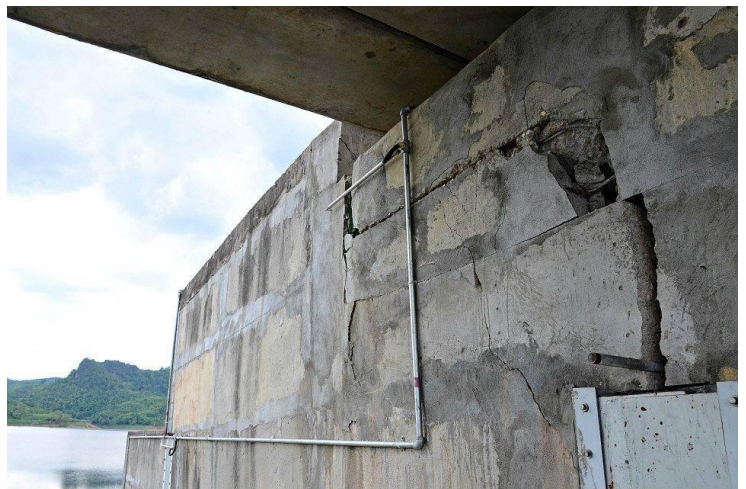




Objective

- to store water resource for 148,000 rai of Mae Lao irrigation area and 2,000 rai of Mae suai irrigation area.
- to prevent flooding in Mae Lao basin, locating in downstream of the reservoir in Mae Suai, Mae Lao and Mueang district.
- to provide small fishery for local people.
- to be recreation site for tourist attraction in Mae Suai district.
- to generate hydropower electricity in the future.

The earthquake occurring in the north on 5 May 2014 with 6.1 magnitude coincided with epicenter at Dongmada tambon, Mae Lao district, Chiang Rai province. The Mae Suai reservoir cracks on Guide-wall Block and Walkway that have safety on capacity as the overseer of the earth dam.



03

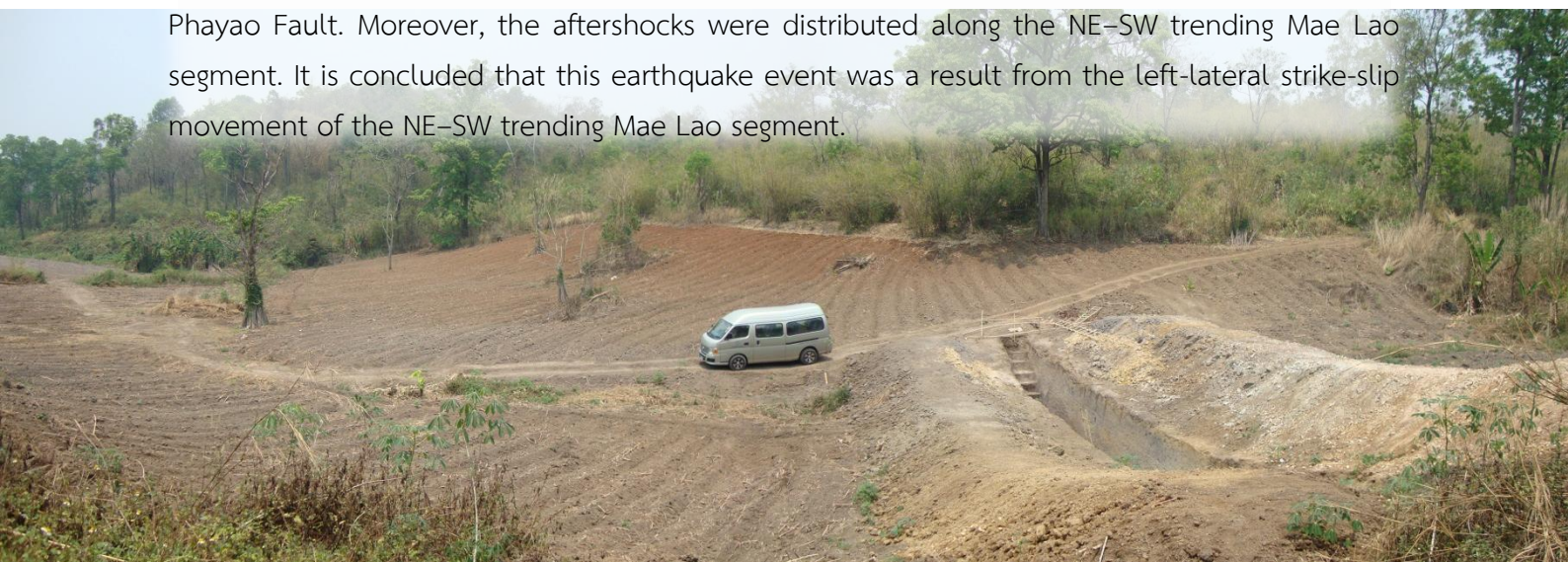
Trench

Ban Huai San, Dong Mada subdistrict, Mae Lao district

Chiang Rai province



According to the Thai Meteorological Department report, the ML 6.3 Mae Lao earthquake occurred on 5 May 2014 in the Huai Sai Khao subdistrict, Phan district, Chiang Rai province. The magnitude was recalculated by using the SEISAN software, and 478 epicenters meanwhile hypocenters were also relocated by using the double-difference method in the HypoDD software. The magnitude of this earthquake was recalculated to ML6.1. After relocation, an epicenter of main shock was located at the Dong Mada subdistrict, Mae Lao district, Chiang Rai province where situated in the southeast of the NE–SW trending Mae Lao segment of the Phayao Fault. Moreover, the aftershocks were distributed along the NE–SW trending Mae Lao segment. It is concluded that this earthquake event was a result from the left-lateral strike-slip movement of the NE–SW trending Mae Lao segment.





