แบบจำลองธรณีวิทยาโครงสร้างซึ่งแสดงในชั้นหินมหายุคมีโซโซอิกบริเวณภาคใต้ตอนบน โดยใช้หลักฐานอ้างอิงบริเวณจังหวัดกระบี่และสุราษฎร์ธานี

นาย พิษณุพงศ์ กาญจนพยนต์

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GEOLOGIC STRUCTURAL MODEL ILLUSTRATED BY THE MESOZOIC STRATIGRAPHIC UNITS IN THE UPPER SOUTHERN THAILAND, WITH SPECIAL REFERENCE TO CHANGWAT KRABI AND SURAT THANI

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Thesis Advisor	Assistant Professor Nopadon Muangnoicharoen, Ph.D.
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พิษณุพงศ์ กาญจนพยนต์ : แบบจำลองธรณีวิทยาโครงสร้างซึ่งแสดงในชั้นหินมหายุคมีโซโซอิกบริเวณภาคใต้ตอนบน โดยใช้หลักฐานอ้างอิงบริเวณจังหวัดกระบี่และสุราษฎร์ธานี(GEOLOGIC STRUCTURAL MODEL ILLUSTRATED BY THE MESOZOIC STRATIGRAPHIC UNITS IN THE UPPER SOUTHERN THAILAND, WITH SPECIAL REFERENCE TO CHANGWAT KRABI AND SURAT THANI) อ.ที่ปรึกษา : **ผศ. ดร. นภดล ม่วงน้อยเจริญ**, อ.ที่ปรึกษาร่วม : **ผศ. สมภพ เวชกาญจนา**, จำนวนหน้า 103 หน้า. ISBN 974-17-9793-1

การวิจัยทางธรณีวิทยาโครงสร้างครั้งนี้กระทำที่บริเวณภาคใต้ตอนบนของประเทศไทย จากจังหวัดชุมพรถึงจังหวัดตรัง การศึกษาประกอบด้วยการสำรวจเบื้องต้นในภาคสนามของลำดับชั้นหินมหายุคมีโซโซอิกและการศึกษาลักษณะธรณีวิทยาโครงสร้างโดยทั่วไป ส่วนการวิจัยในรายละเอียดนั้นได้ปฏิบัติการในด้านตะวันออกของจังหวัดกระบี่ต่อเนื่องไปทางจังหวัดสุราษฎร์ธานีตามแนวตัดขวาง 3 แนวความยาว 50, 24 และ 29 กม.ตามลำดับ โดยวัตถุประสงค์เพื่อให้เข้าใจถึงกระบวนการกระทำให้ผิดรูปที่เกิดขึ้นกับชั้นหินมหายุคมีโซโซอิก หินในพื้นที่วิจัยประกอบด้วยหมวดหินไสบอนซึ่งเป็นหินตะกอนทะเลยุคไทรแอสซิกและกลุ่มหินตรังซึ่งเป็นหินตะกอนที่ไม่ได้เกิดจากสะสมตัวในทะเล กลุ่มหินตรังยังแบ่งย่อยออกเป็นหมวดหินคลองมีน, ลำทับ, สามจอม และพุนพิน หน่วยหินทั้งหมดนี้วางตัวแบบไม่ต่อเนื่องเชิงมุมอยู่บนกลุ่มหินราชบุรียุคเพอร์เมียนและกลุ่มหินแก่งกระจานยุคเพอร์โมคาร์บอนิเฟอรัส นอกจากนี้หน่วยหินดังกล่าวยังถูกปิดทับแบบไม่ต่อเนื่องด้วยกลุ่มหินกระบี่ยุคเทอร์เชียรี และตะกอนยุคควอเทอร์นารี

หินมหายุคมีโซโซอิกได้ถูกกระทำให้ผิดรูปกลายเป็นโครงสร้างประทุนหงายลำดับต้นขนาดมหึมา ซึ่งภายในประกอบด้วยโครงสร้างประทุนหงายลำดับรองลงมาใน 4 บริเวณ ได้แก่ โครงสร้างประทุนหงายชุมพร, ตาปี, กระบี่อีส และตรัง โครงสร้างประทุนหงายเหล่านี้วางตัวแบบเรียวยาวในแนวเหนือ-ใต้ ถึงตะวันออกเฉียงเหนือค่อนไปทางเหนือ-ตะวันตกเฉียงใต้ค่อนไปทางใต้ ในโครงสร้างประทุนหงายนี้ยังประกอบไปด้วยโครงสร้างรอยพับย่อยพาราซิติกแบบไม่สมมาตร โดยแขนของรอยพับที่เอียงเทไปทางตะวันออกจะแสดงมุมเอียงเทปานกลางถึงชันมาก และแขนของรอยพับที่เอียงเทไปทางตะวันตกมีมุมเอียงเทน้อย โครงสร้างรอยพับนี้ถูกตัดโดยรอยแตกโดยรอยแตกที่ทำมุมชันกับแนวโครงสร้างคือรอยเลื่อนแบบเหลื่อมข้าง และรอยแตกที่ทำมุมตั้งฉากคือรอยแยกที่เกิดจากการดึงและรอยเลื่อนแบบปกติ ลักษณะธรณีวิทยาโครงสร้างนี้บ่งชี้ถึงการผลักในแนวตะวันออก-ตะวันตก พร้อมกับการเกิดการลากแบบเฉือน และในขณะเดียวกันนั้นได้เกิดกระบวนการดึงตามแนวของโครงสร้างประทุนหงาย กระบวนการดังกล่าวนี้ได้เกิดขึ้นก่อนการสะสมตัวของตะกอนยุคเทอร์เชียรี หลังจากกระบวนการนี้แล้วไม่พบหลักฐานของการเกิดรอยพับ ยกเว้นการเกิดแอ่งตะกอนยุคเทอร์เชียรีซึ่งถูกควบคุมโดยรอยเลื่อน

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

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

ปีการศึกษา.....2545..... ลายมือชื่ออาจารย์ที่ปรึกษาร่วม.....

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KEY WORDS : STRUCTURAL GEOLOGY/ MESOZOIC ROCKS/ SOUTHERN THAILAND

PITSANUPONG KANJANAPAYONT: GEOLOGIC STRUCTURAL MODEL ILLUSTRATED BY THE MESOZOIC STRATIGRAPHIC UNITS IN THE UPPER SOUTHERN THAILAND, WITH SPECIAL REFERENCE TO CHANGWAT KRABI AND SURAT THANI. THESIS ADVISOR: ASST. PROF. NOPADON MUANGNOICHAROEN, Ph.D., THESIS CO-ADVISOR: ASST. PROF. SOMPOP VEDCHAKANCHANA, M.Sc., 103 pp. ISBN 974-17-9793-1

A structural geologic study was performed in peninsular upper southern Thailand from Changwat Chumphon to Trang. The study includes a field reconnaissance on the stratigraphy of the Mesozoic units and a general structural geologic survey. A detailed study was done in eastern Changwat Krabi and Changwat Surat Thani along 3 traverse lines, which are 50, 24, and 29 Km. long respectively. The study was meant to understand the deformation pattern imprinted on to the Mesozoic stratigraphic units in this area. The study area is underlain by the marine Triassic Sai Bon Formation and non-marine Jurassic-Cretaceous Trang Group. Trang Group is further subdivided into Khlong Min, Lam Thap, Sam Chom, and Phun Phin Formations. These units angular-unconformably overly the Permian Ratburi Group and Permo-Carboniferous Kaeng Krachan Group, and are further unconformably overlain by Tertiary Krabi Group and the Quaternary sediments.

The Mesozoic rocks were folded to form a huge first-ordered syncline, within which is composed of 4 major lower-ordered gentle synclines, Chumphon, Ta Pi, Krabi-East, and Trang synclines. These synclines are somewhat elongated in the north-south to northnortheast-southsoutheast direction, with asymmetric lower-ordered parasitic folds. The folds have moderately to steeply eastward dipping limbs and more gently westward dipping limbs. These folds were transected by fractures, at high angle by the strike-slip faults, and being perpendicular by the extension joints and normal faults. These geologic structures indicate the east-west pushing, perhaps also with the shear drag, and concurrently or immediately followed by the extensional mechanism along the synclinal trend. This occurred before the deposition of the Tertiary sedimentary units. After then, no more major folding was recognized, except the formation of fault-controlled Tertiary basins.

Department……..Geology…….. Student's signature…….

Field of study…...Geology…….. Advisor's signature…….

Academic year……2002……... Co-advisor's signature……..

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Finally, the author is indebted to his parents who encourage him in everything to the highest education.

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CHAPTER 1

INTRODUCTION

The Mesozoic stratigraphic units widely exposed in upper southern Thailand have received much interest since sometimes in the past (Garson and others, 1975, Asama and others, 1981, Prasomsap and Supasunthornkul, 1989, Chonglakmani and others, 1990, Ampornmaha, 1995, Hinthong, 1999). The rocks were noted to underlie the low-relief terrain bounded to the west by the difficult terrain of Tanaosri mountain of Chumphon-Ranong area and Khao Luang mountain to the east in Nakhon Si Thammarat.

Because of the severaly weathering processes such that the area has been much soil covered, only few outcrops expose, and many works had to be done in the past in a field reconnaissance fashion and added by some remote-sensing studies using aerial-photographic interpretation. These studies were mostly aimed to understand the stratigraphic sequences of the Mesozoic units and their older basement rocks while the geologic structural studies were even less emphasized because of the unclear stratigraphic successions, disconnected and scattered exposures, and the confusing nature of the older basement units. Until recently Raksaskulwong(1994) and Teerarungsigul(2000) performed more throughout stratigraphic studies, and the Third-year Geology students of Chulalongkorn University had used this region for their summer field works in 1996, 1998, 2000, and 2002. These works together with the work of Kanjanapayont(1998), and with the area being more developed while more roads having been constructed according to the Southern Seaboard Development Project thus allow the present attempt to gather more information on the tectonic history in this region.

However the attempt is limited only to that imprinted onto the Mesozoic units because of less complicated stratigraphy and less-severed deformation having been occurred, a geologic condition being simple enough for a better understanding.

1.1 Propose and Scope of Study

A study in structural geology is regularly done to the structures of 3 scales; macroscopic, mesoscopic and microscopic. For this study the mesoscopic study is emphasized and the microscopic scale is only added to interpret for the macroscopic one. The aim is to compile the structural geology of the Mesozoic sedimentary rock in the upper southern Thailand and conclude a structural model. Hopefully, it could indicate some or all regional tectonic events after the Mesozoic era.

1.2 Location and Accessibility

The study area is located in peninsular Thailand extending southerly from Changwat Chumphon, Nakhon Si Thammarat, Krabi, Surat Thani to Trang. A particular emphasis is on eastern Krabi and Surat Thani in an area of approximately 2,200 square kilometers. This area is between Latitudes 8°22"30' N to 8°58"00' N, and Longitudes 98°50"00' E to 99°16"20' E, and is covered in 5 sheets of 1:50,000-scale, series L7017 topographic maps, namely Sheets 4726I (Amphoe Phanom), 4826IV (Amphoe Khian Sa), 4826III (Ban Bang Pha), 4825IV (Amphoe Khao Phanom) and 4826I (Amphoe Ban Na San).

This area is about 700 kilometers from Bangkok. The highways provided the access to the study area include Highway 4 (Phetkasaem Road) and Highway 41. The roads in the study area are the Krabi-Khanom Land Bridge and many other good-conditioned asphaltic roads. The accessed highways and roads are shown in Figure 1.1.

1.3 Physiography

The physiography of the area concerns the topography, drainage pattern, and climate. The landforms could somewhat indicate the lithology, stratigraphy, and structural geology.

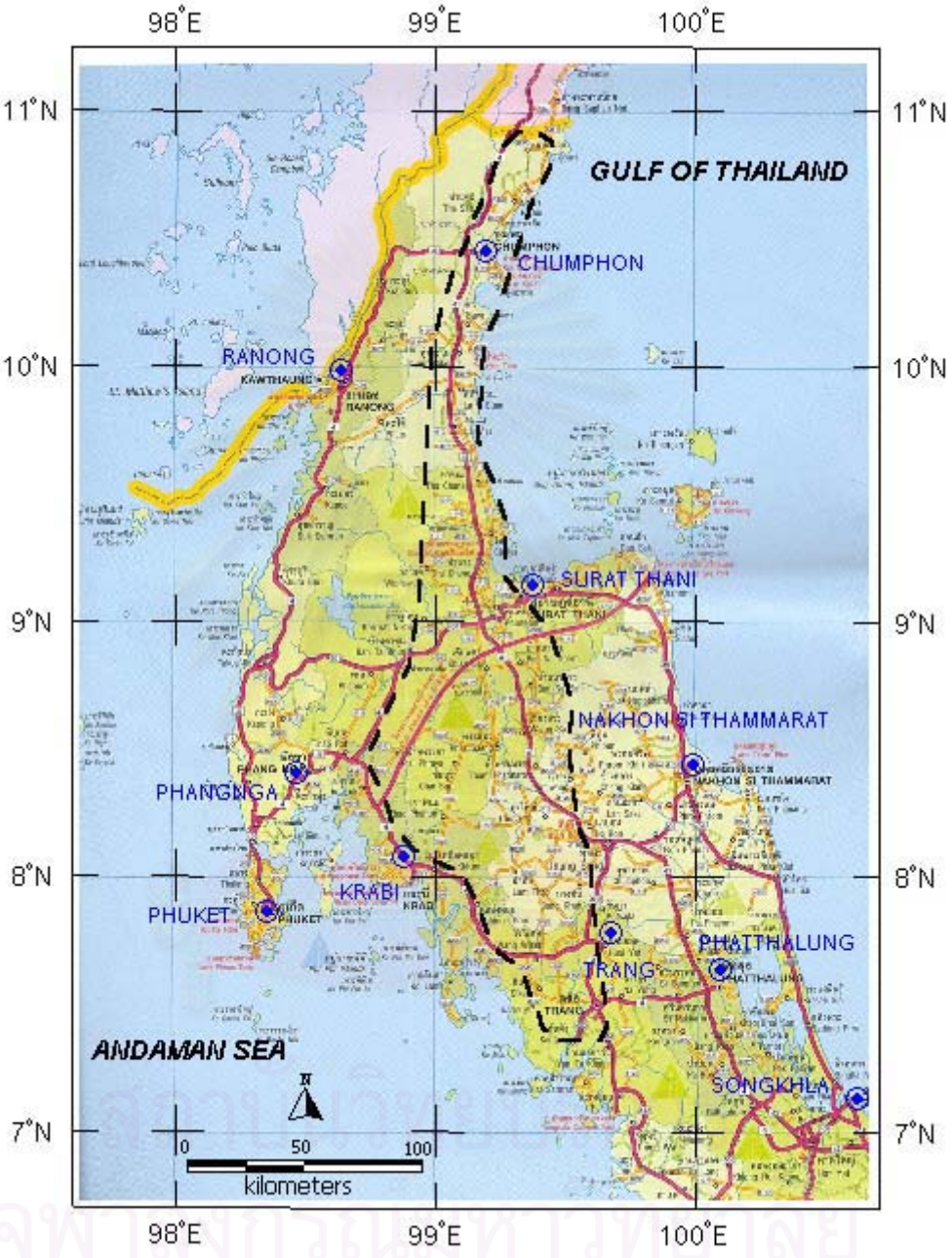

Figure 1.1. Location of the study area.

1.3.1 Topography

The topography of upper southern Thailand can be divided into 3 types, namely an area of high elevation, the undulating terrain, and an area of low elevation (Figure 1.2). The area of high elevation includes the hill chains with the elevation higher than 200 meters above the mean sea level (MSL). It locates to the western and southeastern parts of the study area, and covering about 25% of the region. The highest mountain is Khao Si Suk with the approximate elevation of 550 meters MSL.

The undulating terrain includes an area with the elevation between 100-200 meters MSL. This is an area of para-rubber and oil-palm plantations and cover 45% of the region, and covers the most part of the present study area.

The area of low elevation includes the flat floodplain with the elevation below 100 meters MSL. The floodplain deposits are along Ta Pi River and its tributaries to the rover month. It covers about 30% of the region.

1.3.2 Drainage Pattern

The surface drainage system here is composed of Ta Pi River and its tributaries such as Khlong Bang Pra and Khlong I Pan. The main river flows east and northeastward into the Gulf of Thailand. There are 2 types of drainage patterns in the study area, subangular and subdendritic. The subangular type is occurred in the undulating terrain in the east of the study area while the subdendritic type is occurred in the area of low elevation. They are believed to be under the structural and lithologic controls.

1.3.3 Climate

The climate of the study area, which is a part of peninsular Thailand, is generally a tropical monsoon type. The rainy season is normally longer than the dry season.

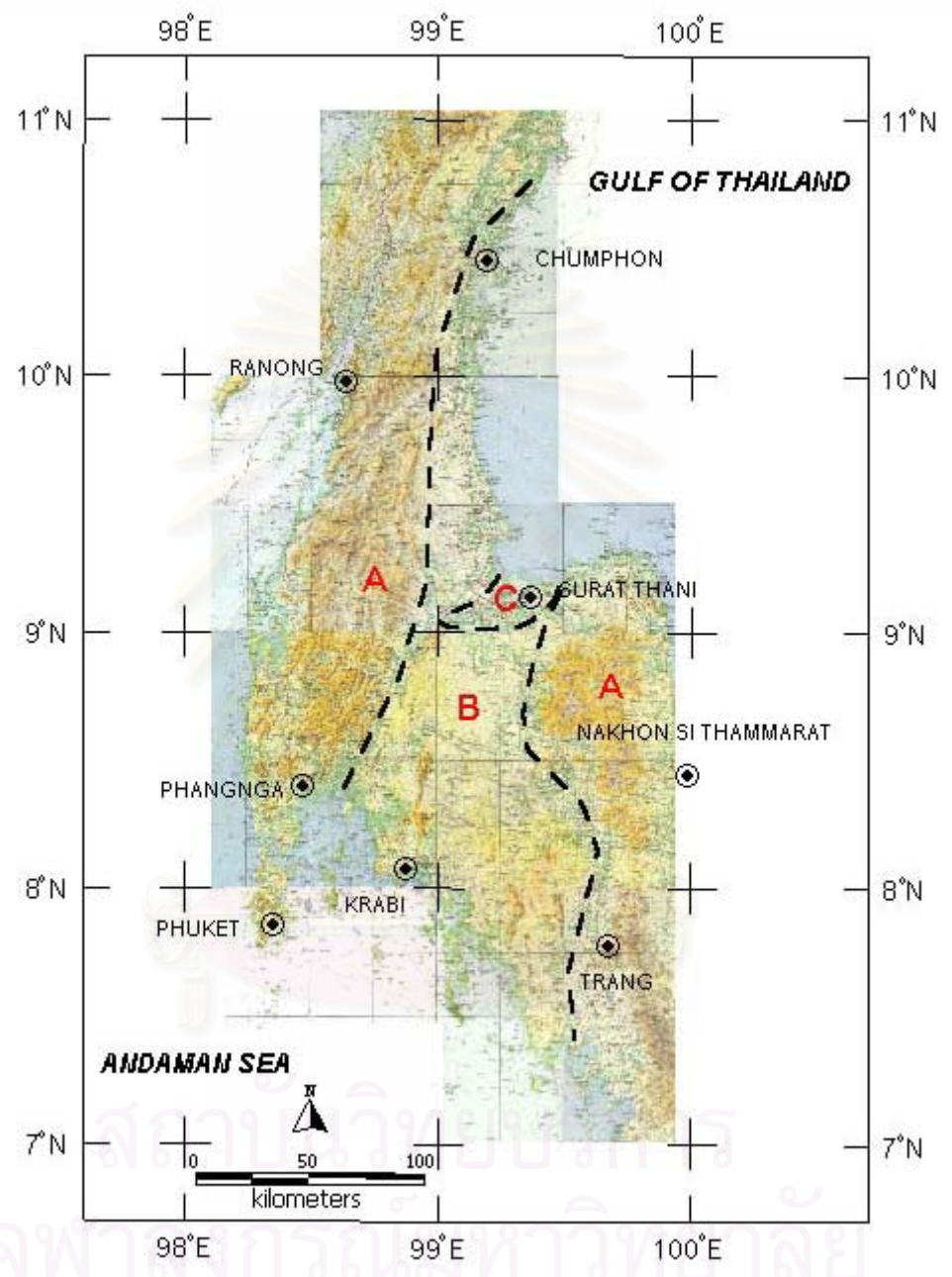

Figure 1.2. Topography of the study area. The terrains are (A) area of high elevation, (B) undulating terrain, and (C) area of low elevation.

According the meteorological records from 1995 to 1999, the maximum summer temperature 38.8°C was noted in 1998, and the minimum cool-climate temperature 17.8°C, also in 1998. The year-round temperature is 26.7-28.3°C.

The average annual rainfall of the region is normally very high. The maximum rainfall was 2,242.2 mm in 1996, and the minimum rainfall was 1,148.5 mm in 1998.

1.4 Previous Works

Among the oldest systematic studies in peninsular Thailand was perhaps that on the structural geology of the Mesozoic rocks reported by Garson and others (1975) around Phuket, Phangnga and Takua Pa. The report revealed the deformation to have been resulted from folding and from vertical and lateral movements along the high-angle faults. Fold axes trended northerly to northeasterly while the plunged of many structures could not be determined accurately, but probably rarely exceeded 20°. In general the fold limbs are steepest in the western part of the region and along the NE-trending faults. Most of the longer faults had a northeasterly trend, while a few major faults trended approximately east-west, and there were a number of minor faults with a northwesterly trend. The largest fault is the northeastery-trending Khlong Marui Fault with a length exceeding 55 km.

Asama and others (1981) studied the fossil plants in strata of gray to brownish red siltstone, silty sandstone, and fine-grained sandstone in Trang area. They described altogether 6 species as follow; Family Filicales: *Gleichenoides gagauensis* Kon'no, *Gleichenoides pantiensis* Kon'no; Familly Bennettitates: *Otozamites gagauensis* Kon'no, *Otozamites* sp.; and Family Coniferales: *Podozamites pahangensis* Asama, *Frenelopsis* sp. They concluded that the age of fossils was Early Cretaceous and that the plant fossils in this Trang area were different from the plant fossils of the Huai Hin Lat Formation of Korat Group (Kon'no and Asama, 1973) but were similar to those in Gagau Group in Malay Peninsula.

The systematic mapping of the lithologic units in a scale of 1:50,000 in southern Thailand began in 1989 by the Geologic Survey Division, Department of Mineral Resources. Raksaskulwong and others (1989) classified the Mesozoic rocks in Thung Yai-Khlong Thom area and grouped them into 5 formations in ascending order as Sai Bon, Lam Thap, Khlong Min, Sam Chom, and Phun Phin formations. The Khlong Min formation was reestablished from the Khlong Min member in Sin Pun formation then of the Tertiary age. The fossils of pelecypod in Khlong Min formation, *Corbulanjalindungensis* of Jurassic age, suggested such change.

The geological report of Amphoe Khuan Sa, Ban Bang Pha and Amphoe Khao Phanom map sheets was prepared by Prasomsap and Supasunthornkul (1989). According to this work, the structural geology of the area was primarily the faults which also affected the folding. Thus the faults controlled the trending of the basement rocks as well as the Tertiary basins. Three major faults groups were the north-south normal faults, northwest-southeast strike-slip faults and northeast-southwest strike-slip faults.

Chonglakmani and others (1990) studied the conchostracans fossils from the locations half way between Trang and Krabi in peninsular Thailand. The rocks bearing abundant and well-preserved conchostracan fossils were light yellow shale and calcareous dark gray mudstone. The fossils of crocodile teeth, fish teeth and scales as well as insect remains, etc were also found. These conchostracans fauna of at least 3 genera and 6 species were recognized. The assemblage, demonstrated strongly Middle Jurassic age, consisted of *Pseudograpla* cf. *Yuzhongensis* Chen, *Pseudograpla jialingensis* Duan, *Pseudograpla siamensis* (sp. nov), *Pseudograpla* sp., *Paleoloplestheria chinensis* Chen, and *Palaeolimnadia*? sp.

Raksaskulwong (1994) then gave a name Trang Group to the sedimentary unit and re-subdivided it into 4 formations in ascending order as Chumpon Red Beds formation, Khlong Min formation, Khao Sam Chom formation and Phun Phin formation, respectively. The Chumphon Red Beds formation consisted mainly of brownish red to light brown quartzitic and arkosic sandstones interbedded with siltstone and gray

mudstone with plant remains and pelecypods. The rocks were believed to be deposited in a transitional marine environment. Khlong Min formation composed of mudstone, fossiliferous mudstone and oil shale. Fossils of both vertebrates and invertebrates were abundant in this formation. These fossil assemblages reflected a lacustrine environment. The Khao Sam Chom formation predominantly composes of conglomerate and poorly cemented coarse-grained sandstone of alluvial fan and braided stream origins. The Phun Phin formation composed mainly of brownish red, fine-grained sandstone and siltstone. Trough and planar cross-beddings reflecting a braided stream environment were very common in this formation.

Raksaskulwong (1994) also reported the fossils in paralic massive fine-grained sandstone of Chumphon Red Beds formation, which were bivalves of *Modiolus* sp., fern-like leaves, small lenses of bituminous jets and trace fossil of *Thalassinoides*, and the fossils in muddy limestone of Khlong Min formation, which were vertebrate fossils as the turtle shell plate, crocodile teeth, amphibian remains, and bivalves. The fossils were considered to be equivalent to those of the lower part of the Khorat Group in northeastern Thailand, and to some parts of Gagau Group in Malay Peninsula.

Ampornmaha (1995) studied the carbonate rocks in the Phatthalung area, and proposed Chaiburi Formation to represent the Triassic rocks in this area. The carbonate rocks in the Phatthalung area and elsewhere in peninsular Thailand was previously believed to be Permian Rat Buri Limestone. In Ampornmaha's (1995) report, Chaiburi Formation was divided into 3 members, the Phukhaothong Dolomite, Chiak Limestone, and Phanomwang Limestone, in respectively ascending order. The conodont identification indicated Dienerian to Smithian (Early Triassic) to Carnian (Late Triassic) in age.

The third year geology students of Chulalongkorn University did the summer fieldwork studies in this area from Chumphon down to Trang in 1996, 1998, 2000 and 2002. They had found that the Mesozoic rocks lied angular unconformably on the Upper Paleozoic basement. The major structural trend in the Mesozoic units was north-south to

northnortheast-southsouthwest. The structures here were essentially synclines and anticlines. Many folds were the parasitic ones of yet the major folds. Some parasitic folds were noted to be overturned. The faults in the area are only minor faults composing of the northeast-southwest and northwest-southeast strike-slip faults.

Kanjanapayont (1998) studied the structural geology in Amphoe Wangwiset and Amphoe Sikao, Changwat Trang where the Mesozoic rocks covered most of the area. The study indicated that the area was tectonically deformed so that the major structure was an elongated N-S trending, open upright plunging syncline with associating lower-ordered anticlines and synclines. The smaller-scaled folds were with the moderately west-dipping normal limbs and somewhat steeply east-dipping normal limbs, which sometimes became west-dipping overturned limbs. Thus the axial planes or the folds steeply inclined toward the west.

Hinthong (1999) compiled the geologic data of the Southern Seaboard Development Project area in upper southern peninsular Thailand, namely Changwat Phangnga, Krabi, Surat Thani, and Nakhon Si Thammarat. The development project comprised five significant components; Surat Thani Areal Development Program, New East-West Road Link and Regional Highway Improvement Program, Khanom Deep Sea Port Complex, Krabi Deep Sea Port Complex and Nakhon Si Thammarat City Development Program. The study revealed the geology of the area to be affected from the intrusion of Cretaceous granitic rocks. The Khao Luang batholith, exposing on both the western and eastern coastal highland ranges, were tectonically deformed. The structural feature of the central part were essentially a north-south elongated basin in where the younger sediment deposited.

