ธรณีแปรสัณฐานยุคใหม่ของระบบรอยเลื่อนเถิน บริเวณแอ่งลำปาง ภาคเหนือของประเทศไทย

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NEOTECTONICS OF THE THOEN FAULT SYSTEM, LAMPANG BASIN, NORTHERN THAILAND

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วิริยะ ด่านไพบูลย์ผล: ธรณีแปรสัณฐานยุคใหม่ของระบบรอยเลื่อนเถิน บริเวณแอ่งลำปาง ภาคเหนือของประเทศไทย. (NEOTECTONICS OF THOEN FAULT SYSTEM, LAMPANG BASIN, NORTHERN THAILAND) อ. ที่ปรึกษา : รศ. ดร. ปัญญา จารุศิริ, อ. ที่ปรึกษาร่วม : ดร. ภาสกร ปนานนท์, **101**หน้า. ISBN 974-14 -3372 -7.

ธรณีแปรสัณฐานยุคใหม่ของรอยเลื่อนเถินซึ่งอยู่ทางตอนเหนือของประเทศไทยยากที่จะสามารถทำความเข้าใจได้ง่าย เนื่องจากเครื่องมือและวิธีการที่ใช้ในการสำรวจทางธรณีวิทยาส่วนใหญ่นั้นไม่สามารถอธิบายลักษณะโครงสร้างทางธรณีแปรสัณฐานยุคใหม่และไม่สามารถบ่งบอกถึงรอยเลื่อนมีพลังในหินฐานของแอ่งสะสมตะกอนมหายุคซีโนโซอิกได้ รอยเลื่อนส่วนใหญ่นี้อยู่บริเวณขอบทางด้านตะวันออกของแอ่งสะสมตะกอนมหายุคซีโนโซอิก ซึ่งได้เคยมีการประมาณการจากการแปรความหมายจากวิธีโทรสัมผัสระยะไกลในบริเวณกว้างมาบ้างแล้ว ส่วนด้านการแปรความหมายโทรสัมผัสขั้นรายละเอียดและข้อมูลที่จำเป็นในภาคสนามนั้นยังมีไม่มากนัก ดังนั้นการอธิบายถึงลักษณะของแรงเค้นธรณีแปรสัณฐานในหินฐานที่มีความสอดคล้องกับธรณีแปรสัณฐานยุคใหม่ที่มีการเคลื่อนที่ในมหายุคซีโนโซอิกยังมิอาจที่จะเข้าใจได้ชัดเจน

พื้นที่ศึกษาวิจัยครั้งนี้อยู่ในบริเวณรอยเลื่อนเถินซึ่งวางตัวในแนวเหนือ-ตะวันออกเฉียงเหนือซึ่งยาวประมาณ 120 กิโลเมตร พาดผ่านแอ่งสะสมตะกอนแม่เมาะ แอ่งลำปางและแอ่งเถิน วิธีที่ใช้ในการศึกษาวิจัยครั้งนี้ประกอบด้วย 3 วิธีการหลัก คือ การศึกษาทางด้านโทรสัมผัสระยะไกล การศึกษาทางด้านศิลาวรรณา และการศึกษาลักษะโครงสร้างใต้ชั้นตะกอนระดับตื้น ซึ่งจากการศึกษาวิธีทั้ง 3 วิธีข้างต้น ผลที่ได้มาสามารถอธิบายลักษณะโครงสร้างทางด้านธรณีแปรสัณฐานยุคใหม่ของการศึกษาครั้งนี้ได้เป็นอย่างดี จากผลการวิเคาะห์แนวเส้นโครงสร้างอย่างละเอียดได้นำไปสู่การได้มาของหลักฐานทางด้านธรณีแปรสัณฐาน หลักฐานการเลื่อนตัวของรอยเลื่อนในตะกอนยุคควอเทอร์นารีและตัวอย่างหินที่เหมาะสมใช้สำหรับการทำการวิเคราะห์ศิลาวรรณา และท้ายที่สุดคือการได้มาของพื้นที่เหมาะสม และน่าสนใจสำหรับการสำรวจทางด้านการหยั่งลึกเรดาร์(GPR) ทั้งหมด 6 พื้นที่สำรวจ

จากผลการศึกษาทั้งหมดสามารถนำมาสร้างแบบจำลองโครงสร้าง และพบว่ารอยเลื่อนเถินนี้สามารถจัดให้เป็น **รอยเลื่อนธรณีแปรสัณฐานยุคใหม่** ซึ่งโครงสร้างอายุอ่อนที่สุดเกิดขึ้นหลังจากการชนกันของแผ่นอินเดียกับแผ่นยูเรเซียประมาณ 40 ล้านปีมาแล้ว รอยเลื่อนระนาบเอียงแบบซ้ายเข้าซึ่งวางตัวแนวตะวันออกเฉียงเหนือ-ตะวันตกเฉียงใต้ที่ได้ผลมาจากแบบจำลองโครงสร้างเป็นรอยเลื่อนที่สอดคล้องกันกับกระแสธรณีแปรสัณฐานในปัจจุบัน และรอยเลื่อนไม่ปกติที่พบในชั้นตะกอนระดับตื้นใต้พื้นผิวมีมุมเอียงปรากฏไปทางด้านตะวันตกเฉียงเหนือประมาณ 12-20 องศา นั้นถูกตรวจจับได้อย่างชัดเจนจากเครื่องหยั่งลึกเรดาร์ (GPR) ในแอ่งตะกอนมหายุคซีโนโซอิก เป็นตัวชี้บอกอย่างชัดเจนว่ามีกระบวนการธรณีแปรสัณฐานเกิดขึ้นกระแสของธรณีแปรสัณฐานปัจจุบัน ซึ่งการเคลื่อนตัวเหล่านี้ตรงกับคำนิยามของ "**รอยเลื่อนมีพลัง**" และในการศึกษาครั้งนี้ได้นำเสนอขั้นตอนและวิธีการที่เหมาะสมสำหรับการศึกษารอยเลื่อนมีพลังไว้ด้วย

ภาควิชา..............ธรณีวิทยา........ ลายมือชื่อนิสิต..

สาขาวิชา.............ธรณีวิทยา........ ลายมือชื่ออาจารย์ที่ปรึกษา..

ปีการศึกษา...........2548............... ลายมือชื่ออาจารย์ที่ปรึกษาร่วม..

4572497723 : MAJOR GEOLOGY

KEY WORD: NEOTECTONICS/ THOEN FAULT ZONE/ LAMPANG BASIN/ TECTONIC REGIME

VIRIYA DANPHAIBOONPHON: NEOTECTONICS OF THOEN FAULT SYSTEM, LAMPANG BASIN, NORTHERN THAILAND. THESIS ADVISOR : ASSOCIATE PROFESSOR PUNYA CHARUSIRI, Ph.D., THESIS COADVISOR : DOCTOR PASSAKORN PANANONT,101 pp. ISBN 974-14-3372 -7.

Neotectonics of Thoen fault zone in the northern Thailand is far from understood, mainly because of the poor tools geologists have in assessing neotectonic structures and determining active faults in basement rocks of the Cenozoic basin. The major faults along the eastern edge of the Cenozoic basin were previously estimated from imagery remote-sensing interpretation on regional scale and no detail of remote-sensing and field based data are investigated. The behavior of the tectonic stress field in basement rocks and its relation to the neotectonics in Cenozoic basins are within poorly understood.

The study area is located within the N-NE striking Thoen fault zone, with a total length of about 120 km cross the Mae Moh, Lampang, and Thoen basins. The three main methods of study, remote-sensing study, petrographic study, and subsurface study, show good results for determining the neotectonic structure in the study area. Detailed result from lineament analysis had lead to the good field evidence of morphotectonic and Quaternary faulting Rock sampling for petrographic analysis, and six exploratory locations for ground penetrating radar (GPR) were performed subsequently using the results of field surveys.

The overall results lead to the reconstruction of evolution model and the Thoen fault system is defied as **Neotectonic fault zone** which is the youngest structure formed since 40 Ma age after Indian – Eurasian collision. The NE-SW oblique - sinistral strike-slip movement is agreed with the dominantly current tectonic regime. The very shallow subsurface reverse faulting, with dip to SE about 12 - 20 degrees apparently were clearly detected from GPR profiles in Cenozoic basin. This suggests that tectonic process have occurred in the current tectonic regime, so its movement is likely to be the "**active tectonics**" definition. The revised method for active tectonic study is also proposed.

Department...........Geology.......	Student's signature..
Field of study.......Geology.......	Advisor's signature..
Academic year.....2005............	Co-advisor's signature..

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CHAPTER I
INTRODUCTION

1.1 General

Thailand has been subject to several large earthquakes since early history of the country (Hinthong, 1995). However, only few studies have been done so far, particularly earthquake geology and neotectonic study. Modern or neotectonic study means the investigation of event and tectonic mechanism which occurred after Miocene age (Slemmons, 1991). Based on combination of different application techniques such as remote sensing, geophysics, geomorphology, petrology, history and sedimentary dating, Charusiri et al. (1998) can divided earthquake risk zones in Thailand into range 4 zones, viz. zone 0, 1, 2, 3. Zone 3 is the region where large -to moderate–magnitude earthquake occurred in the part and has very high potential to suffer earthquake with moderate magnitude. This region includes northern and northwestern part of Thailand. The Lampang basin in northern Thailand belongs to this zone and was disturbed by several earthquake events. Many geoscientists believe that major faults in northern Thailand are still active and can be related to Paleotectonic event (see Fenton et al, 1997; Bott et al., 1997). However, this area never been investigated in detail, particularly active fault systems. Thus neotectonic investigation along the Thoen fault zone is required to provide geological investigation for earthquake protection plan in near future.

Resent geological reports suggest some segments of the Thoen fault zone are active (Charusiri et al., 1998; Hinthong, 1995). However, detail investigation is still lacking. Recently, studies of active faults investigation [or the so-called earthquake faults, such as San Andres fault in southern California, Rundle et al., (2001)] are emphasis on results of remote sensing and sedimentary dating data. However, a few investigations concentrate on the application of ground geophysical information. Ground geophysics, especially Ground Penetrating Radar or GPR (Slater & Niemi, 2003; Wise et al., 2003; Andru et al., 2001; Chow et al., 2001; Dehls et al., 2000; Busby & Merritt, 1999) can define shallow subsurface geological structures obviously when combines with remote sensing data, petrography and field investigations. GPR can display a more accurate position of active fault and significantly reduce cost effective of fault trenching. In addition, currently large magnitude earthquakes often appear close to our country after December 26, 2004 Tsunami in Indian Ocean. Perhaps, this confirms the current tectonic regime is still active in this region and therefore this is a high possibility to reactivate Cenozoic fault system as well in the near future. Hence, the systematically detailed investigation of individual active fault systems in Thailand, especially, those in the northern, western and southern parts must start immediately.

1.1.1 Active fault in northern Thailand

Northern Thailand was classified to an intraplate basin and range province (Fenton et al., 1997). This area comprises north-south trending Tertiary intermountain grabens and half grabens, bounded by north -to northwest-striking normal to normal oblique fault system (Lorenzentti et al., 1994; Polachan et al., 1991). These basins developed in an east-west oriented extensional stress regime were initiated by north-south regional compression of Indian-Australian-Eurasia plate movement during Oligocene, subsequently eastward extension and rotation of Southern China and Southeast Asia along large strike slip fault systems (Fenton et al., 1997). Although the major deformation occurs on the Red River fault and other faults to the north, all of movement mechanisms were generated by moderate earthquake activity and deformation in between this region until now. There are 11 active fault zones in main land SE Asia and the Thoen fault system is grouped in Mae Tha – Phrae – Thoen Fault zone, No. 7, in Figure 1.1.

1.1.2 Thoen fault system

Thoen fault zone, where the study area is located (Figure 1.2) is a series of north -to northeast-striking fault that aligns 120 km cross the region between the Phrae basin to east and the Lampang, Mae Moh and Thoen basins to west (Charoenprawat et al. 1994; Piyasin, 1974). The fault zone is approximately 600 km far from Bangkok (Figure 1.2) and mainly located in Lampang province, northern Thailand.

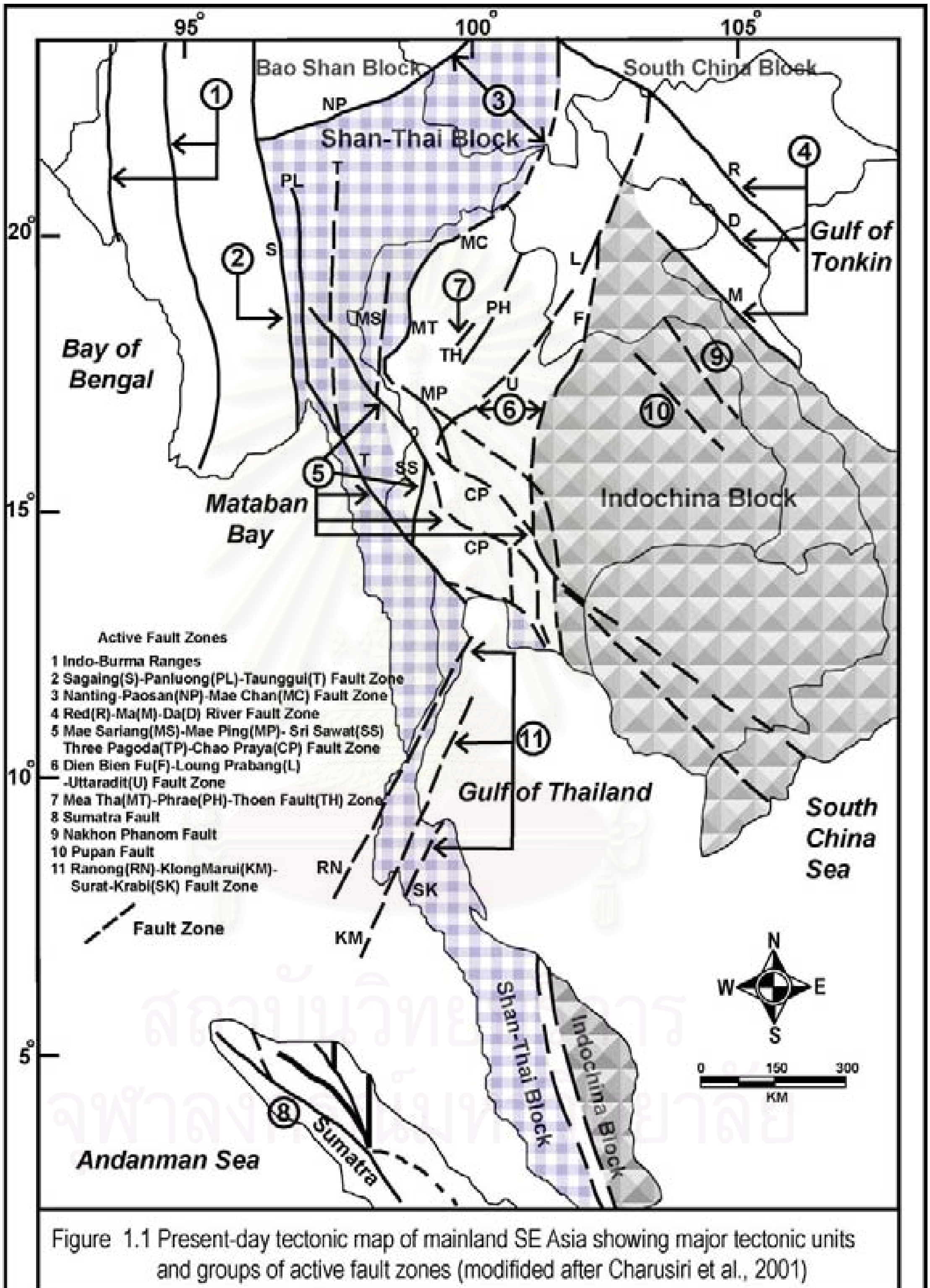


Figure 1.1 Present-day tectonic map of mainland SE Asia showing major tectonic units and groups of active fault zones (modifided after Charusiri et al., 2001)

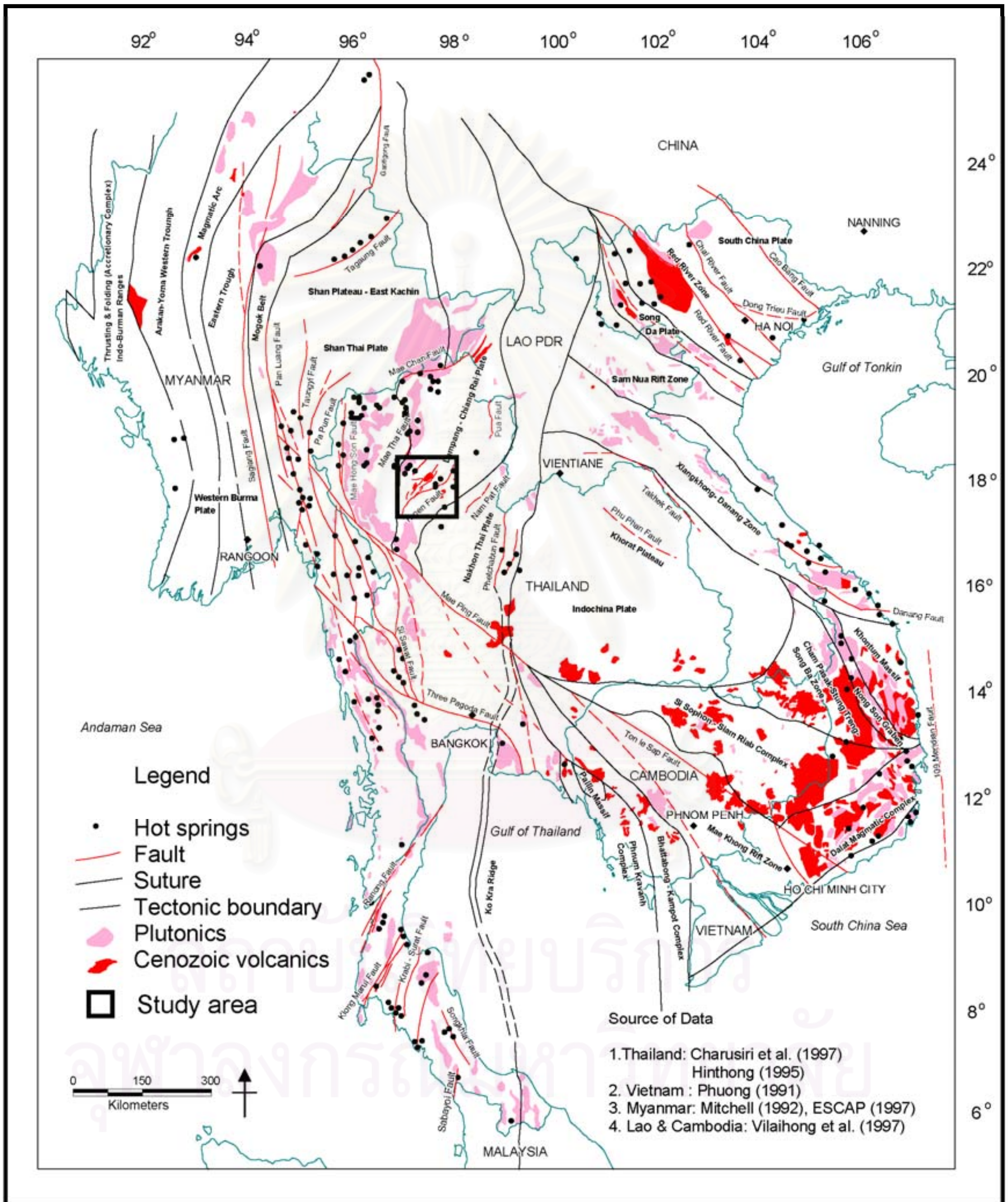


Figure 1.2 Active fault map of Thailand showing the location of study area.

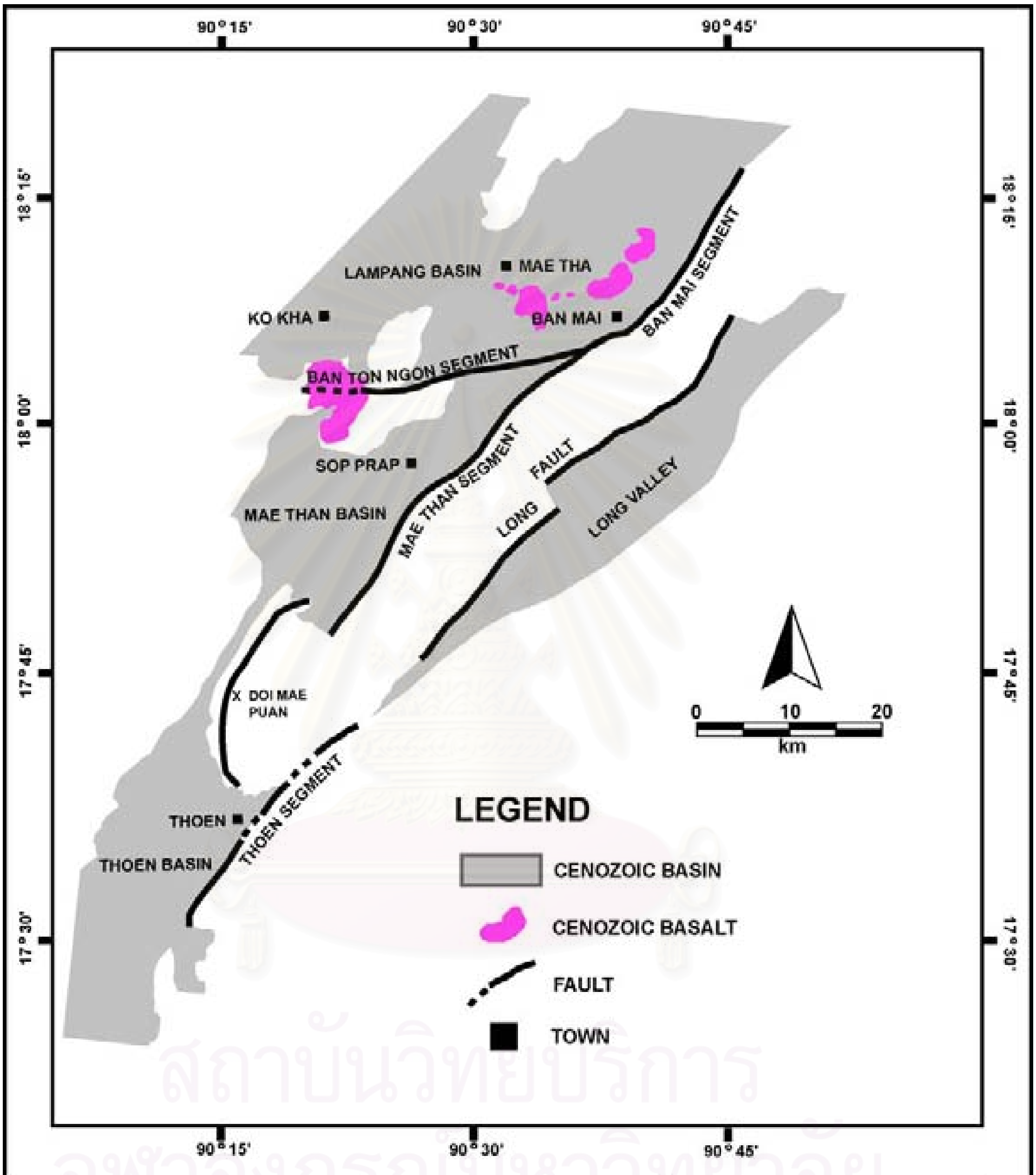


Figure 1.3 Simplified map of the Thoen fault system showing fault segments and localities mentioned in the text (modified after Fenton et al., 1997).

Two major faults within this system prefer a number of structural and geomorphic features indicating evidence of recent movement. They are the fault bounding the eastern margins of the Mae Moh, Lampang and Thoen basins which is called the Thoen fault, and the fault bounding the western side of the Long Valley called the Long fault (Figure 1.3). Result on Landsat TM satellite image (Fenton et al., 1997) displays obvious sharp lineament which can be observed. The Thoen fault can be separated into four segments by geomorphic expression, structural style and offset feature as Thoen, Mae Than, Doi Ton Ngun, and Ban Mai segment. These faults show a complex history of movement that appears to have been confined to the margins of the basin along the main Thoen fault (Figure 1.3).

The Thoen fault segment forms a northwest-facing bedrock escarpment that varies in height from 400 to 600 m. The escarpment comprises a series of facet spurs interrupted by several bench or erosional pediment remnants that such features were the result of episodic fault movement. Mae Moh basin located on the west of Thoen fault. Several studies (Bunopas, 1981; Charusiri, 1989; Polachan & Sattayarak, 1989) have shown that extension began sometime in the early Oligocene. These faults have a complex history of movement throughout the Tertiary. The most recent movement appears to have been confined to the margin of the basin along the main Thoen fault.

Along the Ban Mai fault segment, the lowest faceted spurs are about 250 to 350 m high. Progressive steepening towards the base of a fault scarp or escarpment shows repeated fault movement, the steeper bevels representing more recent faulting episodes (McCalpin, 1996). Several streams crossing the Ban Mai segment exhibit wine-glass canyon profiles. This results from renewed uplift or an increased rate of uplift of the footwall in a normal fault system. The presence of wine-glass canyons and the marked steeping of the faceted spurs at the base of the escarpment, indicate that at least along the Bam Mai segment, The Thoen fault is undergoing renewed or increase vertical displacement. At Ban Mai the Thoen fault crosses the active floodplain of the Huai Mae Mai (River) and vertically offsets down to the northwest by approximately 6 meters. From the preservation of the terrace, consider this surface to be Holocene in age. Assuming approximately 6 meters of vertical offset during the Holocene, this gives an average vertical slip rate of 0.6 mm/yr for the Ban Mai segment.

The 25 km -long east-west striking Doi Ton Ngun fault segment forms a 300 m high rang front with well-developed triangular facets and wine glass canyons. All streams crossing this fault spray show marked incision on the footwall, indicating vertical offset. No evidence for lateral offset is observed. The Late Pliocene-Early Pleistocene Kho Kha basalts (Suthirat et al., 1995) are offset by less than 1 meter, and the fault does appear to through the entire sequence of basalt flows.

The Mae Than segment of the Thoen fault comprise of a number of splays that strike northeast to east-northeast. These splays bound the Tertiary Mae Than basin. The main fault, bounding the eastern side of the graben, forms a 600 meter high, northwest-facing escarpment with well-developed triangular facets and wine glass canyons. South of Mae Than, at the base of the main fault escarpment, at least two possibly three, late Cenozoic, down to the northwest faulting events are preserved as stacked colluvial wedges in a sequence of alluvial fan gravel exposed in a stream cut-bank. The age of these deposits is unknown; however, the degree of reddening and cementation of these gravels almost certainly precludes them for being Holocene. Clasts size, mainly cobbles and boulders, is also incompatible with the size of present drainages issuing from the footwall block. This concludes that these gravels are Plio-Pleistocene in age. The thickness of individual colluvial wedges, approximately 1.0 to 1.5 meter, indicates faulting event with comparable amount throw. To the south of Sop Prab, some of indication of the total vertical offset across the Thoen fault is shown by the displacement of a pre-Tertiary peneplain surface. Assuming 600 to 800 meters vertical displacement of this surface has occurred since the initial of normal faulting in northern Thailand, approximately 33 Ma (Charusiri, 1989), this gives a long term vertical slip rate of 0.02 mm/year.

1.2 Objectives

The objectives of this study aim to understand the evolution of Thoen fault by several applications. The three cores are clearly classified as shown below.
(1) To determine evidence of movement and structural element of Thoen fault,

(2) To identify direction of tectonic force which possibly influence to tectonic feature in the study area, and

(3) To indicate Thoen fault system is active or not.

1.3 Methodology

To accomplish the objectives, research methodology has been divided into six major tasks in order to construct a systematic tract of study. The major tasks are classified into 5 major steps as described below. All of these steps have simplified to a flow chart shown in Figure1.4.

1. Planning and Preparation

   Generally, this step was integrated physical features, regional geology, regional structures, earthquake records around Thoen fault and adjacent area. Furthermore specific techniques in fault investigations, such as remote sensing, ground geophysical survey and exploratory trenching were understood.

2. Morphotectonic Investigation

   This step involves Landsat-TM5 satellite image investigation to construct lineament map and rose diagram. This step can be called lineament analysis. The purpose is to find out the best target area for ground geophysical survey. Detailed interesting lineament features were confirmed by aerial photograph (scale 1:50,000) before field check and ground geophysical studies.

3. Field Investigation

   This step is to find fault evidence at outcrop scale and to conduct GPR survey. Moreover, several rocks samples were collected along the studied fault. Generally petrographic analysis and microstructural data were contributed on thin section to determinate mechanism of the Thoen fault movement.

4. Ground geophysical fault tracing

   By ground penetrating radar (GPR) running on best selected site. This step comprises GPR data acquisition, processing and interpretation. The processes are to define characteristic of fault plane underground at shallow depth.

5. Combination of all data and interpretation

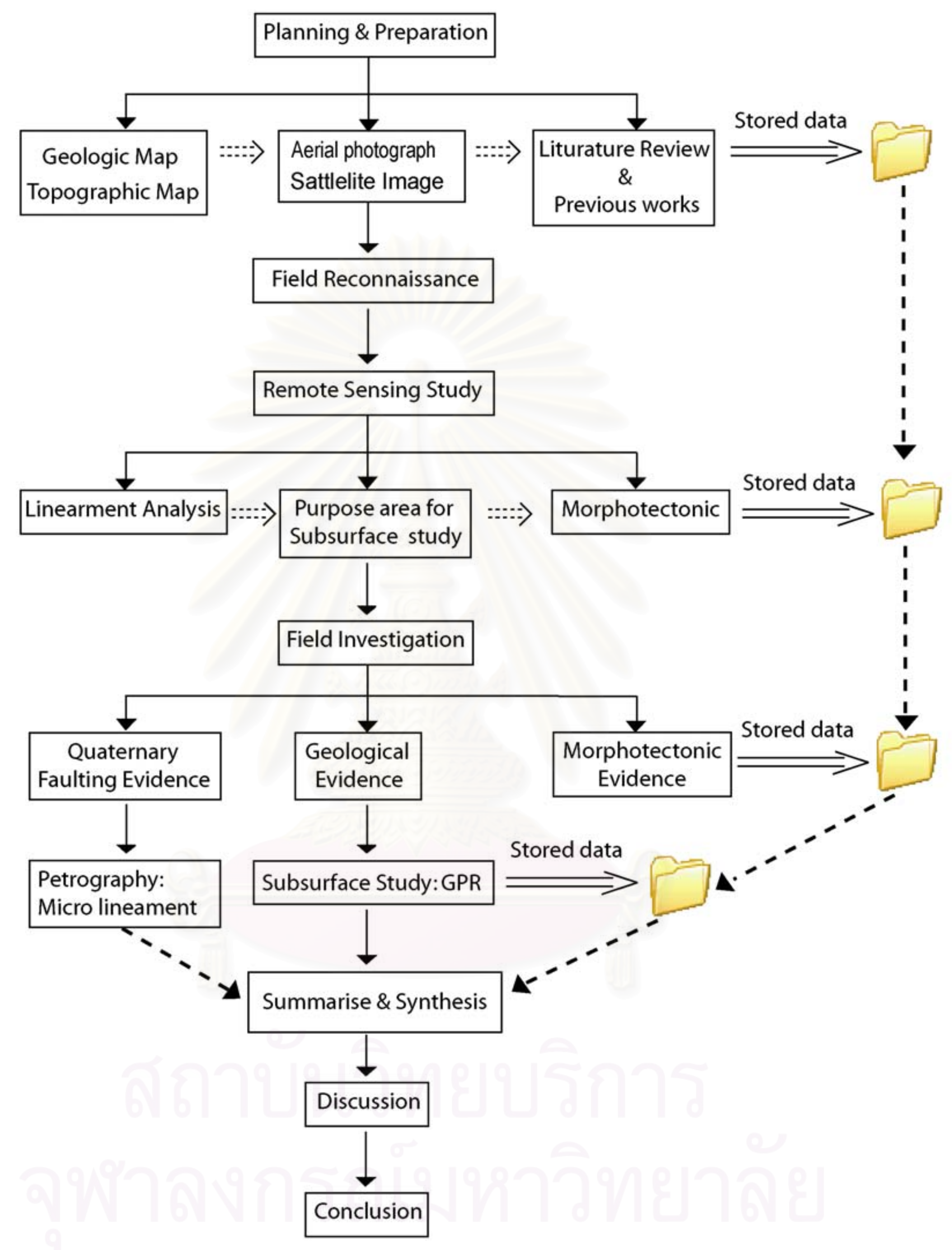


Figure 1.4 Methodological diagram of this thesis study.

1.4 Previous works

In an attempt to clearly understand neotectonic activity and major fault movement mechanism of the study region, the previous research documents include geology, geophysics confederate to earthquake history are necessary to mention and compile.

Nutalaya (1986) had described and characterized seismic source zones in Myanmar, Thailand and Indochina region into twelve seismic source zones. In Thailand, they are covered by zone F and zone G on the west and the north respectively. The Phrae basin is located in zone G, governed by NE-SE trending fault zones, namely the Thoen fault zone located on the west and the Phrae fault zone lay on the east. During 1980 – 1993, approximately twenty microearthquakes ranging in magnitude of 3 to 4 (on the Richter scale) were recorded, mostly limited in south of the Phrae basin. The Phrae fault is believed possibly active.

