Paleoseismic Studies along the Southeastern portion of the Phrae Basin, Northern Thailand

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ABSTRACT

We applied remote-sensing information together with field, thermoluminescence dating, and relevant investigations along the Phrae fault system in northern Thailand to elucidate neotectonic associated with paleoearthquakes of the study region. The result on remote-sensing interpretation, field investigation, seismic profiles, and focal mechanism data reveal that the southeastern segment of the Phrae fault system is a potentially active fault. The studied fault with the northnorthwest trend and t he length of 20 km, is located in the southeastern margin of the Phrae Cenozoic basin. The seismic data reveal that the fault is west-dipping and regarded as the basin-bounded fault. The minor faults observed in high terraces and roughly lying parallel to the major fault is antithetic and with east-dipping to the major one.

Evidence of tectonic geomorphology along the fault segment, including shutter ridges, triangular facets and offset stream channels, are found both in the field and Landsat images. Additionally field evidence supports normal faulting nature along the minor fault. Results on TL-dating and focal mechanism data indicate that the fault segment has undergove sinistral movement with small amount of normal component. The maximum slip rate of fault movement is about 0.06 mm/yr. These lines of evidence are consistent with the result on contemporaneous stress axis orientation in this area which reveals the rough east-west and north-south trends of extensional and compressional axes, respectively. Two paleoearthquake events with large magnitude (Mw~7) were taken place in the study area. The first event occurred quite younger, between 0.9 Ma and 1.1 Ma, and the second event was between 0.05 Ma and 0.17 Ma. We, therefore, estimate that recurrence of large earthquake generated by the fault movement is ca. 0.9 Ma. Additionally, small present-day earthquakes, which have been detected by Chiang Mai seismic stations throughout the year, also indicate present-day active tectonism in this area

Keywords *: neotectonic, the southeastern segment, Phrae basin, Northern Thailand, thermoluminescence dating, paleoearthquake.*

1. INTRODUCTION

Present-day tectonics in Southeast Asia is influenced mainly by 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 occurred on the faults to the north (e.g., Kun Lun, Red River, and Altyn Tagh faults), however, moderate earthquake activity throughout the mainland southeast Asia indicates contemporary deformation in this region (Fenton et al., 1997). Progressive rotation of Southeast Asia results in an increasing strike-slip faults with the associated development of pull-apart basins in Thailand (Polachan amd Sattayarak, 1989). Additionally, Thailand is located in intraplate region, lies immediately east of the Andaman-Sumatra earthquake belt. Many of earthquakes occur in this belt usually felt in Thailand (Hinthong, 1991). Earthquakes in Thailand and adjacent areas may be related to extentional regime. This regime is caused by associated tectonism related to the subduction zone and spreading ridge in Andaman Sea (Siribhakdi, 1986).

There are NW-SE and NNE-SSW major conjugate sets of strike-slip faults influenced in contemporary tectonism in Thailand, particularly in the western and northern regions. According to earthquake fault plane solution, the NW-SE set is undergoing with dextral strike-slip movement, for example, the Mae Ping and the Three-Pagoda faults, and NNE-SSW set is undergoing with sinistral strike-slip movement, for instance, Mae Chan and Phrae faults (Bott et al., 1997). Won-in (1999) revealed that many geological evidences along Three-Pagoda fault correspond to those results such as triangular facets, shutter ridges, offset stream channels. However, there are many schools of thought on the idea of contemporary tectonism in Thailand (see Bott et al., 1997., Pollachan and Sattayarak, 1989., Chauviroj, 1995., and Tapponnier et al., 1986). In fact, the study on neotectonic and paleoseismic in Thailand, are still at the pilot stage. Consequently, this study is aimed at promoting some of progress on paleoseismic study along southeasternportion of the Phrae basin in northern Thailand.

2. GEOLOGIC SETTING AND SEISMOLOGY

The Phrea basin is an intermontain-Tertiary basin located in eastern part of the north of Thailand. The basin is deposited mainly by Tertiary rocks, however, the surface covers by Quaternary sediments. Eastern margin of the basin is bounded mainly by Triassic reddish-brown sandstone, siltstone, conglomerate, Triassic gray to greenish gray siltstone, mudstone, limestone and Permian black shale, gray sandstone, dark gray mudstone and gray limestone with chert nodule. Western margin is occupied by Permo-Triassic volcanic rocks found on the southern part and on the northern part are other rocks which are almost similar to the east.

2.1 Lineaments and epicenters

Lineament interpretation using Landsat TM5 is shown in Fig. 1. The major trends of lineaments lie in NE and NNE, and the minor trends are in N, NW, NNW, E, ENE, and WNW. Long lineaments are found aligned in the NE trend, besides, the shorter are observed in almost all direction.

