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ธรณีวิทยาโครงสร้างของหินคาร์บอเนต
บริเวณบริษัท ปูนซีเมนต์นครหลวง จำกัด(มหาชน)
อำเภอแก่งคอย จังหวัดสระบุรี

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โครงการนี้เป็นส่วนหนึ่งของการศึกษาระดับปริญญาตรี
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ปีการศึกษา 2559

STRUCTURAL GEOLOGY OF CARBONATE ROCKS
IN SIAM CITY CEMENT PUBLIC COMPANY LIMITED,
AMPHOE KAENG KHOI, CHANGWAT SARABURI

Mr.Jirapat Phetheet

A Project Submitted in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Science Program in Geology
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ธรณีวิทยาโครงสร้างของหินคาร์บอเนต บริเวณบริษัท ปูนซีเมนต์นครหลวง จำกัด(มหาชน) อำเภอแก่งคอย จังหวัดสระบุรี

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โครงงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิทยาศาสตรบัณฑิต
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Project Title	STRUCTURAL GEOLOGY OF CARBONATE ROCKS IN SIAM CITY CEMENT PUBLIC COMPANY LIMITED, AMPHOE KAENG KHOI, CHANGWAT SARABURI
By	Mr.Jirapat Phetheet
Field of Study	Geology
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จิรพัฒน์ เพ็ชรหีด : ธรณีวิทยาโครงสร้างของหินคาร์บอเนต บริเวณบริษัท ปูนซีเมนต์นครหลวง จำกัด(มหาชน) อำเภอแก่งคอย จังหวัดสระบุรี. (STRUCTURAL GEOLOGY OF CARBONATE ROCKS IN SIAM CITY CEMENT PUBLIC COMPANY LIMITED, AMPHOE KAENG KHOI, CHANGWAT SARABURI) อ.ที่ปรึกษาโครงงานหลัก : อาจารย์ ดร.สุคนธ์เมธ จิตรมหันตกุล, อ.ที่ปรึกษาโครงงานร่วม : รศ.ดร.ฐาสิณีย์ เจริญฐิติรัตน์, 44 หน้า.

หินตะกอนคาร์บอเนตและหินตะกอนยุคเพอร์เมียนของกลุ่มหินสระบุรี โผล่เห็นชัดในบริเวณเหมืองหินปูนบริษัทปูนซีเมนต์นครหลวง อำเภอแก่งคอย จังหวัดสระบุรี ซึ่งหินตะกอนคาร์บอเนตดังกล่าวสะสมตัวในบริเวณขอบฝั่งตะวันตกเฉียงใต้ของแผ่นอนุทวีปอินโดไชนา ระหว่างช่วงปลายยุคคาร์บอนิเฟอรัสถึงเพอร์เมียน หลังจากนั้นเกิดการมุดตัวของทะเลเททิสโบราณลงใต้แผ่นอนุทวีปอินโดไชนา พร้อมกับการก่อเทือกเขาอินโดไซเนียน ส่งผลให้เกิดชั้นหินคดโค้งและรอยเลื่อนย้อนมุมต่ำวางตัวในทิศทางตะวันตกเฉียงเหนือ-ตะวันออกเฉียงใต้ ซึ่งการเปลี่ยนลักษณะเกิดขึ้นในบริเวณลานคาร์บอเนตเขาขวาง ซึ่งต่อมาจึงเรียกบริเวณดังกล่าวว่าแนวชั้นหินคดโค้งและรอยเลื่อนย้อนมุมต่ำเขาขวาง

การศึกษาในโครงงานนี้ได้ทำการเก็บข้อมูลและวิเคราะห์ข้อมูลจากการออกภาคสนามร่วมกับการสร้างแบบจำลองสามมิติของหินโผล่ เพื่อจัดทำแผนที่ธรณีวิทยาโครงสร้างและศึกษาประวัติการเปลี่ยนลักษณะบริเวณเหมืองหินปูนซีเมนต์นครหลวง ซึ่งจากการวิเคราะห์ความเค้นโบราณ สามารถแบ่งประวัติการเปลี่ยนลักษณะได้เป็น 2 ช่วง ได้แก่ ช่วงแรก เกิดการบีบอัดในทิศทางเกือบตะวันออกเฉียงเหนือ-ตะวันตกเฉียงใต้ ส่งผลให้เกิดโครงสร้างหลักในพื้นที่ซึ่งวางตัวในแนวตะวันตกเฉียงเหนือ-ตะวันออกเฉียงใต้ และทำให้เกิดชั้นหินคดโค้งและรอยเลื่อนย้อนมุมต่ำ ในบริเวณขอบฝั่งตะวันตกเฉียงใต้ของแผ่นอนุทวีปอินโดไชนา นอกจากนั้นพบหลักฐานรอยเลื่อนปกติแบบเฉียงซึ่งบ่งบอกการเปลี่ยนทิศทางของระบบแรงในช่วงเวลาต่อมา

ภาควิชา ธรณีวิทยา ลายมือชื่อนิสิต

สาขาวิชา ธรณีวิทยา ลายมือชื่อ อ.ที่ปรึกษาหลัก

ปีการศึกษา 2559 ลายมือชื่อ อ.ที่ปรึกษาร่วม

5632703823 : MAJOR GEOLOGY
KEYWORDS : SARABURI GROUP / INDOSINIAN OROGENY / FOLD AND THRUST BELT / KHAO KHWANG / DIGITAL OUTCROP MODEL

JIRAPAT PHETHEET : STRUCTURAL GEOLOGY OF CARBONATE ROCKS IN SIAM CITY CEMENT PUBLIC COMPANY LIMITED, AMPHOE KAENG KHOI, CHANGWAT SARABURI. ADVISOR : SUKONMETH JITMAHANTAKUL, Ph.D., CO-ADVISOR : ASSOC. PROF. THASINEE CHAROENTITIRAT, Ph.D., 44 pp.

Mixed carbonate-siliciclastic Permian rocks of Saraburi Group are well exposed in the Siam City Cement quarry. These rocks formed during Late Carboniferous to Permian with development of Khao Khwang Platform along the southwestern margin of Indochina terrane. Structural complexity in this region occurred when palaeo-tethys subducted beneath the Indochina terrane causing NW-SE striking Khao Khwang Fold and Thrust Belt as part of the Indosinian Orogeny. This study investigated the quarry and integrated traditional field data with photorealistic digital outcrop models in order to construct a detailed structural map.

According to palaeo-stress analysis, the structural evolution can be divided into two stages of deformation. First, ENE-WSW compression formed the fold and thrust system. The second stage related to NNE-SSW extension which formed oblique-normal fault along the northeastern portion of the study area which lies in the NW-SE direction.

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

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

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Chapter 1

Introduction

1.1 Introduction

Limestone is one of significant economic mineral resources which mainly occur in Changwat Saraburi that is an important area of Thailand. Nowadays, this material is a major component of the cement industry. Distribution of this limestone in Changwat Saraburi is up to 360 square kilometres. The amount of limestone reserves in Changwat Saraburi is approximately 55,000 million tons (DMR, 2007).

Structural complexity of carbonate rocks in Saraburi area is resulted from various tectonic events. Faults and fractures have been studied by many workers, i.e. Ampaiwan, 2011; Thanudamrong, 2011; Morley et al., 2013; and Warren et al., 2014.These studies provide an understanding of regional structure in this region.

Bunopas (1981) proposed mixed carbonate-siliciclastic Permian rocks which distribute along margin of Indochina Block, namely Saraburi Group. Later Hinthong (1985) and Hinthong et al. (1985) divided the Saraburi Group into six formations: in ascending order, the Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad, and Sap Bon formations which compose of clastic or mixed siliciclastic and carbonate sequences. The Permian rocks in this area are grouped as the Khao Khwang Platform where became the area of deformation. This region has been named the Khao Khwang Fold and Thrust Belt which is characterized by WNW-ESE to NE-SW trending folds and thrusts (Morley et al., 2013). The formation of the Khao Khwang Fold and Thrust Belt is dominantly caused by closure of back-arc basin and amalgamation of Sukhothai island-arc to marginal Indochina during the Middle to Late Permian, and a later closure of Palaeo-Tethys Ocean during the Late Triassic (Sone & Metcalfe, 2008).

In 1985 Hinthong et al. produced a regional geological map, which shows over-thrust area of the Phu Phe Formation onto the Khao Khad and Sap Bon formations, but it has no detailed structural studies on the area (Morley et al., 2013). In spite of extensively detailed studies, there are less simultaneously studies between structural geology and stratigraphy.

This study focuses on the Permian limestone quarry in Siam City Cement Public Company Limited, Changwat Saraburi, central Thailand (Fig 1.1). The study area is located in a zone of deformation where is characterized by highly developed in different structures (i.e. folding, thrusting, strike-slip faulting). The main objectives of this study are to create a detailed structural map and investigate deformation history of the Permian limestone in the study area in order to understand the formation and development of structural elements by using both field survey and analysis from digital outcrop model (DOM) to create a structural evolutionary model.

1.2 Objectives

- To create a detailed structural map in Siam City Cement limestone mine
- To investigate deformation history of the Permian limestone in the mine

1.3 Study Area

This study focuses on structural geology of quarry exposures of Permian carbonate rocks in Siam City Cement Public Company Limited, Amphoe Kaeng Khoi, Changwat Saraburi (Fig 1.2). The total concession area is approximately 5.646 square kilometres. Due to the vast area, this study concentrated on some outcrops which cover mostly rock units. The study outcrops are across the main structure which lies in the NW-SE trending. Both active and inactive quarries were selected for this study. Data from 18 stations where were located within 2 main NW-SE mountain ranges were collected for these structural studies.

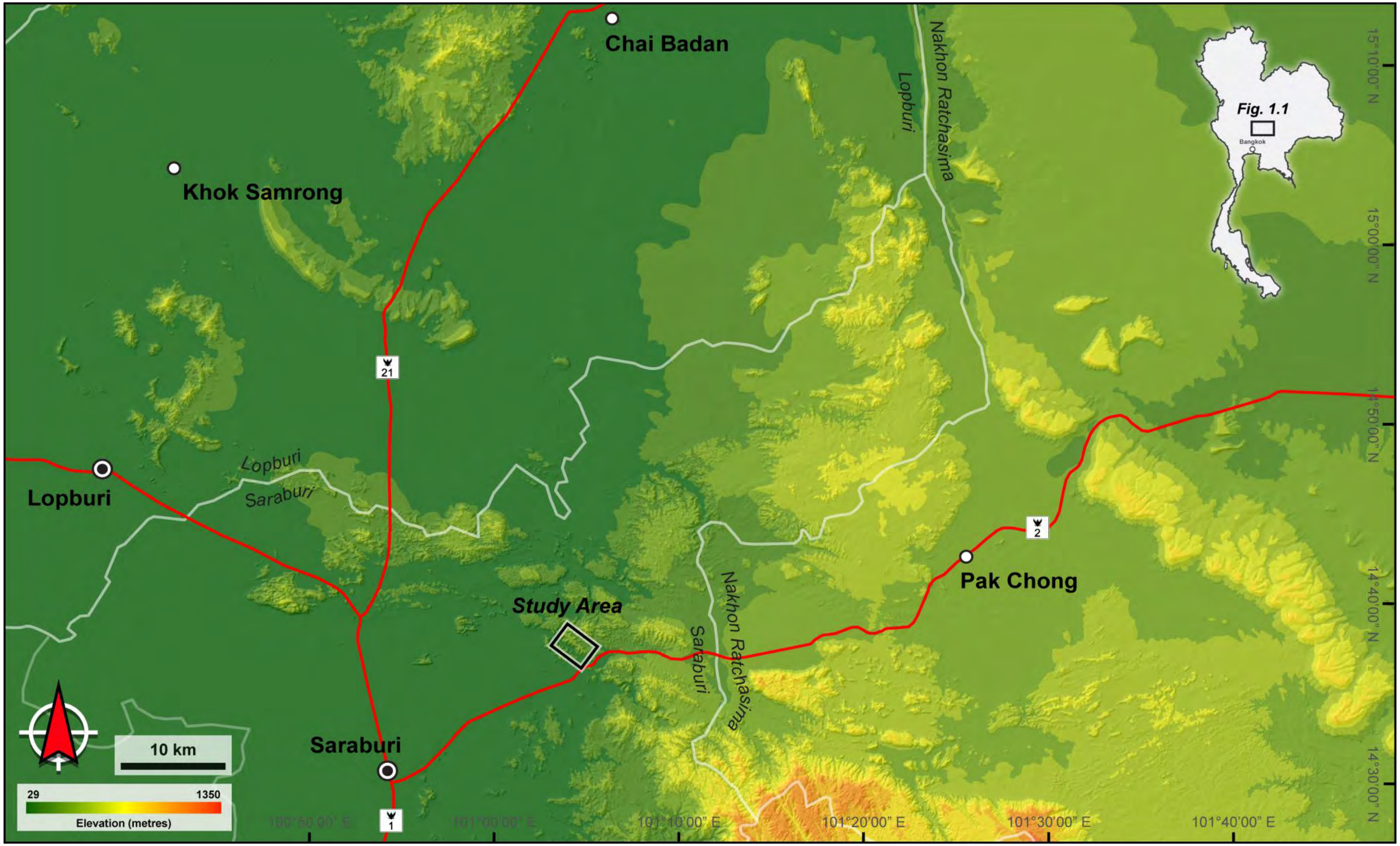


Figure 1.1 A digital elevation model showing elevation map and regional structural trend, central Thailand.

Figure 1.2 Satellite image showing collecting station (red pin) in Siam City Cement Public Company Limited.
Google Earth 7.1.5.1557. 2015. *Siam City Cement quarry, 14°38'32.63"N, 101°04'32.83"E.* Viewed 21 March 2017. <https://www.google.com/earth/index.html>

Chapter 2

Geological Background

Exposed outcrops in central Thailand are located in the region of deformation. It has undergone a complex geological history, dominated by the development of the Indosinian tectonic event during Late Permian to Late Triassic (Sone & Metcalfe, 2008; Arboit et al., 2017) The Indosinian Orogeny is characterized by various collision-related events (Barber et al., 2011). In Southeast Asia, including Thailand, this landmass has formed from continental fragments which derived from the break-up of Gondwana's margin. It comprises of two major continental masses, namely the Sibumasu Terrane and the Indochina Terrane (Sone & Metcalfe, 2008; Barber et al., 2011). After Palaeo-Tethys had closured, the two main terranes began collision. Two sub-parallel suture zones occurred along the convergent area. One is the Changning-Menglian (C-M) and Inthanon suture zones were originated from a closure of the Palaeo-Tethys during Middle Triassic. The other is the Jinghong-Nan-Sra Kaeo suture is interpreted as a collapse of the back-arc basin during Late Permian (Fig 2.1; Sone & Metcalfe, 2008).