Siribhakdi (1986) had compiled previous data with his field investigation on seismogenic regimes of Thailand and periphery. This study suggested the compression stress axis lies in the southwestern direction which may be generated from spreading ridges and subduction zone in Andaman Sea. Furthermore, the most seismicity area in Thailand is located the west, and the present-day seismicity might be related to the Cenozoic basins-opening episode.

Thiramongkol (1986) observed neotectonism and rate of uplift in the eastern margin of the lower central plain of Thailand. The evidence of neotectonic movement found on the difference of elevation between footwall and hanging wall of Ban Pakong fault, which is 18 meters. Uplift rate is found 2.4 mm per year, calculated from topographic difference and timing. Carbon-14 dating on wood fragment indicated 7,300 ± 35 years B.P. for the brackish clay bed.

Hetrakul et al. (1991) evaluated reservoir-triggered seismicity in Khao Laem dam using seismic parameters, earthquake pattern, and focal mechanism solutions. The result revealed that swarm earthquakes have caused by reservoir induced seismicity (RIS) which located along NE direction. Additionally, the movement of the Three-Pagoda and Tak or Mae Ping faults in the past has increased stress accumulation along faults in this area.

Hinthong (1991) integrated many previous works to conclude the roles of tectonic setting to earthquake events in Thailand. The study cited that earthquake in Thailand are closely related to two seismic source zones, namely the Tenasserim Range zone (zone F) and the northern Thailand zone (zone G) of Nutalaya et al. (1985)'s division The fault within zone F are believed to be active more than those of zone G which are inferred to be possibly potentially active.

Klaipongpan et al. (1991) studied on geological and seismicity elevation of Srinagarin dam. The elevation was carried out using several parameters, i.e., earthquake catalogs, focal mechanism solutions, earthquake relocation studies, aerial ground geologic reconnaissance, analysis of remote-sensing imagery and review of the pre-instrumental and instrumental seismicity of Thailand. The study cited that the 1993 earthquake in Srinagarin dam is triggered by water load. Epicentral distribution is coincided with the northwest trending geological lineaments.

Sarapirome and Khundee (1994) investigated neotectonics in the Mae Hong Son-Khun Yuam valley using Landsat TM imagery and aerial photograph for geological lineament and geomorphic interpretations. The result has been analyzed together with statistic analysis of lineament, earthquake epicentral distribution, hot spring location and Quaternary faulting data. The result of this study revealed that northwestern Thailand has been tectonically active since Late Paleozoic to recent times.

Bott et al. (1997) mentioned that northern Thailand is similar to the basin and range province in the western United States of America in term of earthquake processes and tectonics. However, the largest known earthquake in the north has not exceeded M_L 6 compared to the basin and range province in which record on paleoseismic investigation indicated maximum capable earthquake is about magnitude (M_W) 6 and greater. The result based on focal mechanisms reveals that both regions have been formed by undergoing E-W extension.

Fenton et al. (1997) studied on Late Quaternary faulting in northern Thailand. Several tectonic geomorphological features, which indicate recent movements, have been observed along seven faults. These are the Phrae, the Phrae basin, the Long, the Nan Pat and the Phayao faults. Recurrence intervals of these faults ranged from thousands to ten of thousands years. These faults are capable to generate earthquakes equal or greater than (M_W) 7.

Won-in (1999) studied on neotectonic evidences of Three-Pagoda fault using remote-sensing approaches from data on Landsat TM5, JERS-SAR and aerial photograph, and ground-truth surveys as main tools to delineate the fault trace. In addition, TL and ESR dating methods were used to determine age of faulting events. The study revealed that Three-Pagoda fault consists of five segments based on geological and geomorphological analyzes. Several tectonic geomorphology which are frequently observed along the fault, indicated the main right lateral movement. Five events of earthquake faulting are reported based on geological evidences and dating results.

Charusiri et al. (2001) categorized active faults in Thailand into five seismically active belts (SAB) using geologic, geotectonic, geochronological, and seismological criteria. These belts are composed of northern, western-northwestern, central peninsular, southern peninsular and eastern-northeastern SABs. Most of the faults are inferred to be active, with the exception of the Mae Tha, the Nam Pat and the Phayao faults, which are believed to be tentatively active faults.

Udchachon et al. (2002) 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. 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. They, therefore, estimated the recurrence of large earthquake generated by the fault movement is ca. 0.9 Ma.

CHAPTER II
TECTONIC SETTING

2.1 Introduction

This chapter describes the general tectonic definitions, viz. tectonics, neotectonics, and active tectonics or active fault, but it will not go into detail on the theoretical aspect of each definition. The aim of this chapter is to explain what the main interest definition using applies to the study. The others focus on the current tectonic regime in regional scale and structural frameworks in the Northern Thailand covering the study area.

2.2 General definition

In order to make it clear throughout the study and to keep nomenclature cohesive, some terms of tectonic which concern to the purpose of study are briefly explained here as following below.

2.2.1 Tectonics

Generally, in the earth science "tectonics" refers to the deformational structures and architecture of the outer parts of the Earth and to the evolutions of these features through time. Examples include folds, warping and tilting of crustal blocks, and displacement of fault. On the other hand, "tectonic" is the study of the force within the earth that give rise to continents, ocean basin, mountain range, earthquake belt, and other large-scale features of the earth's surface (Cox & hart, 1986).

2.2.2 Neotectonics

The term "neotectonics" was originally proposed by Obruchev (1948) to describe to "the study of young and recent movements taking place at the end of the Tertiary through the first half of the Quaternary era", or "neotectonic" encompasses all structural deformation of the earth's crust during the late Cenozoic (Miocene to

Holocene), in round numbers, during the last 35 Ma (Wegmann, (1955). In addition, Slemmons (1991) wrote: “neotectonics can be broadly described as tectonic events and processes that have occurred in post Miocene time”.

On the other hand, Morner (1990) takes the view that the Neotectonic phase starts at different times in different places, depending on each tectonic regime. This study follows principles of Morner’s thinking and combined with that of Wood & Mallard (1992) who started that neotectonics is agreed. Thus, the different studies region the different current tectonic regime started at different time.

2.2.3 Active tectonics

Active tectonics or active fault has evolved from the many definitions that have been used in the past. The lack of agreement on a single definition has caused confusion and it is difficult to address that a fault is active or not, therefore it depends on the interpreter’s specialty and the aim. Usually, “active tectonics” is defined as tectonic movements that are expected to occur within a future time span of concern to society (Geophysics Study Committee, 1986; Steward & Hancock, 1994).

According to the purpose of this study, it has been proposed on geological basis, that an active fault could be define as a fault which shows a movement in the current (active) tectonic (faulting) regime. Therefore a fault which has not moved during the current regime of prevailing regional stress and strain may be term ‘extinct’ (Wood & Mallard, 1992).

Based on an absolute time-scale, when surface displacement along the fault during the last 10,000 years is evidenced, the fault is a Holocene active fault. A fault that has moved during the last 130,000 years is a Late Quaternary active fault, and a fault that moved during the last 1.6 Ma is a Quaternary active fault (Machette, 2000).

Following the above definitions, it is noted also that active tectonics and neotectonics are not always interpreted in the same way. The former has involved historical time connotation (tectonic movements that are expected to occur within a future time span of concern to society), while the latter became related to the current tectonic regime.

2.3 Current tectonic regime of Thailand

In Thailand and mainland SE Asia as a whole, present-day tectonic, Cenozoic tectonic regimes in this region are a consequence of collision of Indian with Eurasian plate, which has begun about 50 Ma (Middle Eocene) and has resulted in 2,000 to 3,000 km of shortening across the Himalayan orogen (Fenton et al., 1997; Charusiri et al., 1997; Bunopas, 1994; Hintong, 1991; Peltzer & Tapponnier, 1988) (Figure 2.1). The spectacular relief of the Himalayas, Tibet and the Tien Shan are related to Indian and Eurasian divergence which has collided at rate of about 5 cm/yr, starting in the Eocene (Le Pichon et al., 1992). Accordingly, slip-line field modeling and simple plane indentation experiments of rigid block (India) into a plastic body (Asia) indicate lateral expulsion and crustal thickening explaining large strike-slip faults such as the Altyn Tagh - Kunlun, and Red River faults (Molnar & Tapponnier, 1977; Tapponneir et al., 1982; Davy and Cobbold, 1988).

Although the majority of deformation at present occurred on the Red River fault and other faults to the north (e.g. Kun Lun, Red River, and Altyn Tagh faults), however, moderate earthquake activity throughout the mainland southeast Asian (including Thailand) indicates contemporary deformation in this region (Fenton et al., 1997). Integration of geometrical relationship of strike-slip and extensional faults with the evidence of clockwise rotation of crustal block and earthquake analyses is related to strain ellipsoid of dextral simple shear. The major NW-SE trending faults, (the Red River, Mae Ping, Three Pagoda, and Sumatra faults) represent the master dextral faults, and the major NE-SW trending faults (the northern Thailang, Uttaradit, Ranong and Klong Marui faults) are sinistral. It is considered that these faults sets also characterize as conjugate set (Figure 2.2) (Polachan et al., 1991).

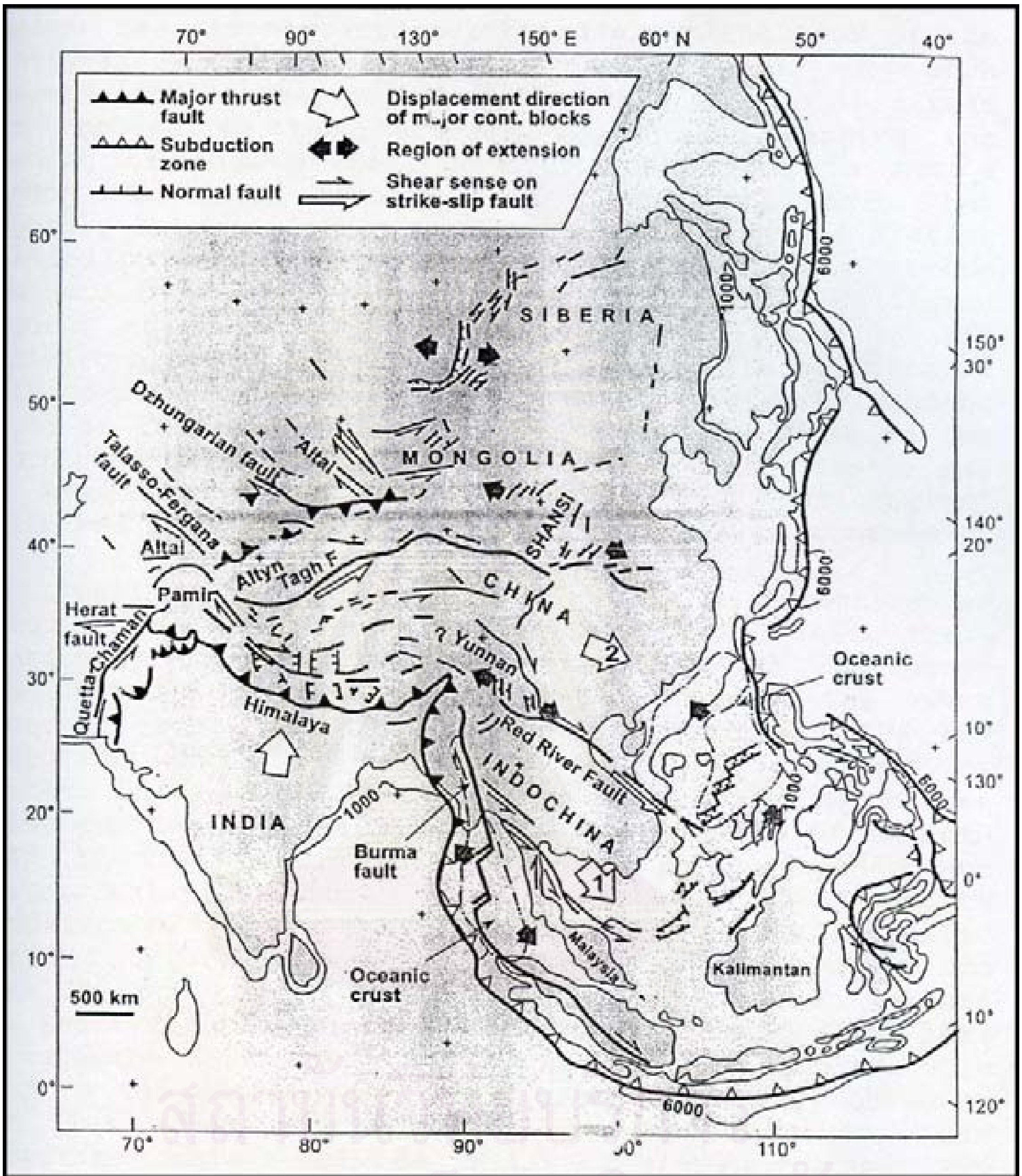


Figure 2.1 Tectonic map of central-east Asia illustrating 'extention' model and its relationship with Cezosoic structure in the region. Number in white color indicate the relative order which certain continental blocks were extruded to ward the southeast (after Tapponnier et al., 1982).

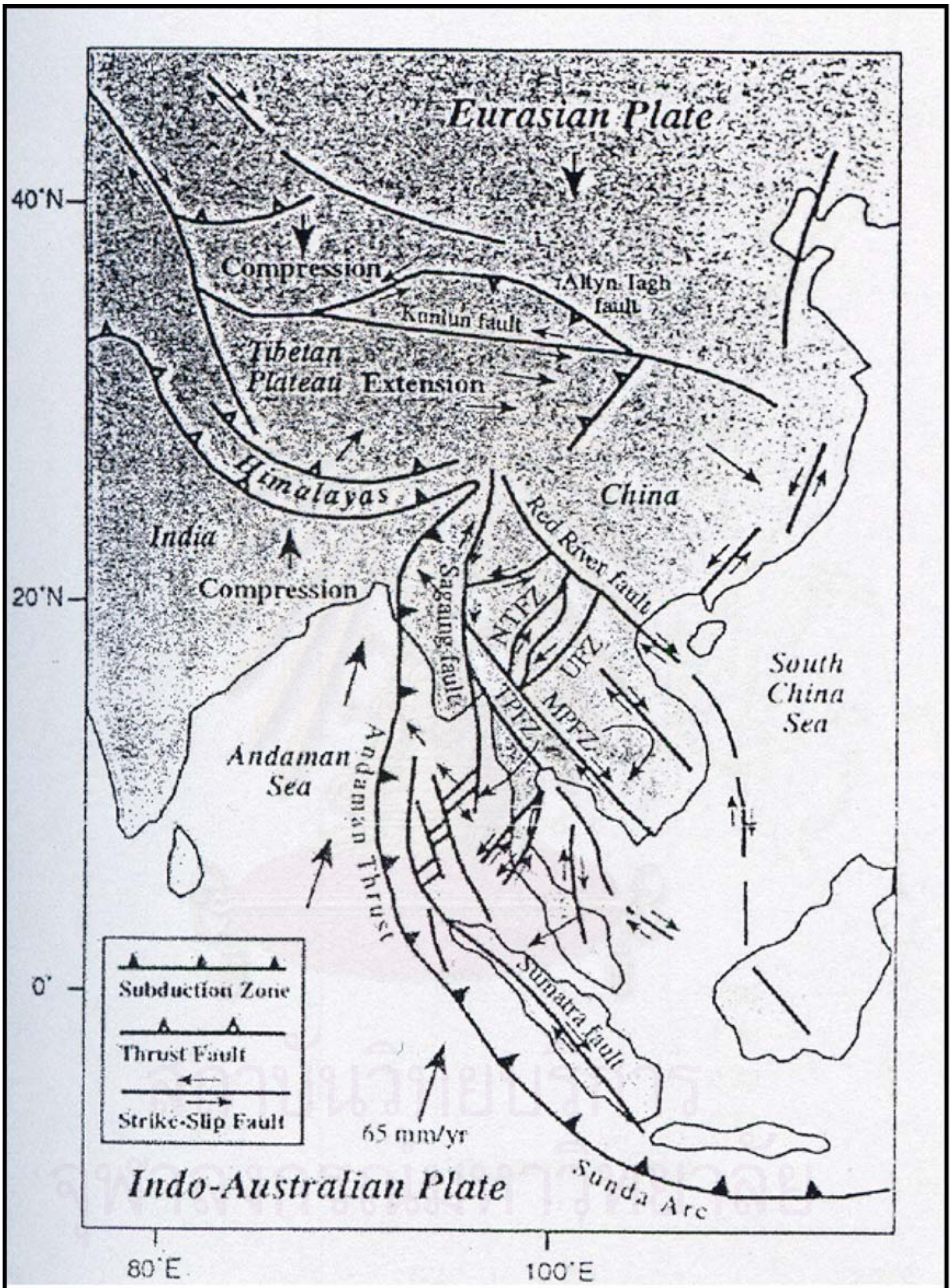


Figure 2.2 Major tectonic elements in SE Asia and southern China. Arrows indicate relative directions of motion of crustral block during the late Cenozoic. MPFZ: Mae Ping Fault Zone; NTFZ: Northern Three Pagoda Fault Zone; UTFZ: Uttaradit Fault Zone (after Polachan et al., 1991).

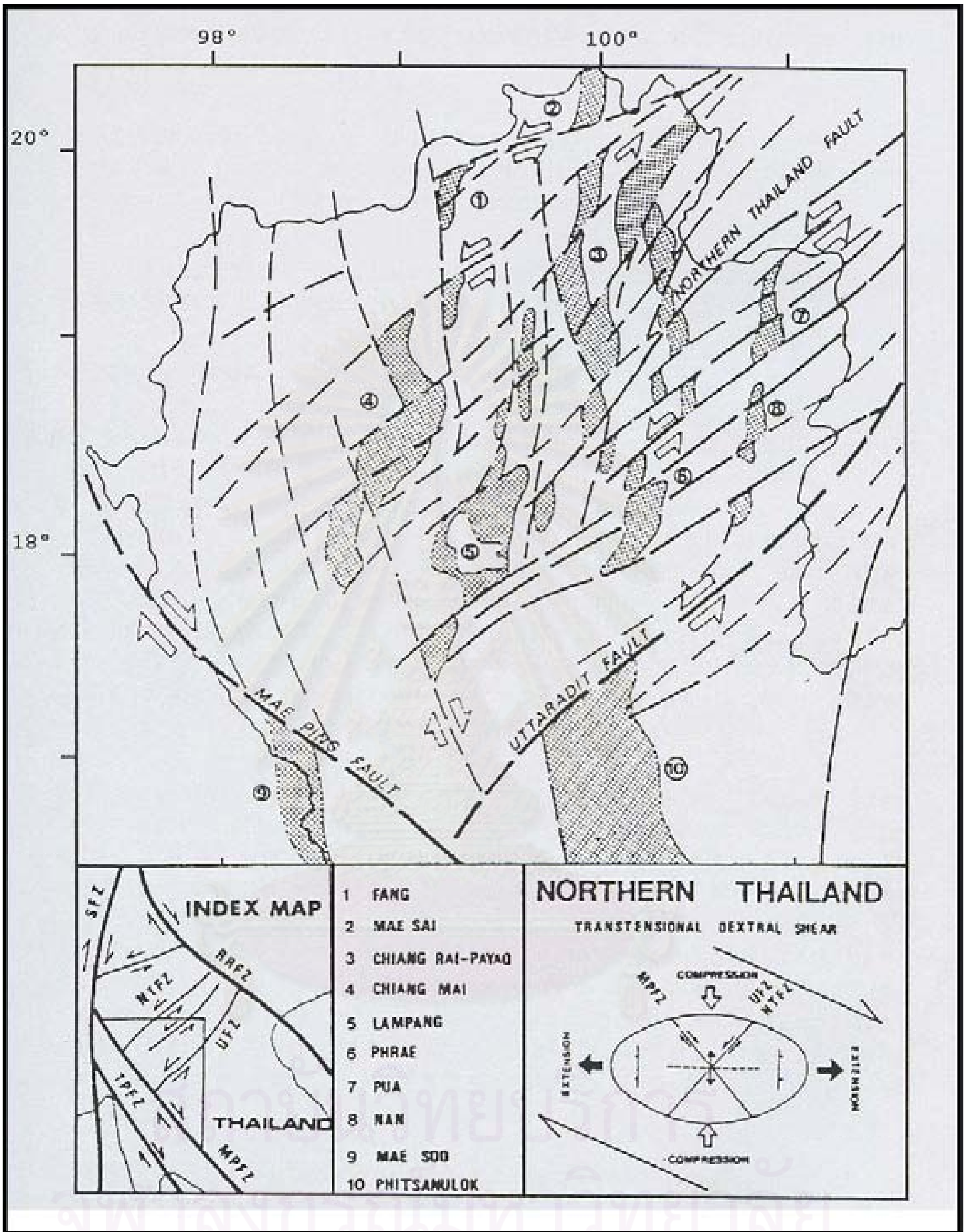


Figure 2.3 Structure map of Northern Thailand showing conjugate set of strike-slip faults and offset Tertiary basins. This evidence of tectonism can be explained by transtentional dextral shear model (after Polachan & Sattayarak, 1989).

2.4 Structural Frameworks in Northern Thailand

There are major conjugate sets of strike-slip faults influenced in contemporary tectonism in northern Thailand, which are surrounded by two large NW-SE and NE-SW strike-slip faults (Figure 2.3).

In the southwestern part of northern Thailand, the Mae Ping fault zone or the so – call Wang Chao fault zone, Bunopas, 1981) mainly occurred in the NW-SE direction. The movement of this strike-slip fault is rather complex. During Oligocene-Miocene, this fault moved in right-lateral direction, whilst during the Plio-Quaternary it moved in left-lateral direction. The total left-lateral direction offset (about 300 km) on this fault zone was result of the Tertiary indentation of Indian within Asian (Lacassion et al., 1997).

In the southeast part of northern Thailand, the Uttaradit fault zone develops in NE-SW direction within sinistral strike-slip movement (Bal et al., 1992). This fault extends towards the southwest under the Chao Phraya plain and formed the northern flank of the Pitsanulok basin. The Uttaradit fault zone occurs parallel to the Nan river suture zone.

CHAPTER III
REMOTE SENSING INVESTIGATION

3.1 Introduction

This chapter presents the use of digital satellite image and digital terrain models (DTM) on structural geological model in the process of fault recognition by mean of remote sensing observations. An integration of remote sensing in lineament interpretation and tectonic geomorphology interpretation combining with DTM is presented as the result in this chapter.

The aim of using remotely sensed observation is to determine the geometrical relations of structural discontinuities at the earth surface, which are used as the first step in analyzing and interpreting their tectonic meaning.

In this chapter, description is divided into three sections. The first section is focused on geological lineament interpretation in a regional scale. The area of interest covers the Thoen, Mae Than, and Lampang basins of Northern Thailand. Landsat TM5 (bands 4 red, 5 green, 3 blue) is applied tool for lineament interpretation. The second section describes tectonic geomorphology interpretation on four segments of Thoen fault system; Thoen segment, Mae Than segment, Ton Ngun segment, and Ban Mai segment. In addition, tectonic geomorphology interpretation using DTM (data source from Google Earth) is emphasized to facilitate visualization and interpretation. Finally, the information derived from remote sensing observation data is the key purpose to extrapolate meaningful locations useful for ground penetrating radar investigation, GPR (Chapter 5), has shown as the final result of remote sensing study.

3.2 Lineament analysis

Lineaments are rectilinear or gently curved alignments of topographic feature on a regional scale, (Denis, 1967). Structural and morphological elements are combined into lineaments of composite nature. Lineaments are long and linear alignments of relatively short morphological structures occurring in a restricted number of trends. They are, but for a few, not treated as individually distinct structural element. They have rather been attributed a statistical significance on the level of a set of parallel linear elements and grouped in lineament swarms.

Subsequent interpretation procedure followed is entirely visual. A clear and straight feature is picked out and traced. The interpretation then looks for any significant cross-cutting linear structures at both ends of traced segments, thus looking for a causative relationship between each pair of lines. This routine analysis is repeated under different viewing angles. Aligned segments are subjectively interconnected in accordance with the formal definition. Tightly disposed parallel lines are replaced by main lineaments. In area of horizon covering rocks and alluvial deposits, straight river segments, abrupt tonal changes and contrasting tonal corridors are treated in the same way as lineaments recognized in dissected terrains with hard rock lithology.

In this study, Landsat TM5 (band 4 red, 5 green, 3 blue), taken on Feb 10, 1991, at scale 1: 100,000 covering the study area were used for lineament interpretation (Figure 3.1). Identification of lineaments was performed by visual justification. Traceable lines were layout on hard copy prior to digitally modified using Map Info program. Finally, rose diagram was also conducted to indicate frequency in direction of lineaments and their length.

3.2.1 The result from Landsat TM5 Interpretation

Lineament interpretation using Landsat TM5 and rose diagrams of the azimuthal frequency distribution covering the study area is shown in Figure 3.2. The major trends of lineaments lie in NE-SW to NEE-SWW directions, and the minor trends are in N-S, E-W, and NW-SE directions. The thick line, which is referred to Thoen fault zone (Fenton, et al., 1997), is shown as the longest lineament in the lineament map. This fault with the NE trend has shown horsetail-splay characteristic, which is normally found in strike-slip regime (Chistie-Blick & Biddle, 1985).

The result from lineament interpretation, show the overall lineament length of 1,830 km as measured on the image. Four main segments are recognized as:

1) Thoen segment showing the major directions at 40 and 70 degrees and the minor directions at 95 and 120 degrees (Figure 3.3);
2) Mae Than segment showing the major directions at 50 and 70 degrees and the minor direction at 120 degrees (Figure 3.4);
3) Ton Ngun segment showing the major directions at 60 and 70 degrees and the minor directions at 25 and 130 degrees (Figure 3.5);
4) Ban Mai segment showing the major directions at 70 and 80 degrees and the minor directions at 25 and 100 degrees (Figure 3.6);

Structural lineament interpretation of this study; indicates the main structural lineament into two trends, the major trend is NEE trending, about N70°E, and the minor trend is NWW, about N300°E. In addition, the NEE trending lineament seems to cut across the NWW trending lineament. Moreover, some of the lineaments showing evidence for surface displacement in young (Quaternary) deposits can be clearly observed at the Mae Than and Ton Ngun segments. Since they cut into Quaternary sediments, thus the structural lineaments or faults are assumed to be young or Cenozoic structure.

Based on combination of lineament map, topographic map, and geological map, the schematic cross-sections and morphological models of Thoen fault system can be made in order to determine the geometrical relations of Quaternary sediment deposition and each segment of Thoen fault system, as shown in Figure 3.7 (modified from Charusiri et al., 2004).

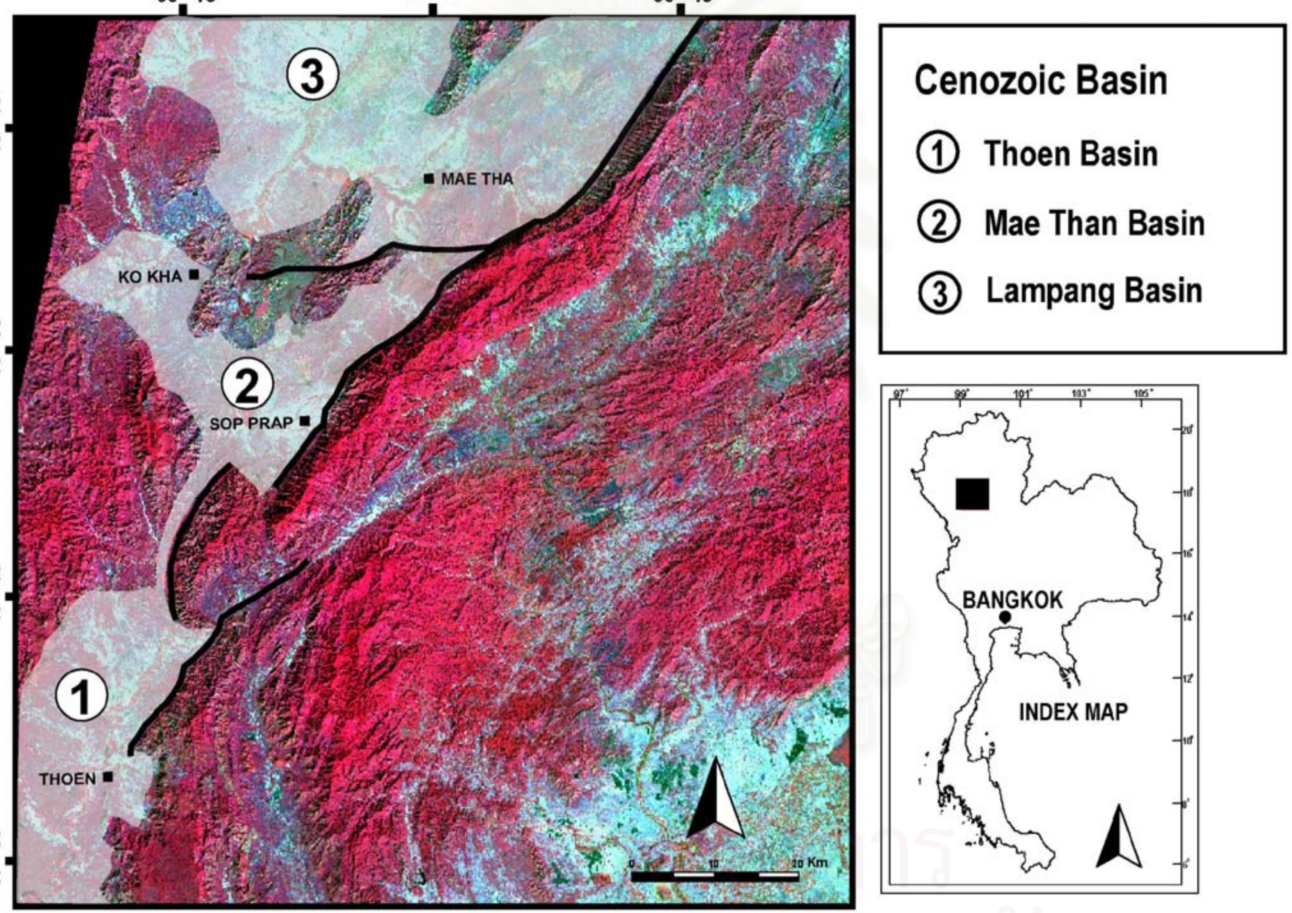


Figure 3.1 Landsat TM5 image showing locations of Cenozoic basin in the study region.

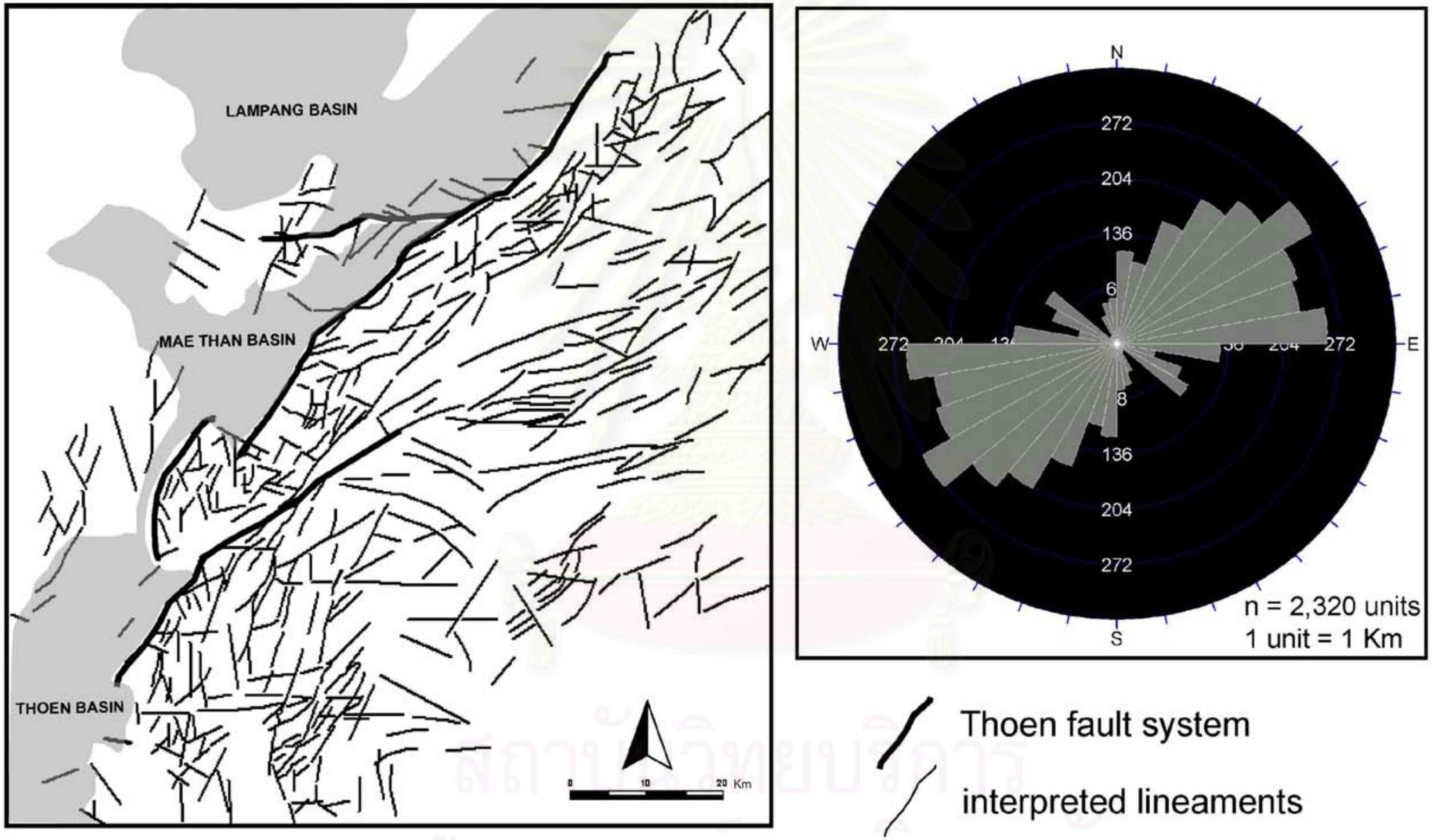


Figure 3.2 Lineament map of Thoen fault system and adjacent areas interpreted using Landsat TM5 (in Figure 3.1).