The longest lineament, which is referred to Thoen fault (Fenton, et al., 1997 and Srisuwan et al., 2000) is located at the bottom left of the map. This fault with the NE trend is observed in the northern part of the Thoen basin and apparently extends to the Phrae basin. The fault shows horsetail-splay characteristic, which is normally found in strike-slip regime (Chistie-Blick and Biddle, 1985). The other interested lineament is a long lineament, found at northeastern part outside the Phrae basin near Rong Kwang district. This lineament also lies in the NE trend in the mountainous area, which seems to connect between the Phrae basin in the southwest and the Nan basin in the northeast. In addition, two long NE-trending lineaments are delineated at southeastern part of the Mae Moh basin. These lineaments are referred to be parts of Thoen fault and characterized as fault-bounded basin (Fenton et al., 1997). In the northeastern part outside the Sukhothai basin, there is long, NE-trending found lineament in mountainous area. This lineament is believed to be part of Uttaradit fault zone (Tulyatid and Charusiri, 1997).

As shown in Fig. 1 inserted box and based on Landsat lineament map, three fairy defined lineament sets are recognized in the study area within the Phrae basin. Two long and distinct, the northern and southern branches, lineaments can be traced in the NNE trend along the mountainous front. These two lineaments are almost parallel to each other. The other lineament which is located between these two lineaments, strikes in the ENE trend and seems to pass through the Phrae basin.

Lengths of the southern and northern of NE-trending branches are about 13 km and 7 km, respectively. The ENE–trending lineament is about 5-km-long.

According to structural geometry of these lineaments, the ENE-trending segment seems to displace the eastern edge of the Phrae basin. Therefore, it is apparently that the ENE-trending lineament cut across the NNE-trending lineaments into two separated lines with right lateral movement.

Based on earthquake instrumental records from Chiang Mai Seismograph Station, 106 small to moderate earthquakes with magnitudes ranging from M_L 1.3 to 5.1, had occurred within and nearby the Phrae basin between December 1993 to January 2000. Interested event was December 9, 1995, near Rong Kwang earthquake with M_L 5.1 located near Rong Kwang district of Phrae province. This event occurred with felt report in Chiang Rai, Chiang Mai, Lamphun, Lampang, Phayao, Uttaradit, and Nan provinces and minor damage found in Phrae province.

Additionally, Gutenburg and Richter (1954) mentioned that in May 13, 1935 earthquake event with M_L 6.5 occurred in Nan province near Thai-Laos border. Between 1980 and 1983 the Phrae earthquake swarms was reported that the swarms began in December 19, 1980 with M_L 3.5. The largest events were found on December 22, 1981 and December 23,1981 with M_L 4.0 and 4.2, respectively. These earthquake swarms were reported locating in the south of the Phrae basin. All of these earthquakes were detected by seismograph station. Earthquakes occurred between 1980 and 1983 had no report of both man-made structural damages and human feeling.

It can be calculated that distribution of earthquake frequency in the Phrae basin and nearby areas is approximately 16 times per year of small to moderate sizes, epicentral distribution in the Phrae basin and nearby areas using the record mentioned above and additional records of earthquake during 1980 and 1983. Earthquake epicenters are found scattered throughout the basin and some of these epicenters were located in mountainous area outside the basin.

2.2 Seismic Profiles

In 1994, nine lines of seismic survey for coal exploration in the Phrae basin were done. These seismic lines were run to cover the basin with the total length of 180 km (Fig. 2).

For seismic interpretation, there are three main sets of normal faults located at the western border, the central, and the eastern borders. The major trend of the western border fault displays east-dipping with about 45°. Noteworthy, the western border in line no. P94-260 of profile characterizes as a splay fault. On the central, there is the most structural complexity in the basin. Due to negative flower structure and fault splay, they are mainly illustrated in the center of the basin. On the eastern border, for the southeastern portion, the fault is dip-to-the west with about 45°. This fault is selected for this study. Hanging wall of the fault is contained the basin-filled sediments and the footwall is occupied by basement rocks. Additionally, this fault is found cut across the basin downward until reaching the basement rocks. Noteworthy, on seismic line no. P94-240, at the upper part of the eastern-border fault, it is a small fault conjugated to this border fault.

2.3 Tectonic geomorphology

Based on aerial photographic interpretation and field investigation along the eastern portion of the Phrae basin, three types fault-related evidences are found. Which are included clearly defined offset stream channels, triangular facets, and a shutter ridge (Fig. 3).