Teerarungsigul (2000) studied the lithostratigraphy of non-marine Mesozoic rocks at Thung Yai-Khlong Tom area of Changwat Krabi. He proposed Trang Group subdivisions to be lithostratigraphically rearranged into 4 formations, namely Khlong Min, Lam Thap, Sam Chom and Phun Phin formations, in respective ascending order. The Trang Group unconformably overlied the marine Triassic rocks of Sai Bon formation,

which was not a part in Trang Group. Sai Bon formation angular unconformably overlied the Paleozoic basement. The total thickness of Trang Group varied from 65 to 1,145 m. The major geologic structures included the folds, fractures and faults, which mainly orientated in the north-south direction. There were 3 sets of faults, northeast-southwest left-lateral strike-slip faults, northwest-southeast right-lateral strike-slip faults and east-west minor faults. It was noted that the northwest-southeast and east-west faults had been offsetted by the northeast-southwest faults. The joints were mainly in northnortheast-southsouthwest, northwest-southeast and east-west directions. The northnortheast-southsouthwest set was the most important fracture set in all formations except in Phun Phin formation, which contained mainly of east-west set. The antiforms were restricted to the sedimentary units being peripherally to the granite plutons and were believed to be the result of foreceful granitic emplacement.

1.5 Methods of Investigation

The present study was done in 4 steps as the followings (Figure 1.3).

(1) Data collection and study planning

The general geological data in the previous works done in the study area were collected, reviewed and complied for the further step of work. Additionally the geological reports were analyzed, the topographic map, LANDSAT imagery and air-photographs were interpreted. Then the further study was planned.

(2) Field investigation

This step includes a field reconnaissance on the stratigraphy of the Mesozoic units and a general structural geologic survey in the study area from Changwat Chumphon down south to Changwat Trang. After then, the detailed studies were emphasized in Changwat Surat Thani and the eastern portion of Changwat Krabi where new outcrops were noted as the road-bank exposures along many newly constructed highways. Three traverse lines along the highways which approximately cross-cut the structural trends were selected for the mesoscopic structural data collection in the

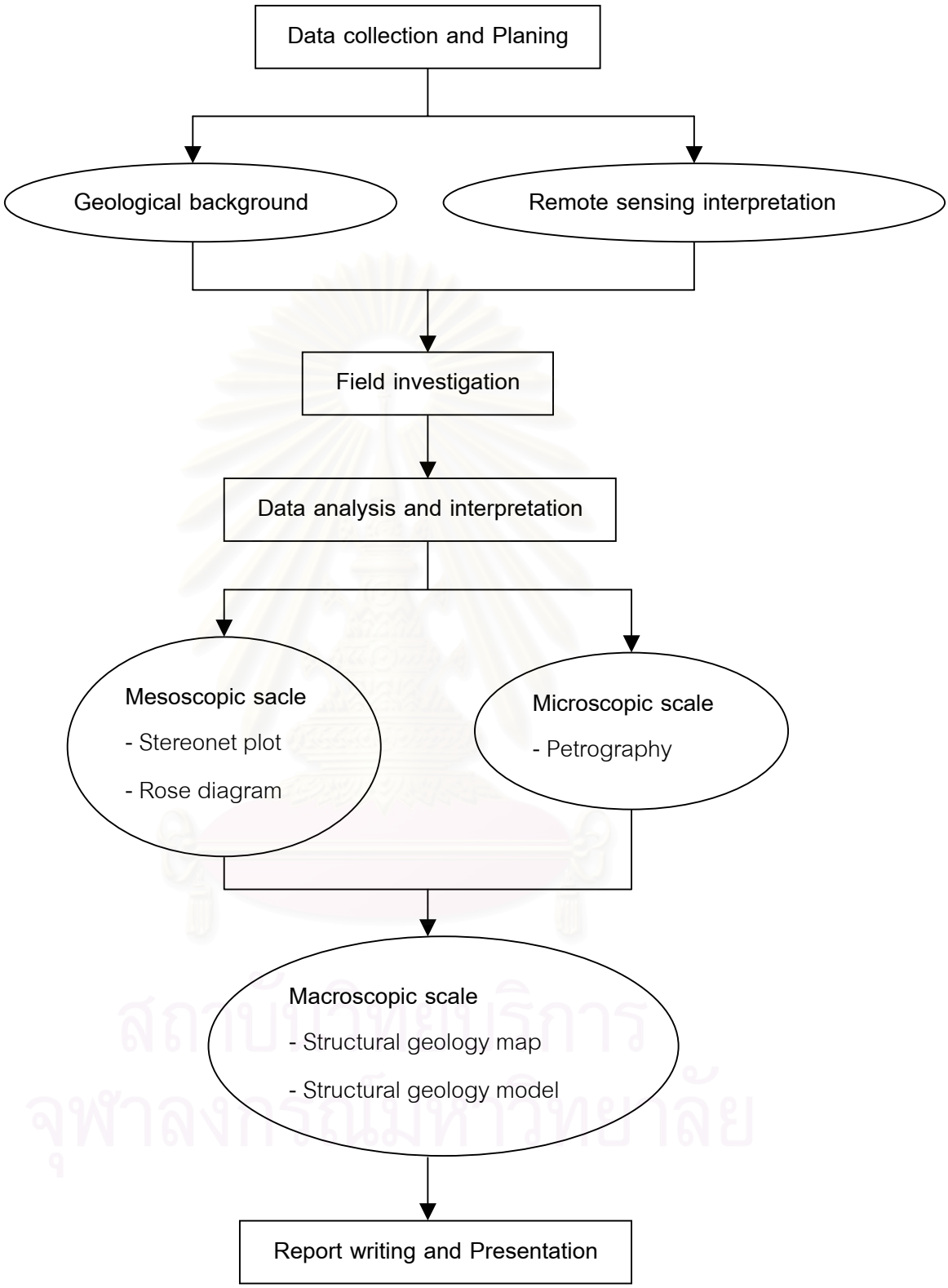

Figure 1.3. The methods of investigation flow chart.

successive Mesozoic units, which the handspecimens were collected for the microscopic description. These traverse lines are named Cross-sections 1, -2 and -3 in the following chapters. The detailed study was done primarily in the area of Ta Pi syncline (See further).

(3) Data analysis and interpretation

The collected mesoscopic data were plotted using a lower-hemisphere, equal-area stereonet and a rose diagram. The plots were further processed using the NETPROG program provided by D.T.Allison of University of South Alabama, U.S.A., while the microscopic structures were described under a polarized-light microscope. The mesoscopic and microscopic study results were compiled for a macroscopic model, and an interpretation of the structural geology sequence and tectonic events was performed.

(4) Report writing and presentation

The report on the descriptive geologic structures of all scales was prepared in accordant with the objectives of the study. This description was accompanied by a surface structural geologic map. The regional geologic structural model with suggestion of the tectonic procedure thereby was also attempted.

CHAPTER 2

GENERAL GEOLOGY

The general geology herewith includes the geologic setting of all stratigraphic units and igneous activities found in and adjacent to the study area, with a special emphasis on the Mesozoic stratigraphy of upper southern Thailand in terms of areal distribution and stratigraphic description. A more detailed stratigraphic description in the present study area will be discussed accordingly. Afterward the knowledge of regional structural features and the presumed tectonic history will be indicated.

2.1 The Stratigraphic Units and Igneous Activities Found in Southern Thailand

The area is predominantly underlain by the sedimentary rocks of different ages ranging from Permo-Carboniferous to Quaternary. The Permo-Carboniferous rocks, namely Kaeng Krachan Group (Raksaskulwong and Wongwanish, 1993), are characterized by the dark-colored pebbly mudstone, graywacke, and siltstone. Above conformably lie the Permian rocks showing a karst topography. The Permian lithology commonly is light- to medium gray limestone, occasionally with chert nodules, and locally becoming dolomitic limestone to dolomite. The name “Ratburi Limestone” (Brown and others, 1951) or “Ratburi Group” (Javanaphet, 1969) had been given for this Permian succession through out southern Thailand.

The Mesozoic rocks in this region which are the rocks of the present interest are subdivided into marine Triassic rocks and non-marine Jurassic-Cretaceous rocks. The Triassic rocks were essentially of Sai Bon Formation, while the non-marine Mesozoic rocks were of Trang Group of Raksaskulwong (1989). The formations of Trang Group are listed in ascending order from older to younger by Raksaskulwong (1994) as follows: Chumphon Red Beds, Khlong Min, Sam Chom, and Phun Phin. Teerarungsigul (1999) had however rearranged the Trang Group into 4 formations as Khlong Min, Lam Thap, Sam Chom and Phun Phin Formations, respectively. The Mesozoic stratigraphic units

angular-unconformably overlie the Permian carbonate Ratburi Group and the Permo-Carboniferous pebbly mudstone Kaeng Krachan Group, and are further angular-unconformably overlain by the Tertiary and Quaternary sediments.

The Tertiary sediments are mainly fresh- and brackish water shale, sandstone, marlstone and coal seams. The name Krabi Group is given to represent the Tertiary strata in peninsular Thailand (Chaodumrong and others, 1983). The isolated Tertiary basins are mainly the graben and/or half garben or tilted fault-block kind, formed by reactivation of the basement structures. The shape and trend of the basins are elongated following the regional strike of the older formations, which are also controlled by faulting. The fossils of the famous Shell Cemetery (extensive gastropod accumulation) tourist attraction and pollen associated with claystone in Changwat Krabi was recently reconsidered to be of Oligocene age.

The Quaternary marine and fluviatile formations spread widely along the coastal zones of the Gulf of Thailand and on the western Andaman coast of the Thai peninsula. The Pleistocene fluviatile sediments are characterised by a fine-grained rock unit of high plasticity, high oxidation, with mottled structure and some traces of plant remains. The unit unconformably overlies the older basement units. The gradual change of depositional environment from fluviatile to shallow marine environment was observed to be reflected by the massive clay with some sand lenses. Chaimanee (1987) proposed that the sea level at that time was generally 10 meters higher than the present one. The marine influence being decreased upward probably was caused by a highly sedimentary influx from upland areas as well as tectonic uplifting and global sea level drop during late Quaternary .

Some volcanics and shallow intrusive rocks are exposed along the north-western margin of Sin Pun basin and eastern margin of Krabi basin (Raksaskulwong and others, 1989). The ages are Cretaceous to Tertiary periods.

2.2 The Mesozoic Stratigraphic Units of Upper Southern Thailand

Throughout Thailand the Mesozoic stratigraphic units are rather common. They are both of the continental and marine origins. The marine type consists of Triassic sediments exposed in numerous areas such as Lampang, Phrae, Nan, Tak, Mae Sarieng in north to northwest, to Chantaburi, Rayong, Kanchanaburi in eastern Thailand, and further to Pattalung and Songkhla in the south (Chonglakmani, 1983). The marine Jurassic sediments are also occurred in Tak, Kanchanaburi, and Chumphon, while the continental red beds are mainly distributed to form the Khorat plateau, and scattered as separate hills elsewhere down to the southern peninsular Thailand.

In the southern region, Ampornmaha (1995) studied the Triassic carbonate rocks in the Phatthalung area, and proposed the Chaiburi formation representing the Triassic rocks there. These carbonate rocks here and elsewhere in peninsular Thailand were previously believed to be the Permian Rat Buri Limestone. According to her work, Chaiburi formation was divided into 3 members, the Phukhaothong Dolomite, Chiak Limestone, and Phanomwang Limestone, respectively in ascending order. The conodont identification indicateds Dienerian to Smithian (Early Triassic) to Carnian (Late Triassic).

Grant-Mackie and others (1978) reported the marine Triassic sequences in Songkhla area being similar to those of the Lampang Group in northern Thailand, except lacking of the volcanogenic components, and containing excessive conglomerate. The informal name, Na Thawi formation, was applied for the most of Triassic rocks in Songkhla region. The formation was characterized by a thin-bedded turbidite sequence with a fold axis trending regionally north-south in so-called Payang syncline. The fossils, *Daonella* sp. (Ladinian-Carnian), were located to the west of syncline, at approximately 60 km. south of Songkhla. The conglomerate namely Khao Mai Kiat Conglomerate consists of poorly sorted clasts up to small cobble size of quartzites, with the current-bedding indicating the northwardly flow direction. This conglomerate was likely to be the basal conglomerate of the Triassic rocks.

The marine Triassic rocks in this area had been studied in detail again by Grant-Mackie and others in 1980. The rock unit was subdivided into 4 lithostratigraphic units in descending order as Sani Formation, Klong Kon Limestone, Chedi Conglomerate, and Suan Chan Formation. At Amphoe Na Thawi, the marine Triassic rocks exposed in descending order as Lam Long Sandstone, Wang Yai Siltstone, Na Thawi formation, and Mai Kiat Conglomerate.

In upper southern Thailand, the Mesozoic sedimentary sequences of marine and non-marine origins were noted from Chumphon, Surat Thani, Nakhon Si Thammarat, Krabi to Trang (Figure 2.1).

(1) Chumphon area

Meesook and Grant-Mackie (1994) studied the rocks in Chumphon area and suggested them to be of Khao Lak Formation. The rocks consist of interbedded sandstones and shales with cherty limestones. The outcrops of these rocks with characteristic fossils are exposed essentially in Amphoe Tha Sae. The fossils of ammonites and bivalves indicating the Early Bajocian age had been found in the shaly rocks at Khao Lak, some 80 kilometers north of Chumphon Town.

(2) Nakhon Si Thammarat area

The Mesozoic rocks in this area expose at Khao Phra Bat and Khao Daeng in Amphoe Chian Yai and Hua Sai. The sandstones, siltstones and mudstones, brown to brownish gray in color, with bivalves and plant remains characterize the rock unit here. Meesook and Grant-Mackie (1994) proposed the name of this lithostratigraphic unit as Pra Bat Formation, and reported the age of the Pra Bat Formation to be Toarcian.

(3) Surat Thani-Krabi-Trang area

Raksaskulwong (1994) proposed the non-marine Mesozoic rocks in this area as Trang group. These rocks compose of reddish brown shale, sandstone, conglomerate and reddish brown fine-grained sandstone of totally 760 meters in thickness. This sequence unconformably overlies Permian Ratburi Group. The Mesozoic unit expose in

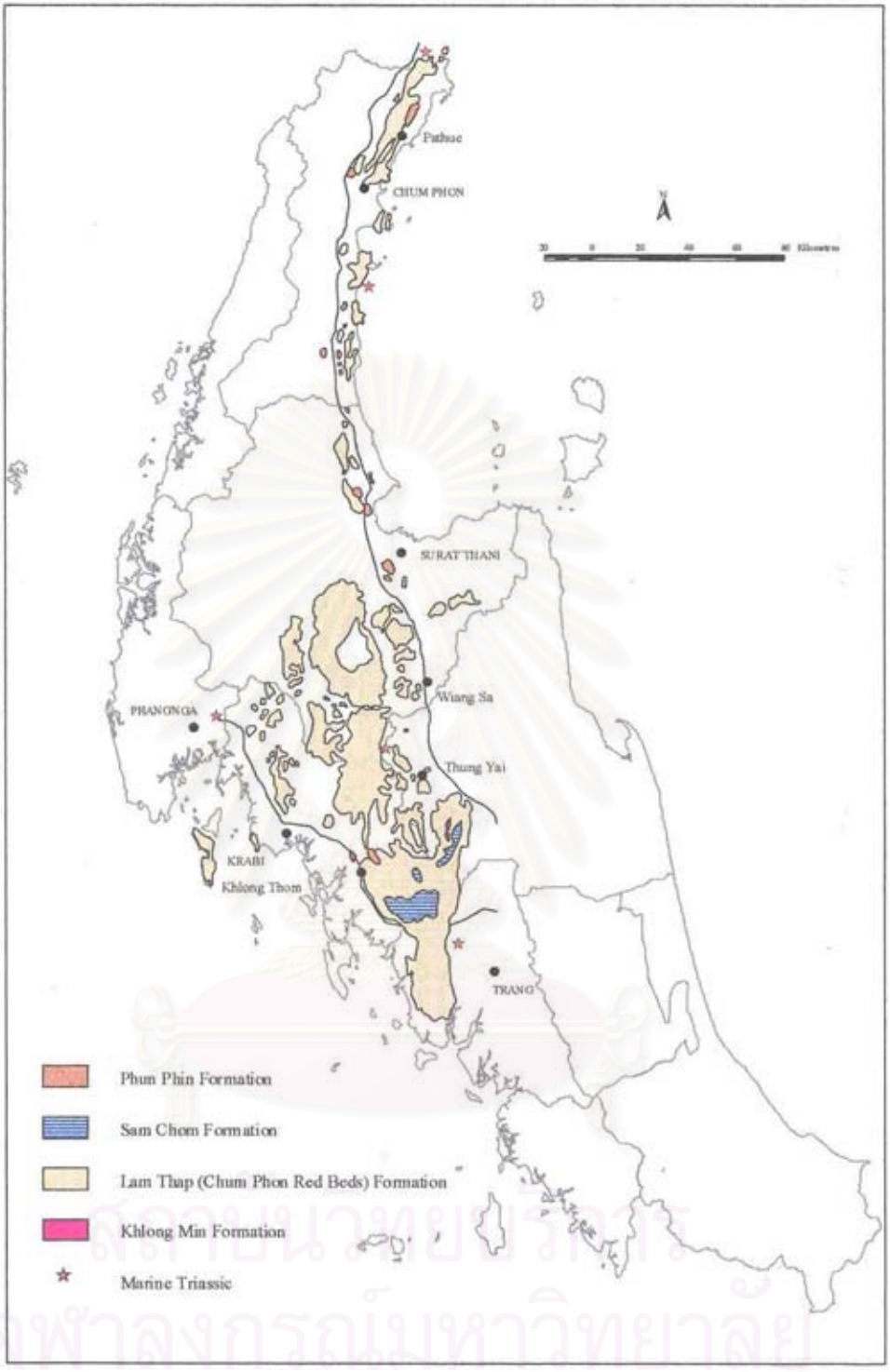

Figure 2.1. The distribution of Trang Group, southern Thailand (modified after Raksaskulwong, 1994).

the area of Amphoe Wiang Sa of Surat Thani, Amphoe Thung Yai of Nakhon Si Thammarat, Amphoe Khlong Thom of Krabi, and Amphoe Si Kao and Wangwiset of Trang covering an area approximately 3,500 square kilometres. Teerarungsigul (1999) had rearranged the Trang Group into 4 formations as Khlong Min, Lam Thap, Sam Chom and Pun Phin Formations, respectively.

2.3 Descriptive Mesozoic Stratigraphy of Upper Southern Thailand

Throughout upper southern Thailand from Changwat Chumphon down to Changwat Trang which is essentially the area of this study, the Mesozoic stratigraphic units are found angular-unconformably overlying the Permian carbonate rock of Ratburi Group and PermoCarboniferous pebbly-mudstone Kaeng Krachan Group. The Mesozoic units are further overlain by the Tertiary (Krabi Group) and Quaternary rocks. They are further subdivided into 2 units, the Triassic rocks and Jurassic-Cretaceous rocks according to the different environment of deposition, marine and non-marine respectively. The Mesozoic stratigraphic units are described from the oldest to the youngest, as following.

Marine Triassic rocks

The Triassic rocks in the upper southern Thailand were of Sai Bon Formation (Raksaskulwong, 1989) whose type locality exposes on a small hill in Amphoe Thung Yai of Changwat Nakhon Si Thammarat. The outcrops of this formation were also found on Khao Kaew, east of Amphoe Thung Yai, and on Khao Khom and Khao Hin Luk Chang, east of Amphoe Khlong Thom.

Sai Bon Formation angular-unconformably overlies the basement rocks composing of the Permian carbonate rocks (Ratburi Group) and PermoCarboniferous Kaeng Krachan Group. Tantiwanit and others (1989) reported that the basal conglomerate of Sai Bon Formation was found at Ban Lang Khao and on Khao Khieo in Amphoe Phanom, Surat Thani. According to Raksaskulwong (1994), the formation consists of mainly brownish red siltstone, mudstone and fine-sand sized sandstone.

Lenses of dolomitic limestone commonly occur among them in the lower part. Pelecypods (*Plaeocardita* sp.), gastropods and plant remains are the common fossils, being found both in the brownish red mudstone and dolomitic limestone lenses. This fossil assemblage indicated that the environment of deposition was a shallow marine during Upper Triassic time (Raksaskulwong and others, 1989).

Non-marine Jurassic-Cretaceous units

The non-marine Mesozoic rocks in southern Thailand have been designated by Raksaskulwong (1994) in ascending order, namely, Chumphon Red Beds, Khlong Min Formation, Sam Chom Formation, and Phun Phin Formation, respectively. The units expose form Changwat Chumphon to Changwat Trang.

(1) Chumphon Red Beds

This unit exposes as a north-south strip at Ban Thang Luang and Ban Nua Khlong of Amphoe Khlong Thom, Changwat Krabi, and west of Amphoe Wiang Sa, Changwat Surat Thani. The basal conglomeratic outcrops are noted at Khao Reak Pol and Khao Kwang as shown in the Ban Nua Khlong map sheet (4825 III). The succession comprises thick-layered, yellowish brown-to-white arkosic sandstone with cross bedding. This sandstone is intercalated with greenish gray, reddish brown siltstone, sandstone and mudstone. Some plant remains are found in mudstone. The unit is believed to be deposited in transitional marine environment. It is Jurassic in age.

(2) Khlong Min Formation

This unit crops out locally at Khlong Min in Ban Map Ching, Pak Phraek and Khlong Tae Pa northwest of Khlong Thom, and Laem Paew in Ban Bo Muang. It mainly consists of fossiliferous limestone interbedded with mudstone containing abundant fossils of vertebrates parts, conchostracans (*Estheria*), bivalves, gastropods, ostracods and pollens. The succession and assemblage of fossils are similar to those of the Khao Lak formation of Meesook and Grant-Mackie (1994). The environment of deposition is concluded to be lacustrine, forming in middle Lower Jurassic.

(3) Sam Chom Formation

This unit is exposed locally at Khao Sam Chom, Khao Nam Daeng, Khao Khao, Khao Chong Din in Ban Map Ching, and Khao Khrop Katha east of Khlong Thom, Changwat Krabi. The morphology of this formation is usually illustrated as the high mountains. Sam Chom Formation predominantly consists of conglomerate and poorly cemented coarse-sandstone. The clasts of conglomerate, occasionally 12 cm. across, are quartzite, chert, volcanic rock, brownish sandstone and siltstone. Raksaskulwong and others (1989) suggested that this formation was deposited in the braided streams of alluvial fans in the Jurassic time.

(4) Phun Phin Formation

This unit represents the rocks being exposed at Ban Wat Kanang, 12 km. east of Amphoe Thung Yai, and west of Amphoe Wiang Sa of Surat Thani, and 10 km. northeast of Amphoe Khlong Thom of Krabi along Highway 4038. The relationship between this formation and the other units in Trang Group is uncertain. It consists of fine-to medium-sand-sized arkosic sandstone, maroon to reddish brown in color, intercalated with thin-layered, reddish brown siltstone, mudstone and conglomerate/breccia. The conglomerate is matrix-supported, and contains angular to subangular pebbles of quartz, chert, quartzite, and sandstone with poorly to moderately cementation. The sandstone commonly displays cross-beddings. This formation is believed to be deposited in a braided stream environment in the Cretaceous time.

Teerarungsigul (1999) however rearranged the Trang Group into 4 formations as Khlong Min, Lam Thap, Sam Chom and Pun Phin Formations, from older to younger respectively. In his study, Raksaskulwong's (1994) Chumphon Red Beds had changed the name to be Lam Thap Formation, and also been exchanged the successive position with Klong Min Formation. Thus Lam Thap Formation is equivalent to Chumphon Red Beds but instead overlying Khlong Min Formation. A detailed description of the successive formations is below.

(1) Khlong Min Formation

This type locality of unit exposes at Khlong Min as that in Raksaskulwong and other (1989). It is also found at Ban Map Ching, Ban Pak Phraek, and Khlong Tae Pa norhtwest of Amphoe Khlong Thom and Laem Paew of Ban Bo Muang, Changwat Krabi. The Khlong Min Formation mainly consists of 4 lithofacies; from bottom to top, the mudstone intercalated with fossiliferous limestone, siltstone, calcareous sandstone, and fossiliferous limestone.

The first, the mudstone intercalated with fossiliferous limestone lithofacies is commonly characterized by mudstone being intercalated with thin-layered fossiliferous limestone and bituminous jets. The limestone is microscopically designated as biomicrite. Mudstone consists of fine-grained bioclasts and shell fragments, which are partly embedded in medium to dark gray micritic matrix. This lithofacies contains abundant fossils such as *Estheria* sp., ostracods (*Darwinulla* sp.), spore-pollens (*Classopollis* sp.), vertebrates and commonly hummocky structures.

The siltstone lithofacies is characterized by siltstone and biomicrite, reddish brown to maroon in colour, with mottled texture. The caliche is also common in this lithofacies. The upper part of this lithofacies generally consists mainly of gray mudstone intercalated with thin layered limestone. Fossils are particularly of the vertebrates of hybodont shark, *Lepidotes*-like actinopterygians, and lungfish (Buffetaut and others, 1994).

The calcareous sandstone lithofacies is mainly calcareous sandstone, yellowish brown, medium-grained, well sorted with common flaser bedding. Petrographically, this lithofacies consists of calcareous sandstone and limestone. The sandstone clasts compose mainly of quartz, feldspar and minor amount of rock fragments with calcareous cement. Most quartz grains are fine-to medium-sand-sized, subrounded and moderately sorted with iron oxide coating.

The fossiliferous limestone lithofacies is characterized mainly by limestone interbedded with calcareous sandstone, medium-grained, well sorted with flaser bedding. The light gray-gray limestone beds contain abundant wood fragments and bivalve of *Modiolus* sp. The calcareous sandstone clasts consist of quartz, feldspar and rock fragments. Most quartz grains are fine-sand-sized, subangular to subrounded, and well sorted. Most of the grains are cemented by calcite and abundant opaque minerals.

(2) Lam Thap Formation

The Lam Thap Formation takes its names from Lam Thap district of Changwat Nakhon Si Thammarat. Lam Thap Formation consists of 2 lithofacies; the thick-bedded arkosic sandstone at the bottom, and siltstone interbedded with shale at the top.

The thick-layered arkosic sandstone lithofacies consists of arkosic sandstone and conglomeratic sandstone, yellowish brown, well sorted and subangular to subrounded, thick-layered with graded bedding and cross-bedding. The lateral facies changes are very common. The arkosic sandstone composes mainly of quartz, feldspar and rock fragments with siliceous and ferrugeneous cements. Most of the clasts are fine-to medium sand-sized and well sorted.

The siltstone interbedded with shale lithofacies is characterized by alternating beds of siltstone, shale, and thin-layered sandstone. The colour of siltstone and shale are reddish brown to maroon. The sandstone is laminated to thin-layered and medium-sand-sized. Shale is gray to brownish gray with abundant fern-like leaves, and the bivalve.

The grain size of the lithofacies suggests a fining-upward condition, while the disappearance of the lithofacies suggest also the thinning upward. Lam Thap Formation conformably overlies Khlong Min formation and is conformably overlain further by Sam Chom Formation. However, in some place it conformably overlain by Phun Phin Formation indicating a local unconformity.

(3) Sam Chom Formation

This unit is exposed locally at Khao Sam Chom, Khao Nam Daeng, Khao Khao, Khao Chong Din, Ban Map Ching and Khao Khrop Katha east of Amphoe Khlong Thom. It is characterized by conglomerate, conglomeratic sandstone and thin-layered sandstone. Conglomerate are matrix-supported and clasts are made up mainly of quartz, chert, sandstone, and some volcanics and size varies from granule to boulder. The sandstone is yellowish brown to light gray, thin-layered, and medium-sand-sized, consisting mainly of quartz, feldspar and dark minerals with common graded bedding, and usually shows sharp contacts with overlies mudstone, siltstone of reddish orange to reddish brown. The lowerest part of this formation is marked locally by thin-layer sandstone.

(4) Phun Phin Formation

Phun Phin Formation receives its name from the exposures of deep-red sandstone at Amphoe Phun Phin, Changwat Surat Thani. The unit exposes at Ban Wat Kanang, 12 km. east of Thung Yai, at the west of Wiang Sa of Surat Thani, and in the northeast of Khlong Thom of Krabi along the road no. 4038, 10 km. from Amphoe Khlong Thom toward Lam Thap of Changwat Krabi. The lower boundary of this formation to the other older Mesozoic units is uncertain. Phun Phin Formation consists of 2 lithofacies: the fine-grained sandstone, and the fanglomerate.

