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แบบจำลองหินโผล่ดิจิทัลและการวิเคราะห์โครงสร้าง
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โดย

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โครงการนี้เป็นส่วนหนึ่งของการศึกษาระดับปริญญาตรี
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ปีการศึกษา 2560

DIGITAL OUTCROP MODEL AND STRUCTURAL ANALYSIS OF BAN PONG QUARRY, CHIANG MAI PROVINCE

Ms.Narudee Saikrsin

A Project Submitted in Partial Fulfillment of the Requirements

for the Degree of Bachelor of Science Program in Geology

Department of Geology, Faculty of Science, Chulalongkorn University

Academic Year 2017

แบบจำลองหินโผล่ดิจิทัลและการวิเคราะห์โครงสร้างทางธรณีวิทยา
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Project Title	DIGITAL OUTCROP MODEL AND STRUCTURE ANALYSIS OF BAN PONG QUARRY, CHIANG MAI PROVINCE
By	Ms.Narudee Saikrasin
Field of Study	Geology
Project Advisor	Sukonmeth Jitmahantakul, Ph.D.

Submitted date..

Approval date..

....

Project Advisor

(Sukonmeth Jitmahantakul, Ph.D.)

นางสาว ณฤดี สายกระสินธุ์ : แบบจำลองหินโผล่ดิจิทัลและการวิเคราะห์โครงสร้างทางธรณีวิทยาของเหมืองบ้านปง จังหวัดเชียงใหม่ (DIGITAL OUTCROP MODEL AND STRUCTURAL ANALYSIS OF BAN PONG QUARRY, CHIANG MAI PROVINCE) อาจารย์ที่ปรึกษางานวิจัย: อาจารย์ ดร.สุคนธ์เมธ จิตรมหันตกุล, 47 หน้า

เหมืองบ้านปง ตำบลบ้านปง อำเภอหางดง จังหวัดเชียงใหม่ เป็นเหมืองลูกรังที่มีลักษณะการเปิดหน้าดินเพื่อนำดินและลูกรังไปใช้ประโยชน์ ลักษณะทางธรณีวิทยาเป็นตะกอนกึ่งแข็งตัวทับถมเป็นชั้น ประกอบด้วยกรวด ทราย ทรายแป้ง ตะกอนโคลนและชั้นถ่านหิน และปรากฏโครงสร้างรอยเลื่อนที่ตัดผ่านชั้นตะกอนดังกล่าว ซึ่งแสดงถึงการเปลี่ยนสภาพเนื่องมาจากธรณีแปรสัณฐานยุคใหม่ในพื้นที่ภาคเหนือ การศึกษานี้มีจุดประสงค์เพื่ออธิบายวิวัฒนาทางธรณีวิทยาโครงสร้างในเหมืองบ้านปง โดยการสร้างแบบจำลองหินโผล่ดิจิทัลชนิดสามมิติของเหมืองบ้านปงจากภาพถ่ายเมื่อวันที่ 21 มกราคม พ.ศ. 2561 และการสำรวจภาคสนาม ผลการศึกษาพบว่ารอยเลื่อนปกติที่ปรากฏในพื้นที่ศึกษามีความสัมพันธ์กับธรณีสัณฐานแบบแยกในแนวตะวันออก-ตะวันตก โดยสามารถจำแนกรอยเลื่อนได้ 2 ประเภท ได้แก่ รอยเลื่อนหลักที่มีมุมเอียงเทไปทางตะวันตกและรอยเลื่อนแขนงขวาง (antithetic faults) ที่มีมุมเอียงเทไปทางตะวันออก โดยกลุ่มรอยเลื่อนแขนงขวางในหินเพดานของรอยเลื่อนหลักเป็นส่วนที่ถูกใช้ในการศึกษาวิวัฒนาการและคำนวณอัตราการยืดของของพื้นที่ศึกษา จากการวิเคราะห์โครงสร้างในหินเพดานของหินโผล่ พบว่าอัตราการยืดมีค่าไม่สม่ำเสมอ โดยส่วนด้านบนของหินโผล่มีอัตราการยืดที่มากกว่าและปรากฏรอยเลื่อนปกติมุมต่ำ (low angle normal faults) ซึ่งการยืดที่ไม่สม่ำเสมอของหินโผล่เป็นผลมากจากการดึงตามแนวรอยเลื่อนหลัก ส่งผลให้หินเพดานของรอยเลื่อนหลักเกิดการหมุนตามเข็มนาฬิกาด้วยมุมประมาณ 35 องศา ความกว้างก่อนการยืดตัวและหลังยืดตัวของหินเพดานถูกใช้ในการคำนวณเพื่อประมาณอัตราการยืดของแอ่งตะกอนอายุซีโนโซอิกในพื้นที่ภาคเหนือของประเทศไทย โดยพบว่าอัตราการยืดมีค่าตั้งแต่ 0.005-0.007 มิลลิเมตร/ปี

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต ....

สาขาวิชา ธรณีวิทยา ลายมือชื่อ อ.ที่ปรึกษา ....

ปีการศึกษา 2560

5732720523: MAJOR GEOLOGY
KEYWORDS: DIGITAL OUTCROP MODEL / BACKSTRIPPING

NARUDEE SAIKRASIN: DIGITAL OUTCROP MODEL AND STRUCTURAL ANALYSIS OF BAN PONG QUARRY, CHIANG MAI PROVINCE ADVISOR : SUKONMETH JITMAHANTAKUL, Ph.D., 47 pp.

Ban Pong quarry in Hang Dong sub-district, Ban Pong district, Chiang Mai province is a surface quarry for soil and gravel products. Lithology composes of semi-consolidated sediments interbedded with coal seams that deposited during Cenozoic age and presents a series of structures related to Cenozoic Tectonic activities in Northern Thailand. This study aims to describe the geological evolution of Ban Pong quarry from Digital Outcrop Model and field investigation that was recorded on the twenty first of January, 2018. The structure in Ban Pong quarry is a family of NS trending normal fault related with the extension in east-west direction. This study divides normal faults in the quarry exposure into two groups, west-dipping normal faults and east-dipping normal faults that is major faults and antithetic normal faults respectively. The antithetic faults on the hanging wall of the major fault is focused in structural analysis process to study the evolution and estimate the deformation rate. According to structural analysis, the stretching of the outcrop exposure is non-uniform in outcrop scale. The upper part of outcrop has higher stretching factor represented by geometry of antithetic faults which is low-angle normal faults. This non-uniform extension is a result from drag along the major fault that caused the hanging wall rotation approximately 35 degrees in clockwise direction. A crustal wideness after extension and an initial crustal wideness were compared to evaluate the length of extension. Therefore, the extension rate of the Cenozoic basin in Northern Thailand based on the hanging wall deformation of the major fault ranges between 0.005-0.007 mm/year.

Department: ....Geology.......... Student's Signature ....

Field of Study: ....Geology.......... Advisor's Signature ....

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Chapter 1

Introduction

1.1 Introduction

Chiang Mai Basin is considerably the largest Cenozoic intermontane and structural basins in northern Thailand (Fig.1.1). Its formation is related to the Low-Angle Normal Fault (LANF), which forms the western margin of the basin (Morley, 2011). Along this margin, the Oligocene to late Pliocene sedimentary rocks are covered by Quaternary semi-consolidated sediments that interbedded with coal seams (Rhodes et al., 2005). Earthquake activity in the western margin is relatively low compared to that occurred on the northern and eastern margins, which more likely associated with active the left-lateral strike-slip Mae Tha Fault (MTF in Fig. 1.1). Low displacement along this active fault suggests the influence of the east-dipping LANF on the geometry of the Chiang Mai Basin. It indicates that strain distribution in the hanging wall during extension creates the largest basin with over 50 km wide.

Although the initiation of the basin remains unclear, continue extension results in the structural deformation of these recent sediments, where exposures are clearly seen in many quarries. Understanding structural styles and their kinematics can improve the evolutionary model of the Chiang Mai Basin and the evaluation of geological hazards associated with Neotectonics in this region.

This study aims to investigate the structural deformation of the Quaternary sediments in Ban Pong quarry, which located in a small valley to the southwest of the Chiang Mai Basin (Fig. 1.2). The quarry geometry was modelled in three-dimension (3D) using photogrammetry technique in order to generate 3D fault model for reconstruction. Extension variation in the quarry and extension rate were calculated and discussed with Neotectonics and the formation of the Chiang Mai Basin.

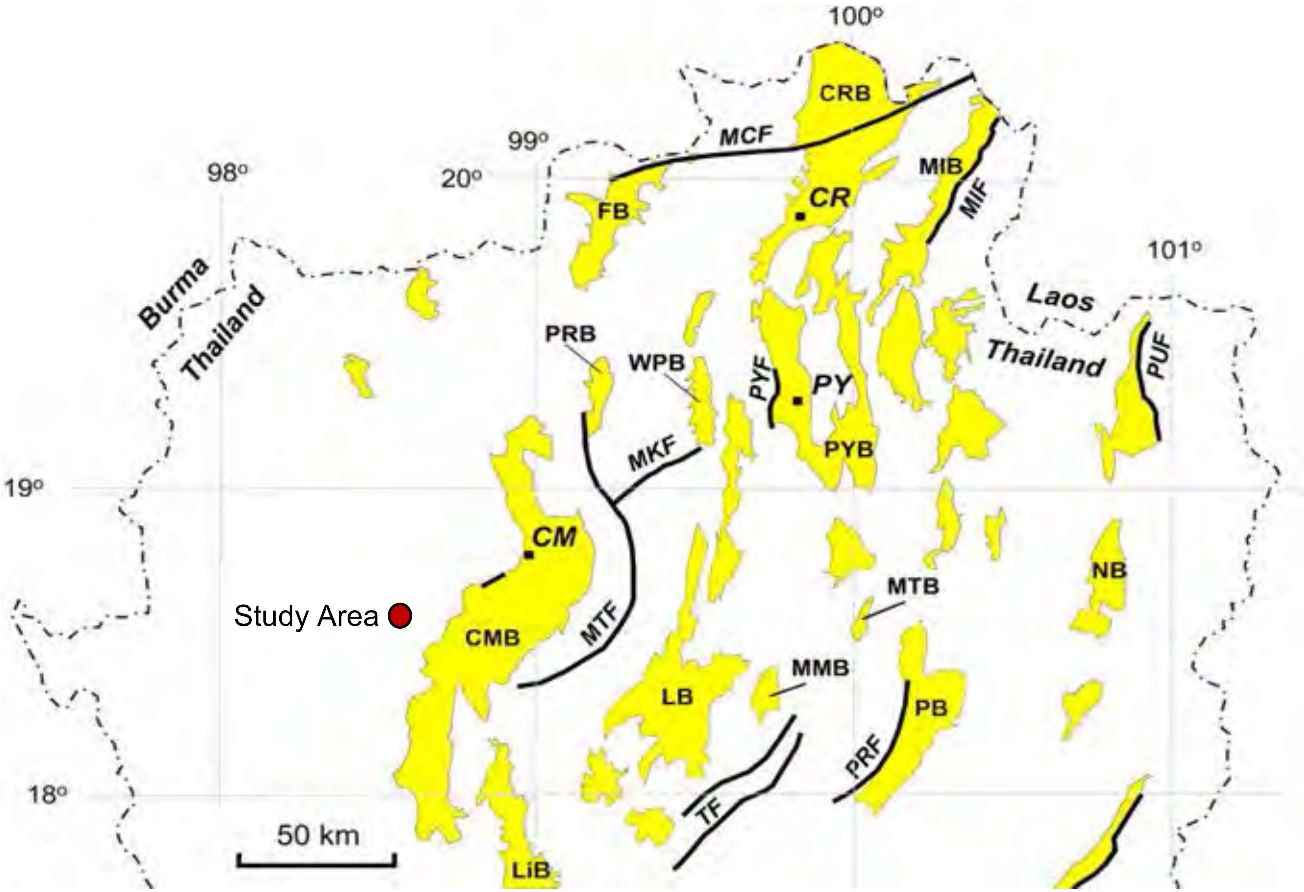


Figure 1.1 Location of Major Cenozoic Basin in Northern Thailand and the study area: CM, Chiang Mai; CR, Chiang Rai; PY, Payao. Faults: MCF, Mae Chan fault; MIF, Mae Ing fault; MKF, Mae Kuang fault; MTF, Mae Tha fault; PRF, Phrae fault; PUF, Pua fault; PYF, Payao fault; TF, Thoen fault. Basins: CMB, Chiang Mai basin; CRB, Chiang Rai basin; FB, Fang basin; LiB, Li basin; LB, Lampang basin; NB, Nan basin; MIB, Mae Ing basin; MMB, Mae Moh basin; MTB, Mae Teep basin; PB, Phrae basin; PRB, Phrao basin; PYB, Payao basin; WPB, Wiang Pa Pao basin. (modified after Rhodes et al., 2005)

Figure 1.2 Satellite image showing study area in Bang Pong quarry, Hang Dong Sub-district, Ban Pong District, Chiang Mai Province Google Earth 7.3.0.3832. 2017. Bang Pong quarry, 18°44'44.4"N 98°53'03.3"E Viewed 25 December 2017 <https://www.google.com/earth/index.html>

1.2 Study area

Ban Pong quarry is situated in Ban Pong Sub-district, Hang Dong District, Chiang Mai province approximately 20 kilometers from Chiang Mai basin in west direction (Fig 1.1). This quarry is an active quarry located in a small intermontane basin named Ban Pong basin with average elevations around 330-360 meters above mean sea level and was surrounded by Paleozoic mountain. The mountain is defined as sedimentary mountain with an elevation approximately 600 meters above mean sea level. The quarry exposure extends around 200 meters in length, 40 meters in height and covers approximately 5 square kilometers. The wall of excavation composes of Quaternary semi-consolidated sediments interbedded with coal seams. A series of structure that related with Neotectonic activity such as fault and fracture well display crosscut the sediment on the wall of the excavation.

1.3 Report outline

- **Chapter 1** introduces the research topic including the study area and the expectation of this research.
- **Chapter 2** provides a literature review about regional geology of the study area, summary result from recent studies and the theoretical approach.
- **Chapter 3** presents a research design and a collection procedure.
- **Chapter 4** presents the results of the interpretation of DOM containing structure description, lithology and analysis from Backstripping model.
- **Chapter 5** discusses the result of the DOM interpretation, backstripping analysis and provide the evolution model and extension rate of the area.
- **Chapter 6** presents the conclusions of the research.

Chapter 2

Literature Review

2.1 Summary from recent studies

The previously geological studies in Ban Pong quarry and nearby area focused on a regional scale. Sedimentary rocks that distributed on Ban Pong sub-district were defined as Paleozoic sedimentary rock by Department of Mineral Resources (2007) (Fig 2.1).

On the other hand, fieldwork report by Rhodes (2000) identified this area as a Cenozoic intermontane basin named Ban Pong basin. The sediments in the basin were determined as Mae Rim formation by Rhodes et al. (2000) .Mae Rim formation occur in artificial outcrops such as quarries and road cuts in north and west of Chiang Mai, and north of Mae Rim district. This formation is a sequence of semi-consolidated sediments in fluvial environment composed of argillaceous limestone interbedded with calcareous shale, black shale, siltstone and coal seam and shows the evidence of deformation by Neotectonic tectonic such as fault and fracture.

Gravity surveying in Ban Pong and Nam Phrae sub-district by Mankhemthong (2014) shown accordingly data with Rhodes. The boundary of Ban Pong basin is identified and shown in complete Bouguer anomaly map (Fig 2.2). Ban Pong basin has lower gravity anomaly at the center of basin than the surrounded mountains that is a Paleozoic rock. Western and eastern boundary faults were identified by abruptly change of gravity anomaly at the margin of Ban Pong basin. Throughout his study, Ban Pong basin is graben shaped basin lied in NS direction with the maximum depth approximately 150 meters in the western part of the basin and extends around 1-1.5 km in length.

According to the lithology and structure studies by Takaew (2015), Lithology consists of coarse-fine grained sedimentary rock such as pebbly, sandstone and mudstone interbedded with coal seam. These sediments were defined as Cenozoic semi-consolidated sediments in fluvial environment. Bedding planes are N-S to NE-SW with gentle dipping in west. For the structural study, focused on fracture analysis, which analyzed the orientation of different fracture sets. Ban Pong basin has compression stress in NW-SE direction. There are normal faults lie in NW-SE direction.

