GEOLOGY OF FAULT ANALYSIS IN PALANRO KEC MALLUSETASI KEB BARRU, INDONESIA

by

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APPROVAL

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DECLARATION

I declare that this thesis entitled "**GEOLOGY OF FAULT ANALYSIS IN PALANRO KEC MALLUSETASI KAB BARRU, INDONESIA**" 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.

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Geology of fault analysis in Palanro kec Mallusetasi keb Barru, Indonesia

Abstract

Research area is located in Palanro of Mallusetasi District, Barru regency, South Sulawesi Province. The research area located on northwest of South Sulawesi. This area has a complex geological structure, as well as 3 tectonic plate movements which forms many structures such as joints, folds, and fault. The method used in fault analysis are lineament analysis, kinematic analysis and dynamic analysis. The lineament analysis will be used for determination of major fault in the study area. Kinematic and dynamic analysis will conducted in order to identify the type, movement and major force of the faults in the study area as well as the effect of the fault to the study area. The main purpose of conducting the geological research is to recommend the risk mitigation against geo hazard such as earthquake, flooding and landslide in Barru. There are Salo Jampue strike-slip fault determined in the study area which occurred during Miocene which creates geological structures such as shear joints and folds. The principle stress direction are relatively in NE-SW direction.

Geology dan Analisa Sesar di Palanro kec Mallusetasi keb Barru, Indonesia

Abstrak

Kawasan penyelidikan terletak di Palanro, Kecamatan Mallusetasi, kabupaten Barru, Provinsi Sulawesi Selatan. Kawasan penyelidikan yang terletak di barat laut Sulawesi Selatan. Kawasan ini mempunyai struktur geologi kompleks, serta 3 gerakan plat tektonik yang membentuk banyak struktur seperti kekar, lipatan, dan sesar. Mete yang digunakan dalam analisis kesalahan adalah analisis garis lurus, analisis kinematik dan analisis dinamik. Analisis garis lurus akan digunakan untuk menentukan kesilapan besar di kawasan kajian. Analisa kinematic dan dinamik akan dijalankan untuk mengenal pasti jenis, pergerakan dan kekuatan utama kesalahan di kawasan kajian serta kesan kesilapan ke kawasan kajian. Tujuan utama menjalankan penyelidikan geologi adalah mencadangkan pengurangan risiko terhadap bahaya geo seperti gempa, banjir dan tanah longsor di Barru. Terdapat Salo Jampue sesar strike yang ditentukan di kawasan kajian yang berlaku semasa Miocene yang mewujudkan struktur geologi seperti shear joint dan lipatan. Arahan tekanan prinsip relatif dalam arah NE-SW.

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LIST OF ABBREVIATION

GRDP	Gross Regional Domestic Product
NW	Northwest
SE	Southeast
WWF	West Walanae Fault
EWF	East Walanae Fault
ESB	East Sengkang Basin
WSB	West Sengkang Basin
NS	North South
GPS	Global Positioning System
S	South
E	East
W	West
N	North
Qac	Quartenary alluvium
TmC	Camba Formation

LIST OF SYMBOLS

º	Degree
σ	Sigma
↓	Arrow
′	Minutes
″	Seconds

CHAPTER 1

INTRODUCTION

1.1 General Background

Sulawesi Island can be easily identified because of its k shaped pattern. The shape formed because of the island's complex region. There are 3 lithospheric plate which causing changes in Sulawesi Island and its surrounding; the westward-moving Pacific plate, and the south-southeast-moving Eurasia plate the northward-moving Australian plate. The constant movement of the plates produces transform faults, subduction zones, oroclines and migrating arcs. In Neogene period, Sulawesi was affected by tectonic force where collision between continents take place. The continent that involved were the Australian Craton-derived blocks and Sundaland. As a result, the geological structures such as folds, large slip strike fault, magmatism and thrust belt can be observed. The movements of the plates forms many recognizable or well-known large faults for example, Matano Fault, Lawanopo Fault, Balantak-Sula Fault, Palu-Koro Fault System, Kabaena Fault Kolaka Fault, and Walanae Fault.

Walanae fault is one of the large fault in Sulawesi projecting over 150 km of linear geomorphic characteristics which covers the south arm of Sulawesi. The Walanae fault system is composed in between East Walanae Fault and West Walanae Fault consists of tapered depression zone. This fault is located along the western margin of Bone Mountains and eastern margin of Western Mountain Range (van

Leeuwen, 1981; Grainge and Davies, 1985). During Neogene to Quatenary, the movement of Walanae fault causes a major production of structural geology such as distinct scales of folds, faults and deformation process. The faults caused by the Walanae fault are lack of detailed information. The faults produce due to Walanae faults may cause geological hazard such as landslides, earthquakes or flooding which threaten the life of the residents. From the length of the faults it can be identified whether the fracture have the ability to conduct an earthquake or not. The lack of detailed information about the faults and the rock type in Palanro area, the geological information is limited and hard to analyse the particular area.

Therefore, the geological features are needed for the region hence, geological mapping is the solution which conducted in a surface or subsurface of the respective region on a large or small scale. The aspects that covered by the geological research are stratigraphy, structures and geomorphology of Palanro, Barru. A detailed mapping constructed with a map scale of 1:25, 000.

1.2 Study Area

1.2.1 Location

Barru known as the city in the province of South Sulawesi, Indonesia. It covers an area of 99.33 km² and has a population of ± 140,000. The town of Barru is located on Makassar Strait. In the north is bordered by Parepare District, to the east by Soppeng and Bone regency and to the south by Maros regency. Based on climatological station records, the average temperature of the Barru City is about 28.5 ° C with a minimum temperature of 25.6 ° C and a maximum temperature of 31.5 ° C. Barru has a tropical climate with two seasons, the dry season in March to September and the rainy season in October to February. Geological mapping held on at Barru on a scale of 1:25,000 with length of 5 km×5km. In geographical factor the study area is located from longitude 119°39′33.81″ to 119°42′25.76″ east and from 3°58′57.09″ to 4°01′45.20″ south. The study area had been included some part of the Walanae fault. By viewing the terrain map in Google Map there are a few lineament on Walanae fault that can be observed. The lineaments' are scattered and in different directions because the constant movements of the tectonic plates. The maximum elevation of the study area is 300m. The lithology of the study area composed of volcanic clastic, Walanae sandstones and alluvial. The Walanae fault is known as left lateral strike-slip fault motion of East Walanae Fault. The Walanae Fault created fault splays, faults that produce by a main fault during displacement.

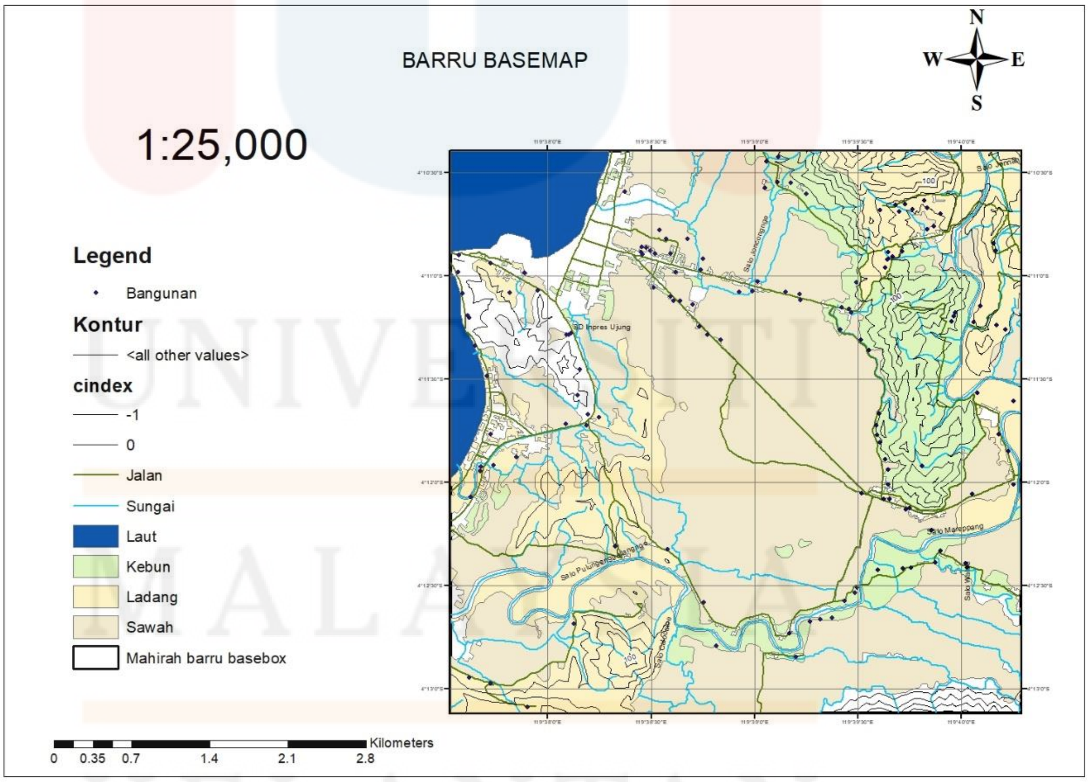


Figure 1.1 Basemap of the study area

1.2.2 Road

The study area are accessible because the sites are connected via roads that been created by the government or the private sectors which ease the people. The public transportation such as bas and train also provided to comfort the residents. Trans-Sulawesi Railway is undergoing construction. The railway will link Makassar and Pare Pare. The railway track of 44 km length, act as linkage from Barru to Palanro and on the end of 2018 the railway may operate. The railway track that covers Makassar-Parepare approximately 150 km length. However, using motorcycle is the most convenient way because of the traffic and also the population density. Besides, facility such as mosque, bank and school has been built for the residents need so that the people can live a comfortable life.

1.2.3 Demography

Sulawesi island of Indonesia composed of many provinces, South Sulawesi is one of the province that have residents of approximately 9.5 million people. The total area of the South Sulawesi is about 4.7 million hectares where, 2.1 million hectares of it are forest area. The population of Sulawesi in 2005 was 15,997,700, accounting for 7.3% of the total population of Indonesia. Makassar is the biggest city in Sulawesi with a population of 1,195,000, followed by Manado with 406,000, Palu with 291,000, Kendari with 236,000, Gorontalo with 153,000, and Palopo with 129,000. Since there are limited plains on the island, the aggregate urbanization ratio (27.5%) is lower than the national average (42.1%).

Barru is one of the developing city in South Sulawesi of Indonesia. The city situated on the south west coast of Sulawesi and the distance of Barru from Makassar is approximately 70 km north. This city have a higher distribution and have a total population of 38,333 people.

1.2.4 Land use

Land use is the activity of developing natural environment into human built environment that benefits the human's socioeconomic activities. There are seven types of land use which are residential, agriculture, industrial, commercial, recreational, institutional and transportational land use.

Residential land use is the area that used for residents to live. The Western part of South Sulawesi was compacted of housing area. The increase in population of the residents eventually increases the demand for land use.

Table 1.1: The Population Density of South Sulawesi Provinces, Indonesia in 2010 (Source: Badan Pusat Statistic (BPS) Indonesia, 2010).

Kabupaten		Laki-Laki	Perempuan	Laki-Laki + Perempuan	Sex Ratio
(1)		(2)	(3)	(4)	(5)
01	Selayar	58.376	63.529	121.905	92
02	Bulukumba	186.649	208.108	394.757	90
03	Bantaeng	85.677	91.307	176.984	94
04	Jeneponto	166.152	176.070	342.222	94
05	Takalar	129.384	139.787	269.171	93
06	Gowa	320.568	331.761	652.329	97
07	Sinjai	110.801	118.135	228.936	94
08	Maros	155.761	162.477	318.238	96
09	Pangkajene Kepulauan	147.136	158.622	305.758	93
10	Barru	79.617	86.283	165.900	92
11	Bone	341.335	375.933	717.268	91
12	Soppeng	105.325	118.432	223.757	89
13	Wajo	183.371	201.323	384.694	91
14	Sidenreng Rappang	131.954	139.847	271.801	94
15	Pinrang	170.374	180.787	351.161	94
16	Enrekang	95.578	94.597	190.175	101
17	Luwu	164.287	168.576	332.863	97
18	Tana Toraja	112.439	109.356	221.795	103
22	Luwu Utara	144.950	142.656	287.606	102
25	Luwu Timur	125.202	117.680	242.882	106
26	Toraja Utara	108.952	106.448	215.400	102
71	Makassar	661.379	677.995	1.339.374	98
72	Pare Pare	63.719	65.823	129.542	97
73	Palopo	72.557	75.476	148.033	96
Sulawesi Selatan		3.921.543	4.111.008	8.032.551	95

The agriculture land use is the place where the agriculture plantation takes place. This land use acts as the food production or wood fibre area. The agriculture land use in South Sulawesi is divided into four types, cropland, mixed garden, Timber garden and monoculture. Crops is known as the commercial plants that grown in a large scale. Mixed garden are the process which the mix crops occurs. Timber garden are where the gardening area are planed around by the timber. Monoculture is the cultivation of a single crop in a respective area. This agriculture also function as an economic value

Table 1.2: The land use system at South Sulawesi (Source: Arif Rahmanullah et.al, 2012)

Category	Land-use type	Products	Scale of operation (ha)	Location (village)
Crops	Maize	Maize	0.5-1	Bonto Cinde
Mixed-garden	Candlenut garden	Candlenut, maize	1	Bonto Cinde
	Kapok garden	Kapok, maize	1	Bonto Cinde
	Coffee garden	Coffee, maize	1	Kayuloe
	Coconut sugar garden	Coconut sugar	1	Tugondeng
	Coconut-cacao garden	Coconut, cacao	1	Tugondeng
	Cacao-coffee garden	Cacao, coffee, fruit	1	Campaga
	Cacao-coffee-clove garden	Cacao, coffee, clove, fruit	1	Campaga
Timber-garden	Gmelina garden	Gmelina	0.5-1	Karassing
	Sengon-gemelina garden	Sengon, gmelina	0.5-1	Karassing
Monoculture	Clove garden	Clove	1	Barong Rappoa

Industrial land use are the major economic value for the country. Industrial land also named as factories which depending on the product of the factory such as oil company, electric providing station and glove producing company. Commercial land use is the real estate business where the main focus is to build shopping mall, restaurant or service station. This land use is to ease the human life for a better living.

Instituitional land use us define as the public building like college, school, museums and government office. This land use is one of the important land use needed in any area. Recreational land use is develop for the purpose of recreation such as parks, playground and camping sites.

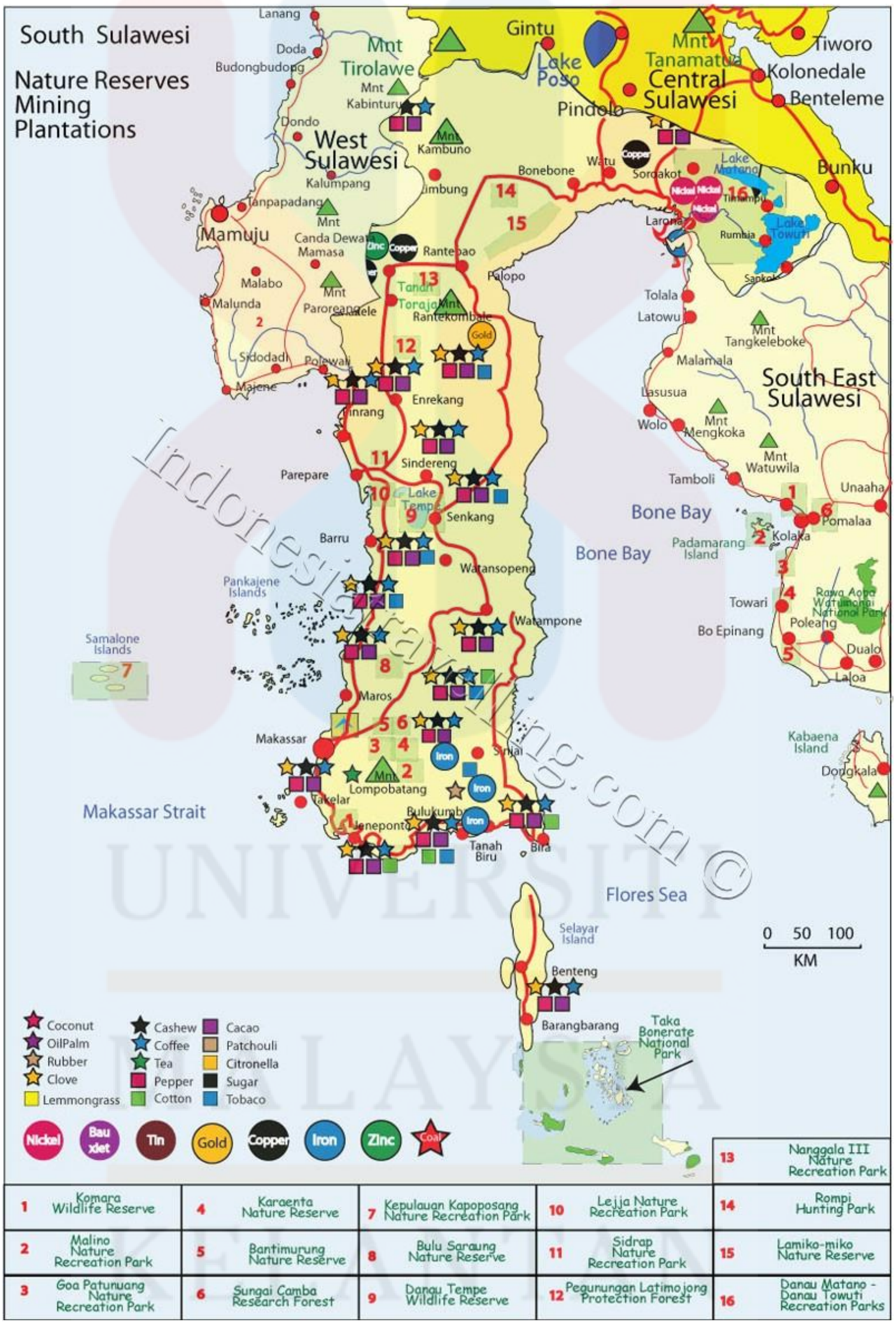


Figure 1.2.: The distribution map of recreational, industrial and agriculture land use of South Sulawesi (Source: The Brunei Times, 2008)

Transportational land use is the associated with the development of public transport such as bas, train and flight. The transportational is one of the crucial sources needed

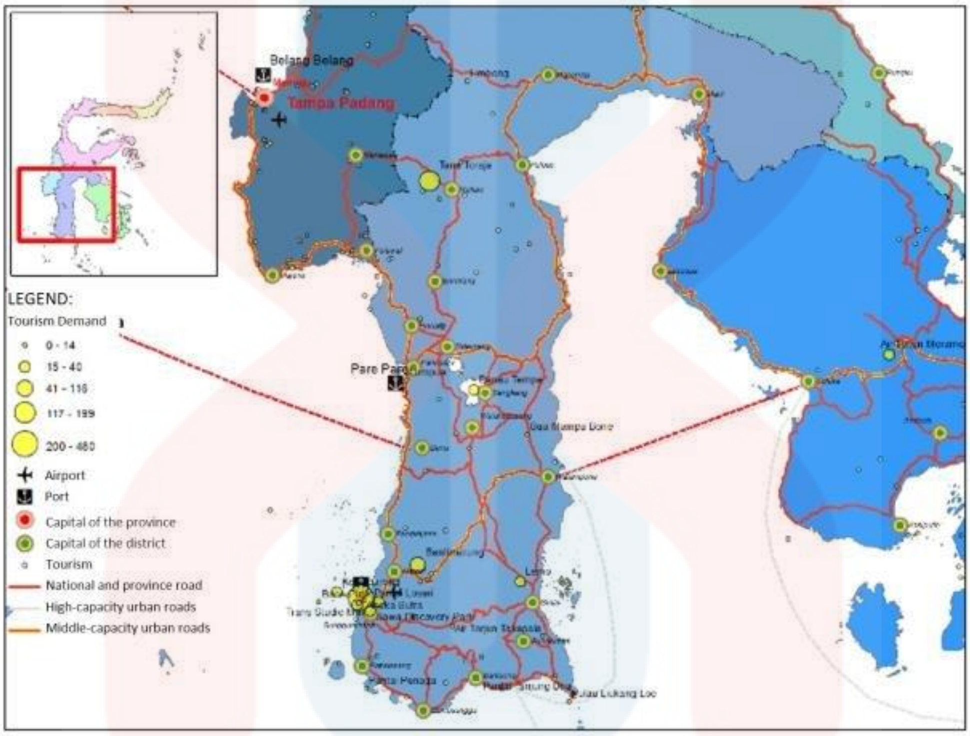


Figure 1.3: Transportation of South Sulawesi (Source: Endy Marlina, 2018)

The forest coverage (53.4% of the island), the agricultural land (such as., paddy fields, plantations and upland farming) covers 26.1% of Sulawesi Island and the settlement lands covers 0.4%. Since most land areas in Sulawesi have already been developed, except for steep slopes.