2.1 Tectonic Evolution of Mainland Southeast Asia

All East and Southeast Asian terranes were formed in or close to the northern margin of Gondwana in the Early Palaeozoic (Metcalfe, 1996a). There are three continents were rifted from the margin of Gondwana, and three successive Tethys oceans were opened and closed (Metcalfe, 1996b). The initial rifting and separation of various Chinese continental blocks (North and South China, Tarim, Indochina, and Qaidam) started in the Middle Devonian. Its fully oceanic stage of Palaeo-Tethys started from the late Middle Devonian (Metcalfe, 1996a; Sone & Metcalfe, 2008). During the Carboniferous, its oceanic width was probably greatest. Then, the Palaeo-Tethys oceanic floor subducted beneath Indochina terrane during the Latest Carboniferous or very Early Permian (Fig 2.2a). Magmatic arc developed along the margin of the Indochina terrane due to its subduction to create a Sukhothai zone. Concurrently, back-arc basins, such as the Jinghong, Nan, and Sra Kaeo basins started to open between the magmatic arc (Sukhothai) and the Indochina terrane during the Earliest Permian. Carbonate platforms, including Saraburi and Sisophon limestones

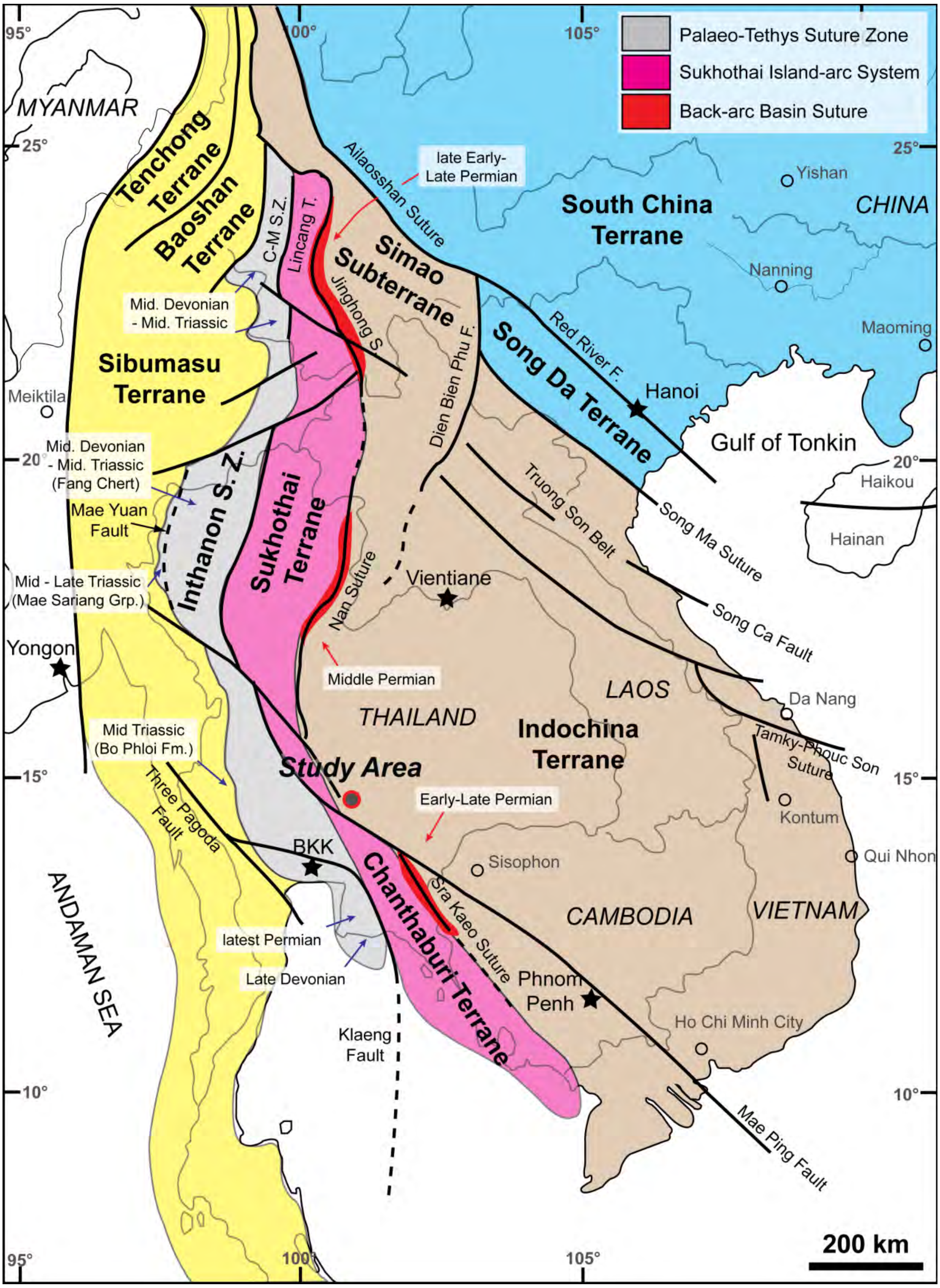
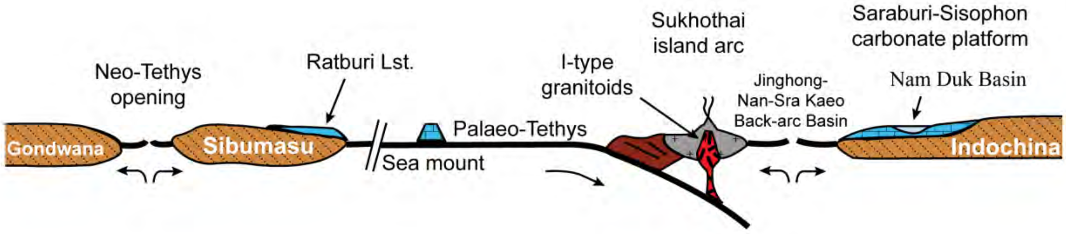
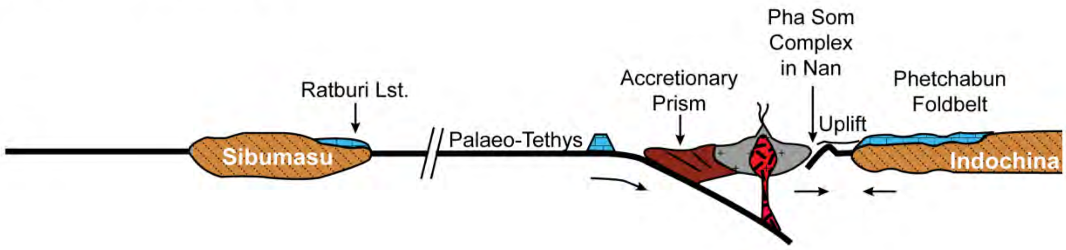


Figure 2.1 Regional tectonic map of mainland Southeast Asia showing the Palaeo-Tethys Suture Zone and back-arc suture (compiled from Sone & Metcalfe, 2008; Ampaiwan, 2011).

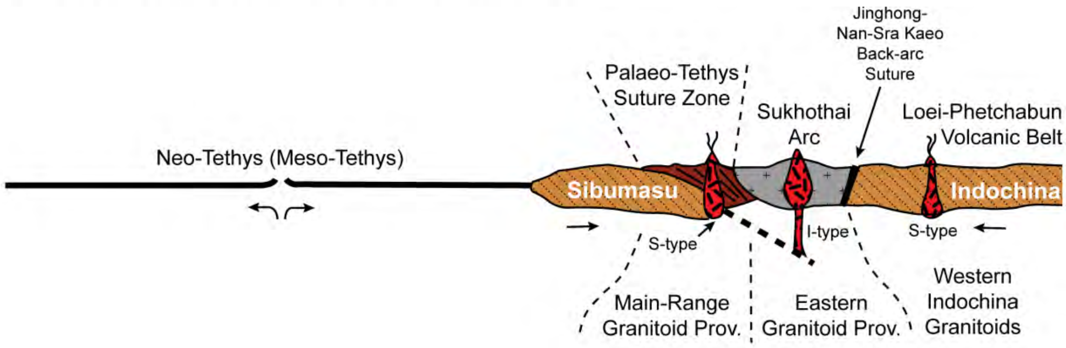
(a) Early - Middle Permian



(b) Late Permian



(c) Late Triassic - Early Jurassic



(d) Cenozoic

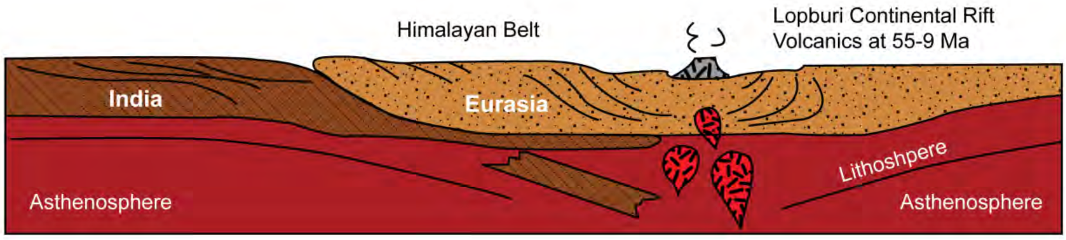


Figure 2.2 Tectonic evolution of Thailand and Southeast Asia during Late Palaeozoic to Cenozoic (Modified from Sone & Metcalfe, 2008; Ampaiwan, 2011).

developed widely over the western Indochina terrane from Early to late Middle Permian. In the Middle to Late Permian (Fig 2.2b) the back-arc basin probably started to collapse and absolutely closed and uplifted in the end of Permian. Carbonate platforms which accumulated in back-arc basin were uplifted in the Late Permian. For this reason, the Sukhothai island-arc was amalgamated to marginal Indochina. The Palaeo-Tethys subducted continuously beneath the volcanic arc. Because of the prolonged subduction, the Sibumasu terrane collided with the Sukhothai arc of the western Indochina terrane by the early Late Triassic, causing the complete closure of the Palaeo-Tethys in this region (Fig 2.2c; Sone & Metcalfe, 2008; Arboit et al., 2017). The extensive accretionary prism was formed after the Palaeo-Tethys has closed. By the end of the Triassic, the Sukhothai Arc ceased magmatism, as the termination of the Palaeo-Tethys subduction (Sone & Metcalfe, 2008). The Permian sedimentary rocks along the margins and the interior of Indochina block in rift basins which were deformed during the Early Triassic were subsequently covered by sediment during the Late Triassic. After that, it was separated by a depositional hiatus from Late Jurassic sedimentation. This unconformity separated the underlying unit from Late Jurassic to Early Cretaceous Khorat Group (Booth and Sattayarak, 2011; Warren et al., 2014). Arc magmatism and metamorphism in the region during Mesozoic which were driven by subduction of Tethyian oceanic crust beneath Burma and Western Thailand caused folding, thrusting, strike-slip faulting, uplifting, and erosion (Warren et al., 2014). This Palaeogene deformation phase was followed by more regional uplift and erosion of central Thailand. As a result of this deformation, some 2-3 kilometres of sediments of Nam Phong Formation and Khorat Group were eroded. It was the cause of exposure of the Saraburi Group to the surface in many parts of central Thailand (Warren et al., 2014).

2.2 Permian Carbonate Rocks in Central Thailand

Mixed carbonate-siliciclastic Permian rocks which distributed on the eastern side of the lower Chao Phraya Central Plain and on the western margin of the Khorat Plateau were defined as the Saraburi Group by Bunopas (1981). Later Hinthong (1981, 1985) and Hinthong et al. (1985) divided the Saraburi carbonate-siliciclastic rocks into six formations, namely the Phu Phe, Khao Khwang, Nong Pong, Pang Asok, Khao Khad and Sap Bon formations, in ascending order (Fig 2.3 & Fig 2.4).

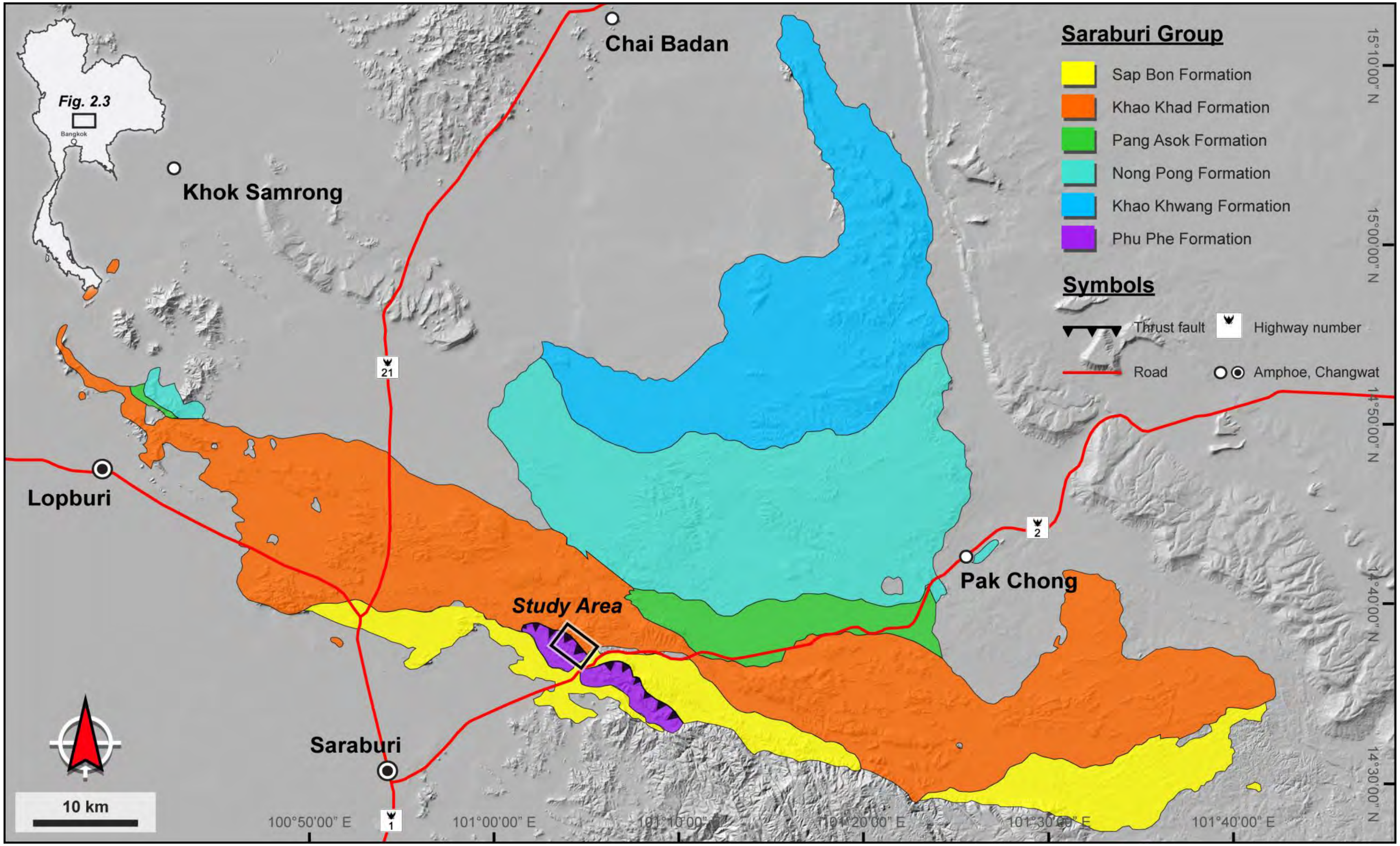


Figure 2.3 Geological map of Saraburi Group in Saraburi area, NE Thailand (Modified from Hinthong et al., 1985).