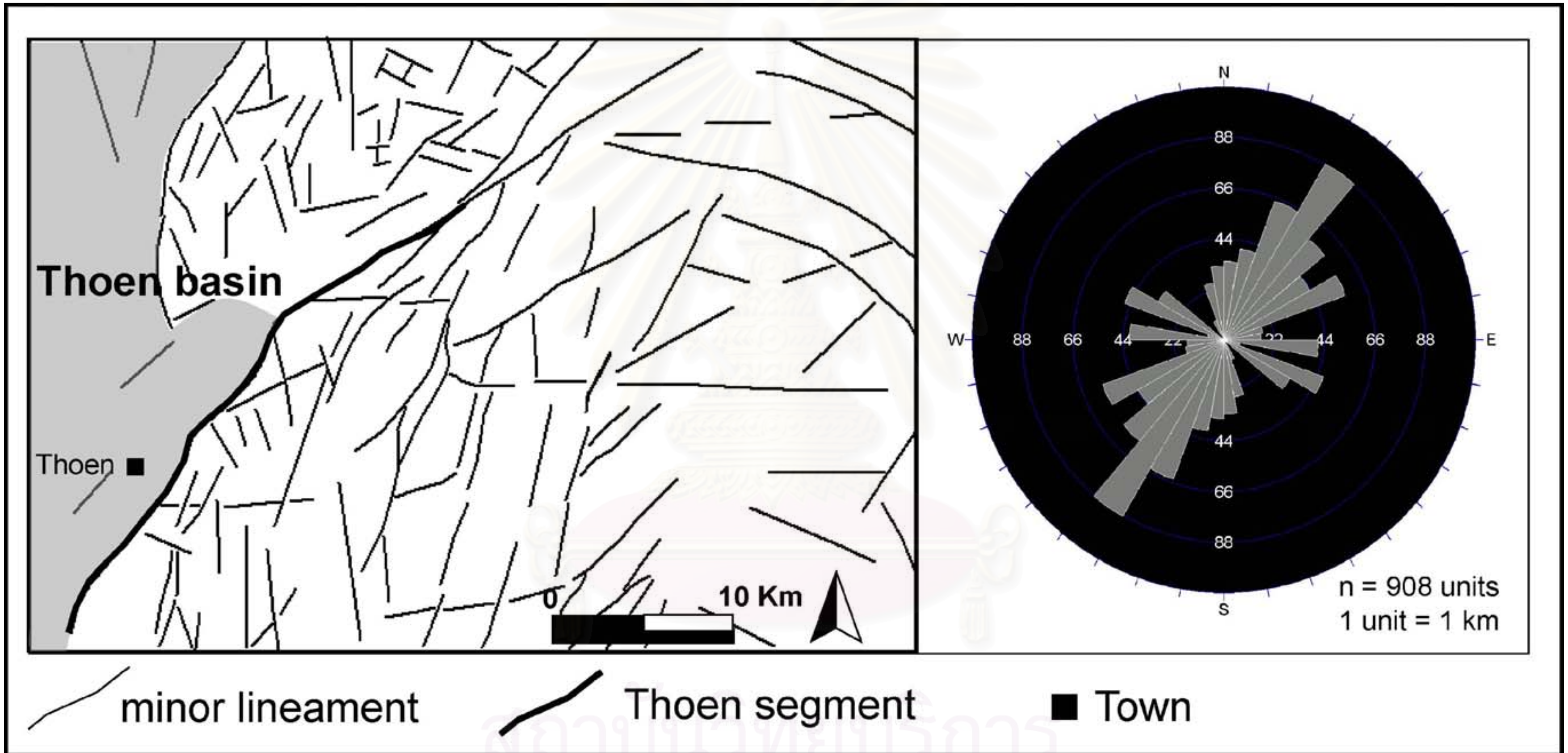


Figure 3.3 Lineament map of Thoen segment and adjacent areas.

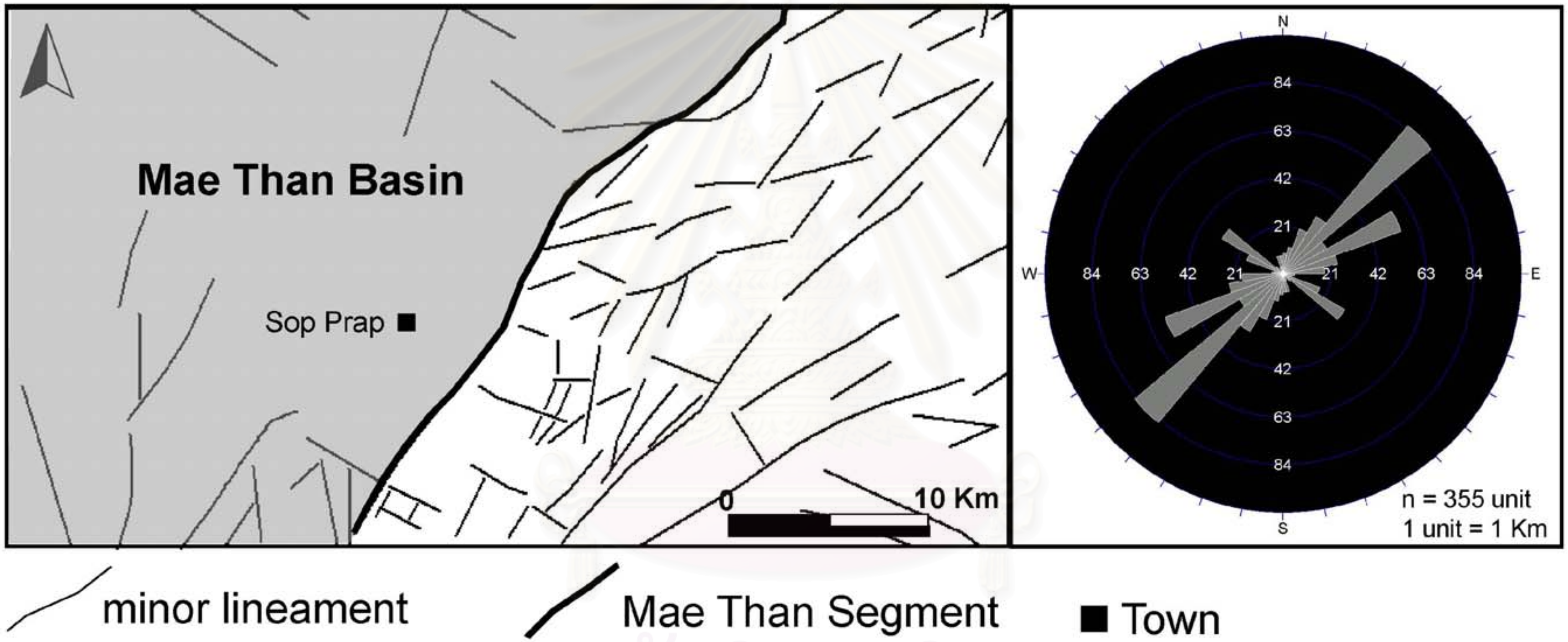


Figure 3.4 Lineament of Mae Than segment and adjacent areas.

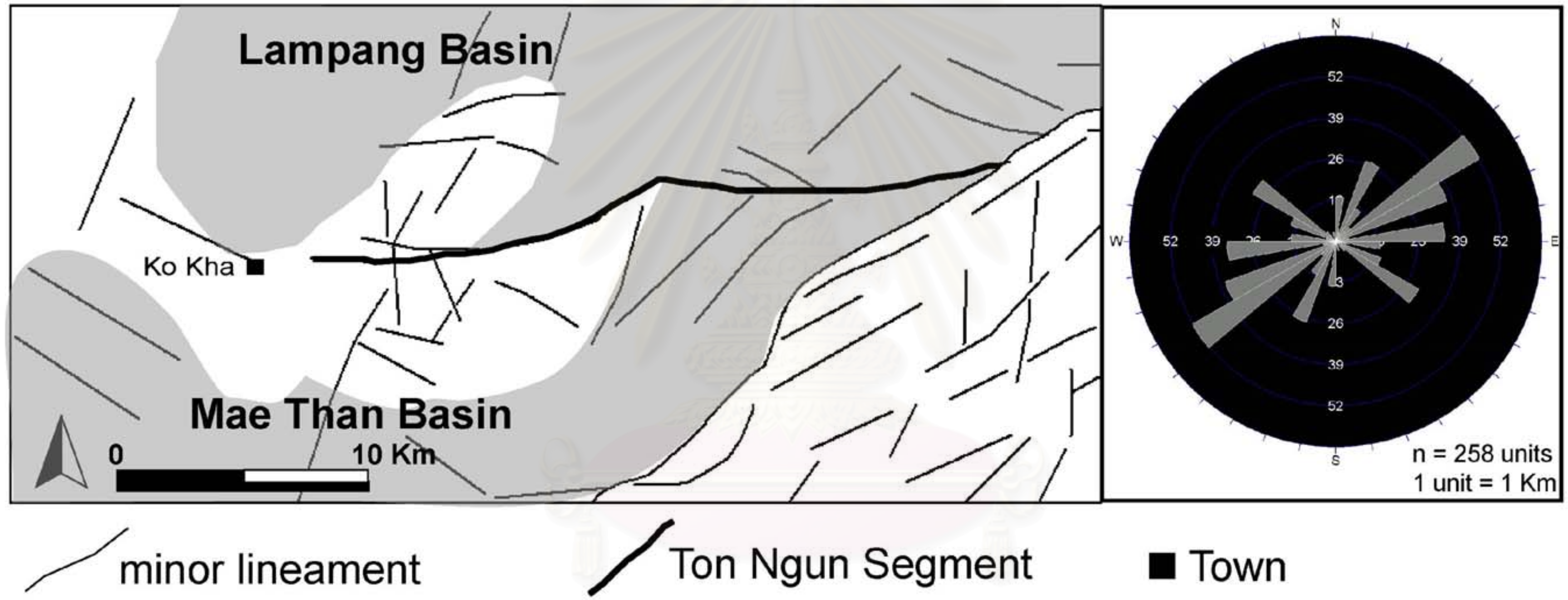
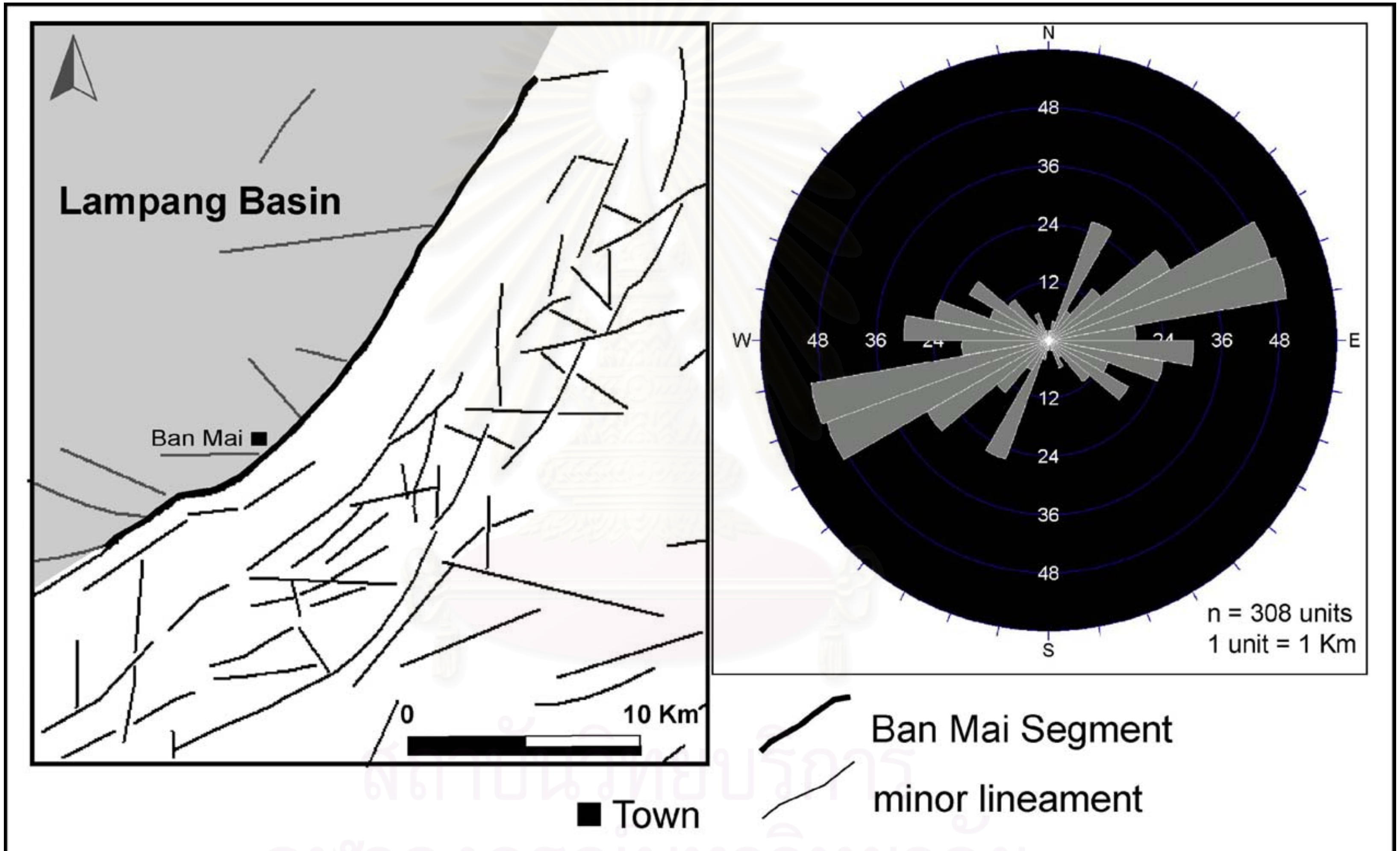


Figure 3.5 Lineament of Ton Ngun segment and adjacent areas.



Figuer 3.6 Lineament map of Ban Mai segment and adjacent areas.

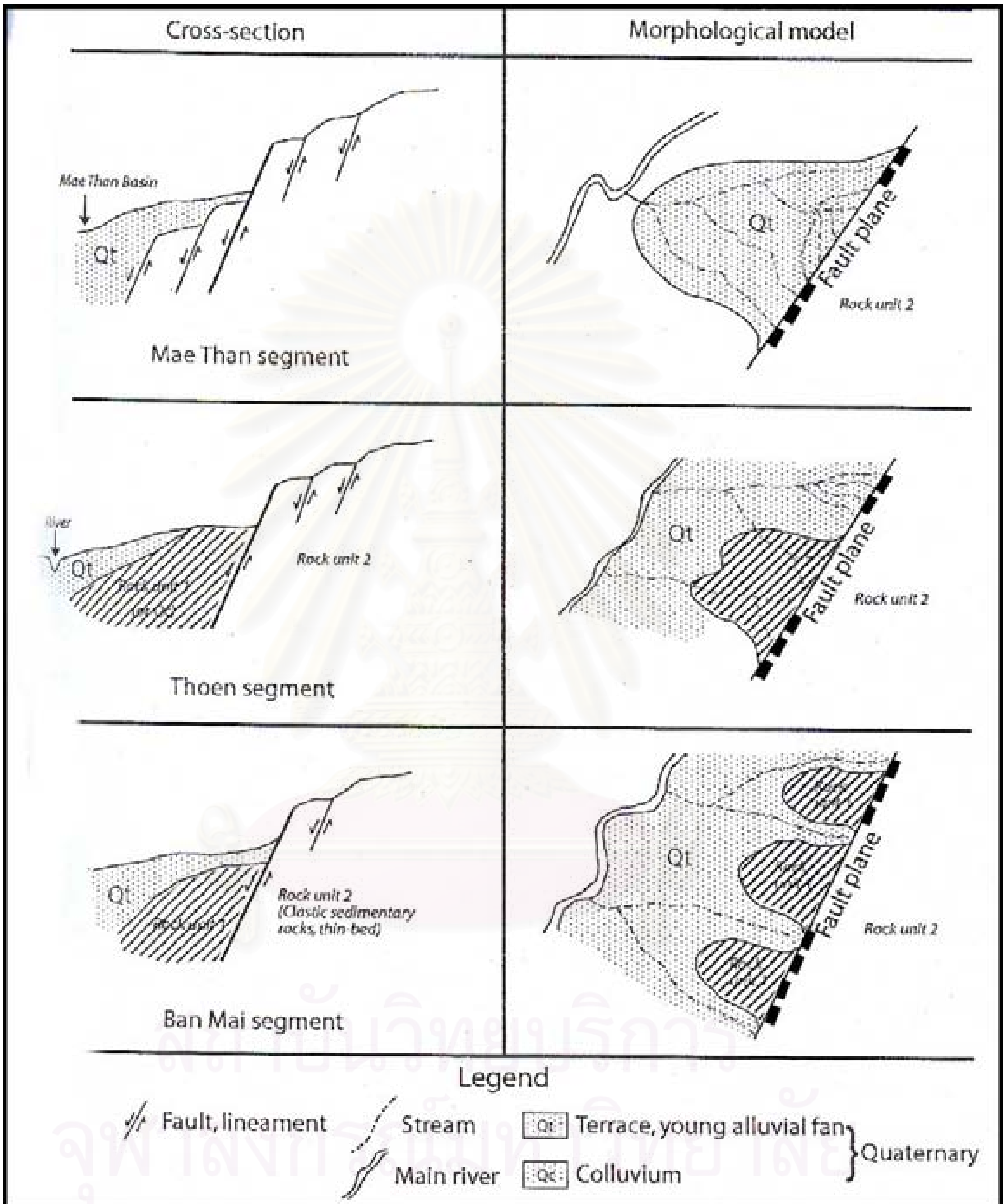


Figure 3.7 Schematic crossections and geological models of the Thoen fault system showing the geometrical relations of Quaternary sediment deposition for the studied fault segment (modified after Charusiri et al., 2004).

3.3 Tectonic Geomorphology

A basic tool in the structural interpretation of remote sensing data is morphotectonic analysis. It relates specific landforms to the tectonic movement causing them. Inferences from morphotectonics are directly related to dynamic and/or kinematic processes.

Lineaments generally do not give as much information concerning the types of structures as trends and extent of the structures. In some cases, however, the adjacent blocks on both sides of the lineament have specific features allowing the estimation the structural types. Difference in lithology and/or relief at both sides of the lineaments can indicate a fault. Tectonic landform and lineament structures such as Ridel shear zone can also indicate type of movement. Active faults can be recognized by the nature of alluvial fans, their relation with topography, displacement of river valleys and of other geomorphological elements.

According to strike-slip fault zone, a variety of structural feature and landforms can be originated by simple shear including fractures, folds, normal faults, trust faults, and reverse faults, shown in Figure 3.8 (Keller & Pinter, 1996), and Figure 3.9 (Christie-Blick & Biddle, 1985). Moreover, there are many features of tectonic landforms produced by strike-slip movement as shown in Figure 3.10 (Burbank & Anderson, 2001).

Generally, however, extensional fault trace can be associated with simple shear zone (Figure 3.10), perpendicular to the maximum extensional stress. Therefore, the idealized cross-section of extension tectonic environments is shown in Figure 3.11 (Burbank & Anderson, 2001). A typical landform of normal fault trace is triangular facets, which can be developed on proper condition of erosion and repetition when active fault has reached (Figure 3.12) (Fenton et al., 1997).

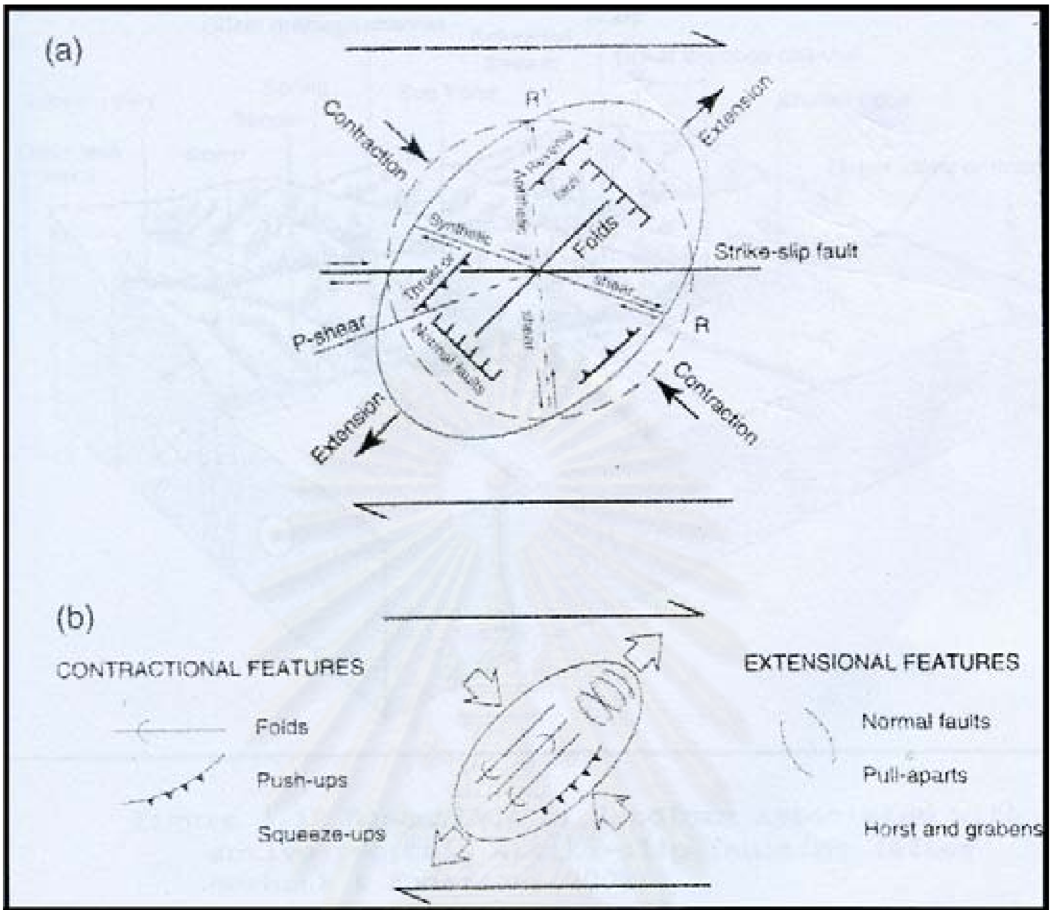


Figure 3.8 Simple shear model associated with strike-slip fault (a), producing contractional and extentional features (b) (after Keller & Pinter, 1996).

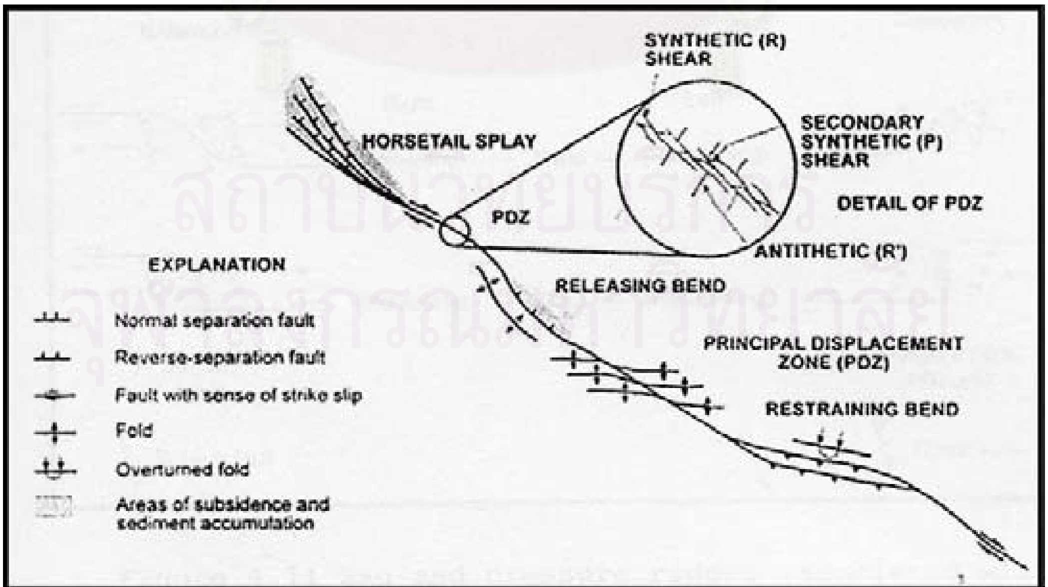


Figure 3.9 Plan view of sytucture associated with an idealized strike-slip fault (after Christe-Blick & Biddle, 1985).

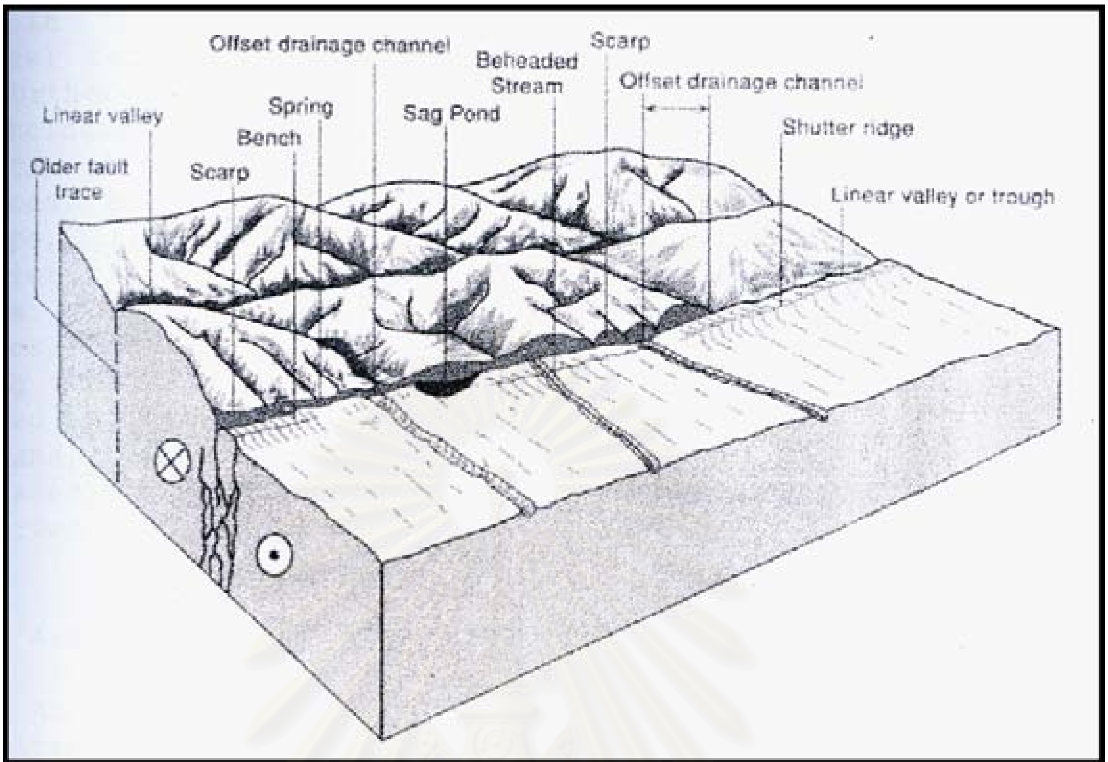


Figure 3.10 Assemblage of land form associated with active tectonic strike-slip faulting (after Burbank & Anderson, 2001).

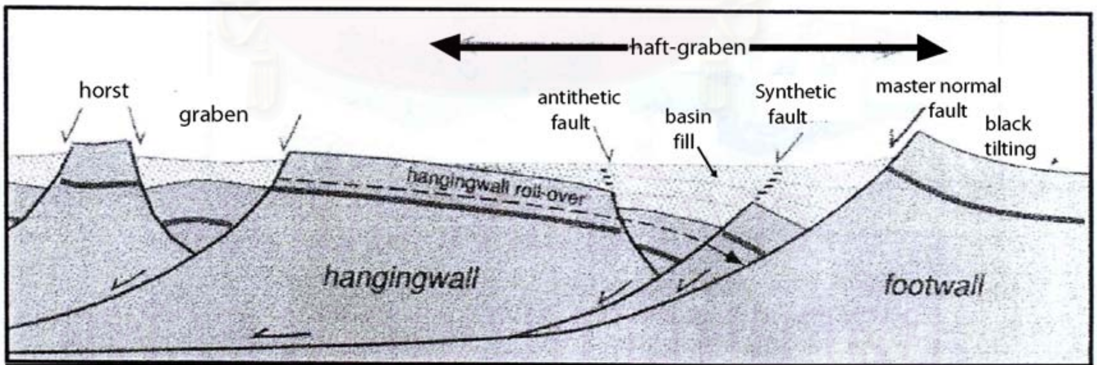


Figure 3.11 Idealized cross-section of extention tectonic environment (after Burbank & Anderson, 2001).

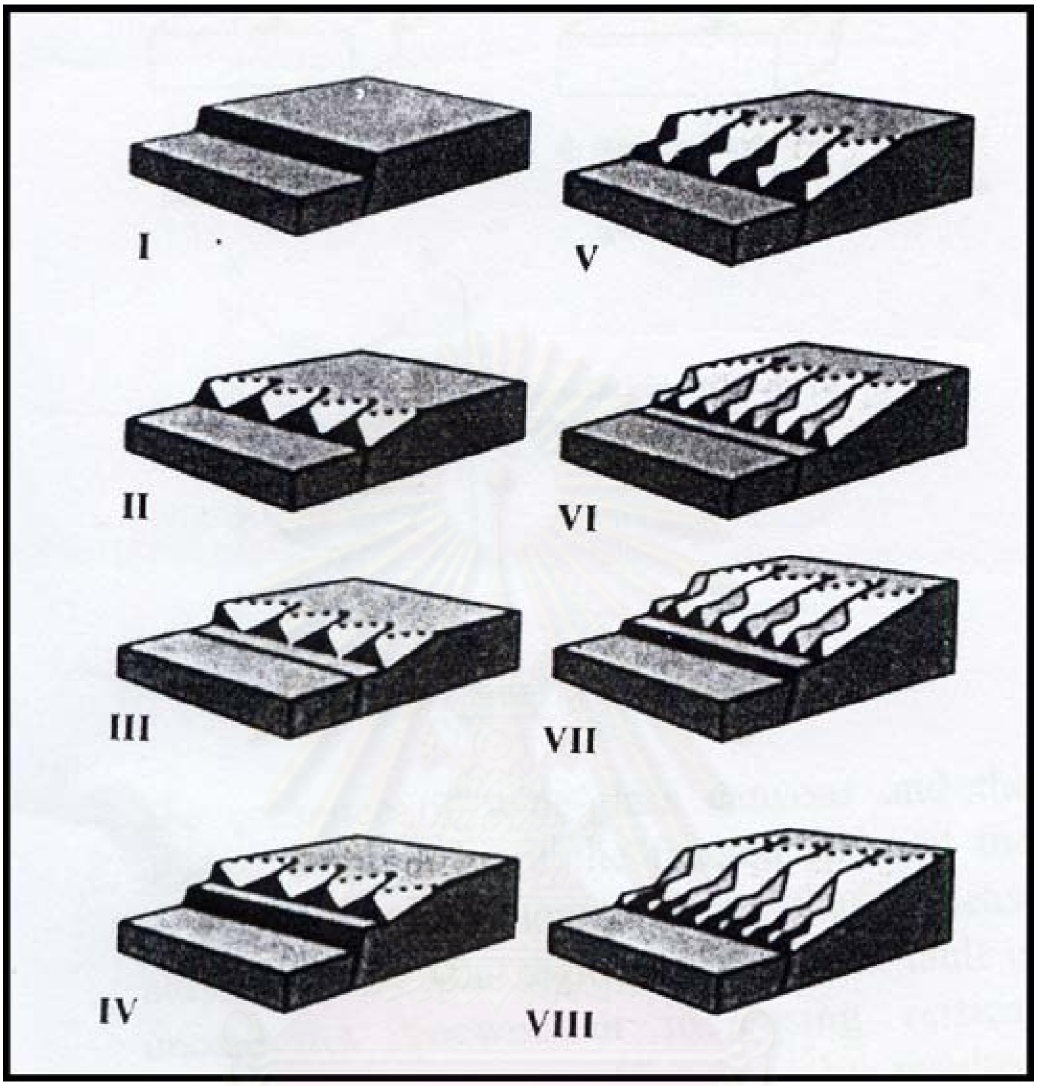


Figure 3.12 Development of triangular facets produced by vertical tectonic movement. I: Undissected fault scarp. II develop of faceted spurs by stream cutting Across the fault scrap. III: period of tectonic quiescence with slope retreat, And development of narrow pediment. IV: renewed fault movement. V: dissection of the new fault scrap by major streams and streams developed on the facet of the facet spurs developed at stage II. VI: a new period of tectonic quiescent, with the development of another narrow pediment within the footwall block at the base of the range front. Remnants of narrow pediments (benches) are preserved at the apices of each set of faceted spurs. Progressive slope retreat is accompanied by a decrease in the slope angle of the facets spurs (after Fenton et al., 1997)

3.3.1 Result from Tectonic Geomorphological Study

In this study, tectonic geomorphological results are mainly conducted using Landsat TM5 image. Digital Terrain Model (DEM) graphic was implied in order to characterize general tectonic features and facilitate visualization. Dominantly four types of evidences related to fault movement have been found. They are clearly defined triangular facets, benches, shutter ridges, and offset stream channels.

