โครงการการเรียนการสอนเพื่อเสริมประสบการณ์

ความหลากหลายทางโครงสร้างตามทางหลวงหมายเลข 12
อำเภอหล่มสัก จังหวัดเพชรบูรณ์

โดย

นายกษิดิศ หล่อศุภสิริรัตน์
เลขประจำตัวนิสิต 5632701523

โครงการนี้เป็นส่วนหนึ่งของการศึกษาระดับปริญญาตรี
ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2559

STRUCTURAL VARIATION ALONG HIGHWAY 12, AMPHOE LOM SAK, CHANGWAT PHETCHABUN

Mr. Kasidis Lhosupasirirat

A Project Submitted in Partial Fulfilment of the Requirements
for the Degree of Bachelor of Science Program in Geology
Department of Geology, Faculty of Science,
Chulalongkorn University
Academic Year 2016

ความหลากหลายทางโครงสร้างตามทางหลวงหมายเลข 12
อำเภอหล่มสัก จังหวัดเพชรบูรณ์

นายกษิดิศ หล่อศุภสิริรัตน์

โครงงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรวิทยาศาสตรบัณฑิต

ภาควิชาธรณีวิทยา คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย

ปีการศึกษา 2559

Project Title	STRUCTURAL VARIATION ALONG HIGHWAY 12, AMPHOE LOM SAK, CHANGWAT PHETCHABUN
By	Mr. Kasidis Lhosupasirirat
Field of Study	Geology
Project Advisor	Dr. Sukonmeth Jitmahantakul

Submitted date……………………………..

Approval date……………………………..

……………………………………………..

Project Advisor

(Dr. Sukonmeth Jitmahantakul)

กษิดิศ หล่อศุภสิริรัตน์ : ความหลากหลายทางโครงสร้างตามทางหลวงหมายเลข 12 อำเภอหล่มสัก จังหวัดเพชรบูรณ์ (STRUCTURAL VARIATION ALONG HIGHWAY 12, AMPHOE LOM SAK, CHANGWAT PHETCHABUN) อ.ที่ปรึกษาโครงงานหลัก : ดร.สุคนธ์เมธ จิตรมหันตกุล, 54 หน้า.

ทางหลวงหมายเลข 12 (กม. 327-347) ตัดผ่านขอบแอ่งเพชรบูรณ์ฝั่งตะวันตกบริเวณอำเภอหล่มสัก จังหวัดเพชรบูรณ์ หินโผล่ที่ปรากฏตลอดเส้นทางแสดงความหลากหลายทางธรณีวิทยาโครงสร้างที่เป็นผลจากธรณีแปรสัณฐานตั้งแต่ยุคไทรแอสซิกจนถึงปัจจุบัน จากการสำรวจภาคสนามร่วมกับการแปลข้อมูลภาพดาวเทียม แผนที่ชั้นความสูง และแบบจำลองหินโผล่สามมิติ พบว่าด้านตะวันตกของพื้นที่มีหลักฐานชั้นหินตลบกลับของหมวดหินภูกระดึงร่วมกับรอยเลื่อนย้อน และรอยเลื่อนตามแนวระดับ ตอนกลางพบรอยเลื่อนปกติเกิดร่วมกับรอยเลื่อนแนวระดับแบบขวาเข้าในหมวดหินน้ำพอง และหมวดหินห้วยหินลาดตอนล่าง ด้านตะวันออกพบรอยเลื่อนปกติในหมวดหินห้วยหินลาดตอนบน โดยหมวดหินเหล่านี้วางตัวไม่ต่อเนื่องกับหินคาร์บอเนตยุคเพอร์เมียน

จากผลการศึกษาสามารถแบ่งวิวัฒนาการเกิดโครงสร้างได้เป็น 3 ช่วง คือ 1) ช่วงไทรแอสซิกตอนต้นเกิดแรงบีบอัดทำให้เกิดการคดโค้งของหินคาร์บอเนตที่สะสมตัวบนขอบด้านตะวันตกของอนุทวีปอินโดไชนา 2) ช่วงครีเทเชียสตอนปลาย ถึง อีโอซีนตอนต้น เกิดแรงบีบอัดในแนวเหนือ-ใต้ภายหลังจากที่หินตะกอนในกลุ่มหินโคราชสะสมตัวในพื้นที่ ทำให้เกิดรอยเลื่อนตามแนวระดับแบบขวาเข้า และยกขอบแอ่งเพชรบูรณ์ฝั่ง ตะวันตกขึ้นจากโครงสร้างแนวเหนือรูปดอกไม้บวกที่สัมพันธ์กับรอยเลื่อนย้อน และโครงสร้างรูปดอกไม้ลบคู่กับรอยเลื่อนปกติ 3) โอลิโกซีน ถึงปัจจุบัน สัณนิษฐานว่ากระบวนการกัดกร่อนเข้ามามีบทบาทสำคัญในพื้นที่

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

สาขาวิชา...........ธรณีวิทยา............ลายมือชื่อ อ.ที่ปรึกษาหลัก...

ปีการศึกษา.........2559....................

5632701523: MAJOR GEOLOGY

KEYWORDS: PHETCHABUN BASIN/ STRUCTURAL GEOLOGY/ STRIKE-SLIP FAULT/ FLOWER STRUCTURE

KASIDIS LHOSUPASIRIRAT : STRUCTURAL VARIATION ALONG HIGHWAY 12, AMPHOE LOM SAK, CHANGWAT PHETCHABUN. ADVISOR : DR. SUKONMETH JITMAHANTAKUL, 54 pp.

Highway 12 along km 327 to 347 cuts through the western margin of Phetchabun Basin, Amphoe Lom Sak, Changwat Phetchabun. The good quality outcrops shows the variation of structures were formed by Triassic to present tectonic activities. The objectives of this study are to create geological map and construct the structural evolutionary model via field investigation, geomorphology interpretation by DEM and satellite image and Digital Outcrop Model. The results found that overturned of Phu Kradung Formation that related to steep reverse faults are on the west of the study area. The middle part are dominated by normal faults associate with right-lateral strike-slip faults in Nam Phong and Lower Huai Hin Lat Formation while Upper Huai Hin Lat Formation only exposes in the eastern part of the road with normal faults.

Furthermore, the structural evolutionary model can be divided into 3 stages as follows: 1) Early Triassic: the Permian carbonate rocks were deformed on the west of Indochina block 2) Late Cretaceous – Late Eocene (N-S compression): Khorat Group completely deposited then strike-slip stress with right-lateral movement caused positive and negative flower structures that create the pop-up or uplifting of the western margin of Phetchabun Basin 3) Oligocene – Present: The tectonic zone of strike-slip was inactive but dominate by erosion.

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

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

Academic Year : .…2016………

Acknowledgements

I would like to give my appreciation to Dr. Sukonmeth Jitmahantakul who is my advisor for all best guidance and suggestions since I was a junior who is tracking my dream of the great geologist. I have learned not only the invaluable visions on research, studying and even on livelihood through 2 years works, but also many skills and knowledges that improved me a lot.

I would like to express my special thanks to Woravich Neumai (P'Big gun) for helping me collect field data. It was the great 3 days with my lovely brother.

I am very grateful to Assist. Prof. Dr. Thasinee Charoentitirat, Assoc. Prof. Dr. Pitsanupong Kanjanapayont, Dr. Kruawan Jankaew and another professor in the Department of Geology who gave me the opportunities to participate in various field during study here. It was one in a lifetime experience that developed my abilities, skills and knowledge.

I would like to extend my appreciation to my friend in team Aj.Au (Jiraphat Phetheet, Suwadee Jirarachwaro and Thanyaporn Panyapradit) and GEO'57 that moving together in all works. We have done the great job and it would be my best memories of having you.

I also would like to thank Science Achievement Scholarship of Thailand (SAST) who support all my expenses during 4 years of studying in Chulalongkorn University

Finally, my deepest gratitude goes to my family and my girlfriend for encouraging and support everything in my life.

List of contents

Content	**Page**

List of figures

Figure		Page

List of tables

Chapter 1 Introduction

1.1 Introduction

Changwat Phetchabun has a complex geology caused by the various phases of tectonic activities through the times. The mountain ranges of the Khorat Plateau lie northwardly on the east of the Phetchabun basin that located between Phetchabun mountain ranges. Phetchabun basin is one of Tertiary inter-mountane basin on Loei-Phetchabun Fold and Thrust belt on the Indochina Block (Searle & Morley, 2011).

The origin of the Tertiary basin in Thailand was believed to be pull-apart by the intersection of three major strike-slip faults, oriented in NE-SW, NW-SE and N-S trending. The evidences were proved by satellite image interpretation, airborne geophysical data and seismic data, but their sense of movements still in researching (Charusiri & Pum-im, 2009). Otherwise, some basins are thought to be a rift basin, Suphan Buri, Ayutthaya, Phitsanulok and including Phetchabun basins, because they appear to be a predominantly extensional basin (Morley, Searle, et al., 2011). From all above, the study of structural variation of outcrop nearby Phetchabun Basins may improve the understanding of the tectonic evolution during the age of Cenozoic.

The study area was defined to the edge of the Phetchabun Basin along highway 12, Khao Kho – Lom Sak (km 327+750 to 347), (Fig 1.1 & 1.2) which pass through the western Phetchabun mountain ranges. Recent road construction exposed magnificent E-W road-cut sections while the structures mainly are N-S trending. In addition, this work can enhance the geological map Phetchabun in part of structures. Because of the currently geological map that published by DMR in 2009 demonstrates the distribution of the Khorat Group with poor structures.

Thus, the objective of research are to determine the structural variation in the study area to interpret the geological map reasonably and create the structural evolutionary model of the western margin of Phetchabun Basin.

1.2 Objectives

1) To create geological map along Highway 12 (km 327+750 to 347) Khao Ko – Lom Sak, Phetchabun
2) To construct structural model and understand its implication for regional tectonic evolution

1.3 Scope of the research

This research focus on the structures of the rocks by observing 4 main outcrops along highway 12 (km 327+750 to 347) Khao Ko – Lom Sak, Phetchabun. The lithostratigraphies have been made to classify the lithology of rock and correlation. Otherwise, the age-dating and biostratigraphy are not applied in this field.

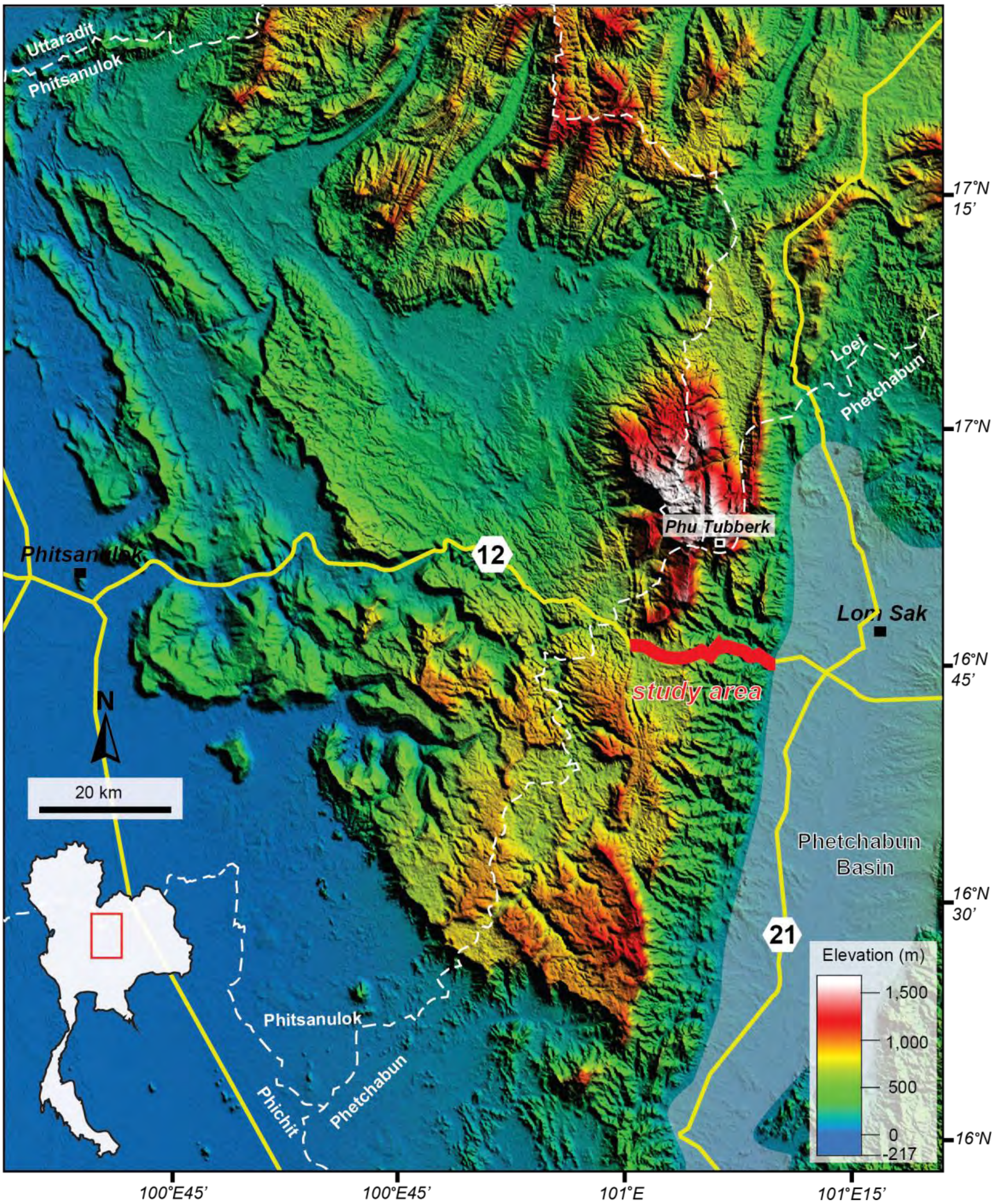

Figure 1.1 Digital Elevation Map (DEM) of western margin of Phetchabun Basin with study area along highway 12 (km 327+750 to 347).

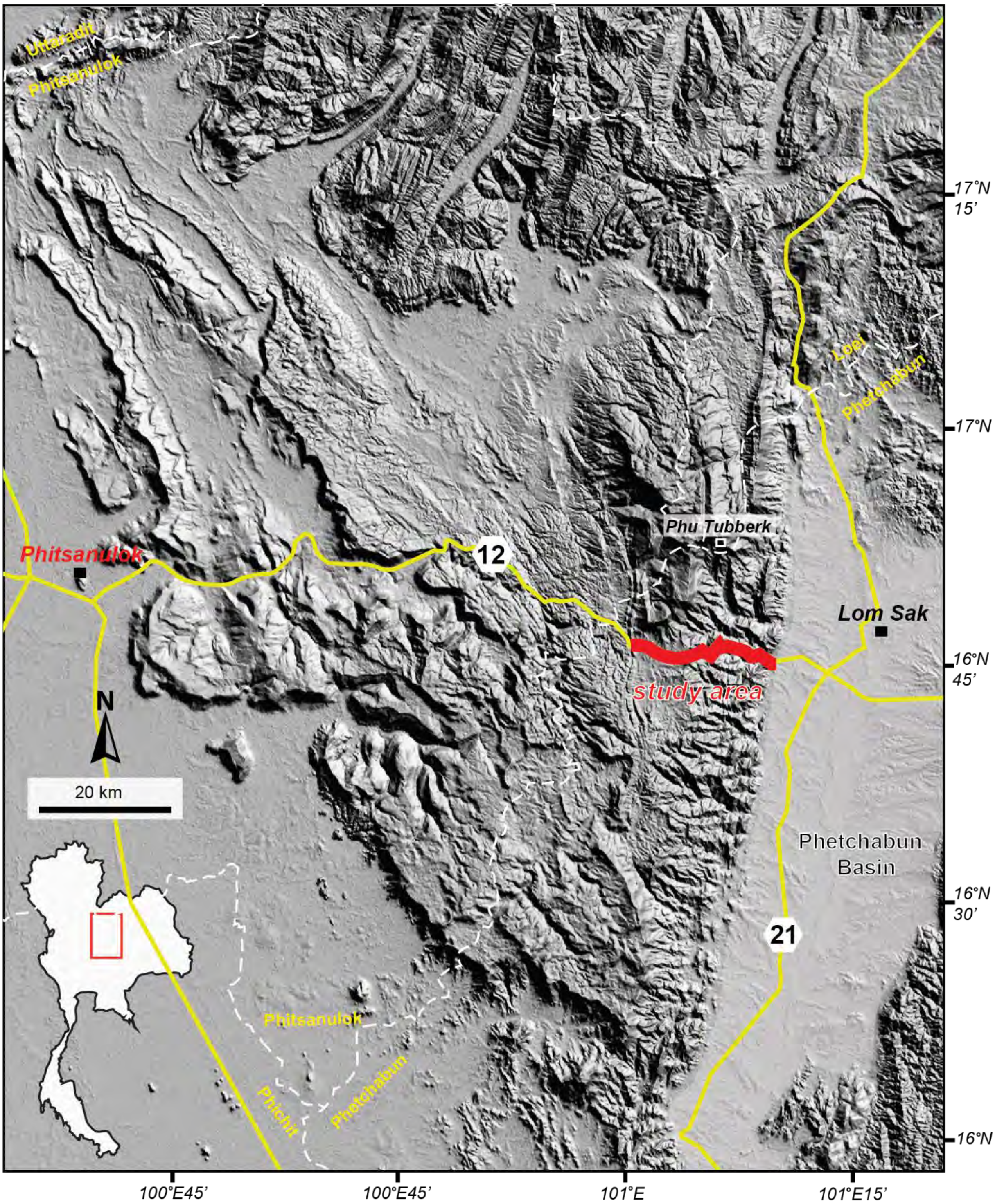

Figure 1.2 Hillshade map of western margin of Phetchabun Basin with study area along highway 12 (km 327+750 to 347).

