GEOLOGY AND GEOCHEMISTRY OF LAVA TYPES IN LEMBANG, WEST JAVA INDONESIA

By

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A report submitted in fulfilment of the requirements for the degree of Bachelor of Applied Science (Geoscience) with Honours

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DECLARATION

I declare that this thesis entitled "**GEOLOGY AND GEOCHEMISTRY OF LAVA TYPES IN LEMBANG, WEST JAVA, INDONESIA**" is the results 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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APPROVAL

"I/ We hereby declare that I/ we have read this thesis and in my/our opinion this thesis is sufficient in terms of scope and quality for the award of Bachelor of Applied Science (Geoscience) with Honours"

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Geology and Geochemistry of Lava Types in Lembang, West Java, Indonesia

ABSTRACT

This research study is conducted in Lembang, West Java, Indonesia. West Java is a part of Java Island which is believed to locate in the transitional zone between oblique subduction in Sumatra and orthogonal subduction at the eastern part of West Java that contribute to the series of volcanism in West Java. At least four volcanic complexes present at the West Java includes Galunggung-Tangkuban Parahu complex. The lithology of the study area is composed of the eruption products of Mount Tangkuban Parahu and its surrounding volcanoes. Mount Tangkuban Parahu is located within Sunda caldera, which is formed from the catastrophic phenomena, the collapsed of the summit of the giant Sunda volcano. The collapsed of the giant Sunda caldera caused the formation of major fault in the West Java known as Lembang fault with the total extends of 29 km. The research area had covered a part of Lembang fault which lies from East to West direction. This volcano-tectonic activity caused the geomorphological changes in the regional scale. Geological mapping is conducted by covering the area about 25 km^2 in Lembang in order to produce the detail geological map and lava study of the research area. Lithology, geomorphology, stratigraphy and structural geology of the study area are been observed and recorded. The raw data of geological mapping is analysed using ArcGIS software and rose diagram software for the geological part. The study area consists of andesite of the Lembang fault scarp, the older volcanic breccia, basaltic lava, young volcanic breccia and tuff units. For the specification part, the five rocks samples are been collected which indicate two types of lava found in the study area, basaltic lava and andesite lava. These five samples are analysed using XRF analysis and been interpret by GCDkit 6.0 software. Based on the interpretation using TAS, SiO_2-K_2O plot and Harker trends diagram, these two types of lava are represent a same magma suite which is calc-alkaline suite but different magma sources.

Geologi dan Geokimia Jenis Lava di Lembang, Jawa Barat, Indonesia.

ABSTRAK

Kajian penyelidikan ini dijalankan di Lembang, Jawa Barat, Indonesia. Jawa Barat adalah sebahagian daripada Pulau Jawa yang dipercayai berada di zon transisi antara subduksi oblique di Sumatra dan subduksi ortogonal di bahagian timur Jawa Barat yang menyumbang kepada serangkaian gunung berapi di Jawa Barat. Sekurang-kurangnya empat kompleks gunung berapi yang terdapat di Jawa Barat termasuk kompleks Galunggung-Tangkuban Parahu. Gunung Tangkuban Parahu terletak di Kaldera Sunda, yang terbentuk dari fenomena bencana runtuhnya puncak gunung berapi Sunda. Keruntuhan kaldera Sunda ini menyebabkan pembentukan sesar besar di Jawa Barat yang dikenali sebagai Sesar Lembang dengan jumlah keseluruhan 29 km. Kawasan penyelidikan merangkumi sebahagian daripada Sesar Lembang yang terletak di arah Timur ke Barat. Aktiviti gunung api-tektonik ini menyebabkan perubahan geomorfologi dalam skala serantau. Pemetaan geologi dilakukan dengan meliputi kawasan sekitar 25 km^2 di Lembang untuk menghasilkan peta geologi yang lebih terperinci dan untuk mengkaji geokimia jenis lava yang terdapat di kawasan kajian. Litologi, geomorfologi, stratigrafi dan geologi struktur kawasan kajian telah diperhatikan dan direkodkan. Data yang diperoleh daripada pemetaan geologi dianalisis menggunakan perisian ArcGIS dan perisian diagram rose. Kawasan kajian terdiri daripada batuan andesit sesar Lembang, breksi vulkanik yang lebih tua, lava basaltik, breksi vulkanik muda dan unit tuf. Untuk bahagian spesifikasi, lima sampel batuan yang telah dikumpulkan menunjukkan dua jenis lava yang terdapat di kawasan Kajian ialah lava basaltik dan lava andesit. Lima sampel ini dianalisis dengan menggunakan analisis XRF dan telah ditafsir oleh perisian GCDkit 6.0. Berdasarkan penafsiran menggunakan TAS, plot SiO2-K2O dan rajah Harker trend, kedua-dua jenis lava ini mewakili satu suite magma yang sama iaitu suite calc-alkali tetapi daripada sumber magma yang berbeza.

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LIST OF SYMBOLS

m	Meter
mm	Millimetres
cm	Centimetres
km	Kilometres
xpl	Cross Polarized Light
ppl	Plain Polarized Light
%	Percentage

LIST OF ABBREVIATIONS

No.		TITLE
1.	GIS	Geographical Information System
2.	GPS	Global Positioning System
3.	XPL	Cross Polarized
4.	PPL	Plane Polarized
5.	XRF	X-ray Fluorescence
6.	TAS	Total Alkali vs. silica

CHAPTER 1

INTRODUCTION

1.1 Background of Study

This research study is about geology and geochemistry of lava types in Lembang, West Java, Indonesia. Lava is molten rock generated by geothermal energy or known as magma that expelled onto the Earth's surface. The expelled of the lava can be directly erupts from the mouth of the volcano or through fractures in planetary crust. The term lava is also used for the solidified rock resulted from the cooling of molten lava flow. There are several types of lava that commonly exposed on the Earth surface. They are pahoehoe lava, 'aa' lava, pillow lava and also common formed as columnar joint.

Formation of lava is common in Indonesia as this country is well known for their numerous episode of the volcano eruption in the world history. Location of multiple plates' interactions that occurred between the Australian, Eurasian and Philippine Sea Plates resulting in the formation of Indonesia Island arc as recognized today and have a chain of active volcanism. These phenomena create Indonesian Archipelago with a close volcano-tectonic relationship displayed by all 128 active volcanoes in the region. Island arc volcanism has portrayed a crucial part in the development of continents and become references in understanding the related processes during the generation of island arc magma as a key to understanding the evolution of the Earth.

According to Widiyantoro and van der Hilst in 1997, a part of the convergence plate boundary between the Australian and Eurasian Plates had represented by the Sunda arc which consisted of West Java. Whitford (1975) had been conducted the research in the spatial variations in the geochemistry of Pleistocene and Recent Lava from the Sunda Arc of Indonesia. Then, there is a study on geochemical variation in Tertiary-Quaternary lavas of West Java which documented by Sendjaja and Kimura (2010). However, none of them had discussed the existence of the lava which presents as the wall of the fault scarp at the Lembang fault. This fault scarp is significantly visible as it acts as the border that separated northern and southern parts of the study area. Besides, the lava at the Lembang fault, there also lava that found along the Cikapundung River. Thus, this research study aims to reveal the relationship between these two lava occurrences found in the study area and correlate them with the Sunda – Tangkuban Parahu volcanism activity.

1.2 Study Area

The study area for this research study is located in the area of Lembang in West Java, Indonesia with 5 km x 5 km widths on scale 1:25,000. This area dominantly covered by high land which the range of elevation is from 912.5 m – 1512.5 m and equally divided into two regencies (Kabupaten); Kabupaten Bandung and Kabupaten Bandung Barat. The northern part of the study area is relatively lower with plain landform compared to the southern part due to the formation of major fault known as Lembang fault. It can be identified from the terrain map. The Lembang fault is lies across from east to west of the study area. Figure 1.1 shows the location of the study area.

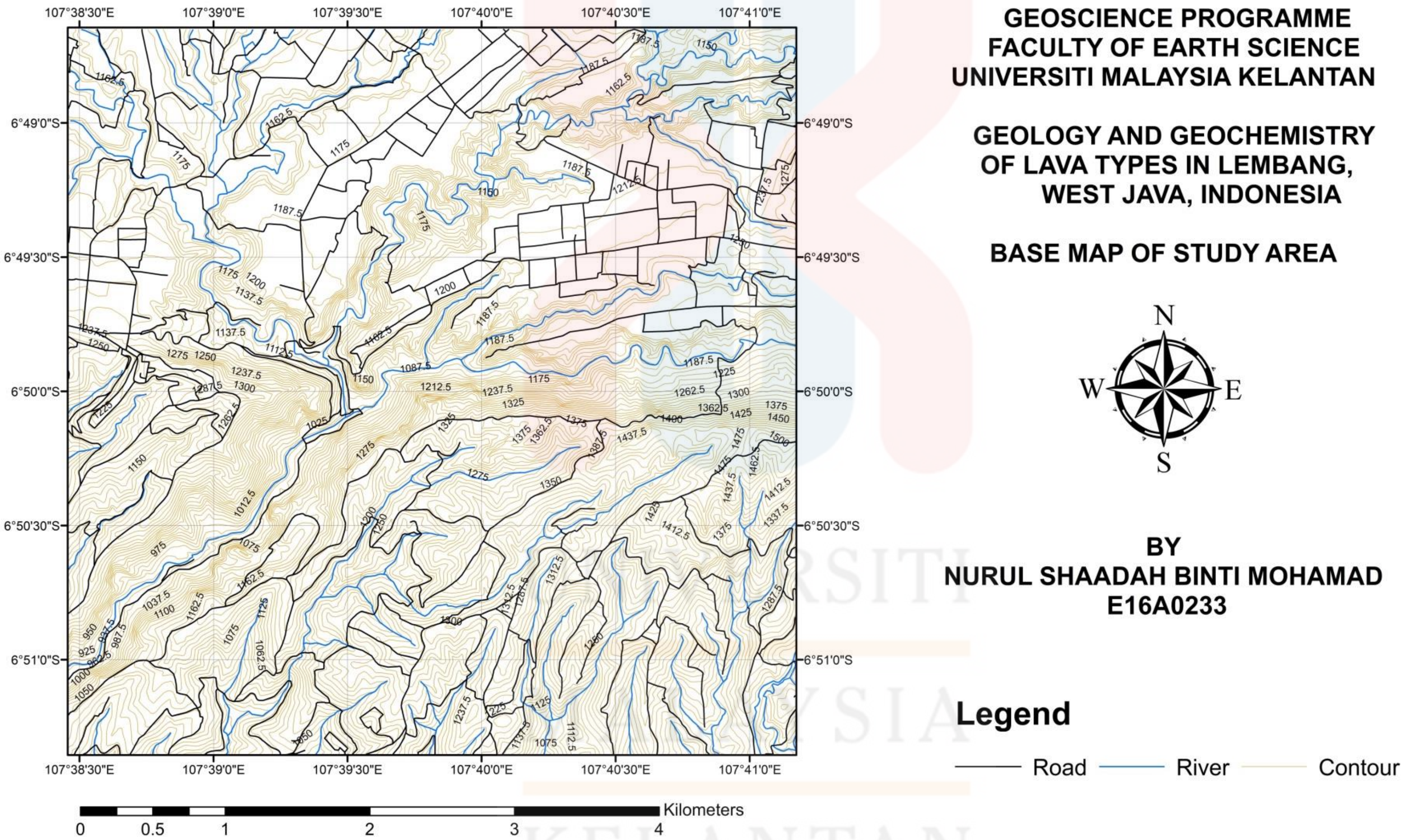


Figure 1.1: Base map of the study area

1.2.1 Location

Lembang is a town and administrative village of West Bandung Regency in the province of West Java which situated between 1,312 and 2,084 meters above sea level. Its highest point is on Mount Tangkuban Perahu. It is the area that surrounds many tourist sites such as Mount Tangkuban Perahu which is one of the major attraction sites in Lembang. Other tourist attraction sites at the study area are Taman Hutan Raya Ir. H. Djuanda, The Lodge Maribaya, Puncak Bintang and Tebing Keraton which concentrate at the centre to southern part of study area.

1.2.2 Road Connection

Lembang is located approximately 15 km from the city centre of Bandung. The main road that connects Bandung to Lembang is known as Jalan Raya Lembang. 2 hours of driving is spent to travel from Bandung to Lembang and the time may take longer during weekends and public holidays. The study area can be reached from any direction but different time is consumed. From Universitas Padjadjaran, about 1 and half hours is consumed to reach there by using motorcycles or cars. The routes that usually used were Jl. Dago Giri, Jl. Maribaya, Jl. Langensari and Jl. Cibodas. Local people usually taking public transport such as “angkot” and online taxis such as “Grab car” that always available in Lembang.

1.2.3 Demography

The Lembang district consists of 16 villages that occupied about 10,620 Ha and the total population of Lembang district as in 2015 is around 187,00. Lembang populations majorly labourer in the agricultural industry, informal sector workers, entrepreneurs and government workers such as teachers, civil servants, and police. According to religion, there are about 148,263 Muslims, 5,200 Protestans, 2502 Catholics and the remaining are Hindus and Buddhists. The Lembang population is list detailed in the Table 1.1.

Table 1.1: Number of Lembang Population (2015)

Village	Gender		Sex Ratio	Total
	Male	Female		
1. Gudang Kahuripan	7.689	7.294	14.983	105,42
2. Wangunsari	5.566	5.388	10.954	103,30
3. Pagerwangi	5.104	4.825	9.929	105,78
4. Mekarwangi	3.099	3.011	6.11	102,92
5. Langensari	6.809	6.526	13.335	104,33
6. Kayuambon	4.564	4.317	8.881	105,71
7. Lembang	9.458	8.739	18.197	108,22
8. Cikahuripan	5.857	5.601	11.458	104,58
9. Sukajaya	6.517	6.301	12.818	103,43
10. Jayagiri	10.213	9.926	20.139	102,89
11. Cibogo	5.992	5.794	11.786	103,42
12. Cikole	7.237	6.899	14.136	104,89
13. Cikidang	4.09	4.038	8.128	101,29
14. Wangunharja	4.023	4.008	8.031	100,36
15. Cibodas	5.492	5.465	10.957	100,50
16. Suntenjaya	4.004	3.969	7.973	100,89
Lembang Subdistrict	95.714	92.101	187.815	103,92

(Source: Development Database of Bandung Barat Regency, 2015, as modified by Nur Najihah Jamari,2018)

1.2.4 Rainfall Distribution

Bandung climate is warm, oppressive and overcast. Throughout the year, Bandung experience typically varies temperature ranging from 18 ^{o}C to 29 ^{o}C and is rarely to reach below than 16^{o}C or above 31^{o}C. Bandung experiences extreme seasonal variation in monthly rainfall. Rain falls in Bandung throughout the year. Based on Figure 1.2, the wettest month with the highest average of rainfall is in December and the dries month is August.

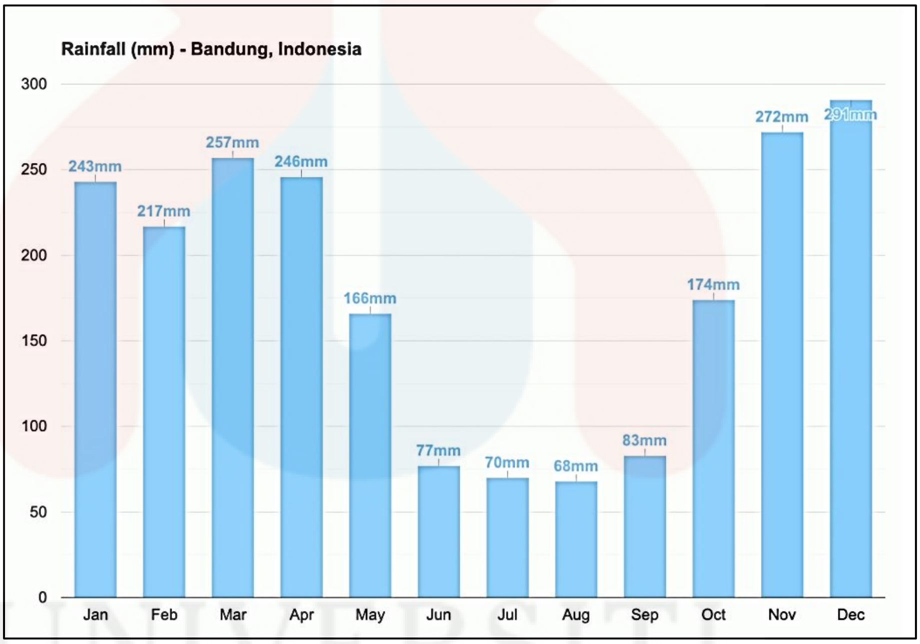


Figure1.2: Bar Chart of average rainfall in Bandung in 2018
(Source: Weather Atlas)

1.2.5 Land Use

Land use study reviewed by Satrika (2016) reported that the Lembang area is dominated by three types of land use; forest plantation (coffee plantation mixed with pine forest), grassland such as shrub, herbaceous plants, *Imperata cylindrical*, and *Eucalyptus* trees, and cultivated land. However, in the past these areas were claimed as deciduous forest which is the forest that loses their leaves seasonally and the existence of these forests was identified from records of the pollen which found at intermediate altitudes in range of 1300 m to 1500 m in Sumatra and West Java. There also a study by Ruswandi et al., (2007) reported that in 1990, the forest area in Lembang was converted into agricultural land until todays. The farmers at Lembang are cropping systems that rotate 3-4 crops in a year with variety of vegetables such as cabbage, tomatoes, cauliflowers and broccoli.

1.2.6 Social Economic

Lembang is a well-known town and administrative village at Bandung for its collections of tourist sites and its agriculture. Thus, it is rapidly developed and highly populated. Lembang is very well known for Mount Tangkuban Parahu which still active until now. Lembang becomes a perfect destination for tourism with pleasant temperature and picturesque scenery. They commonly visit places here such as Floating Market, The Lodge Maribaya, Dago Dream park, Taman Hutan Raya Ir. H. DJuanda, Farmhouse Lembang and many more. The tourists are coming from various places from local people to world-wide tourists. Agriculture activities at Lembang also create beautiful greenish landscapes and become main source of income besides tourism industry. Thus, Balitsa Lembang is introduced and become plantation research centre that monitors the cultivation activities.

1.3 Problem Statement

The geological study conducted in the Lembang area is more focusing on Lembang fault as it is one of the famous geological features to be studied by the researchers. Moreover, it is still active until today and probably can be shift again someday. However, the latest geological map that being published and easily accessible is in the year of 1973 by Silitonga with a scale of 1: 100,000. Thus, this study is aimed to produce an updated geological map with a scale of 1:25,000 which is more details and focusing on the area of study.

As Lembang is nearby with Mount Sunda - Tangkuban Parahu volcano, various volcanic products had deposited widely in the study area such as pyroclastic fall, lahar and lava. The lava that always being discussed by the researcher in the study area is lava at Cikapundung River which uniquely presence as pahoehoe lava which solely found in the subduction system. However, there also others lava existed in the study area which is the lava that presence as the wall of the Lembang fault scarp. From the article published by *Lembaga Ilmu Pengetahuan Indonesia (LIPI),* a researcher named Eko Yulianto claimed that the formation of lava in the Lembang fault scarp is still being debated. Thus, this research study is conducted to investigate the relationship between the lava types that existed in the study area by using XRF analysis.

1.4 Objectives

i. To update the geological map of Lembang with the scale of 1:25,000.

ii. To investigate the geochemistry of lava types present in the study area according to geochemical data.

1.5 Scope of Study

The scope of this study will focus on geology and geochemistry of lava types in the Lembang with the aid of geological mapping and geochemical analysis. In geological aspects, this study will cover the study of lithology, geomorphology, geological structures, formations, mineralogy, stratigraphy, petrology, and sedimentology of the study area. The needs of studying all of these aspects are very important as they provide useful information about the geological setting and previous geological activities that occurred in the research area.

This study had covered an area with a width of 5 km × 5 km of Lembang area. The fieldwork is conducted in order to produce a geological map with details information about the lithology, geomorphology, geological structures and the topography of the area. In this study, it only involved rocks sampling as the study is focused on geochemistry of lava types.

The geochemistry of lava types is the specification part of this research study. In this part, the study is focused on investigating the distribution of major elements in the lava. Then, correlate the relationship between the elemental distribution and its formations history.

1.6 Significant of Study

The significance of this study is to produce the details updated geological map of the Lembang area with a scale of 1:25,000. This updated geological map can become a reference for future researcher as it had details geological information that is focused on the Lembang area. Besides, from all the geological information collected during this study, it can provide useful information for future researchers and the public about the geological setting and previous geological activities that had been taking place at the Lembang area. For specification part, which focuses on the data of elemental distributions in the lava, the data obtained will also be very useful for future researchers in investigating the evolution of lava and geological setting of Lembang fault.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is a comprehensive summary of the previous studies or knowledge about the selected research topic. It helps the researcher to point out inadequate information about the previous studies and suggests furthering the research study.

2.2 Regional Geology and Tectonic Setting

Indonesia's plate tectonic are very complex as several plate tectonic surround it; continental and oceanic plates. The location of Indonesia is between two continental plates, they are Eurasian Plate and Australian Plate, and between a couple of oceanic plates which is the Philippine Sea Plate and Pacific Plate as shown in Figure 2.1. This complex location makes Indonesia one of the countries located in the Ring of Fire which then becomes the main reason for the numerous of volcanic eruptions and earthquakes strikes. The subduction of Indian oceanic plate beneath the Eurasian continental plate caused the formation of volcanic arc in western Indonesia and that area is geologically known as the most seismically active area. Sumatra, Java, Bali and Nusa Tenggara islands were formed by this chain of active volcanoes (Nur Najihah Jamari, 2018).

The area of the collision between Eurasian and Indian-Australian Plate is indicated by the formation of the Java Trench and Timor Trough while Sorong Fault is representing the interaction area between Indian-Australian Plate and Pacific Plate. Subduction of the Indian-Australian Plates beneath the Eurasian Plates has resulted in the developments of the major magmatic arc system which is divided into two segments consists of the Sunda arc in the west and Banda arc in the east.

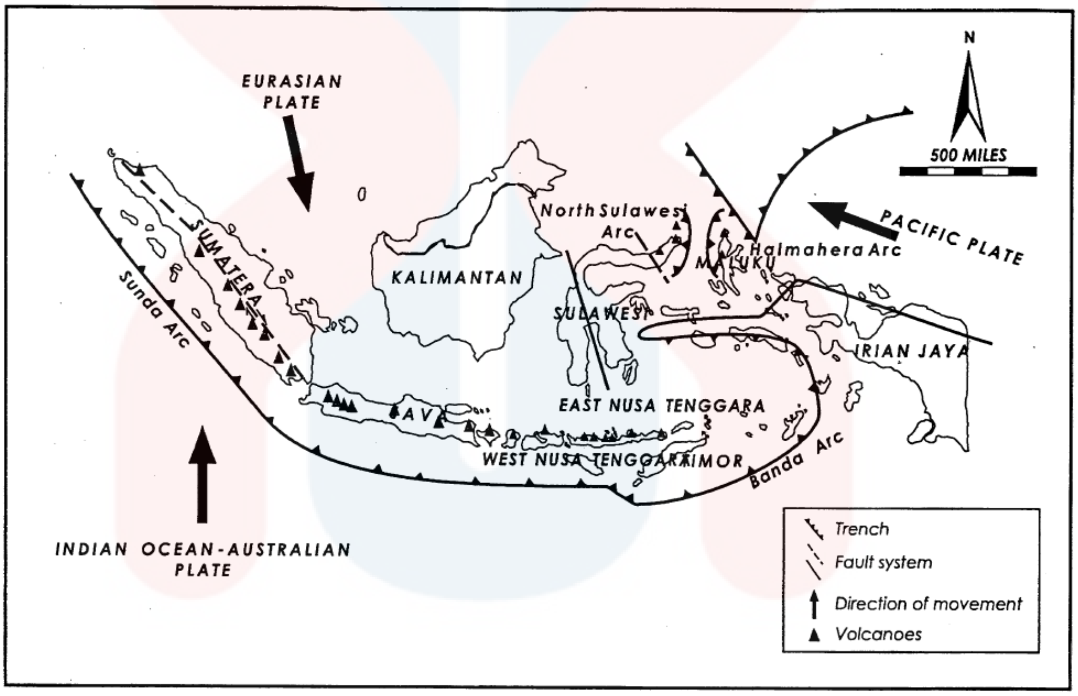


Figure 2.1: The plate boundary of Indonesia (Katili,1973).

2.2.1 Java Island

a) Tectonic framework of subduction zone

Java Island is a part of volcanic arc, which extends approximately about 3,700 km from the northern tip of Sumatra Island to east of Damar Island in the southern side of Banda Sea through Java (Setijadji et al. 2006; Hamilton, 1979; Carlile and Mitchell, 1994). The elongation of this well progressively arc is developed since Mesozoic from west to east direction and is divided into three segments. The three segments are; starting from Sumatra arc consisting Sumatra Island, then the Sunda arc from Java to the Flores Island and terminated at the Banda arc which consists the islands at the east of Flores (Setijadji et al. 2006).

Formation of the Java segment was believed took placed in the early of the Tertiary at a convergent tectonic margin between the Indian-Australian oceanic plates and the SE margin of Eurasian continental plate known as Sundaland (Katili, 1975; Hamilton, 1979; Carlile and Mitchell, 1994 and Setijadji et al. 2006) (Figure 2.2). The subducted oceanic crust is occurred more or less perpendicular to the volcanic arc with subduction rate approximately about 6-7 cm/year (Hamilton, 1979; Simandjuntak and Barber, 1996, Setijadji et al., 2006; Sendjaja and Kimura, 2010). This subduction triggered magmatism and volcanism activities along the Sunda-Banda arc.

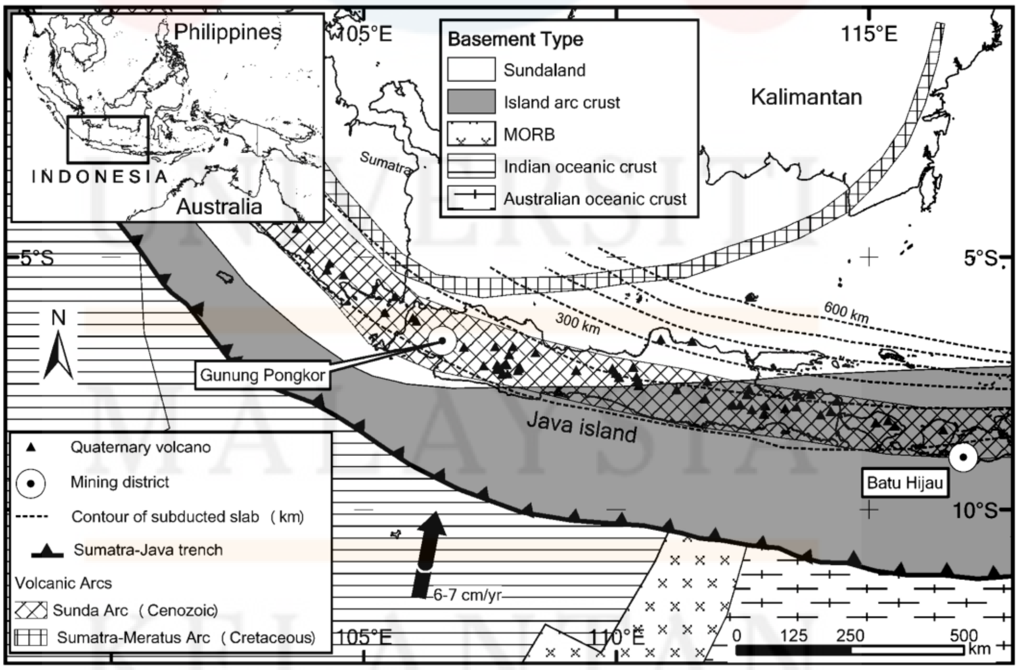


Figure 2.2: Geological framework of Java Island, Indonesia.