The morphotectonic interpretation can be separated consider along four main segments of Thoen fault system from southern end to northern end as follow below:

1. Thoen segment (Figure 3.13) displays clearly defined triangular facets, bench, shutter ridge, beheaded streams and offset stream.
2. Mae Than segment (Figure 3.14) triangular facets, bench, shutter ridge, beheaded stream, and offset stream.
3. Ton Ngun segment (Figure 3.15) clearly defined triangular facets and offset stream.
4. Ban Mai segment (Figure 3.16) there are triangular facets, bench, shutter ridge, deflected stream, and offset stream.

In summary, based on Landsat TM5 image and DEM, tectonic geomorphological evidence along four segments of Thoen fault system indicate that the fault trace should had moved in normal-sinistral motion. Besides, the Thoen segment shows strongly characteristic landform of dip-slip on triangular facets, and the Ban Mai segment shows strongly characteristic landform of strike-slip on offset stream, whereas the Mae Than segment contains both characteristic landform of dip-slip and strike-slip on triangular facets and shutter ridges.

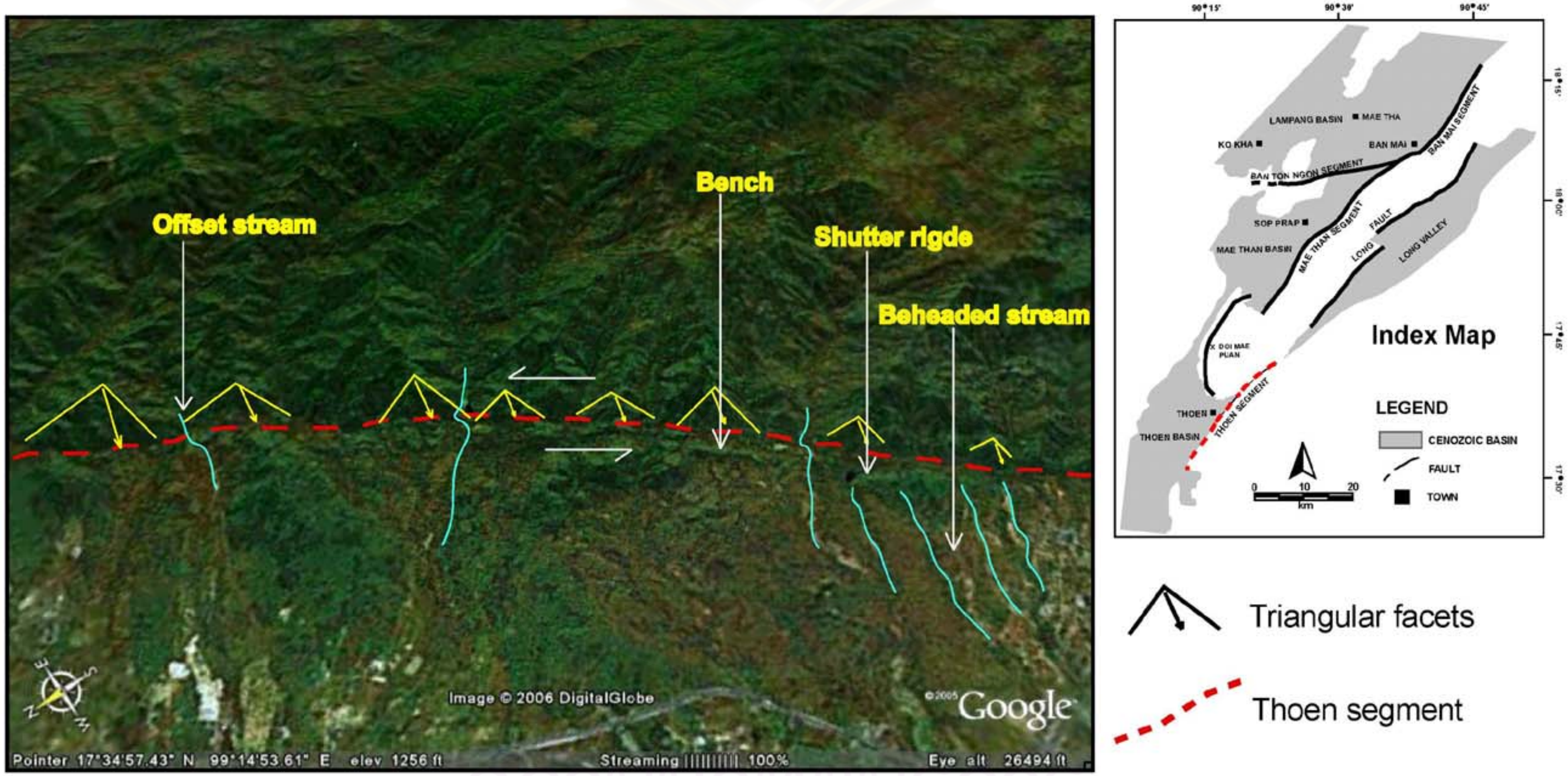


Figure 3.13 Interpreted tectonic geomorphological features on DEM along the Thoen segment (image from Google Earth).

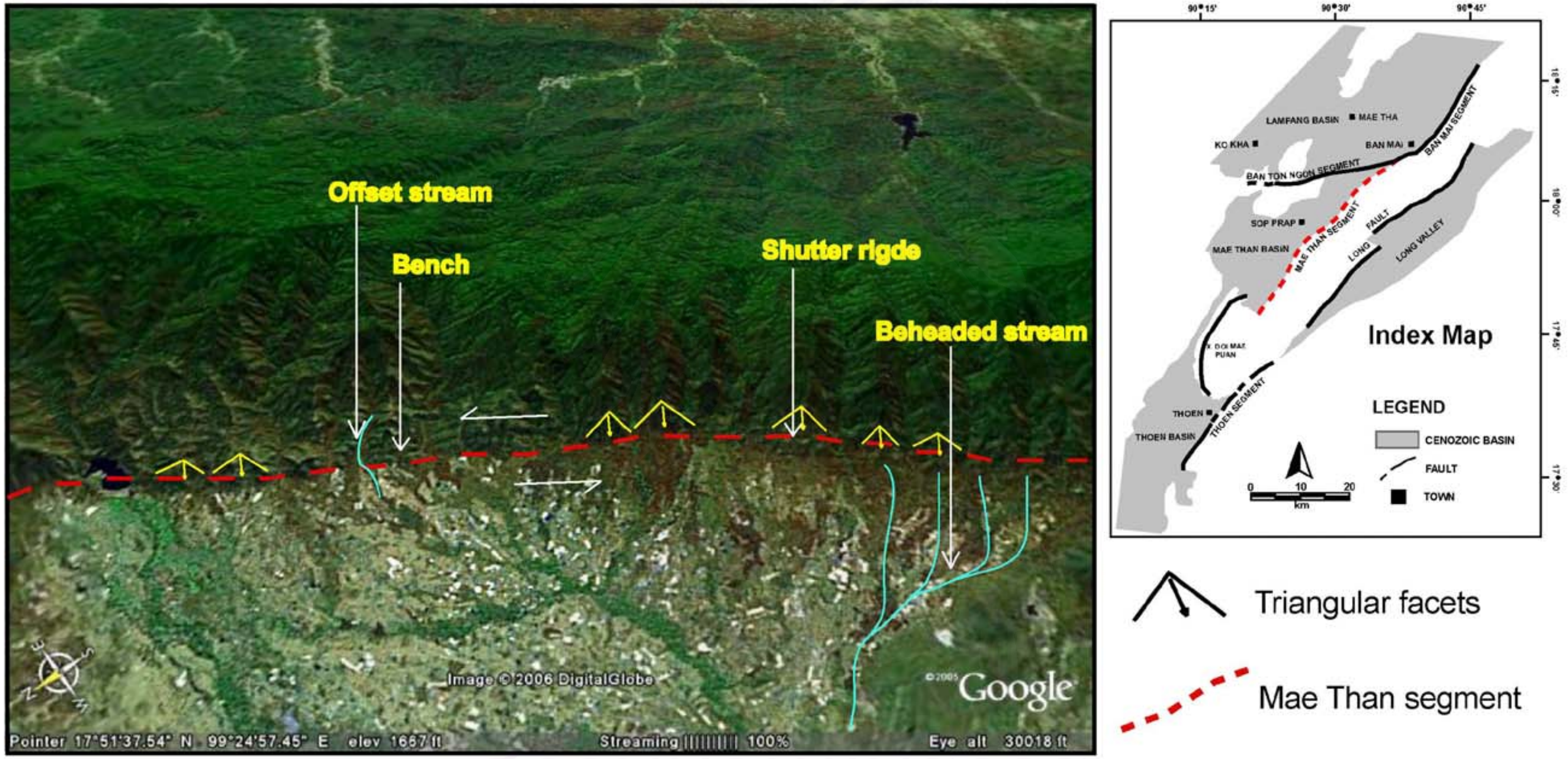


Figure 3.14 Interpreted tectonic geomorphological features on DEM along the Mae Than segment (image from Google Earth)..

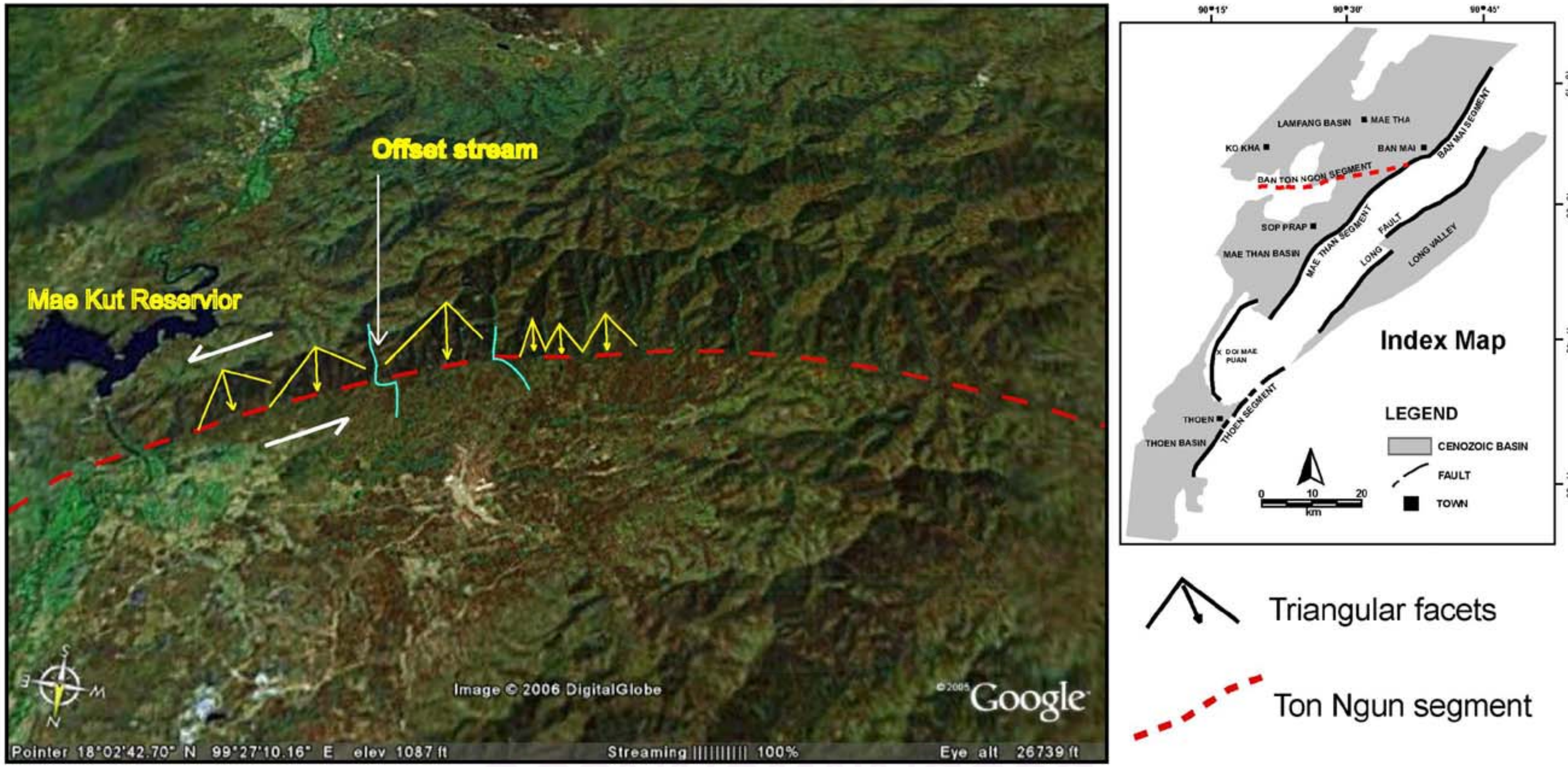


Figure 3.15 Interpreted tectonic geomorphological features on DEM along the Ton Ngun segment (image from Google Earth).

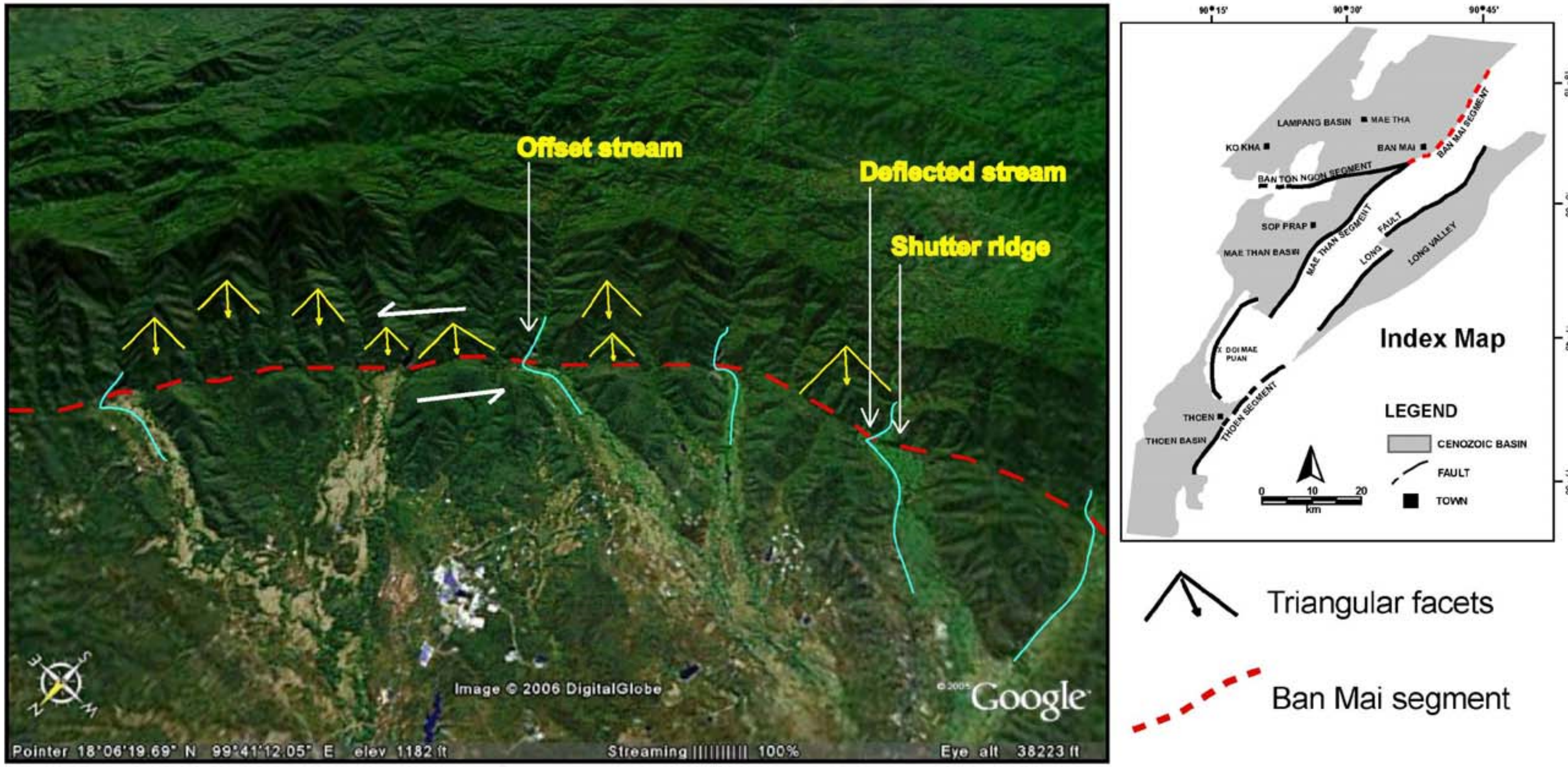


Figure 3.16 Interpreted tectonic geomorphological Features on DEM along the Ban Mai segment (image from Google Earth).

3.4 Result of remote sensing study

The main aims of remote-sensing study are 1) to define the main structural lineament trend, 2) to determine the geometrical relations of Quaternary sediment deposition and the fault segments in each segment, 3) to indicate evidence for surface displacement in young (Quaternary) deposit, and 4) to signify relative sense of movement of the Thoen fault system.

Integration of lineament interpretation and tectonic geomorphology interpretation combined with DTM data allow us to locate the GPR survey. We consider evidences of the cross cut at tip of two structural lineaments (or more) which displace young sediment, and strongly displays geomorphic feature indicative of resent fault activity. Thus the proposed survey area for GPR is delineated (Figure 3.17).

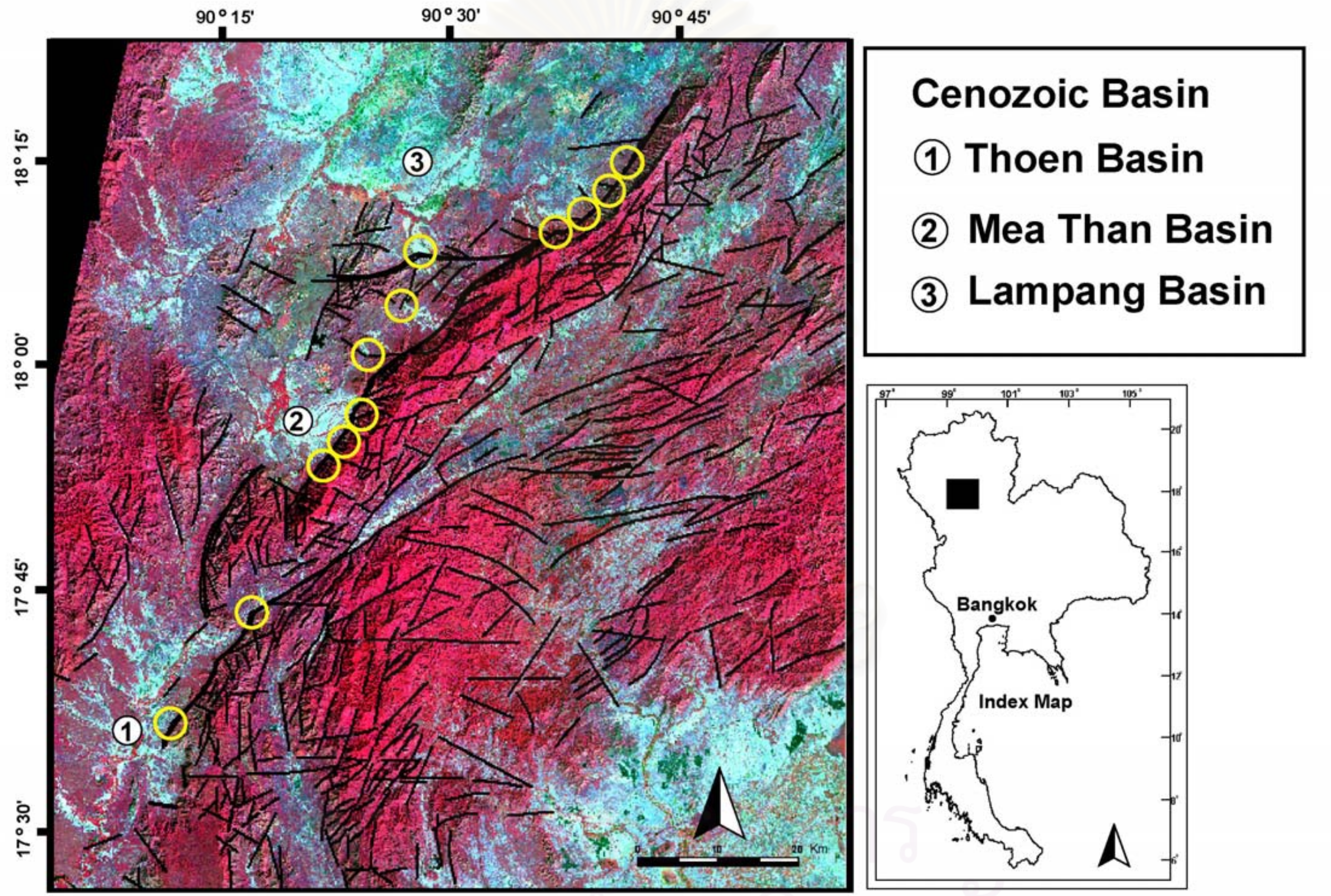


Figure 3.17 Lineament map on landsat TM5 image showing where exploratory GPR are located (yellow circles).

CHAPTER IV

FIELD AND PETROGRAPHIC INVESTIGATIONS

4.1 Introduction

This chapter describes mainly the results from field exploration and petrographic analysis. The first part involves 3 kinds of field evidence including tectonic geomorphology, geological, and Quaternary faulting evidence. The second part describes petrographic analysis in the aspect of microstructural fractures. Finally, model of micro-structures had been made using the integration of the results.

4.2 Field investigation

The purpose of field investigation is to observe tectonic geomorphology evidence, geological evidence, and Quaternary faulting evidence following the research plan designed in section 1.3 (Figure 1.4) and to collect hand-specimens for microscopic study.

4.2.1 Tectonic geomorphology evidence

One site located in the central part of the study area displays a clear evidence of tectonic geomorphology. The study method and the detail on the evidence of tectonic geomorphology have already explained in Chapter 3.

Five prominent triangular facets and a shutter ridge have been observed in the Mae Than segment in the NE trending fault trace (Figure 4.1). These facets are developed in sandstone and siltstone, which is covered by vegetation and showing highly rate of erosion.

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

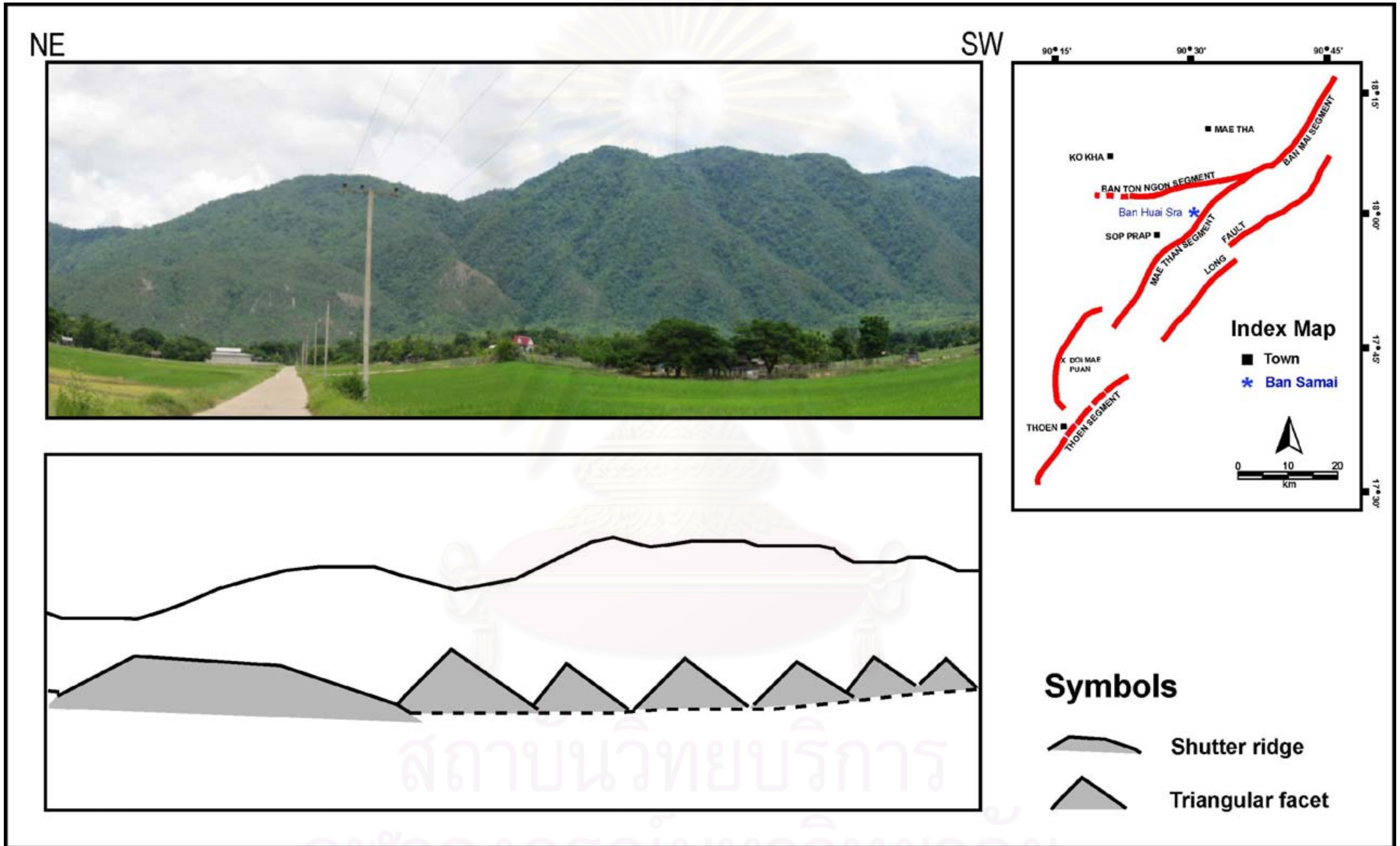


Figure 4.1 A set of triangular fasets and a shutter ridge observed along Mae Than segment (view looking SE) at Ban Samai (1979106 N / 0545853 E).

4.2.2 Geological evidence

Physiography in the intermountain basin indicates that the study area was initially covered by vegetation and showing high rate of erosion and weathering in outcrops. Actually, a lot of outcrops are observed, but mostly they are strongly weathered, some display structure less features, and some are too small for structural analysis. However, there are two good outcrops which contain lithology, stratigraphy, meaningful for analyzing major structures and minor structures. These two outcrops which related to the fault system can be described as follow:

4.2.2.1 Ban Bom Luang outcrop

Ban Bom Luang outcrop is located on Doi Ton Ngun segment, at UTM 2004812 N and 0531320 E (Figure 4.2). The rock is Permo-Triassic volcanic rock overlain by Quaternary terrace deposits (Figure 4.2a). Attitude of the major fault is 180° / 80° with a dextral movement as evidenced by slickenside striations (Figure 4.2b) whereas the minor faults contain evidence of dip-slip and strike-slip, left lateral displacement, in the NE-SW trend (Figure 4.2c). As shown in Fig. 4.2c, the horizontal offset of fault movement range from 8 cm (left) to 15 cm (right). It is noted that the minor structures are in accordance with the result of remote sensing study, suggesting normal-sinistral fault movement.

4.2.2.2 Ban Sam Kha outcrop

Ban Sam Kha outcrop is located on Ban Mai segment, at UTM 2002952 N and 0574535 E (Figure 4.3). The rock is marine Triassic sedimentary rocks, which consist mainly of reddish shale and siltstone and are grouped into Pha That Formation. The major structures in this outcrop are the N-S trending thrust fault (Figure 4.3a) and the nearly vertical normal fault dipping to the west (Figure 4.3b). The minor structures are essentially related to quartz veins showing left lateral displacement (Figure 4.3c).

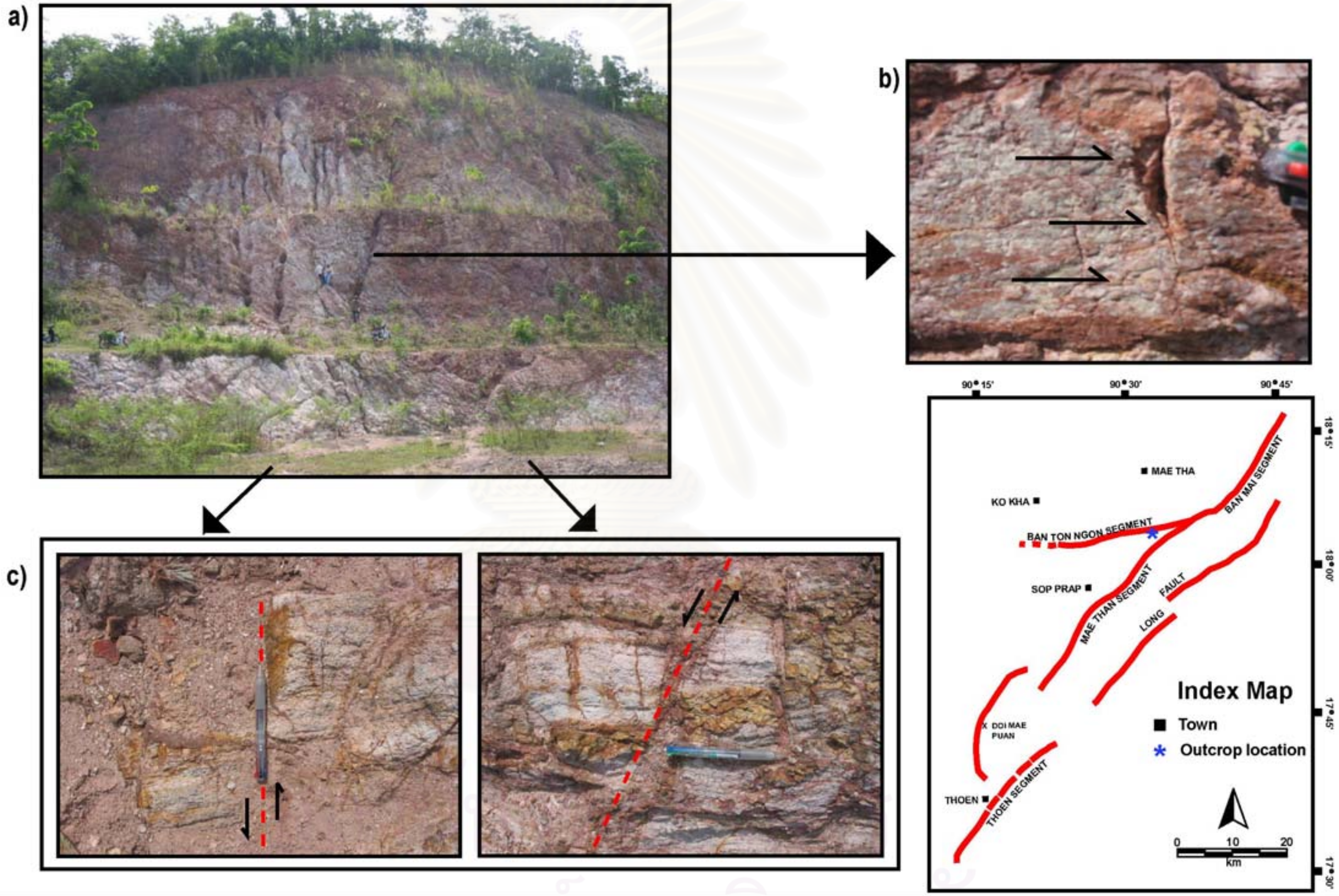


Figure 4.2 Ban Bom Luang outcrop showing a) major structure, b) Slikenside striations indicating right lateral movement and, c) offset structure suggesting a sinistral fault.