At least two offset stream channels have observed in the southernmost part of the Ban Thung Charoen subsegment closed to a mountain front. In this area, the streams flow from mountainous area in the east to the basin in the west. However, in some location the streams are offset due to faulting. These offset streams indicate left-lateral movement with an average of offset length of about 0.5 km across the fault. Two sets of triangular facets were observed in the central part of the study area, developed in sandstone and siltstone, covered by some vegetation. The first set with an average base of 1.5 km long and 40 m high, composes of two west-dipping facets developed on the NNE-trending fault branch. The second set with the average base of 0.7 km long and 40 m high observed along the ENE-trending displays four facet spurs. These triangular facets could be indicated normal movement. A shutter ridge, which is about 0.5 km long and 25 m high, developed in sandstone, found in front of the second set of triangular facets. The ridge blocks a stream channel that flows straight forwards from mountainous area. Flow direction of the stream has changed into sinistral at the ridge.

According to these fault-borne evidences, it could be indicated that once normal-sinistral movement occurred by southeastern basin-bounded fault. Major trend of the fault is in NNE direction with approximately 20 km long, dip to the west about 45°, located at Ban Phae Mai in the south to Ban Pa Deang in the north.

3. PALEOSEISMOLOGY

3.1 Ban Thung Chareon Trench (TC)

This outcrop is closed to Wat Thung Charoen nearby the Mae Man reservoir (0620714E, 1993124N) (see Fig. 6). The outcrop is a well-exposed abandoned quarry with two walls. The first wall lies in the SE-trend composing TC1 and TC2 sites and the second expose in NE-trend composing TC3 site.

3.1.1 Stratigraphy and structure of sediments at TC

On the SE-wall, TC1 site composes of four lithologic units including, reddish brown clayey gravel (Unit A) contained in horizontal layer, found at the top of the outcrop; two layers of Unit B the, top layer and the bottom, both composed of pale brown silty clay of floodplain deposits; reddish brown sandy gravel of fluvial deposits (Unit C); and pale brown sandy gravel (Unit D).

all sedimentary layers of TC1 have been truncated by two normal faults except the top layer, which is unfaulted. The main fault (F1) is located on the center of the outcrop and the minor (F2) is on the left, all of which dip to SE. F1 fault strikes N50E and dip 80° with slips 2.0 m long. F2 fault strikes N40E, dips 45° and slips 0.7 m long.

For TC2 site, lithological layers are almost similar to those of TC1, which are reddish brown clayey gravel bed (Unit A); two layers of Unit B, both are pale brown silty clay of floodplain deposits; reddish brown very coarse sand bed of fluvial deposits (Unit C); light gray coarse to very coarse sand layer of fluvial deposits (Unit D); and pale brown silty gravel bed of fluvial deposits (Unit E).

All sedimentary layers at the TC2 site are cut by normal faults except the top horizontal layer similar to that of TC1 site. There are F1 fault with strike N20E, dip 25° and slip 1.90 m long, F2 fault with strike N30E, dip 20° and slip 0.25 m long, antithetic F3 fault with strike S54W, dip 65° and slip 0.90 m long and F4 fault with strike N50E and dip 80° and slip 1.20 m long.

At the NE wall (TC3), five lithologic units of sediments have been observed including, pale brown gravel bed of fluvial deposits (Unit A); pale brown silty clay layer of floodplain deposits (Unit B); reddish brown sandy gravel bed of fluvial deposits (Unit C); reddish brown sandy gravel bed of fluvial deposits (Unit D); and pale brown sandy gravel bed of fluvial deposits (Unit E).

The major normal fault (F1) is observed at the center of the outcrop, and a minor reverse (F2) and normal faults (F3) are investigated on the downthrown and the upthrown blocks of F1 fault, respectively. F1 fault is found cutting all layers up to present ground surface, with S85E-striking, 40° of dip angle, and 1.40 m of slip length. F2 fault is observed cutting across units C and D with E-striking, 50° of dip angle and 0.30 m of slip length. F3 fault is observed at the bottom of the unit E with strike S85W, dip 35°and slip 0.30 m long.

3.2 Chom Chaeng Trench (CC)

3.2.1 Stratigraphy and structure of sediments at CC

This outcrop is located at the right side of Wat Phra That Cho Hae – Wat Phra That Chom Chaeng asphaltic road, at 0627012E and 1999242N. The outcrop is abandoned quarry atop the hill. A normal fault observed at this outcrop cut across sedimentary layers up to the present ground surface (Fig. 4). The fault is in N15E-striking, dip 30° with 3.0 m of slip length. The layers, which are inclined to NW toward the basin axis with strike S50W and dip 15°, are reddish brown sandy gravel bed(Unit A); pale brown silty clay layer of floodplain deposits (Unit B); pale brown sandy gravel bed of fluvial deposits (Unit C); pale brown gravelly coarse sand layer of fluvial deposits (Unit D); and reddish brown sandy gravel bed of fluvial deposits (Unit E).