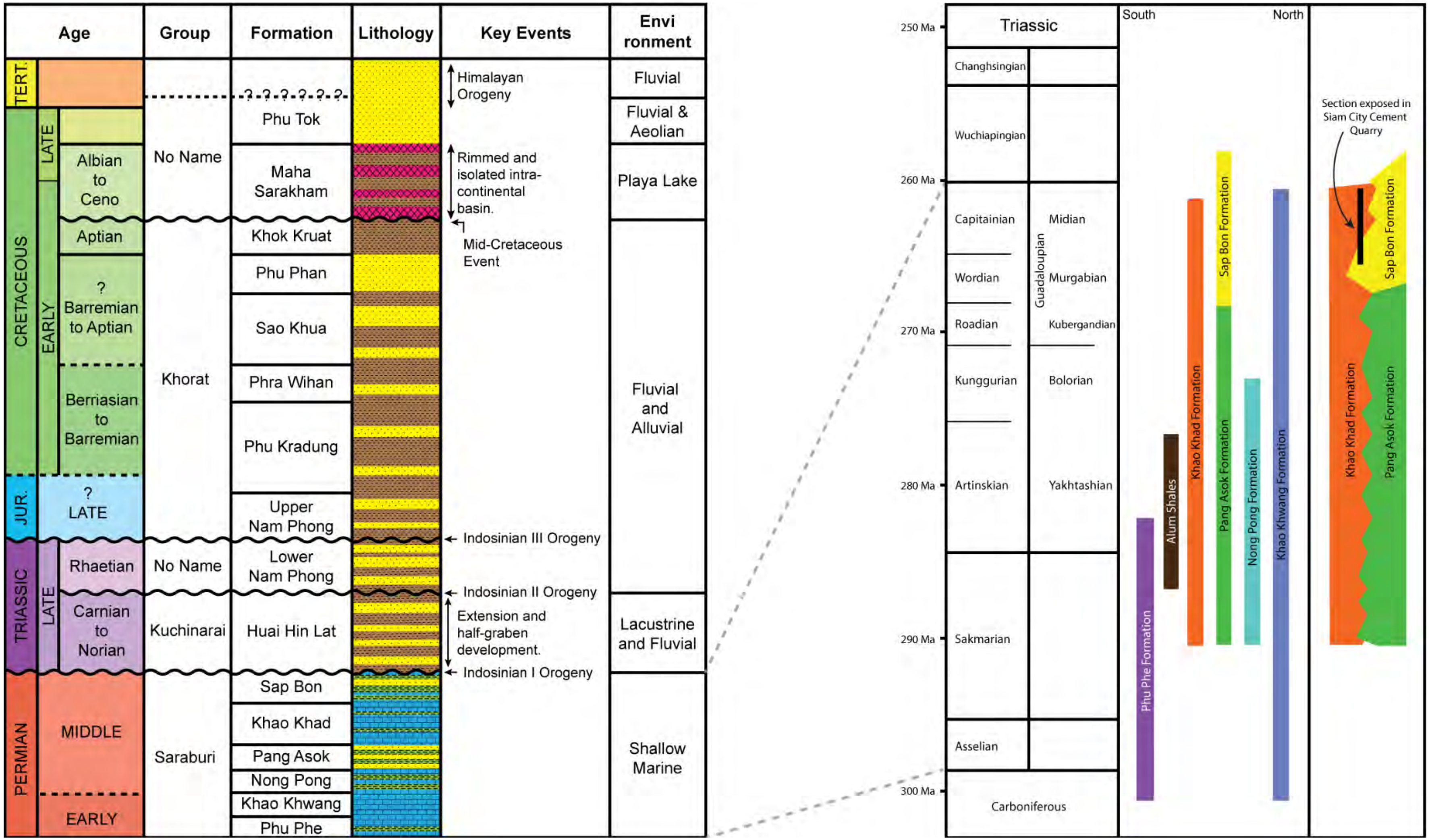


Figure 2.4 Tectonostratigraphy of central and NE Thailand during Late Mesozoic to Early Cenozoic (compiled from Booth and Sattayarak, 2011; Ampaiwan, 2012; Morley et al., 2013).

For detailed study of the Saraburi Group in Saraburi-Pak Chong area, there are various facies belts consisting of the shelf or platform, basin margin and deep basin environments. The platform facies is represented by the Phu Phe, Khao Khwang and Khao Khad formations. The open shelf environment consists of medium-to thick-bedded skeletal grainstones, packstones and wackstones. Laminated micrites and dolomites are portion of the inner shelf environment. The Sap Bon, Pang Asok and part of Nong Pong formations formed a thick succession of bioclastic grainstones and packstones, limestone breccias and conglomerates in the slope or basin margin facies. The deep basin or basin plain facies are characterized by fine-grained sediments which are typical of the Nong Pong Formation (Chonglakmani, 2001). From palaeontological dating and carbonate microfacies analysis, the sequences of carbonate rocks in this region are repeated by folding and thrusting which are the strong evidences of the deformation in this region (Dawson & Racey, 1993; Morley et al., 2013).

2.3 Geology within Study Area

The regional geology of Saraburi province and adjacent area is dominated by Late Palaeozoic to Triassic carbonate and igneous rocks. Carbonate outcrops which are located in study area, Siam City Cement Public Company Limited, and the adjacent area belong to the Phu Phe and Khao Khad formations. According to Ueno & Charoentitirat (2011), the Phu Phe Formation mainly consist of grey to dark-grey, thick- to very thick-bedded skeletal limestone with interbedded nodular chert and slaty shale. This formation was deposited in carbonate platform during Late Pennsylvanian to Early Permian. And the other, the Khao Khad Formation, composes of c. 1,800 metres thin- to very thick-bedded limestone with chert nodule and locally interbedded argillite, dolomitic shale, siltstone, sandstone and conglomerate. This formation is located along WNW-ESE direction. Its lithology indicates shallow-marine deposition in a carbonate platform during Early to Middle Permian. Moreover, both intrusive and extrusive igneous rocks are presented in this region. The distributions of Triassic igneous intrusions are mainly located in amphoe Phra Phutthabat. It composes of biotite granite, biotite-muscovite granite, granodiorite and leucogranite (DMR, 2007). Large areas of volcanic rocks in Saraburi province lie on some parts of the Phetchabun Volcanic Belt which consist mainly of porphyritic rhyolite and andesite porphyry. These volcanic rocks are overlying the

Saraburi Limestone as well as underlying the Jurassic Phu Kradung Formation so these rocks were extruded during Middle Permian to Triassic age (Barr & Charusiri, 2011).

2.4 Summary from Recent Studies

The formerly geological studies in Siam City Cement Public Company Limited and the nearby area have focused on regional scale such as regional mapping by Hinthong (1981, 1985) and Hinthong et al. (1985), Palaeontology, sedimentology and stratigraphy by Dawson and Racey (1993) and Ueno & Chareontitirat (2011), and regional tectonic evolution by Sone & Metcalfe (2008).

Thanudamrong (2011) studied lithofacies and structural geology in the Siam City Cement Public Company Limited. Throughout his lithofacies study, the rocks are divided into six lithofacies which consist of both Khao Khad and Phu Phe formations. For structural study focused on fracture analysis, which analysed the orientation of different fracture sets and density of fractures. Moreover, stable isotope analysis from calcite-filled veins was classified into two groups; one indicates a regional burial and the other represents the Cenozoic karstification.

The study of Ampaiwan (2011), the evidence of deformation history studied from the Permian Limestone quarries in the Na Phralan area which was influenced by N-S directed compression. There are two major thrust faults lie in E-W trending. Stable isotope analysis from calcite vein, carbonate matrix, and recent speleothem deposits was classified into two groups; one formed during bedding plane slipped which calcite fluid came from host rocks during burial and the other was influenced by higher temperature fluids which flew along fractures. This evidence indicates synchronous calcite growth, which is related to thrusting.

Kuenphan (2012) studied a structural evolution of Permian carbonate rocks in Pak Chong, Nakhon Ratchasima by using field investigations as well as stable isotope measurements. The outcrops in this area were deformed by N-S compression during the Indosinian I. After that, they were affected by the E-W to NW-SE trending Indosinian II and/or Palaeogene deformation.

Then Morley et al. (2013) studied the structural geology along the Khao Khwang Fold and Thrust Belt. This belt developed on the southern margin of Indochina terrane during Indochina I Orogeny (Early Triassic). The orientation of the fold and thrust belt lies in WNW-ESE to NE-SW trending. The movement of the Mae Ping Fault is caused the structures in the fold and thrust belt lie in E-W direction and belt moves eastward to Cambodia.

The most recent study in this area was studied by Arboit et al. (2017). This study focused on tectonic evolution of the Khao Khwang Fold and Thrust Belt. This work used calcite twinning analysis in order to calculate the palaeo-stress magnitude. The results showed five stages of deformation. The highest stress magnitude which affected the Khao Khwang Fold and Thrust Belt occurred during the Indosinian Orogeny.

Chapter 3
Methodology

This chapter consists of three parts. The first part presents methodology for field study in the quarry. The second part shows methodology for making three-dimensional (3D) outcrop models. The third part presents structural analysis for determining deformation history. Workflow is shown in Fig 3.1.

3.1 Field Study

According to main structure of study area has almost lain in NW-SE trending, study outcrops are located perpendicular to the main structure of this area. For each station, photography and field sketch are not less important than structural measurement. The following structural information is emphasized for field data collections; rock unit, lithology, bed orientation, bed thickness, fracture orientation, fault and fold orientation, and lineation. Fault and fold data is significant keys to understand not only deformation process, but also state of stress. Furthermore, some interesting outcrops are used an alternative technique for data acquisition and interpretation. This technique creates a virtual outcrop model for structural analysis by using photos. Data collection for this three-dimensional digital model is slightly different from a former method. Data for creating model is collected by capturing outcrop photos and recording some geological references for calibration.

3.2 Digital Outcrop Model

Digital outcrop model is a three-dimensional representative outcrop surface. It is an unconventional fieldwork which is compared as remote sensing technique. Both photos and geological information are sources for creating the three-dimensional digital model (Fig 3.2). This model is processed by Agisoft PhotoScan software which is an advanced image-based 3D modeling software. The processes begin with camera alignment of a series of overlapping outcrop images as shown in Fig 3.2a. The photos must be taken by camera which is able to record its GPS position. After that, software will generate a point cloud model (Fig 3.2b). Then, three-dimensional mesh will be created from a point cloud model (Fig 3.2c). Before exporting model, textured model (Fig 3.3d) must be processed. This model covers an area where

