GEOLOGY AND TSUNAMI HAZARDS IN CARITA AREA, PANDEGLANG REGENCY, BANTEN, INDONESIA

By

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A report submitted in fulfilment of requirement for the Degree of Bachelor of Applied Science (Geoscience) with Honors

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2020

DECLARATION

I declare that this thesis entitled “Geology and Tsunami Hazards in Carita Area, Pandeglang Regency, Banten, Indonesia” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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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."

Signature :

Name of Supervisor :

Date :

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GEOLOGY AND TSUNAMI HAZARDS IN CARITA AREA, PANDEGLANG REGENCY, BANTEN, INDONESIA

ABSTRACT

Carita, Banten is aligned between longitude E 105°49'46.63" to E 105°49'46.545" and latitude S 6°17'29.557" to S 6°20'10.055" in Pandeglang Regency at the most west part of Java Island. The study area covers approximately 25 km^2 area. The main objectives of this research are to update the geological map of the study area in scale of 1: 25,000 and to analyse the geological hazard (tsunami hazard) in the study area. The methods used to produce geological map is by field mapping and Geographic Information System (GIS), while for the tsunami hazard map is by secondary data (data collection from Centre of Vulcanology and Geological Hazard Mitigation) and also using GIS to do the zonation. Based on the observation during field mapping, the study area is mostly covered by alluvium soil and beach sediments. the Young Volcanic Rock Unit which consists of basalt is come from Mt Asupan from Holocene age. There is no structure been founded because of heavy excavation and human activity such as agriculture and plantation. For tsunami hazard analysis, the methods that been use for this research is more to measurement and calculation from secondary data that collected from Centre of Vulcanology and Geological Hazard Mitigation Indonesia.

Keywords- Banten, geological map, tsunami chronology, tsunami hazard, tsunami zonation

GEOLOGI DAN BENCANA TSUNAMI DI CARITA, PANDEGLANG, BANTEN INDONESIA

ABSTRAK

Carita, Banten terletak di antara longitud E 105 ° 49'46.63 " hingga E 105 ° 49'46.545” dan lintang S 6 ° 17'29.557 " hingga S 6 ° 20'10.055" di Kabupaten Pandeglang di bagian paling barat Pulau Jawa. Kawasan kajian meliputi kawasan sekitar 25 km^2. Objektif utama penyelidikan ini adalah untuk mengemas kini peta geologi kawasan kajian pada skala 1: 25,000 dan untuk menganalisis bahaya geologi (bahaya tsunami) di kawasan kajian. Kaedah yang digunakan untuk menghasilkan peta geologi adalah dengan pemetaan medan dan Sistem Maklumat Geografi, manakala bagi peta bahaya tsunami adalah melalui data sekunder (pengumpulan data dari Pusat Vulkanologi dan Mitigasi Bencana Geologi) dan juga menggunakan GIS untuk melakukan zonasi. Berdasarkan pemerhatian semasa pemetaan lapangan, kawasan kajian kebanyakannya diliputi oleh tanah aluvium dan sedimen pantai. Unit Rock Volcanic Young yang terdiri dari basalt berasal dari Gunung Asupan dari zaman Holocene. Tiada struktur yang ditubuhkan kerana penggalian berat dan aktiviti manusia seperti pertanian dan perladangan. Untuk analisis bahaya tsunami, kaedah yang telah digunakan untuk penyelidikan ini lebih kepada pengukuran dan pengiraan dari data sekunder yang dikumpulkan dari Pusat Vulkanologi dan Mitigasi Bencana Geologi Indonesia.

Kata kunci- Banten, pemetaan geologi, bencana tsunami, zon tsunami, kronologi tsunami

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LIST OF ABBREVIATION

HCl	Hydrochloric Acid
GIS	Geographic Information System
N	North
S	South
W	West
E	East
BG	Badan Geologi, Indonesia
PVMBG	Pusat Vulkanologi dan Mitigasi Bencana Geologi
BIG	Badan Informasi Geospasial
FD	Flow Depth
TH	Tsunami Height
RD	Run Up Distance
Kg	Kampung (Village)
GA	Gunung Api (Volcano)

CHAPTER 1

INTRODUCTION

1.1 General Background

Banten is located at western most province of Java island in Jakarta, Indonesia and being one of new province in Republic of Indonesia. Banten Province was established on 17th October, 2000 as the 30th Province. Banten comprises of four regencies and two cities, 94 districts, 128 sub-districts and 1339 villages. The capital of Banten is Serang that govern by Ratu Atut Chosiyah.

Banten consists of several geological formations which are Bojongmanik Formation, Cipacar Formation, Bojong Formation, Young Volcanic Rocks and Alluvial and Beach Sediments. The study area of this research is believed to be under Alluvial and Beach Sediments, Lower Tuff Banten and Young Volcanic Rocks.

Geological structures that presences in Banten area are uplifting and folding of Bojongmanik Formation, and there are predicted to have several faulting that occurred in the northeast-southwest, northwest-southeast, and east-west direction.

1.2 Study Area

1.2.1 Location

The study area for this research is located at Carita, Banten. The study area is between 105°49'46.63"E, 6°17'29.557"S, 105°52'33.172"E, 6°17’29.471” S, 105°52'33.257"E, 6°20'9.884"S, 105°49'46.545"E, and 6°20'10.055"S. Figure 1.1 is the base map of the study area.

