*International Conference on Geology, Geotechnology and Mineral Resources of Indochina (GEOINDO 2005)*
*28-30 November 2005, Khon Kaen, Thailand*

# Late Quaternary paleoseismic history and surface rupture characteristics of the Moei-Mae Ping Fault Zone, Tak Province, Northwestern, Thailand.

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## ABSTRACT

*The Moei-Mae Ping Fault Zone (MPFZ) in Tak province, northwestern Thailand is selected for paleoseismic investigations with particular emphasis on remote-sensing interpretation in conjunction with field and thermoluminescence (TL) dating results. The prime objective is to delineate faults and lineaments as well as their orientations and past movements. Results from remote-sensing interpretation indicate that the MPFZ is the northwest-southeast trending, oblique-slip fault with a total length of about 230 km. The MPFZ can be traced from eastern Myanmar through the border zone of northwestern Thailand to the northern part of central Thailand. About 10 fault segments, ranging in length from 8 to 43 km, are recognized and some of which pass Cenozoic basins. Based on our reconnaissance surveys, several kinds of morphotectonic landforms along the the Khao Mae Song segment (24 km, in length) including fault scarps, triangular facets, shutter ridges and offset streams, are clearly shown in northern part of the study area (Ban Mae Ou Su). We made a detailed topographic map at scale of 1:500 to cover this fault segment. The detailed map together with the result on ground penetrating radar (GPR) lead us to excavate two paleoseismic trenches for paleoseismic age dating.*

*Based on the surface rupture length of the Khao Mae Song segment, we estimated one large pleoearthquake at 6.7 $M_w$. The preliminary TL-dating result for 12 sediments associated with the fault segment constrains the average age of paleoearthquake at about 64 ka. We, therefore, conclude that the slip rate of this fault segment is estimated at 0.12 mm/yr. Consequently, several lines of evidence support that the MPFZ is still active till present.*

*KEYWORDS : Moei-Mae Ping Fault Zone, Tak, Northwestern Thailand, thermoluminescence dating, the Khao Mae Song segment, morphotectonic, surface rupture length.*

## 1. INTRODUCTION

### 1.1 Background

The present-day tectonics in Thailand and mainland southeast Asia (SE Asia) is the result of the collision between Indian and Eurasian plates since middle Tertiary time (Fenton et al., 1997; Charusiri et al., 1997; Bunopas, 1994; Hinthong, 1991). Although the majority of deformation at present occurs along the faults the northern part of this region, e.g., Altyn Tagh, Kun Lun, and Red Rive faults (Allen et al., 1984; Peltzer and Tapponnier, 1988). A moderate earthquake activity throughout the mainland SE Asia indicates contemporary deformation in this region. Progressive rotation of SE Asia results in reactivated strike-slip faults with the associated development of pull-apart basins in Thailand (Polachan and Sattayarak, 1989; Morley, 2001). However, Thailand has been subject to minor to moderate earthquake damages overtime. Stronger earthquakes frequently happen in the neighboring countries, e.g. Myanmar, southern China, northern Laos, and northern Vietnam. Recent geologic and geochronological investigations reveal that late Quaternary faults in northern Thailand appear to be characterized by long recurrence intervals of thousands to tens of thousands of years (Bott et al., 1997; Fenton et al., 1997; Kosuwan et al., 1999).

The major faults in the Myanmar-Thailand border zone are the Taunggyi Fault, the Pan Laung Fault, the Mae Hong Song Fault, the Moei-Uthai Thani Fault Zone, the Si Sawat, and the Three Pagoda Fault (Nutalaya et al., 1985). The Moei-Mae Ping Fault Zone (MPFZ) can be traced from eastern Myanmar through the border zone of northwestern Thailand to the northern part of central Thailand. The MPFZ, or the so called the Moei-Uthai Thani Fault Zone (Charusiri et al., 1996) and the Lan Sang-Wang Chao Fault Zone (Bunopas, 1981), is characterized by narrow and complex fault zones of normal, thrust, and strike-slip nature.

Two earthquakes along this fault zone occurred on 23 September 1933 and 17 February 1975 (Thailand Meteorological Department, 2002). The latter with a magnitude of 5.6 on the Richter scale was felt throughout central Thailand, causing minor damages and shocks (Nutalaya et al., 1985). Therefore it is important to understand landforms which were formed by earthquake activity. The aims of this paper are to apply remote-sensing interpretation based on JERS, Radarsat and enhanced Landsat TM5 images to delineate lineaments (faults and fractures) and to identify major active faults using morphotectonic and geochronological results.

## 1.2 The Study Area

The study area selected for the current paleoseismic analysis is located between latitudes 16°N - 18°N and longitudes 97° 30'E - 99° 30'E, to cover much of the MPFZ, in Tak province, northwestern Thailand. The study area (25,000 $km^2$) is about 440 km from the capital city of Bangkok.

