# GENERAL GEOLOGY, DEPOSITIONAL ENVIRONMENT AND PROVENANCE OF BUKIT PANAU, TANAH MERAH, KELANTAN

by

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## DECLARATION

I declare that this thesis entitled General Geology, Depositional Environment and Provenance of Bukit Panau, Tanah Merah, Kelantan is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ______________________________

Name : ______________________________

Date : ______________________________

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## ABSTRACT

The research is focused at the Bukit Panau area which is located at the northern part of Tanah Merah district. It lies between the latitudes of N 05°49'21.25" to N 05°54'11.25" and longitudes from E 102°8'48.75" to 102°11'11.25". Geological mapping and sedimentary analysis have been done to the rock units in the Bukit Panau area by measuring the outcrops exposed at the Bukit Panau area. Lithology and sedimentary structures are the main aspects to differentiate and establish the nature of depositional environment. The Panau Formation sequence is characterized mainly by channel lags, planar cross-stratified sandstone, ripple laminated sandstone, and mudstone and shale in ascending order. The overall succession of Panau Formation sediments suggests that the depositional environment is fluvial environment. The provenance of sedimentary rocks is carried out by plotting on triangular diagram of QFL and classification of provenance types by Dickinson (1985). The provenance of sedimentary rocks from the Bukit Panau area is concluded to be from recycled orogeny.



Key Words: Sedimentary analysis, depositional environment, Bukit Panau, Panau Formation

**General Geologi, Pengendapan Sekitaran dan Asalan Batuan Bukit Panau, Tanah Merah, Kelantan**


## ABSTRAK

Kajian ini tertumpu di kawasan Bukit Panau yang terletak di bahagian utara daerah Tanah Merah. Ia terletak di antara latitud N 05° 49'21.25"kepada N 05° 54'11.25" dan longitud dari E 102° 8'48.75 "kepada 102° 11'11.25". Pemetaan geologi dan analisis sedimen telah dilakukan kepada unit-unit batuan di kawasan Bukit Panau dengan mengukur singkapan yang terdedah di kawasan Bukit Panau. Litologi dan struktur sedimen adalah aspek utama untuk membezakan dan mewujudkan sifat pengendapan sekitaran. Pembentukan urutan Formasi Panau dicirikan terutamanya saluran lag, satah batu pasir silang berstrata, batu pasir berlapis riak, dan batu lumpur dan syal dalam tertib menaik. Pembentukan turutan keseluruhan sedimen Formasi Panau mencadangkan bahawa pengendapan sekitaran adalah persekitaran fluvial. Asalan batuan sedimen dilakukan dengan memetakkan pada rajah segi tiga QFL dan klasifikasi jenis asalan batuan oleh Dickinson (1985). Asalan batuan sedimen dari kawasan Bukit Panau tersebut didapati dari orogeni kitar semula.



Kata Kunci: Analisis sedimen, Pengendapan Sekitaran, Bukit Panau, Formasi Panau

# CHAPTER 1

# INTRODUCTION

## 1.1 General Background

The research is focused at the district of Tanah Merah which is located at the northern part of Kelantan. It lies between the latitudes of 05˚49’21.25” N to 05˚54’11.25” N and longitudes from 102˚8’48.75” E to 102˚11’11.25” E with an area covers about 40 $km^2$. This study area is nearby to the main road which is known as Malaysia Federal Route 129 that connects Tanah Merah to Pasir Mas. Access to the area is by traveling about 20km northeast from the town of Tanah Merah.

Stratigraphic, primary sedimentary structures, and textures preserved in the sequence are the main aspects to differentiate and establish the lithofacies of the rock units in the Panau Formation and to elucidate the means of deposition. Facies analysis is done to the rock units in the Panau Formation by measuring the outcrops that are exposed between Bukit Panau.

According to Tahir and Musta (2007), stratigraphy is a branch of geology that deals with the properties of the earth and the earth’s physics content that deals with the composition of the earth's crust and layers of rocks that is contained within the earth’s crust. The type of rock is focused on rock that has a sequence that can be distinguished from one another. The Malaysia-Thai Working Groups (2006) reported on the arenaceous and argillaceous facies and dated the facies of the Panau

Formation as Cretaceous based on a mappable stratigraphic horizon of Panau Formation that have been delineated and described within this formation.

Boggs (2009) mentioned that the term facies is defined as a body of rock with specified characteristics that reflect the conditions under which it was formed. The sedimentary facies and stratigraphic position of Cretaceous Panau Formation succession can suggest to the development of depositional environment. The succession will be characterized based on sedimentary logs that will be documented with emphasis on the lithology, sandstone thickness, grain size, morphology of the beds contact, sedimentary structures, and internal characteristics. These features will be used to interpret sedimentary rock succession and the depositional will be constructed for the Panau Formation, Kelantan.

**1.2 Problem Statements**

There are few problems related to the study area. Firstly, the problem encountered while conducting this research is that there are relatively few studies about general geology of the study area. Besides, geological details about study area especially regarding to its background is hard to be find. Next, there are only a few studies has been done regarding sedimentology of Panau Formation in the study area. One of previous research was done in that area only focused on the descriptions of the formation itself including lithology, stratigraphy and age.

This study aims to fill research gaps that show a deficiency of geological studies in sedimentology by presenting a sedimentology study for better understanding of the Panau Formation exposed in Bukit Panau. The study focus aims to improve the current understanding of the sediments provenance and petrographic analysis which assists in evaluating depositional environments in the Panau Formation. Therefore, this research is aim to conduct a sedimentology analysis by field studies and to be able to clarify depositional environment interpretation within the study area as well as to extract provenance-related information from petrographic analysis on sediment-grain size distribution.

In addition, the present topographic map of Bukit Panau with 1: 25000 scale found in past research is not updated. Therefore, by the end of this study, an update geological map of study area with 1: 25000 scales is likely to be produced for future research in the study area by carrying out the geological mapping to cover the surrounding area of study area.

## 1.3 Research Objectives

The objectives of the research are:

a) To produce geological map of Bukit Panau of 1:25000 scale.
b) To evaluate depositional environment of the Panau Formation/ Bukit Panau area.
c) To study the provenance of sedimentary rocks in the study area.

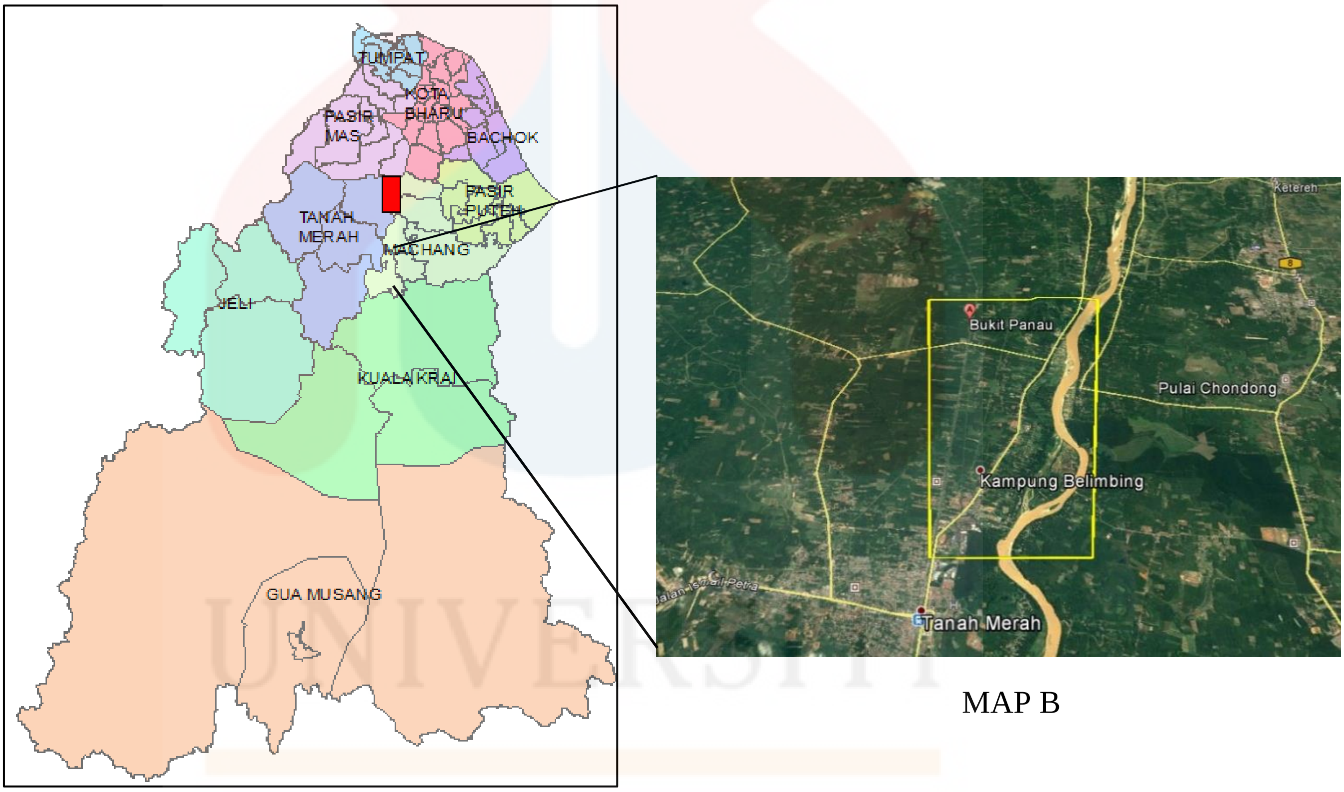
## 1.4 Study Area

### 1.4.1 Location

The study area is located in the northern part of Kelantan. This study area encompasses a small hill namely Bukit Panau which located in the district of Tanah Merah (Figure 1.1). The study area is located at the latitudes of 05˚49’21.25” N to 05˚54’11.25” N and longitudes from 102˚8’48.75” E to 102˚11’11.25” E. Generally, the study area is approximately 40 km$^2$. The study area is located at a distance of approximately 20 km from the town of Tanah Merah. Bukit Panau is situated along

Pasir Mas to Tanah Merah road and separated by Kelantan River with a distance of about 600 meters.

There are several villages that exist in the study area which are Kampung Bechah Kelubi, Kampung Bukit Panau, Kampung Joho, and Kampung Chabang Empat Bukit Panau. Rock formation that made up the study area is recognized as Panau Formation which is believed to be age of Cretaceous based on information stated in Geology of the Batu Melintang-Sungai Kolok Transect Area along the Malaysia-Thailand Border. The base map of the proposed study area is shown in




MAP B

MAP A

**Figure 1.1**: (A) Map of state of Kelantan where the red color in the box represent of the study area (B) yellow box represent the Bukit Panau area in the Tanah Merah District

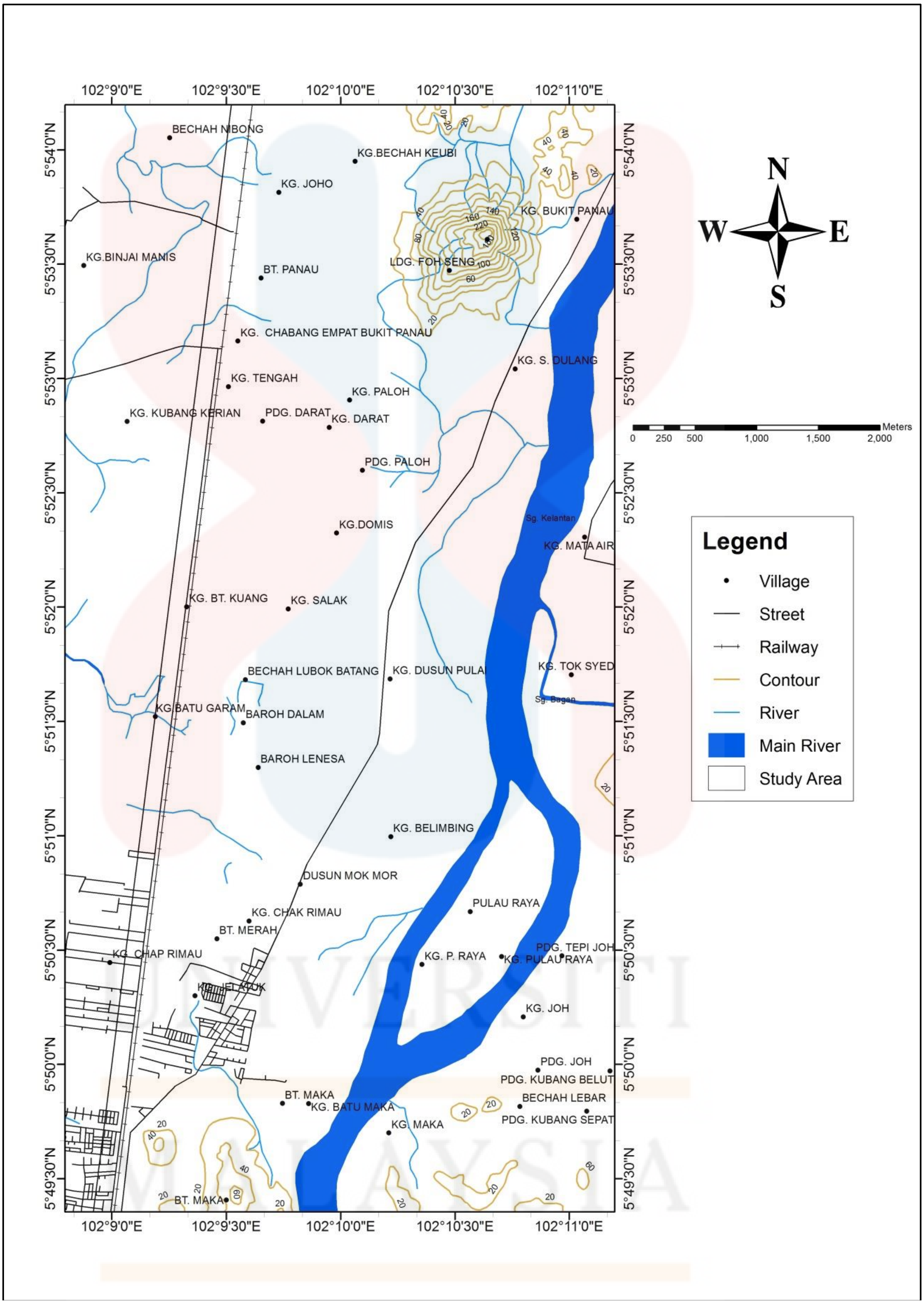



**Figure 1.2**: Base Map of the Bukit Panau, Tanah Merah.

### 1.4.2 Demography

Population census was conducted to determine the number of residents of a given area. Population census data for the area of Bukit Panau is obtained from the official website of Tanah Merah District Council because it is located within the Tanah Merah District. Total population for Tanah Merah is 115,949 people in year of 2010.

Residents in the study area consist of Malay, other Bumiputera, Chinese, Indian and others. Based on the Figure 1.3, the Malay and Chinese ethnics dominate respectively with 95% and 4% of the total population followed by other ethnic groups, Indian, and other Bumiputera.

According to population distribution in Tanah Merah of year 2010 through official website of Tanah Merah district council, Tanah Merah is majority dominated by male which is 58,892 people and female is 57,057 people. The population of male is higher than female with different about 1835 people.

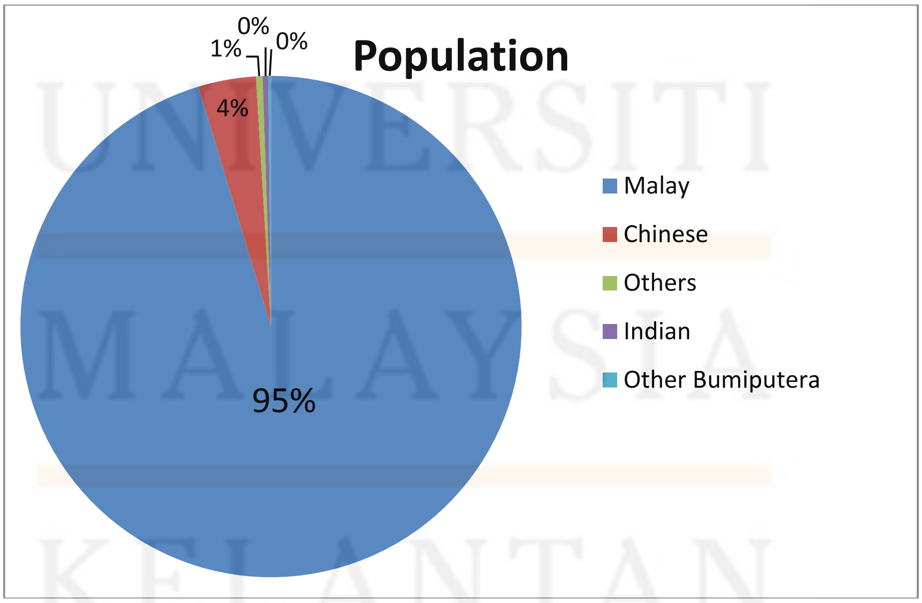



**Figure 1.3:** Population by ethnicity for Tanah Merah district in the year of 2010
(Source: Official Website of Tanah Merah District Council)

### 1.4.3 Rainfall

The study area is located in Tanah Merah area, therefore rainfall distribution data is obtained from the Department of Metereology Malaysia. Based on the bar chart in Figure 1.4, the rainfall data from the nearest station to the study area, which is Pusat Pertanian Batang Merbau shows the average of rainfall distribution in Tanah Merah district for year of 2015, the highest rainfall was in August of 557.6 mm. The monthly rainfall distribution at least for the year of 2015 was in February of 19.8 mm. For year 2016, according to Figure 1.5, the data collected is the rainfall from January to March alone. The highest rainfall was in February of 220.3 mm and the lowest monthly rainfall in March of 21.8 mm.

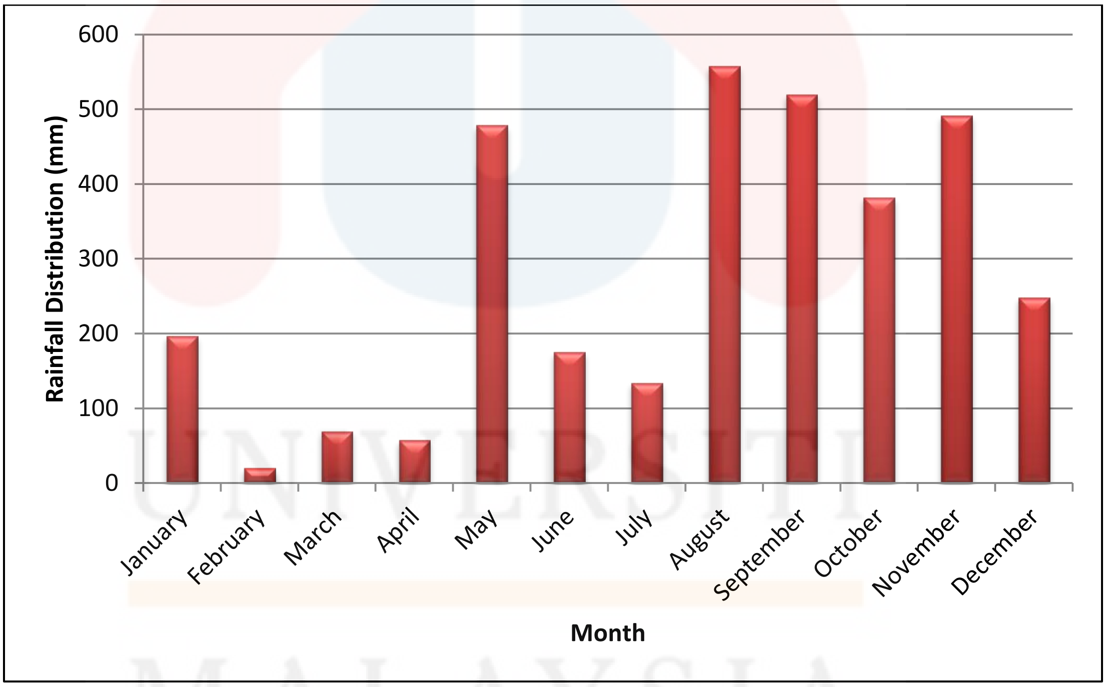



**Figure 1.4**: Average of rainfall distribution in Tanah Merah district for year of 2015 (Source: Department of Meteorology Malaysia)

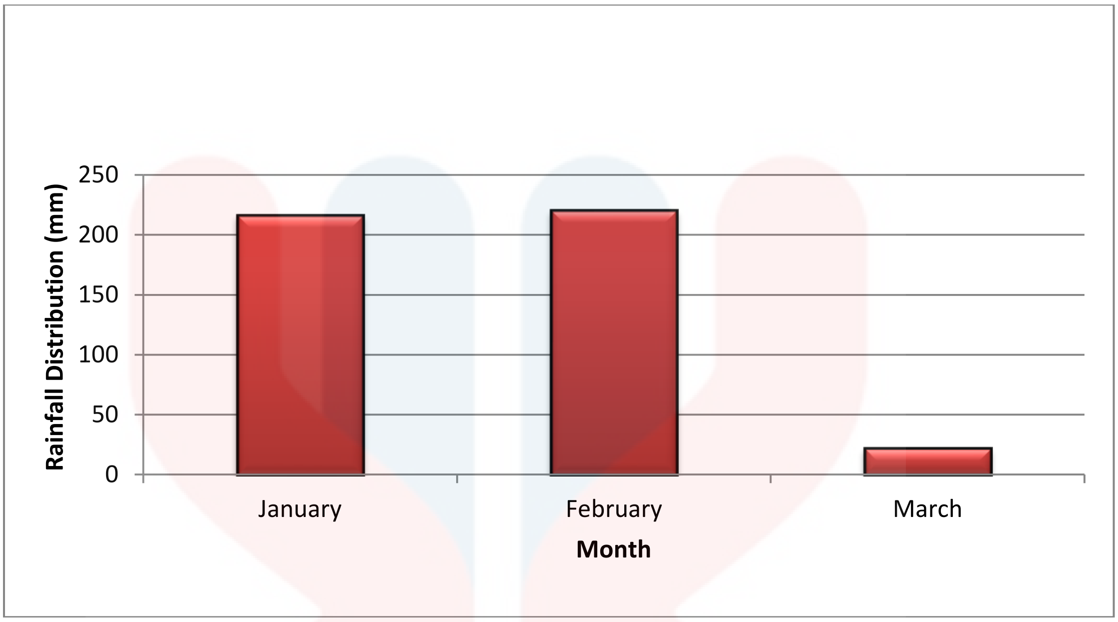


**Figure 1.5**: Average of rainfall distribution in Tanah Merah district for year of 2016 (Source: Department of Metereology of Malaysia)

### 1.4.4 Land Use

About 45% of the land in Kelantan is under state land status, 33% under reserved land, 21% under alienated land and 1% under other status. The category of land use is shown in the generalised land use plan in Table 1.1 below.

**Table 1.1**: Category of Land Use (Source: Kelantan Socio-Economic Profile 2001, State Economic Planning Unit, Kelantan)

| Category | Area (hectare) | Percentage |
|---|---|---|
| Forest Reserve | 894,271 | 59.5% |
| Agriculture | 335,660 | 22.3% |
| Urban | 4,967 | 0.3% |
| Mining | 3,737 | 0.3% |
| Others | 263,565 | 17.6% |
| Total | 1,502,200 | 100% |

About 60% of the state is under forest cover, mainly within state land and reserved land, located in the districts of Jeli, Kuala Krai and Gua Musang in southern Kelantan. Agriculture accounts for another 22% of the land use, being mostly located within alienated land. Urban and mining land is not significant, covering less than 1% of the State.

### 1.4.5 Social Economic

According to Amin *et al.* (2003), the term social economy refers to not-for-profit activity geared towards meeting social needs. The activities can be constitutes of range of services such as training, job and entrepreneurial experience, housing, welfare and consumer services where it provides opportunities for local people and communities to engage in all stages of the process of local economic regeneration and job creation.

Socioeconomic of the study area is divided into three, plantations or farms, businesses and public infrastructure facilities. Based on the observation on study area majority of the people are working as rubber tapper. The rubber plantations which belong to the local people and the worker of these plantations are mostly from the residence nearby.

Total rainfall is sufficient to give fertility to the soil and makes the surrounding area is very suitable for farming and agricultural activities. The agriculture sector is one of the most important sectors due to its economic contribution.


**Figure 1.6**: Rubber plantations by residents in the study area.

### 1.4.6 Accessibility

Communication system is very important to connect and facilitate the movement of local residents to move from one place to another. Based on road connection map in Figure 1.7 and 1.8, Tanah Merah – Pasir Mas road is the paved road that became a key link for accessibility to the Bukit Panau. There are also the small streets that are not paved link to the major highways. The distance between the Bukit Panau to the primary road is approximately about 600 meter. It is easy to find location because the hill of the Bukit Panau can be seen from the far distance and the road connection is in well-developed.

**Figure 1.7**: Paved roads connecting the study area with the nearby town
(GPS: N 05°53'12.3" E 102°10'16.9")

## 1.5 Scope of Study

This study focuses on research about interrelationship between sedimentology processes and different products derived from those processes which then deposited in area of study. Apart from that, this study was conducted with aims to describe and determine depositional environment of the Panau Formation in the selected study area. The aspects looked into were the lithology, sedimentology, stratigraphic, geomorphology, and structural geology elements. A range of methodologies will be used to achieve the desired objectives of this study.