Huai San village area, Dong Mada subdistrict, Mae Lao district, Chiang Rai province

After receiving data from topographic survey and radon data interpretation, Geological Survey team located the trench positions by considering the fault trends and the trenches must be perpendicular with fault trend. The trench locations at Huai San village are flat between valley and small hills showing triangular facet. This topographic features were result of the movement of Mae Lao minor fault which lie on northeast-southwest direction.

Result of excavated the trench and sediments” stratigraphy from Huai San trench showing in picture, the sediments can be classified into 10 units. The details are as follows.

Basement rocks consist of shale interbedded with sandstone and show fractures, folds, faults and high weathering rate.

Unit A is colluvial sediments which were deposited after fault movement in basement rock. Clasts in this unit are usually angular to subangular shape and consist of sandstone, shale and quartz fragments with silt and clay.

Unit B is a colluvial sediments showing white lamination on basement rock. Clasts in this unit are usually angular to subangular shape and consist of sandstone, shale and quartz fragments with silt and clay.

Unit C is a colluvial sediments with reddish brown color on basement rock and intercalated with lens of clay. Clasts in this unit are usually angular to subangular shape and consist of sandstone, shale and quartz fragments with silt and clay.

Unit D is a colluvial sediments and consists of gray clay and partly light orange color. Clay layer consists of subangular clasts of sandstone, shale, siltstone and quartz within this unit.

Unit E is a colluvial sediments and consists of brownish gray clay and partly light orange color. Clay layer consists of subangular clasts of sandstone, shale, siltstone and quartz within this unit.

Unit F is an alluvial sediments consisting of sand, silt, clay. Clasts in this unit are subangular pebbles and compose of sandstone, shale and quartz fragments which are matrix supported unit.

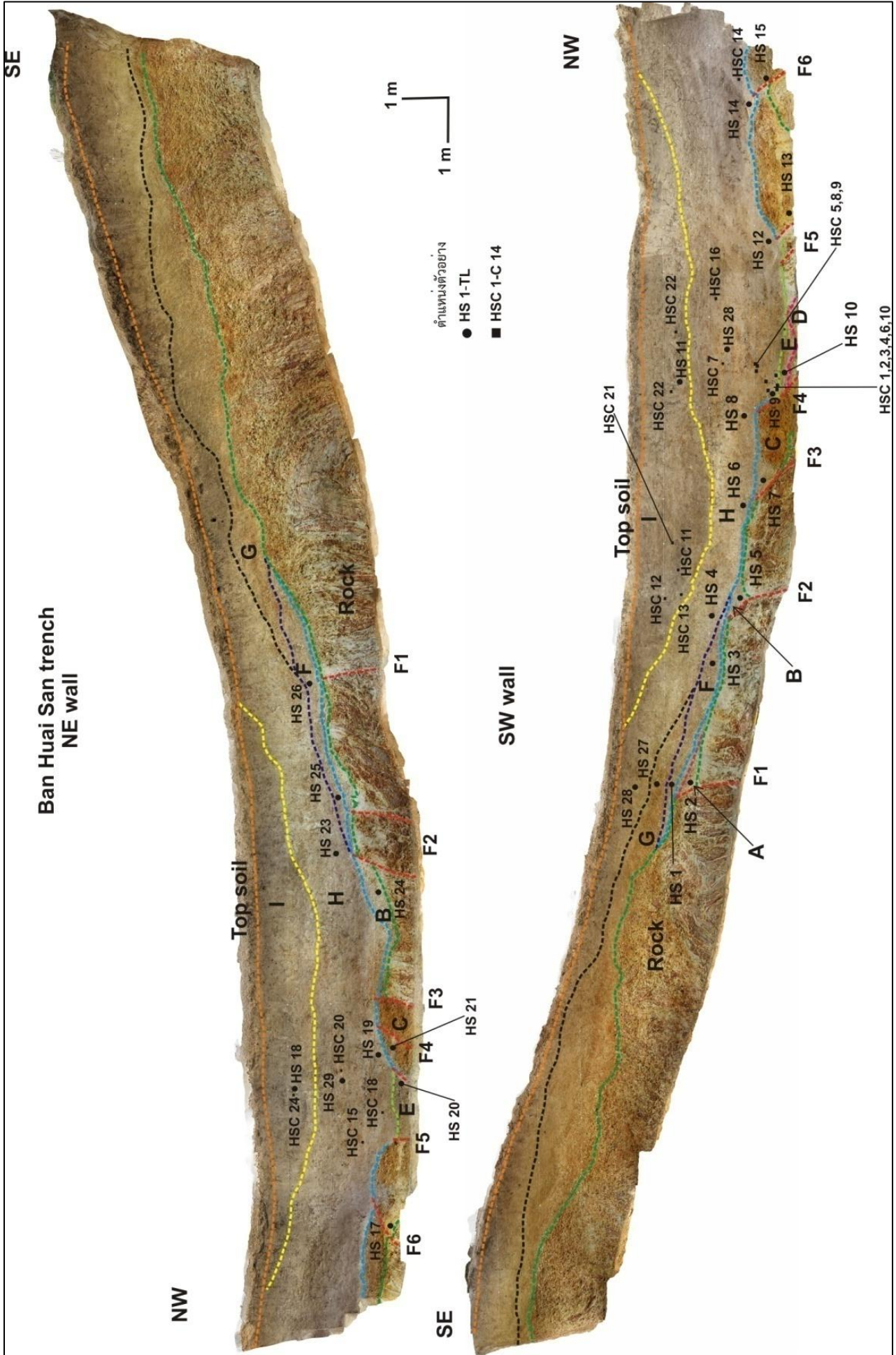
Unit G is an alluvial sediments compose of sand, silt and clay. Abundant clasts mixed in this unit are subangular pebbles and consist of sandstone, shale and quartz fragments.