Additionally, closed to this outcrop to the east, it is CC2 outcrop whereas five normal faults cut across sedimentary layers almost up to ground surface (see Fig. 4). The layers comprises light brown silty clay layer of floodplain deposits, with $CaCO_3$ concretion (Unit A); pale brown silty clay layer of floodplain deposits with $CaCO_3$ concretion (Unit B); light gray coarse to very coarse sand layer of fluvial deposits (Unit C); light gray sandy gravel bed of fluvial deposits (Unit D); and reddish brown silty clay layer of floodplain deposits with $CaCO_3$ concretion (Unit E). According to the faults, F1 fault cuts across present ground surface, with strike N20E, dip 35°and 3.2 m of slip length. F2 fault is synthetic on the right of F1 fault observed cutting two upper most layers up to present ground surface, with strike N25E, dip 45° and 0.70 m of slip length. F3 fault is on the right of F2 fault, expressed as a normal synthetic to F1 and F2 faults, cutting the upper two layers similar to that of the F2 fault. Strike, dip angle, and slip length of F3 fault are N25E, 55°and 0.85 m long, respectively. F4 and F5 faults are located on the upthrown block of F1 fault. F4 fault is on the left of F5, striking N40E, dipping 25° and slipping 0.50 m long. The F5 fault strikes N30E, dips 20° and slips 1.30 m long. Both the F4 and the F5 faults are showing synthetic to F1, the F2, and F3 faults.

