STRUCTURAL GEOLOGY OF NORTHERN KOH SAMET, CHANGWAT RAYONG

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ธรณีวิทยาโครงสร้างของบริเวณเกาะเสม็ดตอนบน จังหวัดระยอง

นส. พิมพร เจิมประไพ

รายงานนี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตร์บัณฑิต

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STRUCTURAL GEOLOGY OF NORTHERN KOH SAMET, CHANGWAT RAYONG

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Abstract: Koh Samet is the biggest N-S Island in Changwat Rayong. This study emphasized in the northern of Koh Samet. There are the metamorphic rocks in Koh Samet that are mainly schist. Based on evidences in mesoscopic structures and microstructures of study area, the ductile deformation dominates all rock types in study area. Dispersion of poles trend of stereonet can show a pattern of folding. S-folded, M-folded, W-folded, conjugate joint set and minor folds in the field supported ductile deformation. Elongated porphyloblasts are mainly evidences for both dextral and sinistral ductile shear in the field. On thin section, S-C and S-C' fabrics, mineral orientations, mica fish, and porphyloblasts indicate shear sense both dextral and sinistral. The bulging (BLG), basal gilde, the local grain boundary migration (GBM), undolose extinction and the local subgrain in quartz together with the mineral assemblage indicate low grade metamorphism at the temperature between 300-400°C in greenschist facies. In conclusion, the mesoscopic structures, structural analysis and microstructures analysis were interpreted as folding with shear sense which fits to the flexural shear fold model.

Keywords: structural geology, northern Koh Samet,Changwat Rayong

บทคัดย่อ

เกาะเสม็ดเป็นเกาะที่ใหญ่ที่สุดในจังหวัดระยอง วางตัวอยู่ในแนวเหนือ-ใต้ โดยงานวิจัยครั้งทำการศึกษาในบริเวณเกาะเสม็ดตอนบน พบว่าหินในบริเวณเกาะเสม็ดเป็นหินแปรพวกหินชีสต์ จารการศึกษาธรณีโครงสร้างในระดับกลางและระดับเล็กของพื้นที่ศึกษา พบว่าหินทั้งหมดในพื้นที่ศึกษาถูกแปรเปลี่ยนลักษณะแบบอ่อนนิ่ม (ductile deformation) ซึ่งจากหลักฐานการกำหนดจุดของการวางตัวของริ้วขนานโดยใช้สเตริโอกราฟิกเนต (stereographic nets) ลักษณะการกระจายตัวของจุดมีรูปแบบบ่งบอกถึง ลักษณะของการเกิดการคดโค้ง (folding) ประกอบกับหลักฐานธรณีโครงสร้างระดับกลางที่พบ รอยคดโค้งขนาดเล็กในรูปแบบต่างๆ รอยแยกจากการเฉือนแบบร่วม 2 แนวตัดกัน (conjugate joint sets) ในภาคสนาม ซึ่งทำให้สนับสนุนกับการเกิดชั้นหินคดโค้งขึ้น นอกจากนี้ยังพบหลักฐานการเฉือน คือ ลักษณะของเม็ดแร่ถูกยืดไปตามแนวแรงเฉือนในทิศทางทั้งขวาเข้าและซ้ายเข้า เมื่อทำการศึกษาธรณีโครงสร้างระดับเล็ก พบลักษณะของริ้วขนานแบบ S-C และ S-C’ fabrics, mica fish และ quartz porphyloblasts ลักษณะเหล่านี้บ่งบอกถึงทิศทางการเฉือนทั้งในแนวขวาเข้าและซ้ายเข้า เช่นเดียวกับในภาคสนาม นอกจากนี้ยังพบลักษณะของ dynamics recrystallization แบบ Bulging (BLG) บางแผ่นหินบางพบลักษณะ grain boundary migration (GBM) พบในบางบริเวณเท่านั้น พบลักษณะของ basal glide, undulose extinction และ subgrain ซึ่งหลักฐานที่กล่าวมานี้ร่วมกับกลุ่มแร่ประกอบหินสามารถบ่งบอกถึงอุณหภูมิของการเปลี่ยนลักษณะหรือระดับขั้นการแปรสภาพได้ ในที่นี้แสดงให้เห็นว่า เป็นการแปรสภาพขั้นต่ำ ณ อุณหภูมิประมาณ 300-400 องศาเซลเซียส เป็นหินแปรพวก greenschist facies ดังนั้นจากธรณีโครงสร้างระดับกลางและระดับเล็กสามารถวิเคราะห์ได้ว่า โครงสร้างของเกาะเสม็ดตอนบนเป็นลักษณะของการคดโค้งของชั้นหินร่วมกับการเกิดรอยเฉือน ซึ่งสอดคล้องกับการคดโค้งแบบ Flexural shear fold.

คำสำคัญ: ธรณีวิทยาโครงสร้าง, เกาะเสม็ดตอนบน, จังหวัดระยอง

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Chapter 1

Introduction

Eastern Thailand was developed from the welding of two main allochthonous continental terranes. They are namely ShanThai terrane in the west and Indochina terrane in the east which along the Nan-Sakaeow Suture Zone in Late Triassic (Bunopas, 1983). Both terranes had their origin on the northwesthern margin of Gondwana in the southern Hemisphere during Lower Paleozoic (Burr and other, 1990). The lithology of those tearranes compose of Precambrian metamorphic and igneous rocks, so they had the origin from the same Precambrian Shield (Bunopas and Vella, 1983)

In the eastern shoreline of Thailand, the rocks lie in the NW-SE direction. Ages of the rocks range from Precambrian to Quaternary period. Precambrian rocks are common in the central and western parts of eastern region. These are some Paleozoic rocks that are located there. Other parts of eastern area are covered widely by Paleozoic rocks. Igneous rocks are exposed from Changwat Sakaeow to Changwat Chanthaburi. Most of igneous rocks are granite which can be found at a part of Changwat Chonburi, Changwat Rayong and Changwat Chanthaburi.

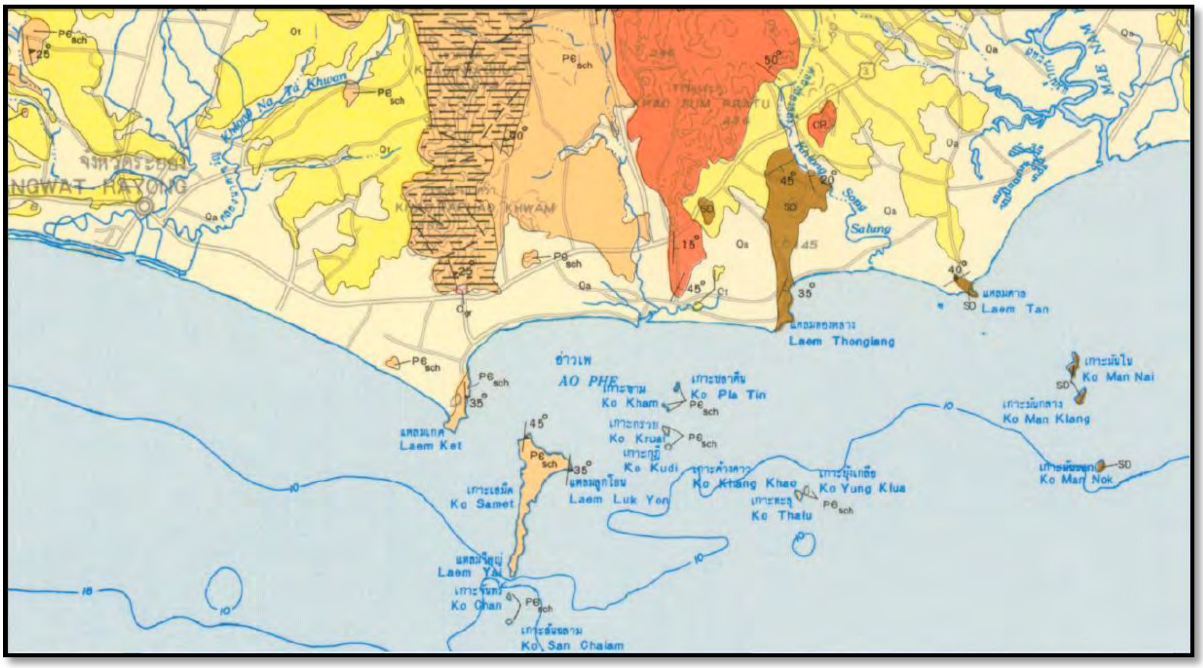
Focusing on Precambrian rocks of eastern region are regional metamorphism that are prominent in Changwat Chachengsao,Changwat Chonburi and Changwat Rayong. These areas were named “Chonburi massif” after Campbell (1975) and Areesiri (1982). The massif is oriented northwest – southeast. Reports on metamorphic rocks in this area are limited to studies of Brown et al. (1951) and Nakinbordi et al. (1985). The detailed geology of Khao Chao, Amphoe Nong Yai, Changwat Chonburi is reported by Areesiri (1982).

In Changwat Rayong, the studies of high grade Precambrian metamorphic rocks have information that is described only in northern area of Khao Chamao in Amphoe Klaeng, Changwat Rayong. They reported that rocks including metamorphic rocks; gneiss, schist, and calc-silicate are the oldest rocks in Changwat Rayong. They are located in a small part of the Northern area where contact with Khao Chao, Amphoe Nong Yai,Changwat Chonburi, and also locate in Khao Wang, Khao Leam Yang and Koh Samet (Department of Mineral Resources,1976) (Figure 1.1).The rocks are mainly quartz-mica schist and quartz kyanite schist. A specific characteristic of these rocks are mineral banding, that both direct bands and curve bands that are developed by deformation. These rocks in Koh Samet were remapped and were

Carboniferous in age (Late Paleozoic) (Department of Mineral Resources, 2008)(Figure 1.2). Rocks are high grade metamorphic rocks which are composed of biotite-gneiss and hornblend-gniess. They are very hard and have a lot of quartz veins. However, A specific characteristic of these rocks are mineral banding of both direct bands and curve bands that are developed by deformation as showing in the geologic map in 1976. Other areas where can find them are Kao Chamao, Kao Mainuan and Kao Thapong. (Department of Mineral Resources, 2008)

Koh Samet is the biggest island in Changwat Rayong long in N-S direction with about 6,500 meters; long from north to south and about 2,500 meters; wide at a northern part. Topography of Koh Samet is mountains and small hills such as Khao Krajome, Khao Ploywan and Khao Prajedee. In the eastern part, there are sand beaches along shore line. There have no studies which are described and explained about structural geology and their evolution before. This study aims to incorporate structural data and lithologic data of Koh Samet; to characterize the structural style, interpret structural evolution and deformation phases which are correlated with the main tectonic evolutions of Thailand. The study is based on 2 main analyse; field observation (mesostructure analysis) and microstructure analysis. This study becomes to informational database about structural geology of Koh Samet, Changwat Rayong and for further study in the future.

Geological map



Explaination :

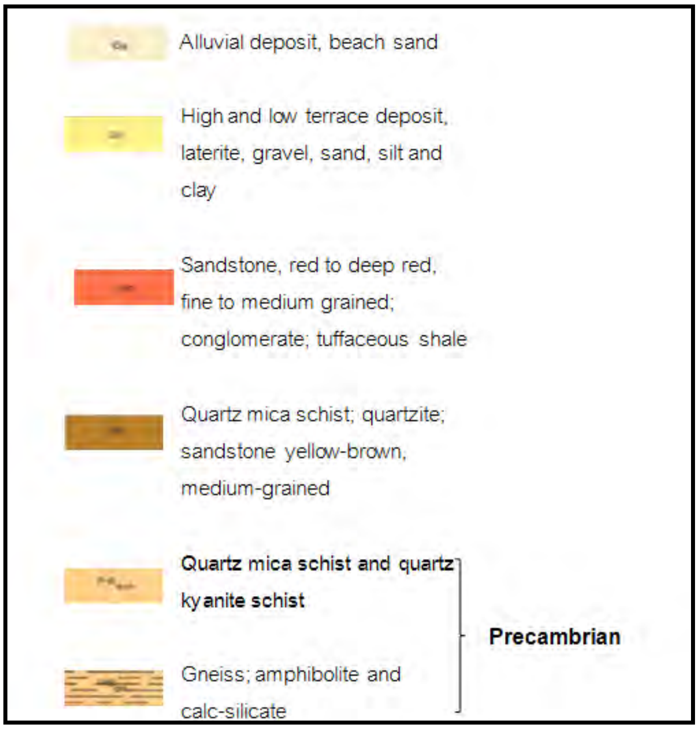


Figure 1.1 Geological map of Koh Samet in Changwat Rayong, eastern Thailand (Department of Mineral Resources, 1976).

Geological map

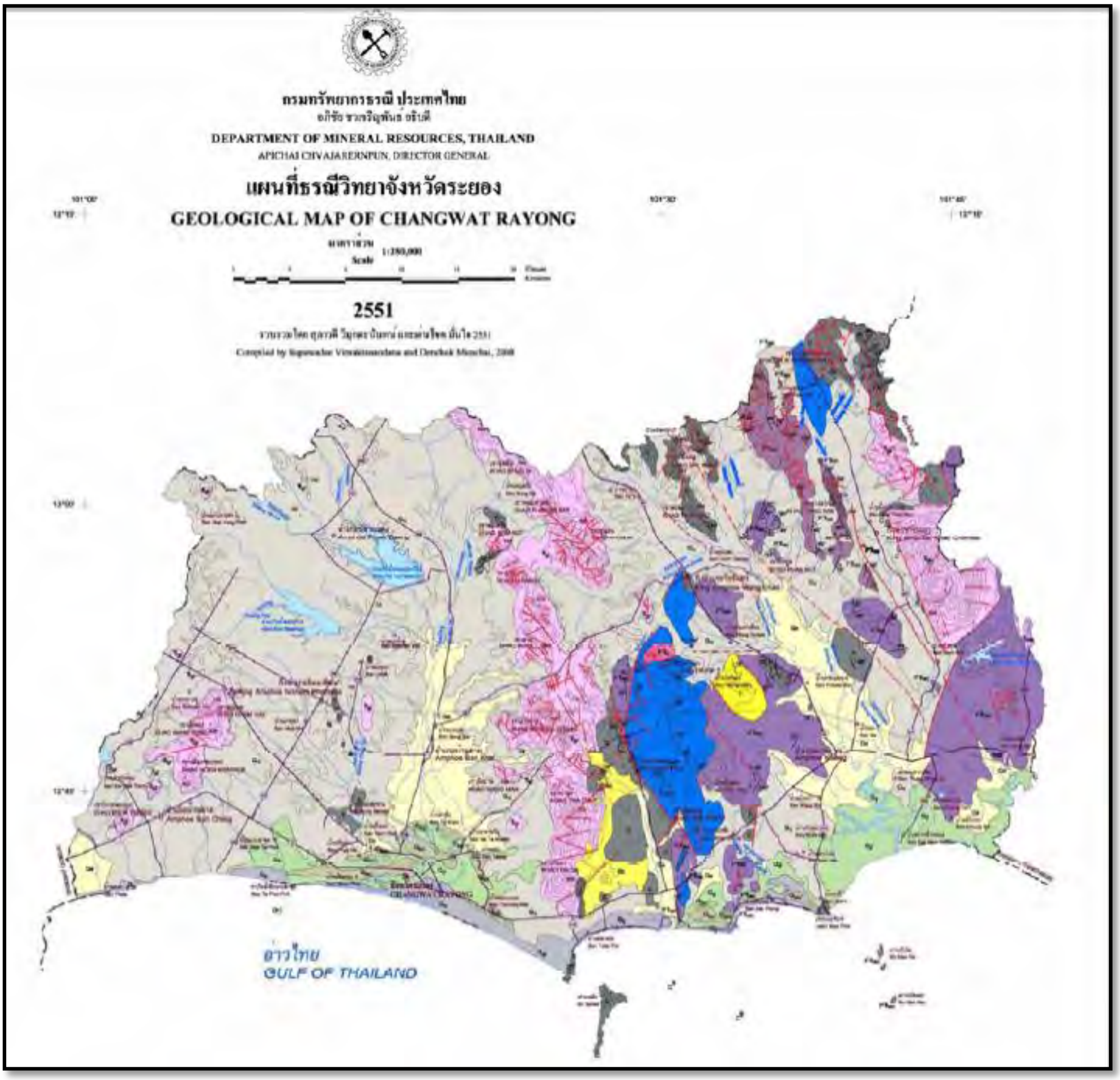


Figure 1.2 Geological map of Koh Samet in Changwat Rayong, eastern Thailand (Department of Mineral Resources, 2008).

Explaination:

Symbol	ตะกอน หินชั้น และหินแปร SEDIMENT, SEDIMENTARY AND METAMORPHIC ROCKS	ชื่อหมวด/กลุ่มหิน FORMATION/GROUP	ยุค PERIOD	อายุ (ล้านปี) AGE (my.)
Qb	ตะกอนชายหาด : ทราย กรวด ทรายแป้ง มีเปลือกหอย เศษปะการัง และเศษซากพืช Beach deposits : sand, gravel, silt, with mollusc, coral and plant remains.		ควอเทอร์นารี QUATERNARY	0.01-1.6
Qtf	ตะกอนที่ลุ่มราบน้ำขึ้นถึง : ดินเหนียวสีเทา หรือสีเทาปนเขียว เนื้ออ่อนนิ่ม ชั้นหนา มีชั้นทรายละเอียด และชั้นพีตแทรกสลับ พบเปลือกหอยบ้าง Tidal flat deposits : clay, gray or greenish gray, soft, thick bedded, intercalated with fines sand, peat layers shell fragments.			
Qa	ตะกอนน้ำพา : กรวด ทราย ทรายแป้ง และดินเหนียว Alluvial deposits : gravel, sand, silt and clay.			
Qbo	ตะกอนสันทรายเก่า ทราย เนื้อปานกลางถึงหยาบ การคัดขนาดปานกลาง ความกลมมนดี มีเศษเปลือกหอยปน Old beach ridged deposits : sand, medium-to coarse-grained, medium sorted, well rounded, with shell fragments.			
Qt	ตะกอนตะพัก : กรวด และทราย Terrace deposits : gravel and sand.			
Qc	ตะกอนคุ้งค้างอยู่กับที่ และตะกอนเศษหินเชิงเขา : หินแกรนิตผุ ทราย และทรายแป้ง เศษหิน ดินลูกรัง และดินเทอราโรซ่า Residual and colluvial deposits : granite washed, sand and silt, rock fragments, lateritic soil and terrarosa soil.			
T	หินโคลน และ หินทรายแป้ง สีเทาแกมเขียว กึ่งแข็งกึ่งร่วน ชั้นบางถึงปานกลาง พบซากใบไม้ Mudstone and siltstone, greenish gray, thin to medium bedded, fossil of leafs.		เทอร์เชียรี TERTIARY	1.6-66.4
J	หินทราย สีน้ำตาลอ่อน ชั้นหนาเป็นชั้นดี แสดงชั้นเฉียงระดับ สลับด้วยหินดินดาน หินโคลน สีน้ำตาลแกมแดง ชั้นบาง และหินกรวดมน สีน้ำตาลแกมแดง ชั้นปานกลางถึงหนา เม็ดกรวดประกอบด้วยแร่ควอตซ์ และเศษหินดินดาน หินทราย สีน้ำตาลแดง Sandstone, light brown, thick bedded, well bedded, cross bedded, interbedded with shale, mudstone, reddish brown, thin bedded, and conglomerate, reddish brown, medium to thick bedded, pebble of quartz and rock fragment of reddish brown sandstone and shale	หมวดหินแหลมสิงห์ Laem Sing Fm.	จูแรสซิก JURASSIC	140-210
TRsw	หินปูน สีเทา ชั้นหนาถึงไม่แสดงชั้น พบซากดึกดำบรรพ์จำพวก ฟอแรมมินิเฟอราขนาดเล็ก สาหร่ายทะเล หอยฝาเดียว ปะการัง และเศษเปลือกหอย หินโคลนสลับหินทราย สีเทาแกมเขียว Limestone, gray to grayish black, thick bedded to massive, with small foraminifers, algae, gastropod, coral and brachioped fragment, interbedded with sandstone and mudstone, greenish grey.	หมวดหินสุขไพวัลย์ Suk Pai Wan Fm.	ไทรแอสซิก TRIASSIC	210-245
PTRko	หินดินดานเนื้อทัฟฟ์ สีเทาแกมเขียวถึงสีเทาแกมม่วง บางส่วนเนื้อหินแสดงการเรียงตัว หินปูน สีเทาดำ ชั้นหนาถึงไม่แสดงชั้น พบอยู่ตอนบน Tuffaceous shale, greenish gray to purple, some of foliated texture; limestone, dark gray, thick bedded to massive ontop of sequence.	หมวดหินเขาชะอางโอน Khao Cha-ang On Fm.	ไทรแอสซิกถึงเพอร์เมียน TRIASSIC to PERMIAN	210-286
PTRkw	หินโคลน สีเทาอ่อน เนื้อซิลิกา ชั้นบาง สลับด้วยหินเชิร์ต สีเทา เป็นชั้นดี และหินดินดาน สีเทาดำเนื้อถ่าน ตอนบนเป็นหินทราย สีน้ำตาลเข้ม เนื้อปานกลาง ชั้นหนา พบหินแอนดีไซต์แทรกตัดทั่วไป Mudstone, ligh gray, siliceous, thin bedded, interbedded with ribbon chert, gray;carbonaceous shale; sandstone, dark brown, medium-grained, thick bedded, on top of sequence; and andesite dike.	หมวดหินเขาวังจิก Khao Wang Chik Fm.		
C	หินไบโอไทต์ไนส์ หินฮอร์นเบลนด์ไนส์ Biotite gniess, hornblende gniess.		คาร์บอนิเฟอรัส CARBONIFEROUS	286-360
C	หินฟิลไลต์ สีเทาดำ หินกราฟิติกชีสต์ สีดำ หินชีสต์เนื้อฟิลไลต์ สีเทาเขียว หินแอมฟิโบไลต์ หินควอตซ์ชีสต์ และสายแร่ควอตซ์ Phillite, dark gray; graphitic schist, black; phyllitic schist, greenish gray; amphibolite; quartz schist and quartz viens.			

1.1 Location

The study area is located along the northern area of Koh Samet in Changwat Rayong, eastern Thailand (Figure 1.3).This area is encompassed in the 1:50,000 topographic maps Sheets 5134 II (Changwat Rayong) (Figure 1.3). It covers an area of approximately 5 square-kilometers. It is in between Latitudes 12°33´44´´N to12°35´N and Longitudes 101°26´44´´E to101°28´17´´E.

The area is only approximately 250 kilometers from Bangkok. This area is a tourists' place, so it is easily to go via Highway 7, Hingway 3 (Sukhumvit Hingway), Highway 36 and Highway 3142. Then,to board a boat at Banpha pier to Satmet Island.

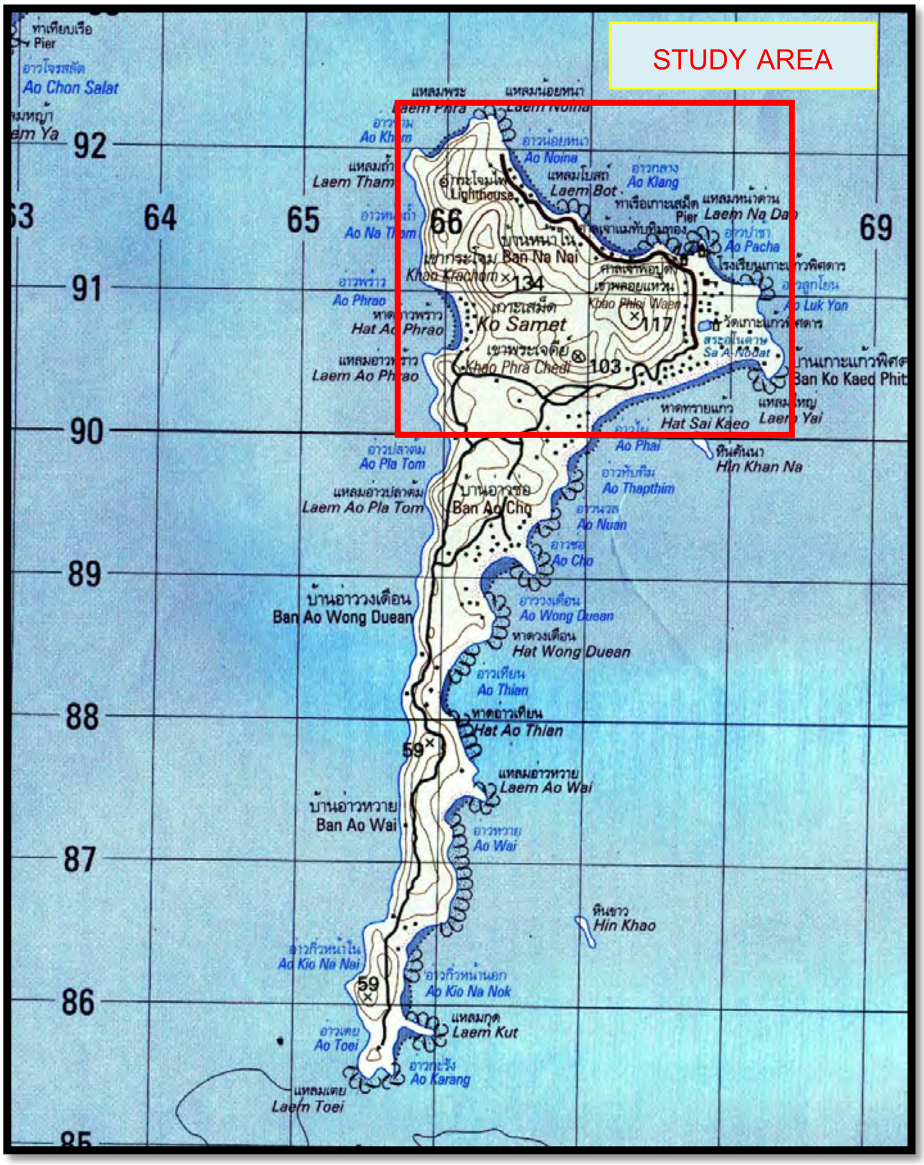


Figure 1.3 Topographic map, scale 1:50,000 (Sheets 5134 II) of Koh Samet in Changwat Rayong, eastern Thailand (The National Imagery and Mapping Agency in cooperation with the Royal Thai Survey Department, 1998).

1.2 Objective

- To characterize the structural geology of Koh Samet in Changwat Rayong.
- To explain the structural evolution in Koh Samet.

1.3 Scope of Work

This study focuses on the structural geology of northern Koh Samet in Changwat Rayong by using previous data and 2 main interpretation scales to achieve this study.

1. The first is the field observation to study mesoscopic scale. The roughly lithologic and mesoscopic structure data such as foliation, lineation, fold and joint. They have been first described, measured and collected respectively.
2. The second is the study of thin sections which is microscopic scale. They have been studied from oriented samples which were carefully collected from field observation.

Then, field investigation data have been quantified plotted and statistically analyzed by equal-area stereographic nets and rose diagrams for structure analysis. Finally, all data are integrated and interpreted for structural style and structural evolution of the area.

1.4 Expected Output

- Structure style and characteristic of metamorphic rocks at Koh Samet in Changwat Rayong.
- Structural evolution of metamorphic rocks at Koh Samet.

1.5 Regional Geology

The rock unit in the northern Koh Samet or all of areas in Koh Samet is metamorphic rock: quartz mica schist, quartz kyanite schist which is Precambrian in age as showing in the geological map in 1976. On other sides the geologic map in 2008 showed that rock is metamorphic rock: biotite gneiss, hornblend gneiss which is Carboniferous in age. They have no dating. The adjacent area of Koh Samet in the onshore area arrounds have rocks age from Precambrian to Quaternary. This survey uses the geological map rock in 1976. The geology in the northern Koh Samet and nearly area is demonstrating the result in geological map sheet Changwat Nakhorn Sawan ND47-16 scale 1:250,000 of Department of Mineral Resources in 1976 (Figure 1.4). The geology in this study area is also showed in the geological map below. However, some rock unit is considered with new units in this study which study in closer view.

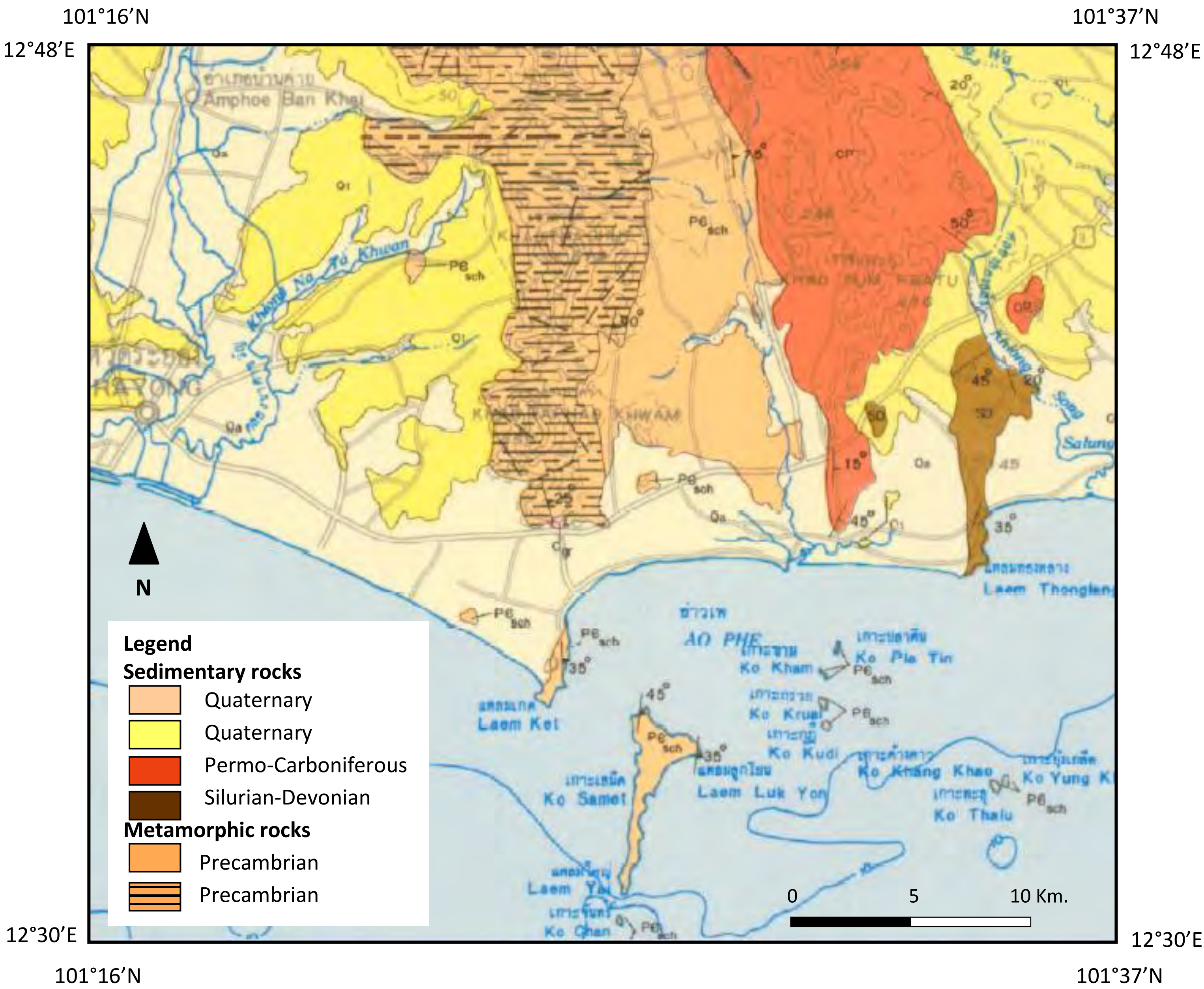


Figure 1.4 Geological map of Koh Samet in Changwat Rayong, eastern Thailand (Department of Mineral Resources, 1976).

1.6 Tectonic setting

Thailand consists of Shan-Thai and Indochina Microcontinents or Tereanes welded together at the subsequently deformed Nan Suture with a west dipping and moderate high angle. The basement complex forming the crust exposed on the both terranes are metamorphic complex of amphibolite, or higher metamorphic rocks (Bunopas and Vella, 1983).

Shan-Thai remained attached along its (on) western edge to its parent craton until early in the Carboniferous, and then rifted away. Continental margin deposits that must have existed along its eastern side, together with an unknown amount of the Precambrian cratonised crust, were separated and carried away either by rifting or transform faulting. After the separation subduction commenced adjacent to the newly rifted margin of Shan-Thai, forming an island arc. The subduction zone of Shan Thai and Indochina Terranes are during the Late Permian to Early Triassic. The continent-continent collisions resulting from the closure of Paleotethys was complete lately in the Triassic. The closure caused folding of continental margin deposits such as the western fold belt (Sukhothai Fold Belt), the eastern fold belt (Loei Fold Belt) etc. (Figure 1.6) and widerspred granite injection known as the Indosinian Orogeny or Cimmerian Orogeny (Figure 1.6). The change in the plate tectonic regime was signaled by the end of subduction and volcanism along the Shan-Thai margin early in the Carboniferous. The end of subduction was accompanied by minor folding and minor granite injection (Lower Carboniferous Orogeny), attributed to collapose of the back-arc area and collision of the volcanic arc with cratonic Shan-Thai (Bunopas and Vella, 1983).