1.2.5 Socio economic

Social economic is the phenomenon that relates the economy and social behaviour of a respective area in order to study the influence cause by the two factors. In South Sulawesi, there are various kind of ethnic but the three major ethnic are the

Torajan, Buginese and Makassarese. In Barru the largest ethnic are the Bugis and most of them belief in Islam. Bugis also held an event in a certain days usually on Wednesday and last Thursday of each month to receive good fortune. Even though, Islam is the main religion, many of them still follow the animistic religion. The religion which believing possess of soul in natural phenomenon and objects as well as the universe.

Barru also well known as trading centre of intra-island for food and fuel. The eastern part of Barru was active on agriculture field mainly on rice field. The South Sulawesi act as the national rice storehouse and even export the rice to Philippines, Papua New Guinea as well as Malaysia. Furthermore, other plants such as cashew, cocoa, maize and coffee planted and exported worldwide.

Besides, mining is one of the factor increasing the Gross Regional Domestic Product (GRDP) of South Sulawesi. Gold, nickel, coal and copper are the elements that mined, the elements then used for industrial purpose.

1.3 Problem Statement

Basically, the geographical features of Walanae Fault were studied in larger scale approximately around 1: 100,000 scale (Asri Jaya and Osamu Nishikawa, 2013). The research project carried out in a scale of 1:25,000 which provide more detailed and closer look of the fault as well as the geological structures caused by the fault. Besides, the rock identification in Walanae fault are lack in detail. The Walanae depression was studied last on the year 1987, the year gap is about 32 years which is huge (Dina Anggreni Sarsito et al, 1987). The tectonic force or any kind of force might happen on the area which can lead to a geographical structures or rocks.

There are lack of information regarding the faults splays caused by the Walanae faults. Based on geological study, faults may cause geological hazard such as earthquake, landslide and tsunami depend on the type and size of the faults. By analysing the faults the danger that might cause by the faults can be prevent from creating bigger impacts to the residents that live on the respective area.

Besides, there been many geo hazard occurred in Sulawesi lately such as flood, tsunami and earthquake which might change the composition and structure of rocks (FloodList, 2019). The changes of the rock may produce new lithological unit and lithology of Palanro, Barru, Indonesia.

The data collection in Palanro, Indonesia regarding fault may produce new discovery or detailed information in geological aspects that left blank by previous researchers (Asri Jaya and Osamu Nishikawa, 2013).

1.4 Aim

The aim of the research is to produce a small scale map of the study area which includes the geological aspects such as lithology, stratigraphy and lineament as well as analyse the faults in the study area with a scale of 1:25,000.

1.5 Objective

I. To determine the geological features of the study area in Palanro

II. To analyse the faults in research area using kinematic and dynamic method

III. To investigate the fault mechanism in the study area (Palanro, Barru).

1.6 Scope of the Study

The main skill that needed to execute is to determine the general geology composed of structural geology, geomorphology and stratigraphy. Walanae fault and the fault splays analysis are the fundamental study of the research. The measurement of the dip and strike enable the analysis process of dynamic and kinematics to take place. Kinematic analysis is the study of the motion of the faults. By obtaining the motion of the faults the type of the fault can be identified. The observation between the fault and the shear zone will classify the motion of the fault. Deformation of rock structure and shape on the shear zone cause by stress act on the rocks. The process of determining stress is known dynamic analysis. Stereographic analysis gives a detailed view of the magnitude displacement and the stress principle of a fault.

The research focus on preventing or reducing the risk may experience by the residents in Barru. The discontinuities such as faults and joint can initiate geo hazards such as landslide and earthquake. By analysing the faults, the possible characteristics of the faults such as the movement, stress applied and the direction of the principle obtained. The geological information collected can be used as reference for investigating the geological hazard the faults may cause in future. Besides, the information regarding the rock conformation will help to produce a new lithological rock unit which may produce a new formation in stratigraphy aspects.

1.7 Significance of study

The significance of conducting the geological research is to recommend the risk mitigation against geo hazard such as earthquake, flooding and landslide in Palanro, Barru. Faults is one of the discontinuity that trigger the geo hazard to occur depending on the force applied during formation of the fault. In order to analyse the characteristics of the faults, small scale map of the study area which includes the kinematics and dynamic analysis of the faults is required. By analyse the kinematics and dynamic of the fault the status of the faults whether active or passive can be identified. By determining the status the risk that may create by the faults can be reduced. There are many residential area around the Walanae faults which may threaten their life. The study may contribute information or awareness for the residents living in that area which help the residents and government in preparing the area from creating a bigger impact in social, economic and politic factor.

One of the way to reduce risk are by mitigating. Mitigating needed a longer process therefore, the faster the information collected the faster the prevention carried out. Furthermore, the studying of the fault analysis benefits the government as well as the residents to live in a safe environment. The information regarding the rock conformation will help to produce a new lithological rock unit which may produce a new formation in stratigraphy aspects.

Moreover, the data collection of the research can be used by the future research that undergo investigation around the Barru area. Barru are lacking in geology related data hence, the research help in gaining geological information of Barru and South Sulawesi for the future researcher.

CHAPTER 2

LITERATURE REVIEW

2.1 Regional Geology and Tectonic Setting

The movements between the lithospheric plates are the main reason for the extremely active tectonics, seismicity and volcanism at Indonesian region. The motion of the plates mostly start occurring in Cenozoic time where the Pacific plate move in the direction of west-north west ward as well as the Australian plate accelerating towards Asian plates via northward. (Heirtzler et aI, 1968).

Sulawesi Island is made up of a complicated region by referring to geological aspects. The reason for the complexity are the three megaplates which constantly moving. The Australian plate moving northward while, the Eurasia plate shifting to southeast and the Pacific plate keep going towards westward. South Sulawesi are separated from Sunda Platform because of sea-spread flooring that occurred during Miocene (Hamilton, 1979, 1989; Katili, 1978, 1989).

North Sulawesi Trench are another geographical activities that occurred because of the process called subduction of oceanic crust of Sulawesi Sea. Throughout, Tolo thrust of Banda Sea and Southeast arm where the convergence takes place (Silver et al., 1983a, and b). Palu-Koro-Matano Fault system are connected with the two geological features, the Tolo Thrust and Trench North Sulawesi. three provinces made up the Sulawesi Island by referring to the tectonic production and the lithology of the Island which are the Eastern Sulawesi Ophiolite Belt, continental fragments originated from the Australian continent and the Volcanic Arc of Western Sulawesi (Hamilton, 1978, 1979; Sukamto and Simandjuntak, 1983; Metcalfe, 1988, 1990; Audley-Charles and Harris, 1990; Audley-Charles, 1991; Davidson, 1991). Faults acts as the contact for the three continents.

The South Sulawesi separated by eastern and western which entirely different, the Walanae Depression are the geological feature that separates the South Sulawesi, Walanae depression get past via Lake Tempe (Van Leeuwen, 1981). The fault that situated at the centre of the South Sulawesi is the Walanae Fault. This fault is known as sinistral slip-strike fault that moving towards NW-SE. The fault in NW direction pass through the Makassar Strait and combined with Phatemoster-Lupar suture located in Kalimantan. In SE direction the fault had terminated at Flores Thrust. However, the fault reactivated transtensionally which produce the Walanae Depression. (Sorono, 2018).

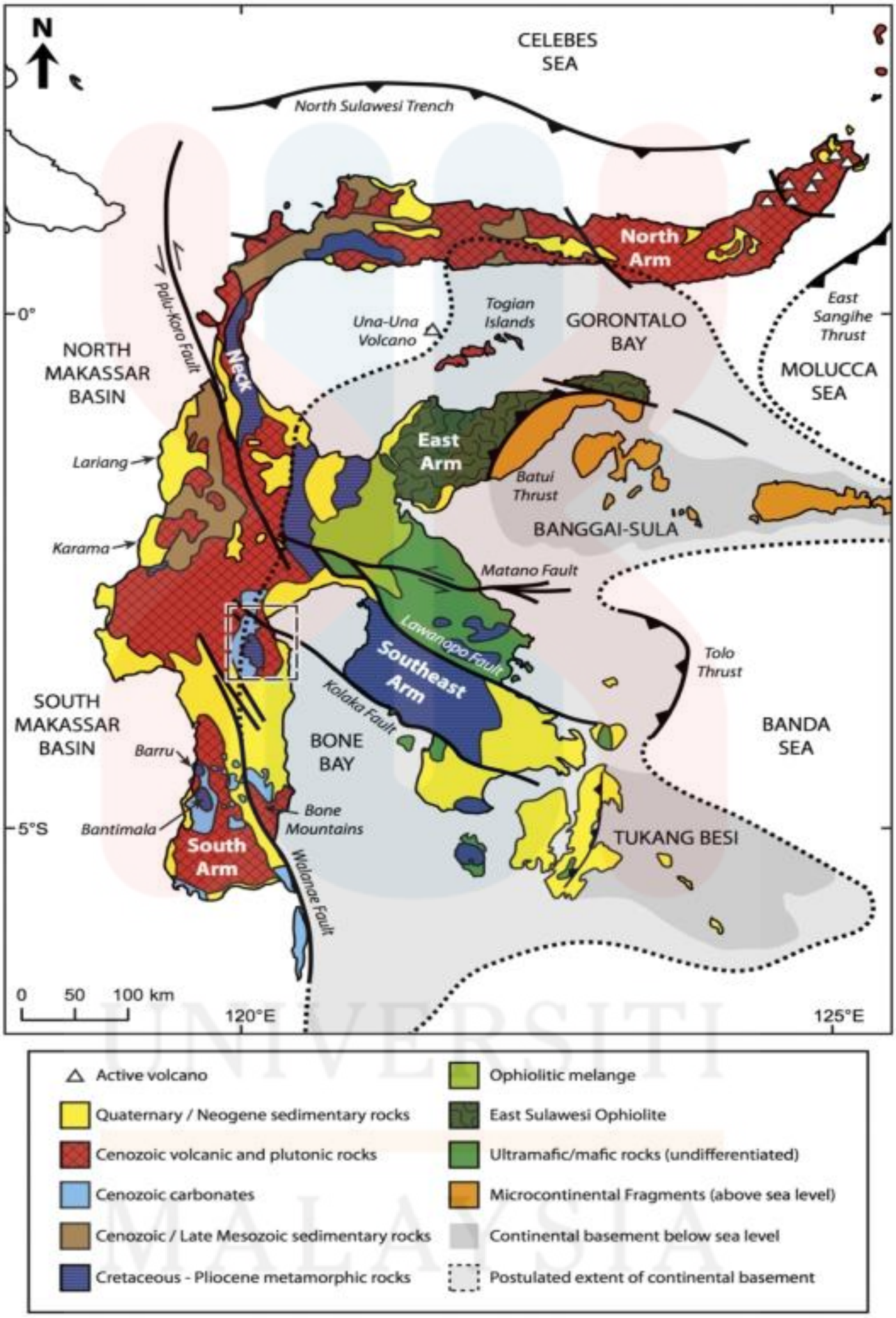


Figure 2.1: The location of the geological terrains and major faults of Sulawesi. (Source: White et.al, 2014)

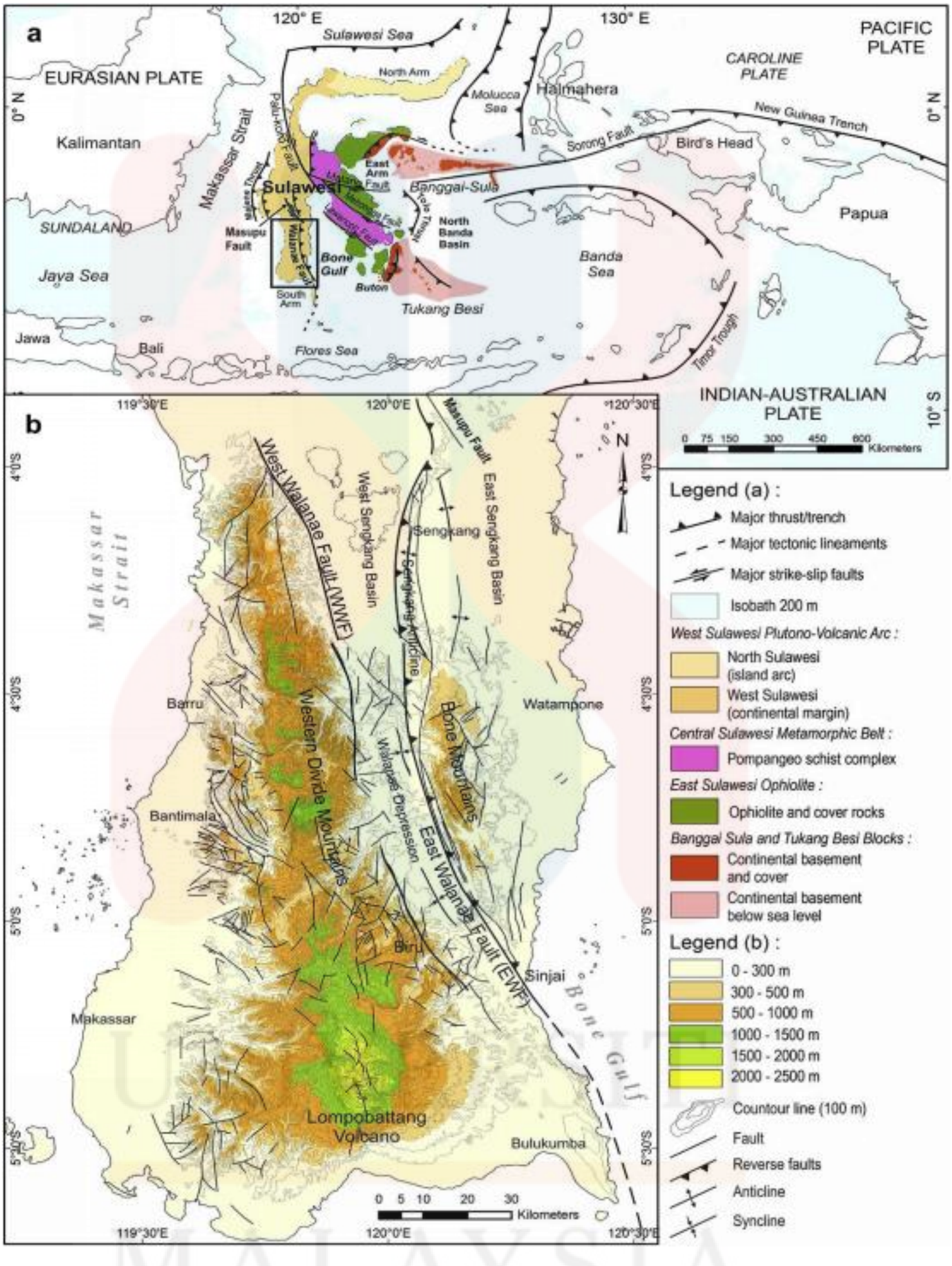


Figure 2.2.: a) Tectonic map presenting the distribution of plates, continents and island arcs in the eastern part of Indonesia (Source: modified after Hamilton, 1979; Hall and Wilson, 2000; Watkinson, 2011). (b) Structural and topographic map of South Sulawesi (Source: modifies after Sukamto, 1982; Sukamto and Supriatna, 1982; Berry and Grady, 1987).

2.2 Stratigraphy

The Sengkang Basin or Walanae Depression was created by a massive north northwest and south southeast moving fault system of the Walanae zone. In Late Neogene the fault developed as structural basin (Suyona and Kusnama, 2010). Clastic sediments consisting fossils of Late Miocene age had occupied the Sengkang Basin. The clastic deposits that composed the basin in South, West and Southeast Sulawesi is given name as "Celebes Mollase" by Sarasin and Sarasin (1901) (Van Bemmelen, 1949). Then, the synorogenic molasses that deposits in South Sulawesi is changed to a term of "Walanae Formation" by Hoen and Zyegler (1917). The Walanae Formation is applied for the clastic sequences during Late Miocene to Holocene which occurred in Walanae Depression (Sukamto, 1982; Grainge and Davies, 1985).

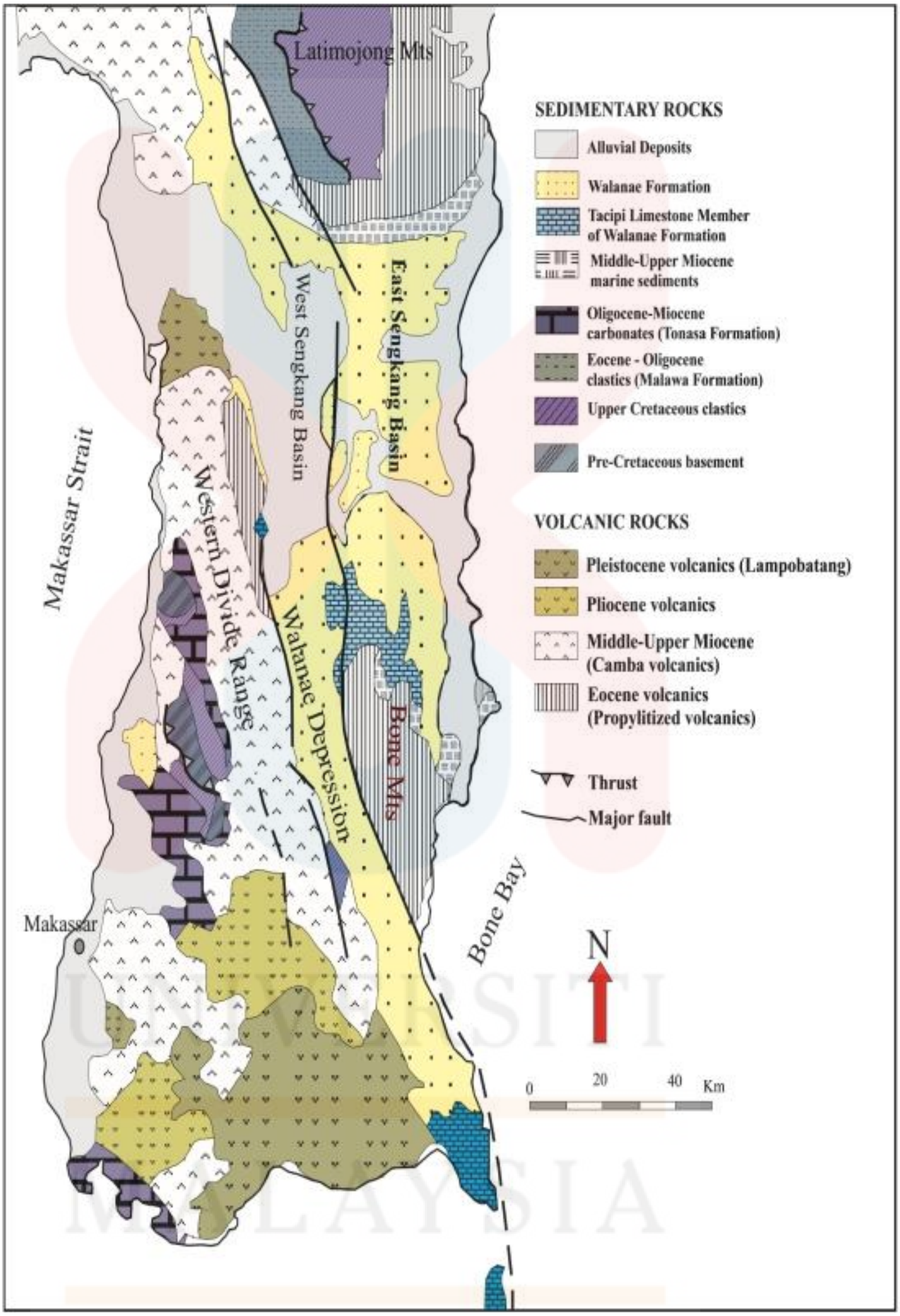


Figure 2.3: Geological map of South Sulawesi (Source: Suyono and Kusnama, 2010)

South Sulawesi was developed during Early Cretaceous and known for the complex basement which consist of old continental crust of Australian origin. Recycled ancient zircons that found in a Miocene age igneous rock, shows that they were established from northern Australia. The igneous maybe accumulated on the Sundaland during the collision event that took place during Oligocene until Miocene period (Bergman et al., 1996; Priadi et al., 1993). Middle till Late Eocene, the Malawa or Toraja Formation composed of volcanic and marginal marine coal-bearing deposited unconformably at the west basement of Walanae depression (Sukamto, 1982).