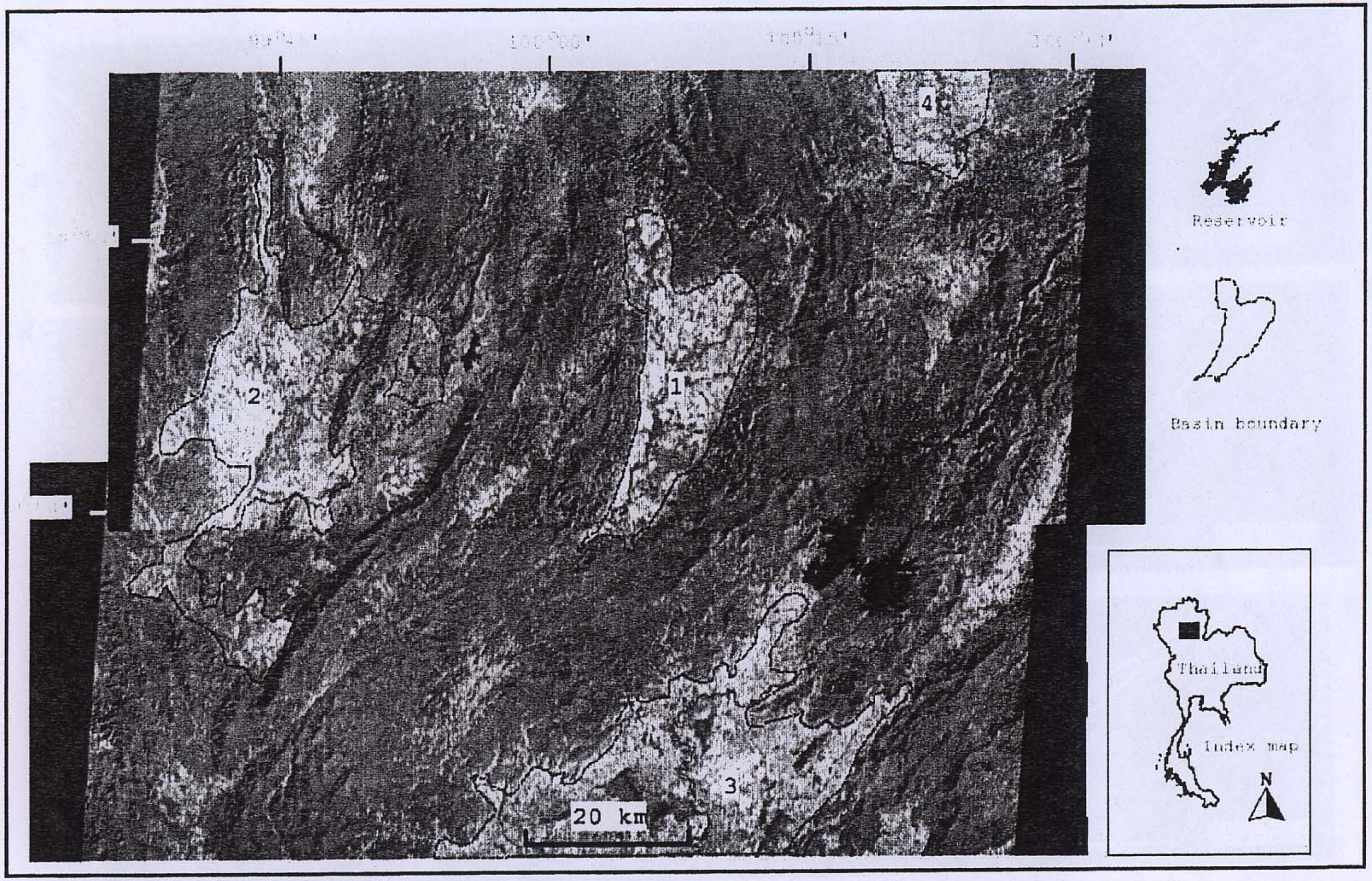

Fig. 1 Landsat image data showing locations of the Phrae Basin(1), the Lampang(2), the Pitsanulok Basin(3), and the Nan Basin(4)

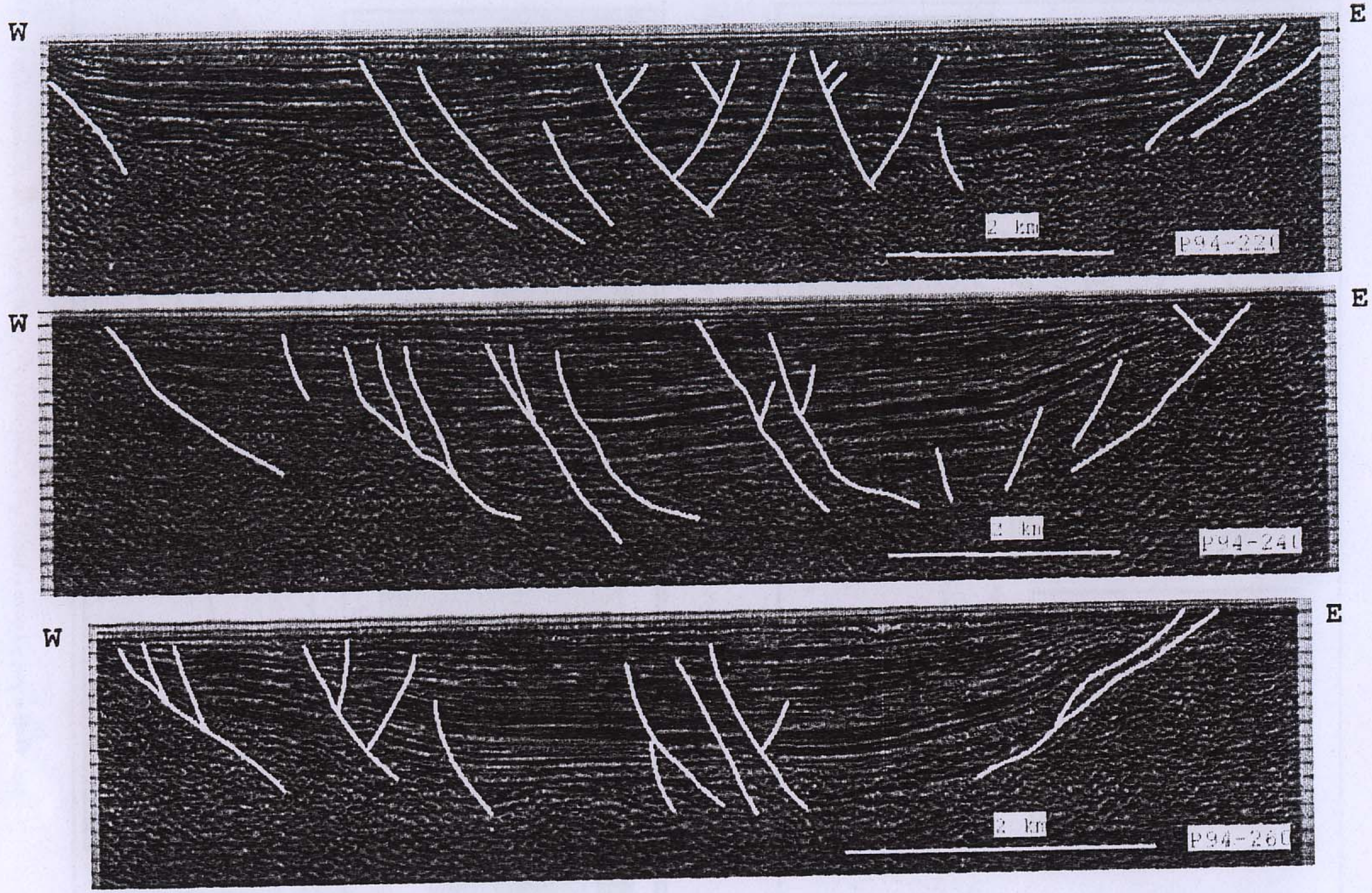

Fig. 2 Seismic interpretation results showing eastern border faults, referred to the southeastern segment of the Phrae fault system and line P94-240 shows antithetic fault on the eastern border.