The fine-grained sandstone lithofacies is characterized at the lower part by mainly fine-sand-sized sandstone and siltstone. The sandstone is composed of quartz in fine-grained matrix, and feldspar with ferrugeneous cement, thick-layered, parallel bed type, red to reddish brown, graded bedding, common planar and trough cross-bedding. The upper part of this lithofacies consists mainly of thin-layered, reddish brown sandstone, and thin-layered conglomerate with small to large cross-bedding, and locally bioturbated. Sharp contacts between fine sand-sized sandstone and conglomerate are common.

The fanglomerate lithofacies consists of conglomerate/breccia with both clast-supported and matrix-supported. Clasts are made up mainly of quartz, chert, quartzite, sandstone and rock fragments, angular to subangular, average granule to boulder size with maximum size of approximately 0.60 m.

Phun Phin Formation conformably overlies Sam Chom Formation and underlies Tertiary units. Raksaskulwong (1994) reported that the basal conglomerate of Tertiary deposits in the vicinity of Thung Yai area, particularly exposing along the margin of Sin Pun basin may overlies the upper part of the Phun Phin Formation. But the actual contact between the basal conglomerate and the Phun Phin Formation has never been observed.

In the present study, the Mesozoic stratigraphic units of the study area include Sai Bon Formation of Raksaskulwong's (1989) and Trang Group of Teerarungsigul's (2000). The rock units were visited in the field especially along 3 selective traverse-lines where the fomations were best exposed, and the lines were somewhat crosscutting the general structural trending. The correlation of the lithology was done accordingly to the description of the above mentioned lithologic units, especially where the typical stratified rocks were said to expose. In addition to the field description of the rocks, the thinsections were prepared for the microscopic and petrographic study.

Sai Bon Formation in this area was noted to be calcareous clastic rocks and dolomitic limestone. The color of calcareous siltstone is light gray with calcite vein (Figure 2.2). The rock is fine-grained, high sphered, subrounded, and well sorted in thin-section (Figure 2.3). Calcareous sandstone is light gray in color (Figure 2.4). The rock is very fine-grained, high sphered, subrounded, and well sorted (Figure 2.5). Dolomitic limestone is also gray (Figure 2.6). In petrography, it shows xenotopic - A texture (Figure 2.7).

The specimens of non-marine Mesozoic units were found only Lam Thap Formation. There is siltstone and arkosic sandstone. The siltstone is yellowish-brown in

Figure 2.2. Gray calcareous siltstone of Sai Bon Formation with calcite vein. Grid reference 197330, Cross-section 2.

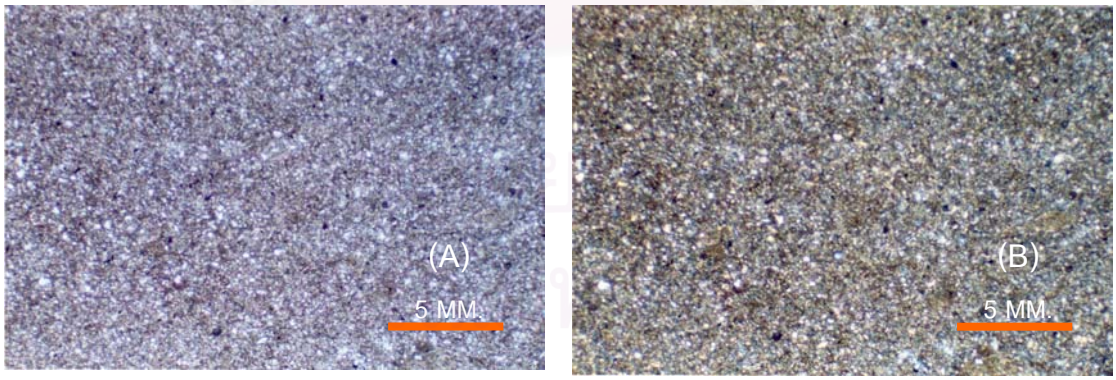

Figure 2.3. Photomicrograph of calcareous siltstone (Figure 2.2). The rock is fine-grained, high sphered, subrounded, and well sorted. (A) uncrossed and (B) crossed nicols.

Figure 2.4. Light gray calcareous sandstone of Sai Bon Formation. Grid reference 907730, Cross-section 3.

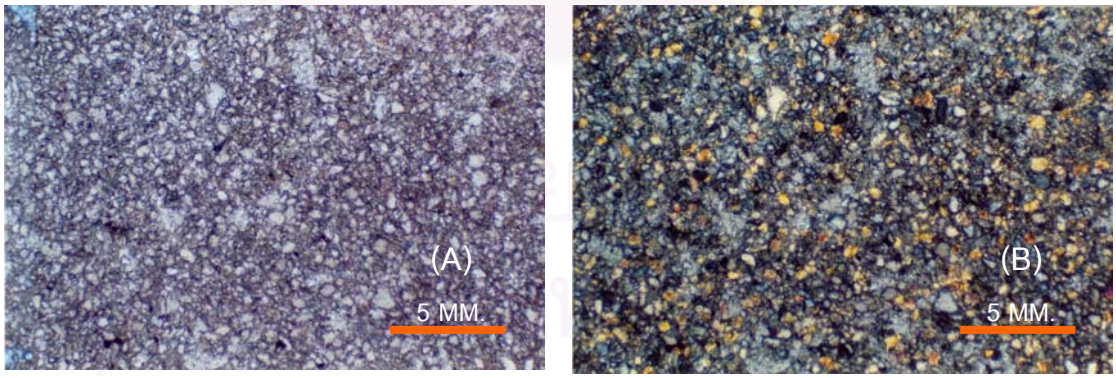

Figure 2.5. Photomicrograph of calcareous sandstone (Figure 2.4). The rock is very fine-grained, high sphered, subrounded, and well sorted, (A) uncrossed and (B) crossed nicols.

Figure 2.6. Gray dolomitic limestone of Sai Bon Formation. Grid reference 958671, Cross-section 3.

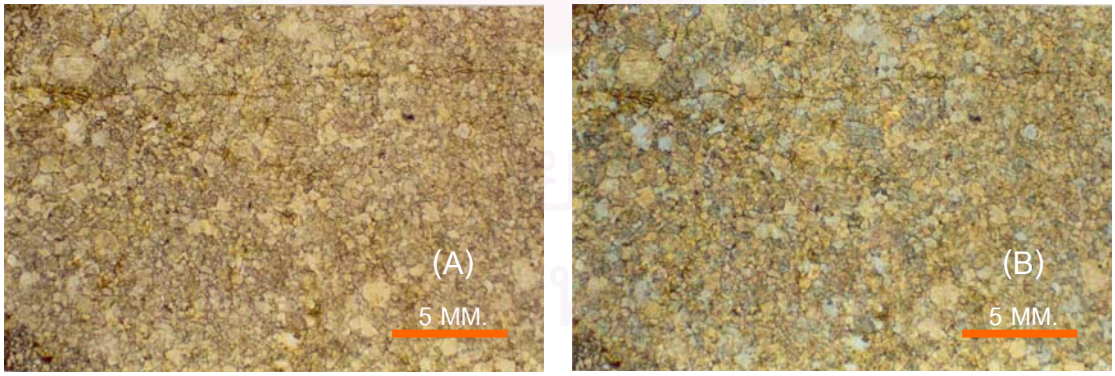

Figure 2.7. Photomicrograph of dolomitic limestone (Figure 2.6). The rocks is xenotopic-A texture (A) uncrossed and (B) crossed nicols.

color (Figure 2.8). Its petrography shows high sphered, well-rounded, well-sorted of quartz (Figure 2.9). The arkosic sandstone is reddish-brown (Figure 2.10). The rock is medium to coarse grained, high sphered, angular to subangular, and modertate-sorted of feldspar and quartz in thin-section (Figure 2.11). The arkosic sandstone from another location is yellowish-brown (Figure 2.12). Figure 2.13 demonstrates medium to coarse grained, high sphered, angular to subangular, and modertate-sorted of feldspar and quartz in petrography.

2.4 Regional Structural Features and Presumed Tectonic History

The Thai-Malay mobile belt is a structurally complex belt of somewhat north-south folding trend with overthrusting towards the east (Bunopas, 1981). The belt extends from northern Thailand through the Gulf of Thailand to here. Furthermore the area is characterized by strong calc-alkaline magmatism, during Late Permian to Middle Triassic. The mobile belt is thus interpreted as a collision belt on sutured zone between the Shan Thai and the Indochina blocks in this mentioned time (Bunopas, 1981, Mitchell, 1981, Hahn and others, 1986).

Two major different fault systems in southern Thailand were observed; the northeast-southwest strike-slip faults and north-south normal faults. The northeast-southwest trending fault zones are essentially Ranong and Khlong Marui fault zones, while the north-south normal faults are pre-dominated in the Gulf of Thailand. Six major anticlines and synclines in north-south trending were further observed in the Gulf of Thailand through Andaman Sea (Suensilpong and others, 1978) (Figure 2.14).

A detailed discussion on the structural features and the associated tectonic history is in the following chapter.

Figure 2.8. Yellowish-brown siltstone of Lam Thap Formation. Grid reference 282858, Cross-section 1.

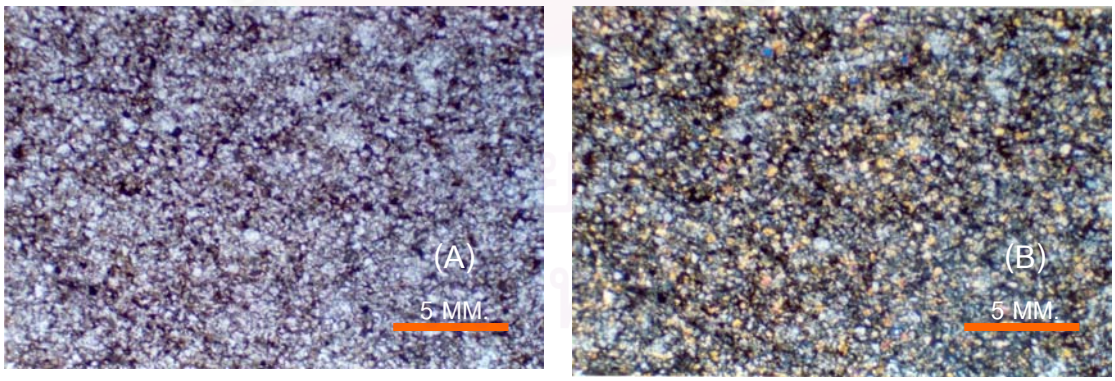

Figure 2.9. Photomicrograph of siltstone (Figure 2.8). The rock is high sphered, well-rounded, and well-sorted of quartz, (A) uncrossed and (B) crossed nicols.

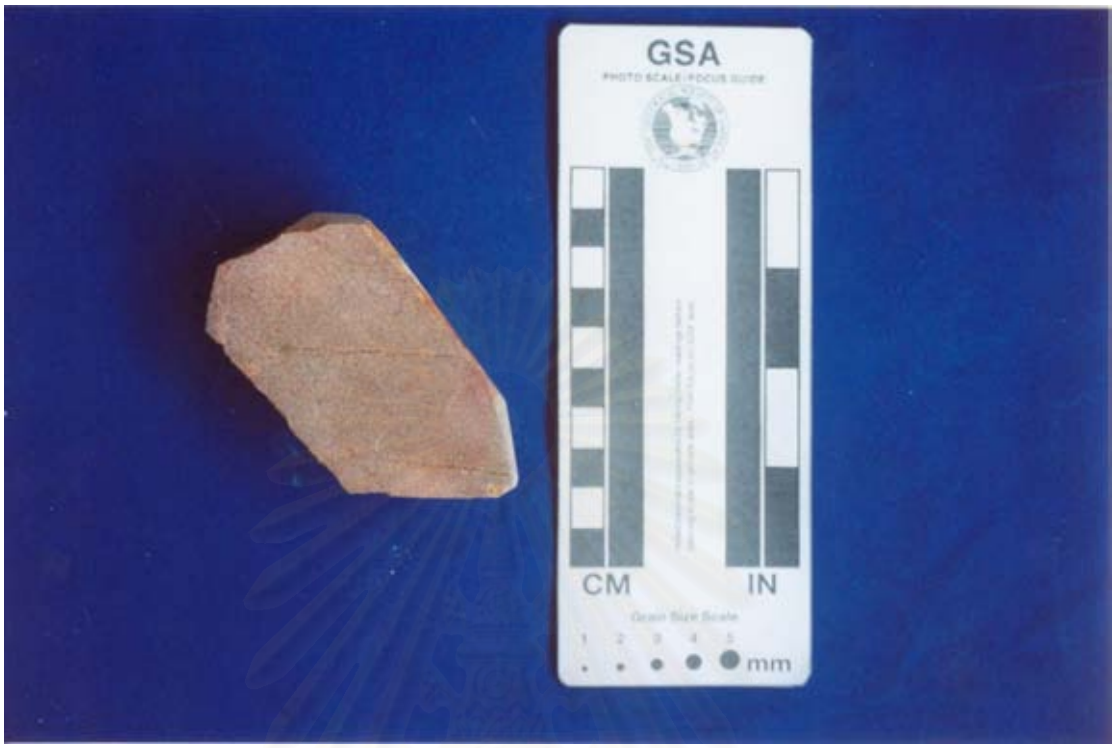

Figure 2.10. Reddish-brown arkosic sandstone of Lam Thap Formation. Grid reference 282858, Cross-section 1.

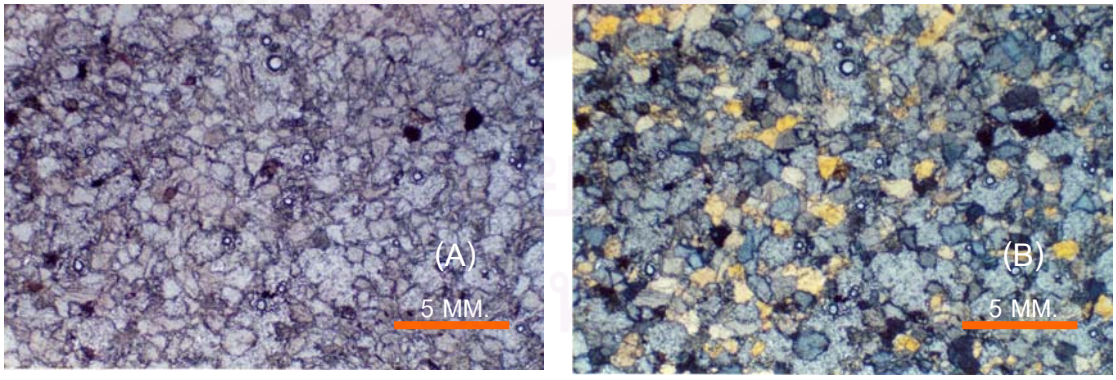

Figure 2.11. Photomicrograph of arkosic sandstone (Figure 2.10). The rock is medium to coarse grained, high sphered, angular to subangular, and moderated-sorted of feldspar and quartz, (A) uncrossed and (B) crossed nicols.

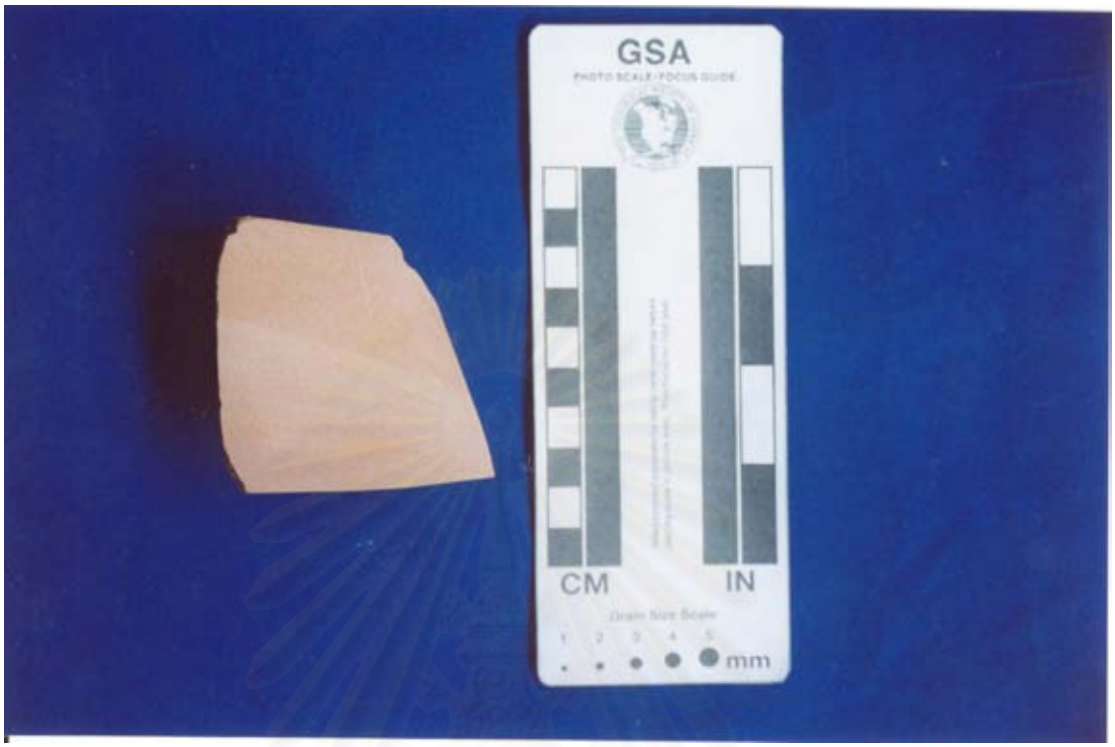

Figure 2.12. Yellowish-brown arkosic sandstone of Lam Thap Formation. Grid reference 204274, Cross-section 2.

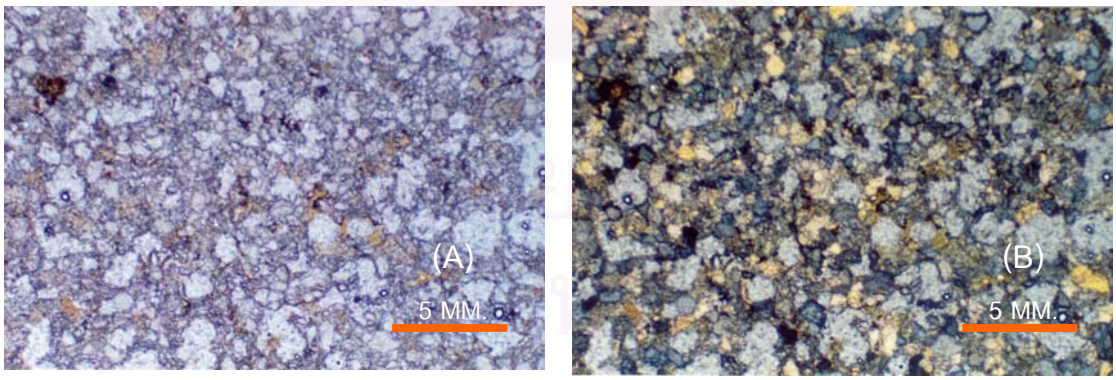

Figure 2.13. Photomicrograph of arkosic sandstone (Figure 2.12). The rock is medium to coarse grained, high sphered, angular to subangular, and moderatate-sorted of feldspar and quartz, (A) uncrossed and (B) crossed nicols.

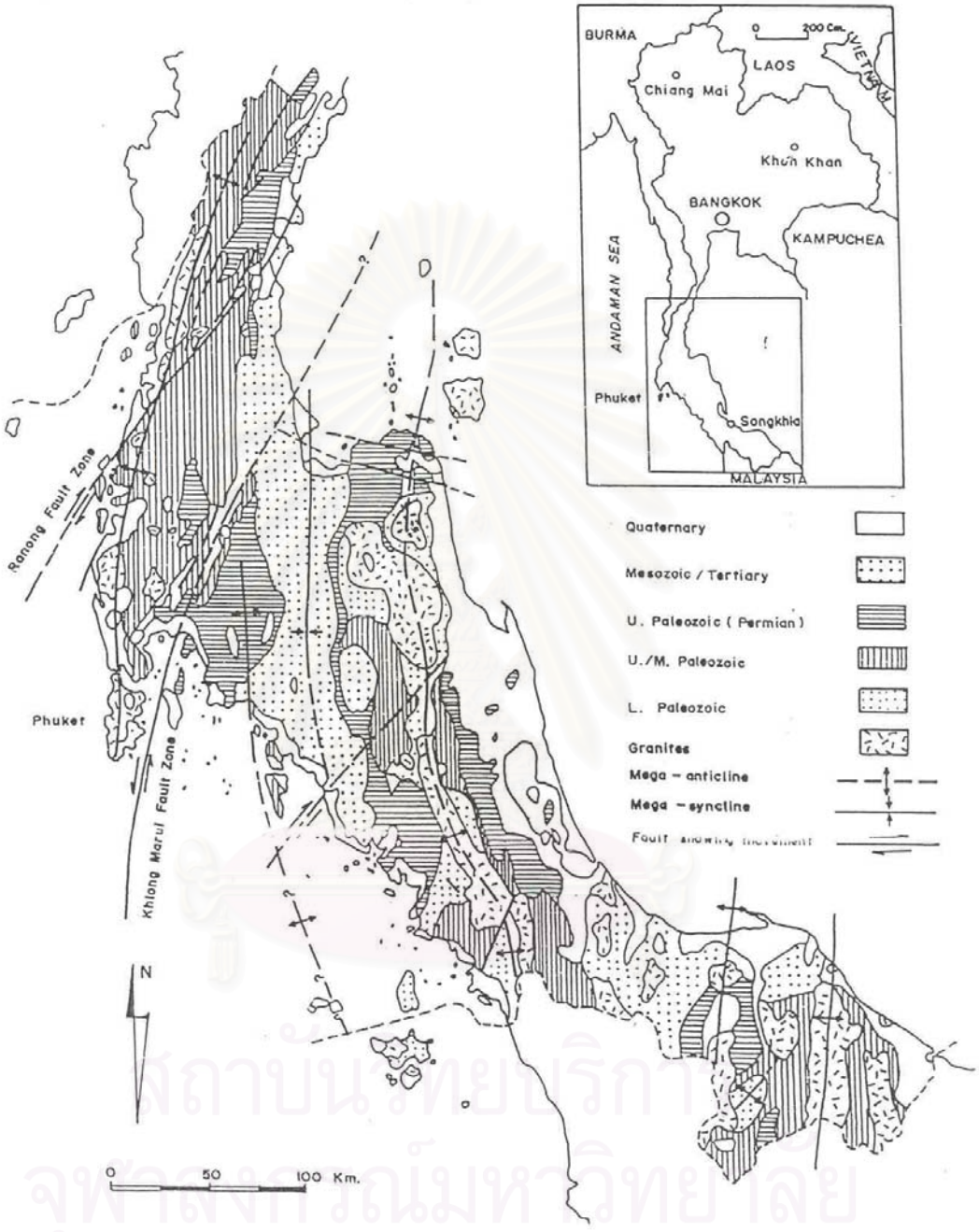

Figure 2.14. Regional geological structures of peninsular Thailand (Modified after Suensilpong and others, 1978).

CHAPTER 3

STRUCTURAL GEOLOGY OF THE STUDY AREA

In this chapter, the study on the structural geology including the remote sensing interpretation and field visits is explained. The further processing of the field collected mesoscopic structural data using the equal-area lower-hemisphere streographic projection and the rose diagram is included where appropriated. The stereonet plots were done using the computer program NETPROG of D.T.Allison of University of South Alabama, U.S.A., through a communication of with J.F.Tull of Florida State University, U.S.A.

3.1 Remote Sensing Interpretation

A remote sensing study is a preliminary structural geologic study to suggest the rock types and their extent, using the topographic pattern, and some structural geologic features, especially the bedding traces and lineaments.

The LANDSAT TM-5 imageries band 4 5 7 strip 129-33, 129-54, and 129-55 of the scale 1:2,500,000 for broad view (Figure 3.1) were used. The black-and-white vertical stereo-paired air-photographs of an approximate scale 1:50,000 were interpreted, and the observed features were transferred to the topographic maps, scale 1:50,000.

The study of the extent of the Mesozoic units is based essentially on the works of Raksaskulwong (1994) and Teerarungsigul (2000). Thus this study, in addition, is to describe the geomorphology, drainage patterns and lineaments, aiming to further describe the geologic structures which control the landform.

The geomorphology in the study area is composed of various terrains, namely the flat areas, undulating terrains, and mountainous areas. The flat areas and undulating

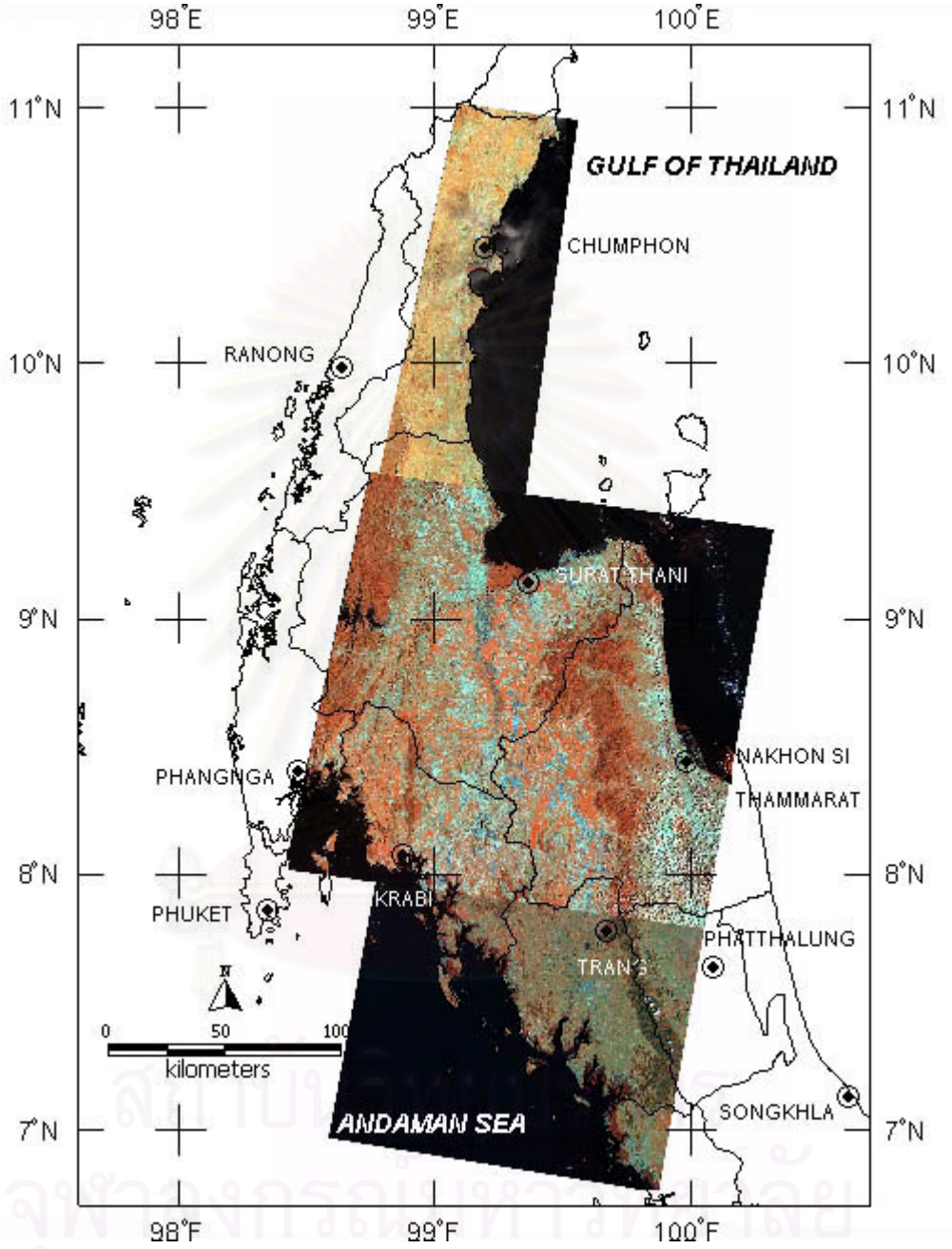

Figure 3.1. LANDSAT imagery of the study area with provincial boundaries.

terrain are bounded on the east and west sides by mountainous areas, trending north-southerly. The drainage patterns are of 2 types. The subangular pattern is that of the main rivers, Ta Pi river and Phum Duang River. Ta Pi river flows from south to north, while Phum Duang river flow from west to east. The subdendritic type is of the tributaries of the 2 main rivers and covers most of the area. These drainage patterns are believed to be under the structural and lithologic control. The subangular drainage pattern follows the geologic structures which allow the easily eroded landform, while the subdendritic pattern indicates the rather uniform lithology without any prominent structure, and with rather gentle sloping.