The Precambrian fragment complex of Thailand is lower high grade metamorphic rocks of an amphibolites facies which form the complex basement of the Shan-Thai block in the main western ranges, the Eastern Gulf and the southern peninsular Thailand. They are similar to those in the Kontum massif of the Indochina block before the pre-Jurassic collision of both paleomicrocontinents. The rocks exposed across all sections in the areas mentioned consist of similar sequences of gneisses, calcsilicates, schists in descending order with an unknown bottom. They are westerly overturned either by folding or tilting. Also, several distinct geological provinces that extended into adjacent parts of Southeast Asia can be distinguished within

Thailand (Figure1.5). All of them except the Khorat Bain in the northeast are more or less linear and trend roughly North-South (Bunopas and Vella, 1983).

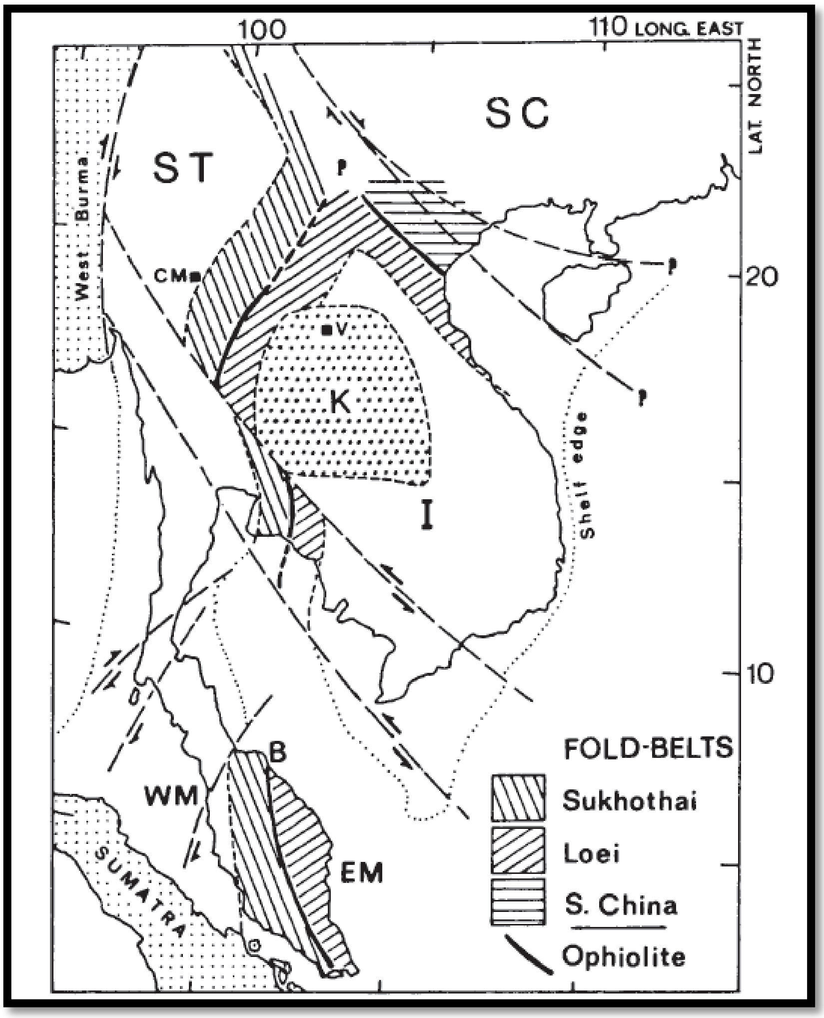


Figure 1.5 Ancient cratonic areas (Indochina, South China, and Shan-Thai). It consists of Sukhothai fold belt, Loei fold belt and S. China fold belt. Adjacent fold-belts are formed of thick mainly marine Paleozoic to Triassic sediments and theleitic volcanic rocks that accumulated along the margins of the cratons. Ophiolites lie between contiguous fold belts. Note: K = Khorat Basin; CM = Chiang Mai; V = Vientiane; WM = West Malay Peninsula; EM = East Malay Peninsula; B = Bentong ophiolite line. (Bunopas, 1983).

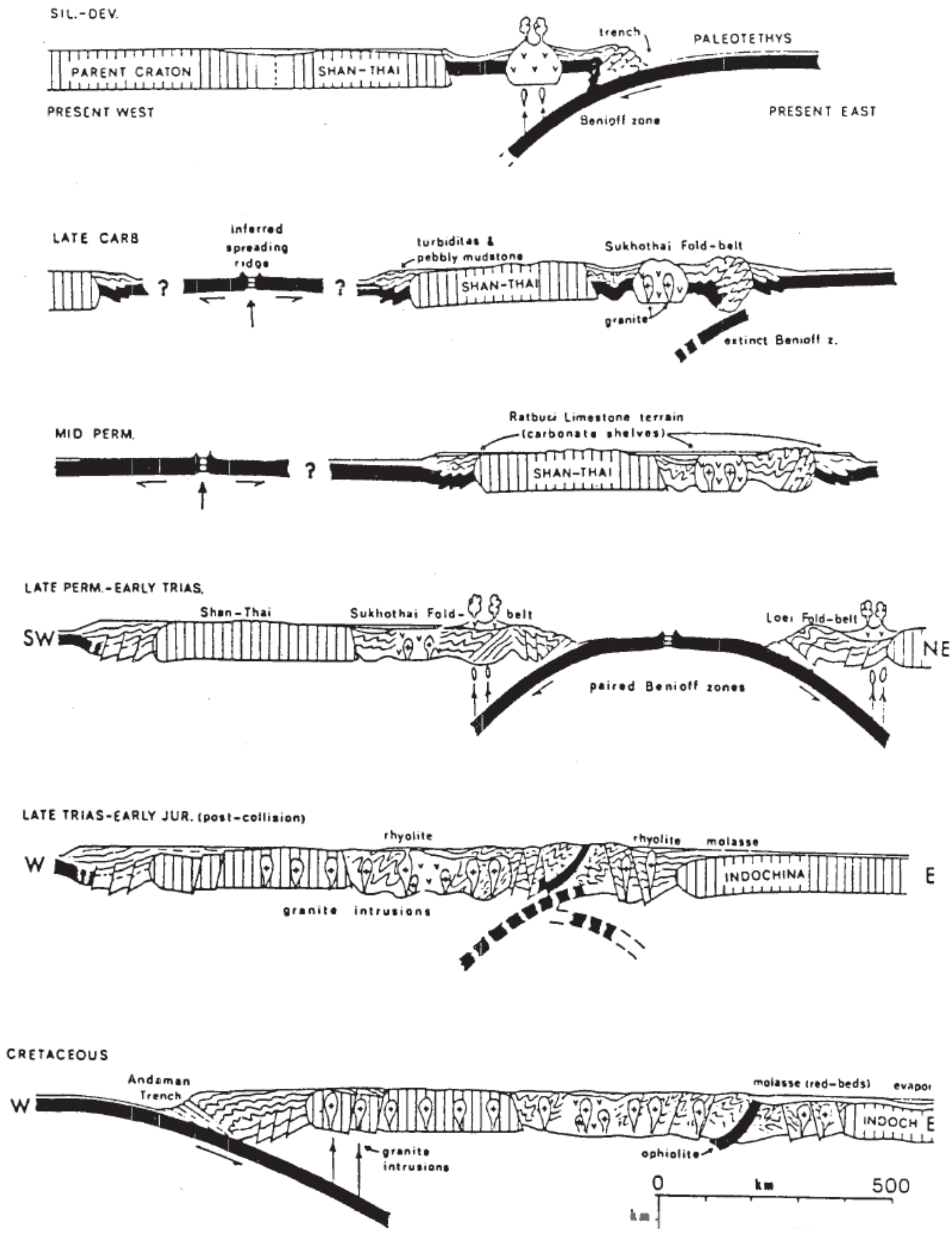
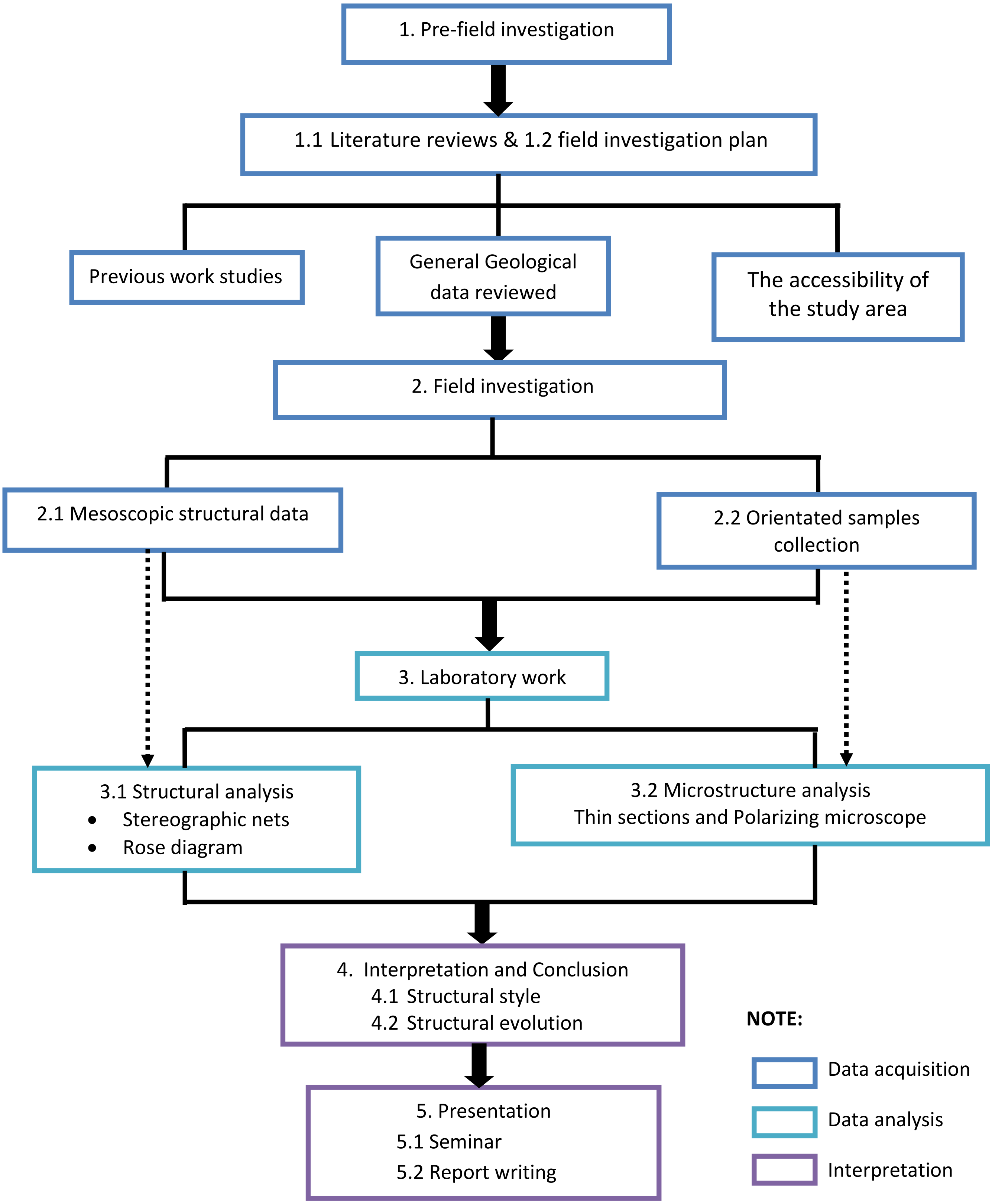


Figure 1.6 Pate tectonic history of Thailand, consisting of Shan-Thai (west) and Indochina (east) (Bunopas, 1983).

Chapter 2

Methodology

This chapter presents the methodological sequence for studying in this project that is followed flow chart (below). It's composed of 3 main part; Data acquisition, Data analysis and Interpretation.



There are 3 main parts that can explain about methodology.

2.1 Data acquisition

2.1.1 Pre-field investigation

The pre-field investigation is important to prepare for a field survey. It's finding out and collecting the general information that is related to this study. The information is basic knowledge for further study and will be benefit to carry out the plan. Planning can make the present study clear for target and scope of work in the field. These lead to getting corrected data in field and safe timing. It's composed of literature reviews and field investigation plan.

- **Literature reviews**

Literature reviews for collecting and being related to the present study area.

Campbell (1975) and Areesiri (1982) have studied about Precambrian Rocks in the eastern Region. Rocks of regional metamorphism origin found in the eastern part of Thailand are prominent in Changwat Chachengsao,Changwat Chonburi, and Changwat Rayong. These areas were named"Chonburi massif". The massif is oriented NW – SE. Reports on metamorphic rocks in this area are limited to studies of Brown et al. (1951) and Nakinbordi et al. (1985). The detailed geology of Khao Chao,Amphoe Nong Yai,Changwat Chonburi reported by Areesiri (1982) as follows;

There are at least three events of rock transformations and two events of metamorphism for the high-grade metamorphic rocks of eastern region. The first rock transformation coincided with the first metamorphism in the late Carboniferous. This combined event was responsible for the formation of Hercynian orogeny. The second and the last rock transformations also coincided with the second metamorphism during the Permian and Triassic generating Permo-Triassic orogeny. The mineral evidences of the first metamorphis were usually obscured by the following events. However, because veins of amphibolite found as penetrated veins are parallel with axial plane cleavage of isoclinal fold which was clearly derived from the second metamorphism, it can be inferred that the first metamorphism had previously occurred in the rock. The second metamorphism caused the melting to crystallize granite and generations of pegmatite and aplite.

Dheeradilok and Lumjuan (1983) summarized the study of the metamorphic belt and "Precambrian" rocks of Thailand. They established two main metamorphic facies series. The first one was a low-pressured Amphibolite facies series of Precambrian to carboniferous rocks which occupied the axial part of belt. Another one was a low-pressured Greensshicst facies series of Lower Paleozoic ages occurred along both flank of belt extending from the Northern to the Southern Peninsula. The high-grade metamorphic rock of amphibolite facies in Northern Thailand was essentially considered to be Precambrain in age.

Pongsapich et al. (1983) reported that all high-grade metamorphic rocks in Thailand have the roughly the same features. The lower most layers consist of orthogneiss and paragneiss and the subsequent layers all the way to the top are schist, calcsilicate, quartzite and marble respectively. Quartzite and marble are only present in some particular portion of the rocks.

Department of Mineral Resources (1998) summarized that Precambrian rocks in Changwat Rayong including metamorphic rocks; gneiss, schist, and calc-silicate are the oldest rocks in Changwat Rayong. They are located in a small part of the Northern area where contact with Khao Chao, Amphoe Nong Yai,Changwat Chonburi, and are located in Khao Wang, Khao Leam Yang and Koh Samet. A specific characteristic of these rocks have mineral banding is both direct bands and curve bands that are developed by deformation. Koh Samet is the biggest island in Changwat Rayong. Other islands are small such as Koh Ku Dee and Koh mud. Rocks are Precambrian metamorphic rocks which is schist in there. (The age is more than 570 Million years).

During either the Late Triassic (Charusiri et al., 1991, 2000), Permo-Triassic (Hutchison, 1983, Bunopas and Vella, 1983) or even earlier (Helmke, 1985), Thailand and her adjoining countries occupied major parts of the two major blocks joined together by continent-continent collision (Fig. 1). These two microcontinents, which were once part of Gondwanaland and attached to the Australian continent (Bunopas, 1981), include: the Shan-Thai (-Malay) craton (western half of Thailand); eastern Myanmar; the northwest Malay Peninsula; and the Indochina craton (eastren half of Thailand, Laos, Kampuchea, southern Vietnam, and eastern Malay Peninsula) (Bunopas, 1981, Bunopas and Vella, 1983, Charusiri et al., 2002). The Lampang-Chiang Rai and Nakhon Thai blocks, lie along the western and eastern parts of the Shan-Thai and Indochina blocks, respectively. Both blocks which consists principally of oceanic crustal materials (see Tulyatid and Charusiri, 1989, Charusiri et al. 2002), have been dislocated by gigantic sinistral strike-slip faults and their N-trending have been modified by sinistral oroclinal bending associated with this faulting (Fig.1). These faults are thought to have been active during 70 - 80 Ma, 55 Ma and 45 Ma (Charusiri, 1989). The Nan River suture zone (Barr& Macdonals 1987) in northern Thailand is also the result of the collision of the two microcontinents. This suture (or the so-call "tectonic line" in this paper) may extend southward (Fig.1) to the Sra Kaew zone in eastern Thailand(Near Changwat Rayong), the Bentong - Raub zone in Malaysia (Hutchison, 1983) and northward into Laos and southern China (Huang, 1984. Other, and probably more important, tectonic lines are the tectonic activities of SE Asia are thought to be very intricate with a major and rapid modification between 20-30 Ma (Suensilponget al., 1981)and 45-55 Ma (Charusiri, 1989).

Bussai (2005) studied about low grade metamorphic terrane along Chon Buri coastal area from Sri Racha to Sattahip. The areas are located near Changwat Rayong. The study reveals three deformation episodes and two metamorphism events. The oldest deformation (D1) which accomplain a dynamothermal metamorphism (M1) is recognized by the elongate tight-to-isoclinal folds with fold axial planes being inclined moderately to the west and the axes trended somewhat N-S to NE-SW with crossed extensional joint and normal faults. The microscopic study of c-axis of quartz grains in four orientated thin sections of quartz tectonite also shows a preferred orientation with a point maximum that conform these fold axes. The second deformation (D2) formed the NW-SE cross folds superimposing on the previous folds thus result type-1 interference pattern of Ramsay (1967). This interference folding episode may occur together with, or being shortly followed by a granitic intrusion in Triassic and caused a thermal metamorphism (M2). The last deformation (D3) cause a low-angle reverse faulting which brought the metamorphosed stratified units to overlie the non-metamorphosed younger igneous body. The age of this faulting is inconclusive, thought to be Middle to Late Mesozoic or very early Tertiary judging from the unaffected Tertiary alluvial-fan unit lying further to the east.

Department of Mineral Resources (2007) reported that Precambrian rocks in areas beyond the above discussion rather have acid composition while those of the Easthern region where have mafic composition. This conclusion is reached after comparing contents of minerals.

This rock has smaller amount of potash feldspar, quartz, and muscovite than amount of hornblende, calc-silicate, biotite, diopside, garnet, and amphibolitic rock in the paragneiss unit.

Department of Mineral Resources (2007) reported that lithological geology in the area North of Khao Chamao , Amphoe Klaeng, Changwat Rayong. This area is NE direction of Koh Samet. Rocks in this area are also high-grade Precambrian metamorphic rocks. This rock unit is located in the easternmost part of the country and is controlled by faulting making the outcrop narrow and long. Several rocks such as mica schist, hornblend, schist, calc-silicate, biotite-muscovite granite, pegmatite, aplite with large garnet crystals, belong to this rock unit. We often find gneiss and mica schist in small hills between Khao Chamao and the municipal center of Amphoe Klaeng.

Department of Mineral Resource (2007) reported that suture is welding of two main microcontinental terranes is developed in the central of Thailand from Changwat Nan to Changwat Utradit, Changwat Chaiyaphum, Changwat Nakhon Ratchasima , Changwat Sakaeow and Gulf of Thailand. Because of movement of the Continenta plates occur all the time that is the cause of strain collection, call ''Tectonic fore''. It includes tensional stress, compressional stress and shearing that lead to rocks bedded movement and metamorphicsm and deformation such as folds, orogeny, faults and joint.

Department of Mineral Resources (2008) reported that rocks which is the oldest in Changwat Rayong is Carboniferous in age (Late Paleozoic).These rocks are high grade metamorphic rocks. A specific characteristic of these rocks have mineral banding is both direct bands and curve bands that are developed by deformation. They can separate to 2 groups that one group is high grade metamorphic rocks. The lithology was composed of biotite-gneiss and hornblend-gniess. They are very hardness and have a lot of quartz veins.Areas that can find them is Koh Samet Kao Chamao, Kao Mainuan and Kao Thapong. Another group is low grade metamorphic rocks include black-gray phyllite, graphitic schist, greenish gray- phyllitite schist, amphibolites and quartz schist. They were injected by a lot of quartz veins but easier weathering. They have founded in Amphoe Kao Chamao, Amphoe Kleang, Amphoe Wangchan and Amphoe Rayong.

- **Field investigation plan**

The Geologic map and Topography maps in the study area and adjacent area have to be prepared to earn background information of the rock types and geologic structure in the study area. Also, the satellite image's Google Earth in this area is used for check outcrops roughly and mark location to be station for survey. In this study, we use submerged rocks that are exposed along the shoreline for being outcrop station. Determining the accessibility of the study area are journey, vehicle, accumulation and connecting with Royal Forest Department which supervises area of Koh Samet. Prepare some equipment for the field investigation such as compass, hammer, gouge, camera, field note and stationery.

2.1.2 Field investigation

- **Mesoscopic structural data**

Field investigation is the main method of obtaining geologic data. Field studies should have purpose, even if it be strictly academic. The study may be as simple as a single outcrop of interest. Field data observations are the mesoscopic structural data such as attitude of bedding, foliation, lineation, fold, fractures and joint for collecting data and plotting on stereographic nets and rose diagram. These simple studies may include a sketch, some digital photos and making notes on relation between rocks.

A section is measured with three main purposes in mind: Frist, to make an accurate description of rock units representative of a particular area. Second, to record full sequential descriptions of the rocks within larger units; these descriptions will for the basic for interpretations of the obvious (local) structural deformation in the outcrop. A careful accounting of the strike and dip of the beds or foliation and lineation of metamorphic rocks using a brunton compass allows you to simply stretch a tape on the outcrop etc. And third to collect typical rocks which different and interesting of each area.

- **Orientated samples collection**

Orientated rock samples in the field for microstructure analysis in thin section by a polarize microscope. The choice of samples for thin sections depends on the topic of interest and methods that are going to be used. In any case, it is important that the main structure in the area is understood in broad lines before samples are taken; thin sections usually contain a lot of information, which is useless in case of no good field record exists.

Sampling is determined by the structural of rocks such as foliation, lineation, fold and shear zone etc, which are represented in most of samples. Also rock on the outcrop that chooses as a collected sample should be fresh as can identify rock types. Rock samples are numbered, marked, and labeled to realize and wrapped or placed in bags to protect them from abrasion.

The sampling rocks in the field for microstructure analysis are very important because it will be the sense of movement indicator. Hand specimens for microstructure study should be oriented. The orientation scheme is designed to provide an unambiguous *in situ* geographic orientation of each sample. This is best done by making dip and strike of a planar surface of the specimen on that surface (Fig. 2.1). Notice, however, that this still leaves two possible orientations, since the mark could be made on the top surface or on the lower side of a sample. An extra mark is therefore needed; for example, a cross on the top surface or an arrow indicating top (Fig. 2.1b).

Mistakes can be easily be made in orienting samples and for the most important sample (e.g. those needed to determine shear sense) it is therefore useful to make a photograph or sample sketch of the sample, its original orientation in outcrop and of the marking. Also, samples should be wrapped in paper or plastic bags to avoid breakage and erosion of markings and numbers.

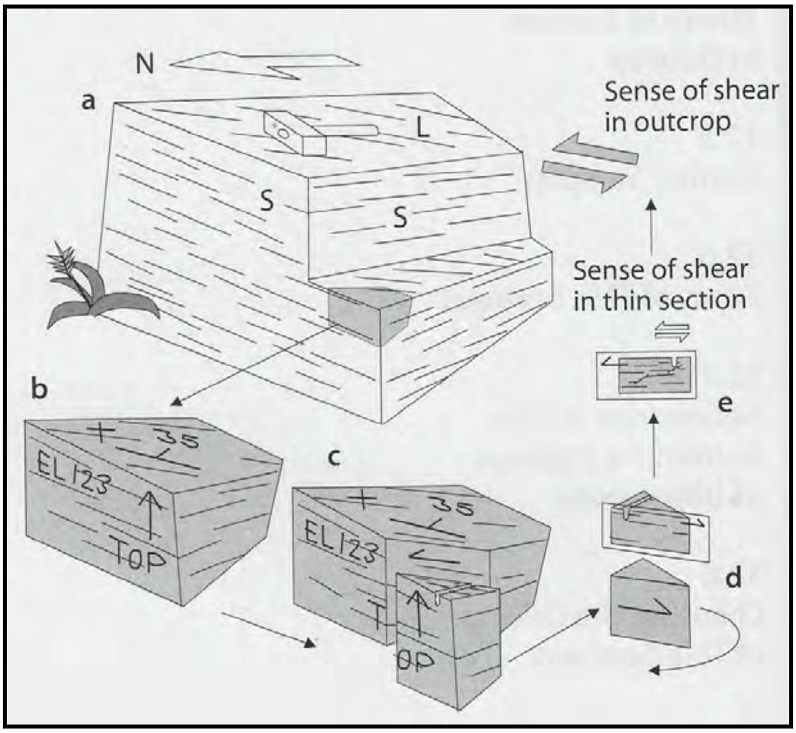


Figure 2.1 Method to obtain an orientated sample from an outcrop and orientated thin section from sample (Passchier and Trouw, 2005).

Based on Fig. 2.1, (a) is an outcrop where sample for structural studies must be collected and oriented. (b) A strike-dip or trend-plunge symbols were draw on the planar top surface of the sample and a cross (marking on the top) fix the orientation of the sample in space. When a thin section is to be cut parallel to the lineation and perpendicular to the foliation or the axial plane, a chip is cut from the sample. (c) In order to orient the chip, an arrow with a single barb pointing in the direction of the top surface can be used and is drawn on both the sample and the chip. (d) Care should be taken that this arrow is copied correctly onto the thin section. Alternatively, a small saw-cut scar can be made in the top surface of the chip, which can be found back in the thin section. (e) Shea sense determined in thin section, e.g. by shear bands can now be directly related to the sample, and the sample to the original outcrop. Here, the outcome it thrusting to the NE.

2.2 Data analysis

This study focuses on structural style and its characteristic. Therefore this study analyses with mesoscopic structures and microscopic structures. So data analysis is laboratory work which can be separated data analysis to 2 parts:

1. Mesoscopic structural data in field for structure analysis by using stereographic nets and rose diagram (Mesoscopic structures).

2. Microstructure analysis from thin sections about micro-fabrics and their orientation (Microscopic structures).

2.2.1 Laboratory work

- **Structure analysis**

In the field, mesoscopic structural data compose of attitude of bedding, foliation, lineation, fold, fracture and fault. Also this study shoulds observe sense of deformation indicators both ductile and brittle like shear zone, mineral fish, and slickenside. These simple studies may include a sketch, some digital photos, making notes on relation between rocks, and especially, collecting some hand samples. All attitude data will be classified, qualified and plotted into stereographic nets and rose diagram to analyze the structural geology in mesoscale for getting the paleostress direction. Finally, mesoscopic structures are interpreted with microscopic structures in the next step.

Structural analysis is used to the kinematic process in study area for local stress field. Spatial data likes foliation and joint will be plotted on rose diagram to compare with experimental model for interpretation a stress field. The experiment about stress field was illustrated into simple circle which distort along strain direction; we call that "strain ellipsoid". For extension and compression in each direction, the fracture trend and sense of movement in strain ellipse will different (Figure. 2.2).

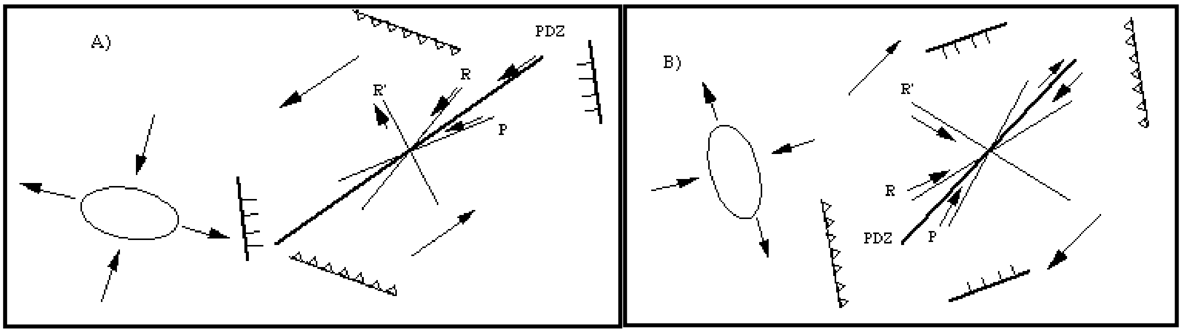


Figure 2.2 Examples for oriented strain ellipse models showing secondary structures and ellipse orientation for A) sinistral and B) dextral movement (Sylvesterm 1988).

- **Microscopic analysis**

Geologists learned to profit from the wealth of data that can be obtained from the geometry of structures studied in thin section, and metamorphic petrologists have appreciated the relation of structural evolution on the thin section scale and metamorphic processes. Deformed rocks are one of the few direct sources of information available for the reconstruction of tectonic evolution. Nevertheless, observations on the geometry of structures in deformed rocks should be used with care; they are the end product of an often complex evolution and we can only hope to reconstruct this evolution if we correctly interpret the end stage.

Observations on the microstructure or *fabric* of a rock, specifically in thin section, can be used in two major fields. They can be applied to thematic studies, to understand mechanisms of rock deformation and metamorphism; or they can be used to reconstruct the structural and metamorphic history of a volume of rock. Thin section studies are mostly in the latter field. Because such thin section studies can serve to reconstruct tectonic evolution, we use the term *microtectonics*. In theory, one could expect that a sedimentary rock, which is buried, deformed, metamorphosed and brought back to the surface, should have the same mineral composition as the original sediment if perfect equilibrium conditions were to be attained at each stage. A simple fabric should be developed in such a case in response to gradual changes in the stress field and in metamorphic conditions. In most deformed rocks, structures with different style and orientation and minerals, which represent different metamorphic grades,overprint each other. Once deformation phases and metamorphic events are defined, it is necessary to determine to what extent they correspond to *tectonic events* or *metamorphic cycles*, i.e. events on a larger scale such as those associated with plate motion or collision. Finally, *orogenies* may encompass several tectonic events with associated metamorphic cycles. (Passchier and Trouw, 2005).

2.3 Interpretation

The macroscopic structures of the study area would later be summed up the analysis of mesoscopic and microscopic structures. Structure style, structure characteristic and the structure evolution were also interpreted. Then, structural style and characteristic can be explained and concluded. Writing and presentation were done.

2.3.1 Interpretation and Conclusion

- **Structural style**

When collection and analysis all of evidences both mesoscopic scale and microscopic scale, we have studied geological structure based on the textbooks and publications for interpretation. Interpretation is to explain phase of deformations and to separate mainly deformation that is brittle deformation and ductile deformation. And then we identify structural style of the study area conform to some structure such as type of fault or type of fold or others. Finally, we identify specific structural style or structural model in the study area following all of evidences.

- **Structural evolution**

We have to study the tectonic of Thailand to finding out the structure in this study area and range of age's occurrence. Therefore, structural evolution is based on tectonic of Thailand and specific structural style in the study area.

2.3.2 Presentation

- **Seminar**

We have to present the project about problem, hypothesis, objectives, scope of works, results, discussion and conclusion by seminar.

- **Writing report**

The all of data from evidences, analysis and interpretation were written into report. The senior report can use basic structural geological information for future study or people who are interested in the area.

Chapter 3

Results

This chapter presents the result from mesoscopic structural analysis in field study and microstructure analysis of the northern Koh Samet, Changwat Rayong. The exposed outcrops are found along the shoreline. But, most of them eroded and weathered by wave, sea and wind. So, the rocks are not good in quality but can be studied. They can give information for this study.

In the field study, we surveyed and collected the geology and structures data of area study and also, collected the oriented samples in each station for totally 8 samples. The sampling stations are along the shoreline of the northern Koh Samet on headlands (Figure 3.1) as follow these:

- The eastern part: Station 1.1 Laem Luk yon, Station 1.2 Laem Nardan, Station 1.3 Ao Klang, Station 2.1 Laem Yai and Station 2.2 Ao Phai
- The western part Station 1.4 Laem Bot, Station 1.5 Laem Noina and Station 2.3 Laem Ao Phrao.