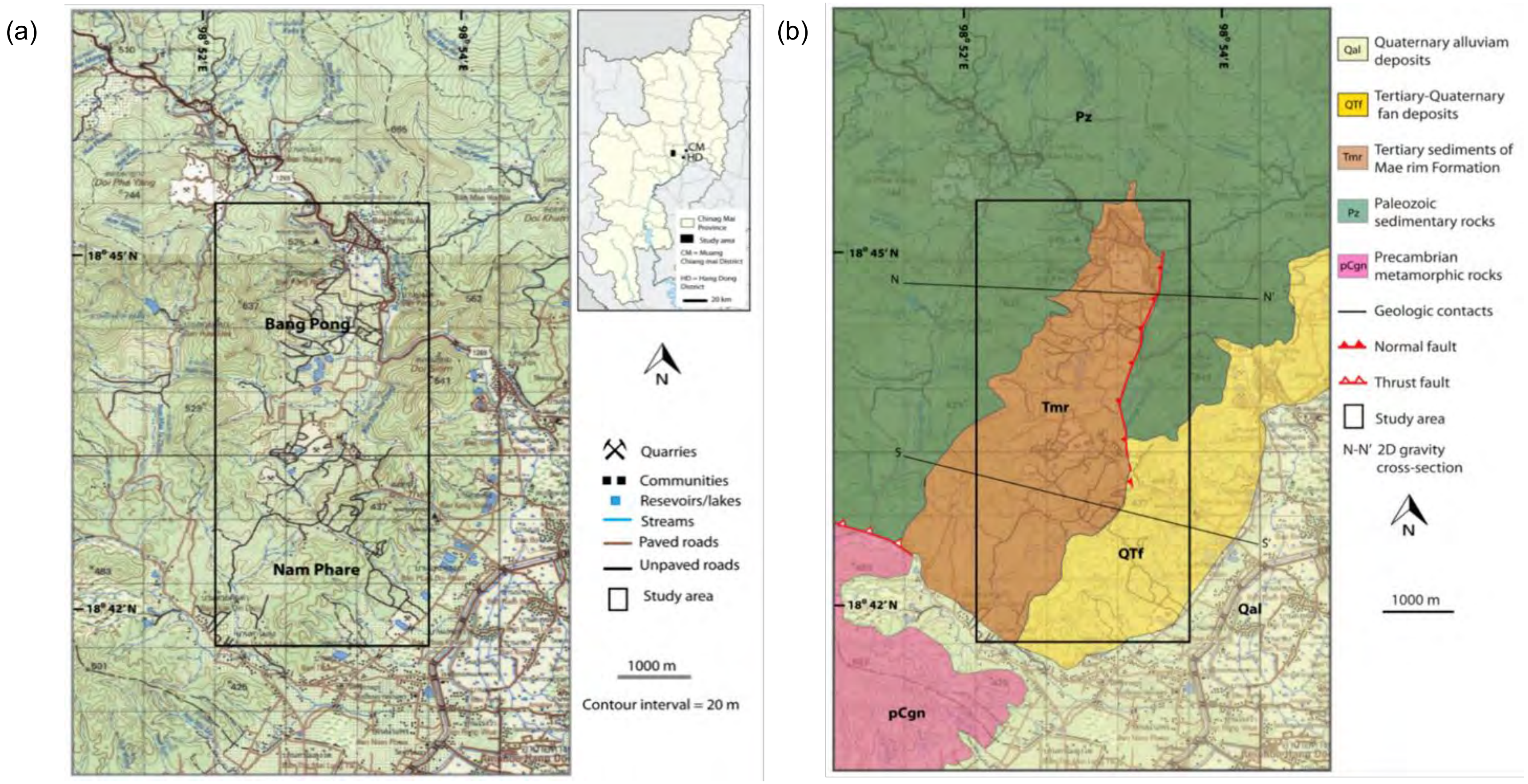


Figure 2.1 (a) Topographic map shows Ban Pong basin in Ban Pong sub-district, Hang Dong district, Chiang Mai province. (b) Geologic map of Nam Phrae sub-district and Ban Pong sub-district, Hang Dong district, Chiang Mai province (modified after Rhodes et al., 2013).

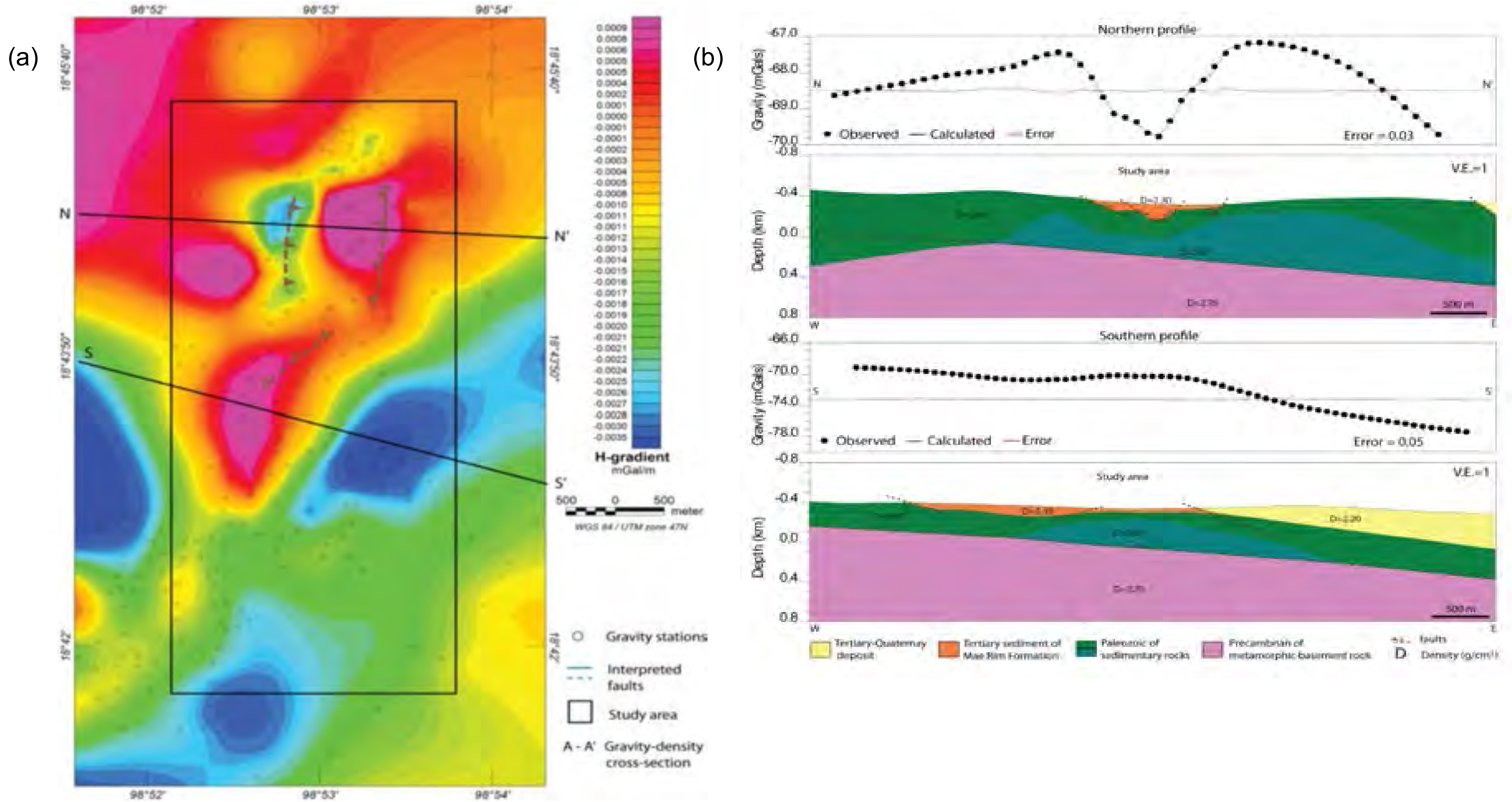


Figure 2.2 (a) A complete Bouguer anomaly map shows the boundary of Ban Pong basin. (b) Cross-section profiles of Ban Pong basin and nearby area (modifined after Mankhemthong, 2014).

2.2 Geology within the study area

The lithology of the excavation is correlated with Cenozoic sediment of Chiang Mai basin and Li basin. These basins were occupied by fluvial or non-marine lacustrine environment during Tertiary ages shown by a fined grained sedimentary rock with coal and overlaid by Quaternary sediments. A summary of stratigraphy of Li basin (Fig 2.3) based on outcrop exposure in Ban Pu mine is given by Morley et al. (2001).

(1) Ban Pa Kha formation in: fluvio-alluvial conglomerate and sandstone interbedded with finer grained sediments from lacustrine deposit; late Oligocene to early Miocene. (Watanasak, 1989). The oldest member is conglomerate and sandstone in alluvial fan deposits. Thickness of this member is approximately 60 meters. Then, this member are overlain by younger sedimentary rocks that compose with grey-brown sandstone and pebbly sandstone interbedded with claystone in braided river environment. Thickness varies between 10 to 50 meters thick.
(2) Mae Long formation: coal sequence; upper Lower Miocene to Middle Miocene. This formation overlaying older strata with unconformity.
(3) Upper Miocene to Pliocene sandstone and conglomerate in fluvial environment
(4) Quaternary sediment composes of semi-consolidated conglomerate

2.3 Neotectonic of Northern Thailand

(5) N-S trending Cenozoic basins in Thailand have developed during late Eocene to early Oligocene by some extent of Southeast Asian block that involved in the major NE-SW trending fault zones. (Morley et al, 2011).
(6) Tectonic evolution of Cenozoic basins can be divided into four main tectonic stages. The first stage is initial of transtensional synrifting associating with the interaction of India and Asia during Early to Middle Miocene (55 – 35 Ma). This event is called the Himalayan–Tibetan orogeny that caused reactivation of the fault movement in Thailand. The basins are dominated by mostly fluvial or lacustrine environment. The second stage in Middle Miocene is quiescent thermal subsidence event (~35 to 15 Ma). The environment became fluvial – deltaic sediments. Then, late - middle Miocene Cenozoic basin was occupied by Transpression wrenching event (~15 to 10 Ma). Tectonic activity in this event caused folding and inversion in Cenozoic basin. The last episode is the post-rifting event (10 Ma to present).

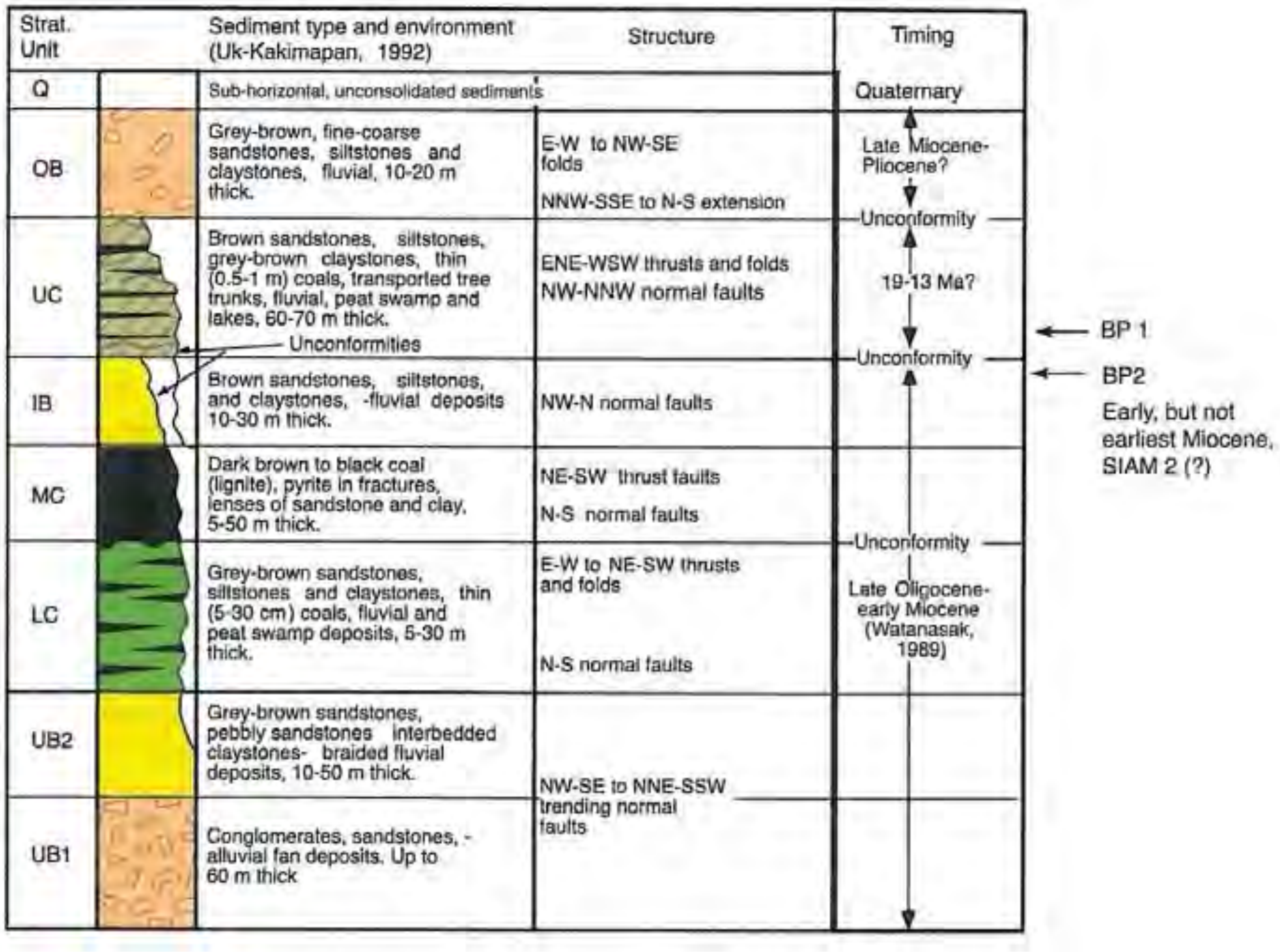


Figure 2.3 Stratigraphy and structural styles in the Ban Pu mine, Li basin during Oligocene to Pliocene (Morley et al., 2001)

2.4 Terminology for Structure

2.4.1 Drag fold

Drag fold is the minor fold or bent character adjacent to the fault that formed from movement of fault. This fold commonly develops by local compressional force in ductile stage before breaking of rock in brittle deformation. Drag fold can be formed in both normal and reverse faults. There was distinguished into two types Grasemann et al. (2005). The sense of drag fold depends on dip angle of fault. Low dip angles prefer normal drag and high dip angles prefer reverse drag.

Normal drag is drag fold which shows a convex marker in the slip surface (Fig 2.4). This type usually presents along fault with low dip angle approximately 20 to 30 degrees. This type of drag is commonly appears in natural than reverse drag. On the contrary, reverse drag presents a convex marker shows in the direction of slip. This type collocates with faults with dip angle steeper than 40 degrees.

2.4.2 Fault parallel zonation

Deformation of fault is classified into two types based on behavior of rock which deformed by movement of fault. There are brittle and ductile deformations. Fault parallel zonation or strain zone is divided into three zones (Fig 2.5) by deformation characters and strain distribution. The brittle deformation is classified into two groups there are fault core or slip surface and fault damage zone (Fossen, 2010).

The distribution of brittle deformation band decreases away from the fault core to background level of rock. Fault core or slip surface is identified by extremely deformed accommodation that defined as high-strain zone. This zone displays several deformed rocks such as fault gouge, cataclasites, fault breccia and glassy fault rocks. Fault damage zone is defined as the volume of brittlely intense deformation around fault surface than the original rock such as deformation bands, shear fractures, tensile tractures and stylolites structure that surrounding the fault core. The last type is ductile zone which is defined as folding layer adjacent to the fault such as drag fold.

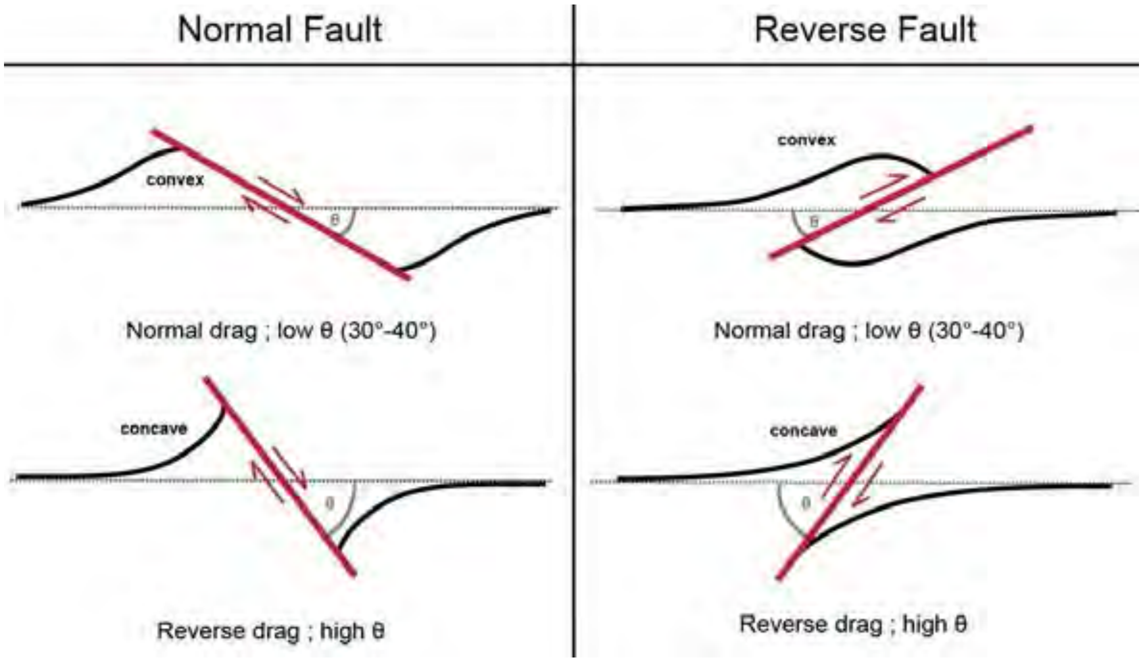


Figure 2.4 Fault drag along normal and reverse fault and character of fault drag is associated with original dip angle modified after Grasemann et al. (2005) .