Chapter 2 Geological background

2.1 Tectonic setting

Thailand is composed of two major sub-continents, the Indochina and Sibumasu Terranes, which collided during the Indosinian Orogeny after the subduction of the Paleo-Tethys Ocean during the Devonian-Triassic (Sone & Metcalfe, 2008). Two suture zones along the collision area have been recognized parallel on N-S trending, indicator of former plate margins (Fig 2.1). In Late Triassic, the continent-continent collision of Sibumasu Terrane and Sukhothai Arc of the western Indochina Terrane formed a major mountain range on N-S trending, known as Indosinian Orogeny I, was built and is associated with what is known as the Main Range (Fig 2.1).

The Palaeo-Tethys started spreading during the Middle Devonian (Fig 2.2). Then the Palaeo-Tethys subducted under Indochina likely started in the Late Carboniferous or Early Permian and formed a magmatic arc along the Indochina Terrane's margin called Sukhothai island-arc. The back-arc basins were still opening during the Early Permian. Atop the western Indochina Terrane, an extensive system of carbonate platforms, including the Saraburi limestone in Thailand, developed in the back-arc basin during the Early to Middle Permian. These carbonate platforms were uplifted in the Late Permian, which was the main phase of back-arc compression. The Sukhothai island-arc was consequently amalgamated to become part of the Indochina margin. The Palaeo-Tethys seafloor continuously subducted beneath the Sukhothai Arc so that seamounts carrying Carboniferous - Permian limestone caps accumulated over the subduction zone during the Early - Middle Triassic. After that, orogenic plutonism occurred in the western Indochina Terrane. During the Late Triassic, the Sibumasu Terrane collided with the Sukhothai Arc of the western Indochina Terrane built a major mountain range (Indosinian Orogeny). In the latest of the Triassic, the Sukhothai Arc magmatism inactive by the last of Palaeo-Tethys subduction (Sone & Metcalfe, 2008).

A series of Late Triassic half-graben basins developed across NE Thailand and were filled with lacustrine - fluvial sediments formed Huai Hin Lat Formation. Then the Indosinian II Orogeny occurred after deposition of the Huai Hin Lat Formation and created regional unconformity at the bottom of Triassic Nam Phong Formation. The Indosinian III unconformity followed the end of Triassic is indicated between the Lower and Upper Nam Phong formations (Racey, 2009). The Upper Nam Phong Formation is the lowermost formation of the Khorat Group, which comprises mostly fluvial - alluvial sediments included the Phu Kradung, Phra Wihan, Sao Khua, Phu Phan and Khok Kruat formations. The Khorat Group is dated as Late Jurassic to Cretaceous. Maha Sarakham and Phu Tok Formation were separated from the Khorat Group by a regional unconformity created by the Mid - Cretaceous inversion. This inversion drove the development of the Phu Phan Uplift in the NE Thailand (Racey, 2009).

During the Eocene to Neogene, the Himalayan Orogeny ,which is a collision between India and Eurasia, caused extensional dextral movement and also resulted in regional uplift and the inversion of the Khorat Plateau, NE Thailand. The dextral strike-slip motion may rotated clockwisely Khorat Plateau. Thus, Khorat Basin's position may not reflect its original relative geographical location (Racey 2009). Although, the sinistral movement of strike-slip fault such as Mae Ping and Three Pagodas strike-slip faults was proved. Strike-slip faults possibly formed a transpressional system during the Palaeogene, composed predominantly of north-south to NW-SE trending faults that were unrelated to escape tectonics (Morley et al., 2011)

In the Late Oligocene-Early Miocene, the major structural trends are north-south to NW-SE trending strike-slip faults that dominated by dextral strike-slip. These strike-slip fault resulted a basin that was believe to be pull-apart basin in the West which were formed at the north-south trending releasing bends (Morley et al., 2011). Then the principal horizontal stresses rotated clockwisely during the Oligocene and Early Miocene and resulted in a strike-slip deformation becoming significant. During the late Miocene and the present, the tectonic setting in Thailand changed from being dominated by extension to reactivation of strike-slip faults. (Morley et al., 2011).

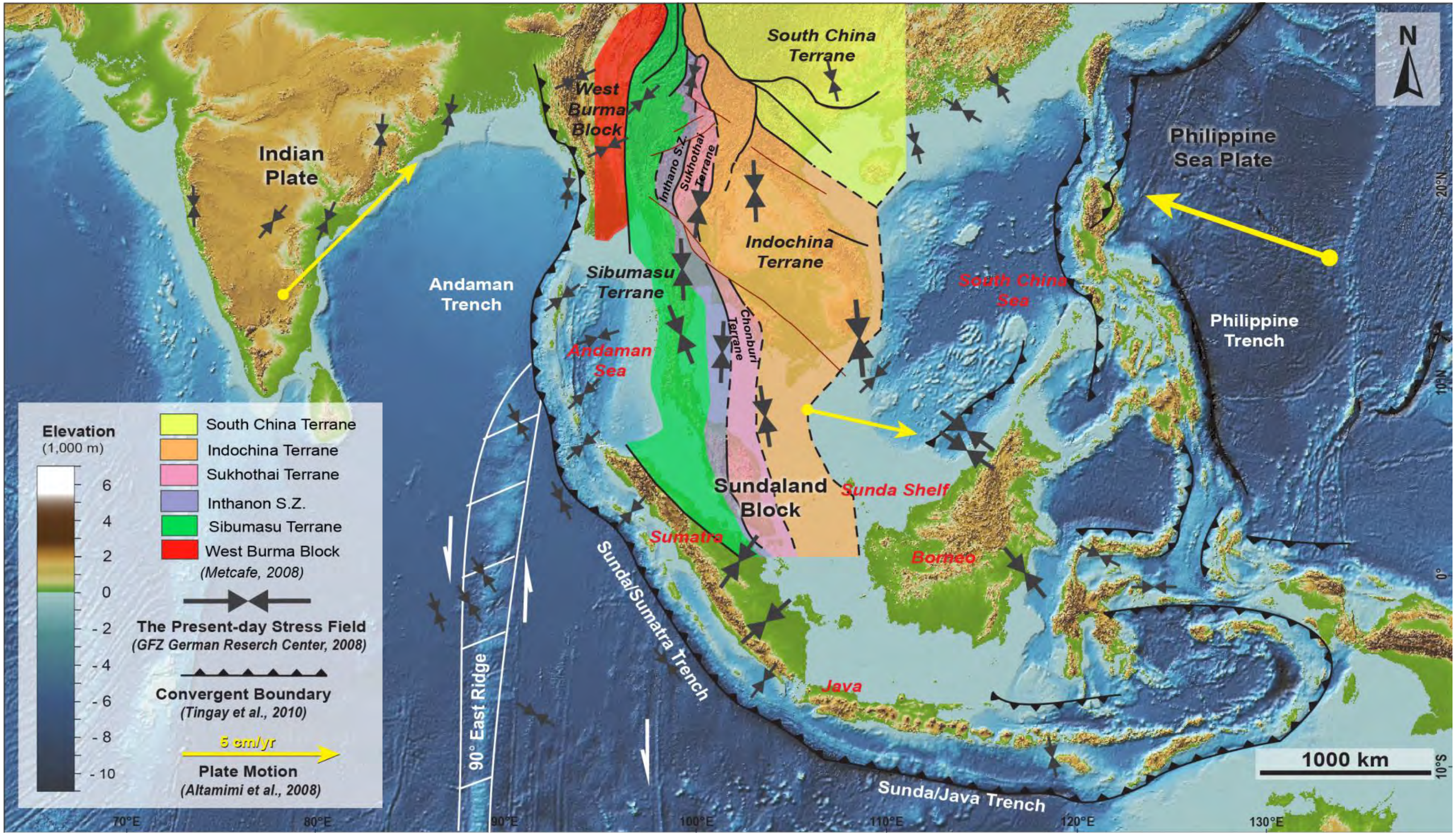

Figure 2.1 Topography of SE Asia and tectonic motions of plate overlay with tectonic subdivision of mainland SE Asia Sundaland. (Modified from Metcalfe, 2013; GFZ German Research Center, 2008; Heidbach et al., 2010 and Altamimi et al., 2008)

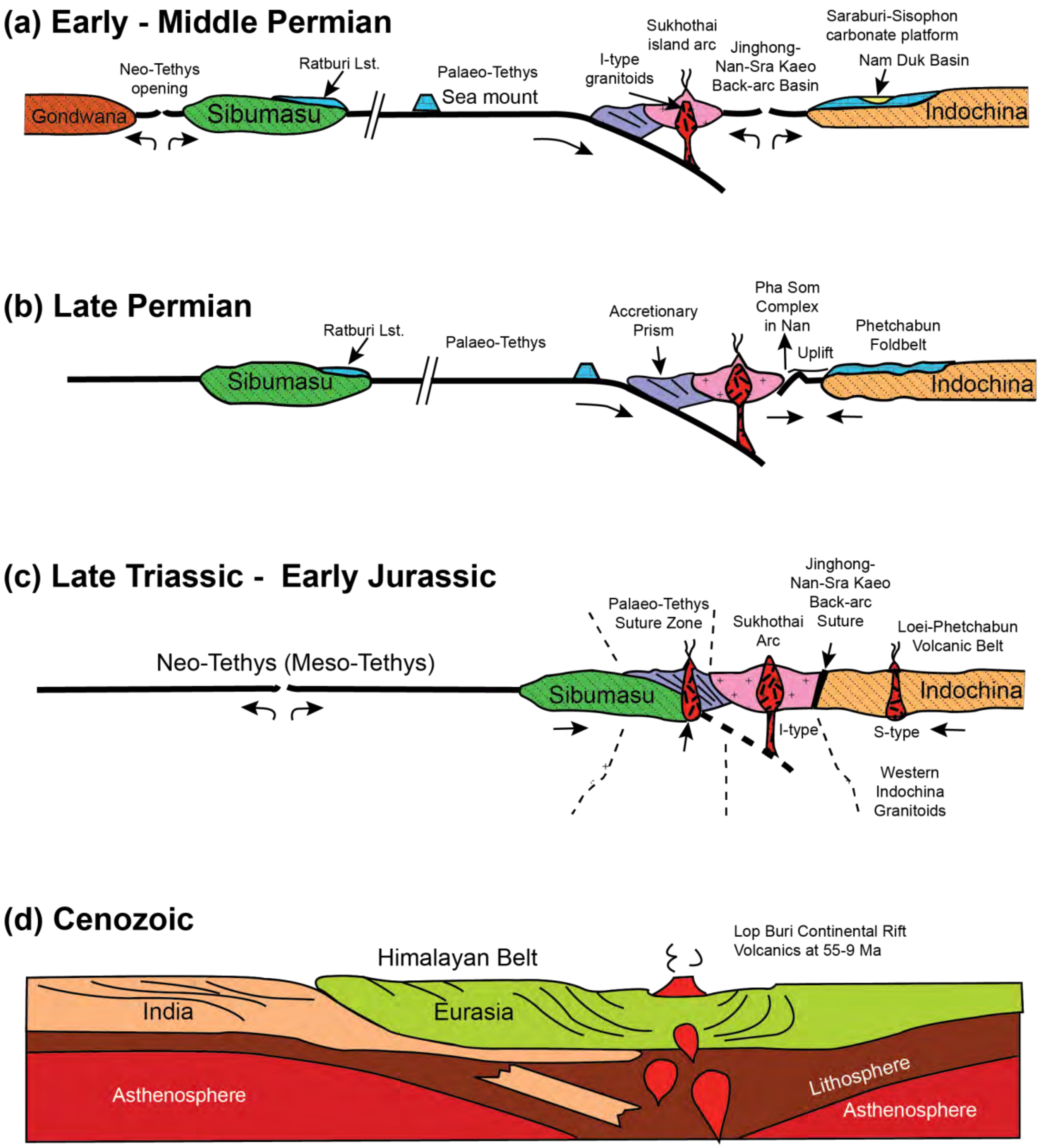

Figure 2.2 Tectonic evolution of Mainland SE-Asia during the Late Paleozoic-Cenozoic. (Modified from Prueksarat, 2011 after Sone & Metcalfe, 2008 and Intasopa, 1993).

2.2 Geology of the study area

The Phetchabun Basin is one of 30 significant Tertiary basins identified in Thailand (Remus et al., 1993). It formed as elongated half grabens on N-S trending and is filled with alluvial, fluvial and lacustrine sediment of Late Oligocene to Holocene age (Polachan et al., 1991). The tertiary basins are discussed on the origin that associated with conjugation of right lateral movement on the NW-SE trending Mae Ping and Three Pagodas faults and left lateral movement along a NNE-SSW trending (Polachan & Sattayarak, 1989).

Phetchabun Basin comprises five grabens located within a narrow, elongate (30 km by 120 km) intermontane rift (Fig 2.3). By the data of seismic interpretation, the grabens are bounded by steep normal and listric faults. NE-SW strike-slip fault may separate the graben. Internally, the extensional faulting are commonly shown with wrench faulted features. (Remus et al., 1993)

Geological map from Department of Mineral Resources defines the rocks in the study area into 2 main formations (Khaowiset & Chanfoo, 2009) (Fig 2.3). Huai Hin Lat Formation (TRhl) most exposes eastwardly of the area. The age of deposition is Late Triassic, during Carnian-Norian, by the dating of its plant remnant (Konno & Asama, 1973), Pollen and spores (Haile, 1973) and also vertebrate faunas. The fossils such as fish fragment, turtle, amphibian and reptile support the interpretation of depositional environment that Huai Hin Lat Formation has been deposited in fault-bounded basin in slightly humid to semiarid conditions or Fluvial-lacustrine (Chaodumrong, 2013)

Huai Hin Lat Formation composes of 5 members as following from top to bottom (Chonglakmani & Sattayarak, 1978);

- ***Mo Member***: grey sandstone, shale and limestone associated intermediate volcanic rocks
- ***Phu Hi Member***: grey sandstone, shale and argilleceous limestone intercalations with conglomerate bed
- ***Dat Fa Member***: grey to black caboneceous, calcareous well bedded shale and argilleceous limestone
- ***Sam Khaen Conglomerate Member***: Comglomerate intercalation with fine sediment
- ***Pho Hai member***: mainly tuff, agglomerate, rhyolite and andesite with some intercalations of sandstone mudstone and conglomerate.