(Source: Hamilton, 1979; Carlile and Mitchell, 1994; and Hall, 2002 and modified by Setijadji et al., 2006)

2.2.2 Volcanism in West Java

According to Hall (2012), location of West Java is considered to be located in transitional zone between oblique subduction in Sumatra and orthogonal subduction at the eastern part of West Java. In West Java, there are four volcanic complexes; 1) Krakatau volcano, 2) Danau complex, 3) Salak complex, 4) Galunggung-Tangkuban Parahu complex. Krakatau volcano and Danau complex are located in western of West Java where separated about 60 km from each other. The Salak Complex is formed with several single chains of volcanoes such as Salak, Perbakti, Kiarabere and Gede.

The Salak complex and Galunggung-Tangkuban Parahu complex is also 60 km apart from each other. Mount Galunggung and some other clustered volcanoes are located along the trench-side volcanic chain, while a line of Mount Tangkuban Parahu, Mount Tampomas and Mount Ceremai are located in the backarc-side volcanic chain, Setiawan et al., (2017) (Figure 2.3).

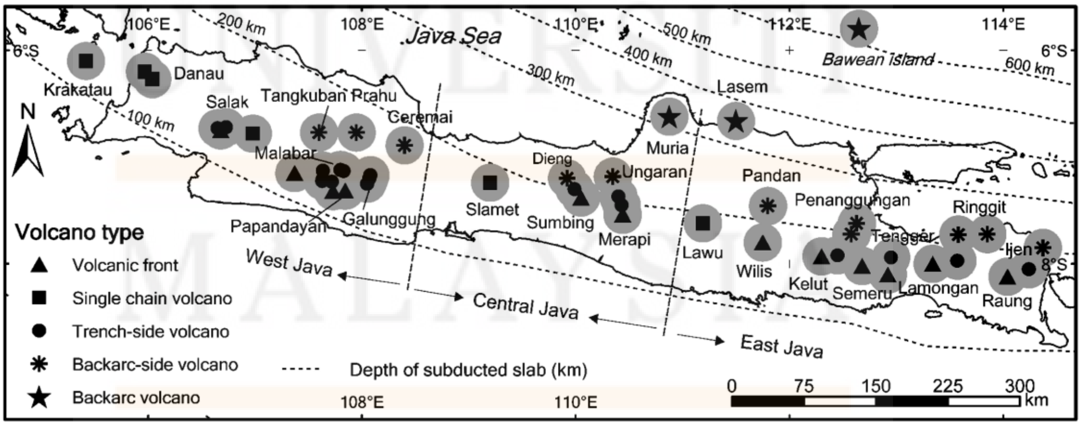


Figure 2.3: Distribution of Quaternary volcanoes in Java. Source: Tatsumi and Enggins (1995) and Setijadji et al., (2006).

2.3 Stratigraphy

The stratigraphy of Lembang is based on Peta Geologi Lembar Bandung (Silitonga, 1973). It is formed dominantly by the eruption of Mount Tangkuban Perahu and also from the surrounding mountains and it is a part of Bandung Basin. Based on Figure 2.4, four types of lithology found in the study area which coded or symbolized as Qyd, Qvu, Qyt and Qyl.

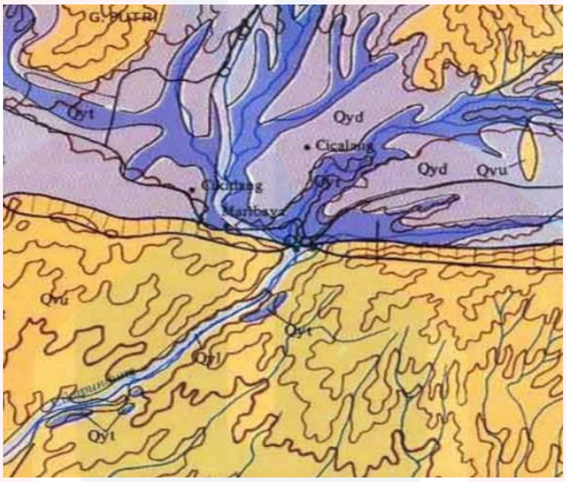


Figure 2.4: Lithology at Lembang area

Qvd is a symbol that represented the deposition of brown tuffaceous sands which contain coarse hornblende crystals, reddish weathered lava, lapilli and breccia that are coming from Mount Dano and Mt. Tangkuban Parahu. Qvu is the result of undifferentiated old volcanic products as it was repeatedly interlayered of volcanic breccia, lahar and lava. While pumiceous tuff that found there in the form of tuffaceous sand, lapilli, scoria lava, bombs and basalt andesite are coming mostly from Mount Tangkuban Parahu and Mount Tampomas, is characterized by the symbol Qyt. Then, the lava which is the result of a young volcano is symbolized as Qyl. Something similar is also stated at Cikole Village as it is located on the southern slope of Mt. Tangkuban Perahu evolved from the eruption of Mt. Tangkuban Perahu (Silitonga, 1973).

2.4 Structural Geology

The most famous geology feature in Lembang is Lembang fault. The fault is a geology feature promoted by tectonic movement. It is a fracture across that formed when two blocks have slipped and the fault plane is parallel to the displacement of adjacent blocks. This fault is located in the southern slope of Mt. Tangkuban Perahu and its geomorphology can be seen due to the tectonic activity of Bandung basin. This Lembang fault with 24 km long is expressed as fault scarp which formed from the volcano-tectonic activity of Mount Sunda during Pleistocene. Fault scarp is tectonic landform which more or less coincident with the fault plane that dislocated from the ground surface (Steward and Hancock,1990). The north facing escarpment wall of this fault has slopes which steeper than 40 degrees and its height above the surface approximately reaches 450 m and the height is gradually decreased to the west ward in the area of Cisarua (Meilano et al. 2012) This fault is still active and mostly earthquake in the north Bandung is resulting from its slight movement.

According to Meilano et al. (2012), the western part of Lembang fault lies in population areas such as Paropong district which experienced an earthquake on 28 August 2011. This fault lies 300 km off- shore to the southern part of Java Island and it parallel to Java subduction zone. Nur Najihah Jamari (2018), had stated that the geomorphology of Lembang fault consists of two other faults which are Cimandiri fault and Rayamandala fault. Cimandiri fault lies in the west of Lembang fault.

2.5 Historical Geology

The historical geology of Lembang is very closely associated with Lembang fault and Mt Tangkuban Perahu.Tangkuban Perahu is a broad shield-like stratovolcano facing Indonesia's former capital city of Bandung. The volcano was constructed within the 6 x 8 km Pleistocene Sunda caldera, which formed about 190,000 years ago.

There is a chronology of Lembang fault formation that relates to the development of volcano-tectonic Mt. Sunda Complex in the flow chart in Figure 2.5, according to Van Bemmelen (1949). According to the events, the stratigraphy of Lembang area was composed of materials from volcanic eruptions.

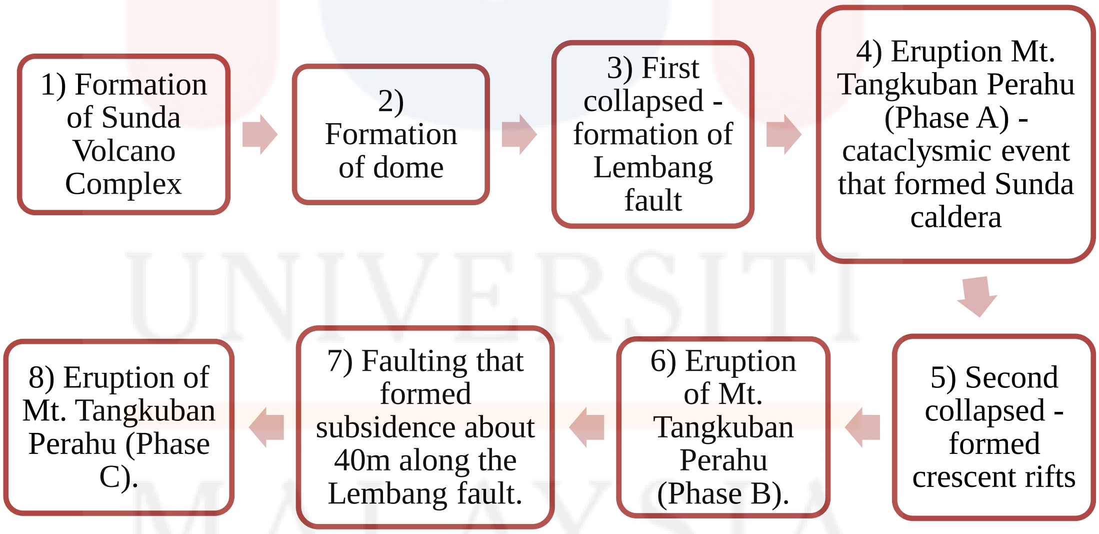


Figure 2.5: Flow chart of development volcano-tectonic Sunda Complex

2.6 Research Specification: Geochemistry of Lava Types

a) Previous Study

The recent study is conducted in the large scale on geochemical variation in Tertiary and Quaternary lavas of West Java by Sendjaja et al,. (2010). Through this study, there were 44 samples of lavas are collected by considering the arc position and the age of the volcanoes. All of the samples were analysed for major and trace elements by using X-ray fluorescence (XRF). Rare earth elements (REEs) and others additional trace elements were also analysed using inductively coupled plasma-mass spectrometry (ICP-MS). In this study the geochemical data were plotted in the total alkali versus silica (TAS) diagram for rocks classification. All of the samples fall in the range of the basalt to dacite and belong to the sub-alkaline suite.

Then, Abdurrachman et al., in the year of 2016, there was a group of researchers conducted a study interested to pahoehoe lava that found in the Cikapundung River. This pahoehoe lava was an eruption product from Mount Tangkuban Parahu. 12 samples were collected for petrographical and XRF analysis of major and trace elements. The rocks sampled were characterized as basalt with common petrographic features as mostly showing porphyritic texture with less than 20% content of phenocryst-microphenocryst. The Harker diagram is used in this research to make the comparison with Tangkuban Parahu Volcanic Rocks in term of the SiO_2 and K_2O contents. Based on Harker diagram, the samples are interpreted with higher amount of K_2O content compared to Tangkuban Parahu volcanic rocks which indicate mixing or assimilation during the magma series.

b) X-ray Fluorescence (XRF) Method

XRF is a method that uses to analyse and determine the chemical composition presence in all types of materials. The analysis materials can be in form of solid, liquid and powder and usually requires only a minimum sample of preparation. Sometimes this method also can be used to determine the thickness, coatings and composition of layers. It is non-destructive method with accurate observation and fast running procedures. It has broad applications including the metal, oil, polymer, cement, plastic and food industries, also along the mining, mineralogy and geology, and analysis of waste materials and together with an environmental analysis of water. XRF is also a very useful analysis technique in clinical research.

XRF method is capable of producing high precision and reproducibility. The precise results are possible to generate when good standards of the specimens are available, but sometimes there is no specific standards can be found. The time consuming for measurement are varies ranging between seconds and 30 minutes which depends on the number of elements to be analysed and the required accuracy. While the analysis time after the measurement only takes a few seconds. The good analysis starts with a well-prepared sample and a good measurement. Two steps do the analysis: Qualitative analysis followed by quantitative analysis. Qualitative analysis determines which elements are present and their net intensities from the measured spectra. The net intensities are used in the quantitative analysis to calculate the concentrations of the elements present.

CHAPTER 3

MATERIALS AND METHODS

3.1 Introduction

This study consisted of five major phases which are preliminary studies, fieldwork, laboratory work, data processing and analysing and report writing. The suitable materials and equipment, and the best methods used in this study are examined very carefully in order to achieve the aims of this study.

3.2 Materials and Equipment

Mapping Equipment:

- Topographic Map (Base map)
- Garmin Global Positioning System, GPS with cable
- Geological Hammer
- Compass: Brunton/ Suunto
- Hand lens (x10 magnification)
- Sampling bag
- 50 Meter Measuring Tape
- Camera
- 0.1 M Hydrochloric Acid (HCl)
- Geological field book
- Stationery

These are the equipment that important in geological mapping :

The topographic map or base map of the study area is the most basic equipment and essential to bring along to the field as it provides information about the geological features of the study area and as the reference for traversing. The scale of the map also an important aspect to consider depends on the areal extent of the field as to helps the correlation information in the map with the real world much easier and precise.

GPS (Global Positioning System) is a technology in navigation system that based on a satellite which comprising three basic interactions; satellites in space, earth monitoring stations and GPS receivers. This equipment is widely used in geological mapping to locate one's position, measuring the elevations, mapping lithology, save tracking and waypoint with the descriptions. The data from the GPS easily can be transferred using the cable to the receivers.

A geological hammer is a tool used by the geologist to collect samples depend on the hardness of the rocks. There are two types of geological hammer; pointed-tip hammer and chisel-tip rock hammer. Pointed-tip hammer which also known as "hard-rock hammer", is the hammer the often used when sampling the hard rocks, igneous rocks and metamorphic rocks. While the chisel-tip hammer, also known as "bricklayer's hammers" and "soft-rock hammer" is often used for sampling sedimentary rocks, soils and sediments.

Compass is an instrument used to determine direction during the fieldwork. It also can be used to measure the strike and dip of the bedding, trench and plunge of the joint, foliation at the field. Although, GPS is capable of doing all of these and much easier to use but sometimes the GPS can be malfunction as it using batteries or do not locate by the satellite in an area that heavily covers by the forest. There are two types of compass which are Brunton and Suunto.

A hand lens is an instrument used in making the first analysis of rocks samples at the field. First analysis of rock samples at the field includes the colour of the rock, texture, type of rock, mineral that can be identified, hardness and some physical properties such as foliation, inclusion, bedding, etc.

Sampling bag where the best use for a geological sample is made of canvas in fabric with sewn in tie tape and include with label tagging at the outside of the sample bag. However, the plastic sampling bag with the zip lock also can be used for geological samples. Measuring tape is also an important instrument for geological mapping for taking an actual measurement of the outcrop, thickness of the bedding, lithology and structures.

Digital camera or photograph also needed in geological mapping for clear visual of the outcrop or formation and also become evidence of some discovery. It also considers as primary data as it collected during the fieldwork. It can be a backup data if the raw data is damage. For each photograph in geological purpose, there need to make sure that a scale is used in each instance. The GPS reading also needs to take for each photograph taken. This kind of photograph is very useful as a reference in making the description during report writing. Hydrochloric acid (HCL) is usually used to determine limestone as it appears varies in colour but common misinterpret as granite. HCL is used to indicate the presence of calcite and carbonate minerals in the limestone as it reacts to the HCL and making "hisss" sound.

Geological field notebook and stationery are needed in recording all the observations in the field. Jot down the data in orderly and concise in a field notebook. Field notebook that hard cover, easy to bring and fit in the pocket is the most suitable notebook for mapping. The stationery such marker pen, ruler and pen or pencil is needed in recording data, sketching and labelling samples.

Laboratory Instruments:

- Polarizing Microscope
- X-ray Fluorescence (XRF) Machine

Software:

- ArcGis 10.2
- Corel Draw 2016
- Global Mapper 16
- Geo Rose
- Google Earth Pro
- GCDkit 6.0

3.3 Methods

3.3.1 Preliminary Studies

A preliminary study is the first step before it comes to the decision of the research topic or point of interest in the research study. The preliminary studies are very important as it gives an idea and overview of the chosen topic. Find the suitable sources of information related to the chosen topic such as articles, journals, books, websites and any inventory that related to the interest of study. From this pre-study, is helpful to narrow down the topic and make it more specific.

Then, after the location and the title have been decided, it is important to make a preliminary study about the geomorphology of the study area. From the base map that produced, it easier to study the type of landforms based on the elevation and identifies the drainage pattern, watershed and lineament. Referring to previously sources such as a geological map, stratigraphy, lithology, and type of land use that related to the study area, the prior estimation of site variability will be done. The awareness of site variability and accessibility is essential before initiate the mapping activity.

3.3.2 Fieldwork

The geological mapping or fieldwork becomes the crucial method in obtaining and collecting field data. Field data will cover all the aspects in the scope study which are geomorphology, stratigraphy, geological structures, paleontology, sedimentology and petrology. Fieldwork is also important in order to determine suitable locations for soil sampling. In the fieldwork, the essentials things to bring along is all the mapping equipment and applying all the safety precautions at the field. During fieldwork, several methods must perform to gain the best field data.

a) Traversing

Traversing is the method to establish a control network or path taken by the researcher during the fieldwork. It helps the researcher to allocate the current location on the map by marking in the GPS. During traversing, a suitable location for soil sampling will be marked.

b) Observation / Data Collection

Field observation data is very important as much data is needed through observation during the fieldwork. The data provided by observation such as rate of weathering, vegetation, size of the outcrop, features of geological structures, morphology and rock distribution. All the observation during the fieldwork must jot down in the notebook or documenting in any digital application.

c) Rock Sampling

During traversing, there will be an outcrop somewhere in the study area, and then the rock sample from the outcrop will be collected. The sample will be collected using a geological hammer in order to get a fresh sample. Then, the sample will be kept in the sampling bag with the details about the location, elevation and type of rock. The number of rock sample depends on the number and the type of outcrop present in the study area. This rock sample will be needed for petrographic analysis.

- **Rock sampling for specification**

For specification, the location of the lava is identified during field mapping with the aid of information from the literature reviews. There are only two types of lava found in the study area. Once the location is identified, the outcrop is observed carefully in terms of physical properties and formation before sampling activity is made. For lava andesite, there are 3 samples are taken according to the different physical properties observed at the field. For lava basalt, there are only two samples are collected according to the different formation where one sample is taken from the path of the lava flow and the other one is taken at the columnar joint.

3.3.3 Laboratory Work

Laboratory work for this research study is conducted at the laboratory at Universitas Padjajaran (UNPAD).

a) Sample Preparation

- **Thin section preparation**

The thin section is a 0.03 mm thick slices of rock that bonding on a glass slide with epoxy as shown in Figure 3.1. Epoxy is an adhesive that used to bond or attached the slices of sample to the glass and also to soak the sample with resin for maintaining its quality during the lapping and polishing step. Thin section slides typically 26 mm × 46 mm. However the larger size also can be produced. Another glass slide; cover slip is placed in the top that also attached to the rock sample with epoxy. Ideally, epoxy has an index of refraction of 1.54 (Hirsch, 2012; Intertronics Technical Bulletin,2006)

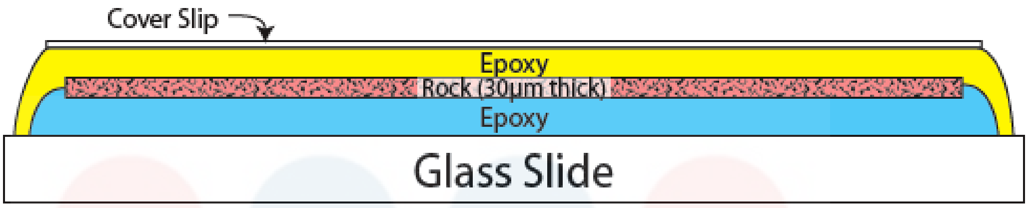


Figure 3.1: Thin section model (Source: www.davehirsch.com)

Thin section equipment:

Five main tools used in making thin section: 1) Slab saw 2) Trim saw 3) Grinder 4) Cut-off saw and 5) Lap wheels. A permanent marker also needed for labelling.

Procedure:

For the procedure in preparing the thin section, firstly is prepared the glass slide. Then, the glass slide is frosted using the grinder. The glass slide that will bond with the sample must be flat so that the thin section has a constant thickness. Note that if there is a reflection from the glass slide, it's not yet frosted well. Using a permanent marker, the region of the rock that will cut is marked by a line. After that, cut a slab from a rock sample along the line that is marked using a slab saw. The rock needs to cut twice to get two slabs. A slab is a flat piece of rock that is typically in a square or rectangular shape.

Next, cleaned the slab to remove any oil and grit that left from the slab saw the process and then, dried the samples with labelled the samples number on paper towel. It has reduced the size of the slab to the size that smaller than a thin section. This step is completed by using a trim saw. The slab that was being cut into a smaller size known as chip. In this step, the frosted side of the slide was attached to the side of the chip that being ground down by constant thickness of epoxy across the section. Epoxy is mixed with the hardener before attached to a glass slide. Let it to attach well and has not slid off the chip. The chip that attached to the glass slide mostly being cut off to get a thin slice. The chip was cut off using cut-off saw. Then, it is ground to have a constant thickness. The cover was added to protect the section from damage or contaminate. Make sure the section is clean before putting the cover slip. Clean up all the instruments that are used properly to avoid it from rusting.

- **XRF Preparation**

Five lava samples that selected according to the types and distinct physical characteristics are separated for the XRF analysis and prepared into pressed pellets. Pressed pallet is chosen in this research study as this type of sample preparation is more precise than pouring loose powder into a sample cup. Pressed pellet preparation is done as follows; firstly, the samples are crushed become small rock fragment using geological hammer. Then, the small fragments with the size about a few cm^2 are undergone grinding process. The samples will be grinding into a fine powder, and mixing it with a binding or grinding aid. The binding or grinding aid is commonly a mixture of cellulose wax which combines with the samples with proportion of 20% - 30% binder to sample. Lastly, pressing the mixture in the pellet between 20 and 30T to produce a homogeneous sample pellet.

3.3.4 Data Processing

Data processing involves in the produces multiple maps in this research study such as traverse, lithology, geomorphology, slope map and others map that represents data in the study area. The processing data is done by using ArcGIS software and the cross section in the geological map is done using Global Mapper and Corel Draw. For the specification part, the geochemical data provided from XRF analysis is being processed using GCDkit 6.0 software.

3.3.5 Data Analysis and Interpretation

For the data analysis and interpretation it is focused on geochemical data received after conducting XRF analysis. The geochemical data collected must be analysed and interpreted properly. The geochemical data should be listed first in Excel before load in the GCDkit 6.0 software. This software has various packages of diagrams that need to be select according to the rock types and objectives of the research study. The geochemical data which is major elements are plotted automatically by the software after the list of the data is loaded in the software. There is some diagram or graph that just can be drawn in the Excel such as the Harker diagram.

The interpretation of geochemical data is made based on behaviour of the data plotted in the selected diagrams. To get an accurate result, then a few diagrams are used to make a comparison or make a relationship between it.

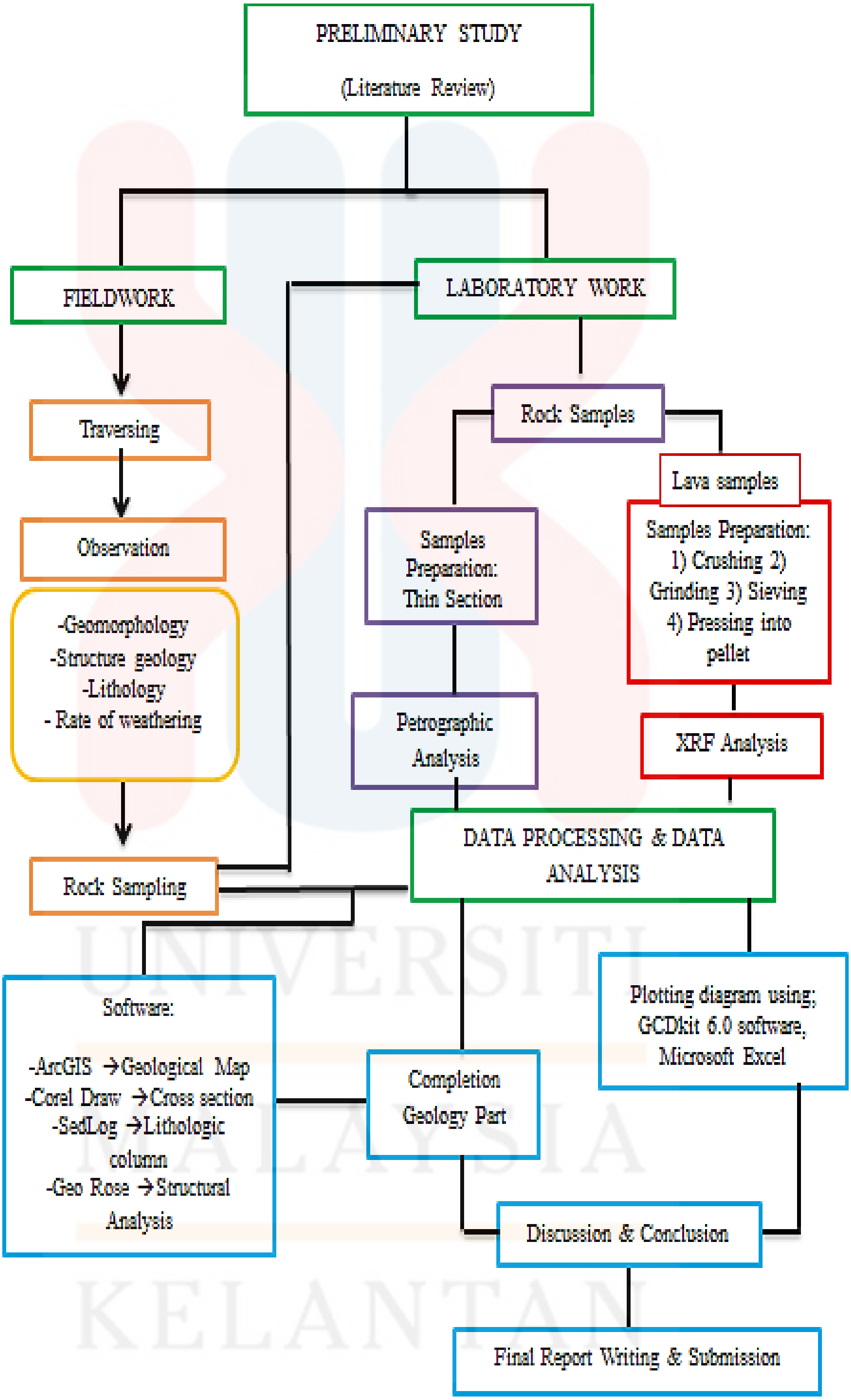


Figure 3.2: Flowchart of the research study

CHAPTER 4

GENERAL GEOLOGY

4.1 Introduction

This chapter will explain the geological criteria that encompassing the area of the study which consists of geomorphology, lithology, petrography analysis, stratigraphy unit, geological structure and the historical geology.