Unit H is a lacustrine sediments with blackish gray color and consists partly of sandy clay and silt. This unit is intercalated with layer of sand and clay. In addition, abundant clay is deposited in this unit.

Unit I is a lacustrine sediments and consists of black clayey sand, few clasts and layer of sand lens.

Top soil is recent sediments which was disturbed by agriculture activities and consists of sand, silt and clay mixed with clasts of sandstone, shale and quartz fragments.

The geological structure of sediments is well continuous but the main structure is dipping beds in north-west direction ($55^{\circ}/310^{\circ}$) and shows faults which cut in this trench at least 6 faults having northwest trend (F1: $50^{\circ}/320^{\circ}$, F2: $55^{\circ}/310^{\circ}$, F3: $25^{\circ}/310^{\circ}$, F4: $40^{\circ}/335^{\circ}$, F5: $30^{\circ}/310^{\circ}$, F6: $35^{\circ}/310^{\circ}$). No geological evidence shows fault that cut into unit B, C and D.



Trench Logging of the Mae Lao fault at Ban Huai San, Amphoe Mae Lao, Chiang Rai province. (Chulalongkorn university, 2016 (unpublished))

04

Wat Rong Khun (White Temple)

Pa O Don Chai subdistrict, Mueang district

Chiang Rai province



Wat Rong Khun, more well-known among foreigners as the White Temple, is an unconventional Buddhist temple in Chiang Rai, Thailand. Designed in 1997 by noted Thai painter-turned-architect Chalermchai Kositpipat, this magnificent temple is a bizarre blend of traditional Thai architecture and the surreal. The main building is painted white to symbolise Buddha's purity, and is covered in mosaics of mirrors, sparkling in the sun. All around the complex are intricate sculptures of demons, skulls, severed heads hanging from trees and other bizarre objects.





<http://www.chiangraiprovence.org/chiang-rai-tourism/famous-temples/wat-rong-khun-white-temple-chiang-rai.html>

To enter the temple you have to walk over a bridge over a moat filled with innumerable sculptures of out-reaching arms, apparently symbolizing desire. Once inside, you will be greeted not by traditional Buddha life scenarios but by contemporary scenes and icons of popular culture. Chalerchai wishes Wat Rong Khun to become a learning and meditation center for people to practice dharma and gain benefit from the teachings of Lord Buddha.



Left picture : effect of earthquake

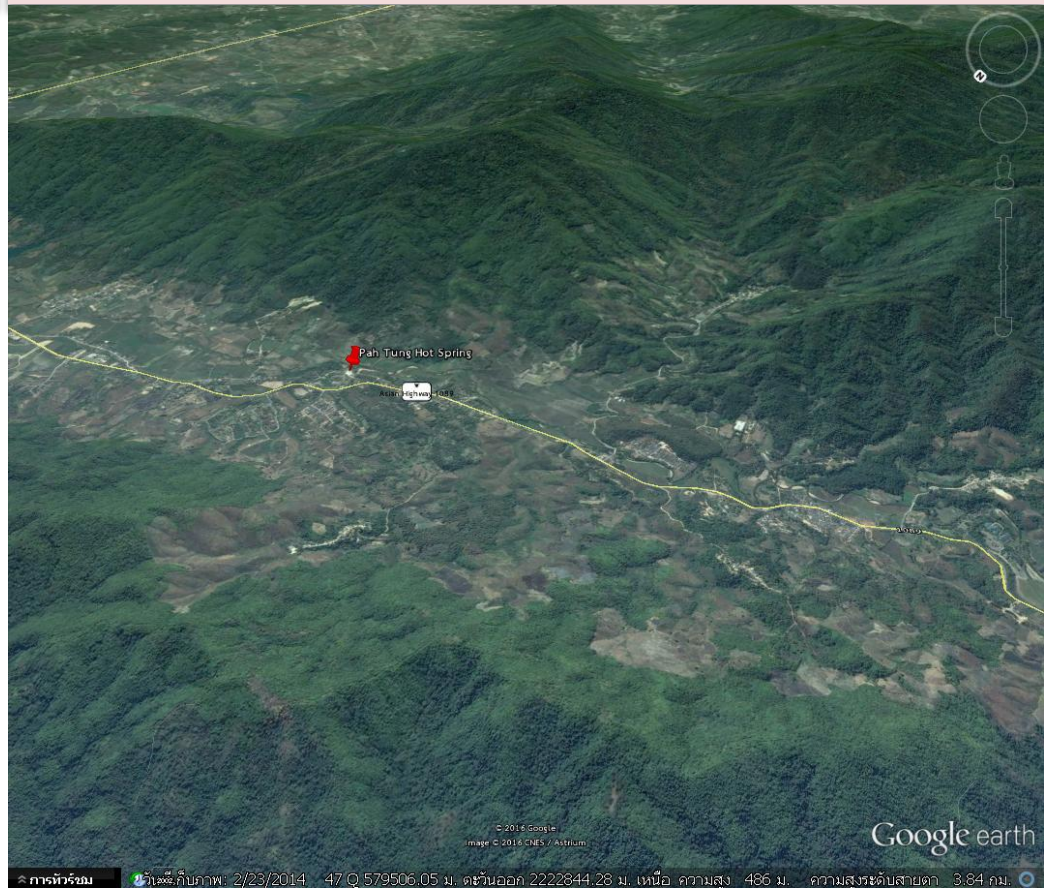
Right picture : has been repaired

05

Pah Tung Hot Spring

Pah Tung subdistrict, Mae Chan district

Chiang Rai province



Pah Tung Hot Spring or Mae Chan Hot Spring It is about 7 kms. on the Mae Chan-Ta Thone road. There are 8 individual rooms with bath tubs and 6 rooms without the tubs. Temperature of the hot spring is between 70-109 °C.. It is situated amid scenic landscape with hidropathic rooms, a pond and a spa garden for those who wish to take a mineral baht for healing purposes.



