Sedimentology & Structural Geology of Sapulut and Tanjong Formations, Southeast Sabah

by

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Special thanks and utmost appreciation are dedicated to the author's supervisor, Miss Sara Izzatti Bashah, parents, lecturers, colleagues and friends for the sincere inspiration, motivation and continuous support since the beginning, till the completion of this project.

ABSTRACT

Sabah is a result of complex tectonic mechanism shaped by the collision of three major tectonic plates in which include the Eurasian, Indo-Australian and Philippine Sea plates triggering the formation of rifts, basins, island arcs and mountainous range. The targeted formations of this study are the Sapulut and Tanjong formations. The relationship of these formations and the circular basins are still constrained. Pinnacle of this study is revolving around the structural geology and sedimentology, with added minor study on how the shale diapirs could be a potential factor of the construction of the inaugural Maliau Basin.

Outcomes of the field study suggests that the area is structurally affected by shearing of wrench faults whereas the sedimentology of the formations indicated deep marine and distal deltaic depositional environment. Interpretation of satellite images, field mapping, thin section and rose diagram are conducted in an attempt to better understand the unfolded story of how these formations were geologically formed.

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CHAPTER 1

1.0 INTRODUCTION

1.1 Background of Study

Borneo is a result of Mesozoic accretion of ophiolitic, island arc crust and microcontinental fragments of south China and Gondwana origin, with their sedimentary cover, onto the Paleozoic continental core of the Schwaner Mountains in the southwest of the island (Hamilton 1979; Hutchison 1989, 1996a; Metcalfe 1996).Rigorous tectonic took place in the northern region of Borneo in which include extensional tectonics, compressional tectonics and subduction of crustal plates.Real life analogy to represent the whole cycle is imagining a young boy playing a plasticine, if he collides two blocks of different coloured plasticines, parts of the plasticine will subduct and some other parts will uplift. Geologically, the denser plates subduct whereas the lighter ones uplift.

During Paleogene, there was uplift due to the south-eastward subduction of the proto-South China Sea oceanic lithosphere under the northwest margin of Borneo. At about the same timeframe, Rajang Group in which includes Sapulut, Trusmadi and East Crocker formations were formed. Hutchinson (1996) refers this uplift as the 'Sarawak Orogeny' and suggested it was probably driven by collision along the northern Borneo margin. Orogeny is the forces or events which contribute to the forces that affect the structural changes of the Earth. Newton's third law is in line with orogeny's definition where he stated, "For every action, there is an equal and opposite reaction". In this case, tectonic forces is the forces that caused deformation of the structural features of the Earth.

The most significant tectonic history in between the Late Eocene and Early Miocene was the collision between Dangerous Grounds/Reed Bank/North Palawan block and the Sabah Cagayan Arc which uplifted the northern Borneo. Southward directed movement of the Northwest Sabah continental plate was linked to the opening of South China Sea, resulting in the initial uplift of the Temburong and West Crocker formations. The uplift and erosion of the Rajang Fold-Thrust Belt (RFTB) and other formations fed the depocentres to the Paleogene basins at the west and east of Sabah. The erosion of the uplifted formations are contributing to the formation of this project's targeted formations which are Sapulut and Tanjong.

At about the approximate geologic time in eastern Sabah, Sandakan and Tarakan rift zones began to form, which was accompanied by explosive tectonism and chaotic deposits. As the rifts were widened, it was filled with the synrift deposits of shallow marine Tanjong and Kapilit formations. Contemporaneous compressional tectonism (west and northwest Sabah) and extensional tectonism (eastern Sabah and Southeast Sulu Sea area) have formed a major period of uplift and erosion, which created the Deep Regional Unconformity (DRU) or also known as Unconformity ‘C’. Approaching Early Pliocene, the Inboard Belt (IB) were uplifted and eroded to feed depocentres, East Baram Delta and Outboard Belt (OB) (Hazebroek & Tan, 1993) which resulted in the formation of Shallow Regional Unconformity (SRU).Imagine a car moving towards a destination, when the driver suddenly remembers he left something, the car turns back, that is an analogy to describe the events where there is a reversal in tectonic plates movement.

In the eastern part of Sabah, Miocene synrift deposits were not only uplifted and eroded, but formed into circular and sub-circular shapes, presumably due to both shale diapiric movement and wrench faulting. Compressional event significantly affected most parts of Sabah since Pliocene, probably extending to Pleistocence. Folds and wrench faults (Semporna fault) emerged as a result of northeast-southwest compressional tectonism. The pinnacle of this study is centralized on Sapulut and Tanjong. Hence, sedimentology and structural geology analysis of this formations will be the key aspects of this research.

1.2 Problem Statement

The project’s main problem to be addressed are to better understand the sedimentology and structural geology of Sapulut and Tanjong formations, Southeast Sabah. The findings will assist in predicting the depositional environment of these aforementioned formations.

1.3 Objectives of Project

(1) To interpret the structural geology of Sapulut & Tanjong formations of the Maliau Basin.
(2) To predict the depositional environment of Sapulut and Tanjong formations.

1.4 Relevancy of Project

By understanding the tectonics evolution, structural geology and sedimentology of the area, this project will contribute to new hypotheses on the Sapulut&Tanjong formations and their relationship to the formation of circular basins of Southest Sabah. Consequently, these hypotheses will shed some lights on understanding the deformation behaviour of the producing neighbouring basin, the Tarakan basin. This project gives the author a chance to integrate all knowledge of his undergraduate study and internship experience. Furthermore, it is also related to his final year major which is, basin reservoir studies.

1.5 Feasibility of Project

Among the biggest challenge for this project is the accessibility of the outcrops for the targeted formations. Besides that, the experiments planned for this project is tailored according to the availability of specific equipment in the author’s university, UniversitiTeknologi PETRONAS.For this project mapping, roadcuts, quarry and river outcrops will be focused on this study.

CHAPTER 2: LITERATURE REVIEW

2.0 Literature Review

2.1 Tectonics Evolution of Sabah

Regionally, the tectonics evolution of Sabah is basically affected by the complex tectonic mechanisms caused by the collision of three major plates in which include the Eurasian, the Indo-Australian and the Philippine Sea plate. This plate convergence led to the formation of various subduction zones, island arcs and marginal seas, which have been formed under variety of conditions like back-arc spreading, continental stretching or trapping of oceanic crust (C. Kopp et al., 1999).It is always unpredictable when three things collide at once as dynamic of each tectonic plate might vary.

Considering the timeframe within Late Eocene-Middle Miocene, there were at least three major episodes associated to the Northwest-Southeast compression coinciding with the ongoing subduction of the proto-South China Sea. It was initiated by the Sarawak Orogeny which was probably driven by collision along the northern Borneo margin and the subduction of the proto-South China Sea in Northwest of Borneo. The uplift and erosion of the Rajang Group accretionary complex provided a source of sediment for the Borneo trough to the Northwest and Southwest where materials were deposited in deep water settings such as the West Crocker, Labang and Kulapis formations (Balaguru & Hall, 2009).When a formation is uplifted, it is subjected to mechanical and chemical weathering which will cause it to erode or deform.

During the Early Miocene, tectonic event which is linked to the subduction and collision of the Dangerous Ground Continental Block to the Northwest Borneo is referred to by Hutchinson (1996) as the 'Sabah Orogeny'. This was followed by a change in deposition environment from deep water to a shallow water deltaic setting (Balaguru, 2001; Balaguru et al., 2003; Van Hattam, 2005).The depositional environment altered as the sedimentation rate is presumed to be fast which rapidly turns the deep water to become shallow. This changes the depositional environment which will affect the grain size, where it is depending on the energy level as well. Alteration in grain size have a significant effect on the formation's reservoir potential.

In light of the aforementioned event, limestone outcrops in southern Sabah are fairly correlated with the Early Miocene Gomantong Limestone Formation which contains clasts of Labang Formation (Noad, 1998). This advocates widespread uplift followed by carbonate sedimentation throughout the central and eastern Sabah. During Middle Miocene, the subsidence in the central Sabah Basin is possibly related to coeval development of the Sulu Sea Basin in a back-arc setting (Nichols et al., 1990) or regional thermal subsidence (Ismail et al., 1995). The theory is supported by the facies distribution and trend in the Tanjong, Kalabakan and Kapilit formations which indicated that detritus eroded from uplifted strata of the Rajang and Kinabatangan groups in the west was deposited in a deltaic shallow marine system.

According to Rangin (1991), arc-continent collision in the northern Borneo between Cagayan Arc and Palawan Continental Block resulted in the formation of Middle Miocene Unconformity (MMU, 15.5Ma) which marks the Deep Regional Unconformity in onshore and offshore Sabah. The aforementioned tectonic event somehow stopped the extensional tectonic activity which caused an inversion of the early Middle Miocene sediments and continued post-rift sedimentation. Late Miocene tectonic event marks another major folding and uplift which can be correlated as the Shallow Regional Unconformity (SRU, 8.6Ma) of this region (Levell, 1987). On top of that, formation of the famous Mount Kinabalu contributed significantly to the supply of sediments. The Late Pliocene tectonismtriggered by Northwest-Southeast trending strike-slip faulting and transpressional fault movement resulted in major structural inversion and uplift.Transpressional fault movement is assumed to be contributing to the formation of the Circular basin.

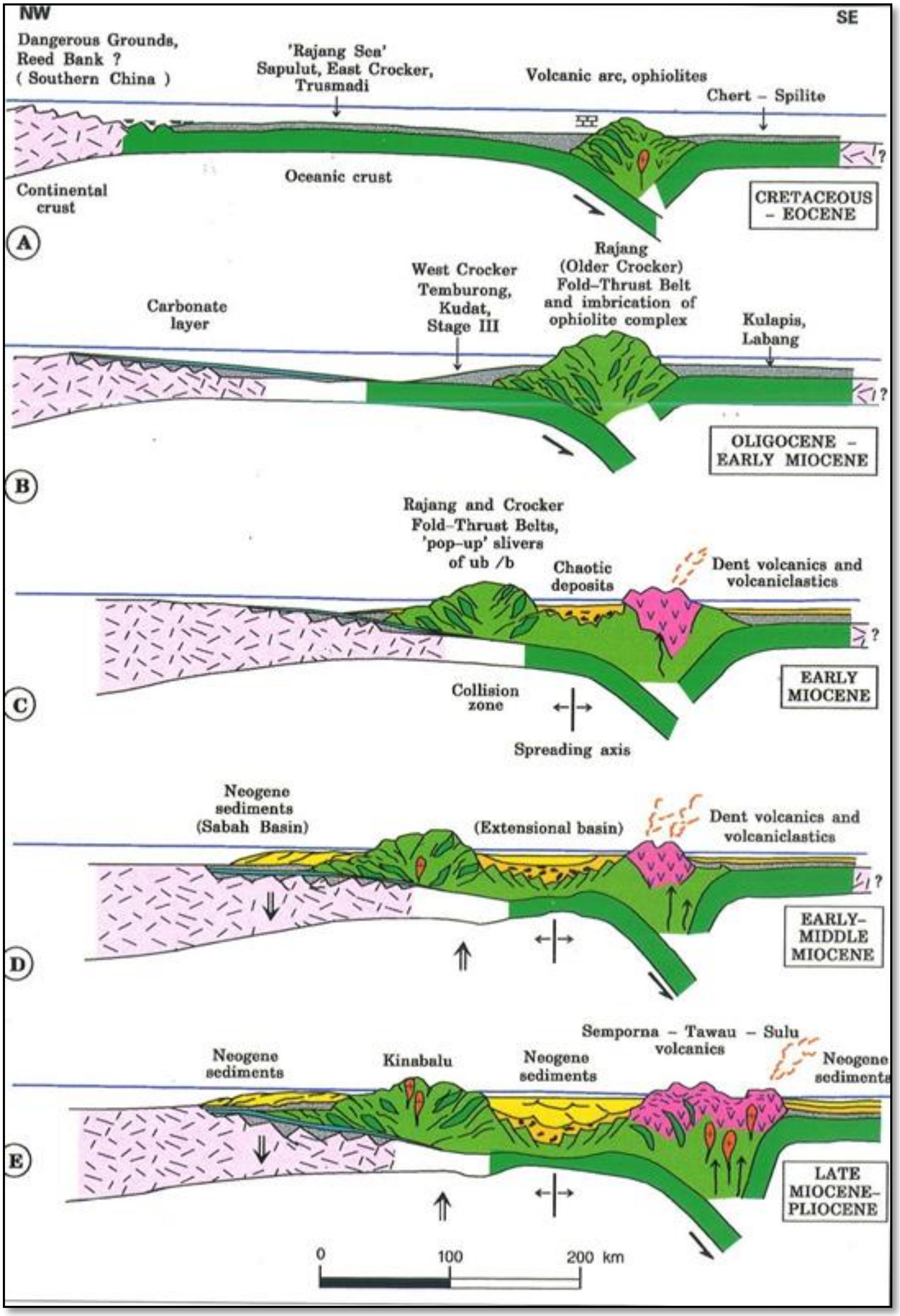

Figure 1 :Illustration of Geological Processes affecting Sabah. Courtesy of PETRONAS.

2.2 Origin of Circular Basins

The origin of circular basin sparks many questions of what really caused the formation of the unique circular shape which is almost crater-like. Some researchers concluded that it originated from broken formations and melanges of Sabah which indicate characteristics of tectonic, sedimentary and diapiric origin, suggested to have formed in Early Miocene (Balaguru, A., Nichols, G. & Hall, R. (2003)). On top of that, uplifting and shallow water sedimentation occured during the Late Early Miocene whereby the sediments deposited unconformably on pre-Neogene (Palaeogene) rocks which are more intensely deformed. These pre-Neogene rocks include this study's formations of interest such as Sapulut and Tanjong.

After being deposited on Paleogene formations, the shallow marine to fluvio-deltaic Neogene sediments which are composed mainly of coal beds had formed unique sub-circular to elliptical shaped structural features. More interestingly, Balaguru found it to be occurring in fault bounded areas. However, the structural style which affects the basin development in Central & East Sabah is still tentatively studied.

Hence, he proposed the theory of transpressional faults which is elaborated more on the upcoming literature review sub-point.With an area as wide as 30km, some of the famous 'Circular Basins' in Sabah include Meliau, Malibau, Tidung, Bangan and Bukit Garam 'sub-basins'.

Therefore, this study aims in cross checking on the theory of transpressional faults with the regional geology affecting Sabah, whether there is any more evidence that could strengthen Balaguru's claim. On a different perspective, Mazlan Madon (1999) suggested circular basins might be due to the effects of shale diapirs. The possibility is also there that the formation of these circular basins are the effect of joint forces of transpressional faults and shale diapirs (discussed on upcoming sub-point: 2.4).

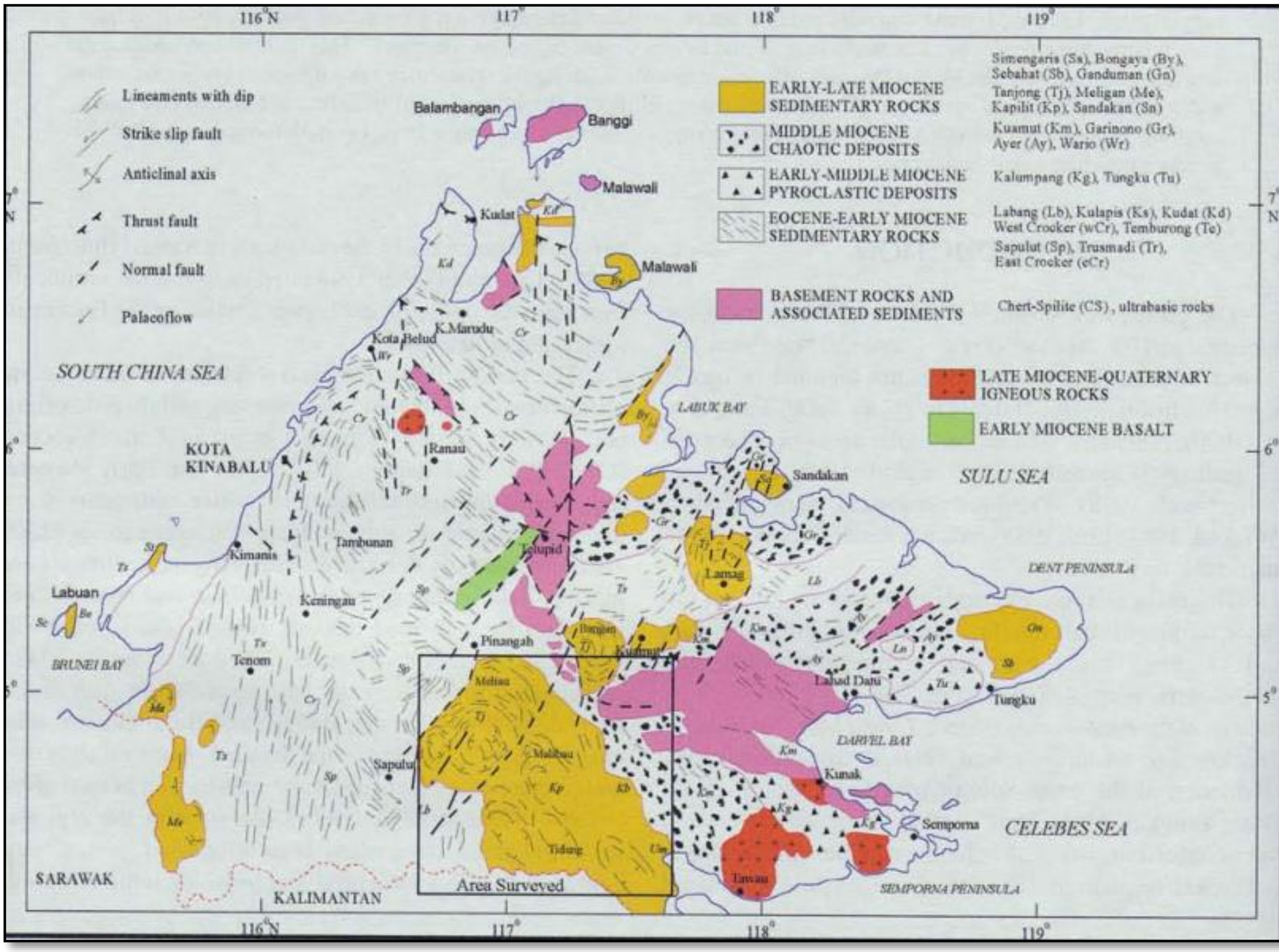

Figure 2 :THE LOCATIONS OF CIRCULAR BASINS AROUND SABAH. COURTESY OF BALAGURU.

2.3 Circular Basin

2.3.1 Tanjong Formation

In the Pensiagan and Upper Kinabatangan Rivers in central Sabah, lies the Tanjong formation which is characterised as a thick succession of sandstone, mudstone and siltstone with some lenses of conglomerate. It is identified to be distributed as occurring in several elliptical or rather, circular to sub-circular basins in the Maliau, Malibau, Bangan and Bukit Garam areas. Although in contrary, present study has shown that the Maliau or Meliau basins are in fact geomorphological features and not basins of sedimentation.

Tanjong formation is divided in two units where Unit I is a lower mudstone and siltstone-dominated sequence. Another unit is known as Unit II which is characterised by a sandstone and mudstone-dominated sequence. Unit I is overlain by Unit II to form a coarsening-upward megastructure. Coarse grained sandstone, conglomerate carbonaceous mudstone and coal seams up to 5m thick are common in Unit II. Tanjong formation's thickness is estimated to be approximately 2800 m, in which include 1200m of Unit I and 1600m of Unit II. Tanjong is dated around Late Early Miocene to Middle Miocene by using nanofossils.

2.3.2 Sapulut Formation

Sapulut formation is a part of the Rajang Group which formed alongTrusmadi and East Crocker Formations. Collenette (1965) stated that the Sapulut formation is a thick succession (possibly 9000m) of slightly metamorphosed deep-marine sandstones and shales with minor conglomerates, which lie unconformably on the basement. There is an unconformity which marks the changes in compositional elements between Sapulut formation and the basement.

Its outcrops are distributed across massive areas of western and northern Sabah. Lithostratigraphic relationships between the three formations of the Rajang Group are obscure and contacts shown on maps of Collenette (1965) and Lim (1985) are generally faulted. Age determinations of Sapulut Formations range from Late Cretaceous to Late Eocene, based on the calcareous benthic and pelagic foraminifera (Collenette, 1965), to Middle Eocene (Rangin et al., 1990).

As it is shown on the stratigraphic chart, most likelySapulut is deposited earlier than Labang where due to its early deposition, it might be the elements which affect the formation of the circular basin from within the subsurface. In this case, it goes back to Mazlan Madon's theory of shale diapirs and wrench faults. Eventhough Labang formation might has more shale composition than that of Sapulut, it is possible that the blend of both formations contributed to the construction of the circular basin.Some of the Labang's shale might contaminate Sapulut formation along the process. However up till today, there is no study to prove this theory.

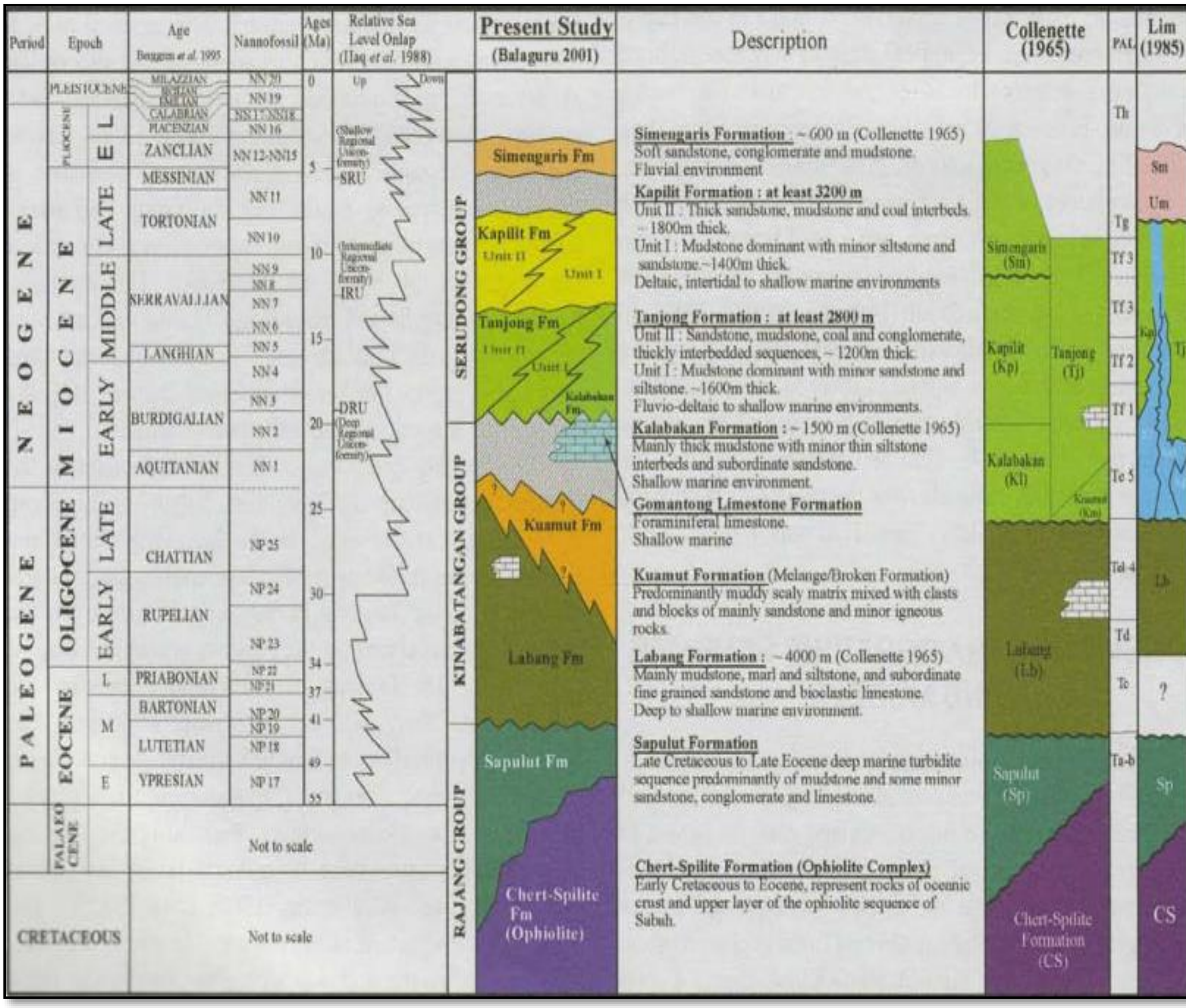

Figure 3 : THE STRATIGRAPHY OF SOUTHERN SABAH STUDY AREA BASED ON NEW DATA FROM FIELD RELATIONSHIPS AND BIOSTRATIGRAPHY INFORMATION.