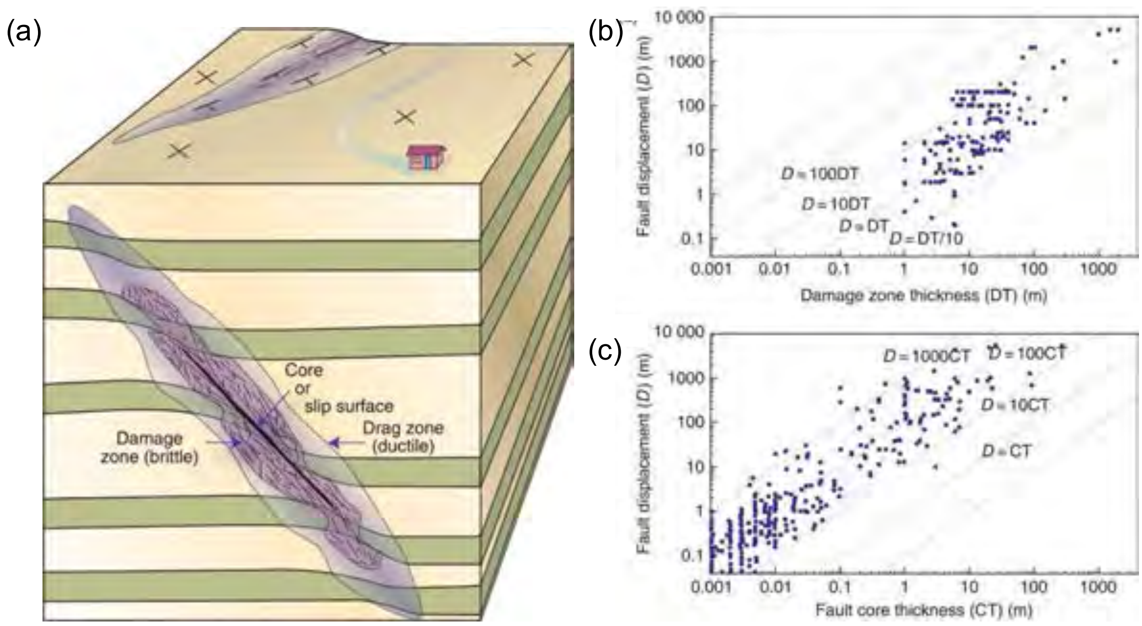


Figure 2.5 (a) Model displays the fault zonation geometry (b) The relationship between fault displacement and damage zone thickness (c) The relationship between fault displacement and fault core thickness (Fossen, 2010)

2.4.3 Low-angle normal fault

Detachment faults are identified as large extent fault in the continental crust with gently dipping. These faults with dip angle less than 30 degrees are identified as Low-angle normal fault (LANF). This type of fault is used to indicate crustal extension. LANF is commonly described as the result of initiated high angle normal fault rotation with pre-rotation dip between 25 and 35 degrees. On the other hand, LANF is studies by Fossen et al. (2010), Lyngsie, (2007) and is reported as low initial fault dip that causes from pre-existing fabrics that controls fault dip direction. Another description of occurrence of this fault is occurred between brittle-ductile transitions. LANF initiates in upper crust with brittle deformation and develops into lower crust. Therefore, ductile flow in lower crust produces basal shear extraction and present in listric low-angle normal fault.

The boundary fault that controls the geometry of Cenozoic rift basins in Thailand approximately 56% of these faults are LANFs. Some small basins are controlled by a single major fault, other larger basins have multiple large fault boundary. A large displacement boundary faults is recognized by seismic reflection data in Thailand. These LANFs curve high angle in sediment section and displays flat orientation in basement. Boundary of Chiang Mai basin is imitated as classic metamorphic core complex that composes of gneiss and Oligocene granite. This metamorphic uplifted in two main domes, Doi Inthanon and Doi Suthep by the footwall of LANF. Age of uplift is identified around 21 Ma and 14 Ma by Morley (2009), using Apatite fission and Ar/Ar dating. LANFs in extensional process with metamorphic core-complex is describe as abnormal crustal conditions by Whitney et al. (2013). This report has been divided the crustal conditions into three types. The first condition is block-rotation model for core complex formation that formed in warm crust condition. Rolling-hinge model is used to describe the formation of metamorphic core complex in hot crust condition. The last condition is hottest crust. This type is characterized into two models that are convergent channel flow of lower crust and channel detachment at the margin of orogenic plateau. The deformation model of every conditions is illustrated in Figure 2.6.

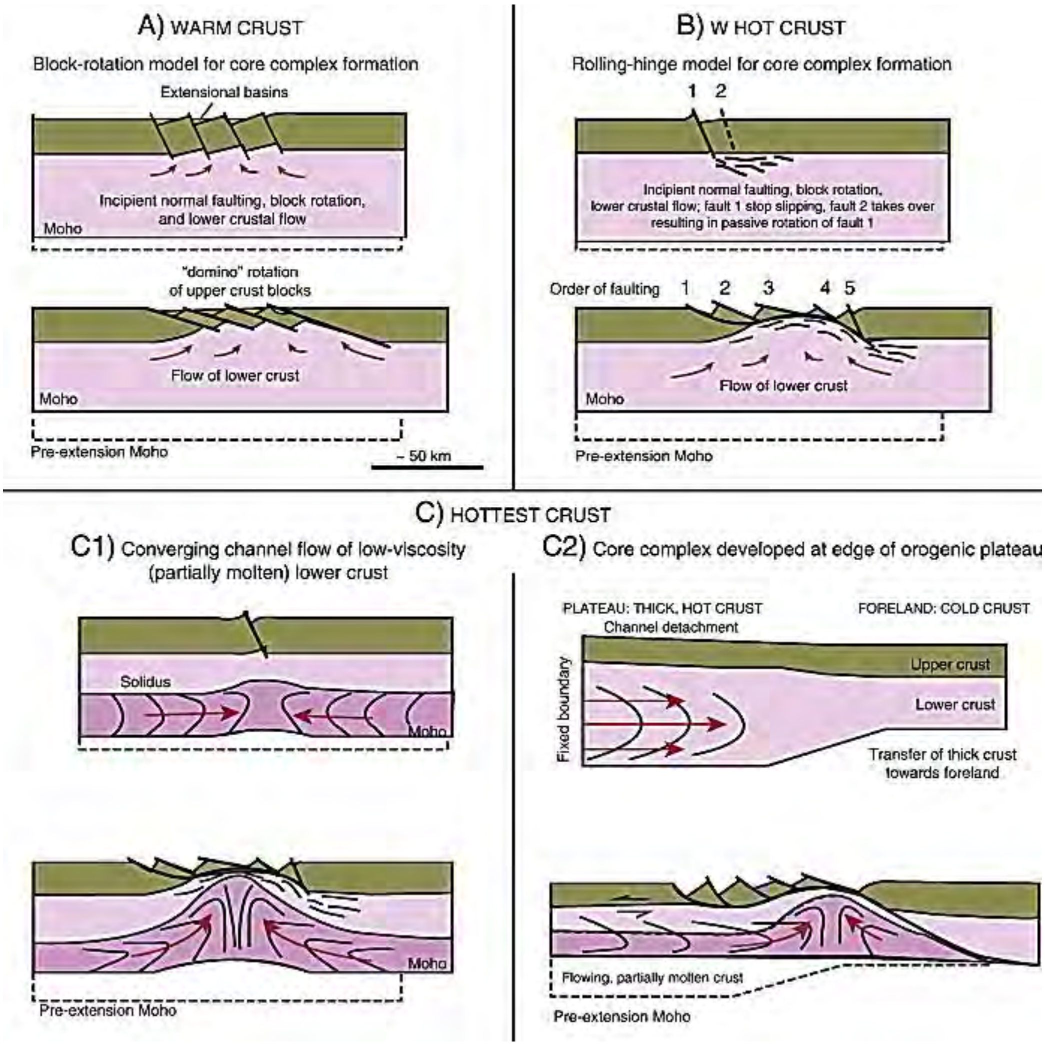


Figure 2.6 Models for the development of low-angle normal faults in response to different initial crustal conditions according to Whitney et al. (2013)

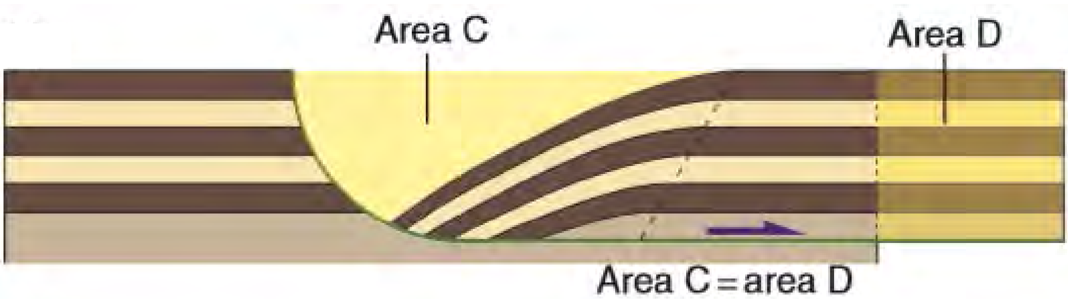


Figure 2.7 Model illustrates void area that formed from deformation of the hanging wall in extension regime by Fossen (2010).

2.5 Geostatistical Analysis

2.5.1 Linear measurement and displacement relationship

The relationship between maximum displacement and linear measurement on the fault surface is used to analyze fault geometry in different length (Kim et al, 2005). The maximum linear measurement consists of two geometric elements, fault length and fault height. Fault length is the longest linear that measured along fault plane. Whereas, fault height is the longest linear of the fault measured in cross-section that obviously shows on the Ban Pong quarry exposure. The relationship between maximum displacement and linear measurement (L or H) always presents in the equation.

$$D_{max} = cL^n$$

Where: *n* is a fractal dimension. The range of n is 0.5 to 2.

c is an expression of maximum displacement.

2.5.2 Faults zonation thickness and displacement relationship

Deformation band there are damage zone thickness (DT) and fault core thickness (CT) along fault is related to displacement (D) of fault. This relationship is studied by Otsuki (1978) from triaxial compression test in siliclastic sedimentary rock. Displacement of normal fault from the experiment between damage zone thickness and displacement ranges between D=10DT to D=DT/10. While, the relationship between the faults core thickness (CT) and displacement (D) is expressed with the equation.

$$\log D = a \log (CT) + b$$

Where: *a* is the growth mechanisms of the fault core thickness, normally 1.

b obtained from experiment up to lithology and fault type.

Sperrevik et al. (2002) confirmed that the fault core thickness depends on lithology. This research proved that sandstone body will give a greater fault core thickness, than sandstone interbedded with shale. The relationship between fault core thickness and displacement is expressed in linear relationship on log-log scale by Fossen (2010). Displacement and faults core thickness ration of normal faults is ranges between D = 10CT and D = 10CT. (Fig 2.5c)

2.6 Backstripping

Backstripping is a geophysical analysis technique that used to analyze the subsidence history of a sedimentary sequence by backward the depositional process and reconstruction the deformation by 2D cross-section of the study area. This model is used to support the realistic interpretation and estimate the strain rate. The procedure begins with create a 2D modelling of cross-section and structural profiles. Then, remove the stratigraphic sequences layer-by-layer, accompanied by decompaction of underlying sediment and the last process is structural reconstruction.

2.6.1 Decompaction

Decompaction process aims to eliminate the top stratigraphic sequence and convert the porosity of the underlying horizon to the initial porosity before burial process. After conversion the porosity, thickness of horizon is corrected to initial thickness by modify specific porosity-depth function of each horizon.

The height of horizon is depended on material or lithology. Flexural isostasy is applied to a 2D cross-section decompaction. This method is reported by Sclator and Christie (1980). The main principle is porosity decrease in exponential function with increasing depth. The relationship between the present-day porosity at depth (f) and the initial porosity at surface (f_0) presents in linear relationship.

$$f = f_0 e^{-cy}$$

Where: f is the present-day porosity at depth

f_0 is the initial porosity at surface

c is the porosity-depth coefficient

y is the depth

2.6.2 Block Restoration

The objective of block restoration is reconstruction every points of the model into the orientation and location before deformation. This procedure assumes the horizon is the rigid block. The objective of this procedure is illustration the pre-deformation location by reversing the displacement and provide data for strain estimation. Block restoration methods are distinguished into two methods that are Flexural-Slip restoration and Simple-Shear restoration. Flexural-Slip restoration principle is horizon lengths and stratigraphic thicknesses were preserved throughout the deformation. Whereas, Simple-Shear restoration method aim to flatten the horizon to the picking reference datum.

Strain estimation can be evaluate by the restoration. After restoration process by flexural-slip, a void area in the hanging wall blocks of fault is shown on the model. This area is equal to lithospheric stretching of the horizon. In extension regime lithosphere has thickness variation that is the consequence of stretching and thinning of crust. The stretching value is measured by a marker point or point of reference that was restored to the initial location before extension (Fig 2.7). Lithosphere stretching factor or beta factor (β) is used to estimate extension quantity in the system based on lateral distribution of strain. The equation of lithosphere stretching factor is researched by McKenzie (1978).

$$\beta = \frac{l}{l_0}$$

Where: l is a crustal wideness after extension.

l_0 is an initial crustal wideness.

Chapter 3

Methodology

The procedure of this project is divided into four main step. The process begins as the pre-field study. Then, the second part presents field study method that covers with field data collection and Digital Outcrop Model (DOM) data acquisition. Next, DOM methodology is presented in the third part. Finally, structural analysis is shown in the final step. The workflow is shown in figure 3.1.

3.1 Pre-Field Study

The pre-field study aims to study geological data and general information by literature review from the recent studies. This collection consists of lithology, structure and tectonic activity in study area that relating to regional tectonic in North Thailand. This process covers a study of regional structure and terrain's surface by satellite image and Digital elevation model (DEM).

3.2 Field investigation

In the beginning, this study accumulated the pictures of Ban Pong quarry from related study in 2015-2017 to analyze the structure. Ban Pong quarry still operates until the present. So, the new surface from outcrop exposure is reveal to the surface and shows new evidences that is valuable for structural analysis process. Therefore, fieldwork is the necessary procedure.

Data collection in field work consists of Lithology identification and Structural measurement. Lithology data is used to indicate the age of basin and geological structure. Stratigraphic column is required to display the geologic sequence of these sediment units. Moreover, lithology is one of the most compulsory factor for backstripping procedure. Structural measurement including bed orientation, bed thickness and fracture orientation is measured with georeferencing record of every structural feature. Because of the high and steep character of an outcrop with approximate 40 meters in height, structural measurement at the upper part of an exposure is impossible. The alternative method, DOMs is used to solve this problem. Advantage of DOMs method is showing of visual outcrop surface from the quarry by remote sensing technology, including photogrammetry and light detection and ranging (LIDAR) that are heavyweight and expensive equipment. Therefore, Agisoft PhotoScan software which create the model from picture is apply for this reason. The procedure of data correction for DOM begins as setting a ground control point and marks its GPS coordinate. This step attempt to control a coordination accuracy of outcrop photo from drone with GPS. Then, capturing outcrop photo. Importantly, the photos should cover an overlap area between the adjacent photos and displays the ground control point in the photos. Photos from drone have a three-dimensional coordinate information that use to represent the location of outcrop surface in DOMs.

3.3 Digital outcrop model

Digital Outcrop Model (DOM) is a 3D visual outcrop model which created from the PhotoScan software. This model requires photos and 3D coordinate information of outcrop surface from fieldwork for a precise location for the model.