## 1.3 Methodology

The methodology of this study is divided into four steps. The first step was conducted in order to contribute general data into a database for supporting further steps of study. This data is composed of relative previous works, enhanced remote-sensing images and digital files, aerial photographs, geologic maps, topographic maps, earthquake distribution information, and other related technical and nontechnical documents. The second step involves remote-sensing interpretation commencing on a small scale using digitally enhanced satellite imagery (1:250,000) and interpretation on a large scale with aerial photographs (1:50,000). Both form the basic data for lithological and structural interpretation. Lineaments were then interpreted to locate their attitudes, orientations, and past movement of the fault zones. The third step commences with identifying morphotectonic landforms, using results from remote-sensing and field check. For this step geomorphic mapping related to neotectonic evidence was launched in evaluating locations and orientation of active faults. Sampling for thermoluminescence dating along with stratigraphic logging were performed in the trench with an aim to identifying ages of sedimentary sequences and fault movement. The fourth step includes integration of all the results from all morphotectonic evidence to construct a fault map. In addition, identification of paleoearthquake events, estimation of paleomagnitudes from surface rupture length, and results on thermoluminescence dating are discussed.

# 2. MAJOR TECTONIC SETTING

Structural framework of Cenozoic basins in Thailand is mainly governed by N-S trending extensional faults that are spatially related to the movement of the NW-SE and NE-SW trending strike-slip faults. The NW-SE trending Red River (RRF), Mae Ping (MPF), Three Pagodas (TPF) and Sumatra Fault (SF) are the principal strike-slip faults whereas the Northern Thailand (NTF), Uttaradit (UF), Ranong and Klong Marui (RKF) and Mergui Faults (MF) are the NE-SW trending conjugate strike-slip faults which are terminated by the major NW-SE strike-slip faults (Polachan, 1988). Almost all of these fault are regards as active faults (Hinthong, 1995). The TPF probably continue southeastward through the Chao Phraya Central Plain of Cenozoic alluvial deposit (Tulyatid and Charusiri, 1999, Lacassin et al., 1997). To the north both the MPF and the TPF are truncated by the Sagaing Fault in Myanmar. The latter extends southward to Mataban Bay to join the SF in Sumatra. The splay of MPF probably extends further southeastward to Chonburi. The other splay continues to the Tonle Sap depression in Cambodia and continues southeastward to the west of Mekhong Basin (Tapponnier et al., 1989; and Lacassion et al., 1997). The UF orients in the NE-SW direction and separates the Lampang-Chiang Rai block the Nakhon Thai block (Charusiri et al., 2002) becoming Nan-Uttaradit suture zone. This suture zone consists largely of dismembered ophiolite suite and blue-schists (Barr and MacDonald, 1987). The NTF is roughly parallel to the UF but it has a sigmoidal shape, swinging N-S through the central to southern parts of northern Thailand. This fault zone is made up of a series of anastomosing strike-slip and dip-slip faults (Strogen, 1994). At present both the UF and NTF show sinistral movements based on earthquake fault plane solution (Le Dain et al., 1984 and Fenton et. al., 1997).

Hinthong (1997) worked on active fault investigation in Thailand and classified most of the distinct faults in northern Thailand as potentially active faults, based on reported thermoluminescence dating results. The hot springs can be observed along the fault zones. In northern and western Thailand, five active fault zones are recognized by several worker at present. They are:

1) The N-trending, Mae Sariang Fault Zone, located in the western close to Thai-Myanmar border, having activity between 0.21 to 0.89 Ma (Hinthong, 1995);

2) The N-trending, Mae Tha Fault Zone, which bounds the eastern part of the Chiang Mai Basin with the sigmoidal shape, having activity from 0.19 to 0.77 Ma (Hinthong, 1995);

3) The NE-trending, Theon or Lampang Fault Zone. Which lies on the middle part of northern Thailand with the sigmoidal shape. The fault activity occurred about 0.002 to 0.004 Ma (Charusiri et al., 2004);

4) The Phrae Fault Zone. Which bounds the eastern flank of Phrae Basin and has the shape similar to Theon Fault, with fault activity about 0.05 to 0.2 Ma. (Won-In, 2002; Udachachon, 2002; Charusiri et al., 2004)

5) The NW trending, Moei-Uthai Thani fault zone, with activities during 0.06 to 0.1 Ma in the past; and

6) The NW trending, Three Pagodas Fault Zone, which has the activities from 0.002 to 0.005 Ma (Won-In, 1999; Nuttee, 2000).