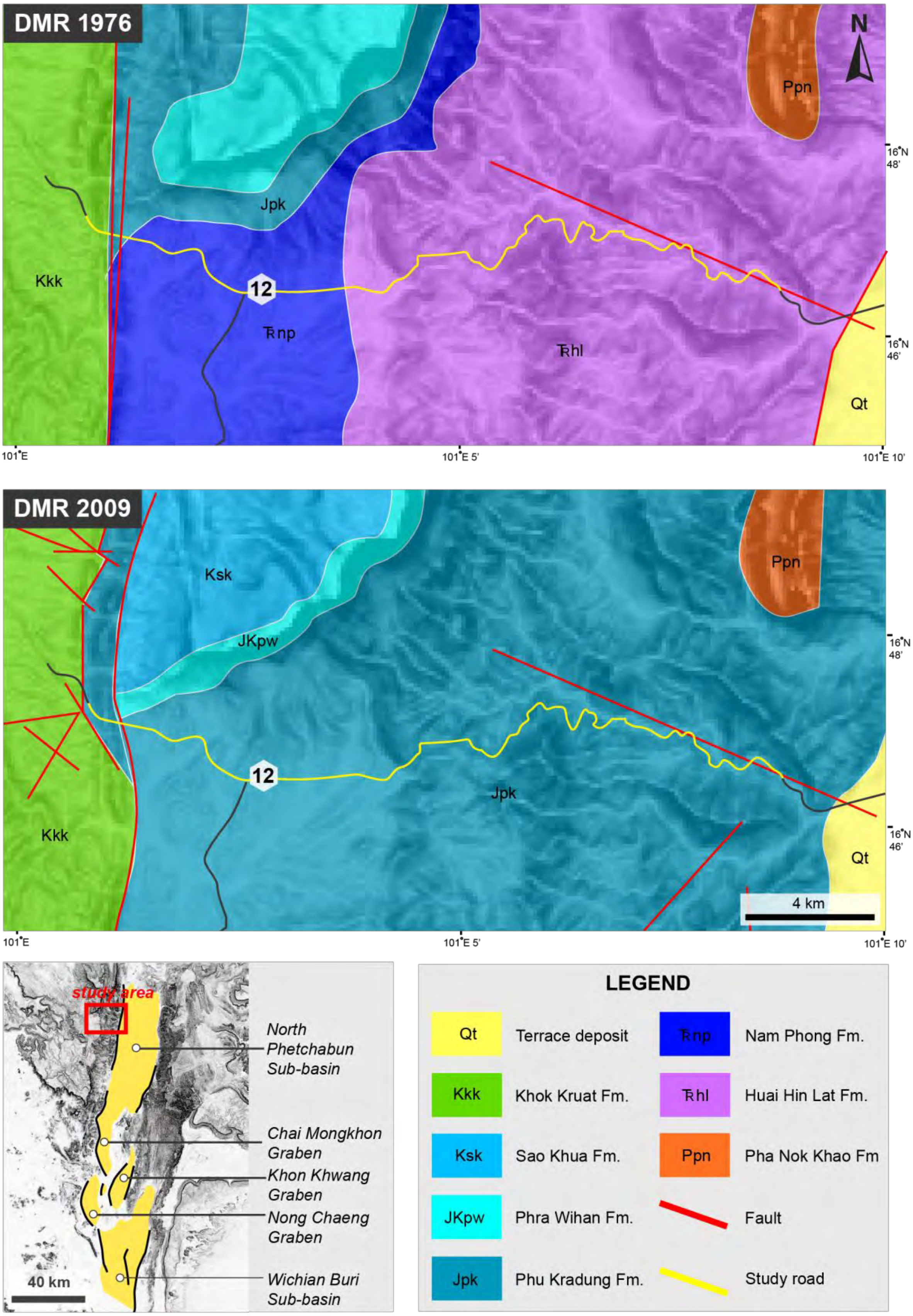

Figure 2.3 Geological map by Department of Mineral Resources (Chonglakmani & Satayarak, 1979; Khaowiset & Chanfoo,2009) along highway 12 in study area in different version were improved during the time.

Nam Phong Formation is widely accepted as the lower unit of the Khorat Group, which overlies unconformably The Late Traissic Huai Hin Lat Formation. It contains of resistant red-brown micaceous sandstones, conglomerate, siltstone and mudstones of mainly fluvial depositional environment (Chaodumrong, 2013). By the seismic interpretation, the Nam Phong Formation can be divided into two units; the Lower Nam Phong and the Upper Nam Phong Member (Booth & Sattayarak, 2011). The distribution of the Nam Phong Formation indicates the beginning of a different tectonic setting. This caused the great variety of depositional environments; debris flow, alluvial fans, braided, meander, oxbow lake and mud flat. The limestone clast in conglomerate weathered from Permian limestone below. Erosion of Permian limestone, most probably in the Loei-Phetchabun fold and thrust belt. In the same way, the Geological Map from DMR recently shows no exposure of the Nam Phong Formation in the study area (Heggemann & Landesamt, 1994).

Phu Kradung Formation predominantly presents maroon siltstone, claystone and sandstone with greenish-grey calcareous conglomerate (Chaodumrong, 2013). Bone fragments and teeth were found and dated the age to Middle to Upper Jurassic. Ward and Bunnag (1964) described the Phu Kradung Formation at its type locality as comprising of the lower beds of calcareous siltstone intercalated with 1-5 cm thick beds of limestone and the upper beds comprising of grayish brown siltstone. The upper beds underlie white massive sandstone of the Phra Wihan Formation. The formation consists of reddish purple siltstone, mudstone, sandstone, and conglomerate. Calcrete nodules, caliches and nodular silcretes are found on top of mudstone. Beds of light gray sandstone with 5-10 m thick are locally intercalated.

The rocks show fluvial depositional environment (especially meandering river) by fining upward sequences from the bottom of conglomerate and channel sandstone to crevasse-splay facies and floodplain at the top (Fig 2.4). The formation in northern Khorat Plateau expose comformably to the Upper Nam Phong Formation at the lowest unit of the Khorat Group while The Phu Kradueng Formation overlay on the Permian rocks unconformably on the southern Khorat Plateau.

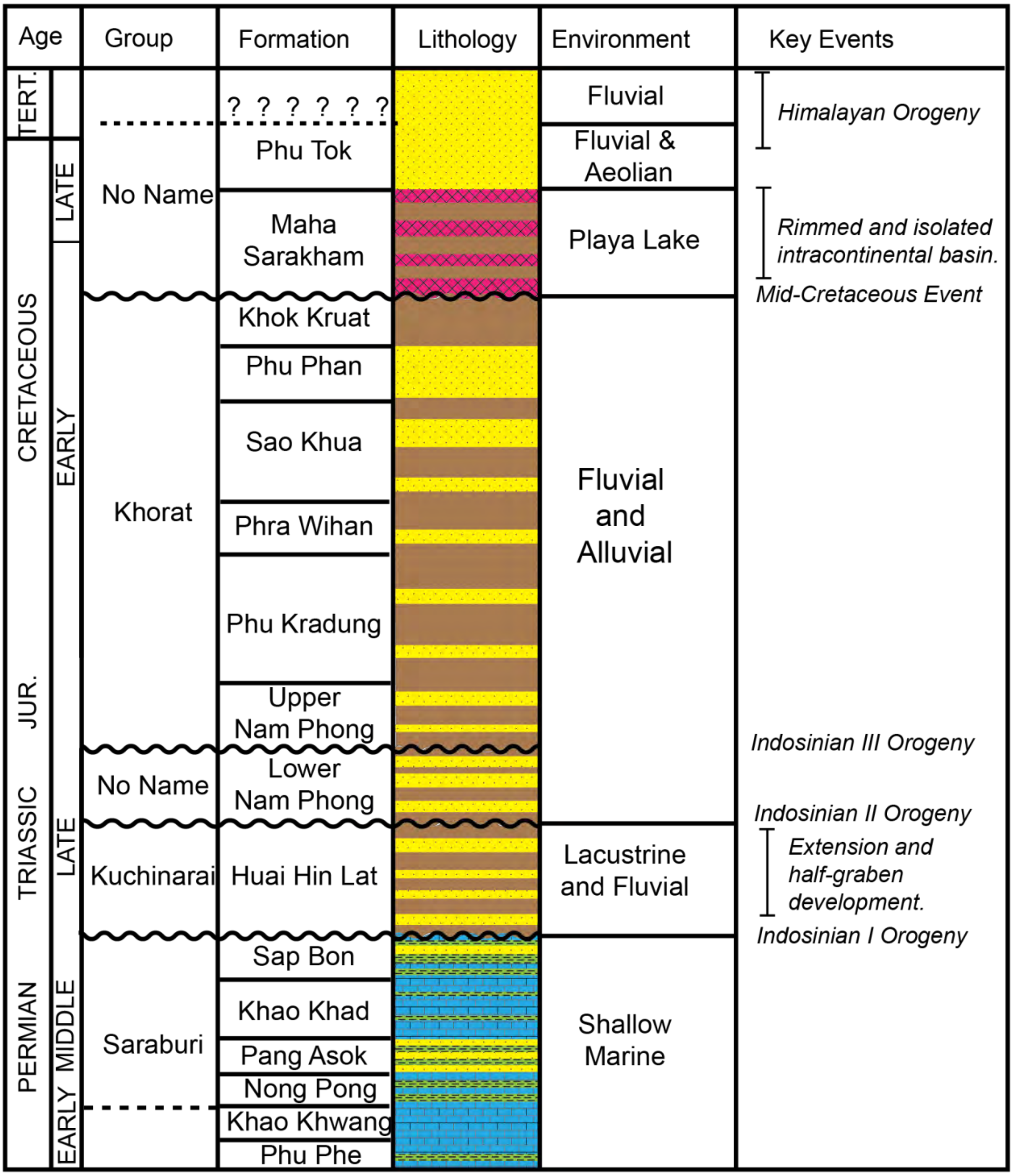

Figure 2.4 Modified stratigraphic column of Mesozoic of central Thailand with the main tectonic events and depositional environments. (modified from thesis of Prueksarat in 2011) (after Hinthong, 1985; Racey, 2009; Booth & Sattayarak, 2011)

2.3 Tectonic related structures

On a regional scale, tectonic stress related to plate movements and plate tectonics as illustrated in figure 2.5. Anderson’s classification of tectonic stress is the traditional classification of tectonic stress regimes into normal, thrust and strike-slip regimes (Fig 2.6). Therefore, the tectonic process at plate margins are thought to have a significant influence on the regional stress pattern. Structures are the result of stress deforms rocks in different ways depend on many conditions. Geologist classifies structures into 2 main types

2.3.1 Fold

The formation deforms under ductile condition of the rocks (under the failure envelope of Mohr-Culomb diagram) caused a vary kind of bending. In general, folds are made up on a hinge that connects two limbs which mostly differently oriented (Fig 2.7). Classification of folds relative to hinge curvature, folds can be separated to kink bands and chevron folds with sharp and angular folds or well-rounded hinges of concentric folds. A spectrum of hinge shapes exists, from the pointed hinges of kink bands and chevron folds (sharp and angular folds) to the well-rounded hinges of concentric folds (Fig 2.7).

2.3.2 Fracture

Once the differential stress in an unfractured rock exceeds a certain limit to the brittle regime as strain-time curve, however, the rock will deform by fracturing once its rupture strength is reached. It can be classified into 2 types upon different criteria.

- **Experimental classification (Stearns & Friedman, 1972)** (Fig 2.8b)
  - ***Shear fractures***

The shear fracture or slip surface is a fracture along which the relative movement is parallel to the fracture. The term shear fracture is used for fractures with small (mm- to dm-scale) displacements, while the term fault is more commonly restricted to discontinuities with larger offset.

  - ***Extensional fractures***

Extensional fracture are fractures that show extension perpendicular to the walls. Joints have little or no macroscale detectable displacement, but close examination reveals that most joints have a minute extensional displacement across the joint surfaces, and therefore they are classified as true extension fractures. Extension

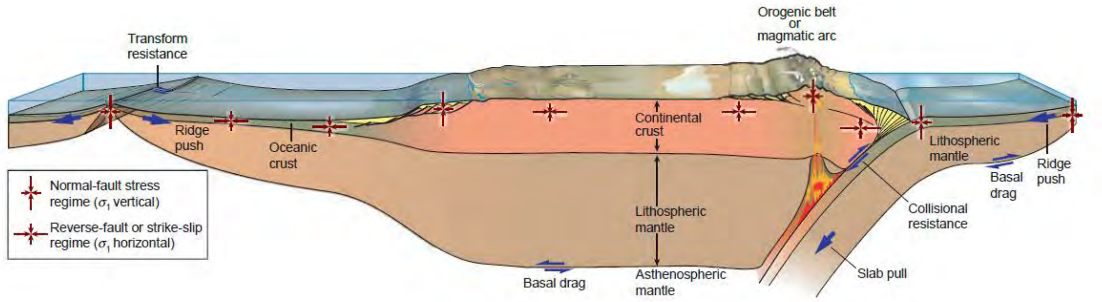

Figure 2.5 Plate tectonics (blue arrows) relates to forces and stress regimes expected from these forces. (Fossen, 2010)

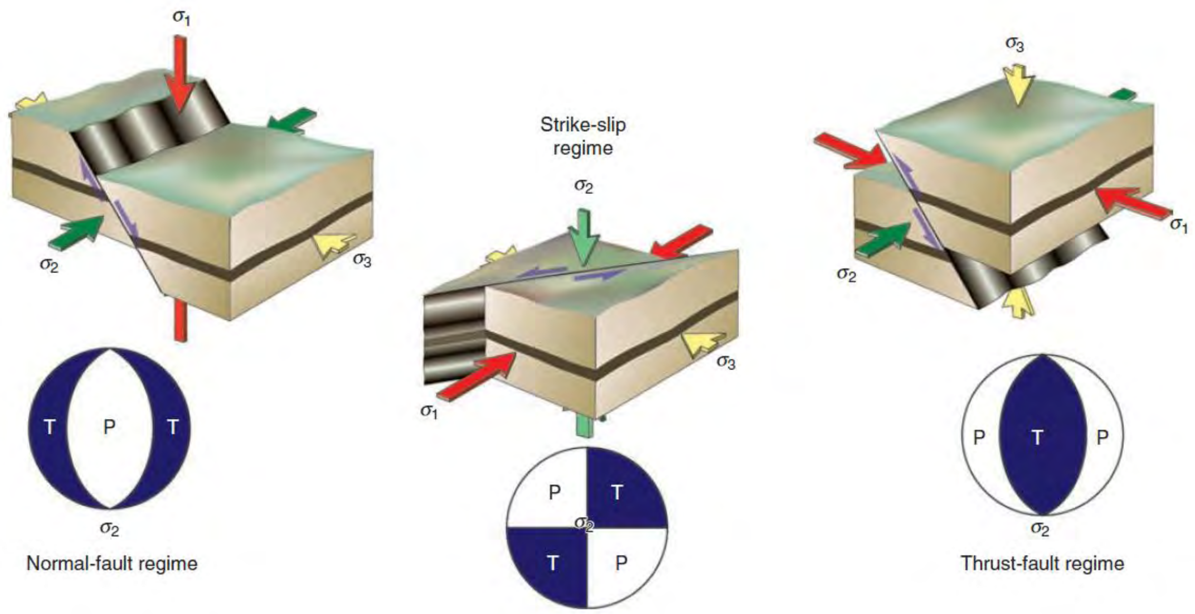

Figure 2.6 Relationship between the orientation of the principle stress and tectonic regimes according to Anderson (1951). Stereonets show fields of compression (P) and tension (T) of normal-fault, strike-slip and thrust-fault regime (Fossen, 2010).