One of the important methods that will assist this study is petrographic analysis of sedimentary rocks found in study area. Thin sections of sedimentary rocks will be observed under polarized microscope to identify sediment composition and mineralogy that made up the particular rocks and to be deduced as rock units.

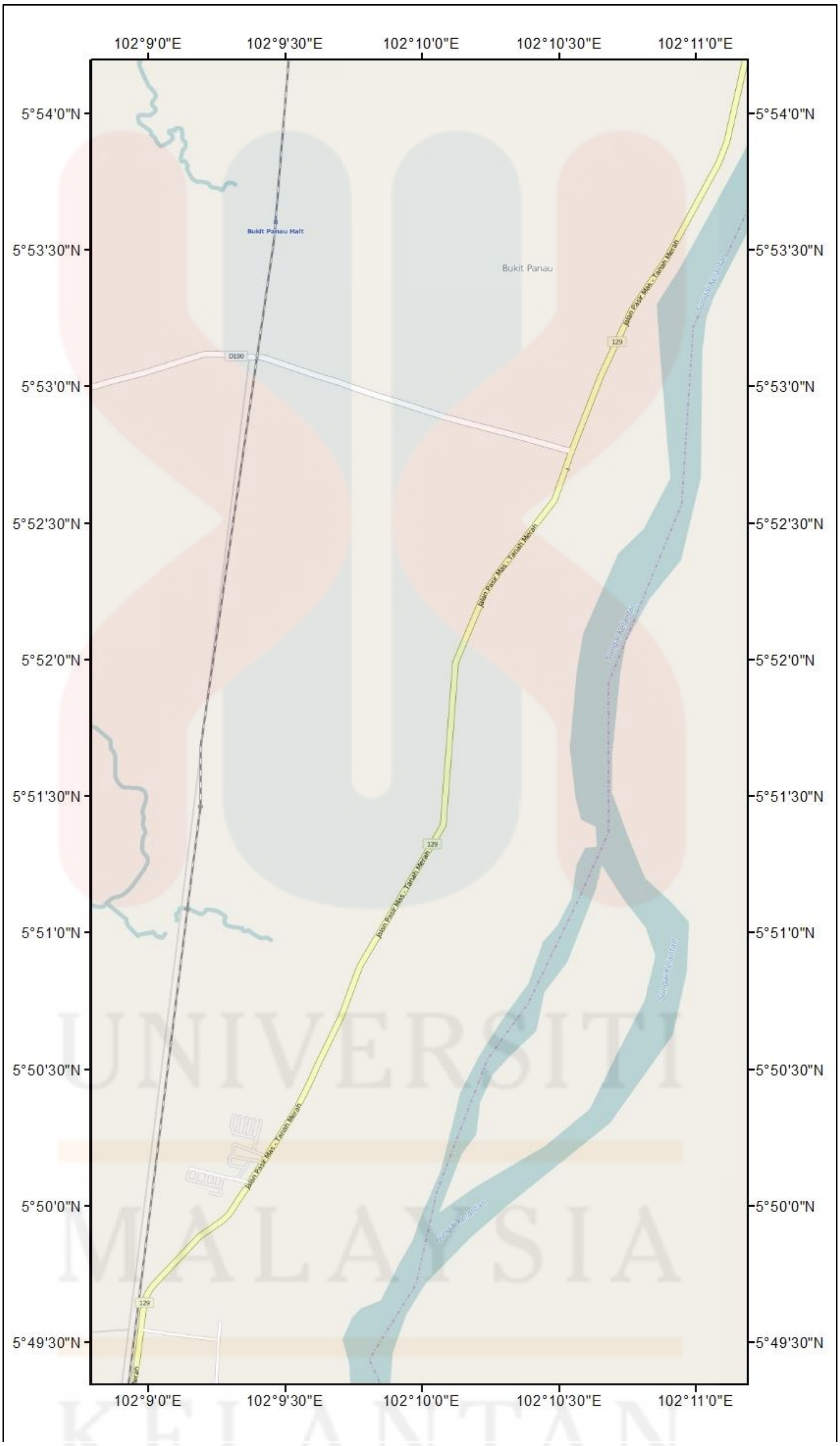



**Figure 1.8**: Road connection map in the study area

Besides, this study also focused on distinguished of lithology unit in sedimentary rock sequences through sedimentary analysis in the study area by collecting particular data in the field from sedimentary succession that can be found in the study area. Results obtained from sedimentary analysis of study area have implications for evaluating depositional environments of the study area.

## 1.6 Research Importance

The sedimentology and stratigraphy of study area will be described and summarized by integrating the sedimentology facies and depositional environment within study area. Based on the study of sedimentology of rocks and sediments, and stratigraphic within the study area, a correlation between ancient sedimentology environments with a process that has occurred in the study area can be established.

The sedimentology aspects of the formation in study area will also be described in details. This study will eventually prove the relationship between the processes by which deposition occurs and the products of those processes to extend the description and interpretation of depositional processes. On the other hand, this study will be dedicated to identification of paleo-depositional environments in study area with a better understanding. All other elements of geology include lithology, sedimentology, stratigraphy, structural geology and geomorphology aspects will be proposed.

# CHAPTER 2

# LITERATURE REVIEWS

## 2.1 Introduction

The study of literature is a source of information that is obtained based on studies of previous researchers. This chapter will discuss aspects such as regional geology, stratigraphy and sedimentology of the study area around Tanah Merah district, Kelantan. Geographical, sedimentological and stratigraphic aspects closely related to each other for providing information related to exogenous and endogenous events that occurred in the study area.

The study of the geographical aspect is more focused on the geological processes that occurred in the study area. This study covers the tectonic history of the region, sedimentology, stratigraphy and study of rock units. The study area involves Panau Formation underlying the area of the Bukit Panau.

In previous studies, there are a few works had been done in this area including geology (e.g. MacDonald, 1967; the Malaysian and Thai Working Groups, 2006), and lithology and stratigraphy of the Panau Formation (e.g. Jamaluddin and Abdul Rahman, 2014). However, no studies have been reported on depositional environment and provenance of sedimentary rocks.

## 2.2 Regional Geology and Tectonic Setting

According to Khoo and Tan (1983), Peninsular Malaysia can be divided into three longitudinal belts, Western, Central and Eastern, each of which has its own distinctive characteristics and geological development. Besides, Hutchinson (1977) also mentioned that Peninsular can be subdivided in four major tectonic regions – the Western Stable Shelf, the Main Range Belt, the Central Graben, and the Eastern Belt. Peninsular Malaysia is part of the Sunda plate, which is a combination of continental blocks and microcontinent of Sibumasu and Indochina. Both of the blocks continents come from the Northeast of Gondwana but at different times.

A tectonic model made by Metcalfe (2006) shows that Malay Peninsular is divided into two tectonic blocks (Figure 2.1). Stauffer (1974) named these blocks as the East and West Malaya Blocks. The two blocks merge together along the suture line known as Raub-Bentong Suture during the Lower Triassic about 240 million years ago. The Raub-Bentong suture line was proposed by Hutchison (1973) as the major tectonic boundary between the western and central belts of Peninsular Malaysia (Tjia et al., 1996).

According to Tjia (2009), the formation of the fault lines in Malay Peninsula is associated with the collision of the Indian Plate and Eurasian Plate, which produced major shear faults towards the east and the southeast in Southeast Asia. The major fault lines in the western part of Malay Peninsula consist of Kuala Lumpur Fault, Bukit Tinggi Fault, Seremban Fault, Karak Fault, Bok Bak Fault and Kledang Fault. Meanwhile, in the eastern part consist of Terengganu Fault, Lebir Fault, Lepar Fault and Mersing Fault (Chai et al., 2011). They are mainly sinistral strike-slip with significant dip-slip components as shown by quartz reefs along their length (Hutchison and Tan, 2009).

Recent trends on the structure of Northwest-Southeast of Peninsular Malaysia accompanied by the formation of massive amounts of granite is resulted from the deformation that occurs during Late Triassic to Early Jurassic of about 200 million years ago. These granite rocks occupy almost half of the peninsular and eventually forming a major range notably in the Main Range. The granite of the Main Range Belt is commonly coarsely porphyritic and was emplaced throughout the Permian and Triassic orogenic event in a deep seated environment during which all the older strata were folded and deformed. The Bentong Suture in southwest Kelantan is 18 km wide. Its western border is an injection complex with Titiwangsa granitoids, its eastern border consists of bedded chert (Hutchinson, 2007).

Kelantan is located in northeastern of Malaysia which is adjacent to the South China Sea (to the north and east) and the international Thailand border to the west (Environmental Earth Sciences, 2015). The regional geology of Kelantan consists of a central zone of sedimentary and metasedimentary rocks bordered on the west and east by granites of the Main Range and Boundary Range respectively (Goh *et al.*, 2006). In Peninsular Malaysia, there are a few major faults in which one of the fault, the Lebir fault strike through Kelantan state (Hutchinson, 2007). Based on the information in Geological Evolution of South-east Asia by Hutchinson (2007), the Lebir fault, the eastern and western margin of the Central Belt covers the entire state of Kelantan.

Tectonically, state of Kelantan is derived from four microplates known as Eastern Malaya Plate, Western Malaya Plate, South China Sea Plate and Natuna Sea Plate. The earliest sediment formed during Silurian period on the land of Kelantan on the edge of Western Malaya Plate which is under the oceans. The process of diagenesis took place within these sediment materials led to formation of mudstone (shale) graptolites, chert quartzite, conglomerate and limestone which known as Bentong Formation rocks (Sources derived from the website of Department of Minerals and Geosciences Kelantan).

The Eastern Malaya Plate moves towards West Malaya Plate at the same time sediments were deposited on the marine environment during Devonian period. Deep-sea deposits can be identified and found in the northern part of Kelantan. These sediments were overlying on top of the rock of Bentong Formation inconsistently. Tectonic activity was interpreted to actively begin as there are few of rhyolite's flows derived from the arc volcanic islands in the sea along with the deposition of sediments (Sources derived from the website of Department of Minerals and Geosciences Kelantan).

Based on the information obtained from website of Department of Minerals and Geosciences Kelantan, deposition of deep-sea sediment materials and volcanic has ended on Carboniferous period about 290 million years ago. During Permian, the whole area in Kelantan became unstable because of a movement of oceanic plates subduction that eventually formed the South China Sea under East Malaya Plate. This condition causes the intruding magma at eastern part and the formation of the volcanic arc in the southern part. Magma intrusion formed igneous batholith of Eastern Range at the eastern part of Kelantan.

In the late Permian, subduction stopped but move away from the plate to the movement that resulted in the expansion zone in the western part of Kelantan. This expansion causes the formation of zones of amphibolite and serpentinite rock in Bentong Formation. This expansion zone associated with Bentong suture that runs from Thailand to Padang Lalang Sumatera (Sources derived from the website of Department of Minerals and Geosciences Kelantan).

Intrusion of batholith granite lifting the side plates of East Malaya formed the mountains and at the same time produce a shallow sea called the Tethys Sea. The sea is formed between the plate of East Malaya and plate of West Malaya. Sedimentation of argillite-arenite and rhyolite volcanic rocks occurs in the ocean (Sources derived from the website of Department of Minerals and Geosciences Kelantan)

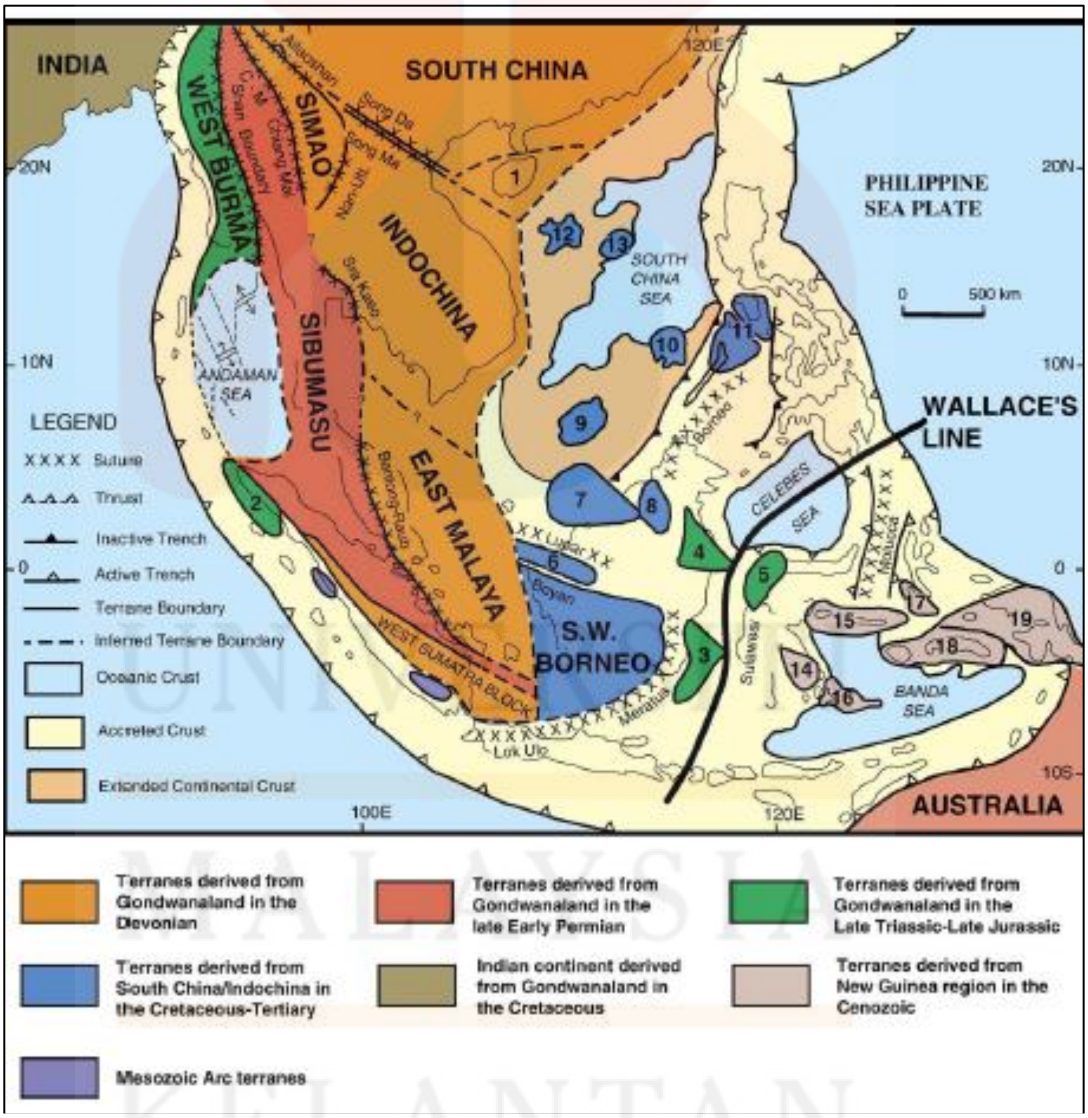


**Figure 2.1**: Distribution of continental blocks, fragments and terranes, and principal sutures of Southeast Asia (Source: Metcalfe, 2006)

## 2.3 Historical Geology

Kelantan state is the second large state in the Peninsular Malaysia. The study area, the Bukit Panau is located in Tanah Merah district which is a town and territory in Kelantan. On the northern side of this town stands Bukit Panau, a barren hill of rocks and deceptive stone-steps running more than 200 metres high.

The formation of the Bukit Panau is started from Mesozoic Era. This resulted from the rocks found in this area. Most of the rock in the Bukit Panau area is dominated by sedimentary rocks.

The plant fossils found in the Bukit Panau indicated the age of the strata. The fragments of *Frenelopsis* sp., *Otozamites* sp., *Calamites* sp., and *Pecopteris* sp. are found with shale layers in the study area (The Malaysian and Thai Working Groups, 2006). These fossils play important roles as index fossils in determining the age of the marine Cretaceous rock formations in Peninsular Malaysia.

## 2.4 Stratigraphy

According to Tahir & Musta (2007), stratigraphy is a branch of geology that deals with the properties of the earth and the earth's physics content that deals with the composition of the earth's crust and layers of rocks contained within the earth's crust. The type of rock is focused on rock that has a sequence that can be distinguished from one another. Another meaning of the stratigraphy is that it is a branch of geology that describes the composition of rock layers that have been formed to represent a space and time.

Based on the stratigraphic record and characteristics, Figure 2.2 shows the area of Peninsular Malaysia is divided into four stratigraphic zones, (i) northwestern zone, (ii) western zone, (iii) central zone, and (iv) eastern zone (Foo, 1983).

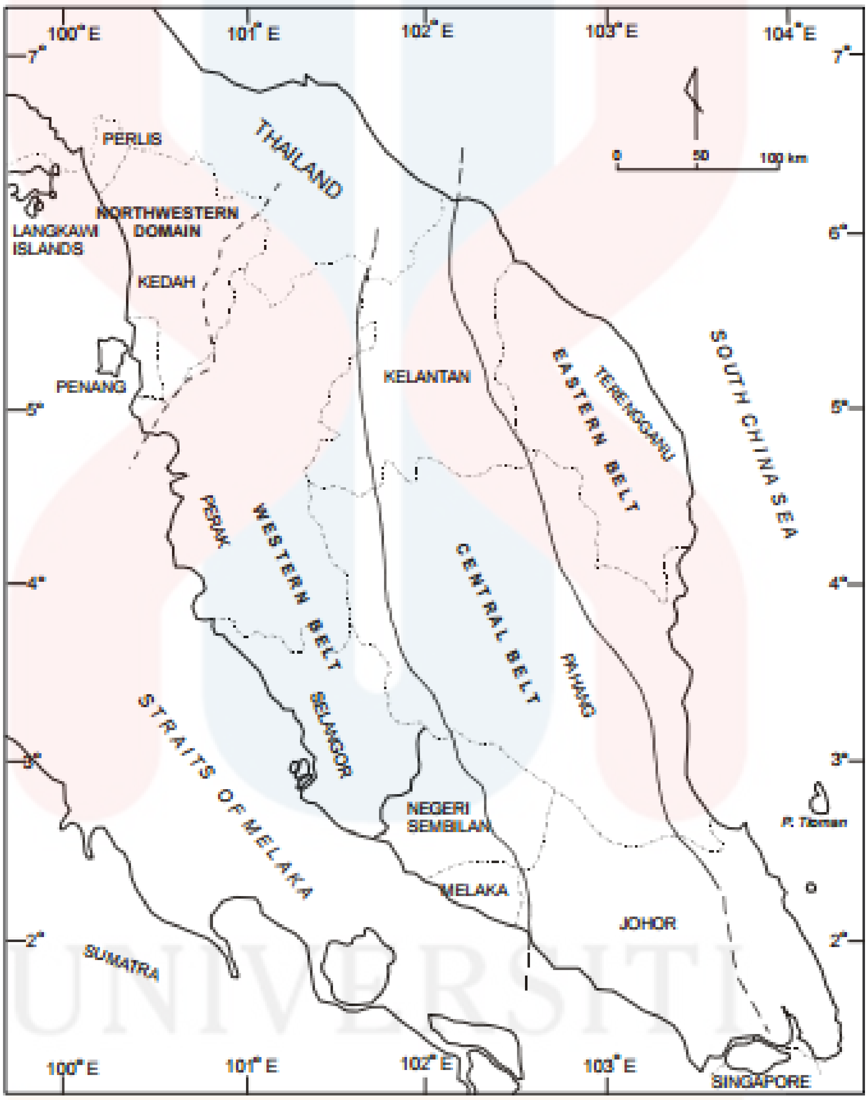



**Figure 2.2**: The three "Belts" of the Peninsular Malaysia and the northwestern domain within the Western Belt (Foo, 1983)

Based on the record in book of 'Geology of Peninsular Malaysia', about 25 percent of Paleozoic rock outcrops can be found in different parts of Peninsular Malaysia and are well distributed in all three belts. The oldest rocks and most complete sequence from Cambrian to Permian are found in the Northwestern

Domain of the Western Belt which consists of Machincang Formation, Setul Formation, Kubang Pasu and Singa Formation and Chuping Formation.

In Kelantan, the Paleozoic rocks can be observed as the Central Belt stretches from Kelantan to Johor. Upper Paleozoic rocks dominated the Gua Musang and Aring Formations in south Kelantan and Taku Schist in east Kelantan. These Upper Paleozoic rocks are predominantly of argillaceous rocks, as well as with subordinate arenaceous and calcareous sediments (Foo, 1983). In 1925, Savage described the wide occurrence of schist in Kelantan known as the Taku Schists which were ascribed to be equivalent to the sedimentary rocks occurring in the nearby area (Reported in Islami, 2012).

According to Khoo & Tan (1983), the Mesozoic system in Peninsular Malaysia is distributed in two separate basins, one on each side of the Main Range. The larger of these occur in a continuous outcrop along the axial belt of the Peninsula running from the north in the state of Kelantan to the south in the state of Johor. The smaller one is at the extreme northeast, in three separate outcrops aligned north to south, from Kedah to south Perak. This continues into southern Thailand.

Islami (2012) reported about Scrivenor who mentioned in his book, 'The Geology of Malaya', the division of the rocks of Peninsular into three major geological components: The Carboniferous – Permian 'Calcareous Series', the Triassic 'Arenaceous series', and Mesozoic granite. She also mentioned that sedimentary rocks were classified as Carboniferous-Permian or Triassic. The rocks of Kelantan State were included in all the three units. Furthermore, Mohamed (2006) divided the southern Kelantan stratigraphically into four areas: Kuala Betis, Gua Musang, Aring and Gunung Gagau.

### 2.4.1 The Panau Formation

The Panau Formation exposed 10km north of the Tanah Merah town. This formation which filled with continental sediments and channel lag deposits is divisible into two lithofacies namely arenaceous and argillaceous facies. Arenaceous facies comprises of predominantly grey to maroon fine- to coarse-grained poorly sorted graded sandstone with subordinate graded grit, maroon paraconglomerate and very thin- to thin-bedded maroon shale, mudstone and siltstone. Meanwhile, the argillaceous facies comprise light grey to grey plant fragment bearing shale, siliceous shale, mudstone and thin-bed of fine grained sandstone and siltstone (The Malaysian and Thai Working Groups, 2006).

The thickness of the Panau Formation beds is varies from 1.0cm to 1.5m. The base of the formation is characterized by Triassic granite due to volcanic activity in the past. After then, the Cretaceous Panau Formation continental, channel lag deposit, sedimentary rocks overlie the granite that eventually caused nonconformity between them. The nonconformity represents the boundary which exposed and can be observed at an abandoned rock quarry at the foothill of Bukit Panau (The Malaysian and Thai Working Groups, 2006).

The Malaysian and Thai Working Groups (2006) stated that the sandstones are arkosic due to high content of feldspar which is mostly altered to kaolinite. This indicates that the provenance of the rock unit come from nearby Boundary Range Granite.

### 2.4.2 Lithology of the Panau Formation

Based on information described in Geology of The Batu Melintang-Sungai Kolok Transect Area along The Malaysia – Thailand Border (2006), detailed lithology of the Panau formation comprises of thin interbedded of argillite, laminated fine-grained sandstone, poorly sorted pebbly sandstone and paraconglomerate. Some of the argillite rocks which are the sandstone beds have channel lenses within it. The argillite rock consists of maroon, sandy shale and some pebbly sandstone and light greyish to light brownish siliceous shale. This rock unit shown the coarsening upward sequence is predominantly by the sandy shale, in which sand-sized quartz grains can be observed towards the top part of the bed.

Meanwhile, the arenaceous rock of the Panau Formation consists of light grey poorly sorted sandstone, mostly pebbly and laminated fine-grained sandstone. The pebbles within the pebbly sandstone are up to 3 cm in diameter. Some sandstone beds show graded bedding. The clasts are angular to subrounded. The laminated fine-grained sandstone exhibits cross bedding which can be observed at the foothill and peak of Bukit Panau. The interbedding of laminated fine-grained sandstone with grey to reddish grey shale can be observed at the foothill of Bukit Panau (The Malaysian and Thai Working Groups, 2006).

**2.5 Structural Geology**

According to Metcalfe (2013), Malay Peninsular has experienced varies of degree and style of deformation regarding 'apparent complexly deformed rocks that may represent sedimentary deformation with superimposed deformation. The evidence that the Peninsular comprises two different tectonic blocks derived from Gondwana at different times which then amalgamated by convergent tectonics, by destruction of the main Paleo-Tethys ocean and a back-arc ocean basin, indicates that a range of deformational styles and ages are expected relating to rifting, subduction, collision, and post collision trans-tension and trans-compression.

According to Metcalfe (2013), Paleozoic rocks of the Malay Peninsular are multiply deformed, exhibit refolded folds, and generally exhibit three phases of folding. This includes Permian rocks, along the Bentong-Raub suture zone that exhibit refolded folds and has yielded Middle Permian conodonts. Middle Triassic and younger strata in the Peninsular generally exhibit a single phase of double plunging upright to asymmetric folds. In addition, an angular unconformity, between isoclinally folded Permian strata and open-upright folded or relatively flat-lying Middle–Upper Triassic marine and Jurassic continental sediments is known in the Central and Eastern Belts of the Peninsular. The most significant structural discontinuity observed in the Malay Peninsula is thus found in the Paleozoic–Mesozoic transition. This has been interpreted as the age of the main orogenic mountain building phase in the Peninsular.