# 3. REGIONAL GEOLOGIC STRUCTURE

Based on geological map of Thailand 1: 1,000,000 (DMR, 1999) and geology of Burma 1:1,000,000 (Bender, 1983), the study region has been disturbed by several sets of faults. However, the major fault is the MPF which cuts through rocks of various ages ranging from Precambrian to Quaternary. The MPF always follows the roughly northwest-trending major structures of the region. The MPF comprises straight lines to curvilinear of several fault branches and seems to deviate to become concentrated in the middle part of the regional study area. The MPF is actually called a spray fault when the southern portion passes Precambrian amphibolite facies metamorphic rocks. To the north, the MPF mostly sprays and cuts the lower-grade metamorphosed marine strata. The Upper Paleozoic rocks, particularly in the south, are also crossed cut by the MPF branches. More interesting is the area in the central part where the MPF represents the principal displacement zone. The MPF seems to concave and concentrates in the Tha Song Yang area of Tak province. Moreover, the MPF seems to cut young clastic strata of Mesozoic to Cenozoic ages. Faults in the unconsolidated Cenozoic deposits are notably important since they indicate seismic tectonic activity which occurred during Cenozoic times. The MPF which passes the Paleozoic strata shows relatively left lateral movement. However, some deformed Mesozoic strata show a vergent structure and indicate a right lateral movement along the fault. This perhaps points to the fact that the MPF moved sinistrally in post-Paleozoic times and moved dextrally in the post-Mesozoic period.

## 4. MORPHOTECTONIC EVIDENCES

### 4.1 Result on Satellite Image Interpretation

We applied digitally enhanced JERS images, Radarsat images (Figure 1) and Landsat TM5 images to the study area with an emphasis along the MPF. The false colored composites (red, green and blue) were digitally added to the image data of bands 4, 5, and 7, respectively. Practically, visual interpretation is to assist in delineating the large-scale neotectonic and deformation features and to define the fault segmentation as well as orientations and directions of the investigated fault segments. The result shows better-looking the appearance of several neotectonic features including fault scarps, triangular facets, offset streams, shutter ridges. Lineaments and faults can be traced from easternmost Myanmar to the border zone of northwestern Thailand. The result from remote-sensing interpretation indicates the major trend of lineaments and faults along the MPF in the northwest-southeast direction, and its branches may extend northward to the Mae Hong Son area. Three other minor trends of lineaments and faults are in northeast-southwest, east-west and north-south directions. Delineation of segments involves identification of discontinuities in the fault zone. In this study, we apply four criteria for subdividing discontinuities of faults including earthquake discontinuity e.g., historic rupture-geometric discontinuity (e.g., sense of movement, intersection, segment branch, termination, orientation), geologic discontinuity (e.g., those bounded by Quaternary basins and geophysical anomalies), and structural discontinuity (e.g., intersection with other faults, folds, and cross structures), following the recommendation of McCalpin (1996). Based upon such criteria and results gathered from interpretation of enhanced image data applied in the current investigation, we found that the MPF within the study area is as long as 230 km and can recognize 10 fault segments (Figure 2) from north to south, viz. the Sob Moei segment (10 km), the Huai Mae Lo segment (8 km), the Ban Tha Song Yang segment (26 km), the Khao Mae Song segment (24 km), the Huai Mae La segment (35 km), the Doi Kala segment (23 km), the Doi Khun Mae Tho segment (25 km), the Doi Luang segment (43 km), the Khao Yao segment (23 km), and the Khlong Phri segment (15 km).

Some lineaments bound Cenozoic alluvial basins in the Tha Song Yang district. Several lineaments are parallel to stream channels such as the Mae Nam Moei, in the northwestern part of the MPFZ and the Mae Ramat basin. Some lineaments pass through alluvial deposits at Yang Pang Chang and Mae Kasa villages, in the northeastern and eastern parts of the Mae Ramat district, respectively. Several lineaments also cut the Nam Mae Lamao eastward of the Mae Ramat basin.

### 4.2 Results on Aerial Photo Interpretation

For detailed investigation, we have selected small areas based on results of lineament analysis by satellite images for aerial photographic interpretation. At the Mae Ou Su village, northwestern of Tha Song Yang district, aerial-photographic analysis reveals several pieces of morphotectonic evidence along the Khao Mae Song segment, such as offset streams, shutter ridges, linear valleys and fault scarps. The offset stream observed in this area, the Mae Ou Su stream southeastward of Mae Ou Su village which change its flow direction from northeastward to southwestward before joining the Moei River. A right-lateral movement Zor a series of movement) has caused shifting of the stream for about 1.5 km and creates a shutter ridge with the northwest-southeast trend, the average base width of about 100 m, and the height of about 55 m from the base. A fault scarp clearly observed in mudstone at Thung Tum village, is almost vertical and rather continuous. The plane of this fault scarp strikes in the northwest-southeast direction, following the main fault. In some places, the fault planes dip steeply to the northeast.

