CHAPTER V

FIELD INVESTIGATIONS

This chapter describes mainly the results as related to the field exploration. The first section involves field evidences of tectonic geomorphology. The second section describes exposures of neotectonic evidences, in which fault characteristics, lithologic units of sediments, and sampling location of fault-related sediments for TL-dating determination have been presented. Finally, stress axis orientations have been determined using outcrop-scale fault and joint data.

5.1 Field Evidences of Tectonic Geomorphology

One site located in the central of the study area displays evidences of tectonic geomorphology (Figure 5.1). Note that the study method on the evidence of tectonic geomorphology has already explained in section 4.3, then it is not necessary to repeat in this section.

Four most prominent triangular facets and a shutter ridge have been observed lying in the ENE-trending fault trace (Figure 5.2). In addition, the other two triangular facets are found lying in the NNE-trending fault close to the south of the former. These triangular facets are developed in sandstone and siltstone, which is covered by vegetation. The average base of the facets is about 1.0 km-long and the average height is about 40 m from the base. Slope of the facets is inclined to the NW direction with the angle of about 45°.

A shutter ridge was found between the mountain range and the basin close to the facets mentioned above. The shutter ridge is developed in sandstone, approximately 0.5 km-long and 25 m-high, covered by vegetation. This shutter ridge obstructs two stream channels, flowing from the eastern mountainous area. According to the shift of stream flow direction and morphology of the shutter ridge, the fault trace in this area shows left-lateral fault movement.

From these tectonic evidences, it can be concluded that the fault trace which contains both triangular facets and a shutter ridge, should have past movement with both dip-slip and strike-slip motions. On the other hand, this fault trace is normal-sinistral fault.

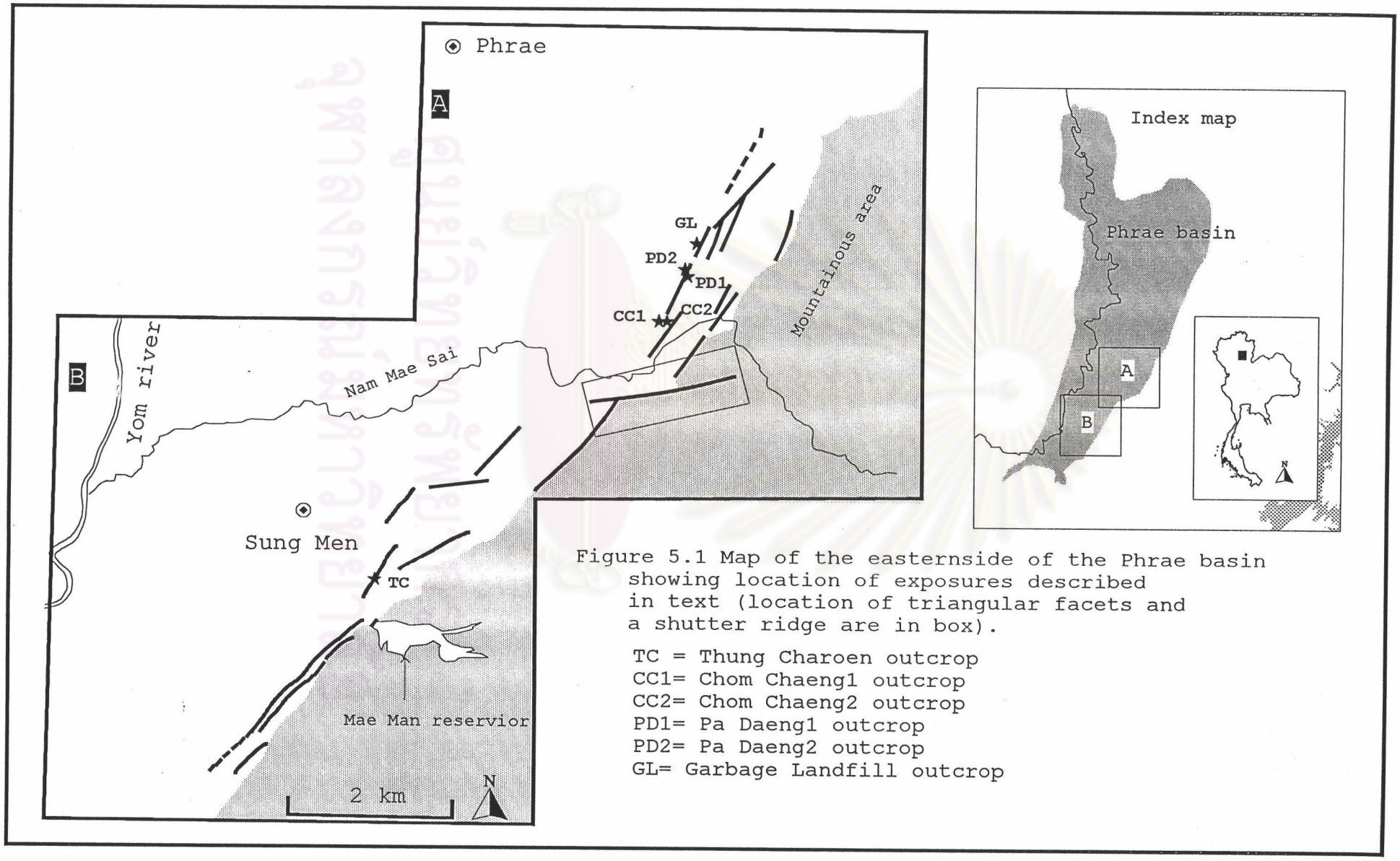


Figure 5.1 Map of the easternside of the Phrae basin showing location of exposures described in text (location of triangular facets and a shutter ridge are in box).

TC = Thung Charoen outcrop
CC1= Chom Chaeng1 outcrop
CC2= Chom Chaeng2 outcrop
PD1= Pa Daeng1 outcrop
PD2= Pa Daeng2 outcrop
GL= Garbage Landfill outcrop

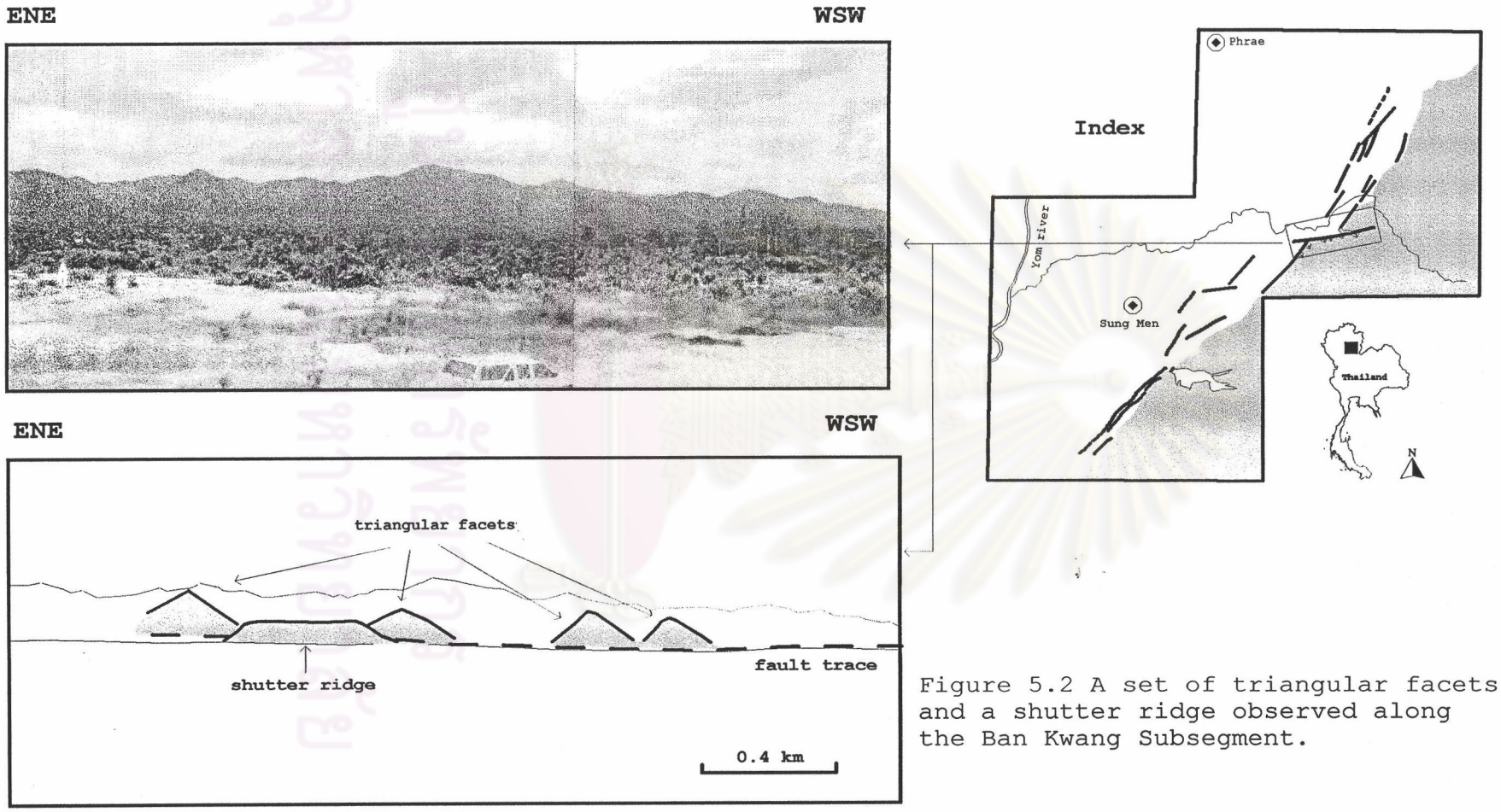


Figure 5.2 A set of triangular facets and a shutter ridge observed along the Ban Kwang Subsegment.

5.2 Exposures of Neotectonic Evidences

Six outcrops of unconsolidated to semi-consolidated sediments have been observed to indicate evidences of small faults, and one of these outcrops also contains joints and fold. These outcrops are located in the high terrace (Won-in, 2002, Charoenprawat et al., 1995, and Chauviroj et al., 1992) which are lying along the southeastern margin of the Phrae basin. The outcrops are Ban Thung Charoen (TC), Chom Chaeng1 (CC1), Chom Chaeng2 (CC2), Ban Pa Daeng1 (PD1), Ban Pa Daeng2 (PD2), and Garbage landfill (GL) (see Figure 5.1). At these outcrops, there are tilted layers truncated by normal fault. All of these layers are inclined to the basin axis in the west. Almost all faults are found east-dipping to the eastern basin flank. However, at Ban Thung Charoen and Ban Pa Daeng1 outcrops, the faults observed are antithetic. Two sets of joints and a fold are found at Ban Pa Daeng1 outcrop.

In this section, lithologic units of sediments together with sampling locations of fault-related sediments and geological structures in each outcrop are described in detail.