The lineaments are recognized in both LANDSAT TM-5 imagery and air-photographs. The shorter north-south lineaments reflect the bedding traces of the Mesozoic stratigraphic units. They broadly widespread in the central part, being limit in a narrows strip to the north and south of the study area. The northnortheast-southsouthwest lineaments denote the large-scale fractures (Figure 3.2). They primarily match the southern part of Khlong Marui Fault Zone of Garson and others (1978).

3.2 Geology and Descriptive Structural Geology of Study Area

Apart from the field visits to check the accuracy of the remote sensing interpretation, a rather detailed, continuous structural data collection was also done. Three traverse lines along the roads, somewhat cross-cutting the regional structural trend at a fairly high angle, were chosen. All 3 traverses were with the series of good exposures of the Mesozoic rocks on the road banks as well as the hill sides. These 3 traverses were named Cross-sections 1, 2 and 3 respectively and their locations are shown in Figure 3.3. The first cross-section is the major one located on the new road being cut in according to the Southern Seaboard Development Project. The other 2 traverses are along the newly developed roads. The purpose to select these 2 traverses is to complete the Mesozoic stratigraphic study. The study comprises 2 essential parts, the descriptive field structural geologic investigation and the graphic expression of the structural elements collected during the field visit.

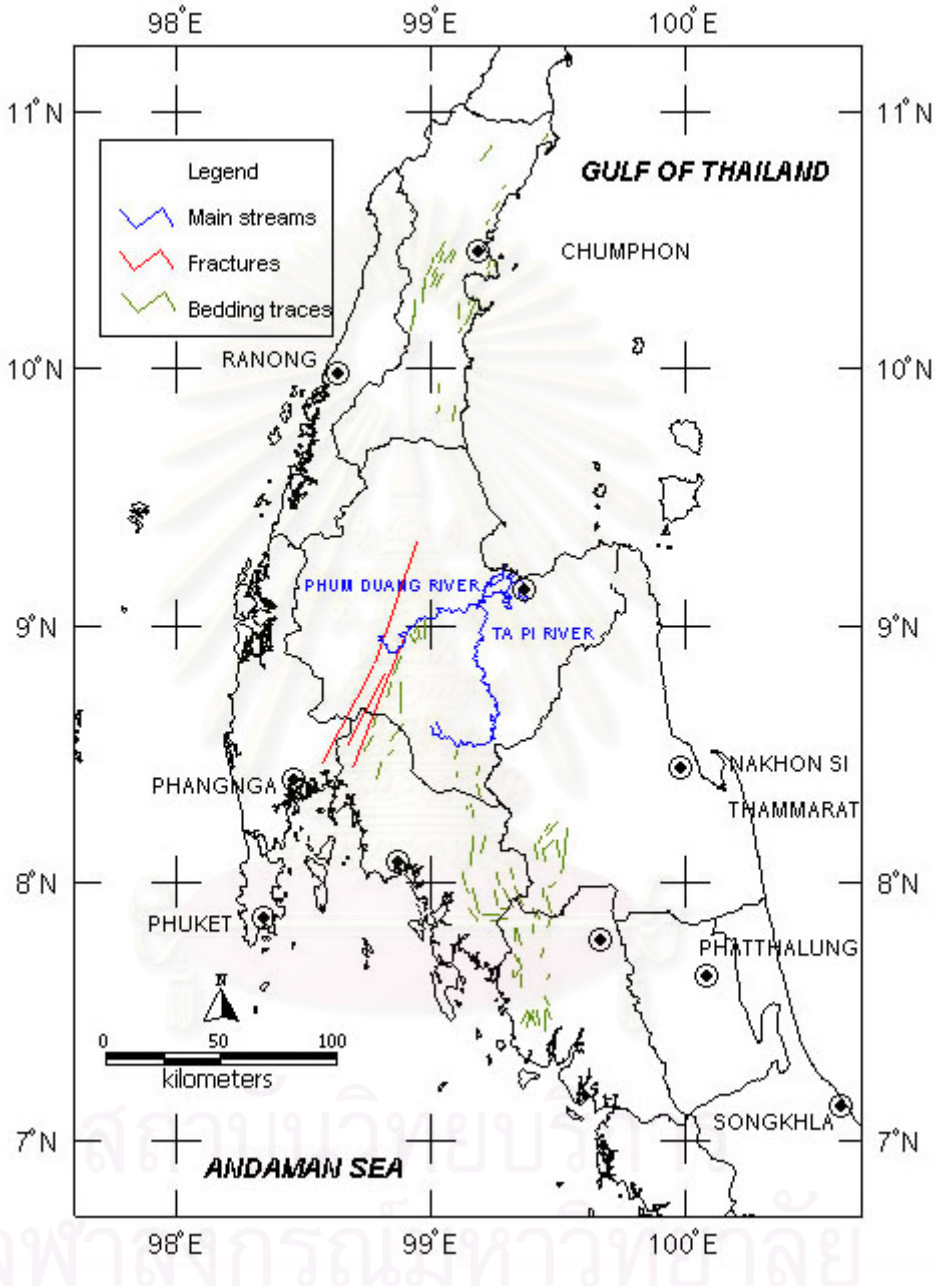

Figure 3.2. Lineament map of the study area.

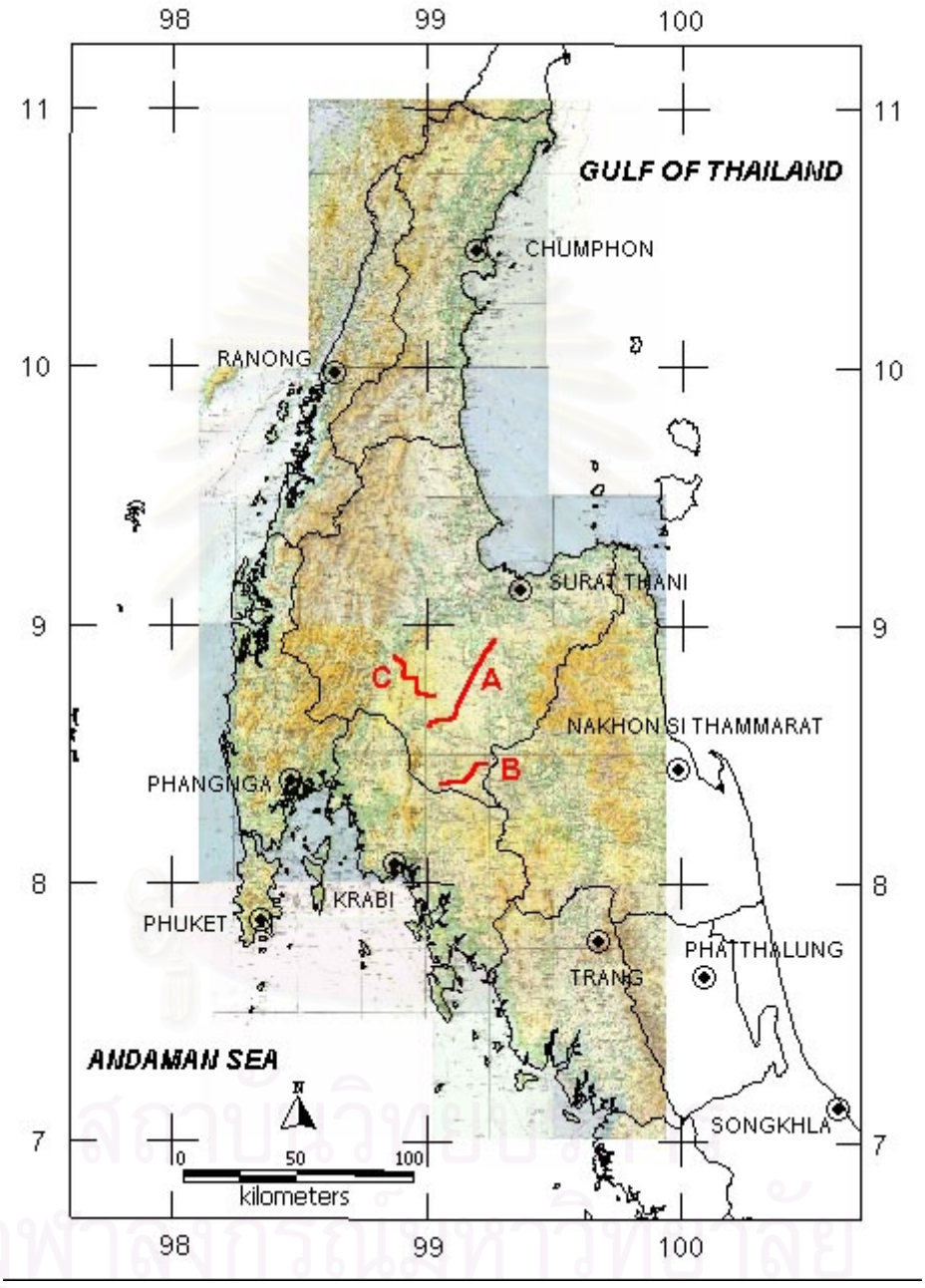

Figure 3.3. Location of 3 traverse lines in the study area. A, Cross-section 1, B, Cross-section 2, C, Cross-section 3. All 3 lines locates within Ta Pi syncline (See further).

In each traverse, the mesoscopic structural data were collected from the road-cut exposures and the natural outcrops. These structural features are the fold elements and fractures. The fold elements observed here are the 3-D minor folds or just the limbs of the larger-scale folds. Unfortunately most of the records are only the strikes and dips of the inclined bedding planes. The mesoscopic fractures are joints and faults. No major faults could be seen in the study except the intense crushing zones, which are parts of larger faults seen in the air-photographs interpretation. The minor normal faults and the intensely crushing rock zones or narrow zones of severely deformed rock mass are observed in many locations throughout the study area.

The structural analysis is done by the graphic expressions, which are stereonet plot of ¶-diagram and rose diagram. The bedding-plane orientation data were plotted in an equal-area, lower-hemisphere stereonet. The ¶-diagram illustrates a great circle of the fold profile and thus the pole to this fold profile is the fold axis. The strikes of the joints are also plotted in a rose diagram. The analysis was done using NETPROG program of Allison's (1999).

3.2.1 Detailed Structural Geology along Cross-section 1

Cross-section 1, the longest traverse, is 50 kilometers long along a newly cut Southern Seaboard Development Project highway. It is in Amphoe Khiansa in the northeastern part of the detailed study area. The traverse passes through the topography of the undulating terrain to the hill chain. However the outcrops are well exposed in the area of undulating terrain.

The rocks founded in this section are both the Mesozoic and Tertiary rocks. The Mesozoic rocks expose in the northern part of the section. They are composed of yellowish brown arkosic sandstone intercalated with siltstone and mudstone, thin-to thick-beds, with cross-bedding, graded-bedding and ripple mark. The bedding planes gently incline to the western directions (Figure 3.4 and 3.5). However, a high-angle west-dipping overturned bedding is found in the southern part of Khao Khiam indicating that

Figure 3.4. The arkosic sandstone of Lam Thap Formation. The bedding planes incline to the west. Grid reference 229791, Cross-section 1. View toward the southeast.

Figure 3.5. Lam Thap Formation at grid reference 282858, Cross-section 1. The beddings also dip to west. . View toward the southeast.

some lower-ordered folds are overturned (Figure 3.6). As small-scaled fault, which is E-W normal fault, was observed in this rock unit (Figure 3.7). The Mesozoic rocks belong to Lam Thap Formation.

The ¶-diagram stereonet plot of 11 data shows a fold trend in north-south direction with fold profile (strike/dip) $270^{o}/66^{o}$N and fold axis (trend/plunge) $180^{o}/24^{o}$ (Figure 3.8). Twenty-five fracture data plotted in a rose-diagram reveal the majority of east-west trending with subordinate trendings in many other directions (Figure 3.9).

The Tertiary rocks occupy from the central to the southern section of this traverse line, thus to the southwest of the Mesozoic unit. The mudstone and claystone are with indicating vertebrate fossils. The bedding planes have a very gentle to subhorizontal dipping (Figure 3.10 and 3.11).

Geologic structural Cross-section 1 indicated the Mesozoic stratigraphic units underly angular-unconformably below the Tertiary rocks. Unfortunately the exact location where both rock groups could be observed to overly one another had never been found. However, according Chaodumrong and Chaimanee (2002) which mentioned the formation of the depositional basin for the Tertiary sediments to be that of the north-south normal-fault control, and the normal faulting progressed concurrently with the Tertiary deposition, it is thus assumed that a normal fault perhaps exists between the Mesozoic and Tertiary units and the fault might control the flowing trend of Ta Pi river (Figure 3.12).

Figure 3.6. An outcrop of overturned-bedding of Lam Thap Formation. The exposure is at the southern part of Khao Khiam. Grid reference 235780, Cross-section 1. View toward the north.

Figure 3.7. Small-scaled fault shows a normal movement in Lam Thap Formation. Grid reference 282858, Cress-section 1. View toward the southeast.

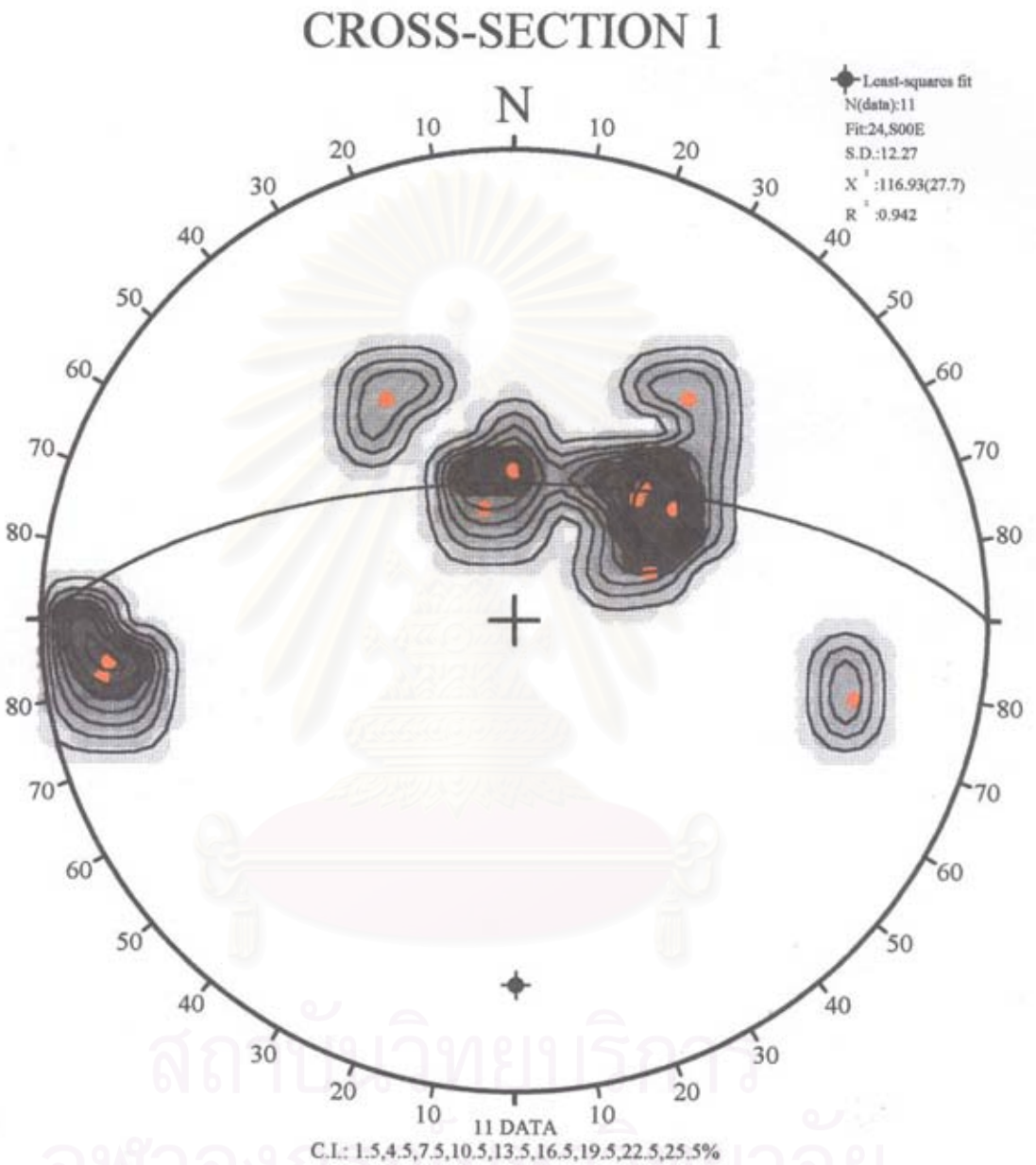

Figure 3.8. Equal-area stereonet plot of 11 poles of bedding planes (orange dots) along Cross-section 1. The great circle of fold profile orientates 270°/66°N indicating fold axis plunging 24° to the south.

Radius:2.70inches

Projection:Equal Area

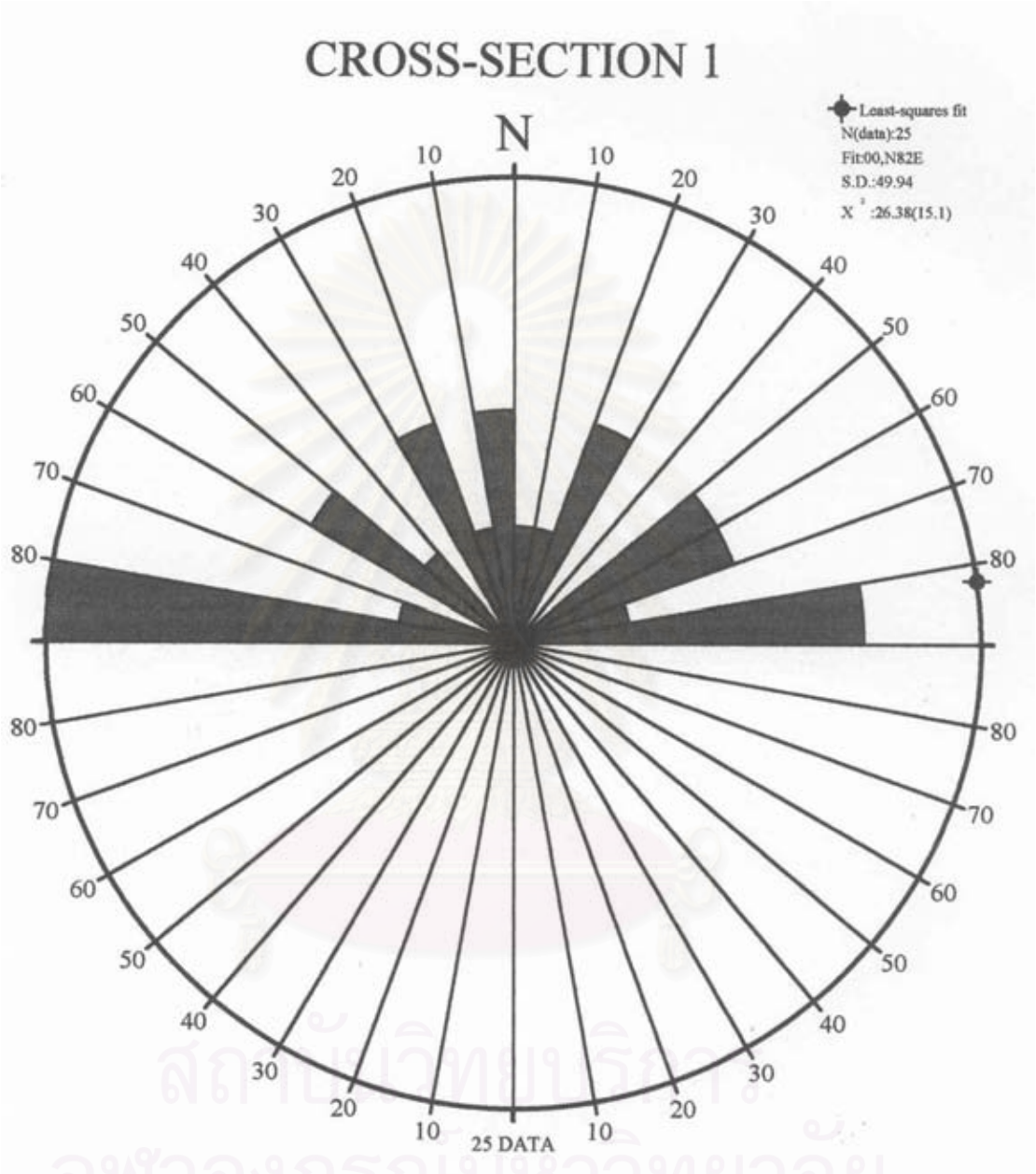

Figure 3.9. Half-rose diagram of 25 strike values of fractures along Cross-section 1. The plot illustrates that the major trending of the fractures is in east-west direction.

Radius:2.70inches

Projection:Equal Area

Figure 3.10. Tertiary sedimentary units show very gentle dipping. Grid reference 197763, Cross-section 1. View toward the east.

Figure 3.11. Tertiary sedimentary units illustrate subhorizontal bedding planes. Grid reference 035547, Cross-section 1. View toward the east.

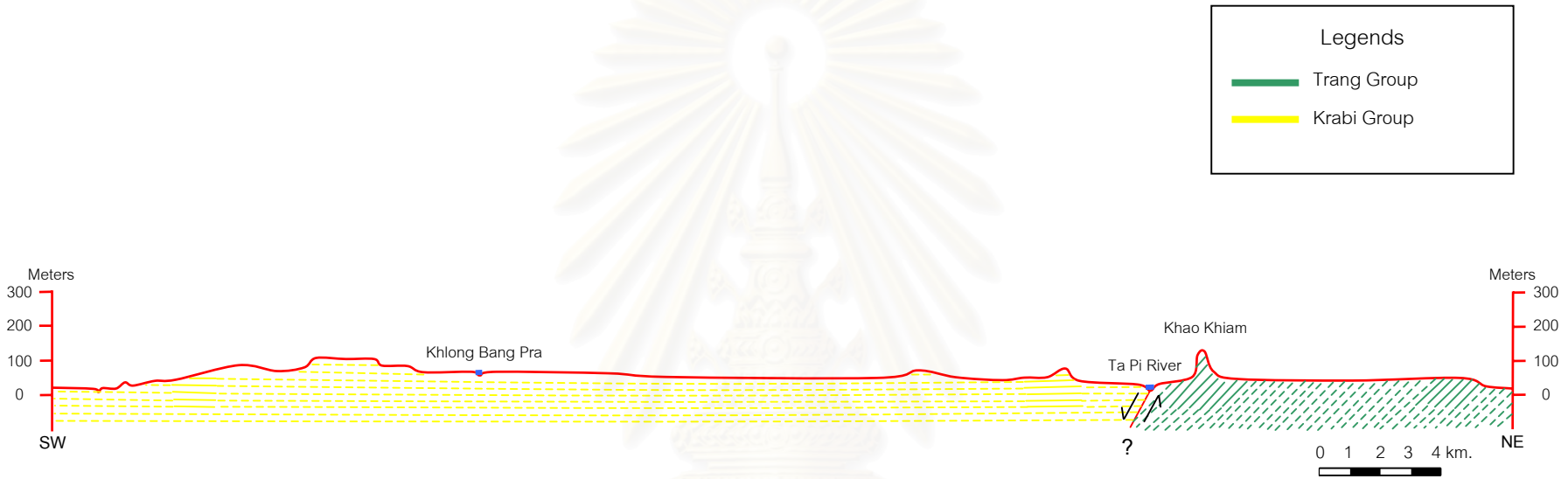

Figure 3. 12. Simplified geologic structural cross-section along Cross-section 1. Mesozoic rocks incline toward the west, while Tertiary rocks is gently to subhorizontally dipping. An angular unconformity should be existed between Mesozoic stratigraphic unit and the Tertiary rocks, or the older unit is brought to be overlain by a Tertiary via a normal fault (as suggested by Chaodumrong and Chaimanee, 2002).

3.2.2 Detail Structural Geology along Cross-section 2

The 24-kilometer route along a road jointing Amphoe Phra Saeng to Amphoe Chai Buri is for Cross-section 2. It is in the southern part of the ditailed study area. The topography is dominantly flat and undulating.

The rocks in this cross-section belong to both Sai Bon Formation and Lam Thap Formation. The rock of Sai Bon Formation is calcareous siltstone (Figure 3.13), while that of Lam Thap Formation is highly weathered arkosic sandstone (Figure 3.14). Here, Lam Thap strata conform those of Sai Bon Formation. Most of the beddings are thin- to medium and incline to the west.

The ¶-diagram of 8 data reveals a north-south fold trend with the fold profile $123^{\circ}/57^{\circ}$SW and fold axis $33^{\circ}/33^{\circ}$ (Figure 3.15). The rose-diagram of 23 fractures reveals the major east-west direction for the fracture trend, with a subordinate however prominent north-south one (Figure 3.16), approximately perpendicular to the major east-west trending.

The geologic structural condition in Cross-section 2 indicates that, at least here, Triassic Sai Bon Formation is conformable with Jurassic-Cretaceous Trang Group without any distinctive unconformity between them (Figure 3.17). The minor folds could be seen also in this area.

Figure 3.13. Calcareous siltstone of Sai Bon Formation illustrates the west dipping bedding planes. Grid reference 197330, Cross-section 2, View toward the southeast.

Figure 3.14. The arkosic sandstone of Lam Thap Formation is dipping to the west. Grid reference 204274, Cross-section 2. View toward the north.

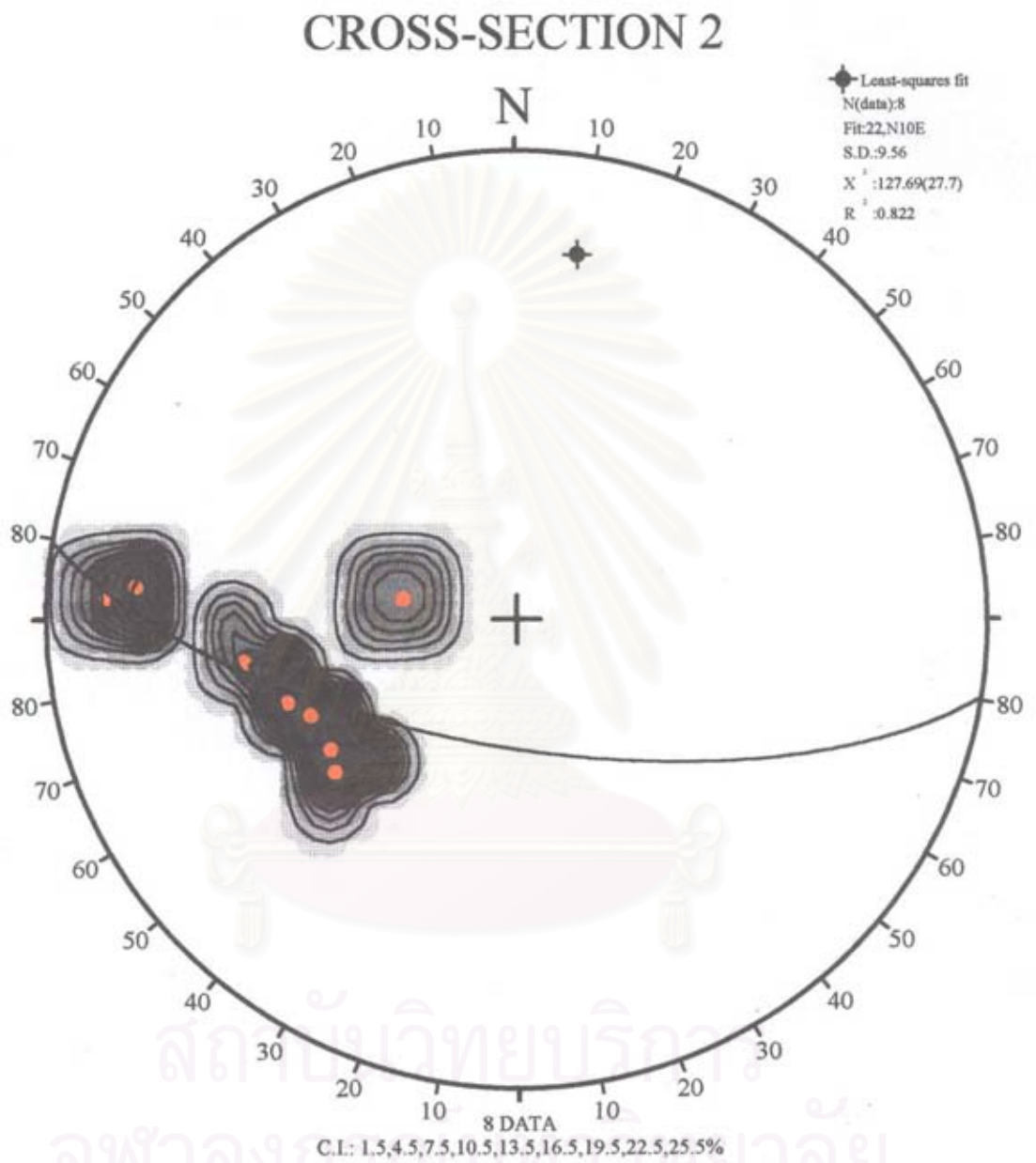

Figure 3.15. Equal-area stereonet plot of 9 poles of bedding planes (orange dots) along Cross-section 2. The fold trend is in northeast-southwest direction indicated by the great circle fitting in 123°/37°SW.