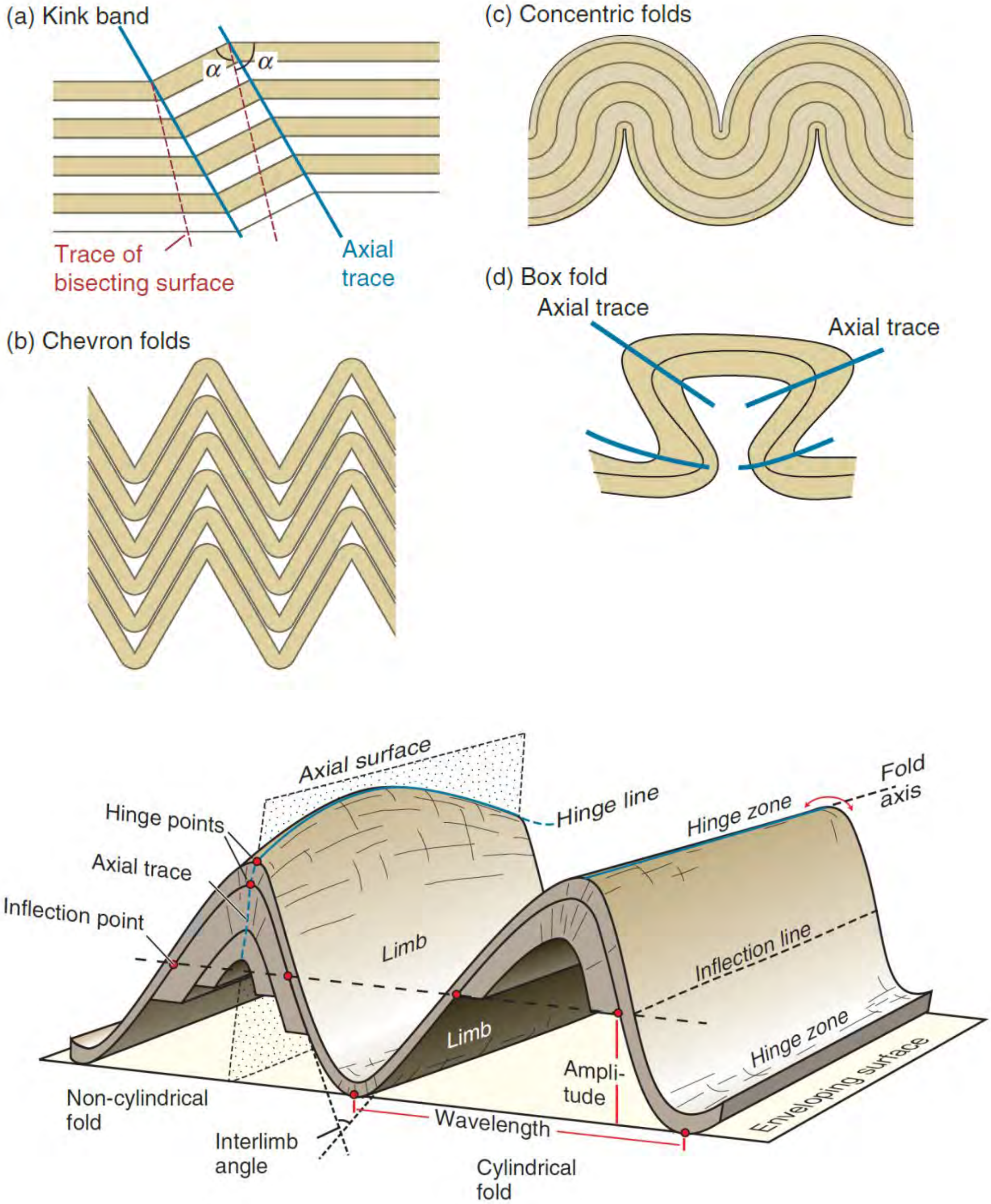

Figure 2.7 Classification of folds relative to hinge curvature a) kink band b) chevron folds c) concentric folds d) box fold. (below) Geometric aspect of fold. (Fossen, 2010).

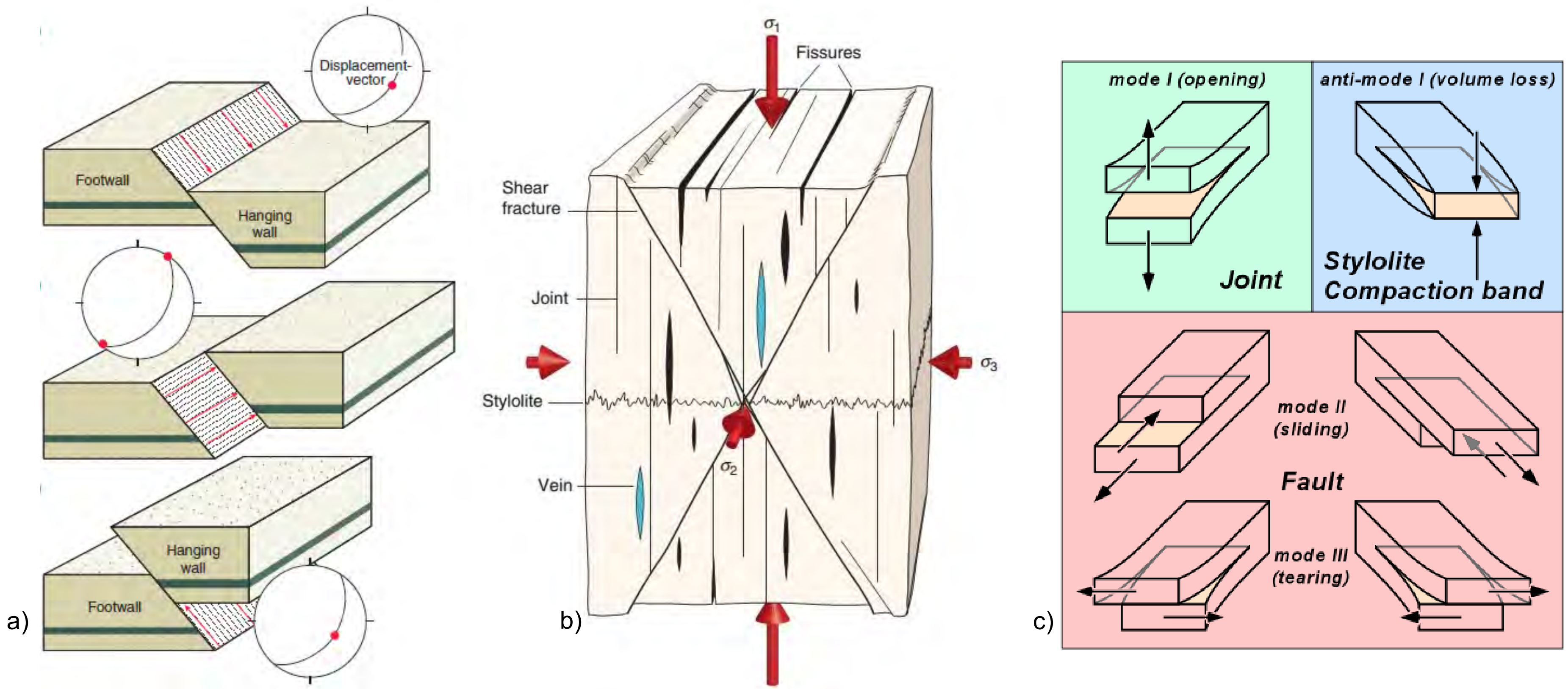

Figure 2.8 (a) The classification of Normal, strike-slip (sinistral) and reverse faults. The stereonet shows the fault plane (great circle) and the displacement vector (red point). (b) The orientation of various fracture types with respect to the principal stresses. (c) mode of fracture classification according to fracture displacement mechanism. Graphic downloaded from http://www.naturalfractures.com/1.1.1.htm in May 2017.

fractures are filled with gas, fluids, magma or minerals. When filled with air or fluid we use the term fissure. Mineral-filled extension fractures are called veins, while magma-filled fractures are classified as dikes. Joints, veins and fissures all refer to extension fractures.

- **Modes of fracture classification**

In the field of fracture mechanics, it is common to classify the displacement field of fractures or cracks into three different modes (Fig 2.8c).

- **Mode I: opening (extension)**

Mode I is the mode where displacement is perpendicular to the walls of the crack.

- **Mode II: sliding**

Mode II represents slip (shear) perpendicular to the edge

- **Mode III: tearing**

Mode III involves slip parallel to the edge of the crack. Modes II and III occur along different parts of the same shear fracture. Combinations of shear (Mode II or III) fractures and tension (Mode I) fractures are called hybrid cracks or fractures.

- **Mode IV: closing**

Mode IV is sometimes used for contractional features such as stylolites. The mode of displacement on fractures is an important parameter, for instance, when fluid flow through rocks is an issue.

Chapter 3 Methodology

3.1 Overview

3.2 Field study

3.3 Laboratory analysis

3.4 Discussion

3.6 Conclusion

The research methodology can be divided into 5 main parts: pre-field study, field study, laboratory analysis, discussion and conclusion (Fig 3.1).

3.1 Overview

Previous reports were reviewed particularly in Structural Geology, Tectonics and Stratigraphy of Khorat Group. Moreover, the program and the method which necessary in this field were praticed and tested. For examples Agisoft PhotoScan, Stereonet, Win-tensor, ArcMap and illustrator.

Remote sensing was applied to observe geomorphology by using Landsat 8 satellite images and Digital Elevation Model (DEM) (Fig 3.2a). The images were composed into 2 band composition which are false color (7 6 4) and Land-water (5 6 4) (Fig 3.2b,c) to classify the object distinctively.

3.2 Field study

Four road-cut outcrops were mapped and geological information documented by taking photo, sketching structures, taking structural related orientation measurements and collecting samples at representative stations for laboratory analysis.

The photos were taken perpendicular to outcrop every two meters to create Digital Outcrop Model (DOM) through software. Any important spots were recorded the coordination, elevation and thickness as a marker.

At individual measurement stations, the following geological information was recorded; rock type, lithology, sedimentary structures, bedding and fracture style, fault plane with slicken line orientation, sense of movement, joint, vein, fold, were measured and detailed fracture data ware noted. These measurements were used to determine the deformation and Paleo-stresses.

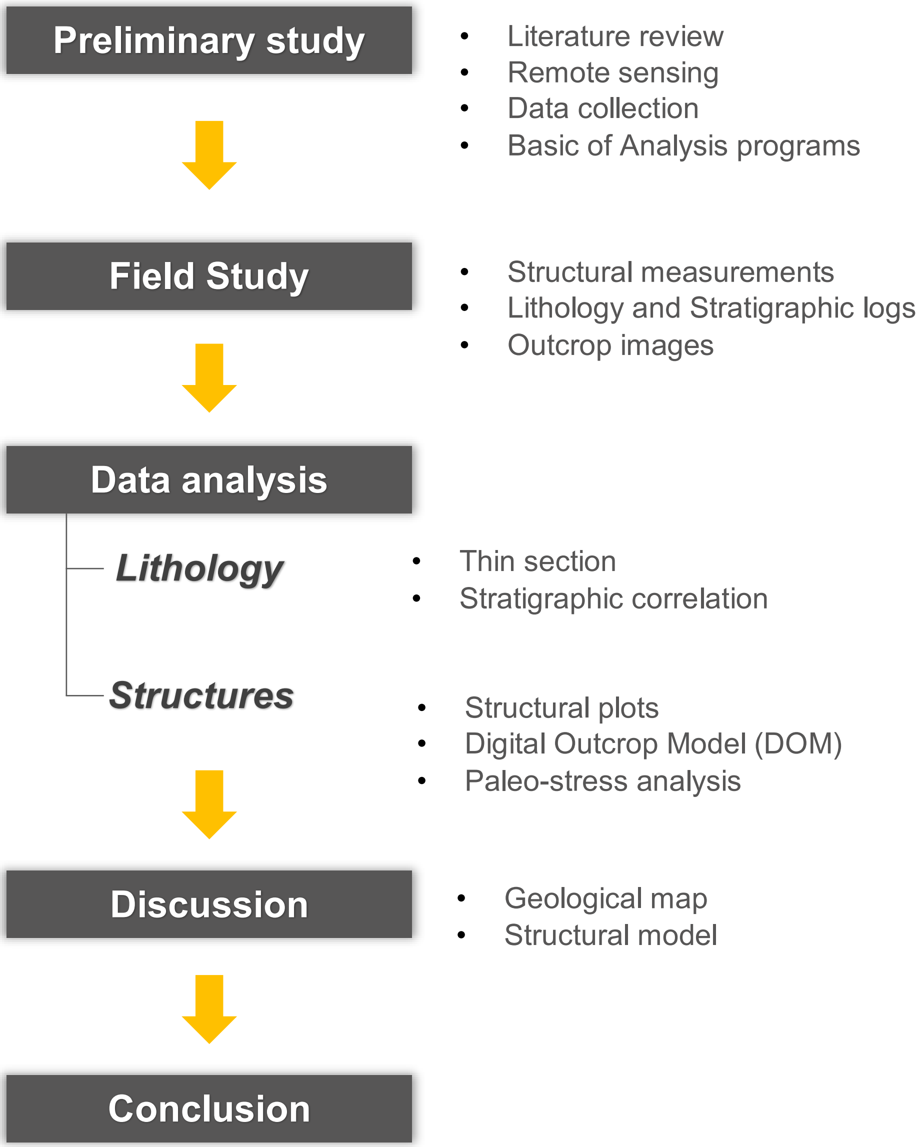

Figure 3.1 Research's work flow.

Figure 3.2 Digital Outcrop Model (DOM) is a 3D surface of outcrop created by using perpendicular-shots of outcrop that have same points between attached pictures. a) Point cloud from the same point the different pictures b) Photoscan user interface outcrop after meshing. c) 3D surface overlay by texture is an output of the technique.

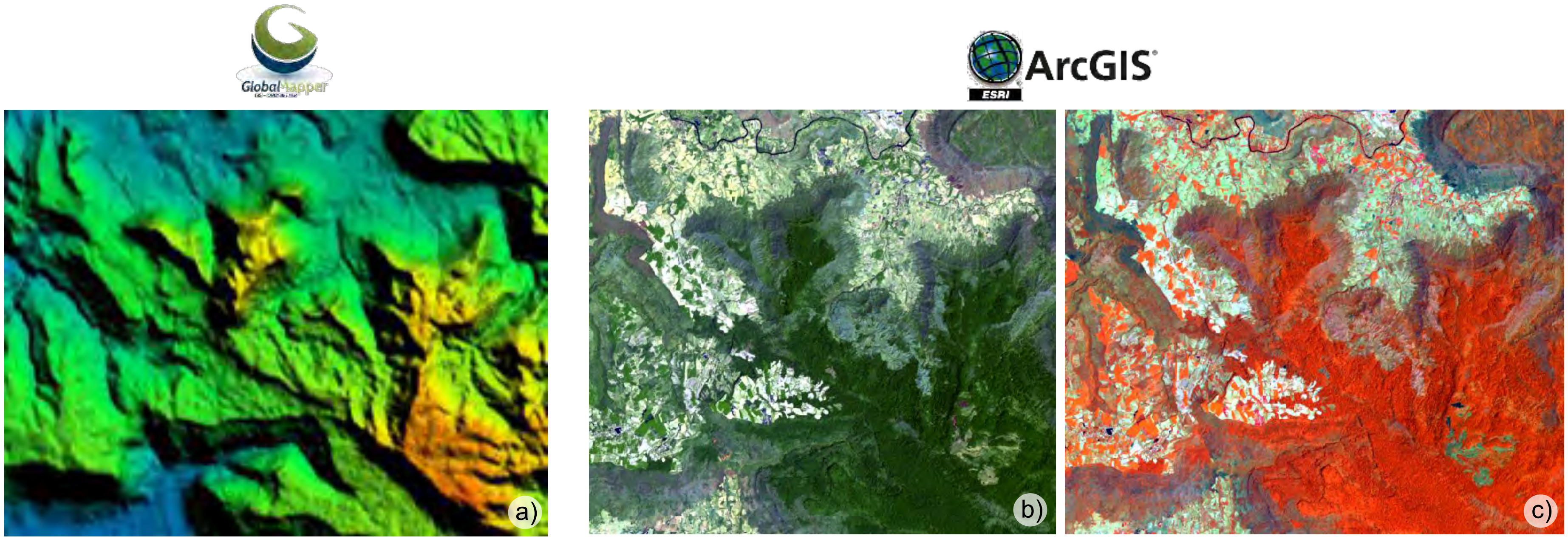

Figure 3.3 Remote sensing tools a) Digital Elevation Model (DEM) helps the interpretation of regional structures more accurate by using Global Mapper b) Satellite images from Landsat 8 are composed as false color (764) and c) Land-water separation band (564) increases the effectiveness of Geomorphology interpretation through ArcGIS.