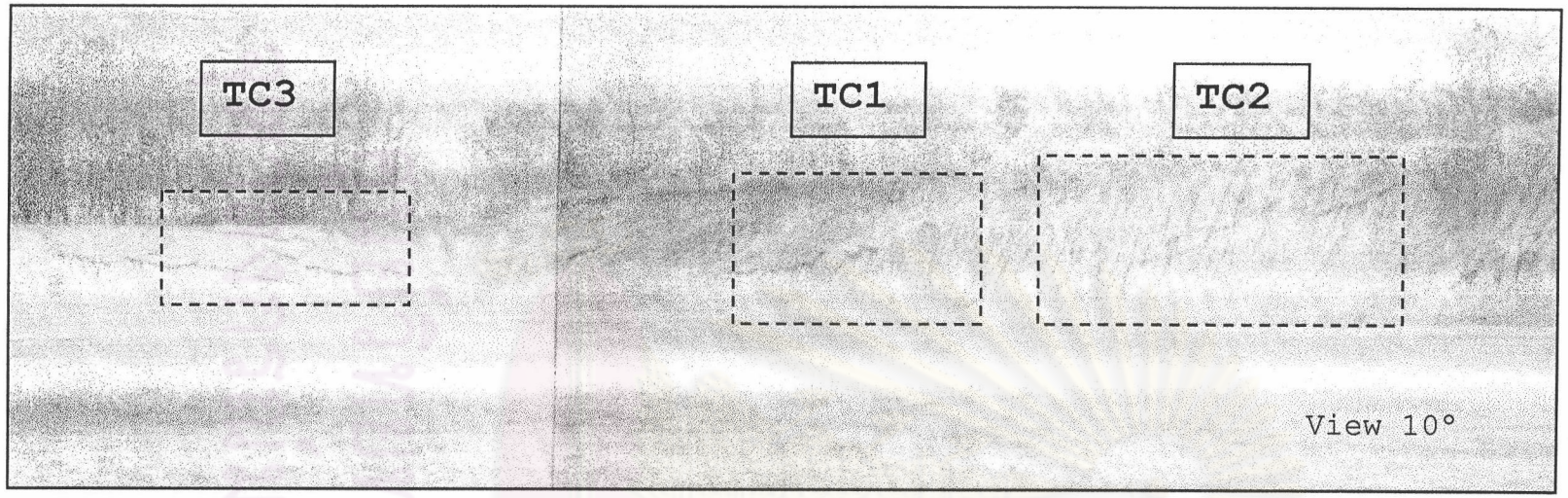
5.2.1 Ban Thung Charoen Outcrop (TC1, TC2 & TC3)

This outcrop is close to Wat Thung Charoen nearby the Mae Man reservoir, at grid reference of 0620714E and 1993124N. The outcrop is a well-exposed abandoned quarry with two walls (Figure 5.3). The first wall lies in the SE-trend and the second exists with the NE-striking.

The SE-trending wall (TC1 & TC2 in Figure 5.3), is about 150 m-long and 4.5 m-high. A well exposure outcrop shows a clarified zone of normal faults.

TC1 site is composed of four tilted sedimentary layers truncated by two normal faults. These layers dip NW at an intermediate angle of 50°. The main fault is located at the center (F1 in Figure 5.4B) and the other on the right of the former (F2 in Figure 5.4B). Additionally, there is a horizontal layer that has found capped on the top of the outcrop not disturbed by these faults (Figure 5.4).

The other four normal faults cut five tilted layers of sediments at the TC2 site. The main fault (F1) is found on the left and the others are on the right of the main one (F2, F3&F4). Regarding to sedimentary layers,



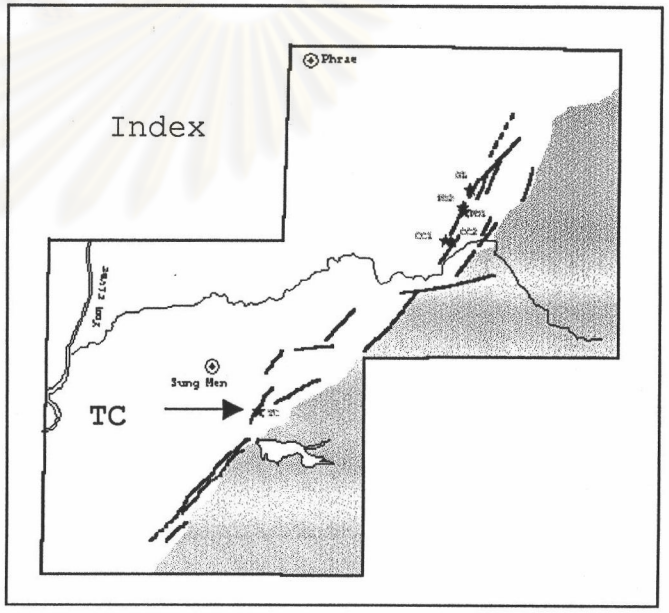
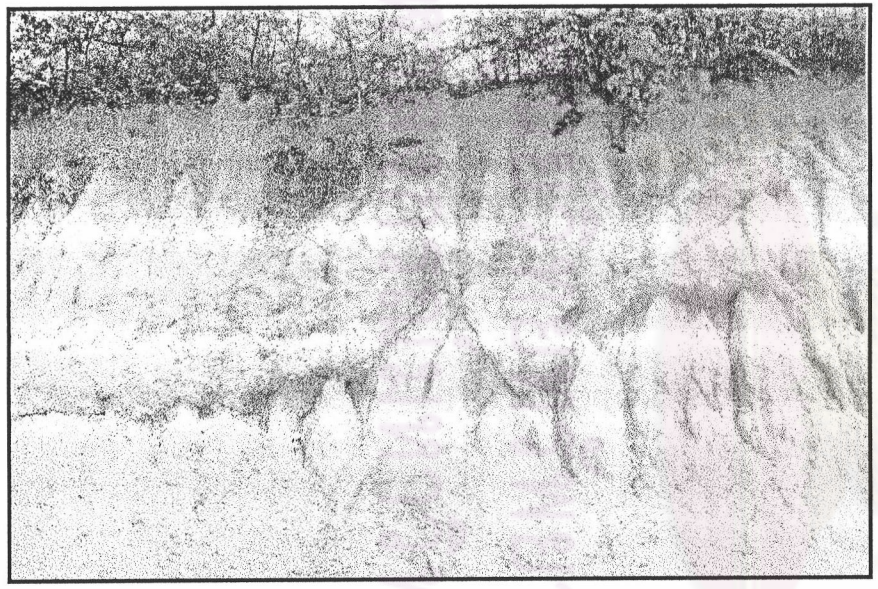
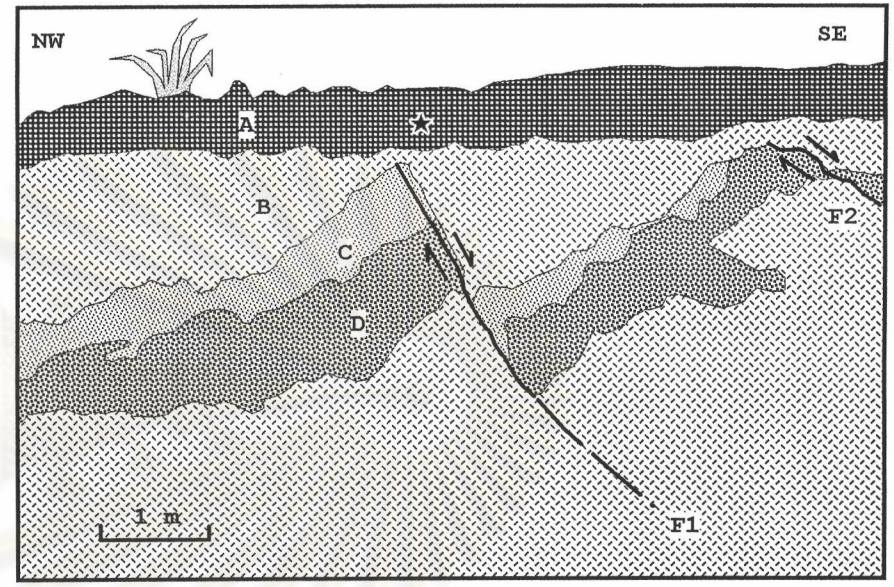


Figure 5.3 View of Ban Thung Charoen outcrop. Detailed description and samplings were done at TC1, TC2, and TC3 sites cutting across by normal faults.



A



B

Explanation

Units

A, reddish brown gravel

B, pale brown silty clay

C, reddish brown sandy gravel

D, pale brown sandy gravel

Symbols

sampling point for dating

contact

observed fault with displacement

inferred fault

Figure 5.4 Stratigraphic expression with normal faulting at the Ban Thung Charoen outcrop (TC1)
A: photograph of the outcrop,
B: outcrop-logging result.

there are NW-dipping with SW-striking and 40° of dip angle. In addition, a horizontal layer which caps on the top of this outcrop is not disturbed by the faults similar to TC1 (Figure 5.5).

Besides, on the NE wall (TC3), this outcrop has observed to be cropped out with dimension of about 10 m x 3.5 m. All sedimentary layers are cut throughout by the main normal fault. In addition, two minor faults have been identified in both upthrown and downthrown blocks. The sedimentary layers in this wall are NW-striking, inclined to SW with approximately 30° (Figure 5.6).

Lithologic units and fault characteristic of the TC1, the TC2, and the TC3 sites are described below.

5.2.1.1 Lithologic Units of the TC1 Site

The TC1 site is composed of four lithologic units. Detailed description is shown in Table 5.1. Four units from top to bottom on the upthrown block of the main fault are briefly described below:

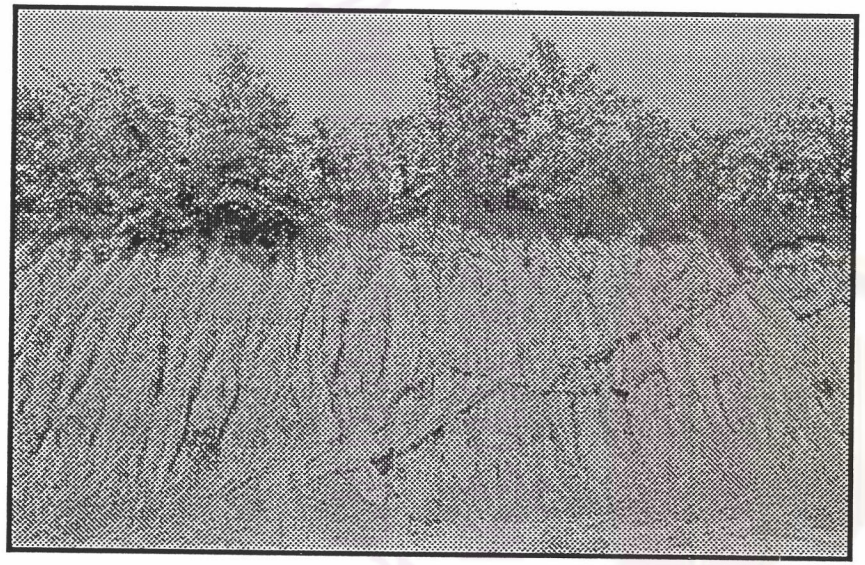
Unit A is reddish brown clayey gravel of colluvial deposits, contained in horizontal layer with a thickness of 0.55 m, found at the top of the outcrop;

Unit B is observed as two layers; the top layer and the bottom, both composed of pale brown silty clay of floodplain deposits. Thickness of the upper layer is at least 2.5 m and that of the lower layer is at least 3.0 m;

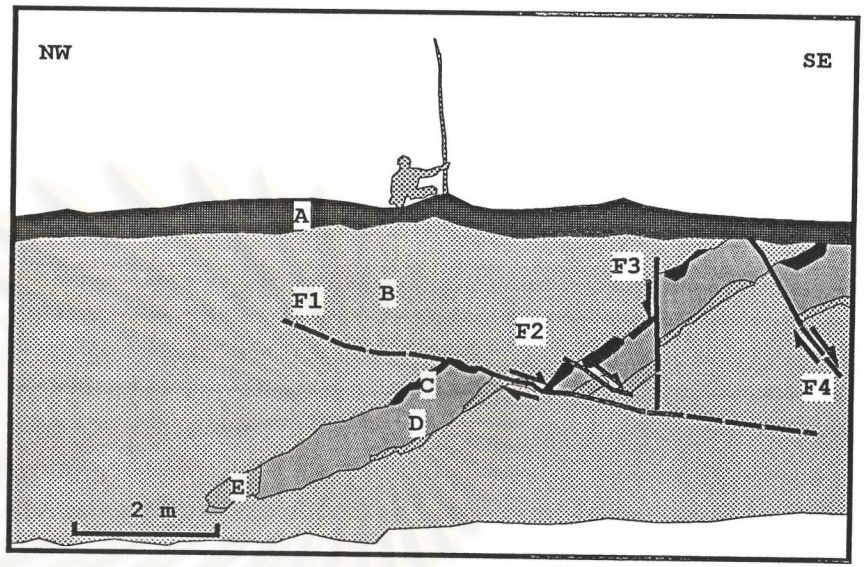
Unit C comprises reddish brown sandy gravel of fluvial deposits with a thickness of 0.80 m; and

Unit D is composed of pale brown sandy gravel, and is about 1.20 m thick.