Radius:2.70inches

Projection:Equal Area

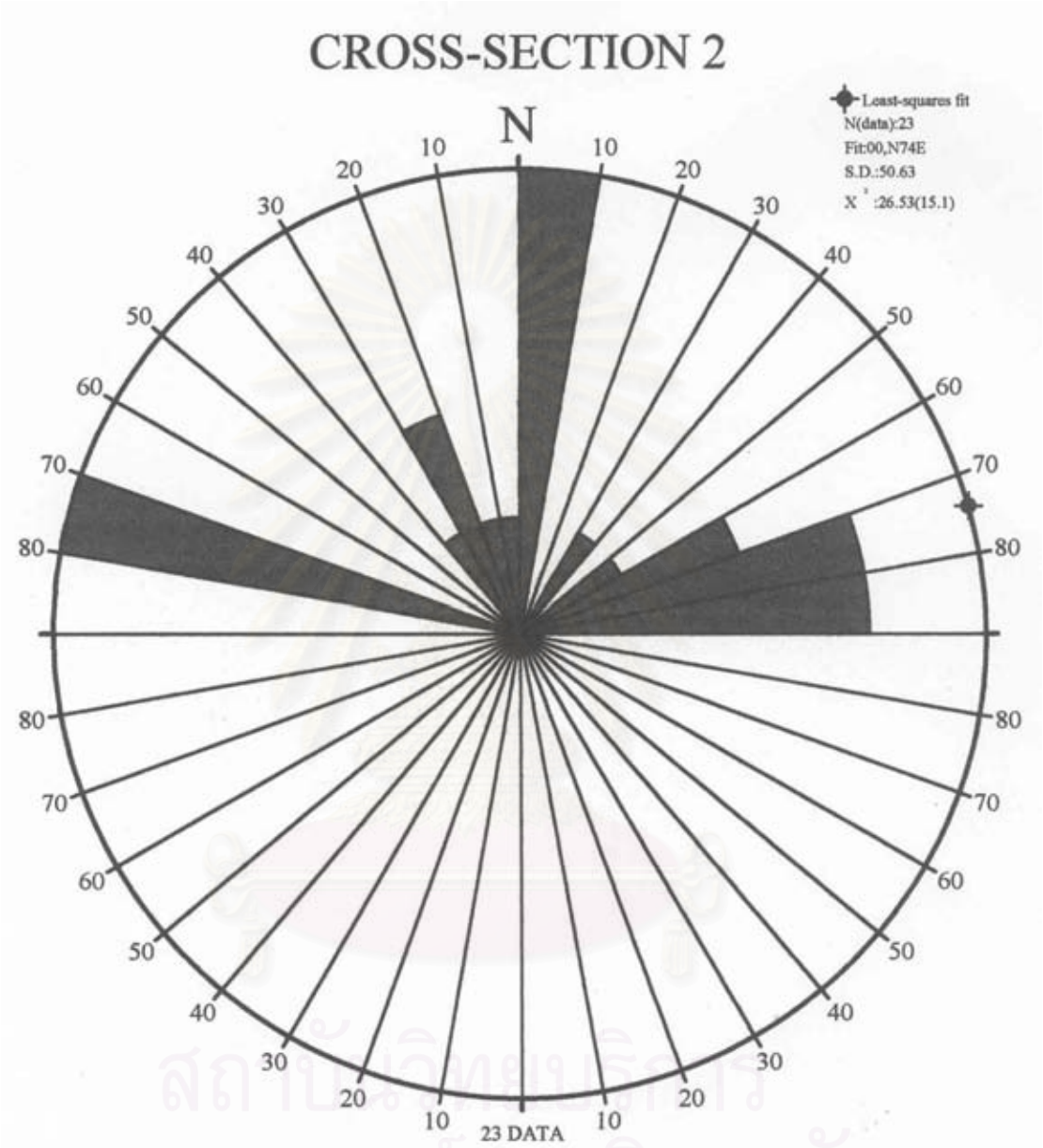

Figure 3.16. Half-rose diagram of 23 strike values of fractures along Cross-section 2. It illustrates the major fractures are in the east-west direction, and the subordinate in the north-south direction.

Radius:2.70inches

Projection:Equal Area

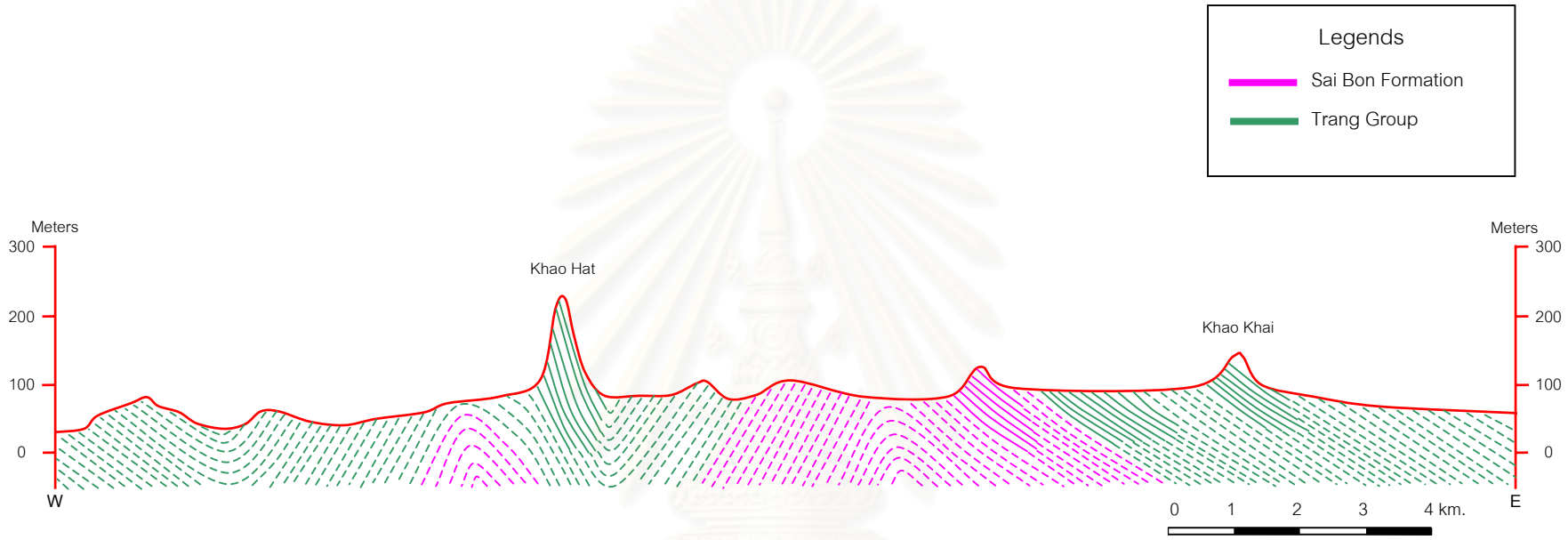

Figure 3. 17. Simplified geologic structural cross-section along Cross-section 2. Here, the Triassic rocks conforms the Jurassic to Cretaceous rocks. A lower-ordered syncline is noted in the middle of the cross-section.

3.3.3 Detail Structural Geology along Cross-section 3

Cross-section 3 is in the northwestern part of the detailed study area. It is 29 kilometers long along a developed road in Amphoe Phanom. The topography in the cross-section 3 is mainly the hill chains and the undulating terrain with some isolated hills.

The rocks are of only Sai Bon Formation. They are medium-to thick-bedded calcareous sandstone and siltstone with dolomitic limestone. The strata mostly incline to the east (Figure 3.18 and 3.19).

From the steronet plot of 11 bedding planes, it shows that the fold profile is $267^{o}/68^{o}$N and fold axis is $177^{o}/22^{o}$ (Figure 3.20). Fold trend is thus approximately in the north-south direction. The rose diagram of 28 fractures shows that the major joints trend both in the northeast-southwest and northwest-southeast directions (Figure 3.21), approximately being perpendicular to each other.

The geologic structural cross section of this Cross section 3 illustrates that the bedding planes are mostly east dipping while some lower-ordered folds are observed in this rock unit as well (Figure 3.22).

Figure 3.18. Dolomitic limestone of Sai Bon Formation. The beds here dip to the east. Grid reference 958671, Cross-section 3. View toward the southeast.

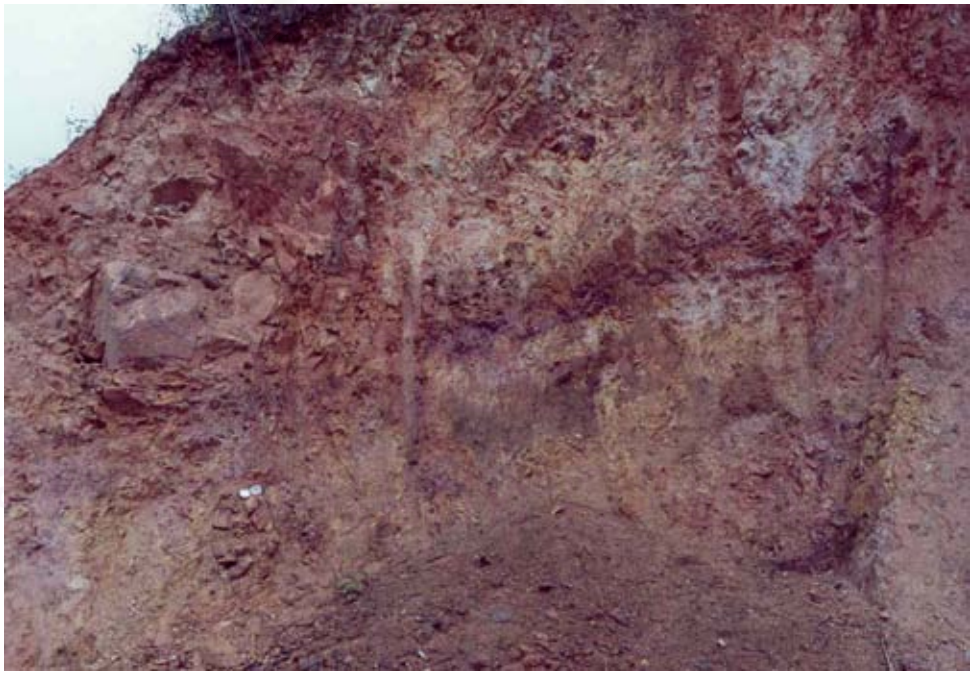

Figure 3.19. Calcareous sandstone of Sai Bon Formation. The beds here dips to the west. Grid reference 907730, Cross-section 3. View toward the southeast.

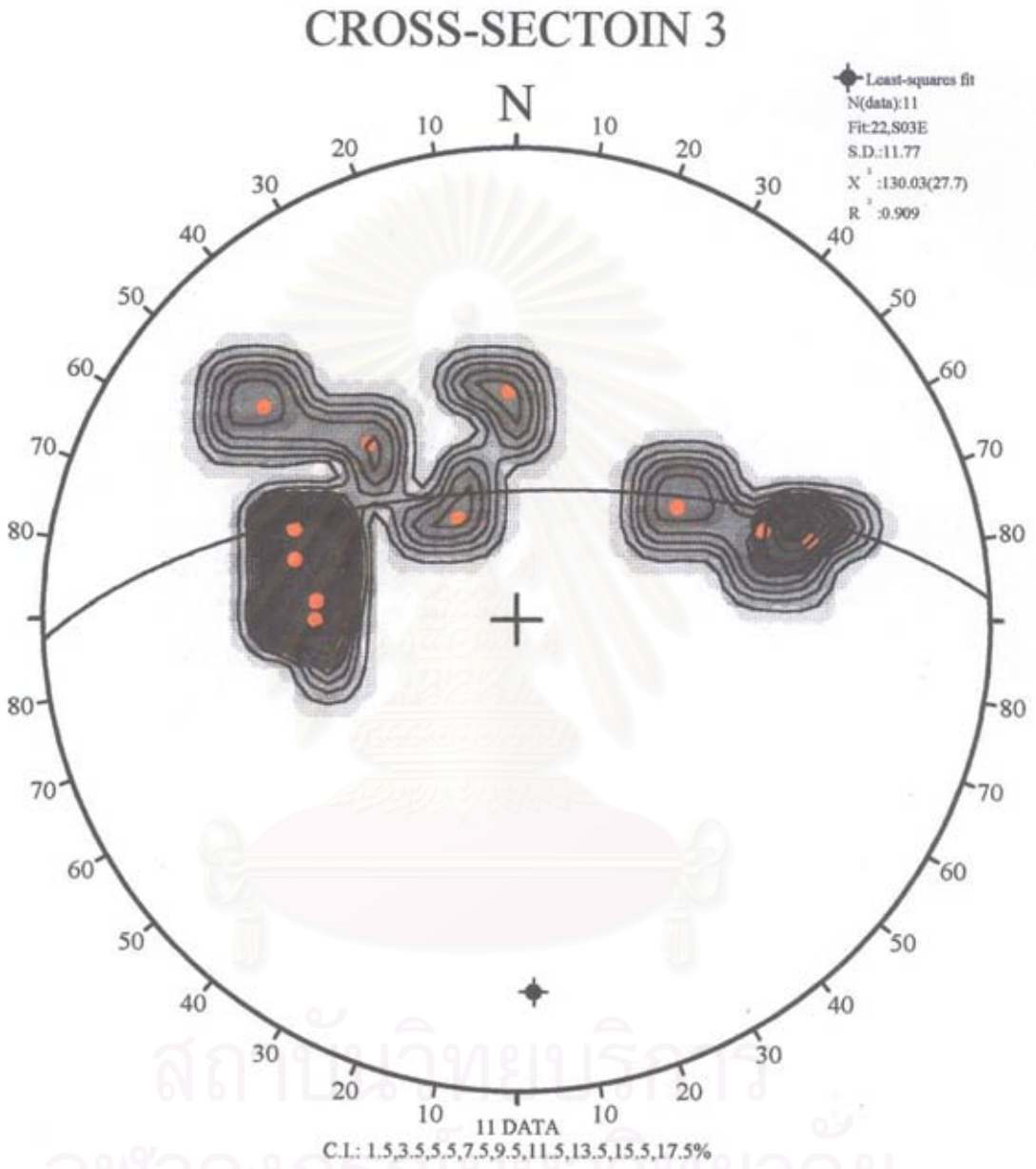

Figure 3.20. Equal-area stereonet plot of 12 poles of bedding planes (orange dots) along Cross-section 3. The great circle, 267°/68°N indicates the fold axis to plunge 22° toward 177° azimuth.

Radius:2.70inches

Projection:Equal Area

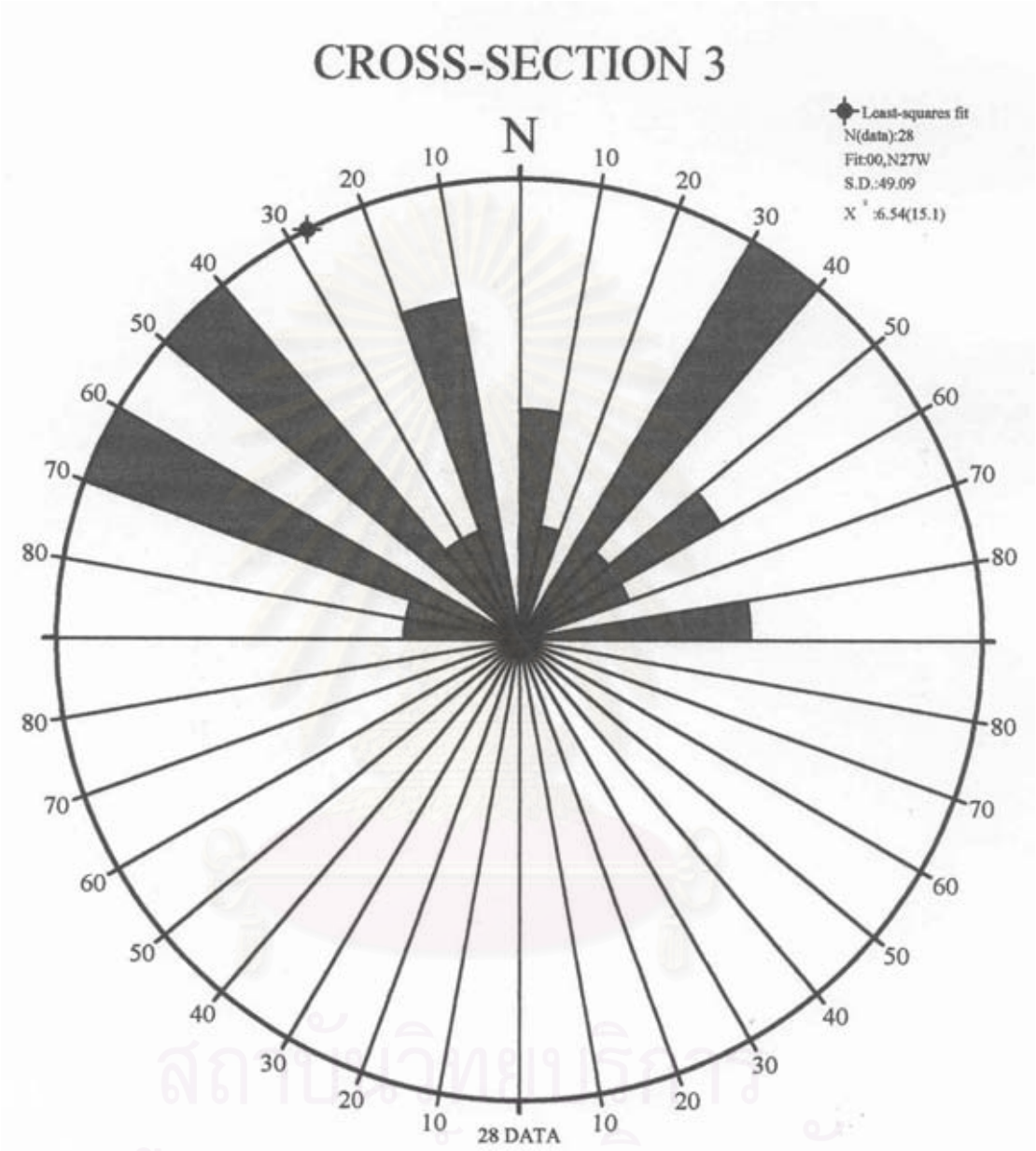

Figure 3.21. Half-rose diagram of 28 strike values of fractures along Cross-section 3. The major fracture trends are in the northeast-southwest and north west-southeast directions, approximately perpendicular to each other.

Radius:2.70inches

Projection:Equal Area

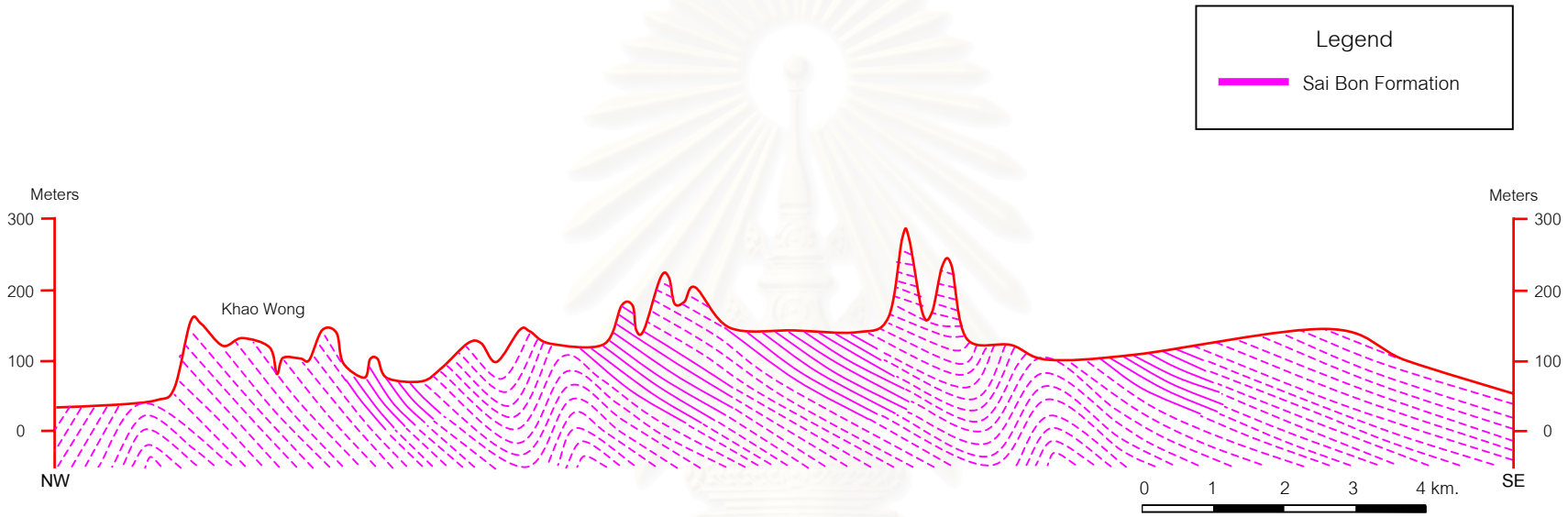

Figure 3. 22. Simplified geologic structural cross-section along Cross-section 3. The Triassic rock inclines mostly to the east associating with asymmetric lower-ordered parasitic folds.

CHAPTER 4

STRUCTURAL GEOLOGY MODEL OF UPPER SOUTHERN THAILAND

The structural pattern of the study area were complied from the present detailed and general studies together with those previously done on the Mesozoic units in upper southern Thailand. Those works are primarily the field work reports of Third year geology students of Chulalongkorn University (1996, 1998, 2000, 2002), Teerarungsigul (2000), and Kanjanapayont (1998). The mesoscopic structural observation together with the remote sensing data was interpreted to form the major macroscopic structures, and consequently continue to the discussion on deformation styles imprinted on to the Mesozoic stratigraphic units. An attempt is to construct a geologic structural model after the Mesozoic Period, the time when the stratigraphic units had been deposited in the now- upper southern Thailand.

4.1 Major Structures in the Study Area

The major structures of the Mesozoic stratigraphic units are those being affected by the post-depositional deformation episodes. The results are folding and fracturing of many scales. The folds in this study are synclines and anticlines, and fractures are noted to be joints and faults. The field study combined with the aerial-photographic interpretation of the regional structures and the knowledge of the regional stratigraphy suggest the composite lower-ordered anticlines and synclines combining together to be a huge first-ordered syncline, perhaps to a scale of a synclinorium extending from Changwat Chumphon down south to Trang, within which four synclines illustrated by the exposed Mesozoic rocks occupying the trough zones were recognized. These 4 synclines are Chumphon, Ta Pi, Krabi-East, and Trang synclines (Figure 4.1). These synclines are somewhat elongated doubly-plunging gentle folds with a number of even lower-ordered parasitic folds. The general trend is northeast-southwest in Chumphon, changing to north-south in the other synclines further southward. Chumphon syncline lies somewhat further north, being separated from 3 other synclines by an area of no

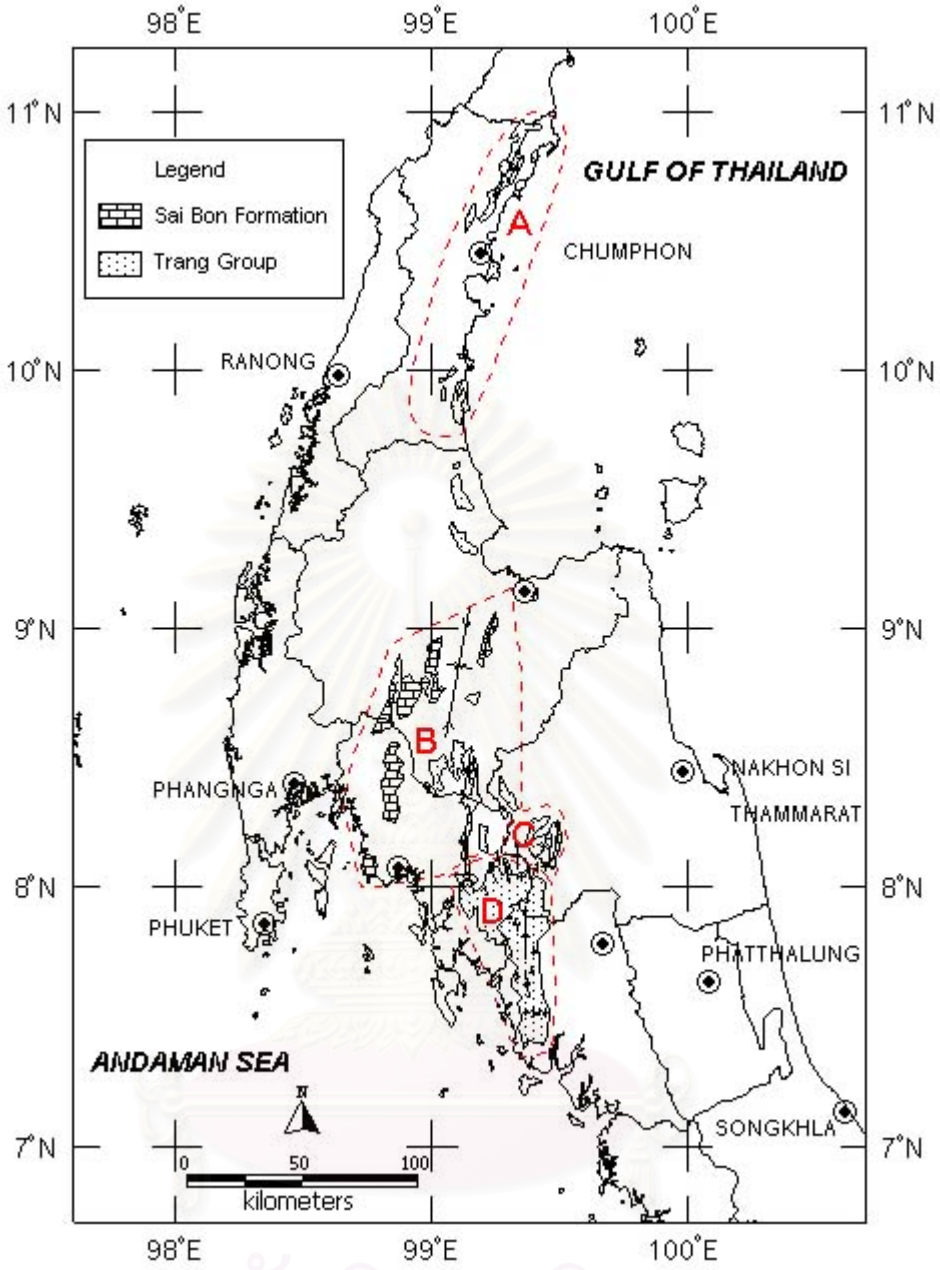

Figure 4.1. Post-Mesozoic Peninsula syncline. It composed of Chumphon (A), Ta Pi (B), Krabi-East (C), and Trang synclines (D).

Mesozoic exposure, perhaps a large culmination there. Three other synclines are also separated using the similar observation of no Mesozoic exposure. To the west of Ta Pi syncline could lie a very narrow elongated anticline, while to the south of Krabi East Syncline, there could be a cross-trended narrow culmination combinded with a significant fracture.