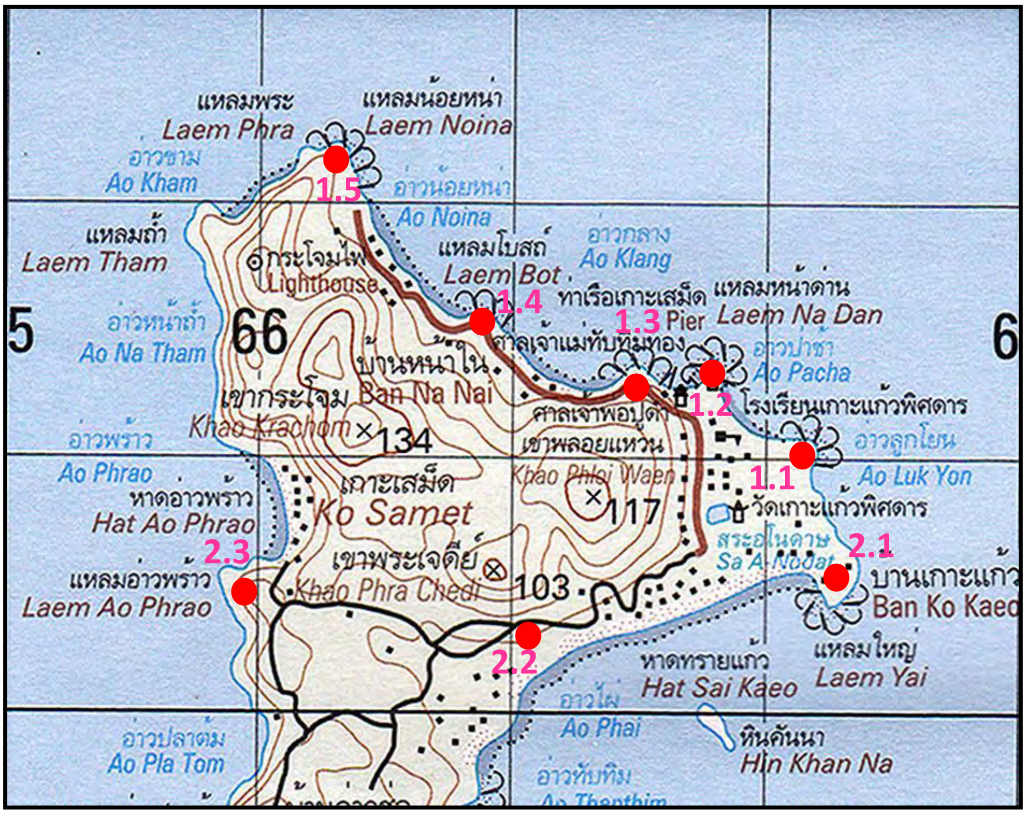


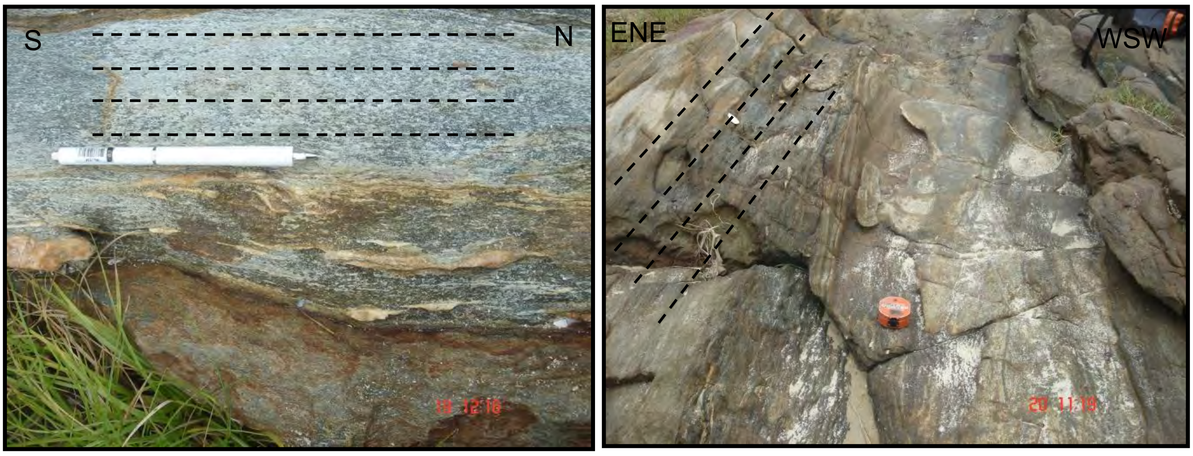
Figure 3.1 Topographic map, scale 1:50,000 (Sheets 5134 II) of Koh Samet in Changwat Rayong showing 8 all of stations along the shoreline of the northern Koh Samet on headlands (The National Imagery and Mapping Agency in cooperation with the Royal Thai Survey Department, 1998).

3.1 Geology

The geology of the northern Koh Samet consists of Schists which have different percent of mineral compositions. Main of them is quartz-muscovite schist. Others are quartz schist and feldspar-quartz schist which are found in some area of east side. The foliation plane of all rock units is nearly N-S direction with gentle to moderate dipping to E direction (eastern part) and W direction (western part). Otherwise, the lineation trend of all rock units is different. There are 2 directions of lineation trends which were noted in the study area. The first trending is in N-S direction that developed on the rocks of eastern part. Another trend is in E-W direction that developed on the rocks of western part. So, from that cause, we can separate units of rocks base on the lineation trends. However all of rock units as defined above have deformed with both of dextral and sinistral ductile shears which are observed from foliation planes and lineation trends. And there are folds, joints and quartz veins in this area.

Schist with the N-S lineation units

Schist with the N-S lineation units (Figure 3.2), Quartz muscovite schist, is located in the western area along shore line the northern Koh Samet, Station 1.4 Laem Baot , Station 1.5 Laem Noina , Station 2.3 Laem Ao Phrao. There are foliation planes in N-S to NNE-SSW direction with gentle to moderate dipping to W-WNW direction. They comprised of mainly quartz, muscovite and feldspar respectively. Quartz muscovite schists are found at Laem Noina and Laem Ao Phrao, can be observed that they have fine gained interbedding corased gained (Figure 3.3). All of the rocks were found that have complex folds (Figure 3.4, 3.5, 3.6) and a lot of shear zone with quartz porphyloblasts. Shear senses have both of dextral and sinistral ductile shears.



(a) (b)

Figure 3.2 Outcrops along the western area along shore line the northern Koh Samet showing major structure of foliation and N-S lineation (black dashed line) of the quartz muscovite schist at Laem Baot (a) and Laem Ao Phrao (b).

Figure 3.3 Quartz muscovite schists can be observed fine gained interbedding corased gained at Laem Noina.

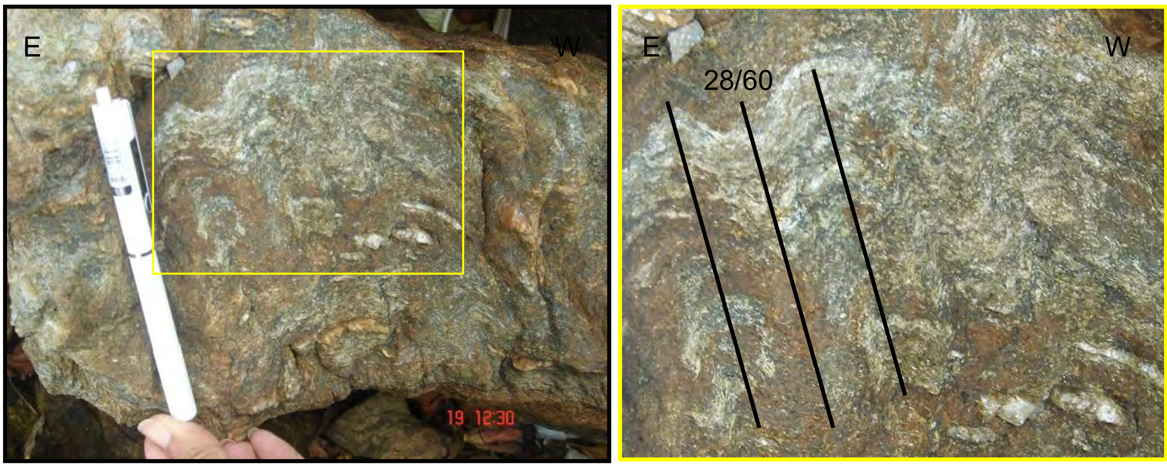


Figure 3.4 Moderately inclined small fold at Laem Bot showing the fold axis is in NNE-SSW,the attitude is 28/60 (trend/plunge).

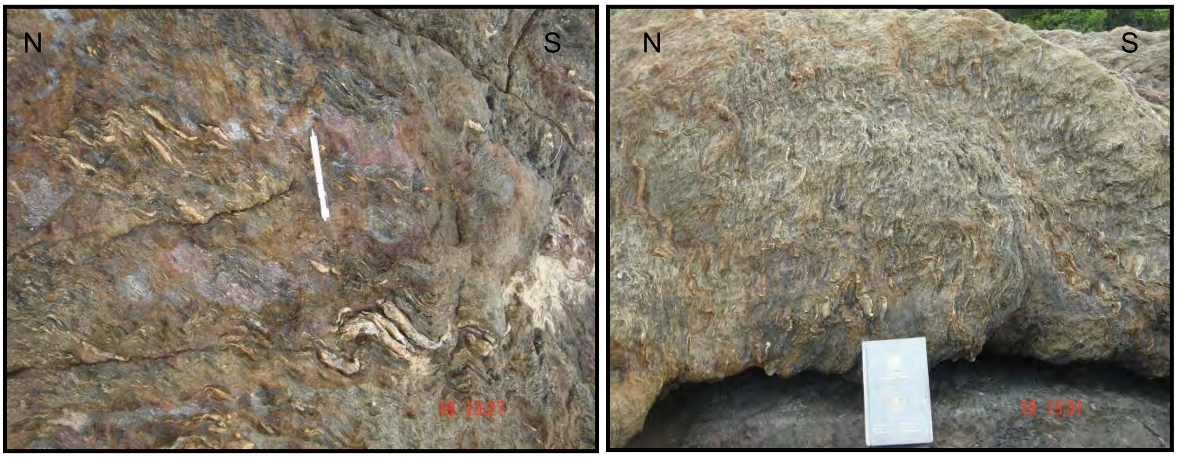


Figure 3.5 Outcrops showing complex folds at Laem Noina.

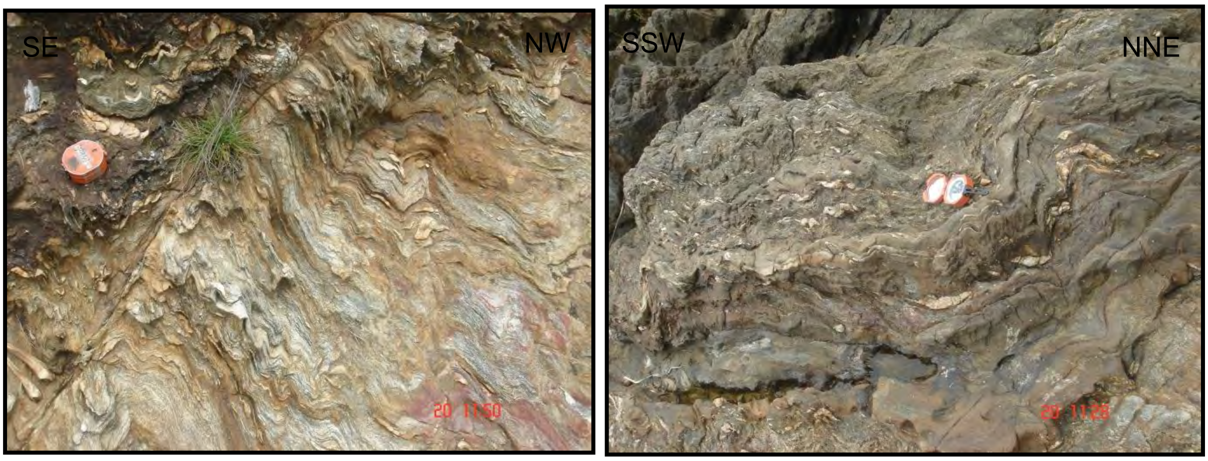
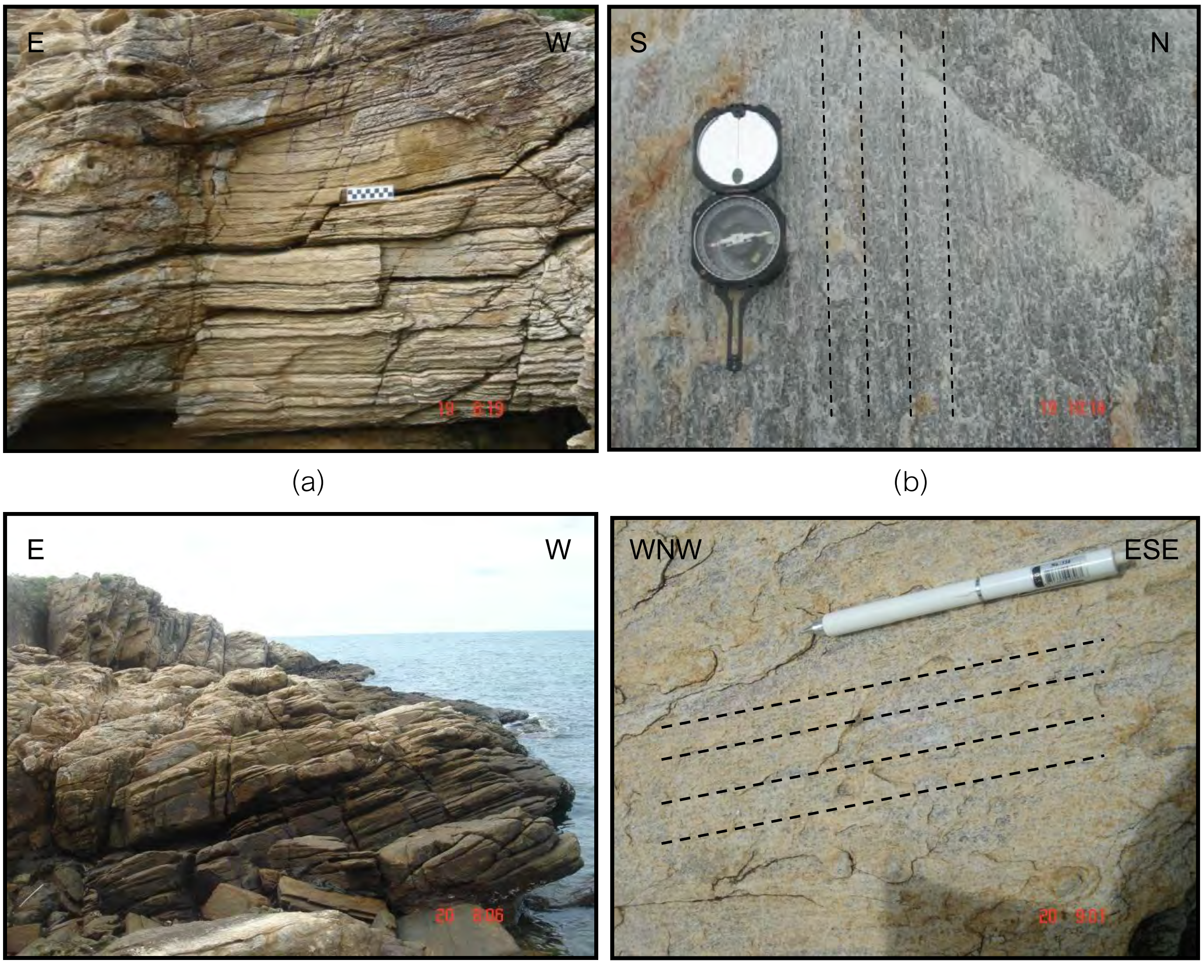


Figure 3.6 Outcrops showing complex folds at Laem Ao Phrao.

Schist with the E-W inneation units

Schist with the E-W lineation units, quartz muscovite schist, is located at station 1.1 Laem Luk yon (Figure 3.7 a). Feldspar quartz schist is located at station 1.2 Laem Nardan (Figure 3.7 b) and station 1.3 Ao Klang. Quartz schist is located at station 2.2 Ao Phai and station 2.1 Laem Yai (Figure 3. c,d). There are foliation planes in N-S to NNE-SSW direction with gentle to moderate dipping to E-ESE direction. But rocks at Ao Klang and Ao phai, where contact with the western part area as defined above, dip to W direction. Quartz muscovite schist at Laem Lukyon, is cut by quartz dyke in E-W direction which parallel to the joint. That quartz dyke caused topography of eastern headland (Figure 3.8). Quartz schist which exposed on Laem Yai, is found conjugate join set and quartz veins (Figure 3.9). The rocks show folds at Laem Lukyon (Figure 3.10). Shear senses is very rarely. There is both dextral and sinistral ductile shears only at Laem Lukyon.



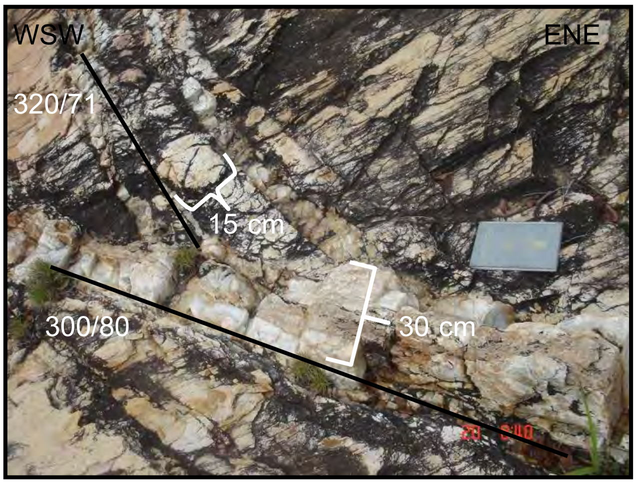
(a) (b)

(c) (d)

Figure 3.7 Outcrops along the eastern area along shore line the northern Koh Samet showing major structure of foliation and N-S lineation (black dashed line) of the quartz muscovite schist at Laem Lukyon (a) The feldspar qurartz schist clearly at Laem Ao Phrao (b). And the qurartz feldspar schist and Laem Yai (c,d).

Figure 3.8 Quartz muscovite schist is cut through by quartz dyke (wide ~2 m) in E-W direction (285°/66°) which parallel to joint and caused topography of eastern headland at Laem Lukyon.

(a)



(b)

Figure 3.9 Conjugate join sets can indicate folding at Laem Yai (a) and quartz veins are cut through joints which have 1 main direction of quartz veins. The one is NW-SE in quart feldspar schist (b).

Figure 3.10 Recumbent fold at Laem Lukyon illustrating axial plane 6°/26°.

So, the fold axis is N-S trending.

3.2 Structural Geology

Mesoscropic structures in the northern Koh Samet record foliations, lineations, folds, joint sets, and shear senses. All of these have been observed and measured in the field. The analysis of the geologic structures is used by the Equal-area stereographic net and Rose diagrams. All structures were classified and described into the ductile deformation and kinematic indicators.

3.2.1 Ductile Deformation

The rocks in the northern Koh Samet are Schist which can be found the foliations, lineations, mesoscopic folds and shear sense indicators. Foliations are well developed in the rocks in this area. They form gentle to moderate dipping foliations dominantly striking N-S parallel with the marked topography (Figure 3.12.a). The eastern part of Koh Samet has E direction dipping foliation contrast with the western part in W direction dipping foliation. And also, we can observed and measured the attitude of foliation in Khao Leam Yang where is near study area, is N-S direction with dipping to E direction (Figure 3.11). So, the rocks have been deformed by folding. From plotting attitude of foliation of all of rocks in the northern Koh Samet represented that dispersion of poles trend can show a pattern of folding. And fold profile is attitude in WNW-ESE direction (Figure 3.12 a, b).The fold axis is in N-S direction with dipping to N direction (Figure 3.13).

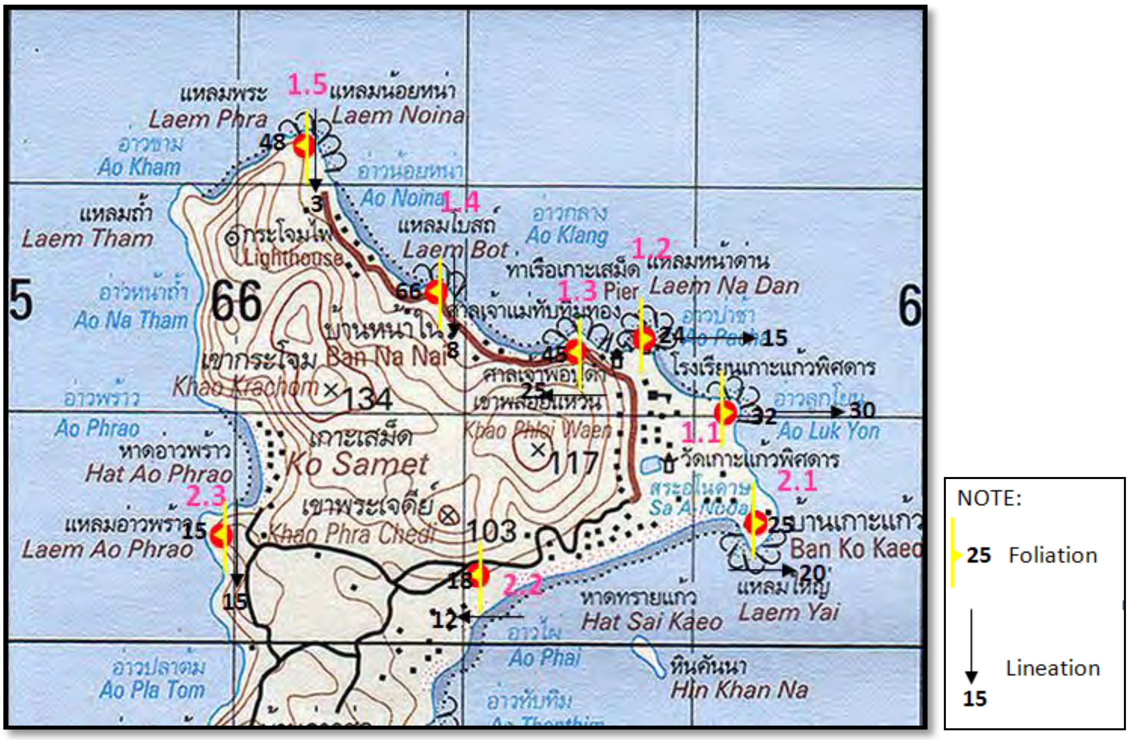


Figure 3.11 Topographic map, scale 1:50,000 (Sheets 5134 II) of Koh Samet in Changwat Rayong showing major structure of foliation and lineation of the rocks each station (The National Imagery and Mapping Agency in cooperation with the Royal Thai Survey Department, 1998).

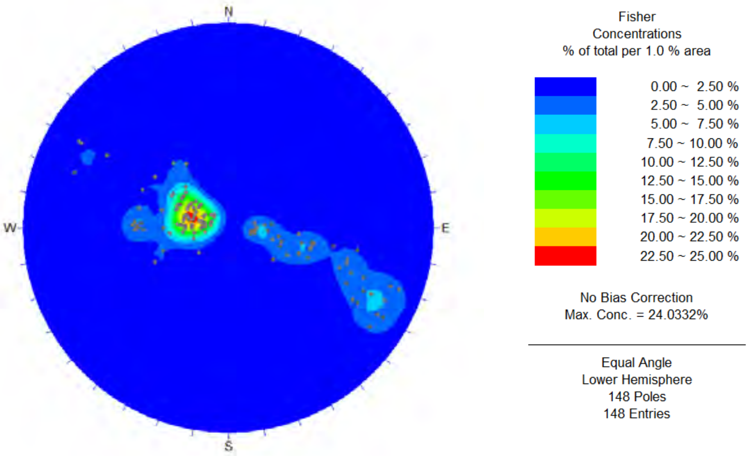


Figure 3.12 a Stereographic plot of the foliations of all of rocks. Contour poles of the foliations or dispersion of poles showing 15° to 60° dipping mainly in nearly N to S.

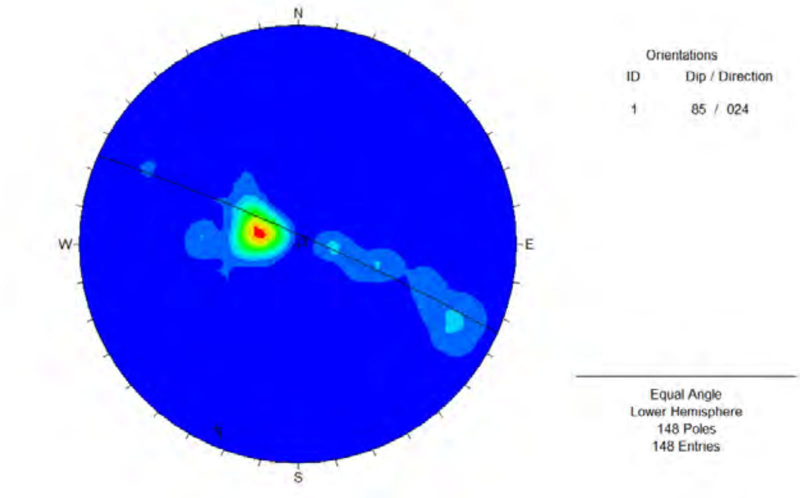


Figure 3.12 b Stereographic plot attitude of foliations of all of rocks in the northern represented that dispersion of poles trend can show a pattern like folding. And attitude of fold profile (black line) is 294°/85° in WNW-ESE direction, so it's showing the fold axis is N-S trending with dipping to N.

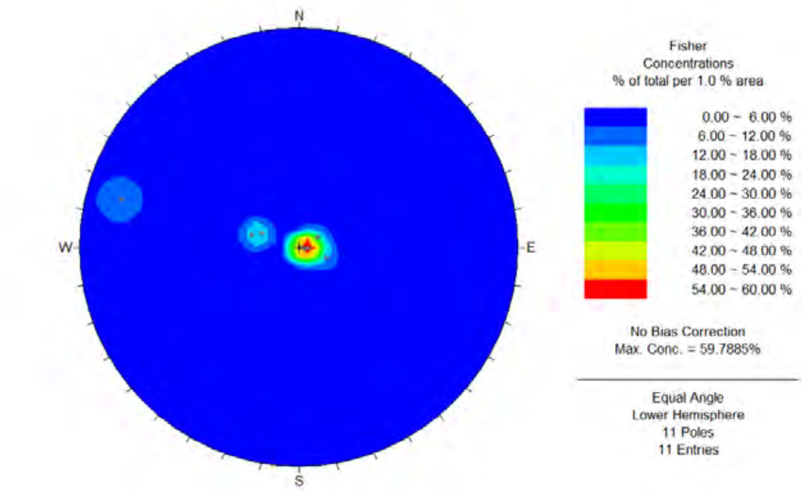


Figure 3.13 Stereographic plots attitude of fold axises of all of rocks in the northern Koh Samet represented contour poles of fold axises is gentle dipping to N in N-S trending.

Stretching lineations are clearly observed in all of rocks. The stretching lineations in western part are parallel to the fold axes in N-S trending (Figure 3.14). Whereas in eastern part are E-W trending (Figure 3.15).

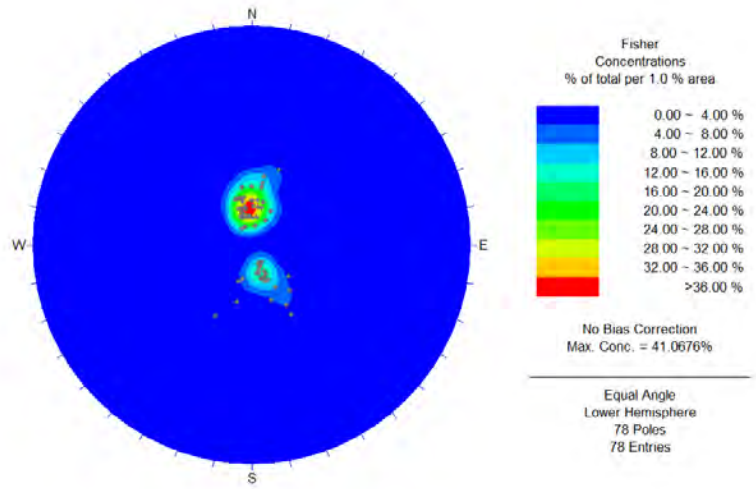


Figure 3.14 Stereographic plots attitude of lineation of all of rocks in the eastern part, the northern Koh Samet .The lineations trend to E-W.

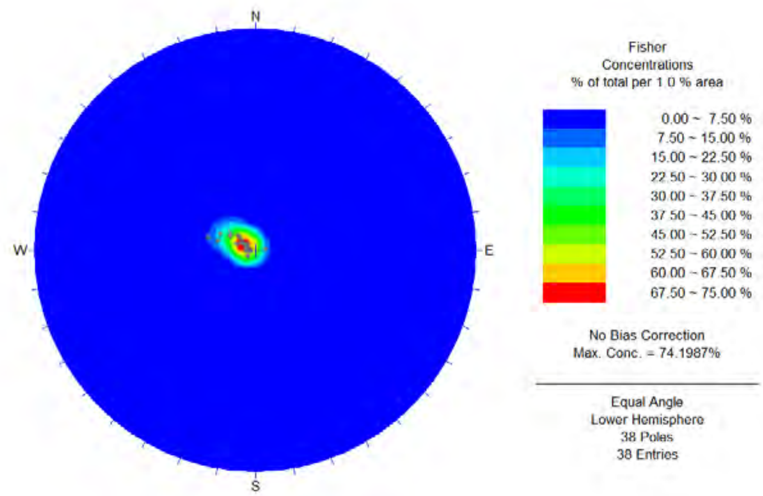


Figure 3.15 Stereographic plots attitude of lineation of all of rocks in the western part, the northern Koh Samet .The lineations trend to N-S.

3.2.2 Kinematic Indicators

Abundant kinematic indicators can be observed within the northern Koh Samet. Mesoscopic fold could be seen in the study area and could be observed clearly at Laem Lukyon and Laem Ao Phrao (Figure 3.16 a,b). The fold elements were observed and measured in the order to determine the orientation of fold axis and axial planes. One main direction of fold axis was noted in the study area that is in N-S direction with gentle dipping to N direction. Actually, there are a lot of small folds is complex especially at Laem Noina and Leam Ao Phrao (Figure 3.17). At Laem Yai,there is conjugate joint sets which are marked with fold geometry (Figure 3.18). Shear sense indicators could found in the study area where is mainly in the western part. Quartz porphyroblasts with frequently σ-shapes and some δ-shapes have represented both of of dextral ductile shears (Figure 3.19, 3.20a,b, 3.21, 3.22) and sinistral ductile shears (Figure 3.23, 3.24). Folding are recorded by S-folded, M-folded and W- folded (Figure 3.25). All of them along the northern Koh Samet indicate that the ductile deformation had folding with both dextral and sinistral movement.

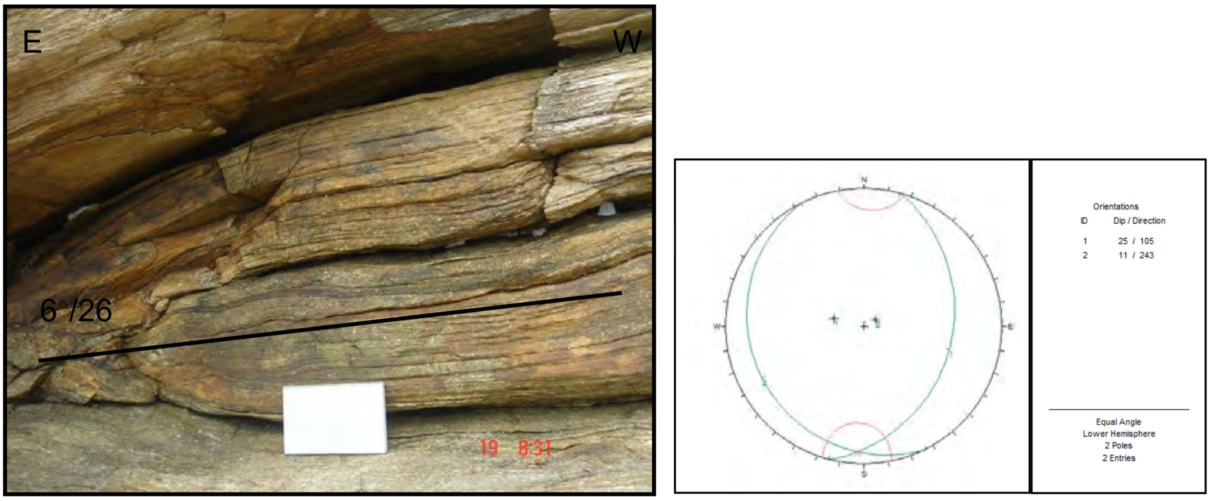
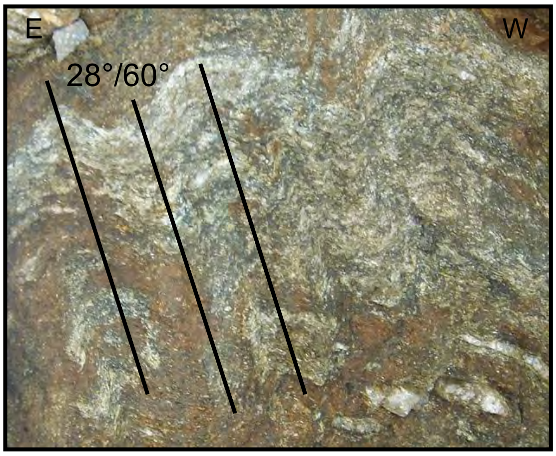


Figure 3.16a Recumbent fold at Laem Lukyon illustrating axial plane 6°/26° (strike/dip). So, the fold axis is N-S trending. And the Stereographic plots of fold limbs are showing fold axis 183°/5° (trend/plunge).