All samples for TL-dating determination is located at unit A.



A



B

Explanation

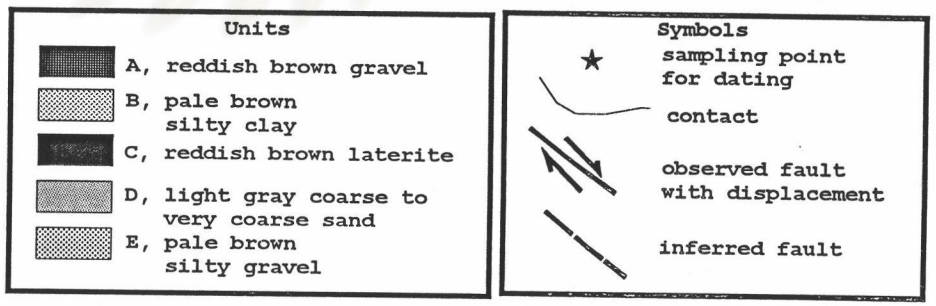
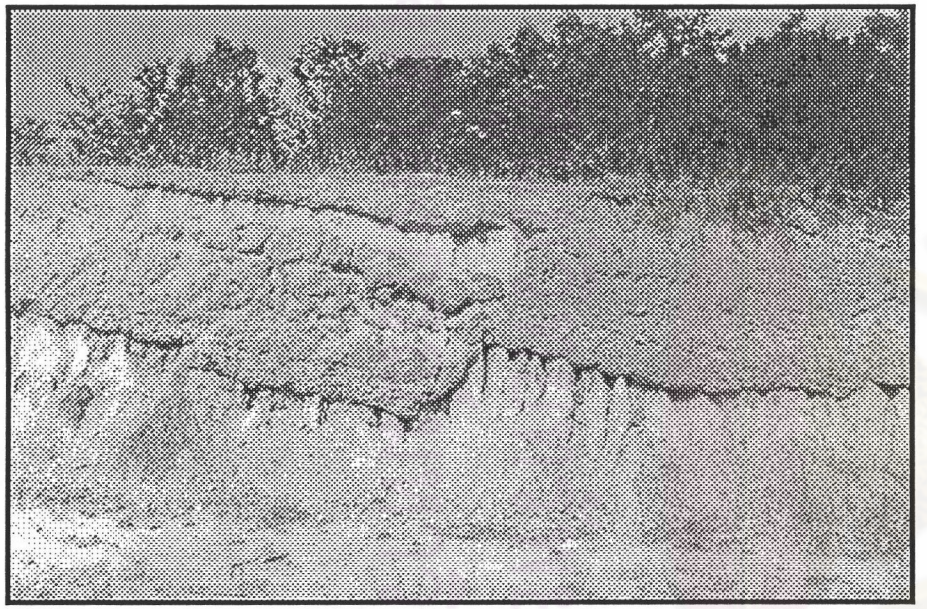


Figure 5.5 Stratigraphic expression with normal faulting at the Ban Thung Charoen outcrop(TC2)
A: photograph of the outcrop,
B: outcrop-logging result.



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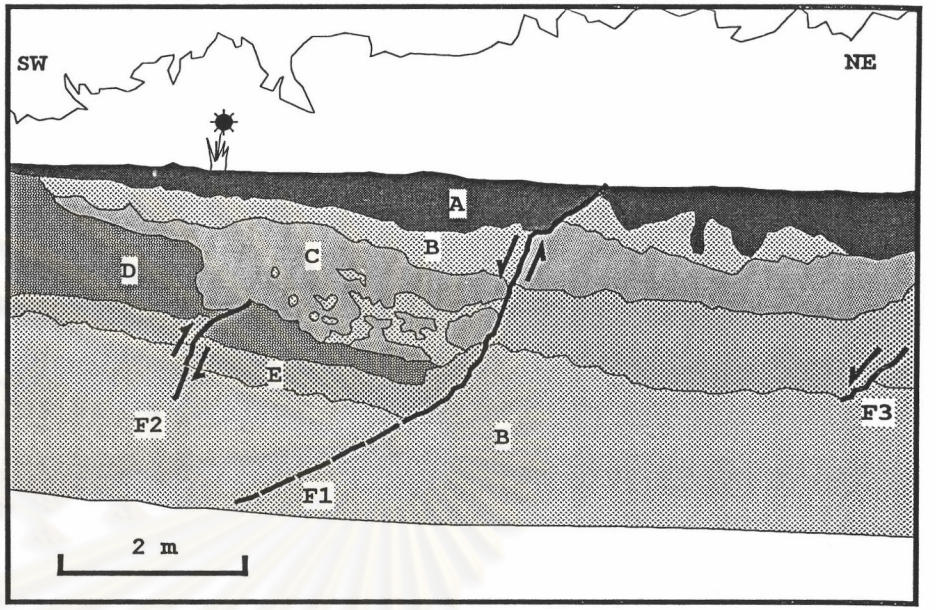


B

Explanation

Units

- A, pale brown gravel
- B, pale brown silty clay
- C, reddish brown sandy gravel
- D, reddish brown sandy gravel
- E, pale brown sandy gravel

Symbols

- sampling point for dating
- contact
- observed fault with displacement
- inferred fault

Figure 5.6 Stratigraphic expression with normal faulting at the Ban Thung Charoen outcrop(TC3)
A: photograph of the outcrop,
B: outcrop-logging result.

5.2.1.2 Geological Structure of the TC1 Site

Fault characteristics

As mentioned earlier, 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 in the center of the outcrop and the minor (F2) is in the left, all of which dip to SE (see Figure 5.4). F1 fault strikes N50E and dip 80° to SE direction with 2.0-m slip. The F2 fault strikes N40E and dip 45° to SE with 0.7-m slip.

Table 5.1 Lithologic units at the TC1 site

Location	Unit	Lithologic description
TC1	A	Reddish brown clayey gravel, clasts of quartz, rock fragments, 3 cm maximum and 0.5 cm medium, angular, poorly sorted, clayey matrix, soft.
	B	Pale brown silty clay, soft.
	C	Reddish brown sandy gravel, clasts of quartz, chert and rock fragments, with 2.5 cm maximum and 0.5 cm medium, subangular to subround, poorly sorted, silty matrix, medium hard.
	D	Pale brown sandy gravel, clasts of quartz, chert and rock fragments, 10 cm maximum and 4 cm medium, angular to subangular, poorly sorted, silty matrix, hard.

5.2.1.3 Lithologic Units of the TC2 Site

Four lithologic units of sediments are observed in this outcrop (see Figure 5.5). Description of individual units from top to bottom of the upthrown block of the main fault(F1) is listed below and on Table 5.2.

Unit A is reddish brown clayey gravel bed of colluvial deposits with 0.55-m thickness.

Unit B consists of two layers; viz. the top and the bottom. Both are pale brown silty clay of floodplain deposits. The upper layer is 2.5 m thick and the lower layer is at least 3.0 m thick.

Unit C comprises reddish brown very coarse sand bed of fluvial deposits with the thickness of 0.1 m.

Unit D is light gray coarse to very coarse sand layer of fluvial deposits, with 0.75 m.

Unit E is composed of pale brown silty gravel bed of fluvial deposits with the thickness of 0.65 m.

This outcrop site is located in the same wall as TC1, thus age of sediments in the top layer of TC1 can be correlated to the same layer of this outcrop.

Table 5.2 Lithologic units at the TC2 site

Location	Unit	Lithologic description
TC2	A	Reddish brown clayey gravel, clasts of quartz and rock fragments, 3 cm maximum and 0.5 cm medium, angular, poorly sorted, clayey matrix, soft.
	B	Pale brown silty clay, soft.
	C	Reddish brown very coarse sand, subangular, fairy sorted, silty matrix, hard.
	D	Ligth gray coarse to very coarse sand, clasts of quartz, rock fragments, subangular to subround, fairly sorted, silty matrix, soft.
	E	Pale brown silty gravel, clasts of quartz, chert and rock fragments, 4 cm maximum and 2 cm medium, subangular to subround, poorly sorted, silty matrix, soft.

5.2.1.4 Geological Structure of the TC2 Site

Fault characteristics

Four normal faults were observed in this outcrop site. All sedimentary layers at the TC2 site are cut by these faults except the top horizontal layer similar to that of TC1 site. The F1 fault strikes N20E and dip 25° to SE direction with 1.90-m slip. The F2 fault strikes N30E and dip 20° to SE direction with 0.25-m slip. The F3 fault is antithetic, strikes S54W and dip 65° to NW direction

with 0.90-m slip. The F4 fault strikes N50E and dip 80° to SE direction with 1.20-m slip.

5.2.1.5 Lithologic Units of the TC3 Site

Five lithologic units of sediments have been observed in this outcrop. Brief description of the units from top to bottom of downthrown block of the main fault is shown below and in Table 5.3.

Unit A is composed of pale brown gravel bed of fluvial deposits, with maximum thickness of 0.75 m.

Unit B comprises pale brown silty clay layer of floodplain deposits, accumulated in two layers; the upper and bottom layers. The upper layer underlies unit A with maximum thickness of 0.40 m and the bottom layer is at least 1.0 m thick.

Unit C is reddish brown sandy gravel bed of fluvial deposits, with maximum thickness of 0.90 m.

Unit D is reddish brown sandy gravel bed of fluvial deposits, with maximum thickness of 0.60 m.

Unit E is composed of pale brown sandy gravel bed of fluvial deposits, thickness of the layer is about 0.30 m.

5.2.1.6 Geological Structure of the TC3 Site

Fault characteristics

A 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 the F1 fault, respectively (see Figure 5.6). The F1 fault is found cutting all layers up to present ground surface, with S85E-striking, SW-dipping, 40° of dip angle, and 1.40 m of slip length. The F2 fault is observed cutting across units C and D layers. The components of the F2 fault are E-striking, SW-dipping, 50° dip angle and 0.30 m fault slip length. The F3 fault is observed at the bottom of the unit E layer. It has a strike of S85W with SW-dipping, 35° dip angle and 0.30 m slip length.