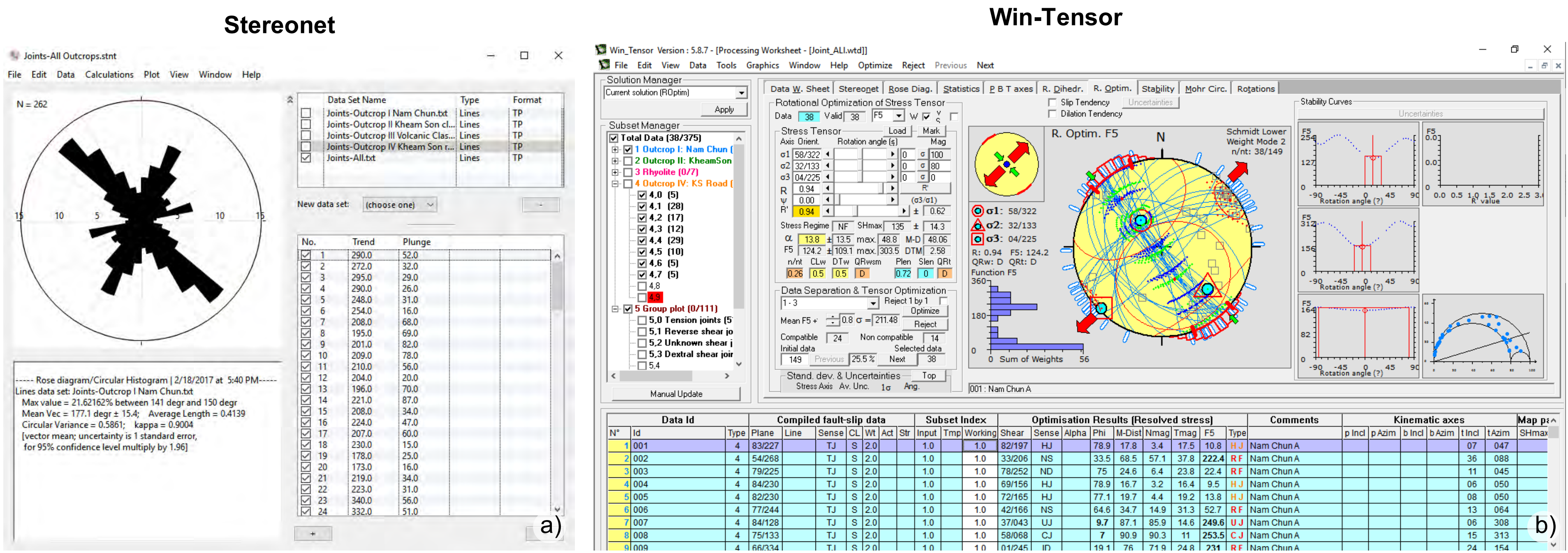

Figure 3.4 Structural analysis programs a) Stereonet can plot any kind of structural for descriptive interpretation b) Win-tensor can calculate the Paleo-stress through the structure such as fault planes, open fractures or shear fractures.

3.3 Laboratory analysis

All field data were analysed into two parts as follows; structural analysis and lithology.

3.2.1 Structural analysis

- All measured field data, mostly fracture and fault geometries, were plotted in stereonets and Wintensor was used for paleo-stress analysis of fault/fracture kinematic data (Fig 3.4).

- Photos were imported to Agisoft PhotoScan and placed the markers before building dense cloud and mesh. Then export 3D surface to MOVE 2016 to analysis the fault plane, fault displacement, joint and fracture.

3.2.2 Lithology

Representative rock samples were chosen for thin sectioning to classify the type and formation of rocks.

3.4 Discussion

3.4.1 Geological map

Detailed geological map along Highway 12 (km 327+750 to 347) Khao Ko – Lom Sak prefer the distribution of rock and particular structures that relate to regional tectonic of western Phetchabun Basin

3.4.2 Structural Model

Block diagram or 4D (3D+time) models that derive by the structural analysis, stratigraphy correlation and tectonic interpretation explains the structural evolution through time of the western margin of Phetchabun Basin

3.5 Conclusion

Summary of tectonic evolution related to the structural style of the western margin of Phetchabun Basin. Furthermore, the concept can be applied in futher research.

Chapter 4 Results

From the field investigation, the study area can be defined the lithology and structures through outcrops as the road map in figure 4.1. There are 4 outcrops were studied the detail as follows from the east to the west;

Outcrop I: Nam Chun (Fig 4.2) located in the most eastern part of the study area. It can be found various types of sedimentary rocks with low existing structures such as faults or folds.

Outcrop II: Kheam Son Clift (Fig 4.3) located in the center of the study area. The highlights of this outcrop are strike-slip faults and listic faults with some reverse faults.

Outcrop III: Pha Sorn Kaew (Fig 4.4) is next to Kheam Son Clift to the west about 100 meters. The vertical fractures mainly expose along the outcrops. Although, the rock's variety is not high.

Outcrop IV: Kheam Son Road (Fig 4.5) is in the westernmost of the road. It has important structures such as steep reverse faults, shear joints and overturned strata which be observed by sedimentary structures (ripple marks, desiccated cracks and bioturbation molds).

The details of each outcrop can explain as follows;

4.1 Lithology

The rocks in study area dominate in bedded sedimentary rocks of sandstone, siltstone, claystone, shale, conglomerate and some of the volcanic clastic rock of agglomerate in the central part of the road. The lithostratigraphic columns of the outcrop are created as illustrate in figures 4.2-4.5.

4.1.1 Sandstone

From east to west, there are different characteristics of sandstone in outcrops.

- ***Greenish grey sandstone*** can only be found in outcrop I: Nam Chun as thick beds interbedded with thin yellowish shale on the most eastern part of outcrop. its thickness is approximately 3 to 150 cm. The normal grading of fine to very coarse sand (Fig 4.2b), which shows in many beds, confirms non-overturned strata. Thin-sections (Fig 4.2a) show the low-maturity mineral grains, olivine, plagioclase and mica etc.

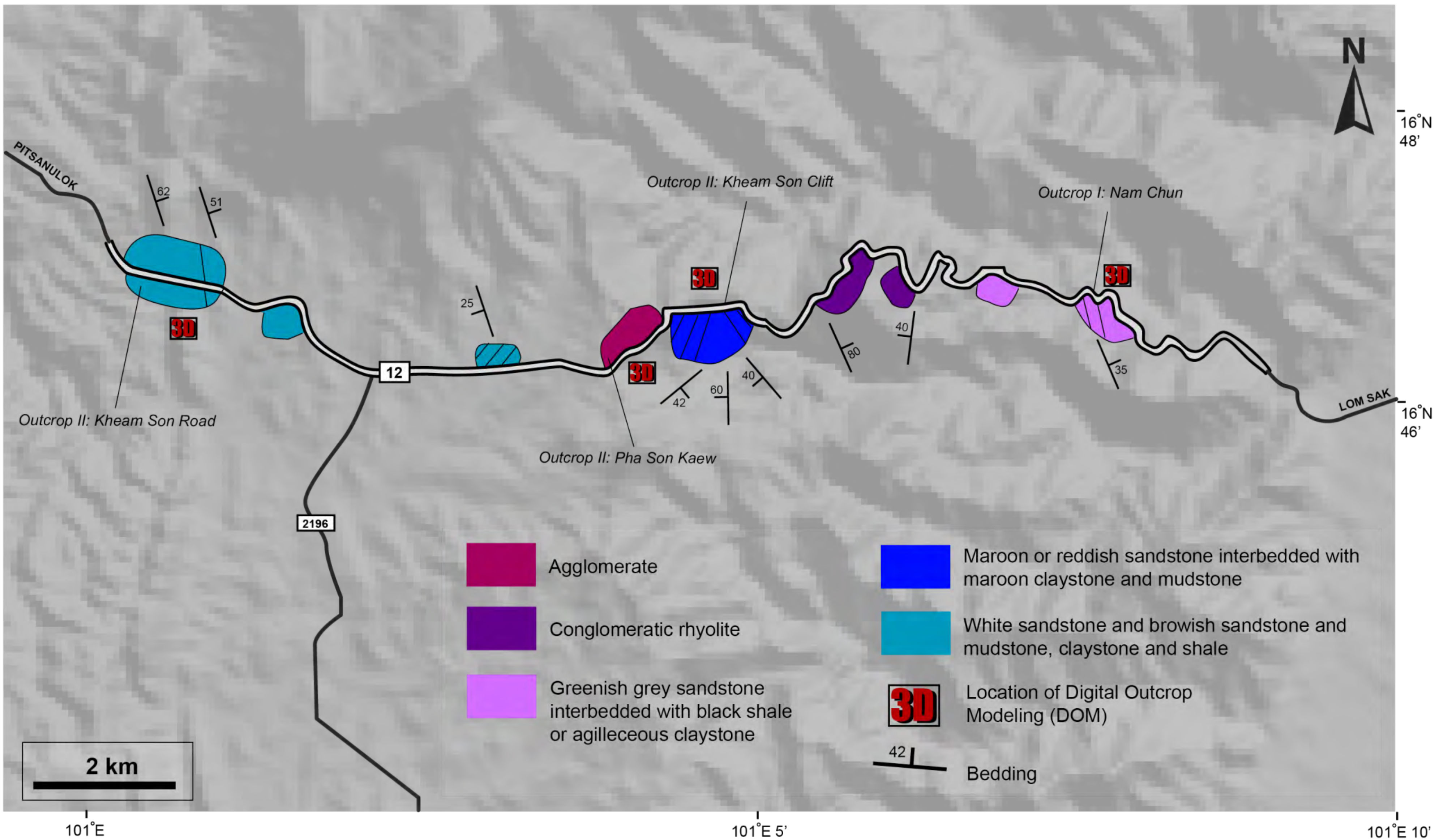

Figure 4.1 The road map of highway 12 with the location of studied outcrops with briefly lithology and bedding plane.

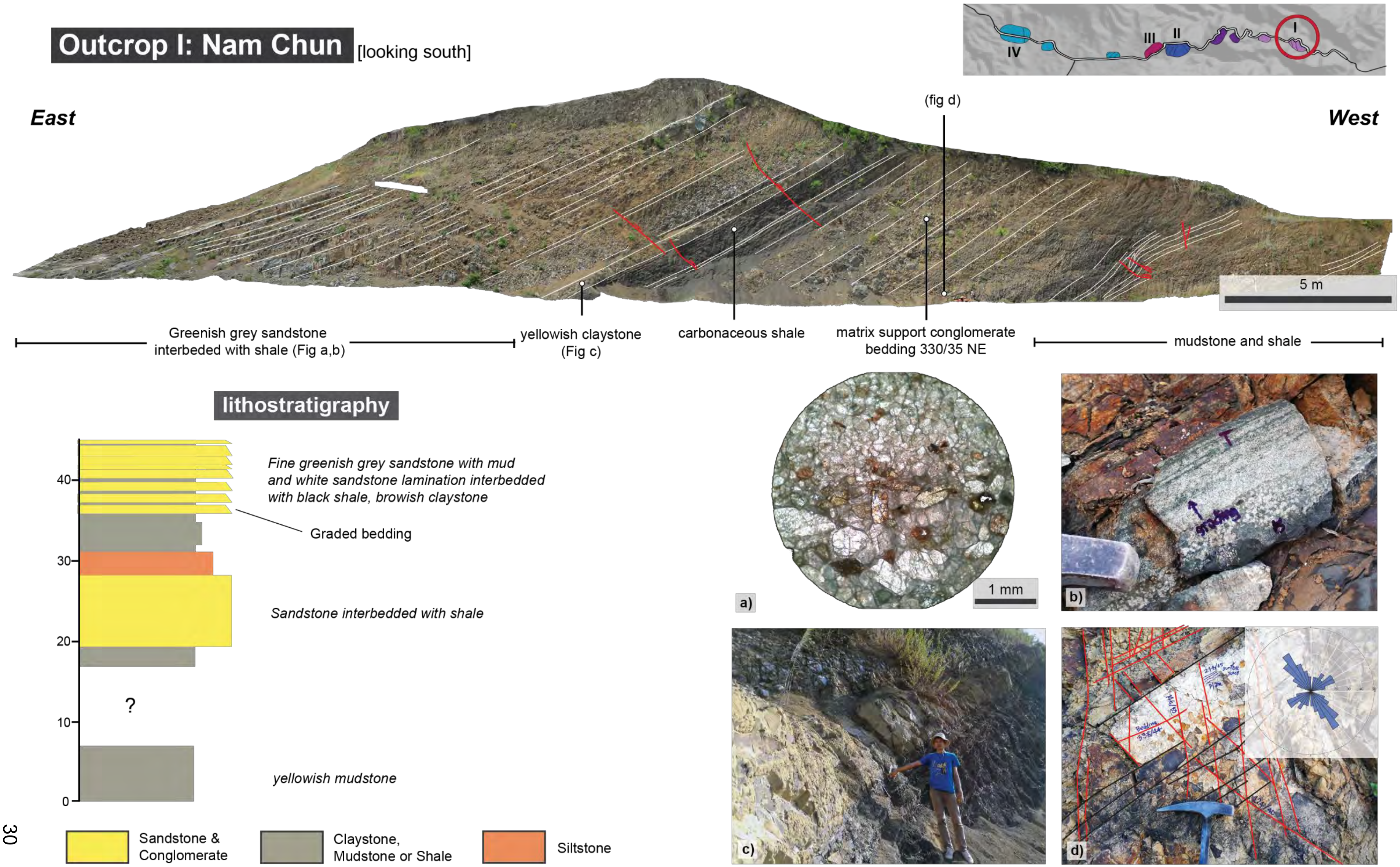

Figure 4.2 The structural sketch, lithostratigraphic column, thin section, zoom photos and structural plots of outcrop I: Nam Chun.

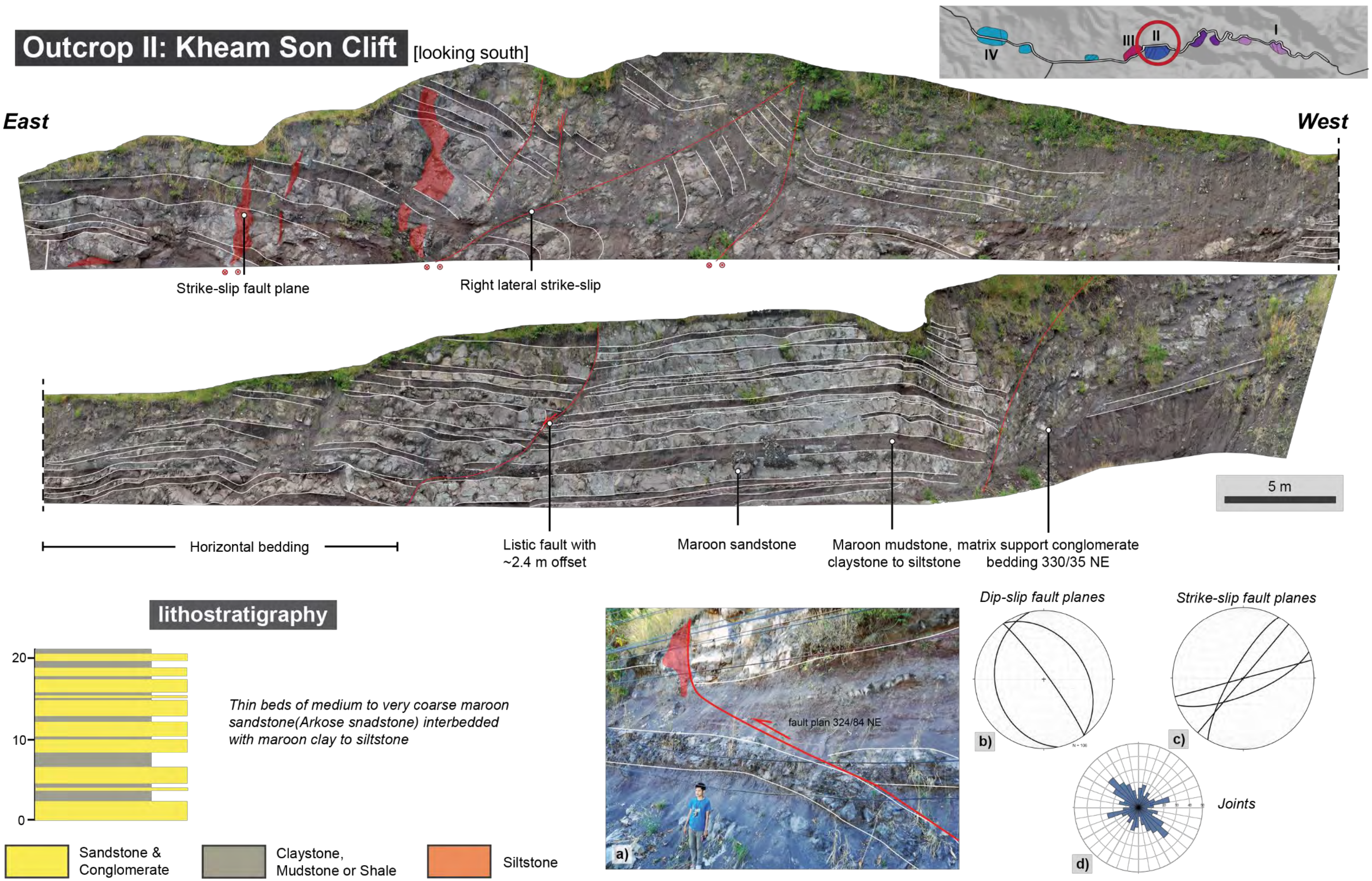

Figure 4.3 The structural sketch, lithostratigraphic column, zoom photos and structural plots of outcrop II: Kheam Son Clift.