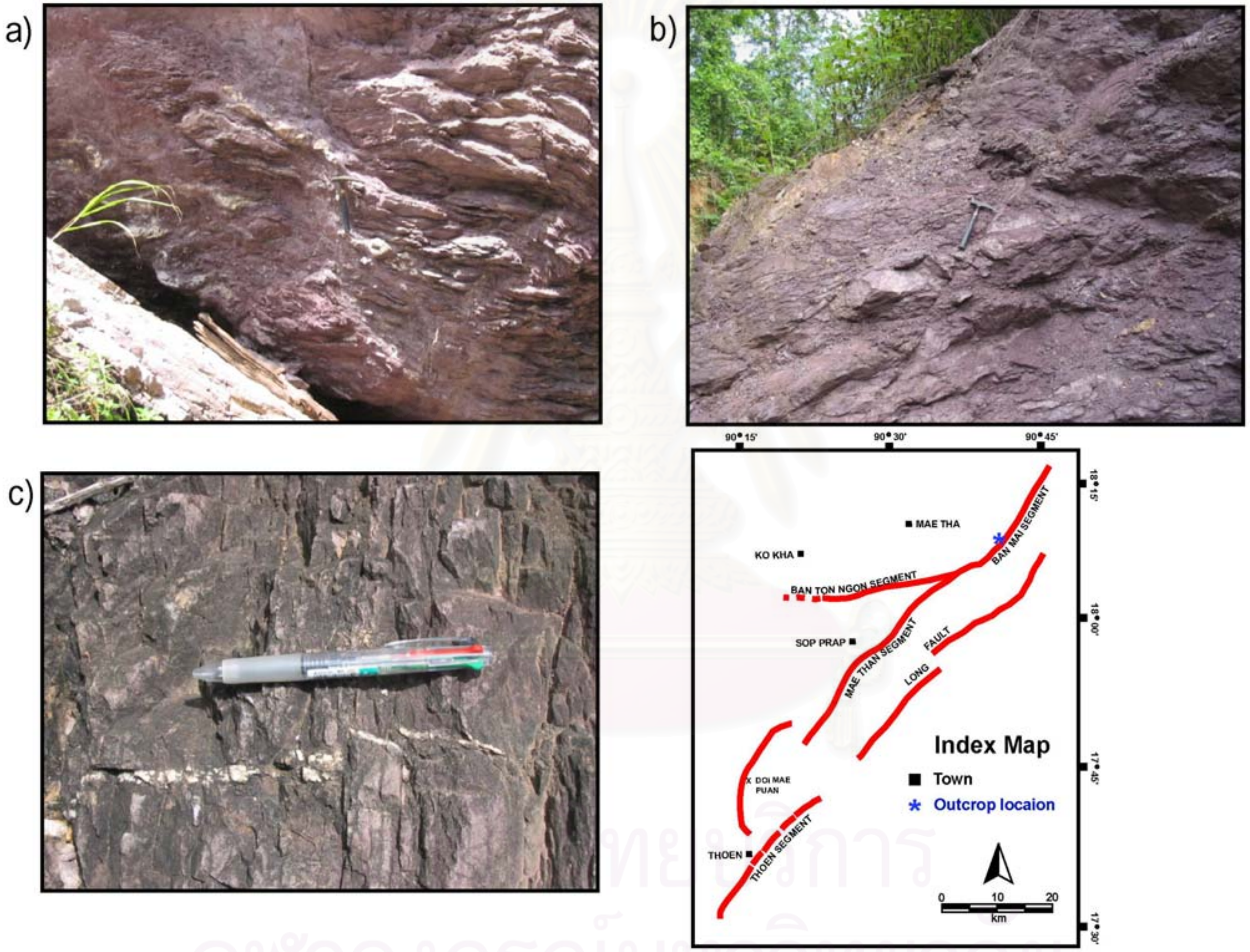


Figure 4.3 Ban Sam Kha outcrop, a) trust fault indicate right lateral, b) Normal fault indicate left lateral, and c) minor structure in ralated with quartz vine indicate left lateral movement.

4.2.3 Quaternary faulting evidence

Exposures of Quaternary faulting evidence in outcrops can be found in semi consolidated to unconsolidated Quaternary sediments. The lineament structures (or faults) in young sediments represent the deformation in Middle Tertiary age or Neotectonic episode as earlier discussed, the following outcrops in Ban Mai and Mae Than segments can provide meaningful detail on the Quaternary faulting.

4.2.3.1 Ban Mai segment

There are two fault-related outcrops located at the Ban Mai segment area, a kilometer away from bases of triangular facets (Fig 4.4). The outcrops are along the Lampang – Long Road (No.11) at 28+600 km and nearby. At the first outcrop, a normal fault cuts into the river gravel beds with the average latitude of 230°/80°NE. The fault shows a vertical offset of 1.5m. This outcrop is overlain by semi-consolidated sediment layers on the top (Figures 4.4a and b). At the second outcrop, a normal fault cuts into unconsolidated river sand sediment in 195° N with 80° dip angle, and approximately 0.5 m vertical offset has been observed. (Figure 4.4c)

4.2.3.2 Mae Than segment

There are two outcrops that show well-preserved fault movement at the Mae Than segment area, around 500 m away from Ban Huai Sra reservoir in Ban Huai Sra area. At the first outcrop at UTM 1976102 N 0544210 E, a normal fault is observed cutting river gravel beds with the overlying a clay layer. The fault attitude strikes 170° and dips 85° to the west. The vertical offset is 1.0 m approximately (Figure 4.5a). The other outcrop was found at about 200 m to the north of the first outcrop. The outcrop displays a gravel bed with the unusual orientation of pebble-size gravels in a sharp contact with the abnormal fabric of gravel has been defined in this outcrop (Figure 4.5b). The rotating of gravels is a good evidence of faulting in the gravel bed.

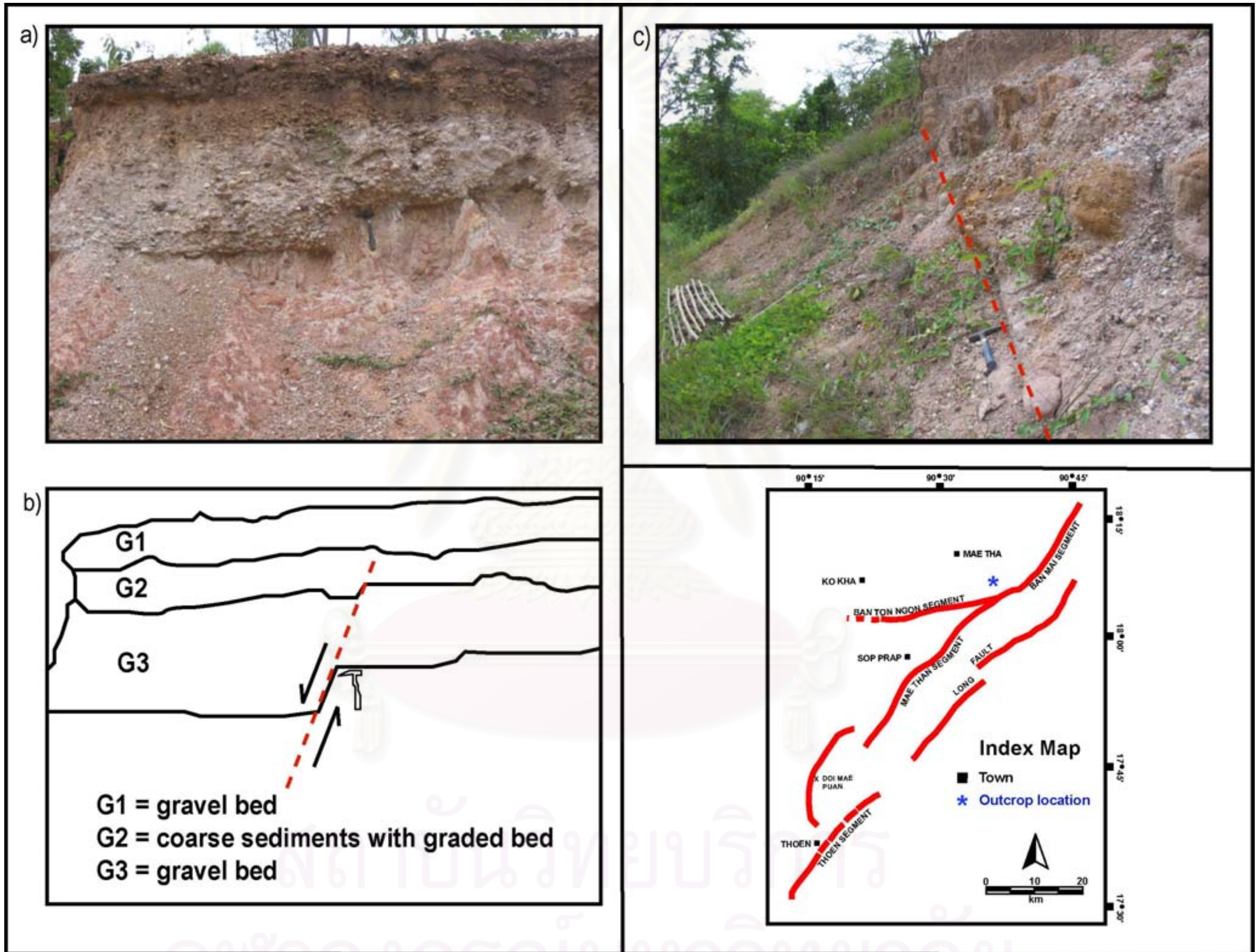


Figure 4.4 Un- to semi-consolidated Quaternary outcrops in Ban Mai segment area a) a normal fault cutting through the river gravel bed, b) shematic section from a) showing a normal fault cutting through alluvial coarse sediments.

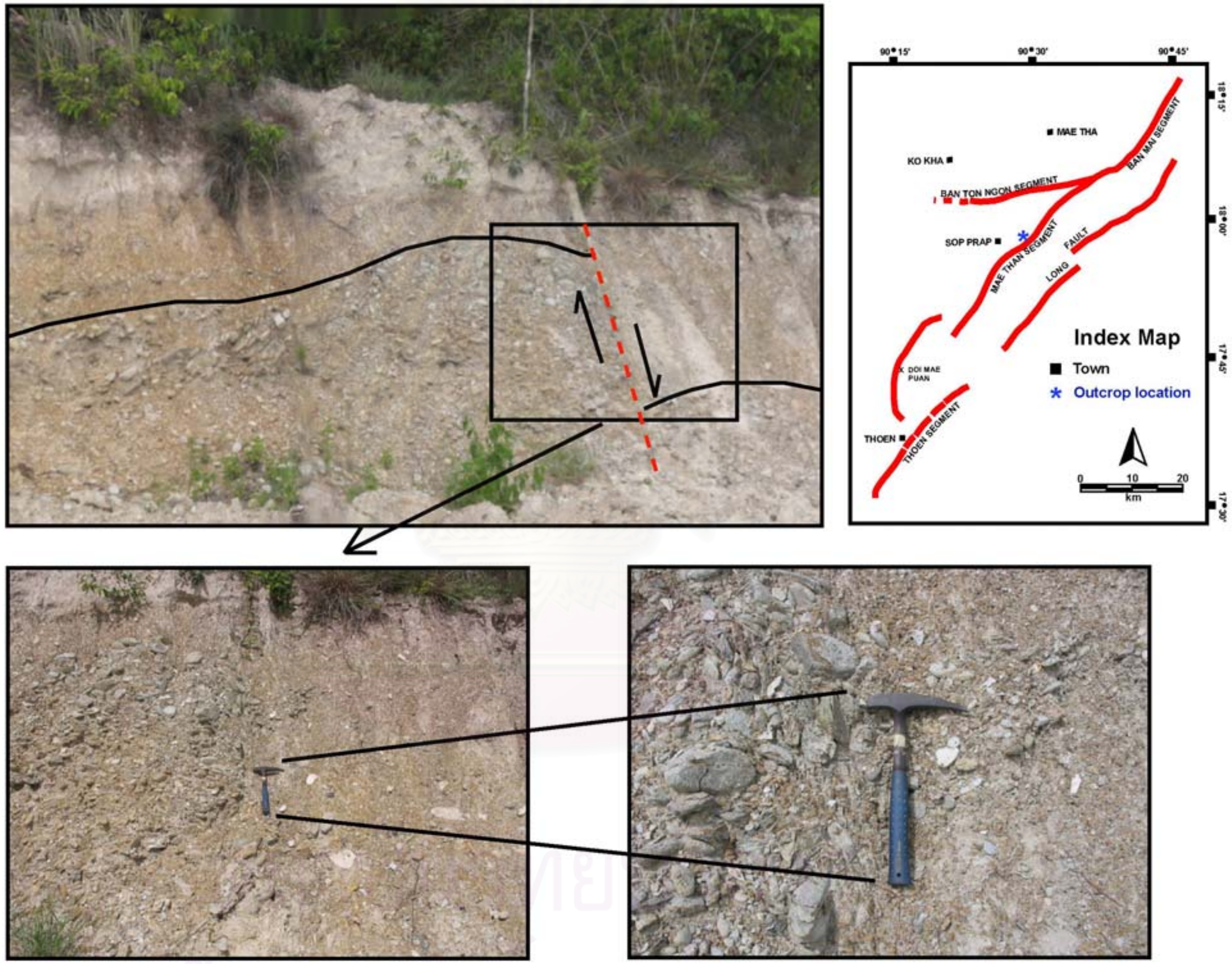


Figure 4.5a Semi-consolidated Quaternary outcrop at Ban Huai Sra (view looking S, showing a normal fault which cuts through the gravel beds and effected to gravel frabic and showing rolltating of gravel grains.

Figure 4.5b) Rolltating of gravel gains in semiconsolidated outcrop indicated faulting in young sediment.

4.3 Petrographic study

A main purpose for the petrographic investigation is to observe the meaningful microstructure under thin sections which are related to the fault characteristic of the TF fault system. Among 50 samples collected, 18 rock samples were selected for microscopic analysis. Most samples are rather friable (Figure 4.6). Only three rock samples are competent enough for thin sections. They are sample No.6 from Bam Sam Kha locality and sample No.7 and No.8 from Ban Mai locality.

4.3.1 Micro-lineament analysis

The micro-lineament analysis in this study means to a method used for defining micro-lineament structures under thin sections. All the selected samples are marked in a way to maintain the original orientation from an outcrop in the field (Figure 4.7).

The result from micro-lineament analysis is an illustrated figure of microscopic which define type and direction of lineament structure, and determine to the sequence and relation of the structural appearance. These are the result from the three rock samples.

4.3.1.1 Sample No.06 BSK (Ban Sam Kha)

This sample was collected from Ban Sam Kha locality (Fig. 4.6), in Ban Mai fault segment. The rock is red siltstone of Triassic age (Charoenprawat et al., 1995), containing several directions of quartz veinlet (Figure. 4.8). Four under microscopic frames (Sketch maps) have been made from 2 thin sections in order to observe characteristics of fault movement.

Micro-lineament analysis (Figures 4.9a-d) reveals 4 types of micro-structures including two quartz veinlets and two lineaments, using structural characteristics, such as mineralogy and fabric orientation. The sequence of structural expression indicates that the quartz veins (blue color in pictures) in NW-SE trending come first, the quartz – calcite veins (green color in pictures) in almost N-S to NE-SW trending come second, the cleavages (red color in pictures) in NE-SW trending come third, and the last is the fault (pink color in picture), left lateral movement, in NE-SW trending.

4.3.1.2 Sample No.07 BM and Sample No.08 BM (Ban Mai)

Both of these samples are collected from Ban Mai locality in Ban Mai fault segment. They are marine Triassic sedimentary rock (Charoenprawat et al., 1995), red shale and siltstone, containing several directions of Quartz vein. From the under microscope frames of them, there are not showing the meaning micro-lineament and geological evidence enough to reconstruct the stage model for these samples.

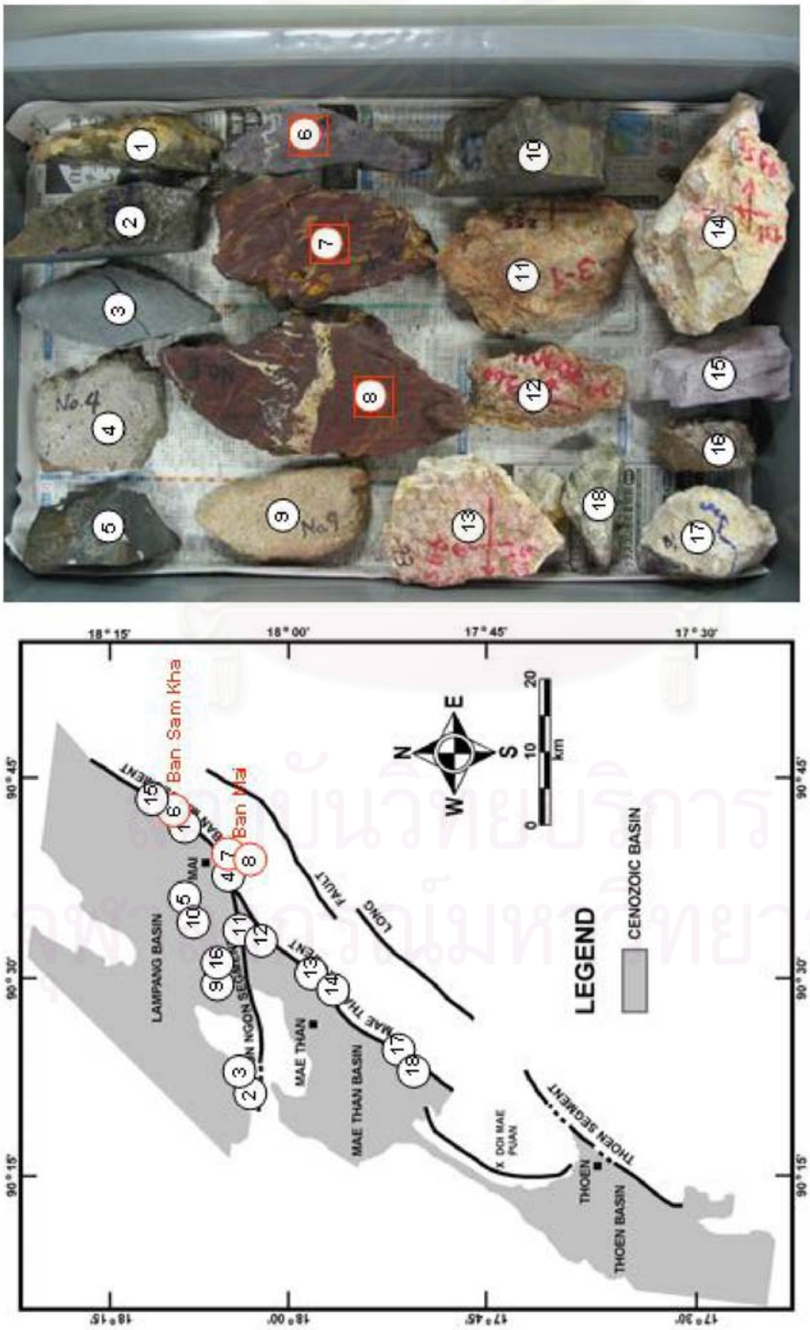


Figure 4.6 Location map of eighteen rock sampling in study area.

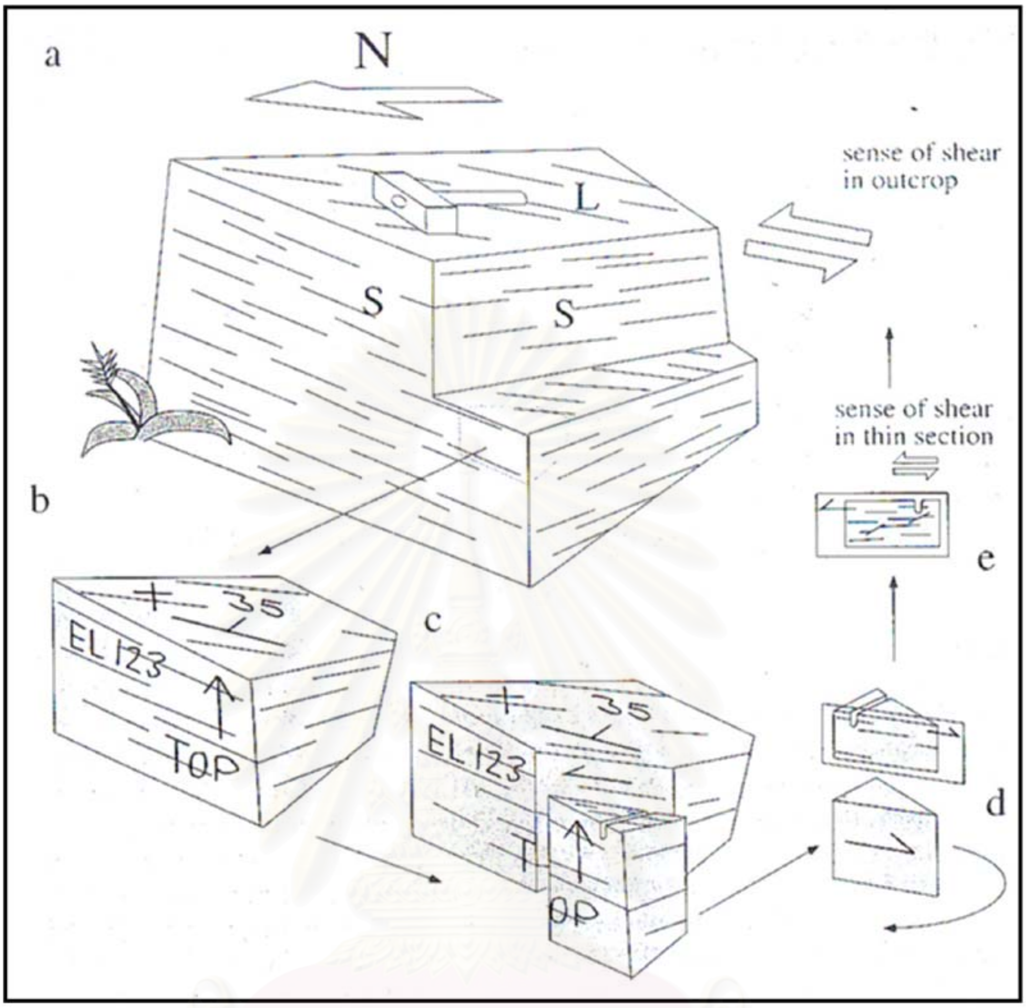


Figure 4.7 Method to obtain an oriented sample from an outcrop and an oriented thinsection from a sample. A sample for structural studies must be oriented, for example as shown in a - e (after Passchier and Trouw, 1996).

Figure 4.8 Rock sample No. 06 BSK, the red square is for this section study.

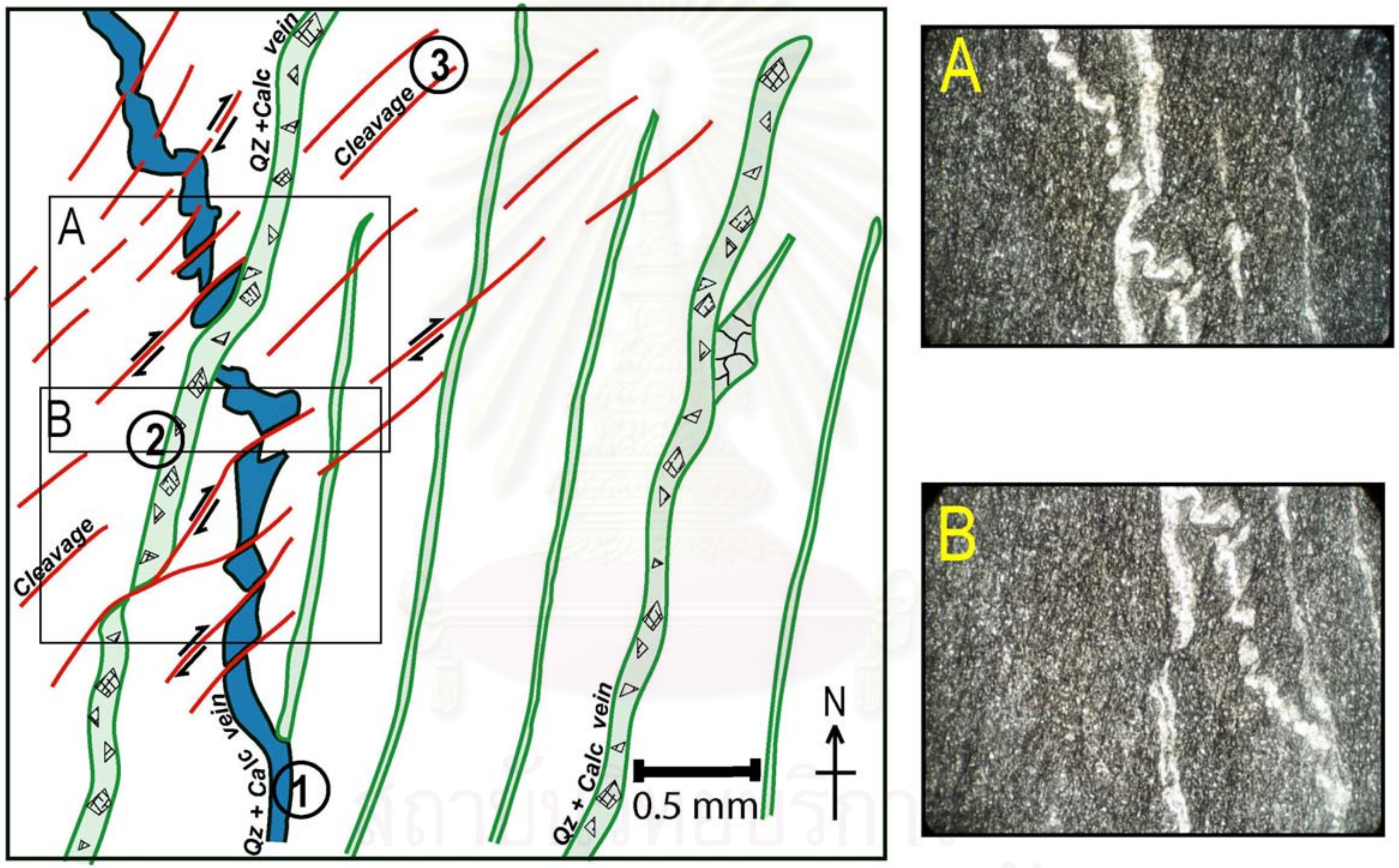
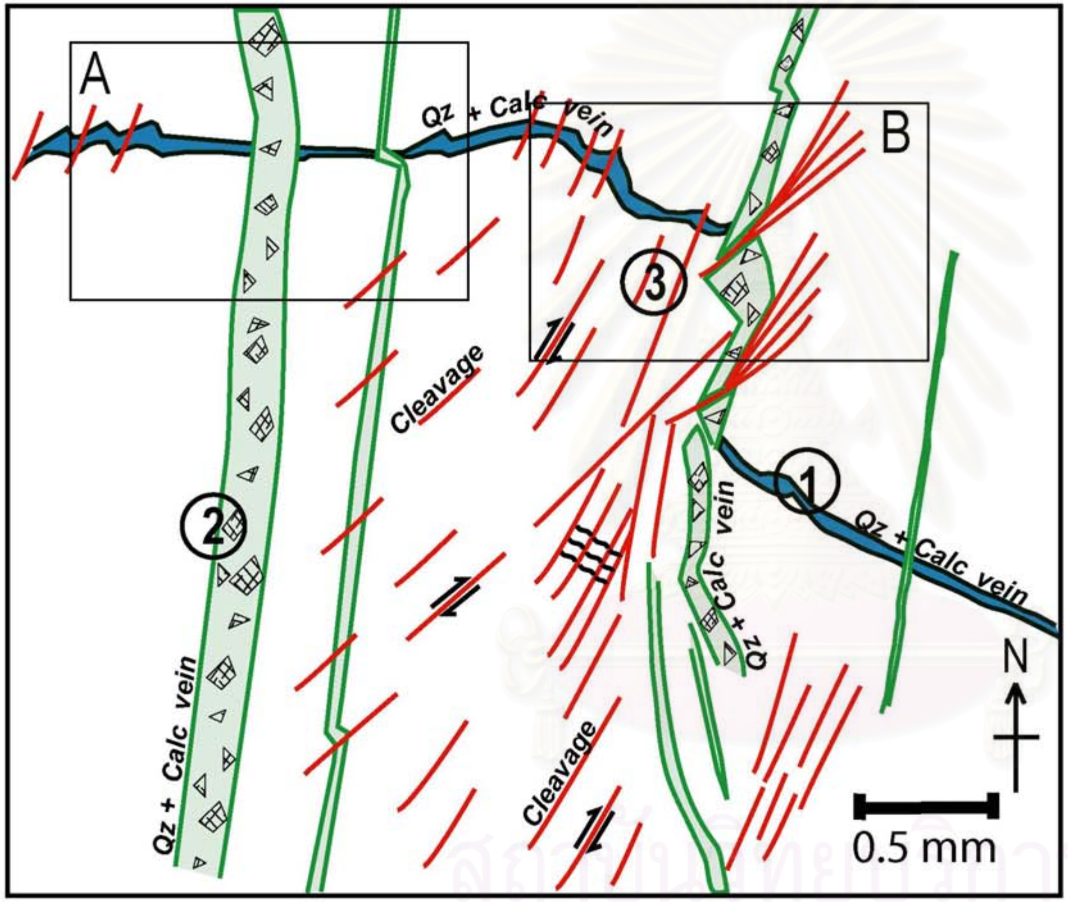


Figure 4.9a Photomicrographs (right) of sample no. 06BSK_01 (A) and (B) showing veinlets and foliation. Sketch map (left) showing combined photographs of (A) and (B) and other nearby thin-section (Note Qz = quartz, Calc = calcite).



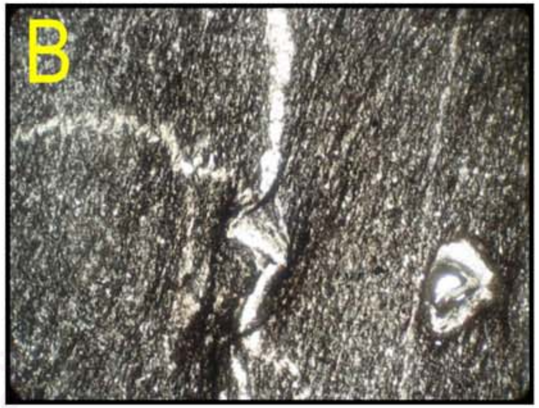


Figure 4.9b Photomicrographs (right) of sample no. 06BSK_02 (A) and (B) showing veinlets and foliation. Sketch map (left) showing combined photographs of (A) and (B) and other nearby thin-section (Note Qz = quartz, Calc = calcite).