5.2.2 Chom Chaeng1 Outcrop (CC1)

This outcrop is located at the right side of Wat Phra That Cho Hae - Wat Phra That Chom Chaeng asphaltic road, at grid reference of 0627012E and 1999242N. The outcrop is abandoned quarry at the hilltop and exposed with dimension of 25 m x 4 m.

The outcrop was excavated in the SE trend. A normal fault observed at this outcrop cut across sedimentary layers up to the present ground surface. The layers are inclined to NW toward the basin axis with S50W of strike and 15° of dip angle. Five lithologic units of sediments have been investigated (Figure 5.7). Detailed description of the units is listed in Table 5.4, in addition, summarized description is shown in section 5.2.2.1.

Table 5.3 Lithologic units at the TC3 site

Location	Unit	Lithologic description
TC3	A	Pale brown gravel, clasts of quartz, chert and rock fragments, 10 cm maximum and 2 cm medium, subround, poorly sorted, silty clay matrix, soft.
	B	Pale brown silty clay, soft.
	C	Reddish brown sandy gravel, clasts of quartz, chert and rock fragments, 3 cm maximum and 0.5 cm medium, subangular to subround, poorly sorted, silty matrix, hard.
	D	Reddish brown sandy gravel, clasts of quartz, chert and rock fragments, with 10 cm maximum and 3 cm medium, subangular to subround, poorly sorted, silty matrix, hard.
	E	Pale brown sandy gravel, clasts of quartz, chert and rock fragments, with 15 cm maximum and 6 cm medium, subangular to subround, poorly sorted, silty matrix, hard.

5.2.2.1 Lithologic Units of the CC1 Site

Lithologic units from top to bottom of the down thrown block, are described as below:

Unit A is reddish brown sandy gravel bed of colluvial deposits, found in the top layer with the thickness of 0.40 m;

Unit B is pale brown silty clay layer of floodplain deposits, with the thickness of 1.20 m;

Unit C is pale brown sandy gravel bed of fluvial deposits, with the thickness of 0.30 m;

Unit D is pale brown gravelly coarse sand layer of fluvial deposits, with the thickness of 0 .50 m; and

Unit E consists of reddish brown sandy gravel bed of fluvial deposits with 1.5 m of thickness.

Note that, the downthrown block is composed of all units list above, however, on the upthrown block only unit E is observed. Sediments of unit B was collected for TL-dating determination.

Table 5.4 Lithologic units at the CC1 site

Location	Unit	Lithologic description
CC1	A	Reddish brown sandy gravel, clasts of quartz and rock fragments, 3 cm maximum and 0.5 cm medium,angular, poorly sorted, silty matrix, soft.
	B	Pale brown silty clay, soft.
	C	Pale brown sandy gravel, clasts of quartz, chert and rock fragments, 8 cm maximum and 3 cm medium , subround, poorly sorted, silty matrix, soft.
	D	Pale brown gravelly coase sand, clasts of quartz and rock fragments, 2 cm maximum, subround, poorly sorted, silty matrix, medium hard.
	E	Reddish brown sandy gravel, clasts of quartz, chet, rock fragments, 20 cm maximum and 5 cm medium, subround to round, poorly sorted, silty matrix, medium hard.

5.2.2.2 Geological Structure of the CC1 Site

Fault characteristic

A normal fault is observed cutting all layers up to the present ground surface (see Figure 5.7). The fault is N15E-striking, dip-to-southeast, dips to SE direction at 30° with 3.0-m slip length.

5.2.3 Chom Chaeng2 Outcrop (CC2)

This outcrop occupies on the left side between Wat Phra That Choi Hair - Wat Phra That Chom Chang route, opposite to CC1 outcrop, with grid reference of 062726E and 1999253N.

The outcrop is an irregular shape open-pit excavated on a hill slope. Five sets of SE-dipping normal faults are investigated on the SE-trending wall. These faults have caused surface rupture.

Well-defined three sets of splay normal faults (F1, F2 & F3) are observed at the center of SE wall, and the other two normal faults (F4 & F5) are found on the left of the F1, F2 & F3 faults as illustrated in Figure 5.8.

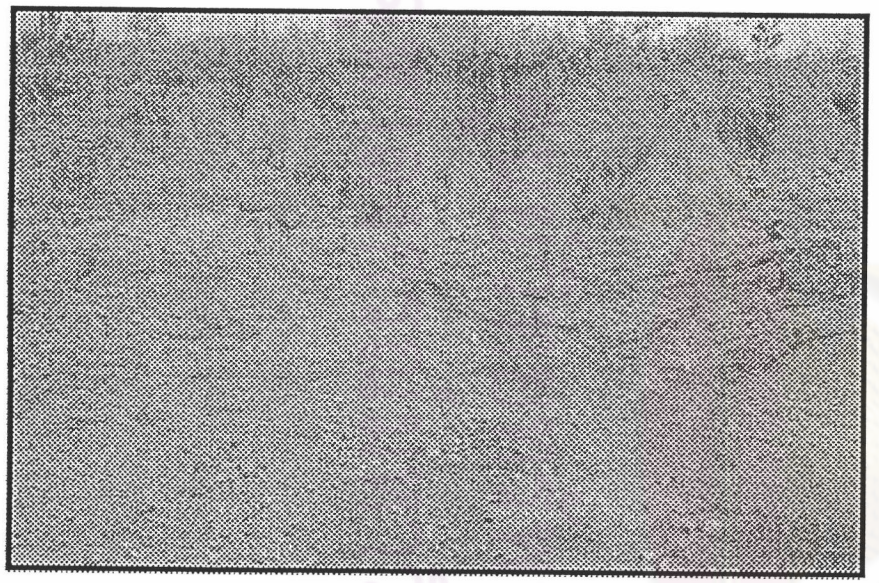
Five lithologic units of sediments have been investigated in this outcrop. They are tilted layers. All layers have SW-striking and dip 30° to the west. Lithologic unit description on the upthrown block of F1 is briefly revealed ranging from the top to the bottom as below. Additionally, detailed description of the units is provided in Table 5.5.

5.2.3.1 Lithologic Units of the CC2 Site

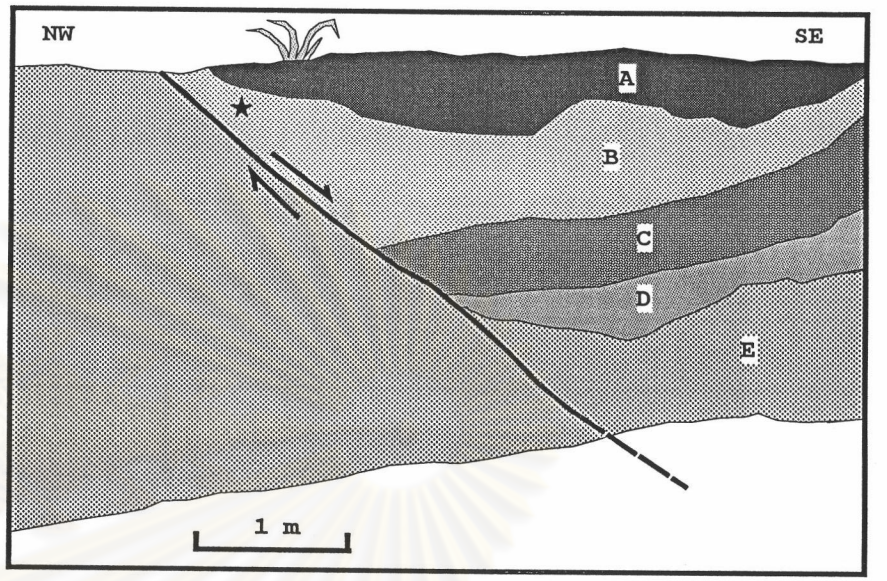
On the upthrown block of the F1 fault, from top to bottom, lithologic units have been described as below:

Unit A is light brown silty clay layer of floodplain deposits, with $CaCO_3$ concretion, with thickness of 1.5 m;

Unit B consists of pale brown silty clay layer of floodplain deposits with $CaCO_3$ concretion, with 2.10 m thick;



A



B

Explanation

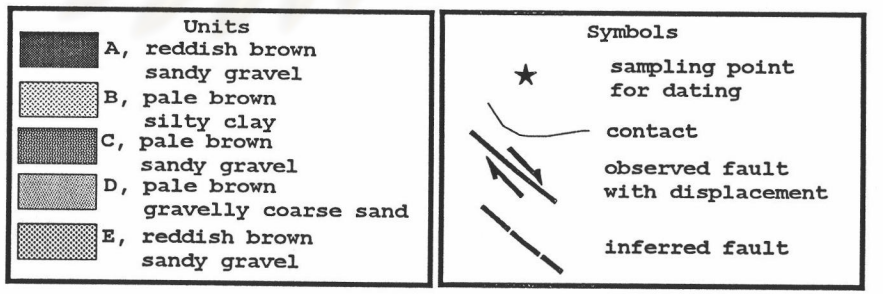


Figure 5.7 Stratigraphic expression with normal faulting at the Chom Chaeng1 outcrop(CC1)
A: photograph of the outcrop,
B: outcrop-logging result.

Unit C is composed of light gray coarse to very coarse sand layer of fluvial deposits, with 0.80 m of thickness;

Unit D is light gray sandy gravel bed of fluvial deposits, with 0.30 m of thickness; and

Unit E is reddish brown silty clay layer of floodplain deposits with $CaCO_3$ concretion, with 2.0 m thick.

Note that, sediments of unit A was selected for TL-dating determination.

5.2.3.2 Geological Structure of the CC2 site

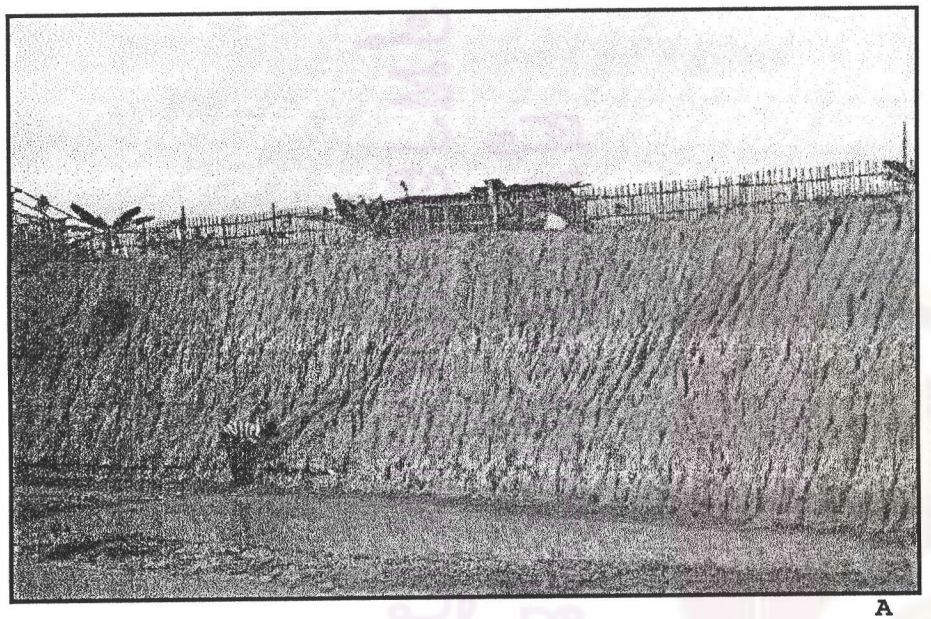
Fault characteristics

Five normal faults was observed in this outcrop (see Figure 5.8). Three faults at the center are characterized as splay faults (F1, F2&F3). The F1 fault is located at the center, the F2 and the F3 faults are located on the dowthrown block of the F1 fault. The F4 and the F5 faults are located on the upthrown block of the F1 fault. According to the F1 fault, it is found cutting across all sedimentary layers up to the present ground surface, with strike N20E, dip 35° to the E direction, and 3.2 m slip.