2.4 Shale Diapirs and Transpressional Faults

As proposed by Mazlan Madon in The Petroleum Geology and Resources of Malaysia, he clearly stated that the formation of circular basin might be due to the occurrence of shale diapirs and wrench fault. Wrench fault or transpressional fault as suggested by Balaguru in his paper could also be the contributing factor.

The theory of shale diapirs as a factor for the creation of circular basin is strongly supported with the evidence of dominant shales composition (argillaceous sandstones) in the Sapulut and Labang formation which is suggested to be deposited and formed the deeper sections of the circular basin. Shale diapirs occur as a result of the lower density shale vertically intruding a denser formation, driven by buoyancy due to the contrast in density. Diapirism might be able to push up some fractions of its overlying strata, whereby this mechanism most likely to cause the formation of uplifted strata enclosing the circular basin. However, there is no further study commenced to prove the shale diapirs theory. Thus, this project is looking forward to find realistic methods suitable with its timeframe to study the effects of shale diapirs to the circular basins' formation.

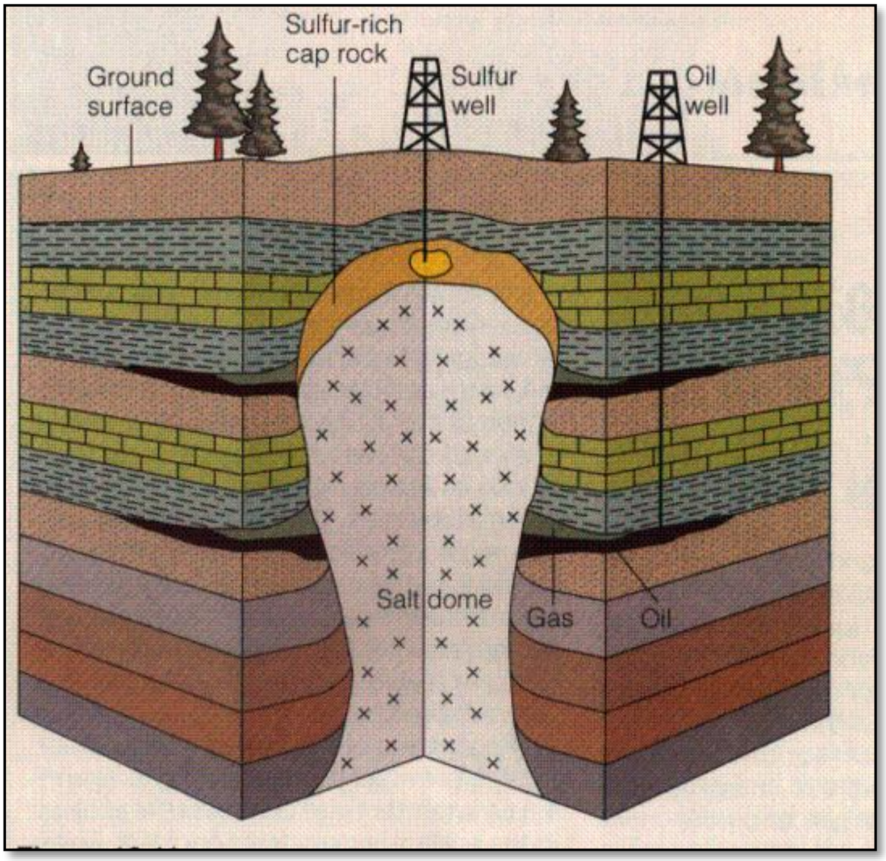

Figure 4 :SCHEMATIC 3D DIARGAM OF THE SALT DIAPIR/DOME.

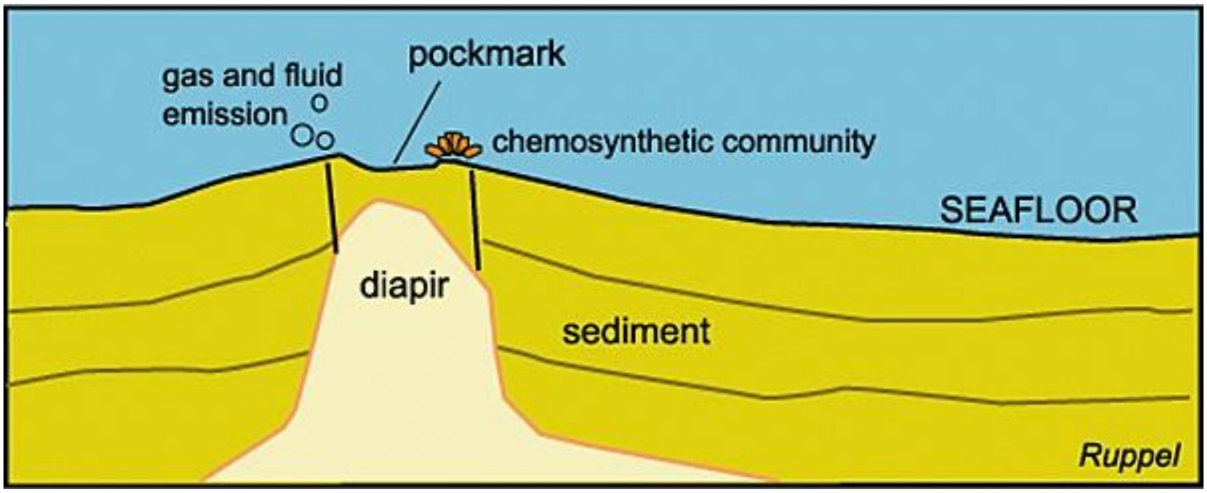

Figure 5 :A CROSS SECTION OF THE SHALE DIAPIRS PUSHING THE OVERLYING STRATA.

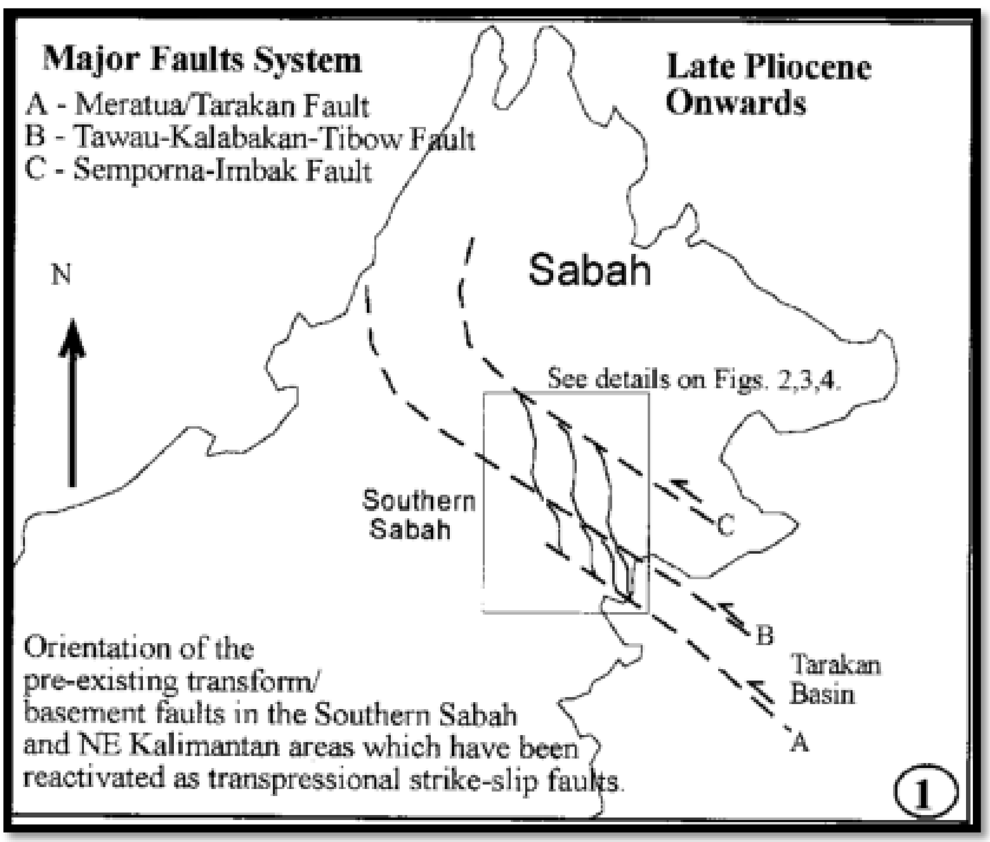

Figure 6 :MAJOR FAULTS SYSTEM WHICH MAY HAVE CONRIBUTED TO THE TRANSPRESSIONAL STRIKE-SLIP FAULTS, COURTESY OF BALAGURU.

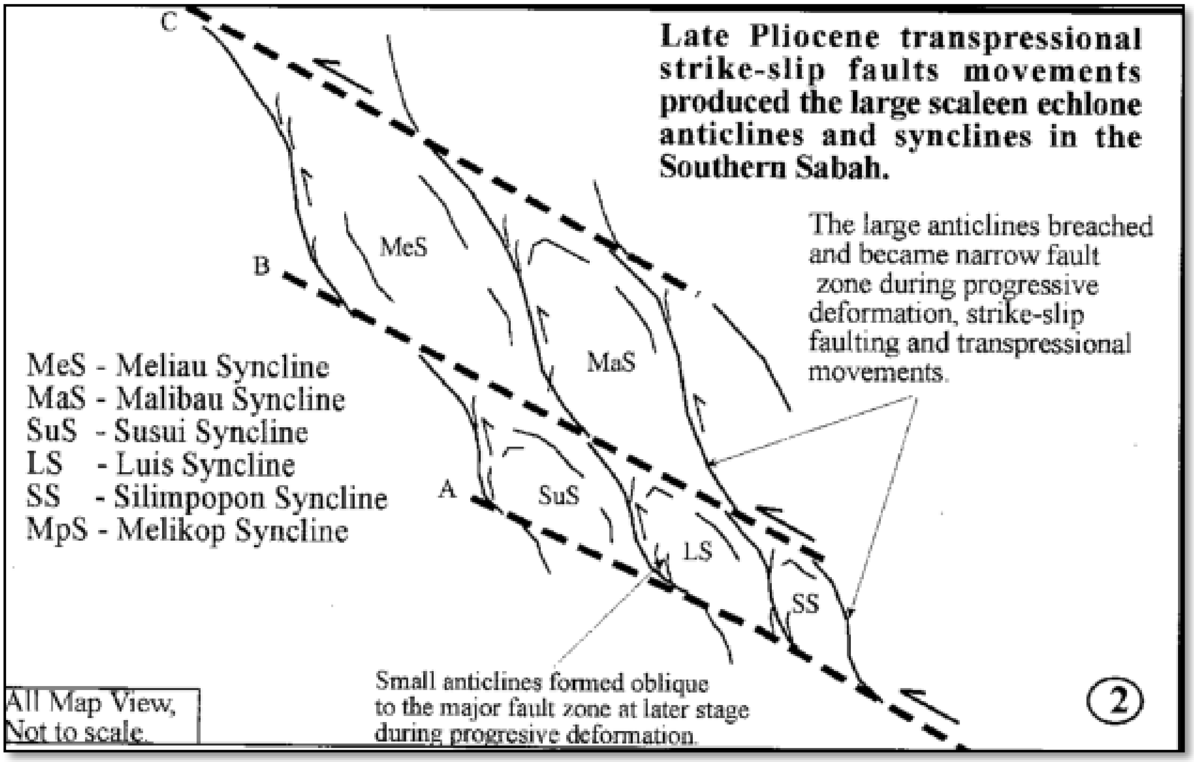

Figure 7 :THE ILLUSTRATION ON HOW THE TRANSPRESSIONAL STRIKE-SLIP FAULTS MOVEMENTS TRIGGERED THE FORMATION OF LARGE SCALE ECHELON ANTICLINES AND SYNCLINE, COURTESY OF BALAGURU.

Figure 8 below displays the formation of "flower structures" as a result of trannspressional faults which contribute the unsual or rather unique sub-circular to circular shapes basins. Perhaps, the "flower structures" act an intermediate form before it turns to be what we could observe today as the Circular Basins.

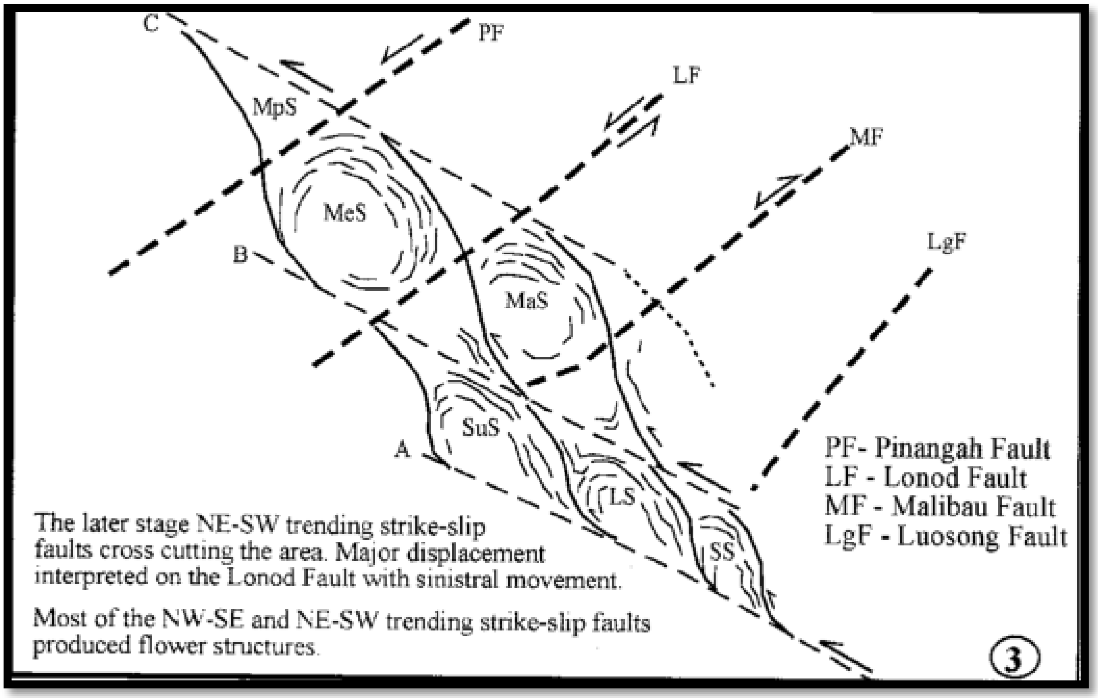

Figure 8 :COURTESY OF BALAGURU, FLOWER STRUCTURES FORMATION AS A RESULT OF NE-SW TRENDING STRIKE-SLIP FAULTS CROSS CUTTING THE AREA.

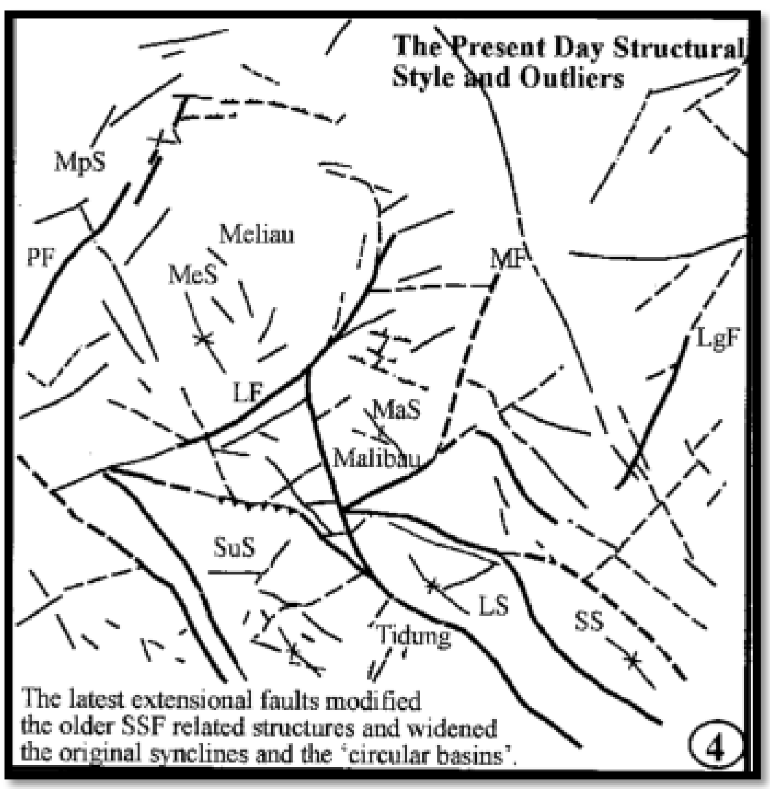

Figure 9 :BALAGURU'S ILLUSTRATION OF THE PRESENT DAY STRUCTURAL STYLES WHICH MAY AFFECT THE FORMATION OF CIRCULAR BASINS.

2.5 Tarakan Basin: Structural & Sedimentology Characteristics

Located in Kalimantan of Indonesia, Tarakan basin is one of the nearest producing basin which share a circular-shape characteristics with the Maliau Basin which is the focus of this study. The Barito, Kutei and Tarakan Basins were part of a large and interconnected area of subsidence and sedimentation in the Early Tertiary. During Miocene, there was an uplift which had segmented the area into separate basins (Weeda, 1958; van de Weerd and Armin, 1992; Awang Harun Satyana, 1999). Barito basin is separated from the Kutei Basin by the Adang Fault whereas the Tarakan basin is disconnected from the Kutei basin by the Mangkalihat Arch. Similarity between Tarakan & Kutei basins is that both form embayments opening to the east towards the deep Makassar Strait. Due to the uplifted western flanks, sedimentary fills of these basins tend to deepen and thicken asymmetrically towards the east. In the Tarakan basin, the origin of structures is closely related to sedimentary loading of successive deltaic deposits (Biantoro et al., 1996; Lentini and Darman, 1996; Awang Harun Satyana, 1999). Awang suggested that the terranes from the Sulu Sea to NNE of Borneo had converged with the Semporna High causing the formation of Tarakan basin's structures.

Tectonics history of Tarakan basin started with extensional tectonics in the Middle Miocene, initiating the basin by block faulting which is similar to neighbouring basins. Middle Miocene was crucial as it marked the subduction of Sulu Sea below the accreted continental crust of North Kalimantan and this resulted in the extrusion of Neogene volcanics in the Semporna Peninsula. It was also responsible in the formation of NW-SE trending, SE plunging folds in the Tarakan Basin. Now, the fold axes are represented by the islands of Sebatik, Buyu and Tarakan. Formation of these folds had been suggested due to wrench faults in the basin itself (Lentini&Darman, 1996; Biantoro et al., 1996; Awang Harun Satyana, 1999). Progradation of deltaic succession during Middle Miocene to Pleistocene resulted in growth-faulting with rollover structures which aligned perpendicular to the sedimentary flow and subsiding towards the east.

Based on Prakash K. Singh's research, it reveals that Tarakan basin coals of East Kalimantan, Indonesia are high moisture, high volatile matter comprises of 'Sub Bituminous' / 'Low-rank A' coal. Generally, Tarakan basin's coals contain telohuminite, textinite, gelohuminite, liptinite, inertinite and pyrite. The macerals found are characterised as predominance of wood derived tissues based on high TPI values. Mineral matter though occurs in small concentration, is mainly dominated by argillaceous one which is seen to occupy cell lumens and fractures. Organic facies obtained from maceral and microlithotype analyses indicated that these coals had evolved in a telmatic environment.

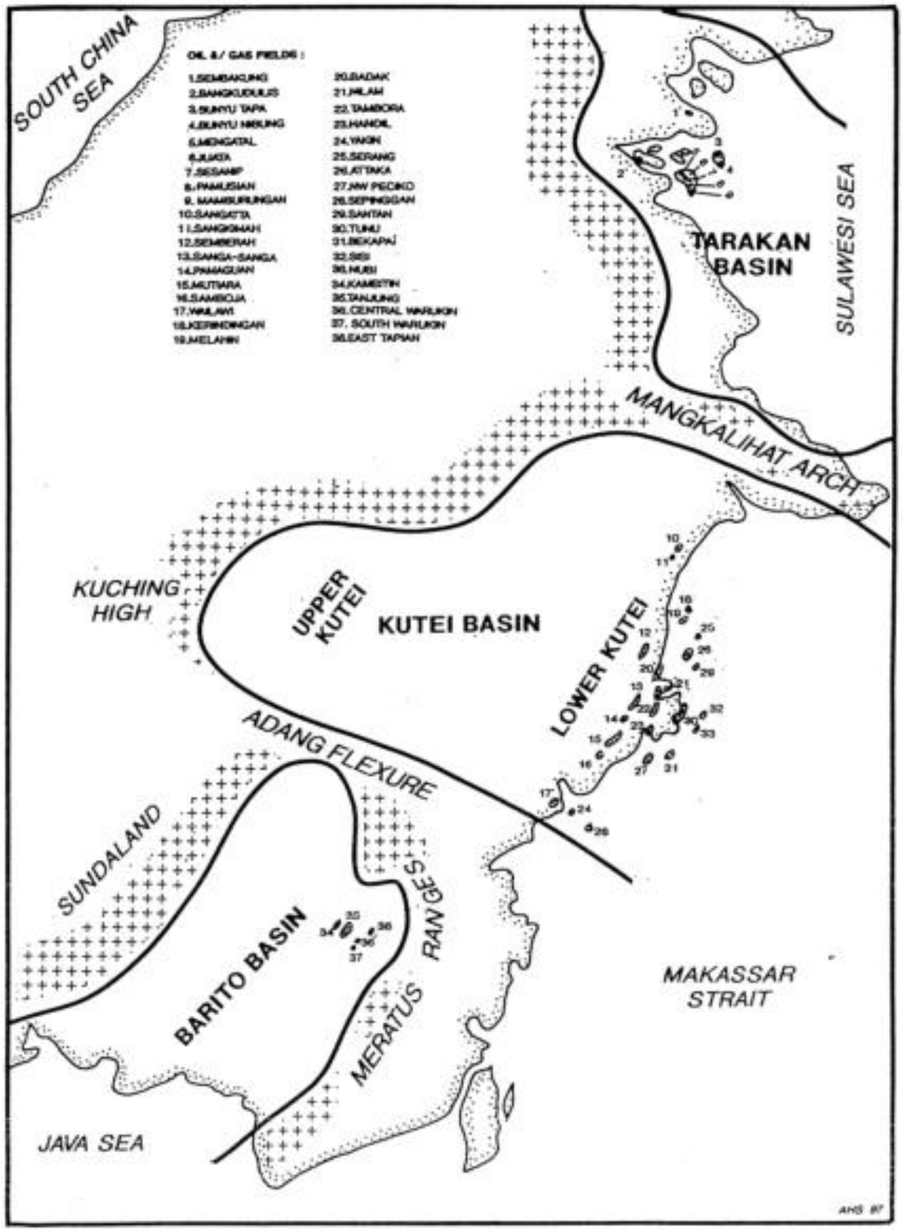

Figure 10 :POSITION OF THE TARAKAN, KUTEI & BARITO BASINS, KALIMANTAN, INDONESIA.