DOM creation uses Agisoft PhotoScan software to align outcrop photos by their 3D coordination. Building a point cloud model is the next step (Fig 3.2b). Afterward, software generates a 3D mesh or a triangular network of points from point cloud model (Fig 3.2c). Next, appointing a georeferencing with GPS data to correct the coordination data into the precise location of an outcrop. Before exporting the model, textured model is processed to eliminate shadows and retrieval the natural color and preserving texture features. The last process is exporting 3D model into Move™ software for structural analysis. DOMs adjustment and modification is done to improve the data for structural analysis process. This method is illustrated by Figure 3.2.

3.4 Structural Analysis

3.4.1 Fault Interpretation

The Move^{TM} software provides a toolkit for structural analysis and geological modeling. Surface attributes is an option in structural analysis process. The attributes can emphasize or highlight structure and lineation in DOM surface by different in dip angle, dip azimuth and curvature of structural features by color scale bar. After this process DOM is available for interpretation process.

This step aim to explain and classify the structural style including bed orientation, bed thickness, fault and fracture orientation of the study area. Then, bedding planes and fault planes that measured in fieldwork are created to illustrate the orientation and used to calibrate the orientation of structure in the upper part. After that, creation of two dimension section of outcrop exposure is done for backstripping.

3.4.3 Backstripping

Backstripping technique promotes a better understanding of the geological evolution of the study area and is used to calculate the stretching value of an outcrop. In this study, this technique uses 2D section from DOMs for backstripping in Move^{TM} software. The procedure comprises of 3 main sections. First is decompaction to reversal the latest compaction by an upper horizon. Then, restoration process is done to reconstruct each horizon into the initial location before deformation by reversing the displacement of fault. This step depends on flexural-slip method that retain the size of each polygon of the horizon. Finally, the last step is unfolding and flatting the horizon to the original location before deformation. This model is valuable for evolution description and ensuring the interpretation. Finally, evolution model is used to describe local tectonic evolution of the study area.

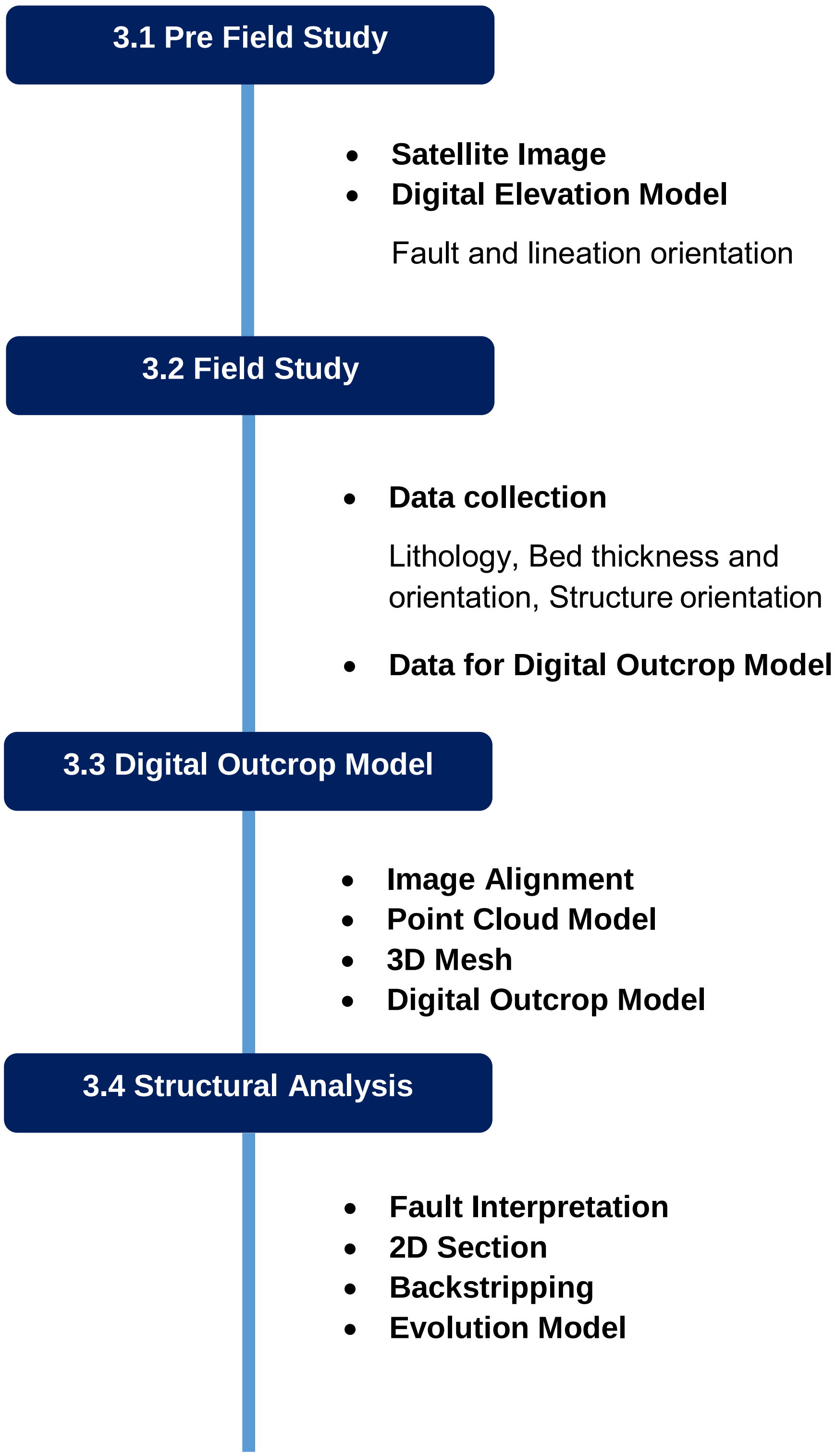


Figure 3.1 Diagram illustrates the main procedures of this study.

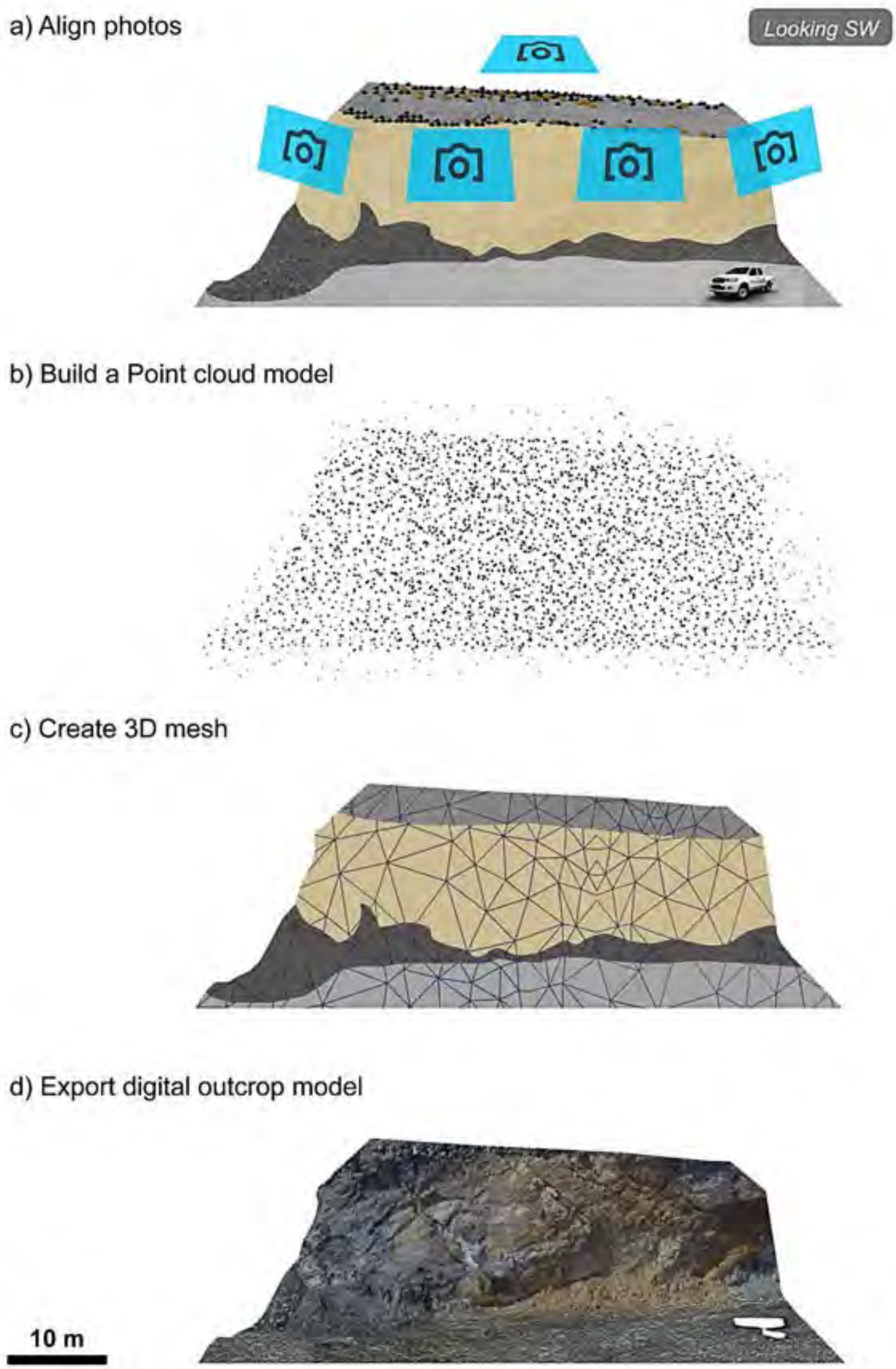


Figure 3.2 The four main stages of 3D model construction by using PhotoScan software (Phetheet, 2016)

Chapter 4

Results

4.1 Stratigraphy

Stratigraphy of the Ban Pong quarry is characterized by Quaternary semi-consolidated sediments. This sequence was dominated in alluvial fan-alluvial plain. Coal bed with fine-grained sediment appears on the footwall of the major fault. The stratigraphic column is done along A survey on the hanging wall of the major fault shown by the red line in Figure 4.1. The oldest sediment is greyish mud which apparently present approximately 8 meters above the ground. Then, the sequence overlies with pebble interbedded with greyish mud. Thickness of this group up to 7 meters. Pebbly composition consists of limestone, quartz and coal fragment. Pebble beds are 1.5 to 2 meters thick. This group overlies with yellowish mud with 7 meters thick. Then, pebbly interbedded with greyish mud appears again on the top of yellowish mud. Finally, the youngest yellowish mud lie on the top of this stratigraphy column.

4.2 Basin structure

The Ban Pong basin is a long shaped basin extends in NS direction 1.5 kilometers wide and approximately 3 kilometers long. (Rhodes et al., 2000; Mankhemthong, 2014). The average elevations of Ban Pong basin is around 330 to 360 meters above mean sea level. While, the border of this basin is Paleozoic sedimentary mountains with average elevation around 600 meters. These elements is presented by Digital Elevation Model (DEM) on Figure 4.3a. Ban Pong basin displays graben-shaped geometry along cross-section of Ban Pong basin and nearby areas in Figure 4.3b.

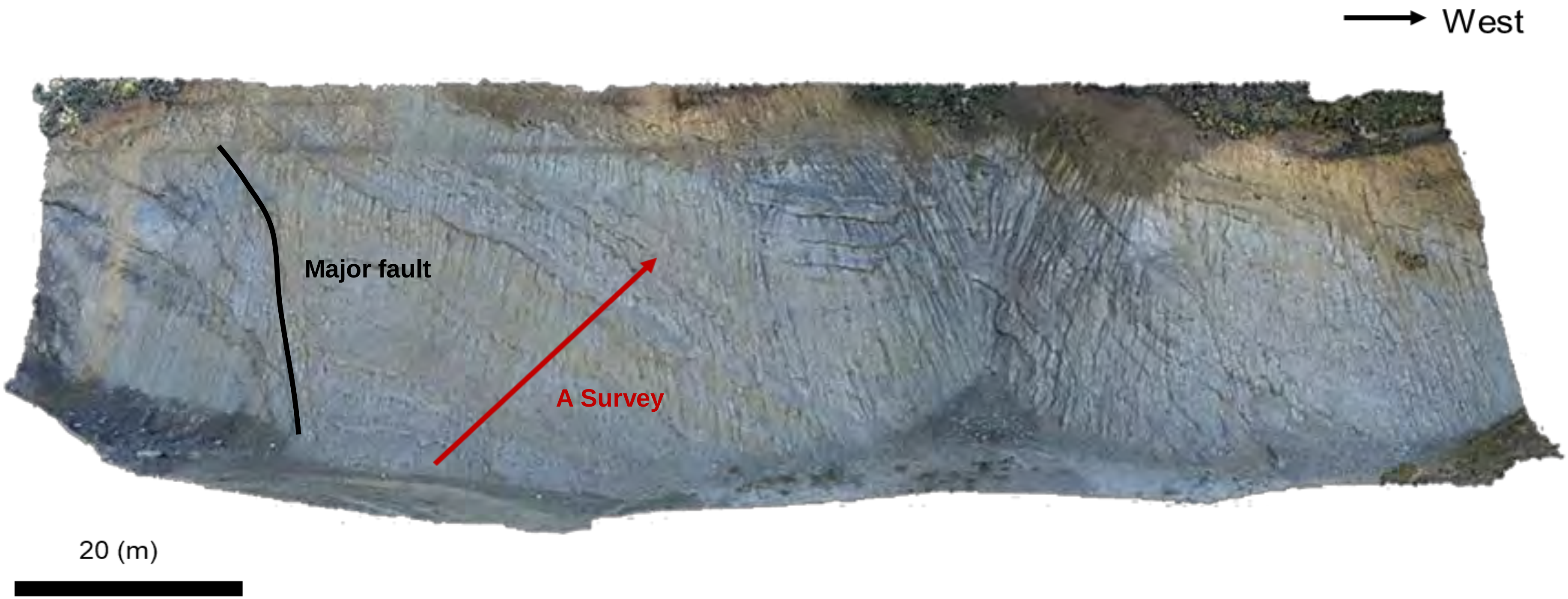


Figure 4.1 A line of stratigraphic survey (red line) on the hanging wall of the major fault (black line) shows on Digital outcrop model recorded on January,2018.

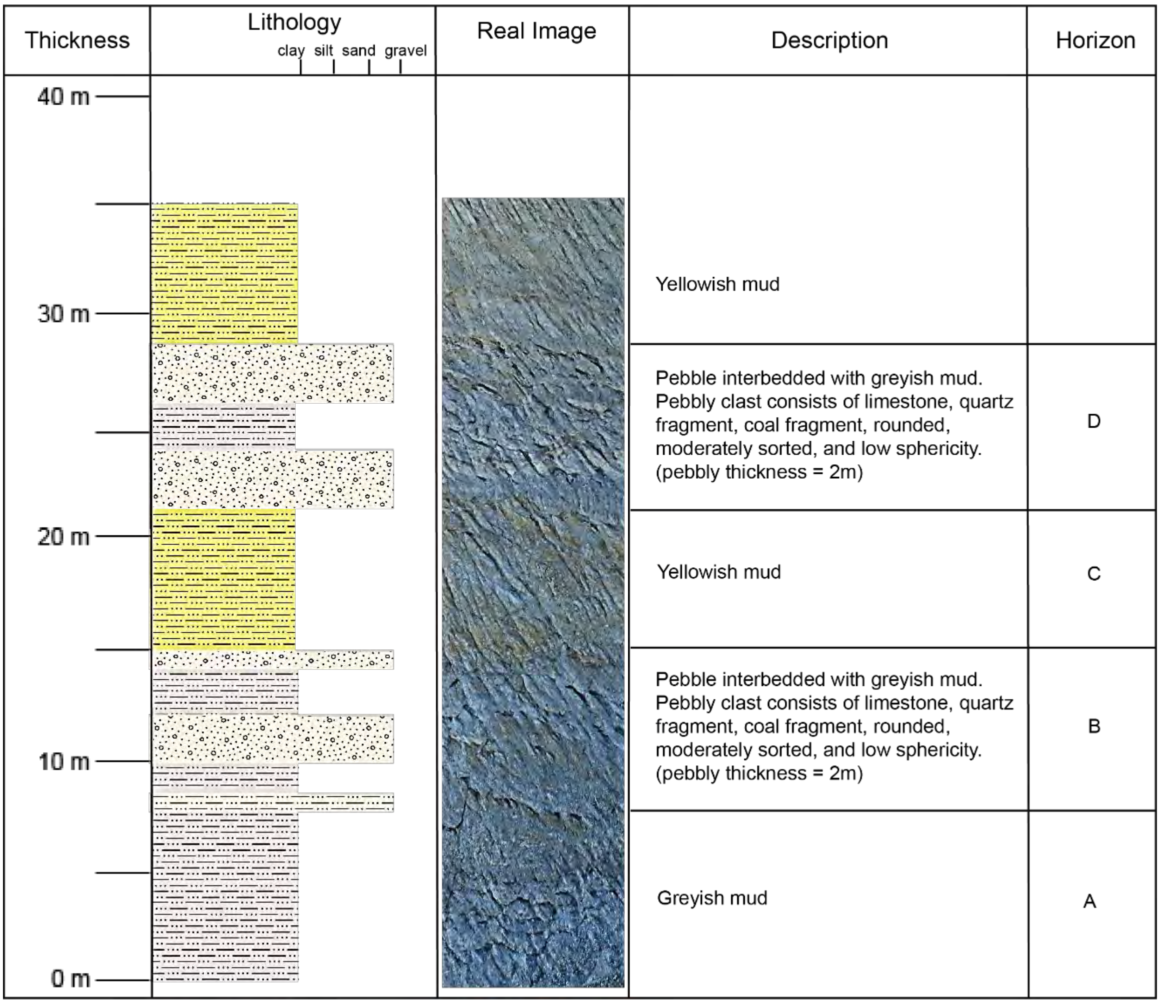


Figure 4.2 Stratigraphic column along stratigraphic survey (red line) with interpreted horizon which used in backstripping procedure