Major faults occurred in the Malay Peninsular has undergone complex repeated movements including both sinistral and dextral movements along the faults (Metcalfe, 2013). Major N–S trending faults in the Peninsular are interpreted as the earliest and related to oblique amalgamation of Sibumasu and the Sukhothai Arc in the Permian to Triassic age. Meanwhile, NNW–SSE major dextral faults are interpreted to be Late Triassic–Jurassic which resulted in the opening of the Jurassic–Cretaceous continental pull-apart basins. Reactivation of these faults as sinistral strike slip faults synchronous with emplacement of several granitoids bodies such as Kemahang and Noring Granites including metamorphic Stong Complex, and deformation of red bed sequences were emplaced in the Cretaceous age. Most faults that cut the Main Range granites shown to be a significant time of folding and faulting in the Malay Peninsula being dated as Middle to Late Cretaceous age (Mustaffa, 2009a &2009b).

## 2.6 Sedimentology

Sedimentology advanced as the observational element in the whole range of natural environments that exist today. It concerned primarily with formation of sedimentary rocks which focusing on the process of diagenesis, erosion and accretion, and deposition. Sedimentology may be approached descriptively, as petrography and provenance analysis. The aim of this study is to describe and evaluate the depositional environment of the Panau Formation by integrating the sedimentary rock sequences characteristics and also determine the provenance of sedimentary rocks at the Bukit Panau area. Sedimentary rocks are the result of geomorphologic processes such as weathering and erosion as well as sedimentation processes, originates from pre-existing igneous and metamorphic rocks, and previously deposited sediments that have been broken down physically and chemically. The various types of sedimentary rocks are classified according to the type of weathering product from which they form.

Grain size characteristics of sediments reflect depositional conditions and processes and thus depositional environments as they exhibit different grain-size properties that distinguish them from sediments of different environments. The grain-size characteristics information can be used to interpret ancient depositional environments.

In Peninsular Malaysia, the oldest sedimentary sequences are found in the northwest portion of Peninsular Malaysia and indicate a Late Cambrian age. These sequences are characterized by bedded sands mixed with small amount of mud, silts and pebbles indicating a shallow water depositional environment.

During Silurian period, as the sea continued to transgress southwards thick successions of limestone and graptolitic shale were deposited under deeper shelf – like conditions (Rajah and Yin 1980). Then, a mild orogeny occurred during upper Silurian-Lower Devonian. Post-orogenic sedimentary sequences exhibit unconformities in the Western Basin, but in other basins sedimentation was uninterrupted from Devonian until Carboniferous. It is shown by the sequences predominantly of limestone in the south part and non-calcareous material in the north (Gan, 1980, Rajah and Yin, 1980).

An upper Carboniferous-Lower Permian orogeny disrupted the deposition and resulting in granitic emplacement in many parts of Peninsular Malaysia. Sediments are mainly calcareous during Permian. In the Lower Permian, sedimentation was restricted. Meanwhile in the Middle Permian, the sea has transgressed to the southern part of Peninsular Malaysia. Tuff and lesser flows of acid to intermediate composition are found in the sedimentary sequences of the Central and Eastern Basins towards Late Permian. During Upper Permian, sedimentation become restricted again and marked the beginning of another orogeny which reaches its peak during Lower Triassic. During Upper Permian-Lower Triassic orogeny, the large scale granitic intrusions and the rise of volcanic island arc also occurred (Rajah and Yin, 1980).

In Middle Triassic, limestone is common but the strata became more argillaceous and arenaceous. The Middle and Upper Triassic sequences are characterized by flysch type sedimentation. Deposition in the Central and Eastern basins occurred simultaneously with widespread volcanic activity with the eruption of andesite and other intermediate to acid tuff and lavas. The Upper Triassic orogeny which is accompanied by granitic intrusions has changed all sedimentary basins into landmass and consequently accounts for the continental character of Post-Triassic sediments. Sediments are widespread and are described as molasses during Upper Triassic to Lower Jurassic. Sandstones, conglomerates and shale with minor coal layer and volcanic made up these sediments.

Tertiary rocks are typically carbonaceous and crop out as small out-linear trending north-south in the western portion of Peninsular Malaysia. They lie unconformably over the older beds and are non-marine. Meanwhile, the older Quaternary sediments are semi consolidated fluviatile and grade into less consolidated ones (Gan, 1980).

## 2.7 Petrography

According to Hamzah (1989), petrography is a branch of science that covers aspects of decomposition of the mineral that exists in the systematic classification of rocks. Petrographic analysis was conducted to classify rock types based on the mineral content and texture of rock samples taken in the field. This analysis is to produce thin sections and analyzed using an optical microscope under magnification four or ten times.

Sedimentary petrology is a particular branch of study that concerned especially with the composition, characteristics, and origins of sediments and sedimentary rocks. It is concerned also with the relationship of these properties to depositional conditions and provenance. Sedimentary rocks possess special genetic significance in terms of their texture, structures, composition, and fossil content. Through petrography, it is an essential method for analyzing sedimentary rock properties as it gives to a revealing of the nature of past surface environments on the earth's surface.

Texture of sediments is concerned with the grain size and its distribution, morphology, surface features of grains, and the fabric of the sediments. The mechanisms and environments of deposition will be able to interpret by considering the important aspect of sediments which is its texture. Thus, the texture of many sedimentary rocks can only be studied adequately under a microscope and thin sections.

## 2.8 Depositional Environment

Reineck & Singh (2012) stated that a depositional environment can be defined as a geomorphic unit in which deposition takes places. They mentioned that such place of deposition is characterized by a unique set of physical, biological, and chemical processes operating at a specified rate and intensity which impart sufficient imprint on the sediment deposited at a particular place, so that a characteristics deposit is produced. As the depositional environments vary from place to place, so does the type of sediment deposited. The presence of sedimentary rocks in the study area indicates the history of the source area which may also construct the depositional environment that responsible for sedimentation of rock particles in the past.

The study of sedimentary sequences is closely related to depositional processes and environments. Sedimentary sequence interpretation is often facilitated by considering the vertical facies succession. Where there is a conformable vertical succession of facies, with no major breaks, the facies are the products of environments which were originally laterally adjacent. This concept has been appreciated since Johannes Walther expounded his Law of Facies in 1894. In the studied sedimentary sequences, it is often found that groups of facies occur together to form facies associations. These groups of facies genetically related to one another and which have some environmental significance can be designate as a facies association. Facies associations are thought to be environmentally related in which they are generally deposited in the same broad environment, in which there are several different depositional processes operating.

Dominant lithologies that present at the sediment outcrop in the study area and their sedimentological characteristics interplays with each other to determine particular paleodepositional environment within certain geological factors.

Concepts of Sedimentology and Depositional Environments

Early sedimentological studies of the Panau Formation were hampered by poor exposure, and uncertainties in stratigraphic position. Sedimentologically, the Panau Formation is predominantly composed of grey to maroon coloured, thin to thickly bedded clastic sedimentary rocks such as sandstones, mudstone, siltstone, conglomerate and shale (The Malaysian and Thai Working Groups, 2006). The recently exposed area at foothill and peak of Bukit Panau and surrounding area were used to conduct a detailed description of depositional environment interpretation.

For this study, most of the data used for defining the depositional environment encountered in the study area come from surface investigation through field studies and descriptions of features that related to sedimentary sequences. Sedimentary log and petrographic analysis should provide a detailed record of sedimentary environments that existed during the formation of Panau Formation in the past. Sedimentary sequence descriptions will be followed by discussion of the depositional process and environments. Interpretation of the various depositional environments will depend on comparison of sedimentary logs from the Panau Formation in the study area.

## 2.9 Provenance of Sedimentary Rocks

Provenance of sedimentary rocks refers to all characteristics of a sediment or sedimentary rock source area, including source area composition, location and relief. Provenance studies are aimed to reconstruct source area geology which will test the relationships between modern sediments in the Bukit Panau area and its past sources. Geomorphologic process like weathering, erosion, transporting and deposition has led to refining of source area from the final deposition of the sediments to the source area. Provenance studies are important in understanding paleogeography and help interpretation of past environment in study area.

Increasing applications of sandstone petrography in provenance studies led to the use of triangular QFL and QmFLt diagrams (Figure 2.3) of sandstone components to distinguish the tectonic setting of the sediment source (Dickinson and Suczek, 1979). The QFL diagram plots quartz of polycrystalline (Qp) and monocrystalline (Qm) grains together with feldspar and lithic fragments. Meanwhile, the QmFLt diagram plots only monocrystalline quartz with feldspar and lithic fragments.

Dickinson and Suczek (1979) suggest that triangular QFL and QmFLt diagrams for plotting point counts of composition of sandstones can be classified into fields that are characteristic of sandstone suites derived from the different types of provenance terranes which depend on plate tectonics setting. Three main classes of provenance are termed as “continental blocks,” “magmatic arcs,” and “recycled orogens”.

Continental blocks composed of sediment sources which are on shields and platforms or in faulted basement blocks. Continental blocks can be subdivided into craton interior, transitional continental and uplifted basement provenance. Magmatic arc provenances composed of sediments that eroded from arc orogens. These arc-derived sediments can be subdivided into those eroded from undissected arcs which are nearly continuous volcanic cover, dissected arcs in which cogenetic plutons are widely exposed, and from transitional arcs between those two. Recycled orogens provenances are uplifted terranes of folded and faulted strata comprised of recycled sediments of sedimentary or metasedimentary origin. The recycled orogens are subdivided into subduction complex, collision orogens formed by crustal collision between continental blocks, and foreland uplifts (Dickinson and Suczek, 1979).

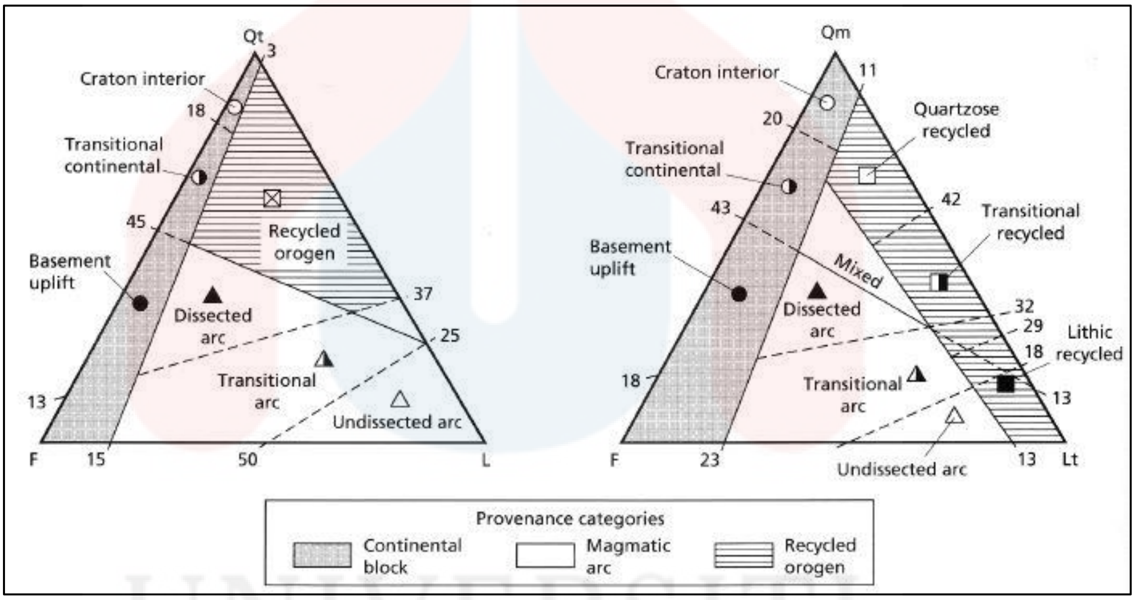



**Figure 2.3**: Triangular diagrams showing average compositions of sand derived from different provenance terranes (Dickinson, 1985).

# CHAPTER 3

# MATERIALS AND METHODOLOGY

## 3.1 Introduction

The method that has been used in order to carry out this study is described under this chapter. In order to complete this study, a few methods is going to be used to make sure that the study can be done in systematic way. Figure 3.1 illustrates the flow chart of methods that will be used in this research.

## 3.2 Preliminary Study

Preliminary study is an earlier study that is mostly influence of the entire study carried out on the early stages by narrow things down and writes a reasonable scope for the topic by gathering information about study area involving the methodology, objective and also the title of the study itself in order to have better understanding about the study area which is the Bukit Panau located in the Tanah Merah district.

The first stage in the research involved gathering all previous research through thesis, journal and reading previous studies and reports that was done before in study area in order to get general knowledge of the study area so that the next step of field study will be ease. In addition, a study through the google maps was done to get the satellite view of the recent condition such as any change across landscape or changes in river channel of the study area. The purpose of this is as the addition data to be added up in the making of base map. For the information about the topography of study area and all the information such as land used, people distribution, road connection, social economy and other relatable information was getting from the Tanah Merah District Council.

### 3.3 Materials

There are a few tools needed and prepared for the field studies. Apart from typical equipment such as field book, clipboard, pens, pencils and marker pen, the basic materials when go to a field study includes a base map, grain size chart, hand lens, compass, GPS (Global Positioning System), a small bottle containing dilute hydrochloric acid, measuring tape, sample bags, geological hammer, lithology sheets and digital camera is compulsory.

#### 3.3.1 Topographic map (base map)

Interpretation of topographic maps is made in order to produce base maps before conducting field work. Base map is important as a guide for gathering information and for use to mark the strike and dip measurements to produce cross section as well as to record the geometric features such as folds, fractures or faults. For the preparation of the base map of the study area, topographic data sources can be obtained from the Department of Survey and Mapping (DSSM). Base map generated using the method of tracing through CorelDRAW 12 and ArcGIS software. Important elements in the preparation of the base map are the contour line, communication systems, drainage and settlement.

#### 3.3.2 Global Positioning System (GPS)

The most important equipment of a field geologist is the GPS receiver. GPS is a satellite based navigation system comprising three basic parts; the satellites in space, monitoring stations on earth and the GPS receivers. This equipment is used in

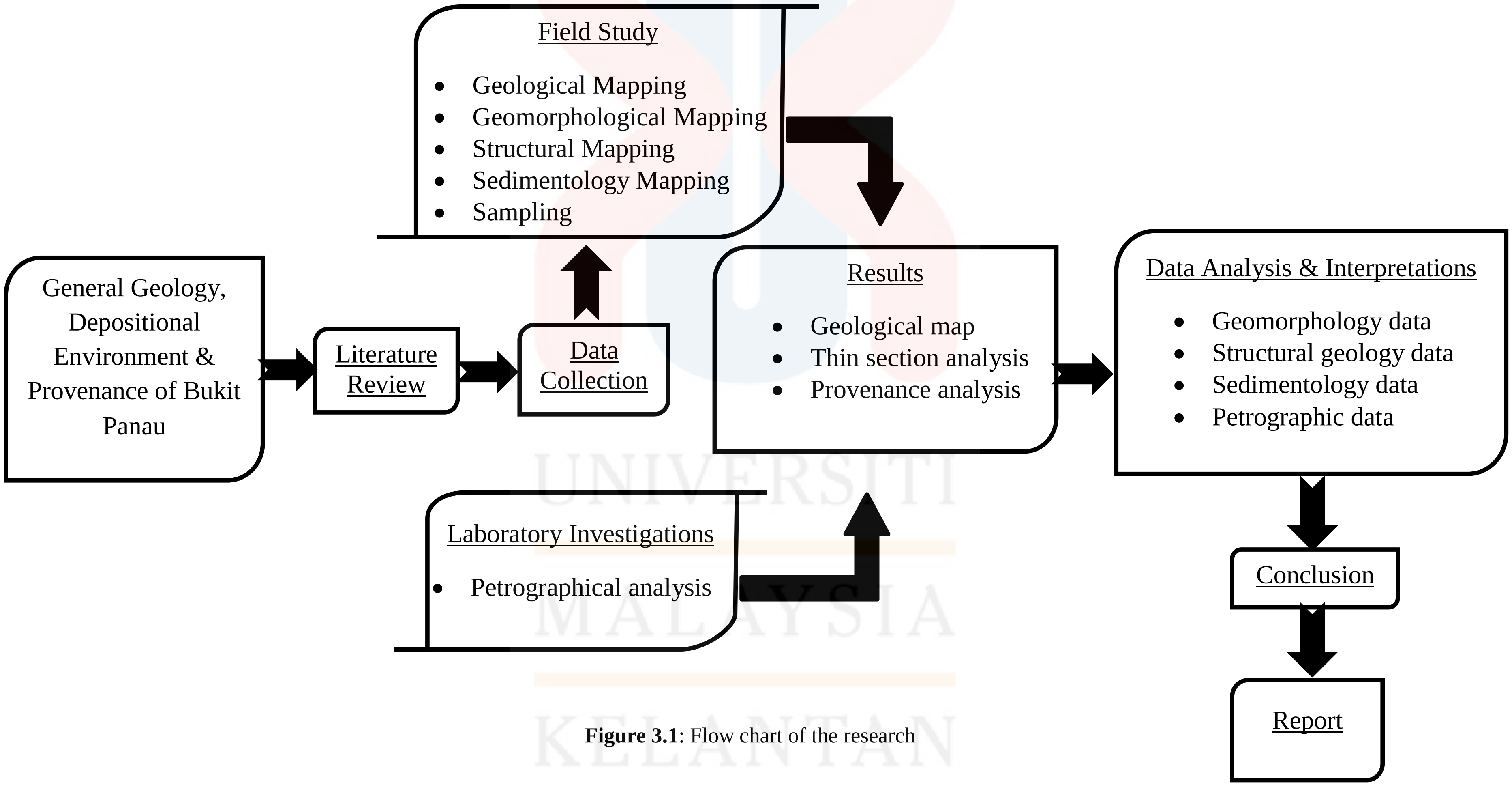



**Figure 3.1**: Flow chart of the research

geological field mapping by recording the track in the field area. It is also used to follow traverse line that has been determined and the interval of traverse track recording can be manipulated in GPS.

The device is also used to mark the point of intersect in term of longitude, latitude and elevation of the map, for finding ones position, mapping lithology, tracking structures, storing sampling points and descriptions of formations when samples are collected.

**3.3.3 Hammer**

Hammer is a tool used mainly by geologist to obtain rock specimens for laboratory work and for chipping away weathered rock surfaces. The best geological hammers are the chisel-tip rock hammer, the one that has a hammer head made of hardened steel on one end and a slightly curved chisel-shaped blade on the other and a rubber coated shock reduction handle.

The flat end of this hammer is used for breaking rocks and light chisel work. The chisel end is used for splitting the layers of sedimentary rocks, trimming rocks and digging in soils and sediments. Without a hammer, geologist cannot take rock sample from the outcrop.

**3.3.4 Compass**

Compass is an important tool in mapping. It is an instrument used to get directional degree measurements (azimuth) through use of the Earth's magnetic field. Other than that, compass is used to measure strike direction and dip value of a surface of exposed outcrop. It is also used in following traverse line in order to go to the pointed point as it can be set to the planned direction. Direction of the tilted bed is taken in azimuthal reading as it can prevent errors in reading.

### 3.3.5 Hydrochloric acid (HCL)

Hydrochloric acid (HCL) is used to test on limestone rock where calcite minerals need to be distinguished. Limestone rock will produce gas bubble or the rock will fizzes as a result of reaction between HCL and calcite mineral in the rock when hydrochloric acid is applied to it.

### 3.3.6 Hand lens

Hand lenses also play important role in geologist because by using it, first analysis of rock samples in the field can be made before performing further analysis in the laboratories. It was used to observe and determine features like mineral grain and grain shape of the rock in the field. A magnification of between 7 and 10 times is probably the most useful.

### 3.3.7 Sample bag

Geological sample bags are a must have item when go to field where it used to carry the collection of rock sample from site to laboratory. Sample number and location point of every rock samples taken is remarked or labelled on the outside of the sample bags that contain the rock samples by using permanent marker pen.

### 3.3.8 Measuring tape

Measuring tape is used to measure size of exposed outcrop in the field. It is also useful in taking actual measurement of bed thickness or other geology information. Features such as bed thickness, joint spacing can be accurately recorded.

### 3.3.9 Digital Camera

Digital camera is used to record picture of the exposed outcrop in the field. It is very important to take photographs of all interesting features ensuring a scale is used in each instance. It is necessary to take a GPS reading for each photograph taken. Photographs are important for descriptive purposes especially during report writing and for making presentations.

### 3.3.10 Lithology Sheets

Lithology sheet refers to graphic log that is used to collect and record field data of sediments and sedimentary rocks by constructing a graphic log of a succession. It is recommended to prepare the log sheets before going to field studies. Features that it is needed to record which require columns on the log sheet are bed or rock unit thickness, lithology, texture, sedimentary structures, colour and fossils. Visual display from these lithology sheets assists in the interpretation of particular succession.

## 3.4 Methodologies

### 3.4.1 Field Studies

Field study or field work is the most important method in a geological study in order to achieve the objectives of this study. As the field work is done, data can be gathered and direct observation can be done as well as geological map of the study area can be completed. Field works are including mapping and traversing are the most effective method for obtaining data and materials that can be used for further analysis of the study area. Without geological mapping, sample cannot be obtained. The method also can give direct information about structural geology of the study area. Other than that, the field work also more accurate than desk studies which only guided by theories and not the real things compared to field work. In order to achieve the desired goals in this study that are to identify each facies and depositional environment within study area, the following methods will be described.

i) **General Geological Mapping**

General geological mapping was done on 1:25000 scales to obtain general geology information such as topography and drainage system of the study area. The field data that were taken during field study includes locality details and sketches, lithology, texture and colour of the rock, bedding, and sedimentary structures of outcrop in proposed study area. Moreover, traversing is also one of method of covering the study area that are required by observing the topographical map and is set by passing the point of interest in the study area. It is a method that is usually made by walking from one point on map to another and recorded by using GPS. All data such as strike and dip of structures and outcrop properties are marked the point of interest along the traverses.

ii) **Geomorphological Analysis**

According to Djauhari (2014), American Geological Institute defined geomorphology as the study of changes in the earth and is generally defined as the study of nature, which include landforms and the changes that occurred during the evolution and the relationship with the underlying structures, and history of geological changes that are shown or depicted on the terrain.

Geomorphological study is mainly focus on morphological characteristics such as landforms and other geologically remarkable area as well as processes that reworks on its surface including the geomorphological processes, geomorphological features, lithology and structure within study area through mapping in the field to generate an overview of the area.

iii) **Structural Analysis**

According to Hills (2012), structural geology is among the branches of geological science that lies in the recognition, representation, and genetic interpretation of rock structures. Geological processes and mechanisms of structure formation such as folds, layers, faults, joints and cracks that formed as a result of the deformation of the Earth's crust movement and interaction.

For detailed geological work, mapping is normally carried out at scales of 1:25000, and it will be possible to record most of the important geometric features of faults, folds and fractures. Having arrived at an outcrop, other than identify lithological type and any general features of the rocks, tectonically produced structures such as joints, lineations, cleavages and folds are important deformation marker to be take note while conducting structural analysis.

iv) **Sedimentology and Provenance Analysis**

According to Tucker (2011), there are six aspects of sedimentary rocks to consider in the field which should be recorded in as much as detail as possible. These are the lithology, that is the composition of the sediment; the texture, referring to the features and arrangements of the grains in the sediment; the sedimentary structures, present on bedding surfaces and within beds; the colour of the sediments; the geometry of the beds or rock units to each other; and the distribution of fossils contained within the sedimentary rocks.

Sediments and sedimentary rocks will be identify together with the process of transport and deposition that take place within study area through the field visits according to the various attributes of a sedimentary rock which combine to define a facies, which is the product of a particular depositional environment.

Sedimentary sequence identification and sedimentary analysis are the next steps after the field data have been collected. All the aspects of sedimentary attributes of a succession were examined in detail to look closely for similar attributes. There are a relatively small number of distinct sediment types with similar attributes which will be under the same facies.

### 3.4.2 Sampling

Sampling is an important aspect because the sample taken from the field will be used to carry out laboratory experiments. For sedimentary laboratory investigations, the sample of the study area involved is in situ rocks which are fresh, unweathered and representative of the lithology. Rock samples collected in the study area are for the purposes of petrographic studies to identify the minerals present in the rocks. The sample collection for bed sediment focuses on obtaining samples of fine-grained surficial sediments from natural depositional zones during low-flow conditions and on compositing samples from several depositional zones within a stream reach.

### 3.4.3 Laboratory Investigations

Each rock samples taken from the field was made into thin section by applying the standard method of preparing thin section. Thin sections were used to investigate texture and composition of rock samples for detailed description. A selection of thin section material made from various geological samples for viewing under a petrological microscope. The thin sections are prepared for all the rock types to describe the texture mineralogy, alteration and deformation.

Siliciclastic sedimentary rocks samples taken from the study area were selected for provenance analyses. Provenance analyses permit to accurate calculation of the mineral contents of rocks which were carried out using point-counting technique in sedimentary petrology and were performed by using light polarized microscope. The samples were observed to minerals and mineral groups which are commonly found in sediments as provenance analyses require the nature, compositional and textural modifications of sedimentary rocks in order to track the relation between parent-rock assemblages of sandstone and the environment conditions under which sediments formed

## 3.5 Data Analysis and Interpretations

The data that obtained from the field such as geological data and photograph are considered as resource material. Analysis and interpretation of the data was based on the information obtained from library research, field studies and laboratory analysis and the results of the analysis are presented through and tests that have been performed and analyzed as well as interpretations obtained through observations in the field, or derived from certain agencies.

### 3.5.1 Geomorphology Data

Interpretation and description of landforms and geomorphological process including the lithology in the study area to show erosion of the outcrops as a whole are dependent on the scale of 1:25000 used for data collection.