PAH TUNG HOT SPRING

Pah Tung Hot Spring or Mae Chan hot springs occurred in two different areas, covering area about 5,000 square meters. The first and the main discharged area situated on northern side of Mae Chan tributary where more than 10 hot springs and numerous seepages occurred. Most of the springs are hot-pool type, bubbling out at regular intervals provided surface temperature higher than 90°C. Flow rate measured at weir is 12-15 liters/second (Geotermica, 1984). The second discharged area located along Nam Mae Chan river about 300 meters southeast of the first area. Four hot springs and numerous seepages exposed along the river bank.

GEOCHEMICAL CHARACTERISTIC

Thermal waters of the Mae Chan geothermal field characterized as sulphur deposit and hydrogen sulphide smell. Silica sinter is slightly developed coating on outcrops and boulders. The waters is rather clear, colorless and expressed high concentration of bicarbonate, Na, F and SiO₂, TDS contents and high pH (7.5 - 8.5).

Water samples were collected and analyzed by many workers both from hot springs and drilled holes (Table 7). Subsurface temperature estimated by water chemical geothermometer ranges between 130 - 190 °C.

Geotermica (1984) predicted that geochemical temperature of water in shallow reservoir is 135 ± 2°C while geochemical temperature of deeper reservoir is 220°C.

Chemical compositions of thermal waters collected at the Mae Chan geothermal field.

CONTENT	HOT SPRING WATER				DRILLED HOLE WATER	
	1	2	3	4	PR1	PR2
Temperature °C	99	99	54.5	98.2	42.2	90
pH	8.6	8.6	7.5	7.5	8.0	7.0
Total dissolve solid	550	550	Nd	nd	Nd	Nd
Alkalinity as HCO ₃	232	231	479	483.5	212.4	254.3
Acidity CaCO ₃	nil	Nil	Nd	Nd	Nd	Nd
Sulphide saturated H ₂ S	Nd	Nd	Nd	Nd	Nd	Nd
Na (ppm)	138	137	104.6	106.4	91.3	109.3
K	8.1	8.1	9.1	9.5	10.1	9.9
Ca	1.6	1.7	2.7	3.2	7.1	3.3
Mg	0.03	0.03	2.0	0.7	2.2	2.1
Fe	Nd	Nd	1.1	0.5	0.1	0.06
Mn	Nd	Nd	nd	Nd	Nd	Nd
SiO ₂	169	165	77.4	75.0	58.7	76.4
Cl	28.0	25.0	12.2	1.1	11.3	1.9
F	Nd	Nd	nd	Nd	Nd	Nd
SO ₄	53.0	52.0	72.6	72.2	77.6	67.2
NH ₃	Nd	Nd	0.34	0.36	0.04	0.2
T _{qtz} (°C)	169	167	121	120	109.1	120.4
T (Na, K, Ca: °C)	173	171	205	209	225.3	208.9

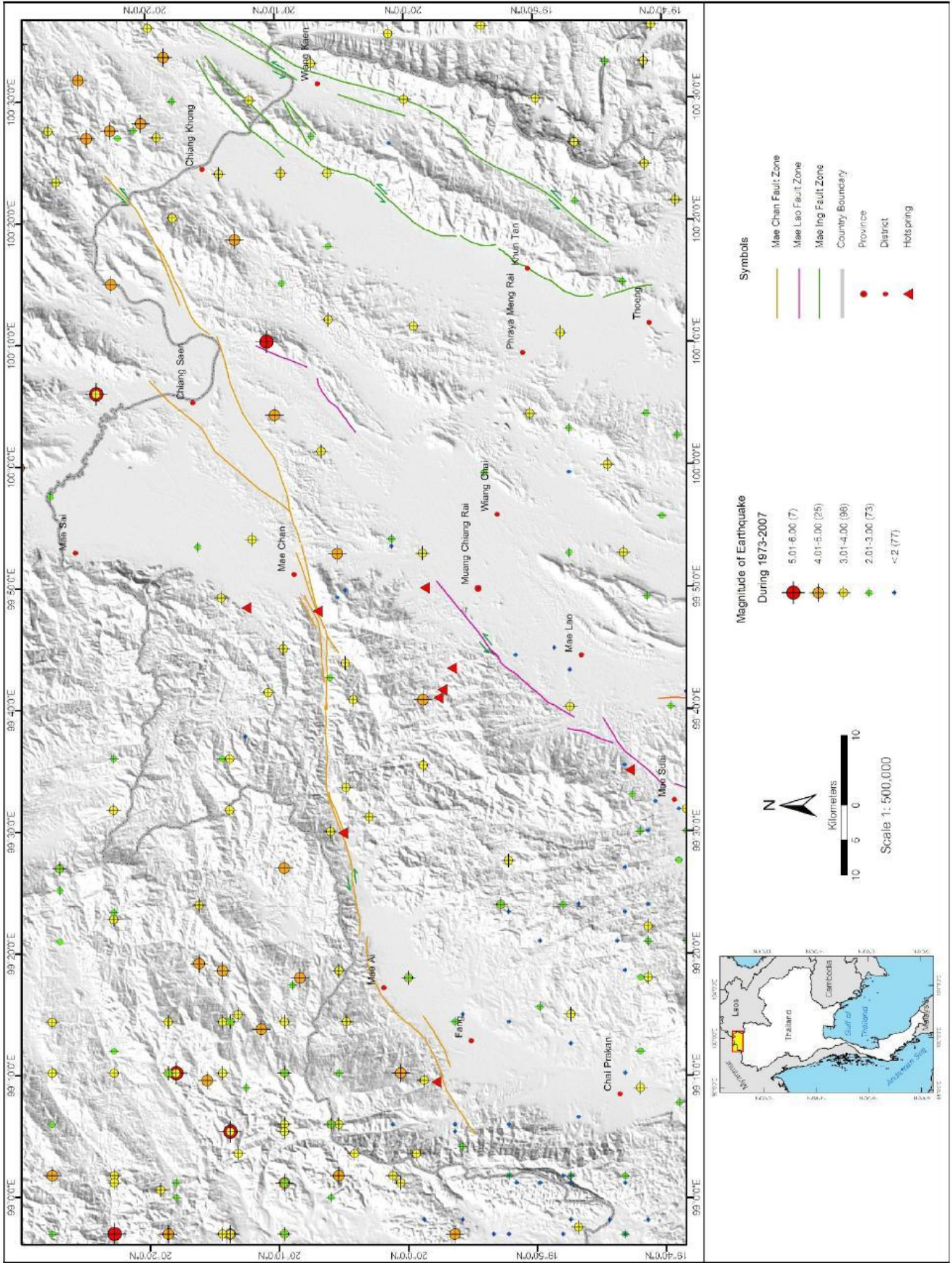
1, 2 Thienprasert et al., 1987; 3, 4 and drill hole Manoonvoravong and Virapun, 1996: Tqtz Quartz-no steam loss and T(Na, K, Ca) are subsurface temperature