The attitude of the parasitic folds for these major synclines was observed so that the western synclinal limbs are normally steeply-dipping to overturned, while the eastern limbs are mostly moderately dipping to the western directions. The geometry of the parasitic folds could suggest a similar orientation for the higher-ordered synclines although the degree of dipping is less for the generalized fold limbs. As the erosion is now approaching the lower part of the Mesozoic units, the Permian and older-aged basement rocks thus expose in many localities where the parasitic anticlines prevail, or where they use to be the location of the basement-high during the time of deposition of the Mesozoic units. Below is the more detailed explanation of the 4 synclines.

4.1.1 Chumphon Syncline

Chumphon syncline is the northern most structure of these composite synclines. Chumphon syncline takes its name from Chumphon province because it locates mostly in Chumphon province from Amphoe Pathiu to Lamae. The fold is 55 km. wide and 150 km. long, and from the field observation trends northnortheast-southsouthwest (Figure 4.2). This syncline is bounded by the karst towers of the Permian limestone in the west, and extends further off the Gulf of Thailand coastline in the east. The Mesozoic rocks here are made up of the continental Trang Group rocks forming hill chains along the major structure. The rocks of Chumphon syncline are shown in Figures 4.3, 4.4, and 4.5.

The fold here is open and upright. The axis plunges gently to northnortheast-southsouthwest. The fold profile from a stereonet plot of 177 bedding planes is (strike/dip) $316^{o}/71^{o}$NE and thus the fold axis is (trend/plunge) $226^{o}/19^{o}$ (Figure 4.6). The rose diagram of 59 fractures in Chumphon syncline reveals 4 major directions that are

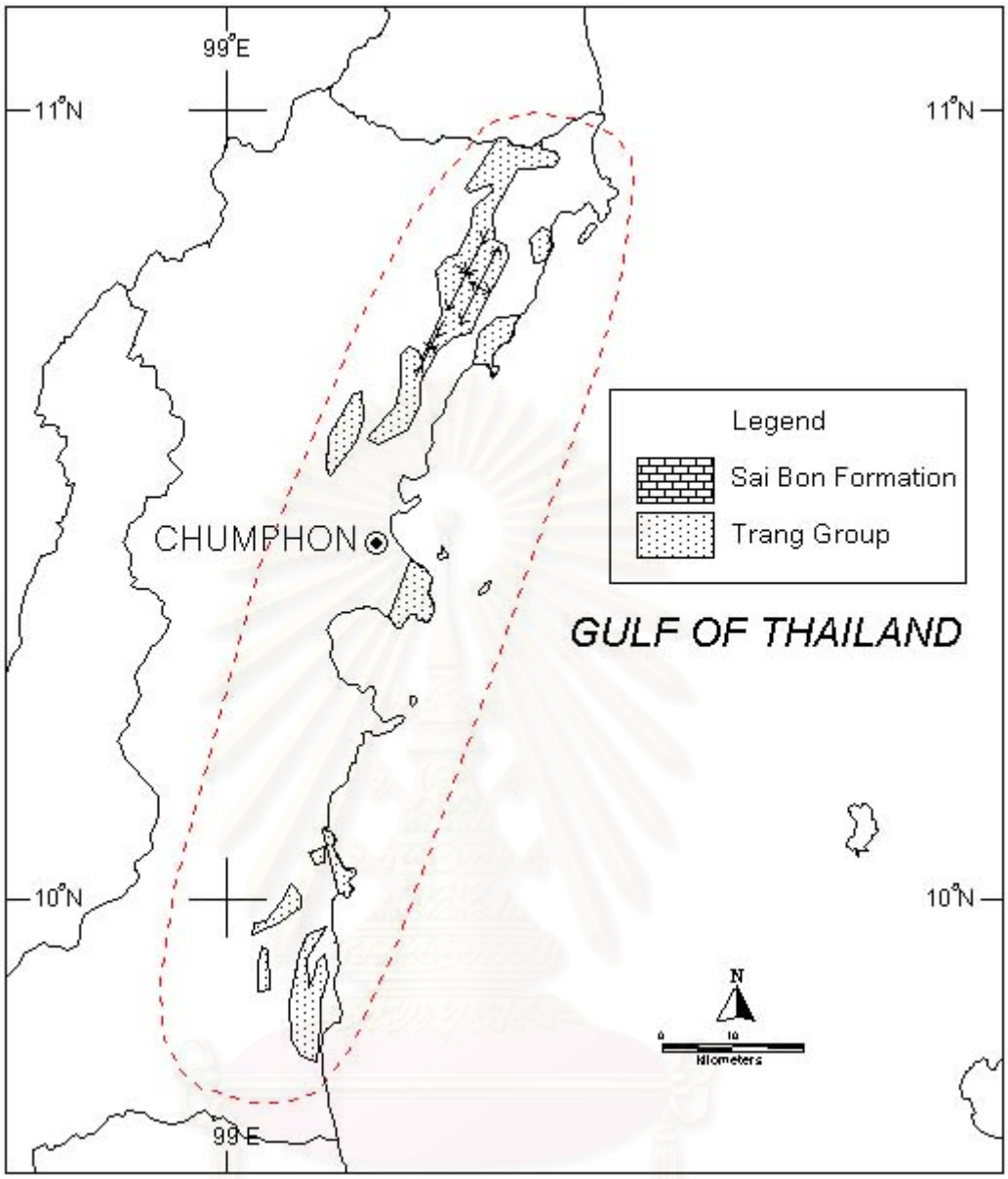

Figure 4.2. Location of Chumphon syncline. The structure is modified after Third year Geology students of Chulalongkorn University (2000, 2002). The red dash-line approximates the limit of the syncline indicating by the Mesozoic units, with speculation for this limit in the Gulf of Thailand.

Figure 4.3. The western limb of Chumphon syncline showing dipping to the east. The rocks in the northern part of syncline are of Lam Thap Formation. Grid reference 395746. View toward the north.

Figure 4.4. Lam Thap Formtion showing a west-dipping eastern limb. It is located at the southern part of Chumphon syncline. Grid reference 298823. View toward the north.

Figure 4.5. The red fanglomerates of Phun Phin Formation of Chumphon syncline. The east-dipping western syncline limb is shown here. Grid reference 399877. View toward the south.

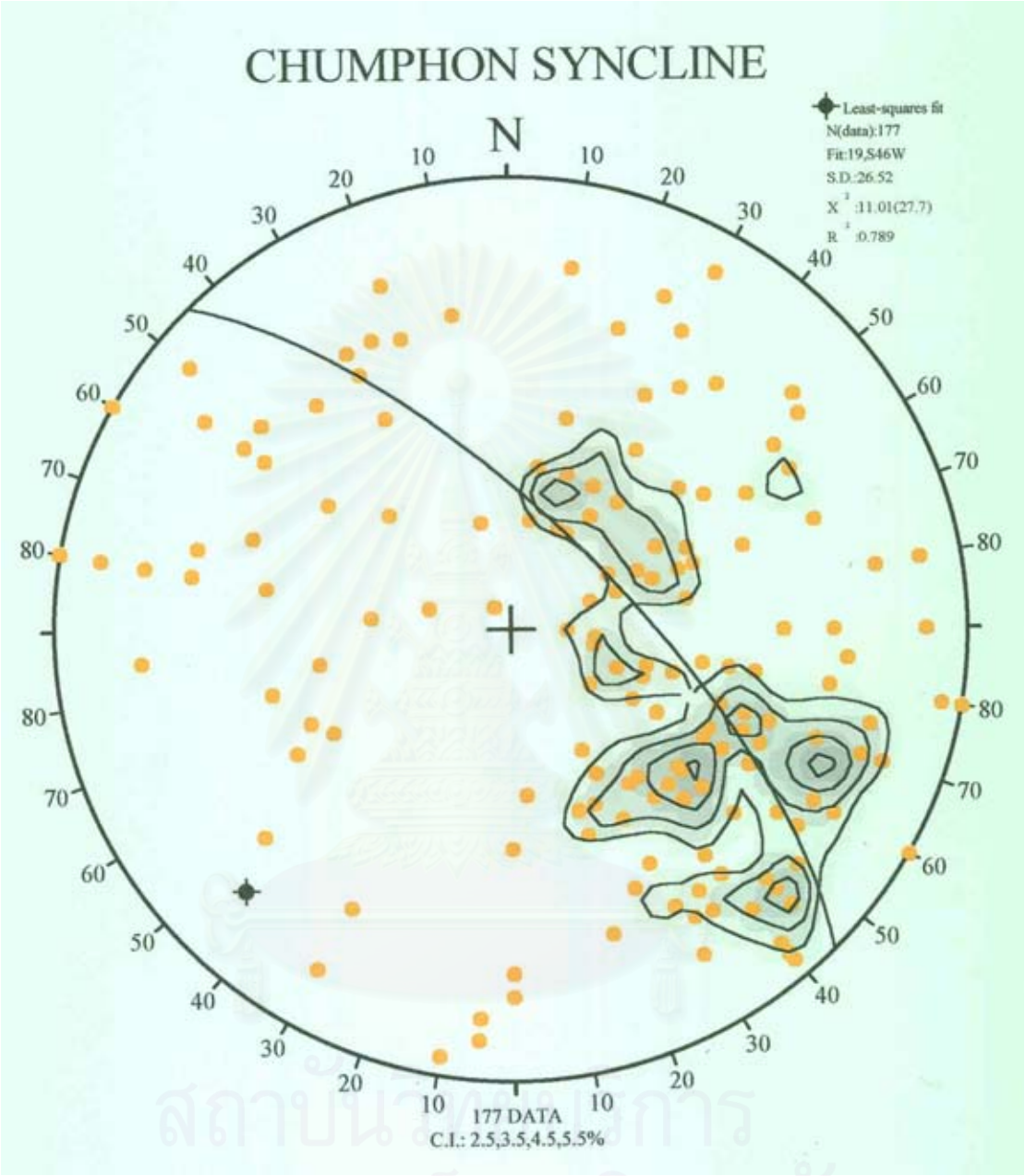

Figure 4.6. Equal-area stereonet plot of 177 poles of bedding planes (orange dots) of Chumphon syncline. The great circle of the fold profile fits in 316°/71 °NE Indicating that the fold trend is in the northeast-southwest direction. However, the bedding-plane plot is rather scattered to really justify this conclusion.

east-west, northeast-southwest, northwest-southeast, and north-south (Figure 4.7). No significant trending is instified in this case.

4.1.2 Ta Pi Syncline

Ta Pi syncline is situated in Amphoe Khian Sa in the southern part of Changwat Surat Thani where Ta Pi river flows northward into the Gulf of Thailand. Ta Pi river has many of its important tributaries being spreaded in the area this synclinal structure. The syncline is approximately 60x90 km.^{2} in size (Figure 4.8). The rocks here are of both Sai Bon Formation and Trang Group. The Sai Bon Formation rocks are at the western part, while those of Trang Group generally widespread at the southeastern portion of the syncline. In the central part, the Tertiary sediments were found as a thin-layered unit. They angular-unconformably overly the Mesozoic stratigraphic units. Ta Pi syncline was most discussed in the preceding Chapter 3.

The fold here is interpreted from the field observation and the graphic expressions. From ¶-diagram of totally 31 bedding planes, the fold axis is 169^o/18^o and the fold profile is 259^o/72^{o}N (Figure 4.9). The fold trend thus lies almost in the north-south direction. The rose diagram of 59 fractures reveals 2 major fractures directions that are east-west and north-south, with subordinated northeast-southwest and northwest-southeast (Figure 4.10).

4.1.3 Krabi-East Syncline

Krabi-East syncline is located at Thung Yai and Khlong Thom districts in the eastern part of Changwat Krabi, thus be so named. It lies to the southeast to Ta Pi syncline. The doubly-plunging syncline lies in the north-south trending, 15 km. wide and 25 km. long (Figure 4.11). The rivers Khlong Tom, Khlong Min, and Khlong Lam Daeng, which are the tributaries of Ta Pi river, flow through this synclinal area. The rocks observed are the marine Triassic rocks of Sai Bon Formation and continental Trang Group. These rocks were mostly exposed on the low altitude hill chains that surround

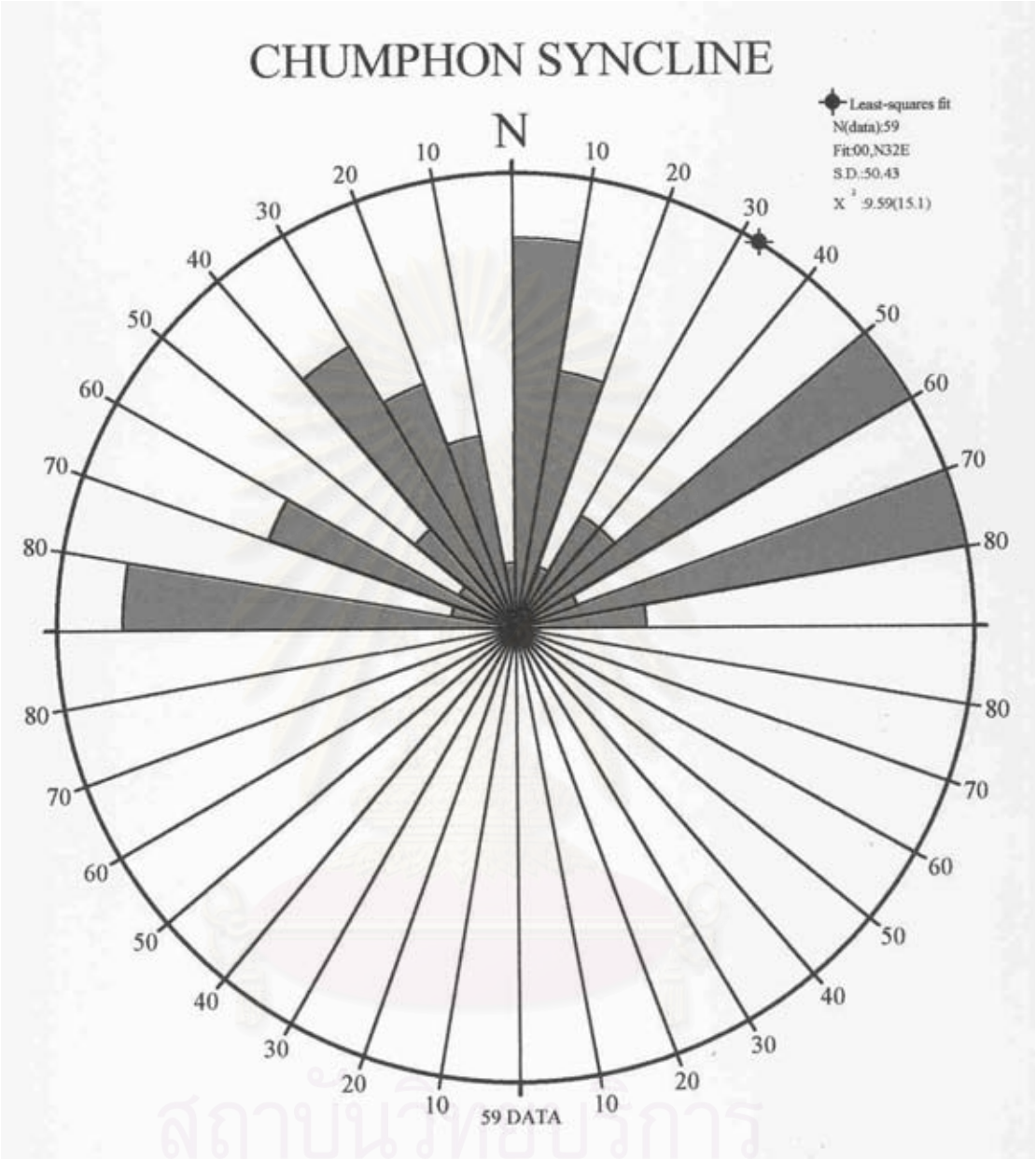

Figure 4.7. Half-rose diagram of 59 strike values of fractures of Chumphon syncline. Several major fracture trending from the east-west, northeast-southwest, northwest-southeast, and north-south directions are illustrated.

Radius:2.70inches

Projection:Equal Area

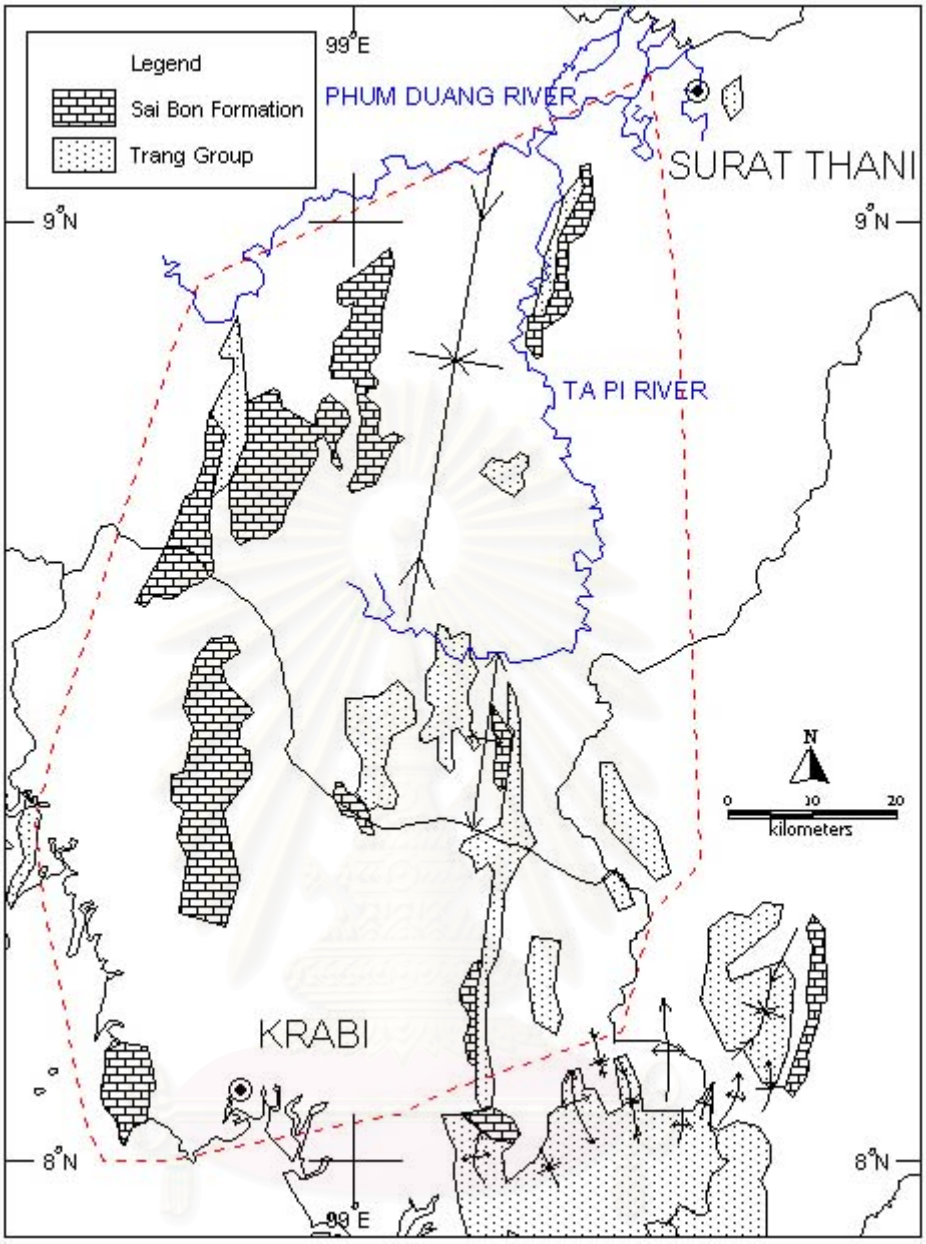

Figure 4.8. Location of Ta Pi syncline. The red dash-line approximates the extent of the syncline.

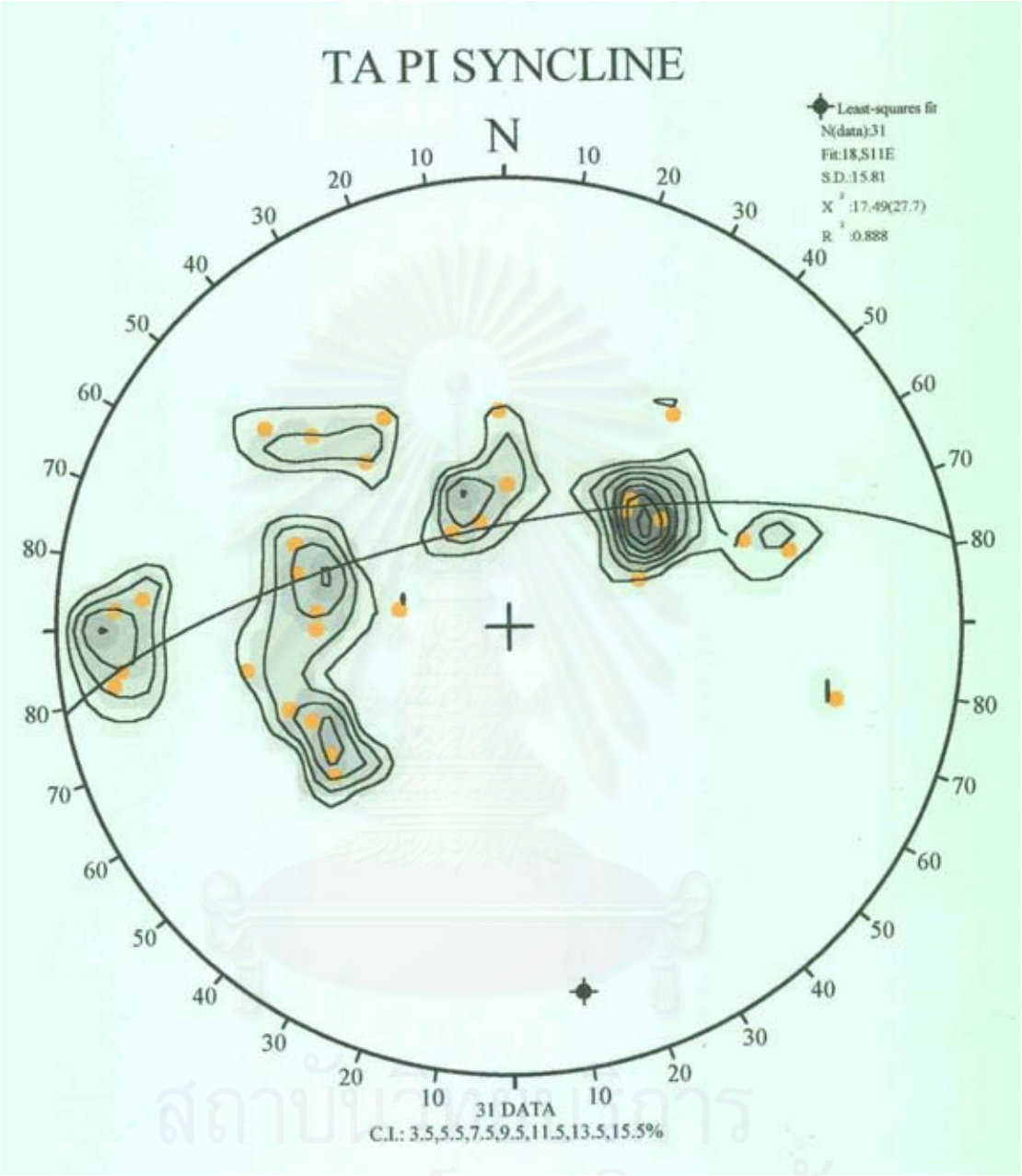

Figure 4.9. Equal-area stereonet plot of 31 poles of bedding planes (orange dots) of Ta Pi syncline. The great circle of fold profile orientates in 259°/72°N indicating a fold axis plunging 18° to southsoutheast.

Radius:2.70inches

Projection:Equal Area

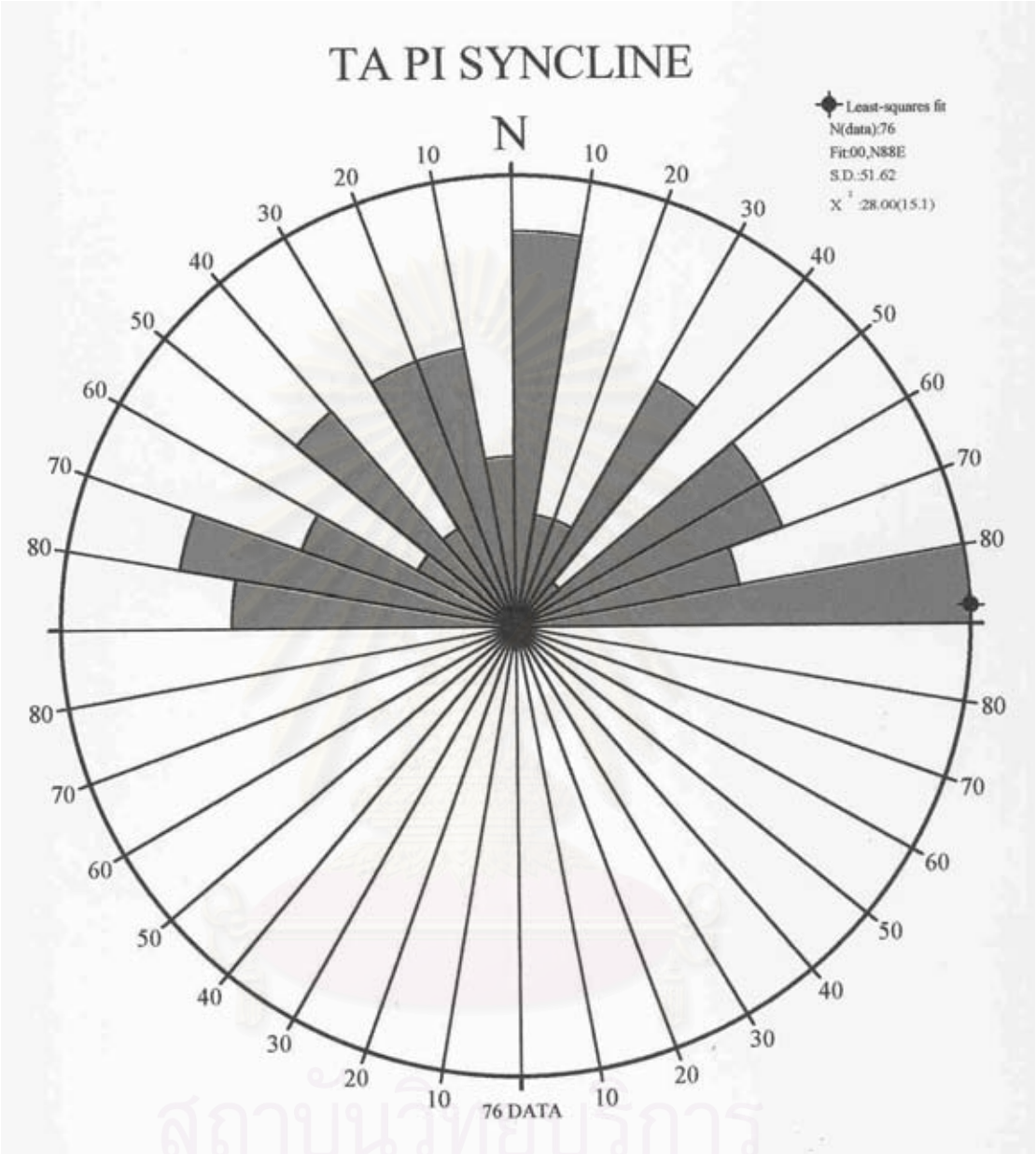

Figure 4.10. Half-rose diagram of 76 strike values of fractures of Ta Pi syncline.
The diagram shows that the most fractures trend roughly in the east-west direction with subordinated trends in invarious other directions from the northeast-southwest to the northwest-southeast.