4.1.1 Accessibility

Lembang is one of the famous vacation spots in Bandung, thus the roads are extremely busy on the weekends and worsen during national day celebration. In the study area, there are only 2 main roads which are Jalan Raya Cibodas – Bukit Tunggul and Jalan Raya Maribaya that connected lies across the study area. There are many residential roads such as Jalan Dago Giri, Jalan Dago Pakar, Jalan Pakar Bar, Jalan Langensari Maribaya, Jalan Cicalung, Jalan Sukarasa and Jalan Nyampay that make the mapping area easy to access. However, there are also a few parts of the study area cannot be fully covered such as area of thick forest and a very steep sided river valley. There also numerous unpaved roads in this study area as it mostly covered by vegetation area.

4.1.2 Settlement

The northern part of the study area is mostly dominated with residential areas while at the southern part is moderately inhabited because the vegetation area mostly covers this part and also has a part of reserve forest as shown from satellite imagery in Figure 4.1. The residential area is more focused in northern part as it nearer to the Lembang city, Mount Tangkuban Parahu and other tourists' spots such as The Lodge Maribaya, Farm House, Floating Market and Taman Begonia. There are a few attraction spots in the southern part of the study area such as Taman Hutan Raya Ir. H. DJuanda, Puncak Bintang and Tebing Keraton.

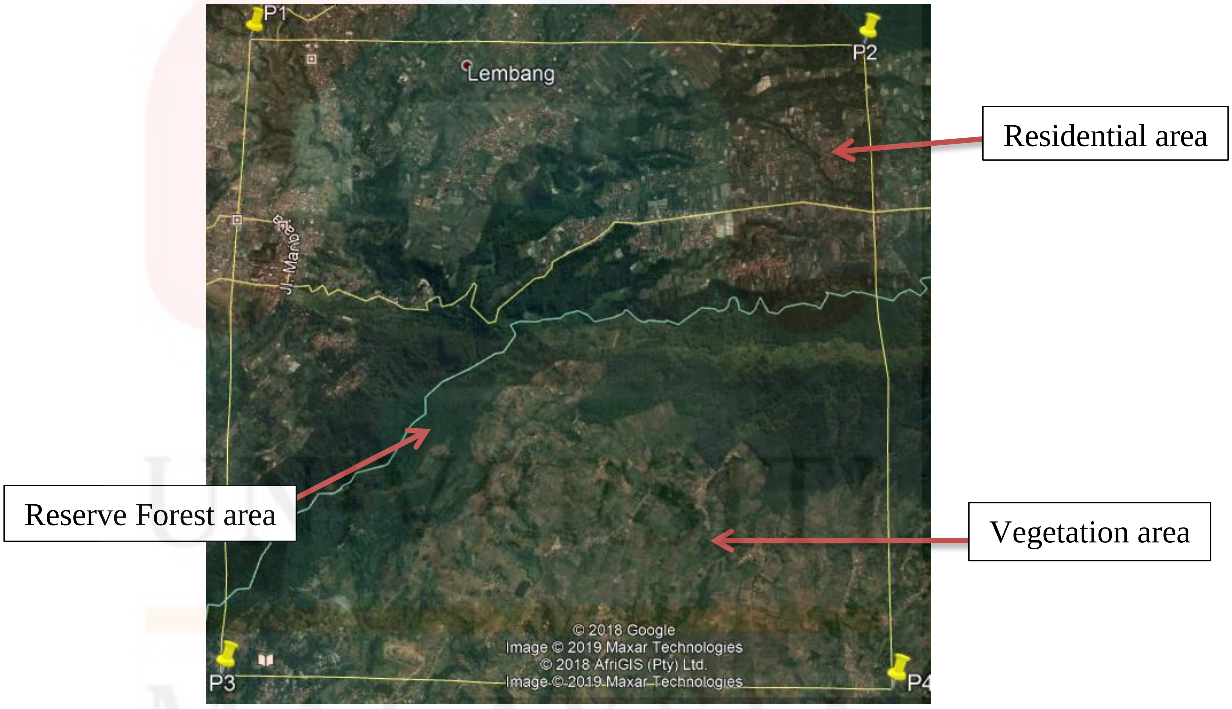


Figure 4.1: Satellite imagery of the study area

4.1.3 Forestry

Lembang is very well known with its agriculture activities for the great combination of the micro-climate and the unique characteristic of the volcanic soils that good in soil fertility. Example of the vegetation area is shown in Figure 4.2. The volcanic soils at the study area is directly from the various eruptions episodes that historically begins from the eruption of Mount Sunda, Mount Tangkuban Parahu, an actively volcano and also from nearby mountains as explained in the Geology Map of Bandung Quadrangle, Java by Silitonga, 1973 and Geologic Map of Tangkuban Parahu Volcano / Sunda Complex Volcano, West Java by Soetoyo and Hadisantono, 1992. Various crops that cultivated in the study area such as tomato, lemon, lettuce, cranberries, broccoli and also coffee trees. The climate at Bandung which is average annual temperature about 26.8 ^{o}C and even cooler in Lembang area as it is situated in the high lands makes it suitable for the pines trees to grow actively in the northeast part of the study area.

Figure 4.2: Vegetation area in Bukit Moko near Puncak Bintang

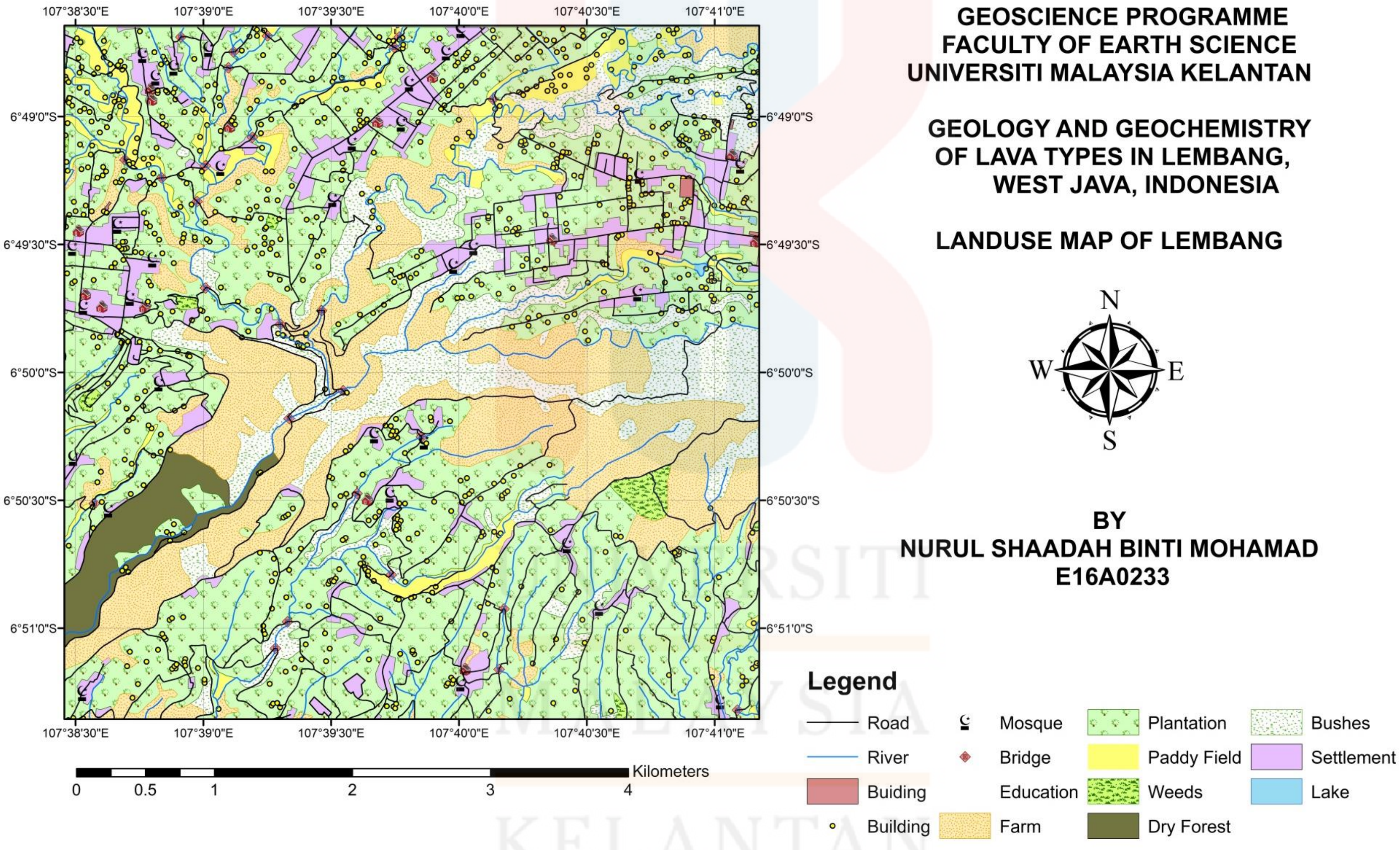


Figure 4.3: Land use map of Lembang.

4.1.4 Traverse and Observations

Traverse is a crucial activity in conducting geological mapping. Another activity that must include during traverse is observation. Observation is taken along the traverse and must take note with all the changes in the lithology, stratigraphy, geomorphology, rate of weathering and structural geology. Field observation is classified as primary data as it is taken directly from the sites and to support the written observations, the digital observation which is digital also being taken along the traverse.

Traverse is done by ride a motorcycle, hiking and walking. Sometimes traversing along the river is needed as no other option at a certain place. The geological mapping is done within a week which covered from north to the south and from the east to the west of the study area. Some areas could not be accessed due to thick forest and steep sided of rivers that become the challenges during the traversing. The traverse and observation map is shown in Figure 4.4. 5 distinctive mappable rock units being observed in the study area and rock samples are being taken for each. The geomorphology of the study area is taken at the Puncak Bintang and Tebing Keraton. The elevation of these geomorphology stations is range from 1300 m – 1500 m which is the highest point in the study area.

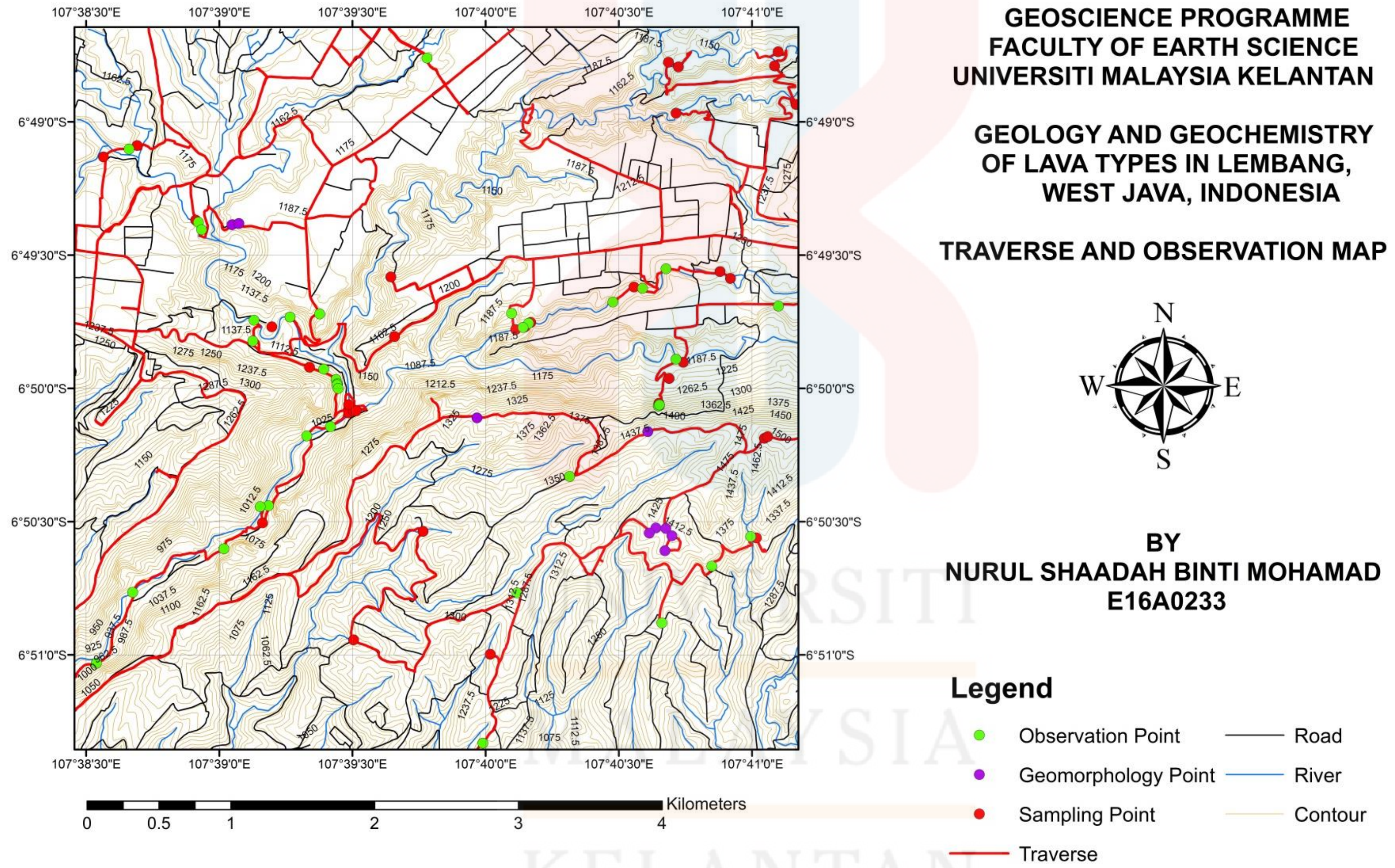


Figure 4.4: Traverse and observation map of Lembang

4.2 Geomorphology

Geomorphology is one of the important aspects in Geology which focusing on it geomorphologic process / morphogenesis, formations, types of landforms and it relatedness to the rock and mineral types in geomorphologic interpretations. The formation and the alteration of the Earth's surface are directly related and resulted from the geomorphologic process. Interactions of both physical and chemical between the Earth's surface and the natural forces which act upon it resulting in formation of various landforms. The processes are more concentrate on such natural environmental variables as the geomorphology changes occur on the regional scale. The natural environmental variables are such as the geology, climate, vegetation and base level.

The geomorphological processes are divided into two main processes which are terrestrial processes and extra–terrestrial processes. The terrestrial processes are then subdivided into other two processes; exogenetic process and endogenetic process. Exogenetic processes are the processes that take place on or close to the Earth's surface which involve the processes of weathering, wind, climate and water which occurred on a large scale and create relief. This process is causes slow movements such as erosional and depositional. Endogenetic processes are the processes whose origin is within the Earth in which create irregular and distinctive features of the Earth's relief such as mountain ranges, volcanoes, folds, faulting, oceanic basins and oceanic ridges and others more. This process causes sudden and rapid movements such as earthquakes and faulting.

According to Dam et al., 1996, the landforms that present today in the Bandung area are dominantly determined by tectonic subsidence, paroxysmal eruptions, volcanism-induced faulting/rifting, drainage pattern adaptations and intramontane lacustrine sedimentation. As the study area is located nearer to the eruption centre of Sunda-Tangkuban Perahu volcanic, there is a huge and visible E-W Lembang fault which formed as the results of volcano-tectonic faulting. The formation of this Lembang fault, then controlled the distributions of volcaniclastic sediments and become the reason for the changes of drainage system in Lembang area. A part of Lembang fault that lies across the study area becomes a border that separates the north and south area. The highest elevation in the study area is 1512.5 m and the lowest elevation is 912.5 m as shown in Figure 4.5. Geomorphology of the study area is observed from Puncak Bintang which located at the eastern part of study area and Tebing Keraton which located in the centre of the study area. Both of these locations are located on the Lembang fault line where their elevation of this is ranging from 1300 m – 1512.5 m which is the highest point in the study area.

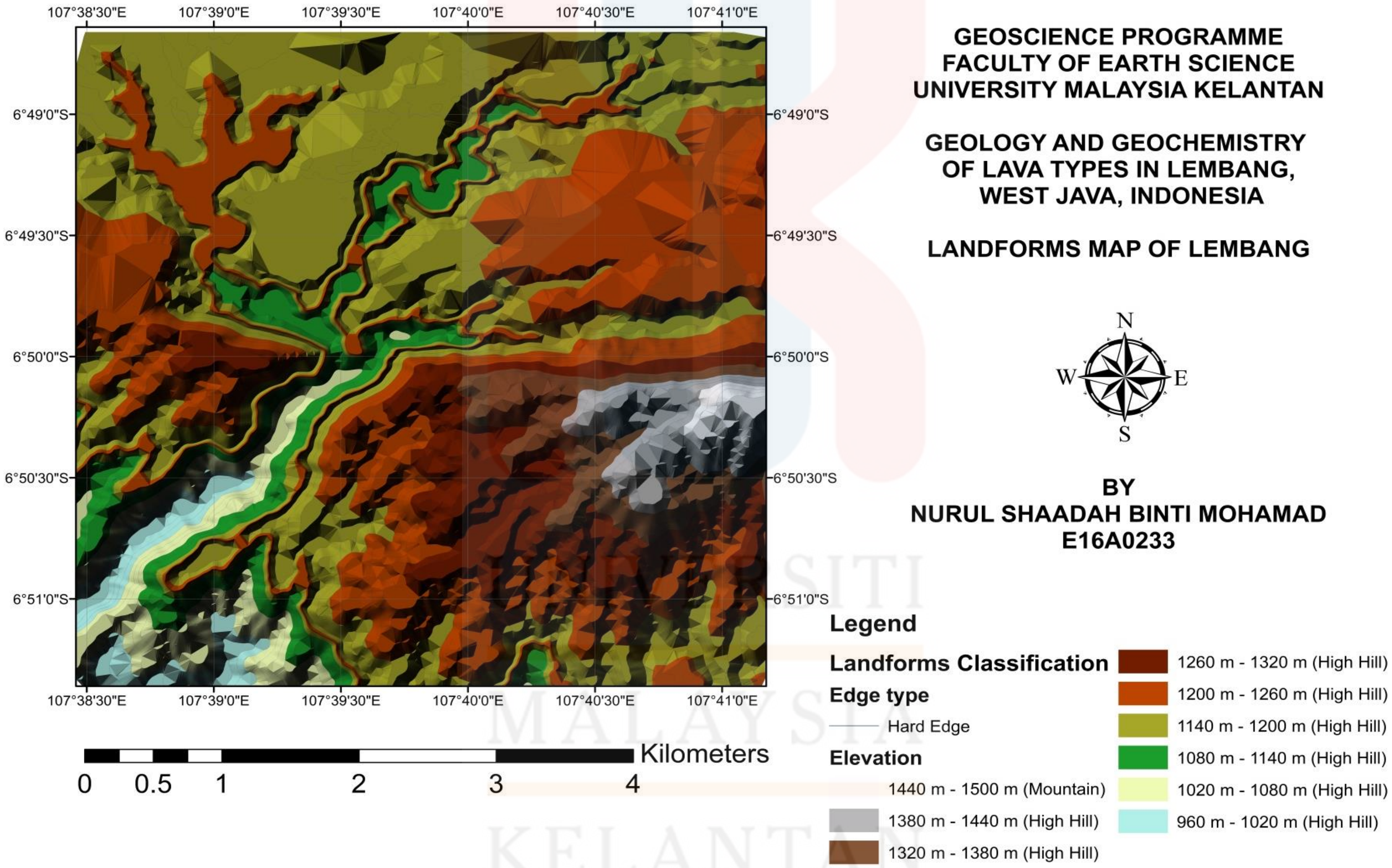


Figure 4.5: The landforms map of the study area

4.2.1 Geomorphologic Classification

Geomorphological classification in the study area has been determined and interpreted using geomorphologic classification by Van Zuidam, 1985. Several geomorphology aspects that need to be considered include:

a. Morphology is aspect that studies the relief in general.

   - Morphology - the features that cover the architecture of the earth's surface such as hill, valley, ridge, plains, mountains and alluvial fan.
   - Morphometry - the aspects that being measure quantitatively from a particular landform such as slope, relief, slope shape, rate of erosion, drainage pattern and elevation.
   - Morphography - can be classified as the area of the geomorphological extents.

b. Morphogenesis is the aspect that focused on the morphology process which is the process that controlled the formations and the developments of the landforms. In this study area, the morphogenesis is closely related to the structural geology, lithology and geological processes.

   - Active Morphostructure – is originating from the endogenetic processes in which related to uplifting, faulting and folding.
   - Passive Morphostructure – is the landform that classify based on lithology and rock structure.
   - Morphodynamic – is formed from exogenetic processes that related to the forces from water, glacier, climate and volcanism.

Table 4.1: Relation between absolute elevations with morphography (Van Zuidam, 1985).

Absolute Elevation	Morphography
< 50 meter	Lowland
50 meter – 100 meter	Medium lowland
100 meter – 200 meter	Low hill
200 meter – 500 meter	Medium hill
500 meter – 1500 meter	High hill
1500 meter – 3000 meter	Mountain
>3000 meter	High mountain

Table 4.2: Relation between relief unit, slope and topographic differences (Van Zuidam,1985)

Relief Unit	Slope (%)	Topographic differences (m)
Flat – almost flat	0 - 2	< 5
Undulating / gentle slope	2 -7	5 – 50
Undulating – rolling / sloping	7 - 15	25 - 75
Rolling-hilly / moderately steep	15 - 30	75 - 200
Hilly – steeply dissected / steep	30 - 70	200 - 500
Steep mountains	70 -140	500 -1000
Very steep mountains	>140	>1000

Table 4.3: Geomorphologic classification according to Van Zuidam (1985)

Code	Geomorphology Unit
S	Structural
V	Volcanic
D	Denudational
M	Marine/beach
F	Fluvial
G	Glacial
K	Karst
A	Aeolian

4.2.2 Geomorphologic Classification of Study Area

Morphology of the study area is related to volcanism as it is located to the vicinity of eruptions centre. Volcanism is the morphology that has interaction between endogenetic and exogenetic processes in which formed irregular and distinctive morphology. Volcano morphology does not only depend on its eruption products and types but also controlled by its activity rate, erosion and also the structural factors that applied upon it. Based on geomorphological observations in the field and correlation to the topography of the study area the geomorphologic classification of the study area had been interpreted with the aid of geomorphologic classification by Van Zuidam (1985).

According to the geomorphological aspects that been discuss above, there are five geomorphology units in the study area.

- Structural geomorphology unit (Fault scarp) – S2
- Structural geomorphology unit (Subsequence valley) – S18
- Volcanic geomorphology unit (Upper volcanic slope) – V3
- Volcanic geomorphology unit (Lower volcanic slope) – V5
- Volcanic geomorphology unit (Lava flow) – V11

Table 4.4: Geomorphologic classification of the study area.

Geomorphology Aspects \ Geomorphology Units			Fault Scarp S2	Subsequence Valley S18	Upper Volcanic Slopes V3	Lower Volcanic Slopes V5	Lava Flow V11
Morphology	Morphography		Escarpment wall	Valley	High hill, mountain	Plain	Valley
	Morphometry	Slope	Very steep (30–140%)	Steep (30-70%)	Steep (15–70%)	Gentle (0-7%)	Flat - Gentle (2-7%)
		Drainage Pattern	Rectangular	Parallel	Parallel	Rectangular	Parallel
Morphogenesis	Morphostructure Active		Volcano-tectonic	Volcano-tectonic	Volcano-tectonic	Volcanism	Volcanism
	Morphostructure Passive		High resistance Lithology unit - Andesite	Medium-low resistance Lithology unit – Volcanic breccia, basalt	Low resistance Lithology unit – Volcanic breccia	Low – medium resistance Lithology unit- Volcanic breccia, tuff	Medium resistance Lithology unit – Basalt
	Morphodynamic		Rock fall, weathering	Erosion, weathering	Erosion, weathering	Erosion, weathering	Erosion, weathering

4.2.2.1 Geomorphology Unit Structural (Fault Scarp) – S2

This geomorphology unit formed as the result of the volcano-tectonic activity of Sunda-Tangkuban Parahu volcanic. This fault scarp or Lembang fault was believed been initiated during 105 kyr B.P which triggered by the catastrophic event, the collapse of Sunda caldera. Lembang fault is both characterized as normal fault as suggested (Van Bemmelen, 1949) and more recent studies (Daryono et al., 2018; Afnimar et al., 2015; Madrinovella et al., 2013) claimed as sinistral strike-slip fault. This geomorphology unit has a very steep relief with slope 30 – 140% and the elevation of this morphography is ranging from 1300 – 1500 m which covers the area of Puncak Bintang, Tebing Keraton and Cikapundung. This type of landform generally has a rectangular drainage pattern which is the valley laterally linear due to fault movement. The lithology of this fault scarp is andesite to basaltic andesite and has high resistance to weathering.

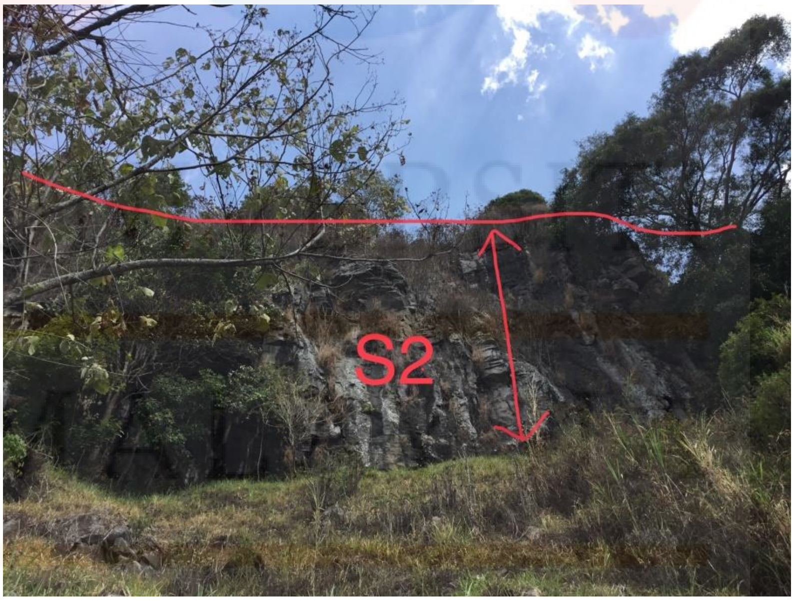


Figure 4.6: The fault scarp of Lembang fault.

Figure 4.7: The fault scarp from the panorama view.

4.2.2.2 Structural Geomorphology Unit (Subsequence valley) – S18

The subsequence valley is the geomorphology unit that controlled by dynamic geological structure which active fault according to classification by Morisawa (1985). A subsequent valley formed as they shifted from original consequent valley and then follows the paths that determined by the weak rocks belts. This type of valley follows the strike of the beds, Figure 4.8. This landform formed as a result of the formation of Lembang fault. According to Dam et al,. 1996, after the formation of Lembang fault, it resulting in initiation of drainage system and it also controlled the distribution of volcaniclastic sediments. This Lembang fault is classified as sinistral strike-slip with the evidence of major stream offset at Cikapundung River as shown in Figure 4.9. The drainage pattern in this morphology usually characterized by parallel to rectangular drainage pattern as both controlled by movement of active fault, in this study area, the valley at the Cikapundung river classified as parallel as it portrayed a linear valley. The lithology is volcanic breccia and basalt that found along the valley. The volcanic breccia is very low resistance to weathering while basalt is medium resistance to weathering. The erosion is commonly occurs at volcanic breccia.