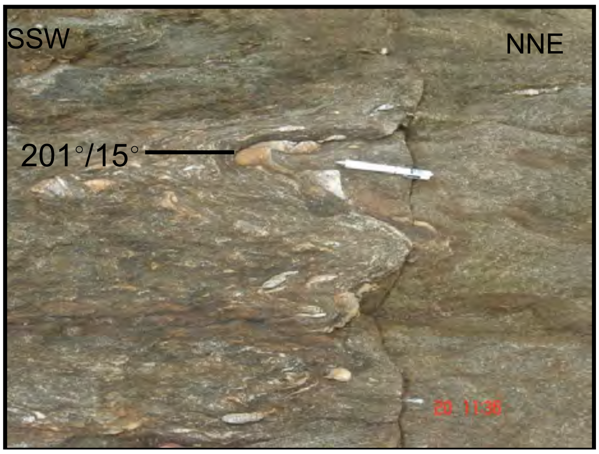
Figure 3.16b Recumbent fold at Laem Ao Phrao illustrating the fold axis is N-S trending.

(a)



(b)

(c)



(d)

Figure 3.17 Small folds is complex especially at Laem Noina (a) A small fold with axial plane is 28°/60° (NNE-SSW direction) at Laem Bot(b). A small fold with axial plane is 205°/30° (NNE-SSW direction) at Laem Ao Phrao (c). And Loot less fold with fold axis is 201°/15° (NNE-SSW direction) at Laem Ao Phrao (d).

Figure 3.18 Conjugate join sets can indicate folding at Laem Yai.

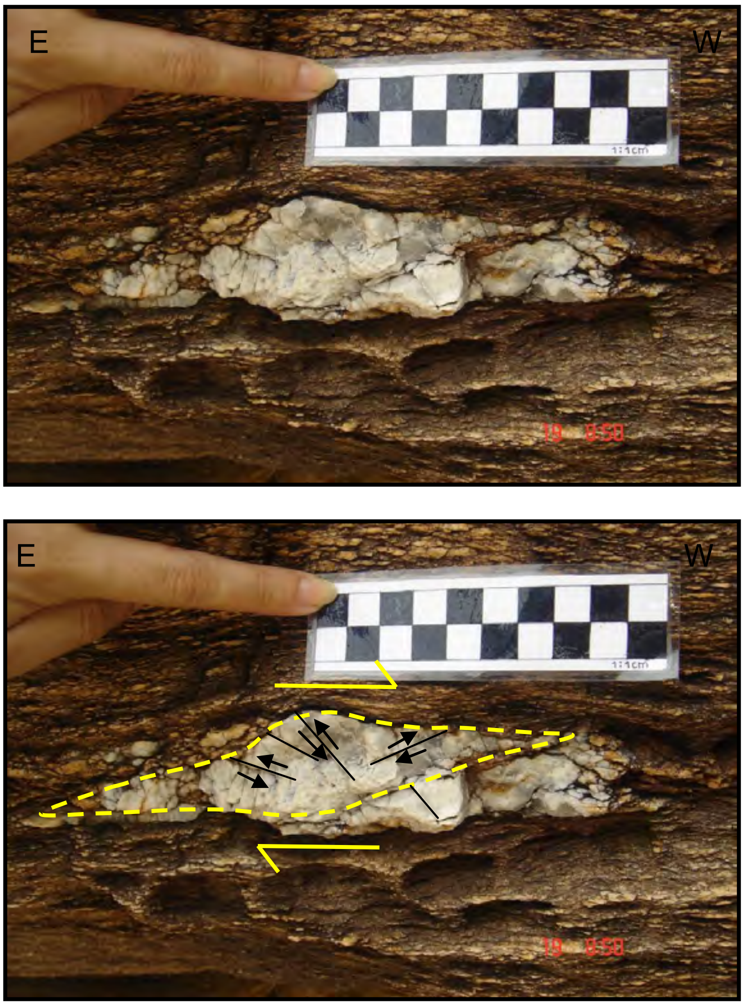


Figure3.19 Quartz porphyroblast with σ-shape showing dextral shear movement and its fractures are both synthetic (the following fracture adds to direction of main shear movement) and antithetic (the fracture contrasts direction of main shear movement) at Laem Lukyon.


S
N


S
N


S
N


S
N


S
N


S
N


S
N


S
N

Figure 3.20 a Quartz porphyroblasts with σ-shape and δ -shape showing dextral shear movement at Laem Bot.

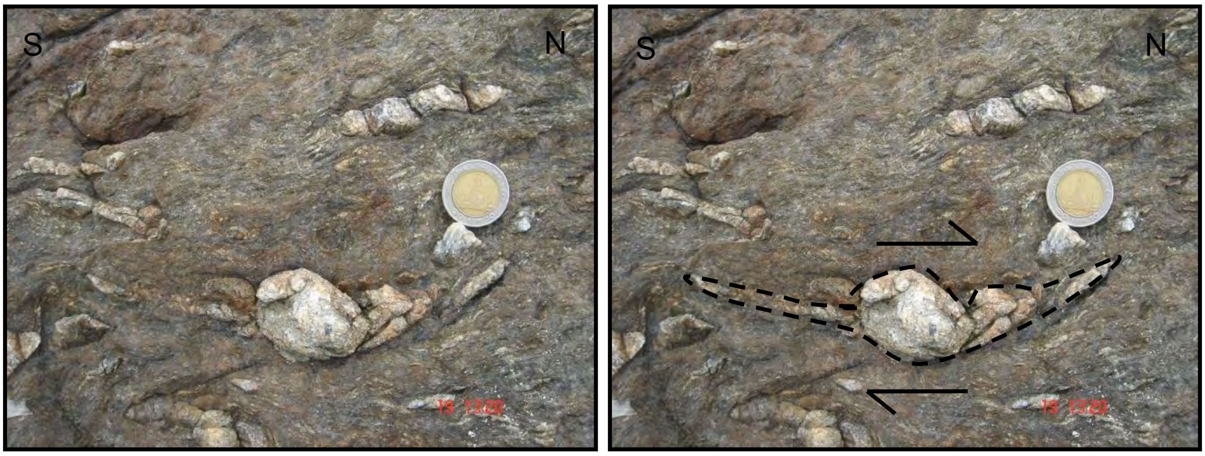
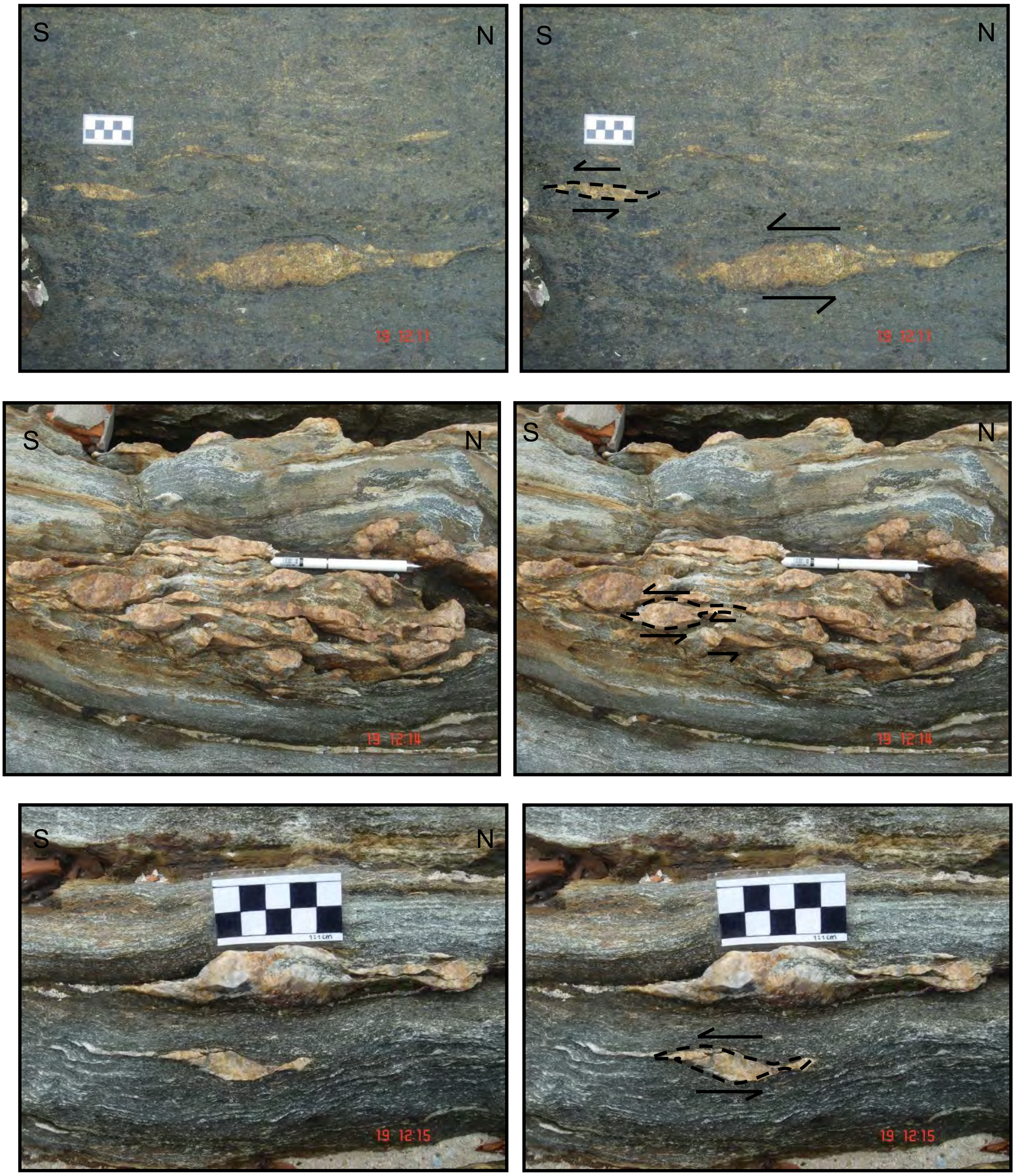


Figure 3.20 b Quartz porphyroblast with δ -shape showing dextral shear movement at Laem Noina.

Figure 3.21 Quartz porphyroblasts with σ-shape showing dextral and sinistral shear movement at Laem Ao Phrao.

Figure 3.22 Shear sense showing dextral shear movement at Laem Bot.


S
N
19 12:11
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19 12:14
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19 12:14
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19 12:15
19 12:15

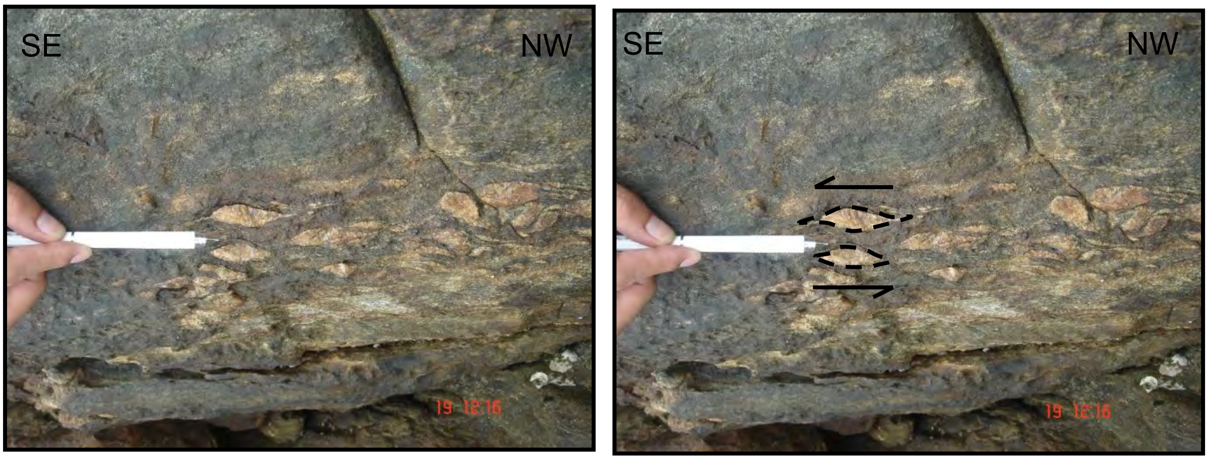
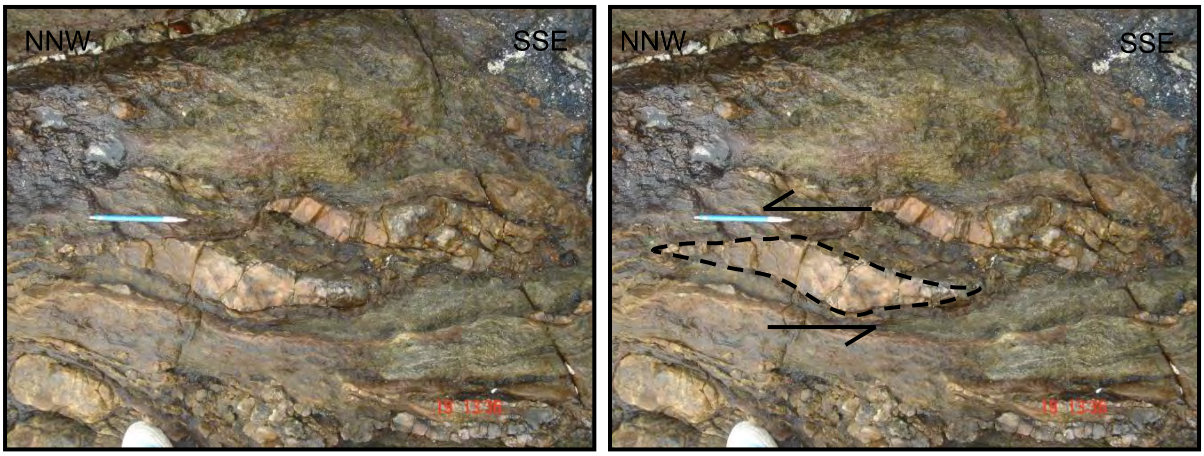


Figure 3.23 Quartz porphyroblasts with σ-shape and δ -shape showing sinistral shear movement at Laem Bot.



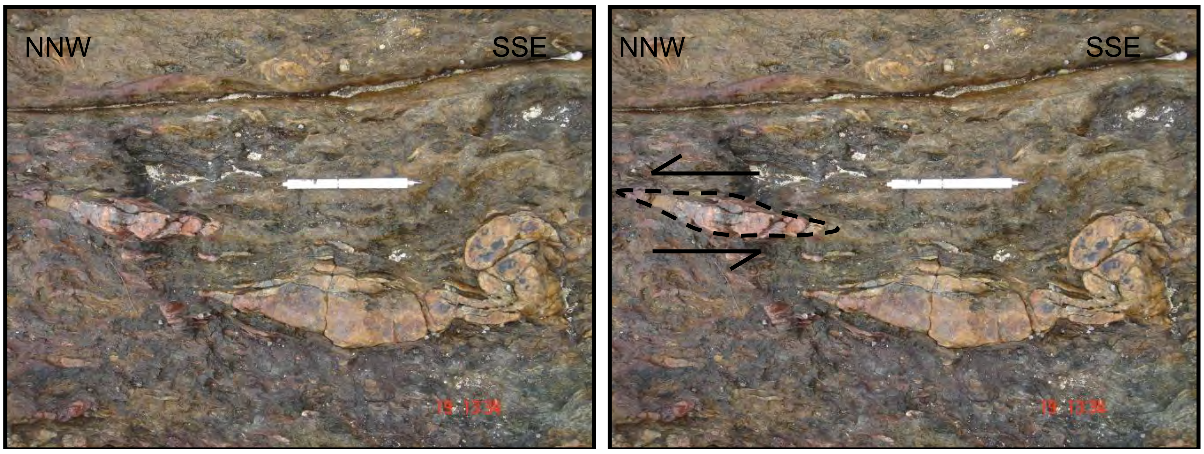
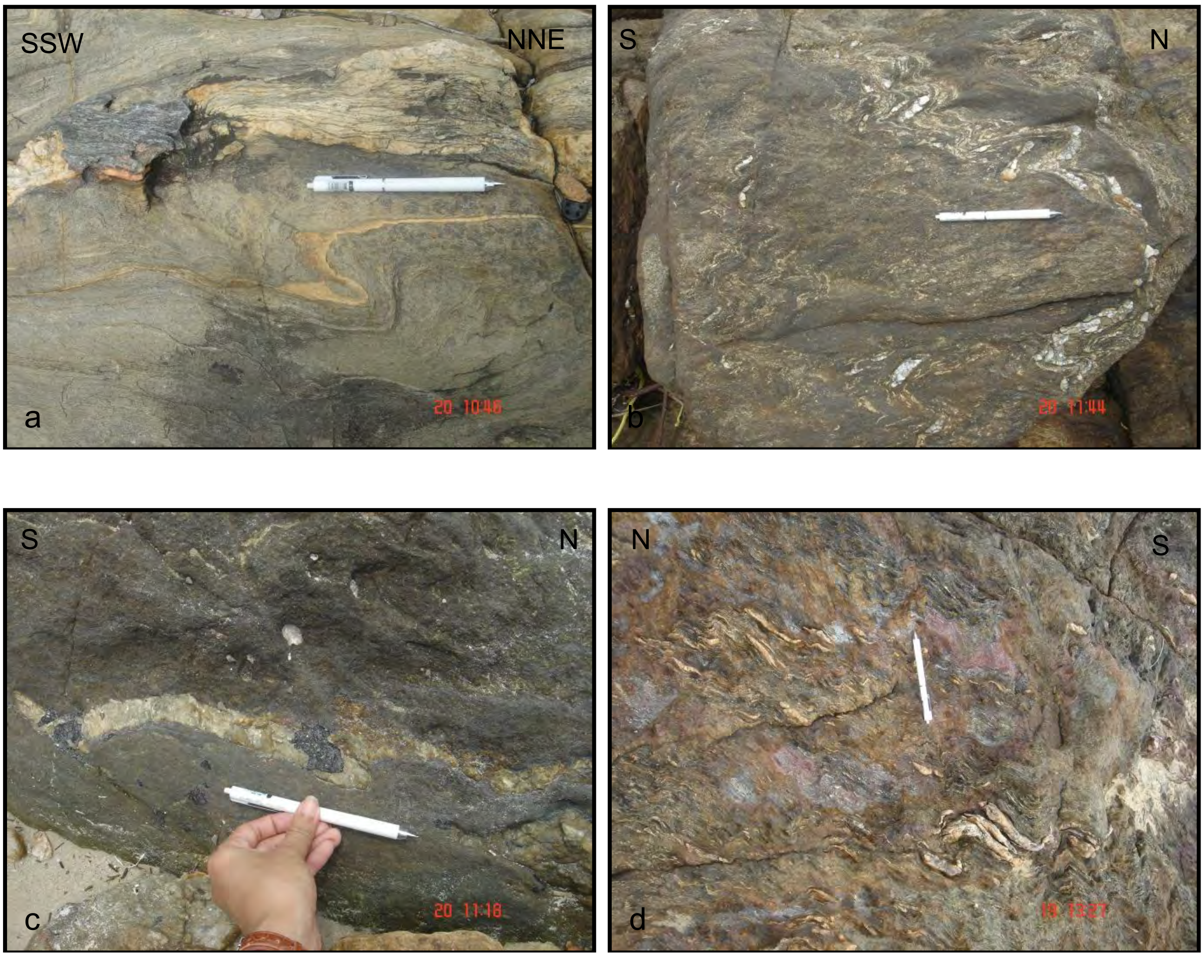


Figure 3.24 Quartz porphyroblasts with σ-shape showing sinistral shear movement at Laem Noina.



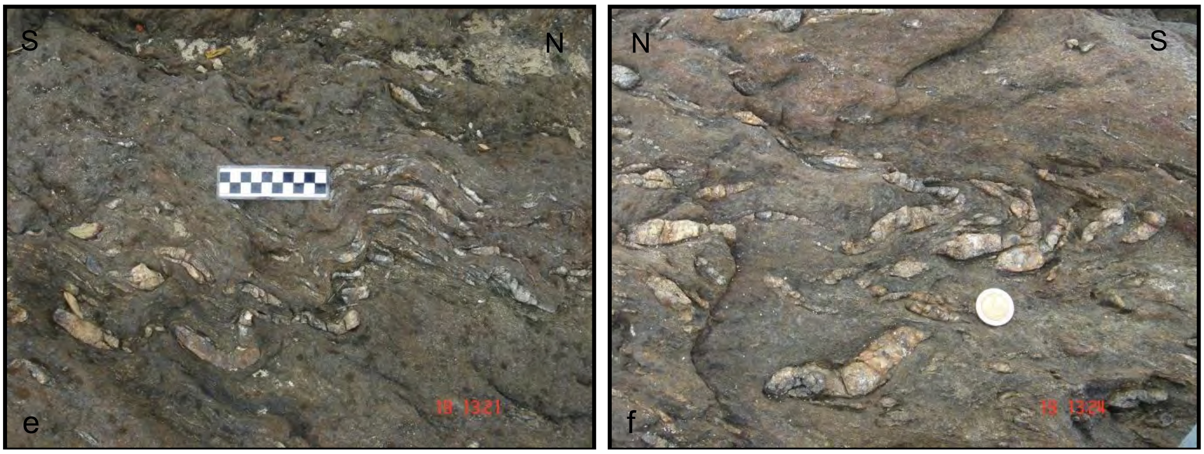


Figure 3.25 S-folded, M-folded and W- folded are reflected from folding at Laem Ao Phrao (a-c) and at Laem Noina (d-f).

3.3 Petrography and Microstructures

The topic deal with the description and interpretation of small scale structures in deformed rocks as seen in the thin sections under the polarized-light microscope. The microstructure gives information on the shear sense and the deformation mechanisms. The mineral content and the textural relationships within the rocks are described along with their deformation behavior. Kinematic indicators were observed in order to understand the sense of shear. Constraining temperatures during deformation is based on deformation behavior of the minerals. Microstructures of the rocks from the study area show deformation structures, which are ductile behavior. Ductile deformation of the northern Koh Samet is represented by shear band cleavages, porphyloclasts and mica fish in schist. Also, there are other evidences that show deformation of rocks.

From studying on thin sections by polarizing microscope, main mineral components of all of rocks are quartz, feldspar, muscovite and chlorite. Nevertheless, they are different percent of mineral components. Therefore, Schist can be classified based on percentage of the mineral components, as follows:

Schist with the N-S lineation units

A: Quartz muscovite schist

- The major components of rock are quartz, muscovite, chlorite, K-feldspar and plagioclase
- Location: Laem Bot, Laem Noinar, Laem Ao Phrao

Schist with the E-W inneation units

A: Quartz muscovite schist

- The major components of rock are quartz, muscovite, chlorite, K-feldspar and plagioclase

Location: Laem Lukyon

B: Feldspar quartz schist

- The major components of rock are K-feldspar, plagioclase, quartz, muscovite and chlorite.
- Location: Laem Nardan, Laem Ao klang

C: Quartz schist

- The major components of rock are quartz, K-feldspar, plagioclase and muscovite.
- Location: Laem Yai

A: Quartz muscovite schist

The major components of the quartz muscovite schist are quartz, muscovite, chlorite, K-feldspar and plagioclase. Most mineral were deformed and orientated parallel to foliation plane. S-C fabrics and S-C' fabrics or C type and C'-type shear bands cleavage (Figure 3.26) are found clearly in the thin sections. The S-C fabrics or S-C' fabrics, which are common in ductile shear zones, indicate the dextral shear sense (Figure 3.27). Porphyloblasts have a shape to σ-type (Figure 3.28) and mica fish (Figure 3.29) indicator the dextral ductile shear. Whereas other porphyloblasts (Figure 3.30) and mica fish (Figure 3.31) indicate sinistral ductile shear. Bulging (BLG) recrystallization (Figure 3.32), basal glide (Figure 3.33), undulose extinction (Figure 3.32) and subgrains (Figure 3.32, 3.34) of most of quartz show deformation mechanism and degree of deformation with low temperature metamorphism or low deformation (Passchier and Trouw, 2005). All of them were defined in quartz muscovite schist. Some thin section also found grain boundary migration (GBM) recrystallization (Figure 3.35), but just found in local scale. Feldspar deforms mainly by brittle fracturing (Figure 3.36). Some of them show twins with steps (Figure 3.37), tapering deformation twins (Figure 3.37) and undulose extinction (Figure 3.37). The deformations of feldspar indicate low temperature of metamorphism (Passchier and Trouw, 2005).

- Kinematic indicators
  - Dextral movement

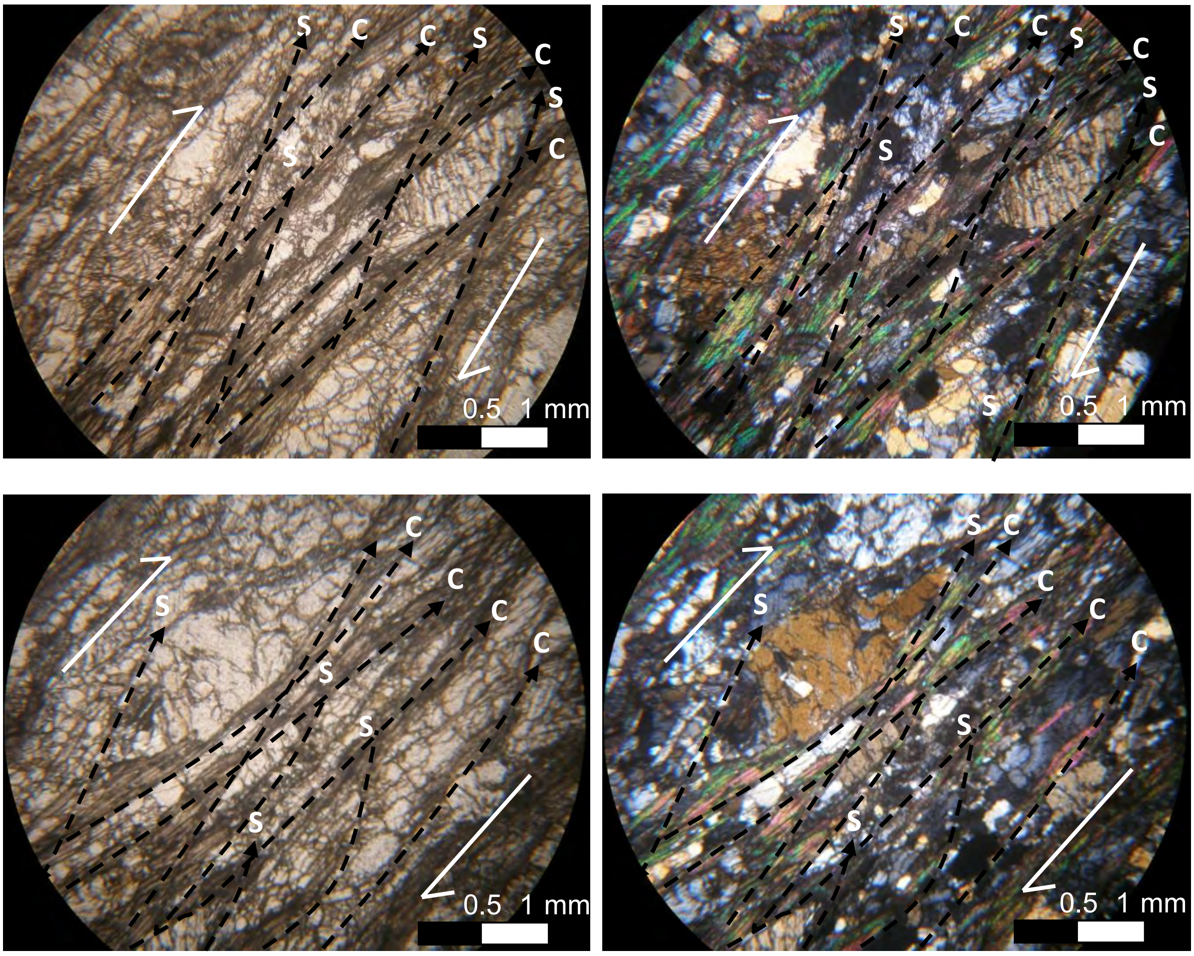


Figure 3.26 S-C fabrics (C-type shear bands) in Quartz-muscovite schist indicate dextral ductile shear sense at Laem Lukyon.

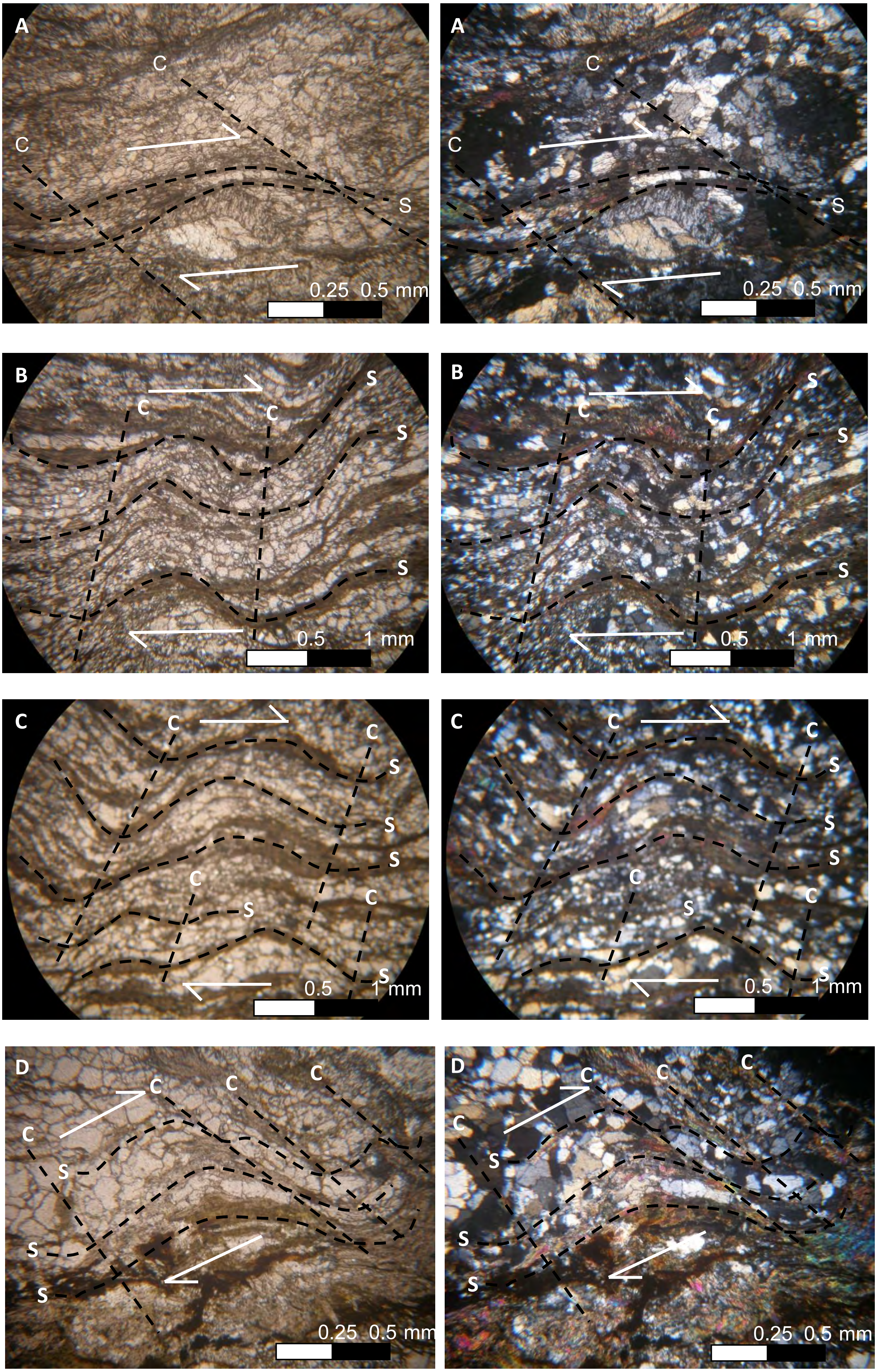


Figure 3.27 S-C' fabrics (C'-type shear bands) in Quartz-muscovite schist at Laem Lukyon (A), Leam Noina (B-C) and Laem Ao Phrao (D) indicate dextral ductile shear sense.