From all the examined morphotectonic evidence, it can be summarized that the major fault trace shows a right-lateral movement with some dip-slip component. The vertical displacement is characterized by sets of triangular facets, and the dextral movement is supported by the appearance of offset streams, shutter ridges, and a linear valley.

### 4.3 Result on Field Investigation

Field reconnaissance survey in the Mae Ou Su village, indicates that the Khao Mae Song fault segment has a continuous length of 24 km. Additionally, we recognized one fault scarp trending in the northwest-southeast direction and the limestone outcrop showing a shear zone. Our result from the field investigation conforms very well with that of the aerial photograph interpretation.

With the combination of remote-sensing result and the field investigation survey, we select Ban Mae Ou Su area, 12 km in northwestern from Tha Song Yang district, and made a detailed topographic map at a scale of 1:500 to cover the Khao Mae Song fault segment. Surveying was applied to clearly identify the fault orientation and displacement type. Both offset stream and shutter ridge show a horizontal movement at 75 meter in a right lateral sense. Subsequently we applied a ground penetrating radar (GPR) (Thitipattanakul et. al., 2004) in a northeast trend almost perpendicular to the Khao Mae Song fault segment with the well-precise estimate of the data obtained from the GPR for the location of the fault segment. Two paleoseismic trenches at Ban Mae Ou Su were launched for paleoseismic studies.