DRILLING

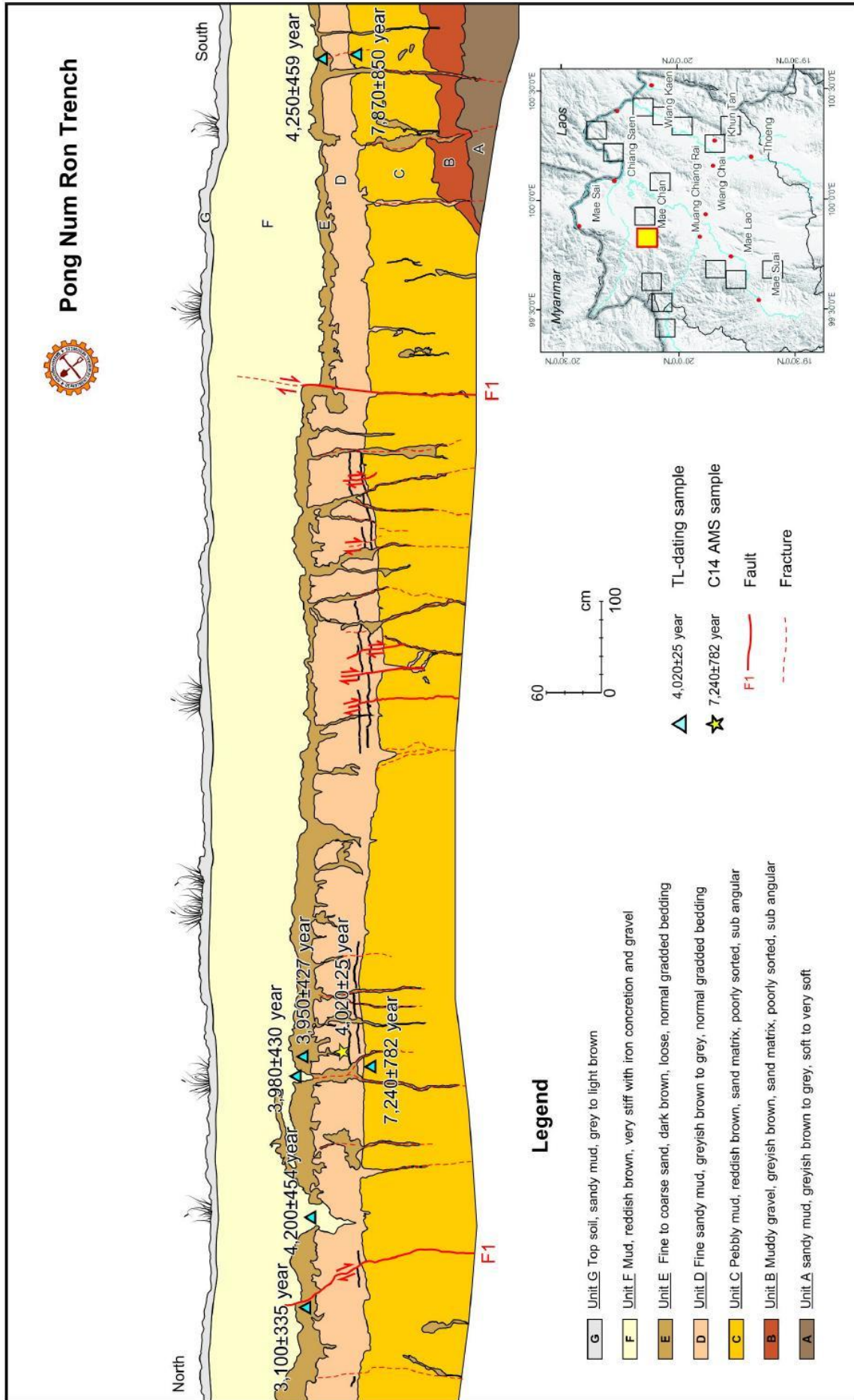
The Department of Energy Development and Promotion (DEDP) investigated the Mae Chan geothermal field to exploit the resources for non-electrical applications. The objective is to utilize thermal water at depth less than 100 meters for small-scale direct uses and crop drying (Manoonvoravong and Virapun, 1996). Two exploration wells named PR1 and PR2 were drilled in the granite to depth 100 and 80 meters respectively.