Radius:2.70inches

Projection:Equal Area

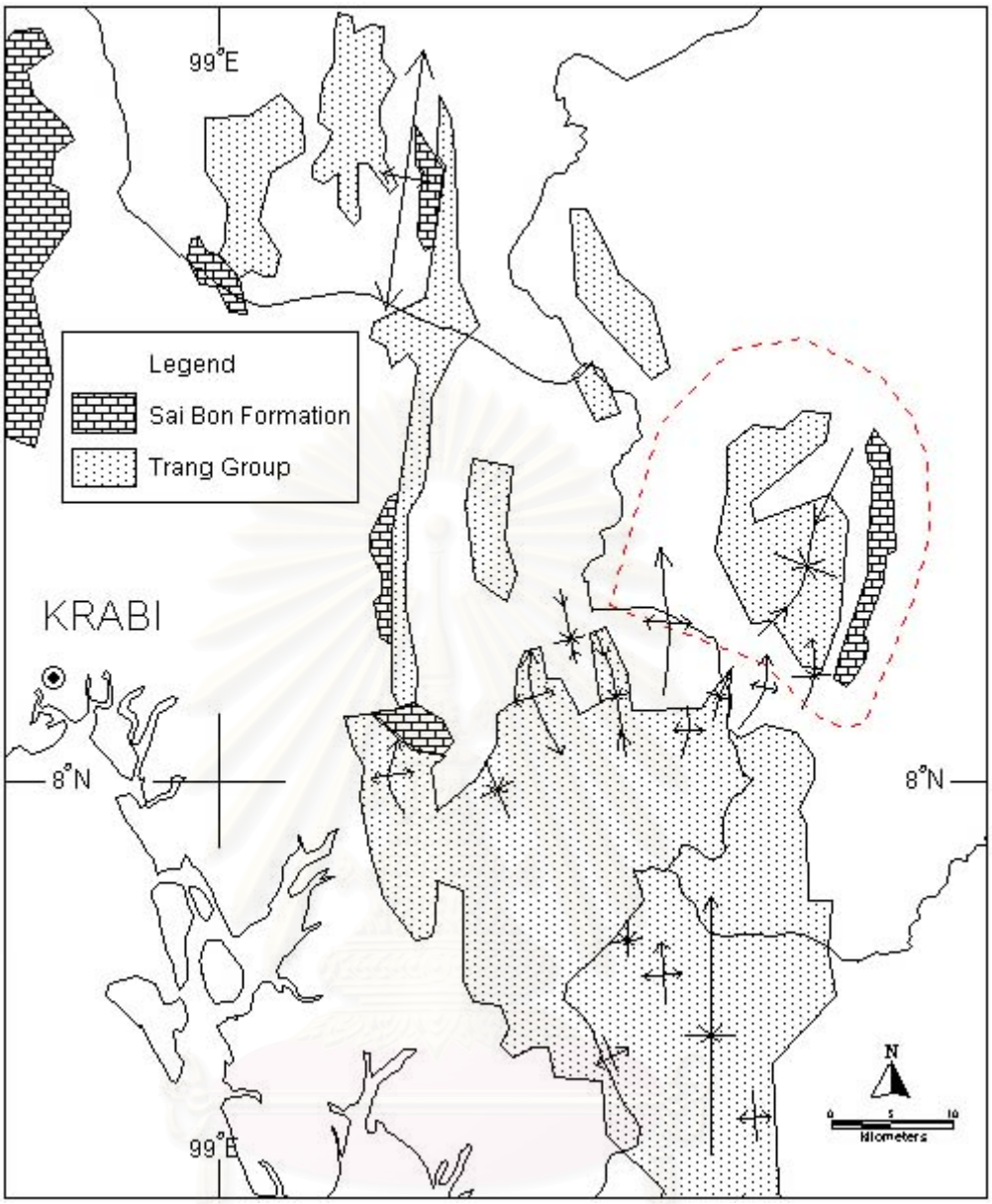

Figure 4.11. Location of Krabi-East syncline. The structure, in addition, is modified after Teerarungsigul (2000). The red dash-line approximates the extent of the syncline.

the central low land of the syncline. The type-section localities of Trang Group are situated here because Krabi-East syncline contains the obvious rock types, fossils, and structures (Figure 4.12, 4.13, 4.14, and 4.15).

Krabi-East syncline is an open fold with the gentle plunging to somewhat the north-south direction. The fold trend from stereonet plot of 66 bedding planes lies in north-south direction with fold profile $267^{o}/83^{o}$N and fold axis $177^{o}/7^{o}$ (Figure 4.16). The 44 fractures rose-diagram plot shows distinctively an east-west direction (Figure 4.17).

4.1.4 Trang Syncline

Trang syncline is the southern-most structure of the 4 composite synclines. It is named after Changwat Trang in where the structure locates locates within its administrative districts of Amphoe Sikao and Wangwiset. This fold could be the southern extension of Krabi-East syncline, but with a narrow, cross-cutting culmination in between the 2 structures. It was also observed that an intensive zone of small-scale fractures locates here.

This elongated syncline trends north-south, about 30 km. wide by 70 km. long (Figure 4.18). It is bounded by the Permian limestone exposures to the east, while the western flank disappears under the young unconsolidated sediments and extends into the Andaman Sea. The Mesozoic lithology is generally of Sai Bon Formation and all other formations of Trang Group (Figure 4.19, 4.20, 4.21, and 4.22). The Mesozoic units here commonly forms the low hill chains around the syncline, while the central area is an undulating terrain. The main stream, Khlong Chi flows in the middle, being parallel to the fold trend, into the Andaman Sea.

Trang syncline is an open, upright, gently doubly-plunging fold with the associating lower-ordered anticlines and synclines. The smaller-scaled parasitic folds, like those in the other synclines, are sometime inclined to overturned with the moderately

Figure 4.12. Khlong Min Formation at Krabi-East syncline dipping to the east. Grid reference 508001. View toward the northwest.

Figure 4.13. The arkosic sandstone of Lam Thap Formation in Krabi-East syncline. The bedding planes are dipping to the east . Grid reference 497944. View toward the southwest.

Figure 4.14. Sam Chom Formtion of Krabi-East syncline composing of conglomerates and conglomeratic sandstone. The rocks are much weathered and eroded. Grid reference 510001. View toward the east.

Figure 4.15. The arkosic sandstone of Phun Phin Formation in Krabi-East syncline.
A steeply-dipping joint set is shown in this outcrop. Grid reference 497943.
View toward the west.

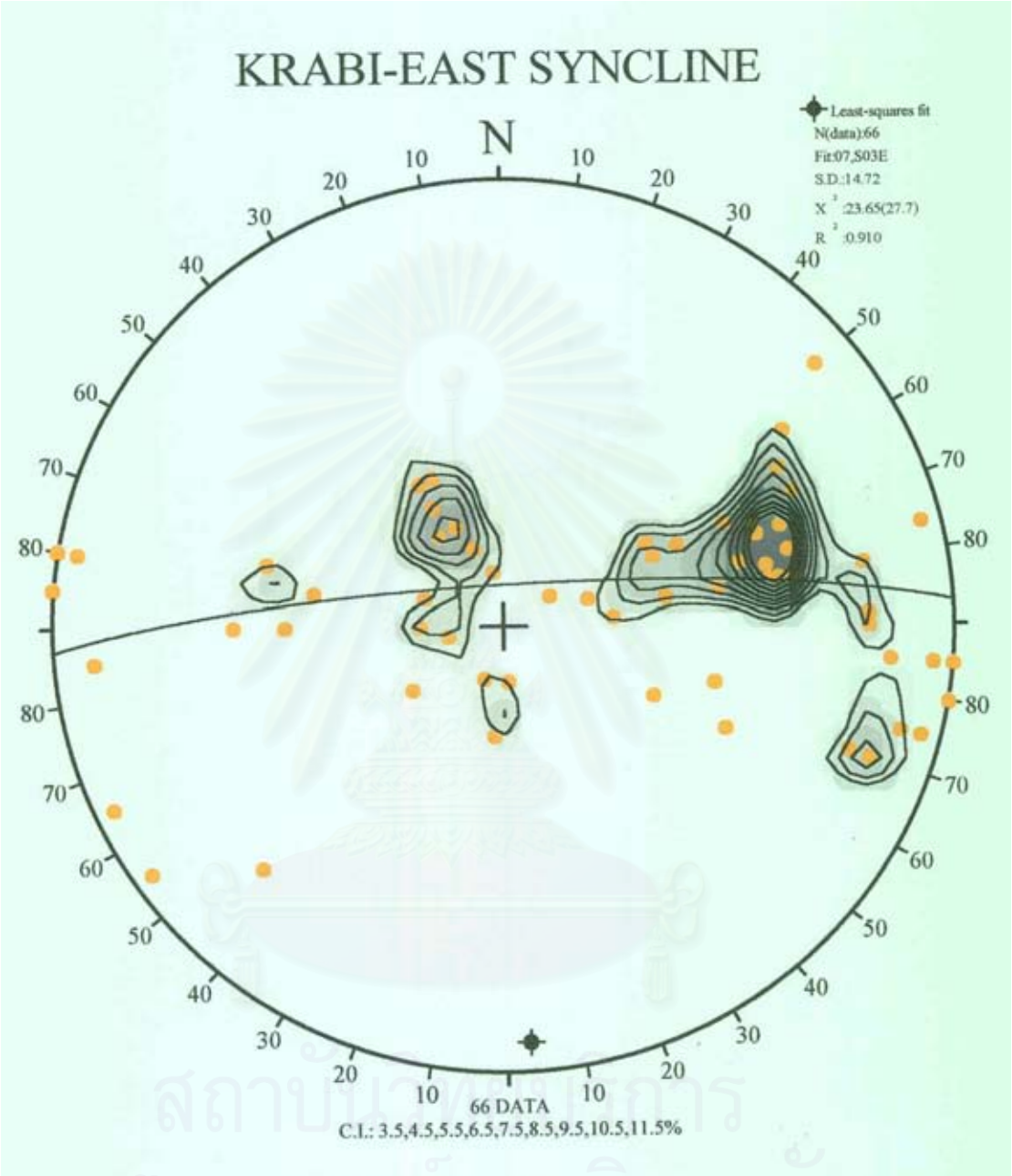

Figure 4.16. Equal-area stereonet plot of 66 poles of bedding planes (orange dots) of Krabi-East syncline. The best-fit great circle of the fold profile orientates 267°/83°N indicating the fold axis with subhorizontal plunging in the north-south direction.

Radius:2.70inches

Projection:Equal Area

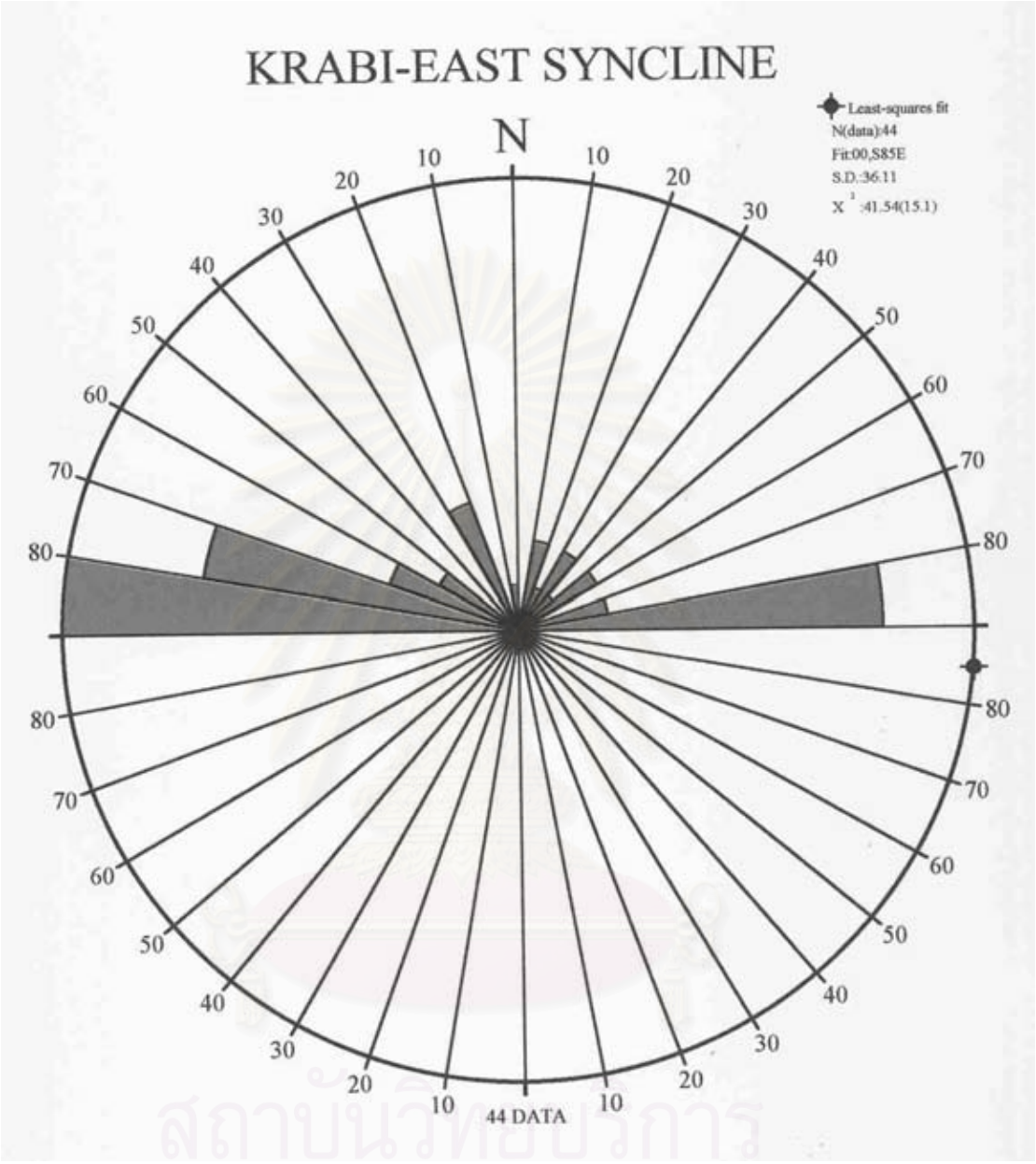

Figure 4.17. Half-rose diagram of 44 strike values of fractures of Krabi-East syncline. It illustrates a distinctive east-west direction.

Radius:2.70inches

Projection:Equal Area

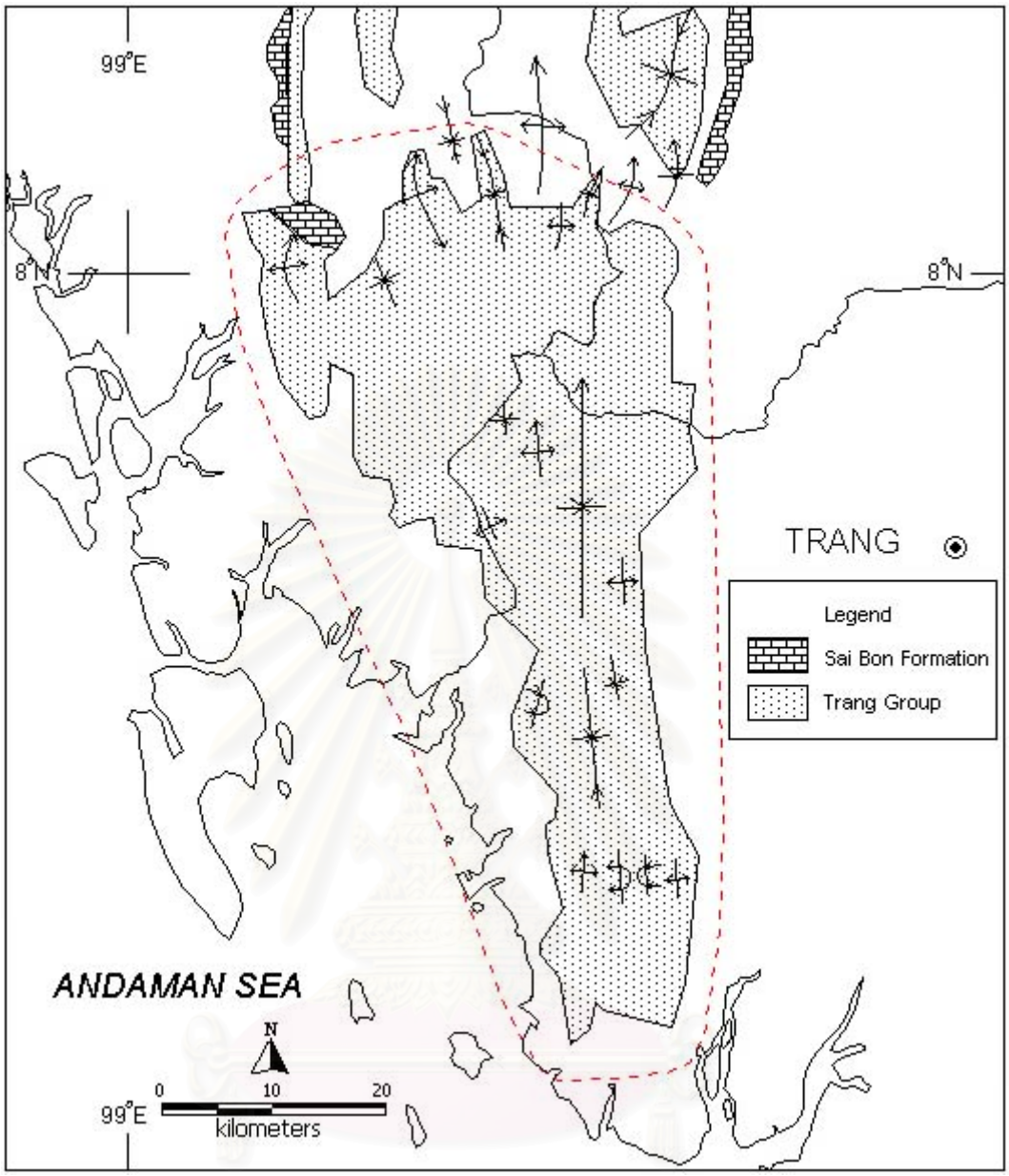

Figure 4.18. Location of Trang syncline. The structure is modified after Kanjanapayont (1998). The red dash-line approximates the extent of the syncline.

Figure 4.19. The marine Triassic Sai Bon Formation in Trang syncline. The rock, the dolomitic limestone, is west dipping. Grid reference 369688. View toward the northwest.

Figure 4.20. The arkosic sandstone of Lam Thap Formation at the northern part of Trang syncline illustrates an east dipping. Grid reference 545721. View toward the northeast.

Figure 4.21. The overturned bedding planes of Lam Thap Formation in Trang syncline. Grid reference 412581. View toward the north.

Figure 4.22. The arkosic sandstone bedding planes of Phun Phin Formation in Trang syncline. The bedding planes incline to the east. Grid reference 459549. View toward the southeast.

west-dipping normal limbs and somewhat vertical east-dipping normal limbs to steeply west-dipping overturned limbs. The axial planes dip toward the west. The fold profile from ¶-diagram of 267 bedding planes is $89^{\circ}/89^{\circ}$S and fold axis is thus $359^{\circ}/1^{\circ}$ (Figure 4.23). The rose-diagram of 179 fractures here show a fairly distinctive 3 directions being east-west direction, with less obvious northnortheast-southsouthwest and northwest-southeast trending (Figure 4.24).

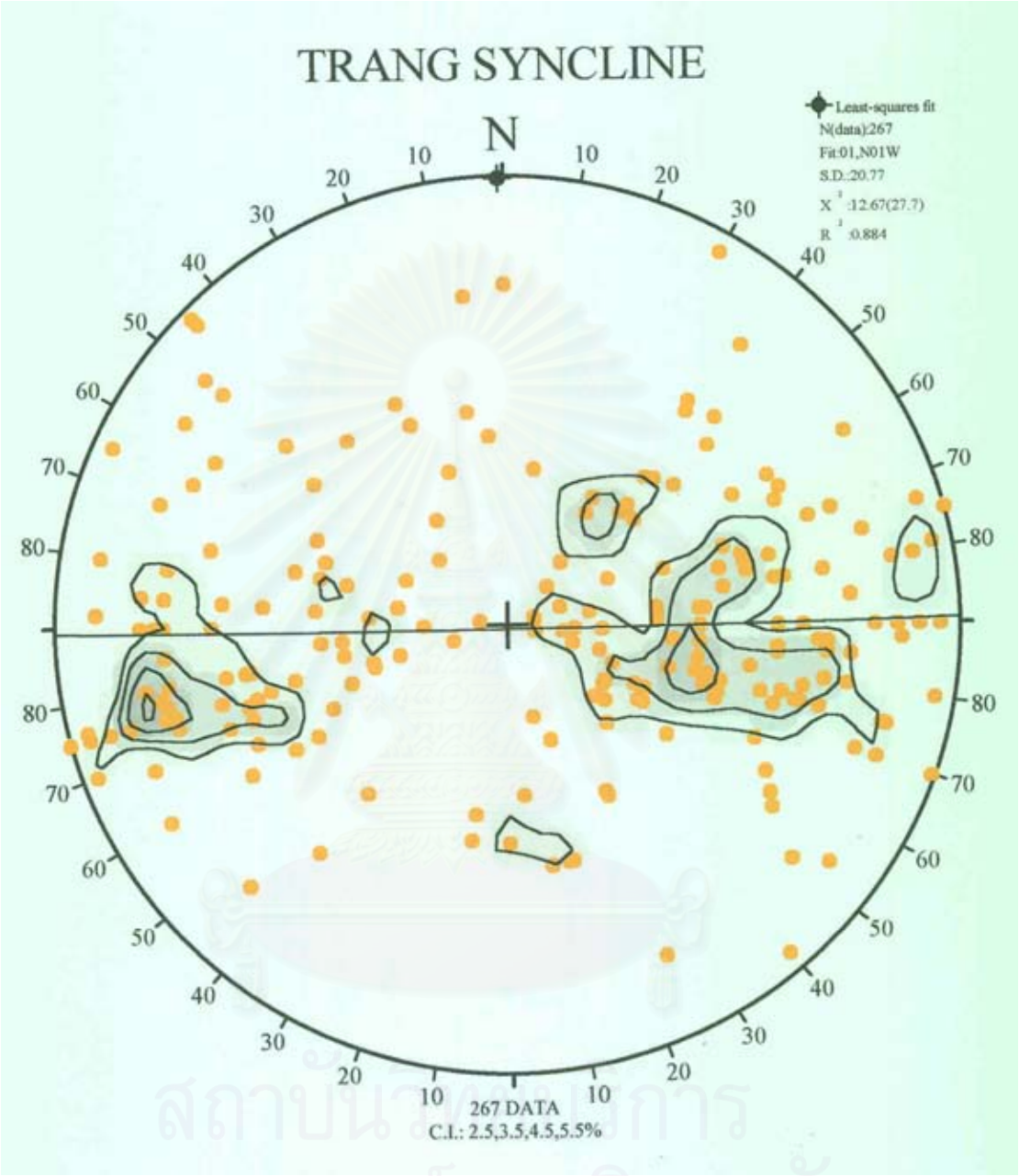

Figure 4.23. Equal-area stereonet plot of 267 poles of bedding planes (orange dots) of Trang syncline. The great circle of the fold profile fits in 89°/89°S indicating that the fold trend is in the north-south direction. However, the bedding-plane plot is too scattered to really justify this conclusion.

Radius:2.70inches

Projection:Equal Area

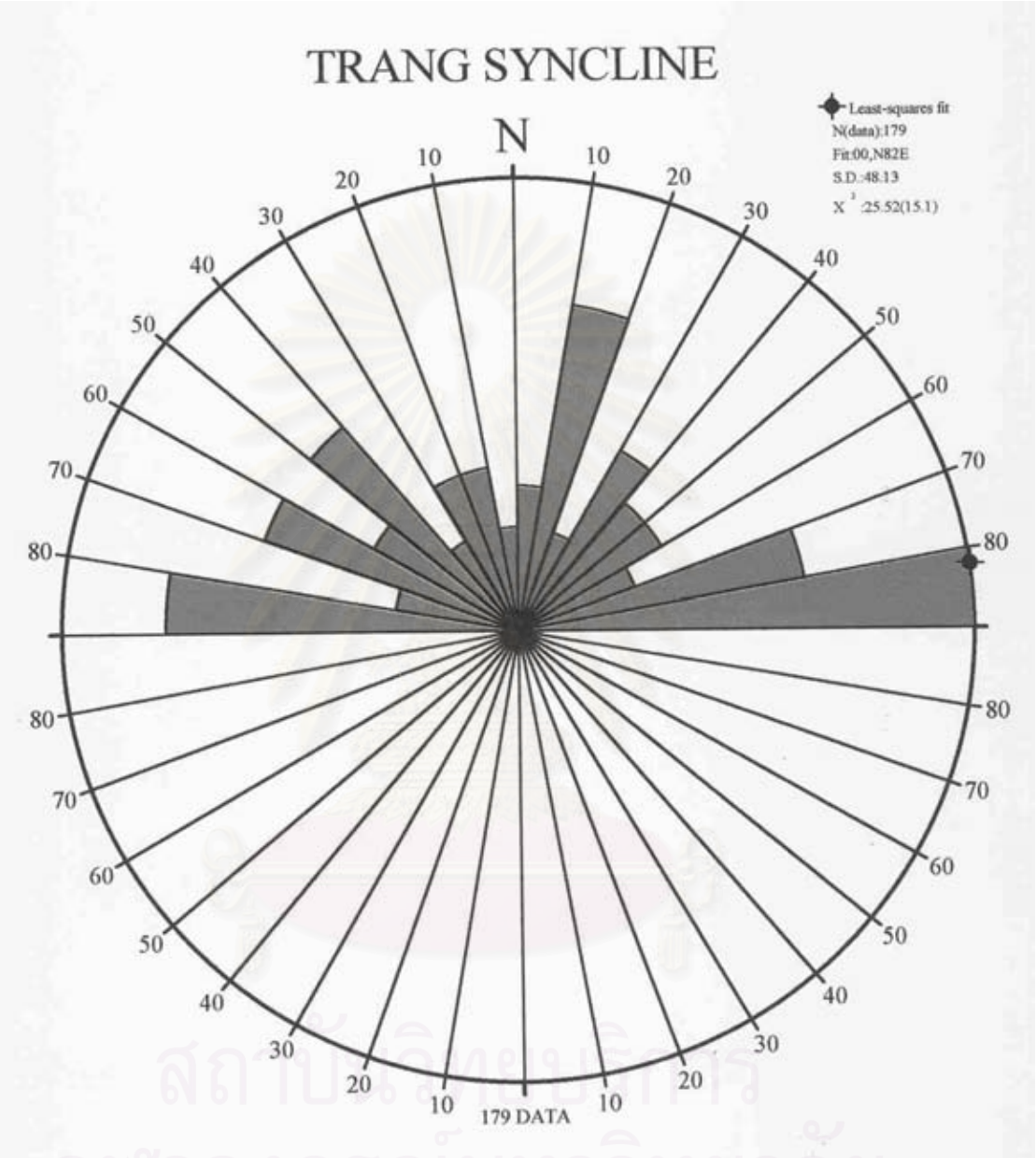

Figure 4.24. Half-rose diagram of 179 strike values of fractures of Trang syncline. Several major fractures show distinctive trending in the east-west direction, with subordinate trending in the northeast-southwest and northwest-southeast directions.

Radius:2.70inches

Projection:Equal Area

CHAPTER 5

GEOLOGIC EVOLUTION OF STUDY AREA

5.1 Discussion on Fold Styles in Mesozoic Stratigraphic Units

Since the major structures in the study area being the composite synclines are essentially the results of the folding mechanism, a discussion to understand the folding events and tectonism is made here.

The Mesozoic stratigraphic units are bounded by the angular-unconformities with the Paleozoic units below and Tertiary sedimentary units above. The Paleozoic units are characterized by the Permian limestone, perhaps with the associated clastic rocks that look very similar to the rocks of the Mesozoic era in some locations, and PermoCarboniferous clastic unit. Both basement units were with the more deformed characteristics. Because the Paleozoic rocks were more deformed than the Mesozoic rocks, some of the structures of the basement, namely folds and fractures, do not conform the Mesozic structures. This certainly confirms an angular unconformity below the lower horizon of the Mesozoic sequence.

Above the upper horizon, the structures of the Tertiary sediments typically claystones are rather simple with flat-lying bedding planes without any distinctive fractures. The Tertiary sediments are said to deposit in the tilted-fault block basins whose western limits were noted to be the north-south normal faulting. Like down above, the 2 rock units do not conform, and another angular-unconformity between the two rock units is thus proposed. The angular-unconformities also lead to another suggestion that the different deformation patterns in different rock units indicates no more than two significant folding events after the deposition of the Permian units. The first one is before the deposition of the Mesozoic rocks but probably after the deposition of the Permian units, and the second one is before the deposition of the Tertiary sediments.