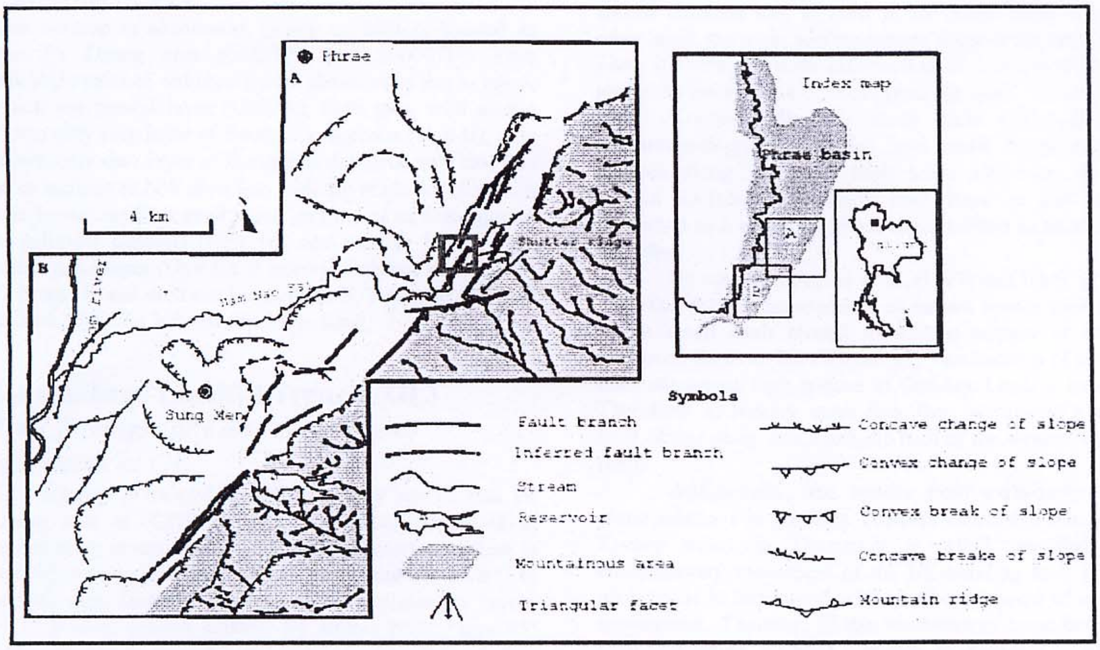

Fig. 3 Tectonic geomorphological map along the southeastern segment of the Phrae fault system

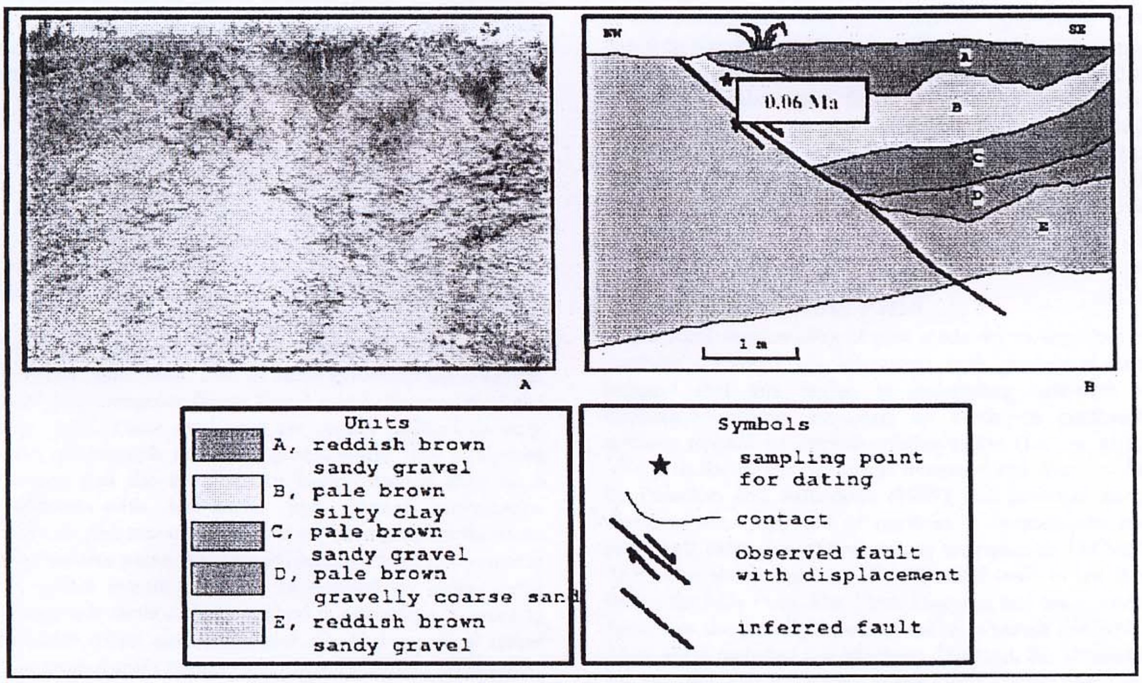

Fig. 4 Paleoseismic trench at Chom Chaeng (CCT) site (box in Fig 3) and outcrop logging with TL date