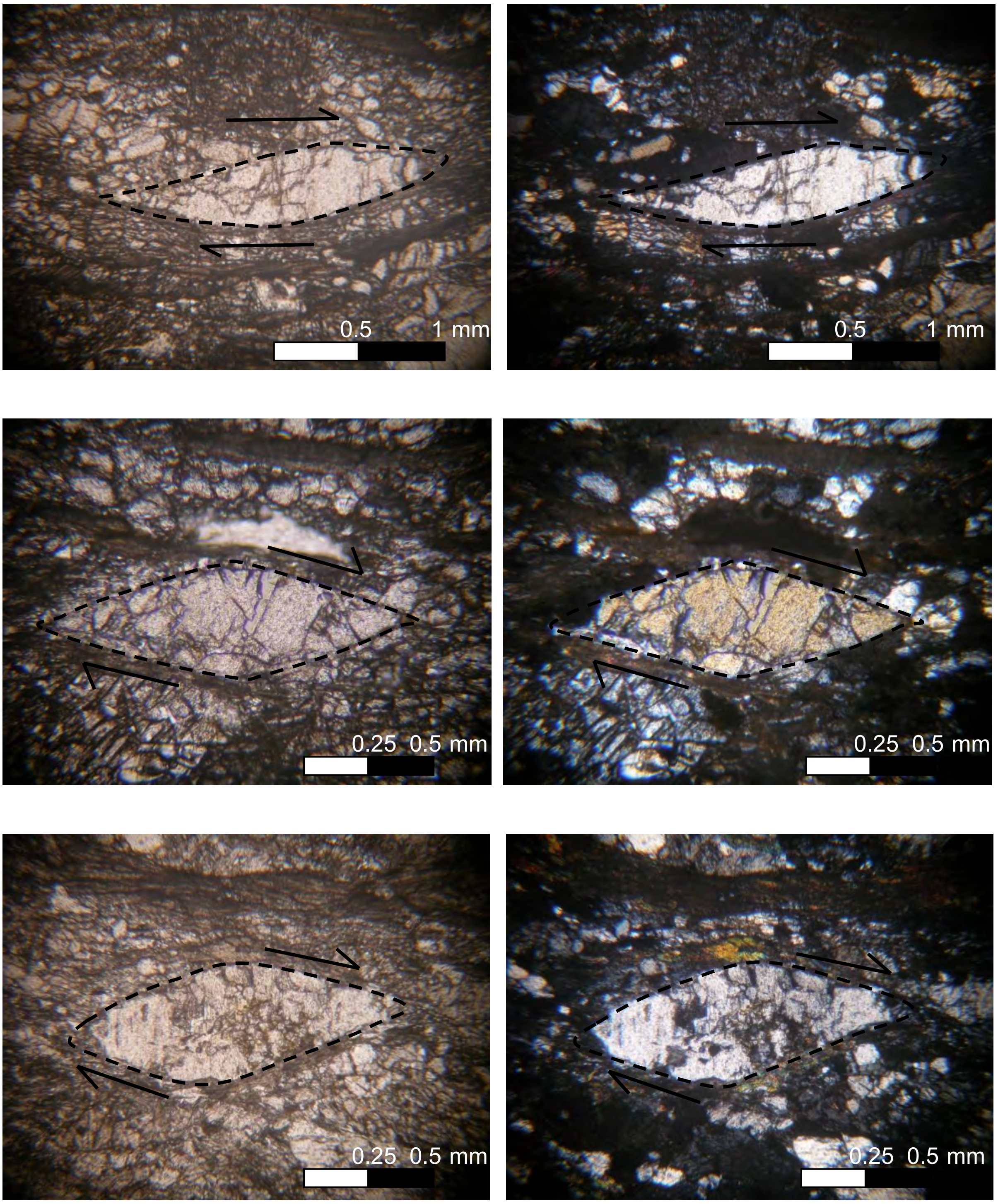


Figure 3.28 Quartz porphyloblasts with **σ**-type shape in quartz muscovite schist referred to dextral ductile shear sense.

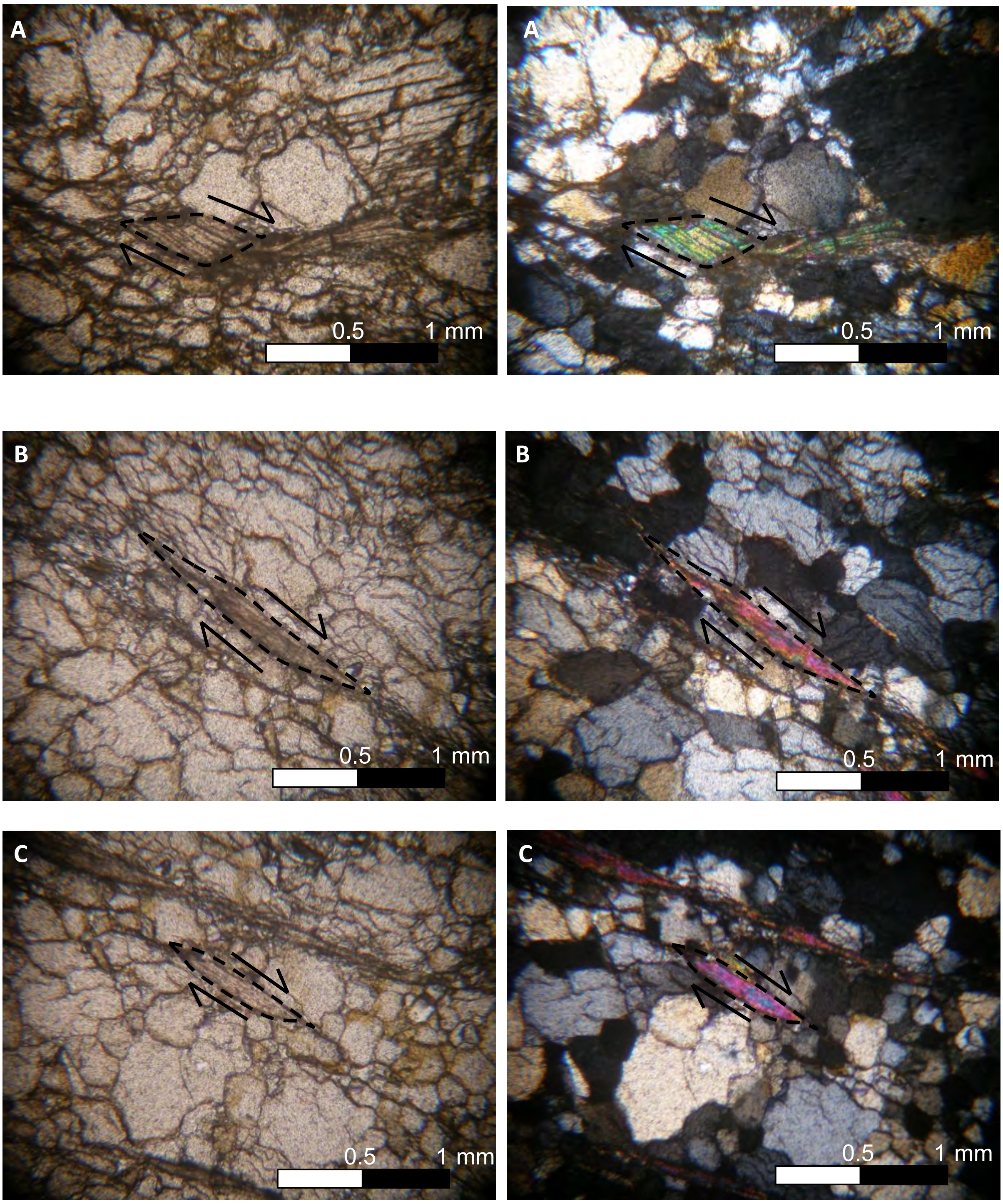


Figure 3.29 Mica fish in quartz muscovite schist have different types; (A) is lenticular mica fish; (B, C) is rhomboidal mica fish. Shear sense in all mica fish is dextral.

- Sinistral movement

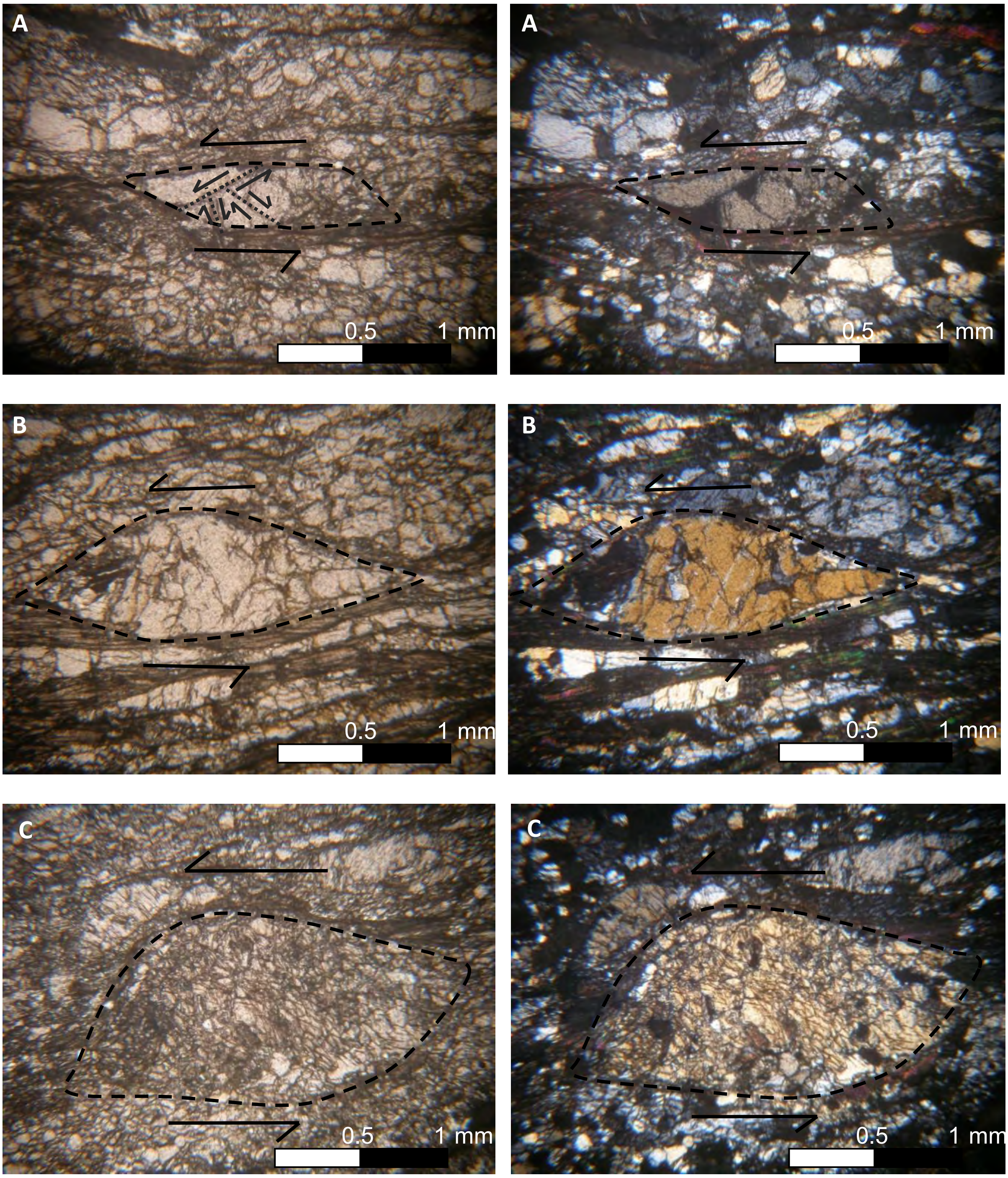


Figure 3.30 Quartz porphyloblasts with σ-type shape in quartz muscovite schist indicate sinistral ductile shear sense. Also Quartz porphyloblasts with σ-type shape in picture A showing syntithetic and antithetic fractures which are the same as found in the field at Laem Lukyon.

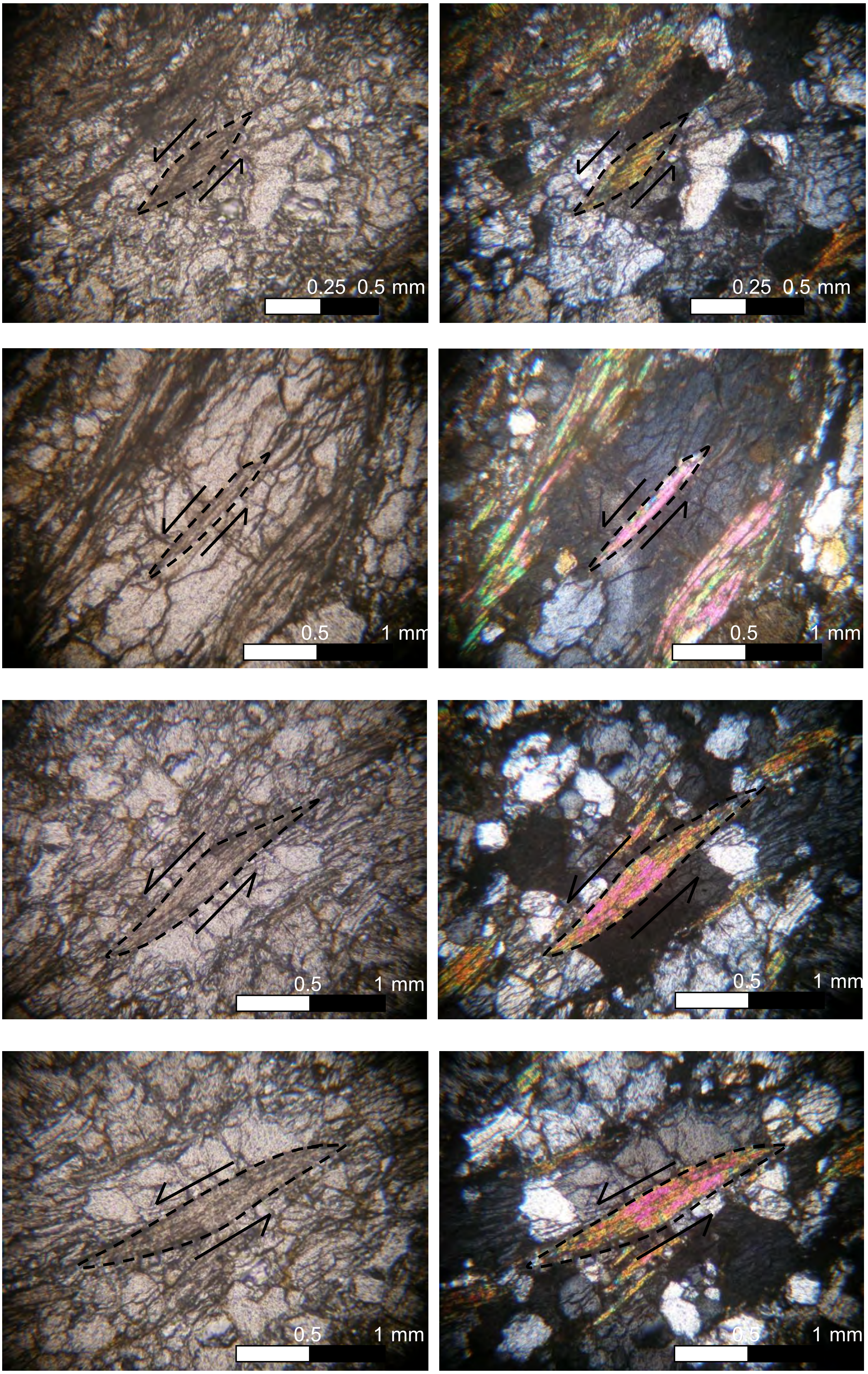


Figure 3.31 Showing all of muscovite is elongated look like fish. These are called mica fish which referred to sinistral ductile shear sense.

- Deformation mechanisms

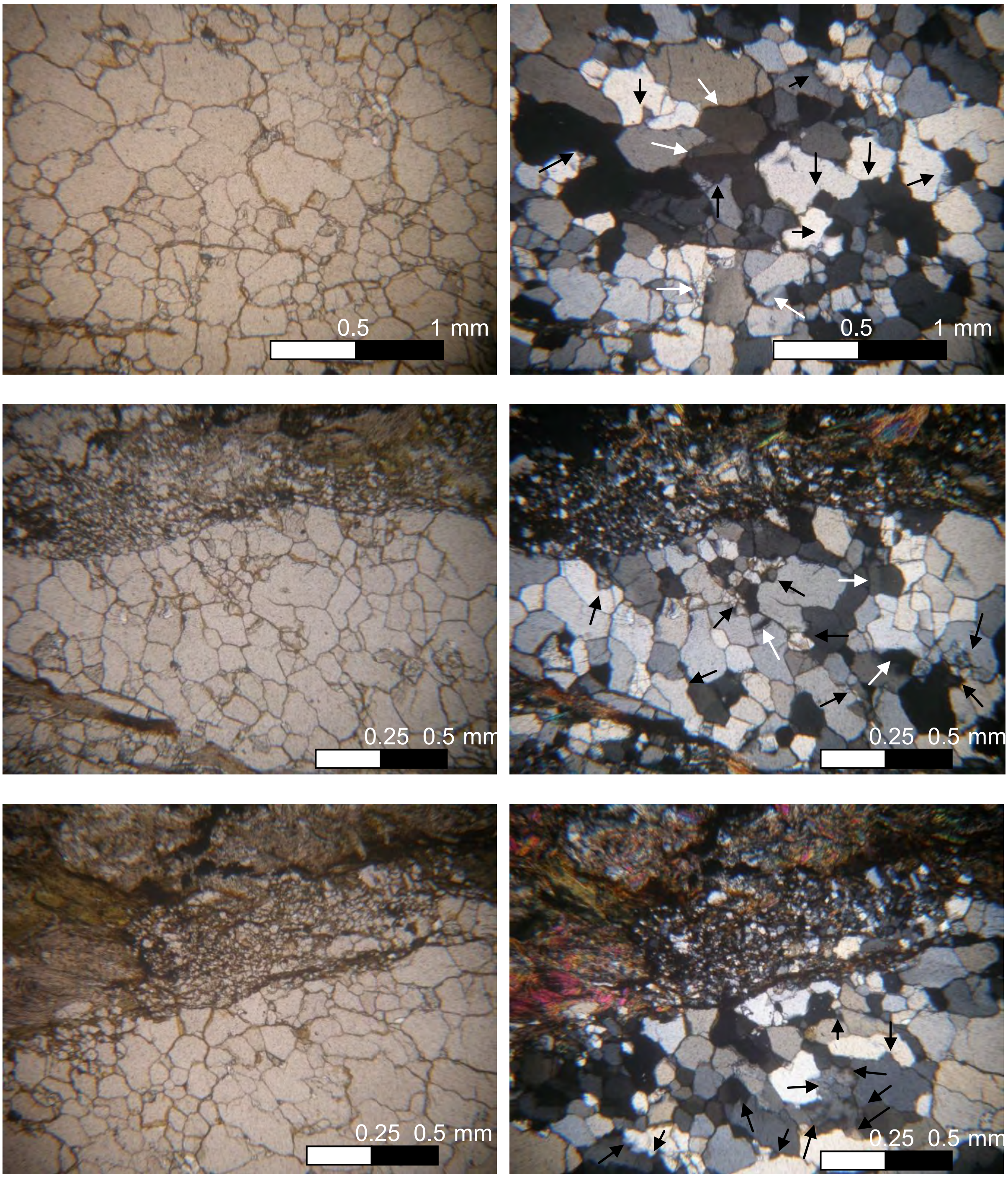


Figure 3.32 Dynamic recrystallisation is Bulging (BLG) recrystallization. Grain boundaries may bulge into the crystal with high dislocation density and the bulges may separate from the host grain to form small independent new grains (see at black arrow). This process is known as low-temperature grain boundary migration (Baily and Hirsh 1962; Drury et al. 1985; Shigematsu 1999; Stipp et al. 2002). Bulging (BLG) recrystallization occur mostly with undulose extinction and subgrain (see at white arrow). The evidences indicate low temperature of metamorphism (Passchier and Trouw, 2005).

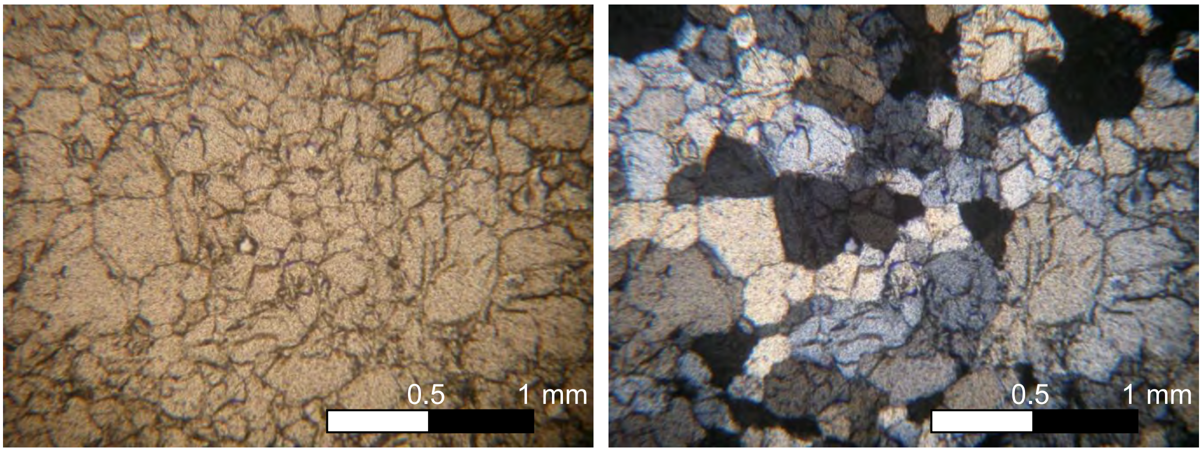


Figure 3.33 Basal glide can observe by boundary of grains that are non-clear and have some practices near its edge. This causes the ice crystal to deform by friction between mineral grains. Basal glide indicate low temperature of metamorphism (Passchier and Trouw, 2005).

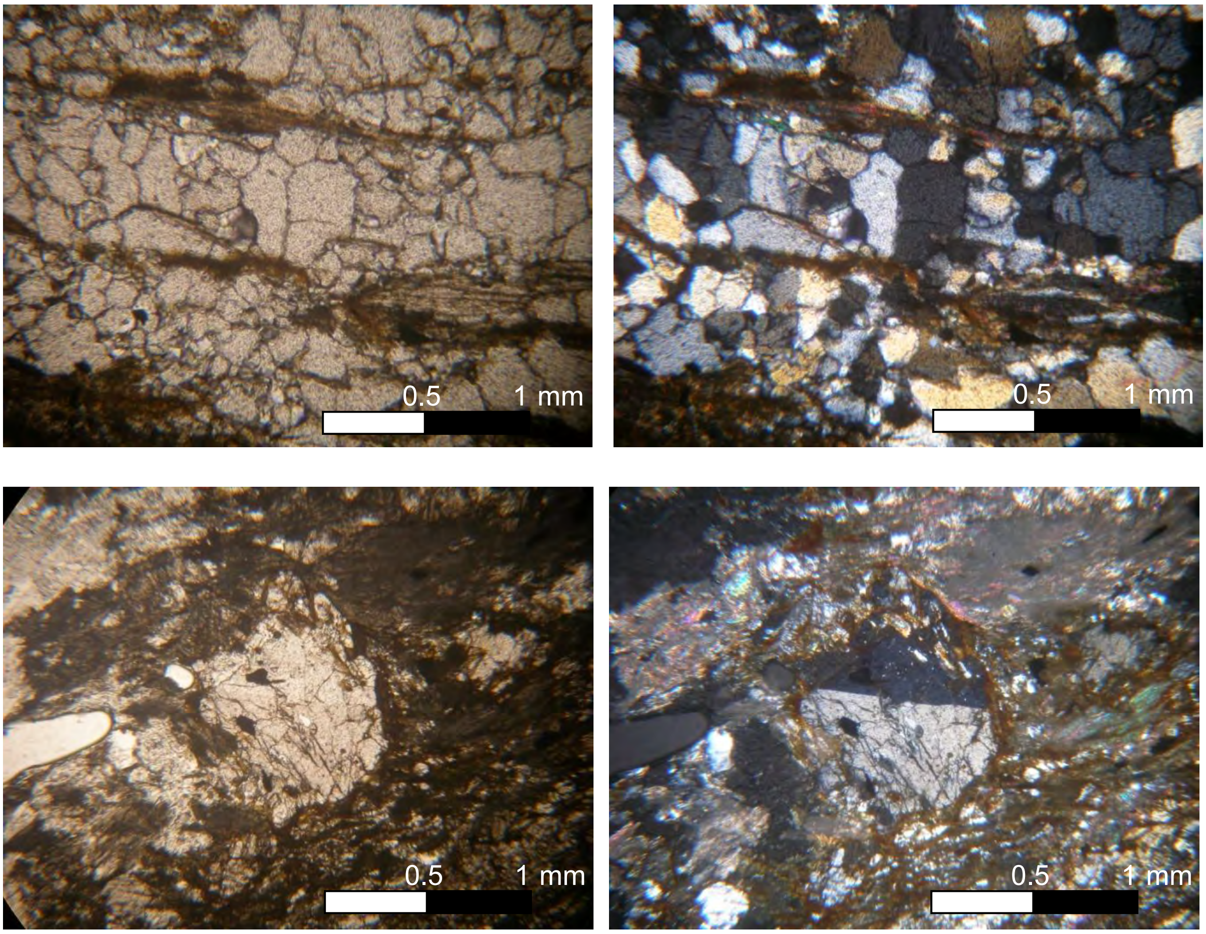


Figure 3.34 Subgrains of quartz in quartz muscovite schist occur from dislocation in the crystal lattice which referred to low temperature of metamorphism (Passchier and Trouw, 2005).

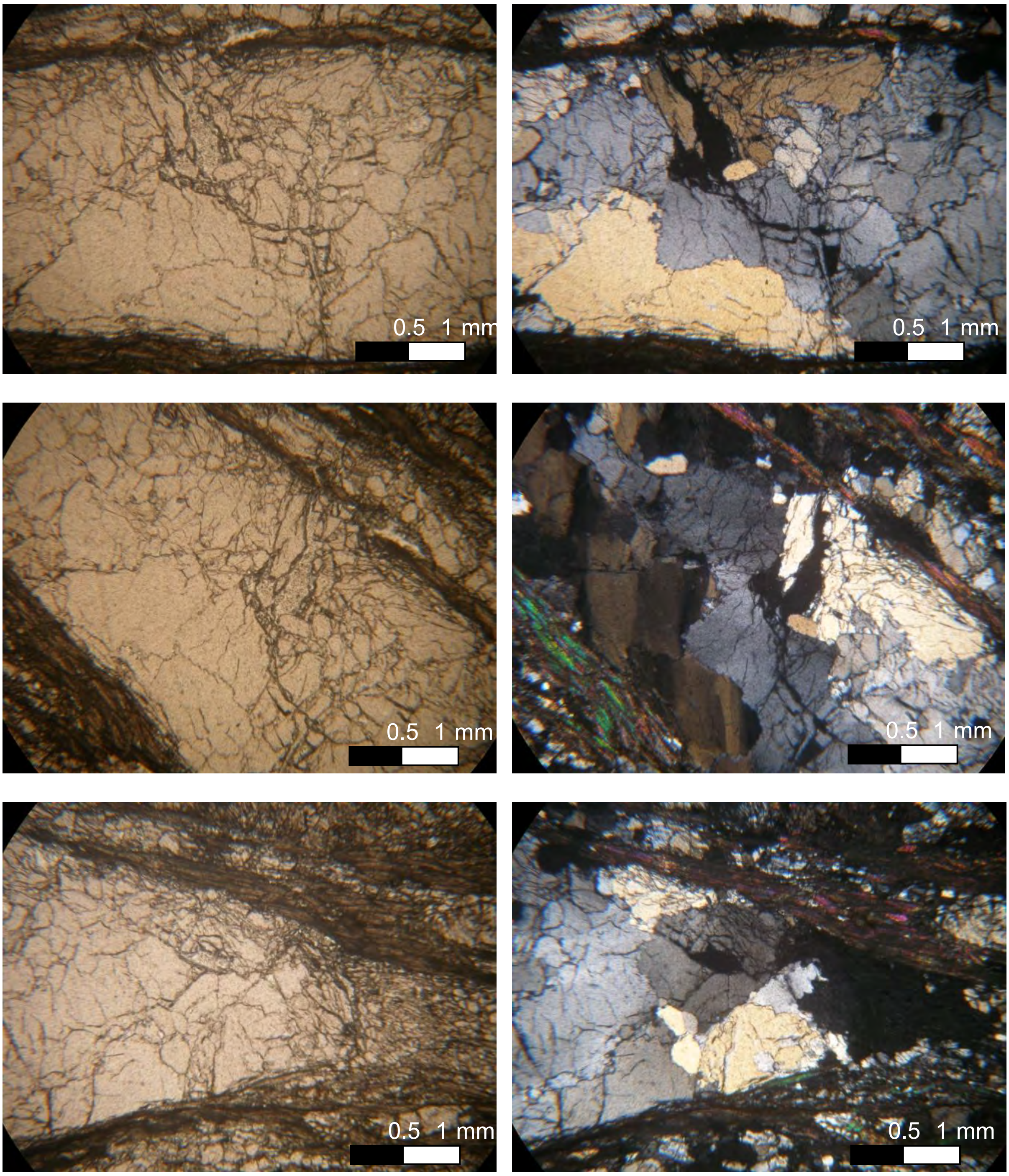


Figure 3.35 Dynamic recrystallisation is Grain Boundary Migration (GBM) recrystallization. At high temperature, grain boundaries become highly mobile and may sweep the material in any direction to remove dislocations and subgrain boundary. Grain boundaries are lobate and grain size is variable. However, Grain boundary migration is found at local scale and just noticed in quartz muscovite schist. Therefore, it can present that the rock is lower than others and low temperature of metamorphism (Passchier and Trouw, 2005).