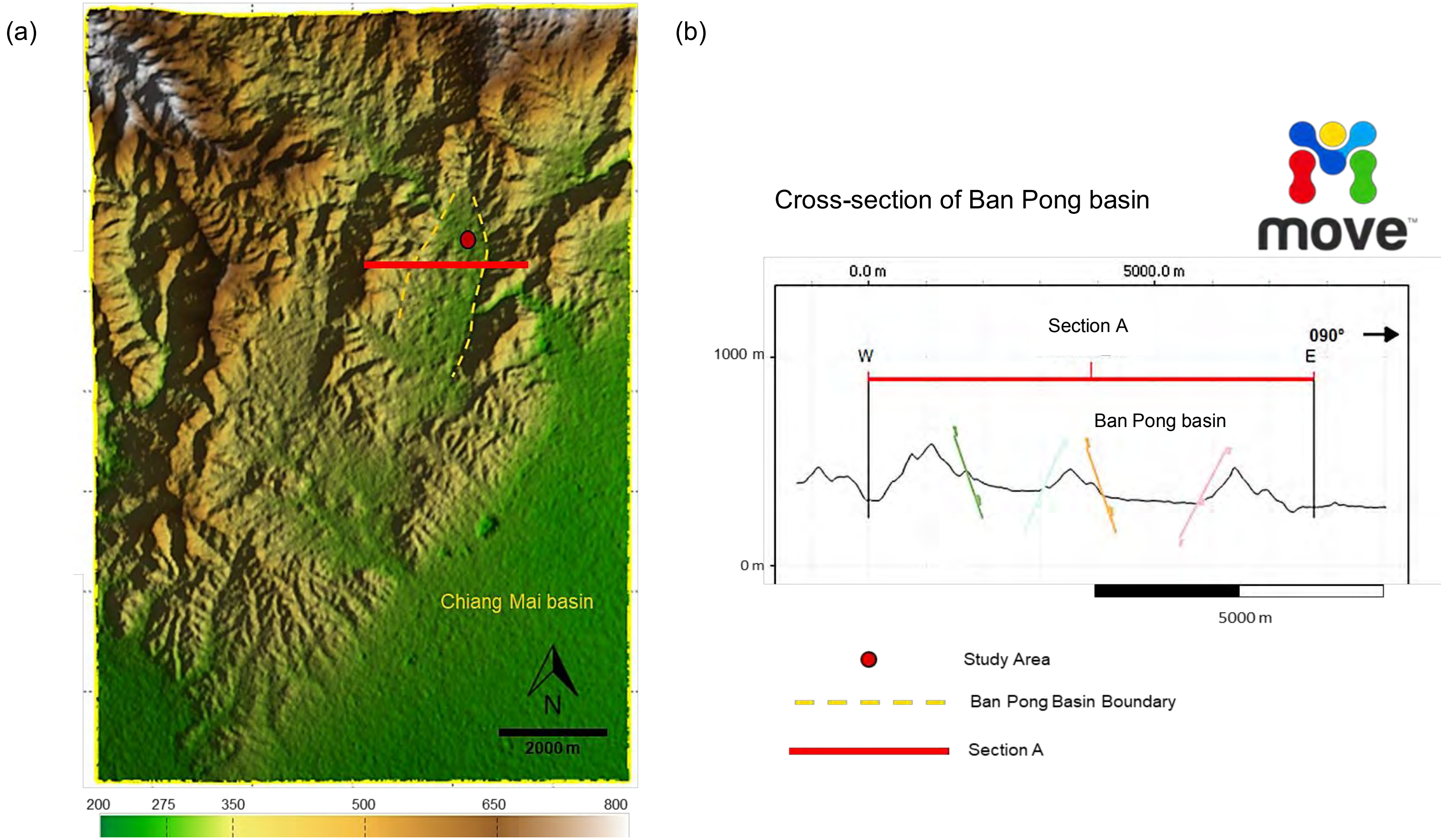


Figure 4.3 (a) Digital elevation model and (b) cross-section of Ban Pong Basin and nearby places

4.3 Digital outcrop modelling

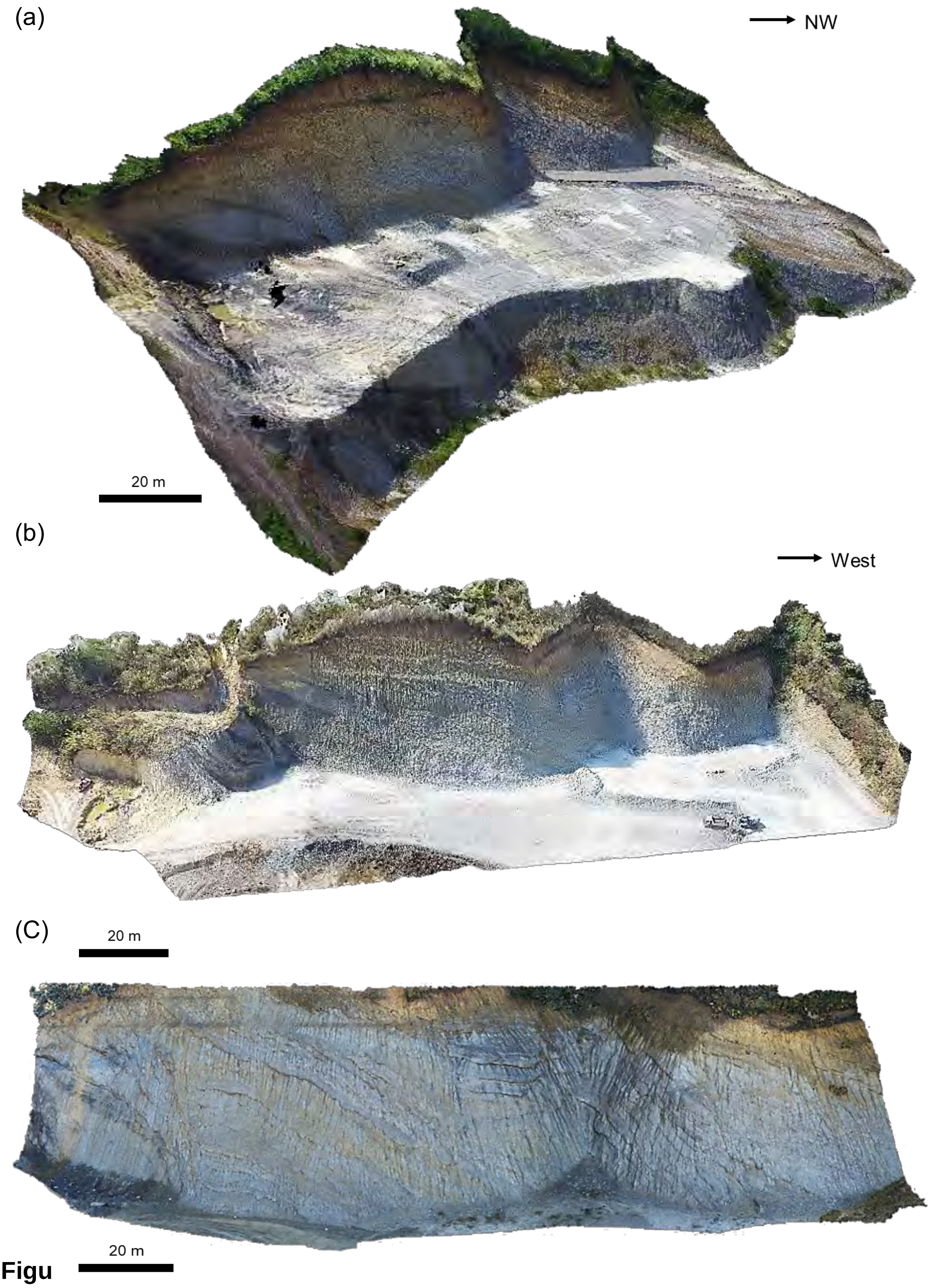
DOMs of the study area visibly display the geological structure such as fault, fold and bedding planes. In the beginning, this study accumulated the pictures of Ban Pong quarry from related study on 2015 to generate the DOMs. The first model represents the surface of an outcrop on November, 2015. This model can obviously see the strike of a major fault that is significant for an interpretation process. But, Ban Pong quarry still operates until the present. The deeper surface of the outcrop is expose to the surface by the operation. Thereby, the following two models is done on March, 2017 and January, 2018 for structural analysis. Structural interpretation and structural plane simulation are created by the combination of all models in Move™ software. All DOMs of Ban Pong quarry is illustrated by Figure 4.4. Surface attributes are used to classify geological structure and artificial fracture by a quarry operation including dip angle, dip azimuth and curvature of triangular mesh surface. Dip attribute and curvature attribute can highlight lineation from geological process including fault and bedding which has lower dip and curvature than the background (Figs 4.5a & 4.5c). While, dip azimuth can sort out the artificial trace from quarry operation from geological structure. The vertical scrape from quarry operation is shown in yellow vertical line on dip azimuth attribute (Fig 4.5b).

4.4 Structural interpretation

Geological structures in this excavation is comprised into four types. There are bedding plane, west-dipping normal fault or major fault, east-dipping normal fault or antithetic fault on the hanging of the major fault and roll over anticline.

4.4.1 Bedding planes

The orientation of bedding planes in this study are NS to NE-SW trending with gentle dipping into W-SW direction. The dip angle of the bedding is larger in westward direction that is a consequence of fault drag along the major fault. Figure 4.6 shows the difference of bedding orientation in Ban Pong quarry.



Figu
re 4.4 Digital Outcrop Model of Ban Pong quarry, Chiag Mai on (a) November, 2015 (b) March, 2017 and (c) January, 2018

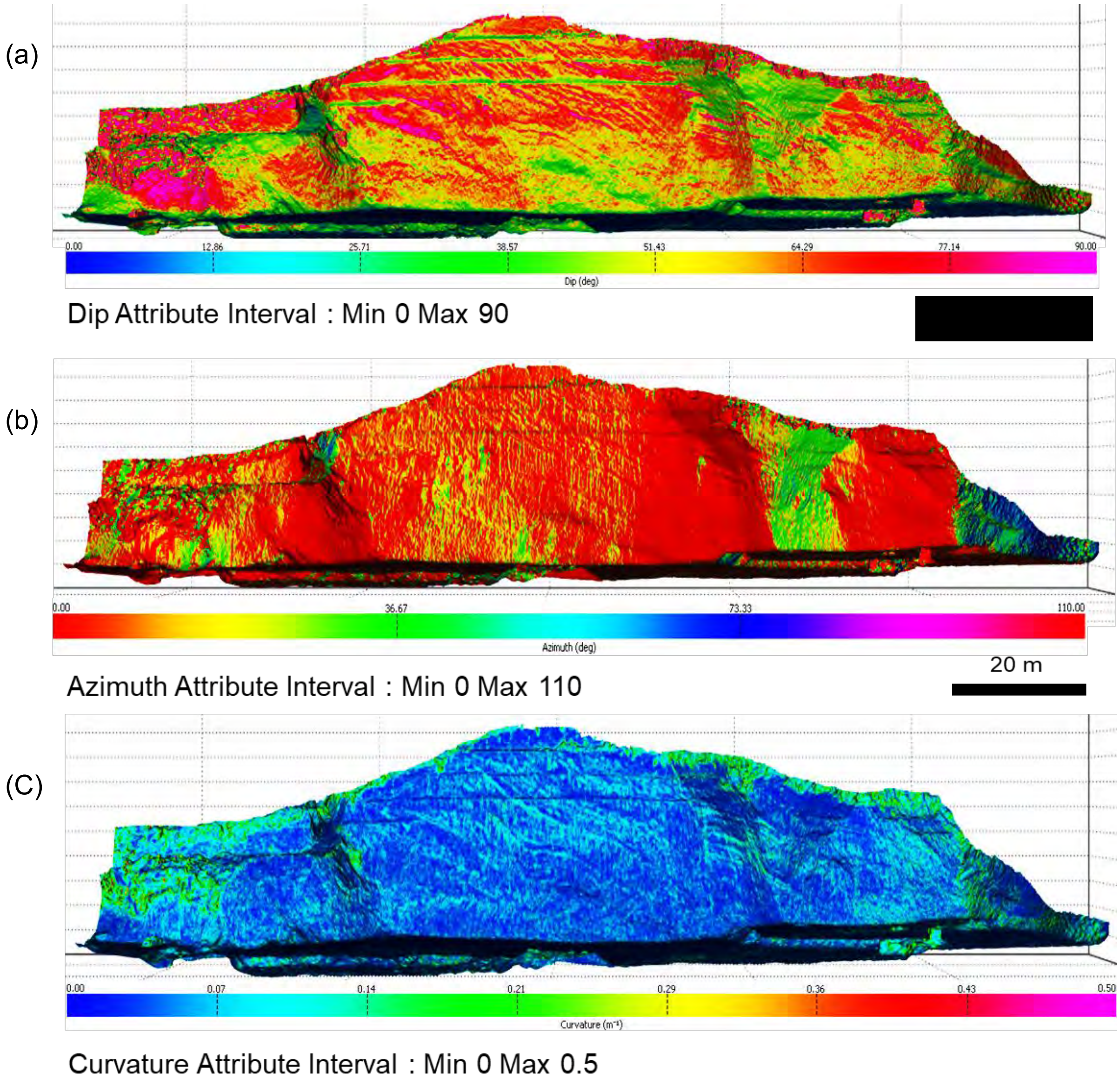


Figure 4.5 Surface attributes of Digital Outcrop Models on March 2017 a) Dip b) Azimuth c) Curvature

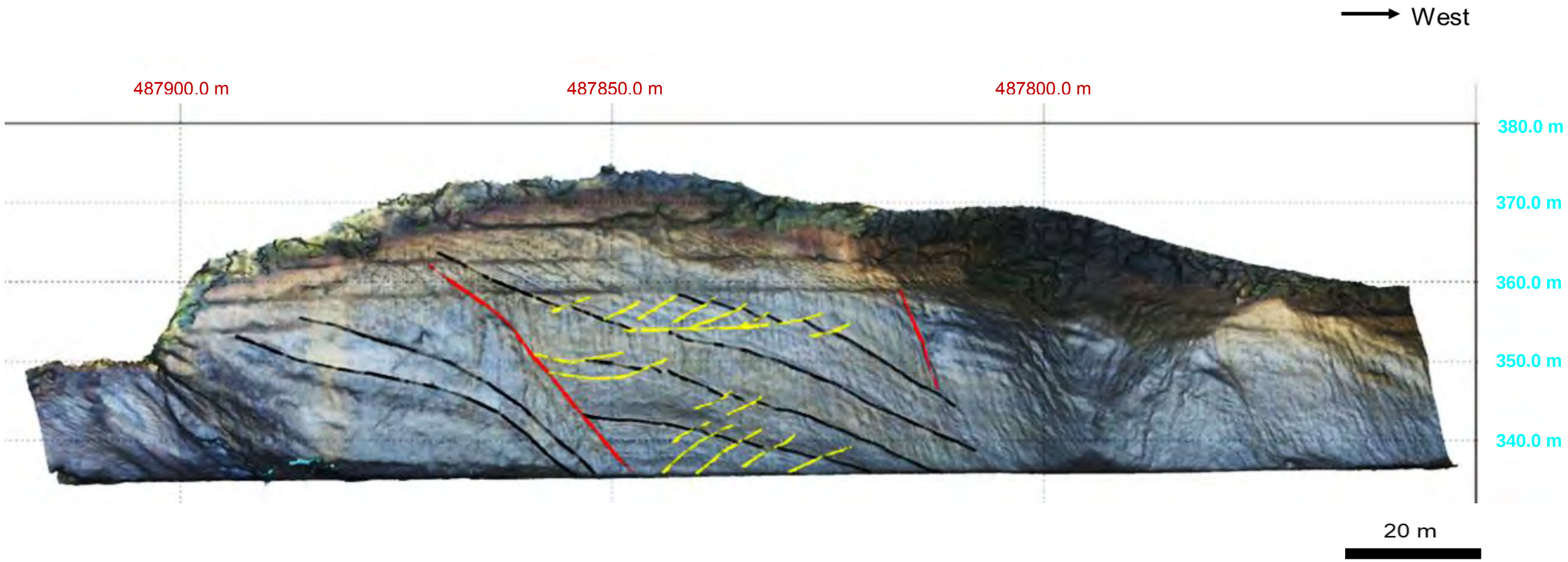


Figure 4.6 Structural interpretation from Digital Outcrop Model recorded on January, 2018; bedding (black line), west-dipping normal fault or major fault (red line) and east-dipping normal fault or antithetic fault (yellow line)

4.4.2 West-dipping normal fault

The first group is a major fault in the outcrop exposure. This fault is defined as fault zone which composes of several steep normal faults. Orientation of these faults is NS direction with dip angle around 60 to 70 degrees in W direction that is the same direction with sedimentary bedding. Fault spacing between two major faults is around 50 meters. This fault zone presents in both eastern and western boundaries in the quarry exposure and is accreted with fault drag. Convex marker in drag fold presents in foot wall of the major fault adjacent to the fault zone. This drag fold is defined as normal drag which associated with normal fault with initial dip angle approximately 30 to 40 degree as reported by Grasemann et al. (2005). While, the dip direction of the major fault in the study area is inclined to W direction with angle about 60 to 70 degrees. Commonly, this type of fault drag should appear with lower dip angles. Therefore, this marker shows some evidence of a clockwise rotation approximately 30 to 40 degrees in the study.