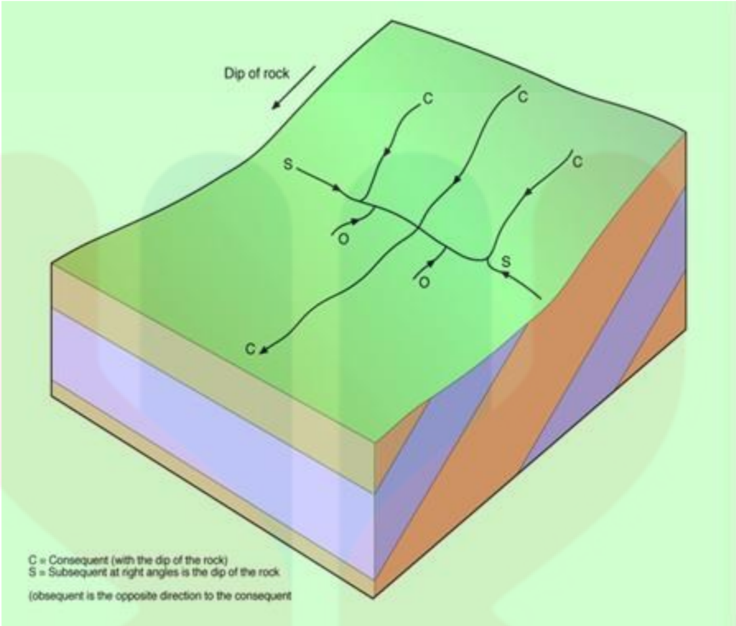


Figure 4.8: Valley model.

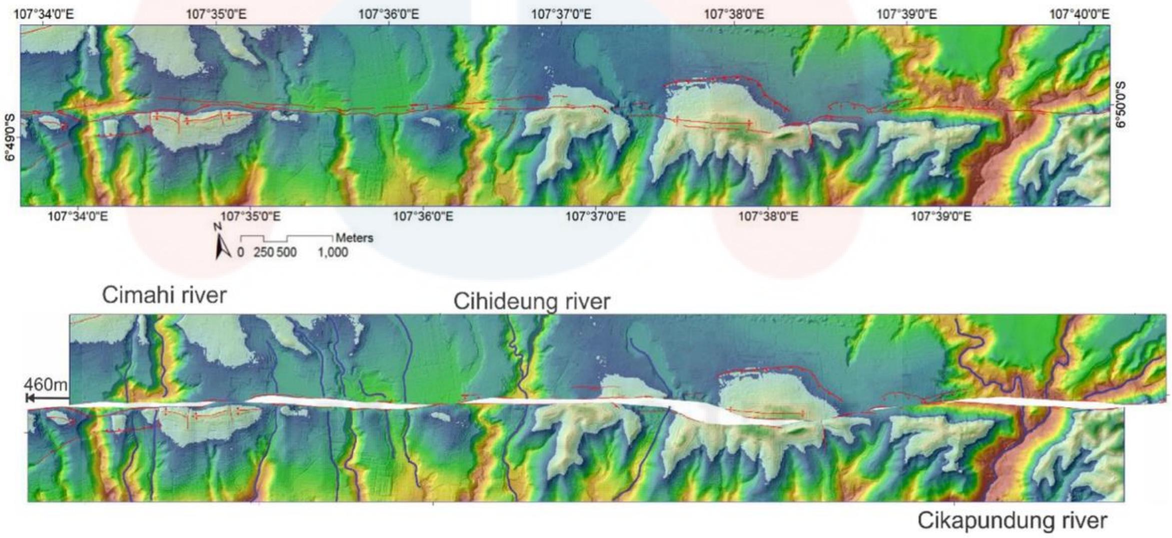


Figure 4.9: Mismatch of major stream offsets (Daryono et al.,2018)

The first figure above shows the current geomorphology of at the Cikapundung, Cihideung and Cimahi rivers which showing the stream offsets. While the second figure shows the conditions when a sinistral strike-slip fault is shifted back to initial positions. The sinistral movement is being measured about 460 m (Daryono et al,. 2018).

4.2.2.3 Volcanic Geomorphology Unit (Upper Volcanic Slopes) – V3

This landform is classified as upper volcanic slopes because of the deposition of volcaniclastic sediments in the steep slopes. The elevation of this morphology is ranging from 950 m – 1500 m which indicates high hill and mountainous. The slope in this landform is from 15 – 70% which considers as steep slopes. This landforms covers the southern part of the study area which bordered by visible escarpment wall of Lembang fault. The differences of elevation and slopes compared to the lower volcanic slopes are obviously controlled by the faulting of the Lembang fault. The drainage pattern is parallel and the lithology is volcanic breccia which is highly weathered and undergoes erosion. This lithology is very suitable for agriculture as mostly this landform is covered by vegetation.

4.2.2.4 Volcanic Geomorphology Unit (Lower Volcanic Slopes) – V5

This lower volcanic slope shows the plain morphography in the high elevation which is between 1080 m – 1260 m with the slopes of 0 – 7%. This plain morphography is known as a wide and flat Lembang basin. This flat Lembang basin is consisted of young alluvial and Quaternary volcanic products where located along the adjacent of the southern flank of the active Tangkuban Parahu volcano (Daryono et al., 2018; Marjiyono et al., 2008; Dam et al., 1996; Silitonga, 1973; Tjia, 1968; Van Bemmelen, 1949). The drainage pattern is rectangular as it associated with Lembang fault. The lithologies are volcanic breccia and tuff, and the weathering and erosion also took place as their resistances are medium to low. This morphography is mostly covered by residential and vegetation.

Figure 4.10: The flat plain landform at lower volcanic slope.

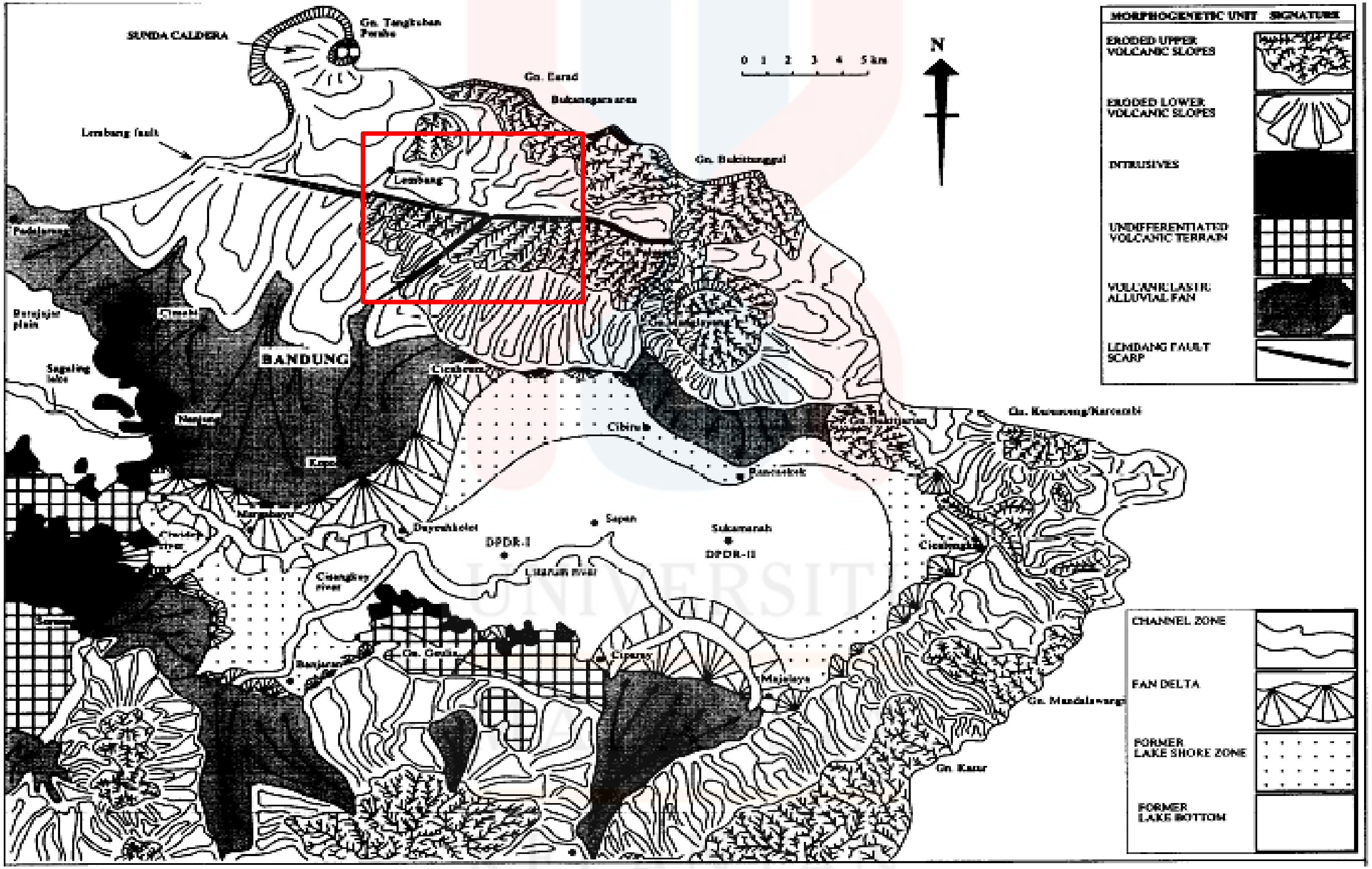


Figure 4.11: Geomorphological map of Bandung (Dam et al., 1996)

4.2.2.5 Volcanic Geomorphology Unit (Lava Flow) – V11

The morphostructure of this unit is of course originated by volcanism as lava is the magma that flows on earth's surface. This geomorphology unit has been observed at the Cikapundung gorges. The slope is ranging from 2 - 7% that indicates the flat to gentle landform and the elevation is between 960 m – 1080 m. The drainage pattern is parallel and the lava flow is basalt lava flow that infilled the valley. It has medium resistance in which the erosion and weathering are also occurred but not very intensely.

Figure 4.12: The lava flow at Cikapundung River.

4.2.3 Slope Classification

Table 4.5: Relationship between slope and process, characteristics and landforms condition, Van Zuidam (1985)

Slope	Process, Characteristics and Landform Condition
0^o- 2^o (0 -2 %)	Flat to almost flat, no large erosion, soil in this landform can be cultivated easily in dry condition
2^o – 4^o (2 – 7 %)	Have a gentle slope, landslide may occurs in the low velocity, weathering and erosion occurs.
4^o – 8^o (7 – 15 %)	Undulating landform to slightly steep, landslide occur in low velocity. Erosion prone area.
8^o – 16^o (15 – 30 %)	Moderately steep to steep, prone to landslide, surface erosion and channel erosion.
16^o – 35^o (30 – 70 %)	Hilly – steeply dissected, erosion and steady movement of surface soil (soil creep). Erosion and landslide prone.
35^o – 55^o (70 – 140%)	Steep mountains, usually outcrop are found and erosion prone.
>55^o (>140%)	Very steep mountains, outcrop exposed in the surface, prone to rock fall.

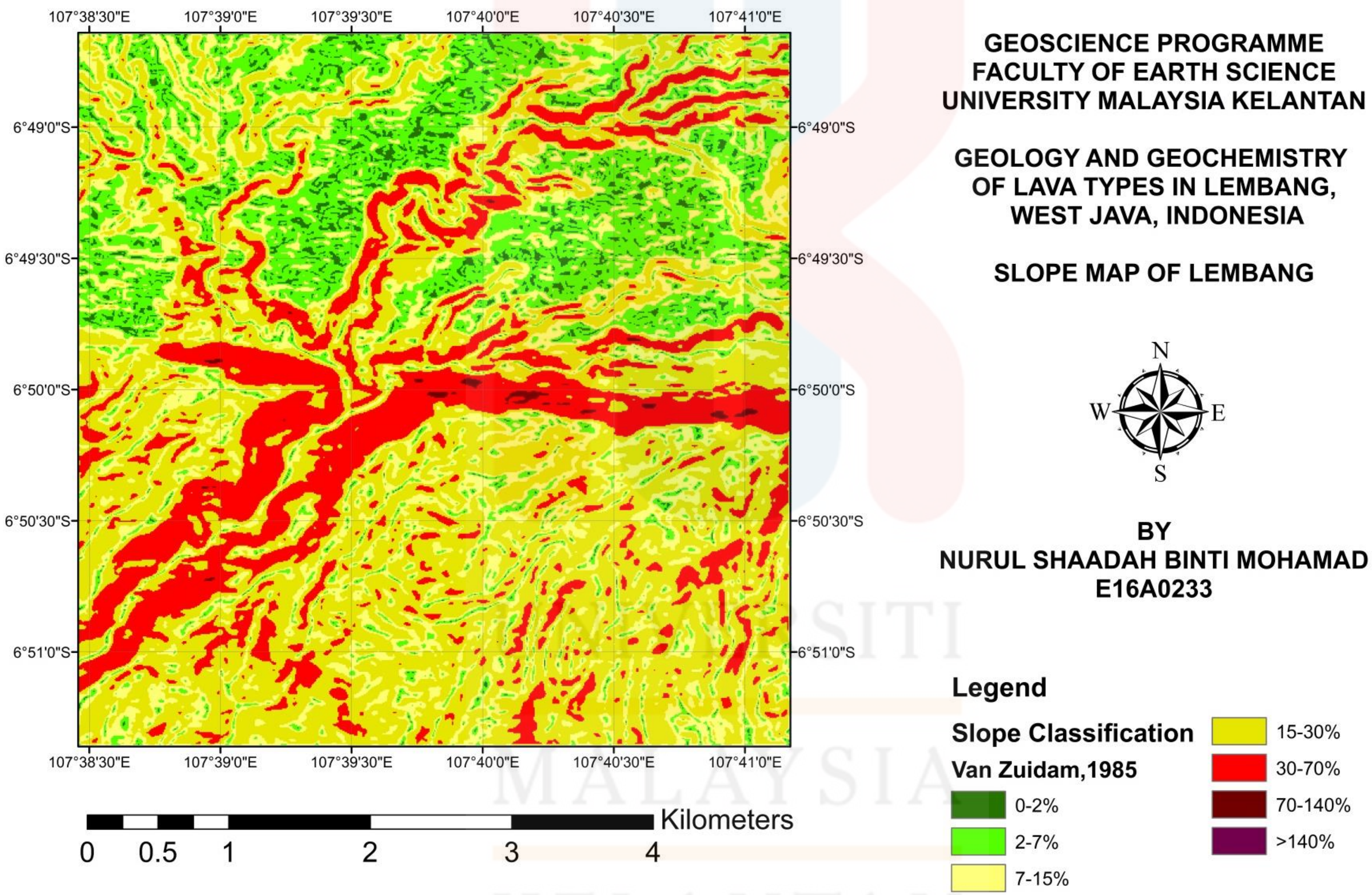


Figure 4.13: The slope map of the study area

4.2.4 Drainage Pattern

The drainage pattern is the pattern posed by the streams, rivers and lakes in a drainage basin. The drainage pattern is closely related to the lithology unit, structural geology, erosion and its historical geology. The development of the drainage system on the earth's surface in regional scale is controlled by slopes, the types and thickness of the lithology layer, structural geology, types and vegetation intervals, and also climate. Referring to the classification of the drainage pattern by Van Zuidam (1985) and the structural controlled valley by Morisawa (1985), the drainage pattern of the study area is classified as two main patterns which are parallel and rectangular drainage patterns.

4.2.4.1 Parallel Drainage Pattern

This drainage pattern usually indicates the streams at the structural geomorphology unit and have controlled by the normal or reverse or strike- slip faults. It also indicates the uniform or nearly uniform topographic slopes which the slope between steep to moderately steep. This drainage pattern usually found in the linear hilly landform. The modification of this drainage pattern commonly occurs between dendritic with parallel or trellis drainage patterns.

4.2.4.2 Rectangular Drainage Pattern

The rectangular drainage pattern is sometimes called as rectangular dendritic or angular dendritic or sub dendritic. This pattern is the modified version of dendritic pattern. It also has controlled by the structural geology which is faulting or jointing of the underlying bedrock. This drainage pattern characterized by abrupt, close to 90 degree, changes in streams direction and the stream juncture is distinctively obtuse or acute angle.

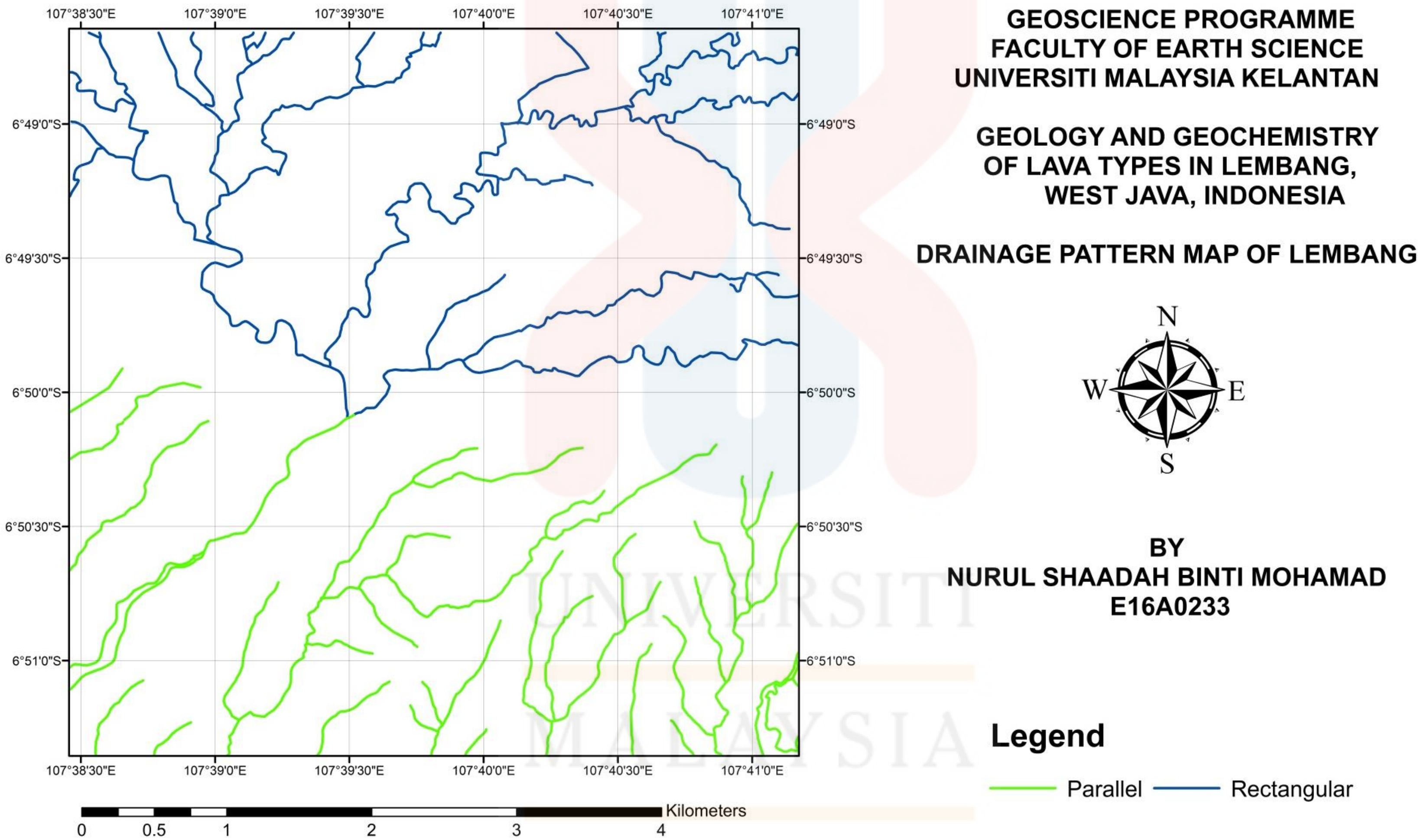


Figure 4.14: Drainage pattern map of Lembang

4.2.5 Weathering

Weathering is the process of decomposition or disintegration of the geological elements. It is the process that includes any physical or chemical modification of Earth material's characteristics and properties. Weathering is one of the important aspects that need to be considered in geomorphological and geological hazard analysis. The weathering and erosion processes are enhanced by the forces such as water, wind and glacier, these forces known as geomorphological agents. There are three types of weathering; physical, chemical and biological weathering, but the first two are commonly found in the field.

Weathering processes are controlled by the climatic condition, rainfall, temperature variations and humidity. As Bandung has a tropical climate with high hills to mountainous elevation and the rainfall is classified as average, it can lead to the physical weathering and chemical weathering. The chemical weathering that occurs in the study area which is more intense and leads to the decomposition of rocks and mineralogical changes. In the study area, the volcanic breccia in the southern part undergoes extremely high rate of weathering as it is already decomposed into volcanic soil, Figure 4.15. The soil with reddish in colour is resulting from the oxidation of tuff. Figure 4.16 shows the andesite weathered found in the south of the study area. The andesite of the escarpment wall of Lembang fault also shows some physical weathering and biological weathering. The weathering process also makes the light colour of andesite become blackish in the area of the water flow. As the slopes of the fault scrap are very steep, it more prone to mass wasting such rock fall, Figure 4.17.

The resistance of the Earth materials is measures by the resistivity of the existing minerals towards the erosive factors, which is by describes it hardness, chemical activity and cohesion. If the mineral shows the great hardness, it will less reactivity and produced more cohesion of a mineral, the probability it to erode is lowered. There are some minerals that more prone to chemical weathering which is the minerals that in the top of Bowen reaction series such as olivine, pyroxene and amphibole.

Figure 4.15: The vegetation area is set up on the volcanic soil.

Figure 4.16: Highly weathered of andesite fragment.

Figure 4.17: Rock fall from the fault scarp.

4.3 Lithostratigraphy

4.3.1 Stratigraphy

Stratigraphy is the geological study that is focusing on the sequence, relationship and morphogenetic of the various types of rocks that describes the age of the rock strata and the chronology of the events. Stratigraphy of the particular area is being interpreted according to its principles. There are several principles such as principle of superposition, original horizontality, fossil succession, cross-cutting relationship, law of inclusion and lateral continuity. For this study area, as the lithology is composed of Quaternary products, it is not classified as the rock formation and the deposition process is still ongoing. The stratigraphy of the study area is described based on the volcano stratigraphic units as the deposition of volcaniclastic at the study area is based on the episodes of the eruptions and its products.

4.3.1.1 Volcano Stratigraphic Unit

According to the Geological Map of Tangkuban Parahu Volcano/ Sunda Complex Volcano by Soetoyo and R.D. Hadisantono (1992), the volcano stratigraphic of the study area is correlates as below. The volcano stratigraphic unit of the study area can divide into four units which indicates four differences in volcanic activities as shown in Table 4.6;

1. S1 – Lava Sunda Unit
2. Sap – Sunda Pyroclastic Flow Deposits
3. Tjp 1 – Tangkuban Parahu Pyroclastic Fall
4. T1 – Tangkuban Parahu Lava 1

Table 4.6: Correlation of map unit focus on study area, Soetoyo and R.D. Hadisantono (1992)

AGE	Sunda Volcano		Tangkuban Parahu Volcano		Activity Periods
QUATERNARY	Central Eruption				
	Lava Flows	Pyroclastic Flows	Pyroclastic Fall	Lava Flows	
			Tjp 1	T1	The birth of the Tangkuban Parahu volcano
		Sap			Catastrophic Eruption of Pre Sunda Volcano
	S1				

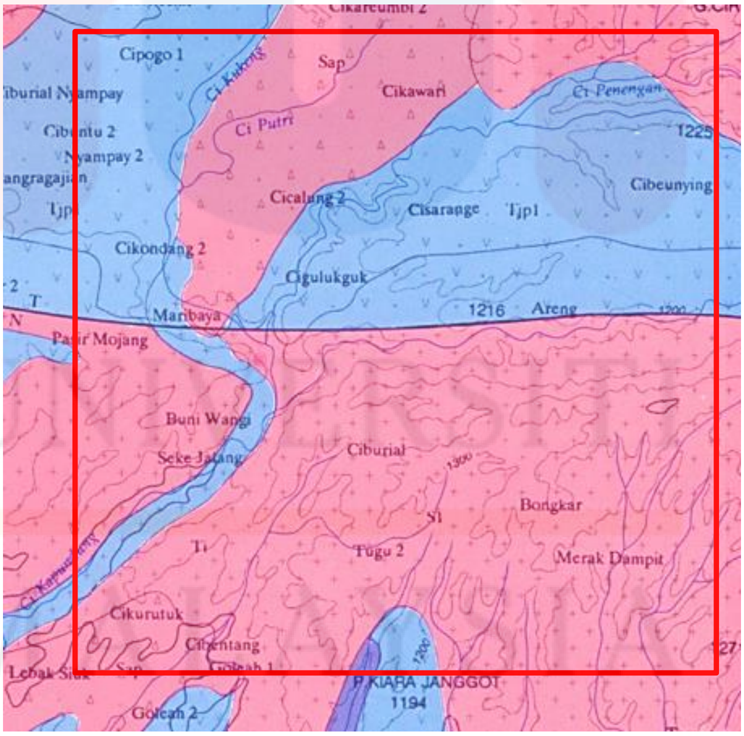


Figure 4.18: Overlay of the study area with Geologic Map of Tangkuban Parahu Volcano / Sunda Complex Volcano

4.3.1.2 Stratigraphic Unit based on Regional Map

Table 4.7: Correlation Map Units focus on the study area, Silitonga (1973).

AGE	Eruption Products	Units based on Geological Map of The Bandung Quadrangle (Silitonga,1973)
QUATERNARY	Young volcanic products	Qyd – Sandy Tuff
		Qyl - Lava
		Qyt – Pumiceous Tuff
	Old volcanic products	Qvu – Undifferentiated of Old Volcanic Products

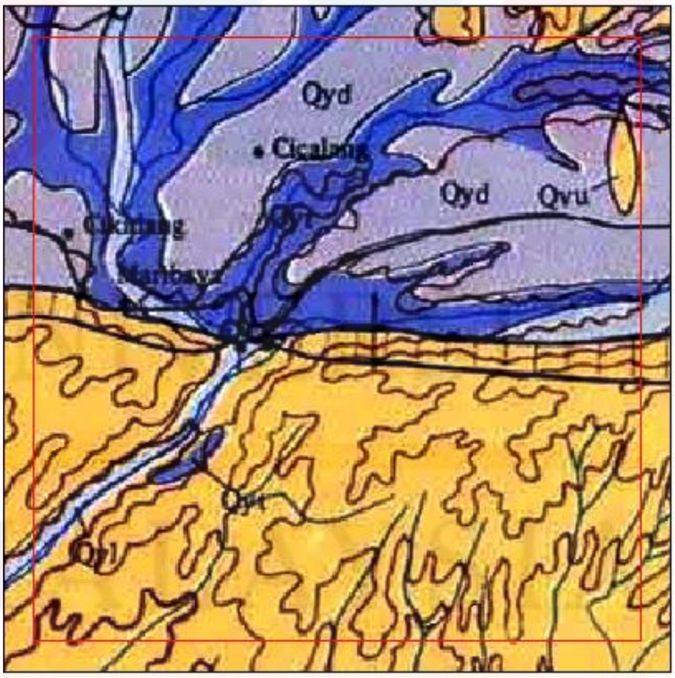


Figure 4.19: Overlay of the study area with regional map

Table 4.8: Relationship between rock unit of study area with regional map and their correlation.