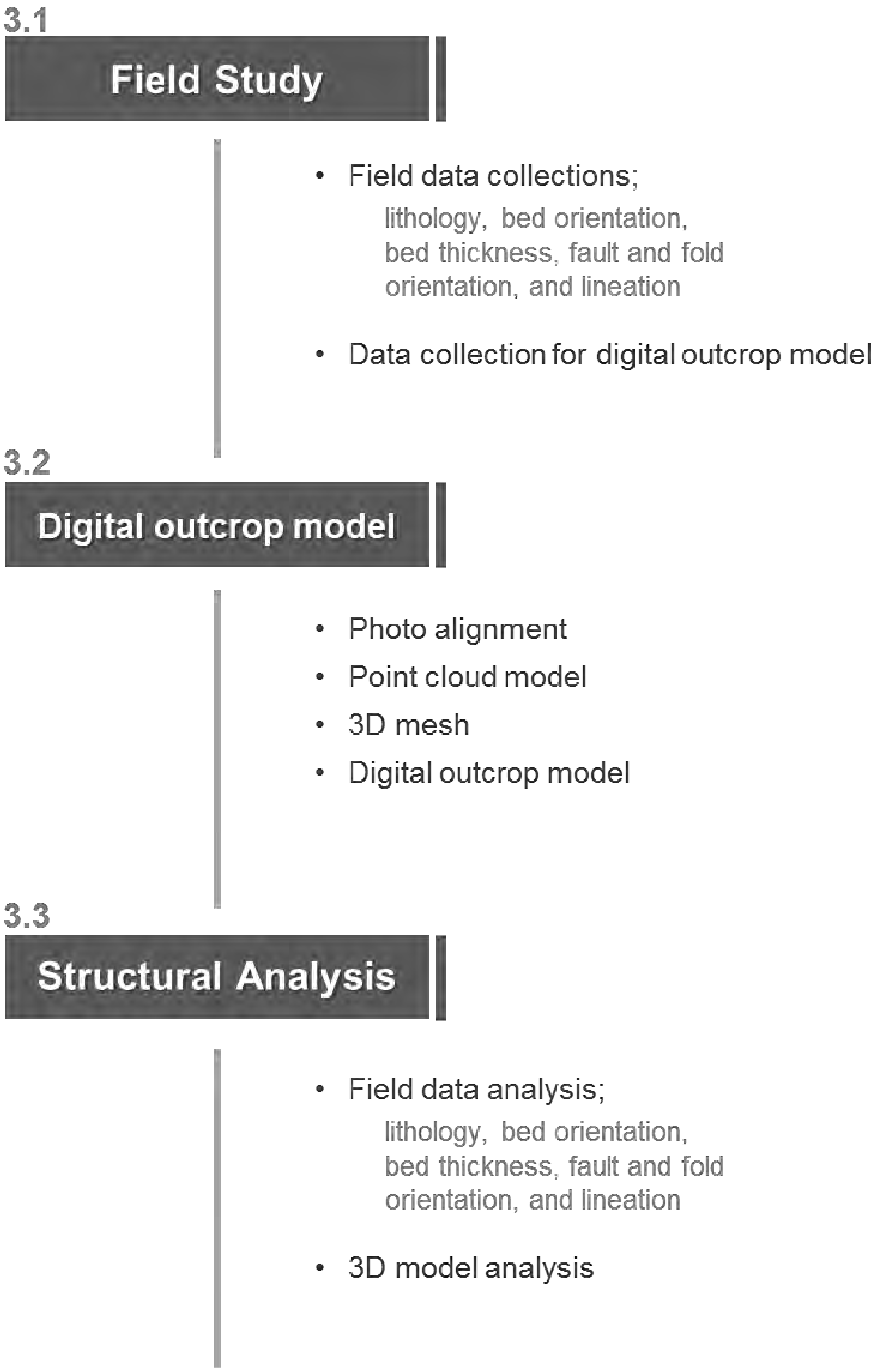
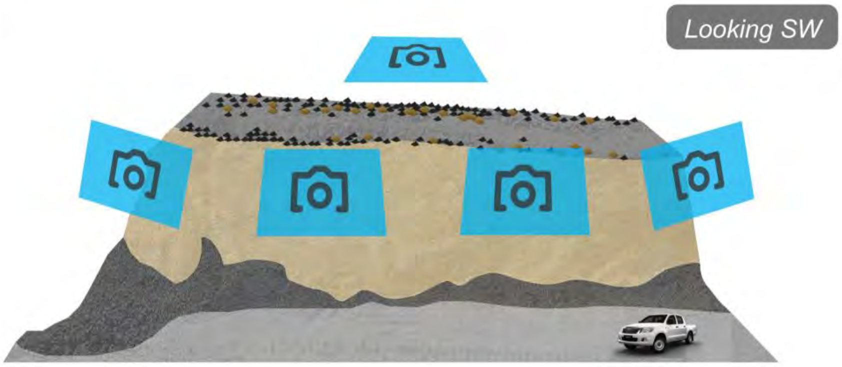
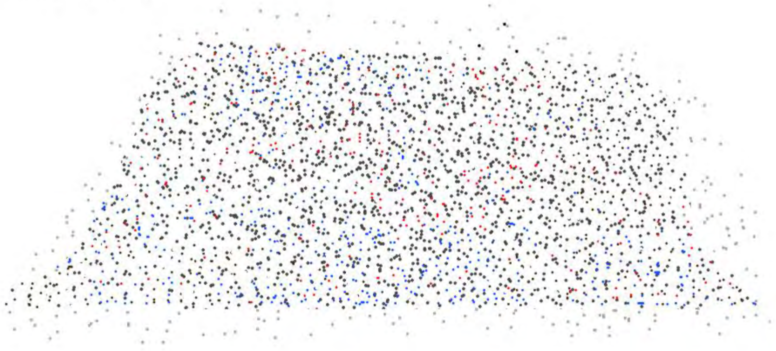


Figure 3.1 Methodology showing the three main stages of this study.

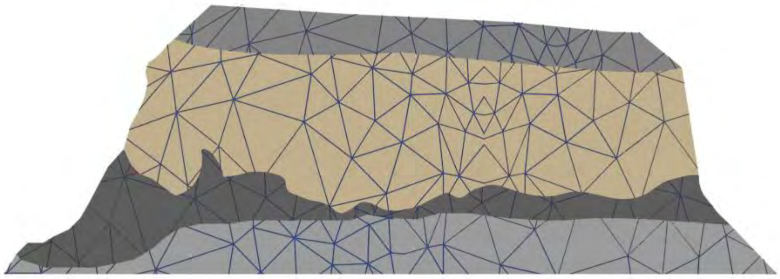
a) Align photos



b) Build a Point cloud model



c) Create 3D mesh



d) Export digital outcrop model

Figure 3.2 The four main stages of 3D model construction by using PhotoScan software.

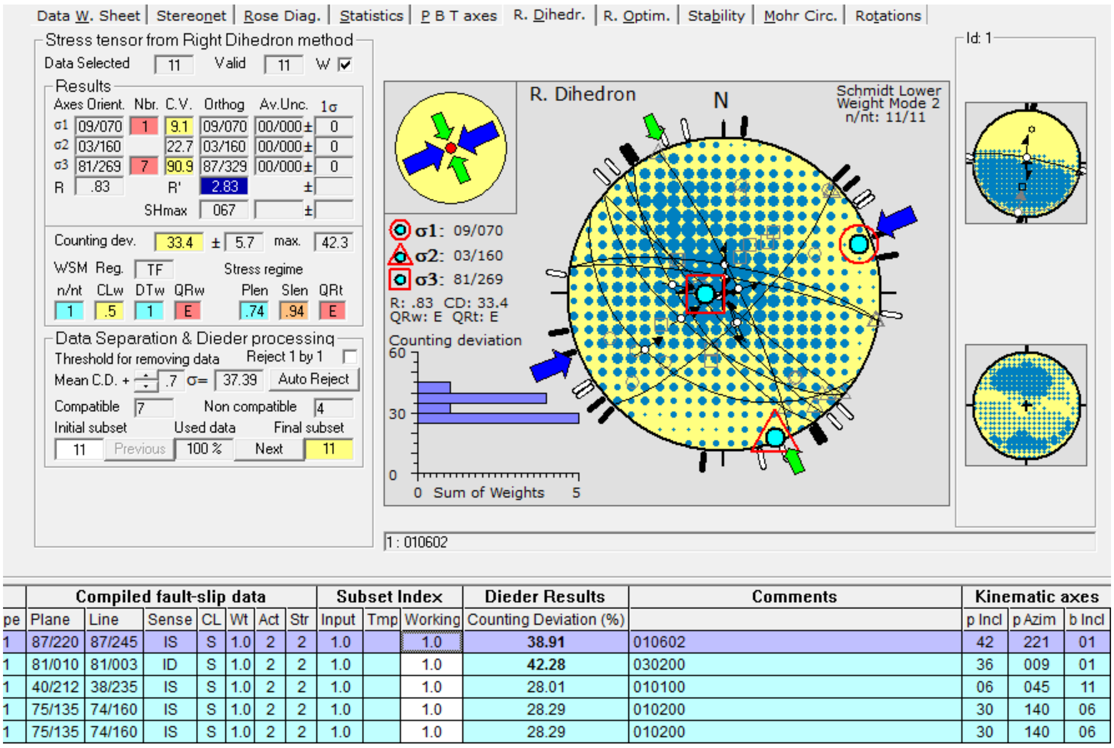
using a conventional methods may be unsafe. It is a newly useful technique for analysis and interpretation of virtual outcrops.

3.3 Structural Analysis

In this procedure comprises 2 main sections. First is field data analysis. All field data such as fault and fold geometries and bedding plane orientation were plotted as lower-hemisphere stereographic projections and rose diagrams. The orientations of fault plane are plotted in stereographic projection by using Win-Tensor software (Fig 3.3).

This program is used for stress determination from fault-slip data. Furthermore, the geological data can be displayed as stereographic projection, and rose-diagram for structural analysis. In this study, palaeo-stress analysis is analysed from fault data by using Right Dihedral method. Fault data include both fault plane and slicken-line orientations; the latter represents the relative sense of movement between the two blocks separated by fault.

The other analysis is based on digital outcrop model. The three-dimensional model which created from the PhotoScan software will be analysed in another program. The structural modeling and analysis software, namely MOVE^{TM} software (Fig 3.4) was used for this study. There are many features for structural analysis such as display positions and orientations, create points, lines, and 3D surfaces including bedding planes as well as fault planes, show surface attributes in order to interpret easily, and use for the advanced structural modules. This model can be acquired some geological data instead of collected them in the field.



Stress tensor from Right Dihedron method

Data Selected 11 Valid 11 W ☑

Results

Axes Orient.		Nbr.	C.V.	Orthog	Av.Unc.		1σ
σ1	09/070	1	9.1	09/070	00/000	±	0
σ2	03/160		22.7	03/160	00/000	±	0
σ3	81/269	7	90.9	87/329	00/000	±	0
R	.83		R'	2.83		±	
			SHmax	067		±	

Counting dev. 33.4 ± 5.7 max. 42.3

WSM Reg. TF

Stress regime

n/nt	CLw	DTw	QRw	Plen	Slen	QRt
1	.5	1	E	.74	.94	E

Data Separation & Dieder processing

Threshold for removing data Reject 1 by 1 ☐

Mean C.D. + .7 σ= 37.39 Auto Reject

Compatible 7 Non compatible 4

Initial subset 11 Previous Used data 100 % Next Final subset 11

σ1: 09/070
σ2: 03/160
σ3: 81/269
R: .83 CD: 33.4
QRw: E QRt: E

1 : 010602

	Compiled fault-slip data							Subset Index			Dieder Results	Comments	Kinematic axes		
pe	Plane	Line	Sense	CL	Wt	Act	Str	Input	Tmp	Working	Counting Deviation (%)		p Incl	p Azim	b Incl
1	87/220	87/245	IS	S	1.0	2	2	1.0		1.0	**38.91**	010602	42	221	01
1	81/010	81/003	ID	S	1.0	2	2	1.0		1.0	**42.28**	030200	36	009	01
1	40/212	38/235	IS	S	1.0	2	2	1.0		1.0	28.01	010100	06	045	11
1	75/135	74/160	IS	S	1.0	2	2	1.0		1.0	28.29	010200	30	140	06
1	75/135	74/160	IS	S	1.0	2	2	1.0		1.0	28.29	010200	30	140	06

Figure 3.3 Palaeo-stress analysis, which is calculated by Win-Tensor software to determine principal stress axes.

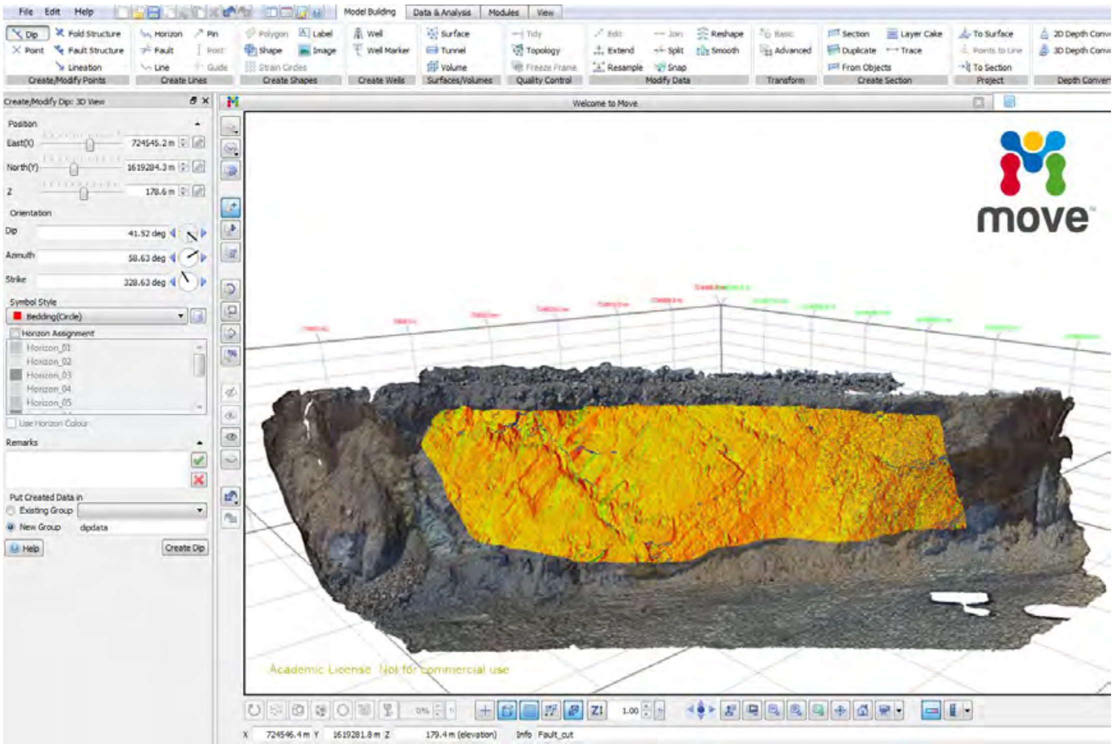


Figure 3.4 MOVE^{TM} software is used for structural modeling and analysis in order to interpret structural geology in study area.

Chapter 4

Results

4.1 Lithology

In this study area, the Siam City Cement Public Company Limited composes of both clastic and non-clastic sedimentary rocks. Moreover, igneous rocks extend on the SW part of study area. Throughout the study area, these rocks can be divided into five units based on their lithology and fossil assemblage as shows in a detailed structural map (Fig 4.1).

4.1.1 Shale (Unit A)

The distribution of shale in this quarry is mostly situated in SW portion of this area. Furthermore, there are minor distributions is located in the center part of this study area. The former classification of this unit is ASh or Shale A unit (SCCC, 2011) which was classified by the Siam City Cement Company. According to petrographic study of two sub-areas, it can be grouped into calcareous shale.

4.1.2 Well-bedded limestone (Unit B)

This rock unit is a limestone unit showing parallel bedding plane of limestone. It distribution is shown in Fig 4.1 where is parallel to the main structure of this area. Thickness of this limestone bedding is approximately 40-50 cm. From petrographic study, it can be classified into bioclastic packstone based on Wright’s classification.

4.1.3 Fractured limestone (Unit C)

According to biostratigraphy, Fossil assemblage within this unit is younger than limestone unit B. The difference between two limestone units is not only their fossil assemblage but also their structural features. This unit is more fractured and absent to show well-bedded features. Due to their fossil assemblage, this study has grouped the two former units, namely SPL (Spatic limestone) and LSh (Lime shale) into this unit (unit C).