Then, Oligocene Tonasa Formation that undergo deposition, presents the expansion of shallow water carbonate platforms in southern Sulawesi, as well as accumulation of whilst deep water marls formed beside the areas (Supriatna et al., 1993; Wilson and Moss, 1999). In southern Kalimantan Basin and East Java Basin, carbonate platform which similar to Oligocene Tonasa Formation was found, where the existence of lateral deposition of reworked carbonate facies in the down faulted blocks were documented due to tectonic movement. The continuous accumulation carried out till Middle Miocene (Wilson and Bosence, 1996). Furthermore, the igneous rocks of Enrekang, Camba, Mamasa Volcanic Complex and derivative volcanic clastics had accumulated and composing greater than 75 % of the surface of Sulawesi west during Middle to Late Miocene. (Suyono and Kusnama, 2010).

This volcanism was connected to a north-south moving volcanic system. By conducting the trace element analysis the Miocene igneous rocks are subduction related. The subduction can be connected with compressional boundaries, where the oceanic crust was subducted beneath the continental crust. Hence, in the East

Sengkang Basin, small carbonate reefs of the Tacipi Member developed, which the shallow marine facies conformably overlaid marine mudstones presenting the base of Late Miocene Walanae Formation. The mudstone deposited in the down faulted Walanae depression and north of the Bone Mountains (Grainge and Davies, 1985; van den Bergh, 1999). In Pliocene, probably compressive deformation is the main contributer for the structural evolution of South Sulawesi. A major north northwest-south southeast moving fault system, the Walanae Fault Zone, divided the eastern and western parts of South Sulawesi and make a change in the deposition during the Late Miocene to Quaternary (Suyono and Kusnama, 2010). (Grainge and Davies (1985) The Walanae fault consists of two massive components, a western part, known as the West Walanae Fault (WWF) and an eastern part as the East Walanae fault (EWF). Moreover, these faults separated the Late Cenozoic of basin on both sides of the EWF into the West and East Sengkang Basins (WSB and ESB). The WSB corresponds with the Walanae and Lake Tempe depression (Suyono and Kusnama, 2010).

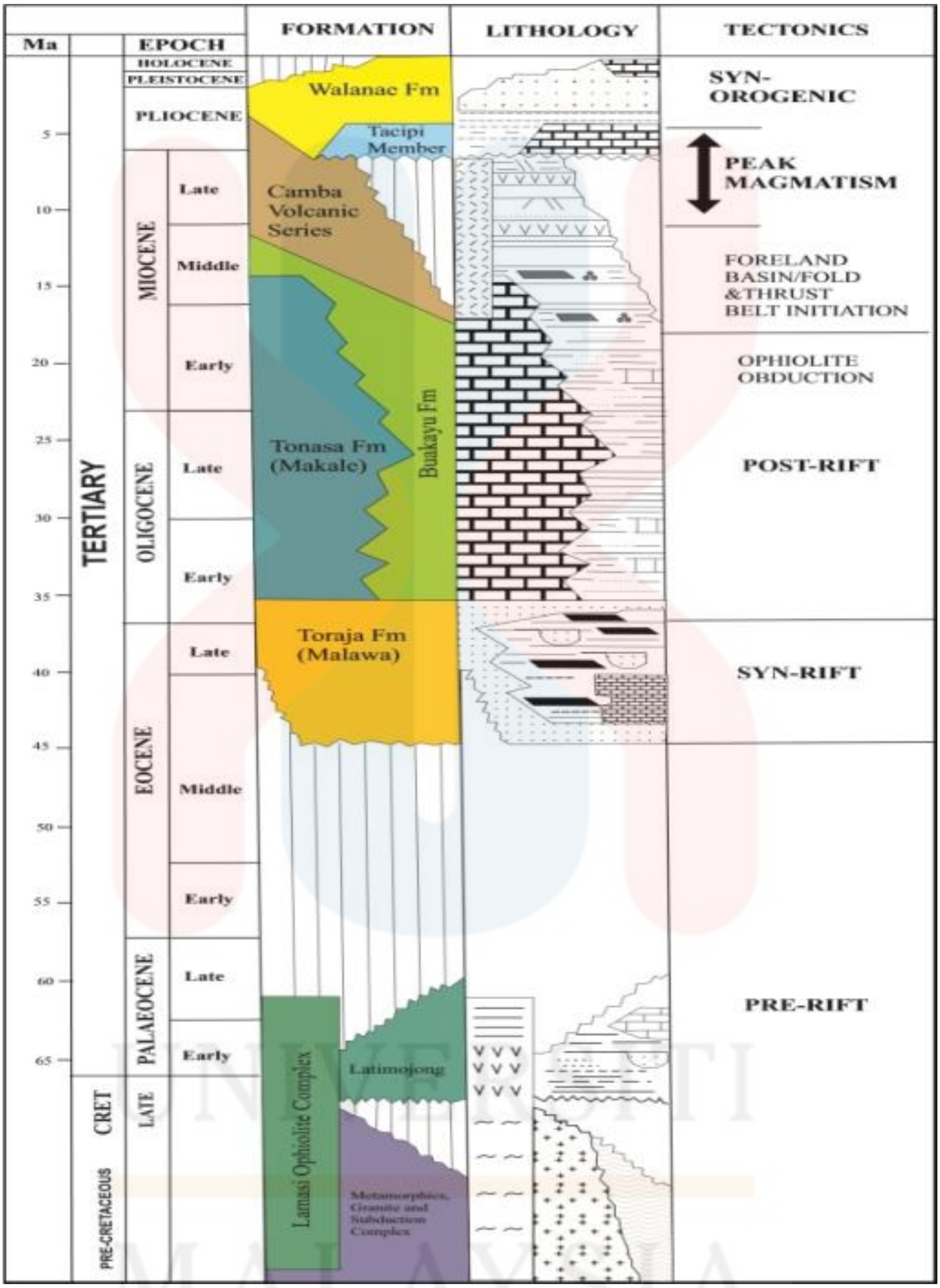


Figure 2.4: Stratigraphic column of southwest Sulawesi (Source: Suyono and Kusnama, 2010)

During Middle to Late Miocene, the deposition of Camba volcanics occurred in the western part of the Walanae Depression as well as the eastern part was mostly covered by the deposition of Walanae Formation with shallow marine of Tacipi and mudstone of Burecing Members. The Walanae Formation composed of four members and each member has a specific characteristic depositional environment from marine to fuvial (Suyono and Kusnama, 2010). The 4 types of members are the Tacipi Member, Burecing Member, Smaoling Member and Beru Member. The Tacipi Member is typically coralline limestones deposited within a shallow marine environment. While, the Burecing Member is mainly by calcareous grey mudstone in the lower part of the Walanae Formation.

The rock sequence which is rich in foraminifera, pollen, and marine mollusks, presents an open marine to transition depositional environment. The Samaoling Member being the middle part of Walanae Formation shows the changes to shallow marine by referring to the rocks such as silty mudstone and sandstone. The Beru Member is the upper part of the Walanae Formation. It is composed by sandstones of the Latte Pleistocene fuvial deposits which later on were shaped into terraces. In the western flank of the Sengkang Anticline, changing fuvial layers and estuarine deposits occurs, indicating that the area was a transition zone between estuarine and fuvio-lacustrine environments (Suyono and Kusnama, 2010).

2.3 Structural Geology

During Late Jurassic-Early Cretaceous period, the tectonic history of Sulawesi have been started in south central Kalimantan where the movement of continental arc occur associated with subduction of Meso-Tethys in north easterly (e.g. Hamilton, 1979; Parkinson et al., 1998; Guntoro, 1999; Hall, 1996; van Leeuwen et al., 2010). In the upper Cretaceous, at Meratus Range in Southesat Kalimantan presents a northwest dipping of subduction zone created an island arc in which volcanic clastic intruded by dykes and stocks (Yuwono et.al, 1998b).

At the end of the Early Miocene the magmatic activity influenced the uplift of the Walanae Graben formation in which changes to a basin where the sediments occupied the Walanae Formation (Sukamto, 1982). The Sengkang Basin probably occurred during this time period (Hamilton, 1979). The major North and South moving marginal fault of Walanae fault is the main reason for the basin formation (Yulihanto, 2004). The tectonic process conducted around 13 to 12 Ma which was during Middle Miocene, associated with Sengkang group segment's juxtaposition and opposite to the Sundaland's continental margin which consists of Salokalupang Member, beside Walanae fault zone. The rocks of Salokalupang Member were slant, folded and tectonic lenses of varies size were cut off (van Leeuwen et al., 2010). The continental fracture of Buton-Tukang Besi together with Sula slam with the east arm of Sulawesi during 13-11 Ma and Sula at 5 Ma, this phenomenon is named as collision of Sula platform (Smith and Silver, 1991; Hall, 1996).

Hence, the movement of the continents had created come geological event such as uplifting and the voluminous granitoid magmatism which occurred in northern of south arm Sulawesi (Bergman et al., 1996; van Leeuwen and Muhardjo, 2005). The Sengkang Basin consist of Neogene sediments have been mainly exposed to folding. Therefore, on Pliocene period the sequence of NS-trending anticlines and synclines (van Bemmelen, 1949) and a general uplift of the southwest Sulawesi region presence (van Leeuwen, 1981). Lompobattang volcano, composed because of high potassium occurs. There no possible connection to the subduction, however it may be present because of distentional intraplate contex (Yuwono et al., 1988a).

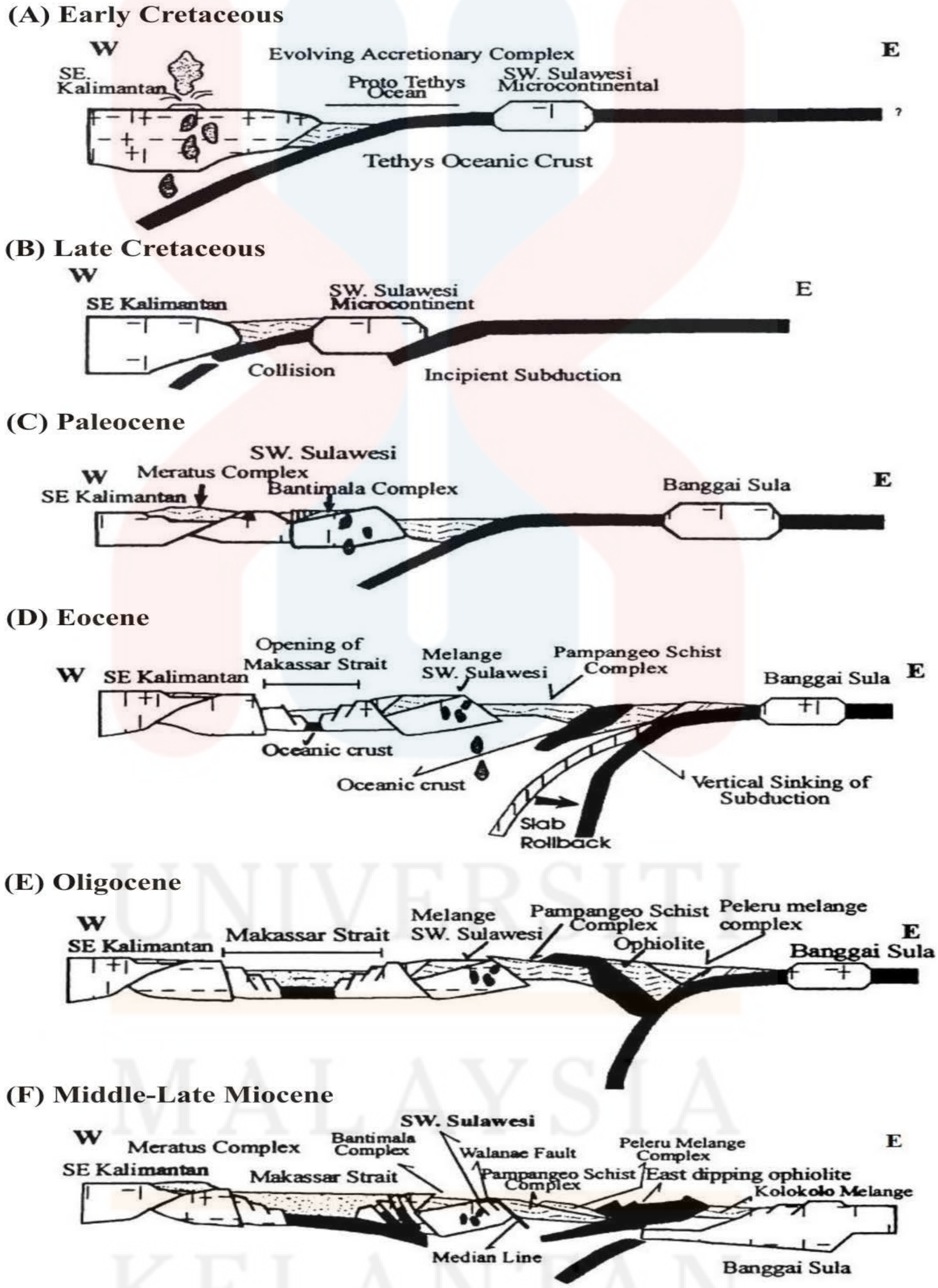


Figure 2.5: Interpretation of tectonic evolution of Sulawesi based on seismic reflection and gravity models, in addition to compilation geological information (Source: Guntoro, 1999).

2.6 Historical setting

There are some major differences in geology between the western and eastern South Sulawesi, where both are separated from each other by the West Walanae Fault (WWF) (van Leeuwen, 1981; Sukamto, 1982, Wilson and Bosence, 1996, van Leeuwen et al., 2010).

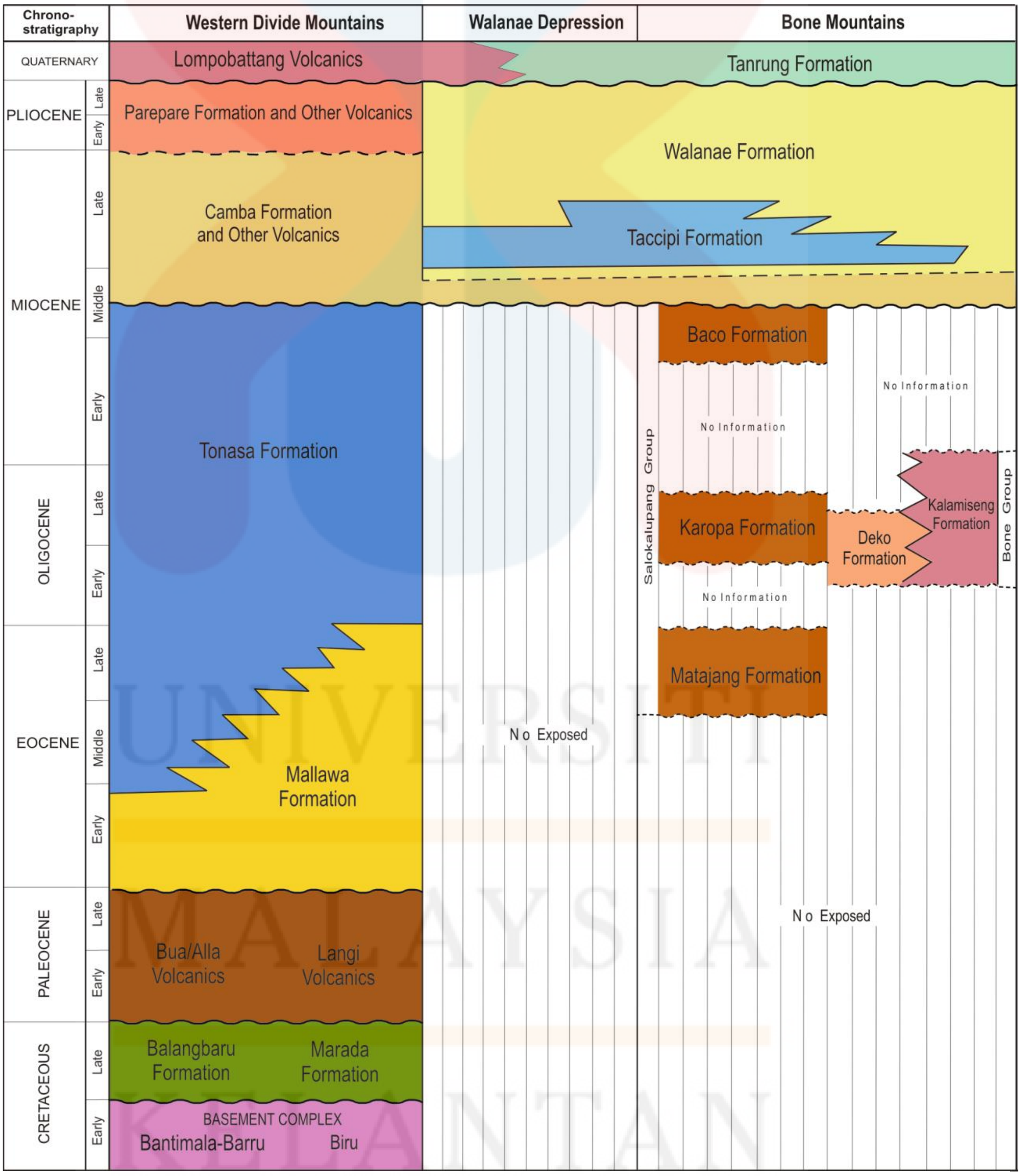


Figure 2.6: Stratigraphic chart from the west to the east of South Sulawesi (Source: Asri Jaya, 2014)

2.7 Fault Analysis

During the Late Cenozoic, the structural development of Sulawesi have been affected by expansive scale strike– slip, fold and thrust belts adaptable to the following collisions of the Western Sulawesi along with the Banda Sea microplate as well as Banggai-Sula and the continuous block rotation (Hamilton, 1979; Smith and Silver, 1991; Beaudouin et al., 2003; Hall, 1996; Bellier et al., 2006). The faults that known for the strike-slip features, mainly of sinistral motion are the Matano Fault (east arm), the Palu-Koro fault system (central Sulawesi), Lawanopo and Mendoke faults (southeast arm Sulawesi), Sadang fault and the Walanae fault (south arm Sulawesi). Fold and thrust belt are usually formed because of the fault movement which act as boundary suture of tectonic origin (Asri Jaya, 2014)

The south Sulawesi is occupied by to large fault which are the Sadang and Walanae faults. The east side of the Mamasa granite of Central Highlands of Sulawesi was the location where Sadang fault or Masupu fault formed (Hamilton, 1979, Coffield et al., 1993; Guritno et al., 2006). It had been classified as sinistral shear however, by referring to the field interpretation and adjacent areas the movement shows dextral (Coffield et al., 1993). The possible interpretation were the zone undergone to phases, the primary phase with sinistral movement and the secondary phase with dextral movement. The fault system maybe expand towards south to Walanae fault zone (Coffield et al., 1993; Guritno et al., 2006).