4.4.3 East-dipping normal fault

This group of fault is antithetic faults of the major faults. Appearance of this group is domino style faulting on the hanging wall. The displacement ranges between 0.5 to 1.5 m. This group presents both planar normal fault and low angle normal fault (LANF). Planar faults appear on the wall around 20 meters height from the ground. Orientation of these faults are NS direction and 30 to 40 dipping in E direction that opposite with bedding plane. Whereas, LANFs appear at the higher elevation with dip angle less than 15 degrees in E. Some of these LANFs is characterized as listric normal fault that is described by decreasing dip angle with depth and curved in fault plane. Listric faults in this exposure is associated with properties of the lithology. The fault is inclined in rigid stratum and is turned to straight faults in a ductile substratum. The different geometry of fault in upper and lower zone of the hanging wall of major fault is an evidence of non-uniform deformation in outcrop scale.

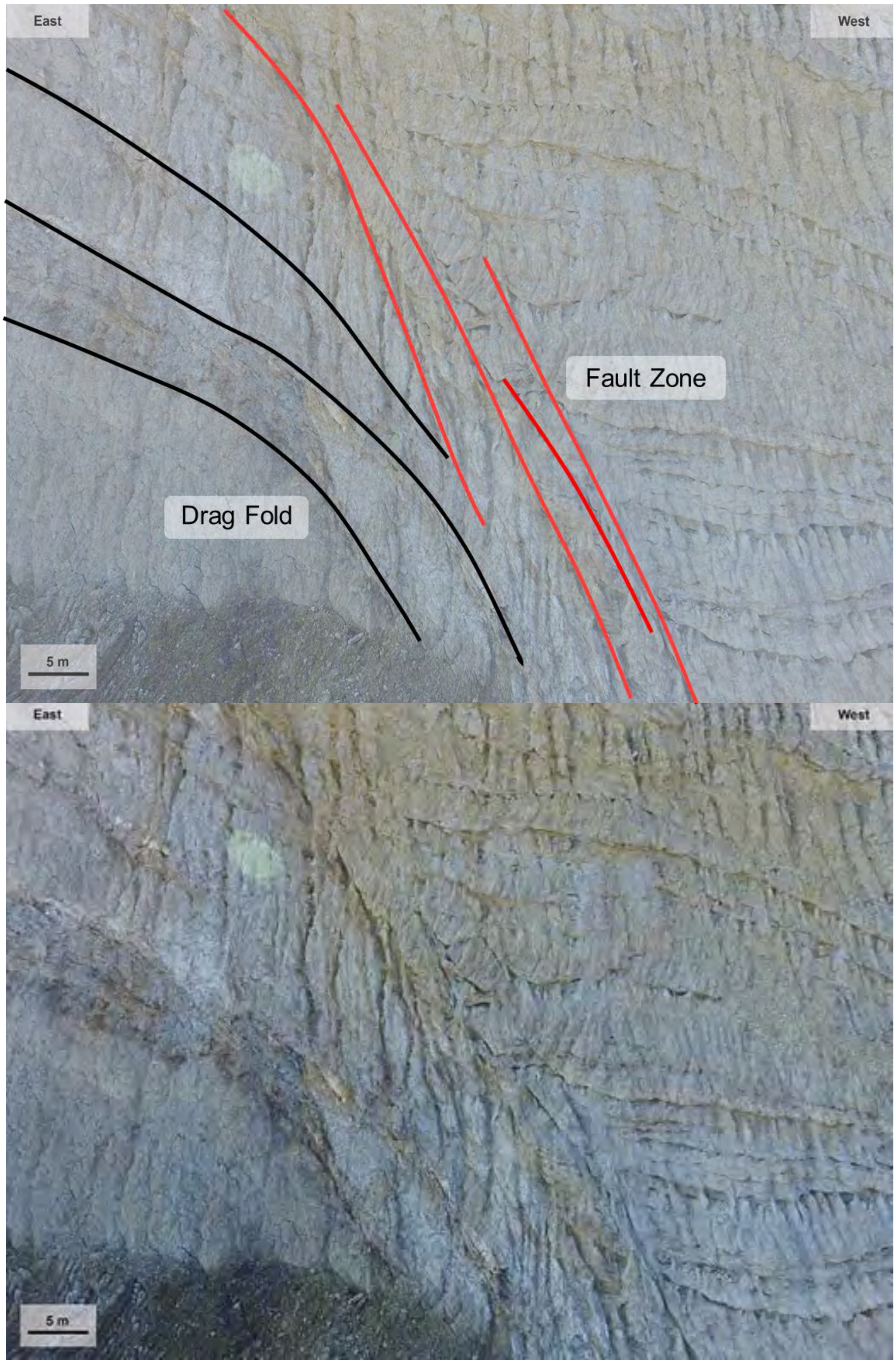


Figure 4.7 A representative normal fault drag on the quarry along the master normal fault

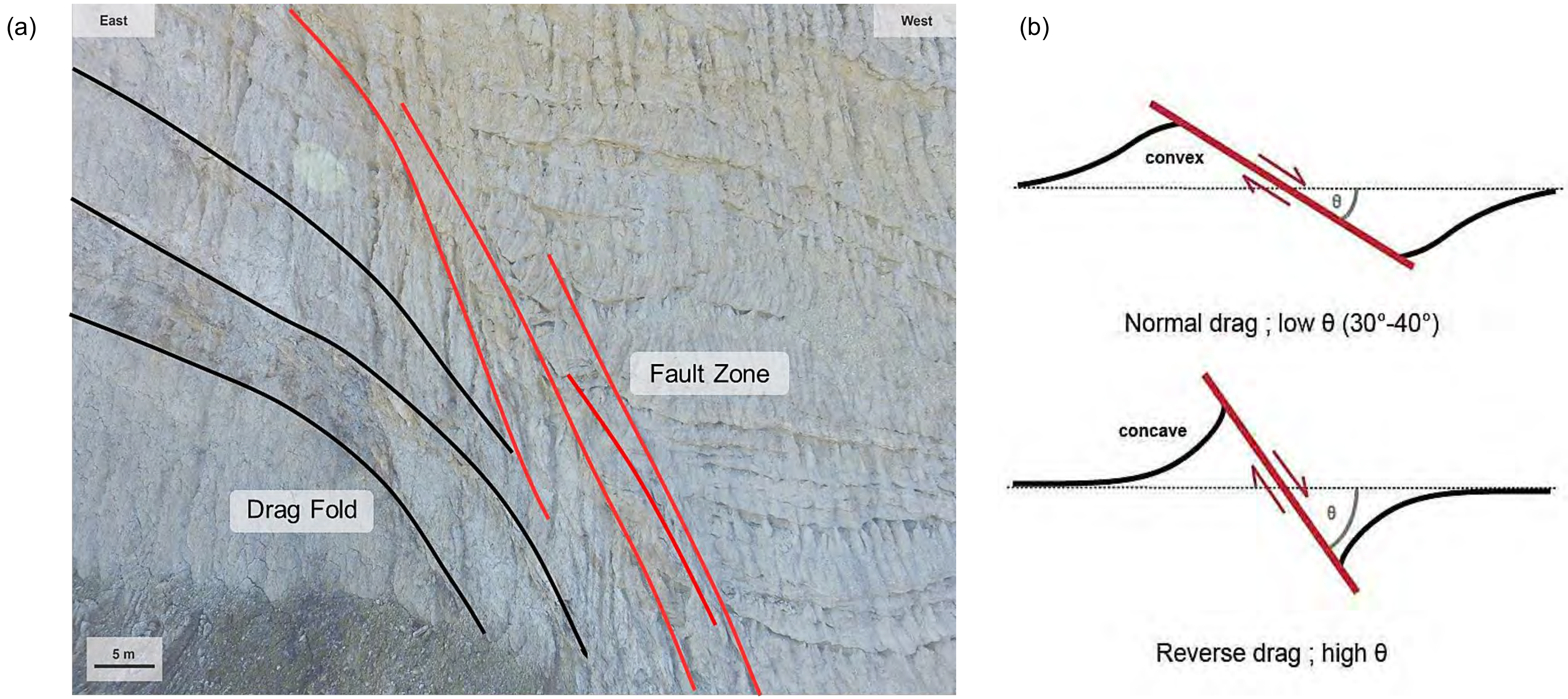


Figure 4.8 (a) Fault drag along major in the study area was identified as (b) normal drag from the convex marker on the footwall of fault (modified from Grasemann et al., 2005)

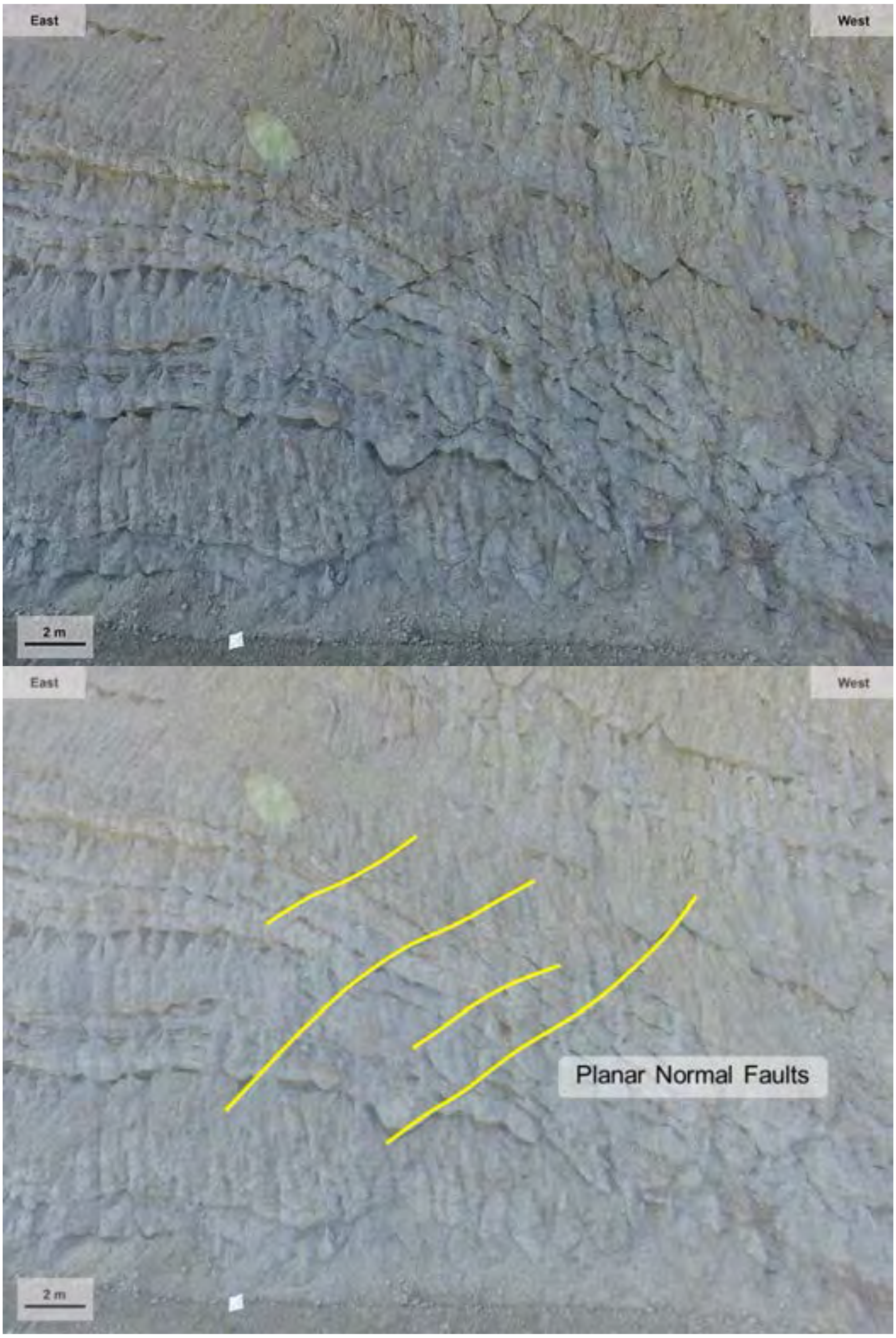


Figure 4.9 A representative planar normal faults in study area.

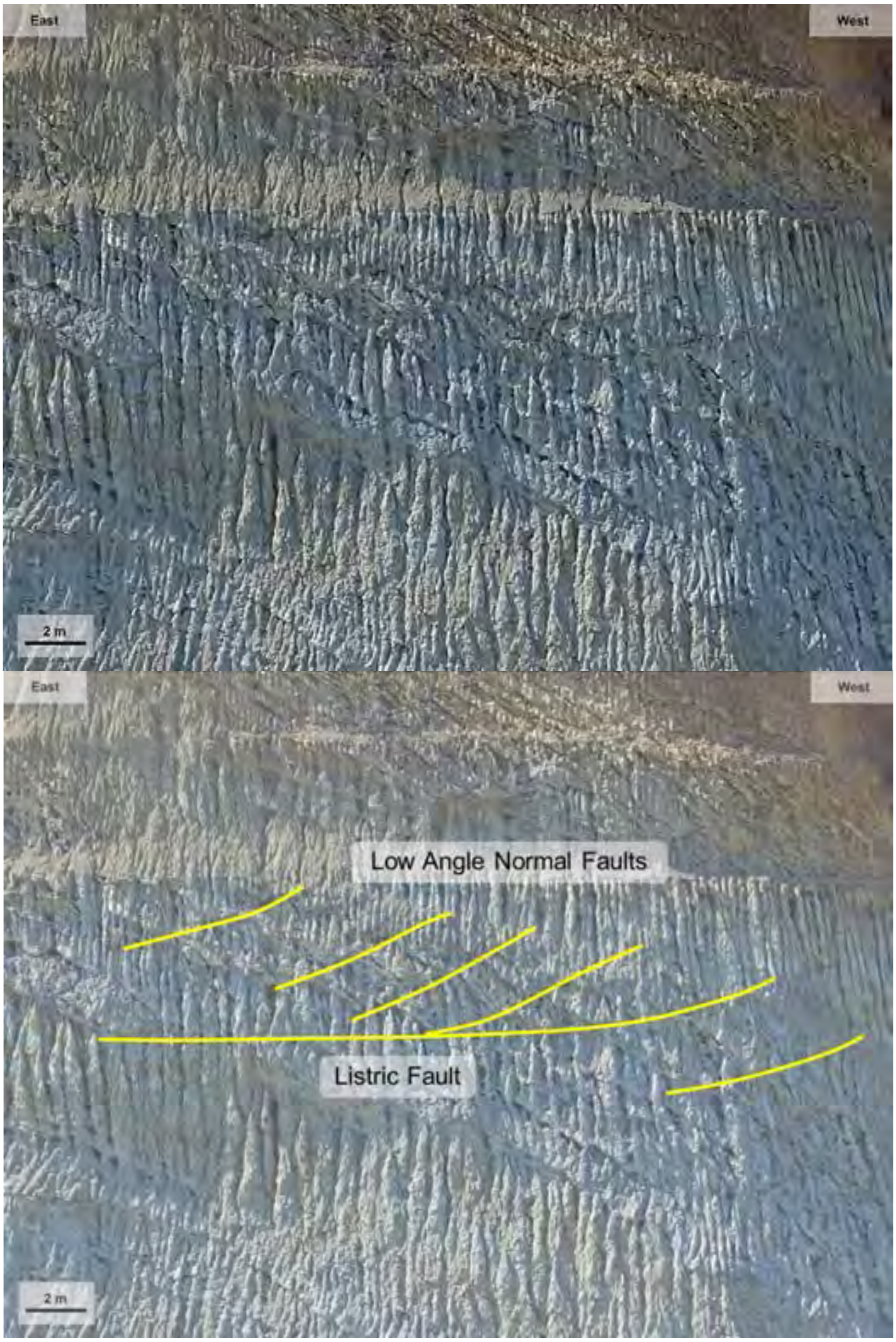


Figure 4.10 Low angle normal faults and soft domino model in study area

4.4.4 Roll over anticline

Well-exposed folding are located in hanging wall of the major fault adjacent to fault line (Fig 4.11). This structure occurs during syn-deposition of Ban Pong basin. This fold is formed after deposition of horizon B (Fig 4.15) and is defined as a roll over anticline that related to normal fault in extension system in EW direction. The roll over anticline is formed from the local compression which occurs in the hanging wall when hanging wall is pulled away from the foot wall. The original horizon deposited with horizontal bed with no dip angle. Angle between fault surface and bedding surface is maintained a constant angle. When fault surface becomes gentler, the beds become tilted to the higher degree. The tilting produced by the fault causes the beds to dip in the opposite direction and creates the anticline that named roll over anticline.