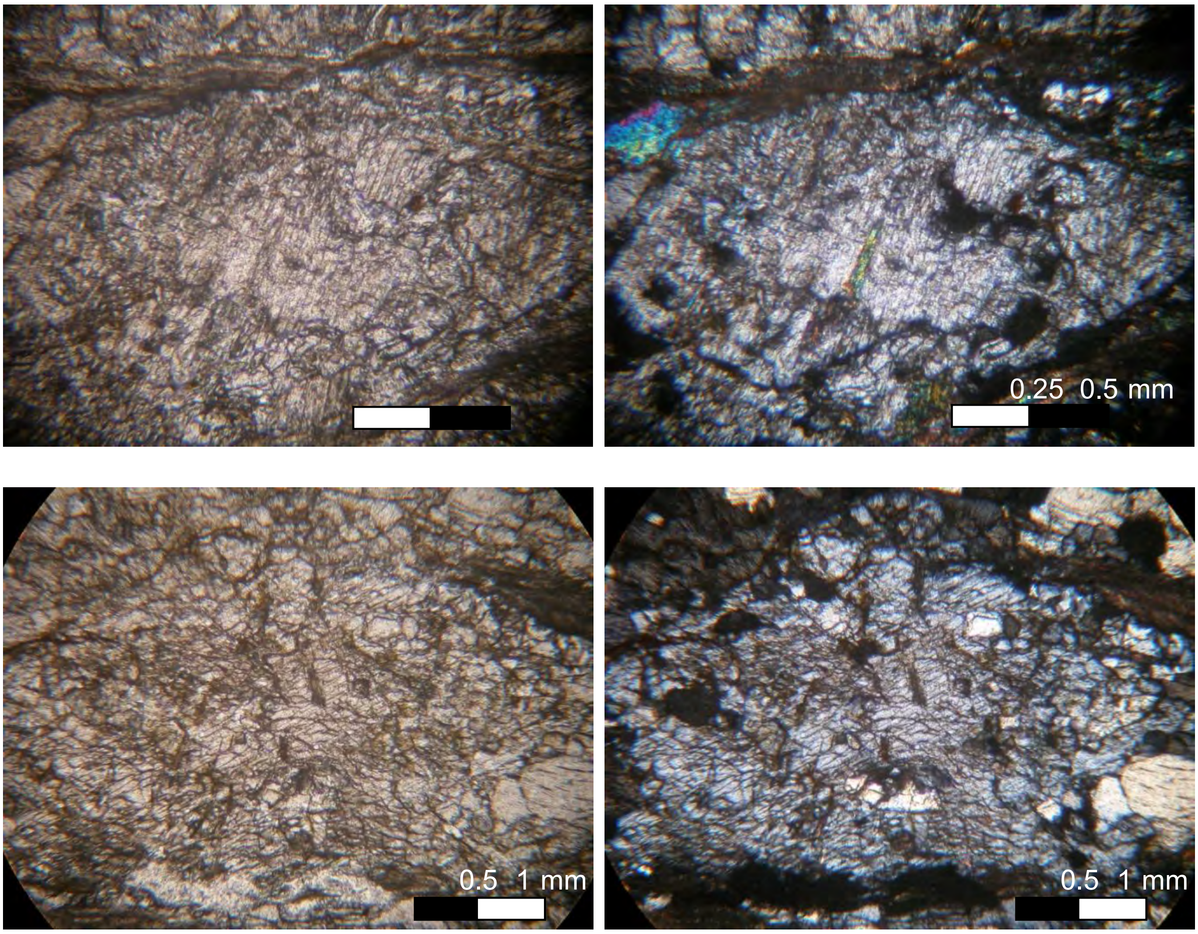
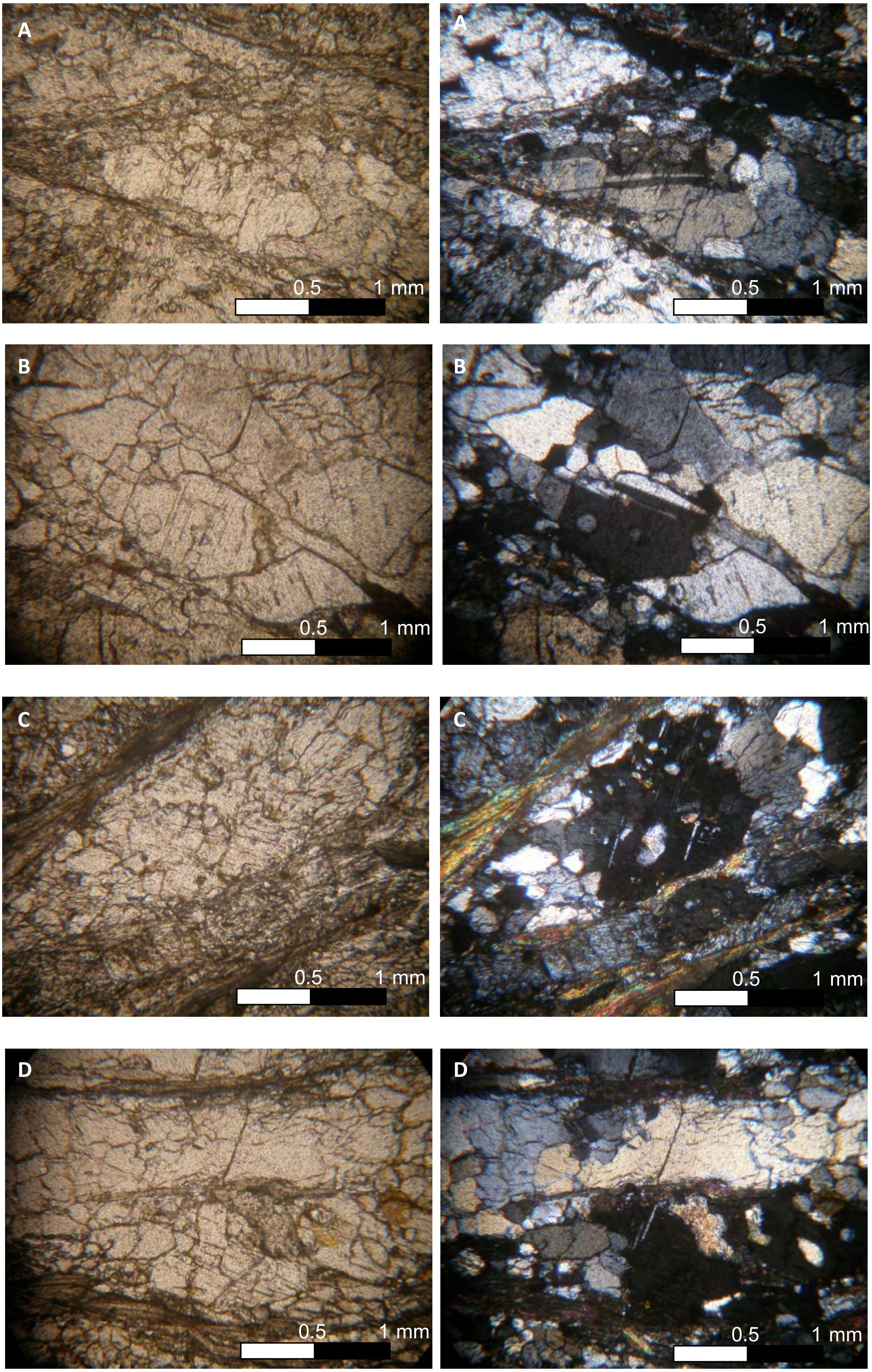


Figure 3.36 Feldspar deforms mainly by brittle fracturing follow in cleavage, which referred to low temperature of metamorphism (Passchier and Trouw, 2005).


A
0.5 1 mm
A
0.5 1 mm
B
0.5 1 mm
B
0.5 1 mm
C
0.5 1 mm
C
0.5 1 mm
D
0.5 1 mm
D
0.5 1 mm

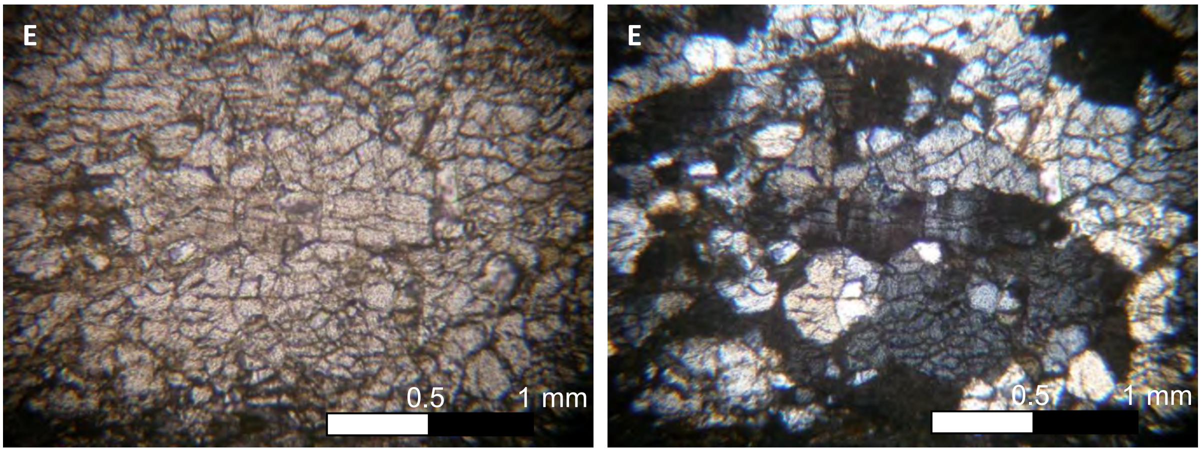
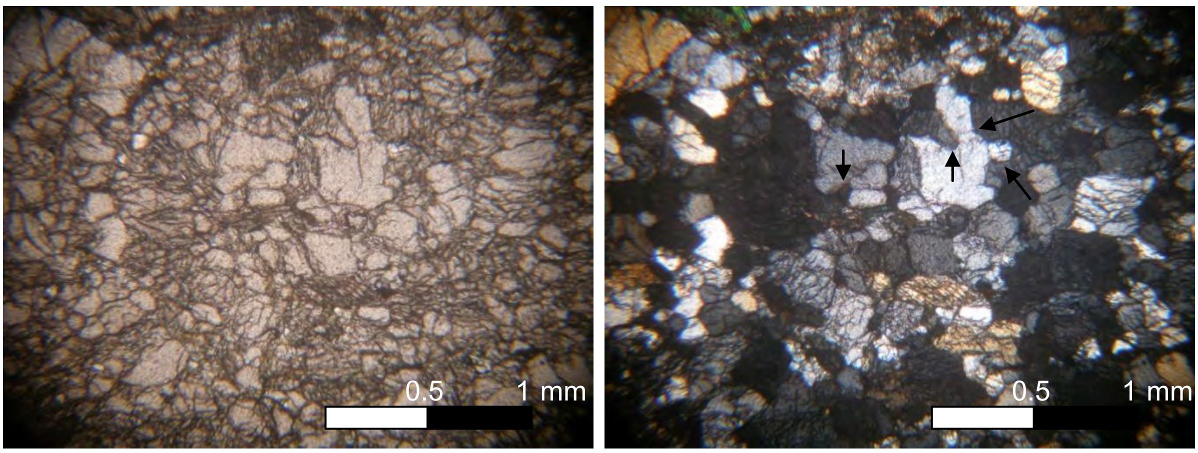


Figure 3.37 Some of K-feldspars and plagioclases show twins with steps (A-B), tapering deformation twins (A-D), undulose extinction (E). The deformation of feldspar can indicate low temperature of metamorphism (Passchier and Trouw, 2005).

B: Feldspar quartz schist

The major components of rock are K-feldspar, plagioclase, quartz, muscovite and chlorite. Evidences of feldspar quartz schist are mostly the deformation mechanism or rarely the kinematic indicators. In feldspar quartz schist can find Bulging (BLG) recrystallization (Figure 3.38), undulose extinction and subgrains (Figure 3.38) of most of quartz that show low temperature of metamorphism (Passchier and Trouw, 2005). Feldspar deforms mainly by brittle fracturing (Figure 3.39). Some of them show twins with steps (Figure 3.40) and subgrain (Figure 3.40) and perthite (Figure 3.41). The deformation of feldspar can indicate low temperature of metamorphism (Passchier and Trouw, 2005).

- Deformation mechanisms



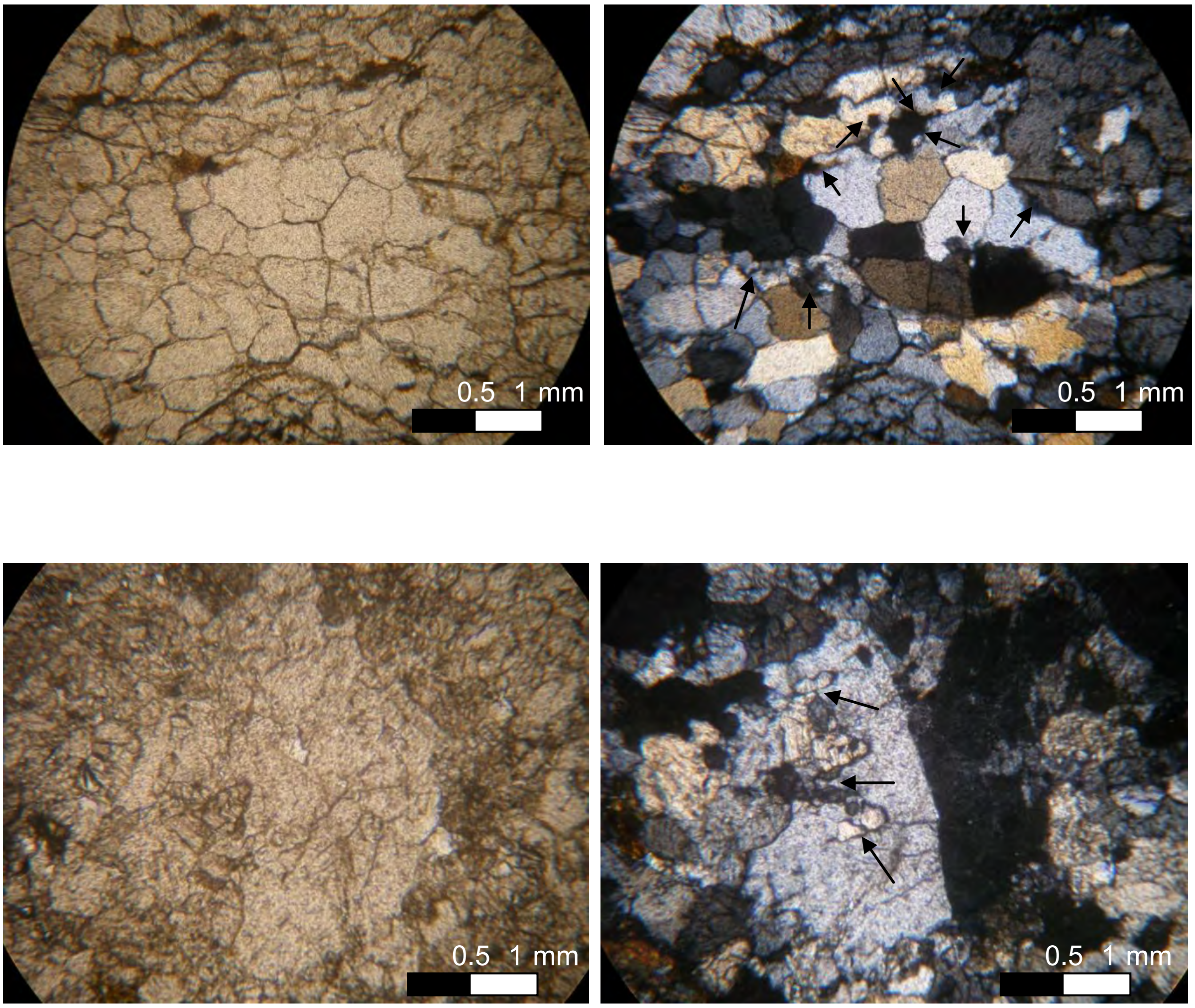


Figure 3.38 Dynamic recrystallisation is Bulging (BLG) recrystallization. Grain boundaries may bulge into the crystal with high dislocation density and the bulges may separate from the host grain to form small independent new grains (see at black arrow). This process is known as low-temperature grain boundary migration (Baily and Hirsh 1962; Drury et al. 1985; Shigematsu 1999; Stipp et al. 2002). Bulging (BLG) recrystallization occur mostly with undulose extinction and subgrain. The evidence indicates low temperature of metamorphism (Passchier and Trouw, 2005).

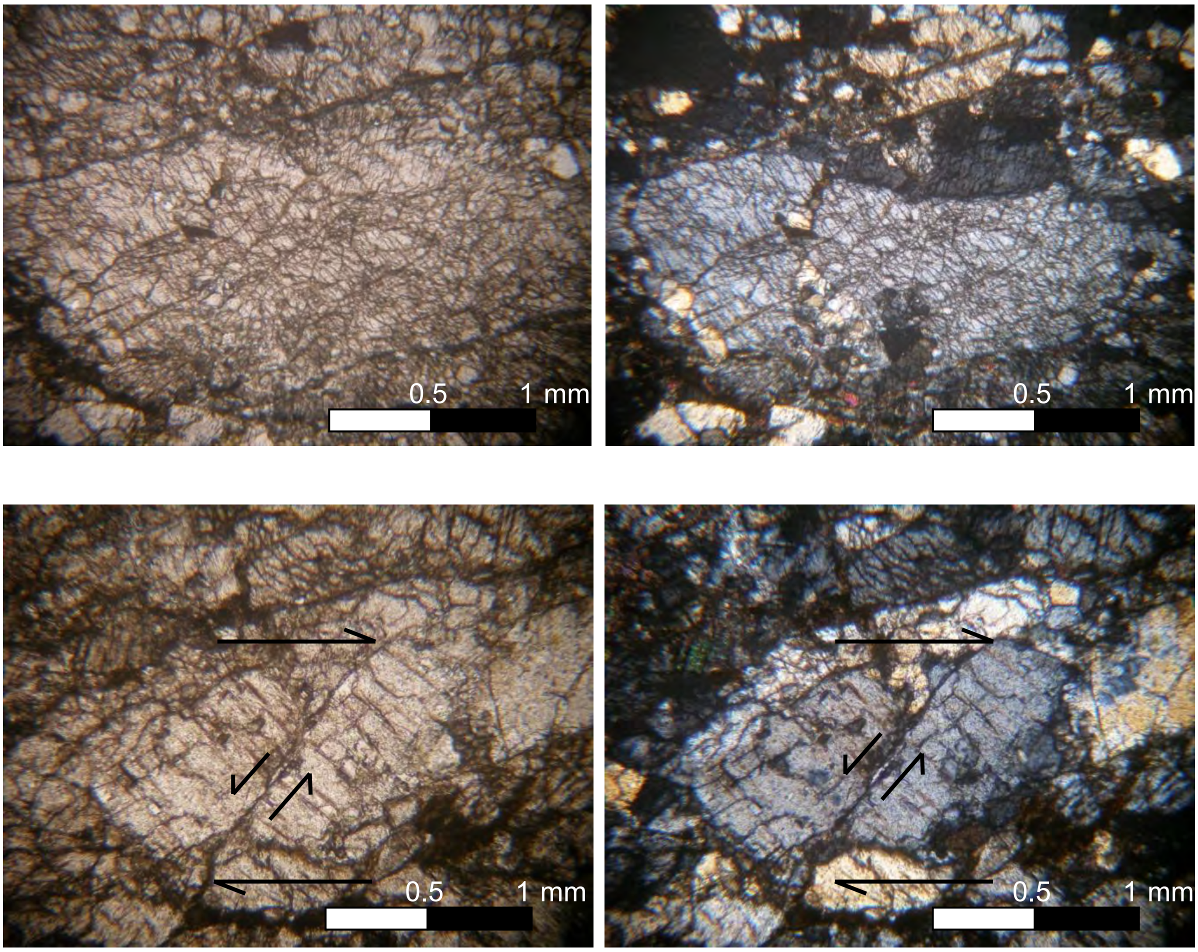
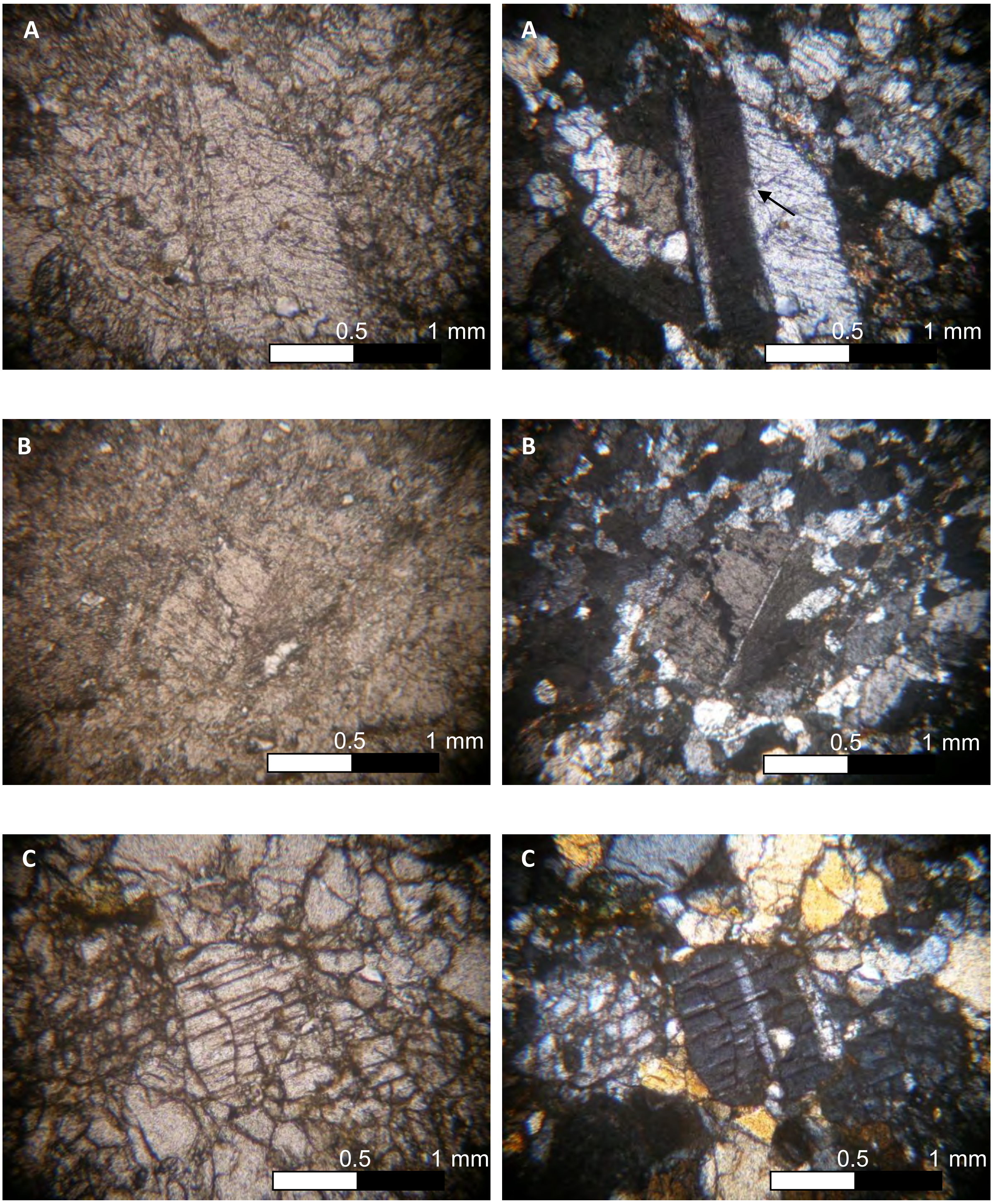


Figure 3.39 Feldspar deforms mainly by brittle fracturing follow in cleavage. The picture in B is sense of shear indicate dextral movement which have antithetic fracture (sinistral movement); can see that in grain feldspar of the picture B. The deformation of feldspar can refer to low temperature of metamorphism (Passchier and Trouw, 2005).


A
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1 mm
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B
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1 mm
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0.5
1 mm

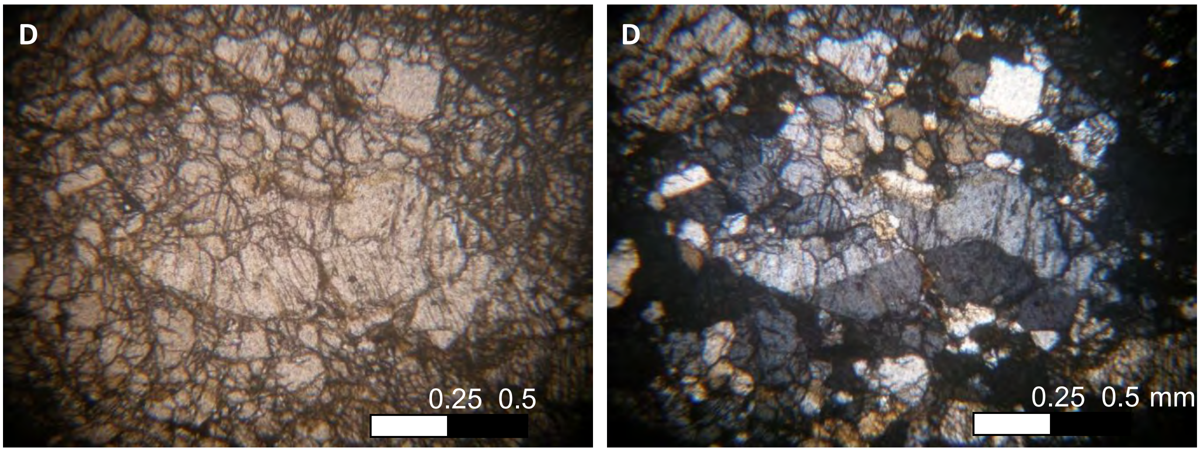


Figure 3.40 Some of feldspars show twins with steps (A), subgrain (B-D). The deformation of feldspar can indicate low temperature of metamorphism (Passchier and Trouw, 2005).

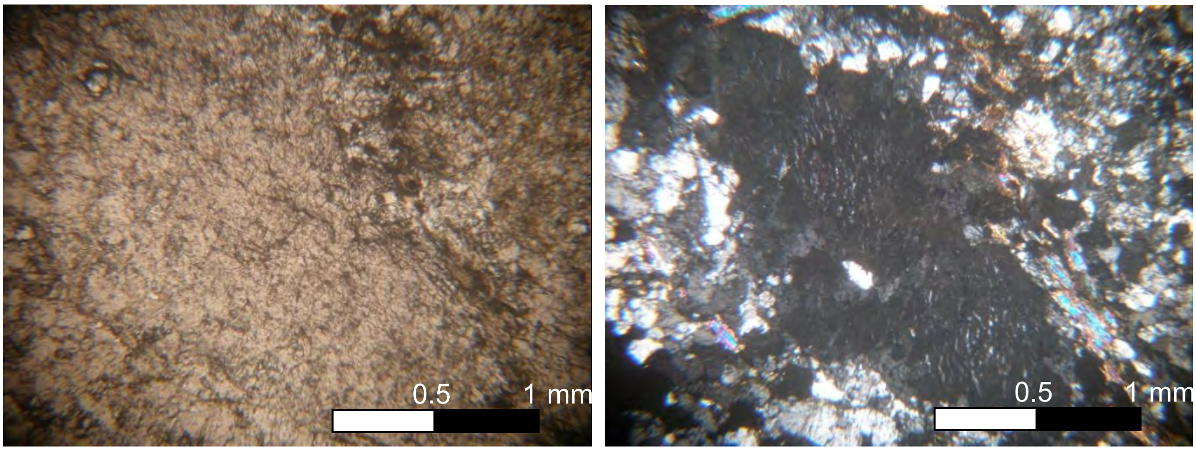


Figure 3.41 Showing perthite can found in feldspar some thin section which is albite lamellae are present in K-feldspar.

C: Quartz schist

The major components of rock are quartz, K-feldspar, plagioclase and muscovite. Evidences of quartz schist are mostly the deformation mechanism. Bulging (BLG) recrystallization (Figure3.42), undulose extinction and subgrains (Figure 3.42, 3.43) were found in most of quartz in this rock. They indicate low temperature of metamorphism or low deformation (Passchier and Trouw, 2005). Feldspar deforms mainly by brittle fracturing (Figure 3.44). Some of them show tapering deformation twins (Figure 3.44), twins with steps (Figure 3.44) and perthite (Figure 3.45). The deformations of feldspar indicate low temperature of metamorphism (Passchier and Trouw, 2005).

- Deformation mechanisms

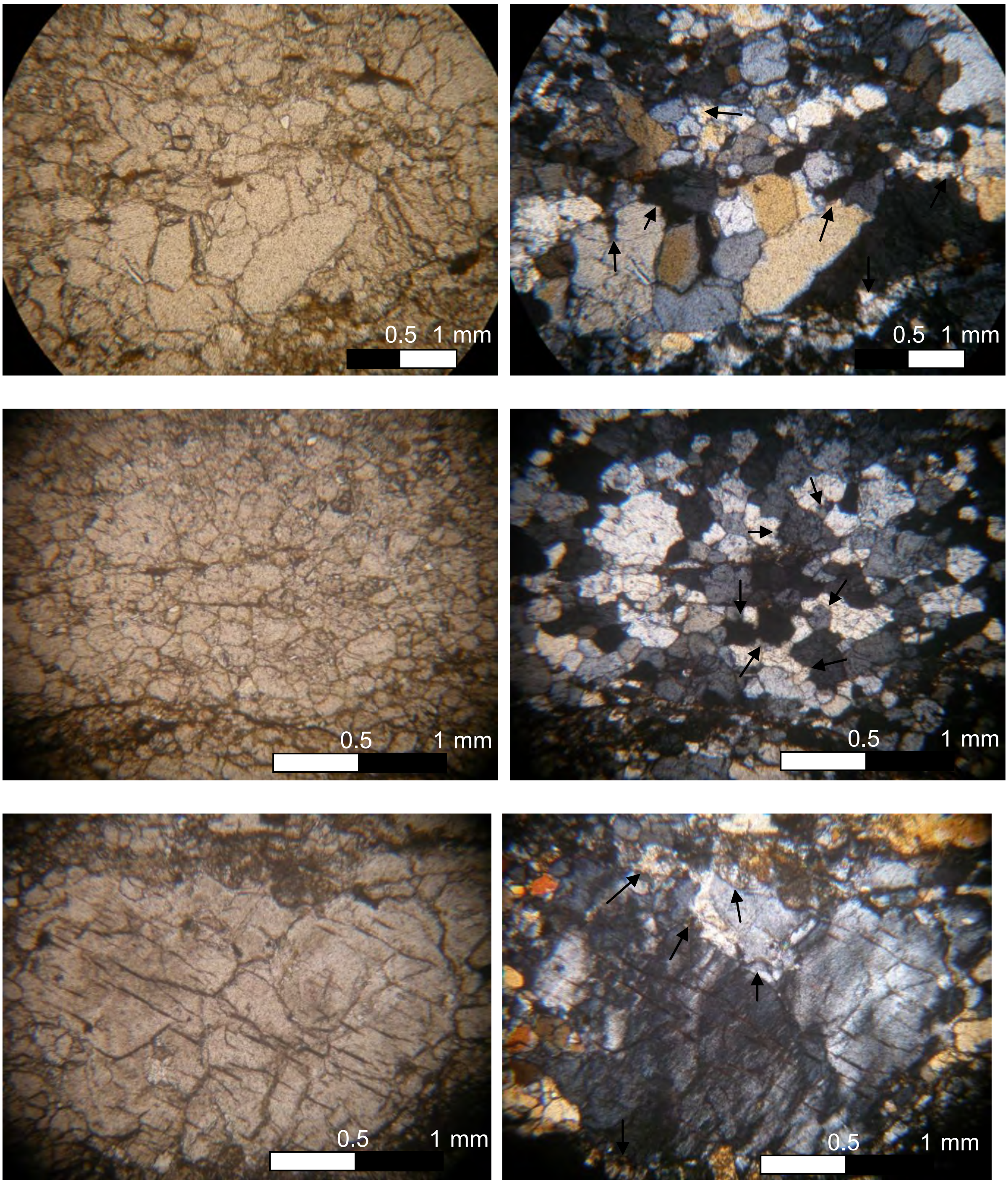


Figure 3.42 Dynamic recrystallisation is Bulging (BLG) recrystallization in quartz (A-B) and feldspar that is rarely (C). Grain boundaries may bulge into the crystal with high dislocation density and the bulges may separate from the host grain to form small independent new grains (see at black arrow). This process is known as low-temperature grain boundary migration (Baily and Hirsh 1962; Drury et al. 1985; Shigematsu 1999; Stipp et al. 2002). Bulging (BLG) recrystallization occur mostly with undulose extinction and subgrain. The evidence indicates low temperature of metamorphism (Passchier and Trouw, 2005).

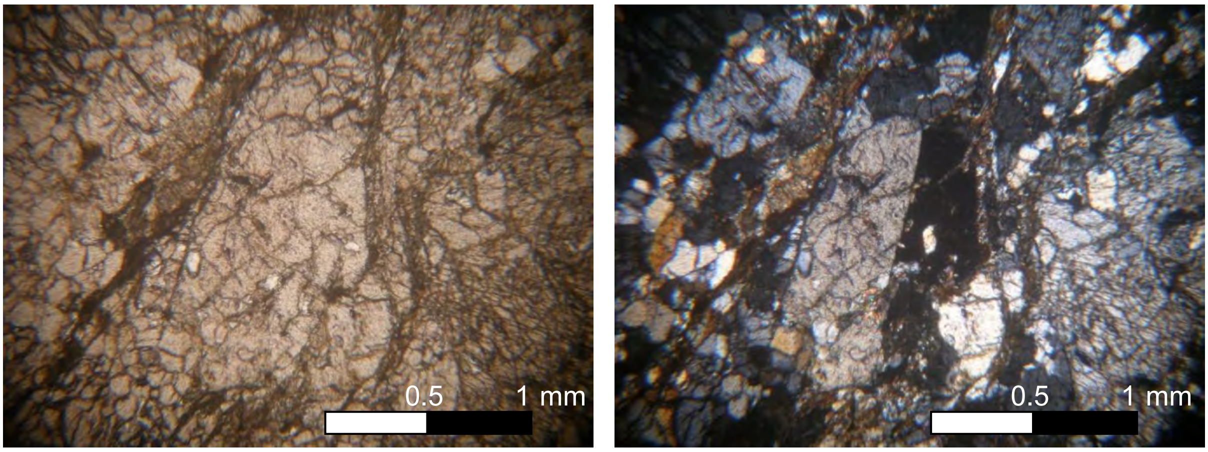
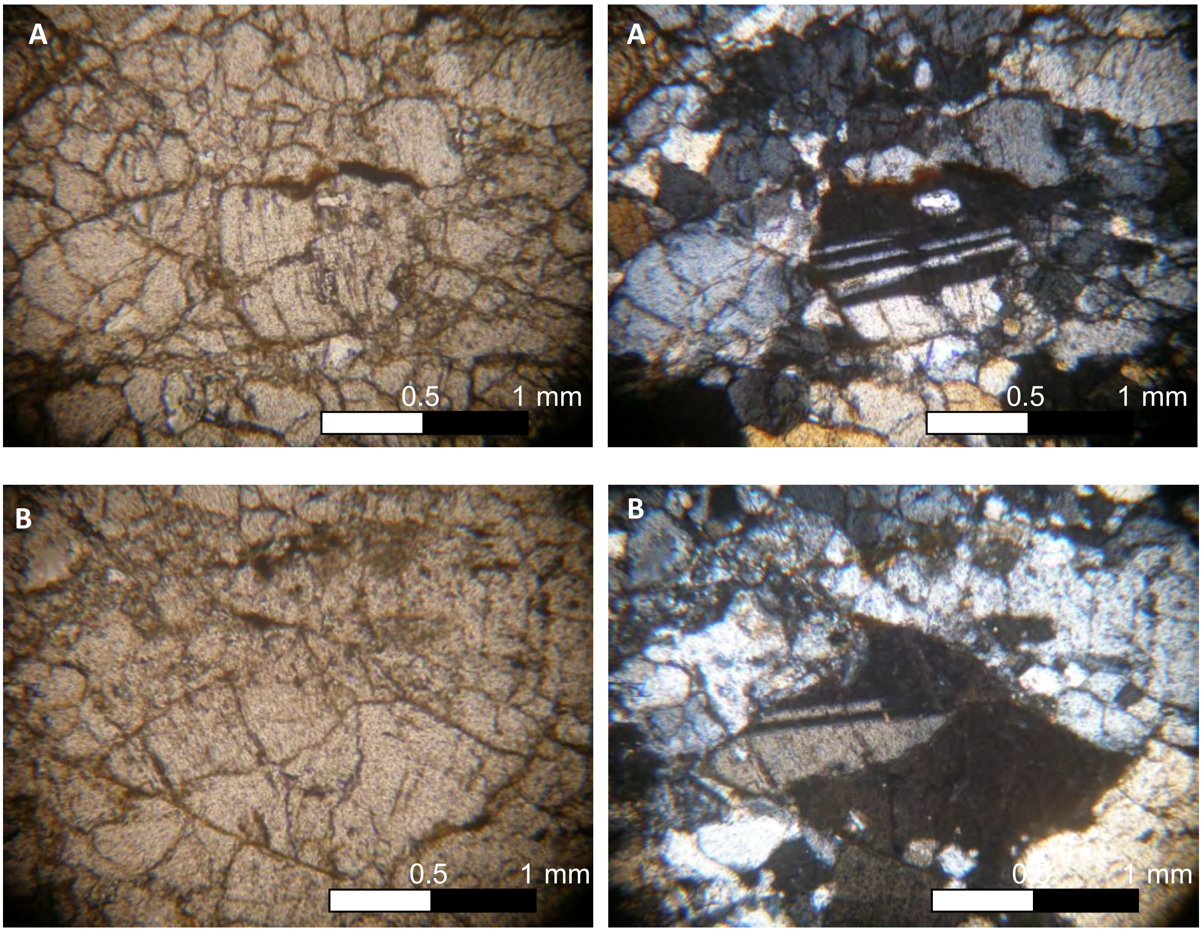


Figure 3.43 Showing subgrain of quartz and the right side show that feldspar is deformed by fracturing which indicate low temperature of metamorphism (Passchier and Trouw, 2005).