The Walanae fault system is the main structure occurred in the southern part of south Sulawesi. This fault was said as a main Northwest to Southeast (NW-SE) strike slip fault (Leeuwen, 1981, Sukamto, 1982, van Leeuwen et al., 2010). The fault is divided to two type of fault systems, East Walanae fault (EWF) and West Walanae fault (WWF). WWF was moving along the eastern of the Western Divide Mountain

Range. Generally, WWF was classified as the factor for uplift of West Divide Mountain Range where basement rocks in cretaceous like Bantimala and Barru metamorphic complex are located and said EWF younger (Sukamto, 1982; van Leeuwen et al., 2010). Meanwhile, EWF was trending approximately north to south (N– S) along the western margin of the Bone Mountains with a different topographic expression (Sukamto, 1982), and simultaneously continues to Masupu fault (Guritno et al., 1996).

In the northern part, EWF split through the east flank of an anticlinal structure of the Neogene sediments (Leeuwen, 1981). EWF separates the Sengkang Basin into two unit-basins (Grainge and Davies, 1985). EWF has been regarded as a sinistral strike– slip fault (Leeuwen, 1981; Sukamto, 1982, Leeuwen et al., 2010). The EWF apparently continues southwards into a deep oceanic trough interpreted as a Neogene trench by Hamilton (1979). The N-S trending narrow ridge in the middle part of Sengkang Basin corresponds to the geomorphic feature of Sengkang anticline. The fold involves Middle Miocene to Pliocene clastic sediments of Walanae Formation.

Summary

The literature review was used as reference to obtain geological information such as tectonic setting, stratigraphy, structural geology, historical setting and fault analysis. By referring to the previous researcher (White et.al, 2014) the lithospheric plate movement occurred between Pacific, Asian and Australian plate during Cenozoic. This movement affected the study area, Palanro, Barru and form Cenozoic volcanic and plutonic rocks. The volcanic rocks was classified under Camba formation because the deposition of Camba volcanics occurred in the western part of the Walanae Depression where the study area involved.

During early Miocene, Walanae fault formation takes place due to the uplifting process occurred in northern and south arm of Sulawesi. The Walanae fault triggered Walanae Graben formation which eventually changes into Sengkang Basin as time passes. This processes has formed many minor and triggers formation of major faults due to the force disturbance.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

Chapter 3 shows the materials and methods that used during conducting the research project. Basically, there are 6 steps needed to carry out, preliminary studies, field studies, laboratory works, gathering data, analysis and interpreting data and report writing.

3.2 Materials

Table 3.1: Materials used during Geological Mapping

Material	Function
Global Positioning System (GPS)	Used to track and navigate any location on the Earth's surface
Compass	This tool is used to measure the dip and strike of the structure on the outcrop.
Hands lens	Used to observe small particles of the rock that cannot be seen in naked eye
Topographic map	Act as a reference for geological field
Sample bag	Needed to keep the sample that collected
Measuring tape	To measure the length of the outcrop, structure and the thickness of sedimentary bed

Hydrochloric acid	Acts as an indicator to identify the presence of carbonate minerals
Digital camera	Used as reference and evidence after leaving the field
Field book	To record the data that are obtained in the field
Hammer	Tool that used to collect the outcrop sample
Arcgis 10.2	Software that used to produce, process and interpret information to create geological map

3.3 Methods

3.2.1 Preliminary studies

This is the first step conducted for the research project. The information and knowledge about the study area is gained by referring the topography map and the literature review related to the research. The base map of the study area was planned and created using the ArcMap 10.2 software. The data obtained from the preliminary study provide a surface view of understanding about the research topic.

3.2.2 Field studies

Field studied is where the data collected by mapping in the study area. Geological mapping is one of the field studies that conducted. The tools such as Global Positioning System (GPS), compass, geological hammer, sample bags, hand lens and digital camera needed while conducting the mapping activity. Mapping gives a closer look of geological features and the changes it made. This step contribute an enormous data for the research project.

Traversing is one of the way to ensure that the study area covered completely. The traversing process uses Global Positioning System (GPS) which later the data been converted to Arcgis software, to update the geological map. The geological structure such as faults and joints will be recorded and the orientation of the structures been measured, hence, the stereography analysis has been created. The samples of the rocks taken and used in studying the petrographic of the rocks hence, produce lithological unit of the study area. Digital camera was used as prove of visiting the area as well as act as a reference after leaving the study area. The observation such as the rock type, geological structures, and geomorphological details were gathered during the geological mapping.

The data collected during the field studies are used to analysis and interpret in order to achieve the objective of the research project.

3.2.3 Laboratory Work

The sample of rocks that been collected during the geological mapping was observed using microscope. The microscopic observation had showed more detailed view of the rocks and the changes that undergone by the rocks. The sample obtained were presented in specimen by thin section process. The rock then been cut into small pieces. The pieces that presented into the specimen ease the microscopic observation of the hand specimen.

3.2.4 Data Processing

The data recorded during preliminary study, field study and laboratory work were gathered and processed. The data that obtained from different stages been compared to produce detailed geological map.

3.2.5 Data Analysis and Interpretation

The data that collected are then analysed and interpreted. There are 3 analysis that need to carry out regarding the research project, lineament analysis, kinematic analysis and dynamic analysis. Lineament analysis was used to determine the position where the fault occurred and what caused the faulting process. Geological mapping is the method used to identify the lineament analysis. The direction of lineament as well as the number of the measurement taken and can be plot using rose diagram in order, to know the force direction. Kinematic analysis and dynamic analysis is the main method used for fault identification and interpretation. The both analysis will gives a better understanding of the fault regarding the directions, stress and strain as well as the type of the fault. Fault mechanism of a specific fault set can be interpreted by using the kinematic and dynamic analysis.

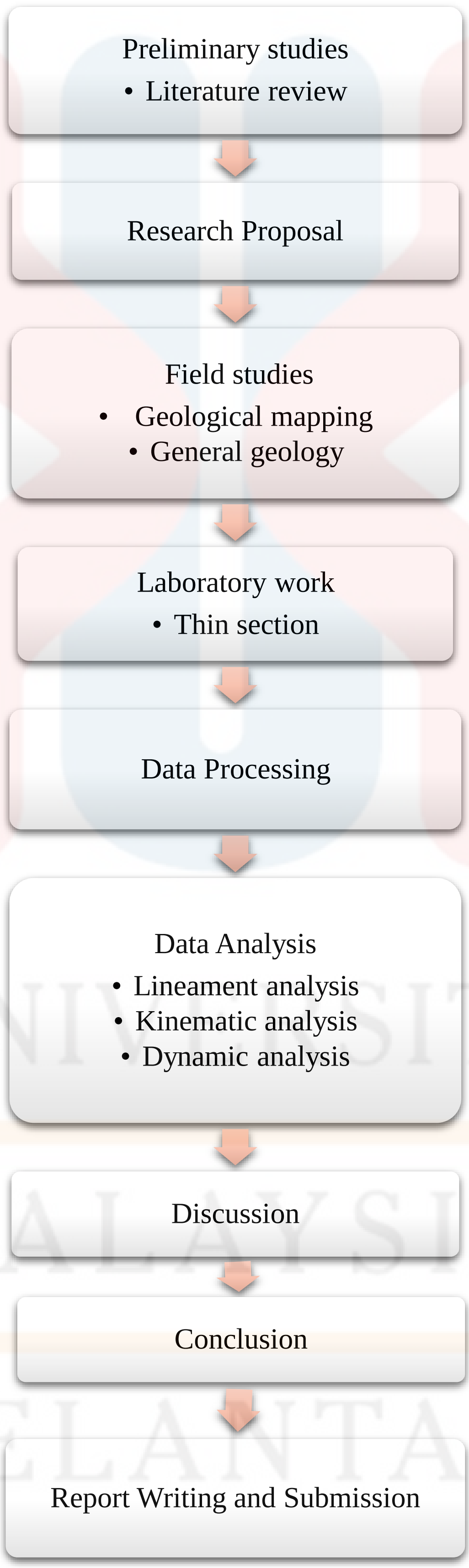
Kinematic analysis was carried out to classify the type and the movement of the fault. The kinematic analysis gives details about the presence of structures that can contributes to the possible direction of an unstable block and the type of the failure that affect the area such as wedge sliding, planar sliding or toppling (Geological Survey of Norway (NGU), 2015). This analysis is divided into two sections, strain analysis and stereographic projection. Strain analysis is studying the effect or the cause that changes the initial shape of rock mass. By identifying the changes in shape the movement of the rock mass can be detected. Stereographic projection conducted with aid of software where the strike and dip angle of the fault inserted. Hence, the type of the fault identified based on the line projected by the software. Each faults have different pole-to-fault direction pattern because it vary in mechanism. Generally, there are four type of pattern multiple deformation, anisotropy reactivation, triaxial deformation and strain compatibility.

Multiple deformation form two different fault-slip kinematic (heterogeneous) because of two deformation occurs at the same rocks. This mechanism may trigger the reactivation of the respective fault. The slip for each deformation is distinct and the may project different mechanisms. Thus, the fault may have multiple direction of slip. Strain compatibility is the pattern where multiple sets of faults having the same slip direction. The pattern shows the intersection of the multiple fault sets and the intersection area is the slip direction for each of the faults. The higher the fault orientation the higher the distinct between the fault's mechanisms.

Triaxial deformation is the phenomenon of three or four fault sets are arranged in orthorhombic symmetry which consist of same number of slip with different direction. Cross cutting fault sets is one of the example of interpretation triaxial deformation pattern. Anistropic reactivation is the deformation that produces heterogeneous kinematic. The pre-existing anistropic orientation was affected by the reactivation deformation which form unsystematically slip differ from the newly formed fault slip. This forms fault that distinct from the other fault sets in a conjugate symmetry, however, the other faults have possibility to produce the symmetry.

Dynamic analysis was classified into three methods, joint analysis, geo tectonic process and rock mechanic. Joint analysis is the method where the bearing and the number of the joint recorded and plotted in rose diagram. The diagram shows the direction of the main force that causes the joint occurrence. The geo tectonic process is the interpretation of identifying the possible ways of the fault form mainly by referring to the past tectonic plate movement of the respective area. Rock mechanism was the characteristic and factors that may changes the shape and size of the rock mass. Rock mechanism mainly uses the stress ellipsoid diagram. Ellipsoidal diagram used to classify the faults, comprises of three magnitude of stresses, vertical stress (σ1) and two horizontal stresses (σ2 and σ 3). These stresses will influence the identification of the types of faults thrust fault, reverse fault and strike-slip fault. The direction of the stresses presented via three unit of vector (S1, S2 and S3) associated with the principal stress (σ1, σ2, σ3). Thus, this derives three type of tectonic movement which are extensional tectonic direction of S1 vertical, strike slip direction of S2 vertical and compressional direction of S3 vertical.

3.2.6 Research Chart Flow



CHAPTER 4

DATA COLLECTION

4.1 Introduction

General geology covers the geomorphology, lithostratigraphy, structural geology and historical geology of the study area. The geological data was projected in the form of thematic map such as geomorphological map, structural map, lithological map and geological map. Geological map was the map that includes structural, lithological and stratigraphical information.

a. Accessibility

The main access to the study area was by the road that connected from southwest to north of the study area, the road is known as Jalan Poros Palopo-Makassar. The road was the main road that connect Makassar to Parepare.

b. Settlement

The study area were covered with many small villages such as Dusung village, Kampung Baru village, Cimpu village, Jampue village, Labukkang village and some other villages. By observing the land use around the study area, the main socioeconomic were agriculture because of the large area of paddy fields and vegetation field.

c. Forestation

The study area were nearly 60% covered by vegetation. The centre of the study area were distributed with a large area of paddy field which were planted by the local residents.

Figure 4.1 Paddy field found in Barantang village at location S 04°12′35.17″, E 119°38′44.77″

d. Traversing and Observation

Geological mapping is the basic and crucial method needed to carry out in order, to gather the geological information of the study area. Geological mapping data was used as indication and evidence of the findings in the study area. There are 3 process involved in recording geological data, field observation, rock sampling and structural data. Geological information for the study area was collected in 3 days and the study area covered by 5 km^2 x 5km^2. The basemap of the study area in Figure 1.1 was used as topography map during geological mapping.

The topography map is a basic geological map which includes contour, river, main road and hill. The main road is included to refer the accessibility of the study area during mapping. The river and hill was used to study the geomorphological feature of the study area. The topography map used for tracking current location without the help of the Global Positioning System (GPS). The traverse map of the study area in Figure shows the places.

The geological data collected was displayed via the station map figure. Generally, station map indicates the geological features that been observed and recorded. The observed station was classified into three types, observation station, observation and sampling station as well as thin section station. Observation station is the station that observed and recorded, mainly for geomorphological purpose such as the river, land use and hills. The geomorphological features helps in identifying structural features and the historical geology that occurred in the study area.

Observation and sampling station were the marked place was observed, recorded and the rocks were collected for further examination regarding the station. The rock sample were taken to identify the type of rock and the geological events that might affected the rock characteristics.

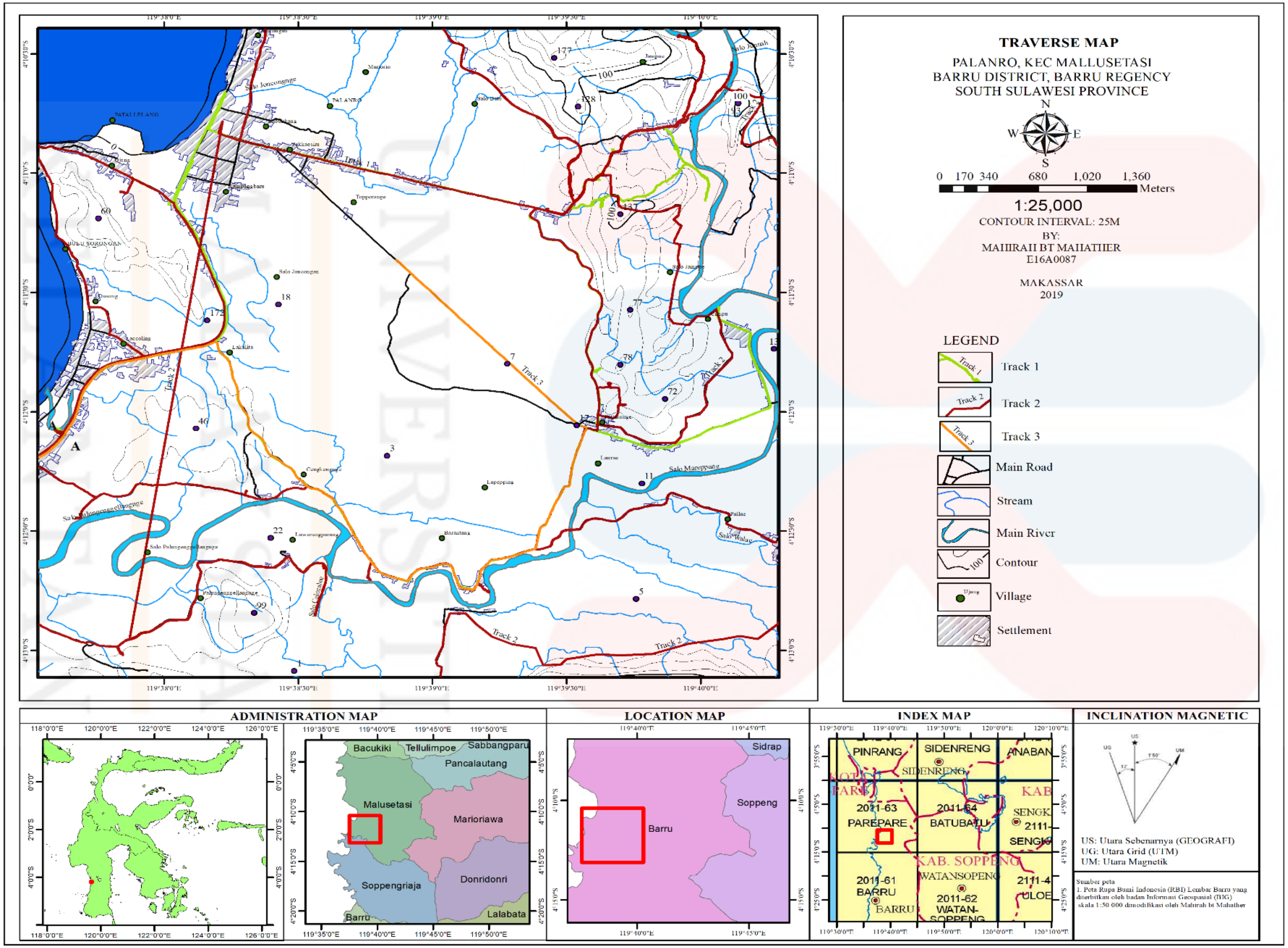


Figure 4.2: Traverse map of the study area

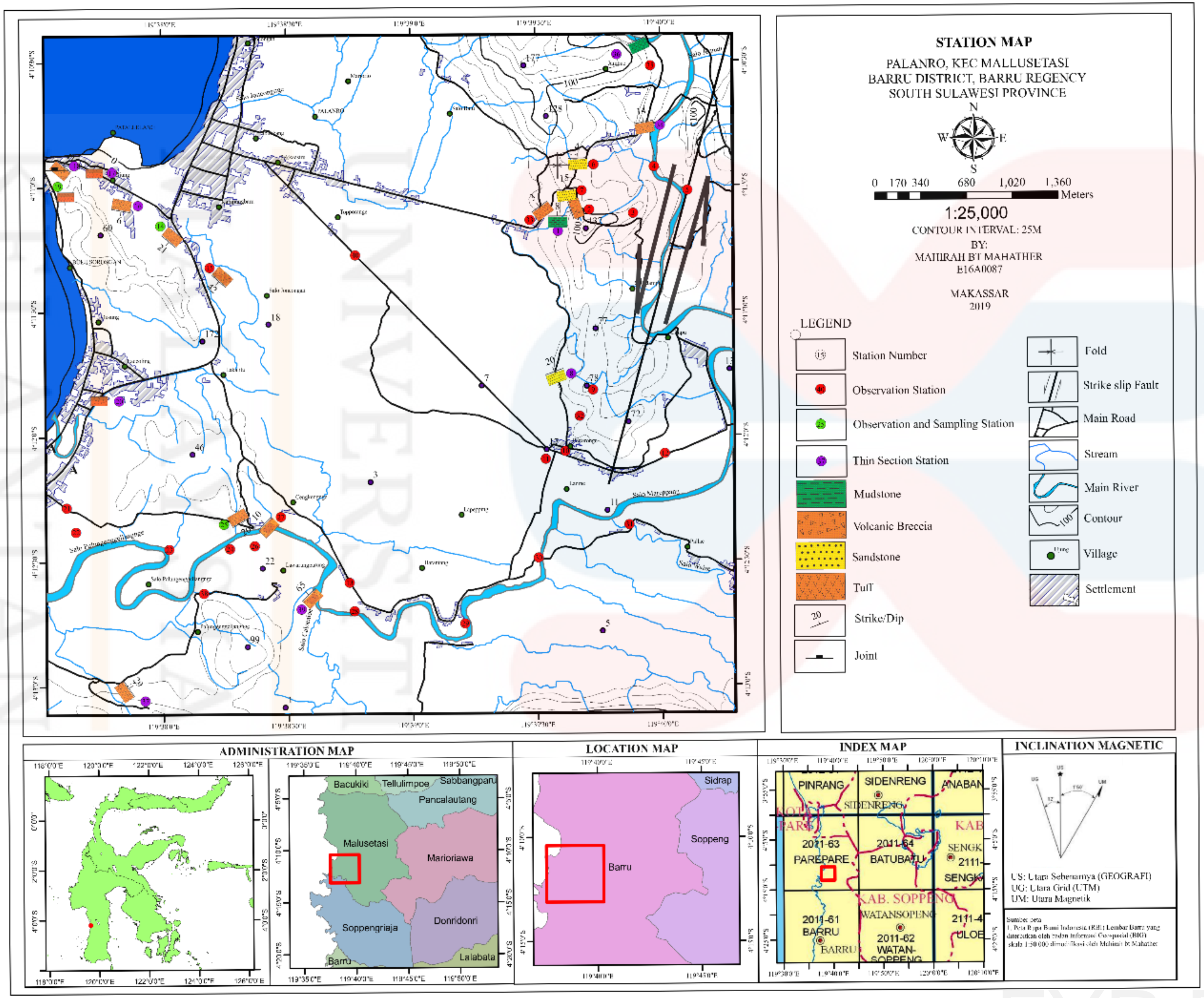


Figure 4.3: Station map of the study area to show the type of data taken for each outcrop

4.2 Geomorphology

Geomorphology studies the landform and the processes that involved in forming the landform. Landform is formed due to erosion, deposition or plate tectonics that influence the shape, composition and size of the sediments or rocks which directly changes the landform of the study area.