4.5 Backstripping

This study focuses on the deformation of the hanging wall of the major fault. Therefore, the section for backstripping must cover the interested structure. The horizon in 2D section was divided into 4 horizons based on lithology in stratigraphic column. (Fig 4.2). Non-uniform deformation in outcrop scale of the study area is represented by different geometry of antithetic faults in the hanging wall including planar fault in the lower part and low-angle fault in the upper part. The stretching factor is calculated from a crustal wideness after extension divided by an initial crustal wideness that can be measured from backstripping model. Ban Pong quarry has higher stretching factor in the upper and decreases downward in outcrop scale. Average stretching factor of this area is 1.05. The highest is 1.106 in horizon C which is yellowish mud and the lowest is 1.036 in horizon A that is greyish mud horizon. Horizon B and horizon D compose of same lithology that is pebble interbedded with greyish mud. But, these two horizon has the different stretching factor. It is 1.096 in horizon A and 1.101 in horizon D. Thereby, lithology is not the main parameter which control stretching factor. The higher stretching in upper part is the result from higher fault drag than lower part. Backstripping model and stretching factor of the study area is illustrated by Figure 4.16.

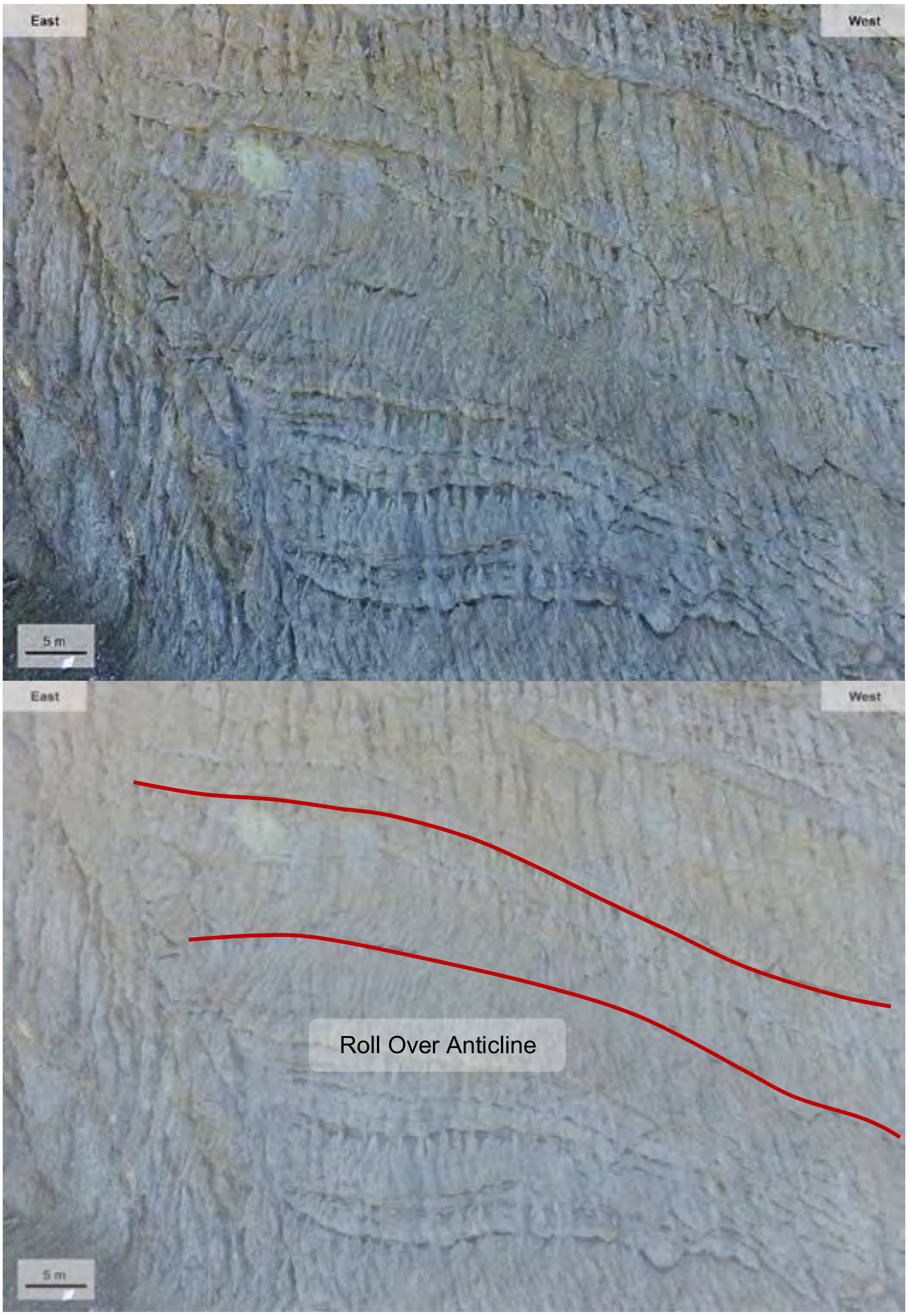


Figure 4.11 Roll over anticline in hanging wall of major fault formed from local compression from rotated major fault.

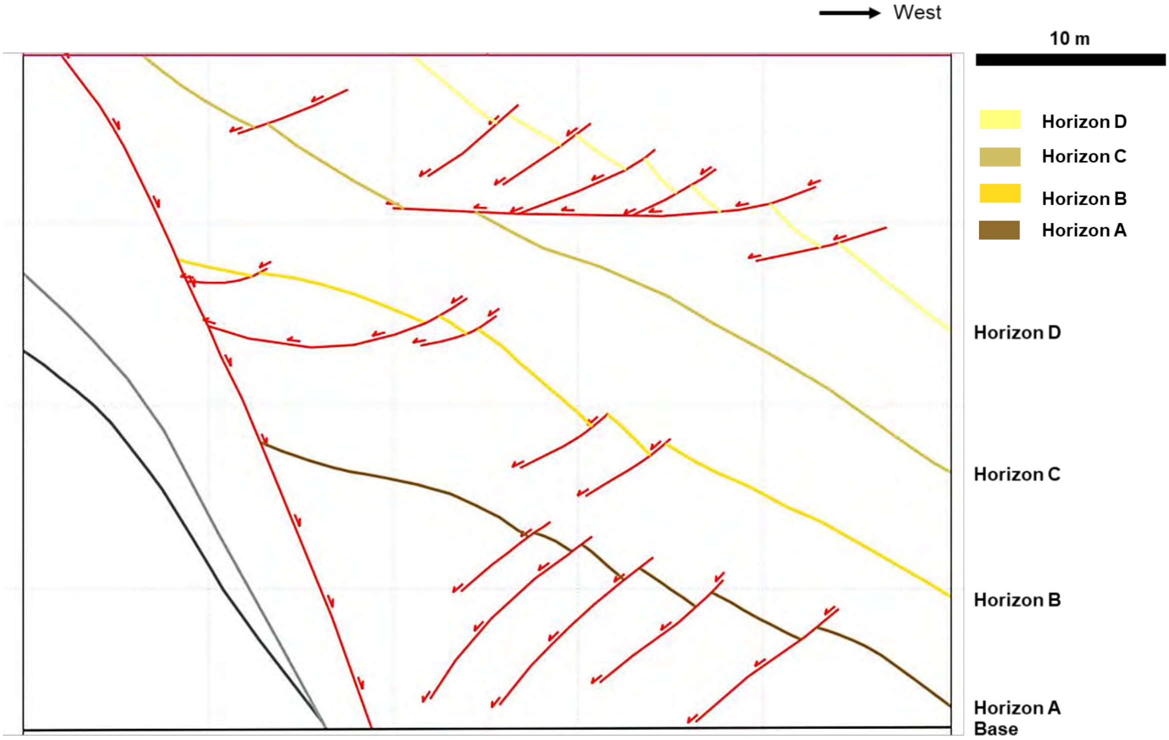


Figure 4.12 2D-Section from Digital Outcrop Model of Ban Pong quarry

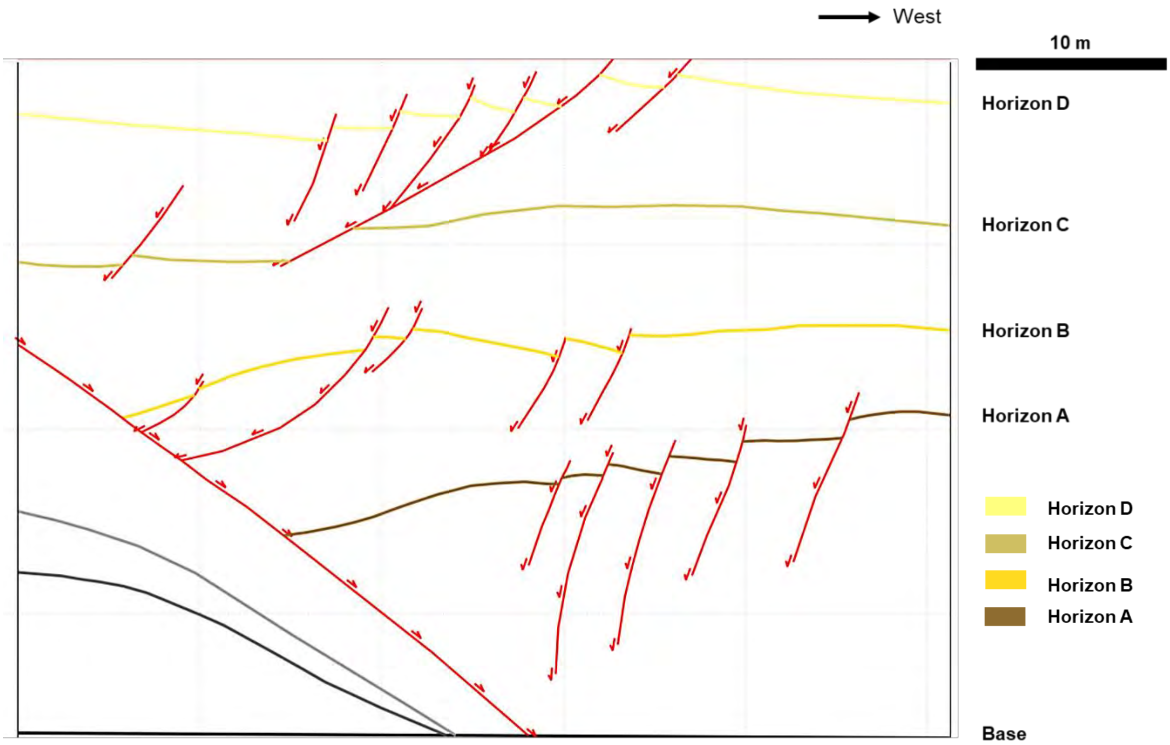
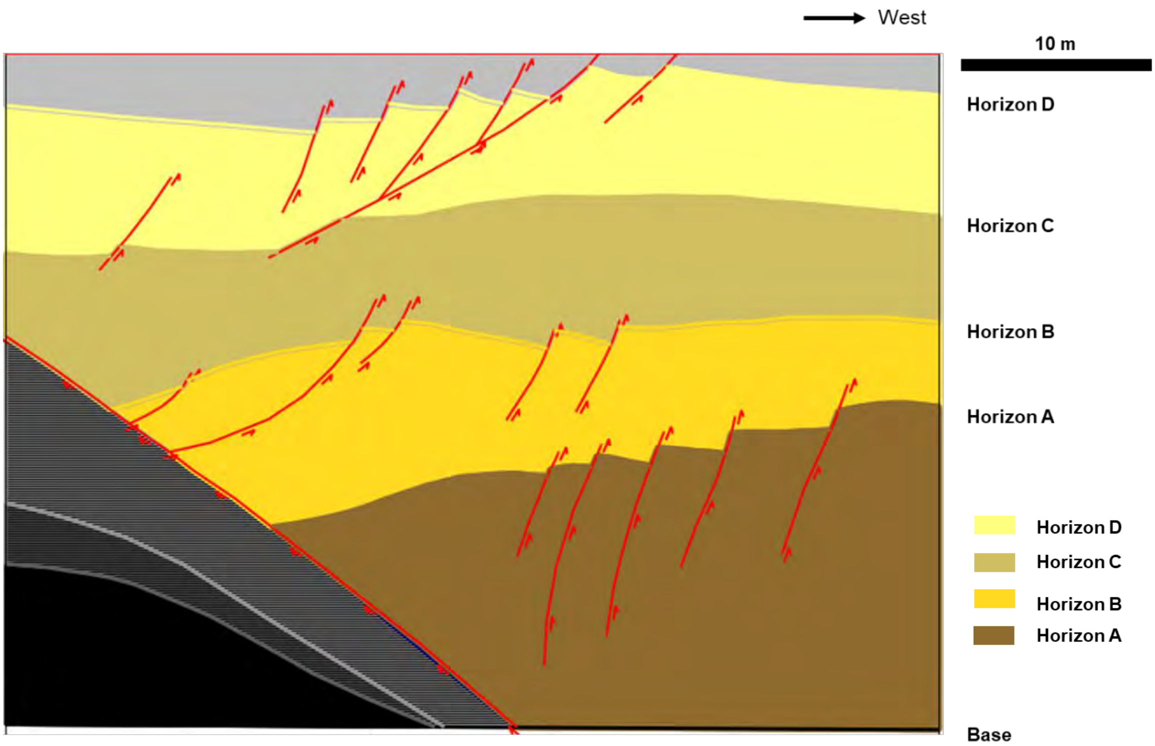


Figure 4.13 Rotated the bedding into horizontal orientation that is the initial position after deposition.



Fidure 4.14 2D section of Ban Pong quarry with created polygon of each horizon based on lithology data

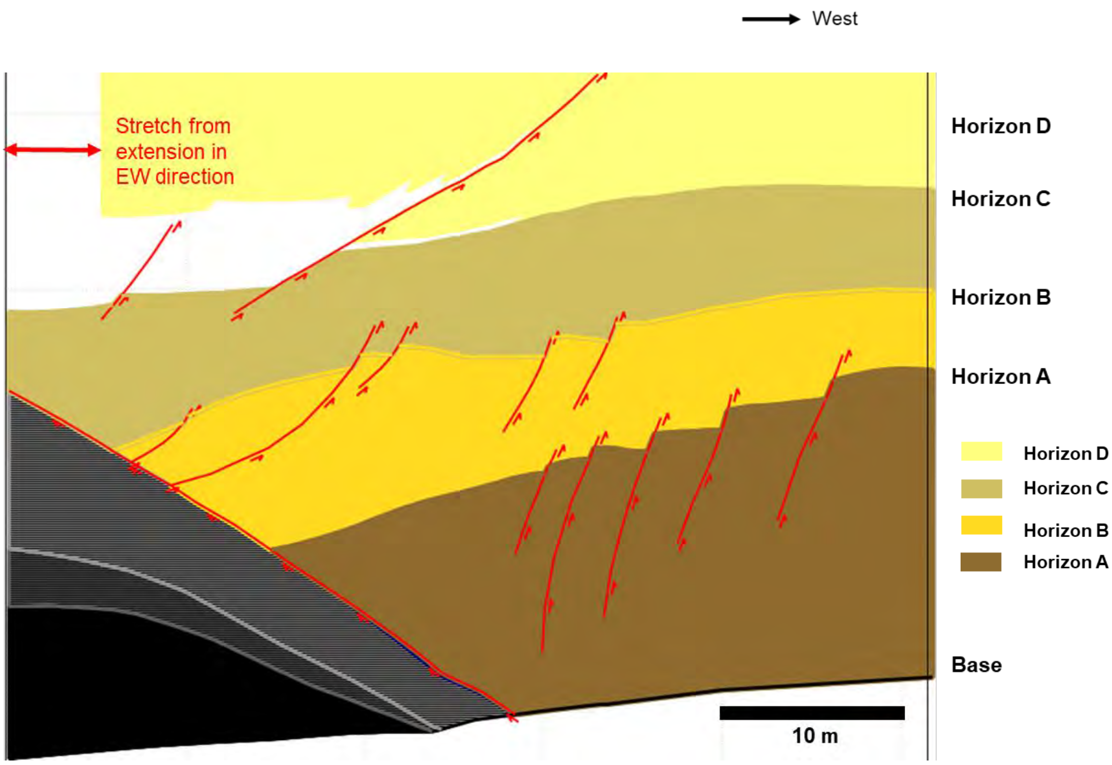


Figure 4.15 A void area formed from extension deformation is exhibit by backstripping model.