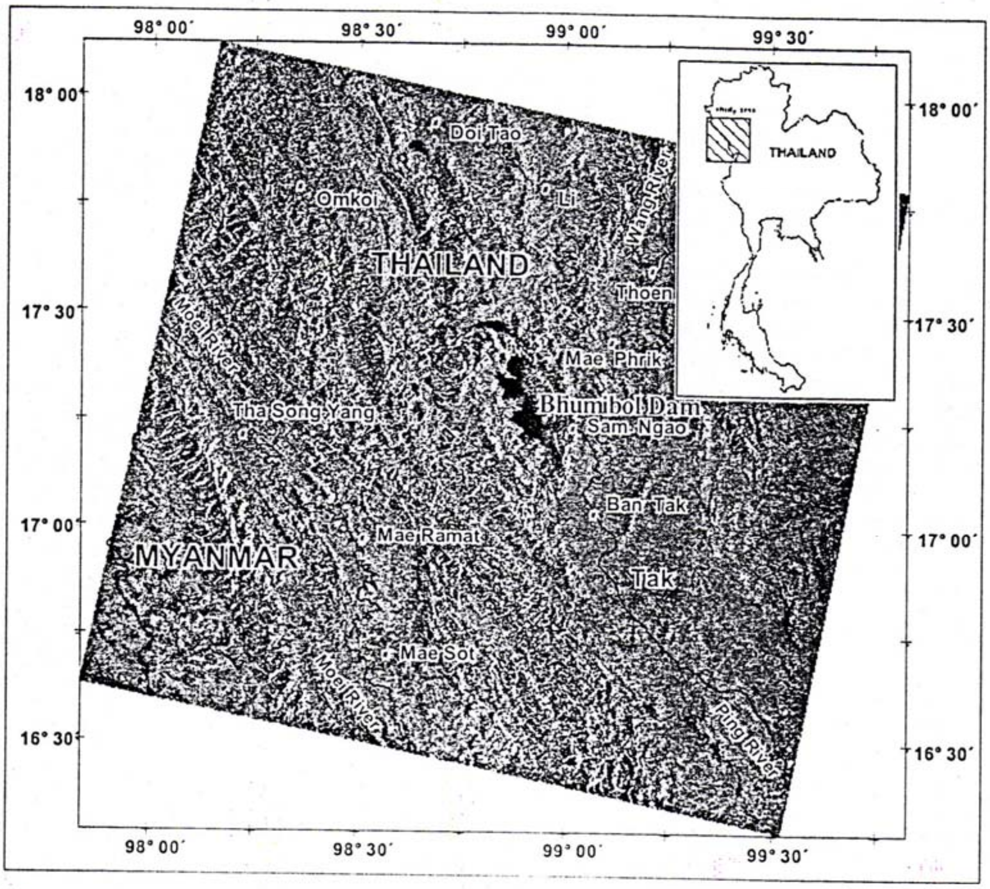


**Figure 1** Enhanced Radarsat image showing lineament map.

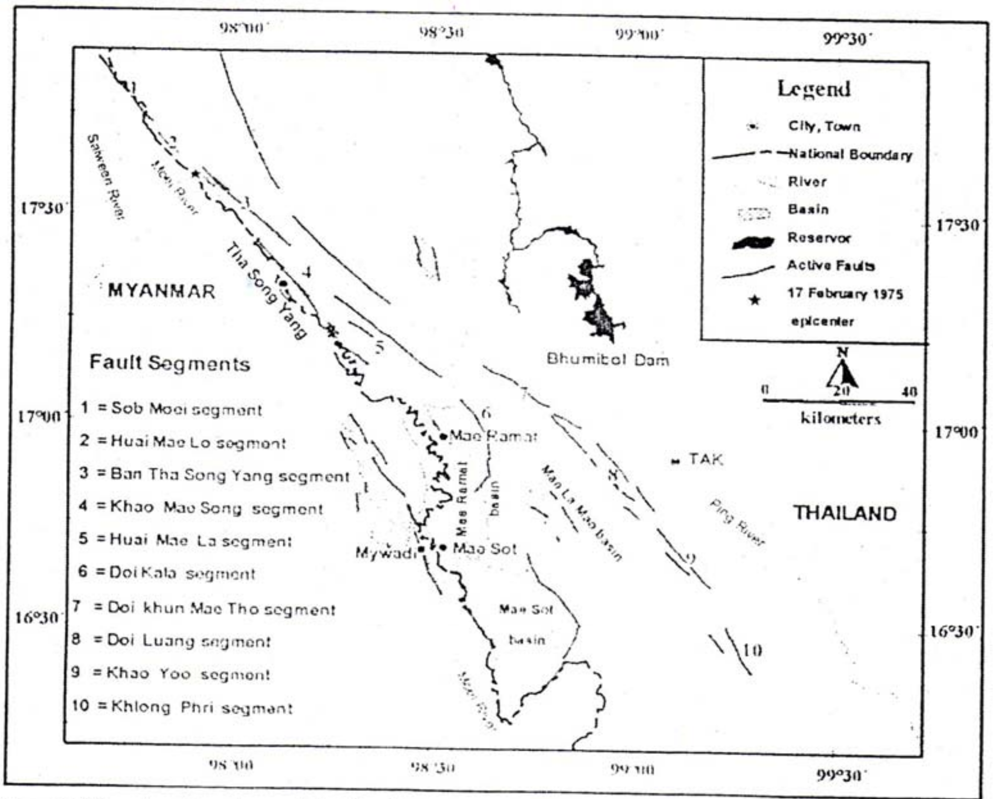


**Figure 2** Map show locations of the Moei-Mae Ping Fault Zone (red line) and its major active fault segments, and 17 February 1975 epicenter.

## 4.4 Paleoseismic Trenching

We mapped a log-stratigraphy at two trench sites, namely MOS1 and MOS2 for detailed studies of faults and description of trench logging. Trench location was defined near the small shutter ridge. The MOS1 trench was about 18.20 m long, 2.5 m wide, and 3.5 m deep, and the MOS2 trench was about 7.50 m long, 2.5 m wide, and 3.5 m deep. They are about 3.5 m apart from one another. From both trench sites, we recognized 5 horizontal stratigraphic units in an decending order below.

Unit A: Disturbed topsoil. This unit is the top soil layer with thickness verying fron 10 to 30 cm and averaging 25 cm. It is pale gray, silty clay with 10% gravel in volume, Gravels are mainly sandstone and limestone with the size ranging from 1 to 5 cm. The topsoil layer is poorly sorted and with moderate roundness. Due to the unit lies at the topmost, it is easily disturbed by human and agricultural activities.

Unit B: Gravelly clay. This unit is a lateritic clay bed composed mainly of yellowish brown clay about 70% and gravel about 20%. It is poorly sorted and subangular to subround. Most clasts are sandstone, quartz and limestone.

Unit C: Silty clay. The unit is drak gray silty clay bed of alluvial deposit composed mainly of clay 70%, silt 20% and gravel 5%. The gravels are mainly sandstone, quartz and limestone from 2-7 cm in size subround and moderate sorting nature. The layer has an average thickness of 1.0 m.

Unit D: Silty clay. Light yellowish brown, silty clay bed of alluvial deposit. It is composed chiefly of clay 60%, silt 10% and gravel 10% in the lower. The gravels are quite similar in size and composition to those of the Unit C. The layer is as thick as 1.0 m.

Unit E: Silty clay. The unit is drak gray-black, silty clay bed of colluvial deposit. It is comprises mainly of clay 60%, silt 10%, and gravel 10% in the lower. The gravels are mostly sandstone, quartz and limestone from 3-20 cm, subangular and poorly sorted. The layer has a thickness of about 2.0 m.