AGE			ROCK UNIT	REGIONAL MAP (Silitonga, 1973)
Era	Period	Epoch		
Cenozoic	Quaternary	Holocene	Sandy Tuff	Qyd – Sandy tuff
			Basaltic Lava	Qyl - Lava
			Young volcanic breccia	Qyt – Pumiceous Tuff
			Andesite Lava	Qvu – Undifferentiated Old volcanic products
			Old volcanic breccia	

	ROCK UNIT	DESCRIPTION
CORRELATION	Sandy tuff	Light brown weathered and greyish white for fresh, poorly sorted. Presence of lapilli and lava.
	Qyd-Sandy tuff	Deposition of brown tuffaceous sands with coarse hornblende crystals, reddish weathered lava, lapilli and breccia from Mt.Dano and Mt. Tangkuban Parahu.
	Basaltic lava	Dark grey in colour, colour index melanocratic, aphanitic texture, inequigranular mineral size and hypocrystalline crystallinity due to the presence of vesicles.
	Qyl-Lava	Lava flow from young volcano overlay the volcanic breccia.
	Young volcanic breccia	Poorly sorted, dominant of tuff as matrix and fragment are andesite and scoria.
	Qyt-Pumiceous tuff	Found in tuffaceous sand, lapilli, scoria lava, bombs and basaltic andesite fragment from Mt Tangkuban Parahu and Mt. Tampomas.
	Old volcanic breccia	Matrix consists of tuff, fragment is agglomerate of andesite. Tuff which undergone intense weathering altered into reddish brown soil. Andesite fragment is greyish black in colour, porphyritic texture, inequigranular minerals, holocrystalline crystallinity.
	Qvu-Undifferentiated old volcanic products	Repeatedly interlayered of volcanic breccia, lahar and lava.

4.3.2 Lithology Units Description

This part will going to discuss details about the lithology in the study area which includes the description of the minerals presence in the sampled rocks. However, due to several problems arose in producing thin sections; some of the thin sections of a few lithologies cannot be produced. So that, some of the lithologies will be described by correlating it station and megascopic descriptions with the previous research (Nur Najihah, 2018) that as her study area also covered the same lithology this study area as referring to the regional map. The area of study by Nur Najihah, 2018 and the current study area have been overly with regional map, Figure 4.20.

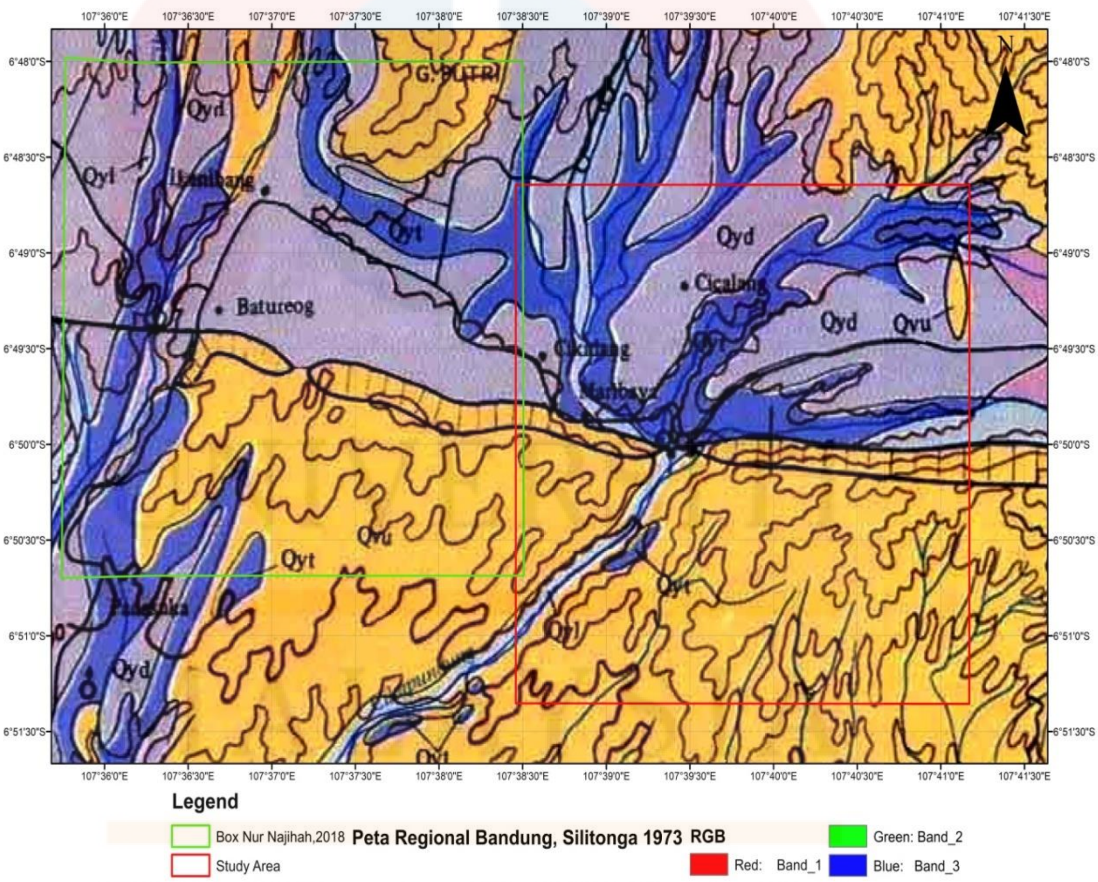


Figure 4.20: Overlaying two study areas with regional map.

4.3.2.1 Andesite

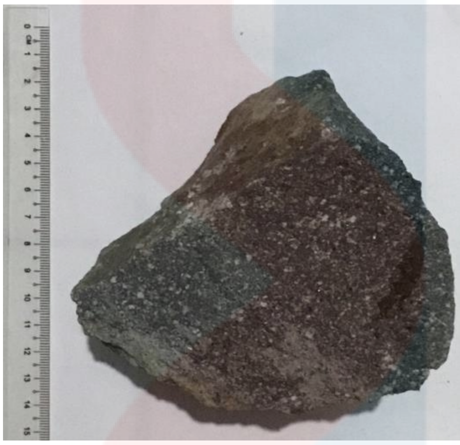
This andesite rock unit is present as dike intrusion which formed as wall of a fault scarp of Lembang fault. This fault scarp is located in the south of Mount Tangkuban Parahu. It extends from the East to the West of the study area. As it exposed as the escarpment wall, the slope is very steep, Figure 4.21. According to Sunardi & Koesoemadinata,1997), the age of this intrusive andesitic rock is around 0.51 Ma.

Figure 4.21: Andesite outcrop exposed at Maribaya.

Figure 4.22: Andesite outcrop, close up view.

The appearance of andesite outcrop at the field show light grey to dark in colour as shown in Figure 4.22. The outcrop appeared in dark colour due to the weathering process while the fresh andesite rocks show greyish dark as represents by coded samples of NS_LF1, NS_LF2 and NS_RLF in Table 4.9. Although the rocks are sampled in the same location but they show different physical properties.

Table 4.9: Descriptions of Andesite samples

Andesite Sample	Description
 **Figure 4.23:** NS_LF1 sample	Locality: At Lembang fault Outcrop: Exposed as a wall of fault scrap Colour: Medium greyish black Texture: Porphyritic Grain size: Medium to coarse grain Rate of weathering: low to medium
 **Figure 4.24:** NS_LF2 sample	Locality: At Lembang fault Outcrop: Exposed as a wall of fault scrap Colour: Medium greyish black Texture: Porphyritic with small vesicles Grain size: Medium to coarse grain Rate of weathering: low to medium
 **Figure 4.25:** NS_RLF sample	Locality: At Lembang fault Outcrop: At the river nearby to Lembang fault Colour: Dark grey Texture: Porphyritic Grain size: Fine to medium grain Rate of weathering: low to medium

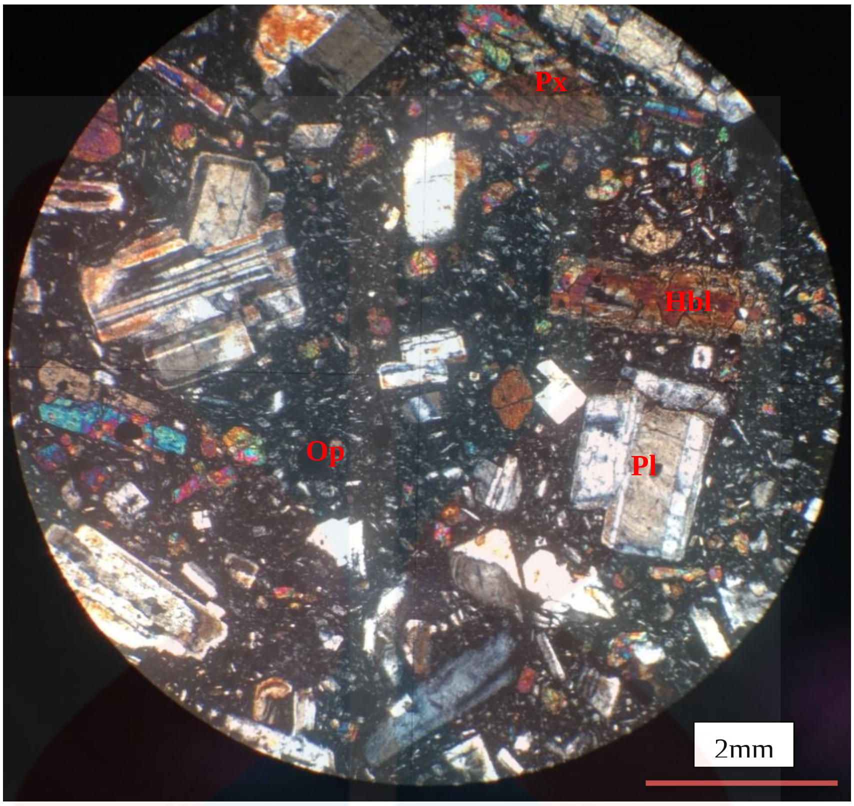


Figure 4.26: Andesite (NS_LF1) under XPL

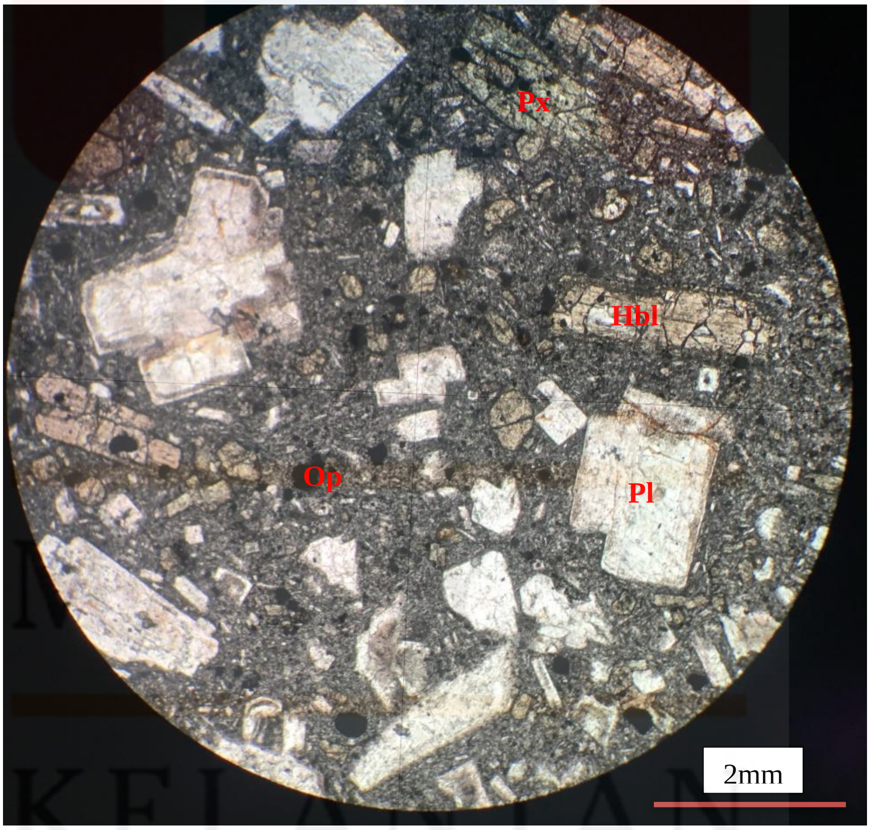


Figure 4.27: Andesite (NS_LF1) under PPL

Table 4.10: Mineralogy descriptions of NS_LF1

Sample Code : NS_LF1 Location : Lembang Fault		Rock Name : *Andesite*
Rock Type : Igneous Rock		
Type of Structure : Porphyritic		
Microscopic : Inteference colour greyish brown, crystallinity holocrystalline, granularity porphyritic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene, hornblende and opaque minerals.		
Mineralogy Description		
Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	55	Colourless, shaped subhedral to anhedral, cleavage (1-direction), low relief, weak pleochroism, twinning albite, measuring 0.5 – 2 mm.
Pyroxene (Px)	30	Pale green to brownish, shaped subhedral to anhedral, have cleavage 1 and 2 direction, low relief, weak pleochroism.
Hornblende (Hb)	10	Yellowish / pale brown, shaped subhedral to anhedral, low relief, weak pleochroism
Opaque (Op)	5	Black, euhedral, high relief
Rock Name : *Andesite* (Travis,1955)		

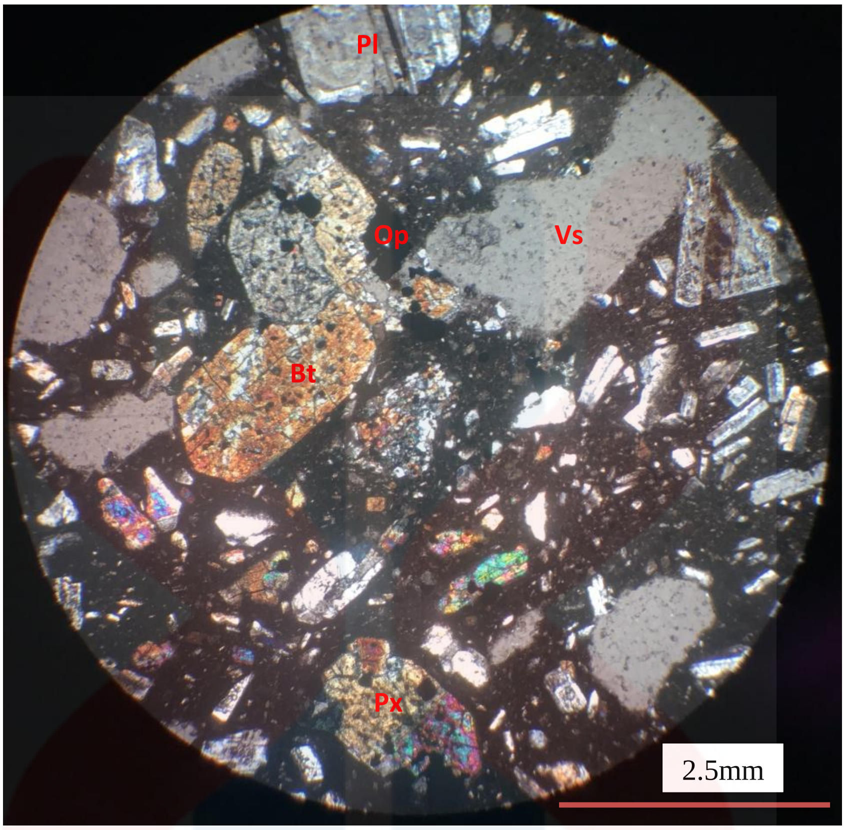


Figure 4.28: Andesite (NS_LF2) under XPL

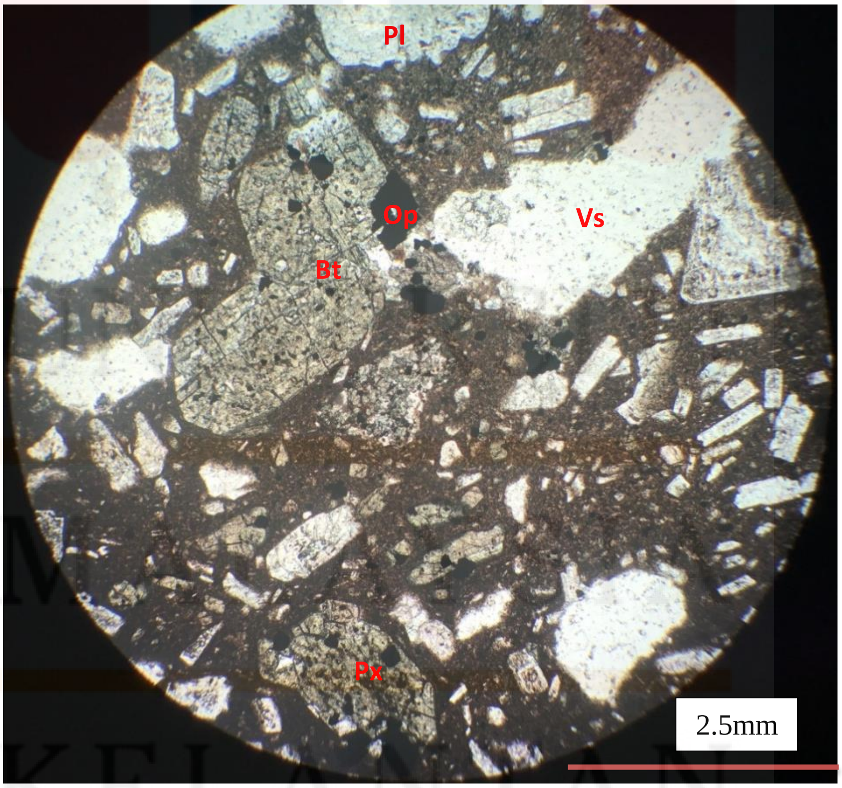


Figure 4.29: Andesite (NS_LF2) under PPL

Table 4.11: Mineralogy description of NS_LF2

Sample Code : NS_LF2 Location : Lembang Fault Rock Name : *Andesite*		
Rock Type : Igneous Rock		
Type of Structure : Porphyritic		
Microscopic : Inteference colour greyish brown, crystallinity hipocrystalline, granularity porphyritic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene, biotite, opaque mineral. Have vesicles.		
Mineralogy Description		
Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	55	Colourless, shaped subhedral to anhedral, cleavage 1-direction, low relief, weak pleochroism, simple twinning
Pyroxene (Px)	25	Clinopyroxene, pale green or light brown, shaped subhedral, as phenocryst and groundmass, weak pleochroism, cleavage 1 and 2 direction.
Biotite (Bt)	20	Pale brown, yellowish brown under XPL, shaped subhedral, no cleavage, have inclusion, texture bird's eye
Opaque (Op)	5	Black, euhedral, inclusion mineral.
Rock Name : *Andesite* (Travis, 1955)		

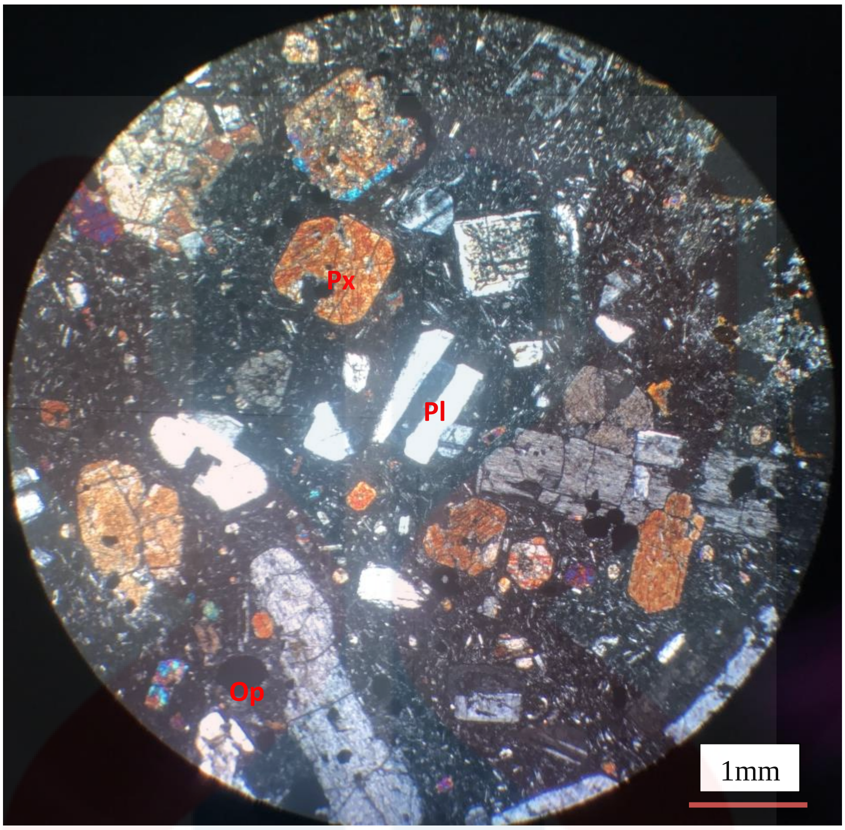


Figure 4.30: Andesite (NS_RLF) under XPL

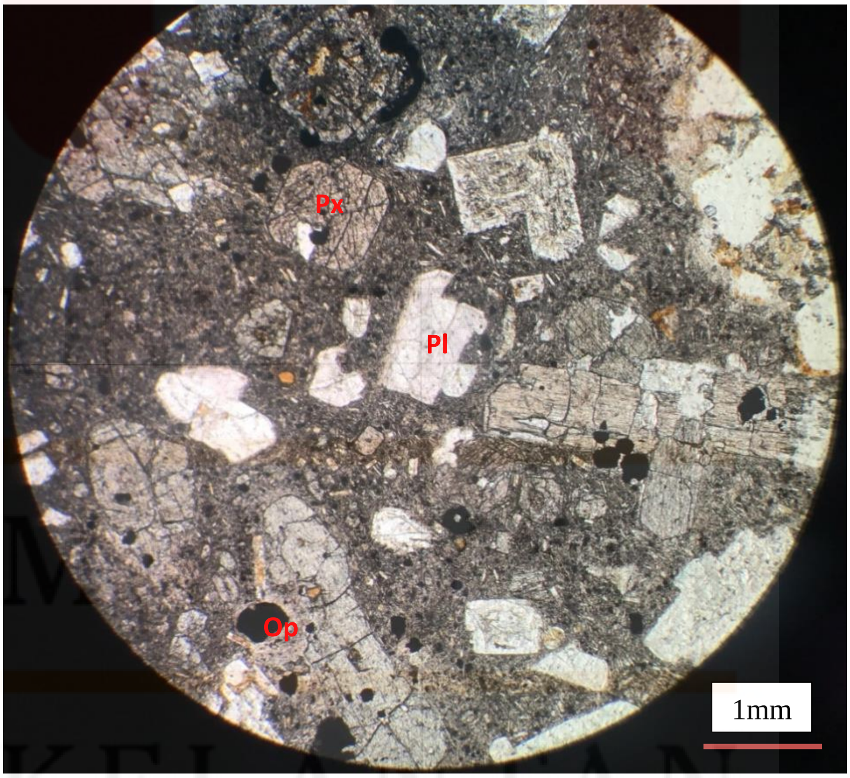


Figure 4.31: Andesite (NS_RLF) under PPL

Table 4.12: Mineralogy description of NS_RLF

Sample Code : NS_RLF

Location : Lembang Fault   Rock Name : *Andesite*

Rock Type : Igneous Rock

Type of Structure : Fine grain

Microscopic :

Inteference colour greyish brown, crystallinity holocrystalline, granularity porphyritic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene, biotite, opaque mineral.

Mineralogy Description

Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	50	Colourless, shaped subhedral to anhedral, cleavage 1 direction, simple twinning, weak pleochroism, low relief.
Pyroxene(Px)	20	Bright brown, Shaped euhedral to subhedral, orthorhombic and elongate, 1 and 2 direction of cleavage, low relief, weak pleochroism
Opaque (Op)	30	As minerals inclusion in pyroxene, shaped anhedral and dark in color.

Rock Name : *Andesite* (Travis,1955)

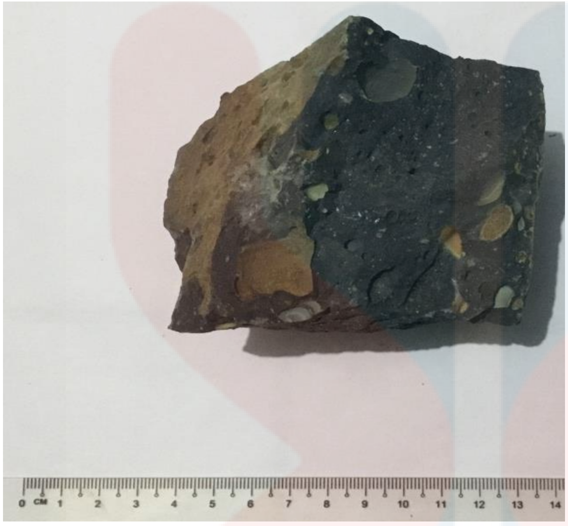
4.3.2.2 Basaltic Lava

This basaltic lava found along the Cikapundung River which located in Taman Hutan Raya Ir. H. Djuanda, Figure 4.32. This lava is believed as a young volcanic product of Mount Tangkuban Parahu. This lava flow is rich with vesicles.

Figure 4.32: Lava flow at Cikapundung River

The exposed surfaces of the lava are weathered with brown in colour and black or dark grey appearance for fresh rocks. As the lava flow follows the river, the weathering and erosion processes are continuously take place by the action of water. The sample NS_Lava is taken at here while sample NS_CJ is taken at the columnar joint which not far from the lava flows. Based on microscopic, both of the basalt samples are showing common petrographic features with needle-like groundmass but NS_Lava showed the Poikilitic texture in which indicate the growth of pyroxene and plagioclase minerals.