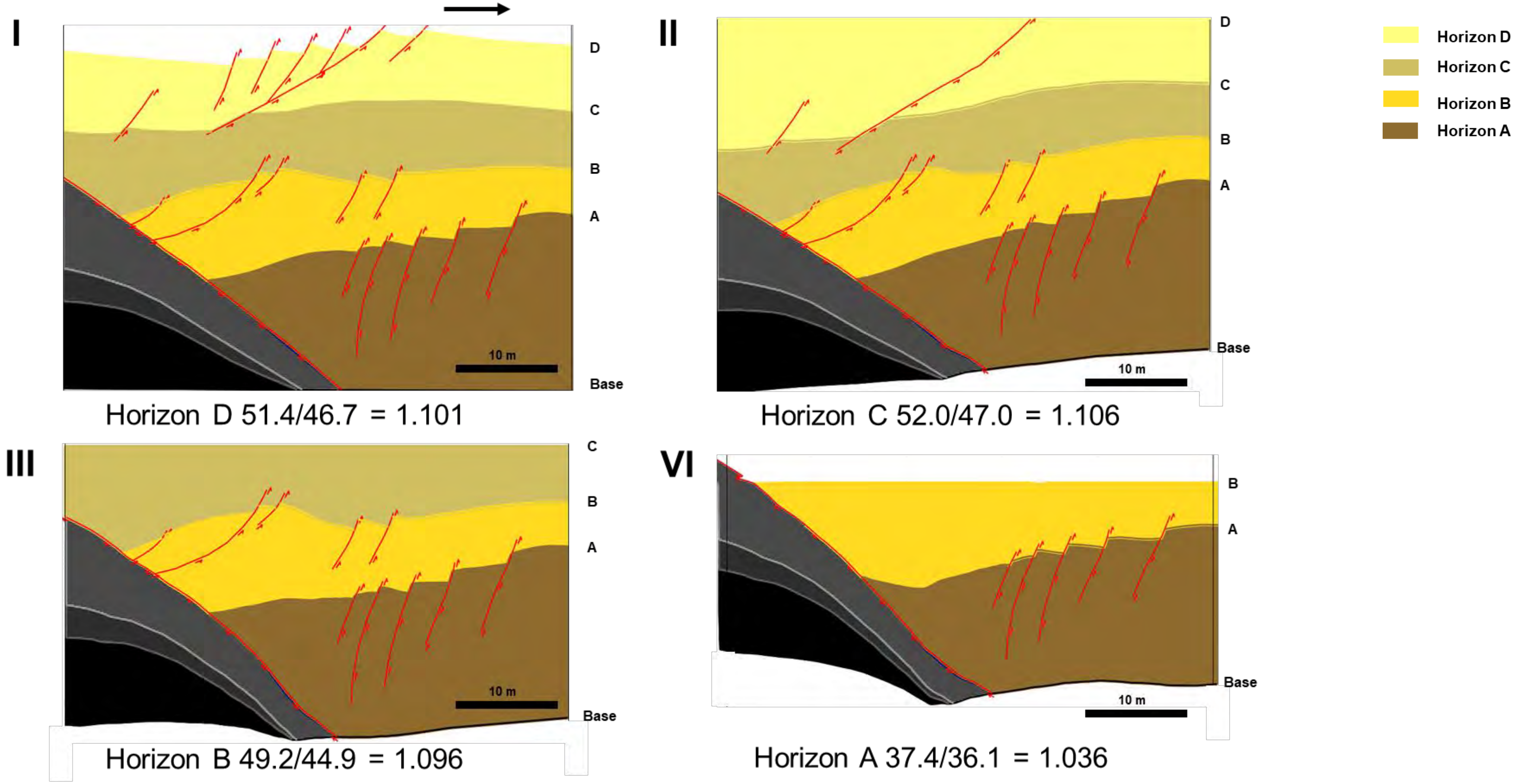


Figure 4.16 The consequence from backstripping process shows calculation of streching factor of each horizon and displays an evolution of depositional process of this sequence.

Chapter 5

Discussion

5.1 Geostatistics analysis

Displacement of major fault cannot measure from the outcrop exposure because of lacking of bed correlation on the outcrop exposure. The relationship between displacement and fault core thickness is applied to estimate the displacement of major fault. As stated by study of the relationship between fault core thickness and displacement by Fossen (2010), displacement and faults core thickness ration of normal faults ranges between D = 10CT and D = 10CT. (Fig 2.5) Fault core thickness of this major fault that measured from DOMs is approximately 0.2 meters. Displacement of this fault ranges between 20 to 200 meters as reported by Fossen (2010).

5.2 Extension rate

The antithetic faults on the hanging wall of major fault is focused for extension rate estimation. A crustal wideness of the study area acquires from backstripping. The difference between an initial crustal wideness and crustal wideness after extension is represented the stretching of the crust. The age of sediment is obtained from dating by fission track of basalt flows overlie a laterized gravel deposit from Ban Mae Tha by Thiramongkol (1983). The age of basalt distances between 690000-950000 Ma, the age of sediment explicitly older than 690000 years. This age is applied to calculate the maximum extension rate of the study area. The consequence of the calculation ranges between 0.005 to 0.007 mm/years.

5.3 Evolutionary model

The family of NS trending normal fault in the study area is related to extension in EW direction that dominated in North Thailand on Cenozoic age. In accordance with structural analysis, the deformation history can be divided into two stages that illustrated in Figure 5.2.

5.3.1 Stage I (Early extension stage)

The series of major fault occur crosscut the Quaternary sediment in extension region with domino style fault system and orientate in NS direction with dip angle around 30 to 40 degrees in west. This type of fault is defined as major fault of the study area. Meanwhile, the hanging of these faults was dominated by antithetic faults in planar normal faults style oriented in NS direction with dip angle approximately 30 to 40 degrees in east direction.

5.3.2 Stage II (Late extension stage)

Accompanying the extension stage, fault drag along the major fault is distributed and created drag fold adjacent to the major fault line. Extension continuously dominated in the study area caused fault blocks rotation approximately 35 degree in clockwise direction. This event appoint the rotation of the major fault and changed dip angle of this fault to 60 to 70 degree as shown in the outcrop excavation. Moreover, pulling by the major fault is higher in the upper part of the exposure that means stretching is higher in upper zone of outcrop. According of this incidence, planar faults in the upper zone of outcrop is stretched and rotated more than the lower part and appear in low-angle normal fault with dip angle around 15 degrees.

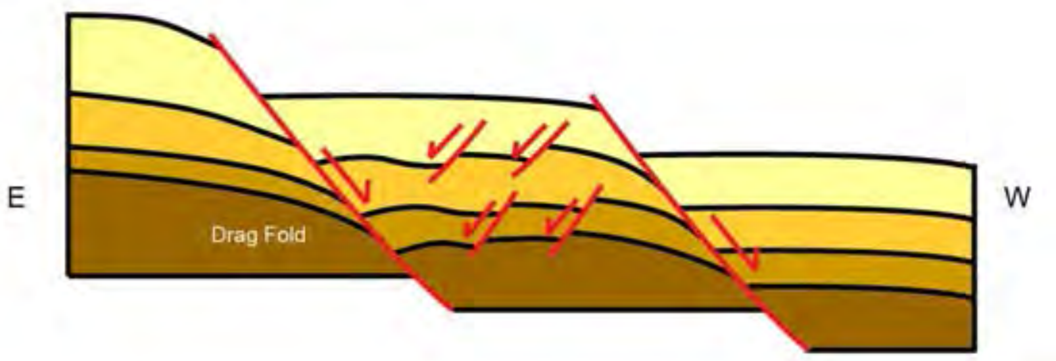
5.4 Fault system

Geometrical analysis of normal fault in the study area is defined as domino model fault that evolve in fault block rotation. A series of normal fault in this area distributes in semi-consolidated sediment. Therefore, the soft domino model is used to describe the behavior of the structure in the excavation. The creation of the soft domino model is described by responsiveness of rock to ductile straining throughout the deformation. Fault block between the major faults performs as soft body that allow the internal strain in fault block and display the variations the in fault width, fault length and fault displacement. The presence of tilted block faulting relates to low-angle structure.

5.5 Low-angle fault

Low angle normal fault appears in several extension regions including LANF in Chiang Mai basin (Fig 5.2). The origin of low-angle fault is explained by two model. First model is associated with rotation of fault from steeper normal faults that was mentioned in the deformation of the hanging wall. But, LANF in Chiang Mai basin is described by another model that involved in isotactic effect to preserve gravitational equilibrium of Earth's crust. This model is situated in brittle-plastic transition that signify as ductile stage of base. The upper plate which defined as hanging wall is rigid body with brittle deformation. In contrast, the lower plate or foot wall is soft body with ductile deformation. The fault that develops between two stages of deformation displays in style of detachment fault. The detachment fault causes unloading area along the fault plane. Isotactic uplift is effective to preserve the equilibrium. This uplift event created new series of fault formed in hanging wall that is rotated domino style blocks. After uplift event, erosion is distributed in high topography and exposed the deep crust formation which is metamorphic core complex in Inthanon range in west boundary of Chiang Mai basin. This process creates the unique topography called basin and range topography distinguished by abrupt changes in elevation between mountain ranges and flat topography or basin. Ban Pong basin is indicated as one of the basin in the same basin and ranges province with Chiang Mai basin. The group of structure in the quarry is the consequence of the same event of Chiang Mai basin and Inthanon metamorphic core complex occurrence. Development of the Doi Inthanon complex have uplifted during late Oligocene to early Miocene. The study by Upton et al. (1999) used fission track ages from apatite to define the age of uplift.

(a) Stage I – Early extension stage



(b) Stage II – Late extension stage

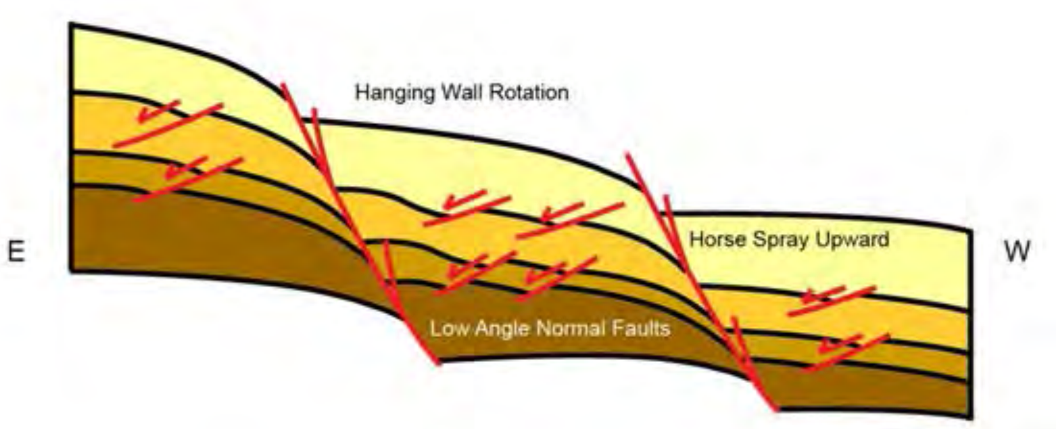


Figure 5.1 The evolutionary model of Ban Pong quarry (a) Early extension stage (b) Late extension stage

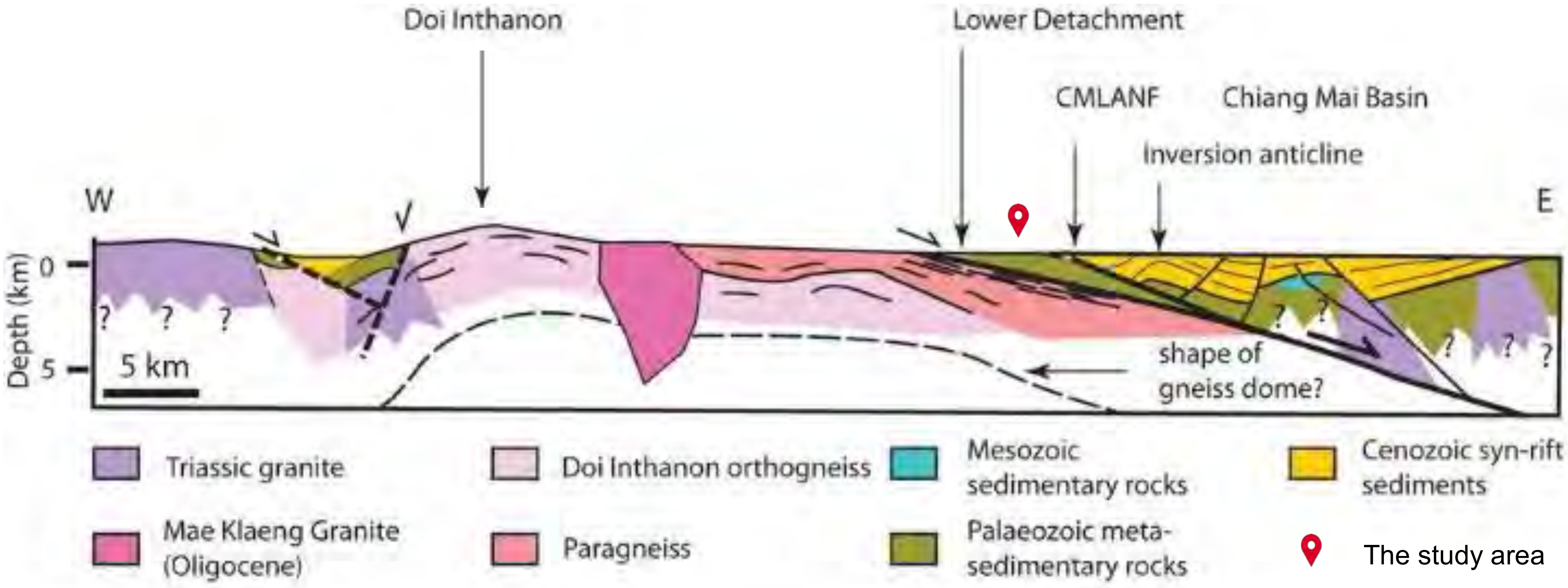


Figure 5.2 Cross-section across the study area, Chiang Mai Basin and Doi Inthanon (modified after Morley, 2009)

Chapter 6

Conclusion

The structure in Ban Pong quarry is a family of NS trending normal fault that relate with the extension in east-west direction. This study divides normal faults in the quarry exposure into two groups, west dipping normal fault or major fault and east dipping normal fault or antithetic fault. Stretching in outcrop scale is non-uniform. There was represented by stretching factor evaluated from backstripping model. Stretching factor in upper part of the hanging wall of major fault is higher than lower part. The evidence of non-uniform stretching is low angle normal faults in the upper part. Extension rate of the study area ranges between 0.005 to 0.007 mm/year based on deformation of the hanging wall of major fault.

A series of the normal fault that dominated in this area is related with east-dipping LANF on the border of the Chiang Mai Basin which located approximately 20 kilometers from Ban Pong basin in east direction. Origin of this LANF is associated with isotactic uplift of metamorphic core complex in the nearby area. This event causes the local extension and created a series of normal faults in the study area.

While, geological hazards in this area is not involved in this family of fault or LANF in Chiang Mai basin. This was demonstrated by backstripping process suggest that deformation of this area is barely active (0.005-0.007 mm/year). Thus, earthquake in this area is associated with active the left-lateral strike-slip of Mae Tha Fault.

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