The granite core samples of the PR1 well indicated depth of weathered rock at 10 to 40 meters. Below 40 meters, core samples expressed slightly weathered to fresh rock. The bottom hole temperature is 110°C and piezometric water level is 2.5 meters below ground surface. The PR2 well provides bottom hole temperature 122°C and a jet of thermal water blow out immediately at 5.94 liter/second into air at about 15 meter high. At present, the thermal water shooting is ceased, suggested due to scaling of silica or calcite.

Due to the hot spring located near main road, the area is decorated to be a tourist attracted sight. It is convenient to visit and it is a nice rest area with naturally nice scenery.



Seismicities in Chiang Rai province. (data from the Thai Meteorological Department and www.usgs.gov)



A drawing of the trench cross section of the Mae Chan segment of the Mae Chan fault at Ban Pong Num Ron, Pah Tung subdistrict, Mae Chan district, Chiang Rai province

Abstract

The study of earthquake recurrence interval along the Mae Chan and Pha Yao active faults in Chiang Rai, Chiang Mai, and Pha Yao provinces aims to evaluate and analyze the size, location, orientation, movement and degree of activeness of the Mae Chan and Pha Yao faults. In addition, this work includes a calculation of the earthquake recurrence interval, generating both active fault map and seismic hazard map in the study area. The study starts from complying and analyzing preliminary data, conducting a field work study to examine the faults' characters (geometry and orientation), ages (Thermoluminescent and C-14 methods) datings of samples related to the faults and earthquakes to identify the last movements of these faults. We then calculate fault movements and slip rates, recurrence interval and magnitudes of the earthquakes occurring in the past and eventually estimate the effect of the paleoearthquake in the study area.

The result of this study indicates that these faults can be subdivided into 5 major fault segments: the Mae Chan fault, the Mae Lao fault, the Mae Ing fault, the Pha Yao, fault and the Muang Pan fault. The Mae Chan fault orientates along almost east-west direction for approximately 150 km in length and can be subdivided into 18 smaller sub fault segments. Both the Mae Lao and the Mae Ing faults orientate along northeast-southwest direction. The Mae Lao fault is 70 km long and can be subdivided into 6 smaller sub fault segments while the Mae Ing fault is 80 km long and can be subdivided into 12 smaller sub fault segments. The Pha Yao and Muang Pan faults orientate due north-south direction. The Pha Yao fault is 90 km long and can be subdivided into 17 smaller sub fault segments while the Muang Pan fault is 40 km long and can be subdivided into 11 smaller sub fault segments. Most of these faults have left-lateral movement, except some segment of the Pha Yao fault where some right-lateral movements were detected. The result of this study also indicates that these faults could potentially cause earthquakes with various magnitudes, for example, the Mae Chan fault can generate an earthquake of Mw 5.1-6.8. The Mae Lao fault can generate an earthquake of Mw 6.0-6.8. The Mae Ing fault can generate an earthquake of Mw 5.9-6.6. The Pha Yao fault can generate an earthquake of Mw 5.5-7.0 and the Muang Pan fault can generate an earthquake of Mw 5.8-7.0.

Trenching work suggests that these faults have generated at least six seismicity periods with earthquakes whose magnitudes from Mw 6-7 in the past. The first and second periods of earthquakes occurred at about 8,800 B.P. and between 8,700-6,500 B.P. on the sub fault segment Khun Tan (Mae Ing fault). The long term fault slip rate (for entire Quaternary) is 0.073 mm/year. In addition, another earthquake on the sub fault segment Mae Kon was detected at about 8,000 B.P. with the long term slip rate of 0.156 mm/year.

The third earthquake period occurred on the sub fault segment Pag Ing (Maelng fault) at about 5,500 B.P. with a long term slip rate of 0.285 mm/year. An earthquake along the Mae Lao fault occurring at about 5,300 B.P. with a long term slip rate of 0.110 mm/year was also detected. In addition, an earthquake on the sub fault segment Phan (Pha Yao fault) with a long term slip rate of 0.175 mm/year occurred at 5,200 B.P. In Addition, an earthquake on the sub fault segment Pang Kha (Mae Ing fault) with a long term slip rate of 0.086 mm/year occurred at 5,200 B.P., in concurrent with an earthquake on the sub fault segment Wang Thong (Pha Yao fault) that occurred at 5,200 B.P.

The fourth period of seismicities occurred at about 4,000 B.P. on the Mae Chan fault with a long term slip rate of 0.289 mm/year. The earthquake along the sub fault segment Wang Thong (Pha Yao fault) with a long term slip rate of 0.342 mm/year also occurred at 4,000 B.P., in concurrent with an earthquake detected on the sub fault segment Tha Ton (Mae Chan fault) with a long term slip rate of 0.156 mm/year.

The fifth period of seismicity in the study area occurred at 2,700 B.P. by an earthquake occurring on the sub fault segment Chiang Khong (Mae Chan fault) with a long term slip rate of 0.292 mm/year. The last earthquake period happened at 2,000 B.P. by an earthquake occurring on the sub fault segment Kiew Sadai (Mae Chan fault) with a long term slip rate of 0.291 mm/year.