The geomorphology of the study area are discussed based on the geomorphological condition such as, drainage pattern, geomorphological unit, type of river genetic, river morphology and vegetation of the study area.

4.2.1 Geomorphological Classification

The geomorphological interpretation of the study area was discussed based on 2 aspects the geomorphological unit and the condition of the river in the study area. The data for the 2 aspects are predicted using 3 methods, field observation as well as interpretation of topography map and satellite imagery, which used in producing geomorphological map.

Geomorphological classification changes and affected by geomorphological process and geological features from time to time. The main processes that influenced the geomorphology of the study area were the lithology, weathering process and tectonic process. The geomorphology of the study area were classified based on geomorphological unit as well as river morphology. River morphology of the study area were interpreted by referring to drainage pattern, land cover and genetic type of the study area. The classification regarding the geomorphological unit were based on the morphometry and morphogenesis.

The origin landform of the earth surface have been affected by the earth processes such as endogenic and exogenic, this processes was known as Morphogenesis. Meanwhile, morphometry is a process that determine by referring some parameters which can be measured and observed during geological mapping such as valley shape, slope, top shape, relief and elevation. The type of landform that can be seen during geological mapping are like hill, rolling, mountain and undulating.

By referring to morphogenesis methodologies, it can be determined that the geomorphological unit of the study area were classified into four units that can be seen in geomorphological map in (figure 4.4).

- Denudational hill landform
- Denudational flat landform
- Fluvial plain landform
- Coastal and marine landform

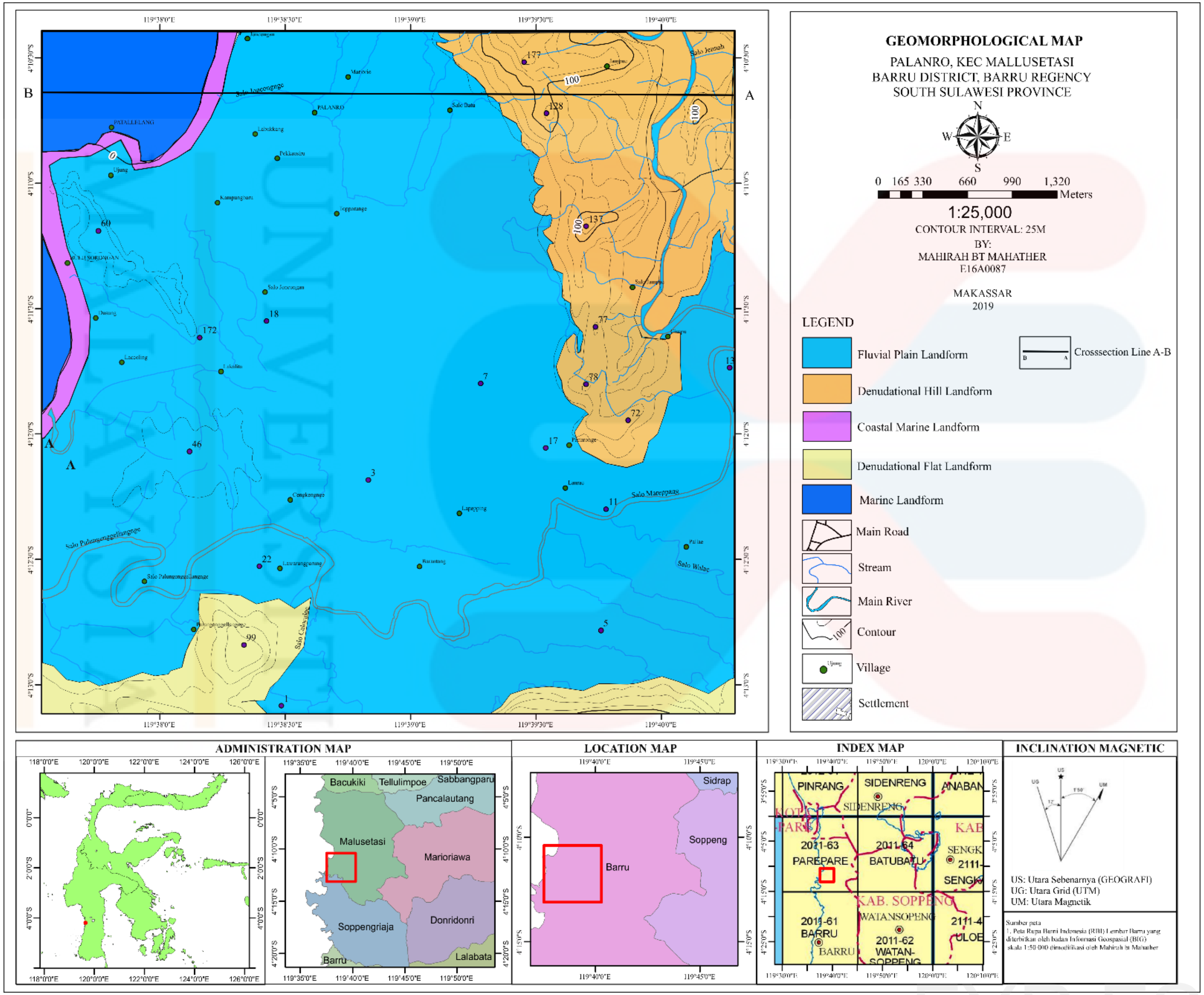


Figure 4.4: Geomorphological map of the study area

a) Denudational Hill Landform Unit

Denudational is the process of erosion or wash away of sediment or rock due to weathering, mass movement, erosion and transportation. The main agent for denudational process are wind, air and water. This landform covers about 30% of the study area with elevation range from 100 m to 200 m. The landform unit in the study area was mainly distributed towards east of the map. This unit was indicated with light brown colour. Geomorphology process in the study area undergo weathering, erosion and mass movement. Based on morphogenesis analysis this landform unit is formed because of denudational process. The geomorphological process in the landform unit undergo weathering and mass movement which indicates denudational process. The mass movement that observed in this landform unit was identified as debris slide. The debris slide was found at station 7 of Barru district (Refer figure 4.5). Erosional process in the study area are known as vertical erosion because the valley was narrow and blunt v shape.

Figure 4.5: Denudational hill landform unit taken at direction of N350W at station 40 (S 4°11′16.48″, E 119°38′46.54″)

Figure 4.6: Excavation (human activity) taken at direction N 175° E were found at station 7 (S 04°10′54.23″, E 119°39′40.14″)

The type of weathering process in the denudation hill landform unit were physical and biological weathering. Biological weathering in the study area was determined in some places in the study area and mainly affect the tuff unit (photo). The genetic type of the river for the study area was subsequent where the river flows towards strike. The type of river for the study area were episodic or seasonal. Episodic river was influenced by rain fall, in rainy season the river flows are normal while when drought season the water will dry.

Lithology of the landform unit are in the form of pyroclastic rock which were not resistance and eventually form fine grain tuff and coarse grain tuff. The vegetation in the study area was relatively low to high concentration however, some places been demolished for development and land use factor. Structural geology that obtained from the denudational hill landform unit were fault and fold.

b) Denudational Flat Landform Unit

Denudational flat landform unit cover about 20% of the the study area. This landform unit was distributed towards the southwest and southeast of the study area. By referring to morphometry (Van Zuidam, 1985) state that denudational flat landform unit have slope percentage between 0% - 2% and have difference in height between 0-5 mdpt. The height of the relative topography in the study area was about 0-90 m which classify the area as denudational flat landform unit.

Analysis of morphogenesis in the study area was focused to the characteristics of the formation results from the processes which changes the landscape of the study area. The processes that take place are mass movement, erosion, weathering, soil and river.

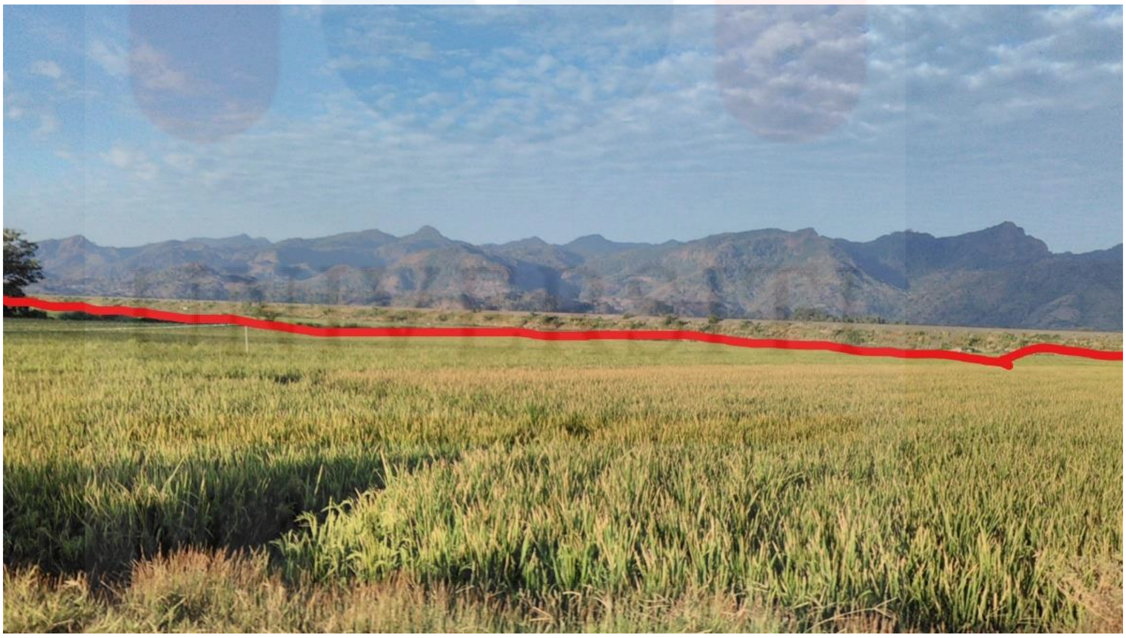


Figure 4.7: Denudational flat landform unit taken at direction N 100° were found at station 13 (S 04°12′35.17″, E 119°38′44.77″)

c) Fluvial Plain Landform Unit

This landform formed because of fluvial processes which associated with rivers and streams and the deposits. The fluvial plain landform unit distributed about 55 % of the study area with approximately 13.75% km^2. The flat topography with low elevation makes the area suitable for agricultural activities and settlement which can be observed during geological mapping.

Fluvial systems are dominated by rivers and streams. Stream erosion may be the most important geomorphic agent. Fluvial processes sculpt the landscape, eroding landforms, transporting sediment, and depositing it to create new landforms. From field observation, the rate of weathering higher along the river because of the large tree growth which affect the outcrop.

Figure 4.8: Fluvial plain landform unit were taken at the direction of N 75° W at Station 4 (S 04°10′58.84″, E 119°39′58.64″)

d) Coastal and marine landform unit

This unit covers 10% of the study area which approximately 2.5 km^2. This landform unit was mainly formed because of deposition and erosion.

Figure 4.9: Coastal and marine landform unit were taken at the direction of N 20° E Station 18 (S 04°10′52.68″, E 119°37′31.44″)

4.2.2 Geomorphology of river

River is known as the water flow directed from upstream to downstream. River analysis of the study area are measured based on some river classification, drainage pattern and river morphology.

a) River classification

River are mainly divided into three types permanent river, periodic river and episodic river. Permanent river are the rivers that flow throughout the year with river channel reaches the water table. Periodic river is a type of river where water flows only during raining season. Episodic river are the flow of water only occur in a short period of time.

Based on the field observation, the study area was influenced by two type of river permanent river and periodic river. The main river of the study area is classified as permanent river. Station was known as permanent river.

Periodic river was observed in station because the water level in the station decreases and exposes point and channel bar. The decrease of water level was due to the drought season.

Figure 4.10: Periodic river were taken at the direction of N 185° E Station 35 (S 04°10′25.50″, E 119°39′55.01″)

b) Drainage Pattern

Drainage pattern a pattern created by stream erosion over time that reveals characteristics of the kind of rocks and geologic structures in a landscape region drained by streams. Drainage pattern is the pattern formed by the streams, rivers, and lakes in a particular drainage basin. They are governed by the topography of the land, whether a particular region is dominated by hard or soft rocks, and the gradient of the land

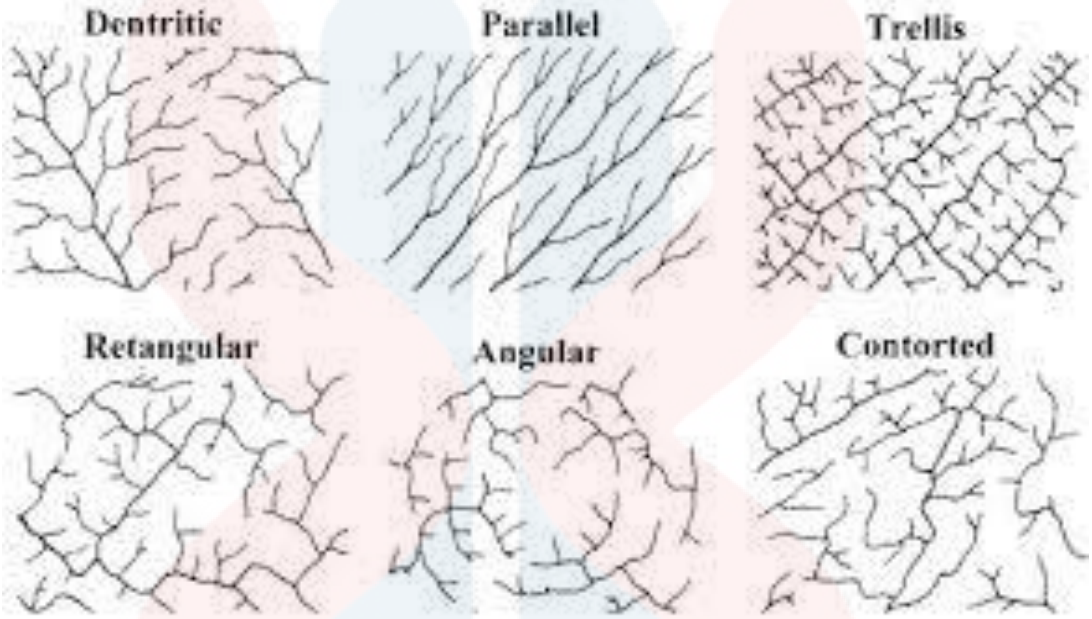


Figure 4.11: Type of drainage pattern. (Thornbury, 1969)

By interpreting the topography map as well as the field observation, the study area shows parallel drainage pattern. Parallel drainage patterns form where there is a pronounced slope to the surface. A parallel pattern also develops in regions of parallel, elongate landforms like outcropping resistant rock bands. Tributary streams tend to stretch out in a parallel-like fashion following the slope of the surface. A parallel pattern sometimes indicates the presence of a major fault that cuts across an area of steeply folded bedrock.

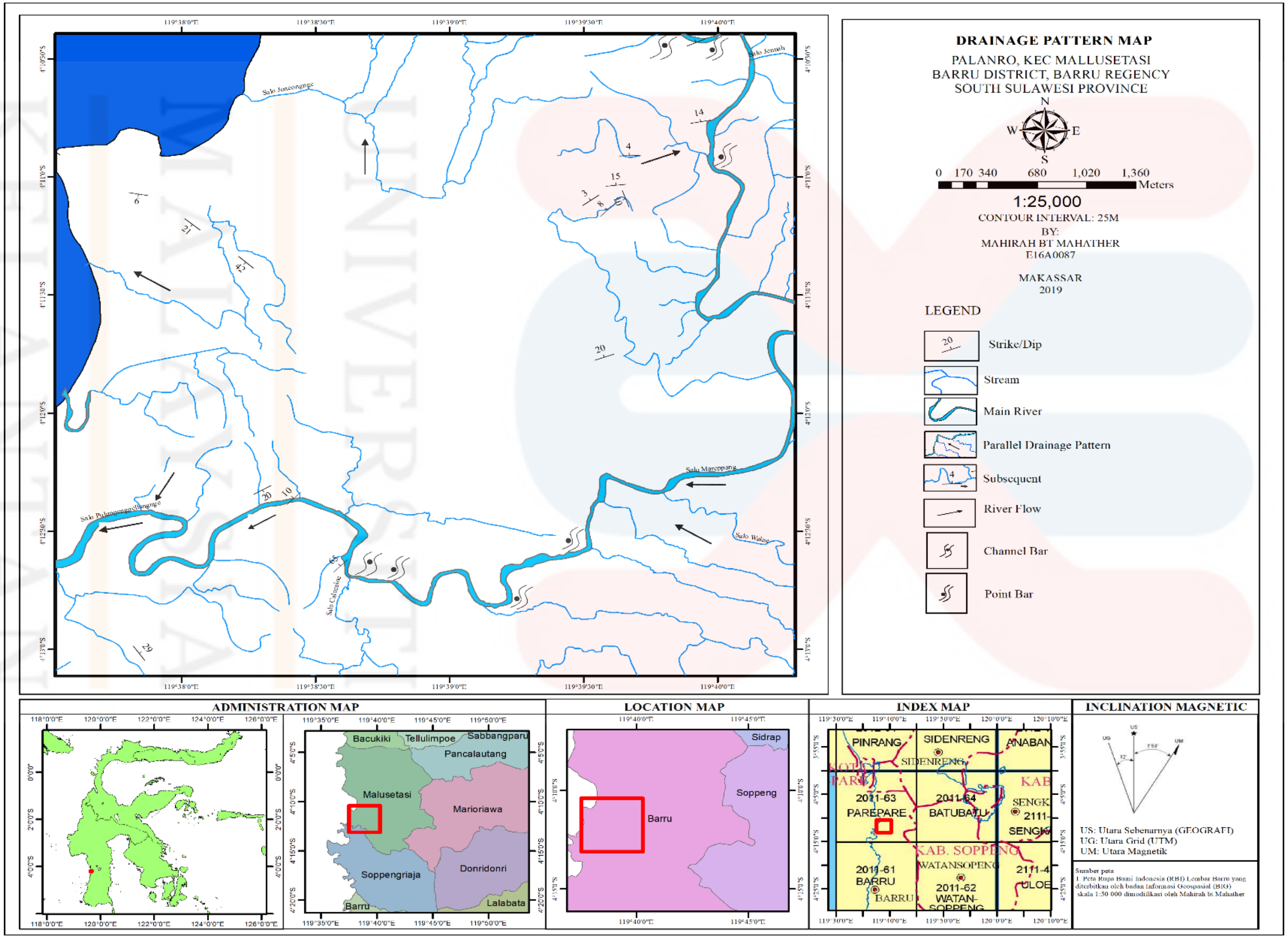


Figure 4.12: Drainage pattern map of study area

c) River morphology

A river system is composed of the main stream and many tributaries. However, there are many cases where several tributaries have similar length and flow, and it is difficult to determine the main stream. A drainage pattern is a plan of a river system. A river develops various landforms through channel processes. The main channel processes or fluvial processes are erosion, transportation and sedimentation. Erosion predominates in the upper reach area of a drainage basin, and valleys composed of channels and slopes are formed. The materials brought to the lower reaches in a channel are sediment load. Weathering of the rocks composing slopes is the main cause of production of sediment load. Sediment load is deposited to form an alluvial plain. Three basic channel patterns are detected in alluvial plains. They are braided, meandering and straight. River morphology is explained by channel patterns and channel forms.

A meandering river is one of a series of regular sinuous curves, bends, loops, turns, or windings in the channel of a river, stream, or other watercourse. It is produced by a stream or river swinging from side to side as it flows across its floodplain or shifts its channel within a valley. A meander is produced by a stream or river as it erodes the sediments comprising an outer, concave bank (cut bank) and deposits this and other sediment downstream on an inner, convex bank which is typically a point bar.