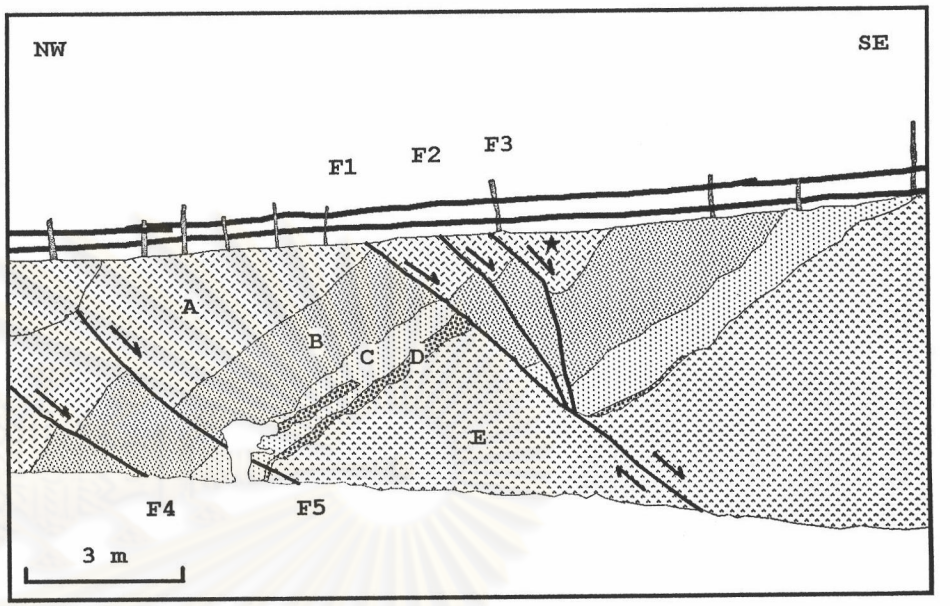
The F2 fault is synthetic on the right of the F1 fault. It is observed cutting two upper most layers up to present ground surface, with strike N25E, dip 45° to the E direction, and 0.70 m slip.

The F3 fault is on the right of the F2 fault, expressed as a normal synthetic to the F1 and the F2 faults, cutting the upper two layers similar to that of the F2 fault. Strike, dip angle, and slip length of the F3 fault is N25E, 55°, and 0.85 m, respectively.

The F4 and the F5 faults were located on the upthrown block of the F1 fault. The F4 fault is found on the left of F5, strikes N40E, dips 25° to SE with slip 0.50 m. The F5 fault strikes N30E, dips 20° to SE, and slip 1.30 m. Both the F4 and the F5 faults are synthetic to the F1, the F2, and the F3 faults.



A



B

Explanation

Units

A, light brown silty clay

B, Pale brown silty clay

C, light gray coarse to very coarse sand

D, light gray sandy gravel

E, reddish brown silty clay

Symbols

sampling point for dating

contact

observed fault with displacement

Figure 5.8 Stratigraphic expression with normal faulting at the Chom Chaeng2 outcrop(CC2)
A: photograph of the outcrop,
B: outcrop-logging result.

Table 5.5 Lithologic units at the CC2 site

Location	Unit	Lithologic description
CC2	A	Light brown silty clay, soft, with $CaCo_3$ concretion on surface.
	B	Pale brown silty clay, soft, $CaCo_3$ concretion on surface.
	C	Light gray coarse to very coarse sand, clasts of quartz, rock fragments, subangular, well sorted, silty matrix, medium hard.
	D	Light gray sandy gravel, clasts of quartz, chert, rock fragments, 1.5 cm maximum and 0.4 cm medium, subangular to subround, poorly sorted, silty matrix, medium hard.
	E	Reddish brown, silty clay, soft.

5.2.4 Ban Pa Daeng1 Outcrop (PDR & PDL)

This outcrop is abandoned quarry on hilltop, located in Ban Pa Daeng area at grid reference 062277E and 200007N. The quarry was excavated in NW trend, with dimension of about 50 m x 5 m.

Two normal faults are investigated in this outcrop on the right (PDR) and the left (PDL) margins of the outcrop (Figure 5.9). The PDR site is contained a NW-dipping normal fault cutting across tilting sedimentary layers. However, two top nearly horizontal layers have not disturbed by this fault (Figure 5.10). The PDL site comprises a SE-dipping normal fault cutting across tilting sedimentary layers but two top roughly horizontal layers are unfaulted similar to that of the PDR site (Figure 5.11).

Lithologic unit of sediments and fault characteristic descriptions of both the PDR and the PDL sites are shown below, and in Tables 5.6 and Table 5.7, respectively.

5.2.4.1 Lithologic Units of the PDR Site

Five lithologic units of sediments were observed in this outcrop, from top to bottom of downthrown block, the units are briefly described below:

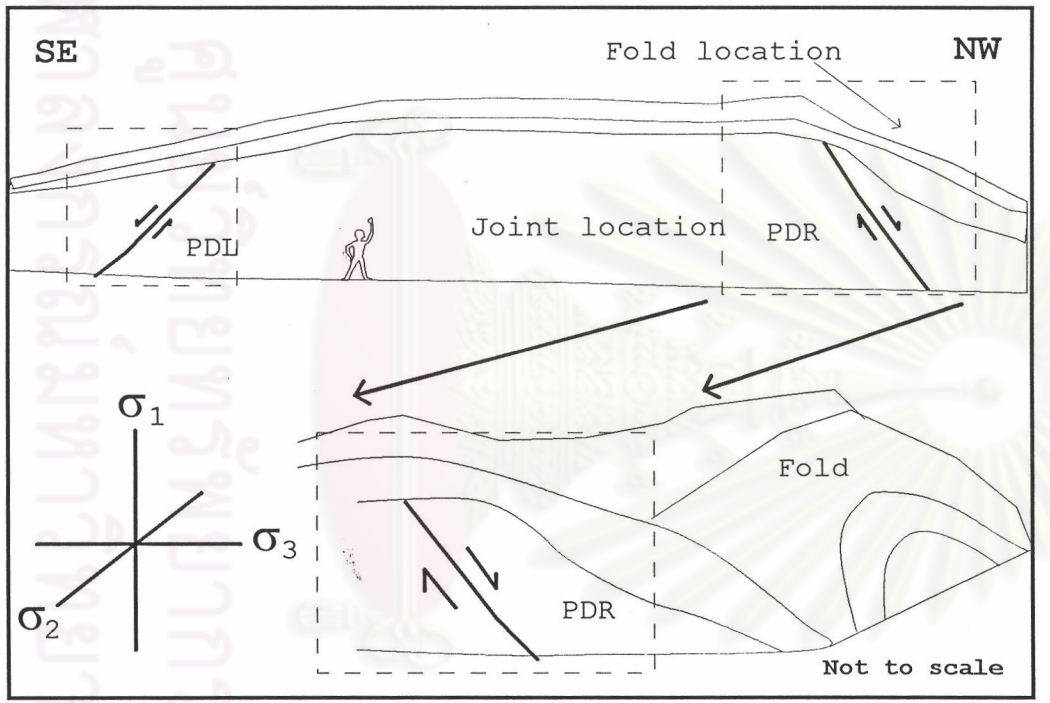
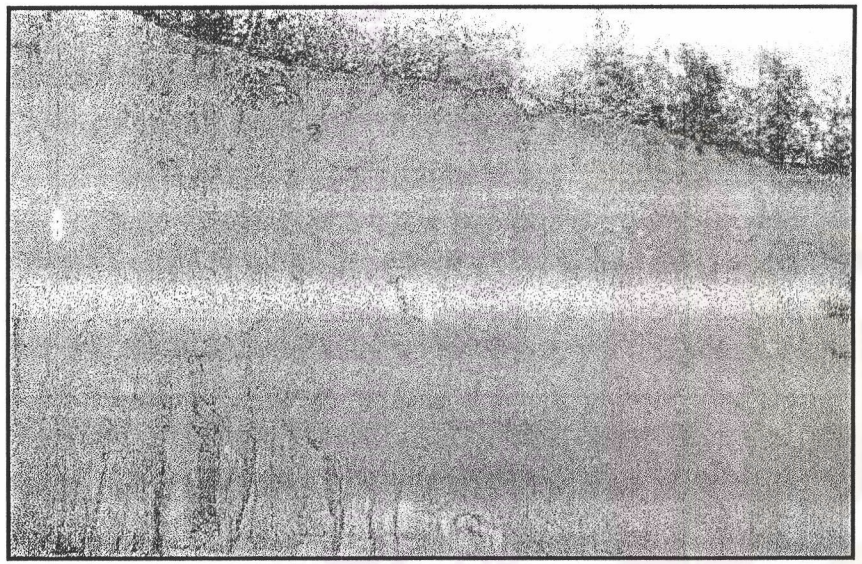
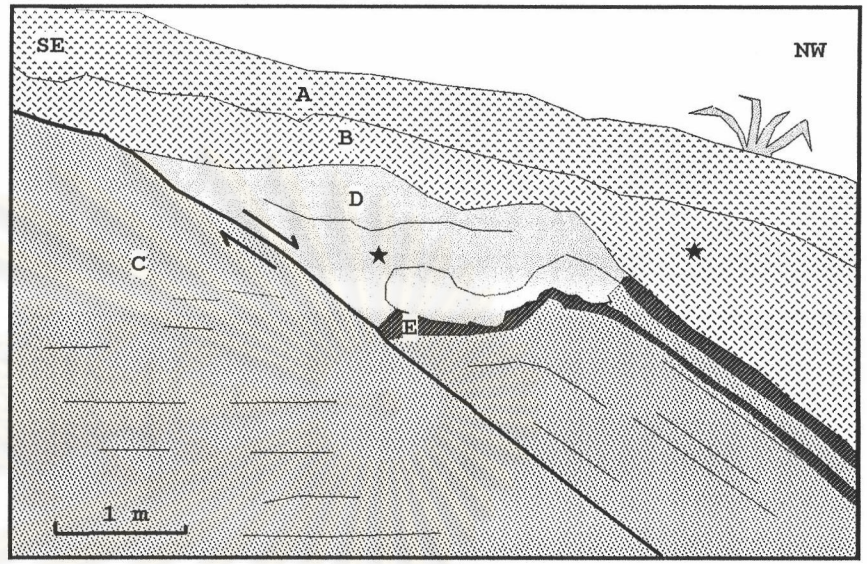


Figure 5.9 View of Ban Pa Deang1 outcrop. The outcrop was divided into two parts; the right side (PDR) and the left side (PDL), for detailed description.