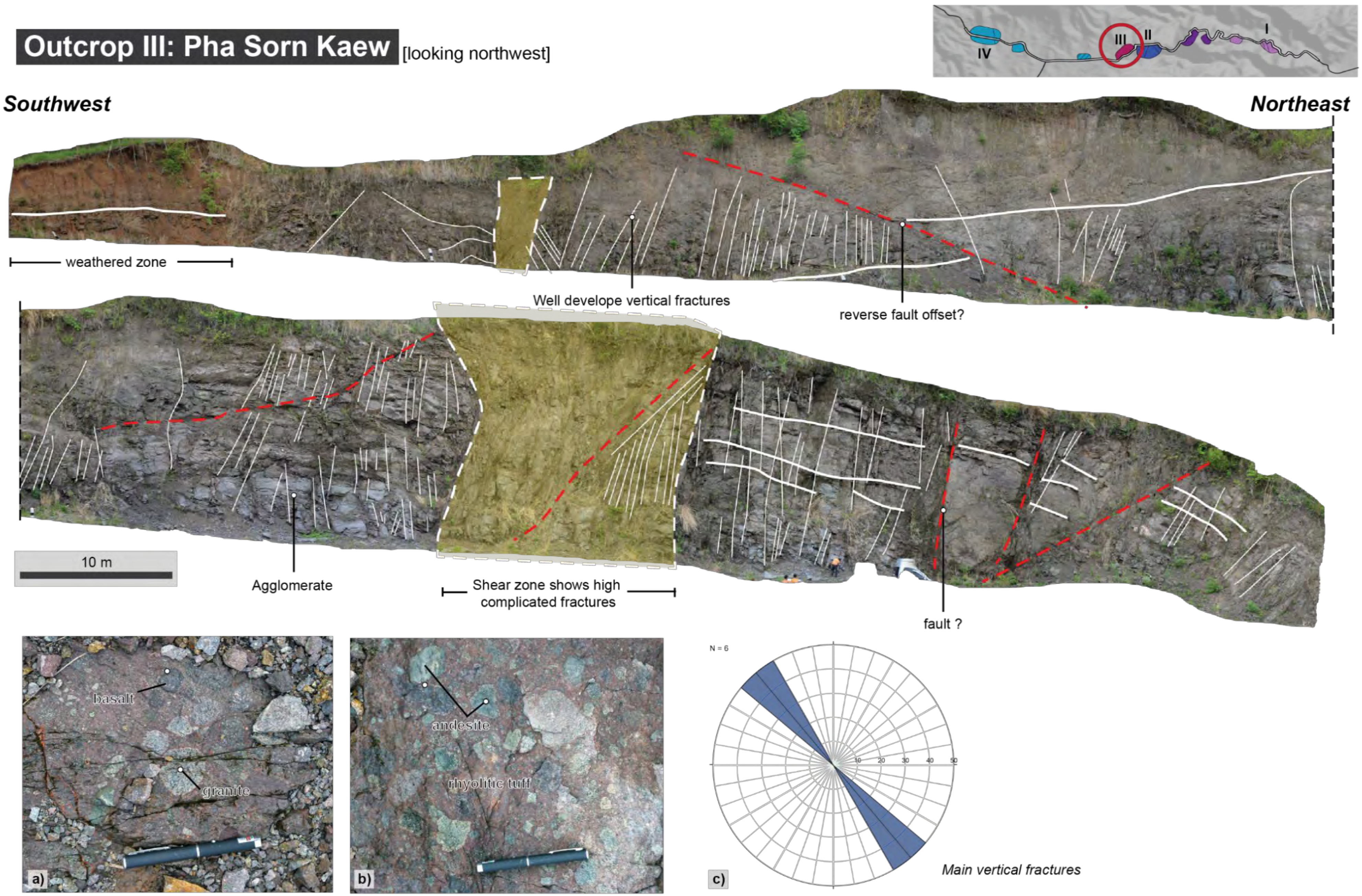

Figure 4.4 The structural sketch, zoom photos and structural plots of outcrop III: Pha Son Kaew.

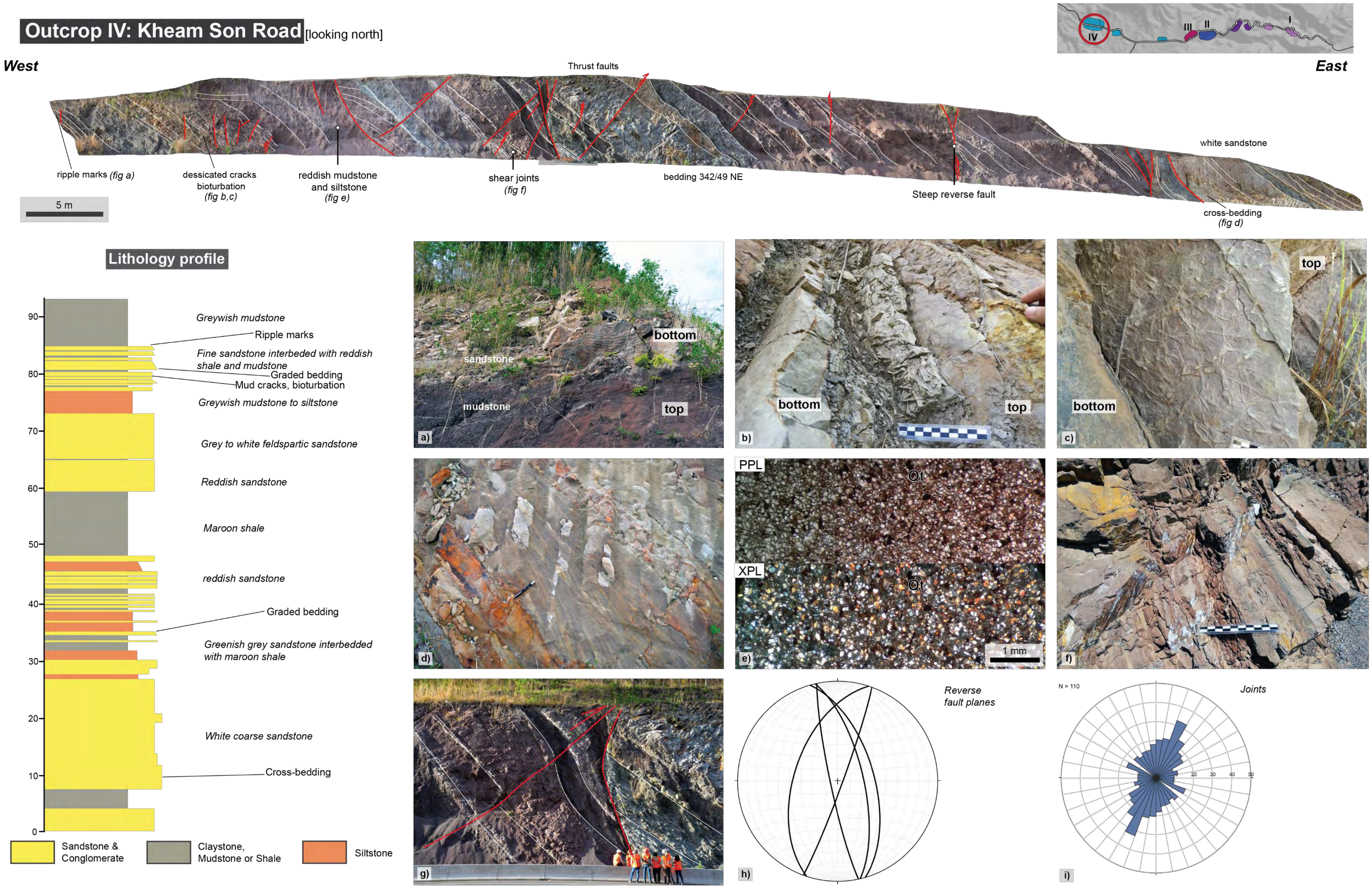

Figure 4.5 The structural sketch, lithological profile, zoom photos and structural plots of outcrop IV: Kheam Son Road.

- ***Maroon sandstone*** *or* ***micaceous sandstone*** mostly found in outcrop II: Kheam Son Clift and some in Outcrop IV: Kheam Son Road. The thick mica-rich sandstone bed lies conformably with maroon claystone, shale and mudstone (Fig 4.3). Its grai-size is medium to very-coarse sands.
- ***White sandstone*** only found in outcrop IV: Kheam Son Road with cross-bedding.
- ***Reddish sandstone*** mainly shows in outcrop IV: Kheam Son Road that interbedded with reddish mudstone and siltstone.

4.1.2 Mudrocks

- ***Carbonaceous shale*** *or* ***black shale*** exposed in only Outcrop I: Nam Chun (Fig 4.2c). It has 100 to 230 cm thick beds conform intercalation with yellowish claystone.
- ***Maroon shale*** (Fig 4.5g) usually associates with bedded sandstone as interbedded in outcrop IV: Kheam Son Road. By the way, thick shale (about 13 meters) shows in the middle of that section.
- ***Yellowish to brownish mudstone*** *is* commonly found in outcrop I: Nam Chun with shale. It is mostly combined with argillaceous cement.
- ***Yellowish claystone*** (Fig 4.2c) attached to carbonaceous shale in outcrop I: Nam Chun
- ***Maroon siltstone to mudstone*** dominate in outcrop II: Kheam Son Clift as thick beds interbeded with maroon sandstone.

4.1.3 Volcanic clastic

- ***Agglomerate*** (Fig 4.4a,b) can be found in outcrop III: Pha Sorn Kaew and between outcrop I and II. It can identify by poorly sorted of a clast of granite, andesite, basalt and diorite with low to high sphericity and angular to rounded roundness. The matrix is also rhyolitic tuff.

4.1.4 Conglomerate

- ***Rhyolitic conglomerate*** looks similar to agglomerate but the clast are more rounded and has high sphericity. The matrix is rhyolitic sandstone.
- ***Metrix support conglomerate*** is only found in outcrop I: Nam Chun. The outcrop is very highly weathered.

4.2 Structural geology

4.2.1 Bedding plane

The road map in figure 4.1 also shows the bedding plane all the way of highway 12. Mostly, the strikes of bed are on NNW-SSE trending. To the east in outcrop I, beds dip to north Phetchabun sub-basin in the east (Fig 4.2). Outcrop II shows the complexity of bedding plane but the strike still in the trend of NW-SE to NE-SW with a variation of dip direction and dip angle. Outcrop III has no bedding plane (Fig 4.4) due to the origin of agglomerate that hardly form depositional horizon. Outcrop IV has conformed dip direction in ENE-WSW trending with 60-45 degrees of dip angle.

4.2.2 Way-up structures

In Outcrop IV: Kheam Son Road, sedimentary structures that define top-bottom were discovered. Firstly, ripple marks on sandstone which is a harder sediment than mudstone beneath it (Fig 4.5a). Secondly, the bioturbation or trace fossils on bedded sandstones (Fig 4.5b). Thirdly, the desiccated crack in top sandstone that beneath mudstone (Fig 4.5c). Lastly, the cross-bedding in white sandstone (Fig 4.5d).

4.2.3 Fractures

The characteristic of fractures is shown differently in different outcrops. Because of each outcrops located away from other and the local stress may change dramatically in different places, the fractures cannot be group out of the outcrop. Thus fractures can be grouped as follows;

- Open fractures

  Outcrop I: Nam Chun has shown well development of open fracture in greenish grey sandstone, conglomerate, siltstone and mudstone as in figure 4.2d. There are two main directions on NNW-SSE and NE-SW trending and they usually relate to bedding as bed perpendicular fractures. Some fractures filled with calcite.

  Outcrop II: Kheam Son Clift can plots open fracture as figure 4.3d to describe 3 main directions on NW-SE, ENE-WSW and N-S trending. These fractures mostly develop perpendicular in micaceous sandstone beds, but in mudrock can be found as well.

  Outcrop III: Pha Sorn Kaew and Outcrop IV: Kheam Son Road rarely found open fractures.

- Shear fractures

Outcrop III: Pha Sorn Kaew is the great example of shear fracture development as vertical fractures. These fracture planes clearly show shear surface or slicken side in NW-SE trending with slicken line on 322/11 NW (strike-slip movement but cannot identified the direction) (Fig 4.4c). Some fractures also filled up with calcite vein.

Outcrop IV: Kheam Son Road (Fig 4.5f & i) represents shear fractures in outcrop. They are 2 domains of fractures which classified by strikes and sense of movement. First, the NE-SW trending fractures with 218/43 of slicken line shows right-lateral movement. Second, the NW-SE trending fractures with 238/56 SW of slicken line responsible for reverse movement. The offset of reverse shear fractures vary from 2 to 40 cm. These fractures can be found significantly in sandstone beds.

4.2.4 Faults

The evidence of faults be observed via field investigation (fault plane, fault offset, slickenline etc.) and interpretation of DOM. This study describes faults by its scale and sense of movement as follows;

- **Reverse fault**

A high angle thrust faults are dominating structures all over 20 kilometers on the road. It can be observed as a gental offset in eastern outcrop such as outcrop I: Nam Chun (Fig 4.2). The offset is about 20-80 cm. The displacement are observed to increase gradually to the western outcrop as Outcrop II. It is found both thrust (low angle) (Fig 4.3a) and reverse faults that associated with right-lateral strike-slip faults. These reverse faults mainly have NW-SE striking (Fig 4.3b).

Outcrop IV: Kheam Son Road’s structures are dominated by reverse fault as sketched in figure 4.5g. its plane plotted main strike is in N-S trending, for example 347/69 NE strikes with 137/58 of slicken line. These faults can not estimate the displacement because of no offsets were defined. By the effect of reverse faults, this outcrop cannot study a lithostratigraphic column.

- **Strike-slip faults**

Literally, strike-slip faults in the study area are not pure strike-slip, but also has vertical offset or oblique, even though the strike-slip seems more dominate than dip-slip. All of strike-slip faults are right-lateral movement (dextral) from the slicken side proved. Ortherwise, these faults does not spread wildly to the east of the study area, but only found in central to west of the framework.

Outcrop II: Kheam Son Clift has many right-lateral strike-slip faults on the east of outcrop. It can be plotted in rose diagram as figure 4.3c. The average trending of strike is on the NE-SW that come up with sub-horizontal slicken line, for example 220/90 NW fault plane with 220/3 SW slicken line.

Outcrop IV: Kheam Son Road has no obvious evidences of strike-slip fault, but only found shear fractures of right-lateral movement.

- **Normal faults**

Normal fault plane in the study area is only found in Outcrop II: Kheam Son Clift and can interpret through the DOM (Fig 4.3). The biggest listic fault has 325/39 NE of fault plane with approximately 2.4 meters of offset that cut through thick micaceous sandstone beds interbedded with maroon mudrocks. In the same way, other normal fault has the same orientation on NW-SE trending.

Chapter 5 Discussion

5.1 Detailed geological map

5.2 Structural evolutionary model

5.3 Digital Outcrop Model for Geotourism

5.1 Detailed geological map

The detailed geological map along highway 12, Amphoe Lom Sak, Changwat Phetchabun with cross-section (Fig 5.1). is the result of the discussion on stratigraphic correlation and structural interpretation below that complied with the geological map of Phetchabun province by DMR (2009).

5.1.1 Stratigraphic correlation

The lithologqy of outcrop can correlate to 3 main formations of the Khorat Group, which are Huai Hin Lat ,Nam Phong and Phu Kradung Formation (Fig 5.2). The distribution of Huai Hin Lat Formation rocks is on the central to the eastern part of study area included Outcrop I: Nam Chun and Outcrop III: Pha Sorn Kaew. However, there are only 3 of 5 members (Chonglakmani and Sattayarak, 1978) exposed along the highway as follows;

- ***I Mo Member*** are the top members that describe as grey sandstone, carbonaceous shale and some limestone. Therefore, Outcrop I: Nam Chun that directly has the same lithology may by the I Mo member
- ***Sam Khaen Conglomerate Member*** represent by the rocks between Outcrop I and II that mainly a rhyolitic conglomerate intercalation with fine sediment.
- ***Pho Hai member*** represents by Outcrop III: Pha Sorn Kaew that only seen agglomerate and rhyolitic tuff with many volcanic clasts.

Unfortunately, two members do not exit in the study area which are Phu Hi member and Dat Fa Member. They are associated to limestone that have never been found in this field.