Table 4.13: Description of Basalt samples

Basalt Samples	Description
 **Figure 4.33:** NS_Lava sample	Locality: Taman Hutan Raya Outcrop: Lava flow along the river Colour: Dark grey Texture: Aphanitic with large vesicles Rate of weathering: Low to medium
 **Figure 4.34:** NS_CJ sample	Locality: Taman Hutan Raya Outcrop: Columnar joint Colour: Dark grey Texture: Fine grain will small vesicles. Rate of weathering: Low to medium

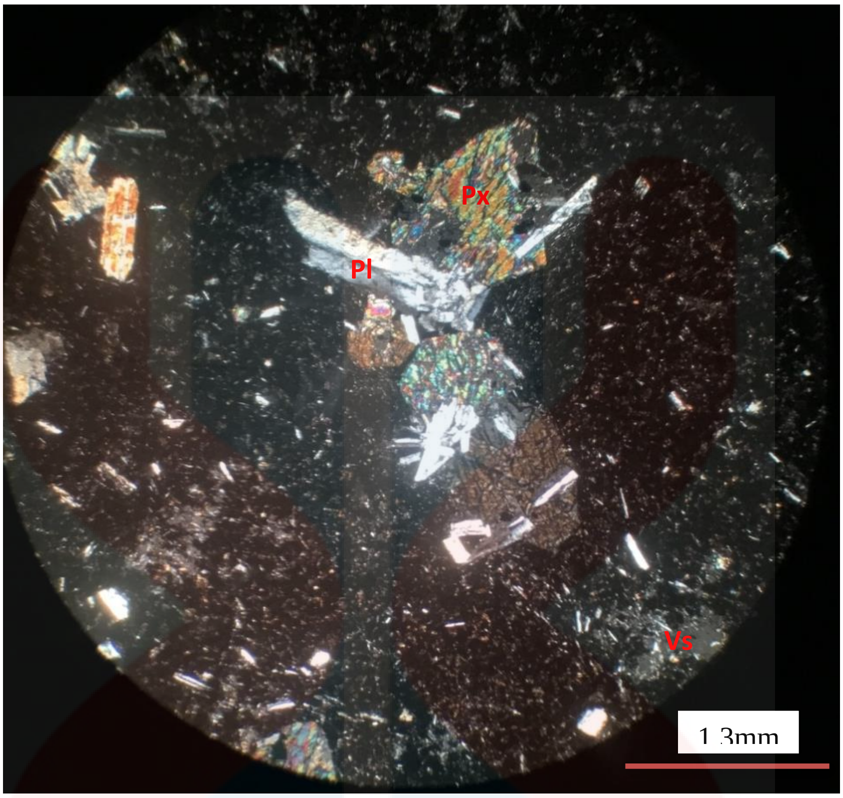


Figure 4.35: Basalt (NS_Lava) under XPL

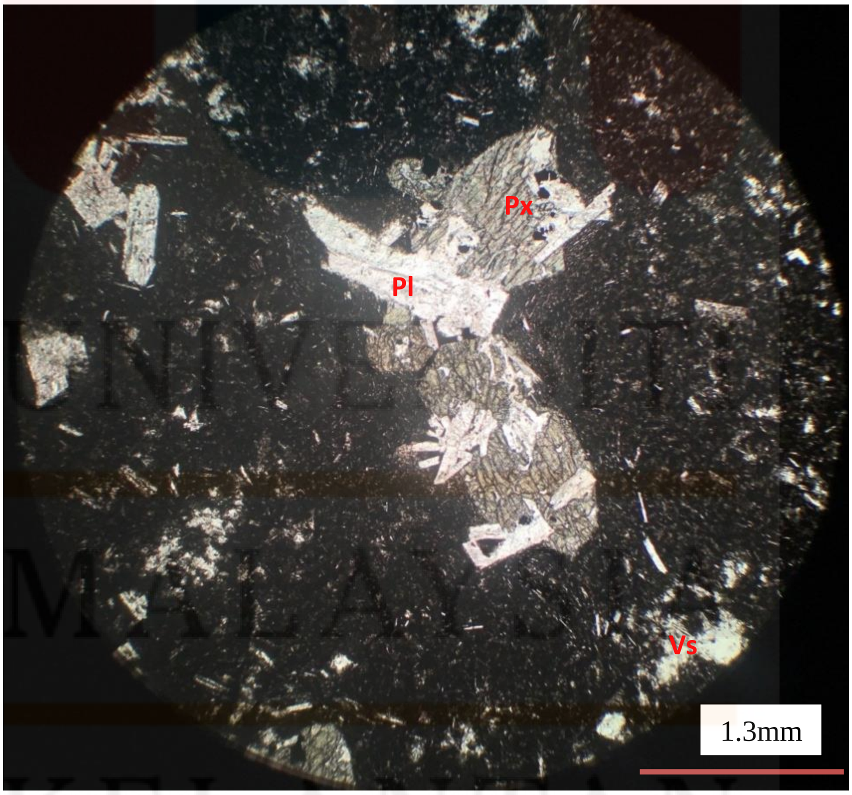


Figure 4.36: Basalt (NS_Lava) under PPL

Table 4.14: Mineralogy description of NS_Lava

Sample Code : NS_Lava Location : Cikapundung River, Tahura Rock Name : *Basalt*		
Rock Type : Igneous Rock		
Type of Structure : Vesicular		
Microscopic : Inteference colour greyish dark, crystallinity hipocrystalline, granularity poikilitic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene. Have vesicles.		
Mineralogy Description		
Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	50	Colourless, shaped subhedral to anhedral, low relief and weak pleochroism. As phenocryst and groundmass. Needle-like shaped groundmass. Plagioclase penetrate into pyroxene
Pyroxene (Px)	20	Pale green to pale brown, shaped subhedral, low relief, weak pleochroism, cleavage 1 and 2 direction
Opaque (Op)	30	As groundmass, dark, usually magnetite
Rock Name : *Basalt* (Travis,1955)		

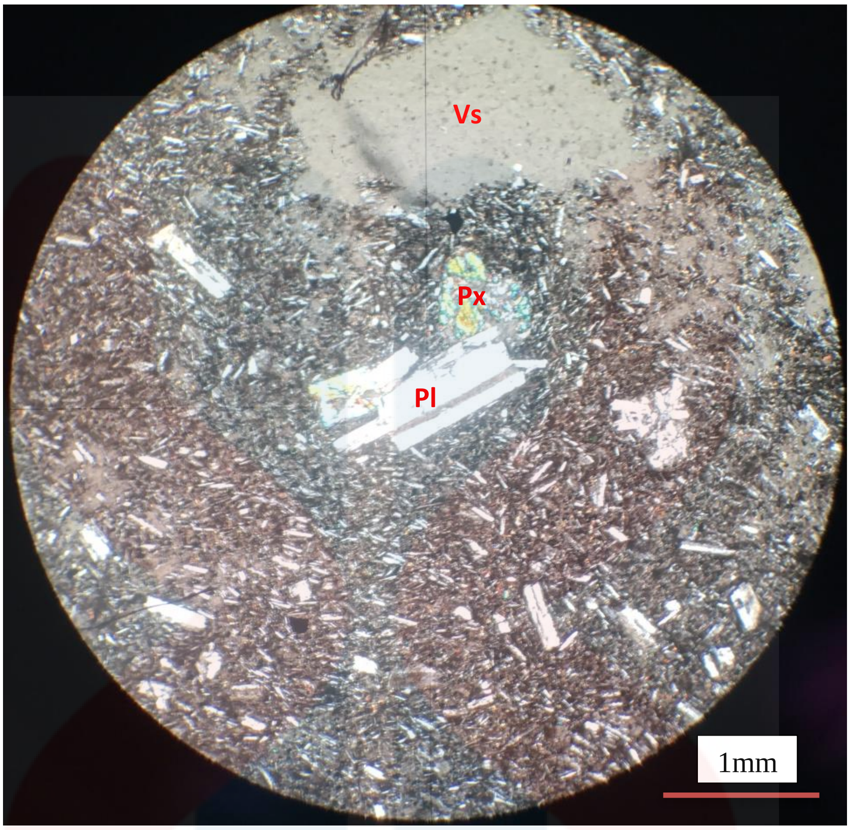


Figure 4.37: Basalt (NS_CJ) under XPL

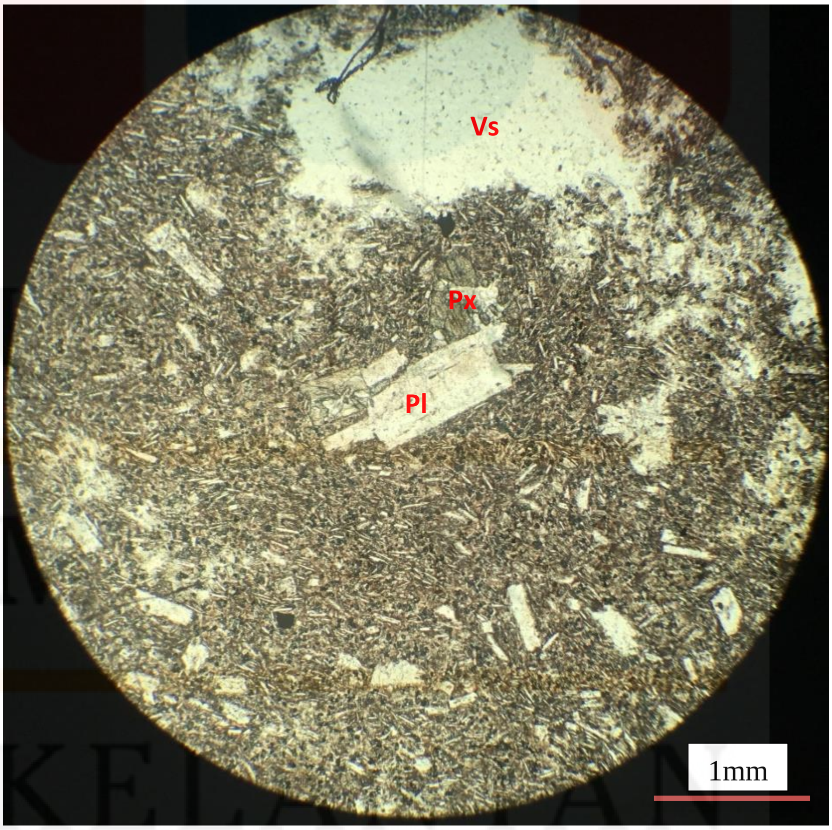


Figure 4.38: Basalt (NS_CJ) under PPL

Table 4.15: Mineralogy description of NS_CJ

Sample Code : NS_CJ Lokasi : Cikapundung River,Tahura Rock Name : *Basalt*		
Rock Type : Igneous Rock		
Type of Structure : Vesicular		
Microscopic : Inteference colour greyish dark, crystallinity hipocrystalline, granularity porphyritic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene. Have vesicles.		
Mineralogy Description		
Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	55	Colorless, shaped subhedral, low relief, weak pleochroism, cleavage 1 direction. As phenocryst and groundmass. Needle-like shaped
Pyroxene (Px)	20	Pale green, shaped subhedral to anhedral, low relief, weak pleochroism.
Opaque (Op)	25	As groundmass.
Rock Name : *Basalt* (Travis,1955)		

4.3.2.3 Old Volcanic Breccia

Volcanic breccia is the oldest lithology unit in the study area as stated in the regional map (Silitonga, 1973). It covered almost 50% of the study area and exposed at the southern part of the study area. Known as breccia as it consists of clast or fragment and matrix. This volcanic breccia is may classified as agglomerate due to accumulation of massive blocks of rock which bombs, rounded to angular clasts in a matrix of ash.

Figure 4.39: Volcanic breccia outcrop

The clasts or the fragments of this volcanic breccia are dominantly consist of andesite and the matrix is tuff. The outcrop is clearly exposed and easy to identify along the track in Taman Hutan Raya Ir D.Juanda especially towards Dago Pakar. As the Taman Hutan Raya is the reserve forest, the outcrop is still intact until today and the alteration only comes from the natural factors of weathering. The outcrop is covered with some shrubs as the tuff is easily to weathered and altered become soil. In consequence, the sample of the matrix cannot be provided. The sample of andesite fragment is taken but it also shows some weathering in the thin section. Although this lithology covered the large area, the significance feature of the outcrops is already diminished maybe because of the intense weathering and rock removals for setting up the vegetation area as present today, Figure 4.40. The reddish brown soil is the weathering products of the tuff and andesite.

Figure 4.40: Reddish brown soil that resulting from weathered tuff, andesite and other pyroclastic materials.

Generally, the fragment of volcanic breccia is about 75% of the andesite matrix and 25% of matrix tuff. From the megascopic petrology, the andesite fragment is greyish black in colour, medium to coarse grain and porphyritic texture. Under thin section, the index colour of the rock is leucocratic. The texture is porphyritic granularity with dominant plagioclase feldspar thus, the mineral shape is inequigranular. The mineral shape is hypidiomorph as the shape is mostly subhedral and the degree of crystallinity is holocrystalline.

Figure 4.41: Volcanic breccia fragments

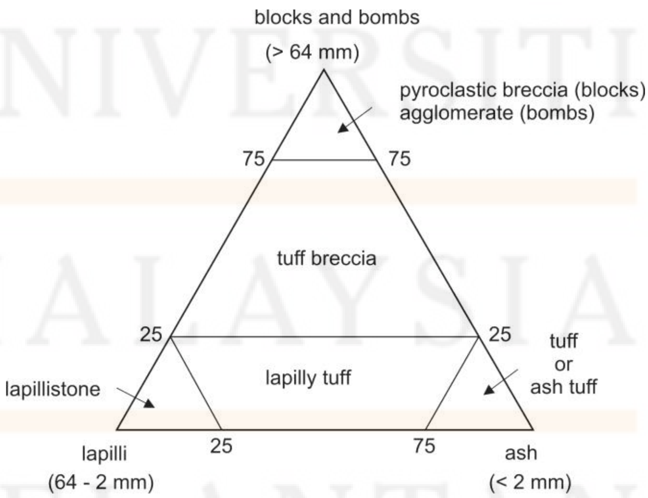


Figure 4.42: Classification of pyroclastic fall according to Fisher (1996).

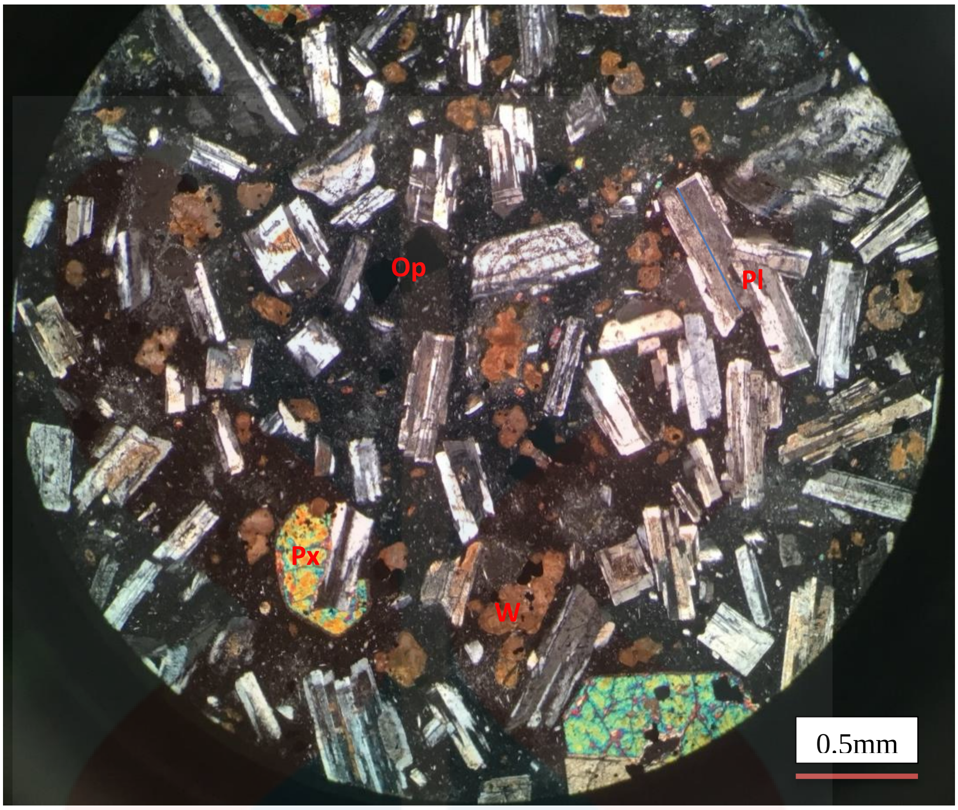


Figure 4.43: Andesite fragment under XPL

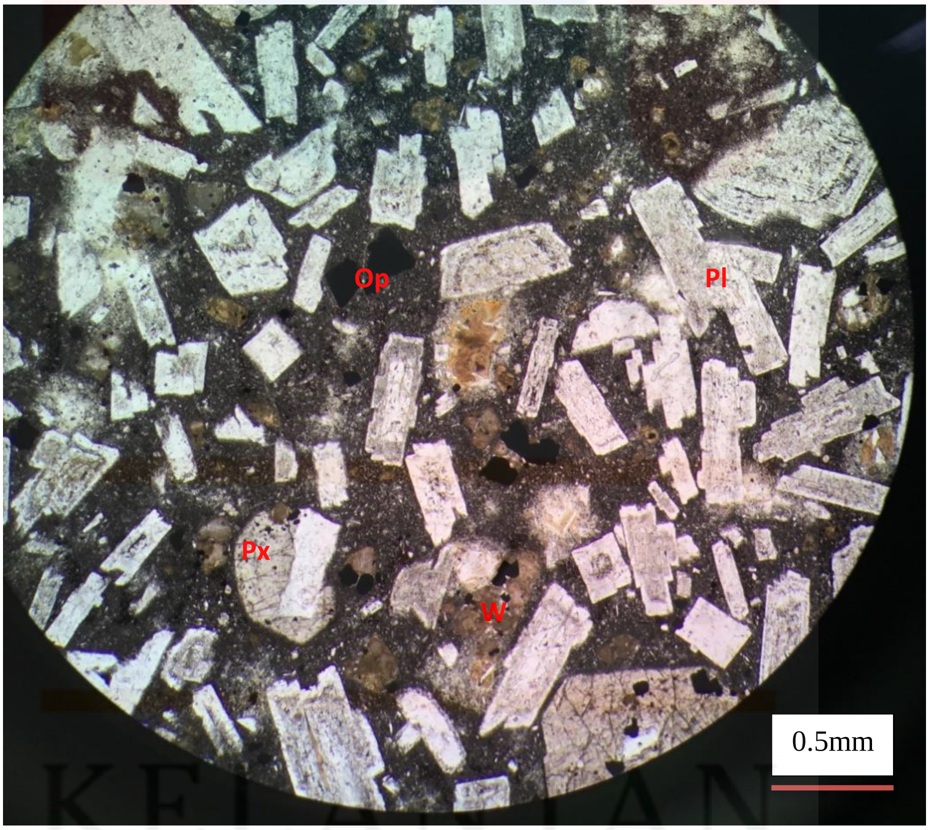


Figure 4.44: Andesite fragment under PPL

Table 4.16: Mineralogy description of NS_RM2

Sample Code : NS_RM2 Location : Taman Hutan Raya Rock Name : *Andesite* (*Agglomerate)*		
Rock Type : Pyroclastic Fall		
Type of Structure : Porphyritic		
Microscopic : Inteference colour light, crystallinity holocrystalline, granularity porphyritic, mineral shaped *subhedral-anhedral*, mineral size inequigranular, mineral composition plagioclase, pyroxene, and opaque mineral.		
Mineralogy Description		
Composition of Minerals	*Amount* (%)	*Description of Optical Mineralogy*
Plagioclase (Pl)	60	Colorless, shaped subhedral to anhedral, low relief, and weak pleochroism, simple twinning, have zoning. As phenocryst and groundmass.
Pyroxene (Px)	10	Pale brown, mostly subhedral, low relief, weak pleochroism, cleavage in 1 and2 direction.
Opaque (Op)	5	As phenocryst and groundmass, dark and euhedral shaped.
Rock Name : *Andesite* (Fisher,1966)		

4.3.2.4 Young Volcanic Breccia

This rock unit is deposited along the river which covered at the north east area. As it deposited along the river, the alteration and weathering is intensely occurred. Young volcanic breccia is composed of tuff matrix and andesite and scoria fragments. The andesite fragments are variable in size from 2 cm up to 10 cm. The weathered young volcanic breccias are presence in dark in colour as shown in Figure 4.45.

Figure 4.45: Weathered young volcanic breccia found at three different locations.

As the unit is found in highly weathered conditions, it thin section cannot be provided. In order to identify the name of the rock type, the megascopic description of this rock unit is correlated with the megascopic description of young volcanic breccia according to Nur Najihah, 2018. Referring to Nur Najihah (2018), this rock shows light grey of fresh rock and the euhedral plagioclase can be observed using hand lens. Matrix tuff is well sorted with angular grain shape. Scoria fragment is found embedded in tuff matrix. The description of this rock unit that observed in the study area is listed in Table 4.15.

Table 4.15: Description of young volcanic breccia sample

Young volcanic breccia sample	Description
 **Figure 4.46:** Andesite fragment	Locality: River Colour: Greyish Texture: Porphyritic Rate of weathering: Highly weathered, weathered plagioclase mineral.
 **Figure 4.47:** Scoria fragment	Locality: River Colour: Black Texture: Vesicular Rate of weathering: Medium to high
 **Figure 4.48:** Matrix tuff	Locality: River Colour: Greyish Texture: well sorted tuff Rate of weathering: Medium to high

4.3.2.5 Sandy Tuff

Sandy tuff is the youngest rock unit in the study area. It covered northern part of the study area which mostly covered the plain area. The appearance of the sandy tuff in field is milky grey of fresh rock while appeared in brown of weathered rock.

Figure 4.49: Sandy tuff at the slope

At the study area, this rock unit is easily been observed at the steep slope around the plain region. This rock unit is composed of lapilli grain with poorly sorted fragment as shown in Figure 4.50. According to the Nur Najihah (2018), this rock unit is medium sorted and open fabric. Besides, this rock unit also dominant with fragment which known as lithic tuff.

Figure 4.50: Sandy tuff fragment

4.4 Structural Geology

According to Daryono et al., (2018), Lembang fault with the length of 29 km is portrayed by active-fault landscape features such as faults scarps, linear valley, shutter ridge, river offsets, beheaded river and winds gap. Lembang fault is a single line fault but the formation is very complex as it broke into 6 different sections, Figure 4.51. This study area covers a Lembang fault that located between Gunung Batu and Cikapundung section. The active-fault landscape observed in the study area is a linear valley, fault scarp and stream offsets. Linear valley and stream offset are already explained in geomorphology part. The other structural geology observed in the area is sheet joint and columnar joint.

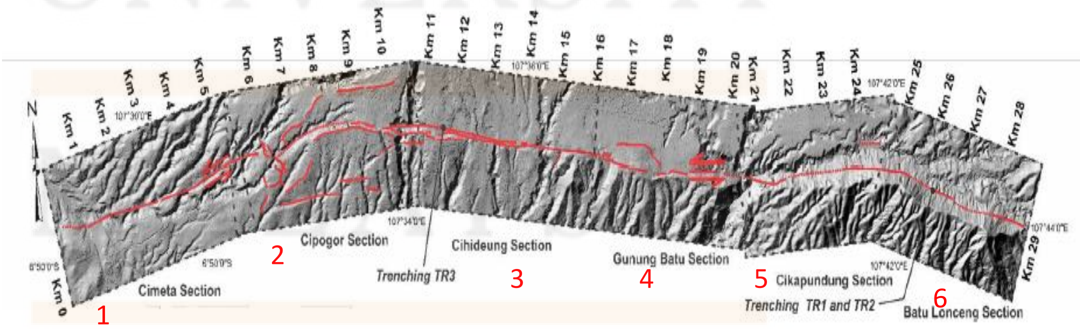


Figure 4.51: Six distinct sections of Lembang fault.

Fault scarp is a feature of topographic expression that shows a displacement of the land surface where one side of the fault has moved vertically. This feature usually contains highly fractured rock for both hard and weak consistency. At this fault scarp there is a presence of fractured rock in terms of sheet joints, Figure 4.52.

Joints are the fractures or crack that caused the rocks to break into blocks or parts and there is no relative displacement. It occurs in all types of rocks but the cause of occurrence is different according to different types of rocks. Joints are formed commonly due to contraction during formation, expansion and contraction and also crustal disturbance. There are three systematic types of joints that regularly occur at igneous rock such sheet joints, columnar joints and mural joints. Joints that occur in the igneous rocks are mostly related to the tensile stresses which developed during the process of cooling and crystallization. Sheet joints and columnar joints are two types of joints that observed in the study area.

In the study area, the sheet joint occurs at fault scrap of the andesite rock. This joint known as sheet joints as it formed in the horizontal set and often divided the rock mass in such a way as to give it appearance of a layered sedimentary structure or bedding. This type of joint formed due to the weathering and removal of the overlaying rock masses which cause the expansion of the underlying igneous rocks as a consequence of loading.

Figure 4.52: Sheet joint exposed at the fault scarp.

A columnar joint is a typical joint in the igneous rocks. It also is known as prismatic joint. The architecture of this joint is very distinctive among other joints as this joint split a rock body into long prisms or columns, Figure 4.53. The diameter of these prismatic columns may range from a few centimetres to several meters and mostly straight with parallel sides. These formations of joints are directly related to the tensile forces during cooling that generates to contraction process. Columnar joints forms in lava flows, sills, dikes, ignimbrites or ash flow tuffs and shallow intrusion of all compositions.

Columnar joints may form in sets. The straight, regular columns are terms as colonnade while irregular with fractured columns terms as entablature, Spry (1962). The columns formed due to stress as the lava cools (Mallet,1875; Iddings, 1886,1909; Spry,1962). As the lava cools, it will contract and the cracks form. Once the crack forms it continues to grow and its growth is perpendicular to the surface of the flow. Entablure probably results from cooling that caused fresh lava being covered by water. The division of colonnade and entablure is the result of slow cooling from the base upward and rapid cooling from the top downward.

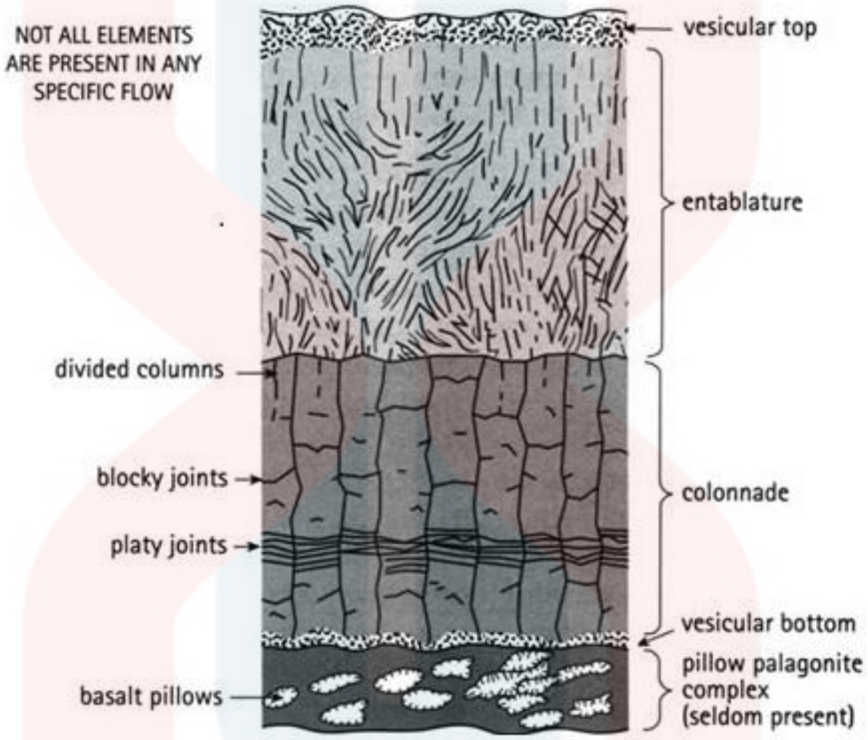


Figure 4.53: Typical Cross-Section of a Flood Basalt Flow / Columnar Joints

Columnar joints exposed in the study area are on a small scale. This columnar joint consists of colonnade and cube-jointing style of entablure above it, Figure 4.54.

Figure 4.54: The columnar joint exposed at Taman Hutan Raya.