A



B

Explanation

Units

A, top soil

B, light gray with mottle brown silty clay

C, pale brown silty clay

D, pale brown medium sand

E, reddish brown very coarse sand

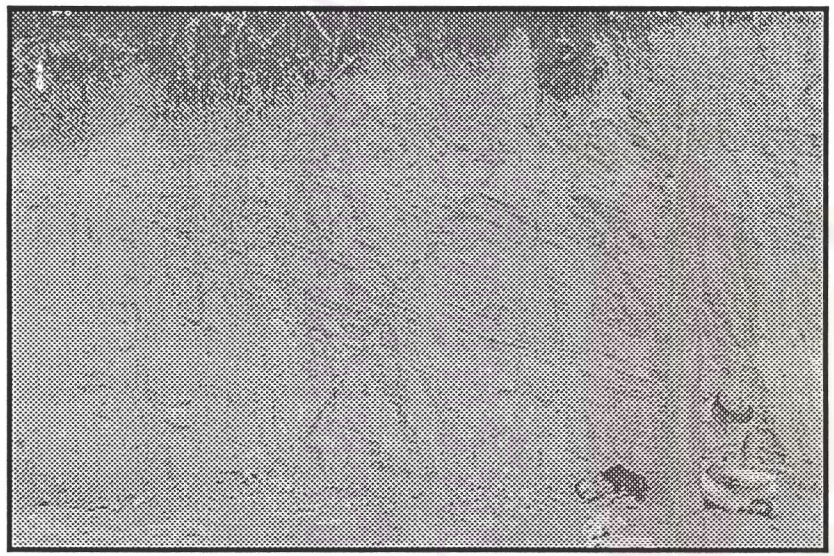
Symbols

sampling point for dating

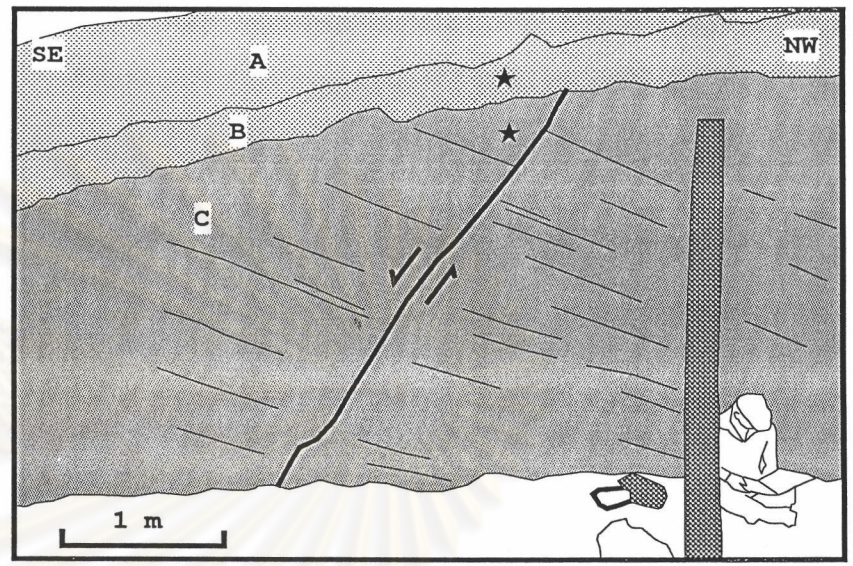
contact

observed fault with displacement

Figure 5.10 Stratigraphic expression with normal faulting at the Ban Pa Daeng1 outcrop(PDR)
A: photograph of the outcrop,
B: outcrop-logging result.

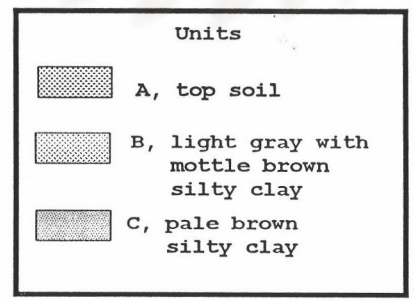


A



B

Explanation



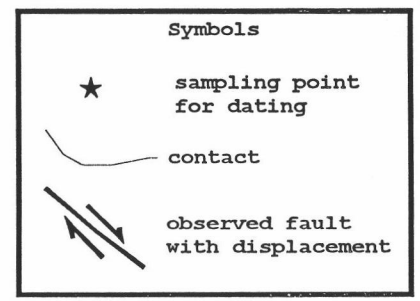


Figure 5.11 Stratigraphic expression with normal faulting at the Ban Pa Daeng1 outcrop(PDL)
A: photograph of the outcrop,
B: outcrop-logging result.

Unit A is topsoil layer with 0.5 m of thickness;

Unit B is light gray with mottle brown silty clay layer of floodplain deposits, with 0.5 m of thickness;

Unit C is pale brown silty clay layer of floodplain deposits, with thickness of 2.0 m. This layer inclins to NW direction with strike S15W and dip angle 45°;

Unit D is pale brown medium sand layer, and traces of some gravel of colluvial deposits; and

Unit E comprises reddish brown very coarse sand layer, with 0.10 m of thickness.

All samples for TL-dating were collected from units B and D.

Table 5.6 Lithologic units at the PDR site

Location	Unit	Lithologic description
PDR	A	Topsoil, reddish brown, soft.
	B	Light gray with mottle brown silty clay, soft.
	C	Pale brown silty clay, medium hard.
	D	Pale brown medium sand, trace gravel, clasts of quartz and rock fragments, 1 cm maximum, subround, well sorted, silty matrix, medium hard.
	E	Reddish brown very coarse sand, medium hard.

5.2.4.2 Geological Structure of the PDR Site

Fault characteristic

A normal fault was observed cut across units C, D and E and died out below unit B (see Figure 5.10). The fault is found strike S30W, dip 30° to NW direction, and slip 3.0 m.

Joint characteristics

Two main sets of joints were investigated including NE-trending and SE-trending sets (Figure 5.12). These joints are found concentrated on the upthrown block of the fault. Note that joint analysis is revealed in section 5.3.

Fold charateristic

An open fold shape had found located on the hanging wall of the normal fault. Fold orientation is defined as upright and horizontal fold (Fletcher, 1978)(Figure 5.13). An axial plane attitude is 185°/05°, left and right limb attitudes are 05°/35° and 180°/40°, respectively. An interlimb angle of this fold is 100°. Sedimentary unit contained in the fold geometry consists of unit C.

5.2.4.3 Lithologic Units of the PDL Site

Three lithologic units of sediments were identified in the PDL site. From top to bottom (see Figure 5.11), lithologic units are cited in Table 5.7 and below:

Unit A is reddish brown topsoil layer with 0.5 m of thickness;

Unit B comprises light gray with mottle brown silty clay layer of floodplain deposits, with thickness of 0.5 m; and

Unit C consists of pale brown silty clay layer of floodplain deposits, with 3.0 m thick.

All sedimentary samples for TL-dating were collected from units B and C.

5.2.4.4 Geological Structure of the PDL Site

Fault characteristic

A normal fault was found cut across unit C, but not truncated units A and B. The fault is strike N40E, dip 65° to SE direction, and slip 0.40 m.

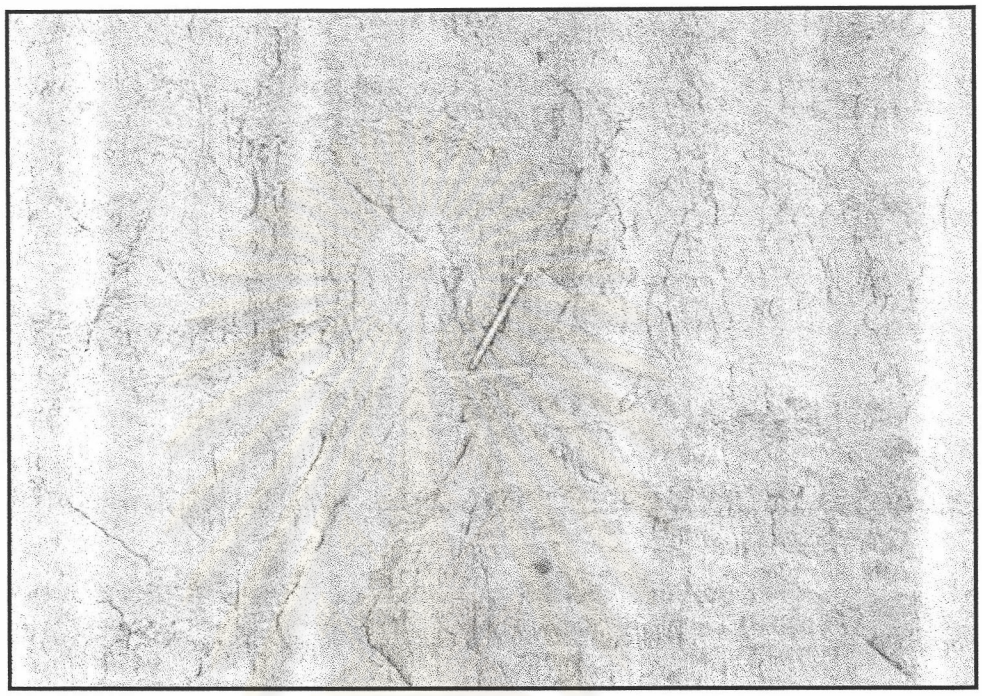
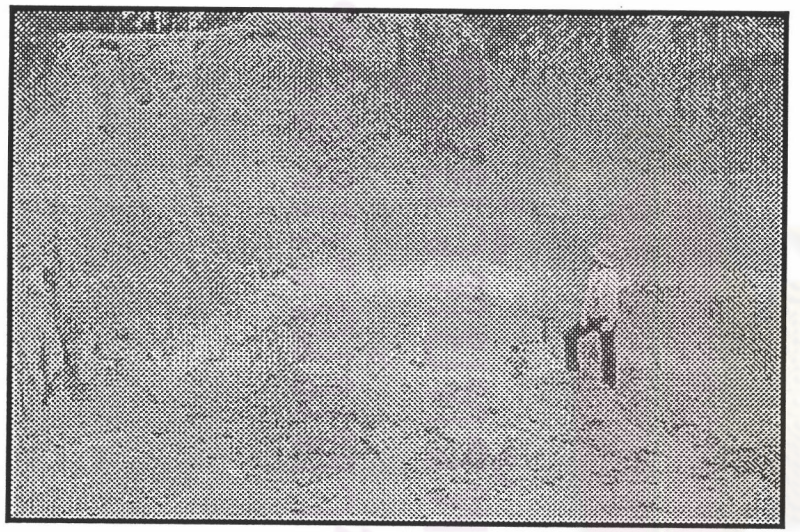
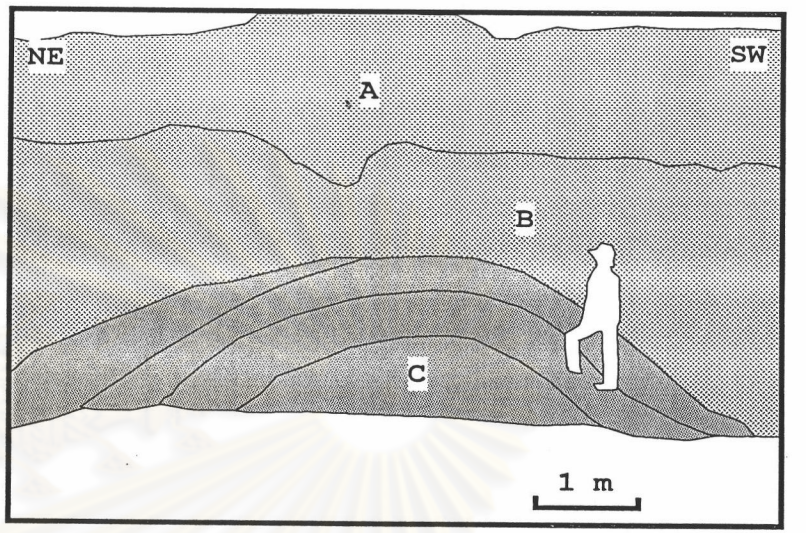


Figure 5.12 Photograph showing part of joints observed at Ban Pa Daeng1 outcrop.