Calculations of the recurrence interval from earthquakes detected in the trenches suggest that the estimated recurrence interval of the Mw 6.8 earthquake on the Mae Chan fault is 1,000 years by using the earthquakes data occurring during the fourth, fifth and sixth seismicities period. The recurrence interval of the earthquake with a magnitude of Mw 6.9 on the Mae Ing fault is 1,500 years, by using the earthquakes data occurring during the first, the second and the third seismicities period. The recurrence interval of the earthquake with a magnitude of Mw 6.8 on the Mae Lao fault is 3,000 years, by using the earthquakes data occurring during the second and the third seismicities period and the recurrence interval of the earthquake with a magnitude of Mw 7.0 on the Pha Yao fault is 1,000 years, by using the earthquakes data occurring during, the third and the fourth seismicities period.

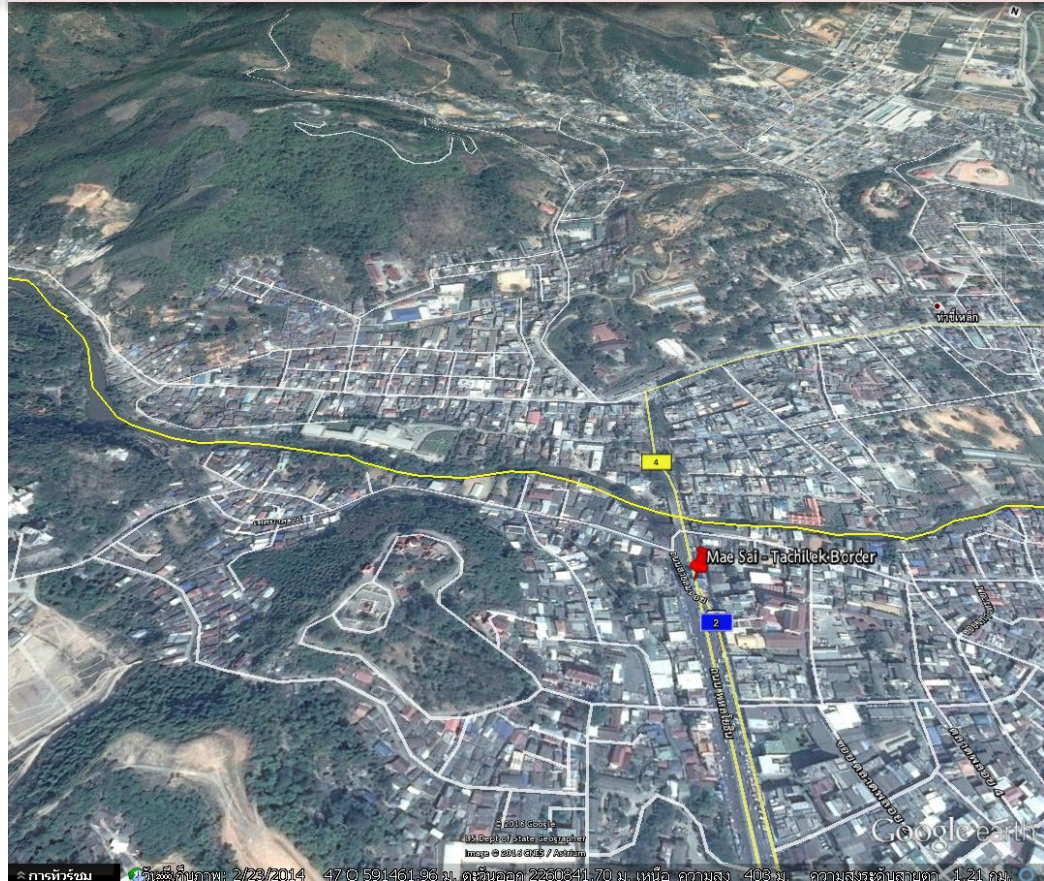
The calculations of the maximum ground peak acceleration (PGA) for the shallow crustal earthquakes occurring in the mid crust (15 km depth) using a deterministic method in the study area yield the values between 0.069-0.280 g. The most affected area are Amphoe Fang and Amphoe Mae Ai in Chiang Mai province, Amphoe Mae Chan, Amphoe Chiang Saen, Amphoe Wiang Kaen, Amphoe Khun Tan, Amphoe Thoeng, Amphoe Muang, Amphoe Mae Lao, Amphoe Mae Suay, and Amphoe Phan in Chiang Rai province, Amphoe Mae Jai and Amphoe Wiang Pa Pao in Pha Yao province. For the areas located further from the faults, the PGAs decrease with the distance. For example, in Amphoe Pong, Pha Yao province, the PGA is 0.08 g.

06

Mae Sai – Tachilek Border

Wiang Phang Kham subdistrict, Mae Sai district

Chiang Rai province



Here, it borders the Burmese town of Tachilek (ท่าขี้เหล็ก) where is marked by the Mae Sai River with a bridge spanning both sides. Foreign visitors are allowed to cross over to the Tachilek market by presenting their passports and paying a fee at the Mae Sai immigration checkpoint.