Figure 11 :LINEAMENT ANALYSIS OF THE TARAKAN, KUTEI & BARITO BASINS, KALIMANTAN, INDONESIA.

CHAPTER 3: METHODOLOGY

3.0 Methodology

3.1 Research Journal and Technical Papers

In an attempt to better understand the regional geology of Sabah, extensive study of previous publications had been undertaken. Tectonics evolution, structural geology and sedimentology of northern Borneo (Sabah) are among the aspects focused in this study.

3.2 Digital Elevation Model (DEM)

Digital Elevation Model (DEM) data is utilized in this project in analysing the geomorphology and structure of the topography. On top of that, it is also applied to search for potential outcrops as well as to understand the general geology of the targeted area. In order to update the map with recent interpretations and discoveries, the geologic map is overlaid on top of the updated DEM. DEM not only can assist in making cross section map, study of drainage distributions can be studied as well. By understanding the drainage patterns, the deformation patterns could be understood as well.

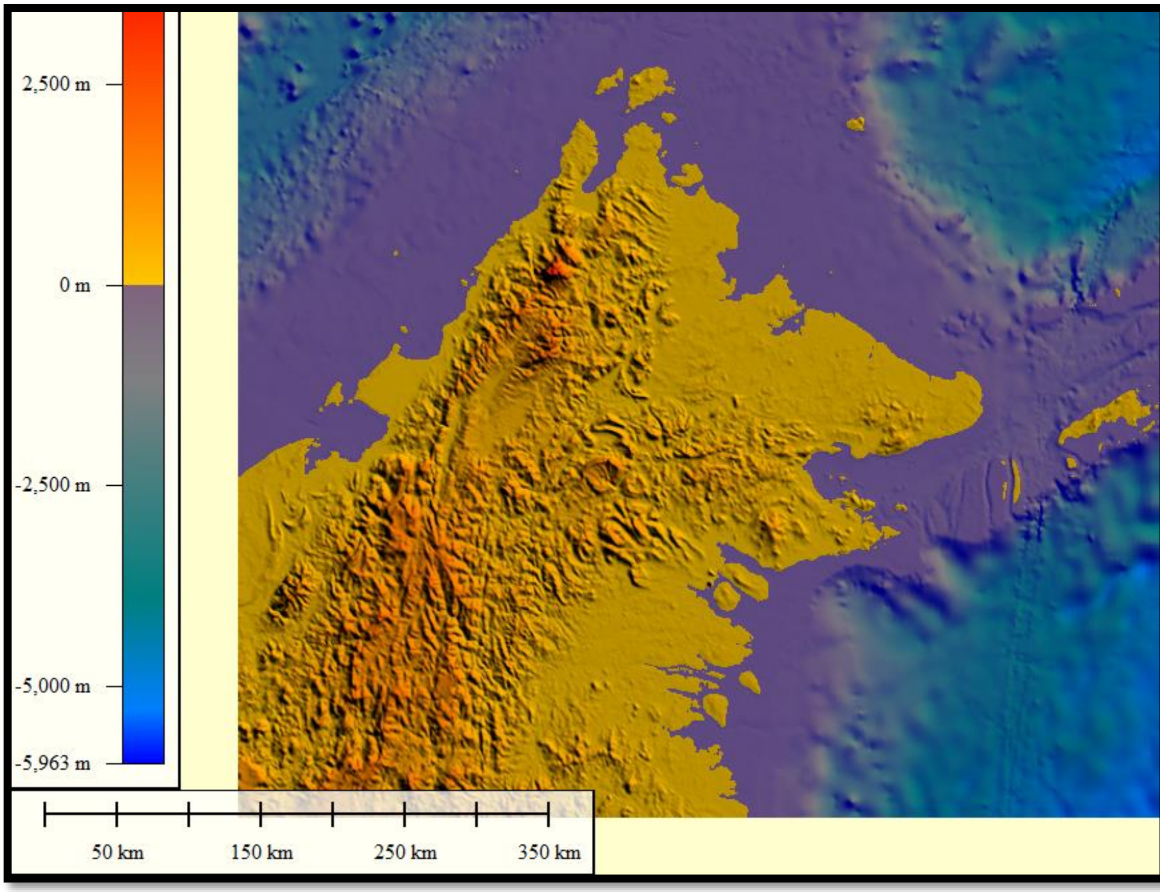

Figure 12 :DEM OF NORTH WEST BORNEO (SABAH).

3.3 Satellite Image Interpretation

Since the study are have limitation in terms of outcrop availability due to vegetation and development, Landsat 7 image or image obtained from Arc GIS (or any other satellite data, search on this, data is free on http://earthexplorer.usgs.gov/) will be used to study the lineaments in this area to give us more information on the deformation behaviour of this area. The advantage of using satellite image is that paleo-drainage system can be analysed by tuning the colour bands.

3.4 Field Work

In balancing between mastering the technological software and understanding the fundamentals of geology, a field work is planned to construct a road transect around the Maliau Basin area. The book entitled "An Introduction to Geological Structures & Maps" is utilized as the main reference in planning the field work during the semester break. During the field work, plenty of samples have been collected to be study on sedimentology of the area and deformation behaviour of each formation. During the fieldwork, strike and dips data acquired will be useful in understanding the orientation of deformation and making sense of the tectonic history of the targeted area. Samples collected have been processed into thin section (discussed in next sub-point), thus the sedimentology and possible depositional environment of the sediments can be interpreted based on the available field data.

3.5 Thin Section

Samples collected from the field trip are processed to produce respective thin sections which are essential for petrography studies. Components, texture, sedimentary structures and lithology of samples have been identified to gain ideas on depositional environment. The main equipment utilized in interpreting and analysing the thin sections is the polarizing microscope. Procedures involved in making the thin sections are the following:

1. The sample was prepared into a size which can fit onto the glass slide.
2. One side of the sample was polished with 75 micron green silicon carbide powder so that the base becomes flat. At the same time, one side of the glass slide was polished with 75 micron green silicon carbide powder to make it become frosty.
3. Resin was applied onto the base of the sample and stick onto the frosty side of the glass slide. The glued sample was dried under UV-ray and wait for the resin to dry.
4. The thin section was polished until it reaches a thickness whereby minerals can be identified under polarized microscope.
5. Thin section was interpreted by using polarized microscope.
6. The image was captured for documentation.

3.6 Rose Diagram

During the field work, an adequate strike and dip data have been collected to construct the rose diagram. This frequency of lineament orientation will be plotted, which is called the rose diagram. Major or high frequency angle will be characterized as the structure of greatest dominance. Furthermore, the direction of forces and mode of fracture affecting the structure development will be determined by interpreting the rose diagram.

3.7 Workflow & Gantt Chart (attached in appendix)

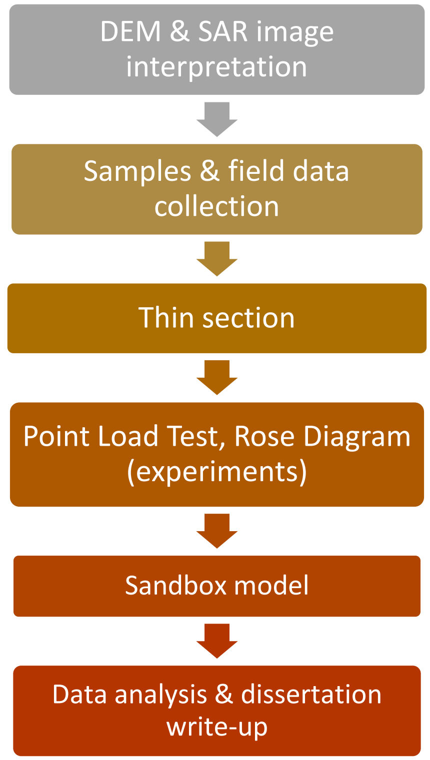

Figure 13 :WORKFLOW OF THE FINAL YEAR PROJECT (FYP) WITH REGARDS TO JOB SCOPES OF THE AUTHOR.

3.8 Project Key Milestones

1. Critical literature review & DEM: January – April 2014
2. Collect samples and field data: 15-23 May 2014
3. Structural data analysis: 26-30 May 2014
4. Thin section preparation: 26 May – 13 June 2014
5. Report writing: 1-31 August 2014

CHAPTER 4: RESULTS and Discussion

4.0 Results and Discussion

4.1 4.1 Synthetic Cross Sectional Map

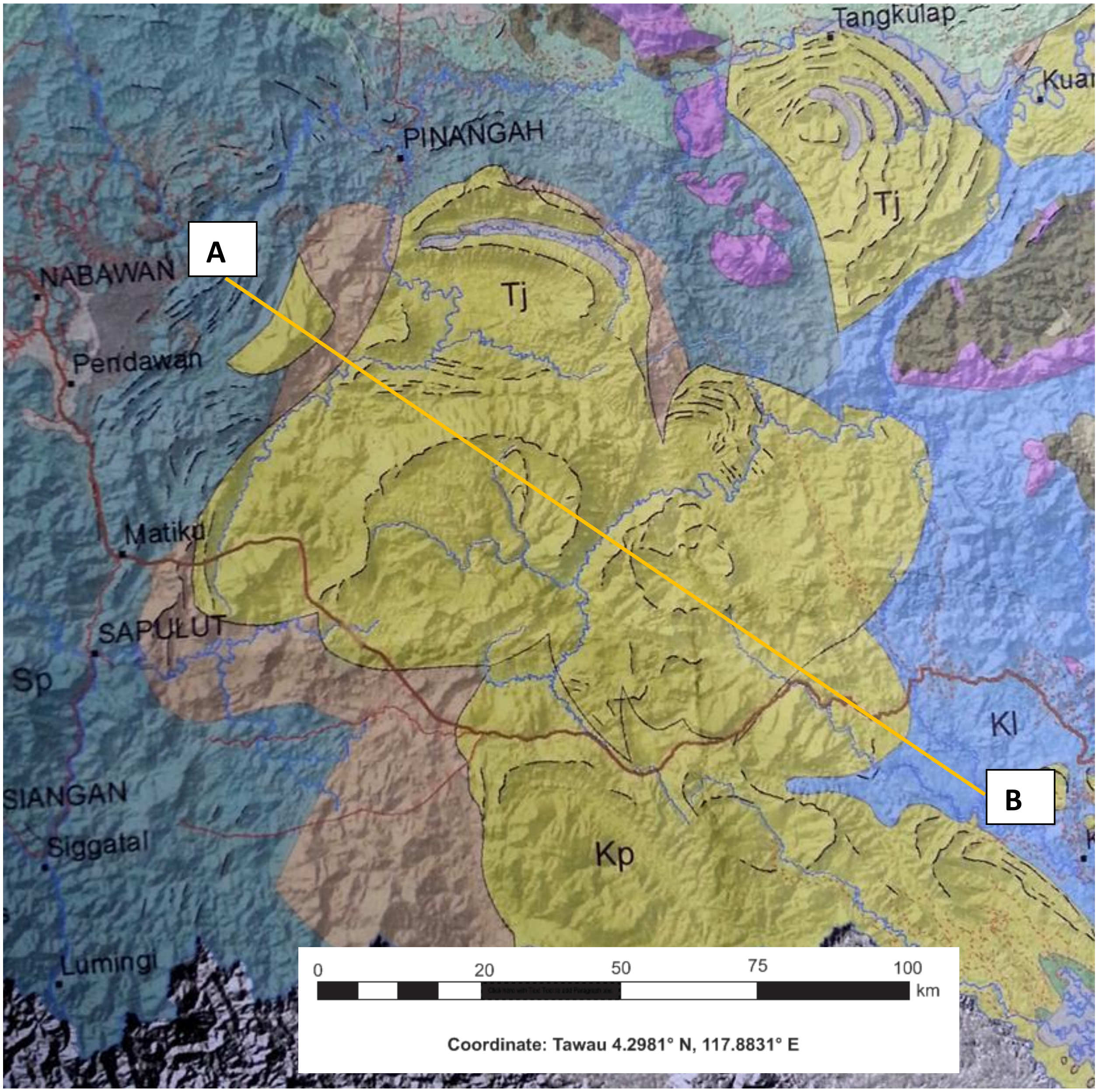

Figure 14 :MORPHOSTRUCTURAL MAP INDICATING THE TARGETED CROSS SECTION LINE.

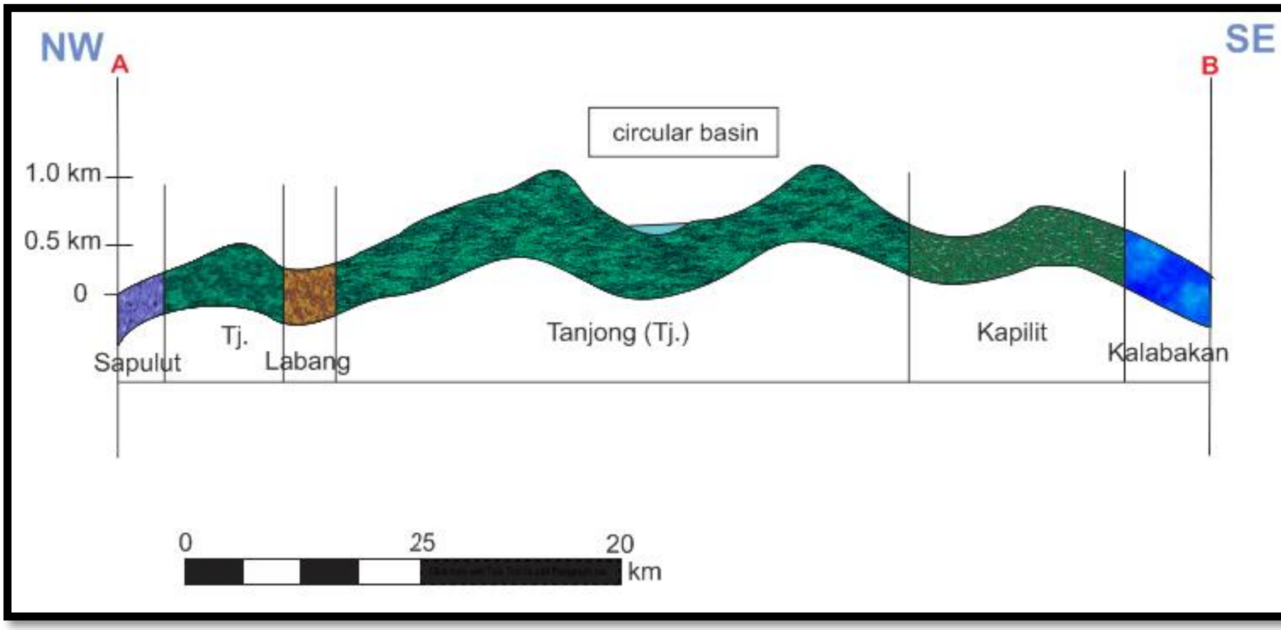

Figure 15 :Synthetic cross section of the Palaeogene and Neogene formations across the Maliau Basin generated based on DEM.

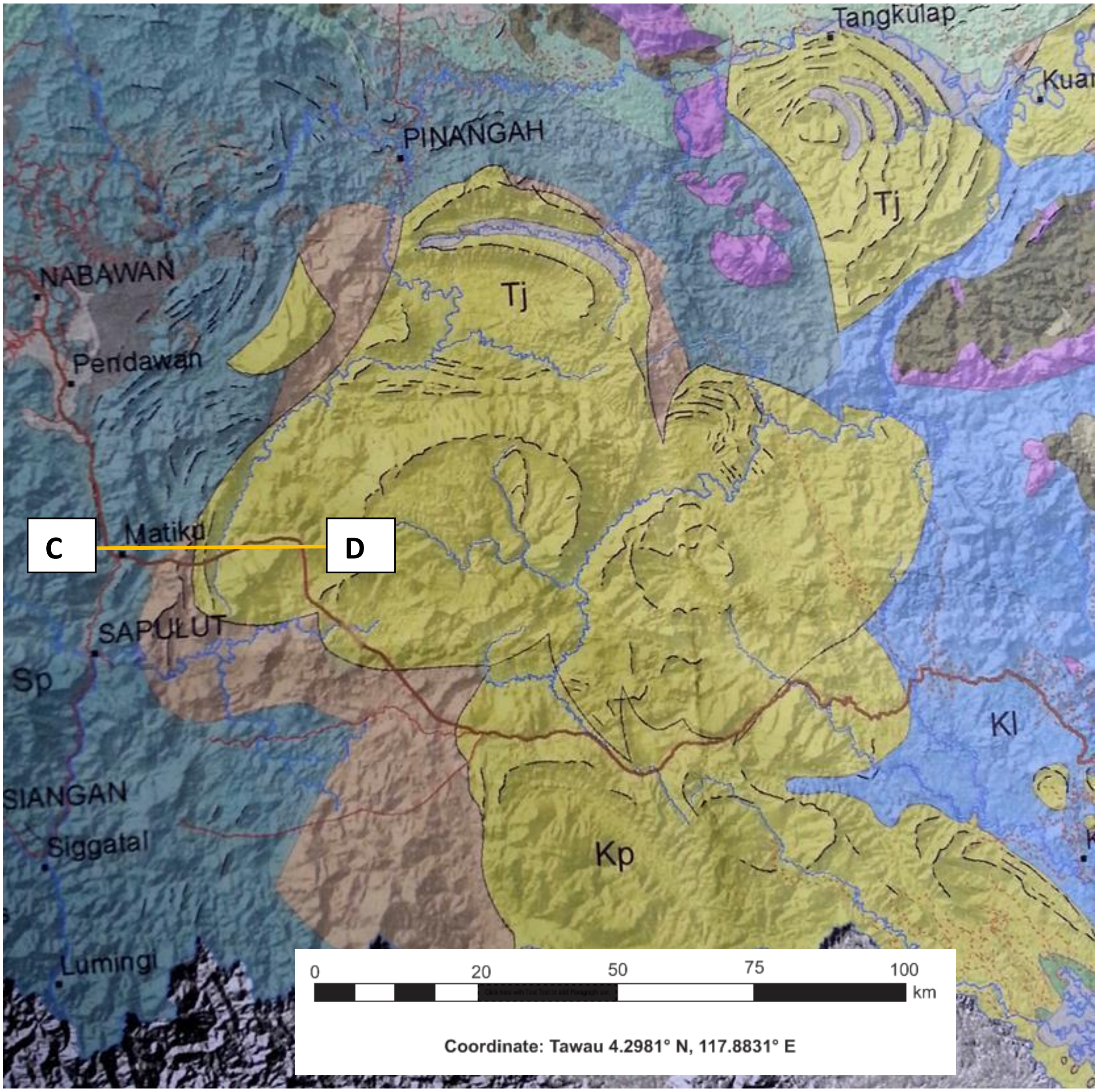

Figure 16 :MORPHOSTRUCTURAL MAP INDICATING THE TARGETED CROSS SECTION ALONG THE ROAD TRAVERSE FOR THE FIELDWORK.

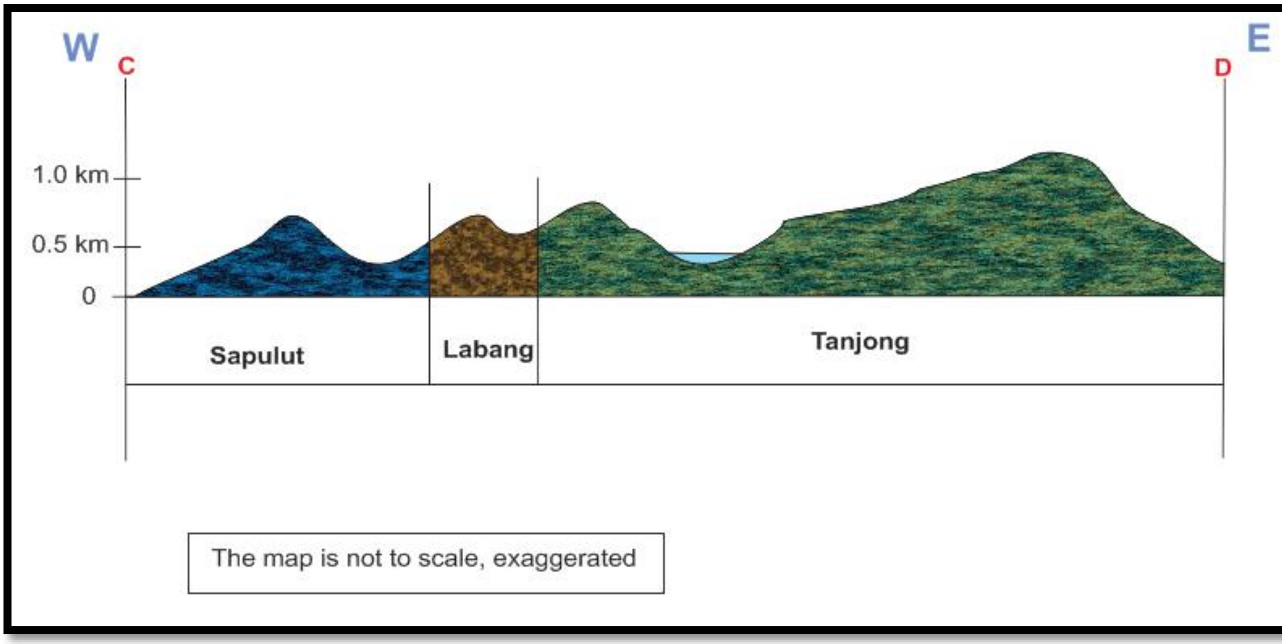

Figure 17 :CROSS SECTIONAL ALONG THE TARGETED ROAD TRAVERSE FOR THE FUTURE FIELDWORK.

Two cross section maps were constructed to study the morphostructural distribution of the area of study as part of the thorough planning for our future fieldwork scheduled in May 2014. The first cross section map represents a broader spectrum of the Maliau basin whereas the second one is more focused on the road traverse which was planned beforehand. Broader spectrum cross section includes my compatriot, Syafiq Anwarie's area of study which covers the Kalabakan and Kapilit formations. This initiative is to provide a general picture of the distribution of Sapulut, Labang, Tanjong, Kalabakan and Kapilit formations in the Central-South East part of Sabah.

4.2 Satellite Image Interpretation Discussion

Located at about 190 km from the town of Tawau and 40km to the north of Kalimantan, satellite image below is the Maliau Basin which has an approximate coverage of 390 km². The image below is a courtesy of the remotely sensed data captured by the Landsat Satellite (source: *borneoforestheritage.org.my*).

Figure 18 :LANDSAT SATELLITE IMAGE OF MALIAU BASIN.

Coordinate: Maliau Basin, between 116° 44' - 117° 3' E and 4° 41' - 4° 56' N.

From this image, the high elevation zones are represented by darker (brown) colour whereas the lower plain is highlighted in brighter (yellowish green) colour, respectively. Furthermore, the drainage system of the environment is clearly shown by the light blue channels, some of which starts flowing from the elevated (uplifted) zones through the lower plain areas.