A



B

Units

A, top soil

B, light gray with mottle brown silty clay

C, pale brown silty clay

Figure 5.13 Fold Characteristic observed at Ban Pa Deang1 outcrop
A : photograph of the outcrop,
B : outcrop logging.

Table 5.7 Lithologic units at the PDL site

Location	Unit	Lithologic description
PDL	A	Topsoil, reddish brown, soft.
	B	Light gray with mottle brown silty clay, medium hard.
	C	Pale brown silty clay, soft.

5.2.5 Ban Pa Daeng2 Outcrop (PD2)

This outcrop is located between Ban Pa Daeng1 and Garbage landfill outcrops. It is well-exposure abandoned quarry cut across by normal fault (Figure 5.14). Exposed face of the outcrop is in SE-NW trend. Grid reference of the outcrop is 0627544E and 2000378N. The outcrop dimension is 15 m x 5 m.

5.2.5.1 Lithologic Units of PD2 Site

Four layers of sedimentary units were observed. All layers are clearly found tilted between 30°-40° to the NW with strike 195°. Lithologic units in this outcrop is provided in Table 5.8 and below:

Unit A is pale brown sandy gravel bed of fluvial deposits with 3.0 m thick;

Unit B contains brown sandy gravel bed of fluvial deposits, with thickness of 0.40 m;

Unit C is brown gravelly coarse sand layer of fluvial deposits, with 0.25 m of thickness; and

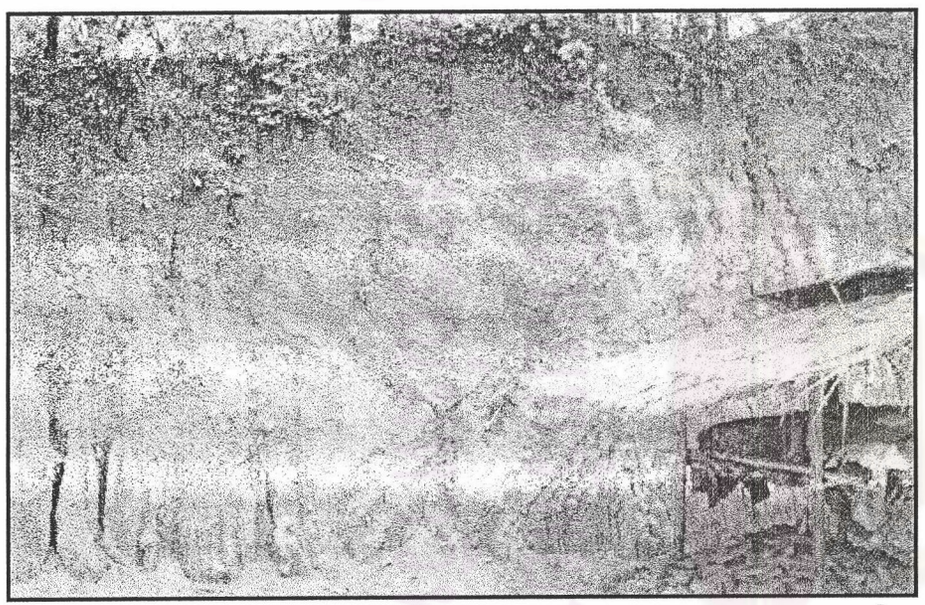
Unit D consists of pale brown silty clay layer of floodplain deposits, with 4.5 m of thickness.

All sampling locations of fault-related sediments are in the upper part of unit A and the lower part of Unit D.

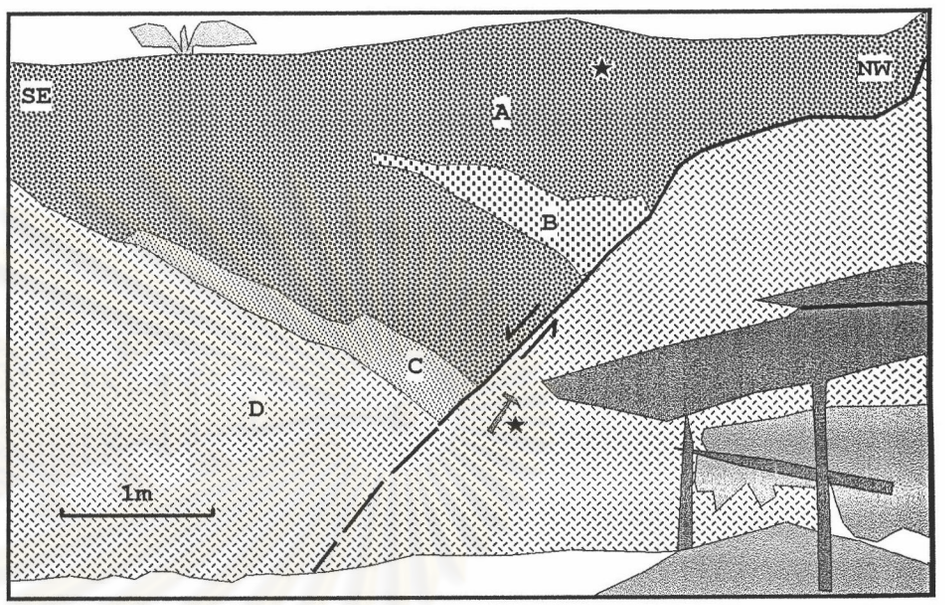
5.2.5.2 Geological Structure of the PD2 Site

Fault characteristic

A clearly defined normal fault is cut across all sedimentary units up to the present ground surface. Fault



A



B

Explanation

Units

A, pale brown sandy gravel

B, brown sandy gravel

C, brown gravelly coarse sand

D, pale brown silty clay

Symbols

sampling point for dating

contact

observed fault with displacement

inferred fault

Figure 5.14 Stratigraphic expression with normal faulting at the Ban Pa Daeng2 outcrop(PD2)
A: photograph of the outcrop,
B: outcrop-logging result.

strike N10E, dip 30° to east direction, and slip 3.10 m (see Figure 5.14). On the hangingwall of the fault contains all sedimentary units mentioned in section 5.2.5.1 whereas the footwall is found only unit D.

Table 5.8 Lithologic units at the PD2 site

Location	Unit	Lithologic description
PD2	A	Pale brown, sandy gravel, clasts of quartz, chert, rock fragments, 2.5 cm maximum and 1.5 cm medium, subround, poorly sorted, silty matrix, soft.
	B	Brown, sandy gravel, clasts of quartz, chert, rock fragments, 9 cm maximum and 3 cm medium, subround, poorly sorted, silty matrix, medium hard.
	C	Brown gravelly coarse sand, clasts of quartz chert and rock fragments, 1 cm maximum, subround, well sorted, silty matrix, medium hard.
	D	Pale brown silty clay, soft, with $CaCo_3$ concretion.

5.2.6 Garbage Landfill Outcrop (GL)

This outcrop is located in abandoned quarry at the landfill site of Ban Pa Daeng area. Grid reference is 0627991E and 2001180N. Outcrop dimension is 7.0 m x 5.0 m.

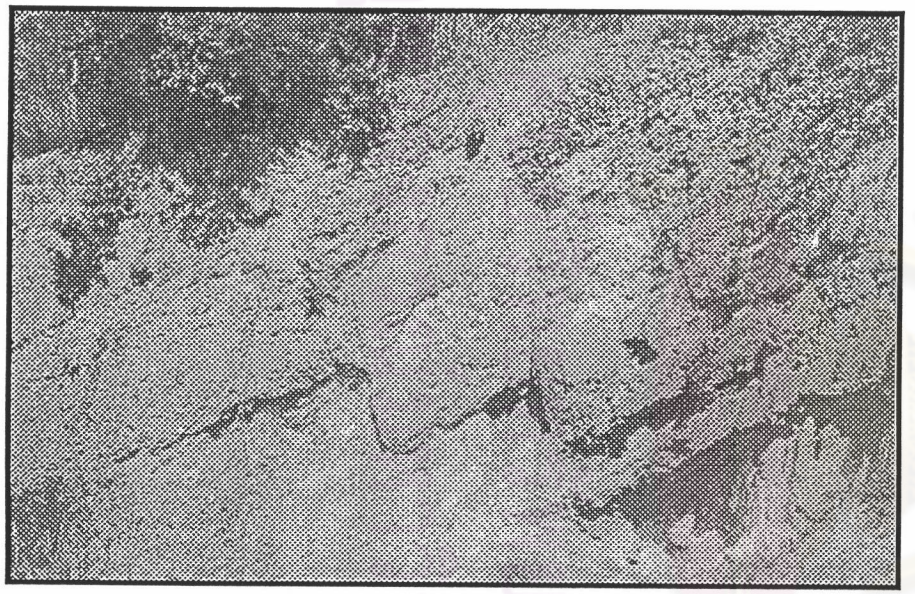
The outcrop was excavated in NW-SE trend. It consists of sedimentary layers that incline 35° to NW direction. Two sets of SE-dipping normal faults were observed, including the left fault (F1) and the right fault (F2), cutting across sedimentary layers up to the present ground surface.

Lithologic units and fault characteristic descriptions are listed below. In addition, detailed descriptions of lithologic units are also shown.

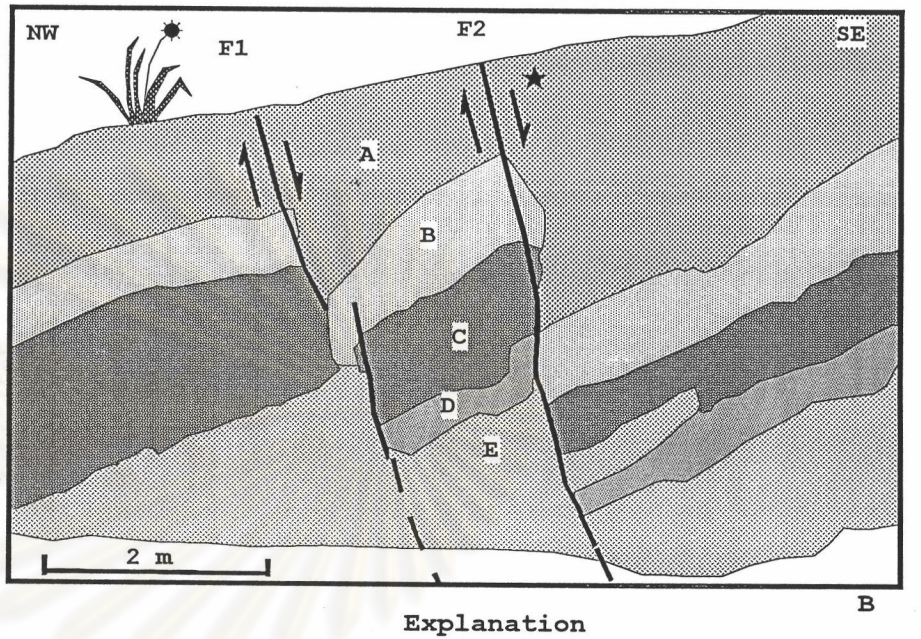
5.2.6.1 Lithologic Units of the GL Site

Five lithologic units of sediments were observed in this outcrop (Figure 5.15). From top to bottom on the downthrown block of the F1 fault, lithologic units are described in Table 5.8 and below:

Unit A is brown sandy gravel bed of fluvial deposits, with 2.0 m of thickness;



A



B

Explanation

Units

A, brown sandy gravel

B, reddish brown gravelly coarse sand

C, pale brown gravel

D, pale brown coarse sand

E, pale brown silty clay

Symbols

sampling point for dating

contact

observed fault with displacement

inferred fault

Figure 5.15 Stratigraphic expression with normal faulting at the Garbage Landfill outcrop(GL)
A: photograph of the outcrop,
B: outcrop-logging result.