Braided rivers have a lot of rock, gravel and sand that is carried along the river bottom. When the amount of water flowing through individual channels deceases the river dumps this material creating islands and bars.

In the study area, the morphology of the river was known s braided river because of the deposition of the sand and gravel bars along the river body. The river in the study area also observed as braided river because of the drought climate which causes the water level of the river decrease. The decrease in water level exposed the river bars such as point bar and channel bar.

Figure 4.13: Formation of gravel bar form due to the decreasing of water volume in river

Figure 4.14: Formation of point bar and outer bank at station 29

4.3 Lithostratigraphy

Lithostratigraphic units are bodies of rocks, bedded or unbedded, that are defined and characterized on the basis of their lithologic properties and their stratigraphic relations. Lithostratigraphic units are the basic units of geologic mapping.

4.3.1 Regional geology of the study area

Barru district in South Sulawesi was identified in Regional Geology Map Sheet of Pangkajene and west Watapone (Sukampto and Supriana, 1982). By referring to regional geology map, the study area consist of two formation which were Alluvial (Qac) and Camba Formation (Tmc).

- Alluvial (Qac) = swamp and coastal deposits
- Camba Formation (Tmc) = the upper member of the Camba Formation described here as the Camba Volcanics, is located in the Western Divide Range

forming the ’backbone’. This member consists of volcanic breccia and conglomerates, lavas and tuffs interbedded with marine sediments (Sukamto, 1982; Sukamto & Supriatna, 1982).

Figure 4.15: Regional map of the study area (Source: Sukamto and Supriana, 1982)

4.3.2 Stratigraphic position

From the field data collection, there were 3 types of lithostratigraphic unit plotted in the study area corresponding to the informal lithostratigraphy, from young to old:

- Alluvial rock unit
- Ash Tuff
- Lapilli Tuff

The rock classification was made based on informal lithostratigraphy together with physical observation in the field as well as thin section analysis. Then the type and distribution of the rock unit was determined and plotted in map scale of 1:25,000 using conformity of the rock unit.

Correlation between the formation of the regional geology map and the lithostratigraphy unit was made in order to identify the age of the rock unit. Relative dating method is one of the method used to determine the stratigraphic position of the rock. Relative dating is the science of determining the relative order of past events, without necessarily determining their absolute age.

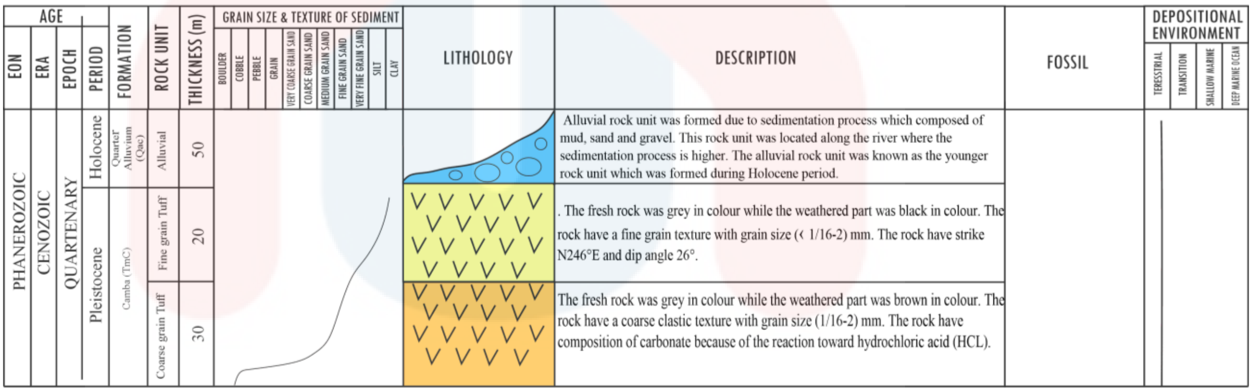


Figure 4.16: Stratigraphic positions of the rock unit in the study area

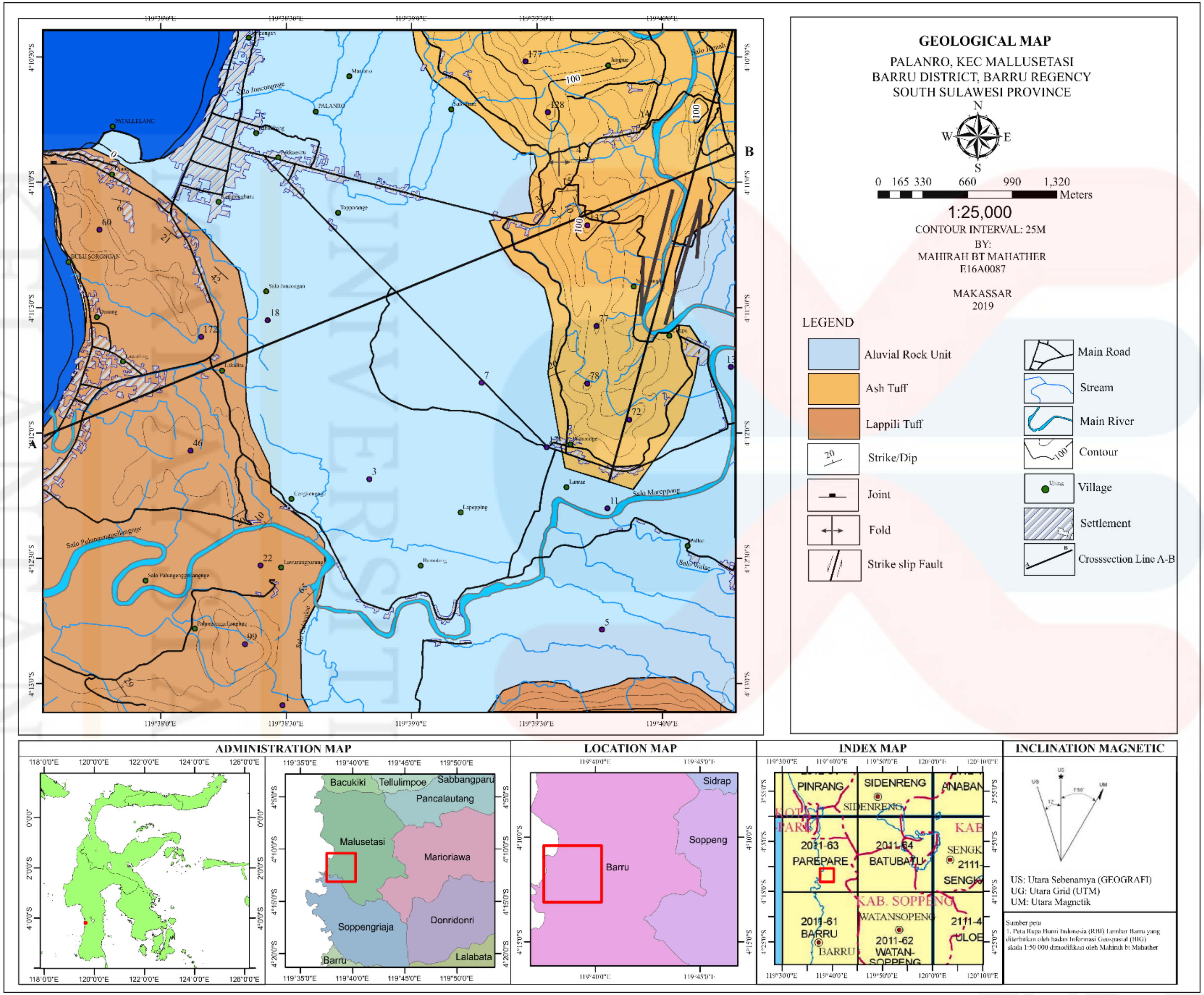


Figure 4.17: Geological map of study area

4.3.3 Lapilli Tuff

Lapilli Tuff also known as coarse grain tuff, are the division of pyroclastic volcanic rock. In the study area, lapilli tuff was identified by observing the colour of the outcrop. The fresh rock was grey in colour while the weathered part was brown in colour. The rock have a coarse clastic texture with grain size (1/16-2) mm. The rock have composition of carbonate because of the reaction toward hydrochloric acid (HCL).

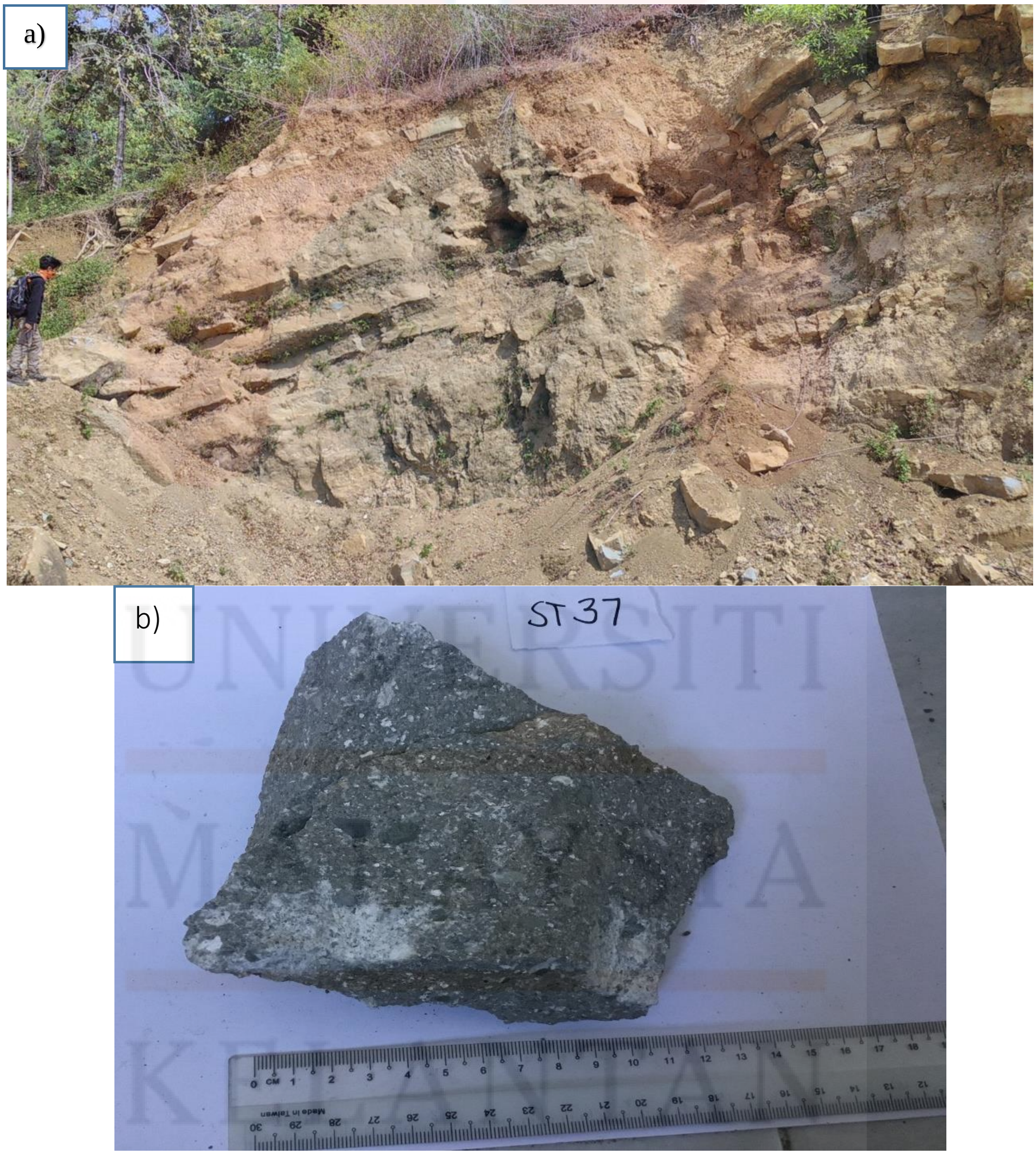


Figure 4.18: a) Outcrop of limestone at station 37
b) Sample of lapilli tuff from outcrop at station 37

4.3.4 Ash Tuff

Ash Tuff also known as fine grain tuff, are the division of pyroclastic volcanic rock. In the study area, fine grain tuff was identified by observing the colour of the outcrop. The fresh rock was grey in colour while the weathered part was black in colour. The rock have a fine grain texture with grain size (‹ 1/16-2) mm. The rock have strike N246°E and dip angle 26°. The sedimentary structure such as bedding displayed.

a)

b)

Figure 4.19: a) Outcrop of limestone at station 35
b) Sample of fine grain tuff from outcrop at station 35

4.3.5 Alluvial

Alluvial rock unit was formed due to sedimentation process which composed of mud, sand and gravel. This rock unit was normally located along the river where the sedimentation process is higher. The alluvial rock unit was known as the younger rock unit which was formed during Holocene period.

4.4 Structural geology

Structural geology is the study of the three-dimensional distribution of rock units with respect to their deformational histories. The primary goal of structural geology is to use measurements of present-day rock geometries to uncover information about the history of deformation in the rocks. The structural data that determined and analysed in the study area were joint and fold. The studies regarding structural geology were mainly determined by strike and dip.

4.4.1 Structural geology of the study area

Determination of the structural geology was made during preliminary studies by using the topographic map. The linear feature of the study area can be seen in topographic map. Linear feature is the straight line features which may cause by geological structure.

Structural Geology aims to characterise deformation structures (geometry), to characterize flow paths followed by particles during deformation (kinematics), and to infer the direction and magnitude of the forces involved in driving deformation (dynamics).

Based on the study area, two types of structural geology was found which were joint and fold. Joint analysis was carried out by taking the trend and the frequency of the joint in the study area hence, plotted using Georose software. This software will show the direction of the force that act on the rock.

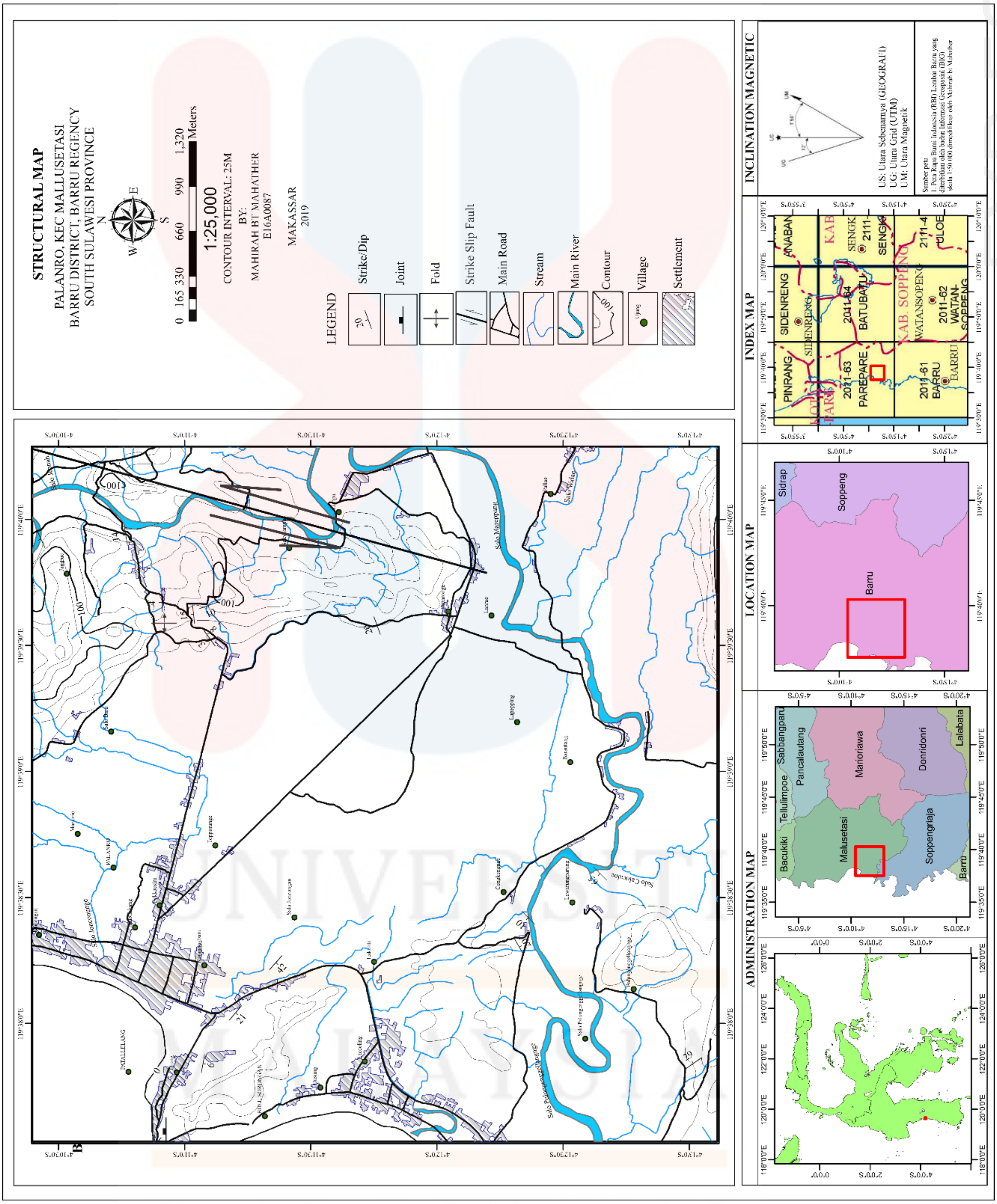


Figure 4.20: The structural map of the study area

4.4.2 Lineament Analysis

Lineament analysis is known as linear feature in a landscape which is an expression of an underlying geological structure such as fault-alligned valley, series of fault and fold-alligned hill. Linear features on the earth surface have been a theme of study for geologists for many years, from the early years of the last century (Hobbs, 1904, 1912) up to now. From the beginning, geologists realized that linear features are the result of zones of weakness or structural displacement in the crust of the earth. A lineament is a mappable linear or curvilinear feature of a surface whose parts align in a straight or slightly curving relationship. They may be an expression of a fault or other line weakness.

Straight stream valleys and aligned segments of a valley are typical geomorphological expressions of lineaments. A tonal lineament may be a straight boundary between areas of contrasting tone. Differences in vegetation, moisture content, and soil or rock composition account for most tonal contrast (O'Leary et al. 1976). In general, linear features are formed by edges, which are marked by subtle brightness differences in the image and may be difficult to recognize. Lineaments could be straight stream and valley, aligned surface depressions, soil tonal changes, alignments in vegetation, vegetation type and height changes, or abrupt topographic changes. All of these phenomena might be the result of structural phenomena such as faults, joint sets, folds, cracks or fractures. The old age of many geological lineaments means that younger sediments commonly cover them. When reactivation of these structures occurs, this results in arrays of brittle structures exposed on the surface topography. Similarly, the surface expression of a deep-seated lineament may be manifested as a broad zone of discrete lineaments (Richards, 2000). In order to map structurally significant lineaments, it is necessary first, by careful and critical analysis of the image, to identify and screen features not caused by faulting (Sabins, 1997).

4.4.3 Joint

In geology, a joint is a fracture dividing rock into two sections that moved away from each other. A joint does not involve shear displacement, and forms when tensile stress breaches its threshold. In other kinds of fracturing, like in a fault, the rock is parted by a visible crack that forms a gap in the rock.

Generally, joints are classified into 2 main types, systematic and non-systematic. On the basis of genetic type the joints are classified into 3 types, tension joint, shear joint and extension joint.

- Tension joints are those, which have developed due to the tensile forces acting on the rocks. The most common location of such joints in folded sequence is on the outer margins of crests and troughs. They are also produced in igneous rocks during their cooling. Joints produced in many rocks during the weathering of overlying strata and subsequent release of stresses by expansion is also thought to be due to the tensile forces.
- Shear joints are commonly observed in the vicinity of fault planes and shear zones where the relationship with shearing forces is clearly established. In folded rocks, these are located in axial regions.
- Compression joints Rocks may be compressed to crushing and numerous joints may result due to the compressive forces in this case. In the core regions of folds where compressive forces are dominant, joints may be related to the compressive forces.