4.1.4 Sediments (Unit D)

There are some sediment where is located in the western portion of this quarry. The distribution is shown in a detailed structural map in Fig 4.1.

4.1.4 Igneous rocks (Unit X)

Igneous rocks intruded and formed a large igneous trend in southern part of the Khao Khwang Fold and Thrust Belt. To study volcanic rocks are important tool to understand the tectonic history in study area (Arboit et al., 2016b). Volcanic rocks within study area mostly expose in southern portion of study area in shale pit (Fig 4.8). There are mainly andesitic to rhyolitic composition. The igneous bodies were formed in both sill and dike. Generally, they follow thrust faults, indicating that these igneous bodies intruded after the main Indosinian deformation. Recent works on geochronology (Arboit et al., 2016b; Arboit et al., 2017) of igneous rocks within the Khao Khwang Fold and Thrust Belt have described age of the rocks in the adjacent area. From U-Pb dating of zircons, the age of andesite which studied by Meffre et al. (in prep.) was 250-240 Ma; moreover, the age of rhyolite which dated by Arboit et al. (2017) was 207±4 Ma.

A detailed structural map (Fig 4.1) is compiled from lithological, biological, and structural data. These rock units were cut by major structures which lie in NW-SE trending. Fig 4.2 shows cross-sections which pass through the major structures in northeast-southwest direction. It consists of 2 cross-section lines, line A-A’ and line B-B’. They represent the four major thrust faults with dip direction in southwest and the other is oblique-normal fault. Line B-B’ is across in the southern portion where igneous rocks are occurred along shale unit.

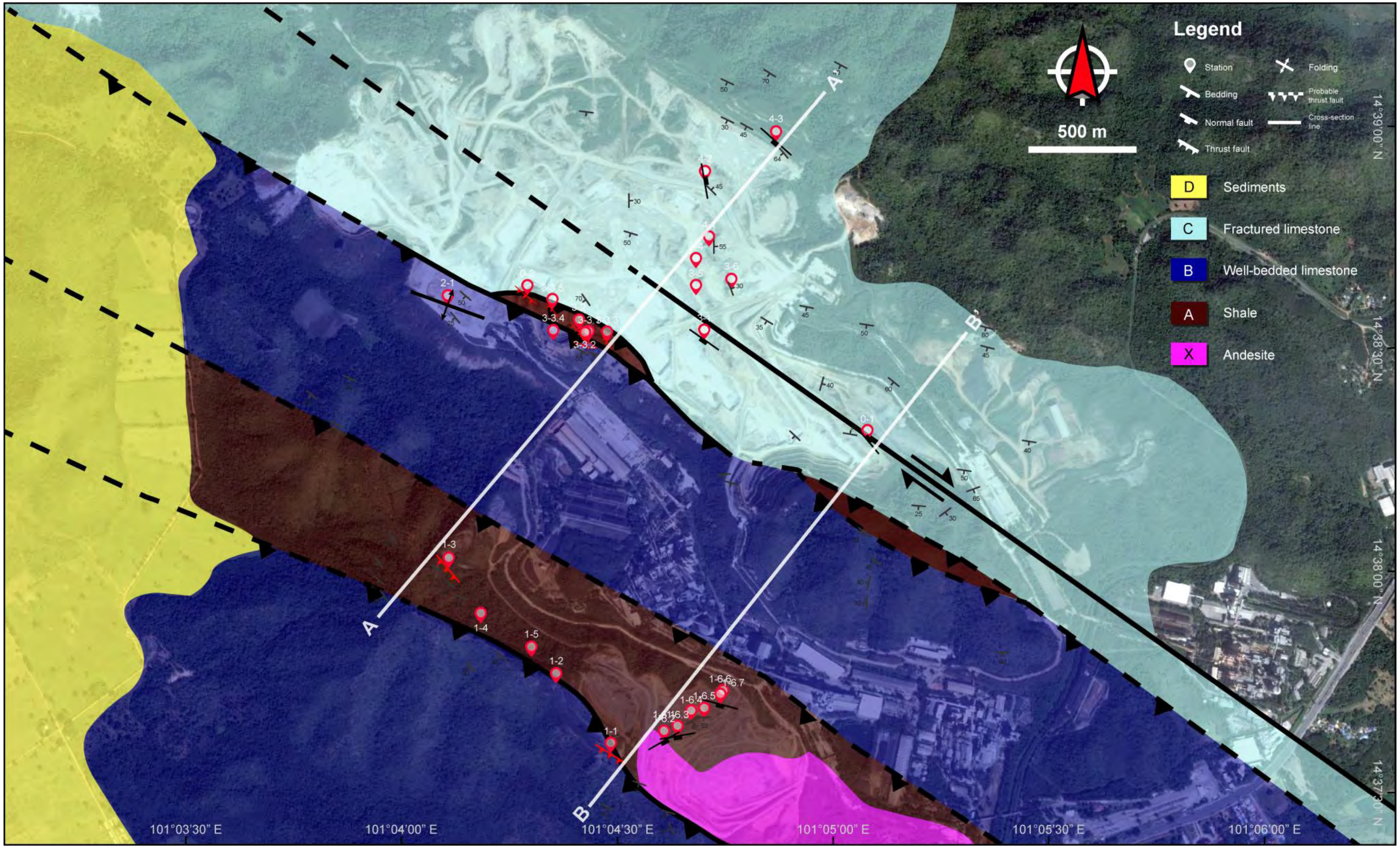


Figure 4.1 A detailed structural map of the Siam City Cement quarry which derived from both petrography and structural data.

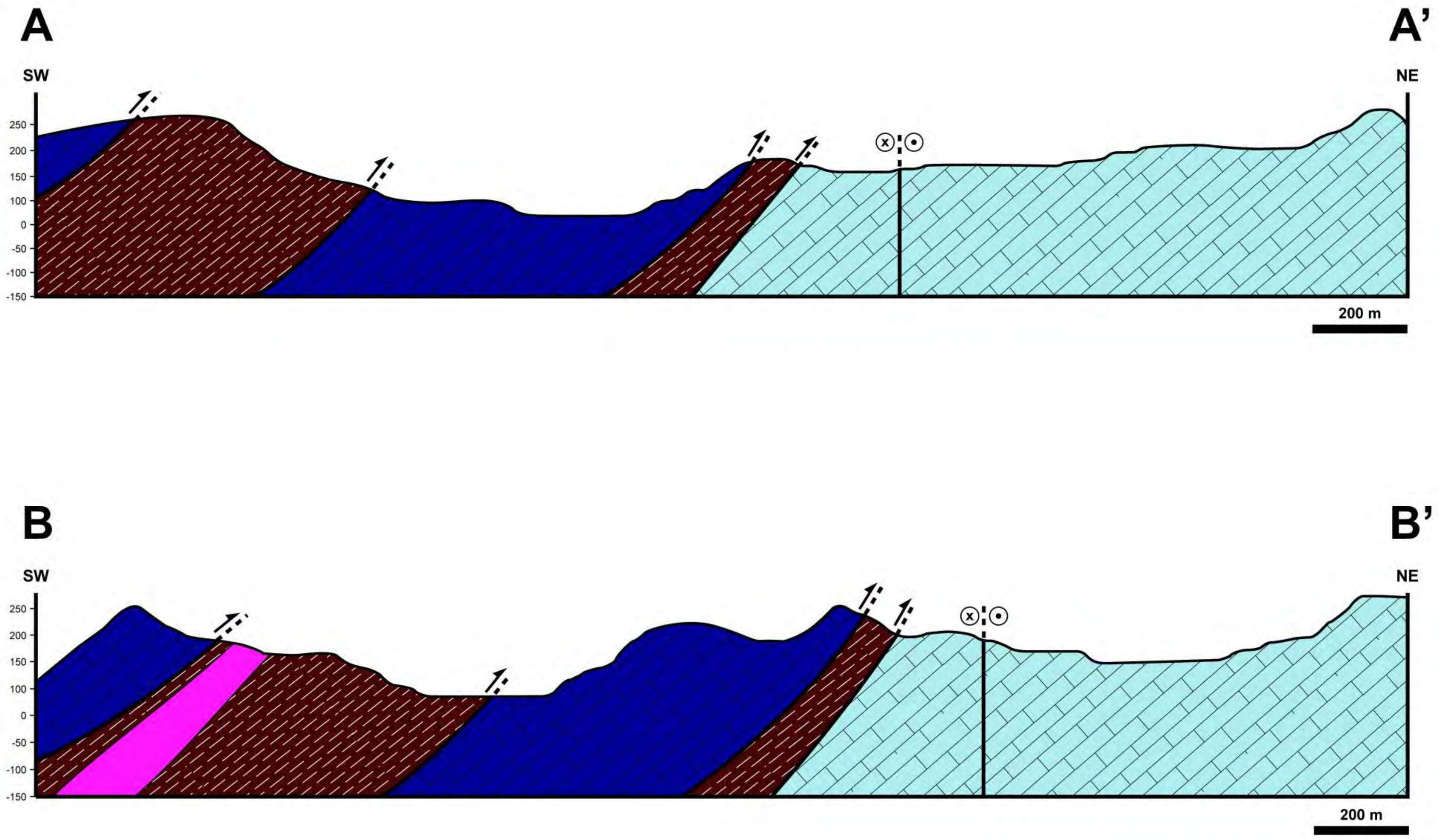


Figure 4.2 Cross-sections of line A-A’ and B-B’ crossing the major structure in study area.

4.2 Structures

4.2.1 Bedding planes

The orientation of bedding planes in this study is separated into 2 groups based on their location. One is located on SW part of study area, namely Khao Mai Nuan. The other is situated on NE part of study area, namely Khao Yai and Khao Nong Kob. The major trend of both groups lies in NW-SE direction. The latter group, local bedding plane lies in ESE-WNW to E-W trending. In some areas are strongly deformed that lead to variation of their orientation.

4.2.2 Reverse faults

Well exposed outcrops are mostly dominant by high-angle reverse fault and thrust fault. These faults are situated in SW of study area (Khao Mai Nuan; Fig 1.2) and central part of the mine. Thrust zone is influenced by strong compressional tectonics. The nearby area where closes to thrust fault is strongly deformed showing by highly weathered rocks. Slickensides, slickenlines, and mineral steps were used to determine the sense of relative displacement along the fault.

Data from field survey, there are two major reverse faults that lie across study area. One is located on the SW part of study area where passes through northeast part of Khao Mai Nuan (Fig 4.3-4.5). This thrust fault lies nearly NW-SE direction. The strike of these fault planes range from 120 to 140 degrees and dip direction leans to SW with angle between 40 and 70 degrees. Furthermore, slickenlines lie in NE-SW to E-W trending which ranges from 230 to 270 degrees.

Two rock units are separated by this reverse fault which acts as a fault contact. This shows limestone unit which locates SW of fault plane overthrust on shale unit that situates NE of fault plane.

In a local area along this fault plane, there is evidence which can be interpreted as two directions of fault movement (Fig 4.5). Two orientations of slickenlines are local evidence of two events of movement.

The other thrust fault is located northward from a previous one. This thrust fault passes through central part of the mine (Fig 4.6). The orientation is the same trend as a former fault. The strike of these fault planes range from 130 to 140 degrees and

Figure 4.3 A representative thrust fault is located in NE part of Khao Mai Nuan.

Figure 4.4 A contact fault showing limestone unit overlying on shale unit.

Figure 4.5 Local bidirectional slickenlines showing two events of fault movement.

Figure 4.6 An aerial photo shows a section of thrust zone where lies in central part of the study area.

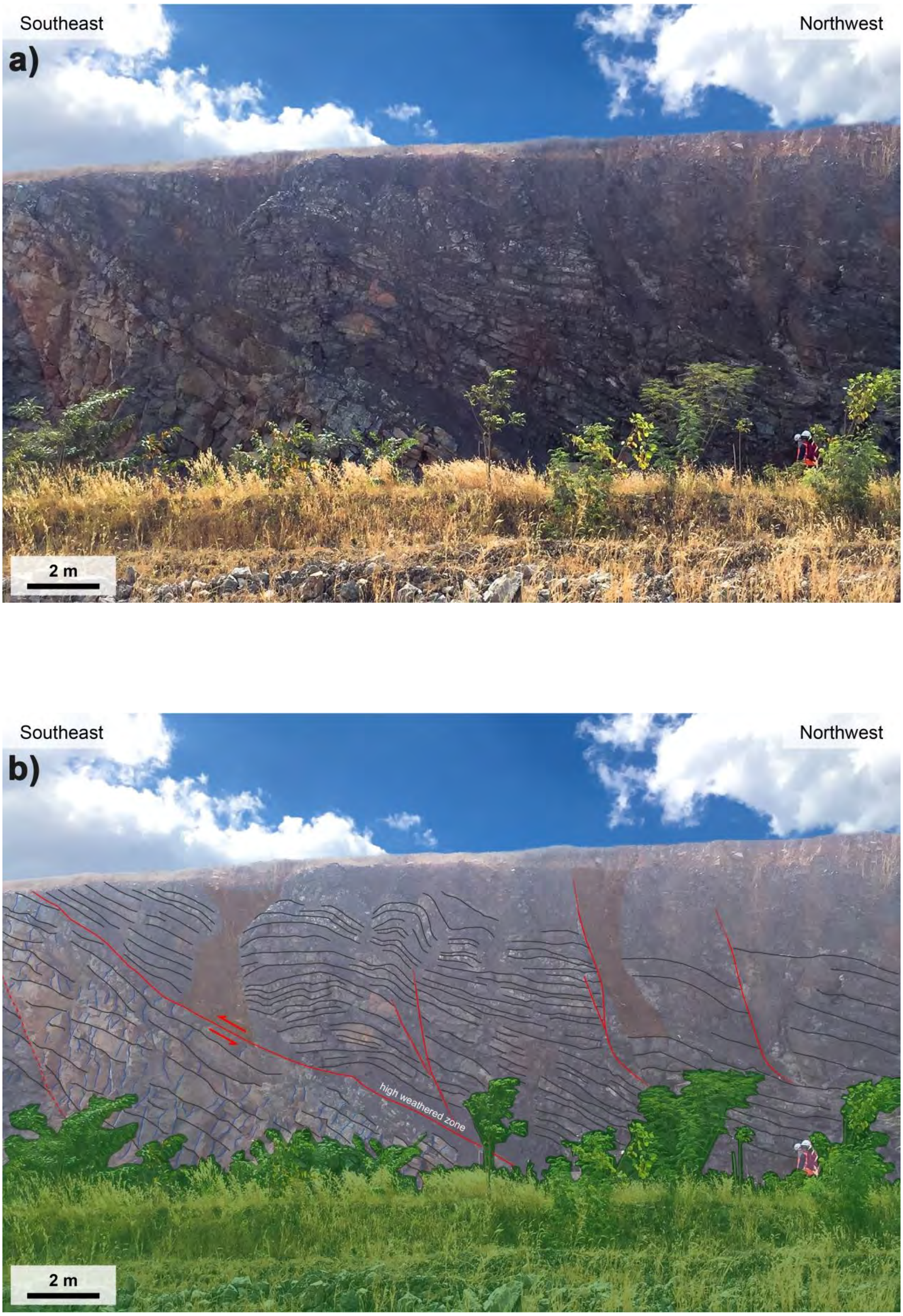


Figure 4.7 (a) NW-SE trending thrust fault which passes through central part of the mine. (b) A section of thrust fault in Fig 4.6 which shows a fault-propagation fold.

dip direction leans to SW with high angle between 60 and 80 degrees. Furthermore, slickenlines lie in NE-SW to ESE-WNW trending which ranges from 240 to 280 degrees (Fig 4.7).