Figure 4.55: Cube-jointing style of entablure when close up.

4.5 Lineament

Lineaments are the linear elements or features of the landscape that expressed the underlying geological structure in which they are visible and can be identified from the air photos, satellite imagery, topographic map, terrain map and drainage patterns. The lineament features are typically presented as a series of fault or fold-aligned hills, fault-aligned valley, a linear coastline or combination of these features. The direction of forces of the geological structures can be analysed using these lineaments data.

4.5.1 Lineament Analysis

The lineaments analysis of the study area is made on topographic and drainage pattern map. The measurements of the lineaments have been recorded and the direction of the force is determined using ross diagram. Referring to ross diagrams show in Figure 4.57 and Figure 4.59, the major force (S1) is coming from North East (NE) and South West (SW) directions. Lineament analysis of the topographic map shows the direction of major force is in between 40^o to 50^o of NE and in between 220^o to 230^o of SW with the higher frequency. For the analysis of drainage pattern, the ross diagram shows the higher frequency of force is approximately from 40^o to 60^o of NE and 220^o and 240^o of SW.

4.5.1.1 Lineament Analysis of Topographic Map

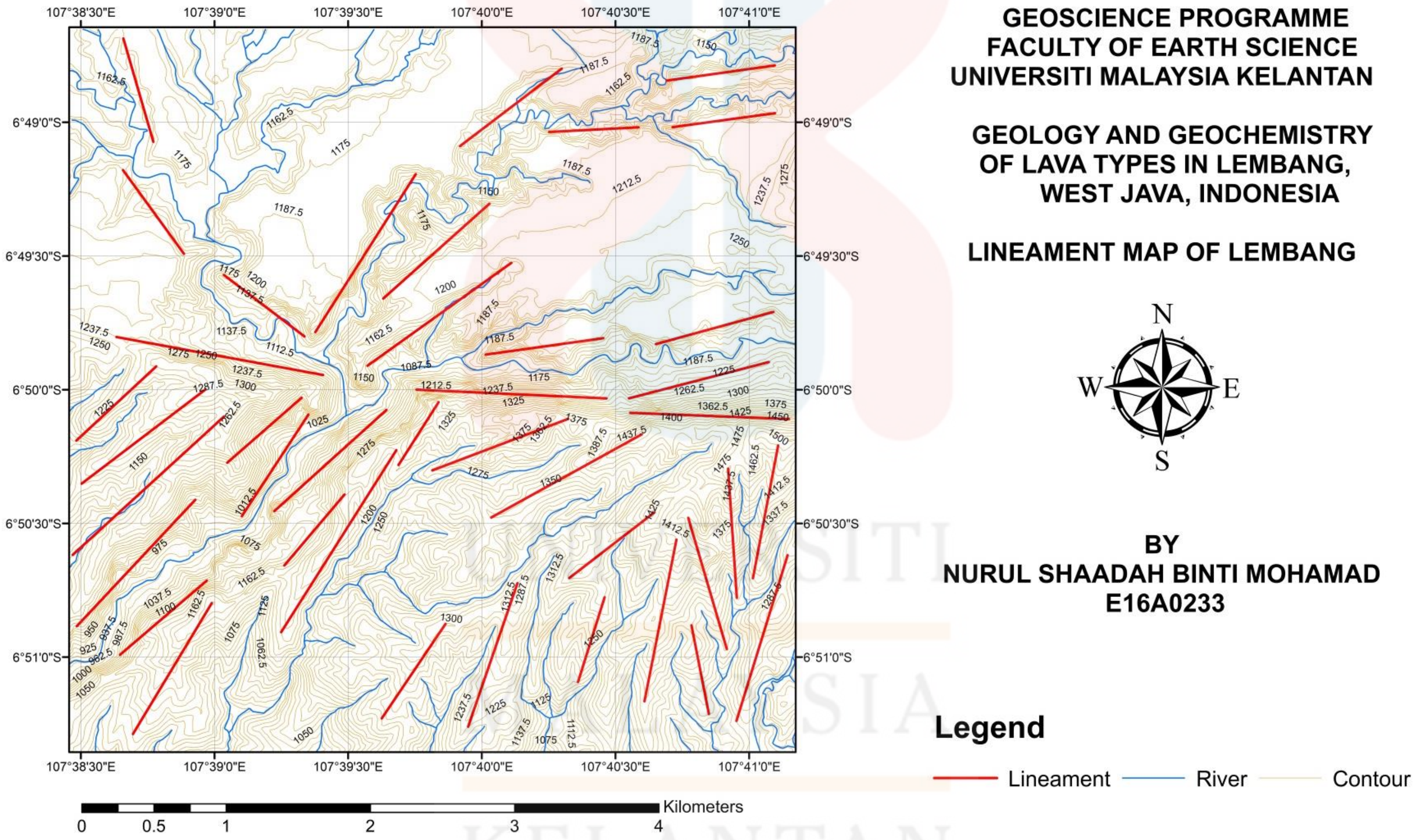


Figure 4.56: Lineament analysis based on topographic

Table 4.16: Lineament reading of topographic map.

1.	30^0	11.	10^0	21.	75^0	31.	140^0
2.	37^0	12.	170^0	22.	40^0	32.	160^0
3.	50^0	13.	165^0	23.	40^0	33.	32^0
4.	45^0	14.	1^0	24.	42^0	34.	47^0
5.	46^0	15.	13^0	25.	40^0	35.	57^0
6.	48^0	16.	17^0	26.	50^0	36.	44^0
7.	33^0	17.	97^0	27.	50^0	37.	89^0
8.	126^0	18.	98^0	28.	83^0	38.	71^0
9.	60^0	19.	50^0	29.	82^0	39.	30^0
10	22^0	20.	22^0	30.	126^0	40.	53^0

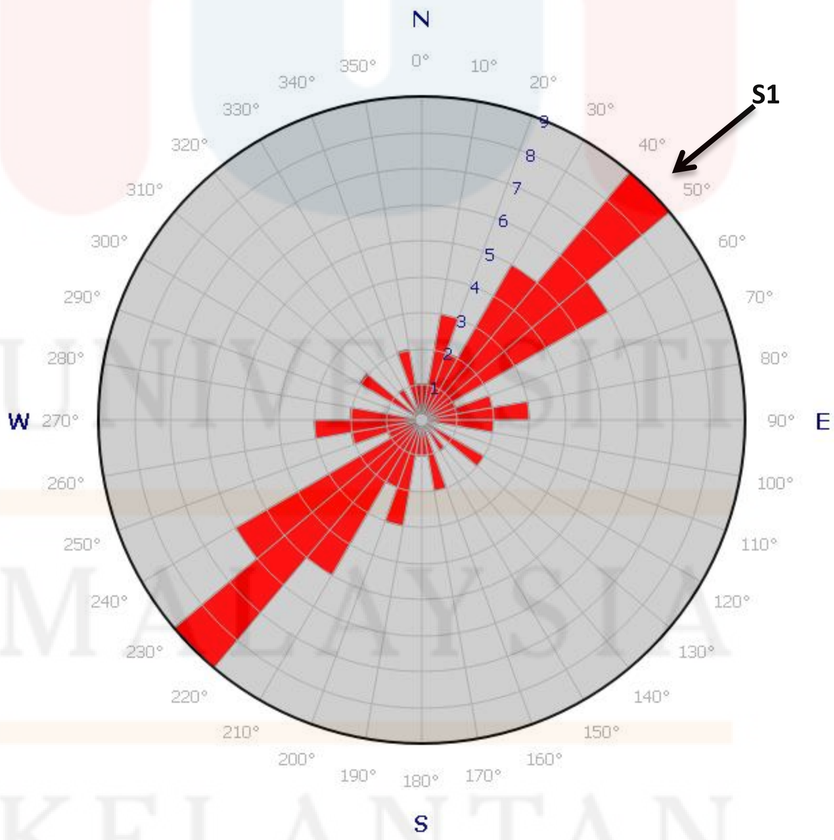


Figure 4.57: Ross diagram of topographic lineaments

4.5.1.2 Lineament Analysis of Drainage Pattern Map

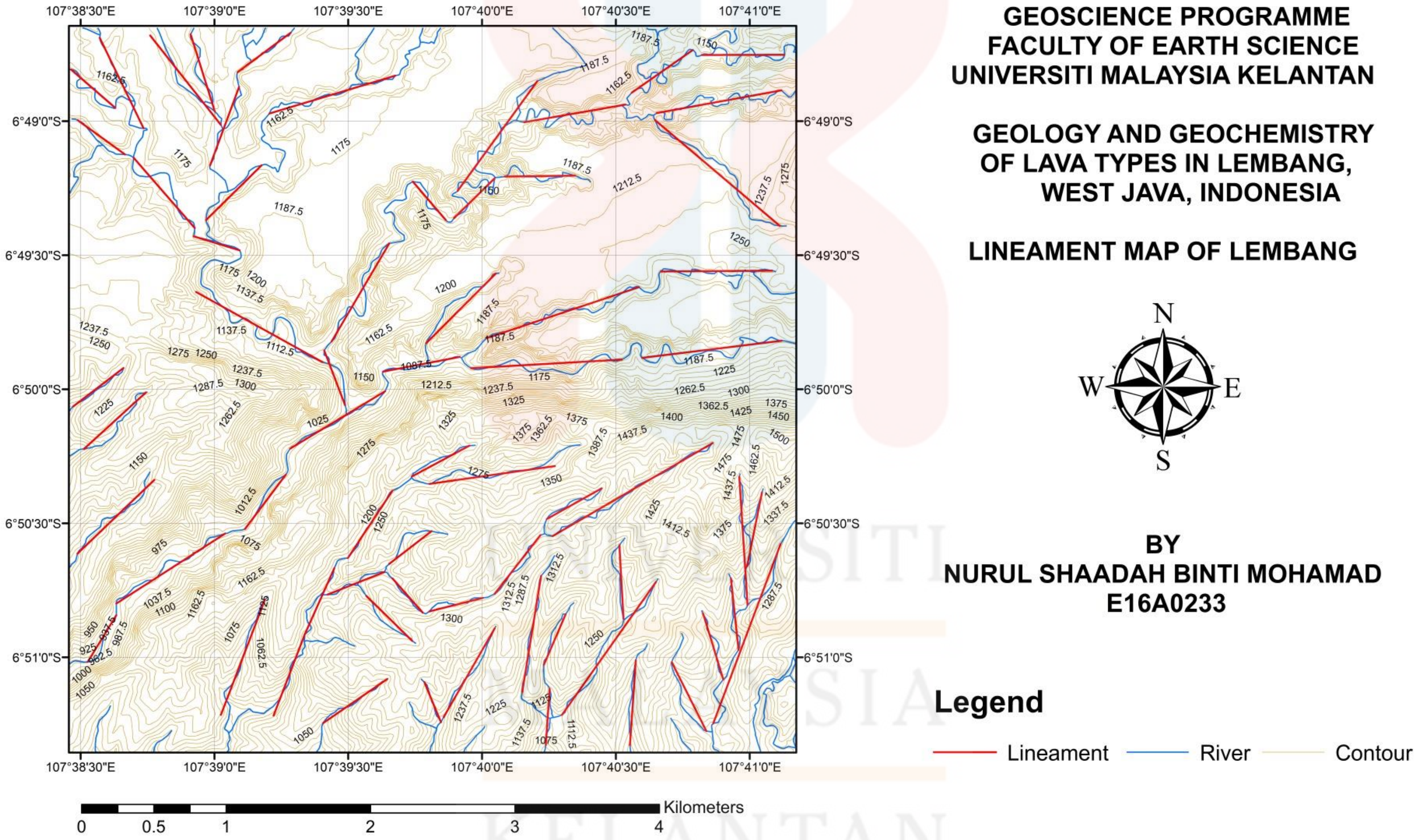


Figure 4.58: Lineament analysis from drainage pattern

Table 4.19: Lineament reading for drainage pattern map.

1.	30^0	11.	10^0	21.	75^0	31.	140^0
2.	37^0	12.	170^0	22.	40^0	32.	160^0
3.	50^0	13.	165^0	23.	40^0	33.	32^0
4.	45^0	14.	1^0	24.	42^0	34.	47^0
5.	46^0	15.	13^0	25.	40^0	35.	57^0
6.	48^0	16.	17^0	26.	50^0	36.	44^0
7.	33^0	17.	97^0	27.	50^0	37.	89^0
8.	126^0	18.	98^0	28.	83^0	38.	71^0
9.	60^0	19.	50^0	29.	82^0	39.	30^0
10	22^0	20.	22^0	30.	126^0	40.	53^0

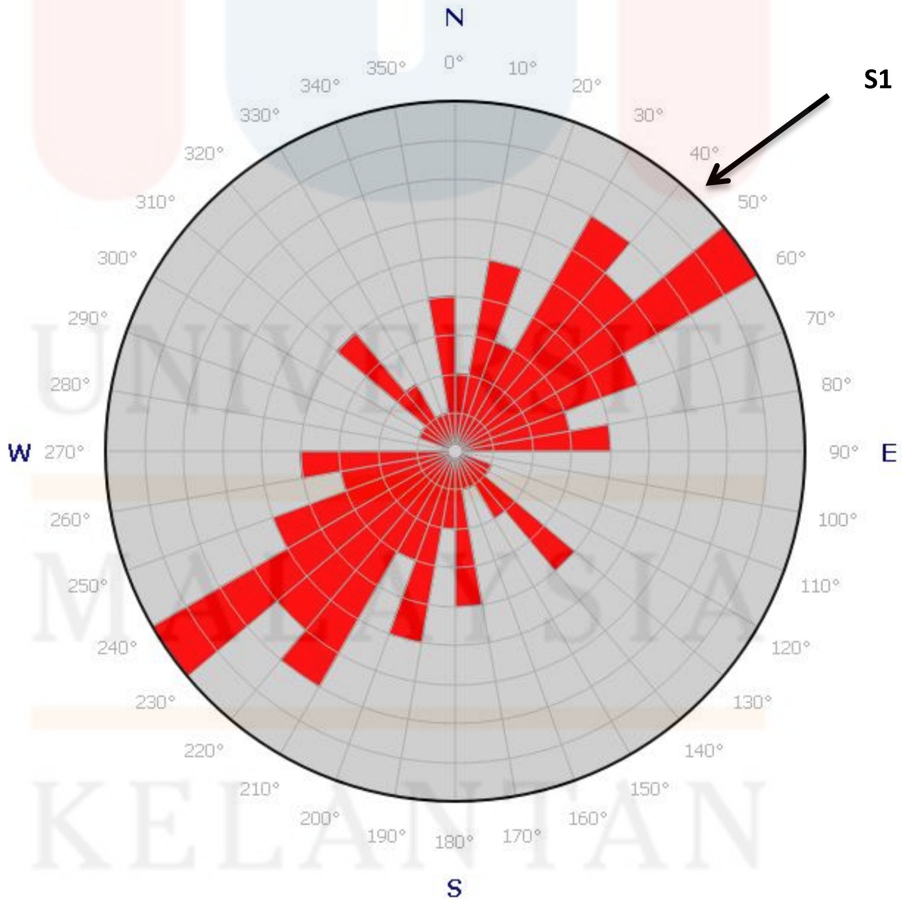


Figure 4.59: Ross diagram of drainage pattern lineaments

4.6 Pahoehoe Lava

Lava flows can form during fountaining eruptions or they can well out of the ground with little or no pyroclastic activity. Basaltic lava flow is divided into two main types of which are ‘a’a and pahoehoe lava which adopted from the Hawaiian phrase. The term pahoehoe is first introduced to the scientific literature is in the year of 1884 and attract worldwide attention including volcanologist (Abdurrachman et., al 2012). Formation of the pahoehoe lava is closely related to the hot spot, as it suggested as factory of pahoehoe lava and it very significant in Hawaii as Hawaiian volcanism generated by hot spot. This type of volcanism is also known as intraplate volcanism. This volcanism is described as the volcanic activity that occurs within tectonic plates and generally it is not related to plate boundaries and plate movements. But the rare phenomenon of pahoehoe lava has found in the area of study.

Back to the regional geology of Indonesia, the formations of volcanic arc in West Java are resulted from the subduction of Indian oceanic plate beneath the Eurasian continental plate. There is no sign of the formation of intraplate volcano in West Java. So, the pahoehoe lava at the study area which found along the Cikapundung River has been introduced as the first example of the pahoehoe lava type in the subduction system (Abdurrachman et al., 2012). This phenomenon is still subject to ongoing debate.

Figure 4.60 and Figure 4.61, show the smooth and gently undulating surface of pahoehoe lava found in the Cikapundung river which indicates the low velocity of lava flows and the lower viscosity. Referring to research study by Abdurrachman et al,. (2016), the high ratios of Th/Yb and Ba/La with the lower ratio of Sr/Nd indicate the mixing of magma with Java sediment. The H_2O present are dissolved in wet Java sediments which then leads to the depolymerize a melt that reduces the viscosity.

Figure 4.60: Pahoehoe lava found at Taman Hutan Raya

Figure 4.61: Gently undulating surface of pahoehoe lava.

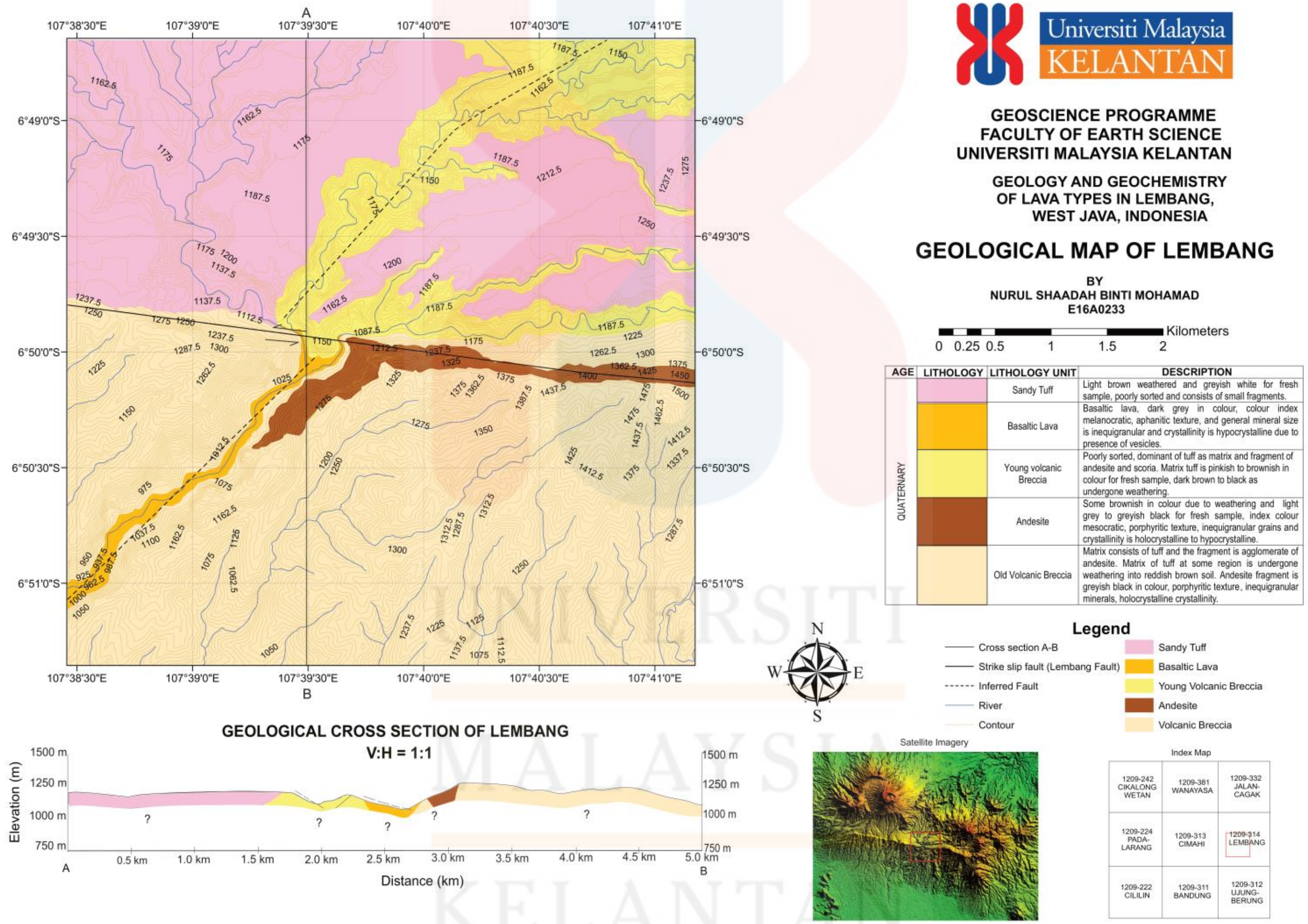


Figure 4.62: The geological map of Lembang

CHAPTER 5

GEOCHEMISTRY OF LAVA TYPES IN LEMBANG

5.1 Introduction

This chapter is going to describe more about lava types in Lembang based on geochemical analysis, XRF. There are two types of lavas found in study area which are basalt lava and andesite lava. Both lavas are chosen for the specification of this research in order to reveal the relationship between the formation of basalt lava and andesite lava in Lembang since both originate from Sunda – Tangkuban Parahu Volcano Complex. Basalt lava which found along Cikapundung River is a product coming from eruption of young Tangkuban Parahu volcano while andesite lava is believed as products of Mount Sunda volcano. However, the origin of andesite lava is still being debated among local geologists. According to Eko Yulianto, the researcher from *Pusat Penelitian Geoteknologi Lembaga Ilmu Pengetahuan (LIPI),* the andesite lava that exposed as a wall of Lembang fault scarp in northern part is formed due to risen of magma along the crack of Lembang fault.

Thus, five samples; two samples of basalt lava and three samples of andesite lava are taken for geochemical analysis. These samples are chosen based on the distinctive features of these rocks such as colour, structure, crystal shape and grain size. The chosen samples are NS_Lava, NS_CJ, NS_LF1, NS_LF2 and NS_RLF.

NS_Lava and NS_CJ are basalt samples while the rest are andesite samples. The details about the physical characteristics and petrographic analysis about these five samples are already explained in Chapter 4.

5.2 Major Elements

Silicate is the chemical compound that widely covers most of the igneous rocks, minerals, and the formation of magma types. This chemical compound consists of a combination of metal with silicon and oxygen. The chemical composition of the complex silicates materials is easy to visualize as its presents as the mixtures of oxides. The mixtures of oxides that usually found in the igneous rocks are SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, MnO and P_2O_5. XRF analysis typically shows the percentage by mass of each of these oxides as shown in Table 5.1 below. The elements listed in table below shows whose oxides found more than 0.1% by mass and classified as major elements. Major elements are important in classification of igneous rock especially volcanic rocks and also essentials in determining the magma series and its tectonic setting.

Table 5.1: The result of the XRF analysis of the five samples

Major Elements (% weight)	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	MgO	TiO_2	P_2O_5	MnO	LOI
NS_Lava	55.85	16.6	11.7	5.79	3.39	2.37	1.08	1.05	0.30	0.19	1.14
NS_CJ	56.23	16.81	11.18	5.72	3.4	2.35	1.07	1.02	0.32	0.16	1.22
NS_LF1	58.58	18.72	7.43	6.92	3.27	1.58	1.43	0.55	0.21	0.14	0.78
NS_LF2	58.55	19.63	7.24	5.92	3.24	1.88	1.01	0.53	0.22	0.15	1.24
NS_RLF	58.38	17.96	8.39	6.34	3.21	1.53	1.38	0.58	0.21	0.14	1.52

The % weight of SiO_2 shows relatively high for all samples and noticeably shows two types of different rocks samples. For the further geochemical classification, these data are plotted in specified diagrams using GCDkit 6.0 software. The LOI or loss of ignition in the table above represents the mass of moisture and volatile in a sample. The value of the LOI can affect the precision of the plotted diagram. If the LOI value is more than 2.0, the data of the particular samples will be ignored as it cannot indicate the actual elements of the sample.

5.2.1 Chemical Classification of Volcanic Rocks

Although the classification of volcanic rocks by petrographic analysis is already explained in previous chapter, but the accuracy is depended on the interpreter and may lead to misinterpret. Thus, the chemical classification is important as it more precise. According to IUGS system, volcanic rocks are classified based on silica content (wt% SiO_2) and the sum of alkalis (wt% Na_2O + K_2O) as these proportions play a crucial role in determining the actual mineralogy and normative mineralogy of the rocks. This classification is known as total alkali-silica (TAS) which shown in Figure 5.1 and Figure 5.2.

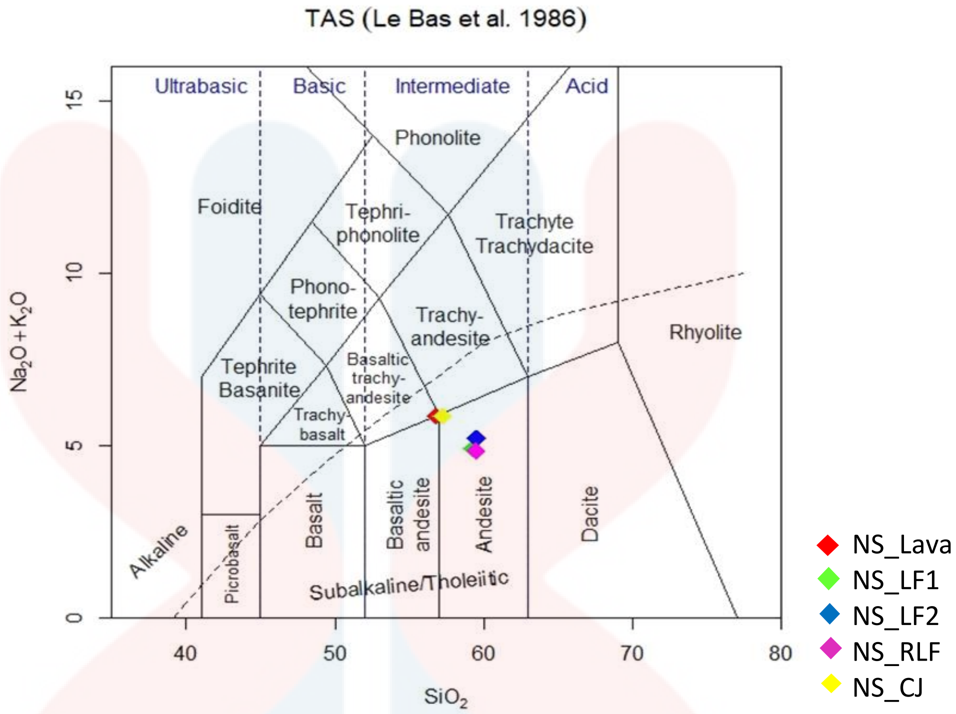


Figure 5.1: Distribution of five samples in Le Bas et al. diagram (1986)

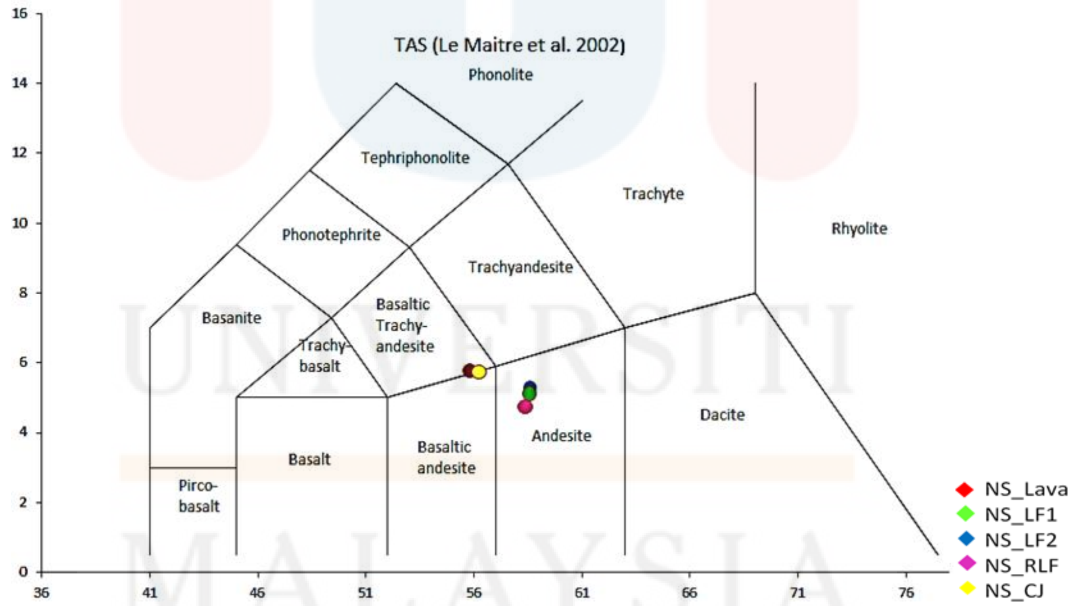


Figure 5.2: Distribution of five samples in Le Maitre et al. diagram (2002)

The geochemical data of SiO_2 and Na_2O + K_2O is plotted in two version of TAS diagram; Le Bas et al. (1986) and Le Maitre et al. (2002) are shown in figure above. This data is plotted in different diagram in order to make the comparison and validation of the result. Based on Le Bas et al (1986) diagram, NS_Lava and NS_CJ are plotted at the intersection of Basaltic andesite, Basaltic trachyandesite and Andesite and the others three samples are Andesite. It shows NS_Lava and NS_CJ are in the state of evolution towards andesite. Based on plotting diagram from Le Maitre et al., (2002), that two samples are plotted at the border of the Basaltic Andesite and Basaltic Trachyandesite and the rest in Andesite column.