Nam Phong Formation is represented by Outcrop II : Kheam Son Clift that contain of red-brown micaceous sandstones, siltstone and mudstones of mainly fluvial depositional environment (Chaodumrong, 2013). Nevertheless, this formation is not wildly spread from the central area.

The Outcrop IV: Kheam Son Road can be grouped its lithology as **Phu Kradung Formation** by maroon to brown siltstone, claystone mudstone similar to the geological map of Phetchabun from DMR (2009).

DETAILED GEOLOGICAL MAP ALONG HIGHWAY 12, AMPHOE LOM SAK, CHANGWAT PHETCHABUN

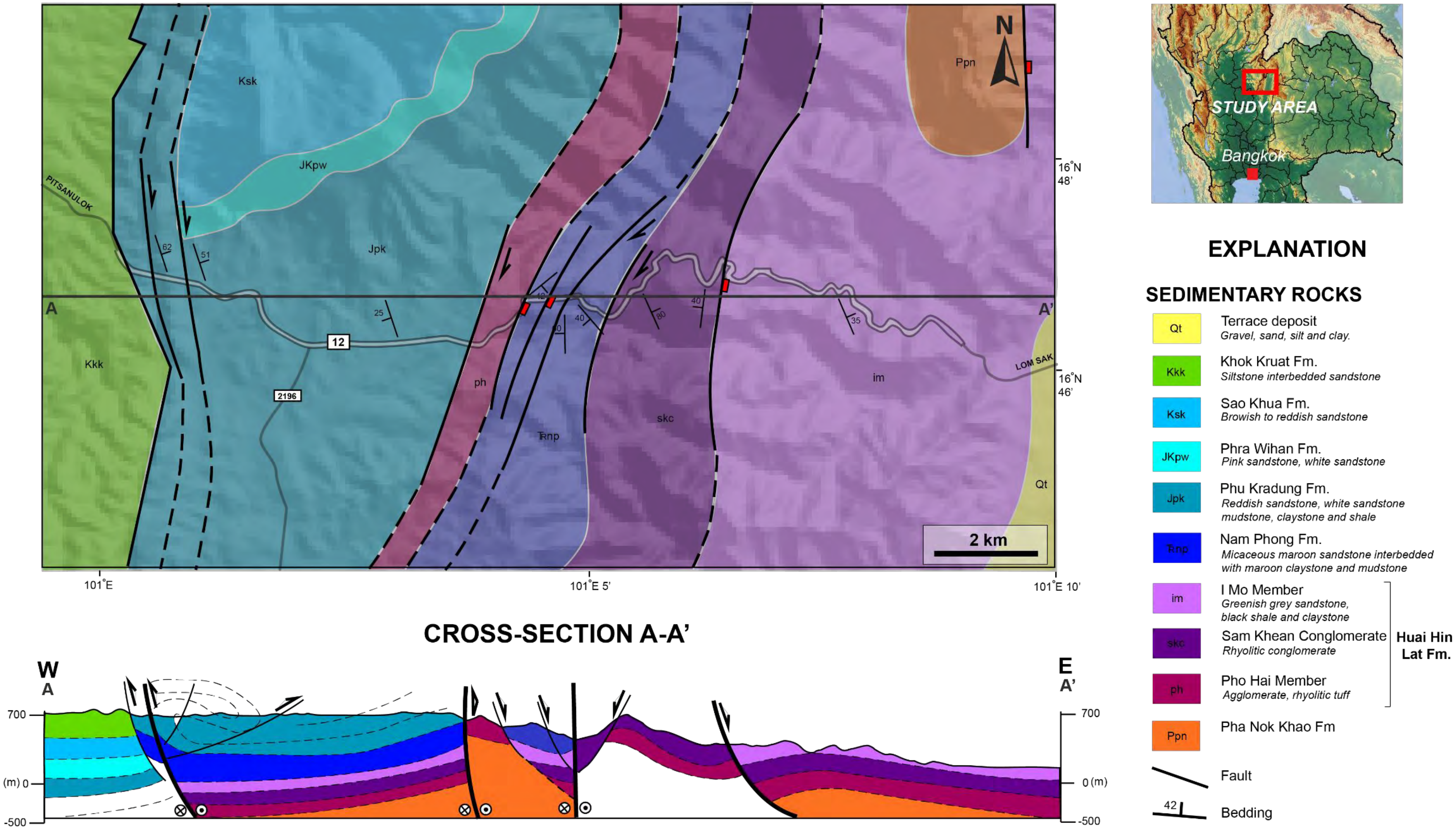

Figure 5.1 Detailed geological map along highway 12, Amphoe Lom Sak, Changwat Phetchabun that complied with geological map of phetchabun province from Khaowiset & Chanfoo (2009). The cross-section a-a' is in E-W which shows the structural setting of the western margin of Phetchabun Basin.

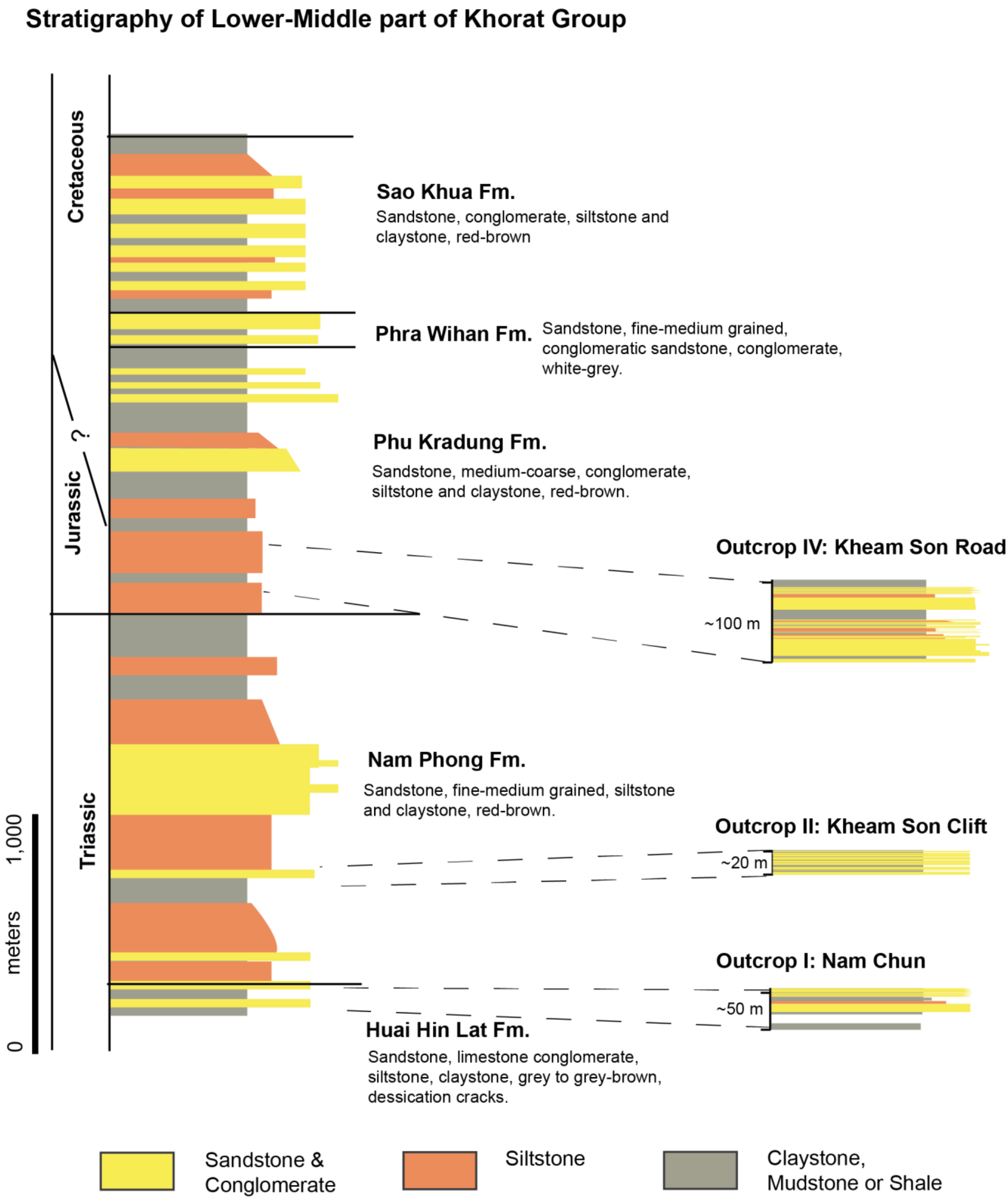

Figure 5.2 The stratigraphic correlation between a lithostratigraphic column of outcrop study and stratigraphy of Lower-Middle part of the Khorat Group (modified from Meesook & Saengsrichan, 2010).

5.1.2 Structural interpretation

From DEM lineament interpreting, there are 2 main structure trends nearby study area (NW-SE and N-S) as sketched in figure 5.2. the NW-SE trend, which pass through Outcrop IV: Kheam Son Road, is interpreted to be a strike-slip tectonic line by the stream offset pattern (Fig 5.3). Moreover, field observation also supports the strike-slip model as right-lateral movement by the dextral shear fractures and faults on N-S trend. A number of reverse faults which dominate this outcrop can explain in this strike-slip model. The steep reverse faults can occur with strike-slip fault in positive flower structures.

The domain structures have changed significantly from the west to east. The right-lateral strike-slip faults, shear fractures and steep reverse fault which supports strike-slip model mostly shows to the west. The most-eastern of area dominated by no fault structures but factures plot and bed geometries convinced them are caused by extensional tectonic by normal faultd. In the same way, the interpreted N-S tectonic line represents extensional line of normal fault (Remus et al., 1993) from seismic interpretation may support the idea. While strike-slip tectonics may affect the west of the study area more than the east that dominate by extensional tectonics, the central part of study area also has both structural styles, listic faults, right-lateral strike-slip faults, some of reverse and thrust fault and open fractures. It can explain by the negative flower structures. Right-lateral strike-slip faults created transtensional region that allows extensional structures developed.

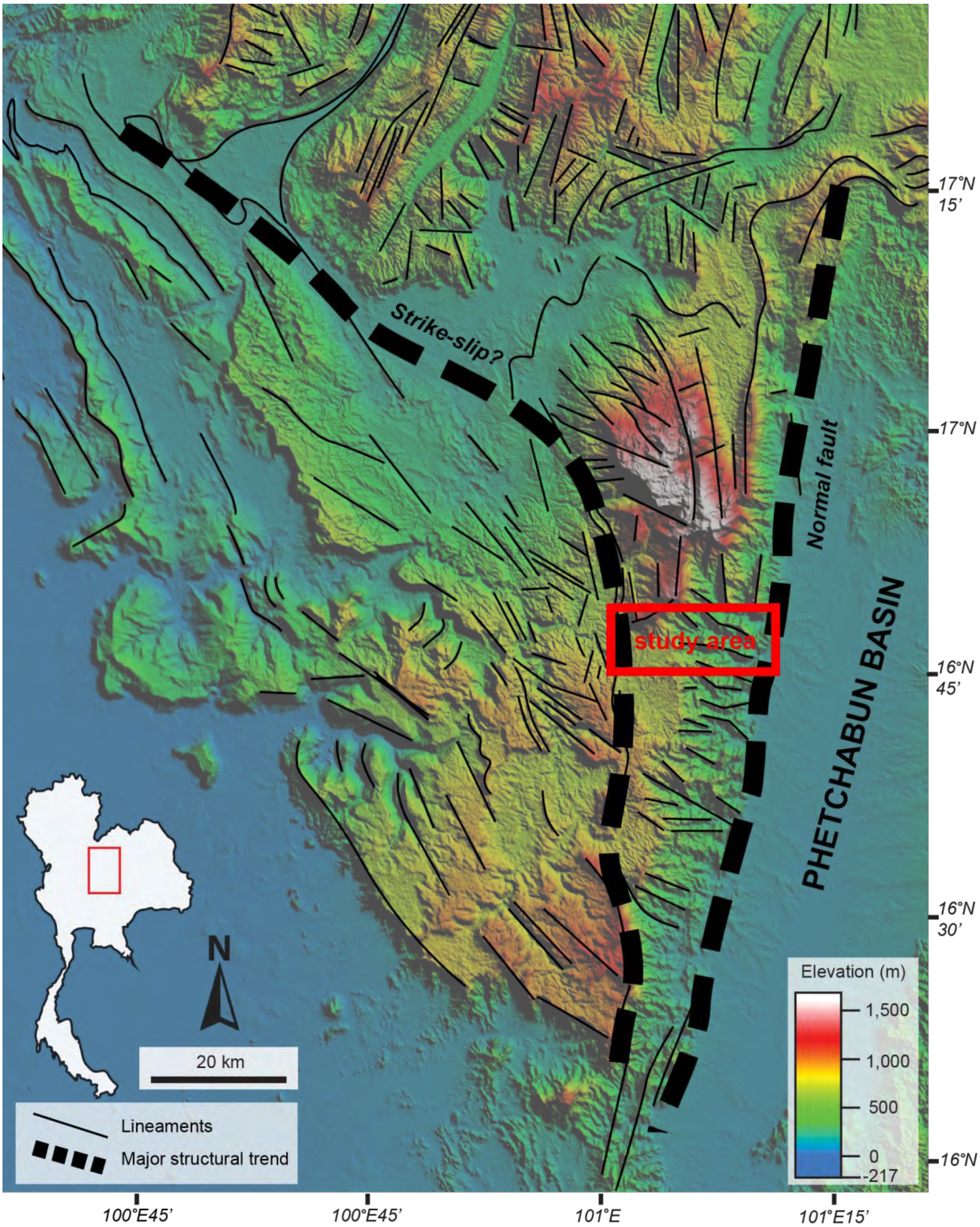

Figure 5.3 Lineament interpretation of the western margin of the Phetchabun basin shows 2 significant tectonic lines. Strike-slip fault trend on the west and normal fault tend on the east of the study area.

5.2 Structural evolutionary model

This work can create 3 stages of the structural evolutionary model of the western margin of the Phetchabun Basin by the lithology, structural styles and geomorphology interpretation.

Stage I: Early Triassic (E-W compression) (Fig 5.4a)

After Metcafe (2013), Permo-Triassic deformation deformed Permian carbonate rocks on the western margin of Indochina block. This rock is the basement of Mesozoic deposition further. The maximum stress is on E-W as compression built-up the Phetchabun fold and thrust belt.

Stage II: Late Cretaceous – Late Eocene (N-S compression) (Fig 5.4b)

Huai Hin Lat Formation deposited in this area unconformable to Permian carbonate rocks follow by Nam Phong Formation in the age of Triassic. After that Phu Kradung Formation unconformably deposited above Nam Phong Formation in Jurassic and other Khorat Group completely deposited in the Late Cretaceous (Chaodumrong, 2013). During Late Cretaceous – Late Eocene, the strike-slip tectonics active in the area by the effect of Himalayan Orogeny (Racey, 2009) made-up right-lateral strike-slip faults caused positive and negative flower structures that create the pop-up or uplifting of the western margin of the Phetchabun Basin.

Stage III: Oligocene – Present day (Fig 5.4c)

During this time, the tectonic zone of strike-slip are inactive in this area and the erosion is more significant until the present.