Based on the study area, joint analysis were taken at station 18. The type of joint that noticed during field observation was classified by spatial relationship and genetic type. The joints discovered in the study area were determined as non-systematic joint because the joints are formed in random orientation. By referring to the genetic type of the joints in station 18, it can be discussed as shear joint. The data joint that measured and recorded are presented in the form of rose diagram using Georose diagram.

Rose diagram was the diagram used to identify the principle stress of the joints in an area. The rose diagram was interpreted based on the acute angle between 2 joint set in data joint. The direction of the stress that influenced the study area been determined with the help of principle stress hence, the interpretation of the historical deformation force exerted on the study area can be explained.

Figure 4.21.: Shear joints on tuff at station 18

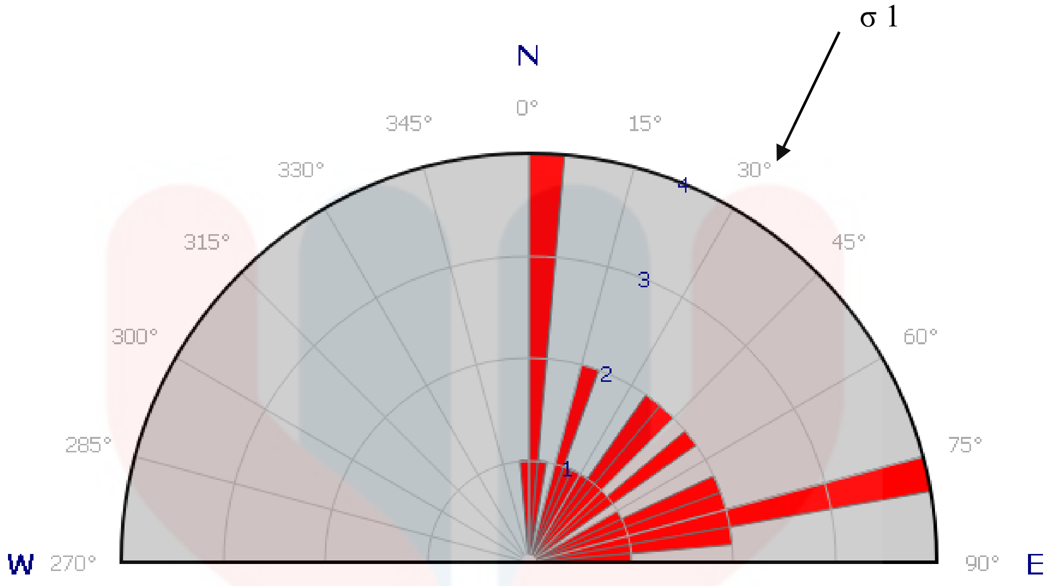


Figure 4.22: Rose diagram of joint at station 18

From the rose diagram, the principle stress of joint at station 18 was at direction 30°. Based on the measurement of the joint, the dominant bearing of the joints were towards north east (N 70° E – N 80° E). The rose diagram shows that the principle stress acted from the north direction and influenced by shear stress.

4.4.4 Fold

In structural geology, folds occur when one or a stack of originally flat and planar surfaces, such as sedimentary strata, are bent or curved as a result of permanent deformation. A wave-like geologic structure that forms when rocks deform by bending instead of breaking under compressional stress.

The fold mechanism are divided into two type buckling and bending:

- Buckling occurs when the deforming force is applied parallel to rock layers. This is usually caused by horizontal compressional tectonic forces and results in layer-parallel shortening of rocks and thickening (relief) of the rock body perpendicular to stress direction.

- Bending of rocks occurs when the deforming force is applied across (at high angle to) rock layers.

Folding structure are found at station 6. The folding in station 6 was formed in tuff which known as anticline with strike/dip of N 189° E/ 81° and N 345° E/ 10°. By referring to the regional map, the folding structure might happen due to tectonic movement which form sinistral strike slip fault. The faulting phenomenon have produced anticline folding.

Figure 4.23.: Anticline folding formed at station 6

4.4.5 Fault

Fault, in geology, a planar or gently curved fracture in the rocks of the Earth's crust, where compressional or tensional forces cause relative displacement of the rocks on the opposite sides of the fracture.

A fault is a fracture or zone of fractures between two blocks of rock. Faults allow the blocks to move relative to each other. This movement may occur rapidly, in the form of an earthquake or may occur slowly, in the form of creep. Faults may range in length from a few millimetres to thousands of kilometres. Most faults produce repeated displacements over geologic time. During an earthquake, the rock on one side of the fault suddenly slips with respect to the other. The fault surface can be horizontal or vertical or some arbitrary angle in between. A fault plane is the plane that represents the fracture surface of a fault. A fault trace or fault line is the intersection of a fault plane with the ground surface. A fault trace is also the line commonly plotted on geologic maps to represent a fault.

Faults are subdivided according to the movement of the two blocks. There are three or four primary fault types:

- Normal Fault, a dip-slip fault in which the block above the fault has moved downward relative to the block below. This type of faulting occurs in response to extension. "Occurs when the "hanging wall" moves down relative to the "foot wall"
- Reverse fault, a dip-slip fault in which the upper block, above the fault plane, moves up and over the lower block. This type of faulting is common in areas of compression, when the dip angle is shallow, a reverse fault is often described

as a thrust fault. "Occurs where the "hanging wall" moves up or is thrust over the "foot wall"

- Strike-slip fault, strike slip fault, a fault on which the two blocks slide past one another. The San Andreas Fault is an example of a right lateral fault. Strike-slip fault movement divided into two types, left-lateral strike-slip fault and right-lateral strike-slip fault.

The identification of fault structure in the study area, was conducted by determining the primary and the secondary characteristics of the fault. The fault structure found in the study area should correspond with the regional map.

Fault can be identified during field observation, morphology as well as the topography map interpretation. Morphological observation can be determine by observing the topography map and during field observation.

Structure identification in the study area were hard to found because of the rock characteristics which were non-resistance (volcanic rocks) that makes structure hard to identify in the study area. By analysing the field data as well as the correlation between the regional maps, the fault that influenced the study area was determined as strike slip fault or known as Salo Jampue strike slip fault.

Type of strike slip fault in the study area are sinistral (left-lateral), which moves North to South of the study area. The presence of the fault were supported by secondary characteristics. The characteristics used for the fault determination are:

1. By analysing the strike and dip of the rocks in the study area during field observation
2. Analysing the bending river via topography map

4.5 Mechanism of Structural Geology in the study area

Based on geological and structural map analysis in the study area, shows that the mechanism of geological structure occur in one period. The direction of the principle stress of the study area were measured using joints that been plotted in a rose diagram. The direction of the maximum force (1) relatively towards North east (N30°E).

The mechanism of the geological structure in the study area is based on the ellipsoid strain system Reidel in Mc Clay (1987) which is a modification of Harding Theory (1974).

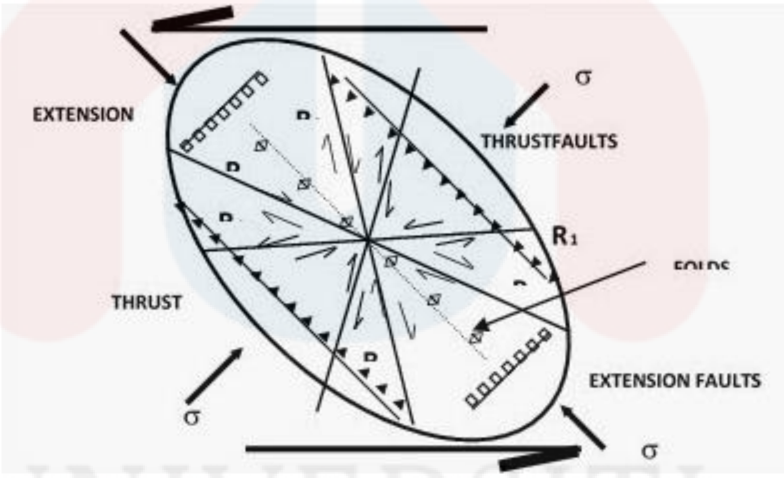


Figure 4.24.: The mechanism of structural geology based on the Reidel system, modification from Harding Theory (1974) in Mc Clay (1987)

At stage one, the study area were affected by the tectonic force that generated by the compressional stress where the direction of the force relatively from the Northeast hence, folding formed.

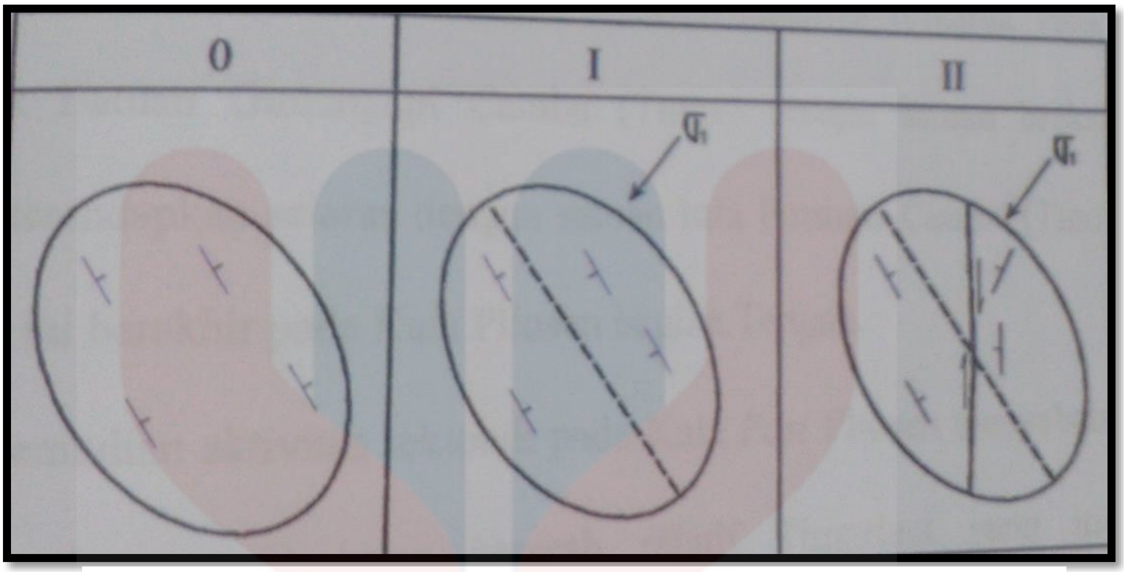


Figure 4.25: The mechanism of structural geology formation in study area with principle stress relatively from Northeast

At stage two, the pressure acted on the rock increases thus, the rocks elasticity exceed its limit and causes the rock to undergo phase of plastic deformation. This deformation will form shear joint. Then, the joints in the rock slides between each other and undergo strike slip fault Salo Jampue. By referring to geological map and strain ellipsoidal the maximum principle stress were relatively from the Northeast. Therefore, the type of fault in the study area were the strike-slip fault Salo Jampue (sinistral). Based on the regional map, the fault might happened on the Post Miocene Last Pliocene.

4.6 Historical geology

Historical geology in the study area begun at Middle Miocene, where the volcanic activities were active. The volcanic activity exerts volcanic ashes from gravel to fine sand. This materials then undergo transportation and deposition during Middle Neritic and form rock unit tuff of Camba formation (Tmc), which consist of fine grain tuff and lapilli tuff. The volcanic activities end during Middle Pliocene.

Then, during late Pliocene tectonic activity takes place thus, forming compressional force on the Northeast direction which generate folding. The force acts on the rock keep increasing until the rock losses its elasticity limit hence, the rock undergo plastic deformation. Later, shear joints were produced on the rocks, as time passes the shear joint undergo strike slip fault of Salo Jampue (sinistral).

In Holocene period, the study area was dominated with younger geological process such as denudational process, weathering process, transportation and sedimentation at fluvial and along the river. This form alluvium deposition forming alluvium rock unit com

Summary

Overall, the four aspects of the general geology of the study area which were, geomorphology, lithostratigraphy, structural geology and historical geology was described. Geomorphological condition was explained mainly on geomorphological landform unit, type of river genetic, drainage pattern and river morphology. Based on the geomorphological map of Palanro, Barru, there were five types of landform, fluvial plain, denudational flat, denudational hill as well as coastal and marine. The landforms was classified based on the morphometry and morphogenesis. The importance of geomorphological landform was to understand the Earth's physical changes. The river in the study area were mostly divided into three permanent and periodic that shows parallel drainage pattern. In th study area, the morphology of the river was identified as braided river due to the identification of point and channel bar.

Lithostratigraphy of the study area was determine based on lithology and stratigraphic position. The study area composed of three rock units namely, alluvial, ash tuff and lapilli tuff. The stratigraphic position of the respective rock unit was determine by correlation between regional geology map as well as relative dating method. Hence, the alluvial rock unit was classified as the youngest rock unit and the lapilli tuff was the oldest. The lithostratigraphic column of the study area was displayed (refer figure 4.16).

In the study area, there are 2 structural geology was found during field observation that were shear joint and anticline fold. The joints were interpreted using rose diagram thus, the principle stress direction was determined at direction 30^{o}. Besides, the study area shows the presence of fault by analysing the strike and dip of the rocks and bending river via topography map.

The historical geology of Palanro, Barru was begun at Middle Miocene where the deposition and transportation process takes place. These processes form Camba formation (Tmc) that composed of tuff rock unit. In Late Pliocene, the tectonic activity occurred which generate shear joints. Hence, when the time passes the shear joints initiate the process of strike slip fault. Then, Holocene period is where the younger geological process was carried out.

CHAPTER 5

FAULT ANALYSIS

5.1 Introduction

This chapter discuss on the fault analysis which involves lineament analysis and fault interpretation. The interpretation uses kinematic and dynamic analysis that effect the Palanro area and its surrounding. The main findings needed for fault analysis is the determination of the pattern and direction of the fault in the study area. The Salo Jampue Strike-Slip fault are the fault that identified in the study area. The evidence of the fault existence was included in this chapter based on field observation and data analysis.

5.2 Lineament Analysis

Lineament is a linear feature landform which used for geological structures identification such as fault and fold. Photointerpretation method was conducted in this analysis in order to determine the lineament using Digital Surface Model (DSM) TerraSAR-X. Lineament analysis covers a bigger area which include the surrounding of the study area. Mostly, lineaments found as valleys, ridge and rivers. Figure 5.1 shows the determined lineaments and Figure 5.2 was rose diagram that used to interpret major distribution of the lineaments.

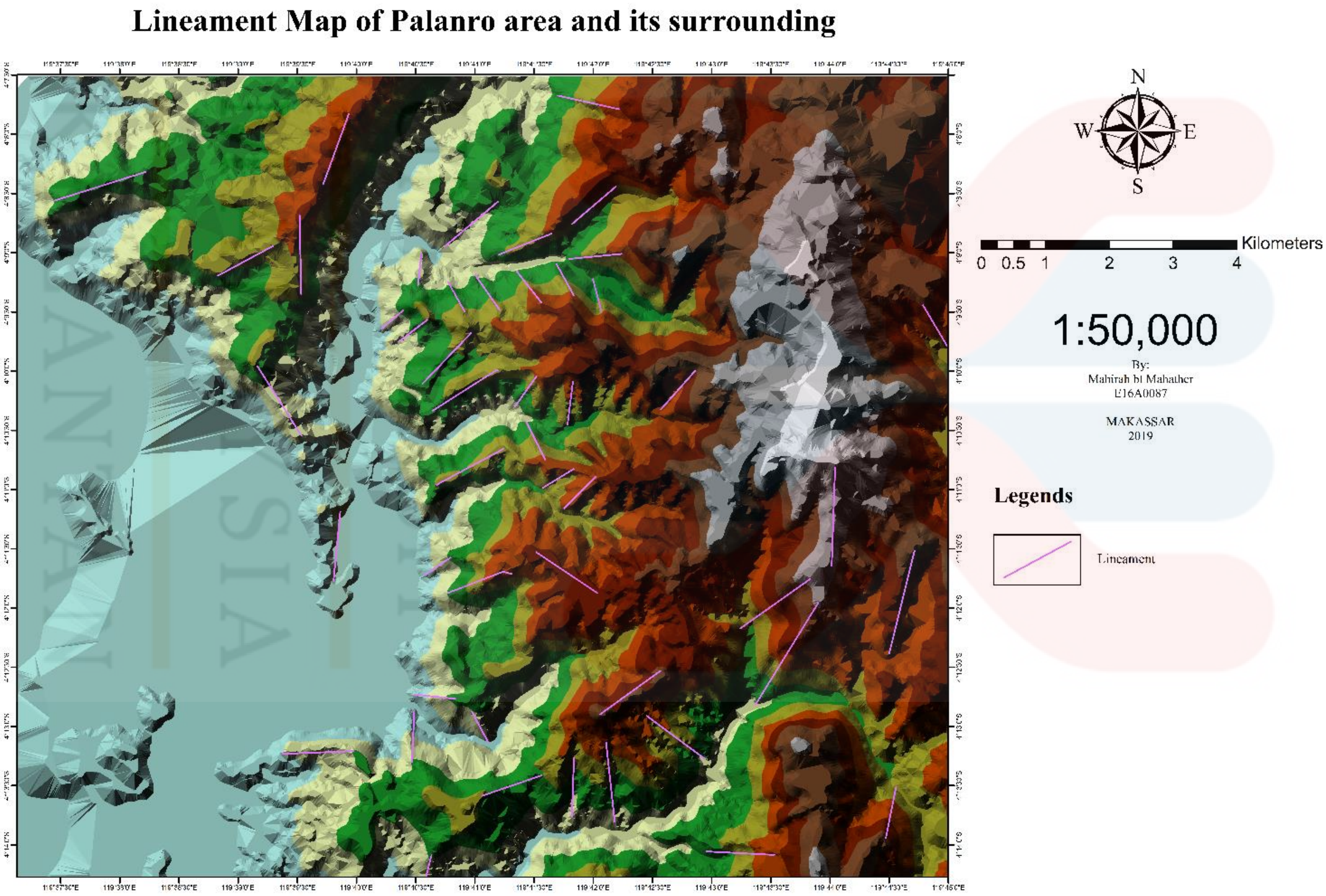


Figure 5.1: Lineaments in the study area and its surrounding

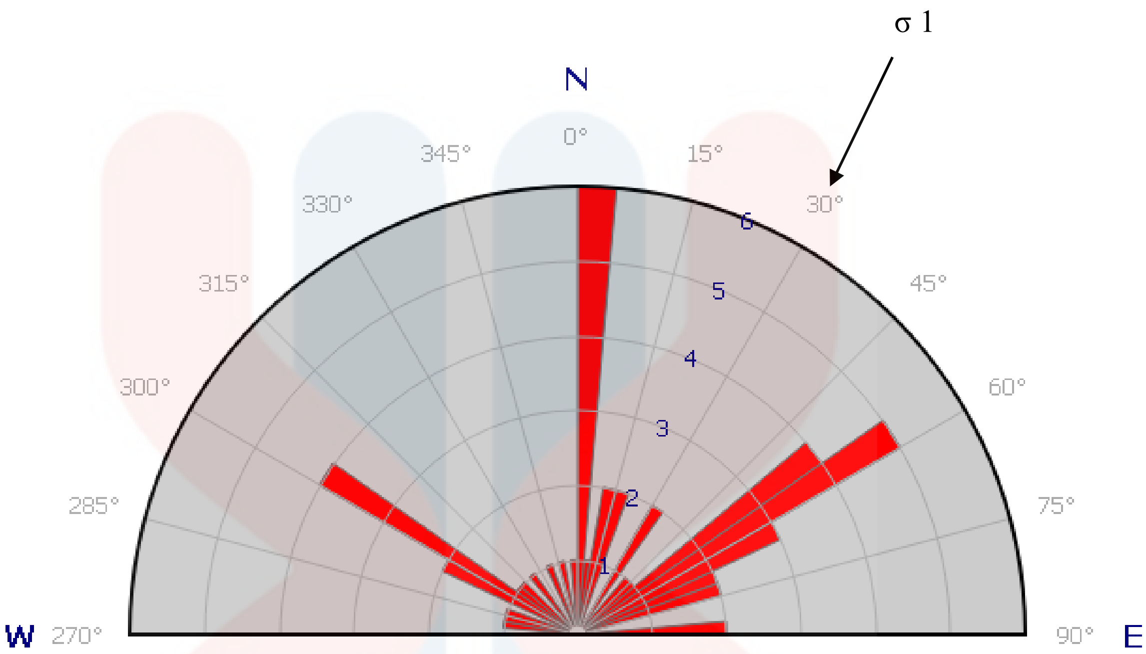


Figure 5.2: Rose diagram for lineament

Forty seven reading were measured in the lineament map of the study area. Based on rose diagram generated in Figure 5.2, an interpretation has been made. The direction of major distribution of lineament in the study area is NNE-SSW. This lineament analysis allows the interpretation of structures and act as an indicator about the presence of geological structures and relate it with major fault in the study area. Table 5.1 shows lineament reading in the study area and its surrounding.