Four faults (F1, F2, F3, and F4) are identified in the southeastern wall of the MOS1 trench (Figure 3). The F1 fault located at about 5.0 m from the northeastern end of the wall side, cuts unit E in a reverse sense of movement. The fault strike N20°W and dip 65° eastward.

The F2 and F3 faults, located at 6.0-6.5 m and 7.5-8.0 m, respectively, also cut Unit E with strikes N30°W and N35°W and dips of 55° and 25° eastward, respectively. The F4 fault on the northern side of the F1 fault is a synthetic fault and cuts unit E, with a strike of S65°W and a dip of 65° westward.

Two faults were observed in the southeastern wall of the MOS2 trench (Figure 4). The F5 fault is located at meter 0.5-1.0, cuts two layers, units D and E with strike N20°W and dip 65° eastward.

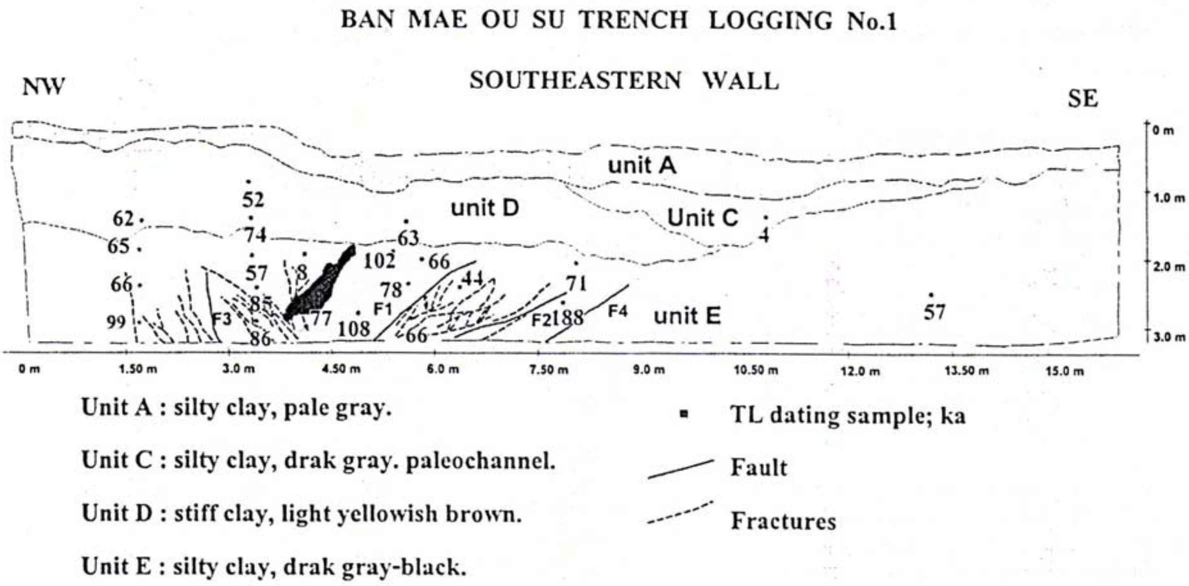


Figure 3 Age of dated samples of the southeastern wall of MOS1 trench

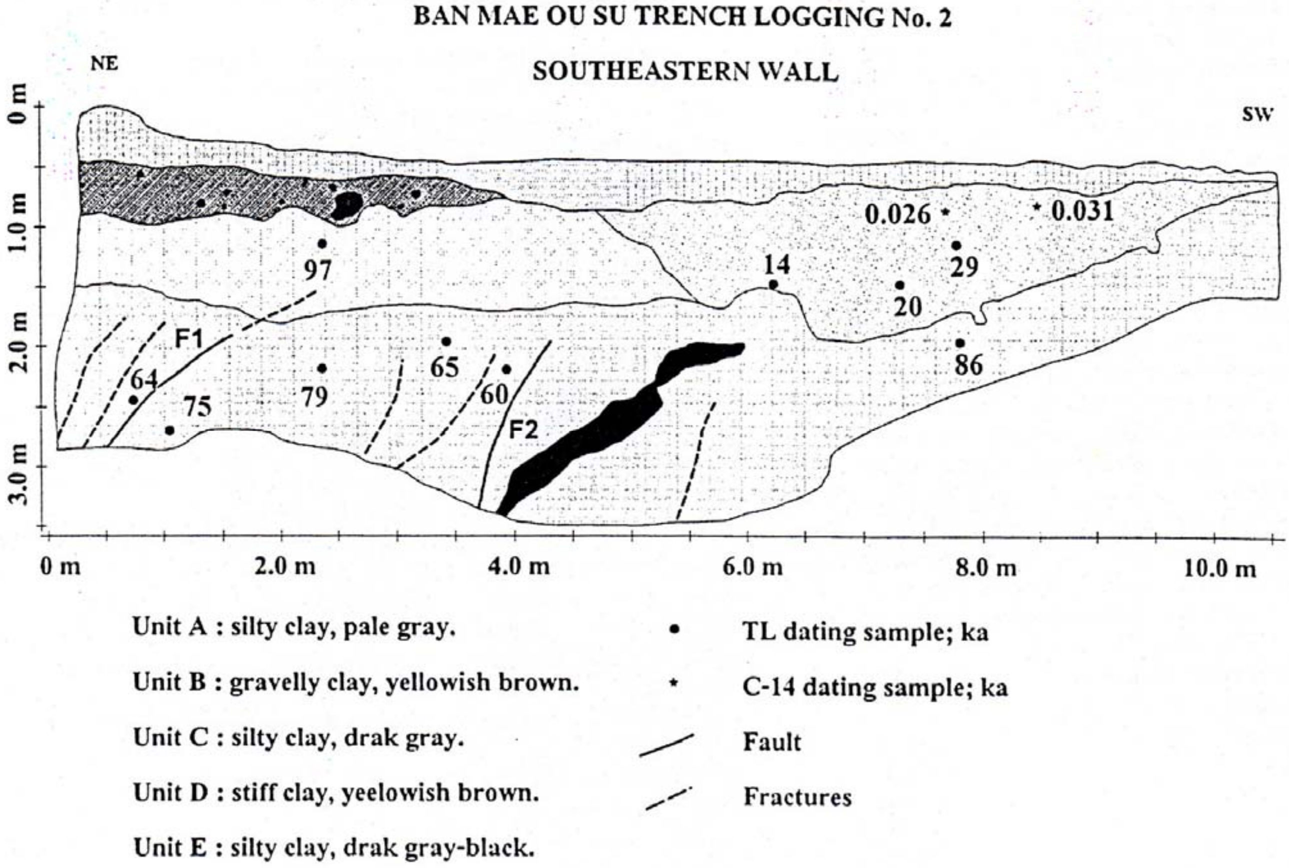


**Figure 4** Age of dated samples of the southeastern wall of MOS2 trench

## 5. THERMOLUMINESCENCE AGE ESTIMATES

Thirty three samples were collected from two trenches for TL age determination and two organic-rich samples for $^{14}C$ dating was found in the trenches.

TL-dating results; 40 samples of Unit D were collected for TL dating. The result of dating reveals the age of this unit at about 52 ± 5 to 81 ± 8 ka. 30 samples of Unit E were collect for TL dating. The result show the Unit E ranging from 57 ± 5 ka to 108 ± 10 ka. For Unit C 3 samples were selected. The TL dates range from 14 ± 1 ka to 23 ± 2 ka.

Additionally, we collected two organic-enriched samples were collected from Unit B for c-14 AMS dating. The samples yield the dates of 260 ± 40 BP and 310 ± 40 BP. These two dates correspond fairly well with the dates obtained from TL dating method.