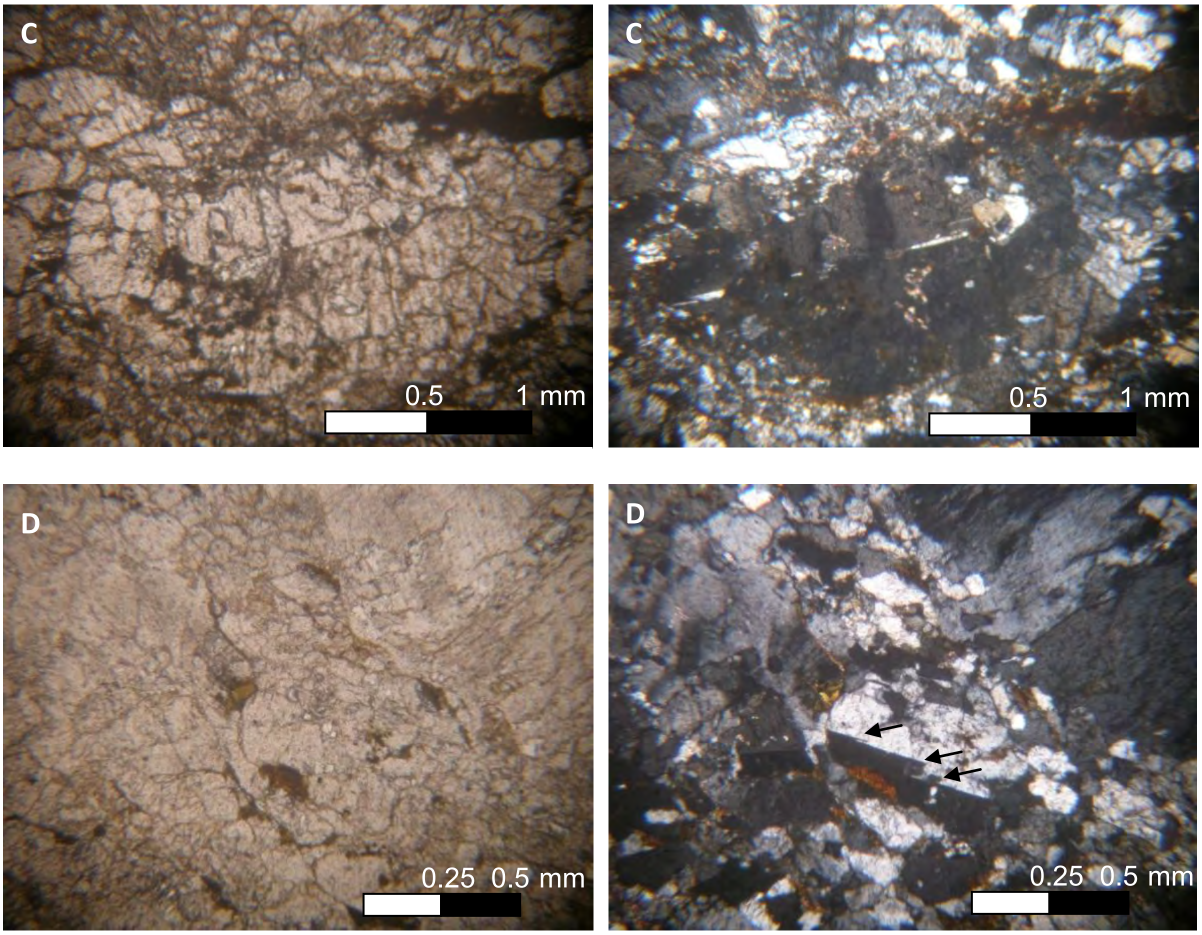


Figure 3.44 Some of feldspars show tapering deformation twins (A-C), twins with steps (D), subgrain (B-D). The deformation of feldspar can indicate low temperature of metamorphism (Passchier and Trouw, 2005).

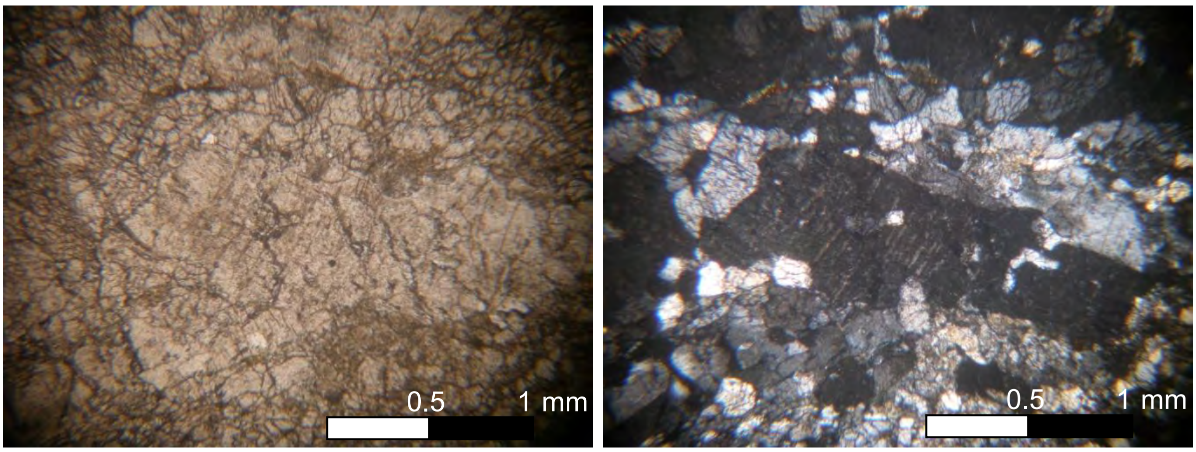


Figure 3.45 Perthite can found in feldspar some thin section which is albite lamellae are present in K-feldspar.

Chapter 4

Discussion

In 2 mains of interpretation, one is mesoscopic structure; field investigation with structural analysis using stereographic net and rose diagram. Another one is microscopic structure; thin sections. All of results can discuss and interpret in terms of structural style and structural evolution of the northern Koh Samet. And they can interpret about metamorphic facies and degree of deformation also.

4.1 Metamorphic facies and degree of deformation

In field investigation, all rocks are metamorphism rocks which are schist. We can notice compositions of rocks that are quartz, mica and feldspar. When we have studied in thin sections by polarizing microscope, we found that main mineral components of all of rocks are quartz, feldspar, muscovite and chlorite that are the same mineral as in the hand specimens in the field. The textures in thin sections can be used to interpret protolith that is sedimentary rock. The textures show old clasts and matrix of sedimentary rock like conglomerate or pebbly sandstone (Figure 4.1). We can notice from quartz that has coarse grain and fine grain (Figure 4.1). Consequently, the index minerals which can identify metamorphic facies, are quartz (Figure 4.1), muscovite and chlorite (Figure 4.2). From the table of the mineral assemblages in the conventationally recongnized metamorphic facies listed according to major chemical group of metamorphic rocks (Turner,1981, Yardley,1989, Blatt and Tracy,1996)(Figure 4.3) can identify the protolith of schist is pelitic rocks. The mineral assemblages or index minerals in the rocks recognized to be greenschist facies. The evidences in thin section which show deformation mechanism, are bulging (BLG) recrystallization, basal glide, the local grain boundary migration (GBM) recrystallisation, undolose extinction and the local subgrain in quartz which indicated low grade metamorphism at the temperature between 300-400°C (Passchier and Trouw, 2005).

Furthermore, deformation of feldspars deforms mainly by brittle fracturing. Some of them show twins with steps, tapering deformation twins. The deformations of feldspar indicate deformation mechanism and degree of deformation with low temperature metamorphism or low deformation (Passchier and Trouw, 2005). Consequentaly, schist in the study area is estimated to metamorphose at lower greenschist facies between 300-400°C (Figure 4.4).

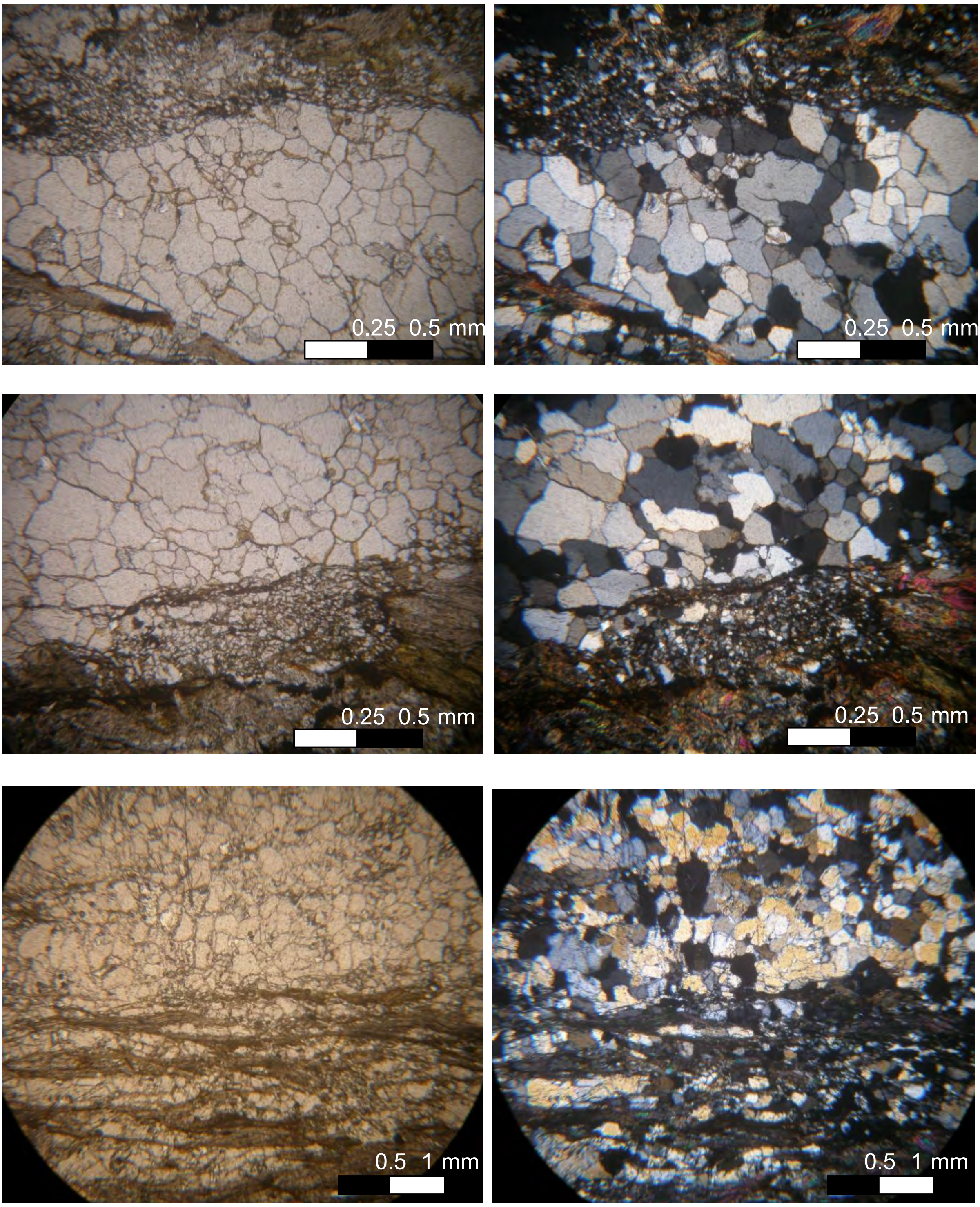


Figure 4.1 The index mineral of greenschist facies (Turner, 1981, Yardley, 1989), Blatt and Tracy, 1996) is quartz that has coarse grains and fine grains. The pictures of thin section show the texture of old clasts and matrix of sedimentary rock; conglomerate or pebbly sandstone.

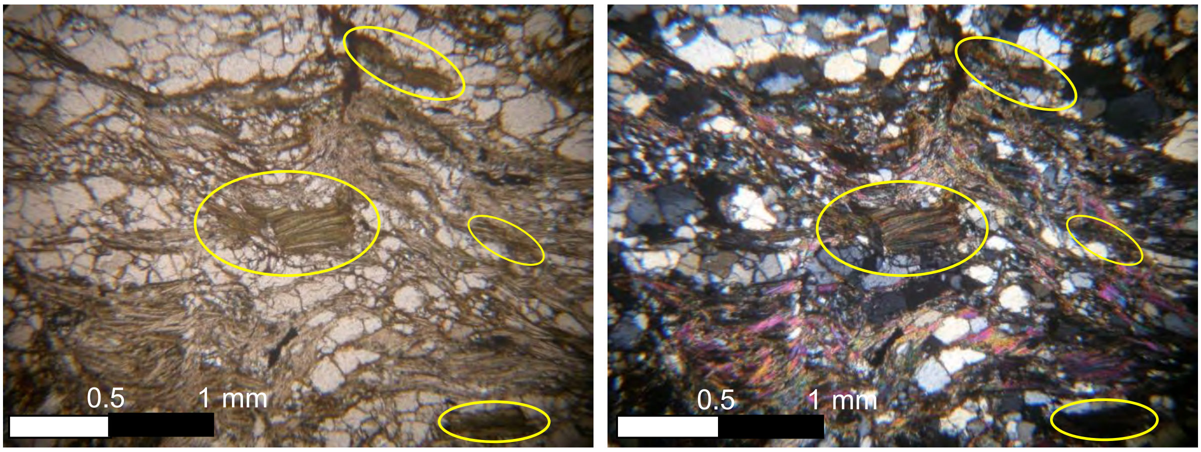


Figure 4.2 The index minerals are muscovite and chlorite (Yellow circles). They are mineral assemblages that can recognize the protolith that is pelitic rock and greenschist facies (Turner, 1981, Yardley, 1989), Blatt and Tracy, 1996).

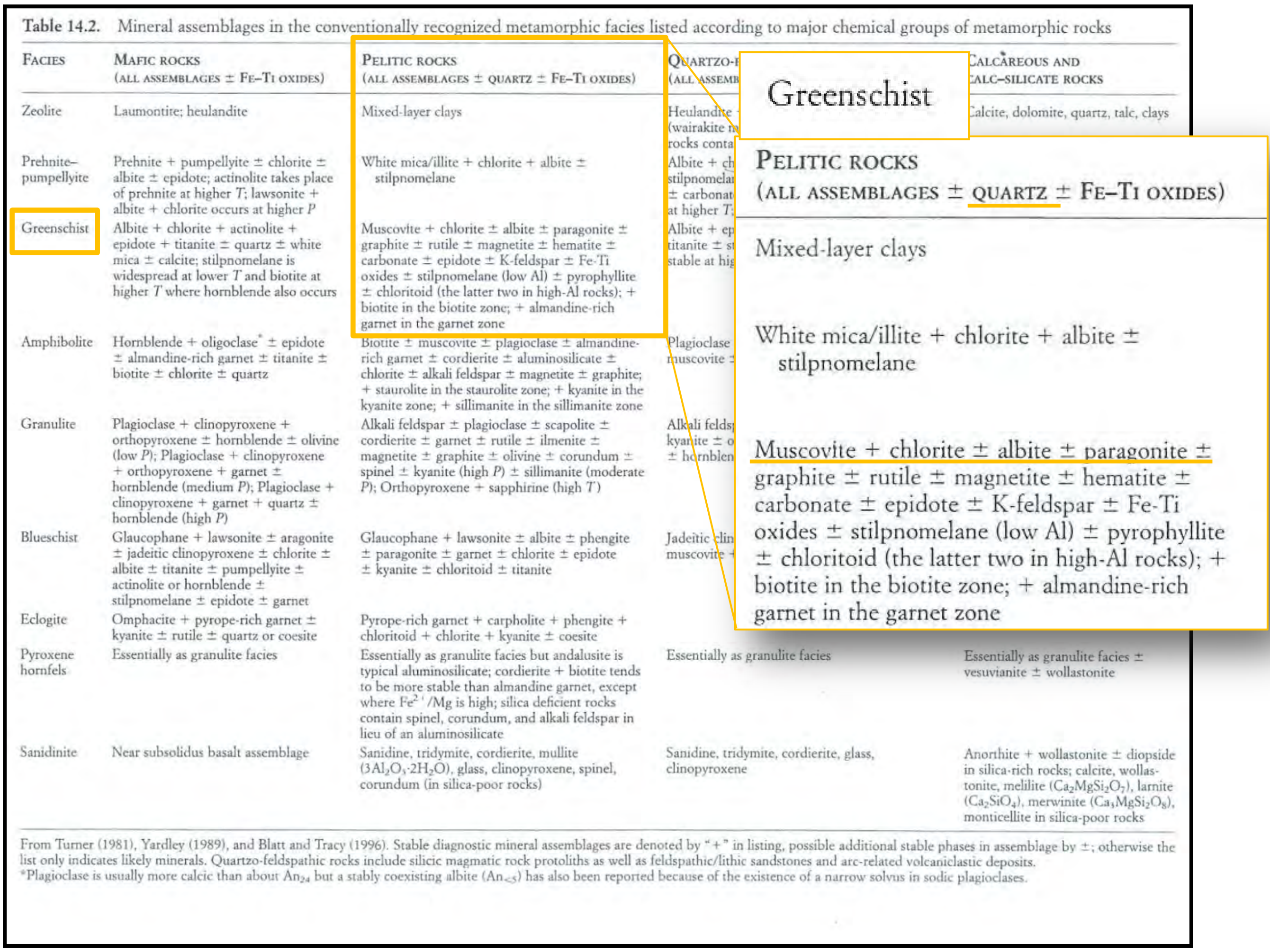


Table 14.2. Mineral assemblages in the conventionally recognized metamorphic facies listed according to major chemical groups of metamorphic rocks

FACIES	MAFIC ROCKS (ALL ASSEMBLAGES ± FE–TI OXIDES)	PELITIC ROCKS (ALL ASSEMBLAGES ± QUARTZ ± FE–TI OXIDES)	QUARTZO-F… (ALL ASSEMB…	…ALCAREOUS AND …ALC–SILICATE ROCKS
Zeolite	Laumontite; heulandite	Mixed-layer clays	Heulandite … (wairakite … rocks conta…	…alcite, dolomite, quartz, talc, clays
Prehnite–pumpellyite	Prehnite + pumpellyite ± chlorite ± albite ± epidote; actinolite takes place of prehnite at higher *T*; lawsonite + albite + chlorite occurs at higher *P*	White mica/illite + chlorite + albite ± stilpnomelane	Albite + ch… stilpnomela… ± carbonat… at higher T…	
Greenschist	Albite + chlorite + actinolite + epidote + titanite ± quartz ± white mica ± calcite; stilpnomelane is widespread at lower *T* and biotite at higher *T* where hornblende also occurs	Muscovite + chlorite ± albite ± paragonite ± graphite ± rutile ± magnetite ± hematite ± carbonate ± epidote ± K-feldspar ± Fe-Ti oxides ± stilpnomelane (low Al) ± pyrophyllite ± chloritoid (the latter two in high-Al rocks); + biotite in the biotite zone; + almandine-rich garnet in the garnet zone	Albite + ep… titanite ± st… stable at hig…	
Amphibolite	Hornblende + oligoclase* ± epidote ± almandine-rich garnet ± titanite ± biotite ± chlorite ± quartz	Biotite ± muscovite ± plagioclase ± almandine-rich garnet ± cordierite ± aluminosilicate ± chlorite ± alkali feldspar ± magnetite ± graphite; + staurolite in the staurolite zone; + kyanite in the kyanite zone; + sillimanite in the sillimanite zone	Plagioclase … muscovite …	
Granulite	Plagioclase + clinopyroxene + orthopyroxene ± hornblende ± olivine (low *P*); Plagioclase + clinopyroxene + orthopyroxene + garnet ± hornblende (medium *P*); Plagioclase + clinopyroxene + garnet + quartz ± hornblende (high *P*)	Alkali feldspar ± plagioclase ± scapolite ± cordierite ± garnet ± rutile ± ilmenite ± magnetite ± graphite ± olivine ± corundum ± spinel ± kyanite (high *P*) ± sillimanite (moderate *P*); Orthopyroxene + sapphirine (high *T*)	Alkali felds… kyanite ± o… ± hornblen…	
Blueschist	Glaucophane + lawsonite ± aragonite ± jadeitic clinopyroxene ± chlorite ± albite ± titanite ± pumpellyite ± actinolite or hornblende ± stilpnomelane ± epidote ± garnet	Glaucophane + lawsonite ± albite ± phengite ± paragonite ± garnet ± chlorite ± epidote ± kyanite ± chloritoid ± titanite	Jadeitic clin… muscovite +…	
Eclogite	Omphacite + pyrope-rich garnet ± kyanite ± rutile ± quartz or coesite	Pyrope-rich garnet + carpholite + phengite + chloritoid + chlorite + kyanite ± coesite		
Pyroxene hornfels	Essentially as granulite facies	Essentially as granulite facies but andalusite is typical aluminosilicate; cordierite + biotite tends to be more stable than almandine garnet, except where Fe^{2+}/Mg is high; silica deficient rocks contain spinel, corundum, and alkali feldspar in lieu of an aluminosilicate	Essentially as granulite facies	Essentially as granulite facies ± vesuvianite ± wollastonite
Sanidinite	Near subsolidus basalt assemblage	Sanidine, tridymite, cordierite, mullite ($3Al_2O_3 \cdot 2H_2O$), glass, clinopyroxene, spinel, corundum (in silica-poor rocks)	Sanidine, tridymite, cordierite, glass, clinopyroxene	Anorthite + wollastonite ± diopside in silica-rich rocks; calcite, wollastonite, melilite ($Ca_2MgSi_2O_7$), larnite (Ca_2SiO_4), merwinite ($Ca_3MgSi_2O_8$), monticellite in silica-poor rocks

From Turner (1981), Yardley (1989), and Blatt and Tracy (1996). Stable diagnostic mineral assemblages are denoted by "+" in listing, possible additional stable phases in assemblage by ±; otherwise the list only indicates likely minerals. Quartzo-feldspathic rocks include silicic magmatic rock protoliths as well as feldspathic/lithic sandstones and arc-related volcaniclastic deposits.
*Plagioclase is usually more calcic than about An_{24} but a stably coexisting albite ($An_{<5}$) has also been reported because of the existence of a narrow solvus in sodic plagioclases.

Figure 4.3 From the table of the mineral assemblages in the conventationally recongnized metamorphic facies listed according to major chemical group of metamorphic rocks (Turner, 1981, Yardley, 1989, Blatt and Tracy, 1996).

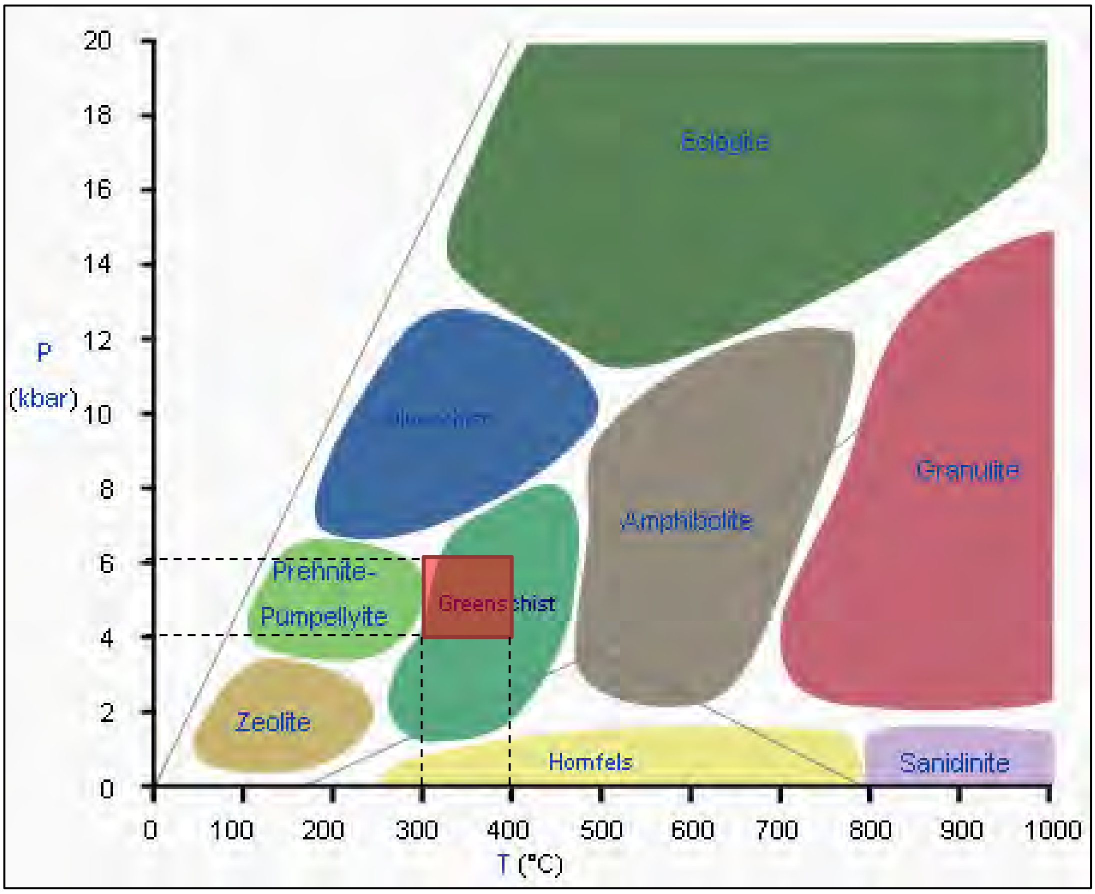


Figure 4.4 Diagram showing metamorphic facies in pressure-temperature space. The domain of the graph corresponds to circumstances within the Earth's crust and upper mantle. From the result, greenschist facies can be estimated for the metamorphic condition of the rocks in the study area (Red box).

4.2 Structural style

From the field investigation, the ductile deformation dominates all rock types in study area based on evidences in mesoscopic structures. The major foliation can be observed and measured in the field, which have major strikes in N-S. Dispersion of poles trend of stereographic net can show a pattern of folding. S-folded, M-folded, W-folded, conjugate joint set and minor folds in the field supported ductile deformation that is the result of folding. Elongated quartz porphyloblasts are mainly shear sense of evidences for both dextral and sinistral ductile shear in the field. Both evidence of folding and shear senses which found in quartz muscovite schist in the west of the northern Koh Samet, are more complex than other rocks. Therefore, we can interpret that quartz muscovite schist in the west of the study area is lower than feldspar quartz schist and quartz schist in the eastern area. Direction of joint developed with folds model is clear in stereographic projection (Figure 4.6). Main direction of joint is W-E because of the extension in N-S. Besides, they orientate in NE-SW and NW-SE directions (Figure 4.6).

In the thin sections, there are kinematic indicators and deformation mechanisms. S-C and S-C' fabrics, mica fish, and quartz porphyloblasts indicate shear sense both dextral and sinistral which conform to sense of shear of mesoscopic structure in the field investigation. The bulging (BLG), basal gilde, the local grain boundary migration (GBM), undolose extinction and the local subgrain in quartz indicate dynamic recrystallisation. Even though we can found grain boundary migration (GBM) recrystallization that shows high temperature deformation, we just noticed in the local in quartz muscovite schist only. Feldspar deforms mainly by brittle fracturing. Some of them show twins with steps, tapering deformation twins and undulose extinction. Those evidences of both kinematic indicators and deformation mechanism were found especially in quartz muscovite schist at mostly in west of the northern Koh Samet. Therefore, quartz muscovite schist may be deformed more than others and can interpret they are lower than others also. In conclusion, the mesoscopic structures, structural analysis and microstructures analysis were interpreted as folding with both two directions of shear senses.

Based on fold mechanism, the flexural shear fold is the limbs of buckle fold are modified by oppositely directed simple shear acting parallel to the layers. The hinge area is unstrained. The sense of shear on the rims of fold changes across the fold axial surface and the magnitude of the shear decreases toward the hinge (Figure 4.5). In this process, a fold produced by buckling, for example, is modified by simple shear acting parallel to the limbs of the fold. This produced a strain distribution in which the long axes of the strain ellipses divergent from the center or core the fold (Park, 1989). Consequently, the folding with both two directions of shear sense fits to the geometry of flexural shear fold in N-S trending with dipping to N direction.

4.3 Structural evolution

Eventually, the simple structural model of the northern Koh Samet has two mains stage that reveals one metamorphism event and one deformation episode. Frist, all of sedimentary rocks metamorphosed to be schist with N-S strike of foliation. And then, schist was deformed with a N-S flexural shear fold (Figure 4.6).

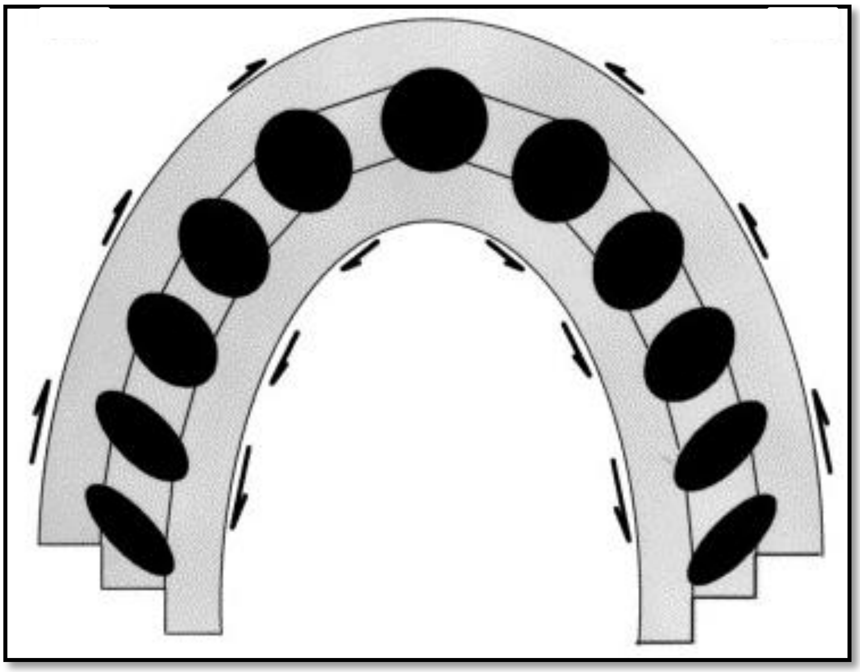


Figure 4.5 The geometry of fexural shear fold and the patterns of local strain ellipses produced during folding and a combination of flexural shear in the limbs (Hippertt and Tohver, 2002).