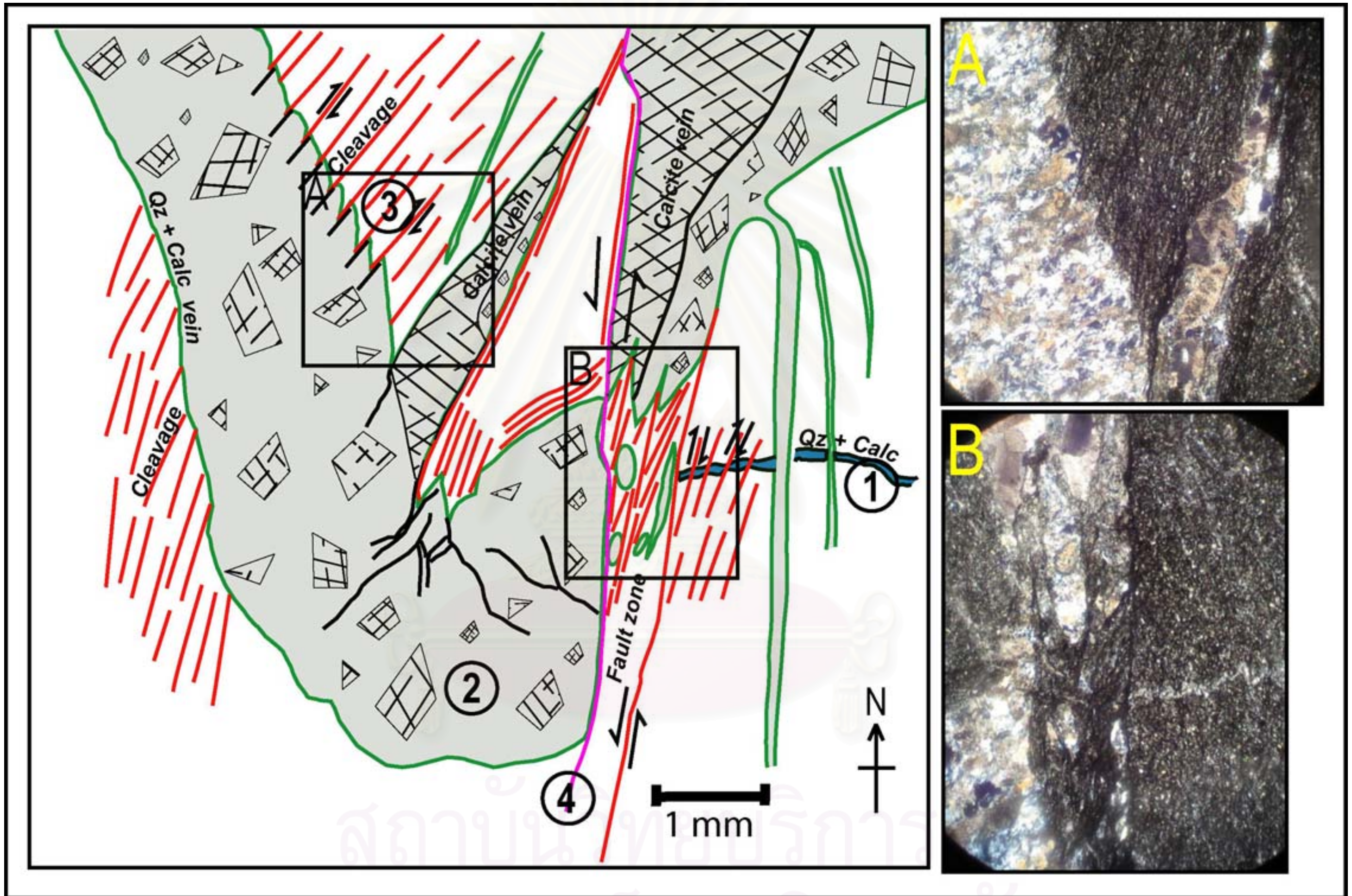


Figure 4.9c Photomicrographs (right) of sample no. 06BSK_03 (A) and (B) showing veinlets and foliation. Sketch map (left) showing combined photographs of (A) and (B) and other nearby thin-section (Note Qz = quartz, Calc = calcite)

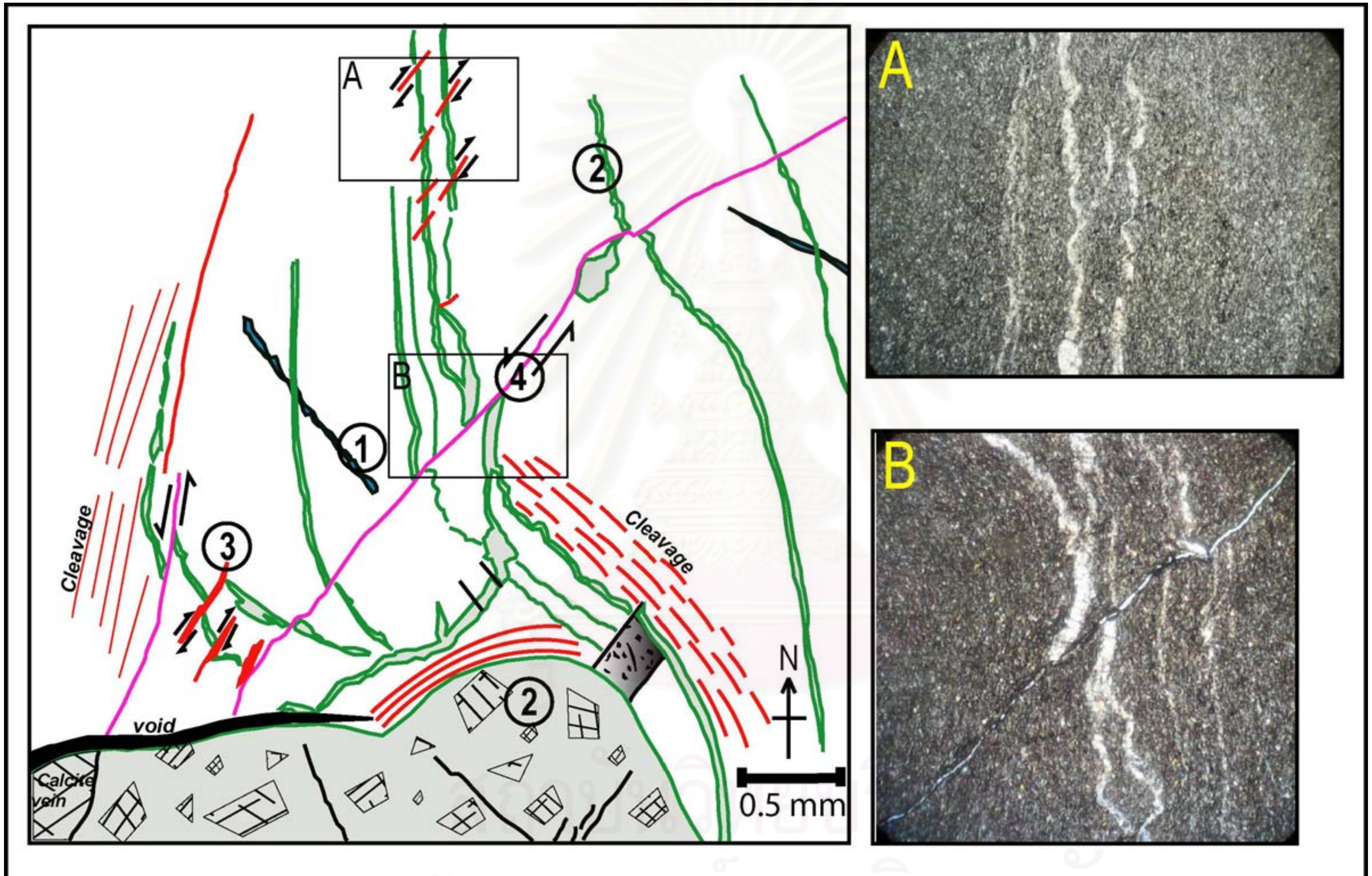


Figure 4.9d Photomicrographs (right) of sample no. 06BSK_04 (A) and (B) showing veinlets and foliation. Sketch map (left) showing combined photographs of (A) and (B) and other nearby thin-section (Note Qz = quartz, Calc = calcite).

4.3.2 Structural Stage Model

Structural stage model in this study is referred to the micro-structure reconstruction from the result of micro-lineament analysis aspect, and to demonstrate the stage of structural expression in the study area. Based on four microscopic frame recognized in sample No. 06 BSK (Figures 4.9a-d), it is possible to construct four structural stage models shown as 3D reconstruction in order to define the direction of tectonic force which is possibly influent to structural features in the study area. The stage model reconstruction has shown as follow:

1 Stage Model N0.01 (Figure 4.10a), this stage model was reconstructed from under microscopic frame No.06BSK_01 (not to scale, in Figure 4.8a).

2 Stage Model N0.02 (Figure 4.10b), this stage model was reconstructed from under microscopic frame No.06BSK_02 (not to scale, in Figure 4.8b).

3 Stage Model N0.03 (Figure 4.10c), this stage model was reconstructed from under microscopic frame No.06BSK_03 (not to scale, in Figure 4.8c).

4 Stage Model N0.04 (Figure 4.10d), this stage model was reconstructed from under microscopic frame No.06BSK_04 (not to scale, in Figure 4.8d).

Finally, the individual models were combined and reinterpreted for structural evolutions of the study area. Five stages are involved in the structural evolution, they are:

1. Stage 1: The initial stage for the occurrence of bedding planes. It is assumed that no deformation was recognized at this stage.
2. Stage 2: This stage is the first stage that the structure was developed. The appearance of the NW-trending (blue color) supports this stage.
3. Stage 3: This stage represents the second stage of deformation. The major supporting structure is quartz-calcite in the NE-SW trend (green color).
4. Stage 4: This stage is the third stage of deformation. The important structure is the NE-SW trending cleavage planes (red color).
5. Stage 5: This stage is the forth stage of deformation. It is characterized by left lateral fault in the NE-SW trend (pink color).

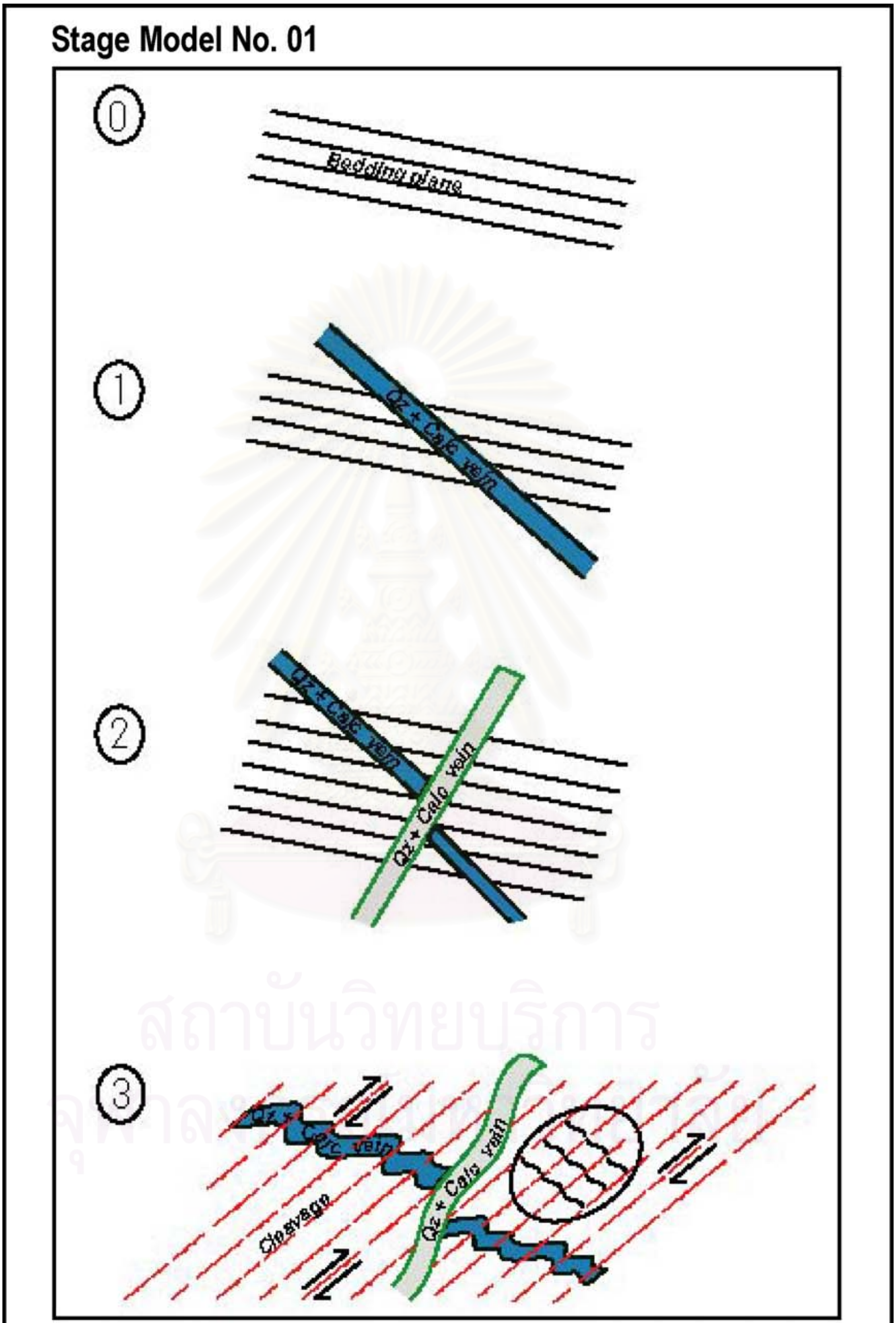


Figure 4.10a Stage Model No. 01 (not to scale) represent structure evolusion of shear and fracture tectonic area.

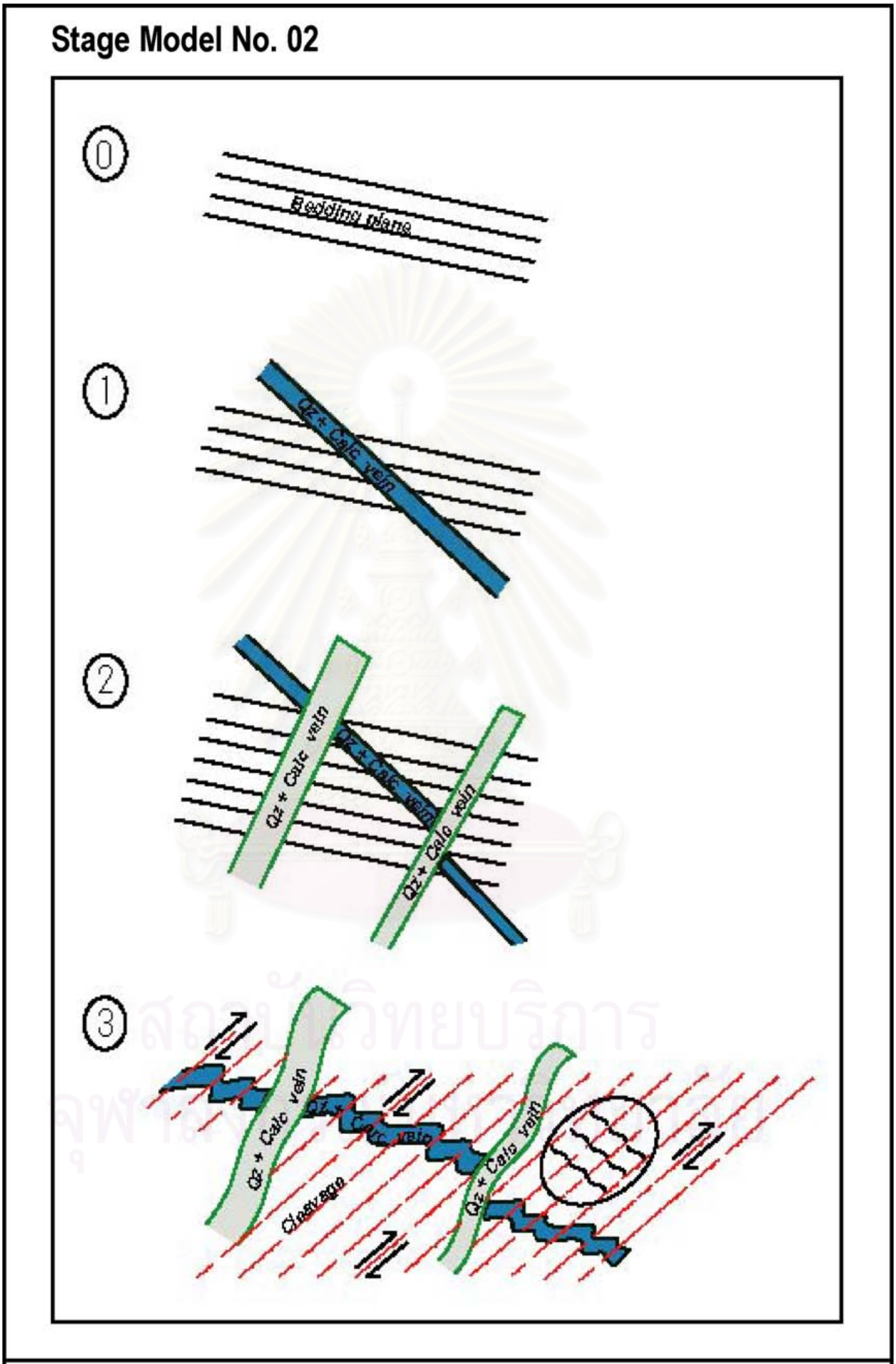


Figure 4.10b Stage Model No. 02 (not to scale) represent structure evolusion of shear and fracture tectonic area.

Stage Model No. 03

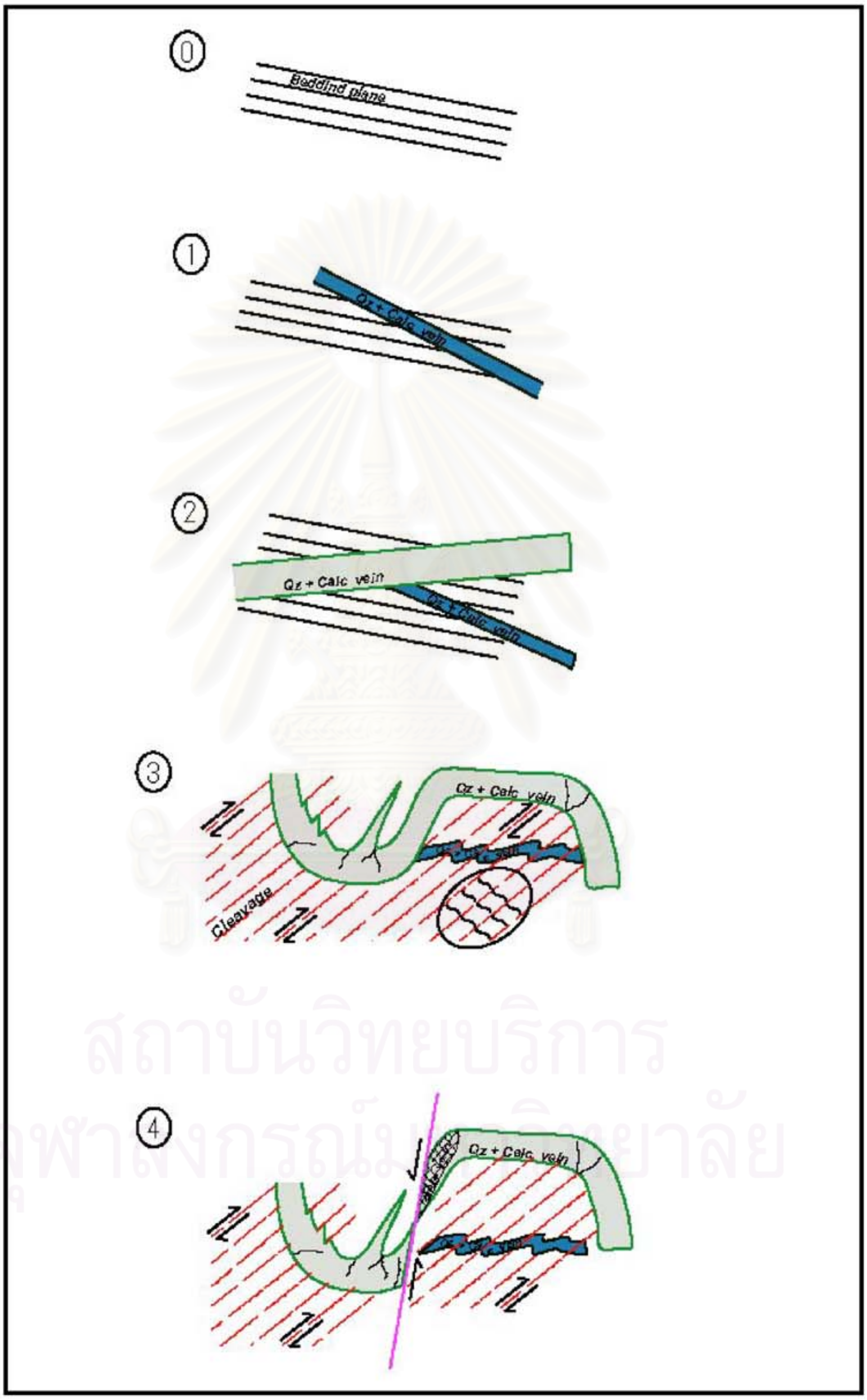


Figure 4.10c Stage Model No. 03 (not to scale) represent structure evolusion of shear and fracture tectonic area.

Stage Model No. 04

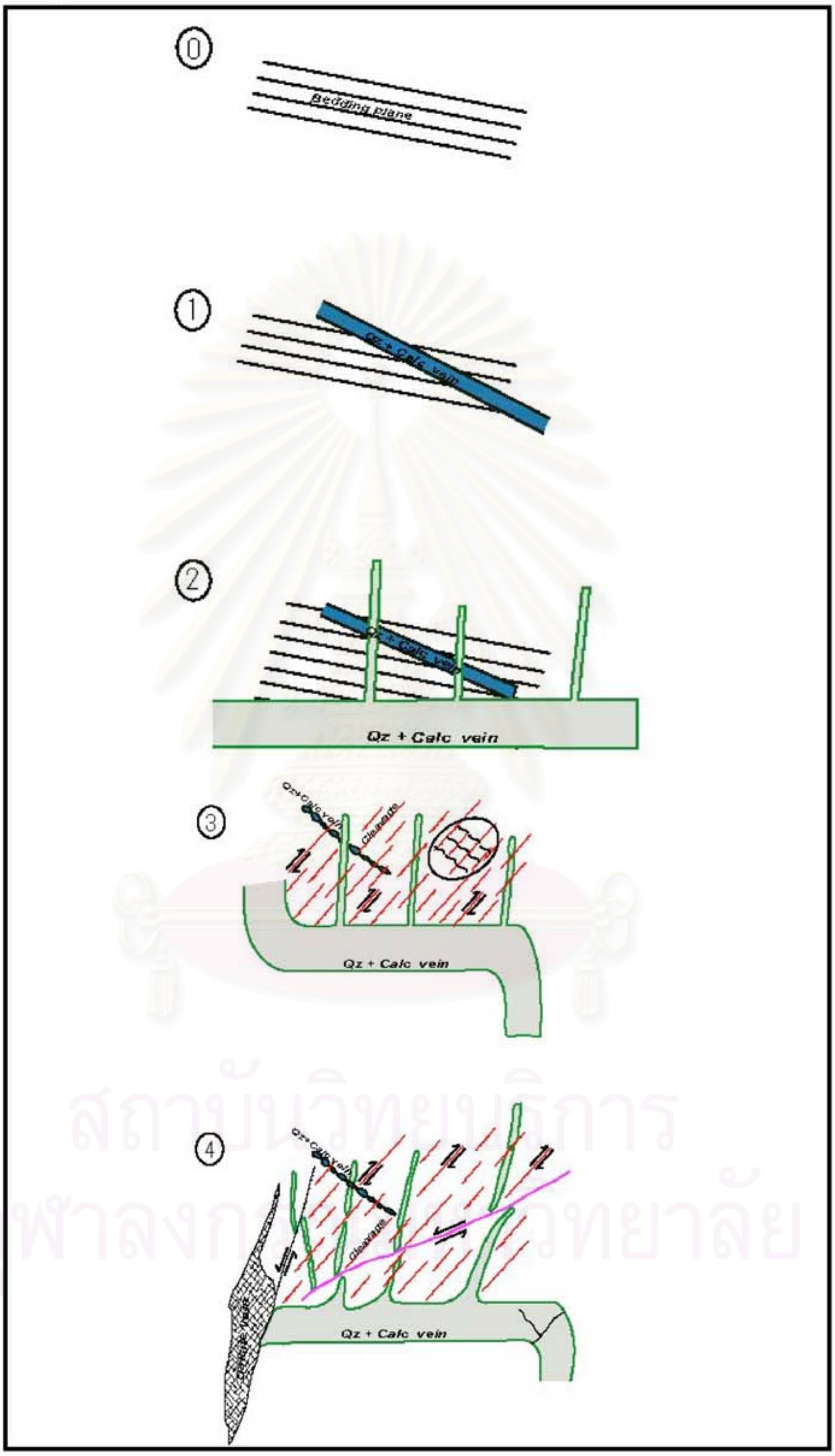


Figure 4.10d Stage Model No. 04 (not to scale) represent structure evolusion of shear and fracture tectonic area.

CHAPTER V
SUBSURFACE INVESTIGATION

At the last step the identification of active fault and structural investigation of neotectonics are performed. This chapter describes the specific ground geophysical tool applied in this aspect with the aim of further identifying fault movement on the one hand, and complementing and specifying the characteristic of concealed fault underneath subsurface young sediment, on the other hand. It will not go into a detail about the theoretical aspect of data acquisition and processing because it is not the main interest of this study to apply methodology developed elsewhere, sometime modifying the techniques for our purpose, rather than to contribute to a new development in this field of science for a geologist.

5.1 Introduction

Ground penetrating radar (commonly called GPR) is a high resolution electromagnetic (EM) geophysical technique that is designed primarily to investigate the shallow imaging and mapping of subsurface soils and rock conditions (Basson, 2000). GPR has been developed over the past 30 years for shallow and high resolution investigations of the subsurface.

GPR uses the principle of scattering of electromagnetic waves to locate buried objects. The basic principles and theory of operation for GPR have evolved through the disciplines of electrical engineering and seismic exploration, and practitioners of GPR tend to have backgrounds either in geophysical exploration or electrical engineering. The fundamental principle of operation is the same as that used to detect aircraft overhead, but with GPR that antennas are moved over the surface rather than rotating about a fixed point. This has led to the application of field operational principles that are analogous to the seismic reflection method (Daniels, 2000).

GPR is a method that is commonly used for geological environmental, engineering, archeological, and other shallow investigations. The fundamental principles that are described in the following text apply to all of these applications.

5.2 Basic concept of GPR

A typical GPR system has three main components: transmitter and receiver that are directly connected to an antenna, and a control unit (Figure. 5.1). The transmitting antenna radiates a short high-frequency EM pulse into the ground, the first pulse is the wave that travels directly through the air (since the velocity of air is greater than any other material), and the second pulse that is the pulse that travels through the material and is scattered back to the surface, traveling at a velocity that is refracted, diffracted, reflected, or resonant primarily as it encounters change in dielectric permittivity (ε) and electric conductivity (Figure. 5.2).

The propagation of a radar signal depends mainly on the electrical properties of the subsurface material. Waves that are scattered back toward the earth's surface can induce a signal in receiving antenna, and are recorded as digitized signal and further analysis.

5.3 GPR method

There are three main steps of GPR investigation that need to be mentioned. One is the data acquisition, two is data processing, and three is data interpretation in briefly information.

In this study, we used the GPR instrument in version of SIR 2000 (Figure 5.3). Two antenna different frequencies -200 and 400 MHz- were designed to cover the depth of interest from surface down to 5 to 10 meters. Both the 200 MHz and 400 MHz antennas are capable of penetrating to that depth (Table 5.1). The reason of using that depth range is on the fact that the depth to the bed rock based on our field reconnaissance survey is generally not more than 10 meters.

Table 5.1The best GGSI antenna to use for a given depth range of investigation.

Depth Range of Interest	Best antanna to use	Second Choice
0-0.5m (0-1.5ft)	1500MHz	900MHz
0-1m (0-3ft)	900MHz	400MHz
0-2.5 (0-8ft)	400MHz	200MHz
0-9m (0-30ft)	200MHz	100MHz
0-20m (0-60ft)	Subecho-70	100MHz
0- >20m (0- >60ft)	Subecho-40	100MHz

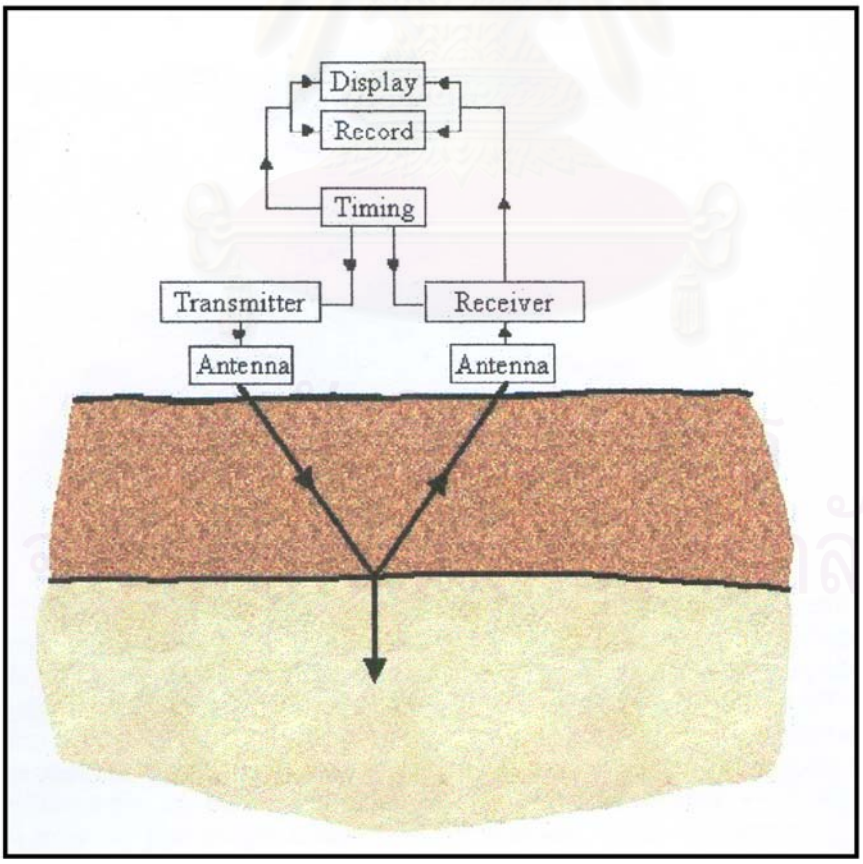


Figure 5.1 Flow chart for a typical GPR system (after Davis et al., 1989).

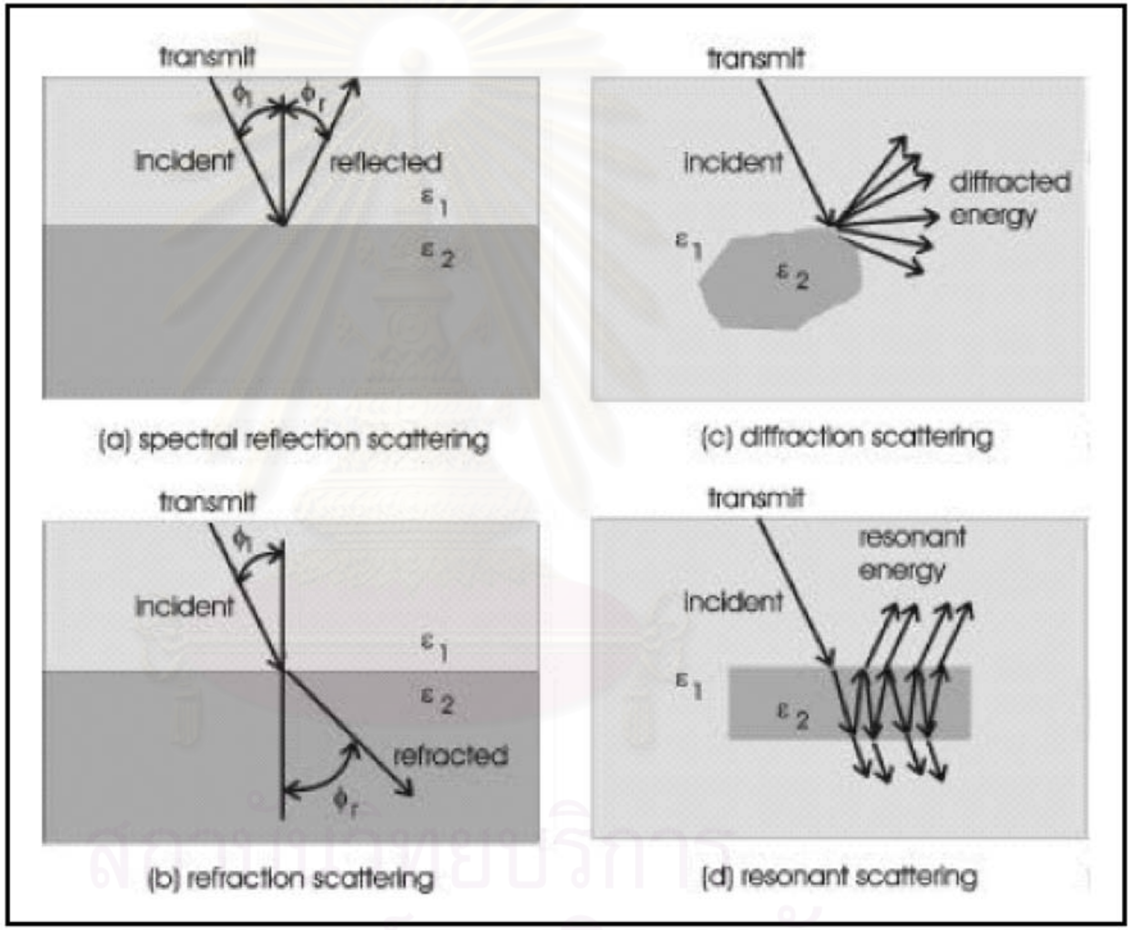


Figure 5.2 Scattering mechanisms: (a) specular reflection scattering, (b) refraction scattering, (c) diffraction scattering, and (d) resonant scattering (after Daniels, 2000).

Figure 5.3 GPR inatrument version SIR 2000. The unit control is on the black box, and the red box on thr ground is antenna 400 MHz. (http://www.du.edu/~lconyers/SERDP/whatis2.htm)

5.3.1 Data acquisition

Figure 3.17 shows the purposed location map of GPR surveys. Among the proposed 12 locations, 6 localities were selected for subsurface investigation depending on the limit of time, accessibility, and permission from the landowner.

From 6 locations, there are 4 locations that can contribute the good GPR sections, and the rest are poor quality profiles due to raining on that day. Thus neither Ban Sob Pad(1) and Ban Bom Luang(4) sections will present in this chapter (Figure 5.4). The GPR sections at Ban Pha Sadej(6) have shown too much diffraction signals on the fracture rock below very thin layers of young sediment (see cross section model in figure 3.7), therefore, the GPR profiles at Ban Pha Sadej can not be used for Quaternary faulting interpretation in this study.

Following are the data acquisition parameters, which are applied in the 200 MHz antenna for the depth 5-9 meters from surface.

Data Collection Mode: Continuous
Range: 120ns
Sample per Scan: 512
Resolution: 16 bits
Number of gain points: 5
Vertical High Pass Filter: 30 MHz
Vertical Low Pass Filter: 400 MHz
Scan per second: 32
Horizontal Smoothing: 5 scans
Transmit Rate: 64 KHz

Following are the data acquisition parameters, which are applied in the 400 MHz antenna for the depth 5-9 meters from surface.

Data Collection Mode: Continuous
Range: 60ns
Sample per Scan: 512
Resolution: 16 bits
Number of gain points: 5
Vertical High Pass Filter: 60 MHz
Vertical Low Pass Filter: 800 MHz
Scan per second: 32
Horizontal Smoothing: 5 scans
Transmit Rate: 64 KHz

Note that, all these parameters were setup on the declared depth of interest, resolution, and the operation manual guidance.