### 3.5.2 Structural data

Interpretation and description of deformations, geological structures and its orientations, and in-situ measurements as well as relationships between these geological structure and landform.

### 3.5.3 Sedimentology data

Interpretation of sediments and sedimentary rocks characteristics were made in terms of transport and depositional processes and determining the environment in which they deposited.

### 3.5.4 Petrographic & Provenance data

Interpretations of types of sedimentary rock were done by analyzing the observed thin sections by using the Pettijohn classification for sandstones and Dickinson & Suezcek classification for provenance of sedimentary rocks that were done to deduce the characteristics of source areas from measurements of compositional and textural properties of sediments.

## 3.6 Report Writing

Writing a dissertation is the last step in this study and produced based on the analysis and interpretation is done through observations in the field, or derived from certain agencies. All data are as complete as the interpretation of data from earlier studies, field studies, maps, diagrams, photographs and an appropriate schedule and results from laboratory studies completed for the preparation of this dissertation. The writing of this dissertation includes six chapters as follows:

a) Chapter 1: Introduction

b) Chapter 2: Literature Reviews

c) Chapter 3: Materials and Methods

d) Chapter 4: General Geology

e) Chapter 5: Depositional Environment and Provenance of the Bukit Panau, Tanah Merah, Kelantan

f) Chapter 6: Conclusion and Recommendation

The thesis contains six chapters. The first chapter consists of the introduction to this research which is describing the background of the study. The second chapter discusses the literature study on the tectonic settings of Peninsular Malaysia and the geographical aspects relating to the establishment and exogenous events that occurred in the study area including stratigraphic studies of the study area. The third chapter is about the data collection and analysis of laboratory as well as field work to be done. The fourth chapter discusses in detail the general geology regarding to the study area. The fifth chapter contains the analysis of the laboratory processing results and the interpretation of depositional environment as well as the provenance of sedimentary rocks. The sixth chapter is the conclusion inclusive of the recommendation for the improvement of this research in the future. Relevant information that has not been included in the chapters is appended at the end of the thesis.

# CHAPTER 4

# GENERAL GEOLOGY

## 4.1 Introduction

This chapter will discussed geology that consists of geomorphology, stratigraphy, structural geology and historical geology of the study area of the Bukit Panau area, Tanah Merah, Kelantan. The relationship among these scopes will be identified. The identification and discussion will support by previous study on this topic. Information and data from various sources collected, analyzed and presented in this chapter.

The geological mapping in the study area was carried out mainly by traversing any area that can be access by all mean within the study area. Traverse is important in geological mapping as to delineate type of rocks, geological structures and occurrence of minerals. Traverse in geological mapping was supported by sampling rocks that present in the study area for petrographic studies. Accessible route which either newly merge or already exist were mapped in the traverse line map of the Bukit Panau area (Figure 4.2).

Based on study that conducted at the Bukit Panau area, most of the area is used for agriculture by the influence of total rainfall in that area which is sufficient to be supplied for the agriculture activities.

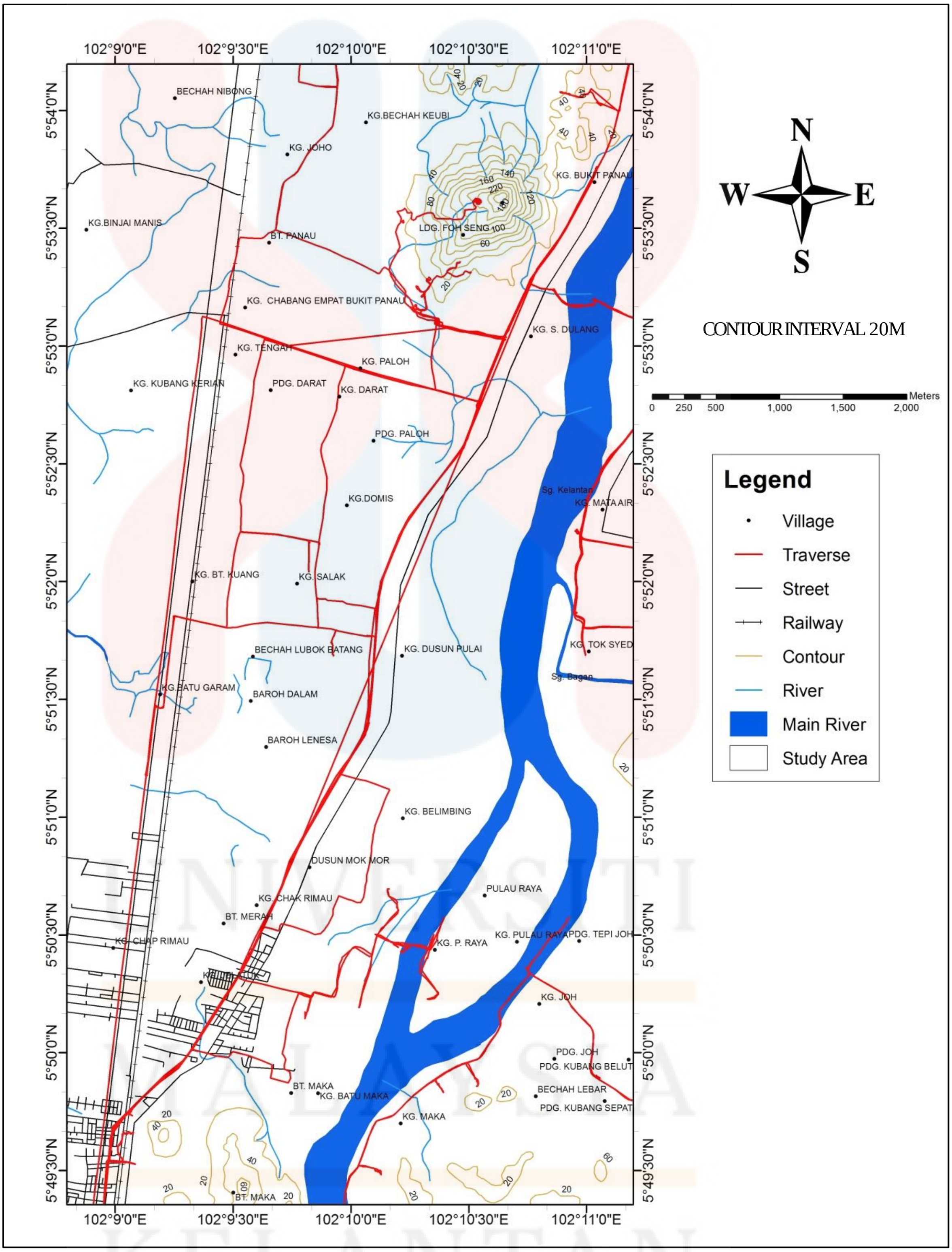



**Figure 4.1**: Traverse line of the Bukit Panau area.

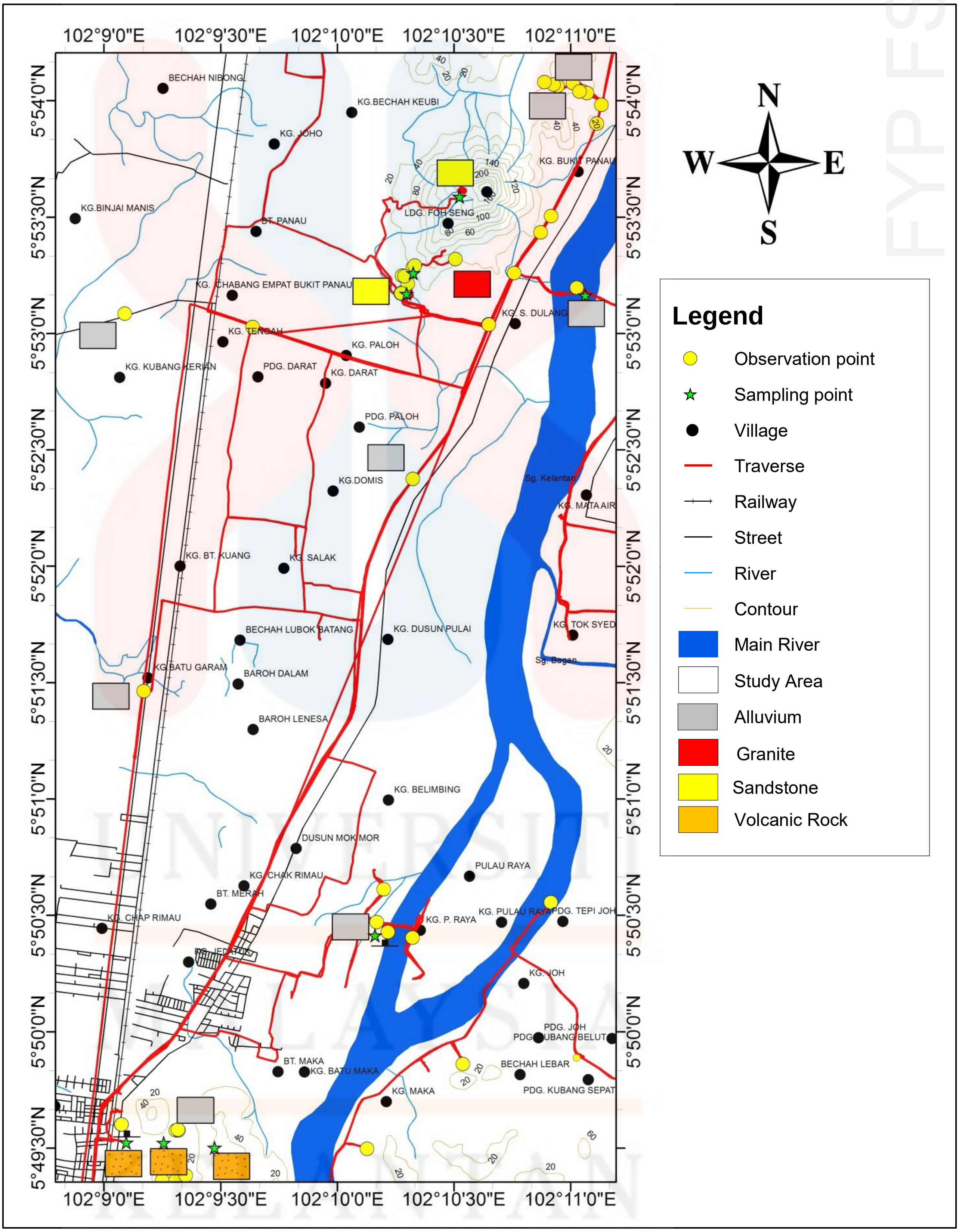



**Figure 4.2**: Sampling station and observation point in the study area

## 4.2 Geomorphology

Geomorphological study is the scientific study of land forms and processes involved in their formation process. The study of the geomorphology more focus on the pattern of drainage systems, topographic patterns and geomorphic processes that occur in the study area as a process of erosion, weathering and mass movement.

### 4.2.1 Topography

Elevation or altitude is a factor that is seen to determine the topography of a place. High topography area is often hilly or mountainous areas while low topography area, an area close to the river or sea. Topographic maps are generated by using satellite imageries and/or observations in the field.

The topography of Bukit Panau area consists of highland and lowland areas with elevation from about 20 to 220 meters above sea level. Increasing steepness found to the northeast of the study area. The contour with elevation of study area is shown in Figure 4.1. This indicates that the high topographic or high land is concentrated in the northeastern part of the study area with elevation of 75 meters to 220 meters above sea level and the highest peak of Bukit Panau is about 220 meters. The rock type predominantly underlying in this area is sandstone. The lowland area is distributed about 20 meters above sea level as alluvial land throughout the map which is around the hill of Bukit Panau and is predominant with sandstone and also siltstone, conglomerate, granite, and, andesite. Lowlands in the study area occupied about 75% of the study area and become a focused place for socio-economic activities by the residents around Bukit Panau. Figure 4.3 shows the topography of the study area.

**Figure 4.3**: Highland topography scenery from flat area with mean elevation 15m above sea level (N 05°53'11.8", E 102°11'01.6”)

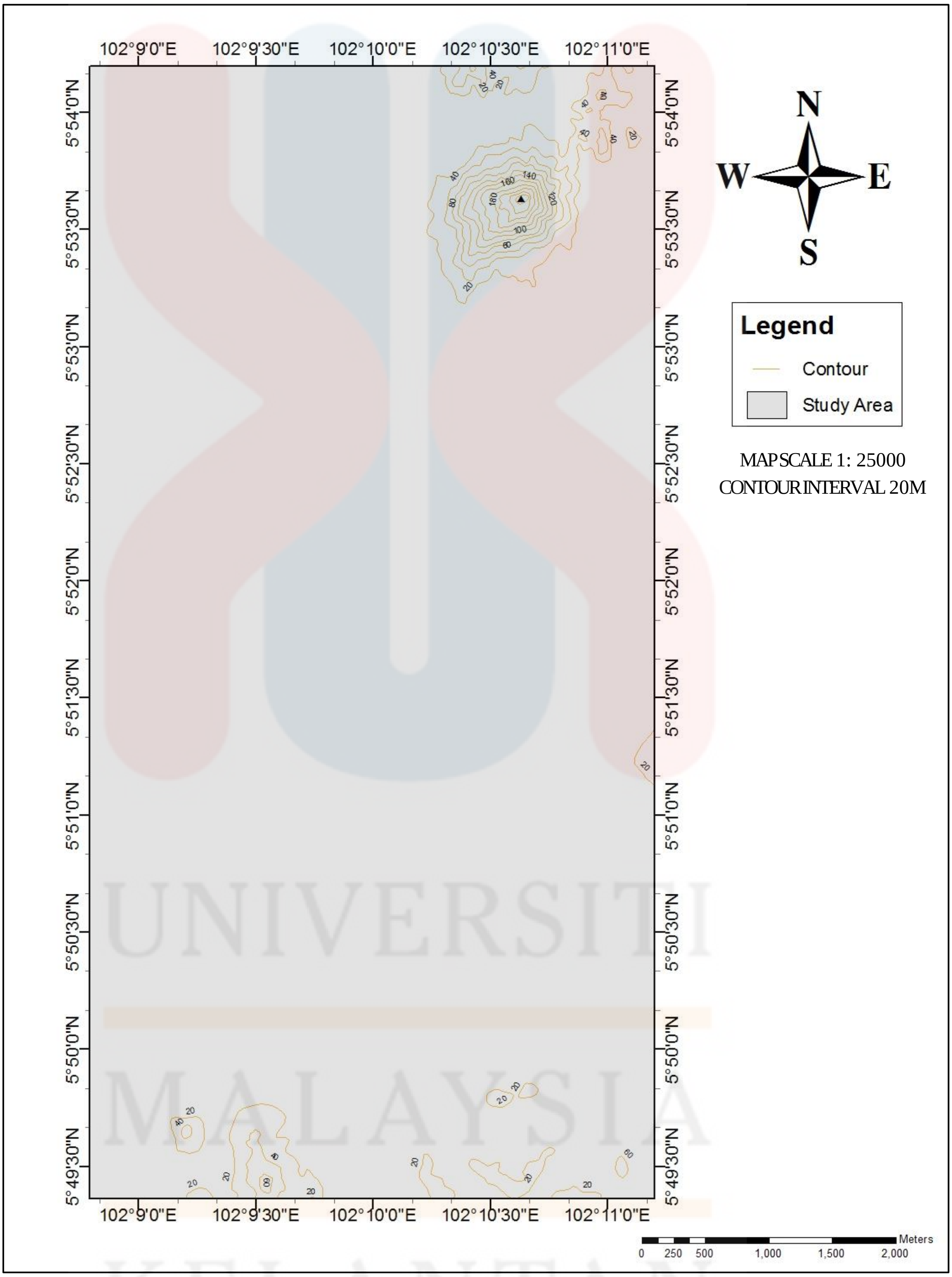



**Figure 4.4**: Contour map of the Bukit Panau area.

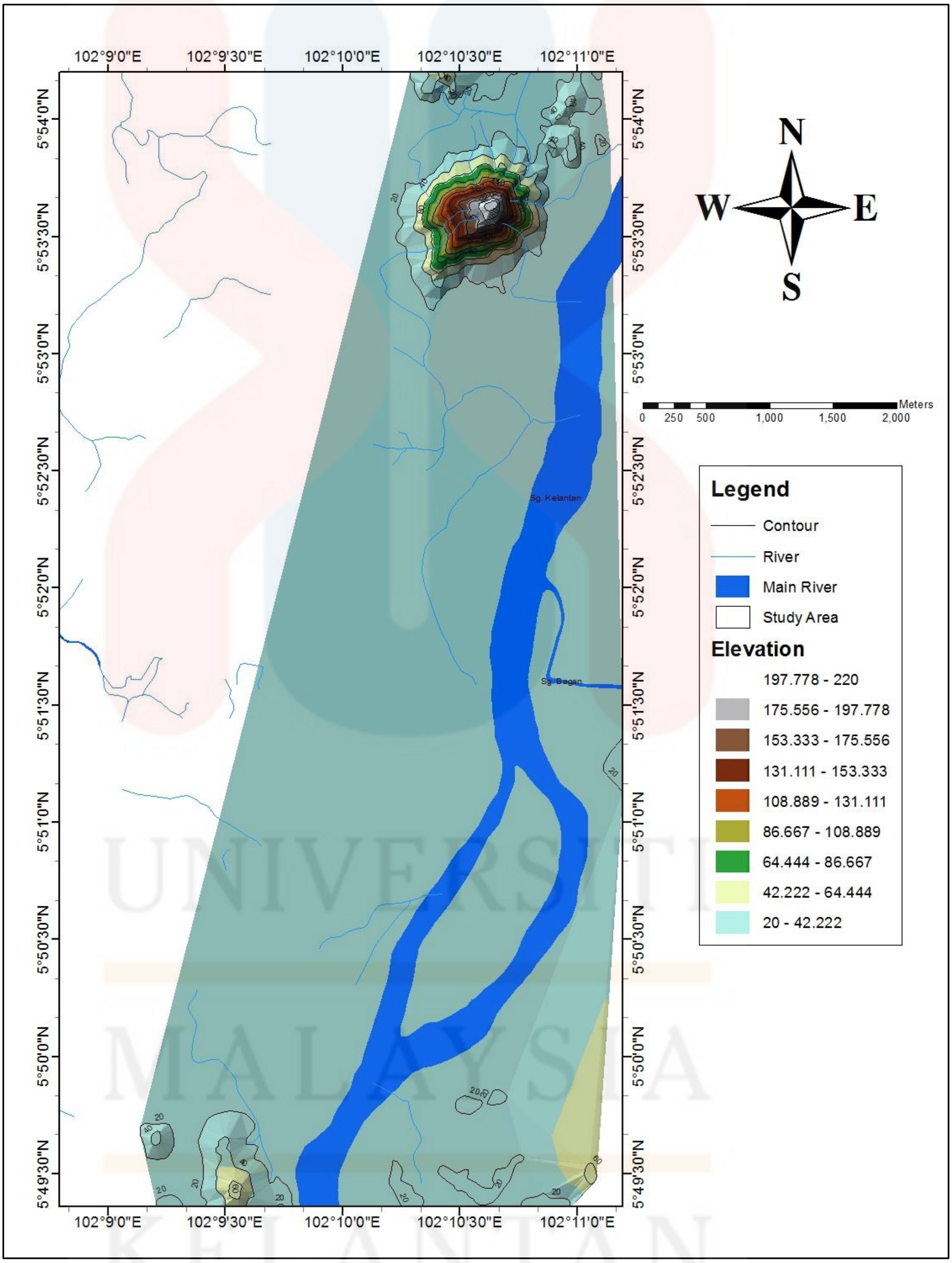



**Figure 4.5**: Topography map of the Bukit Panau area.

### 4.2.2 Drainage Pattern

Drainage pattern refers to stream networks or the way the water flows off a landscape from a place to another. Drainage pattern depend upon the rock type of bedrock and different elevation. According to Tarbuck & Lutgens (1997), the drainage system is a system that drains the water and transporting heavy materials into the sea under the influence of gravity. The ability of the river to erode and transport depends on the flow velocity of a drainage system.

The study area comprised of a major river, namely Sungai Kelantan (Figure 4.5). Based on the drainage map of Bukit Panau, drainage pattern found in the study area is radial which can be seen at high topography located northeastern of the study area (red box labelled 'A' in Figure 4.6). The radial drainage system originate from streams flowing out from a common center, such as off of a volcanic cone, dome or hill with steep slope and flowing down the slope in all directions.

**Figure 4.6**: Sungai Kelantan in the study area

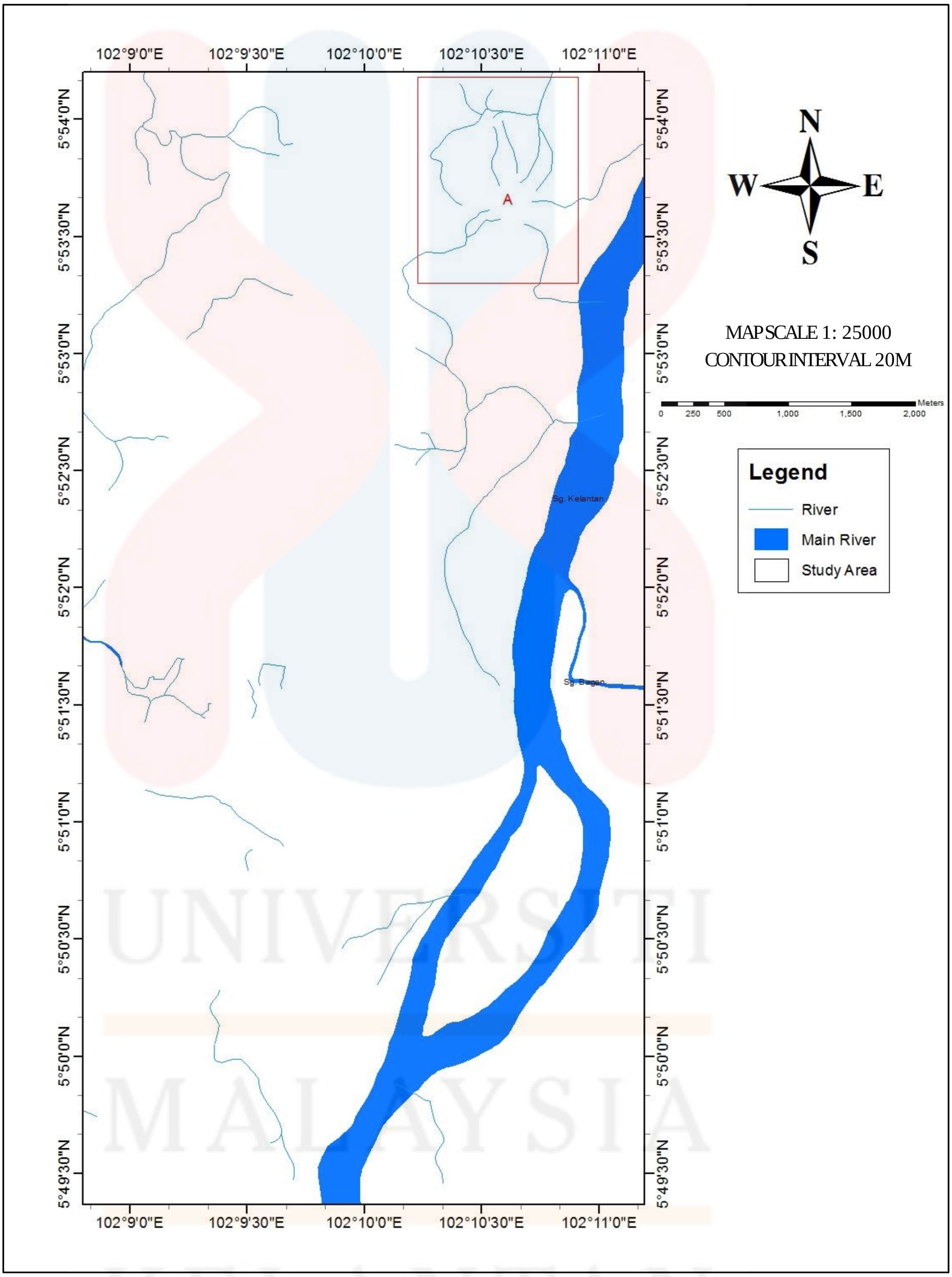



**Figure 4.7**: Drainage map of the Bukit Panau area is shown in A box

### 4.2.3 Weathering

Weathering, other than erosion, is one of the exogenous geomorphologic processes which happened outside of the Earth's surface. Geomorphological processes refer to a process that includes the physical, chemical and biological processes that can lead to changes on terrain which is assisted by geomorphological agents such as water, wind, animals, and plants. Based on observations in the field, the dominant geomorphological processes in the study area is exogenous process involving weathering and erosion while minor endogenous process such as faulting and intrusion also take place within the study area.

According to Skinner et al. (2004), weathering is the chemical alteration and mechanical breakdown of rock materials during exposure to air, moisture and organic matter. Rock those exposed to the land surface it tend to be weathered. During the weathering process the translocation of disintegrated or altered material occurs within the immediate vicinity of the rock exposure, but the rock mass remain in situ. Weathering process can be divided into three types which are physical weathering, chemical weathering and biological weathering.

Mechanical weathering, also called physical weathering, involves application of mechanical forces. It is a geological process of rocks break into smaller pieces without any chemical change. It wills breakdown the rock through the direct contact with atmospheric condition like heat, water, ice, and pressure. By breaking rocks into smaller pieces, physical weathering increases the amount of surface area for chemical attack. Figure 4.8 shows the spheroidal weathering of a weathered rock. The spheroidal weathering resembles exfoliation except that it takes place on a smaller scale.