Unfortunately, the north-south normal faulting which created the graben or tilted fault-block basins for the Tertiary sedimentary deposition cannot be judged in this study. The fractures of this north-south trending, when being viewed in the throughout complication, are only of the subordinate group, while their fracturing nature is also uncertain.

The general areal structures are here again described as the composite lower-ordered anticlines and synclines combining together to form a larger first-ordered syncline, perhaps a synclinorium. Within the huge syncline, 4 major gentle synclines, namely Chumphon, Ta Pi, Krabi-East, and Trang synclines were recognized. It was observed that the eastern limbs of every synclines are with gentle inclination, while the western limbs are more steeply dipping toward the east. The smaller-scaled parasitic folds which are found primarily on the eastern limbs, with similar geometry to that of the 4 synclines, but to a large degree of geometric illustration, from gently to moderately dipping eastern synclinal limbs to somewhat vertical or steeply east-dipping normal western synclinal limbs to steeply west-dipping overturned limbs. The orientation of bedding planes suggested that the largers folds are open, doubly-plunging, inclined structures. The fold axes gently plunge to the north and south, with variation to the northnortheast-southsouthwest in Chumphon syncline, while the axial planes are steeply tilted toward the west.

The general structures are also associated with the brittle fractures, which are extension joints and several faults. These fractures cross-cutting the fold trend at a very high angle to being perpendicular to it, in the east-west, northeast-southwest and northwest-southeast directions. They are from a few meters long up to several kilometers in length. The extension joints are noted to be the *ac*-joints in east-west direction. The small-scale conjugate shear joints are observed in the northeast-southwest and northwest-southeast direction. Furthermore, some cross-cutting faults were noted to be the steeply-dipping normal kind, but other have not yet received a closer look enough to identify their exact nature. However these fractures, most if not all, are believed to simply associate the folds in the same tectonic event. The construction of 3-dimensional

structural modles of the Mesozoic stratigraphic units in this upper southern Thailand is shown as Figure 5.1.

According to the remote sensing interpretation (Figure 3.2), the features of northnortheast-southsouthwest major fractures are only presented in the PermoCarboniferous rocks with its northnortheastern and being disappeared at the approximated extension of the Mesozoic bedding plane zone. It might indicate that these fractures occurred before the Mesozoic time. The location and trending of these fractures probably match the structures in the study of Garson and others (1975) who reported Khlong Marui Fault zone being of the sinistral movement in Late Jurassic to Early Cretaceous and later with dextral movement in middle Tertiary. However, the present study reveals the age of the fractures, not so conform with the above study, and this must be cleared up in the future detailed studies.

The structural geologic data of this study area as resulted from the stereonet plots and rose diagrams plots, together with the field observations, are used to define the tectonic origin of the structures by which a tectonic pure-shear pattern is assumed for the east-west compression and north-south extension (Figure 5.2). It is believed that this folding event, the second occurrence mentioned above, started with the east-west compression stresses to form the buckling folding. The asymmetric parasitic folds perhaps suggest some shear sense with a reverse shear plane subhorizontally dipping to the west. Then as a result, a secondary extensional flow along the fold trend immediately followed the east-west buckle folding to create the *ac*-extension joints and cross-normal faults. These deformation phases had occurred before the formation of fault-controlled Tertiary tilted-fault-block basins being recognized as the north-south Tertiary Khian Sa and Sin Pun intermontane basins, out of the present study area, and perhaps as many other Tertiary basins further west to the Aandaman area and east in the Gulf of Thailand and throughout the country (Figure 5.3). The Tertiary sediments then started depositing and thus rested angular-unconformably on the Mesozoic rocks. And furthermore, without distinctive folding evidence in the Tertiary sediments, it was concluded that the important deformation event never exists after the Tertiary period.

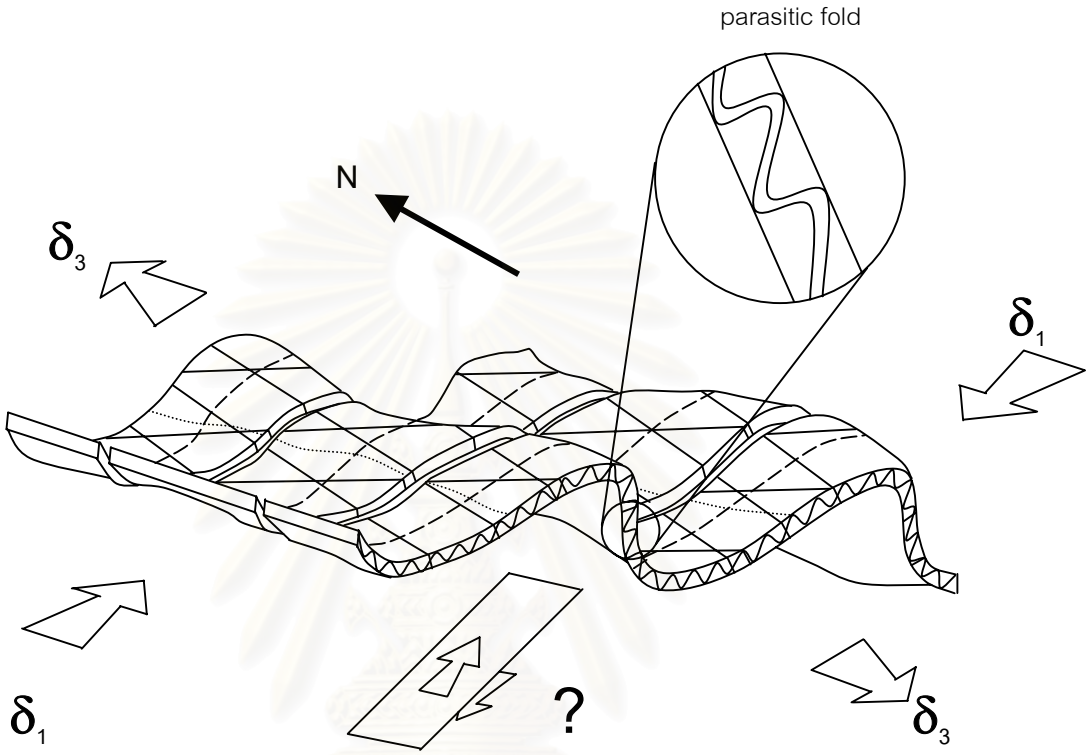

Figure 5.1. Three-dimensional structural model of the Mesozoic stratigraphic units in the upper southern Thailand. It shows the inclined asymmetric fold with parasitic folds. The major fractures are also shown in this model.

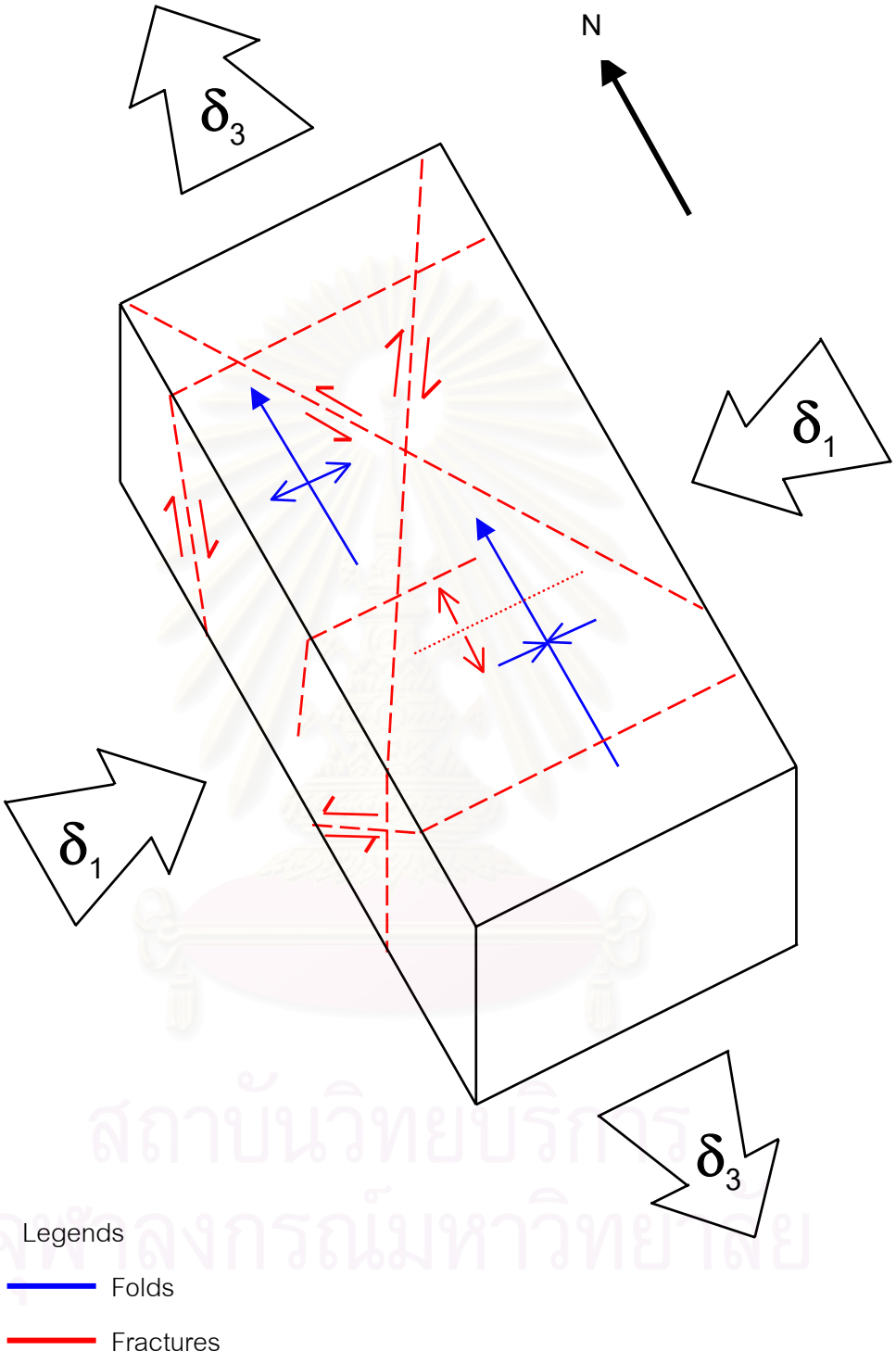

Figure 5.2. Block diagram of the Mesozoic rocks with tectonic structures in the upper southern Thailand.

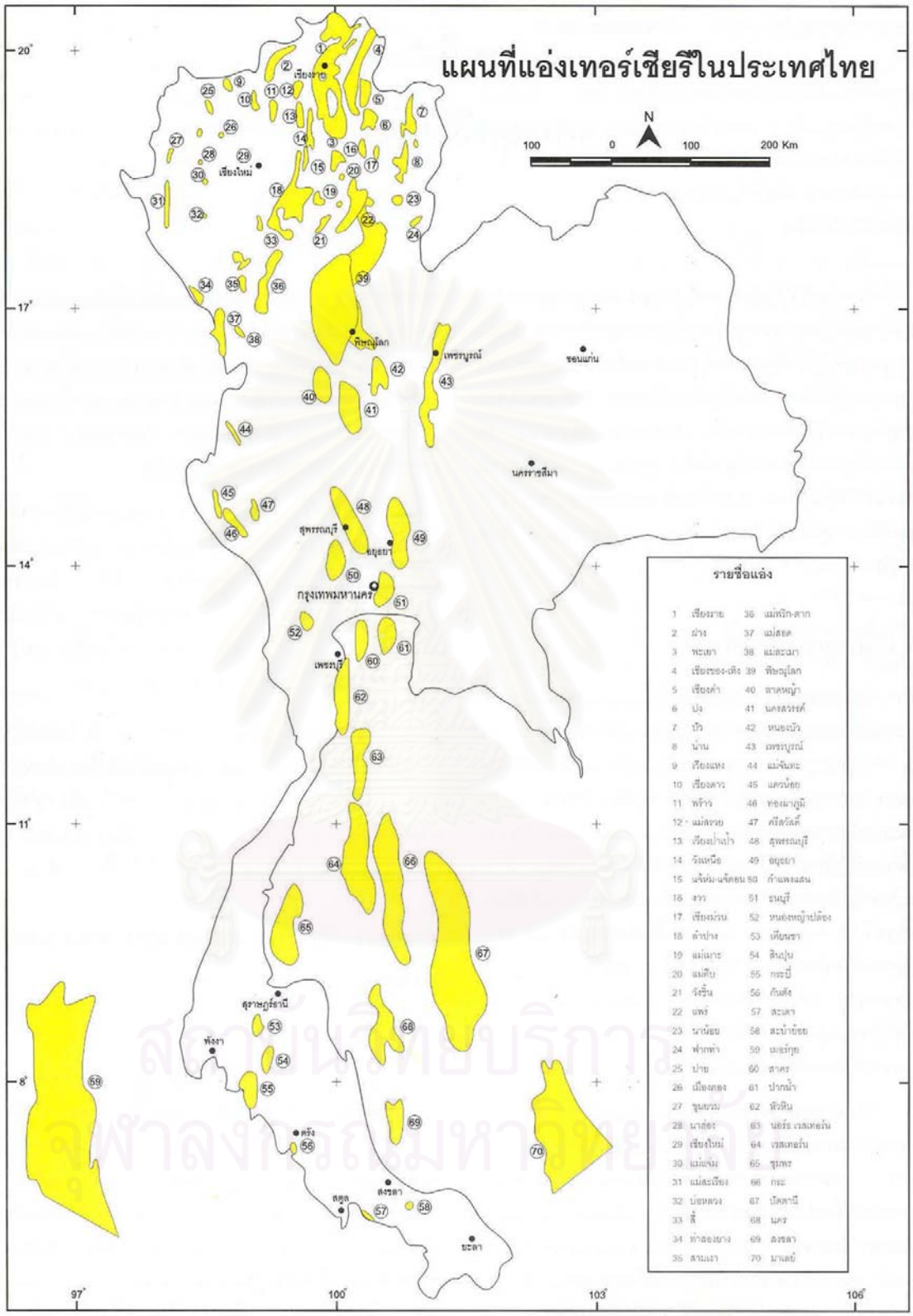

Figure 5.3. Significant Tertiary basins in Thailand (After Chaodumrong and Chaimanee, 2002).

5.2 Discussion on Post-Triassic Tectonic Evolution

According to Bunopas (1981), Thai Peninsula is a part of the Shan-Thai craton. During Precambrian, the Shan-Thai landmass was situated to the west of Australia Gondwanaland which located at the lower hemisphere. The landmass was rifted from Australia Gondwanaland in Early Carboniferous. After then, Gondwanaland rapidly rotated clockwise with an effect to break out Shan-Thai in the north and while Paleotethys was formed, with the Hercynian orogeny in Middle Carboniferous. In Permian, the environment was the deposition of limestones that was the topmost basement strata below the Mesozoic stratigraphic units. Later Paleotethys was closed toward the north and completely disappeared in Triassic by Indosinian orogeny. There were Indosinian I in Early Triassic and Indosinian II in Late Triassic.

In the present study area, the convergence of Shan-Thai and Indochina in Late Permian to Triassic was resulted as changing the environment into shallow marine and folding with the tin-bearing granitic intrusions in Triassic to Jurassic. The marine regression was represented by the deposition of mudstone, siltstone, sandstone, and limestone of the Sai Bon Formation. After that, the marine influence for the deposition of the Lower part of Khlong Min formation under the lagoonal environment. The area was continuously uplifted for the deposition of the upper part of Khlong Min formation under the fluvio-lacustrine environment during the Middle Jurassic to Lower Cretaceous. During Late Jurassic to Cretaceous, Lam Thap formation, Sam Chom formation and Phun Phin formation are deposited under the non-marine environment.

After the deposition of Mesozoic rock, the area had tectonically deformed by the east-west compression with north-south extension, perhaps by the Himalayan orogeny. This folding event started with the east-west compressive stresses to form the buckling folding, and concurrently or consequently followed by the extensional flow along the north-south fold trend. This results as a synclinorium or composite synclines in the north-south trend associated with the lower-ordered asymmetric parasitic folds and extension

brittle fractures. Later, the area was followed by the erosion until the end of the Mesozoic and probably until the Lower Tertiary.

After the Mesozoic folding event, no more folding tectonics had ever been noticed, except that the normal faulting in the north-south trend had been occurred by a tectonic process normally accepted as the east-west extension. These normal faults helped forming the north-south trending basins in which the Tertiary sediments of fluvio-lacustrine origins could accumulate angular unconformably above the Mesozoic basement. The Tertiary sediments here are of Krabi Group. Afterward, the Tertiary strata might be slightly vertically uplifted again, in an epirogenic fashion, before the Quaternary deposition could begin until the present day.

CHAPTER 6

SUMMARY AND CONCLUSIONS

This chapter is devoted to the summary and conclusions from the study ot the previous works, remote sensing interpretation, field investigation, data analysis and interpretation, and discussion.

The rock units in the study area compose of the marine Triassic rocks (Saibon Formation) and the non-marine Jurassic-Cretaceous rocks (Trang Group: Khlong Min, Lam Thap, Sam Chom, and Phun Pin formations, from bottom to top, respectively). Sai Bon Formation consists of mainly brownish red siltstone, mudstone and fine-sand-sized sandstone with lenses of dolomitic limestone. The fossil assemblage composes of pelecypods (*Plaeocardita* sp.), gastropods and plant remains. It lies angular unconformably above the upper Paleozoic rocks, the Permian limestone unit and PermoCarboniferous clastic unit.

In Khlong Min Formation, the lower part of this formation consists of mudstone intercalated with fossiliferous limestone, and maroon siltstone interbedded with thin-bedded limestone containing abundant fossils of vertebrates, conchostracan (*Estheria*), bivalves, gastropods, ostracods and pollens. In the upper part of the formation, the rocks are mainly gray to yellowish gray calcareous sandstone, fine- to medium-grained with flaser bedding and thin-bedded limestone with wood fragments and bivalve of *Modiolus* sp. Khlong Min Formation conformably overlies Saibon Formation.

Lam Thap Formation is predominantly the arkosic sandstone and siltstone unit. The formation is further divided into 2 lithofacies. In some areas, the formation is made up of almost thick-bedded arkosic sandstone. Elsewhere, it is characterized by siltstone/mudstone interbedded with sandstone and conglomeratic sandstone in some areas with commonly a size-gradation being fining upward. In some other area else, the

thinning upward. Lam Thap Formation conformably overlies Khlong Min Formation and is further conformably overlain by Sam Chom Formation.

Sam Chom Formation is characterized by conglomerates, conglomeratic sandstone and thin-bedded sandstone. Conglomerates are matrix-supported and clasts are made up mainly of quartz, chert, sandstone, and some extrusive and size varies from granule to boulder. The sandstone is yellowish brown to light gray, thin-layered, and medium-sand-sized, consisting mainly of quartz, feldspar and dark minerals with common graded bedding, and usually shows sharp contacts with overlies mudstone, siltstone of reddish orange to reddish brown. The lowermost part of this formation is marked locally by thin-layered sandstone.

Phun Phin Formation essentially consists of red to reddish brown fine-sand-sized sandstone, conglomerate/breccia. It conformably overlies Sam Chom Formation. However in some places, Phun Phin Formation conformably overlies Lam Thap Formation instead, i.e. Sam Chom Formation has probably thinned out in this area, thus a local paraconformity exists.

The Tertiary sedimentary unit, in turn, angular unconformably overlies The Mesozoic rocks. And the unconsolidated Quarternary sediments probably overlies all older rocks with yet another unconformity. The structural style in the Mesozoic rocks were essentially an elongated fold in the north-south to northnortheast-southsouthwest direction. The change in the fold trend could only be because of the slight variation of stress pattern and trend and variable strain being occurred to the different to-be-deformed rock units. But as for the major folding event imprinted onto the Mesozoic rocks. The fold formed in first-ordered synclines, perhaps synclinorium with associating lower-ordered anticlines and synclines. The lower-ordered synclines located from Chumphon to Trang, namely Chumphon, Ta Pi, Krabi-East, and Trang synclines. The first-order syncline has the gently westerly dipping eastern limb while western limb dipping steeper toward the east. The smaller-scaled folds which are found primarily related to the eastern limb are mostly inclined to overturned with the moderately west-

dipping normal limbs and somewhat vertical or steeply east-dipping normal limbs to steeply west-dipping overturned limbs. The east-west trending ac joints and normal faults conform to the east-west lineament traces in the LANDSAT TM-5 imagery (Figure 3.2), which cut across the major structure. The northeast-southwest and northwest-southeast conjugate shear joints also appear locally.

The tectonic pattern of the study area suggests an east-west compression with north-south extension, perhaps by the Himalayan orogeny. This folding event started with the east-west compressive stresses to form the buckling folding, and concurrently or consequently followed by the extensional flow along the north-south fold trend. The existence of the north-south trending normal faulting to form the depositional basins of the Tertiary rocks could not be recognized in this study. However, it appears from the structural pattern in the younger overlying Tertiary unit that, after the tectonic event that deformed the Mesozoic units and before the Tertiary rocks are coming to be, no more intensive folding occurred.

CHAPTER 7

SUGGESTIONS FOR THE FURTHER STUDIES

The present geologic structural model was conclusive only to the scale of the study area, which is quite large. However, this is unavoidable as of the sequences of study, which needs the general idea as in the first priority, before the further, more detailed works could be performed. Quite a number of questions is still left for the further studies. Some of the problems are listed below.

1. The contacts between the rock units especially those presumed to be the unconformities, could not be observed in the field because of thick soil cover. It appears that some bedding in different age are conform and some are not. Moreover, no obvious marker beds are found in the study area. The relationship of rock units thus is needed to be proved using such key phenomena.

2. The Mesozoic stratigraphic units disappear between the south of Changwat Chumphon and the north of Changwat Surat Thani, perhaps indicating a large culmination there. This structure is needed to be studied in details.

3. It is believed in this study that the drainage pattern of Ta Pi river and its tributaries is controlled by some structural features. The control and formation are needed to be proved.

4. The trace of Khlong Marui Fault zone could never be confirmed in the present study, though many workers still believe in its existence. This must be cleared up in the future detailed studies.

5. A throughout consideration of the regional tectonics in upper southern Thailand, with an entire picture of the global tectonics model from Andaman Sea, peninsular Thailand, Gulf of Thailand, through the southern Tip of Indochina is still needed.

6. The interpretation of the tectonic episodes here must depend on more realistic geologic knowledge. The supporting evidences are still need for a more correctly tectonic interpretation than just presumption.

7. After the field study was completed, but during the composition of this thesis, Raksaskulwong (2002) had proposed the name Thung Yai Group to replace the name Trang Group in an internal reporting of the annual activity in the Department of Mineral Resources of Thailand. Perhaps any study after this work must use the name Thung Yai Group instead.

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APPENDIX

Localities of Structural data

The structural data of attitudes of bedding planes and fractures were collected from several localities. The attitudes of bedding were plotted in a lower-hemisphere, equal-area stereonet, and fractures were plotted on rose diagram then analyzed using NETPROG program. The following are structural data and their localities.

1. Cross-section 1

Attitudes of bedding (Strike/dip)	Grid reference	Map sheet
90°/26°S	282858	4826 I
75°/20°E	282858	4826 I
60°/45°E	232807	4826 I
315°/30°W	232807	4826 I
325°/34°W	232807	4826 I
13°/63°W	232807	4826 I
308°/50°W	229791	4826 IV
314°/32°W	229791	4826 IV
340°/25°W	230787	4826 IV
352°/77°E	235780	4826 IV
354°/75°E	235780	4826 IV

Attitudes of fractures	Grid reference	Map sheet
10°/80°E	282858	4826 I
280°/56°E	282858	4826 I
89°/26°S	282858	4826 I
354°/80°E	232807	4826 I
315°/70°W	232807	4826 I
303°/51°E	232807	4826 I
25°/75°E	232807	4826 I
271°/54°N	232807	4826 I
272°/58°W	232807	4826 I

Attitudes of fractures	Grid reference	Map sheet
355°/51°W	232807	4826 I
55°/88°E	232807	4826 I
290°/86°E	232807	4826 I
350°/42°E	232807	4826 I
303°/56°E	229791	4826 IV
60°/69°W	229791	4826 IV
20°/74°E	229791	4826 IV
272°/81°E	229791	4826 IV
337°/70°E	229791	4826 IV
340°/25°W	230787	4826 IV
84°/83°W	230787	4826 IV
28°/85°W	230787	4826 IV
66°/47°E	235780	4826 IV
55°/64°E	235780	4826 IV
80°/65°W	235780	4826 IV
75°/33°E	235780	4826 IV

2. Cross-section 2

Attitudes of bedding	Grid reference	Map sheet
351°/49°E	197330	4825 IV
10°/20°E	197330	4825 IV
320°/42°E	203338	4825 IV
335°/40°E	205341	4825 IV
05°/70°E	219271	4825 IV
325°/40°E	204274	4825 IV
340°/43°E	204274	4825 IV
03°/76°E	136281	4825 IV

Attitudes of fractures	Grid reference	Map sheet
85°/74°E	197330	4825 IV
07°/81°W	197330	4825 IV
335°/55°W	197330	4825 IV
75°/74°E	203338	4825 IV
350 62 W	203338	4825 IV
65°/68°E	205341	4825 IV
04°/60°W	205341	4825 IV
322°/50°E	205341	4825 IV
85°/88°W	219271	4825 IV
35°/46°W	219271	4825 IV
05°/50°E	219271	4825 IV
285°/78°E	219271	4825 IV
57°/73°W	204274	4825 IV
290°/70°W	204274	4825 IV
08°/65°W	204274	4825 IV
358°/40°W	204274	4825 IV
71°/64°E	204274	4825 IV
340°/63°W	204274	4825 IV
75°/75°W	204274	4825 IV
285°/70°W	136281	4825 IV
60°/34°E	136281	4825 IV
282°/54°E	136281	4825 IV
85°/47°W	136281	4825 IV

3. Cross-section 3

Attitudes of bedding	Grid reference	Map sheet
325°/34°W	888806	4726 I
40°/59°E	890766	4726 I
50°/40°E	907730	4726 I
88°/40°E	933722	4726 I

Attitudes of bedding	Grid reference	Map sheet
60°/20°E	933722	4726 I
00°/35°E	933722	4726 I
345°/54°W	942723	4726 I
340°/46°W	942723	4726 I
22°/42°E	942723	4726 I
05°/35°E	958671	4726 I
15°/40°E	958671	4726 I

Attitudes of fractures	Grid reference	Map sheet
298°/50°E	888806	4726 I
350°/52°E	888806	4726 I
38°/60°E	893770	4726 I
320°/50°E	893770	4726 I
350°/50°W	893770	4726 I
330°/56°W	890766	4726 I
50°/40°W	890766	4726 I
320°/25°E	907730	4726 I
312°/65°W	907730	4726 I
55°/75°W	907730	4726 I
00°/70°E	907730	4726 I
340°/40°W	907730	4726 I
80°/45°W	907730	4726 I
315°/69°E	933722	4726 I
60°/72°W	933722	4726 I
272°/76°W	933722	4726 I
342°/70°W	933722	4726 I
00°/65°W	933722	4726 I
89°/64°S	933722	4726 I
290°/62°E	942723	4726 I
30°/60°E	942723	4726 I

Attitudes of fractures	Grid reference	Map sheet
295°/65°E	942723	4726 I
15°/60°W	942723	4726 I
295°75°W	958671	4726 I
30°/75°W	958671	4726 I
295°/73°W	958671	4726 I
35°/56°W	958671	4726 I
40°/55°E	958671	4726 I

BIOGRAPHY

Mr. Pitsanupong Kanjanapayont was born on June 8, 1978 in Changwat Ratburi, central Thaland. He finished the high school study in 1995 from Non-formal education center of Changwat Nakhonpathom, then entered Chulalongkorn University. He received a Bachelor of Science degree in Geology form the Department of Geology, Faculty of Science, Chulalongkorn University in 1999. He then subsequently entered the Master's degree program in Geology in the same department. During his graduate study years, he was a teaching assistant in physical geology, structural geology, and mineralogy throughout.