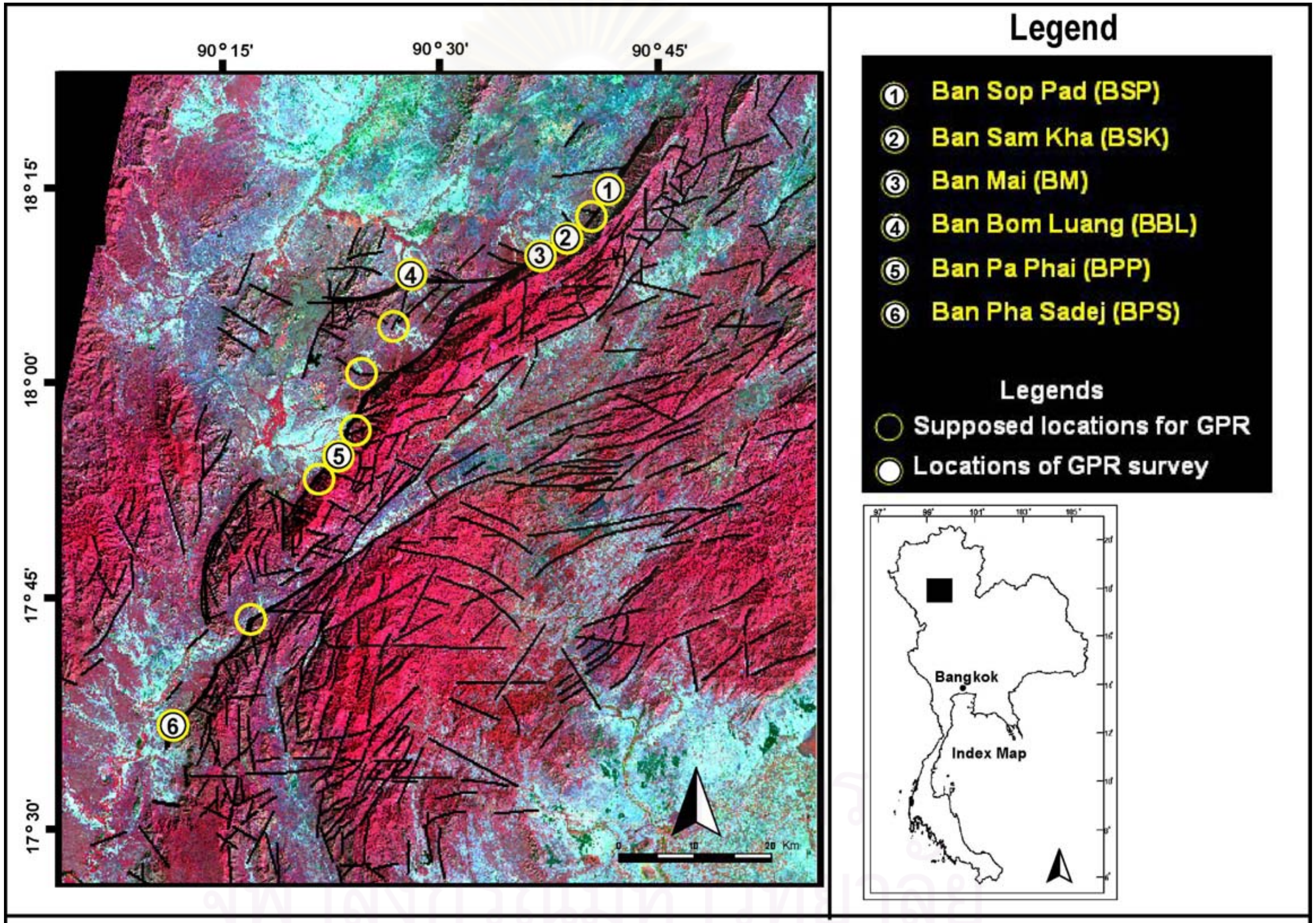


Figure 5.4 Six selected locations for GPR servey covering four segments of the Thoen fault systemin the study area.

5.3.2 Data processing

The processing stage is the step to prepare data into easily understandable and translate pattern. REFLEX® program were used for this research. It is the new Windows™ 9x/NT version of REFLEX – the dos program for the processing and interpretation of transmission data (special application: GPR, reflection and refraction seismic, and ultrasound). In addition, enhancing other functions, such as increasing amplitude values or decreasing amplitude values to the processed GPR profiles may help to facilitate visualization and interpretation also.

4 steps are involved in the processing.

5.3.2.1 Subtract-mean (dewow)

The filter act on each trace independently. With this option activated, a running mean value is calculated for each value of each trace, which this running mean is subtracted from the central point. As filter parameter the **time window** for the calculation of the running mean value must be entered. This filter may be used for eliminating a possible low frequency part (dewow). For this purpose the window range is set to about one principle period.

5.3.2.2 Manual gain (y)

The filter acts on each trace independently. The option allows to interactively define a digitized gain curve in y-direction (normally time axis) and to apply this gain curve on the data. After having activated the option, a table and a new window appears which both allow the interactive input of the new gain curve (**time** in the given time dimension and **factor** in db). The chosen values are automatically transferred to the table input and vice versa to the gain window. Inputs between -20 and 80 db (decibels) are possible. Between the individual marks, the values are linearly interpolated. At the margins the specified value belonging to the smallest or largest y-coordinate, respectively, is extrapolated. The effect of the entered gain values is automatically shown within the filtered trace window.

5.3.2.3 Background removal

This filter acts on the chosen number of traces. The filter performs a subtracting of an averaged trace (trace range) which is built up from the chosen time/distance range of the actual section. The filter performs a so-called background removal. With this option you can eliminate temporally consistent noise from the whole profile and therefore possibly make signals visible, previously covered by this noise. This filter method also suppresses horizontally coherent energy. Its effect is also to emphasize signals which vary laterally (e.g. diffractions). Note that it might happen that the filter causes non real signals. This holds true when the averaged time series contains energy which is not present within any part(s) of the profile.

5.3.2.4 Bandpass frequency

The filter acts on each trace independently. Here you can apply a bandpass filter to each trace in the frequency domain. The filter band is specified by the setting of four frequency values. The first point determines the **low-cut frequency**, the second one the beginning of the plateau (**lower plateau**). Between the low-cut frequency and the beginning of the plateau the filter is represented by a cosine-window. The third point determines the end of the plateau (**upper plateau**) and the fourth the **high cut frequency**. Between these points the filter is represented by a cosine-window, too. The frequency spectrum below the low cut and above the high cut frequency is set to zero. By the corresponding choice of the points of the bandpass either a lowpass or a highpass can be approximately realized. The cosine-range is used to suppress unwanted reverberations resulting from the filter operator. The cosine range should be adapted to the spectral amplitudes existing at the high and low-cut frequencies. If the spectral amplitudes are quite low, the cosine-range can be decreased. Noise can be suppressed with the bandpass filter when it differs from the signal in its frequency content. It is recommended to select a trace containing both a significant portion of noise and of the signal for the filter parameters setting.

After data processing step is to sort out the best data from an individual line survey's data. The 200 MHz antenna is the best instrument for this research because it can give both detail of stratigraphy and structure information, whereas the 400 MHz antenna contribute the most fine data but it is not giving much about stratigraphy information, and too much noise and multiple on the other hand. However, in some case such a tiny offset case, the 400 MHz should been used for the most accurate result.

And therefore, the best individual line surveys were selected from 200 MHz's profile from each location. The 3 enhanced profiles from 3 locations are illustrated in Figures 5.5a, 5.5b, and 5.5c.

5.3.3 Data interpretations

In general, GPR sections of the 200 MHz antenna show clearly images of the shallowest 5-6 m below surface. The interpretation method is based on the anomalous characteristic of the enhanced data. For the fault interpretation, it can be defined by the characteristic change of intensity and discontinuity between layers in the GPR profiles.

Another word, the fault interpretation is referred to that of Rashed and Nakagawa (2003) which concerns about 3 criteria for interpreting faults from GPR profiles.

1. The displacement of the reflections of the side of the fault strand.
2. The presence of the diffraction hyperbola.
3. The drastic decrease of amplitude along the fault plane.

In that way, the upper paragraphs are the principle to use in the interpretation method.

5.3.3.1 Ban Mai interpretation profile

This profile is collected from Ban Mai location in the flat area of rice field, about 60 meters long and 5 meters depth. From the profile, the fault character can be observed at 10 meters to 24 meters of the survey point (Figure 5.6a). The details are:

1. From the intensity of signal, 3 units (A, B, and C) can be interpreted.
2. In the middle part of the profile, the signal shows discontinuity of the layers of unit A, B, and C. Reverse fault is interpreted.
3. The maximum appearance dip angle of the discontinuity plane is about 22^{o} degree.
4. The maximum appearance offset is 1.5 meters approximately.

5. The fault should cut through the sediment layers at least 1.5 meters depth below surface.

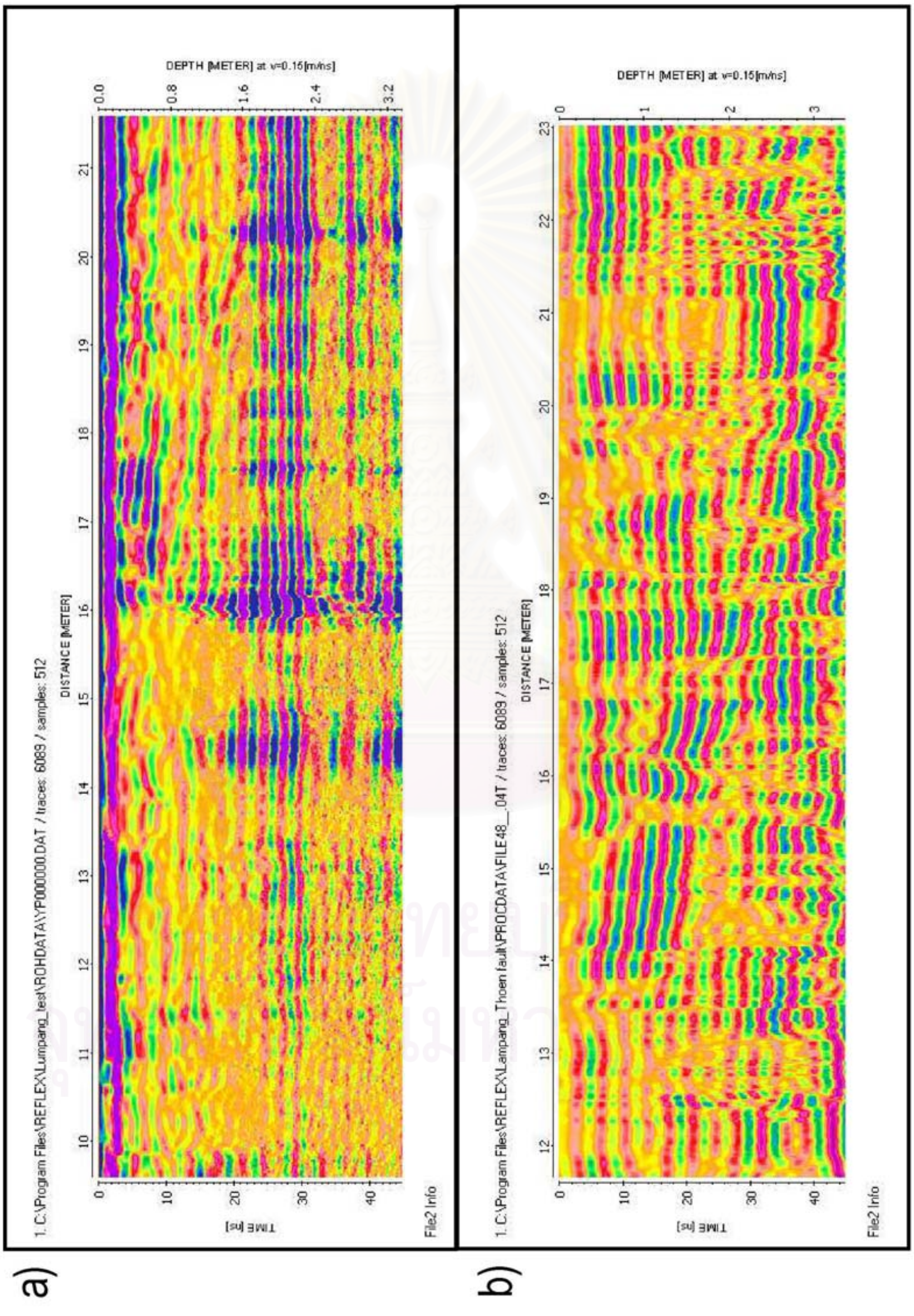


Figure 5.5a GPR section at Ban Mai location, a) a data section, using antenna 200 MHz, b) the enhanced data section of (a).

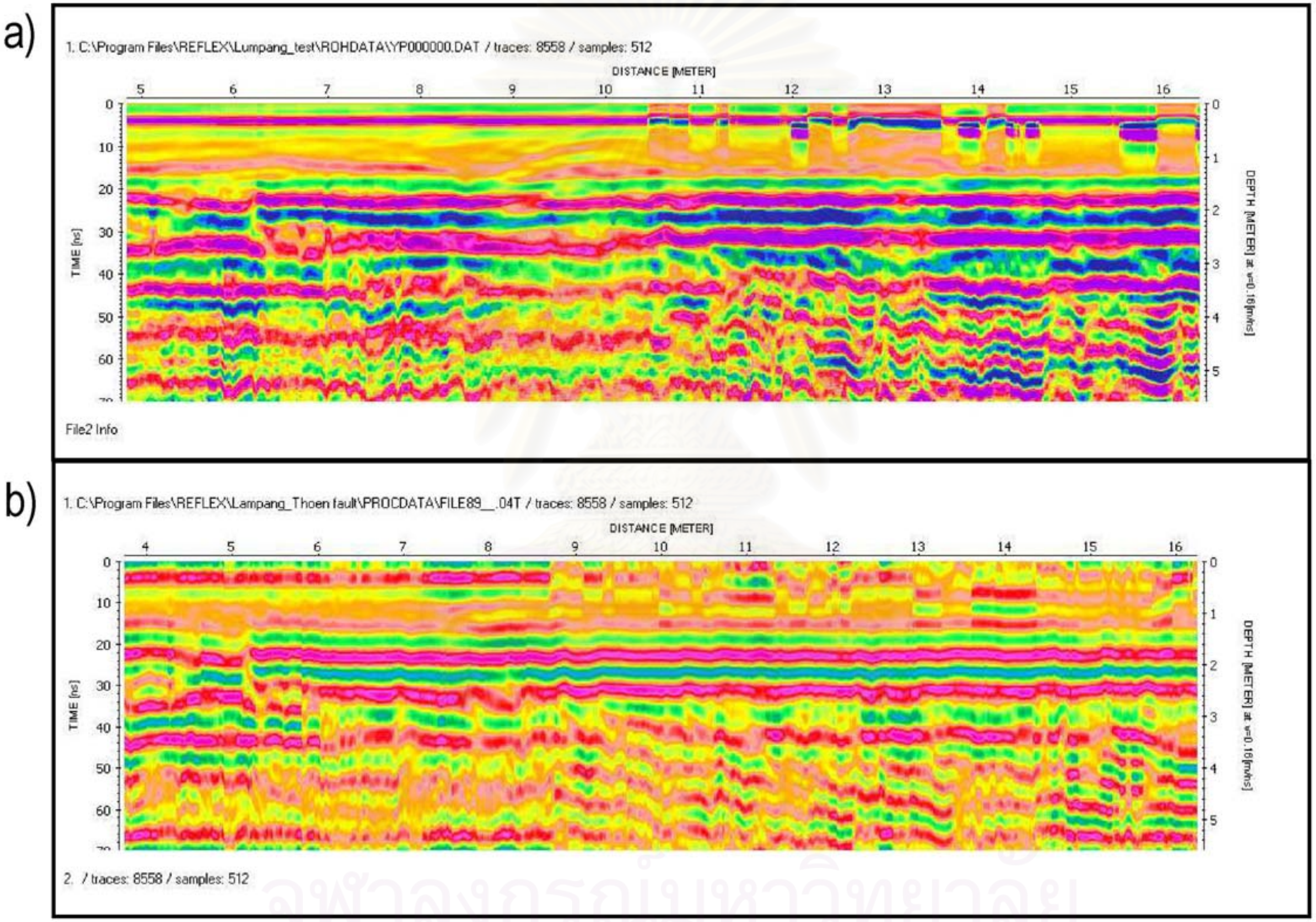
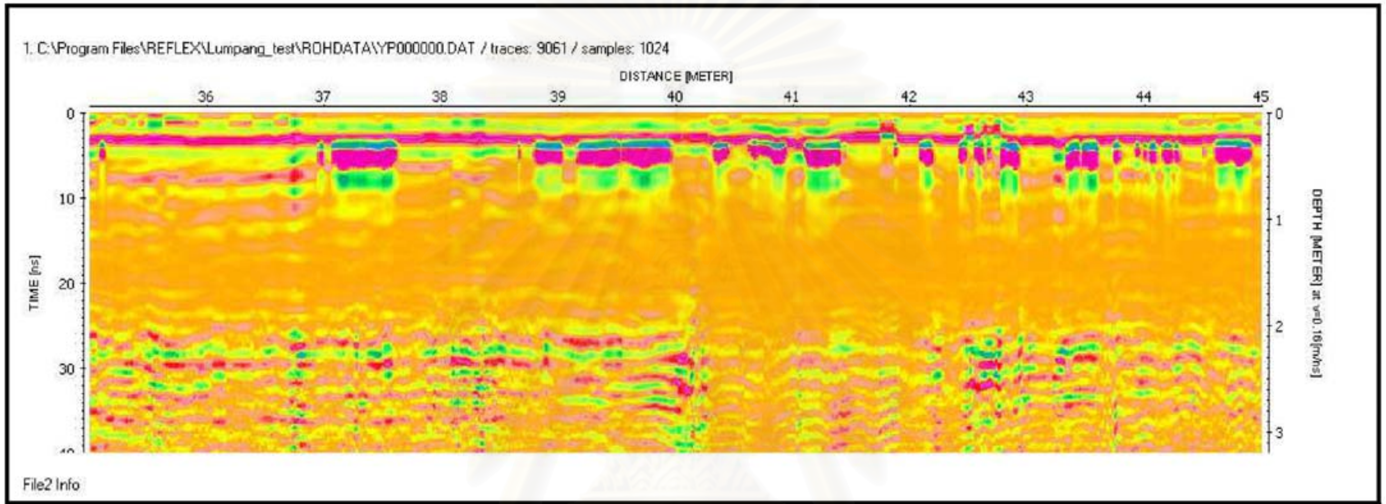


Figure 5.5b GPR section at Ban Sam Kha location, a) a data section, antenna 200 MHz, b) the enhanced data section of (a).

a)



b)

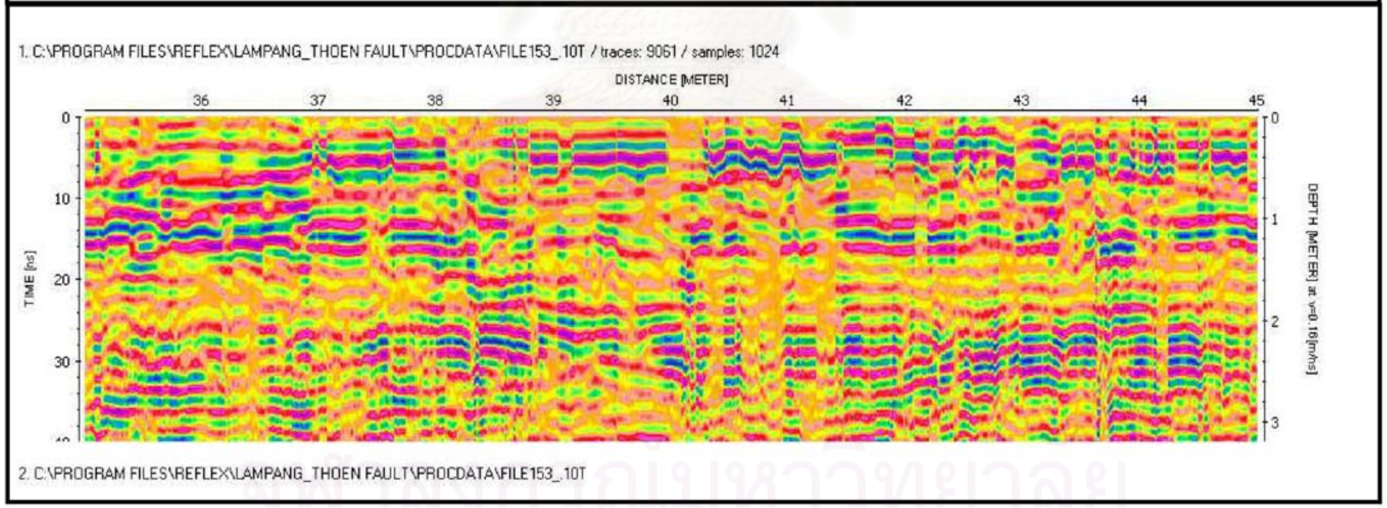


Figure 5.5c GPR section at Ban Pa Pai location, a) a data section, antenna 200 MHz, b) the enhanced data section of (a).

5.3.3.2 Ban Sam Kha interpretation profile

This profile is collected from Ban Sam Kha location in the flat area of rice field, about 60 meters long and 5 meters depth. From the profile, the fault character can be observed at 4 meters to 16 meters of the survey point (Figure 5.6b). The details are:

1. From the intensity of signal the same 3 units (A, B, and C) can be interpreted.
2. In the middle part of the profile, the signal shows discontinuity of the layers of unit A as a reverse fault.
3. The maximum appearance dip angle of the discontinuity plane is about 12° degree at the lower part and about 40° degree at the upper part of the plane.
4. The maximum appearance offset is 1.4 meters approximately.
5. The fault should cut through the sediment at least 2.6 meters depth below surface.

5.3.3.3 Ban Pa Phai interpretation profile

This profile is collected from Ban Pa Phai location in the flat area of rice field, about 60 meters long and 5 meters depth. From the profile, the fault character can be observed at 4 meters to 16 meters of the survey point (Figure 5.6c). The details are:

1. From the intensity of signal the same 3 units (A, B, and C) are recognized.
2. In the middle part of the profile, the signal shows discontinuity of the layers of unit A as a reverse fault.
3. The maximum appearance dip angle of the discontinuity plane is about 18° degree at the lower part and about 60° degree at the upper part of the plane.
4. The maximum appearance offset is 0.4 meters approximately.
5. The fault should cut through the sediment at least 0.3 meters depth below surface.

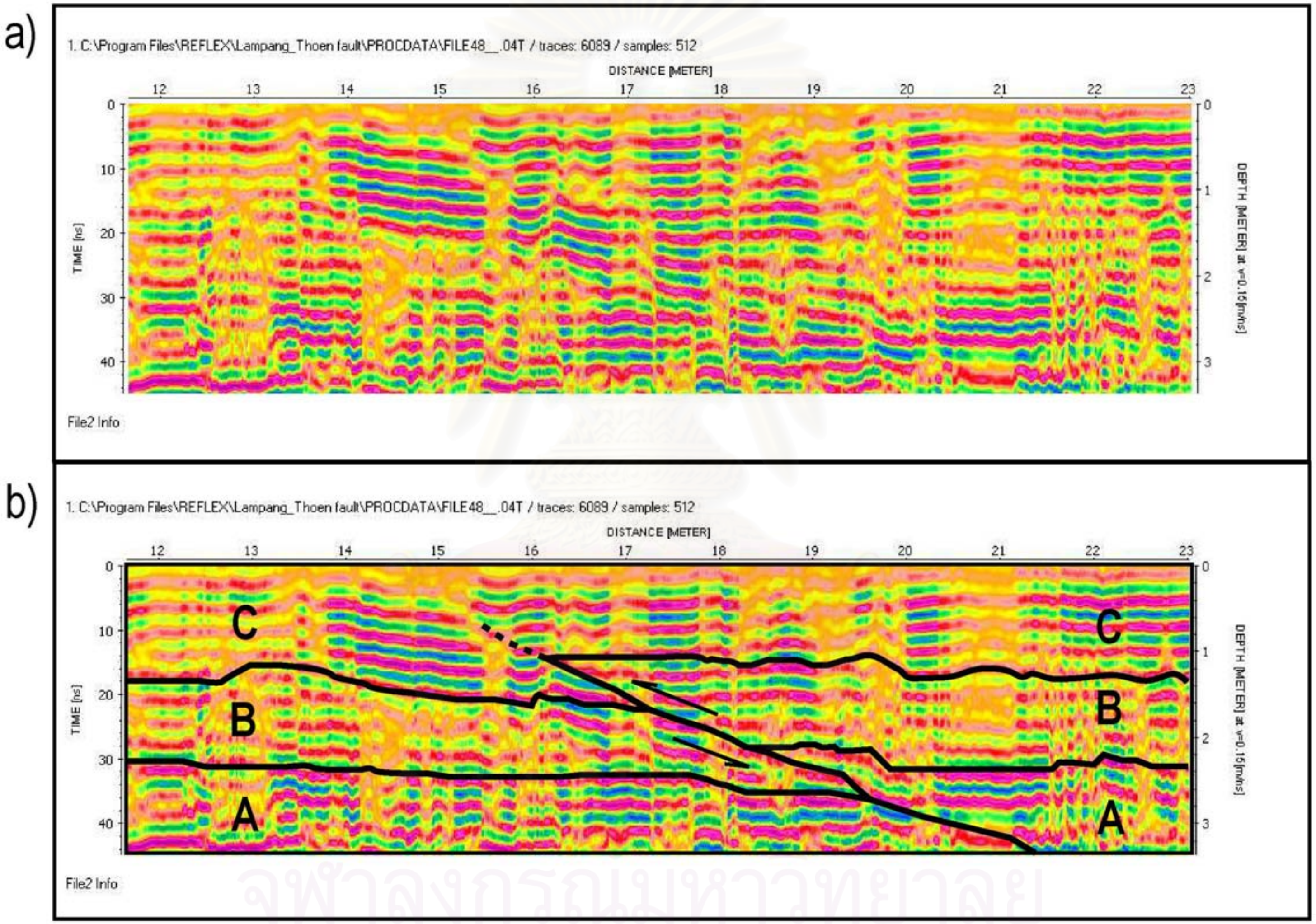


Figure 5.6a The Ban Mai's interpretation profiles of a) an enhanced profile, b) the interpretaion profile showing GPR strtigraphy and a main structure.

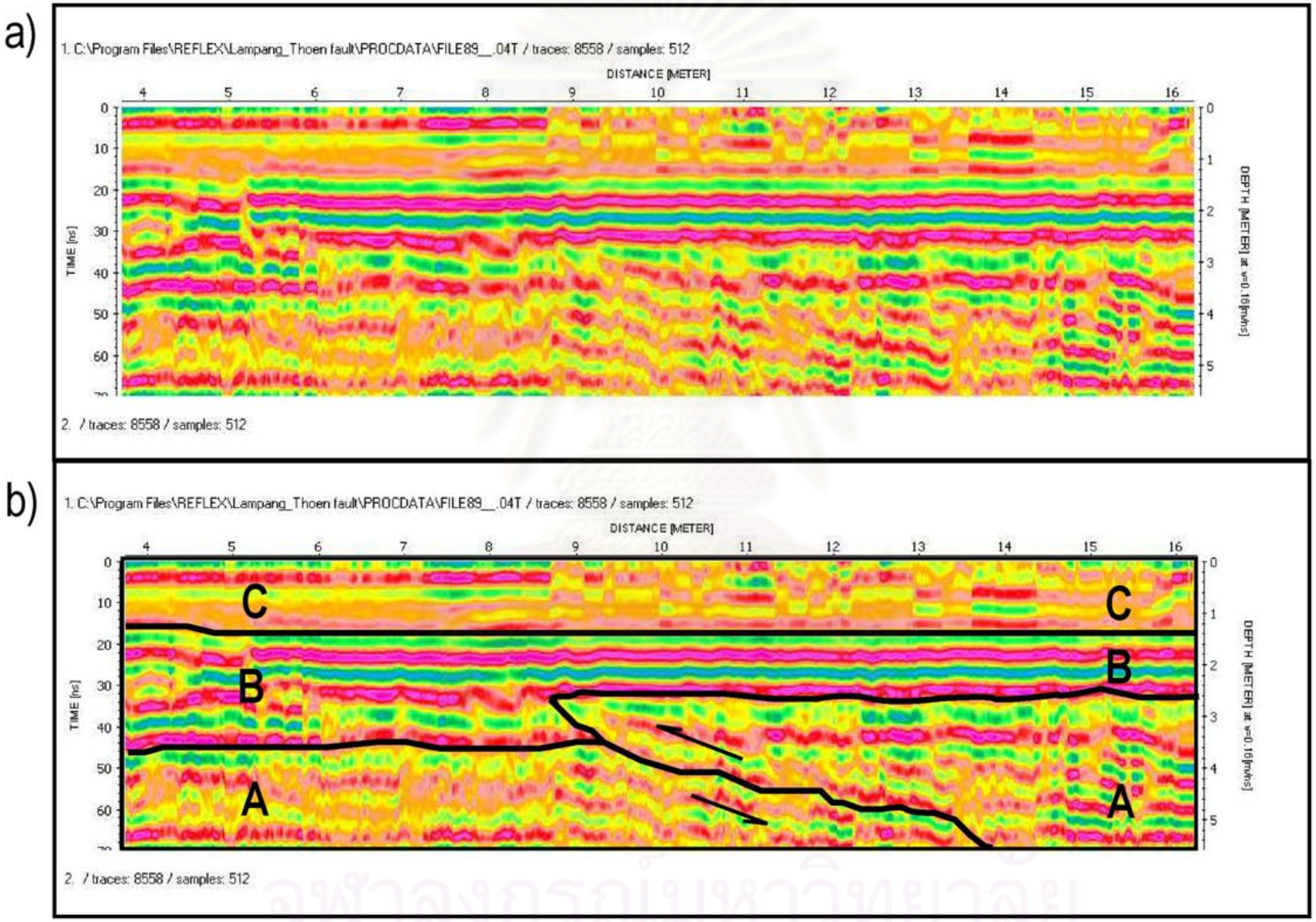


Figure 5.6b The Ban Sam Kha's interpretation profiles of a) an enhanced profile, b) the interpretaion profile showing GPR strtigraphy and a main structure.

Finally, the summary result and location from the 3 interpretation profiles of GPR have show in Figure 5.7.

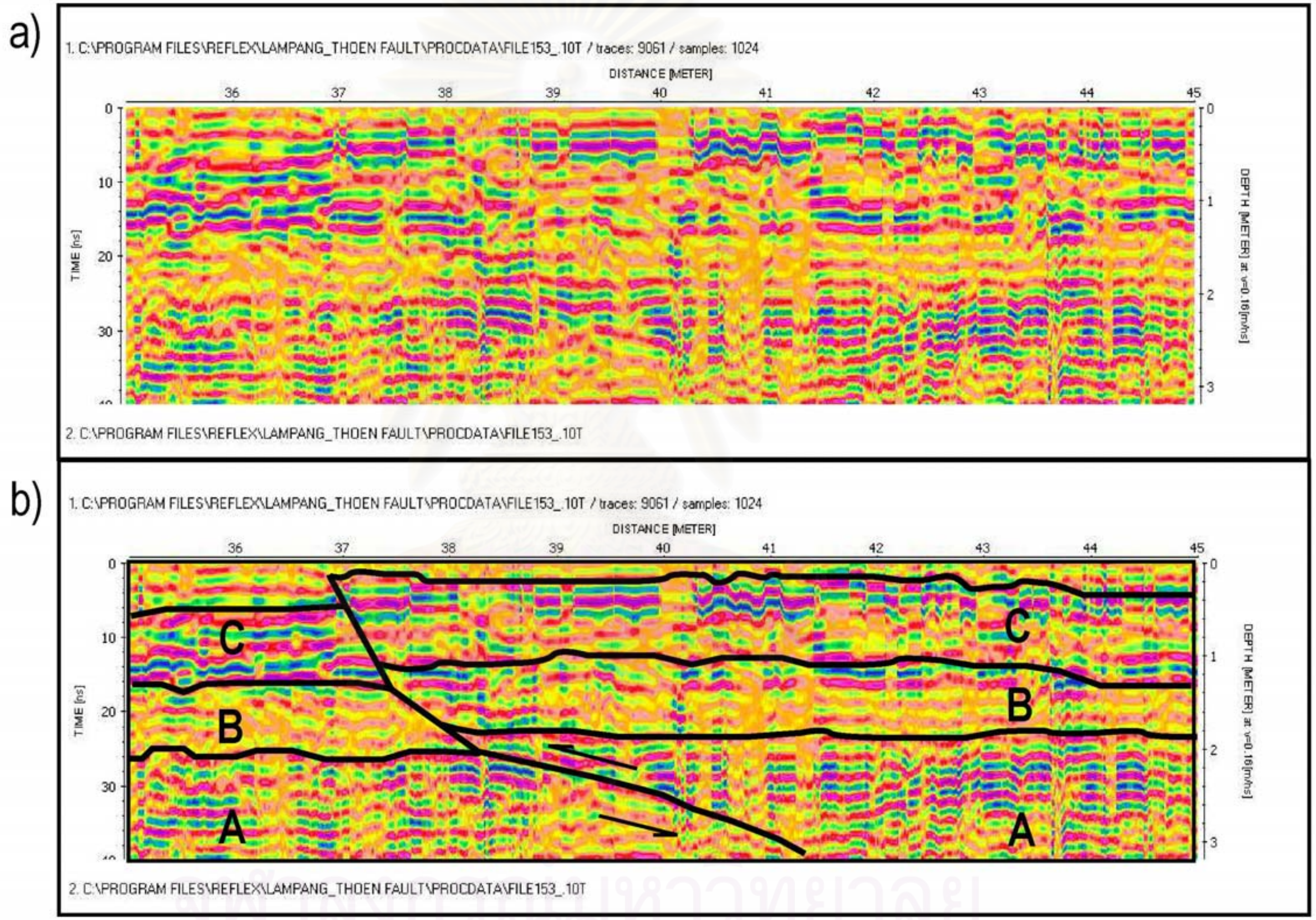


Figure 5.6c The Ban Pa Phai's interpretation profiles of a) an enhanced profile, b) the interpretaion profile showing GPR strtigraphy and a main structure.