4.3 Road Traverse Map

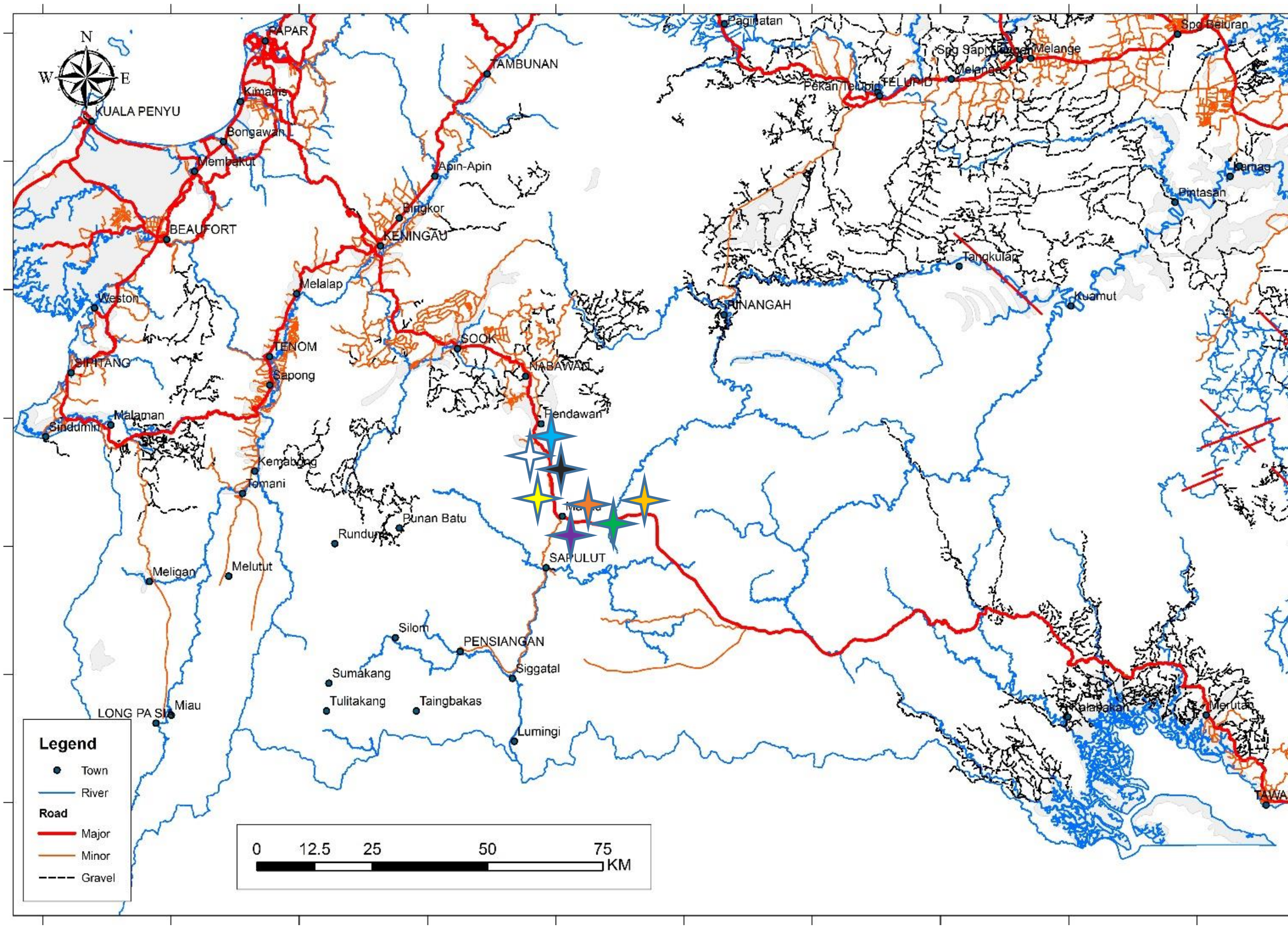

Figure 19 : ROAD TRAVERSE MAP SHOWS THE STATIONS OF OUTCROP ANALYSED AND/OR SAMPLED. ARC GIS SATELLITE IMAGE. (COURTESY OF UMS)

Station Number	Legend
1	
2	
3	
4	
5	
6	
7	
8	

Table for all stations of the study

Station	Formation	GPS Coordinate	Elevation	Lithology
1	Tanjong	$N\ 4°\ 39'\ 17.6''$ $E\ 116°\ 36'\ 45.4''$	$318\ m$	Limestone with boudinage-like structure overlies by shale with calcite veins
2	Sapulut	$N\ 4°\ 42'\ 24.1''$ $E\ 116°\ 29'\ 36.3''$	$315\ m$	Sandstone interbedded with shale, Presence of cross bedding, flute marks & skolithos.
3	Sapulut	$N\ 4°\ 44'\ 32.1''$ $E\ 116°\ 29'\ 14.7''$	$401\ m$	Sandstone interbedded with shale & silt, Flute & ripple marks
4	Sapulut	$N\ 4°\ 46'\ 55''$ $E\ 116°\ 30'\ 26.1''$	$445\ m$	Sandstone with tool & ripple marks structure
5	Sapulut	$N\ 4°\ 48'\ 52.1''$ $E\ 116°\ 30'\ 21.3''$	$439\ m$	Sandstone with ripple marks structure
6	Sapulut	$N\ 4°\ 53'\ 37.3''$ $E\ 116°\ 29'\ 37.7''$	$454\ m$	Sandstone interbedded with shale & silt
7	Sapulut	$N\ 5°\ 4'\ 48.4''$ $E\ 116°\ 27'\ 24.6''$	$488\ m$	Unconsolidated sandstone interbedded with shale
8	Sapulut	$N\ 5°\ 9'\ 32.2''$ $E\ 116°\ 15'\ 31''$	$444\ m$	Unconsolidated sandstone interbedded with shale

4.4 Litho-map

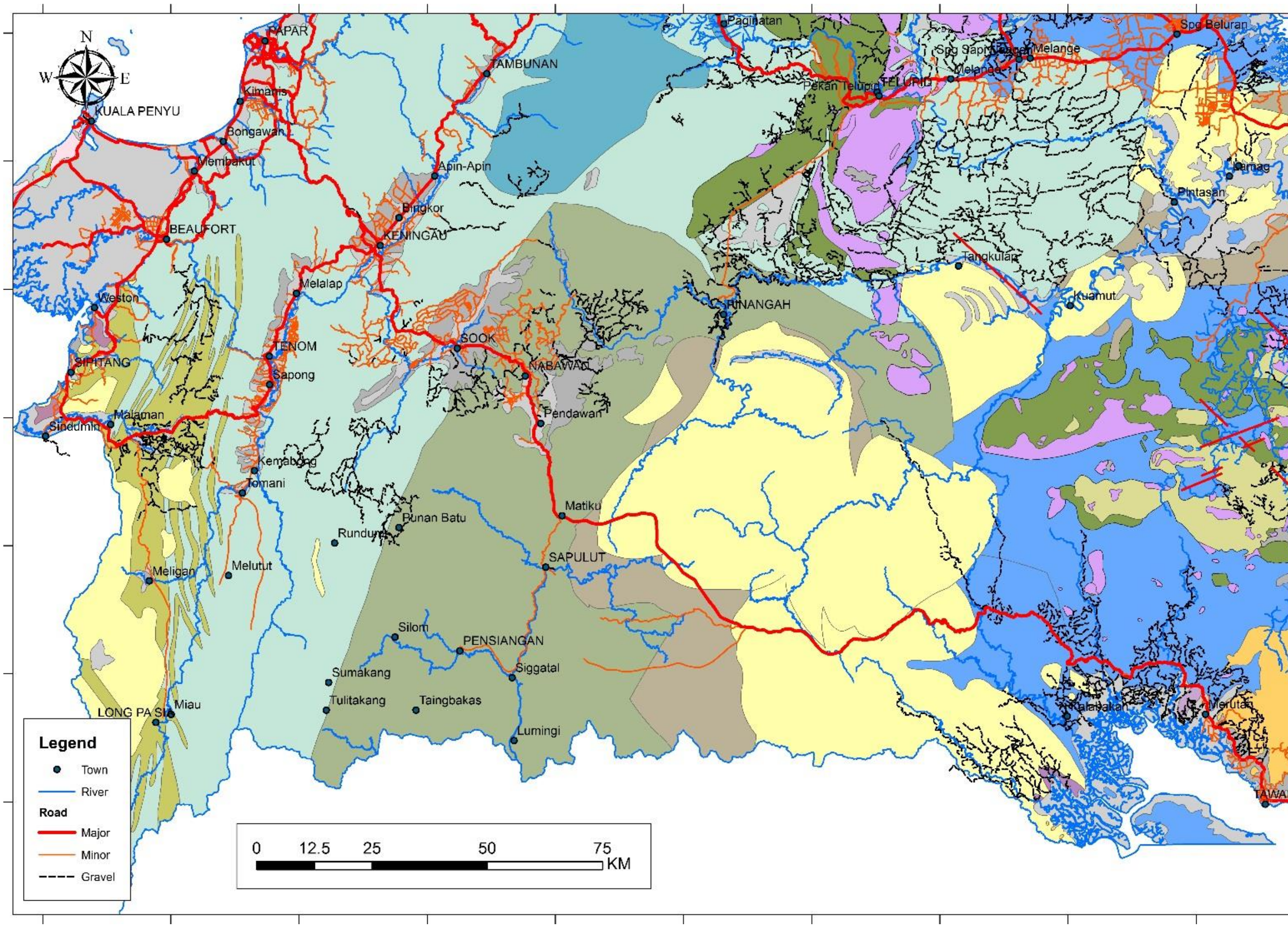

Figure 20 :LITHOLOGY MAP DISPLAYING THE ROAD PATH FROM TAWAU TO KENINGAU. (COURTESY OF UMS)

4.5 Regional (Sabah) Lineament Analysis

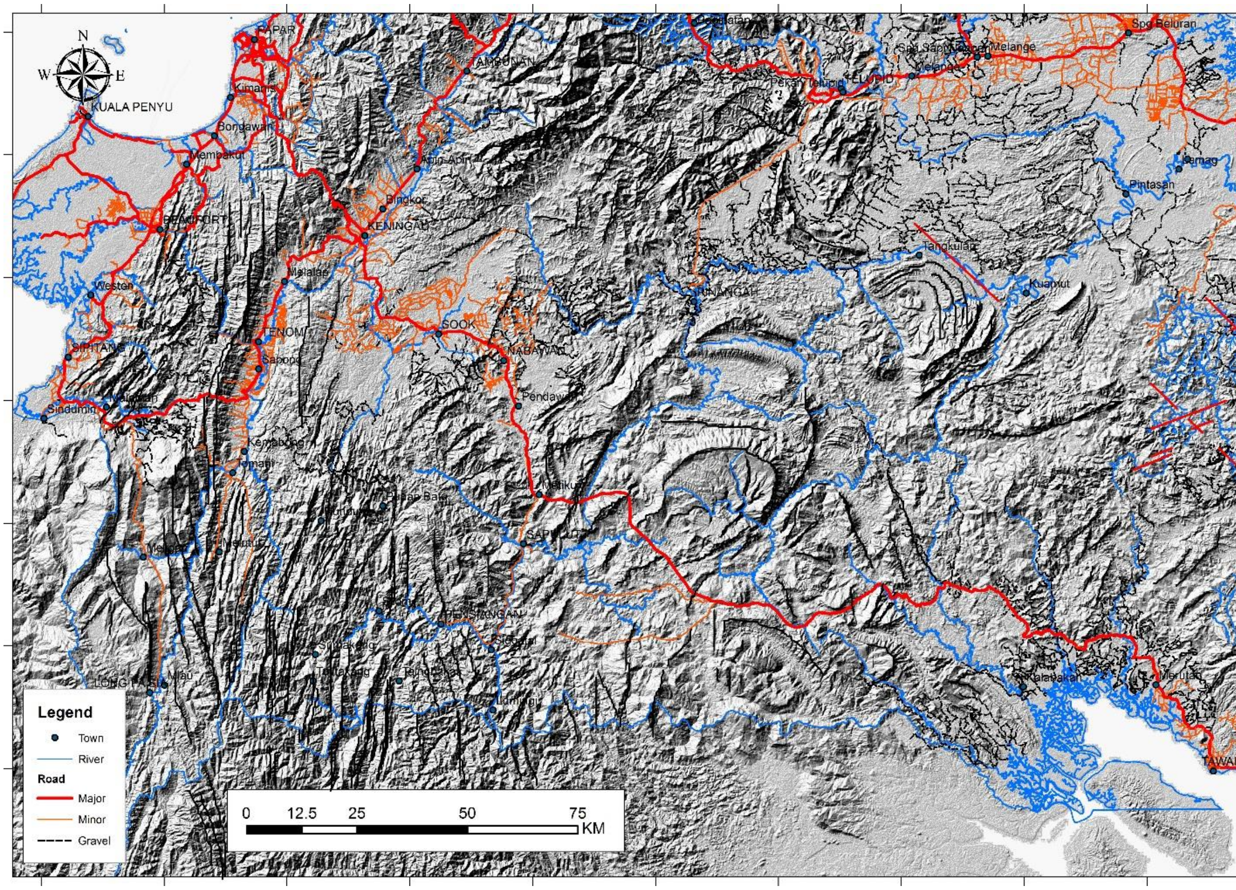

Figure 21 : REGIONAL LINEAMENT MAP COVERING THE WHOLE SABAH, INCLUDING SAPULUT AND TANJONG FORMATIONS. (COURTESY OF UMS)

Figure 22 FIGURE 1: LINEAMENTS INTERPRETED FROM THE PREVIOUS MAP (FIGURE 21).

Figure 22 shows the regional analysis of Sabah's lineaments in which include the Sapulut and Tanjong formations. As early as 1930s, photogeologists studied fracture patterns which are visible on aerial photographs as a means of inferring geologic structures or geologic landmarks. Usually, lineaments are geologic features which correspond rather closely to faults and fractures defined in field. However, more recently, in the context of remote sensing, the term has transformed to represent a broader meaning. According to James B. Campbell in his book, "Introduction to Remote Sensing", lineament can be defined as any linear feature visible on the aerial image. Fracture zones, shear zones and igneous intrusions are among the geological features which can be classified as lineaments. Shear zones might give rise to semi linear feature on the aerial photograph, hence explaining the rounded or semi rounded lineaments around the Maliau Basin area (refer both Figure 21 & 22). Results if the regional lineament analysis will be compared with the station-by-station analysis in order to correlate and verify the regional trends of the fractures.

4.6 Station-by-station Analysis

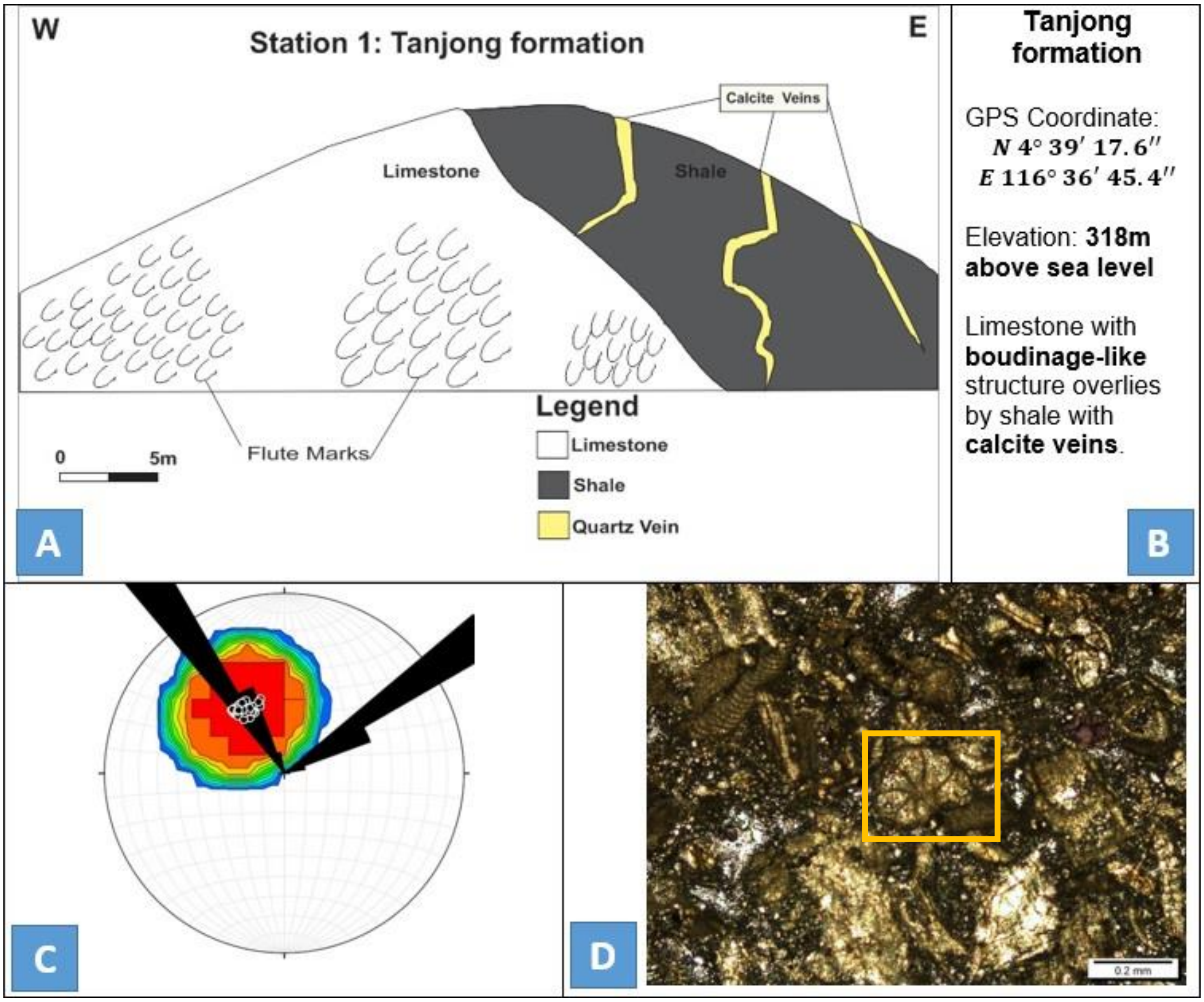

Figure 23 :SKETCH OF OUTCROP, OUTCROP DESCRIPTION, BEDDING STEREONET AND THIN SECTION OF STATION 1, TANJONG FORMATION.

Figure 24 : Boudinage-Like Structure discovered at Station 1, Tanjong Formation.

Lithology of the first station is mainly characterized by limestone which is overlies by shale with calcite veins. The main geological feature found on the limestone is the boudinage-like structure which is somehow connected with each other. It is not exactly the same like the boudinage but, it only resembles the boudinage physical feature. Boudinage-like features which is found here is the result of tectonic-driven extensional forces in this area. Extensional forces subjected to this area causes the limestone to be flattened and formed the interconnected boudinage-like structure. The ebb and flood of the tidal current typically scour the channels between the upper reaches of the intertidal zone and the adjacent subtidal zone (Wayne, 2008).

Furthermore, the calcite vein is also a unique geological structure present on this outcrop where the limestone from beneath it act as the source of these calcite veins. A vein can be formed in varying conditions. To begin with, veins are defined as masses of rock which occupy fissures in other rocks. Veins may have originated in many distinct ways and present a great variety of forms and structures. Three main classifications of veins are veins of igneous rock, veins of sedimentary rock and, veins of mineral deposits either by water or gases. The difference between a vein and a dyke is that dykes are usually narrow, often straight-walled and extends for a considerable distance whereas veins are irregular, discontinuous and of limited extent. As the structure found at station 1 is irregular, discontinuous and has a limited extend in length, hence it is classified as a calcite vein, as shown on the right-hand side of Figure 24. The calcite is younger than the shale as it intrudes into the shale.

Shale is most likely to be deposited in a low energy environment, which may be subjected to deep marine or lagoon environment. However, carbonate (limestone) usually deposits in shallow marine environment as it is the most ideal conditions for carbonate build up. Hence, there is a probability that the shale was deposited in a tidal flat environment during the ebb, which makes it possible for the carbonate to catch up during the flood.

There is no fracture present in this outcrop, thus the stereonet plotted is based on the bedding of the limestone. Based on the stereonet in Figure 23[C], the strike of the bedding trends towards the NE-SW direction. Dip direction, on the other hand, has a trending which propagated relatively towards the NW-SE direction. The fossil found (refer Figure 23[D]), is known as the lepidocyclina cibidices which is dated as Miocene in age.

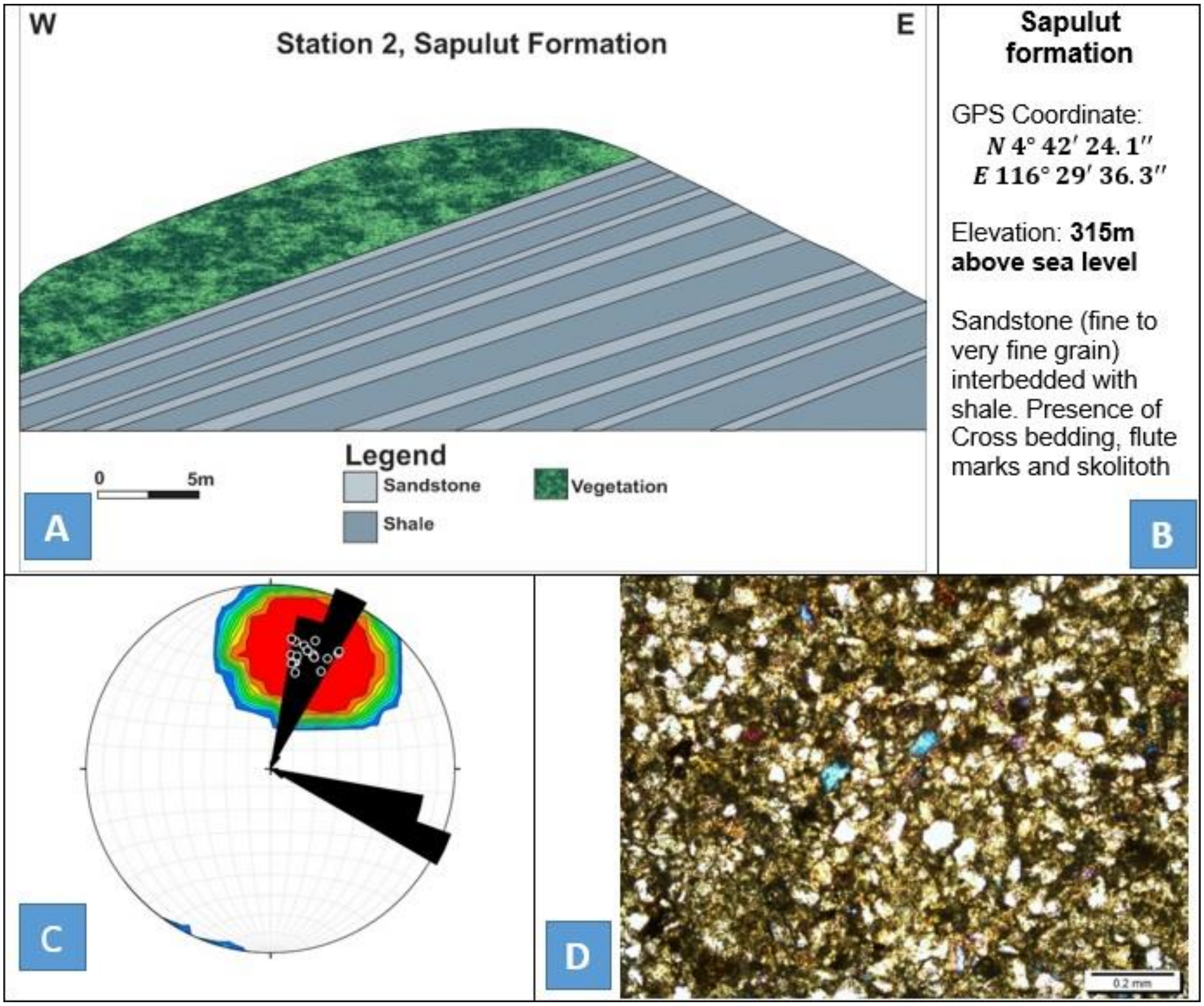

Figure 25 : OUTCROP SKETCH, LITHOLOGY DESCRIPTION, STEREONET, AND THIN SECTION OF STATION 2, SAPULUT FORMATION.