Table 5.1: Lineaments reading in the study area and its surrounding

No	Reading	No	Reading	No	Reading
1.	168	21.	199	41.	130
2.	19	22.	1	42.	117
3.	73	23.	275	43.	197
4.	180	24.	157	44.	68
5.	62	25.	69	45.	85
6.	122	26.	57	46.	45
7.	196	27.	141	47.	121
8.	88	28	123		
9.	18	29.	60		
10.	260	30.	44		
11.	2	31	182		
12.	97	32..	34		
13.	177	33.	57		
14.	190	34.	45		
15.	14	35.	53		
16.	182	36.	135		
17.	32	37.	54		
18.	55	38.	3		
19.	54	39.	302		
20.	143	40.	125		

5.2.1 Descriptive Data

The study area mostly covered by volcanic rocks product which is tuff. The identification of fault structure in the study area, was conducted by determining the primary and the secondary characteristics of the fault. The fault structure found in the study area should correspond with the regional map.

Fault can be identified during field observation, morphology as well as the topography map interpretation. Morphological observation can be determine by observing the topography map and during field observation.

Structure identification in the study area were hard to find because of the rock characteristics which were non-resistance (volcanic rocks) that makes structure hard to identify in the study area. By analysing the field data as well as the correlation between the regional maps, the fault that influenced the study area was determined as strike slip fault or known as Salo Jampue strike slip fault.

Type of strike slip fault in the study area are sinistral (left-lateral), which moves North to South of the study area. The presence of the fault were supported by secondary characteristics. The characteristics used for the fault determination are:

3. By analysing the strike and dip of the rocks in the study area during field observation
4. Analysing the bending river via topography map

5.2.2 Geomorphology

- Alluvial fans

An alluvial fan known as a triangle-shaped accumulation of gravel, sand, and tiny particles of sediment, for example silt. The sediment also named as alluvium. Alluvial fans were normally formed as moving water encounter with mountains, hills, or the steep walls of canyons.

In the study area, the alluvial fan was found in the valley between hills. The possible ways it might form were due to rainwater. The streams that form from the drizzle of rainwater flows down the hills, it gathers up sand and other particles hence, form alluvium. The running water carries alluvium to a flat plain, where the stream leaves its channel to spread out. Alluvium is deposited as the stream fans out, forming the familiar triangle-shaped feature. .

The form of alluvial fan is normally more fertile so it is used for agriculture land in the study area. The presence of shifts, hill valleys and alluvial fans are some of the traits that usually encountered in structural hilly regions.

- River and valley

River are normally occurred because of the fault process. A valley is a hollow or surface depression of the earth connected by hills or mountains, a natural trough in the earth's surface. Slopes down to a stream, lake or the ocean, created by water or ice erosion. Systems of valleys enlarge through plains, hills, and mountains.

The river in the study area, was found in between valleys surrounded by hilly regions. This shows the rivers may form due to erosion or fault process.

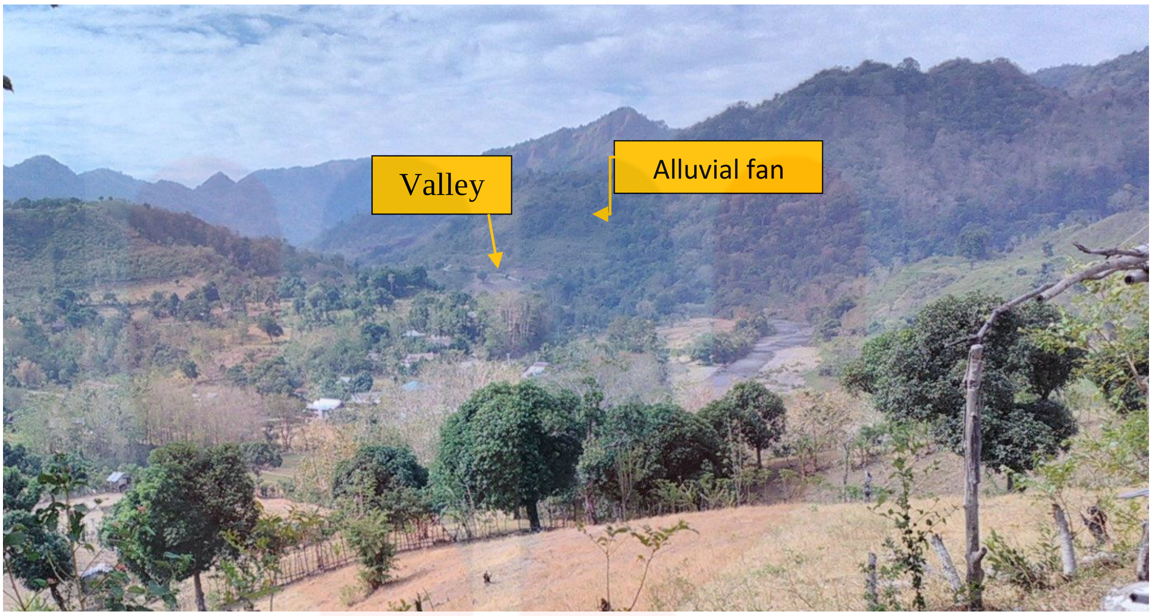


Figure 5.3: Valley and alluvial fan in structural hilly region

5.2.3 Lithology

The study area composed of tuff which formed from the volcanic breccia which undergoes erosion because of weathering. The study area have fine and coarse grain tuff, however, there volcanic breccia was found surrounding the study area mainly on the eastern part. This shows the transition of the volcanic breccia to fine grain tuff. Hence, the structural characteristics of the fault was hard to identify because of the weathering process.

5.3 Kinematic Analysis in Salo Jampue Fault

Kinematic is study of movement of lithosphere such as evaluation of displacement and distortion of rocks that have undergone deformation process. The discontinuities in the study area is analysed using kinematic analysis in order to interpret the forces that affect the fault formation. Discontinuities are geologic breaks such as joints, faults, bedding planes, foliation, and shear zones that can potentially serve as failure planes. Stereonets or stereographic projection is used to show visual of graphical kinematic analysis based on orientation of rock.

5.3.1 Strain Analysis

Strain analysis gives raw data needed for restoration of geological structures to their originally formed or influenced by the distortion produce by folding. Strain ellipsoid is used as a three dimensional way to represent strain. The strain ellipsoid results from the homogeneous deformation of an imaginary sphere, which represents the undeformed state of a body.

In any homogeneously strained, three dimensional body, there will be at least three lines of particles, also known as material lines, that will not rotate relative to each other. After strain, we will therefore have three material lines that remain perpendicular. These lines define the axes of an ellipsoid, and are known as the principal strain axes. They are referred to as X, Y and Z, where $X > Y > Z$.

X = maximum direction of extension

Y = intermediate strain axis

Z = maximum direction of shortening

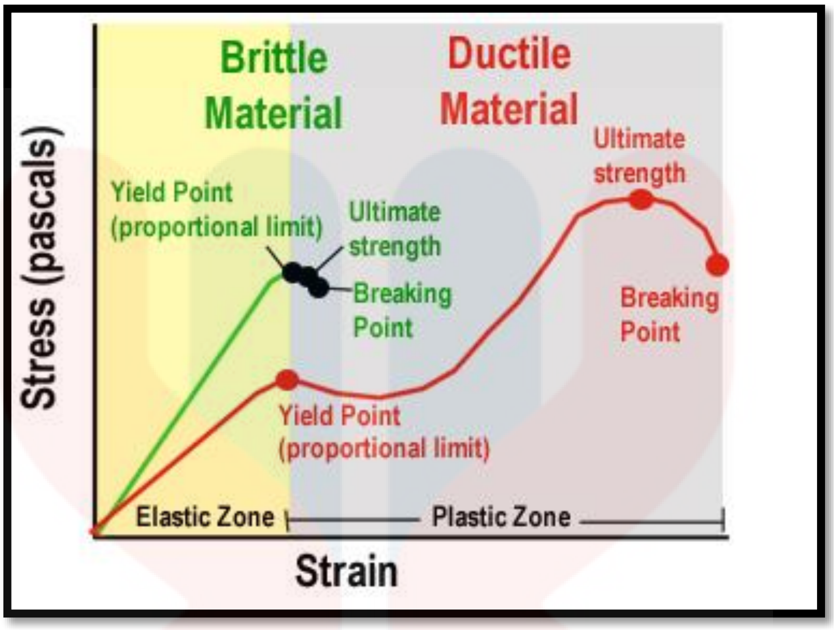


Figure 5.6: Relationship between stress and strain (Source: Civil Engineering, 2018)

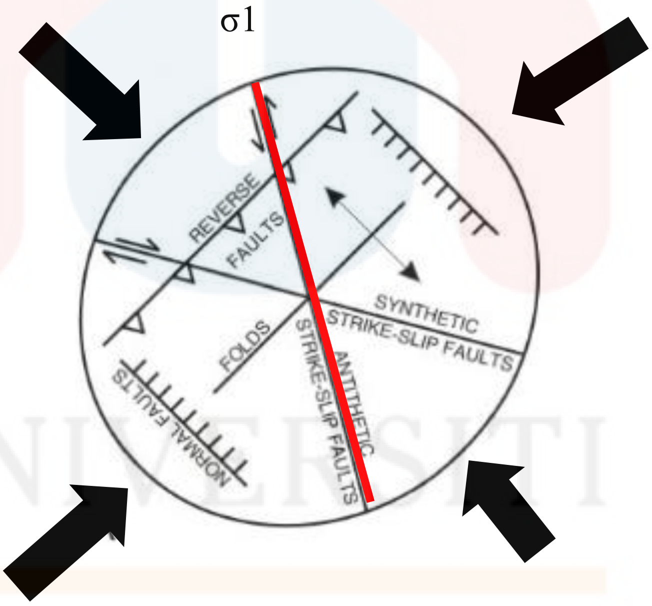


Figure 5.7: Major force identification using strain ellipsoid

Based on the figure above there are only one stress that caused the deformation of rock in the study area which are shear stress. Red line represents the shear stress. The major force comes in direction on North East (NE) and South West (SW). From lineament analysis, major force comes from this NE-SW direction. It caused sinistral strike slip fault occur in the study area.

5.3.2 Stereographic Projection of Fold

Fold is used in geology when one or a stack of originally flat, level surfaces, such as sedimentary strata, are bent or curved as a result of pressure and high temperature. The basic cause is likely to be some aspect of plate tectonics. The folds arise as a result of the tectonic pressure and stress in the rocks and rather than fracture, they fold. They are easily visualized by the loss of horizontality of the strata. Stereonet was used to characterise the geometry of folds from field data.

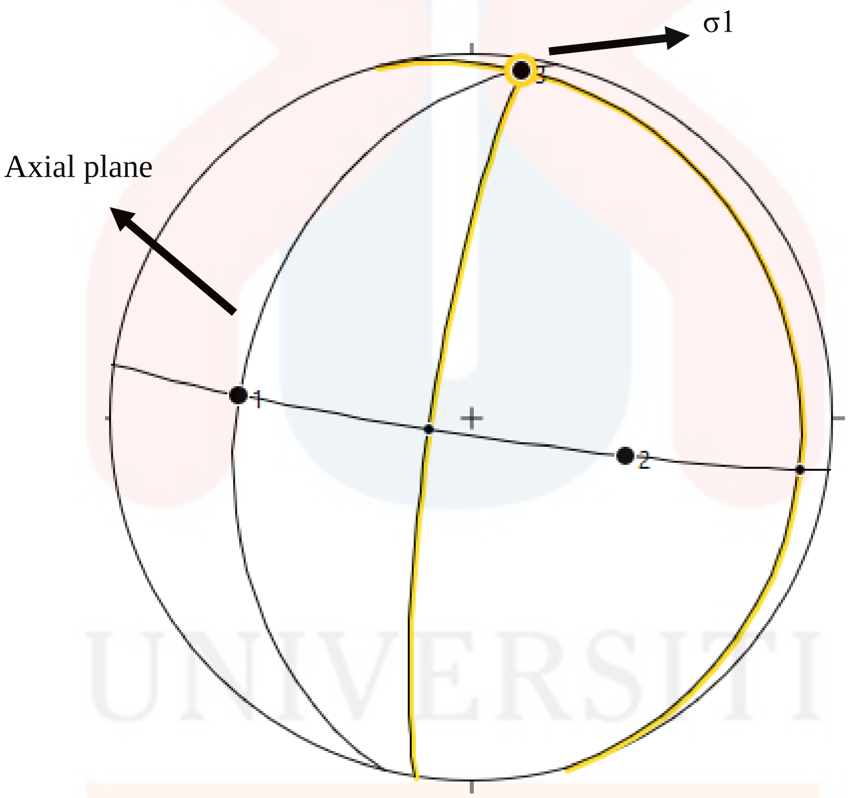


Figure 5.8: Stereonet of fold in the study area

Stereographic projection at the study area shows the trend and plunge value of σ1 = N8°E/ 4 and the axial plane =N14°E/36. The fold analysis shows that major forces come from NE and SW direction and this match with the strain ellipsoid of the study area. This fold occur because of the Salo Jampue strike slip fault. However, this kind of fold might occur in small scales.

Salo Jampue Fault is assumed as strike slip fault because the correlation of the principle strain ellipsoid with the strike slip fault was accepted posed by mud, sand and gravel. The younger geological process will continue.

5.4 Dynamic analysis

5.4.1 Types of Fault

On early interpretation, Salo Jampue Fault shows characteristics of strike slip fault (sinistral) based on the descriptive data. It will be confirmed by fault analysis in the next subtopic. Left-lateral fault or also known as sinistral strike slip fault were identified when the left side of the fault block moves to the left (Figure 5.12).

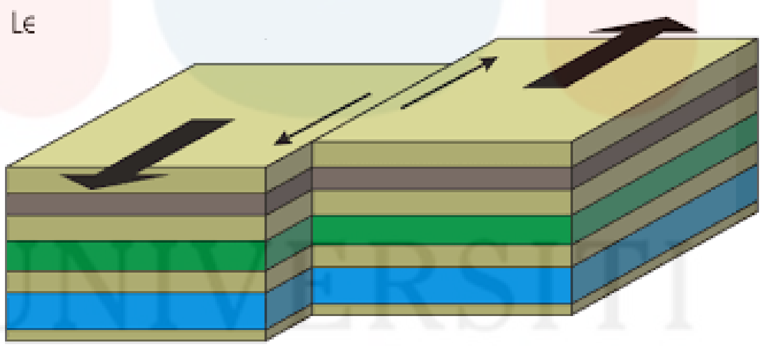


Figure 5.9: Strike slip (sinistral) block diagram (Source: Geology page, 2017)

5.4.2. Joint Analysis

Joint analysis is carried out to get information about the paleo-stress field and to determine the main force affect the study area. There are only one location of joint that have been measured. The joint was identified as shear joint. The principal stress direction of the joint taken shows trending NNE-SSW.

The joint found was found at coordinate 4° 10' 52.68" S, 119° 37' 31.44" E, at tuffaceous mudstone outcrop. Based on Rose diagram shown in Figure 4.20, the major shear stress is from North North-East to South South-West (NNE-SSW). The stress is approximately directed from 90° to 270°. This shear stress caused the development of strike-slip movement in the study area.

5.4.3 Geotectonic Process

During Early Tertiary or older, a westward subduction complex was probably developed to the east of western Sulawesi and Bone Basin was in a fore arc setting. A collisional event occurred between Australian-derived microcontinents and the Early Tertiary accretionary complex during Middle Miocene resulting in eastward obduction of the accretionary complex during Middle Miocene resulting in eastward obduction of the accretionary complex onto the microcontinents. The westerly continental moving microcontinents then collided against and partly was subducted beneath the western Sulawesi during Late Miocene.

The compression from the collision propagated a major back-thrust system westward to the subduction zone generating fold belts as indicated by the west-verging Kalosi and Majne fold belts. The two colliding plates then were locked up during the Pliocene and the continued plate convergence was accommodated by strike-slip movements along the Walanae, Palukoro and other faults. These plate movement forms compressional stress along its surrounding area and hence fold was formed because of the compressional stress. The increase in pressure cause the plastic deformation that form shear joints. The shear stress exerted by the shear joints initiate the formation of Salo Jampue strike slip fault.

5.4.4 Rock Mechanics

The stresses that can be applied to rocks are tensional, compressional and shear. Tensional stress is the force that tends to elongate or pull the rock apart, caused the rocks to be narrower and longer that the original state. A compressive stress is applied from opposite sides. The rock that has experienced this force has tendency to shorten or compress the rock between the opposing stresses which may stretch it parallel to stress-free direction. Shear stress occurs when force from opposite direction create shear plane in an area in which force run parallel to one another.

Based on analysis done in study area, it shows that the largest stress, (σ3) which is most compressive stress is horizontal. This caused the shear joints to develop during compaction of rocks. The intermediate stresses are from vertical (σ1).

Figure 5.5: Differential stress of strike slip fault (Source: Heidbach et al., 2016)

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, the objective of the research was obtained. Firstly, geological base map of Palanro area, Barru was produced in a scale ratio of 1: 25 000. The data to construct the geological map was collected through geological mapping which detailed in chapter 4. The rock unit of the study area was divided into three which were Alluvial unit, Ash Tuff unit and Lapilli Tuff unit. Both Ash Tuff and Lapilli Tuff belongs to Camba Formation (Tmc). Meanwhile, Alluvial was produced during Quarter Alluvium Formation (Qac) which known as swamp and coastal deposits. The rock units selected based on the major rocks found during geological mapping of the respective area. Lapilli tuff unit was the older rock followed by Ash tuff unit and Alluvial unit was the younger rock unit. The age range from Early Pleistocene to Late Holocene hence, the rock units was Quartenary epoch. Based on geomorphological view, the study area comprised into five landforms, denudational hill, denudational flat, fluvial plain, marine and coastal. The main river of the study area was classified as permanent river where the water flows throughout the year even on drought season. Furthermore, the drainage pattern of the streams was identified as parallel. The main river was classified as braided river because of sand and gravel deposition along the river body.

The second objective is to analyse the fault using the kinematics and dynamic analysis method. These methods used to determine the types of fault and relate it with deformation process by using stereographic projection, which was achieved. Based on dynamic analysis, the shear joint in the study area and the lineament was plotted in rose diagram and the principle stress direction was identified trending NNE-SSW. In term of kinematics analysis, fold in the study area was analysed using stereonet and an interpretation of major force was obtained using strain ellipsoid, which proved the study area was affected by major strike-slip fault.

The third, objective is to investigate the fault mechanism of the study area. During geological mapping, there are no visible faults found in the study area. However, there were some indicators of fault in term of lithology, geomorphology, river and valley. Besides, topographic analysis was used in order to determine major fault where the lineament map was created. The, major strike-slip fault was found using topographic analysis and interpretation of the major force for strike-slip fault was obtained based on strain ellipsoid.

6.2 Recommendation

Further research need to study more regarding the faults splays caused by the Walanae fault. There are many area affected by Walanae fault however the data collection is still lack and need improvisation.

Furthermore, University Malaysia Kelantan (UMK) should provide students with enough and advanced lab equipments such as digital microscope which ease the students on undergoing thin section analysis. The limitation of the microscope slows the work pace of the student's regarding thin section analysis.

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