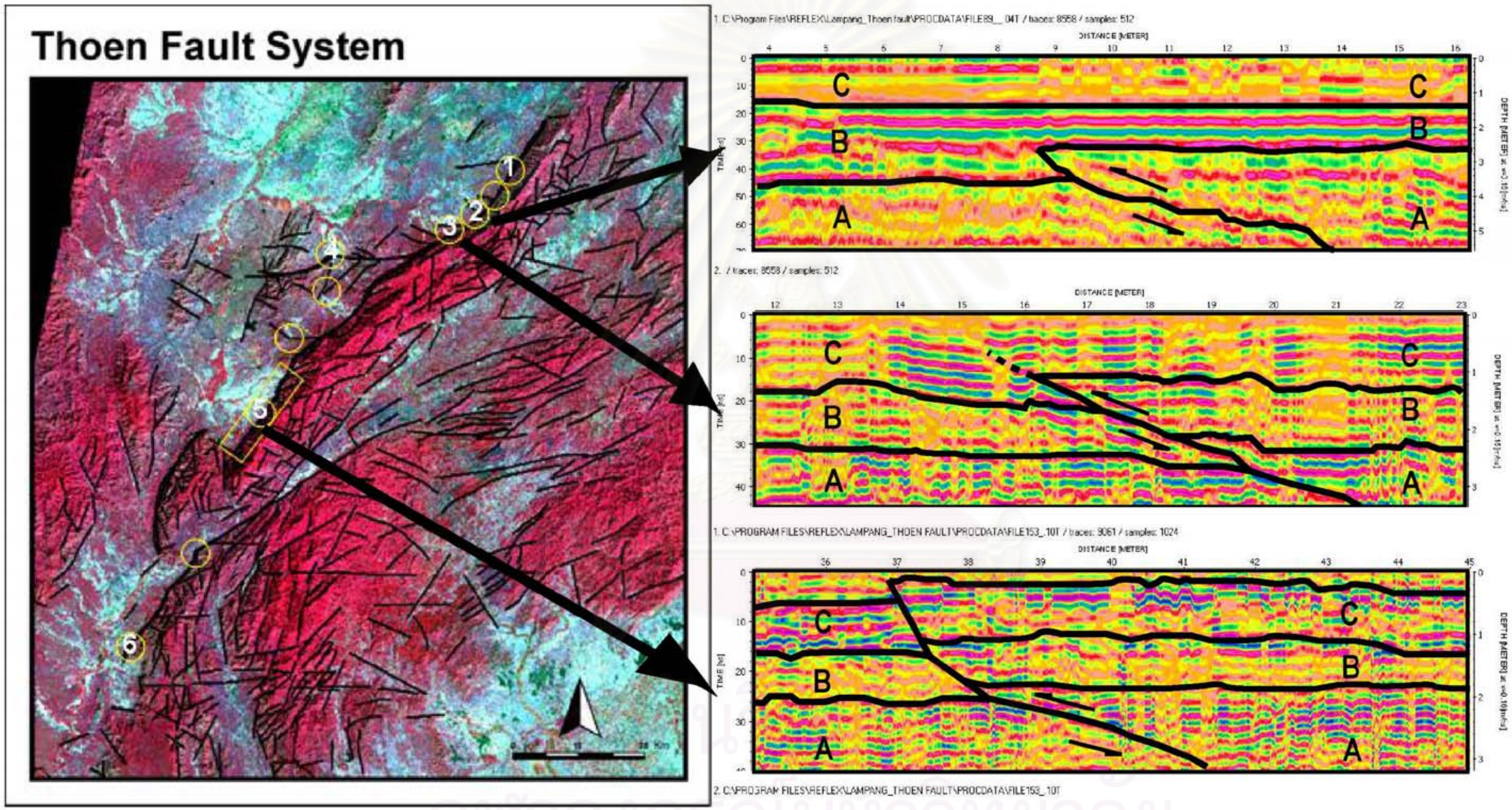


Figure 5.7 The summary map of result and location from the three interpretation profiles

CHAPTER VI

DISCUSSIONS

In an attempt to understand neotectonism in this study area, all of information in previous chapters are integrated in order to discuss in this chapter. Discussion issues in this study consist of neotectonic structural elements, relative timing reconstruction and stress field, active fault classification, advantage of GPR, and sequence of work for neotectonic study. The detailed discussions are cited below.

6.1 Structural element

Based on the interpretation in the previous chapters, it is noted that the structural features in the study area are normal - strike-slip - and reverse-slip components. Actually, in the study area, the normal slip component always occurred associated with strike-slip component, causing oblique slip movement in this area.

Commonly, pure shear deformation of Coulomb-Anderson model (Sylvester, 1988) produce conjugated strike-slip faults, folds and normal faults but can not produce reverse faults (Figure 6.1). Additionally, because of a space problem in a large-scale displacement, conjugate fault movements in pure shear deformation can move along the fault in a limited area and remain relatively small. Therefore most large faults culminating major offset, such as Red River Fault (RRF), Mae Ping (MPF) and Tree pagoda (TPF), have been operated through a simple shear mechanism of Riedel model (Sylvester, 1988). In pure strike-slip tectonics, tight and sometime overturned foldings occur with the vertical axis following the surface zones of strike-slip faulting. In case of extensional tectonic, foldings frequently occur along horizontal axes. So in oblique-slip, both vertical and horizontal components combine.

Regarding the structural patterns in this study, the pattern of normal faults, strike-slip faults, and reverse faults are structural pattern resulting from a simple-shear tectonics produced by the NW-SE dextral shear couple like the simple shear model of Keller & Pinter (1996) (see Figure 3.8). A simplified simple hear model applied in this as shown in Figure 6.2 suggests that the tectonic regime for the study area is strike-slip tectonics.

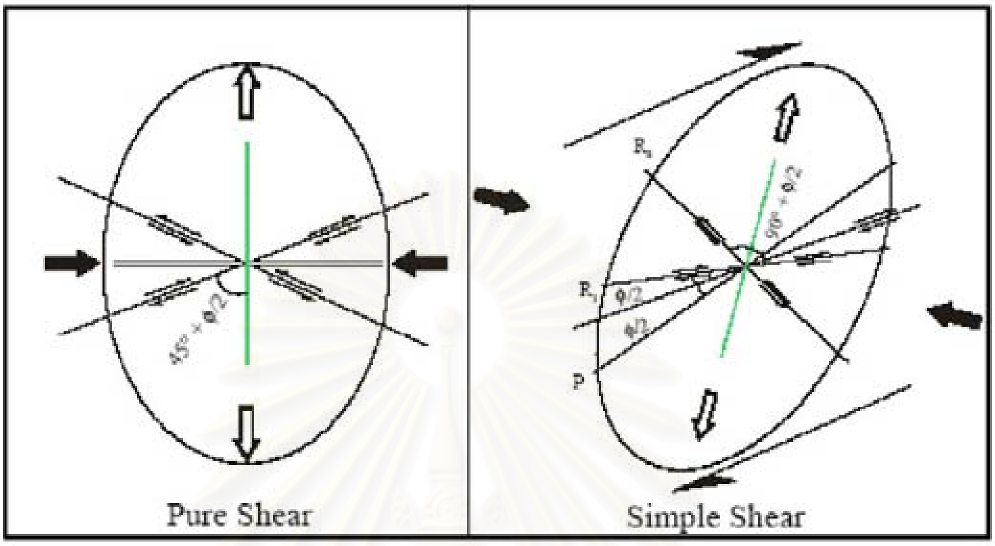


Figure 6.1 Comparison between pure-shear and simple-shear mechanisms. Coulomb-Anderson model shown on the left side. Riedel model on the right. Black arrows indicate the shortening axis, white arrows the extensional axis.The long axis of the strain ellipse is at 45° to the moving boundaries (after Sylvester, 1988).

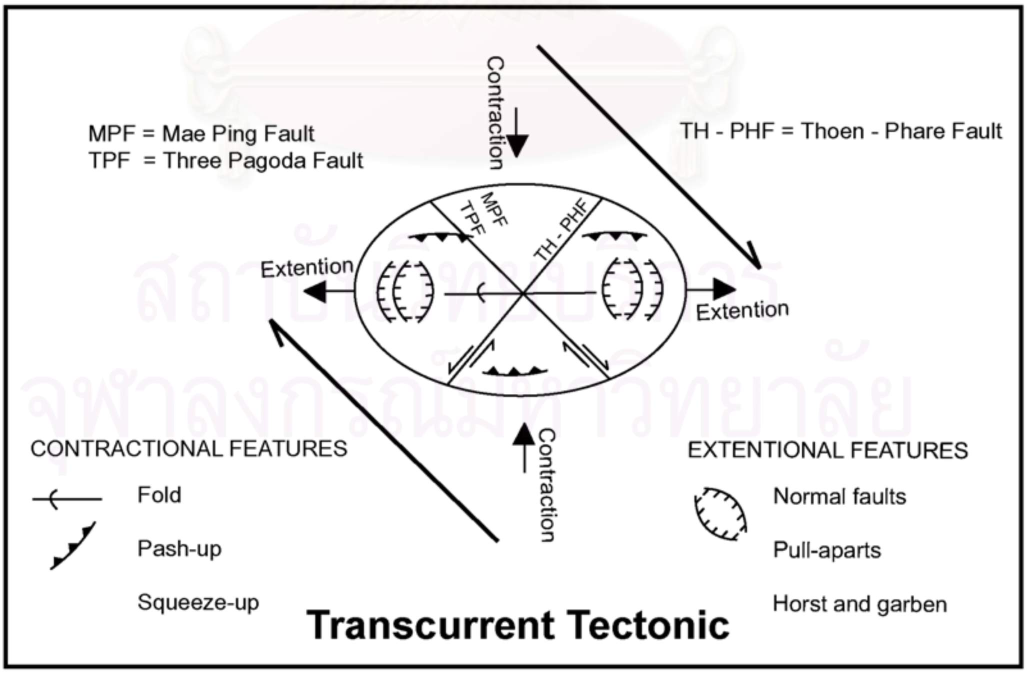


Figure 6.2 Simplify simple shear model of the Thoen fault zone and structural patterns related to strike-slip tectonics in the study area.

6.2 Relative timing reconstruction and stress field

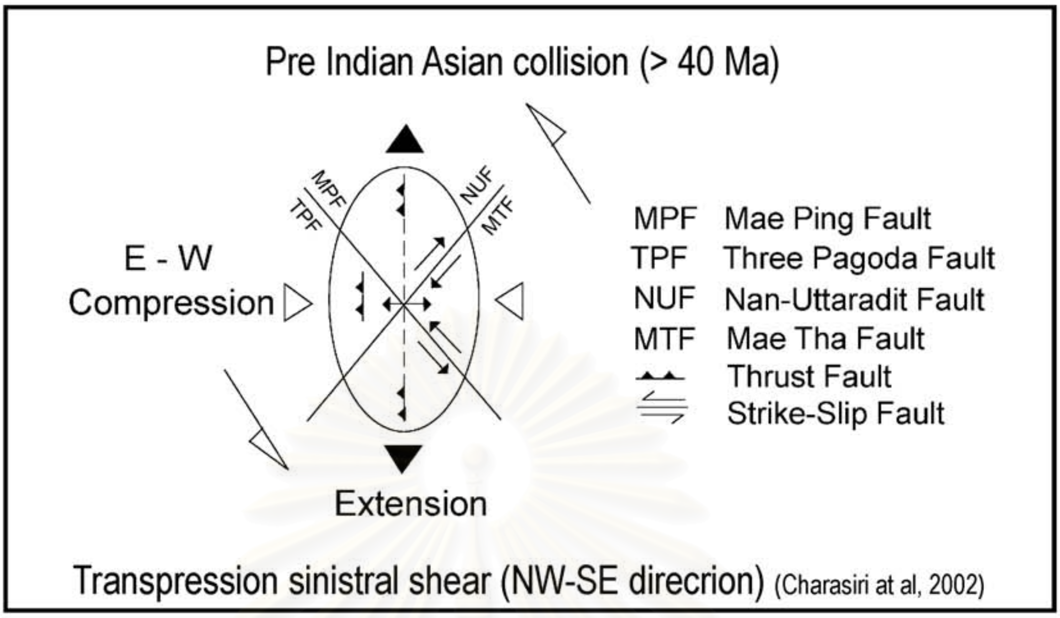
According to the evolutionary model in Chapter IV, the two main structures are the right lateral NE-SW trending cleavages and the left lateral NE-SW trending faults. With the recent strike-slip tectonic model of Northern Thailand region as proposed by Charusiri et al. (2002), it is helpful interpreting the relative timing reconstructed in a 3D structural model as shown in Figures 6.3a and b.

Based on Charusiri et al. (2002), it is concluded that the cleavage structures were formed prior to Indian – Eurasian collision (>40 Ma) or called herein as **Pre-Cenozoic structures.** The left-lateral faults were formed after Indian – Eurasian collision (<40 Ma) which herein are called **Cenozoic structures.** Moreover, the combined data of Cenozoic structures from microscopic structure, evolutionary models, and stress field model point to the oblique-sinistral movement similarly the structural existence as shown in Figure 6.4 by remote-sensing and outcrop interpretation support the tectonic regime called the NW-SE trending **transpression dextal shear tectonic.**

6.3 Neotectonic and Active tectonic classifications

Based on time scale, neotectonics can be broadly described as tectonic events and processes that have occurred in post Miocene time (Slemmons, 1991), or neotectonic is defined as the tectonics occurring in the current tectonic regime (Wood & Mallard, 1992). Based on geological basis, the Thoen fault system is absolutely pointed to both of neotectonic definitions. The result from remote-sensing, field investigation, petrography study, and GPR method indicate that tectonic events and processes have occurred in Quaternary times and in the current Indian-Eurasian tectonic regime.

The thrust faults in young sediments by the GPR result suggest that the faults took place within Quaternary time and the faults which cut through the late Pleistocene sediments as observed at the outcrops and the distribution of epicenter (Figure 6.5) along the lineaments (from remote-sensing study) are totally regarded as a result of the active tectonics which are the movements expected to occur within a future time span of concern to society (Geophysics Study Committee, 1986; Steward & Hancock, 1994),



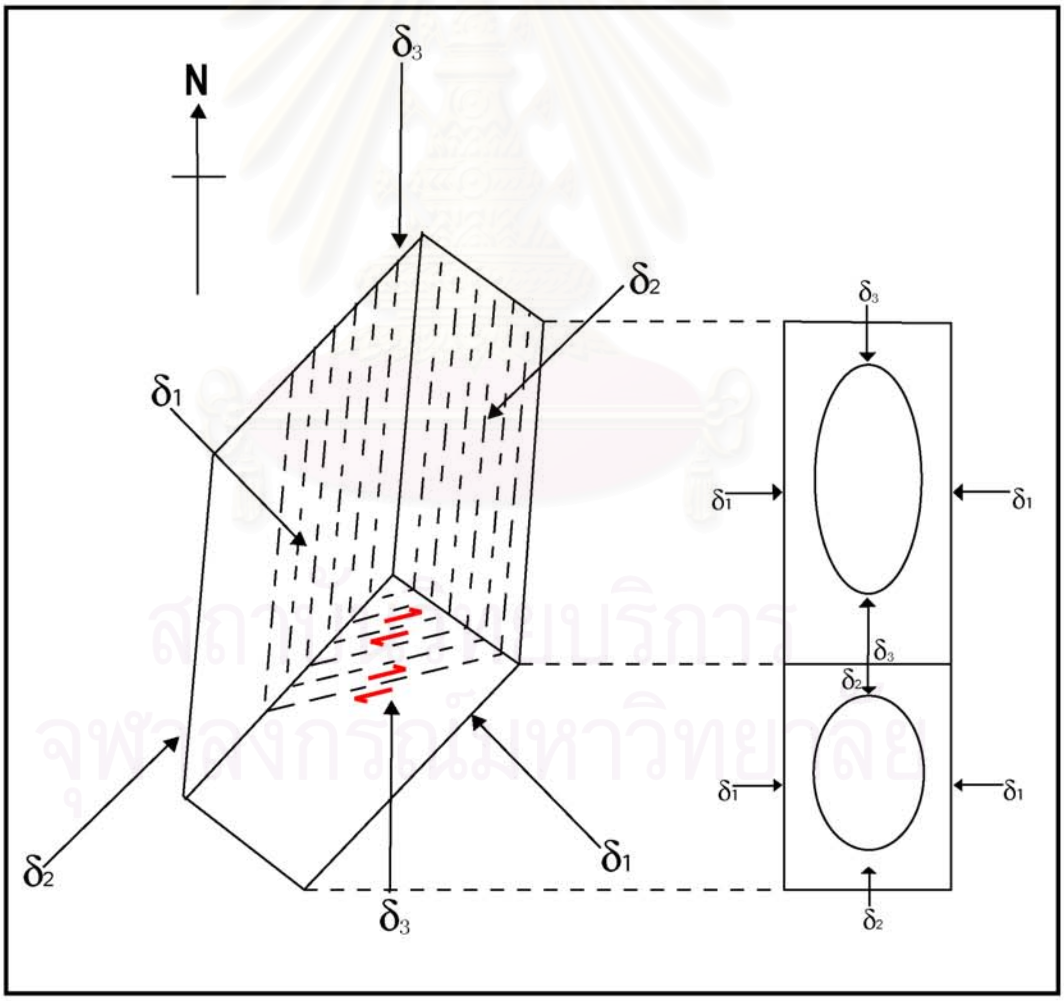


Figure 6.3a Compairison between transpresion sinistral shear (NW-SE) model of Pre Indian - Asian collision (>40) with stress axis and stress direction of NE cleavages.

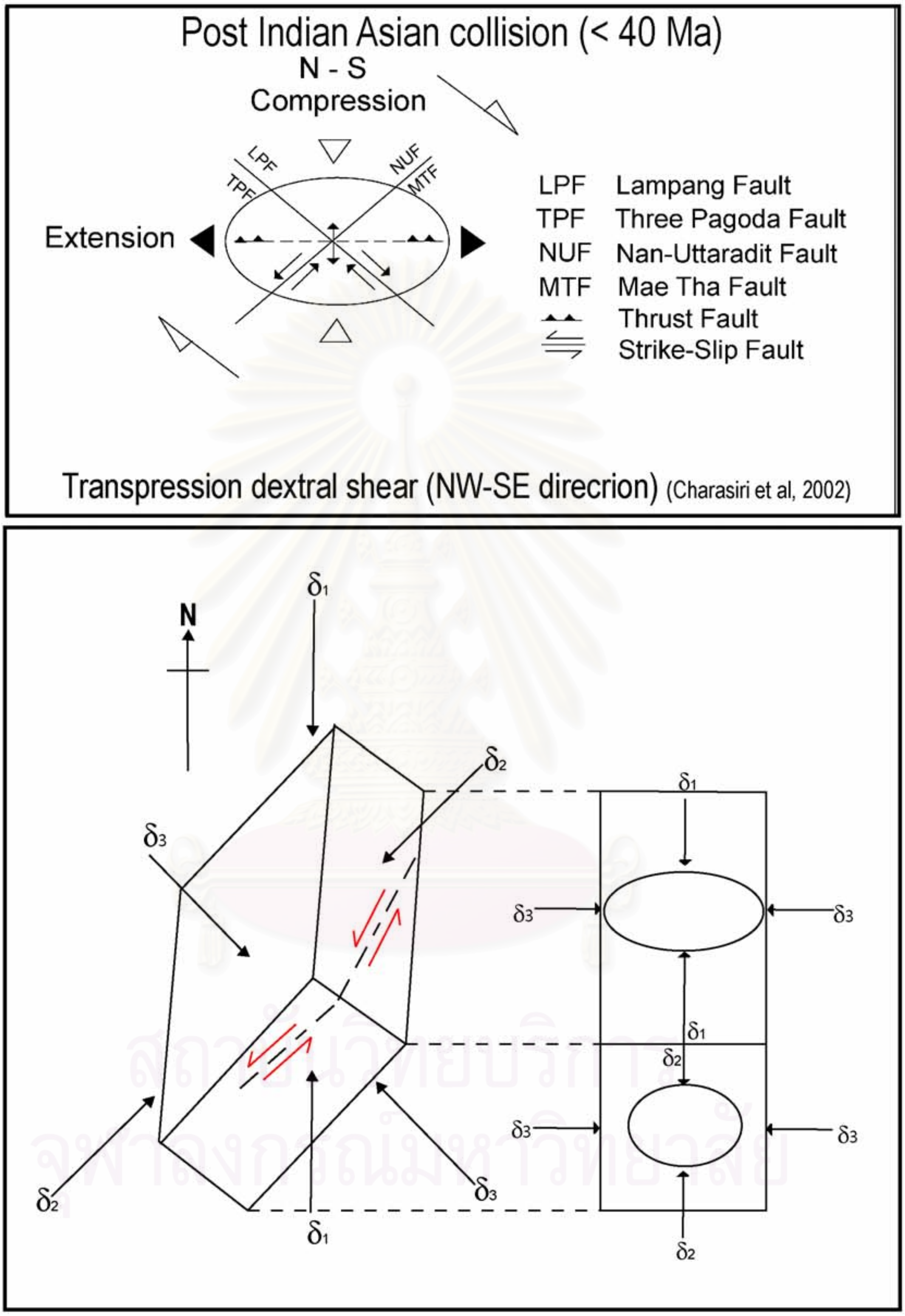


Figure 6.3b Compairison between transpresion dextrall shear (NW-SE) model of Post Indian - Asian collision (<40) and stress axis and stress direction of NE fault by evolutionary model.

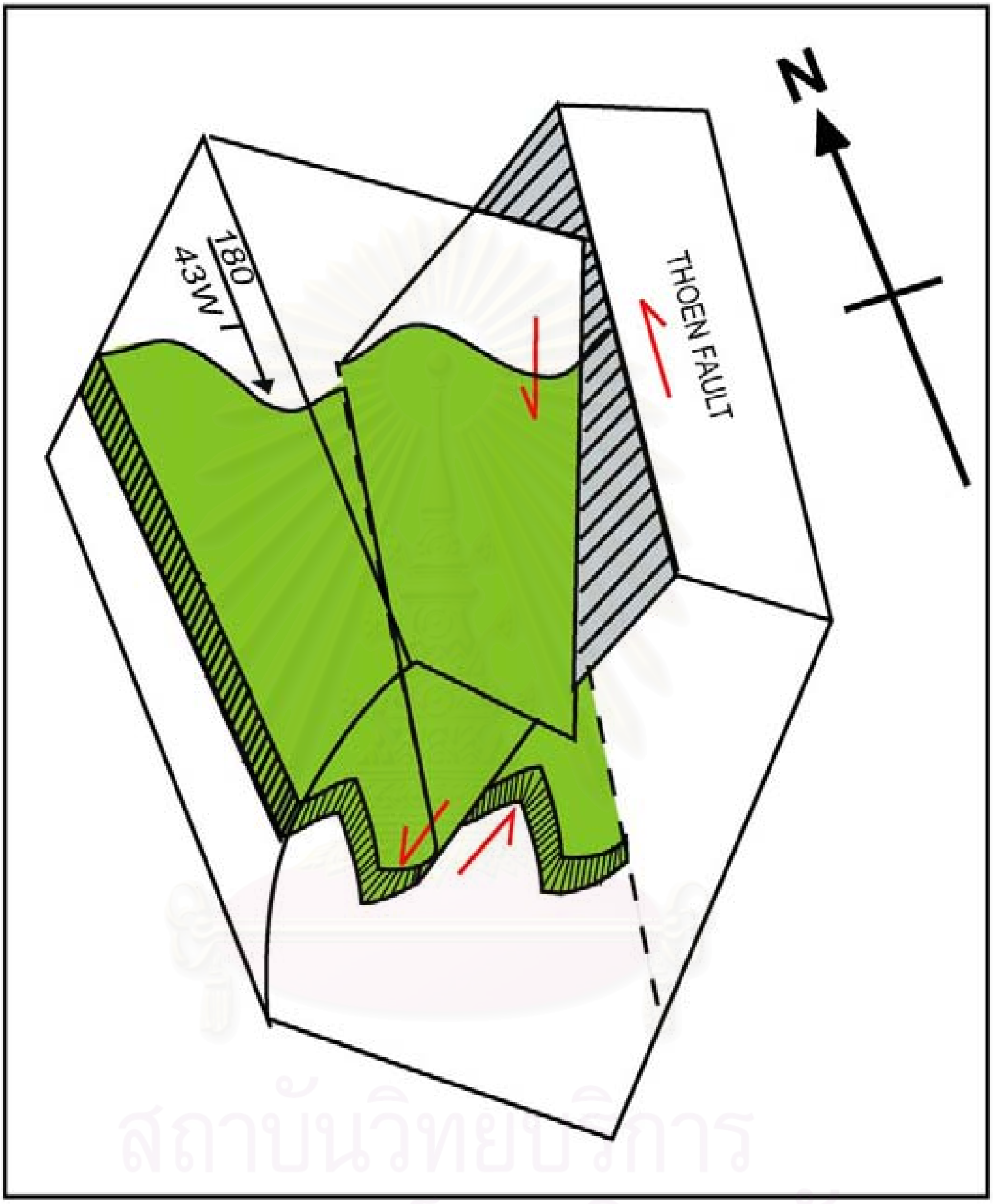


Figure 6.4 Oblique - sinistral strike-slip structure model interpreted from combining data of remote-sensing, field investigation, microlineament analysis and subsurface investigation.

Figure 6.5 Distribution map of epicenters from 1983 -2004 with interpreted lineament showing the present day seismicsity of study area related to the Thoen fault system.

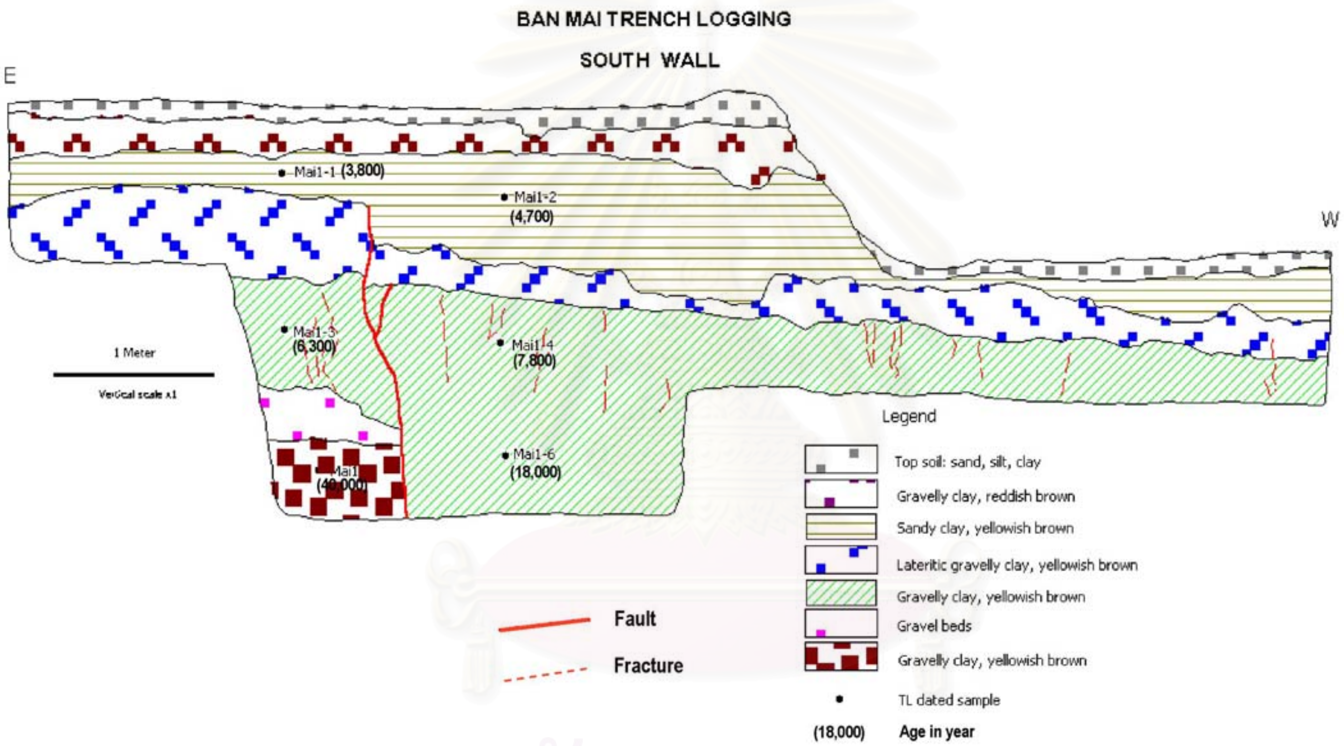


Figure 6.6 Ban Mai trench logging no.1 showing six TL ages and a fault on the south wall. Faulting event occured between 3,800 - 4,700 years ago.

and in the current (active) tectonic (faulting) regime (Wood & Mallard, 1992). Based on an absolute time-scale, when surface displacement along the fault during the last 10,000 years is evidenced, the fault is a Holocene active fault. A fault that has moved during the last 130,000 years is a Late Quaternary active fault, and a fault that moved during the last 1.6 Ma is a Quaternary active fault (Machette, 2000). Our result indicates that, the Thoen fault system is an **active fault** which also can be called a **Late Quaternary active fault** as mentioned earlier by Fenton et al. (1997).

Based on absolute-dating data, Charusiri et al. (2004) had excavated 3 exploratory trenches at Ban Mai area. Six fault-related sediment samples were taken from Ban Mai trenching no.1 for TL-dating. The results of TL-dating (Figure 6.6) indicate that the fault has moved during the last 10,000 years which also can be called a **Holocene active fault** by the definition of Machette, (2000).

6.4 Advantage of GPR method

In consideration of a given depth of interest (see Table 5.1) and resolution of GPR method, both of the 200 MHz and the 400 MHz antenna are suitable for surveying of shallow concealed faults in young sediments. But in this study, because of technical reasons in data acquisitions that the GPR generated too much noise signal in 400 MHz antennas, thus the 200 MHz antenna become the most appreciated for this case.

By using remote-sensing applications, it is clear to indicate a fault trace on surface, but dumb to indicate fault orientation and a subsurface concealed fault especially in flat areas such a rice field. As it happens often, trenching survey has failed to locate the faults because of using only surface trace evidences to indicate the trench locations with unexpected size and deep. Finally causing time and cost problems. It is clearly that GPR method can solve the problem and save cost and time for trenching.

Charusiri et al. (2004) had excavated 3 exploratory trenches at Ban Mai area. The result showed the poorly-defined faults and displacement (see Figure 6.6) whereas the main fault and displacement by GPR profiles, is about 30 meters away from the trenches (see Figure 5.6a), showed in good-define faults. In other words, trenching should have been excavated after interpretations of GPR profiles were completed.

6.5 Sequence of work for Neotectonic study

Based on the methodology shown as a flowchart in Figure 1.4, three main methods which made this study complete are remote-sensing, petrography, and subsurface study. Basically in Thailand, remote-sensing is a necessary method in neotectonic study or any geological survey in regional scale. However, local and outcrop scales will proceed the field study based on remote-sensing data. Then the geologists will go to geophysical method or subsurface study, such as GPR, shallow seismic, trenching, or dating. The microscopic study and evolutionary model are essential data that geologists should in assessing neotectonic structure and determining active fault in basement rocks of Cenozoic basin. Ignorance of microscopic study and evolutionary model (the behavior of the tectonic stress field in basement rocks and its relation to the neotectonic in Cenozoic movements) are still poorly understood.

In order to set up the standard method in Thailand, the sequence of work for neotectonic study is purposed as follow:

1. Literature review and previous work study
2. Remote-sensing study; tectonic morphology, lineament analysis, etc.
3. Field investigation; morphotectonic evidence, Quaternary faulting evidence, etc.
4. Petrographic study; micro-lineament, microstructure, stage model, etc.
5. Subsurface study using geophysical method; Shallow seismic, GPR, or gravity, etc.
6. Trenching and dating; TL dating, C-14, etc.
7. Analysis and discussion

CHAPTER VII
CONCLUSIONS

Based on the results of remote-sensing, field, petrographic, and GPR investigations along the Thoen fault zone, the conclusions can be drawn as follow:

1) Tectonic geomorphology evidences along the Thoen fault system, northern Thailand are mostly supported by triangular facets, shutter ridges, beheaded stream and offset stream channels;
2) Normal faults which cut through the gravel bed which in turn rotated gravels in semi – to consolidated Quaternary outcrops are clear evidence of Quaternary faulting event in the study area;
3) Instrumentally, GPR survey is considered to be appropriate for subsurface investigation to determine the fault characteristic in areas of recent unconsolidated deposits indicated the defined location of concealed fault in shallow subsurface;
4) Structurally, patterns of the Thoen fault system virtualized from both Quaternary deposits and hard rocks fit fairly well with the simple-shear tectonic model. These patterns are inferred to have been produced by northwest-southeast transpression dextral shear, suggesting that the tectonic regime for the study area is strike-slip tectonics;
5) Tectonically, the Thoen fault zone is showing the combination characteristic of vertical and sinistral strike-slip movement, the so – called “Oblique – sinistral strike-slip fault”; and
6) The Thoen fault zone can identify as a neotectonic fault zone, which had moved in the current tectonic regime, also can be identified as a late Quaternary active fault zone.

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