Formation of Station 2 is mainly comprised of sandstone interbedded with shale as shown on Figure 25. In order to interpret the depositional environment of this outcrop, it is not conclusive to only count on the sandstone interbedded shale, which commonly exist in lagoonal environment. Presence of cross bedding significantly assist in unravelling the outcrop's formation history. A normal cross bed tells that it was affected by a flow, whether wind or water.

Figure 26 : CROSS BEDDING STRUCTURE WITH BOTTOM PART ERODED FOUND ON THE SAPULUT OUTCROP, STATION 2.

Figure 26 indicated a cross bedding where the lower part of the sandstone had been eroded, probably by weathering processes after being exposed on the surface. Cross bedding is comprised of horizontal bedding or strata where its internal layers are inclined or tilted. The tilting of the internal layers can be explained by the post-depositional deformation. Cross bedding usually form on the inclined surfaces of ripple marks or dunes. Typically, cross bedding indicated its depositional environment is affected by a flowing (water or wind) media. Cross bedding is a sign of rivers, sub-tidal coastal or marine environments. Cross bedding could also be formed in channelized deep marine slope where there is also flowing water. Presence of skolitoth (burrowing trace fossils) as shown in Figure 53 in the appendix, indicated it was probably deposited in a soft intertidal or shallow subtidal marine environment.

Since the tool marks are discovered at the bottom part of the sandstone, it could mean that the bed was overturned. Tool marks are a type of sole marking formed by grooves which was a result of sticks or anything being dragged by along by current or water flow. It is very useful in indicating the younging direction of an outcrop. Therefore, the cross bedding can be deposited in either river or marine environment as long as there is flowing water to influence the formation of cross bedding. However, the presence of skolithos narrow the depositional environment to be of marine environment. Skolithos ichnofacies is a characteristics of environment with high energy, probably the soft intertidal or channelized deep marine slope environment.

Figure 27 : TOOL MARKS (IN YELLOW BOX) AND PROBABLE SKOLITHOS (FINGER POINTING) FOUND AT STATION 2, SAPULUT FORMATION.

Stereonet on Figure 25[C] indicates that the beddings' strike direction trend is propagated relatively towards the NW-SE direction whereas its dip direction is fairly inclined towards the NE-SW direction. The beddings' strike trend could be correlated with the regional Sabah lineament analysis as lineament includes any geological structures which is observable from the aerial satellite photograph. If compared, the strike trend correlates just fine with the regional lineament analysis (Figure 22) of Sabah. Thin section on Figure 25[D] indicated that the grains are of fine to very fine, which denotes that environment energy to be low and far from the source of deposition. The grain size indicated deep marine environment as its depositional environment. Ratio of quartz to matrix might be around 60:40.

Figure 28 FIGURE 2: OUTCROP OF STATION 2, SAPULUT FORMATION.

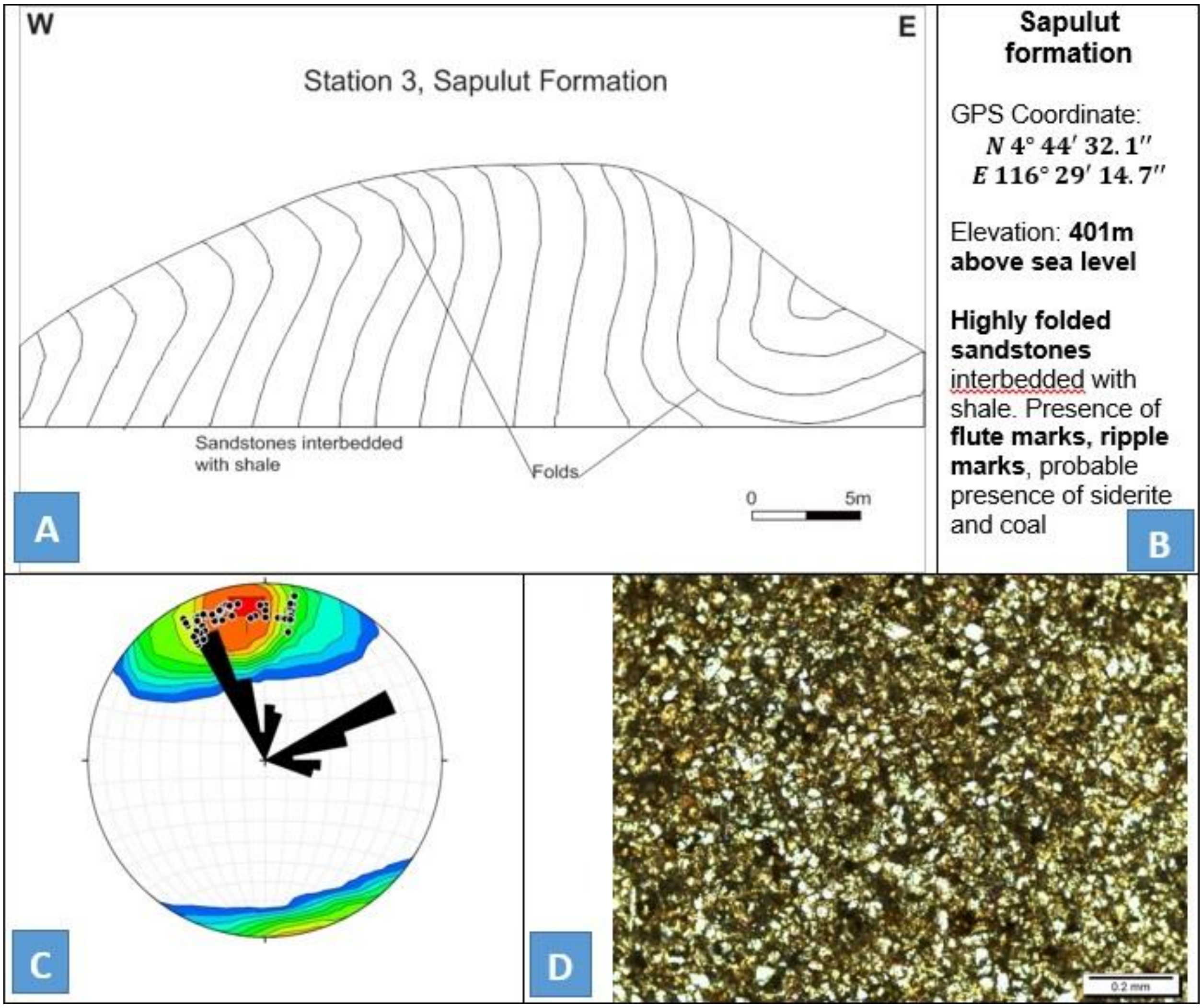

Figure 29 : ILLUSTRATION OF OUTCROP, LITHOLOGY DESCRIPTION, STEREONET WITH ROSE DIAGRAM & THIN SECTION OF STATION 3, SAPULUT FORMATION.

Folding is the main characteristic which is the leading structural geological feature that could support the inference of the deformation history of Sapulut formation based on outcrop of station 3. The composition of the folds of station 3 are sandstone interbedded with shale. A fold is a stack of originally flat and planar beds, which bent or curved as a result of permanent deformation. The permanent deformation normally might be due to compressional forces triggered by tectonic movements. Most likely, the fold is a synsedimentary which means that it was formed during deposition of sediments before it was lithified to be sandstone. Several factors affecting the formation of folds include varying conditions of stress, hydrostatic pressure, pore pressure and temperature gradient. The most prominent factor is that the ductility of the sediment that causes it to bend or fold.

Since the folds (refer Figure 30) on this particular outcrop is massive (large scale) and it was formed as a set of folds rather than isolated, this outcrop is might have been deformed in an orogenic zones. On a regional scale, it is commonly known as fold thrust belt, for example the Rajang Fold Thrust Belt in Borneo. The depositional history of this outcrop stretches back to the Early to Middle Miocene, as it is correlatable to the characteristics of Rajang Fold Thrust Belt, forming the uniquely alternating sequence of folded sandstone and shale. Referring to Figure 27, there are two sets of massive folds, which may be categorized as recumbent folds as one of the folds are overturned and this strengthen the inference that it was deformed in an orogenic zone.

Figure 30 : MASSIVE FOLDS FOUND AT STATION 3, SAPULUT FORMATION.

Figure 31 : SCOUR MARKS IN THE YELLOW BOX FOUND AT STATION 3, SAPULUT FORMATION.

Presence of scour marks and flute casts indicate the younging direction of the outcrop as well as the depositional environment of the outcrop (refer Figure 29). As previously discussed in station 1, the scour marks denote that the facies was deposited an environment with flowing of water or wind to be formed. According to Peter A. Scholle and Darwin Spearing in the book entitled "Sandstone Depositional Environments", they stated that sandstone interbedded with shale might be due to deposition of considerable thicknesses of barrier sandstones and lagoonal shales resulted from an overall balance between rates of sediment accumulation and basin subsidence. The shale thickness within the interbedded feature which is thinning from left to right based on Figure 30, indicated that the sandstone interbedded with shale was most probably deposited in a channelized deep marine slope environment. This inference is supported by the thin section analysis, the grain sizes are ranging from fine to very fine, and this is a significant indication that this outcrop was deposited in a low energy environment, most probably deep marine. Scour marks can also be formed in channelized deep marine slope environment.

The stereonet produced in Figure 29 has a beddings' strike direction which fairly trends towards the NE-SW direction whereby the dip direction trends relatively to the NW-SE. This outcrop's fracture trends can be match with the regional Sabah lineament analysis (Figure 22). In other words, the outcrop scale fracture trends reassure the regional interpretation based on

Landsat 7 satellite image which was further enhanced by utilizing the Sobel and Prewitt filters. Thin section analysis (refer Figure 29[D]) prevail that the grains size vary from fine to very fine (low energy) and the ratio of quartz-to-matrix is approximately 70-30.

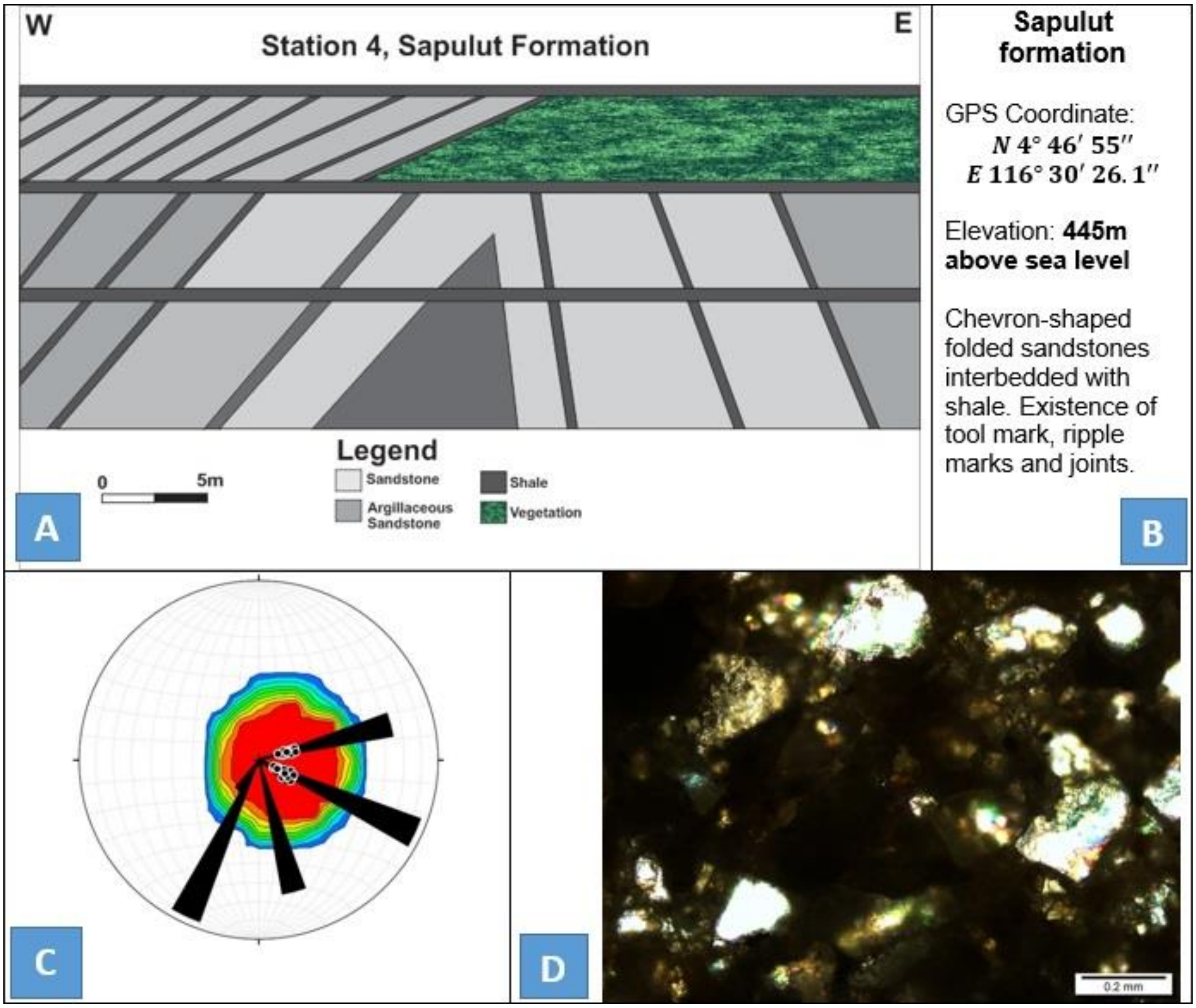

Figure 32 : OUTCROP SKETCH, LITHOLOGY DESCRIPTION, STEREONET WITH ROSE DIAGRAM & THIN SECTION OF STATION 4, SAPULUT FORMATION.

Another uniquely folded sandstone interbedded with shale forms what is famously known as the chevron fold. The main difference or characteristics which differ it from any regular fold is that its folds are angular with straight limbs and small hinges, as shown in Figure 32. Generally, chevron folds have an interlimb angle of around 60°. Chevron folds (Figure 33) typically develop in flysch sequence of alternating competent and less competent layers in which the thickness of the competent layers vary across the complex. In this case, the competent layer is the sandstone whereas the less competent layer is the shale. Grain sizes after thin section analysis prevailed that it ranges from fine to very fine. Hence, this signified that it was deposited in a low energy environment, far from source. Most likely, the deep marine environment.

Figure 33 : CHEVRON FOLDS OF ALTERNATING SANDSTONE INTERBEDDED WITH SHALE FOUND AT STATION 4, SAPULUT FORMATION.

Stereonet of the Station 4's outcrop illustrated that the beddings' strike direction trends in two direction as the chevron folds generally divides the fractures along its limb in two major directions. One of the bedding trend in the NE-SW direction and the other one trends relatively in the N-S direction. The former bedding strike is correlatable to the major strike direction as per interpreted in the regional Sabah lineament analysis (refer Figure 34). Since the bedding strike direction has two trends, the dip direction also corresponds accordingly. One trends in the NW-SE direction correspond to the first bedding whereby the second bedding trends in relatively W-E direction.

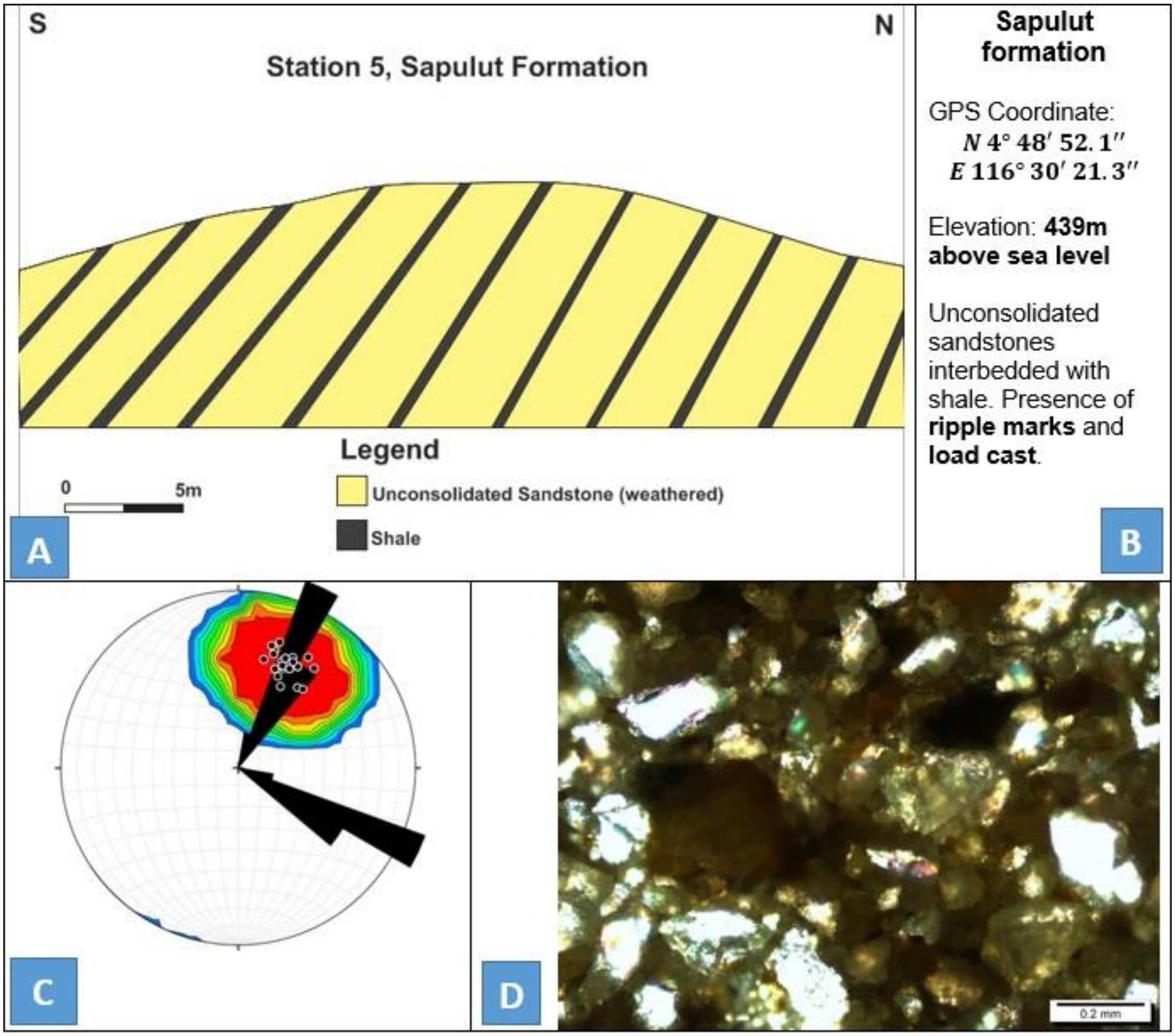

Figure 34 : ILLUSTRATION OF THE OUTCROP, LITHO-DESCRIPTION, STEREONET AND THIN SECTION OF STATION 5, SAPULUT FORMATION.

Figure 35 : PRESENCE OF LOAD CASTS AND DISSOLUTION CRACKS AT STATION 5, SAPULUT FORMATION.

Sapulut formation's next station (Station 5, refer Figure 34) is mainly characterized by the interbedded sequence of unconsolidated sandstone with shale. Interbedded sandstone and shale might be found in lagoonal environment but, unconsolidated sandstone with the presence of load cast and ripple marks (refer Figure 33) might tell a different story. Load casts can be formed in vast range of depositional environment in which include deep marine, shallow marine, fluvial and lagoon. However, ripple marks are commonly found on the fluvial or marine environments which have water flow. Shale indicates low energy environment which may present in the tidal flat or deep marine environment. Since shale most likely indicate deep marine environment, the ripple marks are signature of flow-prone environment, probably the channelized deep marine slope. Load casts can be utilized to determine the younging direction as the beds with the load cast is deposited earlier than the overlying beds which loaded the underlying strata.

Stereonet in Figure 34[C] shows the beddings' strike direction indicated a trend propagating relatively towards the NW-SE direction. Dip direction, on the other hand, trends fairly towards the NE-SW direction. This outcrop might been located in a shearing zone as the strike trend cannot be correlated to the regional Sabah lineament analysis. Set of fractures here might have been sheared due to the wrench faults activated due to compressional tectonic movement. The thin section shows that the quartz-matrix composition has a ratio of 45:65.

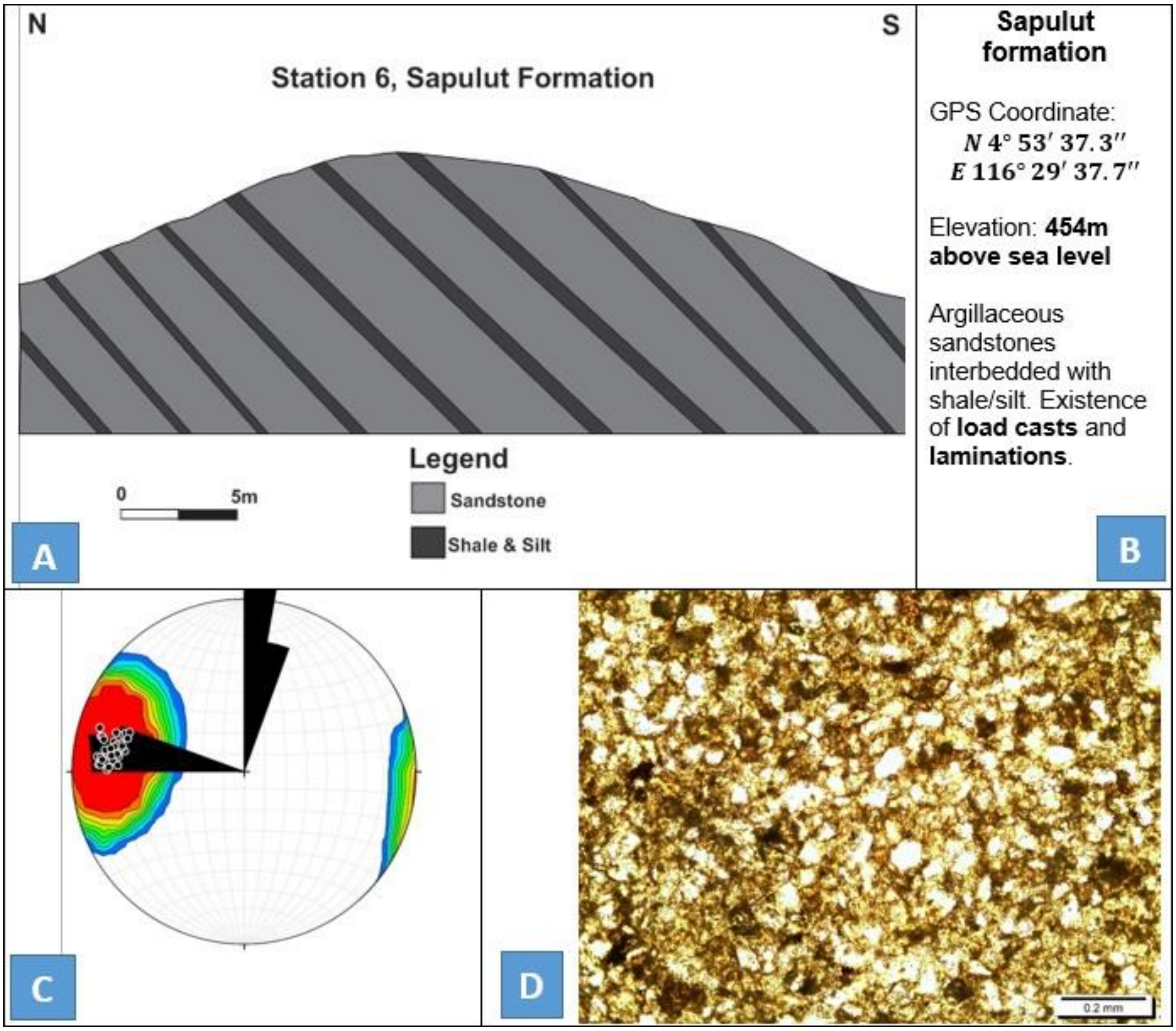

Figure 36 : SKETCH OF THE OUTCROP, GEOLOGY DESCRIPTION, STEREONET PLUS ROSE DIAGRAM AND THIN SECTION OF STATION 6, SAPULUT FORMATION.