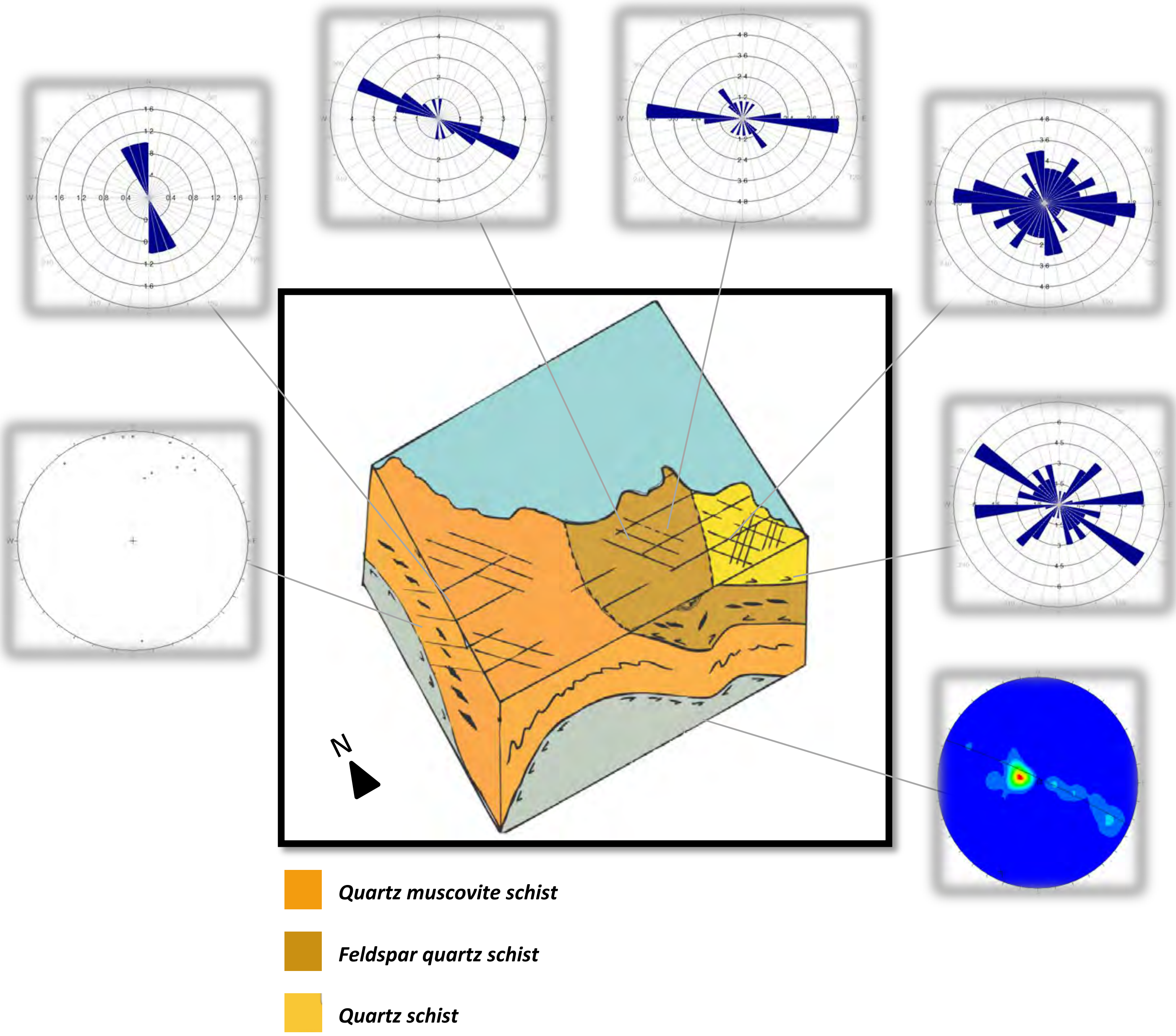


Figure 4.6 The structural style of the northern Koh Samet is flexural shear fold in N-S trending with gentle dipping to N direction (stereographic net plotting fold axis on theleft side and foliations on the right side with blue background). Senses of shear produced during folding in the limbs and minor folds developed in the major fold. Direction of joint developed with folds model showing in stereographic projection. Major joint is W-E inferred to the N-S extension. Moreover, the joints have NE-SW and NW-SE direction.

4.4 Tectonics evolution

Thailand consists of Shan-Thai and Indochina Microcontinents or Tereanes welded together at the subsequently deformed Nan Suture with a west dipping and moderate high angle. The basement complex forming the crust exposed on the both terranes are metamorphic complex of amphibolite, or higher metamorphic rocks (Bunopas and Vella, 1983).

Shan Thai and Indochina were cratonic fragments of Gondwana on NW Australia in the Southern Hemisphere during Precambrian to lower Paleozoic. During Middle Paleozoic to Lower Triassic, Shan Thai and Indochina Terrane were rifed away but still at a proximity from the parent craton during Silurian to possibly an early Lower Carboniferous, starting to build their own sedimentary basin for the first time on both terranes. They drifted father but still in the low southern latitude in the Paleotethys during the late Lower Carboniferous to early Upper Permian time,then drifting of Shan Thai from the low Southern latitude across to the lower Northern Hemisphere was so fast and with a great distance and collided with the Indochina which may have had moved up to that position earlier during the Permian time. The subduction zone of Shan Thai and Indochina Terranes are during the Late Permian to Early Triassic. The continent-continent collisions resulting from the closure of Peleotethys was complete lately in the Triassic. The closure caused folding of continental margin deposites such as the western fold belt (Sukhothai Fold Belt), the eastern fold belt (Loei Fold Belt) etc (Figure 4.7) and widerspred granite injection known as the Indosinian Orogeny or Cimmerian Orogeny (Bunopas and Vella, 1983).

Based on the geometry and attitude of the both Sukhothai Fold Belt and Loei Fold Belt that are main fold belt in Thailand, main fold trends can be distinguished N-S along the Nan-Uttradit and Loei sutures (Figure 4.8) which are the same trend as the fold in the northern of Koh Samet. They reflected the process associated with the collision between the Shan Thai and Indochina Terranes in Southeast Asia. The Loei Fold Belt is extended to Changwat Chanthaburi and Changwat Rayong covering Koh Samet.

Consequently, the fold in the study area can be interpreted that formed as a result of the collision of the Indochina and Shan-Thai Terranes. The folding occurred probably associated with the Sukhothai Fold Belt and Loei Fold Belt which developed by E-W direction of compression stress from the collision during Late Permian–Early Triassic age.

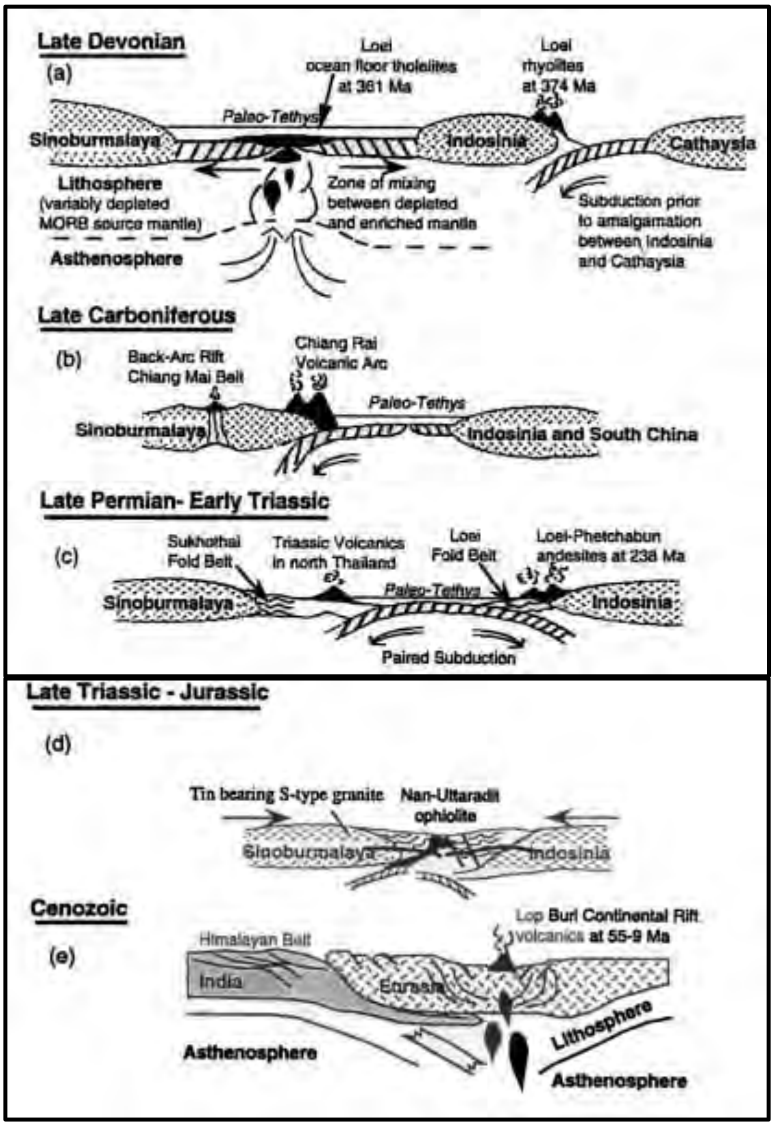


Figure 4.7 Pate tectonic history of Thailand, consisting of Shan-Thai (west) and Indochina (east) (Bunopas and Vella, 1983).

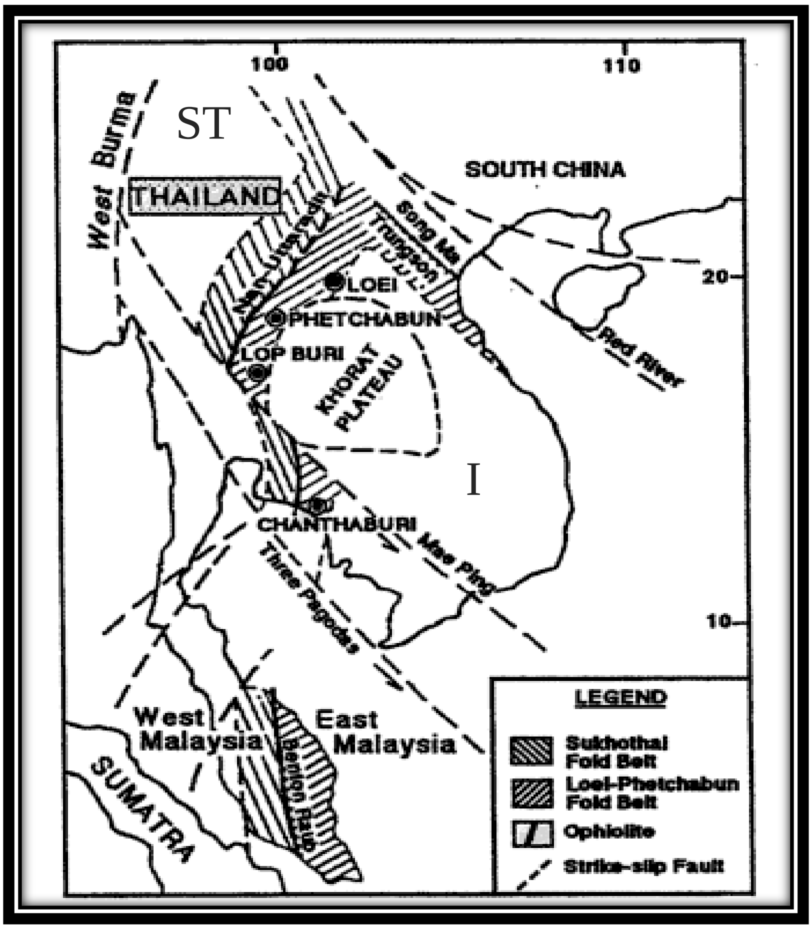


Figure 4.8 Ancient cratonic areas (Indochina, South China, and Shan-Thai). It consists of Sukhothai fold belt, Loei fold belt and S. China fold belt (Bunopas, 1983).

Chapter 5

Conclusion

The results from 2 mains of structural scales, mesoscopic structural scale and microscopic structural scale, were interpreted and discussed in term of structural style and structural evolution of the northern Koh Samet. All of interpretations are summarized into concultions that is as follows.

- The ductile deformation dominates all rock types in the northern Koh Samet.
- The major foliation can be observed and measured in the field, which has major strikes N-S direction. The lineations are two different trending which are composed of N-S trending in the western part of study area and W-E trending in the eastern part of the study area.
- The ductile deformation is folding and the dispersion of poles trend can show a pattern of folding; S-folded, M-folded, W-folded, conjugate joint set and minor folds.
- Fold axis is N-S trending with gentle dipping to N direction.
- Shear zones are both dextral and sinistral movements because elongated quartz porphyloblasts are mainly evidences for both dextral and sinistral ductile shear in the field. In the thin sections present S-C and S-C’ fabrics, mineral orientations, mica fish, and quartz porphyloblasts.
- The bulging (BLG), Basal gilde, the local grain boundary migration (GBM), undolose extinction and the local subgrain show in quartz. Deformation of feldspar is mainly brittle fractures, tapering deformation twins and twins with steps in plagioclase. These can indicate low grade metamorphism at the temperature between 300-400°C.
- The metamorphism facies in the nortern Koh Samet is estimated to the geenschist facies at between 300-400°C based on both mineral assemblages of muscovite plus chlorite and dynamic recrystallization of quartz and feldspar. The textures show sedimentary protrolith of the rocks.
- Fold associated with shear sense in the northern Koh Samet and this fit to the flexural shear fold model.

- The fold in the northern Koh Samet can be interpreted that formed as a result of the collision of the Indochina and Shan-Thai Terranes.
- The folding occurred probably associated with the Sukhothai Fold Belt and Loei Fold Belt with main fold trends in N-S. They developed by E-W direction of compression stress from the collision during Late Permian–Early Triassic age.

References

Areesiri,S. 1983. Genetic consideration of amphibolites and related rock of Bo Kwong Thong, Amphoe Phanat Nikum, Changwat Chon Buri. Proceedings of the Annual Technical Meeting. Department of Geological Science, Chiangmai University: 81-100.

Bunopas,S. 1983. Palezoic succession in Thailand. In P. Nutalaya (ed.),Proceedings of the Workshop on Stratigraphic Correlation of Thailand and Malaysia 1:39-76. Hard Yai, Thailand.

Bunopas,S and Vella,P.1983. Geotectonics and geologic evolution of Thailand. *National conference on "Geologic Resources of Thailand: Potential for Future Development".* Department of Mineral Resources, Bangkok, Thailand, November 17-24 1992, pp 209-229.

Bussai, C., 2005. Geologic Structures of the Low-grade metamorphic terrane, Chon Buri coastal area, eastern Thailand, Unpublished Ph D. Thesis, Department of Geology, Science, Chulalongkorn University, Thailand.

Cambell,K.V. 1975. Basement complex, Department of Geological sciences, Chiang Mai University, Special Publications 1,1:3-12.

Charusiri, P., Clark, A. H. and Farrar, E. 1991c. Miocene (Oligocene) events in Thailand: Evidences from 40Ar/39Ar and K-Ar geochronology. In Proceedings of the Annual Technical Meeting 1989 and IGCP 246, Department of Geological Sciences, Chiang Mai University, Thailand, Feb. 1989, Special Pub. No.9, p.17-26.

Charusiri, P., Daorerk, V., Archibald, D., Hisada, K., and Ampaiwan, T., 2002. Geotectonic Evolution of Thailand: A New Synthesis. *Journal of the Geological Society,Thailand,* 1, 1-20 pp.

Department of Mineral Resources.,1976. *Geological map of Thailand,* sheet Changwat Rayong, ND47-16, scale 1:250,000.

Department of Mineral Resources., 2007. Geology of Thailand. 2000. 2 nd ed. Bangkok:Dokbia.(In Thai)

Department of Mineral Resources., 2008 *Geological map of Thailand,* sheet Changwat Rayong, scale 1:250,000.

Dheeradilok, F., and Lumjuan, A. 1983. On the metamorohic and pre-Cambrian rocks of Thailand, Conference of Geological Mineral Resource, Thailand: 7p. Department of Mineral Resources, Thailand.

Passchier, C.W., Trouw, R.A.J., 2005. Microtectonics, 2nd edn. *Springer-Verlag*, Heidelberg, Berlin.

Pongsapich, W., Charusiri, P., and Vedchakachana, S. 1983. Review of Metamorphic Rocks of Thailand, In P. Nutalaya (ed.), Proceeding Workshop on Stratigraphic Correlation of Thailand and Malaysia: 224-252. Hard Yai, Thailand.

Park, R.G., 1989. Foundations of structural geology, 2nd ed. New York: Blackie & Son Ltd.

Appendix

Appendix A: Field Structural Measurement Data

Laem Lukyon							
Foliation		Lineation		Axial plane		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle	Strike	Dip angle
50	45	100	32	6	26	245	85
44	32	93	20	155	45	102	72
32	30	100	32	197	33	82	89
10	25	90	14	133	35	205	84
40	30	90	30	156	5	250	75
20	20	100	35			172	80
12	22	90	30			15	90
355	32	110	40			121	12
355	25	80	30			141	73
24	49	90	30			262	73
35	47	100	15			234	68
57	41	90	30			340	89
220	77	110	40			244	76
31	69	80	30			290	79
39	23					246	72
45	11					130	85
20	10					281	88
20	20					185	85
340	37					259	65
4	28					320	80
35	30					279	85
320	21					170	75
335	43					180	70
343	20					340	86

Laem Lukyon							
Foliation		Lineation		Axial plane		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle	Strike	Dip angle
20	20					200	60
15	17					3	20
20	30					10	15
						10	10
						100	85
						260	71
						265	85
						300	80
						162	67
						280	83
						210	85
						230	87
						210	80
						270	70
						270	80
						90	50
						270	80
						220	85
						222	75
						346	25
						170	80
						350	30
						15	80
						210	73
						305	20

Laem Nardan					
Foliation		Lineation		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle
225	15	70	16	240	15
352	19	76	25	270	57
3	24	78	23	327	76
30	22	75	20	215	75
0	24	60	10	275	75
30	35	73	25	270	70
30	25	90	23	335	85
4	26	83	15	275	82
4	28	74	18	353	78
23	30	85	15	190	76
30	15	70	10	265	69
10	15	70	15	260	65
4	13	75	15	325	75
		70	25	270	65
		75	17	314	75

Ao Pai					
Foliation		Lineation		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle
185	15	245	11	25	57
195	13	255	23	280	80
175	20	250	18	353	73
185	22	240	10		
175	24				

Laem Yai					
Foliation		Lineation		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle
0	35	75	15	220	73
15	25	80	25	265	80
10	25	80	15	320	85
5	20	70	20	116	74
30	25	80	20	30	70
355	25	80	20	120	83
25	25	81	19	322	86
26	29	80	20	300	75
15	23	87	15	80	85
350	13	100	10	315	80
0	20	105	23	320	71
34	24	97	23	300	80
27	20	75	20	305	85
0	15	100	20	295	82
40	20	105	20	223	70
10	25	120	20	265	70
25	15	75	20	285	81
18	24	100	20	226	75
25	30	105	20	166	80
13	20	120	15	309	81
10	25	120	20	305	80
32	35	75	20	260	65
32	22			260	70
5	20			260	75
				220	73
				283	78
				200	77
				0	70

Laem Ao Klang					
Foliation		Lineation		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle
190	45	240	35	310	61
192	40	220	25	189	58
195	30	230	30	290	65
185	38	250	30	300	70
190	46	285	30	280	60
195	45	297	40	340	85
193	45	250	20	285	75
200	45	290	20	300	80
205	35	245	20	290	80
190	28	285	18	290	60
200	40	240	25	290	70
195	25	240	40		
205	35				
200	30				

Laem Bot					
Foliation		Lineation		Axial plane	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle
200	60	30	8	28	60
200	83	35	5	45	60
215	80	10	30		
195	62	35	5		
200	80				
205	65				
190	55				
210	72				
34	44				

Laem Noina							
Foliation		Lineation		Axial plane		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle	Strike	Dip angle
12	48	20	3	47	33	160	80
359	49	320	5	30	46		
		355	3				
		175	5				
		345	2				
		0	3				

Laem Ao Phrao							
Foliation		Lineation		Axial plane		Joint	
Strike	Dip angle	Trend	Plunge	Strike	Dip angle	Strike	Dip angle
210	82	30	15	262	35	90	82
30	79	15	25	141	20	305	75
30	15	30	15	220	20	250	60
10	10	30	15	315	24	10	60
40	10	40	10	170	5		
210	70			220	15		
				65	73		

Appendix B: Microstructures

Data of structures in thin sections

- Recrystallisation

During deformation of a crystalline material, continuous competition exists between processes that cause distortion of the crystal lattice and processes such as recovery and recrystallisation that reduce the dislocation density. The process may increase the length of grain boundaries and thereby increase the internal free energy of the crystal aggregate involved, but the decrease in internal free energy gained by removal of dislocations is greater.
As a result, new small grains may replace old grains. This reorganisation of material with a change in grain size, shape and orientation within the same mineral is known as recrystallisation. There are three different mechanisms of recrystallisation that can operate during deformation depending on temperature and/or flow stress. With increasing temperature and decreasing flow stress these are: bulging, subgrain rotation, and high temperature grain boundary migration recrystallisation discussed above are known as *dynamic recrystallisation*. (Figs. 1, 2; Urai et al. 1986; Wu and Groshong 1991a; Hirth and Tullis 1992; Dunlap et al. 1997; Stippet al. 2002).

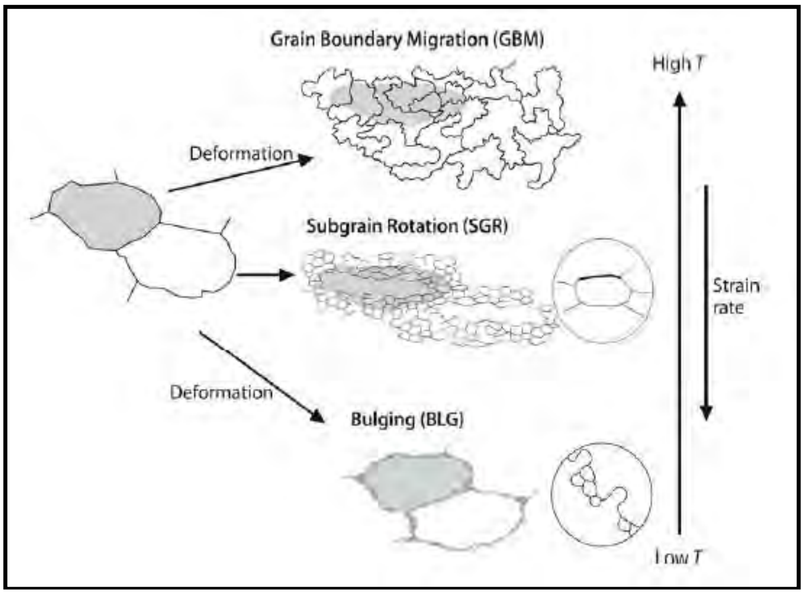


Figure1. The three main types of dynamic recrystallisation in a polycrystal. The substance one of two large grains that recrystallise is indicated by *shading*, before and during recrystallisation

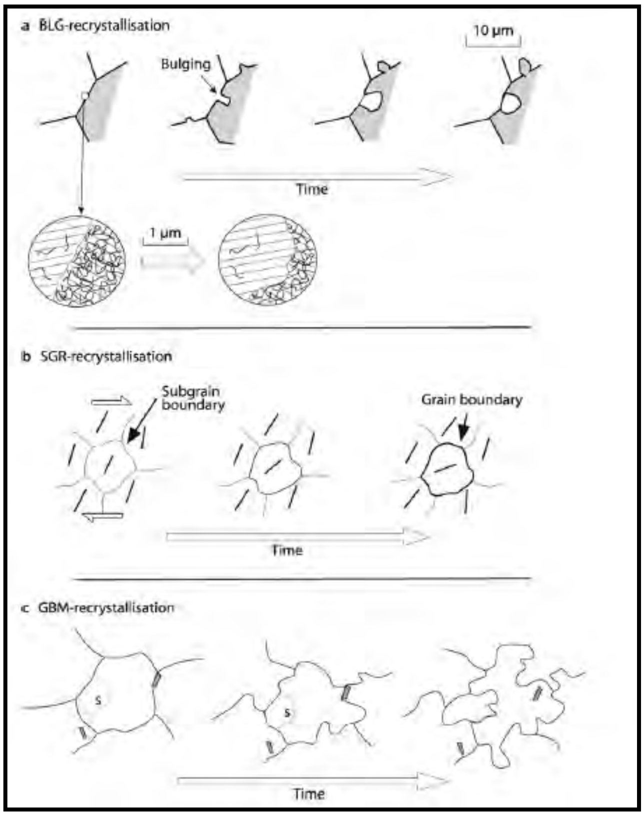


Figure 2. Three mechanisms of dynamic recrystallisation on the grain scale. (Passchier and Trouw, 2005).

From the figure 2.2 showing **a** Bulging (BLG) recrystallisation. If two neighbouring grains have different dislocation density, the grain boundary may start to bulge into the grain with the highest density (*inset*; *grey straight lines* in crystals indicate crystal lattice planes). On the scale of individual grains, the grain with higher dislocation density (*shaded*) is consumed by bulging of the less deformed grain; the bulge may eventually develop into an independent grain. **b** Subgrain rotation (SGR) recrystallisation. Rotation of a subgrain in response to migration of dislocations into subgrain walls during progressive deformation can cause development of high angle grain boundaries and thus of new grains. *Bars* in the subgrains indicate lattice orientation. **c** High-temperature grain boundary migration (GBM) recrystallisation. At high temperature, grain boundaries become highly mobile and may sweep the material in any direction to remove dislocations and subgrain boundaries. Subgrain rotation also occurs, but where subgrain boundaries (*s*) are transformed into grain boundaries, the latter become also highly mobile.

- Sense of Shear

It is necessary to determine the sense of displacement (sinistral or dextral normal or reverse) or sense of shear. Traditionally, this was mainly done using markers in the wall rock such as displaced layering and dykes or deflection of layering or foliation into a shear zone. This means that it is possible to determine shear sense for a shear zone in thin section, even without seeing the zone in the field.

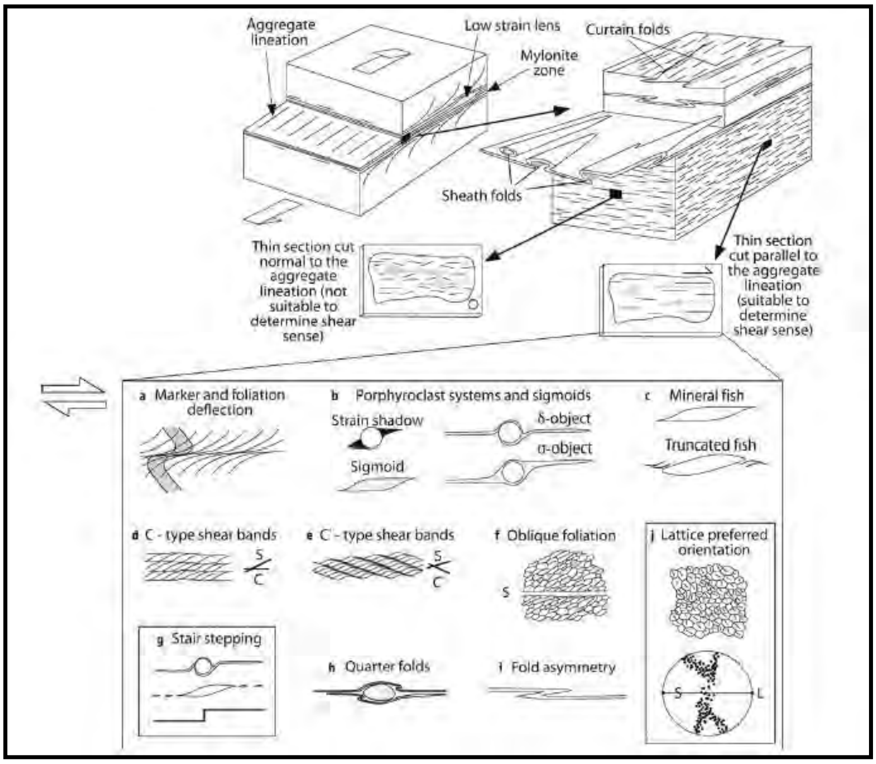


Figure 3 schematic diagrams showing the geometry of a mylonite zone and the nomenclature used. For thin sections parallel to the aggregate lineation, the most common types of shear sense indicators are shown. (Passchier and Trouw, 2005).

- Microscopic Shear Sense Indicators:

<u>*Shear Band Cleavage:*</u> A mica-preferred orientation or compositional layering may be transected at a small angle by sets of subparallel minor shear zones (Figure 2.3d,e). Such minor shear zones are known as *shear bands* and the complete structure is a *shear band cleavage* (Roper 1972; White 1979b; Gapais and White 1982). Shear band cleavage may superficially resemble crenulation cleavage but develops by extension along the older foliation rather than shortening. Two types of shear band cleavage are distinguished: *C-type* and *C'-type* (Figure3 d, e).

-Mantled Porphyroclasts: Mantled porphyroclasts consist of a central single crystal and a fine-grained mantle of the same mineral. Common examples are porphyroclasts of feldspar in a matrix of quartz-feldspar-mica. The fine grained soft mantle can be deformed into *wings* (or trails) that extend on both sides of the porphyroclast parallel to the shape preferred orientation in the mylonite (Passchier and Simpson 1986). Wing shape can be used as a shear sense indicator and contains information on rheology of the matrix and the matrix-clast coherence. Four types of mantled porphyroclasts have been distinguished in the literature based on the shape of the wings (Hanmer 1984b; Passchier and Simpson 1986; Hooper and Hatcher 1988): $\emptyset$ -type, σ-type, δ -type, and complex mantled clasts (Figure. 2.5).

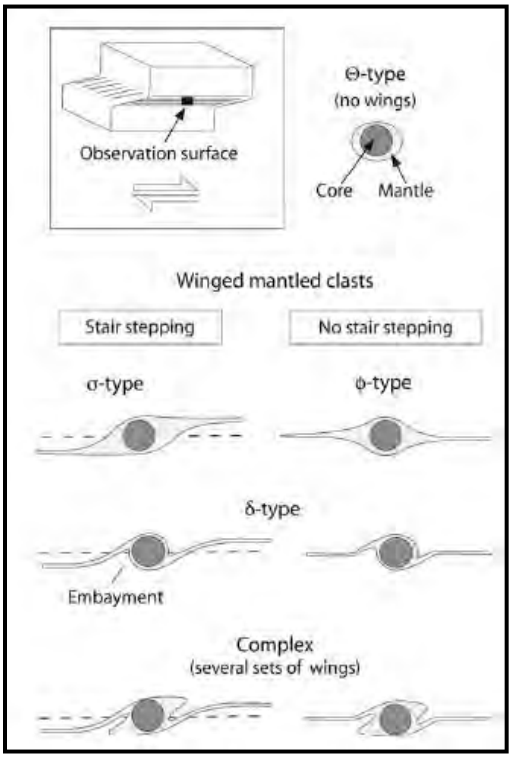


Figure 4. Classification of mantled porphyroclasts. Dextral sense of shear (Passchier and Trouw, 2005).

- Mineral Fish: Mineral fish are elongate lozenge or lens-shaped single crystals. Most common are mineral fish of large single white mica crystals known as *mica fish* in micaceous quartzitic mylonites (Figure. 2.3c). Ten Grotenhuis et al. (2003) proposed a morphological subdivision of mica fish into six groups (Figure. 2.6), based on a study of crystals from an upper greenschist facies mylonite from Brazil. Besides white mica, a number of other minerals can develop as mineral fish with a similar orientation with respect to the mylonitic foliation. Presently known are examples of biotite, tourmaline, K-feldspar, garnet and plagioclase etc.

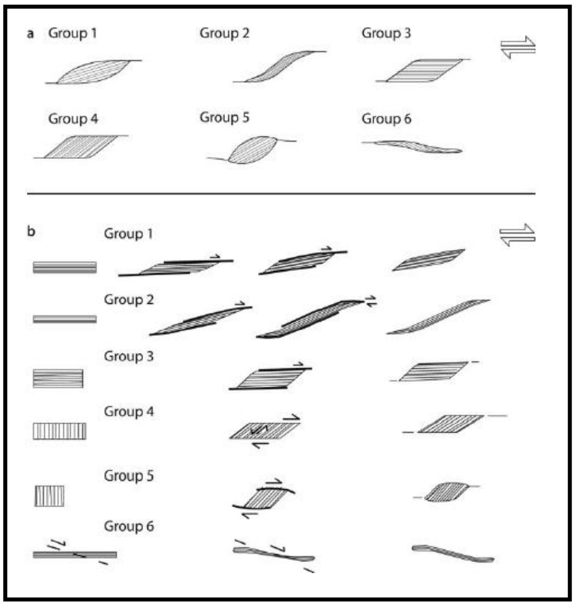


Figure 5. a. The main types of white mica fish recognised in thin section. b. Inferred development of the different types of mica fish. (After ten Grotenhuis et al. 2003).