3.3 Ban Pa Daeng Trench (PD)

3.3.1 Stratigraphy and structure of sediments at PD

This outcrop is abandoned quarry on hilltop, located at Ban Pa Daeng area (062277E and 200007N). Five lithologic units of sediments were observed in this outcrop, which are topsoil layer (Unit A); light gray with mottle brown silty clay layer of floodplain deposits (Unit B); pale brown silty clay layer of floodplain deposits, note that this layer inclines to NW direction with dip angle 45° (Unit C); pale brown medium sand layer, and traces of some gravel of colluvial deposits (Unit D); and reddish brown very coarse sand layer (Unit E). A normal fault cut across units C, D and E and died out below unit B. The fault is found strike S30W, dip 30° and slip 3.0 m long.

3.4 Garbage Landfill Trench (GL)

3.4.1 Stratigraphy and structure of sediments at GL

This outcrop is located at landfill quarry site of Ban Pa Daeng area at 0627991E and 2001180N. It consists of sedimentary layers inclined 35° to NW direction. There is two SE-dipping synthetic normal faults, the left fault (F1) and the right fault (F2), cutting across sedimentary layers up to present ground surface. F1 strikes N50E, dips 45° and slips 1.10 m long. F2 strikes N35E, dips 70° and slips 1.50 m long. Five lithologic units of sediments were observed in this outcrop. Which are brown sandy gravel bed of fluvial deposits (Unit A); reddish brown gravelly coarse sand layer of fluvial deposits (Unit B); pale brown gravel bed of fluvial deposits (Unit C); pale brown coarse sand layer of fluvial deposits (Unit D); and pale brown silty clay layer of food plain deposits (Unit E).

4. DISCUSSION

4.1 Fault Characteristics

Based on Landsat image and aerial photographic interpretations, seismic profiles and field study, the main fault on eastern border of the Phrae basin is definitely located at the southeastern margin. It is delineated in NNE trend with about 20 km long and dip-to-the west about 45°. Three evidences of tectonic geomorphology were found along the fault trace. Two of these evidences are a shutter ridge and triangular facets found along the central of the fault trace. These evidences are clearly defined on both aerial photograph and field investigation. The evidences indicate that the southeastern basin-bounded fault once displaced with left-lateral and normal movements. However, the movements could be taken place in the same event or vice versa. Another evidence of fault movement is two offset stream channels as defined by using aerial photograph method. This method is advantage in order to delineate offset stream channel via bird-eye-view rather than ground-truth survey. The stream channels were found offset by the fault trace with left-lateral displacement. In addition, six outcrops on high terrace, which lie along and close to the front of eastern mountain range, were found truncated by normal faults. Almost all faults are east-dipping cut across west-dipping tilted sedimentary layers. Depending on seismic profile line no. P94-240, the small fault shows antithetic and conjugate characters to the southeastern border fault. The southeastern border fault is the major fault in this study area, the small normal fault is inferred as the minor antithetic faults. It is reasonable to think that if this major fault displaces, the minor fault should displace too, at least in the same sense. On the other hand, the main one movement triggers the small one. Then if there are little information of tectonic evidence along the main one, evidences from the small one could be fulfill. Consequently, this study main information of paleoseismology is collected from small faults on high terraces along the main fault trace. However, on the ground surface, the minor fault trace is not found continued as a single trace but characterized as small fault branches.

By contrast, Fenton et al. (1997) and GMT (1996) cited that there is no evidence of eastern border fault trace but a small fault closed to eastern margin is found. However, these authors found only one outcrop of normal fault cut across high terrace in Garbage Landfill outcrop. Therefore, as lacking more data, they interpreted a small fault of this study as a synthetic fault of the western border fault.