Station 6 of Sapulut formation is also characterized by sandstone interbedded with shale however, the sandstone present in this outcrop is more argillaceous in nature. Argillaceous sandstone simply denotes that the second main composition of the sandstone is clay minerals such as shale/silt, where obviously quartz is the main component making the rock a sandstone. Clay minerals are usually deposited in low energy environment such as the lagoon or deep marine environment. Sandstone are generally deposited in many environments such as deltas, beach or tidal flats however, high composition of clay minerals indicated the environment might be transitional. Transitional environment is an environment with the influence of both fresh and salt water or air, which might be affected by alternating sequence of transgressive and regressive movements of sediments. Transgressive and regressive movements of sediments depends on rise and ebb of sea level. The sea level fluctuations may be the factor causing the interbedded of sandstone with shale/silt. Presence of load cast is essential in identifying the younging direction. As discussed in previous section, the bed with the load cast is older than its overlying beds which loaded the beds with the load cast structures.

The stereonet of the strata's spotted on the outcrop of station 6, sapulut formation has both strike and dip trends which is as shown in Figure 34[C]. Strike of the beds fairly trend towards the N-S direction whereas the dip direction reasonably trend in the W-E direction. The beddings' strike trend does not comply to the trend of the regional Sabah lineament analysis. It might have been subjected to shearing by wrench faulting around the Maliau Basin. Despite that, it may also follows the lineament trends of the western flank of Sabah which fairly trend in the same direction. Somehow, some fracture sets still follow the western flank's trend although it is approaching the central Sabah area.

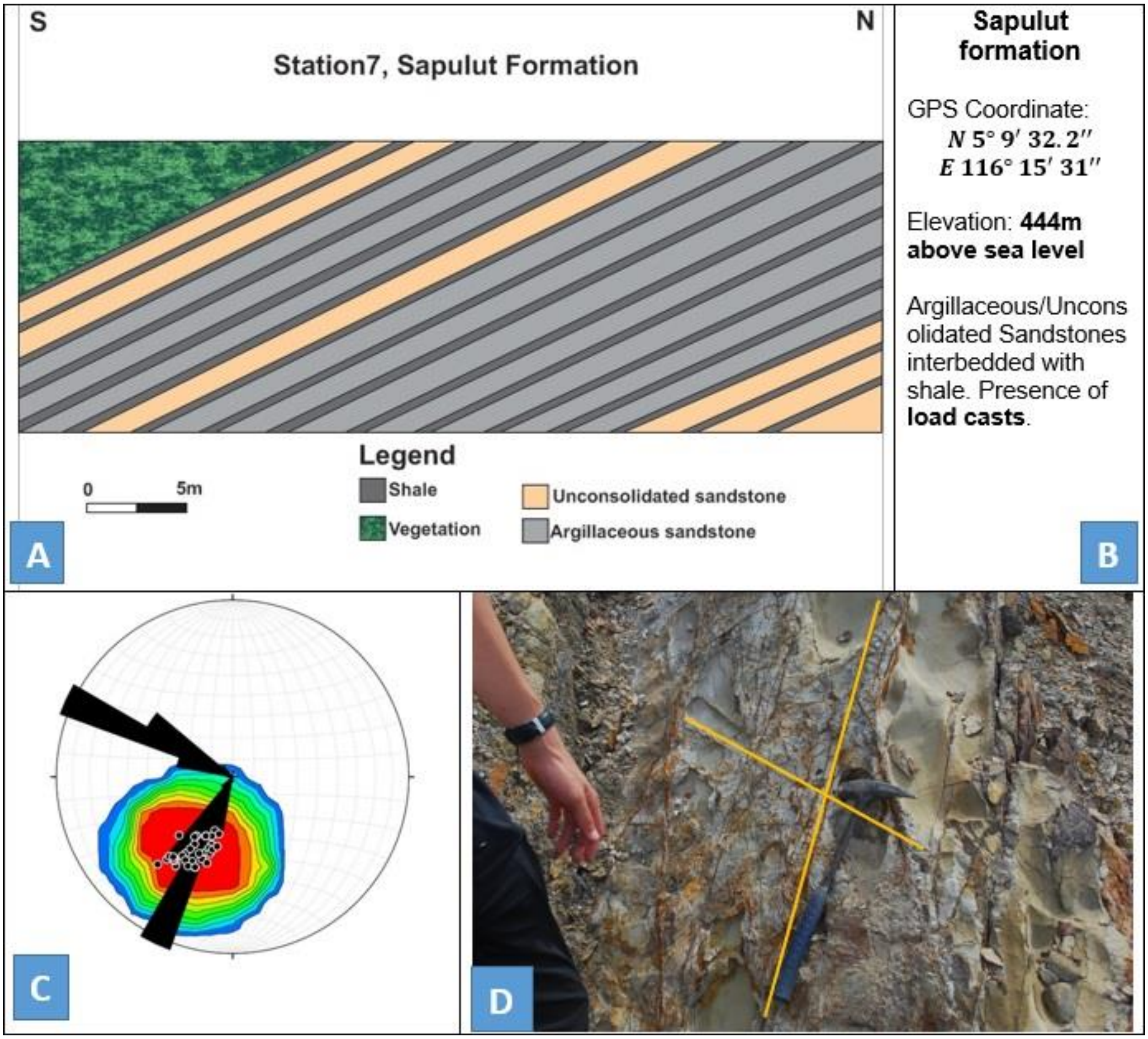

Figure 37 : ILLUSTRATION OF THE OUTCROP, LITHOLOGY DESCRIPTION, STEREONET AND CONJUGATE JOINTS OF STATION 7, SAPULUT FORMATION.

Argillaceous unconsolidated sandstone interbedded with shale is the prominent characteristics of the outcrop in Station 7, Sapulut formation (refer Figure 35). Argillaceous components are fine grained clay minerals such as kaolinite, montmorillonite-smectite, illite and chlorite. For instance, claystone and shale are regarded as predominantly argillaceous. Therefore, argillaceous sandstone is a rock which is dominantly quartz grains but, clay minerals are secondary but significant component. The clay minerals actually fill the interstitial spaces between the quartz grains. Since clay minerals are prominent in shale and claystone in which the grain sizes vary from fine to very fine, hence it is assumed to be deposited in a low energy environment, probably deep marine or lagoonal settings.

Stereonet of station 7 is indicating the beddings' strike and dip trends respectively, shown in Figure 35. The strike of the fractures trend fairly in the NW-SE direction whereas the dip relatively trends in the NE-SW direction. If compared with the regional Sabah lineament analysis (refer Figure 21 & 22), it does not correlate with the major trends. However, this may be an indication of fracture sets which had been affect by wrench faulting which somehow sheared the outcrop.

Presence of load casts, as describe in a few earlier stations, is essential and important in determining the younging direction of the beddings. Load casts are the geological structure formed as a result of deposition of denser beds on a less dense hydroplastic layer. The denser beds could be of sands, coarse sands or gravels. In contradiction, the less dense hydroplastic beds might be muds, silts or finer sands. The less dense hydroplastic layer where the casts formed is actually older than the denser layer simply because the cast cannot form if the less dense hydroplastic layer was not in place.

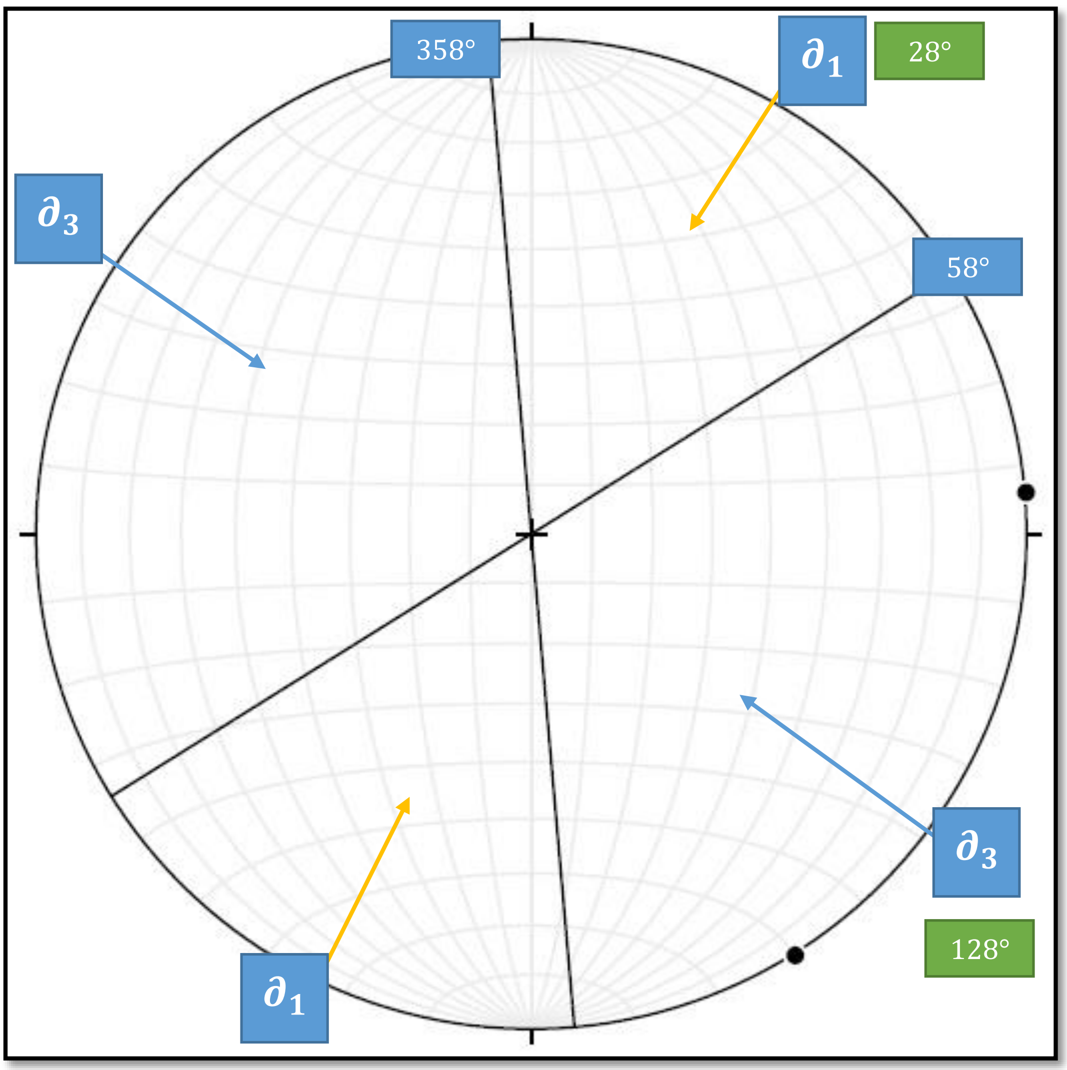

Figure 38 FIGURE 3: ROSE DIAGRAM OF THE CONJUGATE FRACTURE OF STATION 7, FROM FIGURE 35[D].

Rose diagram of the conjugate fracture as shown in Figure 36 displayed the trends of the major principal stress (∂_1) and the minor principal stress (∂_2). Based on the rose diagram above, the (∂_1) fairly trends towards the NE-SW direction whereas the (∂_3) relatively trends perpendicular, towards the NW-SE direction. Since the outcrop is somehow inclined, the rose diagram has to be rotated at about $(40-50)°$ in order to imagine it being placed in the bedding. The (∂_1) forces might be due to the overloading of the overlying sediments/strata.

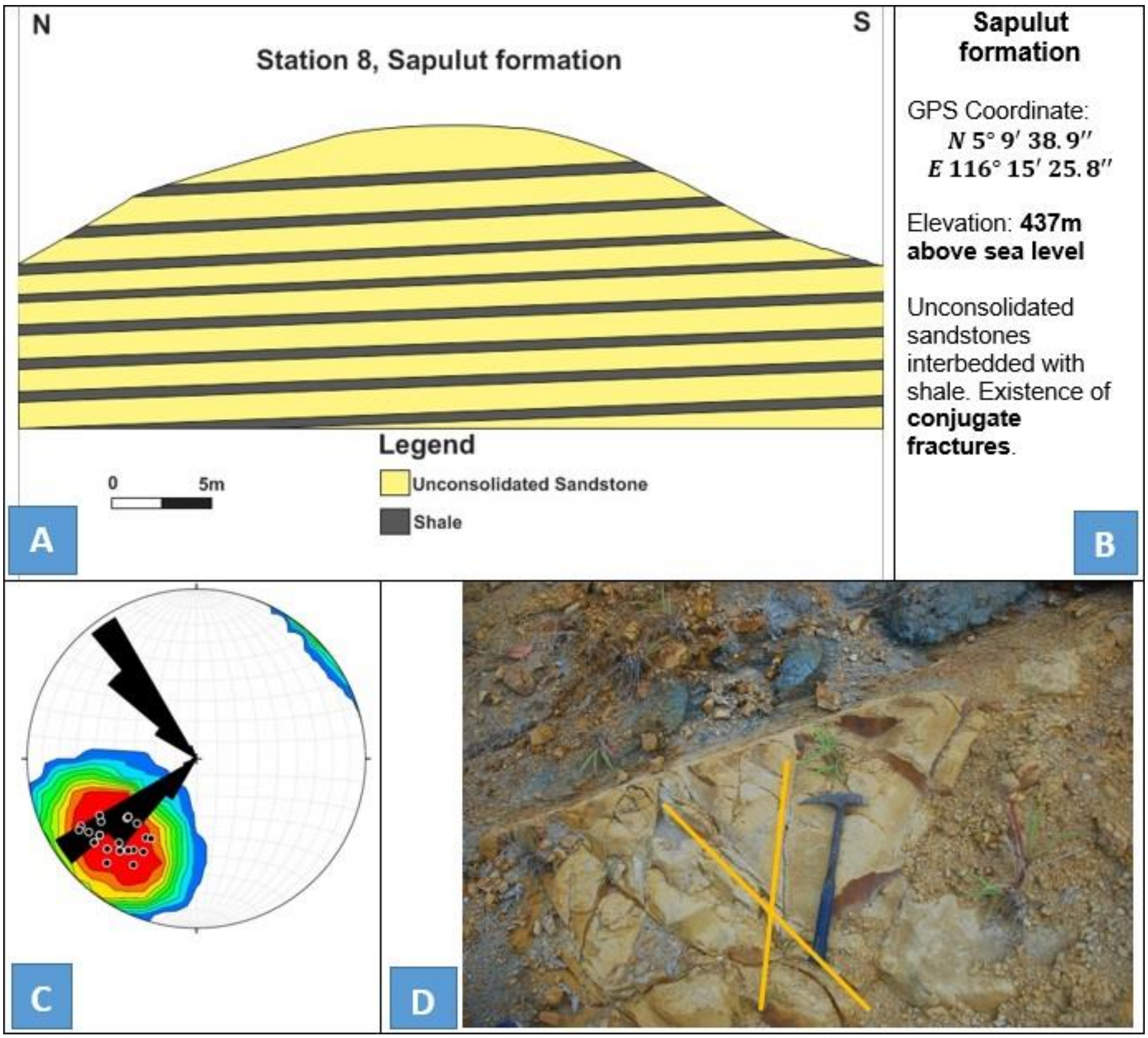

Figure 39 : BASIC SKETCH OF THE OUTCROP, GEOLOGY DESCRIPTION, STEREONET WITH ROSE DIAGRAM AND CONJUGATE FRACTURE OF STATION 8, SAPULUT FORMATION.

The bedding of the outcrop at station 8 is rather gentle based on the first glimpse at the exposed section discovered. It is characterized by sequence of unconsolidated sandstones interbedded with shale. Unconsolidated sandstone and shale, which have varying grain sizes of fine to very fine indicate that it was deposited in a low energy environment which is far from the source. It might be deep marine or lagoon. However, there is no other sedimentary structure to back up the inference made on the probable deposition environment of this outcrop. According to Peter A. Scholle and Darwin Spearing in the book entitled "Sandstone Depositional Environments", they stated that sandstone interbedded with shale might be due to deposition of considerable thicknesses of barrier sandstones and lagoonal shales resulted from an overall balance between rates of sediment accumulation and basin subsidence. No sedimentary feature means it is not channelized deep marine slope. The depositional environment could be of abyssal plain deep marine where the energy is very low. Varying shale thickness between the interbeds might be an indication that it was deposited in an environment of channelized deep marine slope settings.

Stereonet displayed in Figure 37[C] is actually taking into account the bedding data and trends of strike/dip can be interpreted based on the prominent trails of the rose diagram. Based on the rose diagram, the strike of the bedding reasonably trends in the NW-SE direction whereby the dip fairly trends rather perpendicular to that of the strike, towards the NE-SW direction.

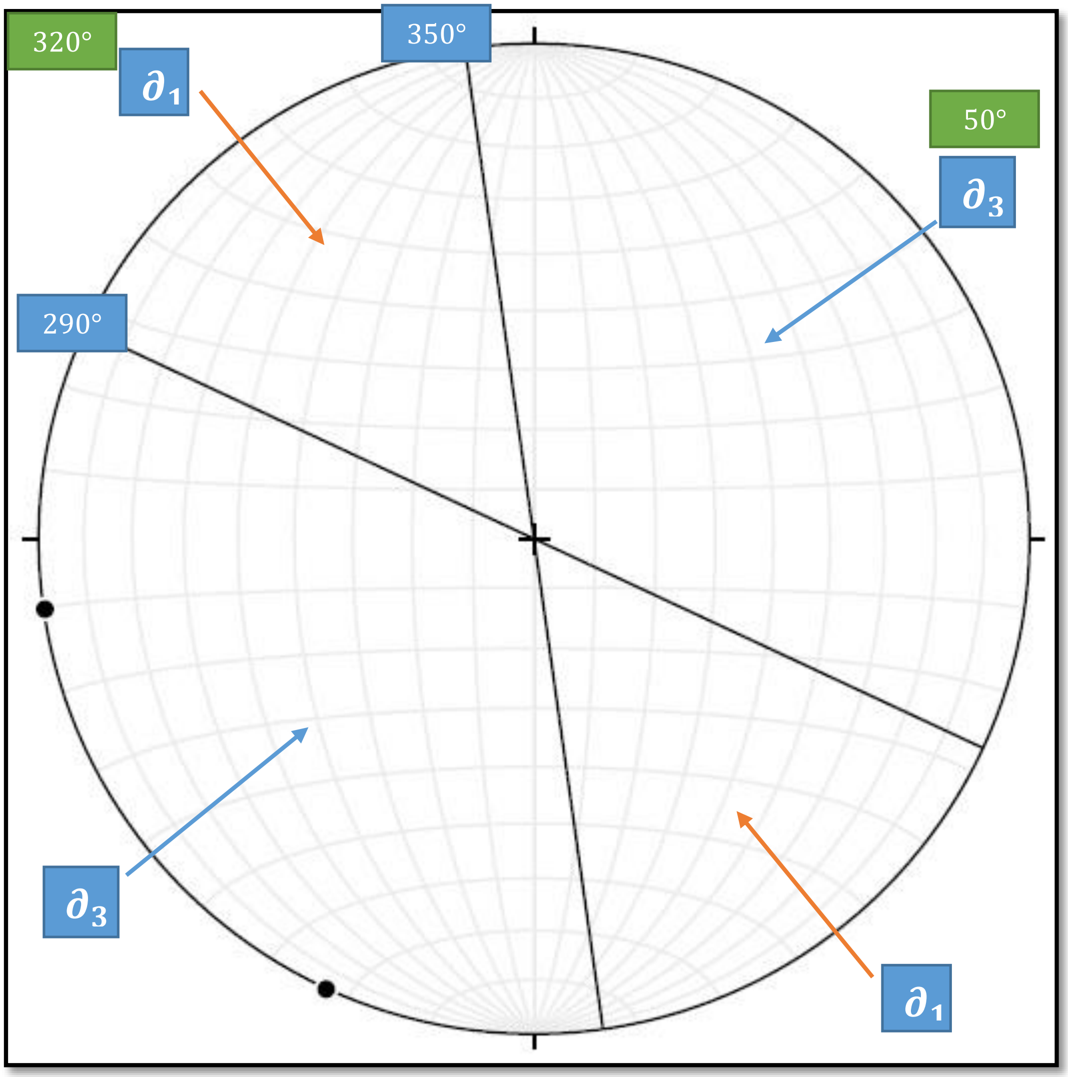

Figure 40 : Rose Diagram of the Conjugate Fracture of Station 8, Sapulut formation.

Referring to the conjugate fracture shown in Figure 37[D], it has been analysed and interpreted via the rose diagram of Figure 38. The maximum principal stress (∂_1) trends in the NW-SE whereas the minimum principal stress (∂_3) fairly trends towards the NE-SW direction. Maximum principal stress (∂_1) might be originated due to the overloading from the sediments deposited above this conjugate fracture.

4.7 Tectonic Model based on Road Traverse (TMRT)

In this section, the author intends to share on the simple tectonic model which could enlighten the reader on the structural history which revolves around the Sapulut and Tanjong formations, South East Sabah.

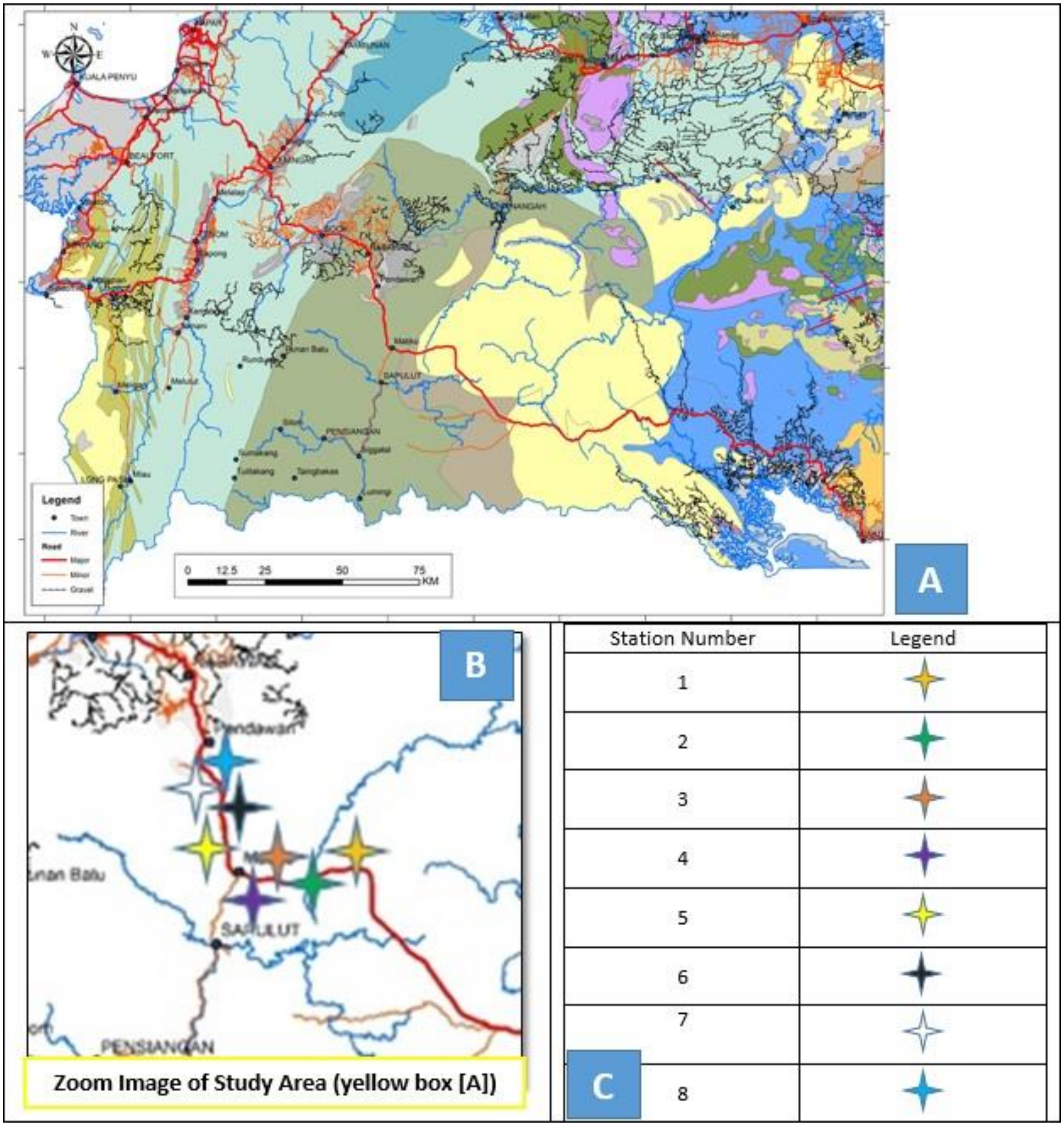

Figure 41 : SIMPLE TECTONIC MODEL BASED ON ROAD TRAVERSE, AROUND THE SAPULUT & TANJONG FORMATIONS, SOUTHEAST SABAH.