## 6. DISCUSSION

### 6.1 Estimation of Paleoearthquake Event

Fault characterization on the bases of the combined results of remote-sensing information and the field reconnaissance survey, the northwest-trending MPF clearly postdated regional geological structures which develop in the north to northwest trend. Morphotectonic evidence including triangular facets, offset streams, fault scarps, shutter ridges and beheaded streams, indicated that there are oblique strike-slip movements with both horizontal and vertical slip components along the studied fault.

Hinthong, (1997) and Charusiri et al. (2001) stated, based on results on TL dating of sediment related fault and fault-gouge material, that ages of paleoearthquake events of this fault zone occurred within Quaternary period. Although they did not specify the exact location and detailed description of the dated sample, we are able to locate their samples at the Ban Tha Song Yang and Huai Mae La fault segments were dated. Samples at the Ban Tha Song Yang segment indicates the TL dates at 0.16, 0.21, 0.37, and 1.17 Ma, and those at Huai Nae La segment yield the TL dates at 0.50 and 0.58 Ma. Additionally, there are two earthquakes along this fault zone on 23 September 1933 and 17 February 1975. The one in 1975 has a magnitude of 5.6 and was felt throughout central Thailand, causing minor regional damage (Nutalaya et al., 1985). A focal-plane solution shows a component of right lateral movement (Bott et al., 1997).

Both results on fault-plane solutions by Both et al. (1997) and our morphotectonic analysis reveal that almost all of the MPF segments show the offset in the right lateral sense. Lineaments obtained from air-borne magnetic studies (Tulyatid and Charusiri, 1999) as well as our interpreted Landsat data reveal that the MPF passes through some Cenozoic basins.