4.2.3 Normal faults

Normal faults which were observed in the study area are not pure dip slip faults, but they were influenced by strike-slip component (Fig 4.10 & Fig 4.11). Normal faults were found in various areas with different strike orientations as a local normal fault. The major normal fault locates in NE of the study area. The strike orientation of this fault lies in NW-SE direction which ranges from 320 to 350 degrees. This normal fault combines with right-lateral component that is called oblique normal fault. And dip direction inclines to NE with angle about 50 to 70 degrees.

The other results of structural analysis were contemplated by a digital outcrop model (Fig 4.12) which can be extracted some geological data from this model. And the other two models (Fig 4.13) show the orientation of this fault plane. The attribute model shown in Fig 4.13a is an azimuth model which shows the orientation. The average of azimuth data which extracted from this model is approximately 52.13 degrees. The other model (Fig 4.13b) is a dip attribute model which shows dip data along this fault plane. The distribution of dip data displays in a different colour along the fault plane model. Dip data can be extracted from the model. The average dip data is approximately 52.50 degrees.

4.2.4 Folding

Well-exposed folding outcrops are located within well bedded limestone unit (Fig 4.14 & Fig 4.15) which can be constructed to 3D model (Fig 4.16). This fold is defined as a fault-bend fold. It is caused by the displacement of block along inclined fault surface. There are many gentle antiforms and synforms which appear on the outcrop. Fold limbs were used to determine the orientation of fold axis by using the stereographic projection. The calculated fold axes of this study range from 277 to 287 degrees and their plunge is about 10 to 20 degrees. The orientation of fold axis relates to the strike of major thrust faults in the study area. Moreover, the major fold axis is mostly perpendicular to the maximum horizontal stress (σ_1). Due to many evidence, both thrust fault and folding are probably affected by the same tectonic events.

Figure 4.8 An igneous intrusion which intruded within a shale unit.

Figure 4.9 A normal fault plane showing slickensides along fault surface.

Figure 4.10 An oblique-normal fault showing an evidence of right-lateral movement.

Figure 4.11 Slickenlines and slickensides showing normal dip slip with right-lateral movement.

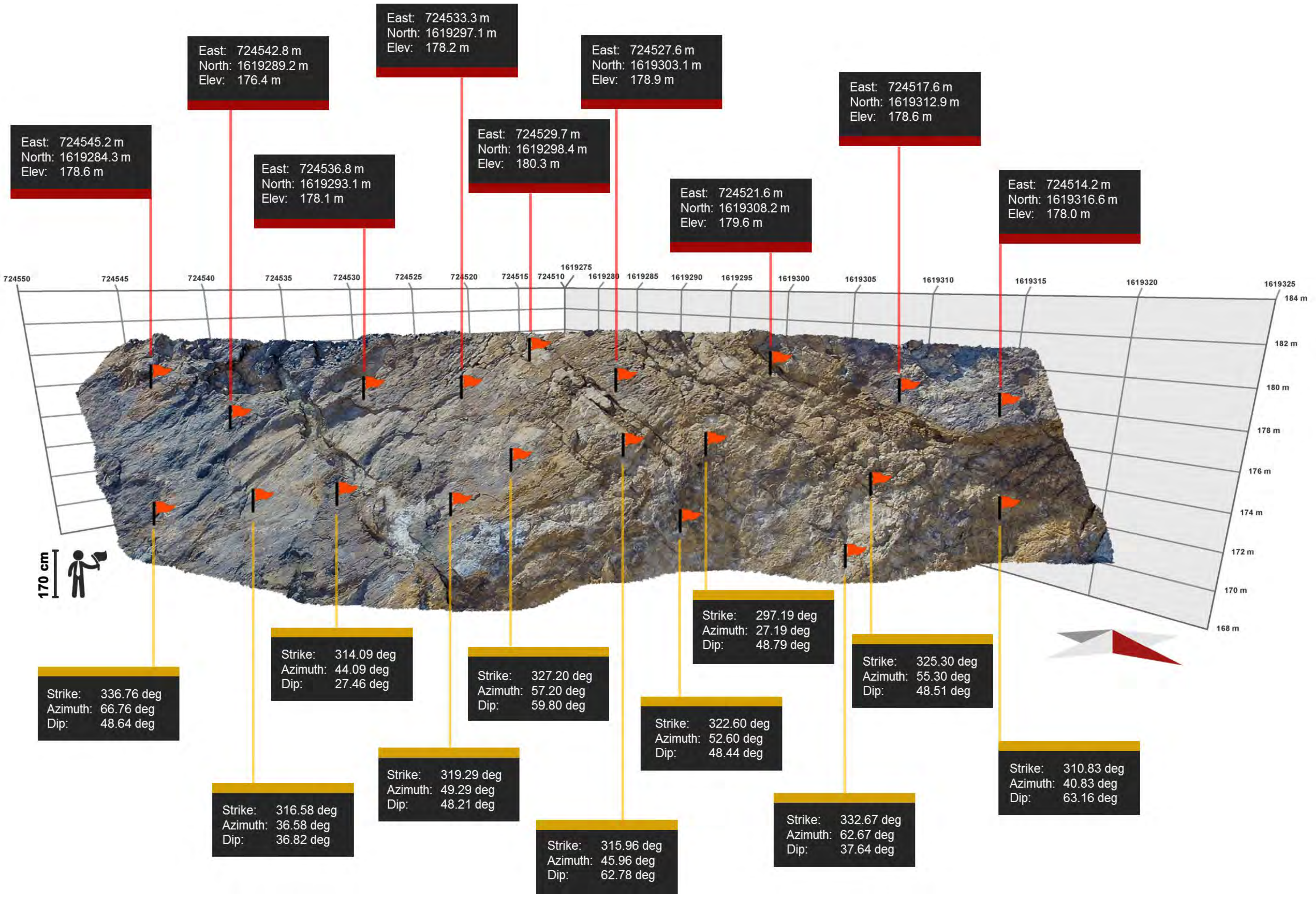


Figure 4.12 Digital outcrop model showing geological data along this fault plane composes of both its position and orientation.

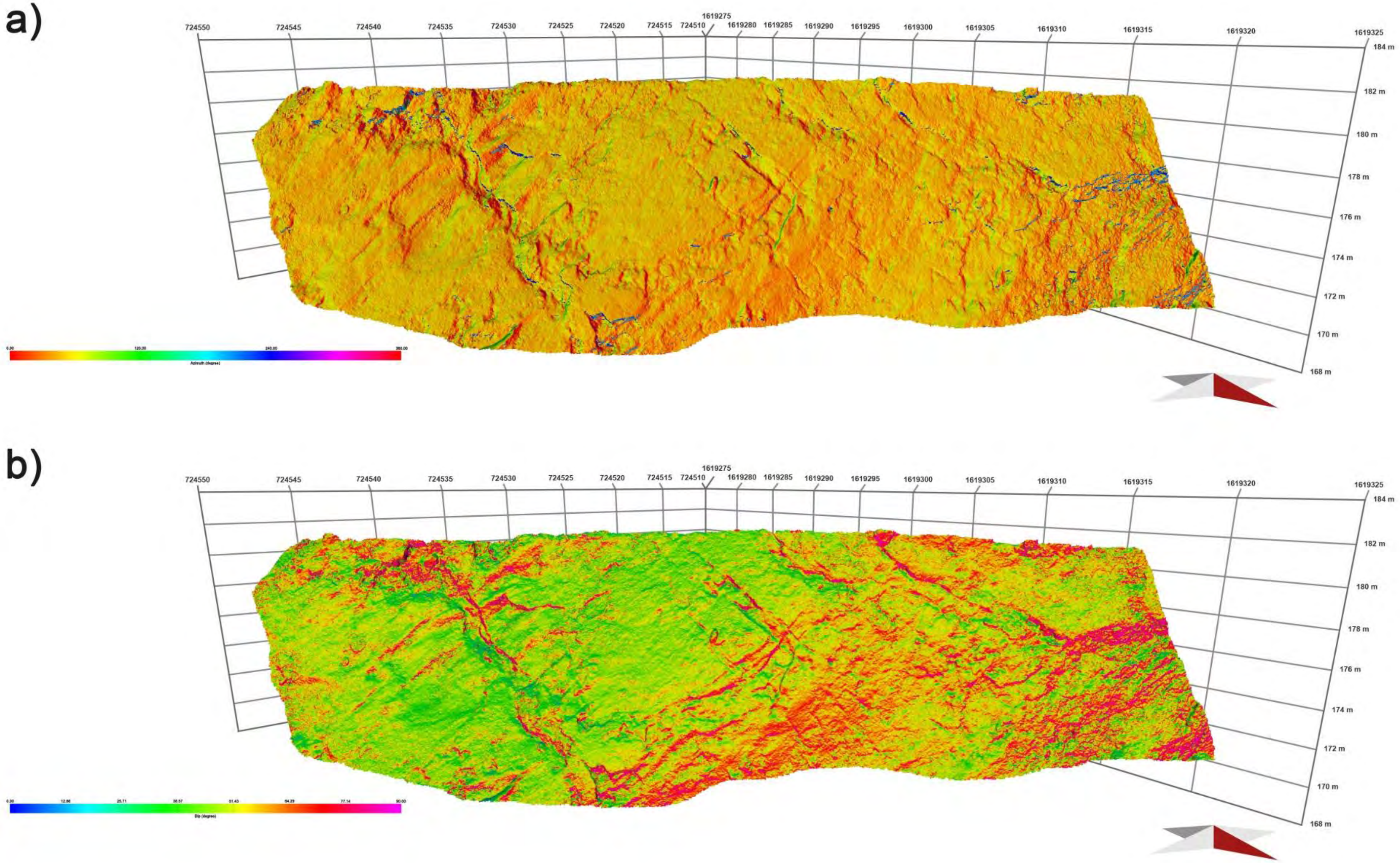


Figure 4.13 (a) and (b) Digital outcrop model showing azimuth and dip angle surface attribute of fault plane, respectively.

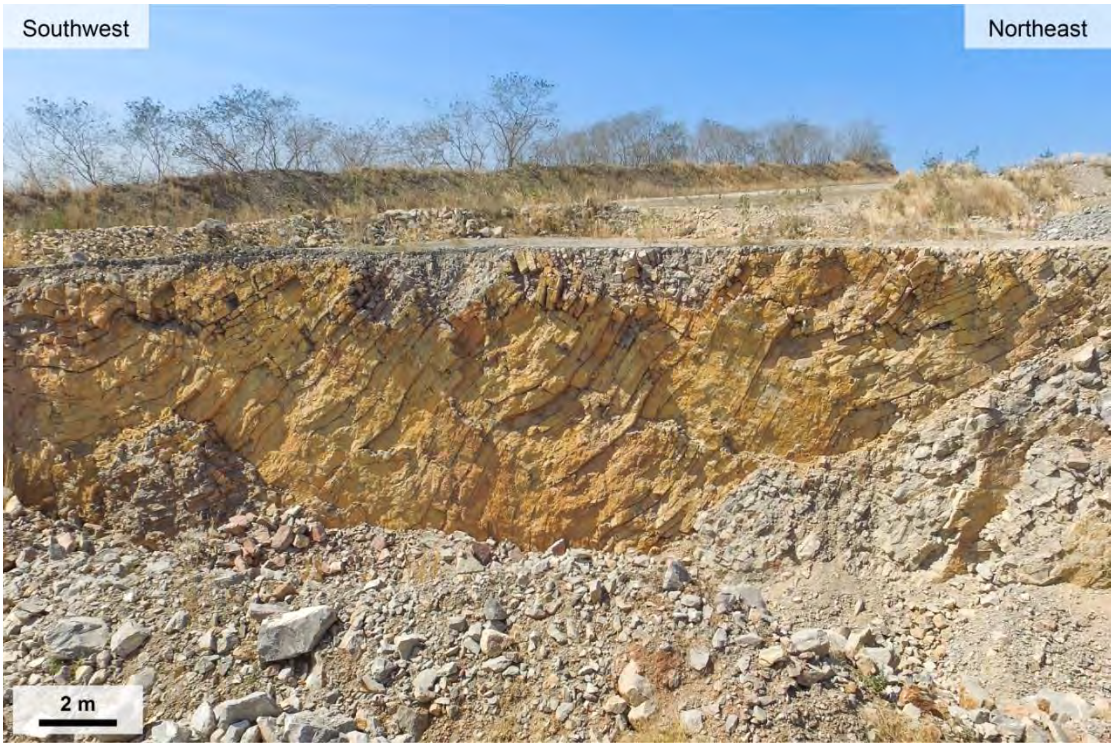


Figure 4.14 A folding outcrop section of well-bedded limestone unit.