Tectonic Model based on Road Traverse (TMRT) as indicated in Figure 39, which the author attempts to propose the structural history by pointing out evidences that could support the inferences made on the depositional environment and significant structural events suggested by previous researchers. The supporting evidences are highlighted and arranged in the table below for a systematic classification of each outcrop.

Station	Evidence	Depositional Environment	Structural History
1	• Limestone • Shale • Scour marks • Fossil: Lepidocyclina cibidices	• Shallow marine • Low energy environment • Environment with water flow (tidal flat)	N/A
2	• Fine to very fine sandstone interbedded with shale • Cross bedding • Skolithos	• Low energy environment, probably deep marine • Environment with water flow (soft intertidal, channelized deep marine slope)	Regressive-Transgressive Tract System (Sea Level Fluctuations)
3	• Highly folded sandstone interbedded with shale • Flute marks, ripple marks	• Shale indicate low energy environment • Flute & ripple marks need environment with water flow (soft intertidal, channelized deep marine slope)	Massive folding: Orogeny of Rajang Fold Thrust Belt (RFTB) – Probably orogenic zone
4	• Chevron folded sandstone interbedded with shale (flysch/molasses) • Ripple mark	• Flysch/molasses formed in deep marine environment • Environment with water flow (soft intertidal, channelized deep marine slope)	Large-scale chevron fold might be due to RFTB as well. – probably orogenic zone
5	• Unconsolidated sandstone interbedded with shale • Ripple marks • Load casts	• Shale: low energy environment • Ripple marks: environment with water flow (soft intertidal, channelized deep marine slope) • Load cast: indicator of younging direction	Regressive-Transgressive Tract System (Sea Level Fluctuations)
6	• Argillaceous sandstone interbedded with shale • Load casts • laminations	• Prominent shale content: low energy environment • Deep marine, lagoon or intertidal zone	Regressive-Transgressive Tract System (Sea Level Fluctuations)
7	• Argillaceous/unconsolidated sandstone interbedded with shale • Load casts • Conjugate fracture	• Prominent shale content indicates low energy environment • Deep marine, lagoon or intertidal zone	Conjugate fracture: probably caused by overloading of Paleogene sediment deposition.
8	• Unconsolidated sandstones interbedded with shale • Conjugate fracture	• Shale: low energy environment • Deep marine, lagoon or intertidal	Conjugate fracture: most likely caused by overloading of Paleogene sedimentation.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.0 Conclusion and Recommendations

5.1 Conclusion

With the blend of thorough planning, week-long fieldwork, superb supervision by the lecturers and continuous efforts, the sedimentology and structural geology of Sapulut and Tanjong formations had been studied as extensive as possible. Through fieldwork and thin section analysis, the mineral composition and grain size distribution were fully understood. Regional fracture analysis and fracture/bedding analysis were correlated to match those present in regional photographs and outcrop scale lineaments. Presence of special sedimentary structures are essential to shed brighter lights on understanding the depositional environment.

Massive folding and large scale chevron folding are indications or characteristics which supports the tectonic history of Rajang Fold Thrust Belt, however it is not very conclusive. Episodic thrust folds revolve around the orogenic zone of the Rajang Fold Thrust Belt which extends from Balingian and it stretches as far as Sapulut formation. Discoveries of various fossils, for instance the lepidocyclina cibidices at Station 1 was dated as Miocene in the geologic time scale.

As a conclusion, based on the evidence discussed, the depositional environment of Tanjong formation can be classified as shallow marine probably the tidal flat areas whereas, the Sapulut formation is characterized as deep marine, most likely varying from the channelized the deep marine slope to the abyssal plain. The outcrop scale fracture patterns are correlatable with the regional Sabah lineament analysis.

5.2 Recommendations

Future recommended works for this project are as listed below:

- Conduct extensive fieldwork involving more outcrops within a larger coverage area.
- Study stratigraphy of this area to relate the timing of deformation with tectonic history of Sabah.
- Analyse the orientation of deformation of the targeted area.
- Perform the point load test or triaxial compression test.
- Interpret the depositional environment and Palaeogene formations more extensively.

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7.0 Appendix

Figure 42 :FOSSIL FOUND AT STATION 1, TANJONG FORMATION.

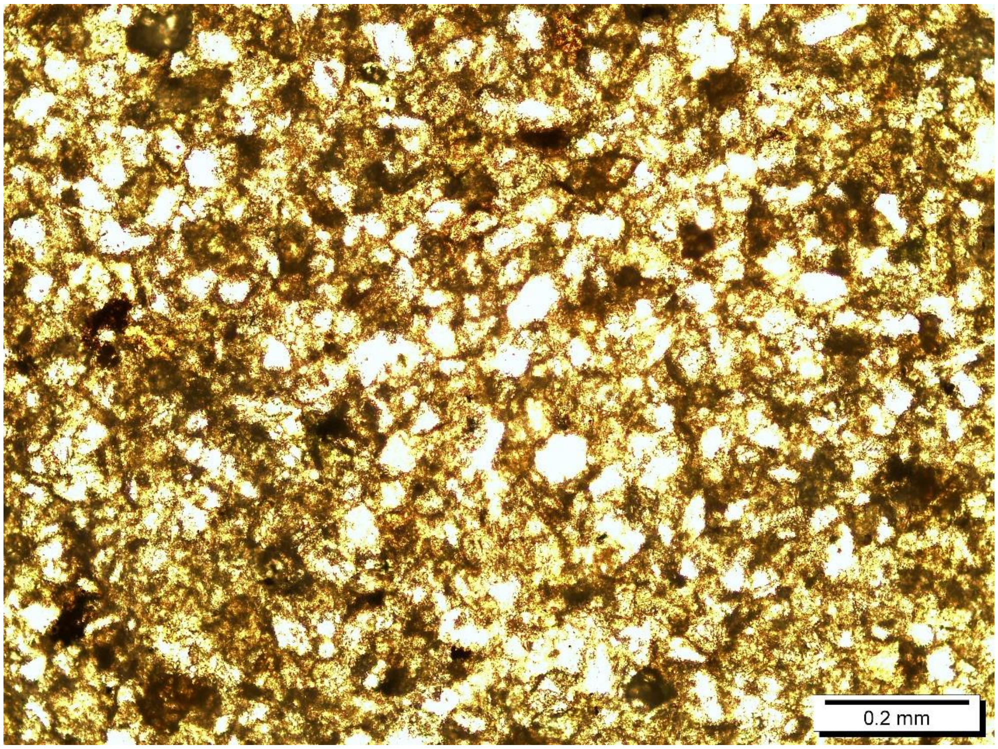

Figure 43 :PLANE POLARIZED LIGHT IMAGE, STATION 2, SAPULUT FORMATION.