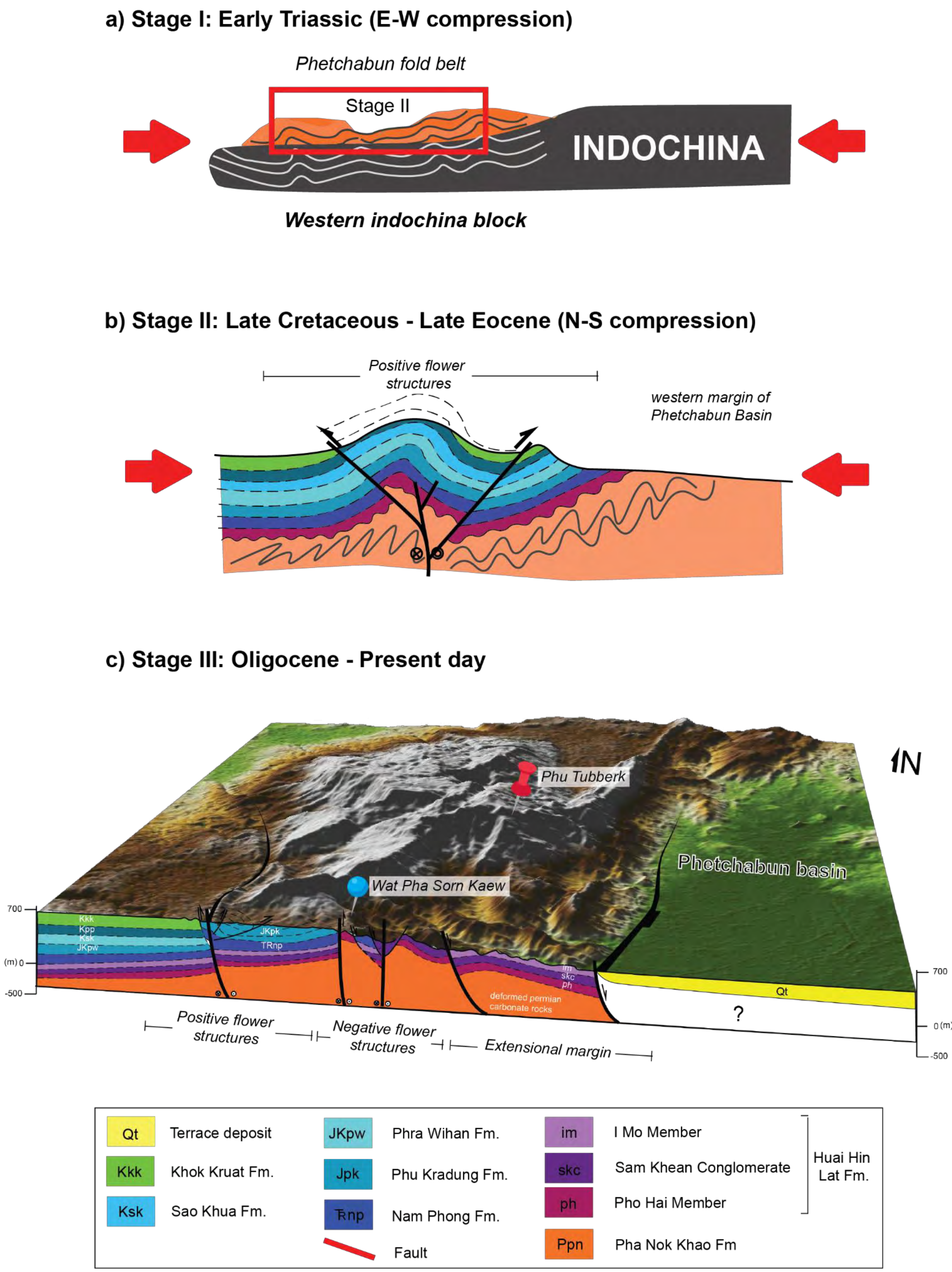

Figure 5.4 Structural evolutionary model of the western margin of Phetchabun Basin can be divided into 3 stages. a) stage I: E-W compression during Early Triassic b) stage II: N-S compression during Late Cretaceous – Late Eocene and c) stage III: Oligocene to present day.

5.3 Digital Outcrop Model for Geotourism

The fact that DOM allows for interpretation and geological data acquisition of outcrop, orientation of geological surfaces, width and thickness of layers. It is a remote sensing techniques to gather the data from low accessible areas such as the cliff higher than 3 m behind the screen. Moreover, it is useful in many fields that usual method may not be safe or there are a lot of data to collect in the short time.

Besides the realistic texture 3D model can record the accurate outcrops that once it is fresh from the construction, etc. and well represent the geology in the area in digital. This surface precisely describes the topography of outcrop when it is destroyed by human-activities, erosion and weathering.

In addition, these models may are interpreted by geologist and exported as visual simulation in the guide book for tourism who interested in the geology get more appreciation of nature and the earth in term of Geotourism.

Chapter 6 Conclusion

Conclusion

- Geological map along highway 12 (km 327+750 to 347) Khao Ko – Lo, Sak, Phetchabun composed of Huai Hin Lat Formation on to the east by 3 members (Phu Hai member, Sam Khean Conglomerate and I Mo) which determined by agglomerate, carbonaceous shale, greenish grey sandstone etc.
- The Nam Phong Formation is assumed to be upperpart of Huai Hin Lat formation around the center of study area by the succussion of maroon micaceous sandstone interbeded with maroon shale, mudstone and siltstone.
- Phu Kradung Formation (mainly red bed sandstone interbedded with shale) only found in the most-west of study area and particularly shows overturned of stratigraphy.
- The structures in study area are mainly interpreted to be *right-lateral strike-slip fault* that caused positive and negative flower structures. This effect the relocation of rocks as cross-section present.
- The evolution of western margin of Phetchabun basin can be divided into 3 stages as follow;
  - Stage I: Early Triassic (E-W compression): After Permo-Triassic deformation, the Permian carbonate rocks were deformed on the west of Indochina block.
  - Stage II: Late Cretaceous – Late Eocene (N-S compression): Khorat Group completely deposited then strike-slip stress o right-lateral movement caused positive and negative flower structures that create the pop-up or uplifting pf western margin of Phetchabun Basin.
  - Stage III: Oligocene – Present day: The tectonic zone of strike-slip are inactive and move to extension of basin by N-S compression.

References

Ampaiwan, P. 2011. *Structural Development of Thrust, Folds and Fractures in Quarry Exposures of Permian Limestones, Saraburi Province, Central Thailand: Implication for Fractured Reservoir Development in NE Thailand*. Unpublished manuscript, Chulalongkorn University, Bangkok, Thailand.

Booth, J., and Sattayarak, N., 2011, *Subsurface Carboniferous – Cretaceous Geology of NE Thailand*. In: Ridd, M.F., Barber, A.J. & Crown, M.J. (eds), The Geology of Thailand, The Geological Society of London, p. 185-222.

Chairangsee, C., & Assavapatchara, S., 2009, *Geological map of Thailand on 1:250,000 scale: Sheet Changwat Loei*, in D. o. M. R. Geological Survey Division, ed., Bangkok.

Chonglakmani, C., 2011, *Triassic*. In: Ridd, M.F., Barber, A.J. & Crown, M.J. (eds), The Geology of Thailand, The Geological Society of London, p. 137-150.

Chonglakmani, C., & Satayarak, N., 1979, *Geological map of Thailand on 1:250,000 scale: Sheet Changwat Phetchabun (NE 47-16)*, in D. o. M. R. Geological Survey Division, ed., Bangkok.

Chaodumrong, P., 2013. *Lexicon of Stratigraphic Names of Thailand*, Bureau of Geological Survey, Department of Mineral Resources, Bangkok, 271 p

Charusiri, P., & Pum-im, S., 2009. *Cenozoic Tectonic Evolution of Major Sedimentary Basins in Central , Northern and the Gulf of Thailand*, 2(1), 40–62.

Department of Mineral Resources, 2014, *Geology of Thailand: Department of Mineral Resources*, Ministry of Natural Resources and Environment, Bangkok, Thailand, 508 p

Heggemann, H., & Landesamt, H., 1994. *Sedimentary Evolution of the Mesozoic Khorat Basin in Thailand*, (May).

Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D., & Müller, B. 2010. *Global crustal stress pattern based on the World Stress Map database release 2008*. Tectonophysics, 482(1–4),. https://doi.org/10.1016/j.tecto.2009.07.023

Hinthong. C., S. Chuaviroj, W. Kaewyana, S. Srisukh, C. Pholprasit, and S. Pholachan, 1985, *Geological map of Thailand on 1:250,000 scale: Sheet Changwat Pra*

Nakhon Si Ayutthaya (ND 47-8), in D. o. M. R. Geological Survey Division, ed., Bangkok.

Khaowiset, K., Chanfoo, N., 2009, *Geological map of Thailand on 1:250,000 scale: Sheet Changwat Phetchabun*, in D. o. M. R. Geological Survey Division, ed., Bangkok.

Leewongcharoen, S., & Yathakum, W., 2009, *Geological map of Thailand on 1:250,000 scale: Sheet Changwat Pitsanulok*, in D. o. M. R. Geological Survey Division, ed., Bangkok.

Meesook, A., & Saengsrichan, W., 2011, *Jurassic*. In: Ridd, M.F., Barber, A.J. & Crown, M.J. (eds), The Geology of Thailand, The Geological Society of London, p. 151-168.

Metcalfe, I., 2013. *Gondwana dispersion and Asian accretion: Tectonic and palaeogeographic evolution of eastern Tethys*. Journal of Asian Earth Sciences, 66, 1–33.

Morley, C. K., Charusiri, P., & Watkinson, M., 2011. *Structural geology of Thailand during the Cenozoic Modern tectonic setting of Thailand*, In: Ridd, M.F., Barber, A.J. & Crown, M.J. (eds), The Geology of Thailand, The Geological Society of London, p. 273-334.

Polachan, S., Pradidtan, S., Tongtaow, C., Janmaha, S., Intarawijitr, K., & Sangsuwan, C., 1991. *Development of Cenozoic basins in Thailand*, 8(1).

Racey, A., & Goodall, J. G. S., 2009. *Palynology and stratigraphy of the Mesozoic Khorat Group red bed sequences from Thailand*. Geological Society, London, Special Publications, 315(1), 69–83.

Remus, D., Webster, M., & Keawkan, K. 1993. *Rift architecture and sedimentology of the Phetchabun Intermontane Basin, central Thailand*, 8, 421–432.

Searle, M. P., & Morley, C. K., 2011. *Tectonics and Thermal evolution of Thailand in the regional context of South-East Asia*. Geology of Thailand., (August 2016).

Sone, M., & Metcalfe, I. 2008. *Parallel Tethyan sutures in mainland Southeast Asia : New insights for Palaeo-Tethys closure and implications for the Indosinian orogeny*, 340, 166–179.

Ward, D. E., & Bunnag, D., 1964. *Stratigraphy of the Mesozoic Khorat Group in Northeast Thailand*. Report of Inverstigation 6. Department of Mineral Resources, Bangkok, 1-95.

Appendix

Table 1 Structural data from field investigation with location.

Outcrop	UTM X	UTM Y	Elevation (m)	Bedding		Fault plane		Fault slicken line	
				strike	dip	strike	dip	trend	plunge
Outcrop I: Nam Chun	0725707	1856264	343	337	35	-	-	-	-
Outcrop I: Nam Chun	0725657	1856264	351.8	334	30	-	-	-	-
Outcrop I: Nam Chun	0725655	1856260	349.6	312	34	-	-	93	24
Outcrop I: Nam Chun	0725618	1856246	356.0	338	44	-	-	-	-
Outcrop I: Nam Chun	0725595	1856233	356.6	333	27	-	-	-	-
Outcrop II: Kheam Son Clift	0720295	1855986	632.9	136	61	-	-	-	-
Outcrop II: Kheam Son Clift	0720140	1855962	660.5	174	39	-	-	-	-
Outcrop II: Kheam Son Clift	0720263	1855978	649.6	182	36	-	-	240	20
Outcrop II: Kheam Son Clift	0720254	1855976	652.2	-	-	210	77	230	17
Outcrop II: Kheam Son Clift	0720200	1855971	657.5	264	10	168	30	204	20
Outcrop II: Kheam Son Clift	0720166	1855967	662.0	177	58	324	84	-	-
Outcrop II: Kheam Son Clift	0719829	1855904	671.9	51	42	-	-	-	-
Outcrop II: Kheam Son Clift	0719881	1855926	671.4	-	-	325	39	-	-
Outcrop II: Kheam Son Clift	0719906	1855929	672.5	-	-	255	90	255	0
Outcrop II: Kheam Son Clift	0719946	1855928	670.9	-	-	220	90	220	3
Outcrop II: Kheam Son Clift	0719968	1855931	674.7	-	-	54	83	-	-
Outcrop II: Kheam Son Clift	0719996	1855936	673.2	-	-	68	71	237	24
Outcrop II: Kheam Son Clift	0720027	1855942	669.3	-	-	138	61	-	-
Outcrop II: Kheam Son Clift	0720042	1855945	668.4	63	8	-	-	-	-
Outcrop III: Pha Sorn Kaew	0719460	1855487	724.8	-	-	145	26	322	11
Outcrop IV: Kheam Son Road	0712793	1856420	766.1	331	62	-	-	-	-
Outcrop IV: Kheam Son Road	0712816	1856410	763.4	-	-	183	59	255	57
Outcrop IV: Kheam Son Road	0712818	1856408	765.5	346	58	-	-	-	-
Outcrop IV: Kheam Son Road	0712822	1856405	763.7	-	-	347	69	137	58
Outcrop IV: Kheam Son Road	0712849	1856405	760.8	-	-	168	84	-	-
Outcrop IV: Kheam Son Road	0712855	1856403	760.5	348	59	-	-	-	-
Outcrop IV: Kheam Son Road	0712864	1856403	762.0	342	49	198	54	-	-
Outcrop IV: Kheam Son Road	0712888	1856395	757.7	343	51	217	67	-	-
Outcrop IV: Kheam Son Road	0712915	1856392	760.9	-	-	175	83	273	81
Outcrop IV: Kheam Son Road	0712945	1856384	754.7	327	51	197	80	-	-
Outcrop IV: Kheam Son Road	0712976	1856384	753.8	-	-	176	70	-	-
Outcrop IV: Kheam Son Road	0712791	1856390	762.9	351	64	-	-	-	-
Outcrop IV: Kheam Son Road	0712813	1856385	767.2	342	63	-	-	-	-
Outcrop IV: Kheam Son Road	0712892	1856368	760.0	-	-	344	60	-	-
Outcrop IV: Kheam Son Road	0712921	1856362	757.2	-	-	20	86	-	-
Outcrop IV: Kheam Son Road	0712951	1856356	756.0	336	56	-	-	-	-

Table 2 Open fractures plane of Outcrop I: Nam Chun.

Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip
137	83	204	54	337	74	146	85	38	84	333	88
178	54	315	90	137	76	168	90	43	75	132	43
135	79	142	77	232	63	124	40	244	66	142	82
140	84	320	89	157	79	214	65	245	90	162	38
140	82	137	88	239	84	127	90	252	68	242	62
154	77	145	47	149	88	198	49	232	56	141	83
292	51	318	89								

Table 3 Open fractures of Outcrop II: Kheam Son Clift.

Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip
307	81	258	78	258	51	150	81	323	87	130	52
304	85	339	14	135	49	137	83	324	70	247	55
314	85	300	80	254	47	144	78	254	82	247	54
130	85	316	63	263	51	134	76	28	43	246	55
132	90	129	82	33	51	215	79	321	86	136	76
138	88	131	84	37	39	336	26	136	79	134	80
123	86	126	85	259	44	94	88	150	81	136	77
126	89	305	86	256	50	155	57	124	82	137	81
102	69	203	77	17	57	129	54	103	78	254	49
101	56	191	54	7	69	136	63	319	86	257	51
108	72	214	80	138	62	55	38	115	47	235	61
296	84	194	90	132	71	136	82	266	50	43	40
297	86	346	13	145	67	168	89	260	59	46	32
280	53	345	12	129	59	176	30	17	51	144	74
4	22	2	13	145	71	124	87	12	52	12	45
322	34	154	50	142	69	193	81	250	58	240	59
336	26	140	53	147	78	252	45	157	76	251	64
254	68	341	43	1	55	3	65	255	78		

Table 4 Shear fractures of Outcrop III: Pha Sorn Kaew.

Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip
137	80	134	75	141	78	144	75	142	80	132	75
135	70	130	72	140	68						

Table 5 Open fractures of Outcrop III: Kheam Son Road.

Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip
323	19	340	56	216	44	239	54	208	68	221	87
322	13	332	51	235	37	227	79	195	69	208	34
340	22	42	82	209	51	170	56	201	82	224	47
331	19	36	82	208	55	212	89	209	78	207	60
321	19	217	73	211	46	163	56	210	56	230	15
314	17	188	62	248	31	115	61	204	20	178	25
213	57	209	78	254	16	95	84	196	70	173	16
219	34	223	31								

Table 6 Shear fractures of Outcrop IV: Kheam Son Road.

Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip	Strike	dip
276	37	174	61	235	46	313	24	287	42	209	64
290	52	178	63	191	77	203	52	188	67	206	64
272	32	185	71	190	80	227	65	190	66	202	89
295	29	349	79	194	76	232	80	185	74	208	64
290	26	4	72	297	65	207	65	180	75	251	17
332	22	186	83	315	65	214	79	186	73	214	79
339	26	164	43	230	79	204	78	193	80	151	52
324	24	196	56	250	56	266	52	203	48	212	78
318	26	205	55	200	69	268	46	207	55	289	5
317	14	193	74	192	68	178	38	206	38	200	62
299	22	174	80	207	63	223	78	7	67	218	61