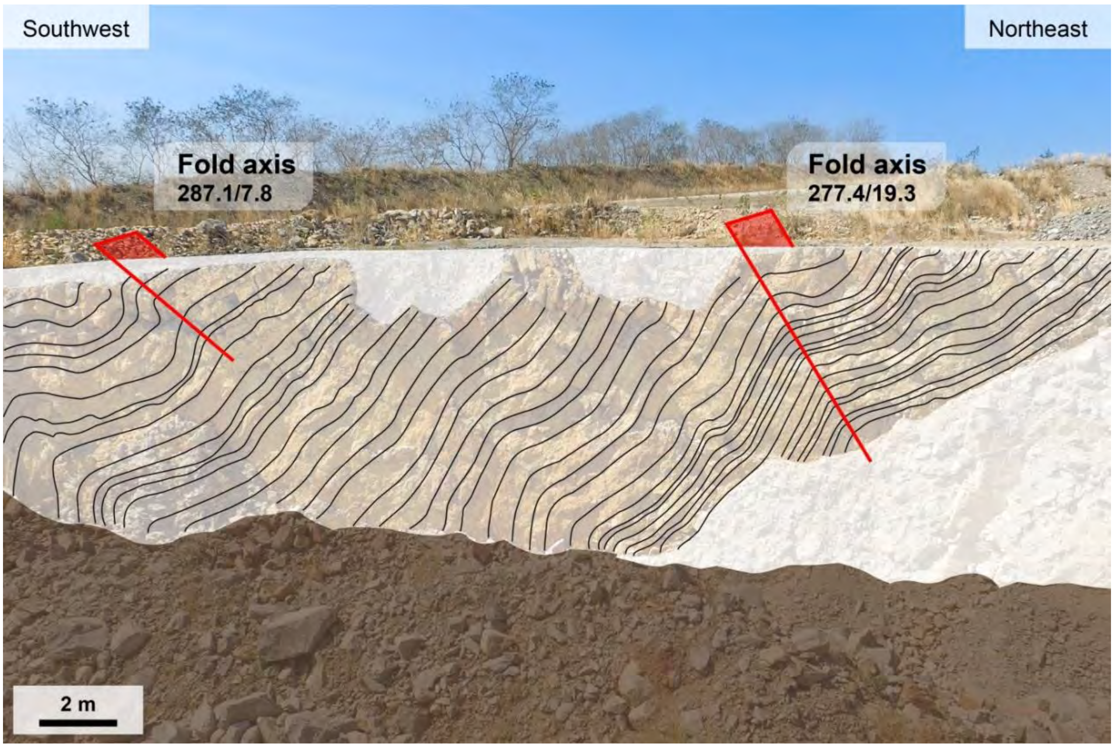


Figure 4.15 Calculated fold axes of this folding outcrop.

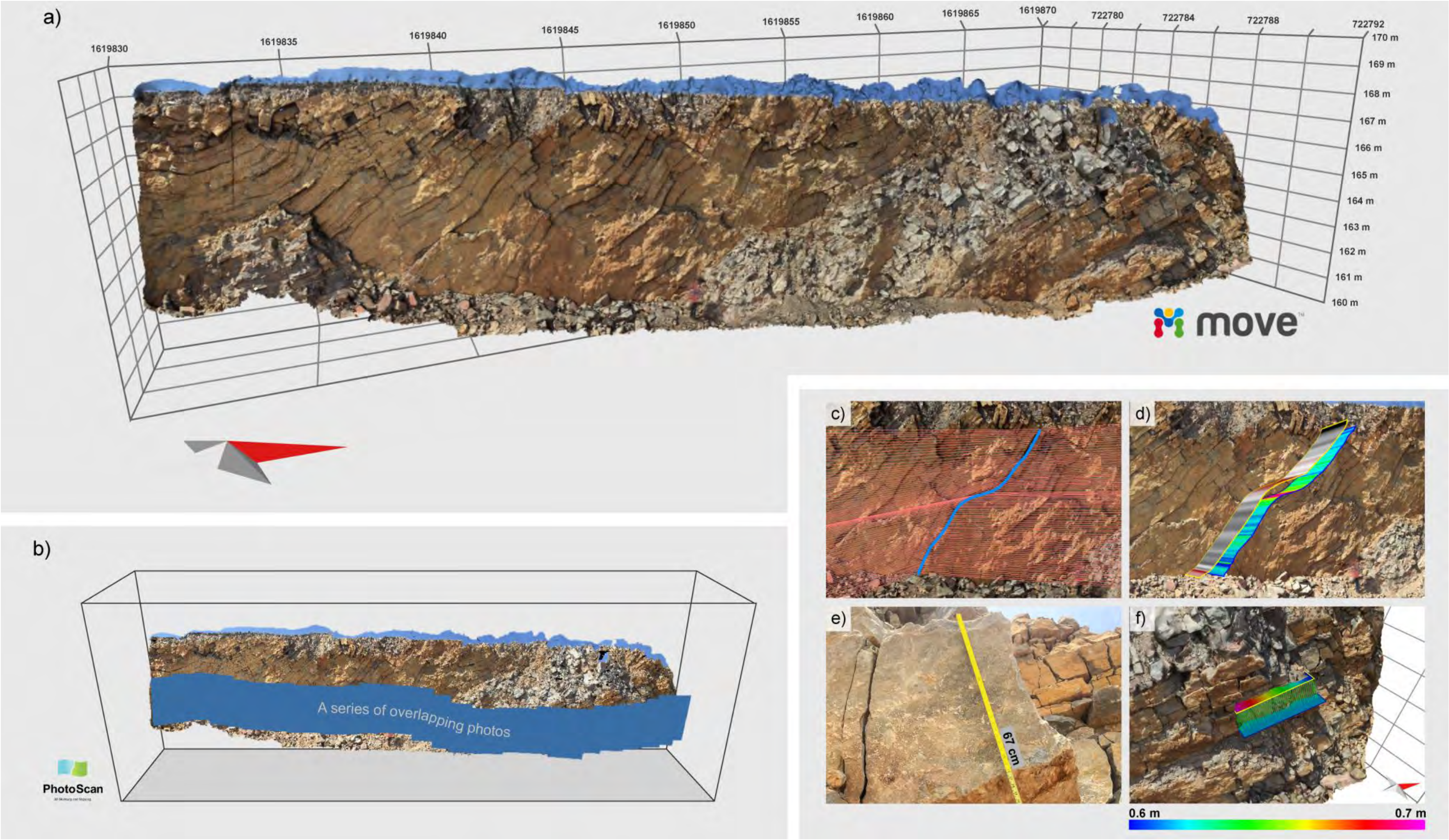


Figure 4.16 (a) A folding outcrop model (b) A construction process of the model by using Agisoft PhotoScan software (c) Bedding plane construction method (d) Surface attribute which analysed on virtual beds (e-f) Thickness measurement of bedding plane.

4.3 Palaeo-stress Analysis

Fault slip data were collected from outcrops which comprise fault orientations, attitude of slickenlines, and sense of movement. Slickenlines are parallel lines, tapering ridges, or grooves parallel to the slip direction. The slickenlines on fault plane are used as kinematic indicators that record the relative displacement between two blocks separated by fault. Measurements were recorded at 15 stations and 26 fault slip data (see in appendix 1). The attitude of slickenlines were recognized by smooth, shiny, or reflective fault surfaces, accretionary mineral steps, tool marks, and friction fractures.

All of fault slip data, including strike and dip direction of fault planes and trend and plunge of slickenlines, were used to calculate a palaeo-stress tensor, which procure a dynamic interpretation as stress orientation as well as a kinematic analysis. A palaeo-stress tensor define as stresses that acted in the geological past which contain three parameters; namely maximum principal stress (σ_1), intermediate principal stress (σ_2), and minimum principal stress (σ_3). The palaeo-stress tensor of this study area is defined by using Right Dihedron method that processed by Win-Tensor software.

The fault slip data were separated into two groups based on their sense of movement; the calculated palaeo-stress tensor (Fig 4.17) is characterized as σ_1: 070/09, σ_2: 160/03, σ_3: 269/81. The maximum horizontal stress lies in ENE-WSW direction (SH_{max}: 067). It represents a compressional thrust fault regime in ENE-WSW compression. The palaeo-stress tensor shows that σ_1 (SH_{max}) and σ_2 are sub-horizontal and σ_3 (SH_{min}) is sub-vertical which is influenced by a major compressional tectonic regime.

The other (Fig 4.18) is characterized as σ_1: 251/83, σ_2: 116/05, σ_3: 025/05. The maximum horizontal stress lies in ESE-WNW direction (SH_{max}: 114). It represents an extensional normal fault regime and responding to NNE-SSW extension. The palaeo-stress tensor shows that σ_2 (SH_{max}) and σ_3 are sub-horizontal and σ_1 is sub-vertical which is influenced by a major extensional tectonic regime.

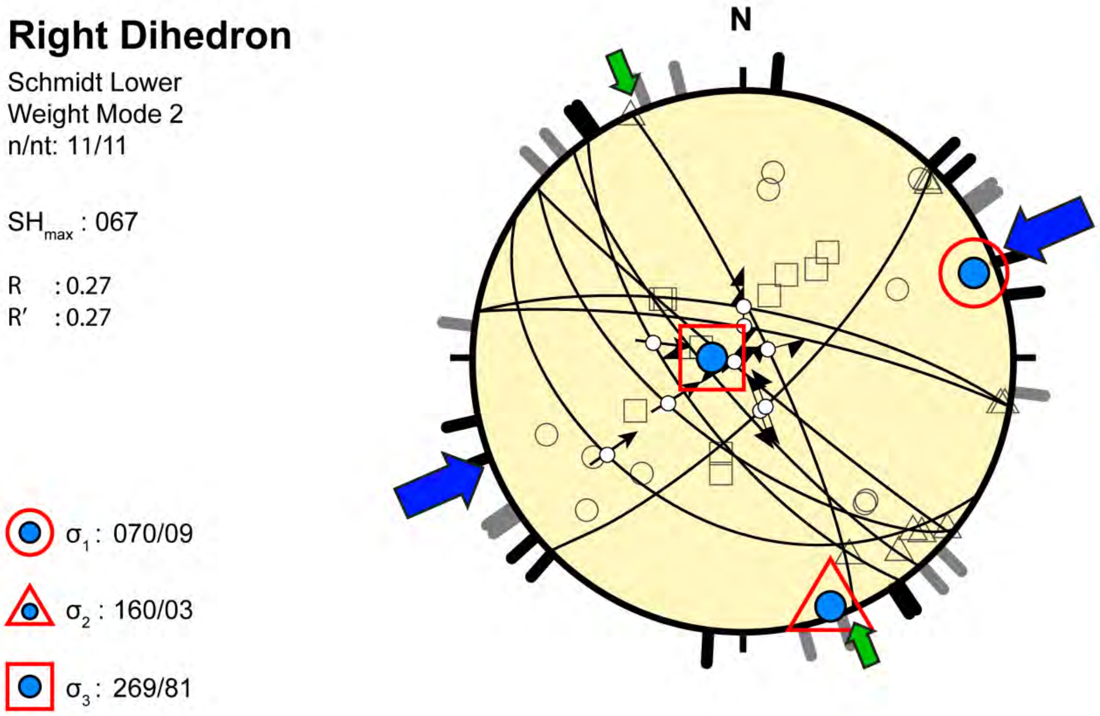


Figure 4.17 Palaeo-stress analysis showing calculated stress tensor of compressional tectonic regime.

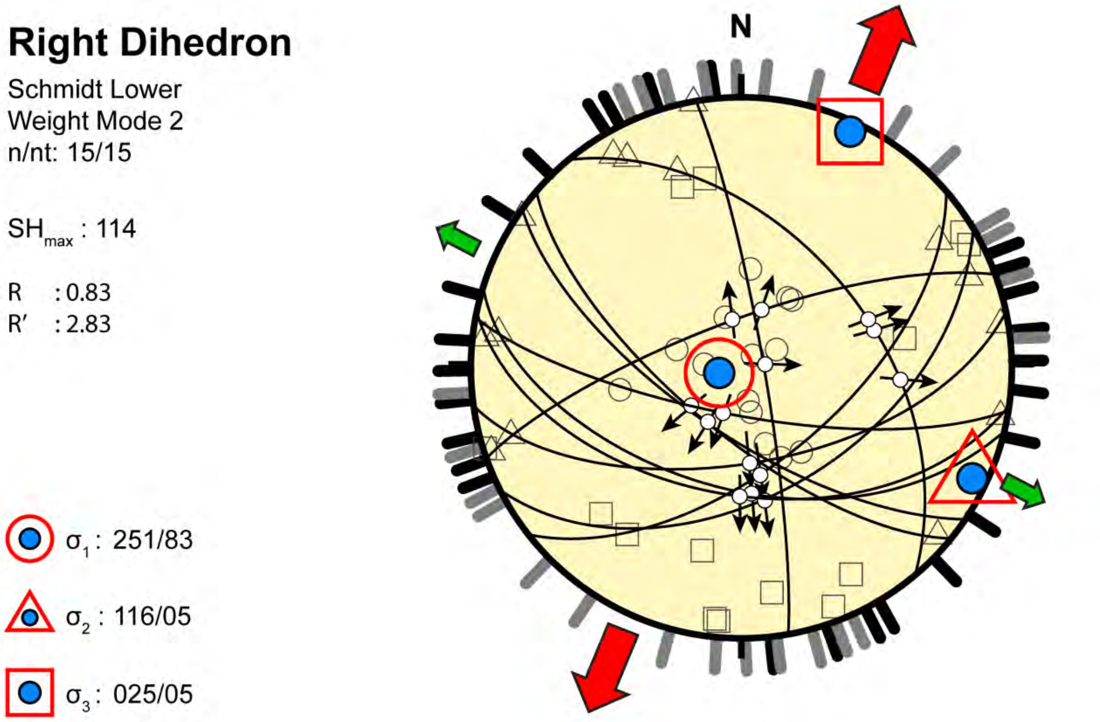


Figure 4.18 Palaeo-stress analysis showing calculated stress tensor of extensional tectonic regime.

Chapter 5
Discussion

5.1 Comparison to palaeo-stress analysis in adjacent areas

Palaeo-stress analysis which calculated from fault plane orientations and fault slip data was used to find principal stress. Ampaiwan (2011) and Kuenphan (2012) studied palaeo-stress of carbonate rocks in the adjacent areas (Fig 5.1). The study area of Ampaiwan (2011) is located on Na Phralan limestone quarry where major structure such as folding and thrusting lies in an east-west direction. The result of this study shows the maximum principal stress and intermediate principal stress are in sub-horizontal component; while, the minimum principal stress is sub-vertical in stress tensor. Moreover, Kuenphan (2011) has studied the palaeo-stress in limestone mine in Amphoe Pak Chong where is located approximately 30 kilometres away from the Siam City Cement quarry. The main structure in this area lies in the same trending as Ampaiwan (2011)'s. The result of this study is similar to the previous one. Both studies developed within the thrust fault system in north-south direction. After that, Morley et al. (2013) concluded that these studies occurred during stage 1 deformation of Indosinian Orogeny or Early to Middle Triassic.