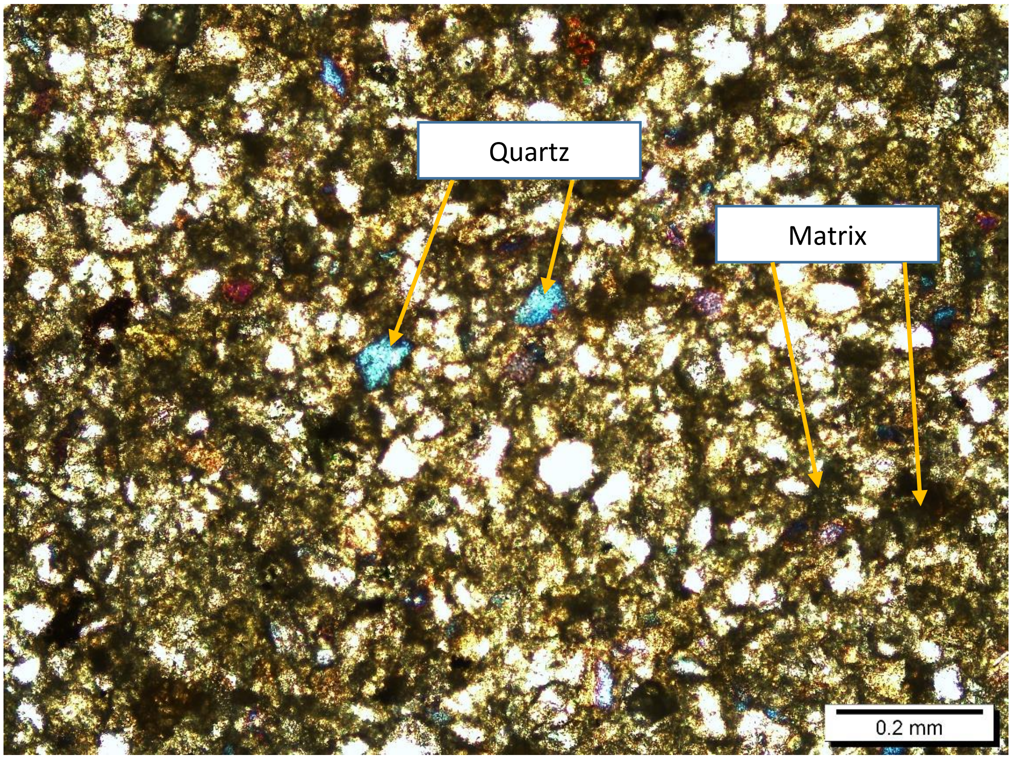

Figure 44 :CROSS POLARIZED LIGHT, STATION 2, SAPULUT FORMATION

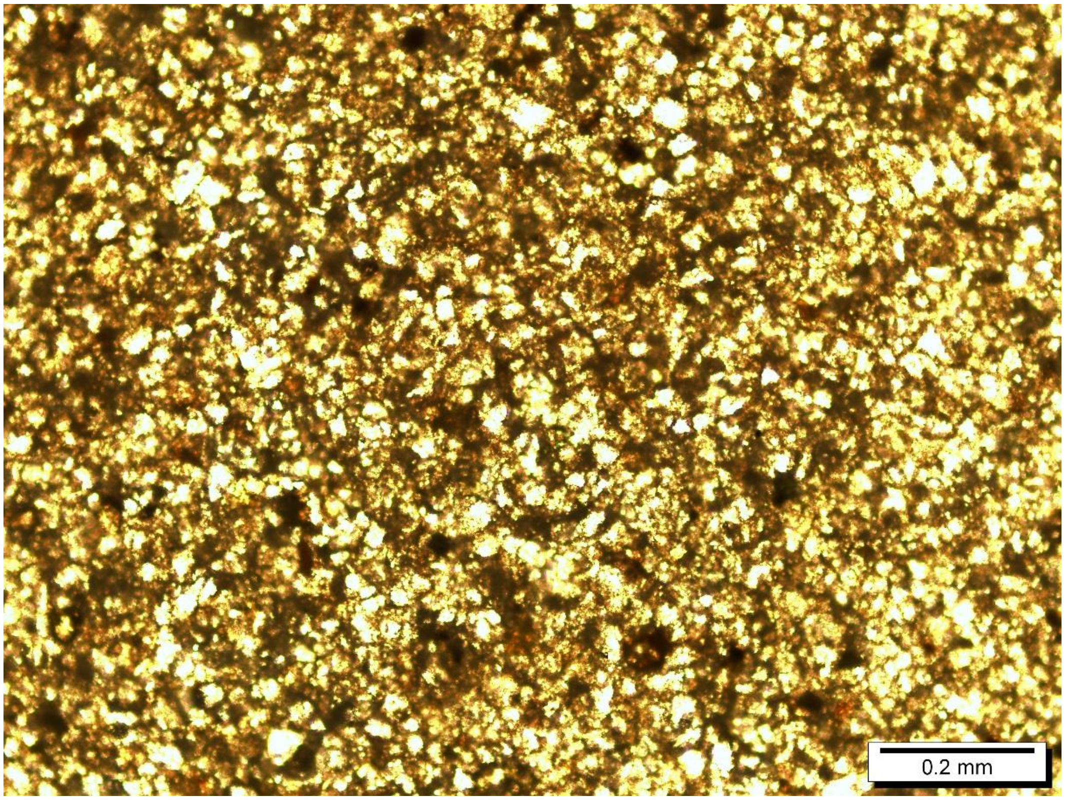

Figure 45 :PLANE POLARIZED LIGHT, STATION 3, SAPULUT FORMATION

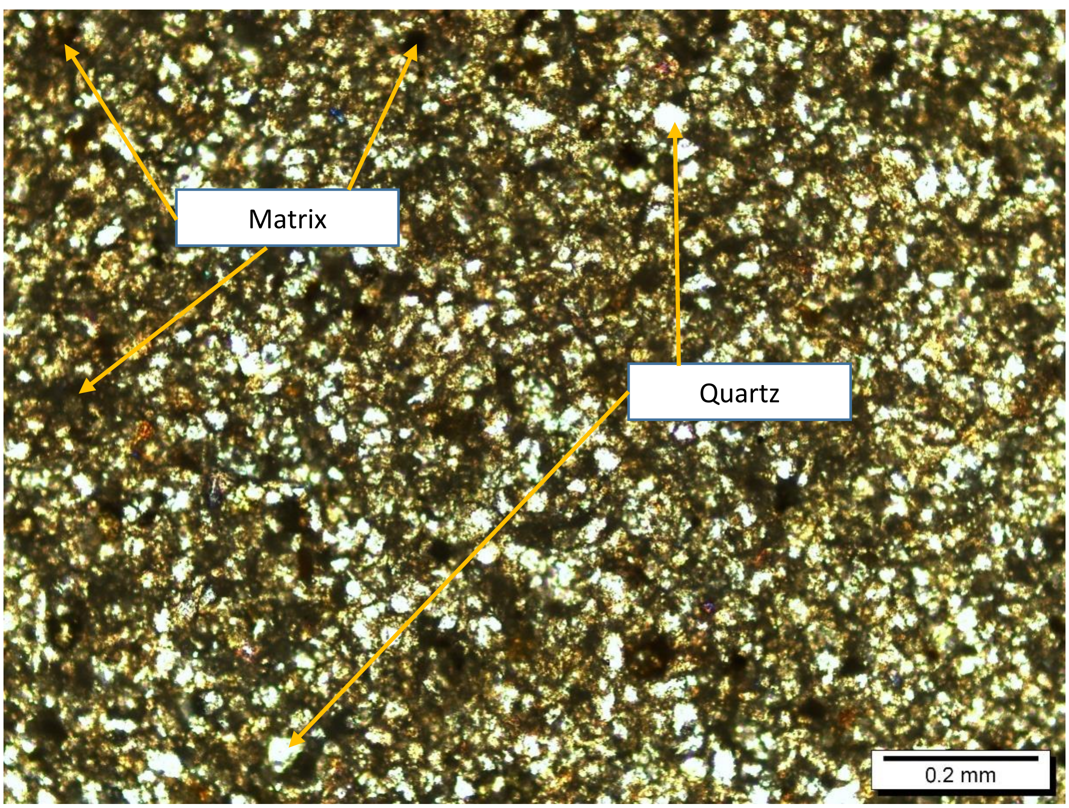

Figure 46 :CROSS POLARIZED LIGHT, STATION 3, SAPULUT FORMATION

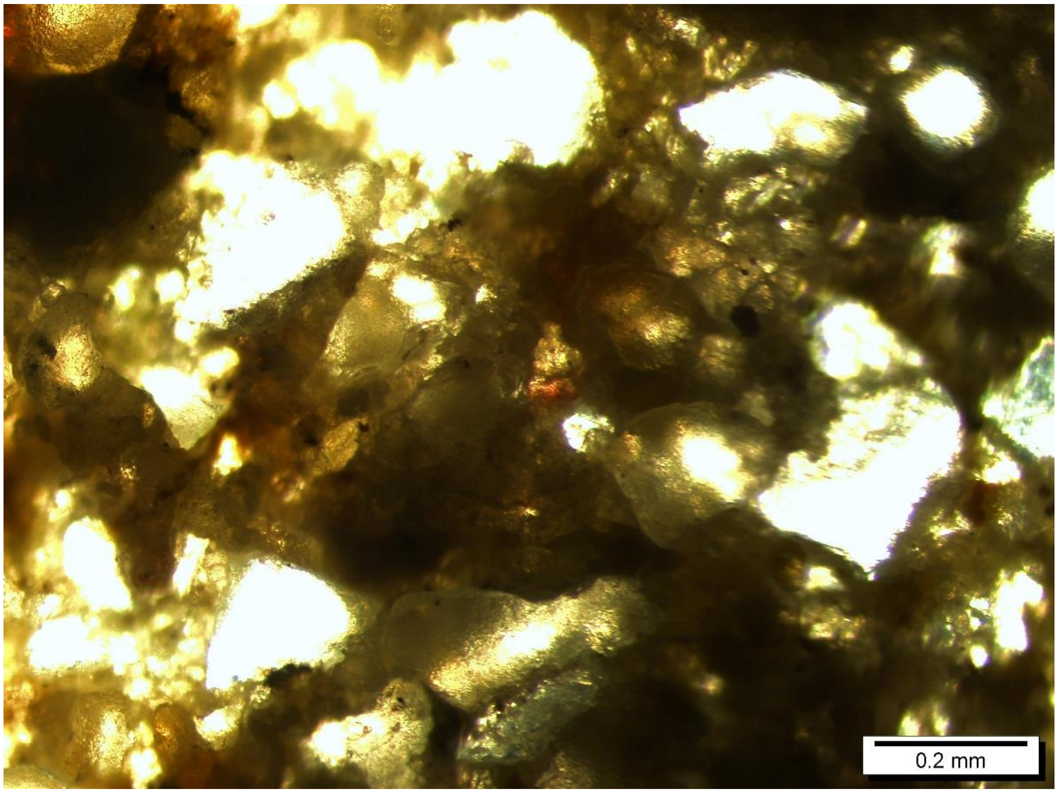

Figure 47 :PLANE POLARIZED LIGHT, STATION 4, SAPULUT FORMATION

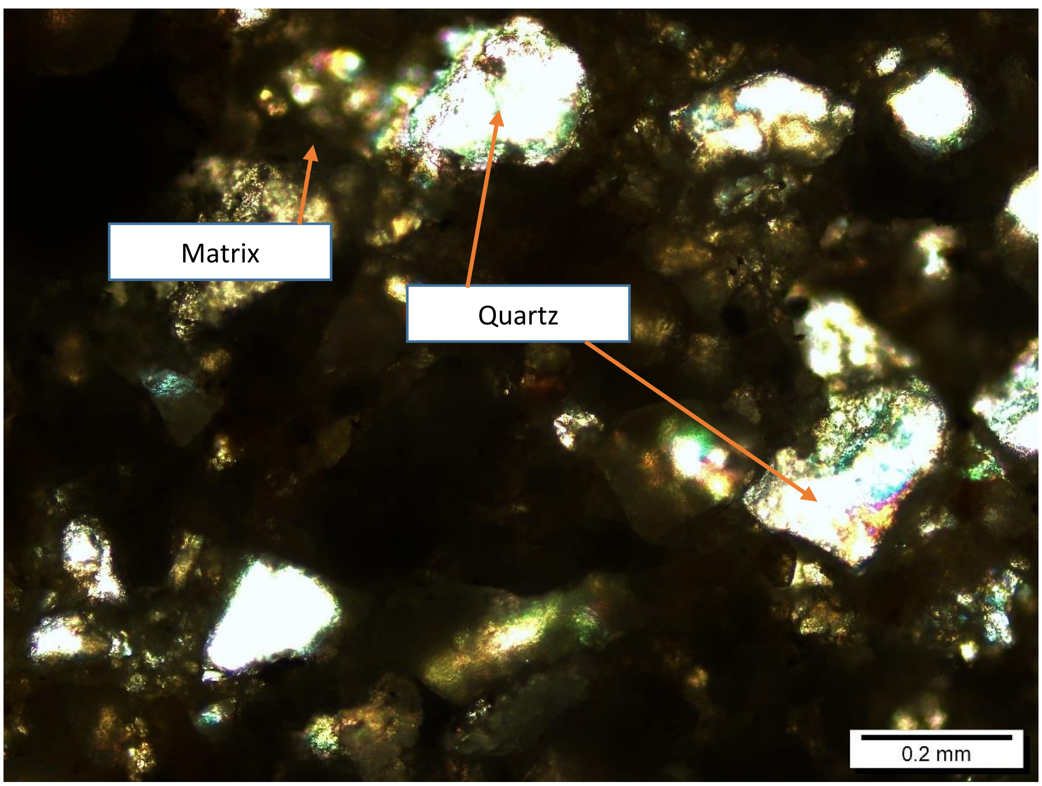

Figure 48 :CROSS POLARIZED LIGHT, STATION 4, SAPULUT FORMATION

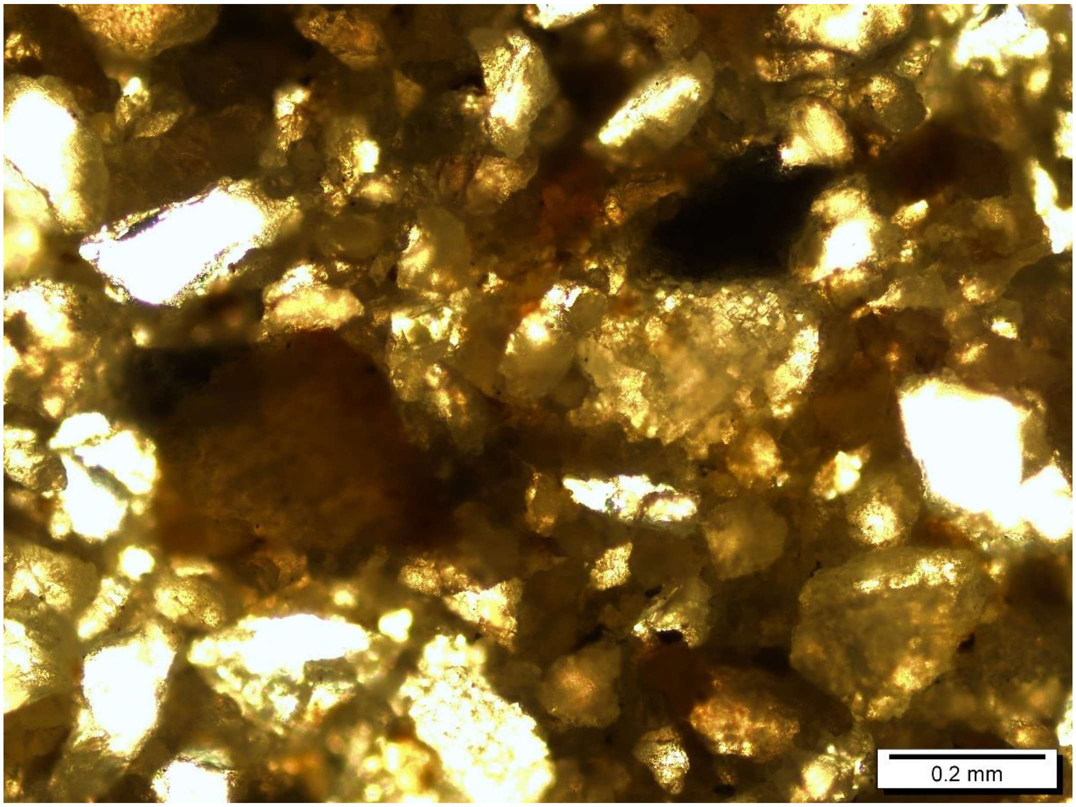

Figure 49 :PLANE POLARIZED LIGHT, STATION 5, SAPULUT FORMATION

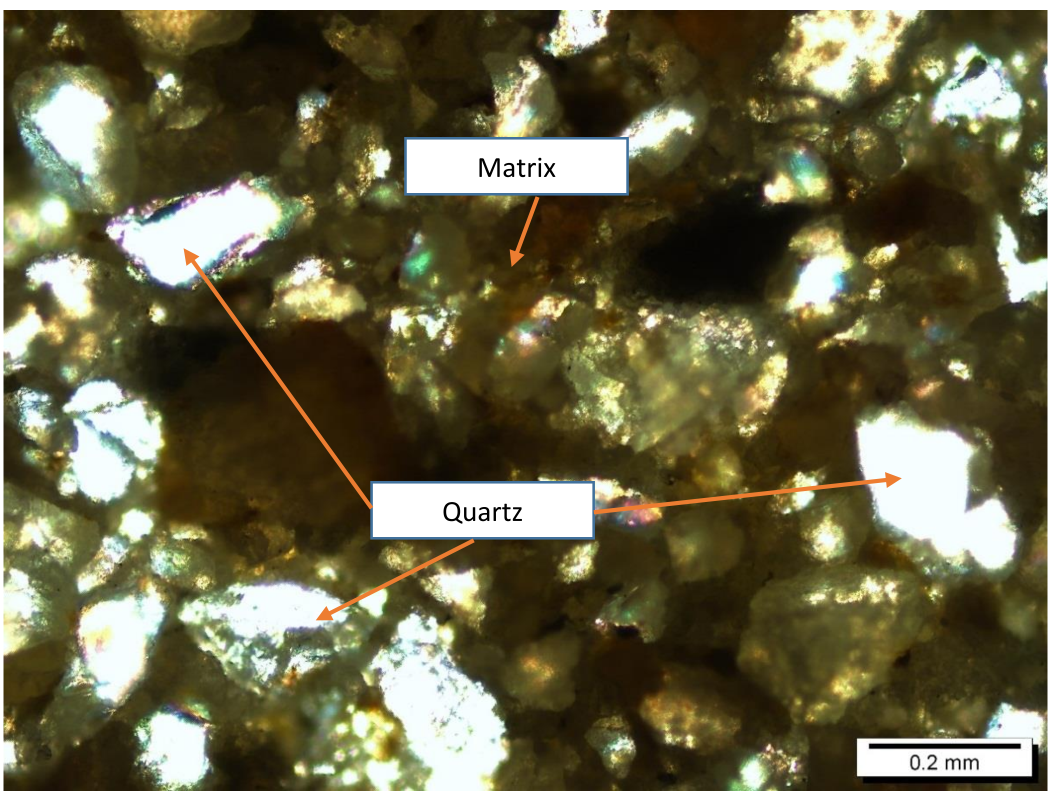

Figure 50 :CROSS POLARIZED LIGHT, STATION 5, SAPULUT FORMATION

Figure 51 :ZOOM-IN FOSSIL OF STATION 2 SANDSTONE, TANJONG FORMATION

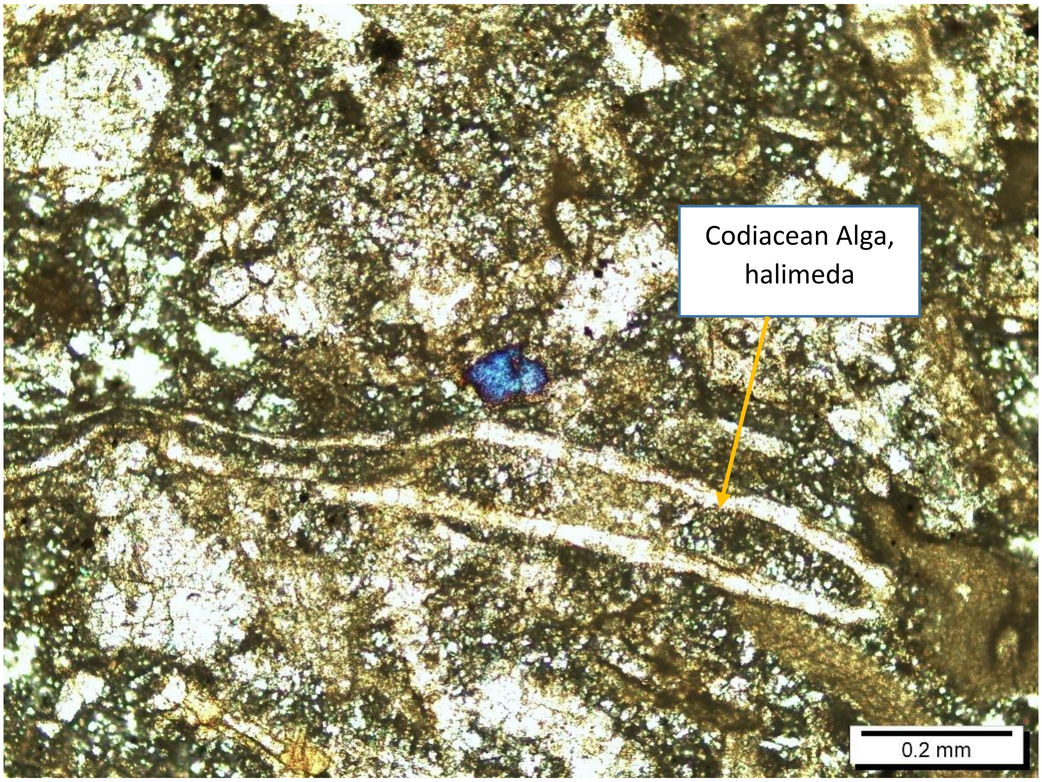

Figure 52 :CROSS POLARIZED ZOOM-IN OF A FOSSIL, STATION 1, TANJONG FORMATION

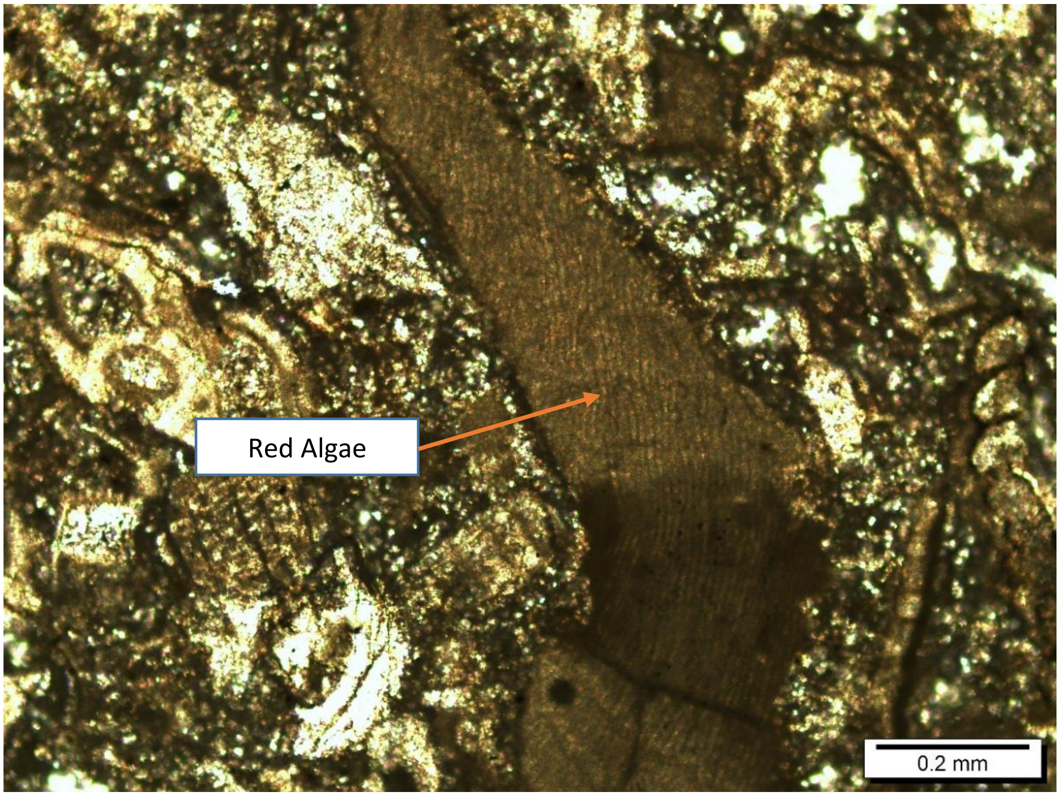

Figure 53 :ZOOM-IN OF A FOSSIL OF STATION 1, TANJONG FORMATION

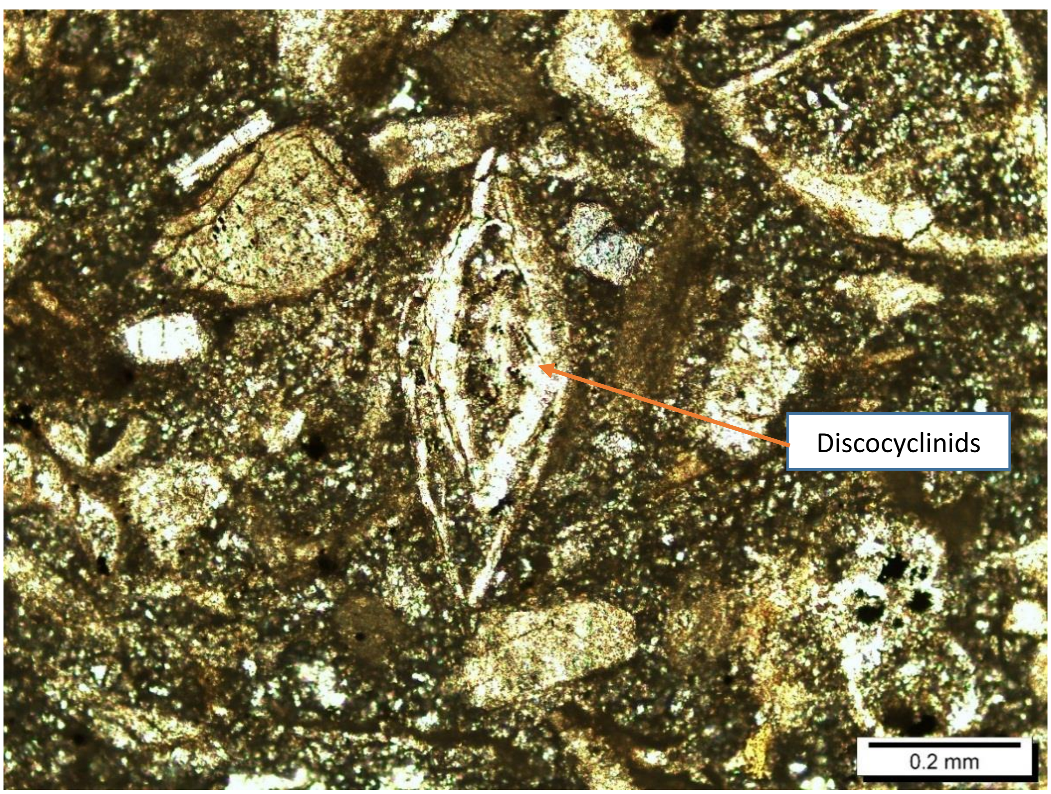

Figure 54 :CROSS POLARIZED ZOOM-IN IMAGE OF A FOSSIL, STATION 1, TANJONG FORMATION

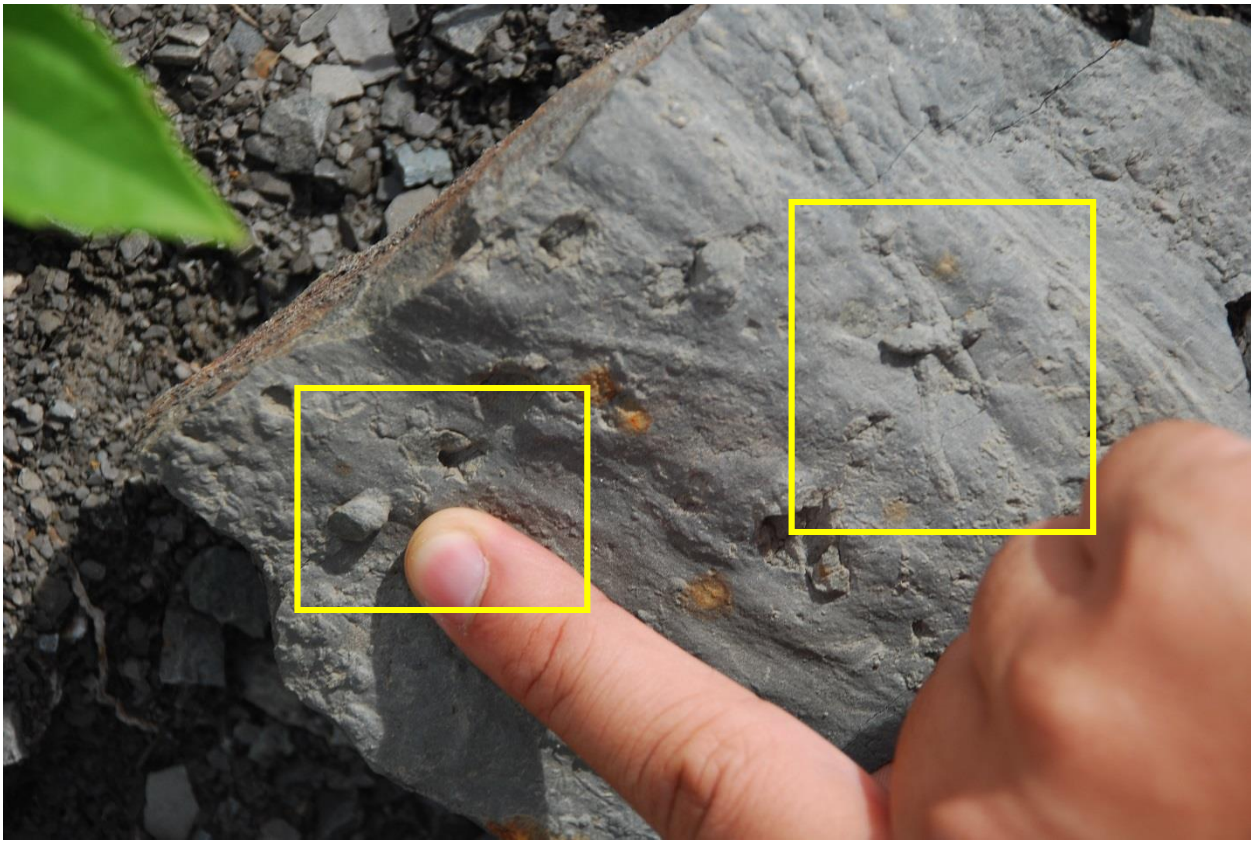

Figure 55 : SKOLITHOS (IN YELLOW BOXES) DISCOVERED AT STATION NUMBER 2, SAPULUT FORMATION.

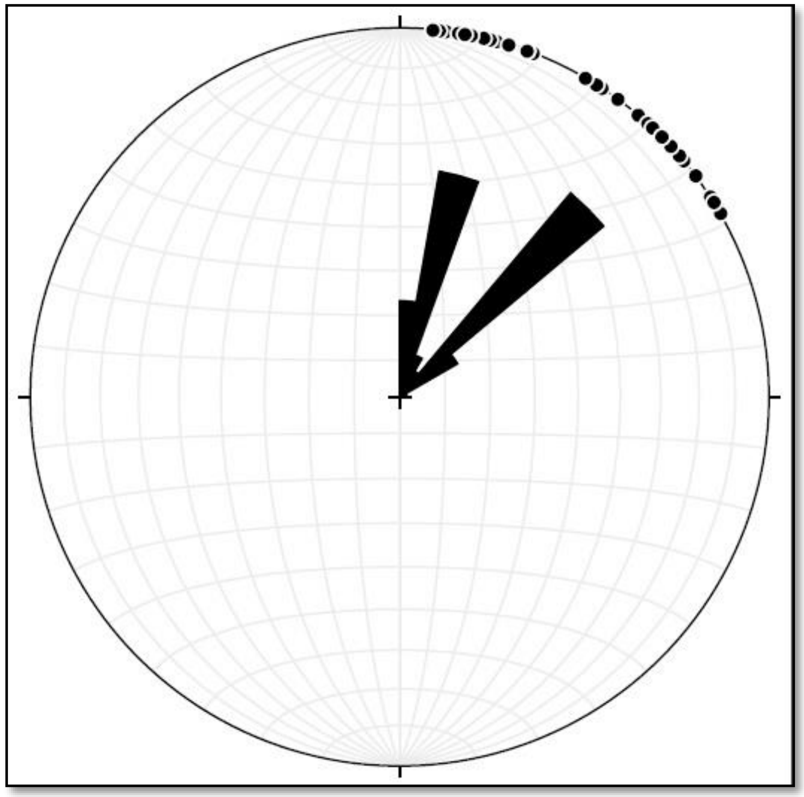

Figure 56 : ROSE DIAGRAM OF THE REGIONAL SABAH LINEAMENT ANALYSIS, THE LINEAMENTS HAVE TWO MAJOR TRENDS: N-S DIRECTION AND NE-SW DIRECTION.

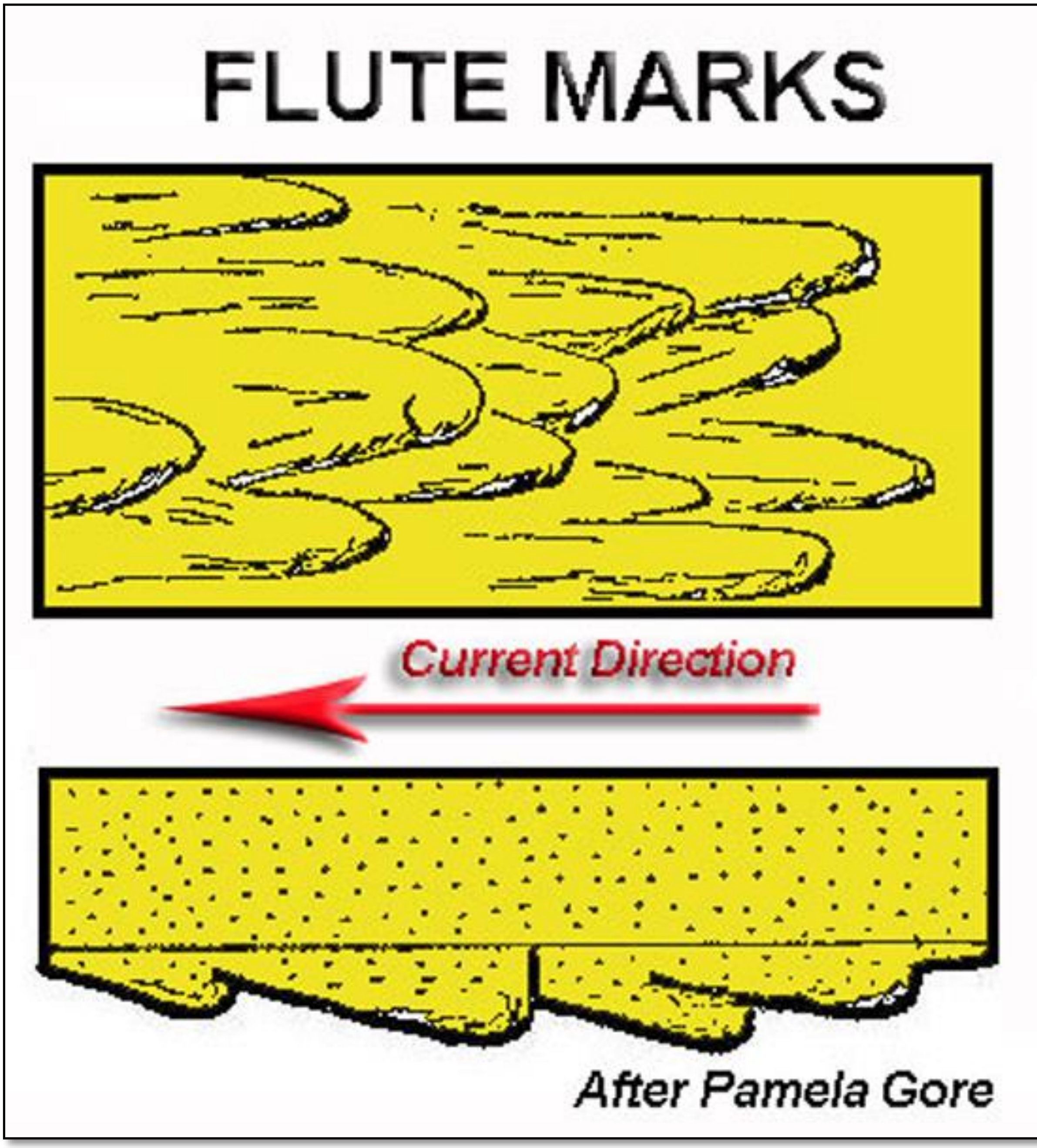

Figure 57 : ILLUSTRATION SHOWING HOW TO DETERMINE THE FLUTE MARKS' PALEOCURRENT DIRECTION. (COURTESY OF PAMELA GORE)

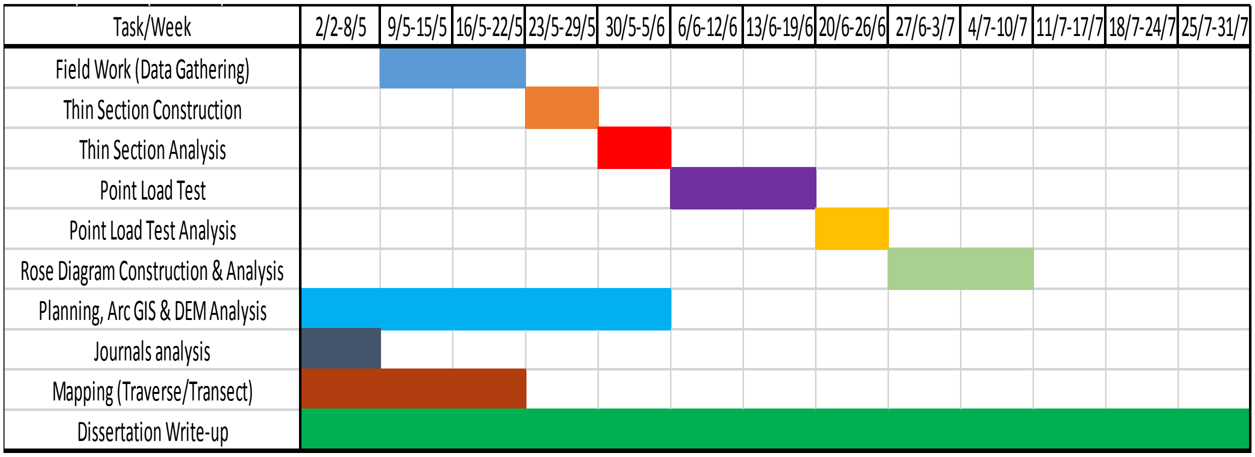

Figure 58 :GANTT CHART OF THE AUTHOR'S FINAL YEAR PROJECT (FYP).