Additionally, the results from earthquake fault plane solutions in northern Thailand especially near Rong Kwang event in December 9, 1997 revealed that contemporary movement of the NE-trending fault in this province is in left-lateral with small component of normal movements. Therefor, if the southeastern basin-bounded fault still active, all fault branches or segments should be undergoing with the same normal-sinistral movement. This study is consistent to Srisuwan et al. (2000) in term of location and sense of movement of the fault. However, Charoenprawat et al. (1995) stated that eastern border fault of the Phrae basin was determined as right-lateral fault based on the offset of Triassic rocks. Moreover, Chauviroj (1995) also noted that the Phrae fault zone characterized as a dextral displacement fault. In order to explain this contrary of ideas, the fault could be dextral in the past offsetting some old rocks. But sense of movement has changed to normal-sinistral since contemporary period, which is indicated by evidences from this study and focal mechanisms.

4.2 Tectonic Stress Field

Three focal mechanisms of past moderate earthquakes in northern Thailand are consistent with geological data inferred that this region is undergoing east-west to northwest-southeast extension on north- to northeast-striking normal or normal-oblique faults (Fenton et al, 1997). In the report of dextral transtensional shear model by Polachan and Sattayarak (1989), two principal stress elements are composed of north-south compression and east- west extension of present-day tectonism in Thailand. They also stated that the NW-SE trend such as the Red River, the Mae Ping, The Three Pagodas, and the Sumatra faults are the principal dextral faults, whereas the NNE-SSW trend included the Northern Thailand, the Uttaradit, the Ranong, and the Klong Marui faults are the conjugate sinistral faults, which are found terminated to the dextral faults. Consequently, based on all results stated above the southeastern segment of the Phrae fault system, which is delineated in NNE-SSW trend, should be undergoing normal-sinistral movement.

According to field data, fault and joint components were measured then analyzed using stereogram. There are sets of results, including fault analysis from high terrace outcrop, joint analysis of Ban Pa Daeng high terrace outcrop, and joint analysis from hard rock outcrop nearby Mae Man reservoir. Fault analysis reveals extension axis in the ESE-WNW trend. Ban Pa Daeng joint analysis data suggests that tensional axis is in E-W trend whilst compressional axis is in N-S trend. Rock-preserved joint analysis shows that compressional and extensional axes are determined in E-W and N-S trends, respectively. Based on these analyses, it can be proposed that stress axis orientation in this area has been changed at least in two episodes. The first episode is determined by roughly N-Sorientation of extensional axis due to rock joint data analysis. This result is consistent with past right-lateral offset of Triassic rock in the central of study area, which is inferred to be the resultant of N-S extension. The second episode has changed from the first to E-W orientation of extensional axis deduced from fault and joint data of high terrace outcrops. However, there is no joint orientation as preserved in Ban Pa Daeng outcrop found in that hard rock outcrop. It could be explained that after the second episode then the stress axis orientation has changed, faulting events have generated only small to moderate magnitudes of earthquakes. These earthquakes might not created new set of joint in hard rock, which is distantness from hypocenter. However, on the high terrace outcrops, which are composed of semi-consolidated to consolidated sediments. Their strength is must lower than Triassic rock, therefore earthquakes could create joint sets easier than in the hard rocks.

4.3 Paleoseismic Events

Based on normal fault data from high terraces and TL-dating results, paleoseismic in this area can be delineated into at least two main events. Event 1 occurred between 0.88 ± 0.14 Ma and 1.1 ± 0.28 Ma, evauated from data of Ban Pa Daeng outcrop and event 2 taken place between 0.06 ± 0.002 Ma and 0.17 ± 0.02 Ma, from data of Chom Chaeng1 outcrop.

Ages from these events are composed of younger age of unfaulted layer and older age of faulted layer. In addition, on the other outcrops of high terraces, ages of those faulting event are located in the ranges of these two events. Then it could be emphasized from these present data that at least two events of past earthquakes taken place in this area.

4.4 Earthquake Magnitude Estimation

Based on maximum displacement method, magnitude of paleaoseismic events is found between M_w 6.8 and 6.9 (Table1). However, Fenton et al. (1997) estimated paleoearthquake magnitude using the surface rupture length for the Phrae basin fault, from the minor fault of this study, with an almost similar result of M_w 7.0. They applied surface rupture length method difference from this recent study. On account of no faulting surface rupture evident observed in the study area, Fenton et al. (1997) assumed rupture length from the mapped fault trace, which may cause over estimation, as parameter for their evaluation. Nevertheless, both this study results and Fenton et al. (1997)'s result are quite similar since the results revealed large paleoearthquake magnitudes occurred within the Phrae basin.

5. CONCLSION

Based upon results on our recent geomorphological mapping and TL age data together with the previous studies, it is concluded that the southern portion of the Phrae Basin consists of the NE-trending active faults. There are at least two paleoseismic events with the average magnitude of about 7 in Ritcher scale occurring at ca. 0.9-1.1 Ma and ca. 0.06-0.17 Ma in the study area. However, our work is now in the preliminary stage, more geological and geophysical data are required to obtain more knowledge on earthquake geology in the Phrae Basin.

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