Chemical weathering is a process in which rocks are broken down by chemical decay of minerals. During chemical weathering, a set of chemical reactions act on rocks which changes their minerals to more stable forms. It also a gradual ad ongoing process as the mineralogy of the rock adjusts to the near surface environment. The principal agent of chemical weathering is water. Water can become a powerful chemical agent when it dissolves with oxygen and carbon dioxide. The main reactions in the chemical weathering are oxidation, hydration, carbonation and dissolution. The Figure 4.9 shows the chemical weathering occurs on sandstone due to oxidation process.

Biological weathering is the processes that are caused by the present of vegetation. It also occurs caused by growth of roots and burrowing of animals. There are two main types: mechanical and chemical. Plant root are most efficient agents of the biological weathering as the roots grow, they widen the cracks, eventually breaking the rock into pieces. Figure 4.9 shows the biological weathering caused by plant root within cracks.

**Figure 4.8**: Spheroidal weathering of a weathered granite

**Figure 4.9**: Chemical weathering of sandstone due to oxidation process

**Figure 4.10**: Biological weathering involves plant roots in study area.

## 4.3 Stratigraphy

### 4.3.1 Stratigraphy of Study Area

Based on the lithology of this study area (Figure 4.11) with scale of 1: 25 000, there are four lithology of rock in the study area composed of three rock unit and one surface deposit which are granite unit, sandstone unit, and extrusive volcanic rock unit then the surface deposit of alluvial. The sandstone is the main focus in study area.

The four rocks unit form in ascending order in age which recognized in the study area are the alluvium deposit, the granite intrusion, the Panau Formation, and the Tanah Merah Volcanics. A stratigraphic column for the rock units with their respective ages is shown in Table 4.1. The oldest formation in the study area is the Tanah Merah Volcanics.

For the Panau Formation, there is only one lithofacies distinguished from the formation which is the interbedded of sandstone, conglomerate, mudstone and shale. The age of the Panau Formation is Cretaceous. Lastly, the youngest formation in the study area is the Quaternary alluvium deposit which was deposited on top of it.

The sandstone unit is the most studied sequence of the Panau Formation. Previous study conducted research on the plant fossils bearing shale layers in Panau Formation sequence. This resulted in several plant fossils being identified. The plant fossils are *Frenelopsis* sp., *Otozamites* sp., *Calamites* sp., and *Pecopteris* sp. The plant fossils assemblages indicate an age during Cretaceous (The Malaysian and Thai Working Groups, 2006). However, during recent conducted research, there is no plant fragments/fossils found at the Bukit Panau area. The lower parts of the sequence of Panau Formation are displaced by a nonconformity structure/an intrusive contact of granite. Based on the observation, nonconformity at the study area (Figure 4.10) is below the overlying units of Panau Formation, indicating that the granite is younger than the Panau Formation.

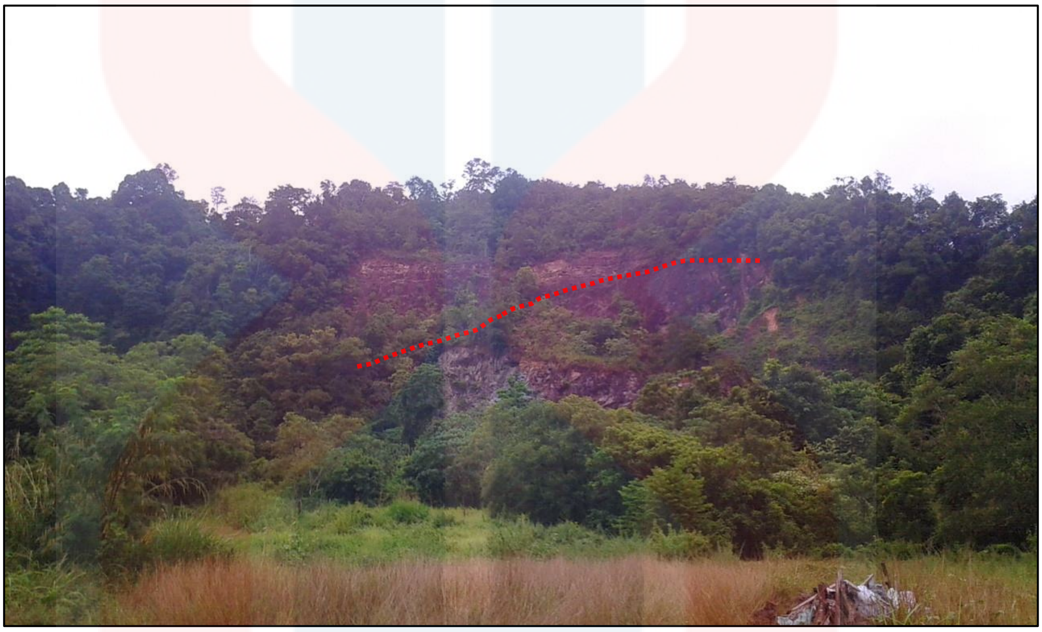
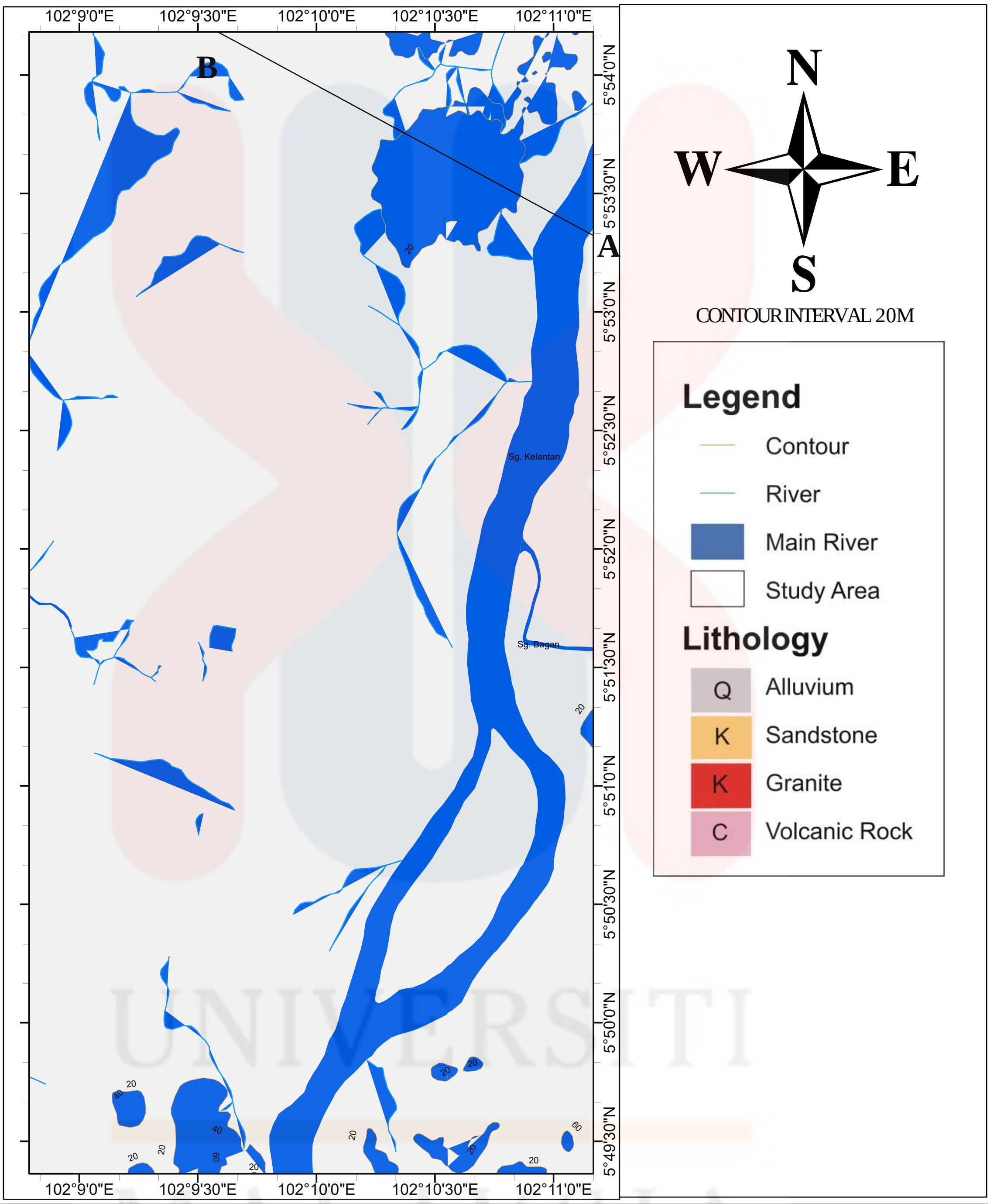


**Figure 4.11**: Big scale of intrusion of granite



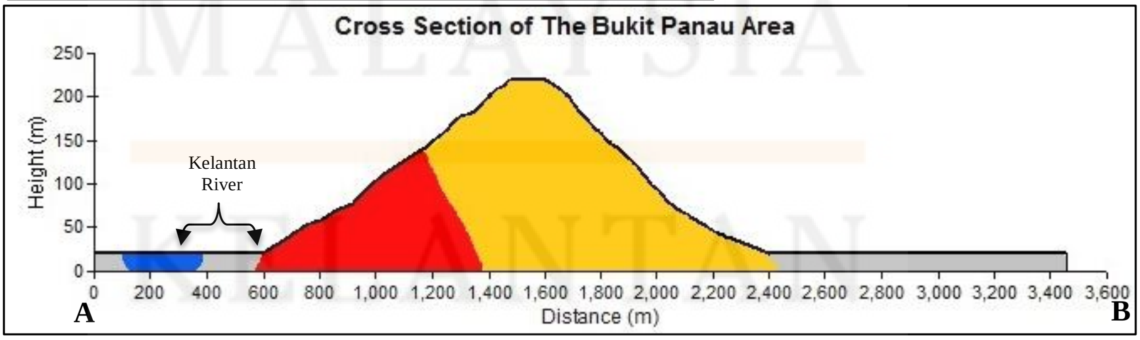




**Figure 4.12**: Geological Map of the Bukit Panau area.

**Table 4.1**: Stratigraphy column of the study area.

| Formation | Era | Period | Lithology Unit | Description | Observation |
|---|---|---|---|---|---|
| - | Cenozoic | Quaternary | Alluvium | Composed mainly of pebble, sand, silt and clay which widespread in the study area. | |
| - | Mesozoic | Cretaceous | Granite Intrusion | Granite | The grain size of granite is medium-grained, white and pinkish colour. Mineral composition consists of quartz, alkali feldspar, plagioclase, biotite which are subhedral in shape. |
| Panau Formation | | Cretaceous | Sandstone | Interbedded of sandstone, conglomerate, mudstone, and shale unit. | The grain size of sandstone is coarse to fine-grained, colour ranging from brownish to yellow. Sandstone dominated at the peak and foothill of the Bukit Panau with presence of nonconformity. |
| Tanah Merah Volcanic | | Carboniferous | Extrusive Volcanic Rocks | Composed of andesite flow, andesitic lapilli tuff | Composed of andesite flow. The colour of these rocks are generally light greenish grey with white spots |

### 4.3.2 Lithology unit

There are four lithology units at the study area of Bukit Panau from the oldest to the youngest which are extrusive volcanic rocks, sandstone, granite intrusion, and alluvium.

**i. Extrusive volcanic rocks/Tanah Merah Volcanics**

An andesitic volcanism occurs in southern part of the study area which located near to Tanah Merah town. It covers only about 5% of the study area. These volcanic rocks bodies exposed at a quarry where the quarry is actively extracting out andesite rocks from a hill known as Bukit Maka.

**ii. Sandstone (Interbedded of sandstone, conglomerate, mudstone and shale)**

The study area is occupied about 25% of sandstone. Most of the sandstone exposed at the Bukit Panau area consists of planar laminated fine-grained sandstone that can be found at the peak of hill with some of the sandstone beds show graded bedding, presence of ripple marks, and exhibits cross-bedding. While, at the foothill of the Bukit Panau can be found the fine-grained sandstone interbedded with conglomerate, mudstone and shale. The thickness of the beds varies from 2 cm to 3 cm up to 1 m. Figure 4.14 shows the outcrop of conglomerate that present at the study area.

The sandstone unit was named as Panau Beds by The Malaysian and Thai Working Groups (2006). In the following discussion (Chapter 5), the beds are called as the Panau Formation, which its deposition environment and provenance analysis will be explained.

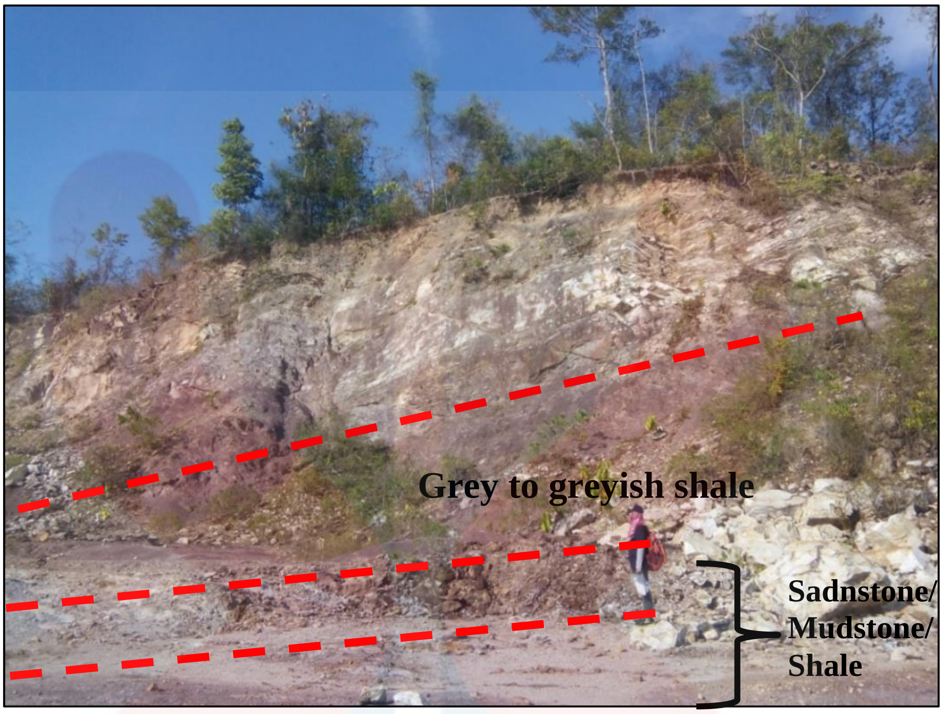


**Figure 4.13**: Big scale outcrop of interbedded sandstone with mudstone and shale

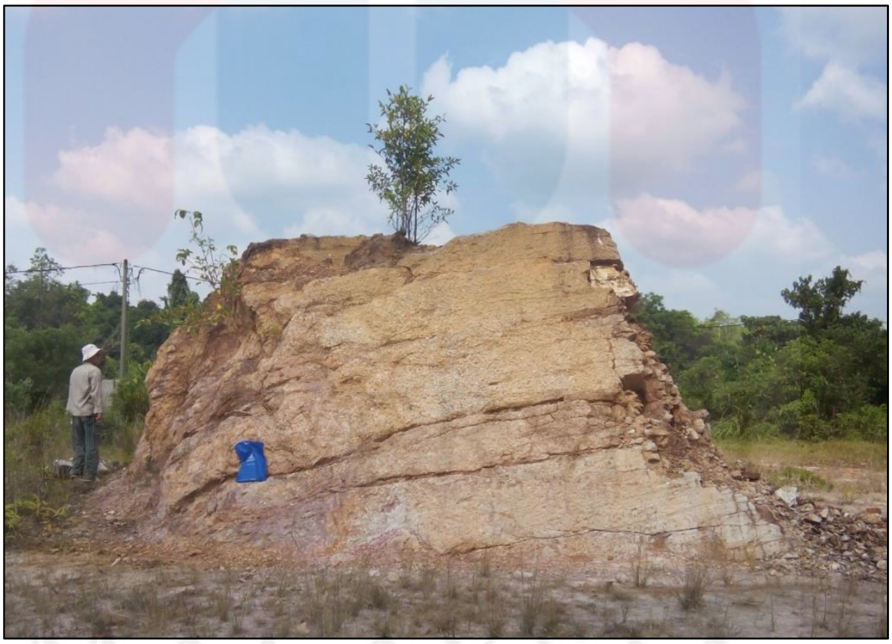


**Figure 4.14**: The outcrop of conglomerate consists of clasts bound in a matrix of sand and clay

### iii. Granite Intrusion

The northern part of study area near to the Bukit Panau, covering about 20% is underlain by granitic rocks. Granite is an intrusive rock that composed of essentially of feldspar and quartz with minor amount of biotite and accessory minerals of chlorites, muscovite and pyroxene. The granite intrudes involve magma moving along a plane of weakness such as bedding in sedimentary rocks and forming a layer. This intrusion can simply push the surface of Panau Formation up as it has cut Panau Formation rocks in the study area which composed of interbedded of sandstone, conglomerate, mudstone and shale. Based on hand specimens taken from exposed granite in the study area, the samples show that all of the grains are coarse grained which indicate slow crystallization of magma below the Earth's surface.

Other than that, andesite dike also occur between those granite rocks. Andesite rock is an extrusive rock that formed from the rapid crystallization of magma on the earth's surface. Based on observation at the locality, the colour of andesite is greenish grey and it display aphanitic texture due to small grained size.

**iv. Alluvium**

Based on the study area at around Bukit Panau, alluvium is widely distributed about 60% in the whole study area. Alluvium deposit usually found in low plain areas and formed at the rivers (Figure 4.15), valleys and foot ridge at an altitude of 10 to 20 m above sea level. Alluvium deposit which varies in size range from fine particle of silt, clay to large particle of sand which is pebble and granule (Figure 4.16) can be viewed deposited in modern stream channel that is along minor streams and Sungai Kelantan. These sediments lay unconformable atop of granite and Panau Formation rocks. Besides, it is found that these alluvium deposits also composed of plantation area (Figure 4.17).

Most alluvium is geologically very young or quaternary age. In the geological time scale, quaternary is marked by the evolution of various cultures which resulted in geomorphological changes like the development river valley and shifting of river courses. These alluvium deposits formed when it has been exposed to the earth's surface due to geomorphological changes and experienced weathering.

**Figure 4.15**: Alluvium deposited at riverbank of Sungai Kelantan

**Figure 4.16**: Pebble and granule of sand deposits

**Figure 4.17**: Quaternary deposit of plantation area

### 4.3.3 Tanah Merah Volcanics

According to (Nordiana *et al.*, 2012), Tanah Merah is composed of andesite flow, andesitic tuff and agglomerate but predominantly pyroclastics. It is mostly extrusive in nature, probably contemporaneous with the deposition of the associated sedimentary rocks. The most impressive andesite in the transect area is located in the Tanah Merah area, to the east of the Temangan Ignimbrite. The volcanic rocks comprise strongly sheared, highly altered andesite, andesitic tuff and agglomerate. The colours of these rocks are generally pale brown, pale purple grey to light greenish grey with white spots (1-5 cm in diameter). Volcanic clasts are white or yellowish grey in colour. MacDonald (1967) assigned this rock unit as Carboniferous to Triassic in age. Aw (1990) reported that the main volcanic activities occurred during Permo-Triassic period.

Based on field study, an igneous body is distinguished as a component of andesitic volcanism which is locally isolated from the Panau Formation. This volcanic event is believed to be developed in time frames different from the Panau Formation. The main rock type of the volcanic activity is andesite. This rock is of greenish gray colour.

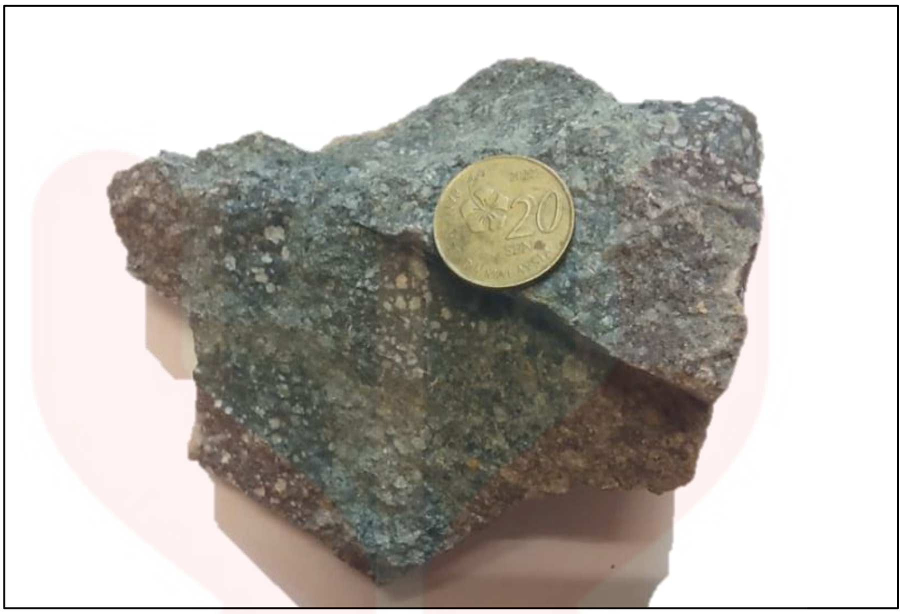


**Figure 4.18**: Hand specimen of sample 1 of andesite

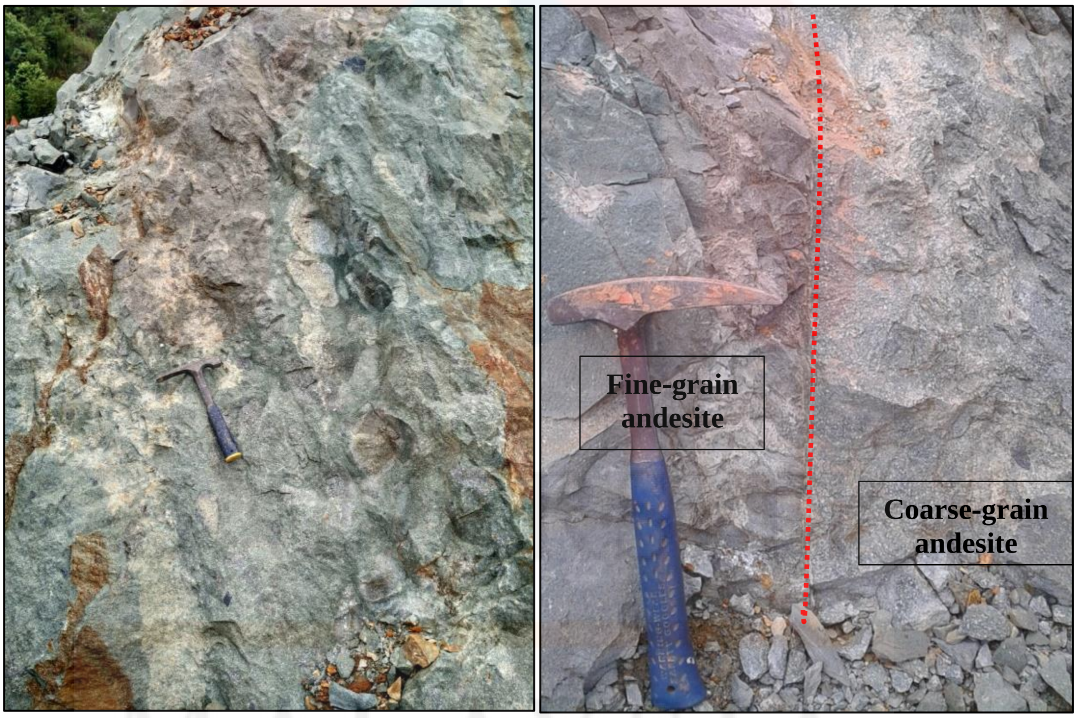



**Figure 4.19**: The surface of coarse-grained andesite (right). The contact between coarse-grain andesite and fine-grained andesite (left)

The rock (Figure 4.18) is a crystal-rich andesite that contains fine-grained andesitic inclusions which show evidence of has been molten when incorporated into the host andesitic (intermediate) magma. The mineral composition and texture of the hand specimen are interpreted as reflecting non-uniform reheating. This non-uniform reheating shows that the rock unit has experienced different thermal histories depending on proximity to the intruding andesite or intermediate composition magma. Based on observation at the hand specimen, the texture of andesite rock demonstrates the existence of at least two main cycles of volcanic activity.

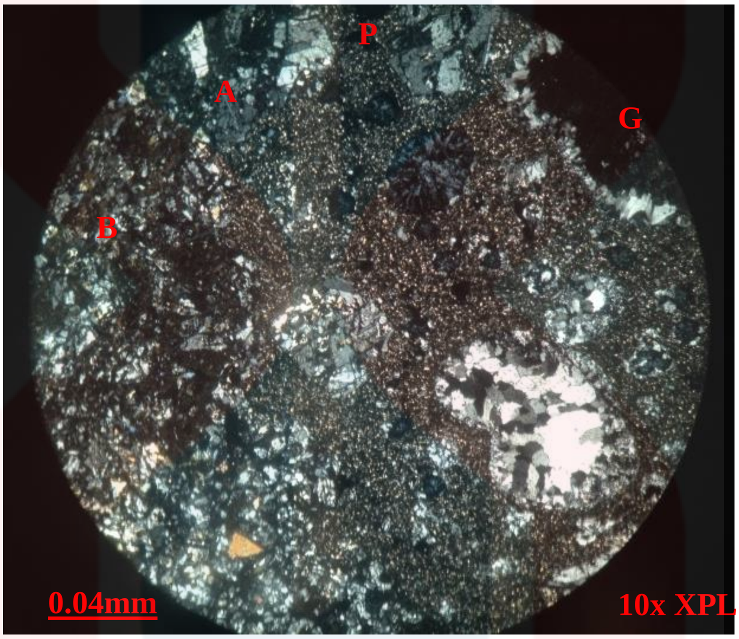



**Figure 4.20(a)**: Thin section of andesite rock sample 1 from Tanah Merah Volcanics. G-Glass: Q-Quartz; P-Plagioclase; A-Alkali Feldspar; B-Biotite; with fine-grained groundmass. (XPL; Magnification: 10x).