This study area is located between the two former areas. The major structure has been changed from east-west trending to northwest-southeast trending. Thanudamrong (2011) has studied structural geology in the Siam City Cement quarry and concluded a horizontal principal stress in a northwest-southwest direction which analysed from orientations of fault plane in study area. In this study, the palaeo-stress analysis calculated from both fault plane orientation and fault slip data. The calculated palaeo-stress tensor is characterized as σ_1: 070/09, σ_2: 160/03, σ_3: 269/81. The maximum horizontal stress lies in ENE-WSW direction (SH_{max}: 067). It represents a compressional thrust fault regime in ENE-WSW compression. The result of this work is close to the previous one which studied in the same study area.

Variation of palaeo-stress tensor along the Khao Khwang Fold and Thrust Belt indicates that the kinematic and mechanical features are different.

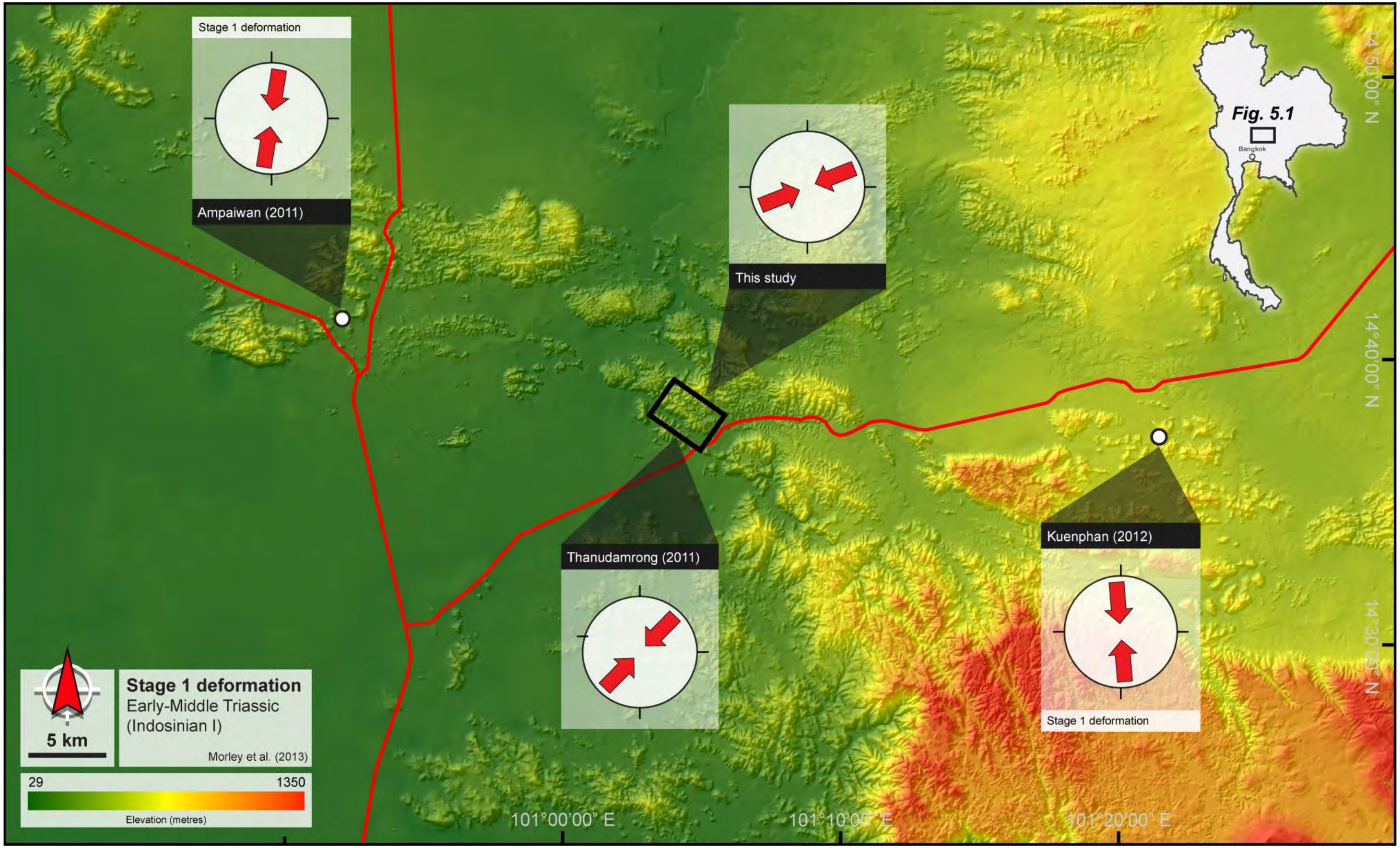


Figure 5.1 Calculated stress tensor compares with the previous work along the Khao Khwang Fold and Thrust Belt.

5.2 Evolutionary model

According to the palaeo-stress analysis, it can be divided the deformation history into two stages based on tectonic activities in mainland Southeast Asia. This evolutionary model (Fig 5.2) started after mixed carbonate-siliciclastic Permian rocks were accumulated along the southwestern margin of Indochina terrane.

5.2.1 Stage 1 (Compressional stage)

According to palaeo-stress analysis from the orientations of fault plane and fault slip data were used to interpret the direction of stress. In addition, the evidence of folding and thrusting provides strong evidence of a deformation history in study area. Palaeo-stress tensor can be interpreted in ENE-WSW compressional regime. This fold and thrust system was caused by subduction of palaeo-tethys beneath Indochina terrane during Indosinian Orogeny. Morley et al. (2013) interpreted this stage as stage 1 deformation which occurred during Early to Middle Triassic. This deformation stage developed fault-propagation folding within the Khao Khwang Fold and Thrust Belt.

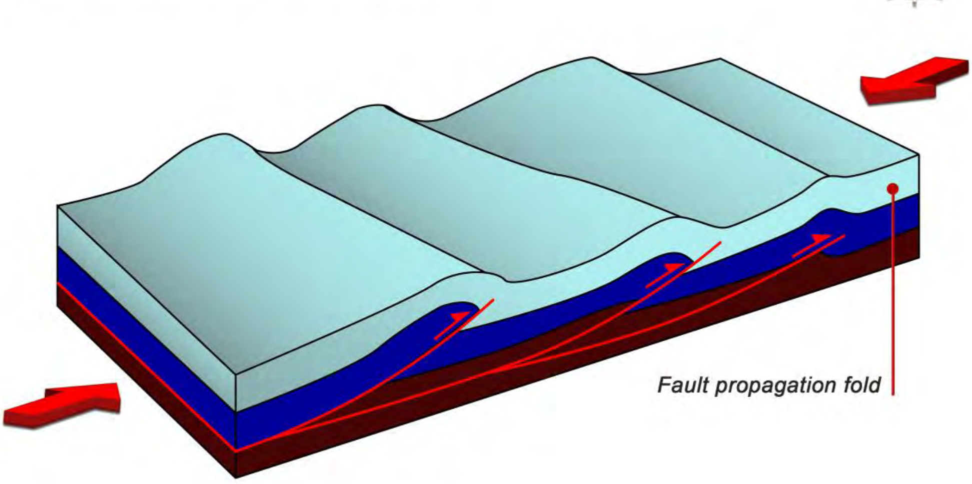
5.2.2 Igneous intrusion

The distribution of igneous rocks in Siam City Cement quarry was formed as sills and dikes which follow along faults or some weak zones. These magmatism processes begin after the end of compressional stage. From the previous study, the recent U-Pb dating of zircons by Meffre et al. (in prep.) in the adjacent area indicate the presence of 250-240 Ma andesite. It acted as a key event in this study which intruded after the deformation stage.

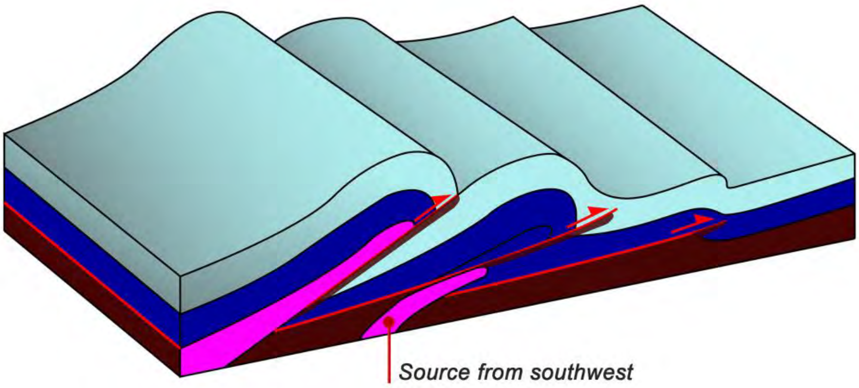
5.2.3 Stage 2 (Extensional stage)

After the magmatism activities have ceased, there are other tectonic events which formed oblique-normal faults in study area. From calculated palaeo-stress tensor, the maximum principal stress axis is in sub-vertical so it represents an extensional regime and responding to NNE-SSW extension.

(a) Stage 1 Indosinian compression



(b) Igneous intrusion (250-240 Ma)



(c) Stage 2 Extension

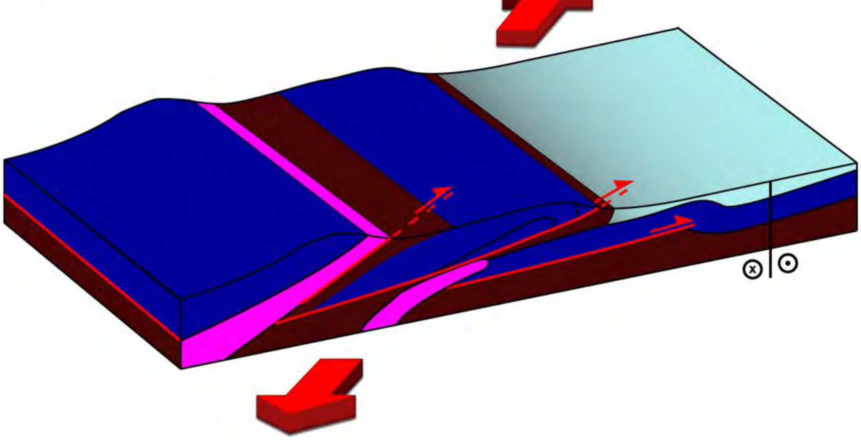


Figure 5.2 The evolutionary model showing deformation stages. (a) First stage, compressional stage during Indosinian Orogeny (b) Igneous intrusion (c) Stage 2 extensional stage formed normal faults around study area.

Chapter 6
Conclusions

This study reports a detailed structural map and evolutionary model of the Permian carbonate rocks in Siam City Cement quarry. The study area is situated in a deformation zone of southwestern margin of the Indochina terrane where is called the Khao Khwang Fold and Thrust Belt during Early to Middle Triassic. This study considered data from traditional field investigation together with photorealistic digital outcrop models which are a new technique for data acquisition and structural analysis.

1. The major structure such as bedding plane, thrust fault, and fold axis lies in NW-SE trending
2. Thrust faults are a dominant structure in this area. It contains both reverse faults and high-angle thrust faults. The strike of fault planes ranges from 110 to 140 degrees and dip 40 to 70 degrees to the SW.
3. Palaeo-stress analysis from fault plane orientations and fault slip data indicates two events of deformation.
    - Stage 1 is ENE-WSW compression which formed the major NW-SE structures such as thrust faults and folding. This stage occurred during the Indosian Orogeny which caused a fold and thrust system along the southwestern margin of the Indochina terrane.
    - The magmatic activities probably formed after the first deformation events. There are mainly andesitic to rhyolitic composition. They were intruded during the Early to early Middle Triassic or 250-240 Ma.
    - Stage 2 is NNE-SSW extension formed NW-SE oblique-normal fault which was influenced by right-lateral movement which possibly reactivated during Cenozoic time or later stage 1 deformation.

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Appendix

Appendix 1 Fault plane database which has collected from field survey

Station	Latitude	Longitude	Elevation	Fault plane		Fault slip data	
				Strike	*Dip*	*Trend*	*Plunge*
000100	14.637841	101.084754	191	320	50	n/a	n/a
000200	14.643380	101.071674	152	130	65	n/a	n/a
010100	14.626202	101.074733	241	122	40	235	70
010200	14.628805	101.072651	258	45	75	160	55
010300	14.633197	101.068553	205	140	80	270	77
010400	14.631108	101.069768	221	n/a	n/a	n/a	n/a
010500	14.629834	101.071705	212	n/a	n/a	n/a	n/a
010601	14.626653	101.076788	136	50	60	170	45
010602	14.626653	101.076788	136	130	87	245	42
010603	14.626829	101.077319	136	80	60	175	45
010604	14.627394	101.077853	122	n/a	n/a	n/a	n/a
010605	14.627480	101.078374	117	25	70	n/a	n/a
010606	14.628025	101.079010	106	105	52	180	70
010607	14.628115	101.079094	101	n/a	n/a	n/a	n/a
020100	14.643037	101.068608	178	n/a	n/a	n/a	n/a
030100	14.641665	101.078507	150	125	70	210	67
030200	14.642088	101.073667	155	280	75	3	50
030301	14.641669	101.074025	165	130	64	n/a	n/a
030302	14.641643	101.073894	171	110	40	n/a	n/a
030303	14.641645	101.074739	168	145	70	280	64
030304	14.641681	101.072670	165	335	82	71	40
030305	14.642865	101.072634	168	138	45	n/a	n/a
030400	14.644361	101.078217	168	n/a	n/a	n/a	n/a
030500	14.643331	101.078198	155	180	40	n/a	n/a
030600	14.643572	101.079555	185	n/a	n/a	n/a	n/a
040100	14.645161	101.078707	175	n/a	n/a	n/a	n/a
040200	14.647619	101.078601	198	350	83	80	83
040300	14.649068	101.081352	208	130	70	230	65

Remark: Station: XXYYZZ is refer to Day//Station//Stop
Coordinate system: WGS84