07

Golden Triangle

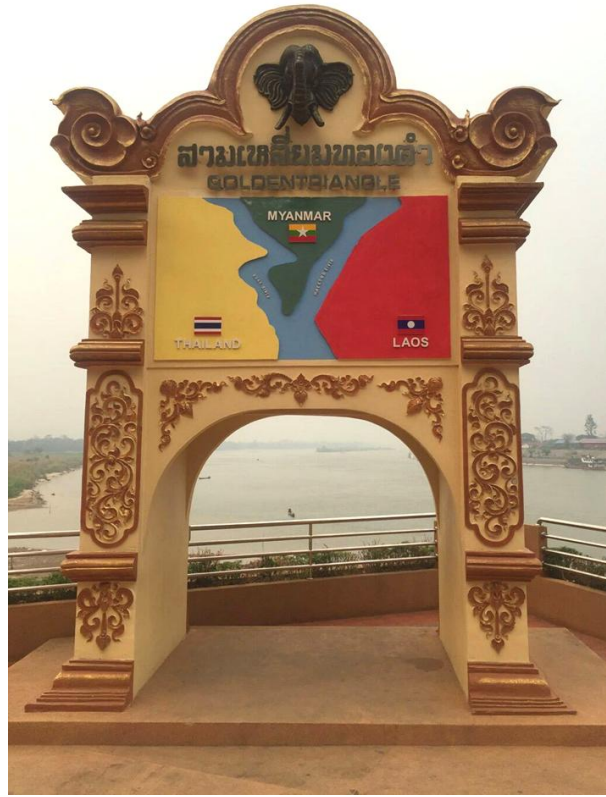
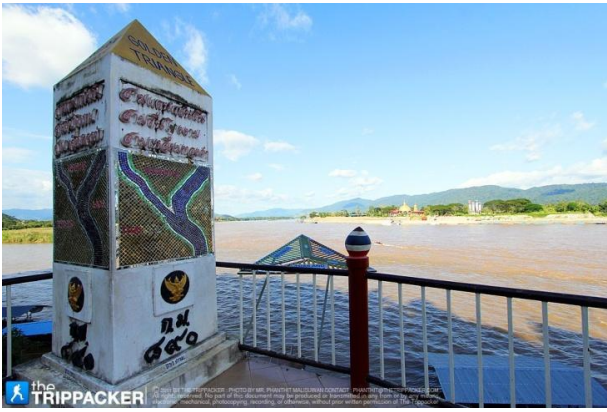
Ban Sob Ruak, Wiang subdistrict, Chiang Saen district

Chiang Rai province



Golden Triangle (สามเหลี่ยมทองคำ) or **Sop Ruak** is about 9 kilometres from the Chiang Saen old town to the north along the road parallel to the Mekong River. The area is locally called “Sop Ruak” where the Mae Khong meets the Ruak River and also where the borders of three countries, Lao PDR, Myanmar and Thailand meet together. There are remains of many ancient places and structures. It is revealed that the area was the community settlement in the past. In addition, boats can be hired to view scenery around the golden triangle along the Mekong River from Sop Ruak to Chiang Saen and Chiang Khong which takes around 40 minutes and one and a half hours respectively.





REFERENCES

- Chulalongkorn university, 2016, Seismic Hazard Evaluation from Active Faults and preliminary retrofit analysis of buildings in northern Thailand and in Bangkok Region, (unpublished)
- Department of Mineral Resource, 2006, Geology of Chiang Rai province, Bangkok, Thailand, 60p
- Department of Mineral Resource, 2008, Geological map of Chiang Rai province on scale of 1:250,000.
- Department of Mineral Resource, 2009, The study of earthquake recurrence interval along the Mae Chan and Pha Yao active faults in Chiang Rai, Chiang Mai, and Pha Yao provinces
- Department of Mineral Resource, 2012, Active Fault Map in Thailand.
- Department of Mineral Resource, 2013, Guide book for The Renewal Energy (Geothermal) Excursion at Chiang Mai and Chiang Rai province, 13-16 May 2013, Thailand, p.21-25.
- Geothermica Italiana Srl. (1984). Geothermal reconnaissance survey of northern Thailand. UNDP final report, Project No. THA/002/1982, PISA. 79 pp.
- Manoovoravong, P., and Virapun, T. (1996). Mae Chan Geothermal prospect, Amphoe Mae Chan Changwat Chiengrai. Bureau of Energy Study, Research and Development, Department of Energy Development and Promotion, Bangkok. 11 pp.
- Thienprasert, A., Chuaviroj, S., Chaturongkawanich, S., Jarach, W., Soponpongpipat, P., Surinkum, A., and Raksaskulwong, M. (1987). Geothermal resources in northern Thailand. Report of Investigation, Department of Mineral Resources, Bangkok. No. 1, 208 pp.
- Wiwegwin, W., Kosuwan, S., Limpisawat, S., Saithong, P., and Pananont, P., 2015, The biggest earthquake of the century in Thailand: ML 6.1 Mae Lao earthquake, Chiang Rai province, Journal of The Geological Society of Thailand 2015 volume 1: Geohazards and Environmental Geology, Thailand, p. 1-11
- www.chiangrai.net/ebooks
- www.chiangraiprovince.org
- www.nsecbiz.com/provincial-profile/chiang-rai-province/
- www.thetrippacker.com
- [https://en.wikipedia.org/wiki/Chiang_Rai_\(city\)](https://en.wikipedia.org/wiki/Chiang_Rai_(city))
- https://en.wikipedia.org/wiki/Kok_River
- https://en.wikipedia.org/wiki/Chiang_Rai_Province



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อ่าวไทย
Gulf of Thailand

ประเทศไทย-อนุภูมิภาคมกน
THAILAND-GREATER MEKONG SUBREGION (GMS)

โครงการพัฒนาและบูรณาการอนุภูมิภาคแม่น้ำโขง (GMS) เป็นโครงการความร่วมมือระหว่างประเทศไทย, ลาว, พม่า, เวียดนาม, กัมพูชา และจีน เพื่อส่งเสริมการเติบโตทางเศรษฐกิจและสังคมของภูมิภาคนี้ โดยเน้นการพัฒนาโครงสร้างพื้นฐาน การค้า และการลงทุน

Greater Mekong Subregion (GMS)
The Greater Mekong Subregion (GMS) comprises Thailand, Cambodia, Lao People's Democratic Republic, Myanmar, Viet Nam and Yunnan province of the People's Republic of China. The program has contributed to the development of infrastructure to enable the development and sharing of the resource base, and promote the free flow of goods and people in the subregion. It has also led to the international recognition of the subregion as a growth area.