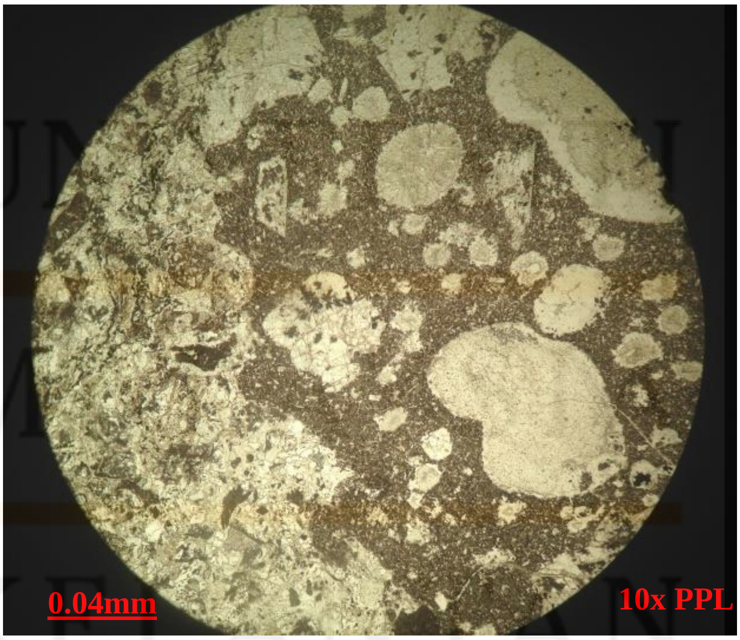



**Figure 4.20(b):** Thin section of andesite rock sample 1 from Tanah Merah Volcanics. G-Glass; Q-Quartz; P-Plagioclase; A-Alkali Feldspar; B-Biotite; with fine-grained groundmass. (PPL; Magnification: 10x).

The petrographic analysis of andesite sample revealed that the hand specimen of a volcanic rock with porphyritic texture is hypocrystalline in which the rock occur crystals but at the top, right corner appears glass. The crystals are subhedral in shape. The porphyritic texture of the andesite indicates that there are two stage of magma cooling has taken place beforehand. Porphyritic texture means larger, well-shaped crystals, phenocrysts are set in a finer groundmass or matrix. The phenocryst in the andesite consists of orthopyroxene, clinopyroxene, plagioclase and hornblende which suspended in about 55% of fine-grained groundmass consists of light and dark minerals which give greyish color to the rock. The phenocryst exhibits poikilitic texture as it contains several discrete crystals of other mineral which refers to crystals growth phenomena. The aphanitic groundmass indicates that it is a volcanic rock. Light yellow to light brown biotite is present in small amounts in the andesite sample.

**Figure 4.21**: Hand specimen of sample 2 of lapilli tuff

Lapilli tuffs (Figure 4.21) are a common form of volcanic rock typical of andesite pyroclastic eruptions, where thick layers of lapilli can be deposited during a basal surge eruption. The lapilli tuff of andesite composition is composed of quartz, plagioclase, pyroxene, and alkali feldspar minerals. Lapilli tuff consist mixtures of ash and lapilli.

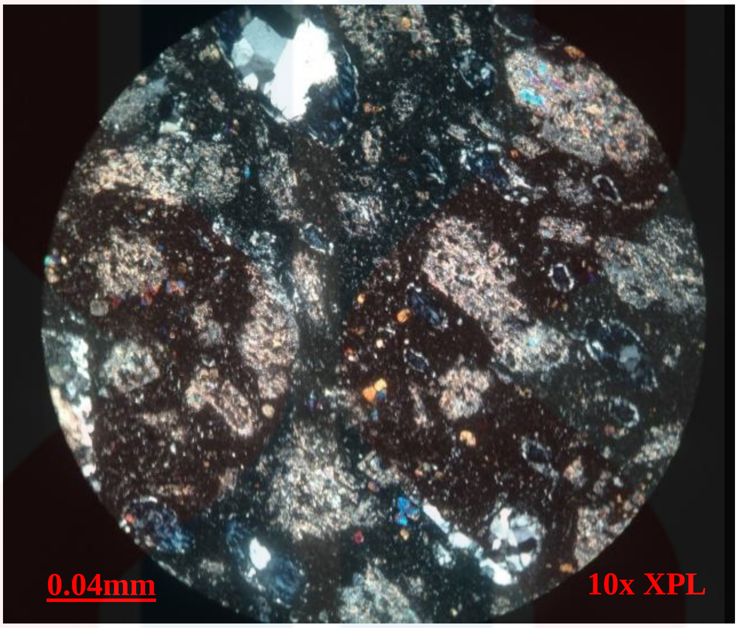



**Figure 4.22(a):** Thin section of lapilli tuff sample 2 from Tanah Merah Volcanics. Abundant of crystal fragments (lapilli tuff clasts) of quartz in fine-grained groundmass. (XPL; Magnification: 10x).

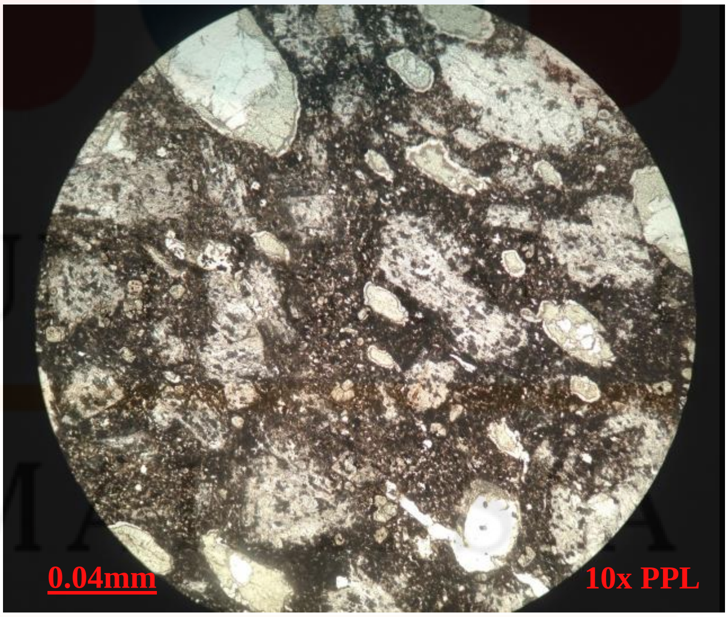



**Figure 4.22(b)**: Thin section of lapilli tuff sample 2 from Tanah Merah Volcanics. Abundant of crystal fragments (lapilli tuff clasts) of quartz and olivine in fine-grained groundmass. (PPL; Magnification: 10x).

### 4.3.4 Panau Formation

The Panau Formation refers to the sequence of continental sediments, channel lag deposits, and sedimentary rocks comprised of thin- to thick-bedded grey to maroon sandstone, siltstone, mudstone, shale and siliceous shale (The Malaysian and Thai Working Groups, 2006). In study area, this unit is exposed at the foothill and peak of the Bukit Panau which is locally at northern part of Tanah Merah district.

**Figure 4.23**: Hand specimen of sample 3 of sandstone

This sample (Figure 4.23) is taken at peak of the Bukit Panau. The sandstone is reddish brown and fine-grained.

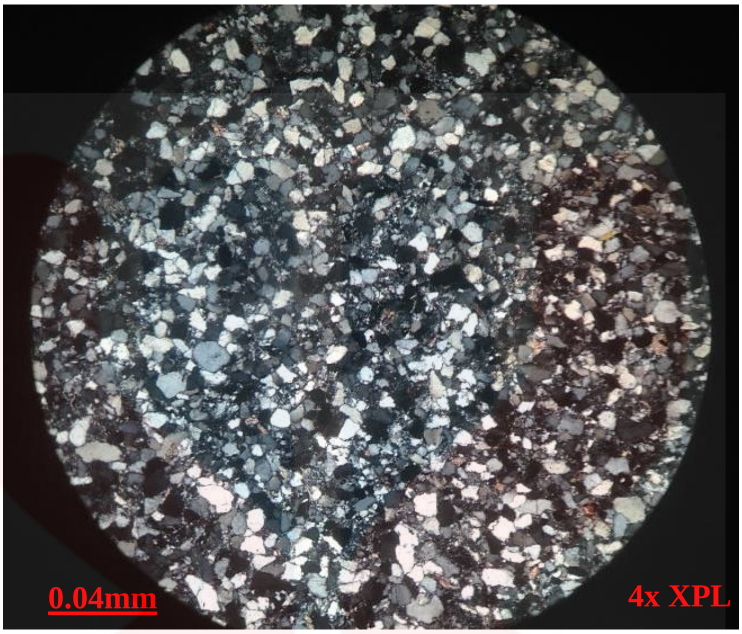



**Figure 4.23(a)**: Thin section of sandstone sample 3 from Panau Formation. Dominated by Quartz about 75% and 15% of fine-grained matrix. The remaining percent represent by feldspar and other accessory mineral such as opaque. Q-Quartz; B-Biotite; M-Muscovite; O-Opac; A-Alkali feldspar (XPL; Magnification: 4x).

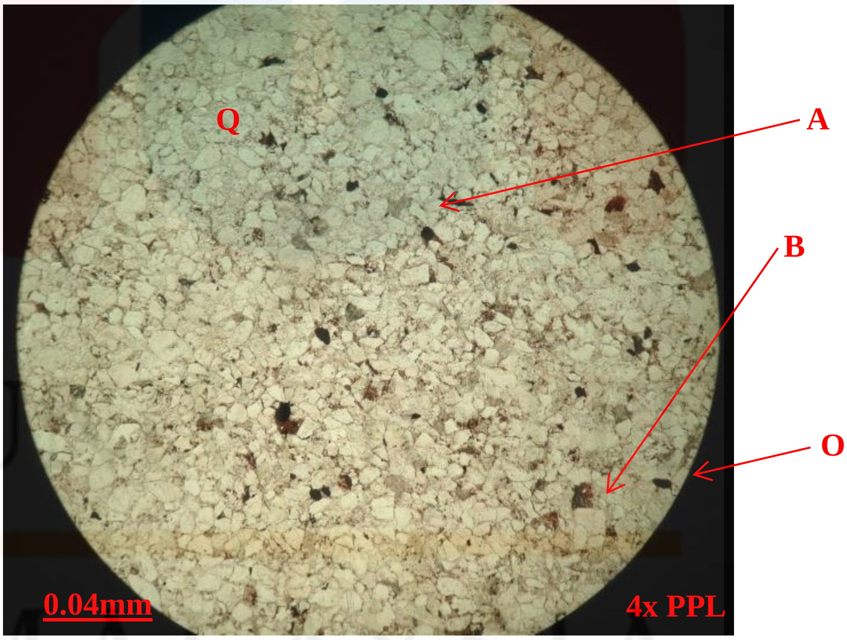



**Figure 4.23(b)**: Thin section of sandstone sample 3 from Panau Formation. Dominated by Quartz about 75% and 15% of fine-grained matrix. The remaining percent represent by feldspar and other accessory mineral such as opac. Q-Quartz; B-Biotite; M-Muscovite; O-Opaque; A-Alkali feldspar (PPL; Magnification: 4x).

**Table 4.2(a):** The table shows the percentage of mineral composition of sandstone of Panau Formation in the study area.

| Mineral Composition | Numbers of Grains counted | Total (%) |
|---|---|---|
| Quartz (Q) | 1015 | 67 |
| Feldspar (F) | 158 | 10 |
| Rock Fragments | 334 | 22 |
| Total | 1507 | 100 |

**Table 4.2(b):** The table shows the percentage of mineral composition of sandstone of Panau Formation in the study area.

| | | |
|---|---|---|
| Name of rock : Feldspathic Litharenite Sandstone | | |
| Magnification : 4x10 | | |
| Type of rock : Clastic sedimentary rock | | |
| Classification : Pettijohn 1975 (Derived from Nichols, 2009) | | |
| Microscopic :This is thin section of sandstone, the colour is brownish (ppl), dark brown (xpl) | | |
| **Mineral composition** | **Total (%)** | **Description of mineral** |
| Quartz (Q) | 63 | True colour is colourless,<br>Interference colour - white to grey<br>Relief is low<br>Shape anhedral<br>No pleochroism, angle of extinction is 45°<br>Type of extinction is inclined extinction |
| Alkali Feldspar (A) | 11 | True colour is colourless<br>Interference colour – grey to blackish<br>Relief is moderate<br>Shape euhedral<br>No pleochroism |
| Rock Fragments | 22 | Detrital particles made up of two or more mineral grains |
| Biotite (B) | 2.5 | True colour is brown, interference colour is dark brown, shape is anhedral and pleochroism is present. |
| Muscovite (M) | 0.5 | True colour is colourless and shape is anhedral. Relief is low. |
| Opac (O) | 1 | Shape is anhedral, displays black colour under both PPL and XPL due to impervious of light |

Point counting Plot :

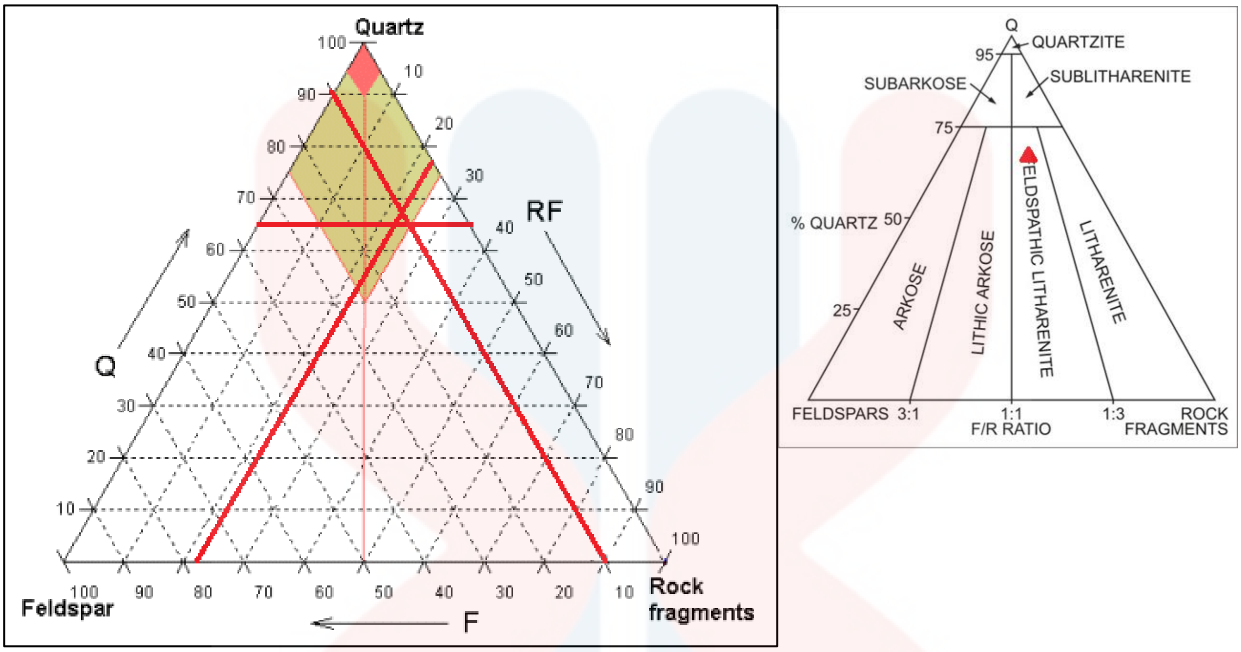



**Figure 4.24**: The classification of sandstone is (Pettijohn, 1975). (Source derived from Nichols, 2009)

The petrographic analysis of sandstone sample revealed that quartz is the most dominant detrital mineral averaging about 75–90%. The quartz grains are large anhedral crystals that are sub-angular to subrounded in shape. Mineral content of cement is silica and iron-oxide. The feldspars observed is mainly alkali feldspar which has been significantly weathered giving it a brown coloration. They constitute about 10% (Table 4.2). The rock fragments or lithic constituents average about 22%. The sample contains mica, in which biotite is more abundant than muscovite. The reduction or oxidation process of the iron oxide may be responsible for this. Classifications based on quartz, feldspar and rock fragment (after Pettijohn, 1975) classified the rock into a different rock type which is feldspathic litharenite sandstone (Figure 4.24).

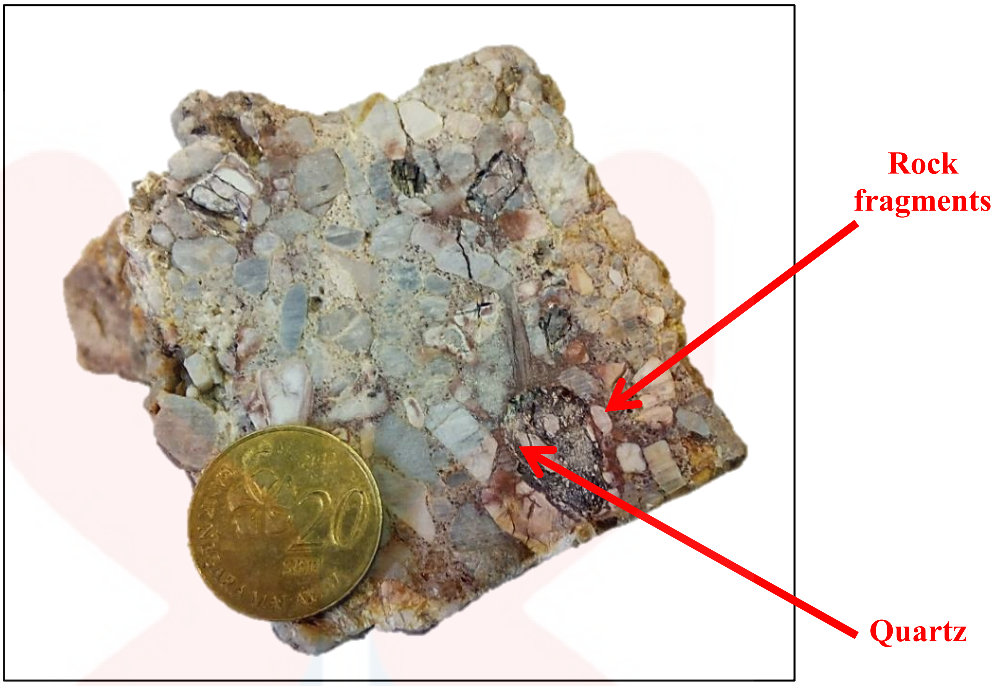



**Figure 4.25**: Hand specimen of sample 4 of conglomerate

This conglomerate (Figure 4.25) is taken at front side of foothill of the Bukit Panau. The conglomerate is composed of largely of pebble and granule of rocks or of minerals. These pebble and granule clasts display typical rounded to subrounded shape with one to two inches in diameter and they are cemented in a matrix which might be siliceous or argillaceous. The rounded clasts could be contains clasts of any rock material, sedimentary fragments or mineral particles such as quartz.

### 4.3.5 Granite Intrusion

**Figure 4.26**: Hand specimen of sample 5 of granite

This granite (Figure 4.26) is found at the backside of foot hill of the Bukit Panau. Type of rock is igneous rock and type of structure is massive. Classification for igneous rock is Travis 1955. From the interpretation of the hand specimen, the entire sample of granite in study area is coarse crystal which shows porphyry texture and composed of alkali feldspar and quartz. All of the grains of granites in study area are large enough to be visible with unaided eyes.

**Table 4.3:** The table shows the percentage of mineral composition of granite in the study area.

| Mineral Composition | Total (%) |
|---|---|
| Quartz | 27 |
| Alkali Feldspar | 30 |
| Plagioclase | 24 |
| Biotite | 13 |
| Olivine | 3 |
| Muscovite | 3 |

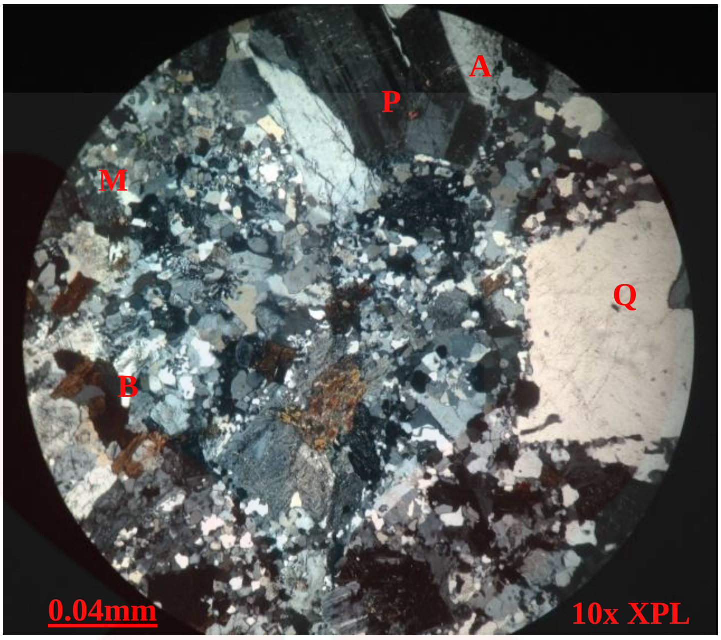



**Figure 4.27(a):** Thin section of granite rock sample 5 from the area of Bukit Panau. Q-Quartz; B-Biotite; P-Plagioclase; M-Muscovite; A-Alkali feldspar (XPL; Magnification: 10x).

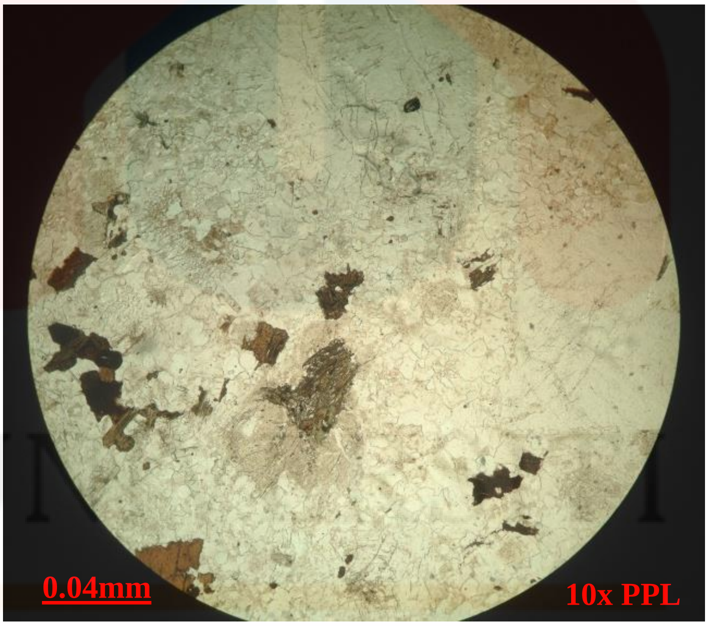



**Figure 4.27(b):** Thin section of granite rock sample 5 from the area of Bukit Panau. Q-Quartz; B-Biotite; P-Plagioclase; M-Muscovite; O-Olivine; A-Alkali feldspar (PPL; Magnification: 10x).

Point counting plot :

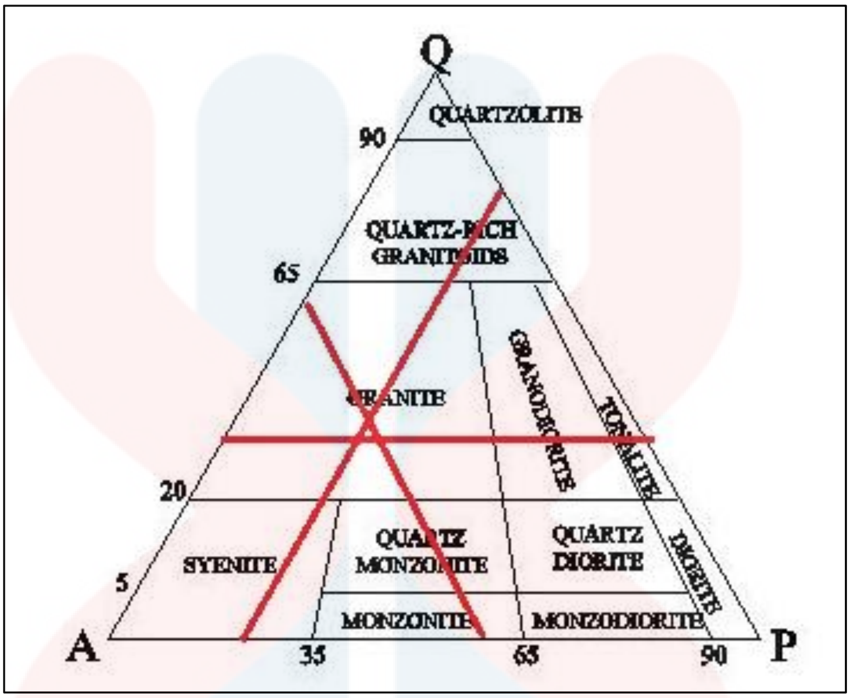


**Figure 4.28**: The classification of plutonic igneous rock (Travis, 1955).


**Figure 4.29**: Hand specimen of sample 6 of andesite

Andesite (Figure 4.29) occurred as intrusion between granite rocks (Figure 4.30). It composed by fined grained igneous rock. It is greyish-green in colour. The grains are much finer compared to granite and cannot be seen by unaided eyes. These rocks exhibit aphanitic texture in which its matrix grain size is small.