Unit B is reddish brown gravelly coarse sand layer of fluvial deposits, with 0.50 m of thickness;

Unit C is pale brown gravel bed of fluvial deposits, with 0.70 m of thickness.

Unit D is pale brown coarse sand layer of fluvial deposits, with 0.20 m of thickness.

Unit E is pale brown silty clay layer of foodplain deposits, with thickness of 1.0 m.

All samples for TL-dating determination were collected from unit A.

Table 5.9 Lithologic units at the GL site

Location	Unit	Lithologic description
GL	A	Brown sandy gravel, clasts of quartz, chert and rock fragments, 15 cm maximum and 4 cm medium, well round, poorly sorted, silty clay matrix, soft.
	B	Reddish brown gravelly coarse sand, clasts of quartz, chert and rock fragments, 3 cm maximum, subround to round, poorly sorted, silty matrix, medium hard.
	C	Pale brown gravel, clasts of quartz, chert and rock fragments, 15 cm maximum and 3 cm medium, round to well round, poorly sorted, silty sand matrix, medium hard.
	D	pale brown coarse sand, clasts of quartz chert and rock fragments, well sorted, silty matrix, medium hard.
	E	Pale brown silty clay, soft.

5.2.6.2 Geological Structure of the GL Site

Fault characteristics

Two synthetic normal faults were identified in this outcrop cutting across the present ground surface. The faults are composed of the left fault (F1) and the right fault (F2)(see Figure 5.15). The F1 fault strikes N50E, dips 45° to SE direction and slips 1.10 m. The F2 fault strikes N35E, dips 70° to SE direction and slips 1.50 m.

5.3 Determination of Stress Axis Orientation Using Geological Data

5.3.1 General Background

Basically, stress accumulation in both around or within intraplate and interplate regions is the result of tectonic movement. The major tectonic episodes have changed geological structures into various forms and caused some discontinuities in the earth. Orientations of stress axis activated by individual tectonic events are of interest in order to compare stress field orientation of each tectonic events whether or not have changes through time.

State of stress in the brittle upper crust is characterized as three principle stresses; the maximum compressional stress (σ_1), the intermediate stress (σ_2) and the minimum (σ_3). Figure 5.16 illustrates common three types of conjugate fault systems with principle stresses in both block diagrams and stereograms; (a) conjugate normal faults, (b) conjugate reverse faults and (c) conjugate strike-slip faults. Principle stress axes are indicated by direction and magnitude of stresses ($\sigma_1 > \sigma_2 > \sigma_3$). However, natural in-situ stress fields in the brittle upper crust are not only generated from tectonic movement but also from other sources, for instance, thermal effects and local topography and superficial ground movements (Becker et al., 1990). In addition, stress fields can be divided into two episodes depending on geological time scale; paleostress and neostress. Table 5.10 summarizes two methods (geological and geophysical) to determine paleostress and neostress fields (Steward & Hancock, 1994).

Determination on neotectonic stress axis orientation method is mainly derived from both geological and geophysical data. However, the most broadly used method to carry out contemporary stress orientation and relative magnitudes is geological method which fault slip data collected from active or other neotetonic fault is analyzed (Stewart & Hancock, 1994). Nevertheless, the most powerful way to conduct contemporary stress axis orientation remains focal mechanisms analysis of geophysical method (Stewart & Hancock, 1994). In contrast, paleotectonic stress axis orientation can be observed using only geological data.

Noteworthy, in this section, stress axis orientation has determined by using only geological method, since

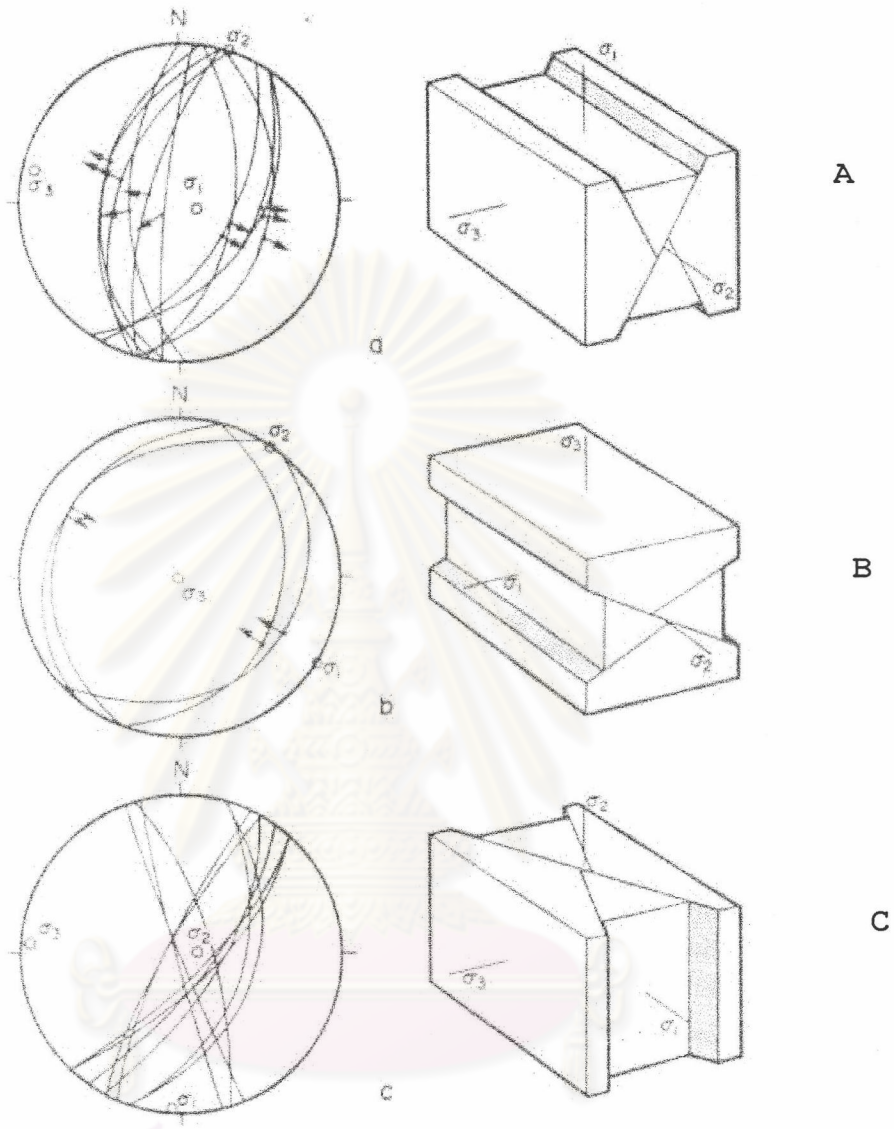


Figure 5.16 Model of normal(A), reverse(B) and strike-slip (C) faulting associated with maximum(σ_1), moderate(σ_2) and minimum (σ_3) principal stresses(after Angelier, 1994).

earthquake focal mechanisms based on the geophysical method have been already cited in chapter II.

Table 5.10. Neotectonic and paleotectonic stress determination methods from geophysical and geological data (after Stewart & Hancock, 1994).

Determination of contemporary stress axis orientations and/or magnitudes
Geophysical/geodetic
-earthquake focal mechanisms (fault plane solutions)
-borehole breakout elongation directions
-hydraulic fracturing (hydrofracture) tests
-in situ stress measurements
(1) strain relief (overcoring, e.g. the 'doorstopper' and triaxial methods)
(2) loading methods (e.g. the flatjack technique)
-ground-or satellite-based geodetic surveying
Geological/geomorphological
-attitudes of Quaternary faults on which the orientation and sense of the slip vector is known from one or more of the following: 1 striae or other lineations, (2) the displacement of geological markers, or (3) the offset of landforms
-axial trends of fold ahead of blind thrusts
-alignments of active volcanic vents, fissures and dykes
-alignments of active fissures and ridges in Quaternary travertine deposits
-attitudes of neotectonic joints formed at shallow crustal depths
-long axes of quarry-floor buckles and other pop-ups
-offset boreholes
Detrmination of paleostress axis orietation and /or magnitudes
Geological
-fault and brittle shear zones on which the orientation of a slip vector is known from one or more of the following: (1) a lineation, (2) the offset of geological markers, or (3) an array of en echelon crack or veins within a shear zone
-aligned dykes in swarms
-roughly coeval sets of stylolitic seams and veins within the same volume of rock
-system of single or orthogonal extention joints or systems of conjugate hybrid joints

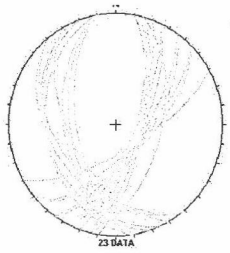
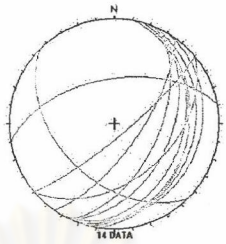
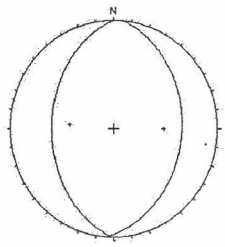
5.3.2 The Results of Stress Axis Orientation Analysis

Four groups of geological data have been collected from the field area in order to analyze and reconstruct stress axis orientation. These data include a group of fault data, two groups of joint data and one orientation of fold data. 14 data of normal faults were collected from six high terrace outcrops, which mentioned in section 5.2. The first group of joint data is composed of

23 joint data collected from Ban Pa Daeng1 outcrop. Another group of joint data was measured from Triassic siltstone, exposed by road cut at the right abutment of Mae Man reservoir nearby Ban Thung Charoen outcrop. Finally, fold data was collected from a folding exposure in Ban Pa Daeng1 outcrop.

All of these data are plotted on lower hemisphere stereogram. As a result, according to fault analysis, tensional axis (T-axis) was found in the WNW-ESE trending and compressional axis (P-axis) is in NNE-SSW trending. Almost all fault data plotted on stereogram are correspondence, excepted two data are inconsistent. Major strike from this analysis is found about N25E. For joint analysis of Ban Pa Daeng1 outcrop, T-axis lies almost in east-west trending. Major strikes are found about N35E and S30E. Besides, joint analysis of Mae Man outcrop shows approximately north-south extension. Lastly, fold limp attitudes reveals that T-axis is in the N-S trending. All of the results are summarized in Table 5.11.

Table 5.11 Stereograms of joints, faults, and fold.

Joint plane	Fault plane	Fold limb
 Extension: E-W Location: Ban Pa Daeng1 outcrop	 Extension: ESE-WNW Location: Six outcrops along southeastern segment	 Extension: N-S Location: Ban Pa Daeng1 outcrop
 Extension: N-S Location: Right abutment of Mae Man reservior		