The left lateral movement along the MPF after Paleozoic lead us to believe that this event was caused by the east-west compressive tectonics due to collision of shan Thai-Indochina and their affiliated block during Late Triassic (Charusiri et al., 2002). Reactivation of the left-lateral movement is supported $^{40}Ar/^{39}Ar$ dating of muscovite-bearing Sn-W pegmatite occurring along the MPF. The results yield the $^{40}Ar/^{39}Ar$ age of 78 Ma. We therefore consider that this subsequent faulting episode was due to western Burma-Shan Thai continental collision in the east-west direction. However, a change in tectonic style happened along the MPF when Indo-Australian mega-block collided with Asia continental block during 45 Ma (Le Dain, 1984). This definitely causes extrusion tectonic of southeast Asia, since then the movement has become right-lateral along the MPF.

## 6.2 Eatimation of Paleoearthquake magnitude, slip rate, and recurrence interval

The method of paleomagnitude estimation is applied in this study based on the analyzed historic data set adopted by Wells and Coppersmith (1994). This involves estimating prehistoric surface rupture length, and comparing its rupture length to the surface rupture lengths (SRL) of historic earthquakes of known magnitude. To estimate a paleomagnitude from an inferred paleorupture length, we uses a regression of M on SRL (length, measured as a straight-line distance between the rupture endpoints) from the equation

$$M = 5.08 + 1.16 * \log(SRL) \quad (1)$$

In this study, we applied the Khao Mae Song fault segment which is morphotectonically young fault near Tha Song Yang village. The fault with the continuous length of about 24 km exhibits several well-defined, continuously and clearly traced morphotectonic features. Our estimation indicates the movement of this fault in the past with the maximum earthquake at $M_w$ 6.7. Based on our study, it is quite likely that there is one large earthquake with the magnitude of 6.7 on the Richter scale occurred near the Ban Tha Song Yang village about 64,000 years ago.

We also estimated that relationship between recurrence interval by Slemmons and dePolo, (1986), the Khao Mae Song segment, based on the assumption that a $M_w$ 6.7 earthquake, has a slip rate at 0.12 mm/yr. It has a recurrence interval of about 2,000 yrs.

## 7. CONCLUSIONS

Based upon results of remote-sensing interpretation together with field evidence, conclusions can be drawn for the MPF in Tak area as shown below;

1) MPF is the northwest-trending, 230 km-long fault extending from easternmost Myanmar to northwestern Thailand, and perhaps to central Thailand and Tonle Sap in Cambodia.

2) Lineaments belonging to the MPF orientated in the northwest-southeast, northeast-southwest, north-south, and east-west direction. The major trend of lineaments are the northwest-southeast directions and are regarded as a major fault zone.

3) MPF can be divided, based on discontinuity criteria, from north to south in to 10 fault segments, viz. the Sob Moei segment (10 km), the Huai Mae Lo segment (8 km), the Ban Tha Song Yang segment (26 km), the Khao Mae Song segment (24 km), the Huai Mae La segment (35 km), the Doi Kala segment (23 km), the Doi Khun Mae Tho segment (25 km), the Doi Luang segment (43 km), the Khao Yao segment (23 km), and the Khlong Phri segment (15 km). All segments more or less align in a northwest-southeast directions, but Doi Kala segment is in a north-south direction.

4) Significant and well-defined pieces of morphotectonic evidence are triangular facets, fault scarps, beheaded streams, offset streams, shutter ridges, and linear valleys. They are discovered along the MPF, particularly where bed rock connects with the roughly northwest-trending Cenozoic basins.

5) Tectonic morphology elucidates that the MPF has an oblique strike-slip movement with a more horizontal sense than vertical. Both left and right lateral senses of movements are recognized for almost all fault segments, however the right-lateral movements are much more common and seem younger than those of the left ones. Such a result corresponds very well with 1975 earthquake data.

6) Estimation from the surface rupture length of about 24 km the Khao Mae Song segment indicates that earthquake may have occurred in this area with the maximum earthquake at $M_w$ 6.7. The reconnaissance TL date indicates the age of the movement about 64 Ka age. We, therefore, conclude that the slip rate of this fault segment is estimated at 0.12 mm/yr. Consequently, several lines of evidence support that the MPFZ is still active till present.

7) Past of the Moei-Mae Ping Fault shows a slip rate of 0.12mm/yr with a recurrence of 2,000 yrs.

## 8. ACKNOWLEDGEMENTS

This paper was supported by several agencies including Chulalongkorn University, the Thailand Research Fund (TRF), the Geo-Informatics and Space Technology Development Agency (Public Organization), and the Environmental Geology and Geohazard Division, the Department of Mineral Resources. Many thanks go to the GIS team of the Environmental Geology and Geohazard Division for their helpfulness in processing Landsat TM7 and Radarsat image data.

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