**Figure 4.30**: Nonconformity of andesite dyke occur between of granite rocks

### 4.3.6 Lithostratigraphy

Lithostratigraphy is the study of rock layers based on its lithology and their stratigraphic relations. There are two lithostratigraphy present in the study area which are lithostratigraphy at the Bukit Panau area and lithostratigraphy at a quarry located at the southern part in the study area near to Tanah Merah town.

The Bukit Panau is dominated by sandstone and containing interbedded of sandstone with conglomerate, mudstone and shale. The lithofacies is classified as Panau Formation. Besides, granite rock occurs by intrusion which lies under the rock unit of Panau Formation by nonconformity boundary. This indicates that Bukit Panau bed is older than the granite.

Furthermore, extrusive volcanic rocks can be found at southern part of the study area. The extrusive volcanic rocks composed of andesite and lapilli tuff. The volcanic rock is considered to be age of Carboniferous (Nordiana *et al.*, 2012)

## 4.4 Structural Geology

Structural geology is a branch of geology that studies the deformation occurring on rock, including the origin, geometry and kinematic (Carlson et al., 2008). It is an analysis that signifies structure formation like faults, folds, bedding and joints which has been produced by deformation that is by the action of forces on and within the Earth’s crust. Sub-topic will discuss lineament, fault and joint analysis in the study area.

### 4.4.1 Lineament Analysis

Lineament refers to straight linear structures and can be observed through aerial photographs, satellite images and topographic maps. Lineament can be divided into two which are positive lineament and negative lineament. Positive lineament refers to ridges, mountain range or an uplift body. Negative lineament refers to the valley, drainage, and rivers in an area.

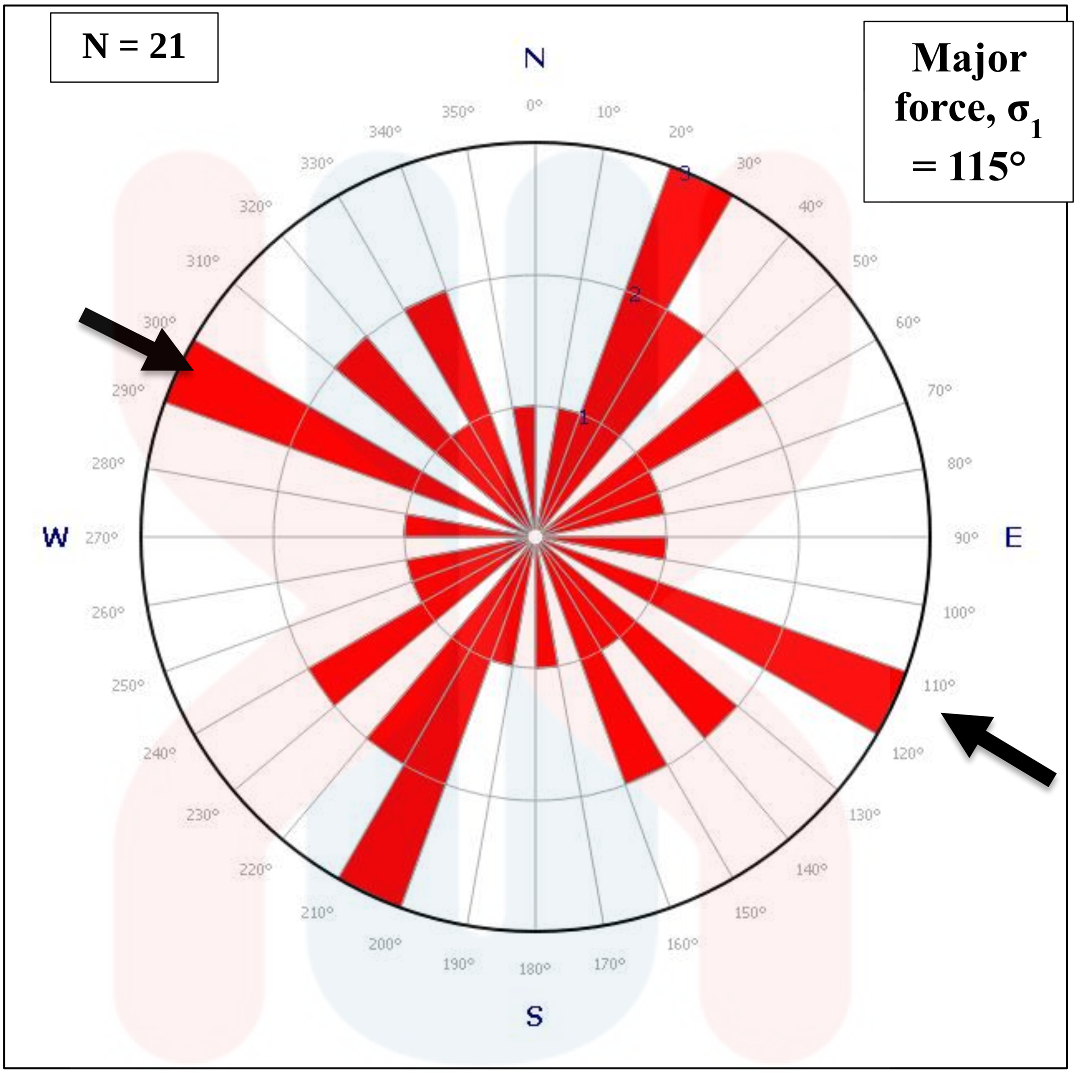



**Figure 4.31**: Rose diagram of lineament analysis

From the study area, the values of lineament were obtained. Based on the picture lineament of regional and study area (Figure 4.32), the rose diagram has been plotted (Figure 4.31). From the rose diagram, the direction of the major force is Northwest-Southeast. The value of major force is 115°.

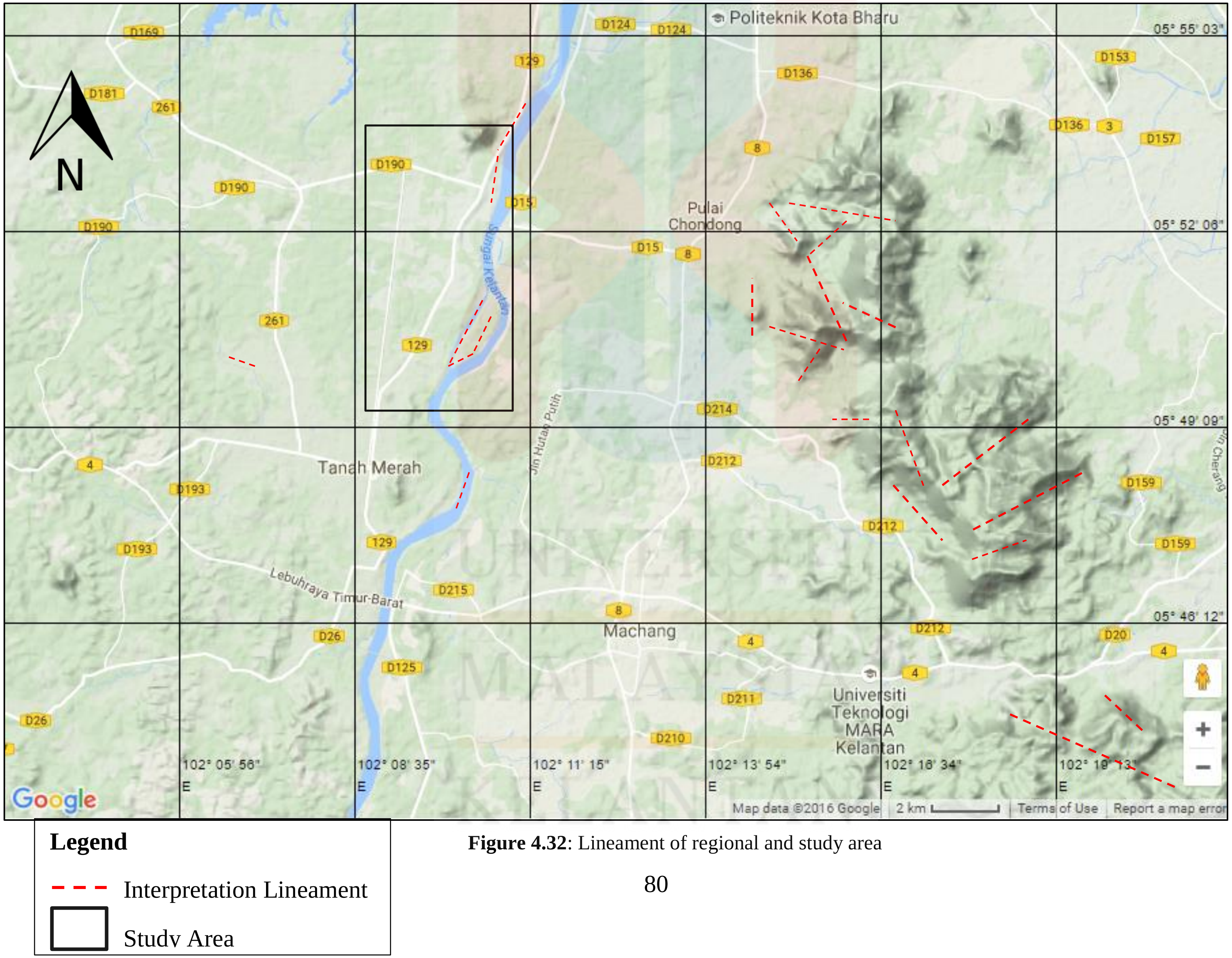



**Figure 4.32**: Lineament of regional and study area

### 4.4.2 Fault Analysis

Strike and dip of the fault plane occurring at the Bukit Panau is taken in the field and analyzed using software Stereonet to determine the direction of deformation occurring in the study area.


**Figure 4.33**: Normal fault at large-scale outcrop of moderately-weathered sandstone (Azimuth: N248°)

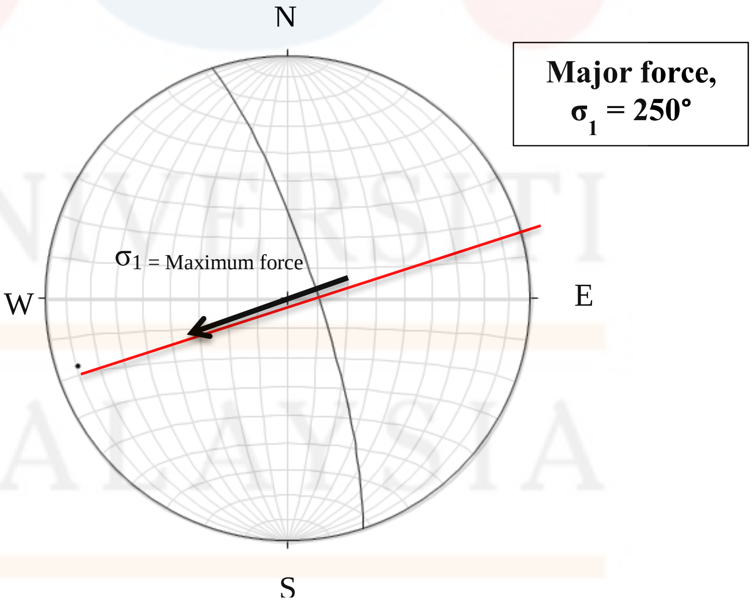



**Figure 4.34**: Stereonet Plot of fault plane in study area

### 4.4.3 Joint Analysis

Joints are planes of separation on which no shear displacement has taken place. The two walls of the resulting opening typically remain in tight contact. Joints may result from regional tectonics or internal stress release during uplift or cooling. They often form under high fluid pressure. Joint growth is controlled by the mechanical layer thickness of the deforming rock. Systematic joints are roughly planar, parallel to each other and usually regularly spaced.

The presence of joints in the rocks in the study area is quite scarce. This is because most outcrops have experienced active weathering and crumbled to the ground. The analysis results are shown in rose diagram (Figure 4.36) with the deformation of the study area (Figure 4.35). Through joint analysis that has been done, the deformation of the study area is from direction of Northwest-Southeast with the degree of force is 120°.

**Figure 4.35**: Systematic joints found in the study area

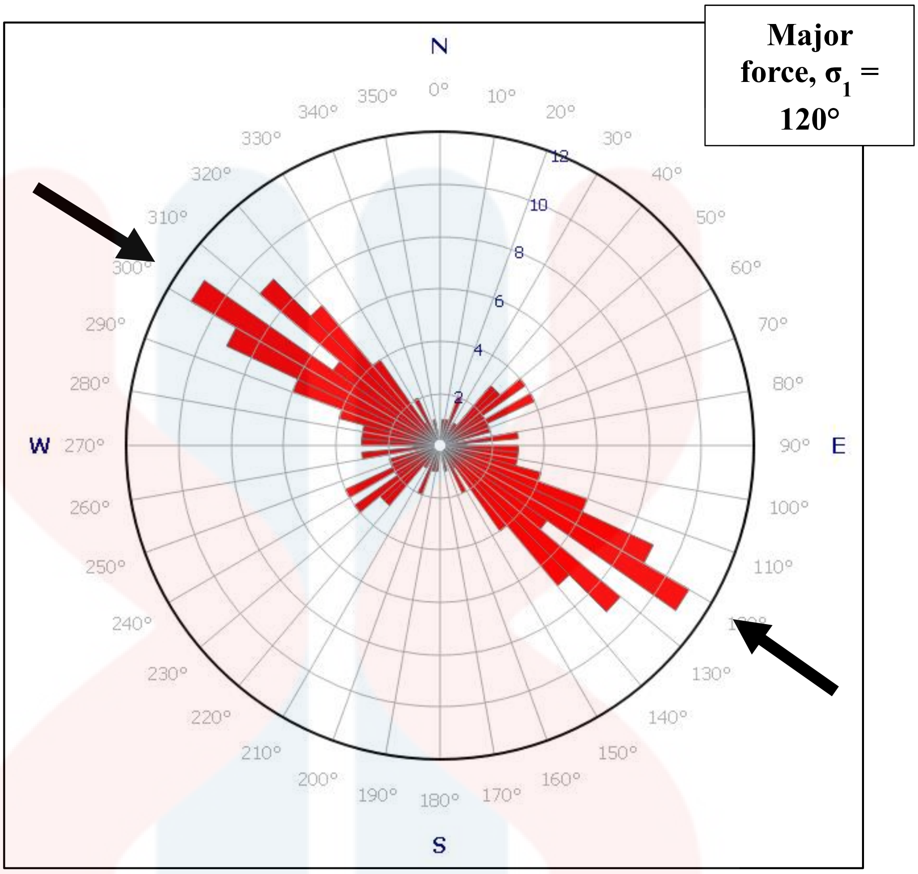



**Figure 4.36**: Rose Diagram of joint analysis in the study area.

## 4.5 Historical Geology

Based on the literature review the age of sandstone is Cretaceous due to the nonconformity structure between the granite and the overlying unit can be observed at an abandoned Bukit Panau quarry (The Malaysian and Thai Working Groups, 2006).

The intrusion of granite is probably from Cretaceous due to its intrusion process. Based on stratigraphically, it can be divided into two lithofacies namely: interbedded sandstone with conglomerate, mudstone and shale which represent respectively arenaceous and argillaceous facies and another is granite intrusion which comprised of granite rock. After that, followed by Tanah Merah Volcanics which emerges from Carboniferous.

CHAPTER 5

# DEPOSITIONAL ENVIRONMENT AND PROVENANCE OF BUKIT PANAU, TANAH MERAH, KELANTAN

## 5.1 Introduction

Depositional environment is where the place of the sediment was deposited. These deposited sediment were characterized by the position or placed it was deposited. Each depositional area has their owned characteristic to differentiate the depositional environment of each of the sediment. The depositional environment can be proposed by the depositional environment model. The data that was required is provided by the sedimentary logging conducted at selected outcrop. A total of eight thin sections were prepared, three of them were analyzed to certain characteristics of sedimentary rocks to reconstruct and to interpret the history of sediment from the initial erosion of parent rocks to the final burial.

## 5.2 Interpretation of Depositional Environment of the Panau Formation

The sedimentary log 1 of the Panau Formation (Figure 5.1) shows the outcrop is predominantly composed of sandstone bed occasionally with siltstone and mudstone, displays a fining upwards sequence from the base. It is a graded-bedding with an erosional base boundary (Figure5.2). The fining upward sequence may be produced when progressive settling of sandstone grain from coarse to fine in comparatively calm bodies of water and represents an abrupt change from much finer grained sediment underneath which indicate seasonal fluctuations in energy conditions or seasonal variation in river discharge where finer sand may be deposited when flow conditions occur. The presence of ripple mark (Figure 5.3) implies that the sediment was under the influence of wave action. Sandy meandering river deposits are typically consist of fining upward succession from a sharp scoured base trough and planar cross bed, laminated and cross-laminated sandstone (Figure 5.4) which can be seen at the peak of the Bukit Panau (Figure 5.1). Besides, there are a few paleocurrent values which have been recorded. Paleocurrent are oriented sedimentary structures which also referred as paleoflow is interpreted as the evidence for the direction of flow at the time the sediments deposited. The value of paleocurrent can be obtained by taking the value of dip direction of cross-beds slip faces or ripple mark orientation.

The sedimentary log 2 of the Panau Formation (Figure 5.6) is composed of bedded of conglomerate which represents the deposition of meandering river deposits that took place on channel bars along the meandering river. The lithology can be found at the foothill of the Bukit Panau. Besides, it also composed of interbedded of arenaceous and argillaceous rocks. The rock is classified as Panau Formation. Floodplain deposits are mainly alternating between thin sandstone sheets and mudstone.

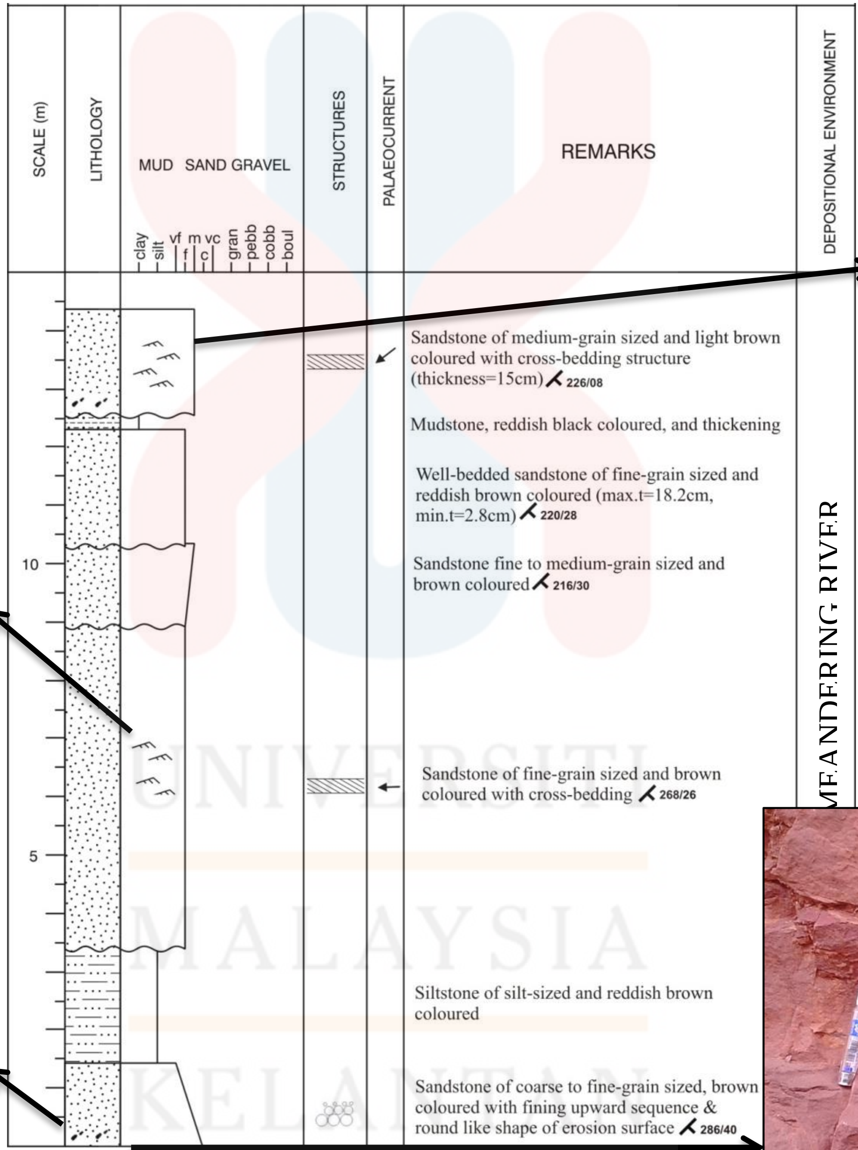
Figure 5.1 and 5.6 shows that the depositional environment for these lithologies is sandy fluvial environment. Fluvial environment is characterized by flow and deposition that take place in river channels and associated overbank sedimentation. Channels are structures that show a U-shape or V-shape in cross section and cut across earlier formed bedding and lamination. They are formed by erosion principally by currents but in some cases by mass movement. Channels may be filled with sediments that are texturally different from the beds they truncate.

In meandering rivers, sand and some gravel are stored in channel beds and especially in point bars, and mud is stored in floodplains. So, meandering river deposits end up as large sand bodies, shaped like lenses and shoestrings, partly connected but often mostly isolated from one another, enclosed in mud. Lateral accretion surfaces characterize meandering river which are also often associated with a relatively high proportion of overbank facies. The low-lying area on either side of a river is called a floodplain. The floodplain is covered with water when the river overflows it banks during floods or periods of heavy rain. When rivers flood, fine-grained sediment will be deposited on the floodplain. As the floodplain is larger than the channel, deposits of meandering river systems are dominated by fine-grained material while coarse-grained channel deposits tend to be relatively minor. The deposits of a meander bend have a characteristic profile of coarser material at the base, becoming progressively finer-grained up the inner bank.

The whole sequence of the rock units in the Panau Formation is interpreted as the result of regression which happened at the whole research area ever since the deposition of the oldest formation to the youngest formation. The Panau Formation is interpreted to be deposited at the alluvial environment, which is as meandering river.