Besides plotted the data of silica and total alkali in TAS diagram, Whitford (1979) introduced a simple and faster way in volcanic rocks classification just by using the value of silica content as shown in Table 5.2 below. The classifications of the five samples are shown in Table 5.3.

Table 5.2: The classification of volcanic rocks based on silica content

Name of Rock	Silica Content (SiO_2)
Basalt	<52%
Basaltic Andesite	52% - 56%
Andesite	56% - 63%

Table 5.3: The classification of five samples based on silica content

Sample	Silica Content (SiO_2)	Name of Rock
NS_Lava	55.85%	Basaltic Andesite
NS_CJ	56.23%	Andesite
NS_LF1	58.58%	Andesite
NS_LF2	58.55%	Andesite
NS_RLF	58.38%	Andesite

Based on rocks classification in Table 5.3, it shows different results for NS_Lava and NS_CJ. Only NS_Lava is classified as Basaltic Andesite while the other four samples are classified as Andesite. NS_Lava is at the final stage of Basaltic Andesite as the silica content is 55.85% which only 0.15% less to being classified as Andesite and NS_CJ is at the prior stage of Andesite. The differences between these both compared to TAS diagram may be due to the silica content value as in TAS diagram the value used is normalized value while classification in Table 5.3 is extracted from raw data value. Based on classification from TAS diagram according Le Bas et al., (1986), Le Maitre et al., (2002) and SiO_2 content classification by Whitford (1979), concluded that these five samples are ranging from basaltic andesite to andesite.

5.2.2 Geochemical Trends of Major Elements.

In order to interpret the possible genetic relationships with different types of magma and to aid the comparisons of igneous rocks in distinct areas, petrologists had introduced a number of chemical and graphical schemes to describe the igneous rock. One of them is the Harker diagram as shown in Figure 5.3. Harker diagram is a variation diagram where plots the weight percent of all other oxides against the weight percent of one oxide. SiO_2 and MgO usually form as x-axis, because they act as informative indicators in describing magma evolution. This diagram usually used to facilitate in determining the order of crystallization of minerals during magma cooling.

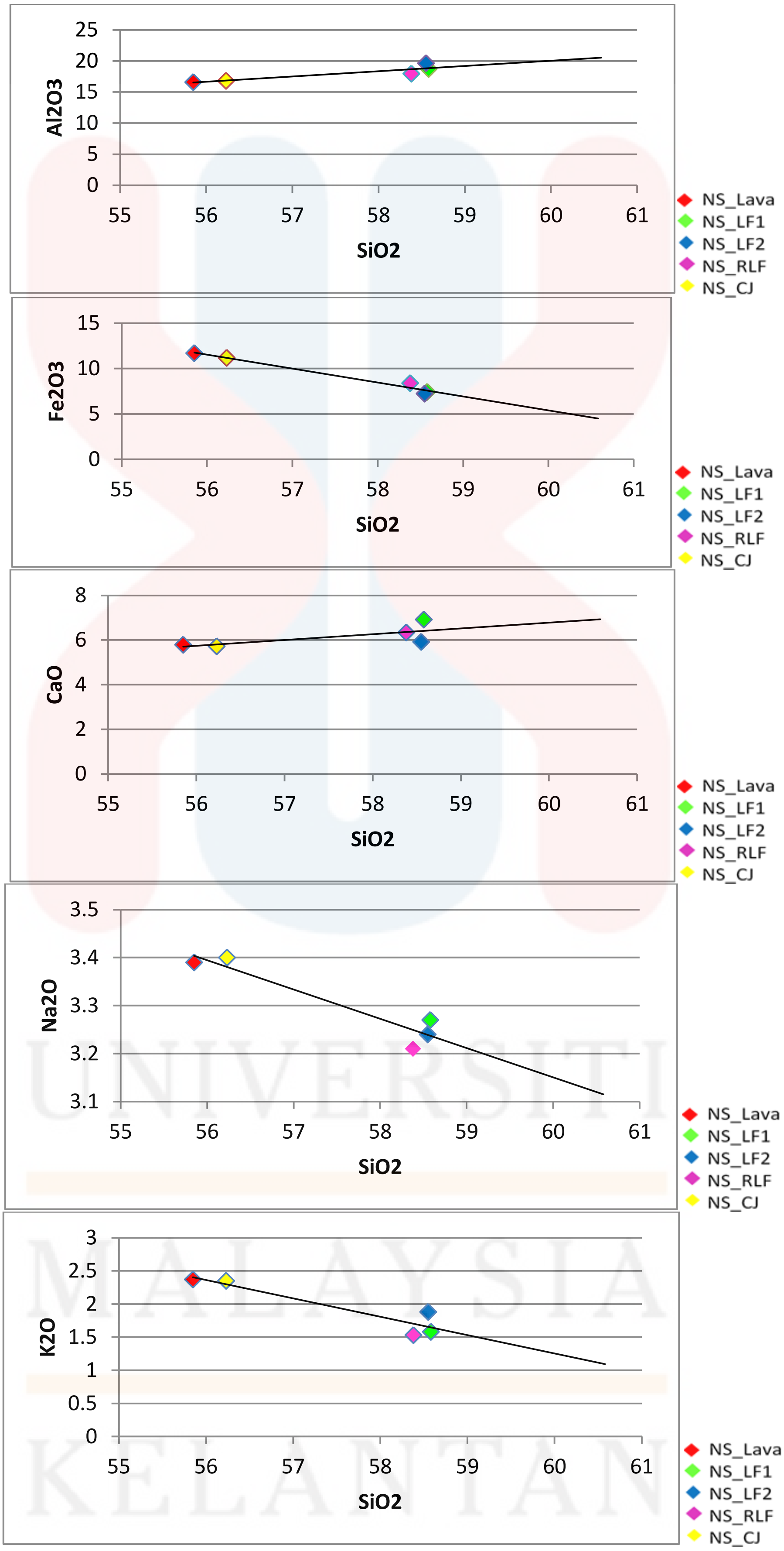


Figure 5.3: Harker SiO_2 content variation diagrams of the five samples

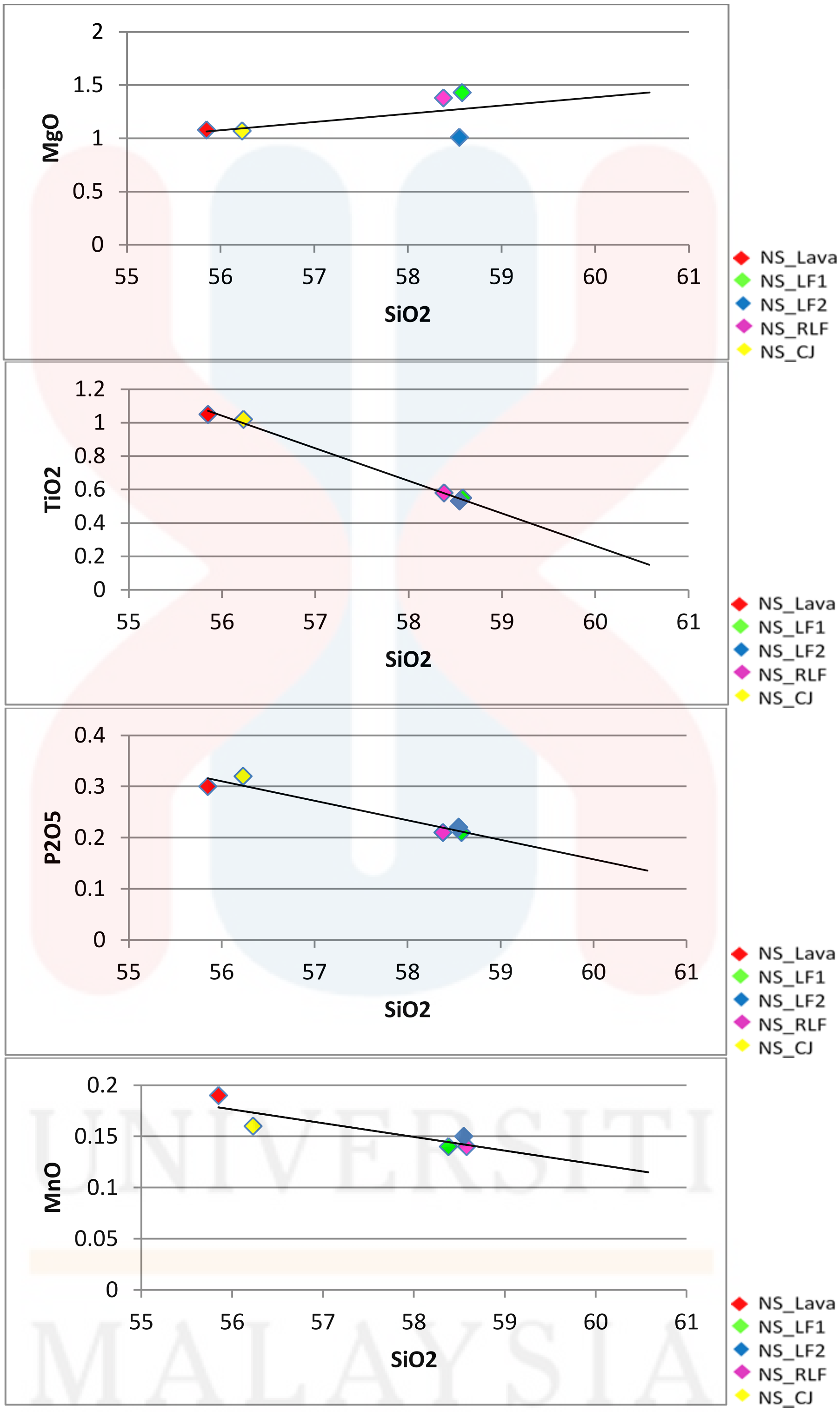


Figure 5.3 (cont.): Harker SiO_2 content variation diagrams of the five samples

West Java is a part of the Sunda arc, which an arc that represents a part of the convergent plate boundary between Eurasian Plate and Australian Plate. The collision of convergent plate boundary usually resulting in the formation of volcanic rocks with very diverse suite and known as basalt-andesite-rhyolite association (Harvey et al. 2006). As samples in this research are ranging from basaltic andesite to andesite and they show more variation in SiO_2 content than MgO content, thus SiO_2 is used as horizontal axis. Different oxides on the vertical axis indicate different types of minerals that initiated to crystallize.

Based on Figure 5.3, they show a decreasing trend of Fe_2O_3, Na_2O, K_2O, TiO_2, P_2O_5, and MnO and increasing trend of Al_2O_3, CaO and MgO. Although all of these samples fall on the trend but these trends not showing the correct trends for basaltic andesitic magma series. Trends of Al_2O_3, CaO and MgO supposed to be in decreasing trends as the crystallisation order for basaltic andesite to andesite is downward of Bowen reaction series. Besides, Na_2O and K_2O should be in increasing trends as when basaltic andesite crystallized toward andesite they should be higher in Na_2O and K_2O elements.

Based on the Harker diagram and interpretation above, the basaltic andesite and andesite samples in the study area are not in the same magmatic series. The samples fall on trend is may be due to the sequence of melting events.

5.2.3 Classification of Magmatic Series

Harker diagram proved that these samples are not related and coming from different magma series. Thus, in order to determine the magmatic series of these samples the binary classification suggested by Peccerillo and Taylor (1976) had been used. This diagram is more details as its classification range is wider where includes Tholeiite, Calc-alkaline, High – K Calc-alkaline and Shoshonite series. This diagram is plotted using weight percent of Si_2O and K_2O.

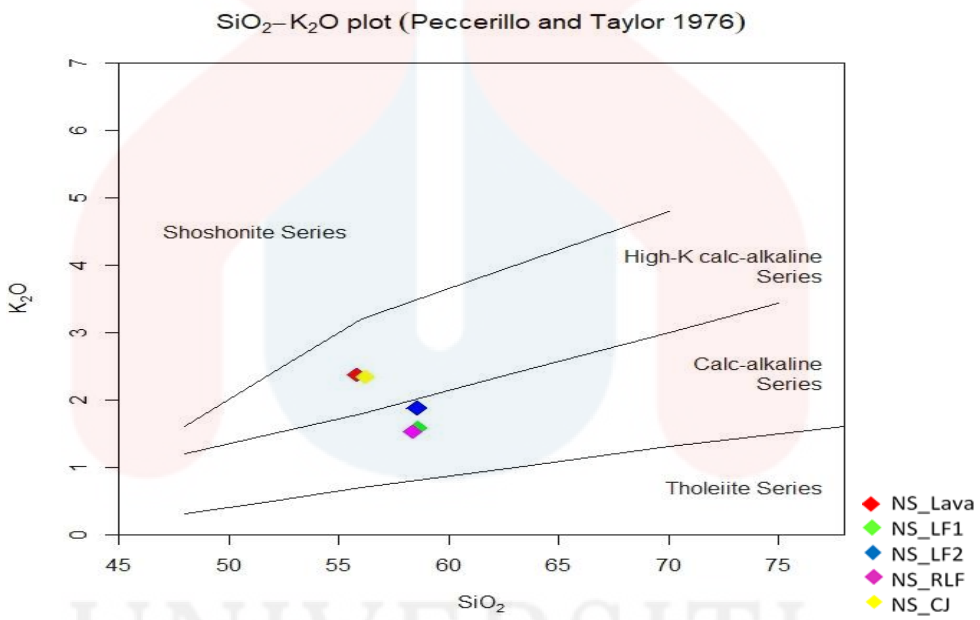


Figure 5.4: Classification of magmatic series based on Peccerillo and Taylor (1976)

Based on Figure 5.4, the analysed samples are being classified into two magmatic series where NS_Lava and NS_CJ in high- K calc-alkaline series while NS_LF1, NS_LF2 and NS_RLF in calc-alkaline series. The terms high-K calc-alkaline in this research study is used to describe the most potassic representatives of the calc-alkaline suite. Thus, proved that basaltic andesite samples of Cikapundung lava and andesite of Lembang fault samples in this research study are not related in terms of magmatic evolution as the andesite lava is erupted earlier than basaltic andesite lava. However, both are in calc-alkaline suite but magma sources.

CHAPTER 6

CONCLUSION

6.1 Conclusion

This chapter concludes the results that obtain from the research of Geology and Geochemistry of Lava Types in Lembang, West Java, Indonesia. The detailed geological map of the study area with the scale of 1:25,000 is produced by completing the geological mapping. For the specification part, the geochemistry of the lava types at the study area is investigated according to the geochemical data that obtain from the XRF analysis. The data of lithology, geomorphology, structural geology and the stratigraphy of the study area are obtained from the field observation, secondary data and literature review.

Based on produced geological map, the study area is composed of five lithology units; older volcanic breccia, andesite, basalt, young volcanic breccia and tuff which significantly coming from the eruption products of Mount Sunda-Tangkuban Parahu Volcano except the andesite units which exposed as a dike intrusion at the fault line of the Lembang fault. All the units are dated in Quaternary age. The geomorphology of the study area is classified into two main geomorphology units which is structural and volcanic geomorphology unit. This study area is composed by high land and the elevation is ranging from 912.5 m to 1512.5 m with slope percentage of 0 – 140%. It also characterized by two main drainage pattern that structural controlled due to the formation of sinistral strike-slip fault. Two main drainage patterns are parallel and rectangular pattern. For the structural geology, this study area is covered a part of Lembang fault between the Gunung Batu and Cikapundung section. The formation of Lembang fault caused the geomorphologic changes in the regional scale with the evidence of the major stream offset of Cikapundung river. Lineament analysis from topographic and drainage pattern map are both showing the main forces are coming from N-E direction.

For geochemistry of lava types, 5 samples are collected. These 5 samples are analysed for major elements using XRF analysis. From the geochemical data, using TAS diagram (Le Maitre et al., 2002), the 5 samples are classified into two distinct types, basaltic andesite and andesite. Based on the Harker diagram, significant high trend of K_2O is portrayed by basaltic andesite compared to the andesite. This high trend of K_2O of basaltic andesite samples considerably due to the assimilation or magma mixing. From the weight percentage of Si_2O and K_2O plotted, the basaltic andesite samples are located in the high-K calc-alkaline series while andesite samples are located in calc-alkaline series. Thus, conclude that these two lava types presence in the study area coming from different magma source but in the same calc-alkaline suite.

6.2 Recommendation

This research study of the geochemistry of lava type will be one of the references sources for the future researcher as the lava at study area especially andesite lava that exposed at the Lembang fault is poorly understood and still being debated for it style of formation and exact dated. This research study only used XRF analysis method for determined the distribution of the geochemical elements.

For further study in this particular study, different method of analysis can be used or maybe used several method of analysis in order to make sure the precision of the geochemical data. To achieve a better result of the geochemistry of the lava in Lembang, it requires more samples of lava to be collect. Beside the analysis of major and minor elements, the analysis of the trace elements is also helpful in understanding the magmatic evolution and its relatedness with subduction rate.

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APPENDICES

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HASIL UJI KIMIA METODE XRF
(XRF METHOD CHEMISTRY ANALYSIS RESULT)
Nomer lab. (*lab. number*) : 118/GL/2.2/10/2019
Tanggal (*date*) : 4 Oktober 2019

Kode sampel (*sample code*)	: NS-Lava (Curug)	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0658	Tanggal diuji (*analyzed date*)	: 3 Oktober 2019
Lokasi (*location*)	: -	Metode uji (*method*)	: GL-MU-2.2
Kedalaman (*depth*)	: -	Metode preparasi (*preparation method*)	: *Pressed Pellet*
Pemilik (*property*)	: **Kevin Heinrich Pesch UNPAD**		

Compound	m/m%	StdErr	El	m/m%	StdErr
SiO2	55.85	0.25	Si	26.11	0.12
Al2O3	16.60	0.20	Al	8.79	0.10
Fe2O3	11.70	0.15	Fe	8.19	0.10
CaO	5.79	0.12	Ca	4.14	0.09
Na2O	3.39	0.09	Na	2.51	0.07
K2O	2.370	0.080	K	1.967	0.070
MgO	1.082	0.070	Mg	0.653	0.040
TiO2	1.0494	0.0500	Ti	0.6291	0.0320
P2O5	0.3033	0.0180	Px	0.1324	0.0080
MnO	0.1936	0.0100	Mn	0.1500	0.0080
SO3	0.0119	0.0008	Sx	0.0048	0.0003

LOI 1.14

Kepala Subbidang Geologi Dasar dan Terapan
selaku Manajer Teknis,

Aries Kusworo, S.T., M.T.
NIP. 197203112006041001.

Catatan (*notes*):
Hasil pengujian ini hanya berlaku untuk sampel yang diuji (*this analysis result is only valid for the tested sample*).

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HASIL UJI KIMIA METODE XRF
(*XRF METHOD CHEMISTRY ANALYSIS RESULT*)
Nomer lab. (*lab. number*) : 118/GL/2.2/10/2019
Tanggal (*date*) : 4 Oktober 2019

Kode sampel (*sample code*)	: NS-LF 1 (Tebing Fault)	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0659	Tanggal diuji (*analyzed date*)	: 3 Oktober 2019
Lokasi (*location*)	: -	Metode uji (*method*)	: GL-MU-2.2
Kedalaman (*depth*)	: -	Metode preparasi (*preparation method*)	: *Pressed Pellet*
Pemilik (*property*)	: **Kevin Heinrich Pesch UNPAD**		

Compound	m/m%	StdErr	El	m/m%	StdErr
SiO2	58.58	0.25	Si	27.38	0.12
Al2O3	18.72	0.21	Al	9.91	0.11
CaO	6.92	0.13	Ca	4.94	0.09
Fe2O3	7.43	0.12	Fe	5.20	0.08
Na2O	3.27	0.09	Na	2.42	0.07
MgO	1.433	0.080	Mg	0.864	0.050
K2O	1.581	0.070	K	1.313	0.050
TiO2	0.5537	0.0290	Ti	0.3319	0.0180
P2O5	0.2092	0.0120	Px	0.0913	0.0050
MnO	0.1407	0.0070	Mn	0.1090	0.0060
SO3	0.0094	0.0007	Sx	0.0038	0.0003

LOI 0.78

Kepala Subbidang Geologi Dasar dan Terapan
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HASIL UJI KIMIA METODE XRF
(*XRF METHOD CHEMISTRY ANALYSIS RESULT*)
Nomer lab. (*lab. number*) : 118/GL/2.2/10/2019
Tanggal (*date*) : 4 Oktober 2019

Kode sampel (*sample code*)	: NS-LF 2 (Tebing Fault)	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0660	Tanggal diuji (*analyzed date*)	: 3 Oktober 2019
Lokasi (*location*)	: -	Metode uji (*method*)	: GL-MU-2.2
Kedalaman (*depth*)	: -	Metode preparasi (*preparation method*)	: *Pressed Pellet*
Pemilik (*property*)	: **Kevin Heinrich Pesch UNPAD**		

Compound	m/m%	StdErr	El	m/m%	StdErr
SiO2	58.55	0.25	Si	27.37	0.12
Al2O3	19.63	0.21	Al	10.39	0.11
CaO	5.92	0.12	Ca	4.23	0.09
Fe2O3	7.24	0.12	Fe	5.06	0.08
Na2O	3.24	0.09	Na	2.41	0.07
K2O	1.877	0.070	K	1.558	0.060
MgO	1.009	0.060	Mg	0.608	0.040
TiO2	0.5312	0.0280	Ti	0.3185	0.0170
P2O5	0.2174	0.0130	Px	0.0949	0.0060
MnO	0.1453	0.0080	Mn	0.1126	0.0060
SO3	0.0094	0.0007	Sx	0.0038	0.0003

LOI 1.24

Kepala Subbidang Geologi Dasar dan Terapan
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Catatan (*notes*):
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HASIL UJI KIMIA METODE XRF
(*XRF METHOD CHEMISTRY ANALYSIS RESULT*)
Nomer lab. (*lab. number*) : 118/GL/2.2/10/2019
Tanggal (*date*) : 4 Oktober 2019

Kode sampel (*sample code*)	: NS-RLF (Sungai D3 Near Faulting)	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0661	Tanggal diuji (*analyzed date*)	: 3 Oktober 2019
Lokasi (*location*)	: -	Metode uji (*method*)	: GL-MU-2.2
Kedalaman (*depth*)	: -	Metode preparasi (*preparation method*)	: *Pressed Pellet*
Pemilik (*property*)	: **Kevin Heinrich Pesch UNPAD**		

Compound	m/m%	StdErr	El	m/m%	StdErr
SiO2	58.38	0.25	Si	27.29	0.12
Al2O3	17.96	0.20	Al	9.50	0.11
Fe2O3	8.39	0.13	Fe	5.87	0.09
CaO	6.34	0.13	Ca	4.53	0.09
Na2O	3.21	0.09	Na	2.38	0.07
MgO	1.380	0.080	Mg	0.832	0.050
K2O	1.531	0.060	K	1.271	0.050
TiO2	0.5761	0.0310	Ti	0.3454	0.0180
P2O5	0.2110	0.0120	Px	0.0921	0.0050
MnO	0.1393	0.0070	Mn	0.1079	0.0060
S	0.0035	0.0003	S	0.0035	0.0003

LOI 1.52

Kepala Subbidang Geologi Dasar dan Terapan
selaku Manajer Teknis,

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NIP. 197203112006041001.

Catatan (*notes*):
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HASIL UJI KIMIA METODE XRF
(*XRF METHOD CHEMISTRY ANALYSIS RESULT*)
Nomer lab. (*lab. number*) : 118/GL/2.2/10/2019
Tanggal (*date*) : 4 Oktober 2019

Kode sampel (*sample code*)	: NS-CJ (Columnar)	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0662	Tanggal diuji (*analyzed date*)	: 3 Oktober 2019
Lokasi (*location*)	: -	Metode uji (*method*)	: GL-MU-2.2
Kedalaman (*depth*)	: -	Metode preparasi (*preparation method*)	: *Pressed Pellet*
Pemilik (*property*)	: **Kevin Heinrich Pesch UNPAD**		

Compound	m/m%	StdErr	El	m/m%	StdErr
SiO2	56.23	0.25	Si	26.28	0.12
Al2O3	16.81	0.20	Al	8.90	0.10
Fe2O3	11.18	0.15	Fe	7.82	0.10
CaO	5.72	0.12	Ca	4.09	0.09
Na2O	3.40	0.09	Na	2.52	0.07
K2O	2.345	0.080	K	1.947	0.070
MgO	1.072	0.070	Mg	0.646	0.040
TiO2	1.0225	0.0500	Ti	0.6130	0.0310
P2O5	0.3163	0.0190	Px	0.1380	0.0080
MnO	0.1604	0.0080	Mn	0.1242	0.0070
SO3	0.0091	0.0007	Sx	0.0036	0.0003

LOI 1.22

Kepala Subbidang Geologi Dasar dan Terapan
selaku Manajer Teknis,

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NIP. 197203112006041001.

Catatan (*notes*):
Hasil pengujian ini hanya berlaku untuk sampel yang diuji (*this analysis result is only valid for the tested sample*).