Figure 5.4: Cross-bedding of sandstone bed

Figure 5.2: Erosional surface at the base boundary of sandstone



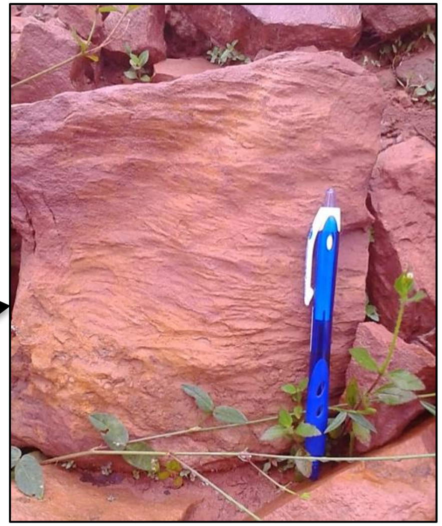



Figure 5.3: Ripple marks at sandstone bed

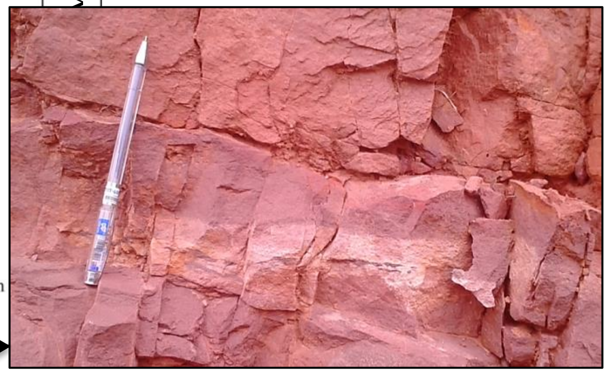
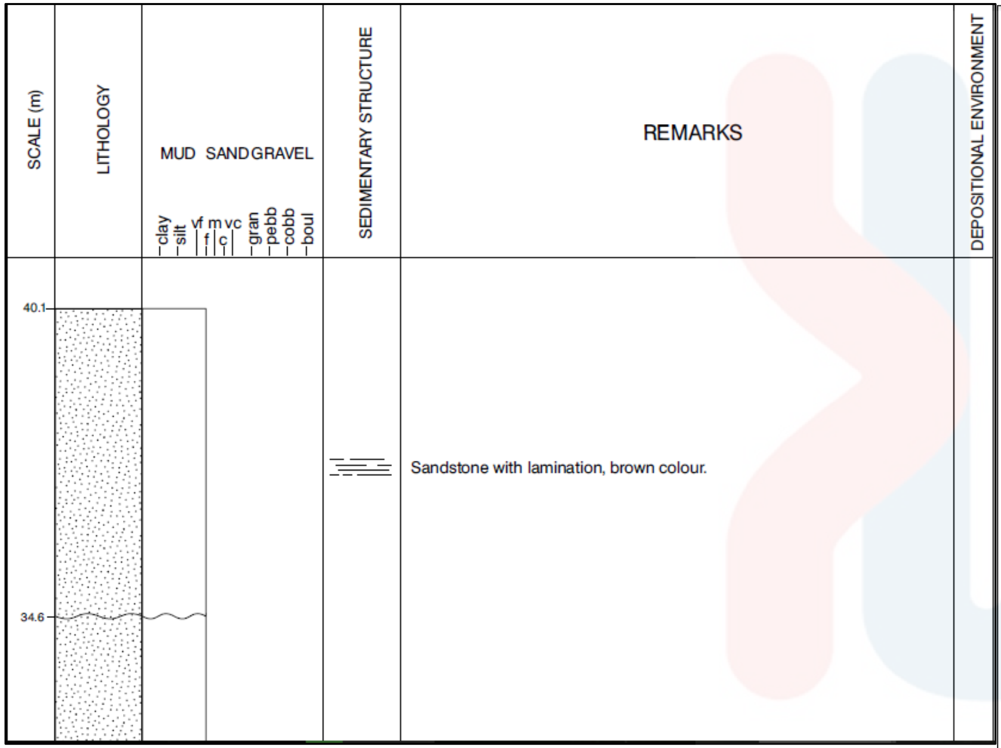


Figure 5.5: Lag deposits at sandstone bed



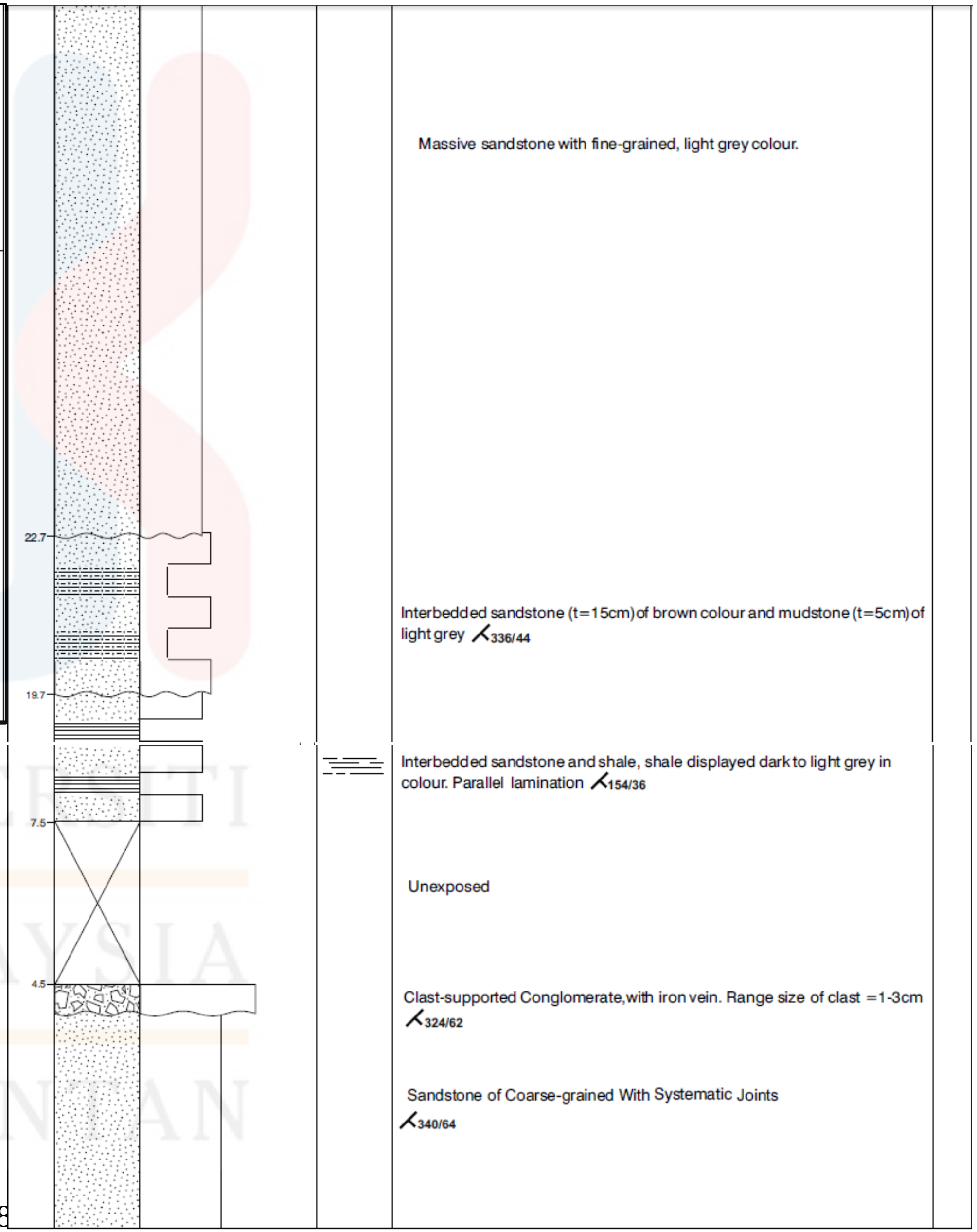




**Figure 5.6:** Sedimentary log 2 at foothill of the Bukit Panau. (N 05°53’10.3”, E 102° 10’ 16.4”)

## 5.3 Provenance of Sedimentary Rocks of the Bukit Panau

Thin sections of 2 clastic sedimentary rocks were examined in an attempt to evaluate crystallinity in detrital quartz grains for the determination and characterizing the lithology of the source of the sediments.

<u>Sample 1 – Medium grained sandstone</u>

Point-counts of medium-grained Cretaceous sandstone sample 1 from the study area have mean QFL percentages of 63-10-23. On the Q-F-L diagram, mean detrital modes plot near Q pole and near Q-L leg, thereby, suggesting a recycled orogenic provenance (Figure 5.11). Based on petrographic observations of the sample under microscope, the medium-grained sandstone have considerably high percentages of monocrystalline quartz (93%) compared to polycrystalline quartz (7%). This indicates the maturity of the sandstone as polycrystalline quartz has been removed by weathering and recycling.

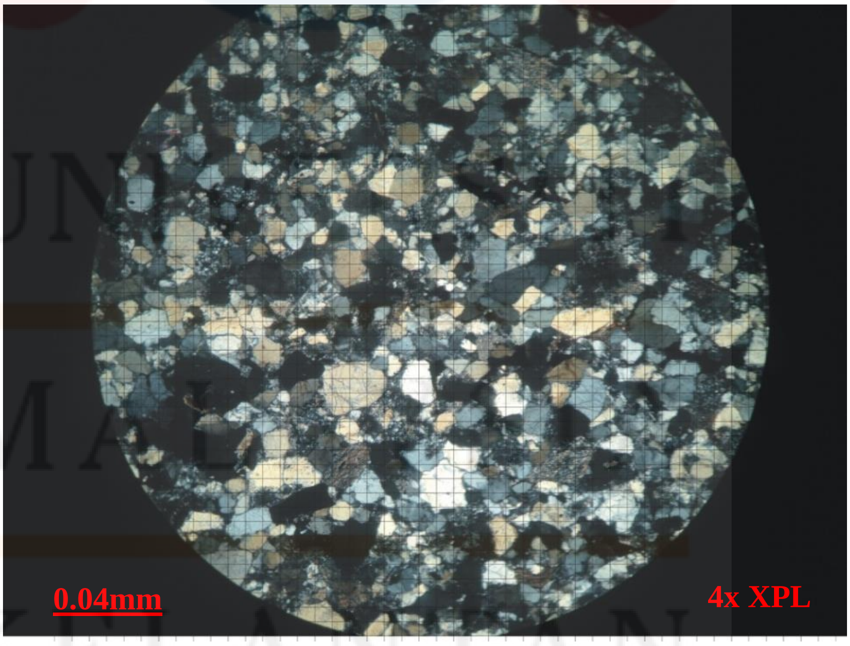
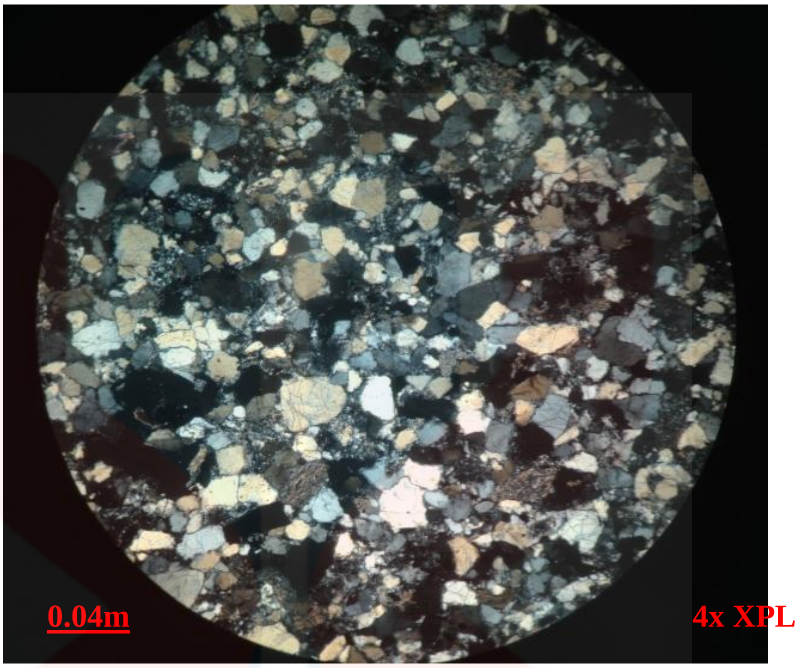



**Figure 5.7**: Point-counts of medium grained sandstone



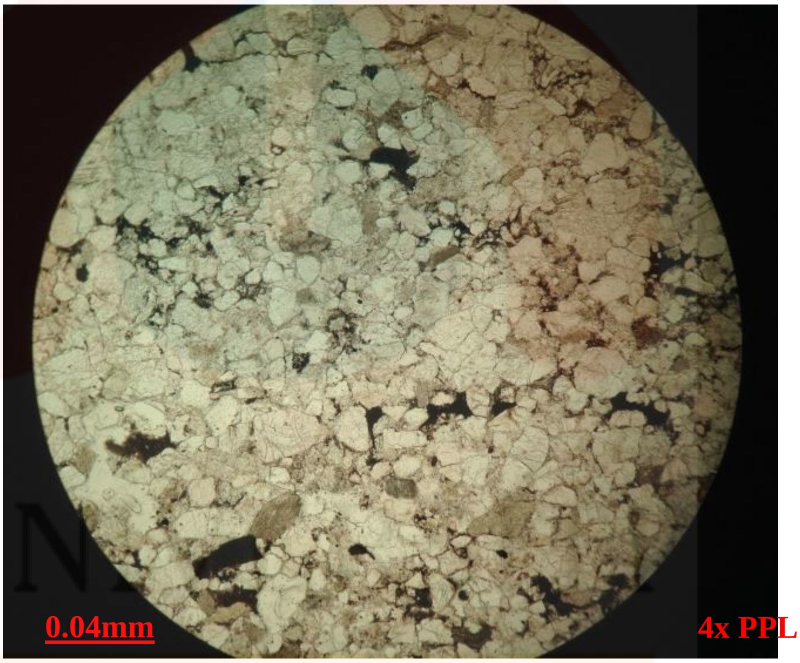




**Figure 5.8**: Photomicrograph of framework grains of medium-grained sandstone under plane and cross polarized microscope.

Sample 2 – Fine grained sandstone

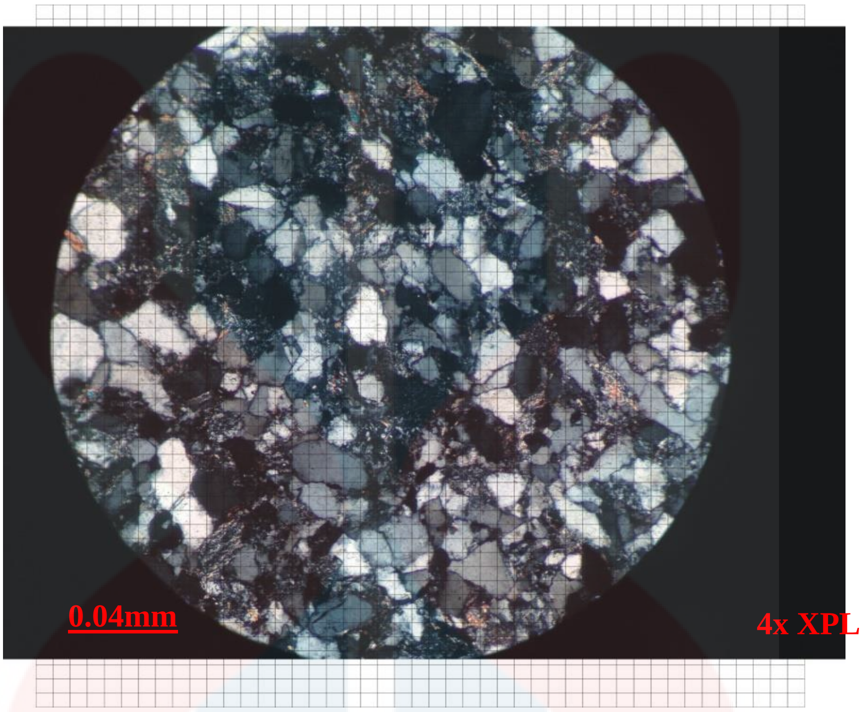



**Figure 5.9**: Point-counts of fine-grained sandstone under 10x magnification

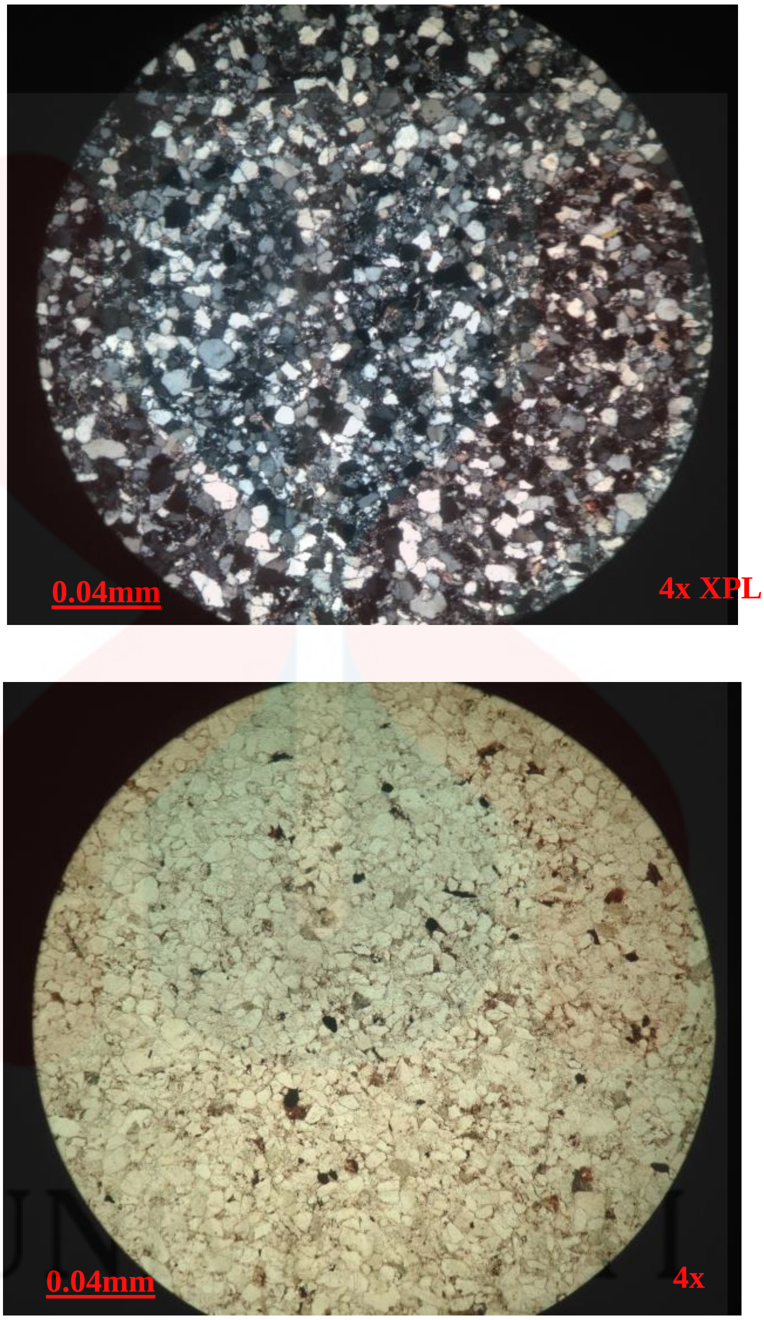



**Figure 5.10**: Photomicrographs of fine-grained sandstone (Sample 2) under 4xmagnification

Point-counts of fine-grained Cretaceous sandstone sample 2 from the study area have mean QFL percentages of 60-30-10. On the Q-F-L diagram, mean detrital modes plot near near Q-F leg, thereby, suggesting a recycled orogenic provenance (Figure 5.11).

Based on petrographic observations of the sample under microscope, the fine grained sandstone have considerably high percentages of monocrystalline quartz (87%) compared to polycrystalline quartz (13%). A comparison to sample 1, percentage of monocrystalline quartz grain in Sample 2 is less compared to percentage of monocrystalline quartz grain in Sample 1 but still predominantly constitute in the whole framework grains for both samples respectively. This indicates the maturity of the sandstone as polycrystalline quartz has been removed by weathering and recycling. A population shift towards Q-F leg is evident in the Q-F-Lt diagram.

From the ternary plot (Figure 5.11), both sandstones can be classified as a product of recycled orogen for which sources are deformed and uplifted strata sequences in subduction zones, along collision orogens, or within foreland fold-thrust belts (Dickinson & Suczek, 1981). Terrigenous sediments derived from recycled orogens are more felsic which explains the reason why quartz minerals are more dominant. This indicates that the sandstones are texturally mature (Folk, 1951). It also implies a high degree of mechanical and chemical stability for the sandstones. It can be suggest that the sandstone has been transported a long distance from their source. The quartz crystals occur as monocrystalline to polycrystalline crystals, with the polycrystalline quartz having crystals with sharp to sutured intra-grain boundaries typical of metamorphic rocks (Pettijohn et al., 1972). The quartz also have straight to strongly undulose extinction which is as a result of strain on the crystals and the polycrystalline crystals appear slightly less in number than the monocrystalline quartz. This character of quartz revealed possible contributions from both igneous and metamorphic sources. The occurrence of very little feldspar suggests lower source relief, moderately to long transportation distance and probably slow sedimentation rate. This can be ascertained from the quartz content (75–90%) that is more stable to weathering.

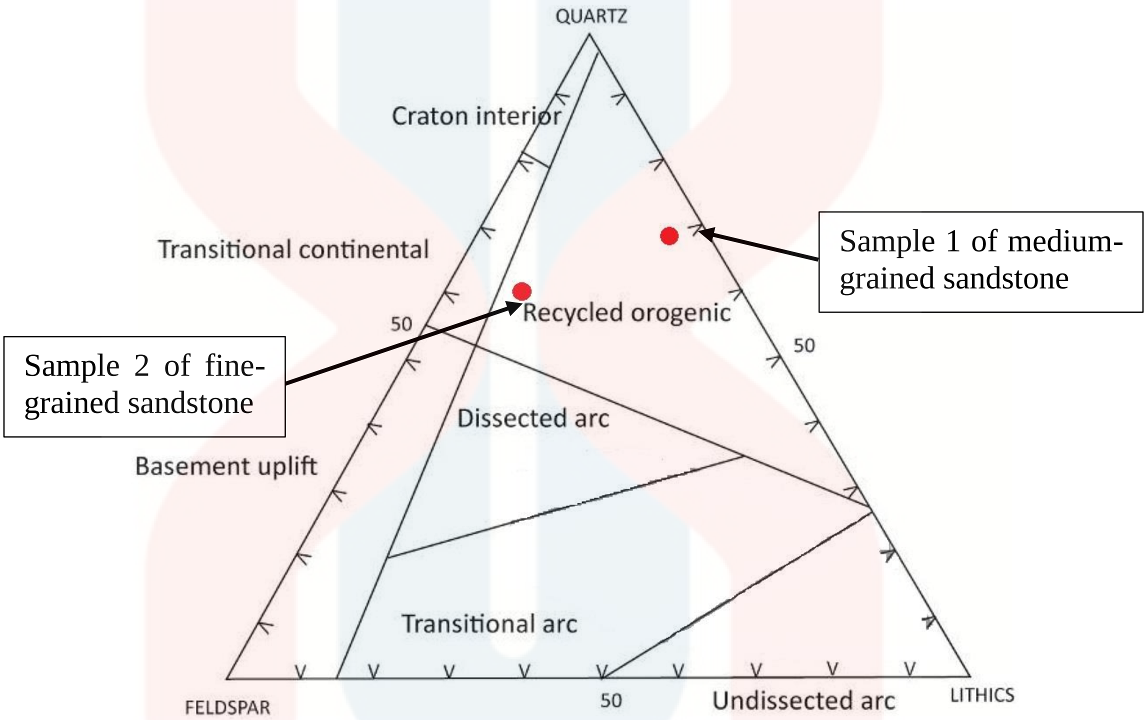



**Figure 5.11**: Plots on QFL diagram for both Sample 1 and Sample 2

# CHAPTER 6

# CONCLUSION AND RECOMMENDATION

## 6.1 Conclusion

There are three objectives which have been stated in this research. All three objectives were able to be achieved through conducted research. The first objective is to produce a geological map of Bukit Panau with scale 1:25000. This chapter will conclude results from field study and petrographic analysis of thin sections prepared from rock samples collected from the Bukit Panau area. The mapping area is about 40km$^2$. Based on the study of general geology, stratigraphy and sedimentology of study area, the geological map of Bukit Panau, Tanah Merah, Kelantan with scale 1: 25000 is produced. The geological map (Figure 4.9) consists of lithology units of alluvium, granite, interbedded sandstone, conglomerate, mudstone and shale, and also volcanic rocks. According to The Malaysian and Thai Working Groups (2006), overlying rock units at Bukit Panau were previously believed to be Cretaceous in age based on paleontological evidence. However, throughout the research conducted recently, the age of Bukit Panau which said to be younger than granite based on its formation cannot be correlated as there are no fossils found.

The study area has four units of lithostratigraphy which are alluvium, sandstone, granite and Tanah Merah Volcanics. The age for lithostratigraphy in the study area is from Carboniferous, Cretaceous and Quaternary.

Based on the specification of this study which is depositional environment, the depositional environment of Bukit Panau had been identified through complete sedimentary log conducted in the study area with the help of petrography on rock samples. The arenaceous and argillaceous rocks found at Bukit Panau act as indicator to determine depositional environment in study area. The study area is classified to be in depositional environment of fluvial. The presence of graded bedding with fining upward sequence as well as cross-bedded sandstone and ripple marks structure in the sedimentary rock sequence at the Bukit Panau area indicated that the rock sequence was deposited in meandering river of fluvial environment.

By analyzing the petrographic of two thin sections of sandstone, the provenance of the study area can be determined which is in recycled orogens, supported by the grain size, and shape. The plots of Panau Formation sandstones on Qt-F-L diagram suggest that the detritus of the sandstones were derived from the recycled orogens shedding quartzose and mixed debris of the continental. Recycled orogen are zones of plate convergence, where collision of major plates created uplifted source areas along the collision suture belt.

## 6.2 Recommendation

Malaysia is constituted by rocks of Jurassic-Cretaceous age (203-65 million years) in some places such as Mount Panti in Johor, Mount Gagau (border point Terengganu, Kelantan and Pahang) and Bukit Panau in Kelantan with the potential for dinosaur fossils found in the rock sequence because the rocks are similar in terms of age and lithology of the rocks in Plateau Korat, Thailand, which contains many dinosaur fossils.

Following the discovery of a sequence of sedimentary continent-old Cretaceous (140-65 million years) in Bukit Panau by the Working Group of Malaysia under the Malaysia-Thailand Border Joint Geological Survey Committee (The Malaysian and

Thai Working Groups, 2006) and The lithology and stratigraphy by Mohamad Hussein Jamaluddin & Mat Niza Abdul Rahman (2014), further studies emphasize will hopefully continue this approach by carrying out studies on geological mapping of Jurassic-Cretaceous rocks in Bukit Panau, Kelantan to give additional insight into the lithology, geomorphology, structural geology, geohazard and geochemical of the Bukit Panau area.

For researcher, in the future they need to do more investigation and identification of the various bedrock features. Based on the geological structure found in Bukit Panau area, joint is mostly found in the study area. The active weathering and erosion in the area has bring some negative impacts on the environment and natural disaster such as flood which lead to landslide occur and the degradation of water quality. So, students should studies and learn about the relation between geological mapping and the understanding to identify the effect of the weathering and erosion to the environment. So, they can find the alternatives to solve the problem or perhaps lessen the badly consequences.

The geological and biological diversity in Bukit Panau area and cultural heritage associated with Adi Putra, professor of Hang Tuah can contribute to recognition as heritage geosites. Bukit Panau region has the potential to be upgraded as a national geological heritage geosites in turn can be appointed as geosites of international standard. The Bukit Panau area should be conserved for its historical event. This can help geologists and students to learn more about the lithology that can be found in the Bukit Panau area especially that existed as the outcrops.

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