Figure 1.1 Map of Banten, Indonesia

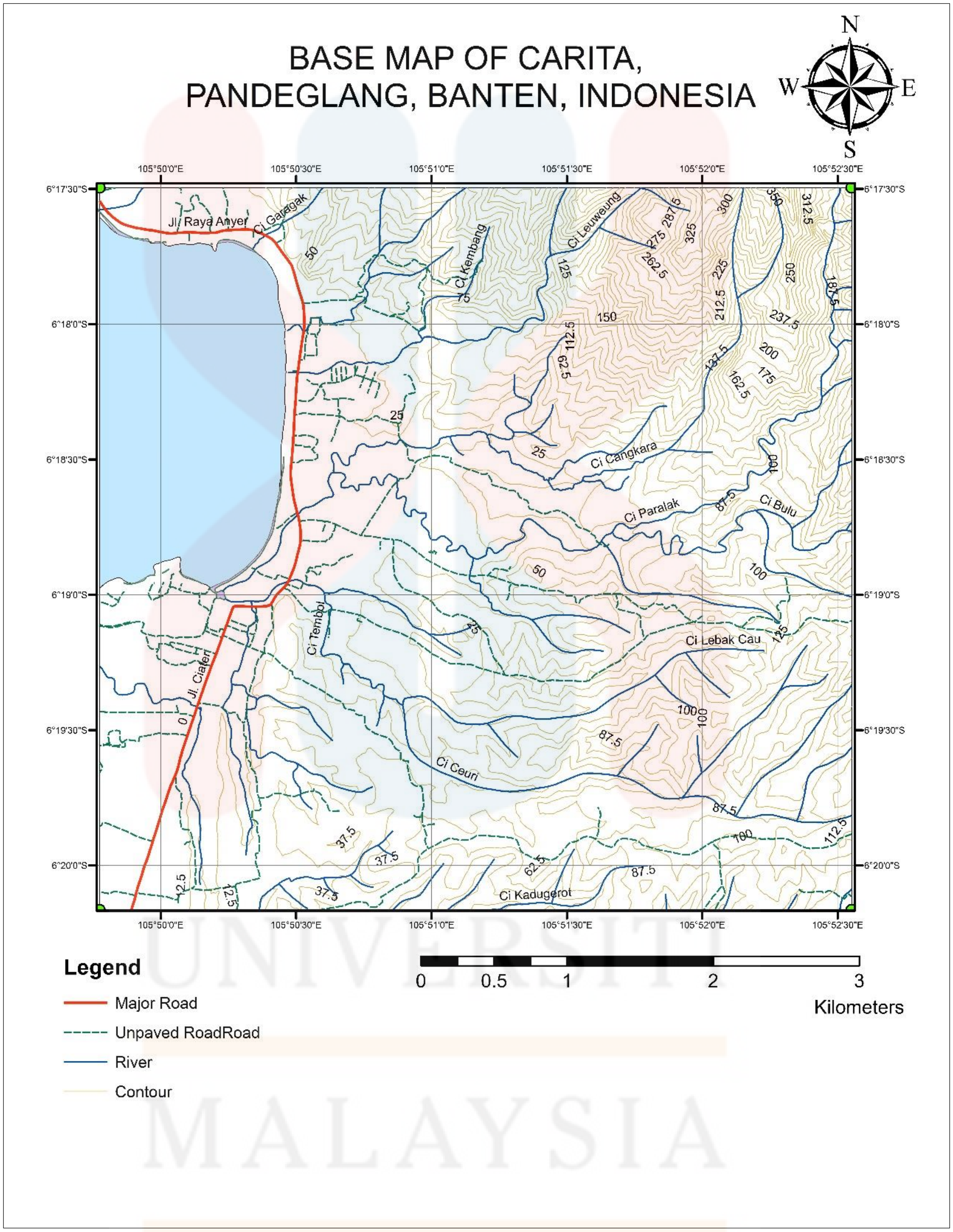


Figure 1.2 Base map of study area

1.2.1 Road connection

The study area is easily accessible as it one of the tourism area and Carita Beach is one of tourist attraction in Banten province. Jakarta to Banten takes several hours to reach but due to increasing of tourism sector, it's become more accessible to foreigner by taking bus or rental car.

1.2.2 Demography

Based on statistic of Central Bureau of Statistics Indonesia and World Population Prospects, Jakarta has been reached 8 million populations in 2019 and being the most populated area in Indonesia.

Table 1.1 Basic populations by district in Indonesia

Name	**Population**
Jakarta	8,540,121
Surabaya	2,374,658
Medan	1,750,971
Bandung	1,699,719
Bekasi	1,520,119
Palembang	1,441,500
Tangerang	1,372,124
Makassar	1,321,717

South Tangerang	1,303,569
Semarang	1,288,084
Depok	1,198,129
Batam	1,164,352
Padang	840,352
Denpasar	834,881
Bandar Lampung	800,348
Bogor	800,000
Malang	746,716
Pekanbaru	703,956
City of Balikpapan	700,000
Yogyakarta	636,660

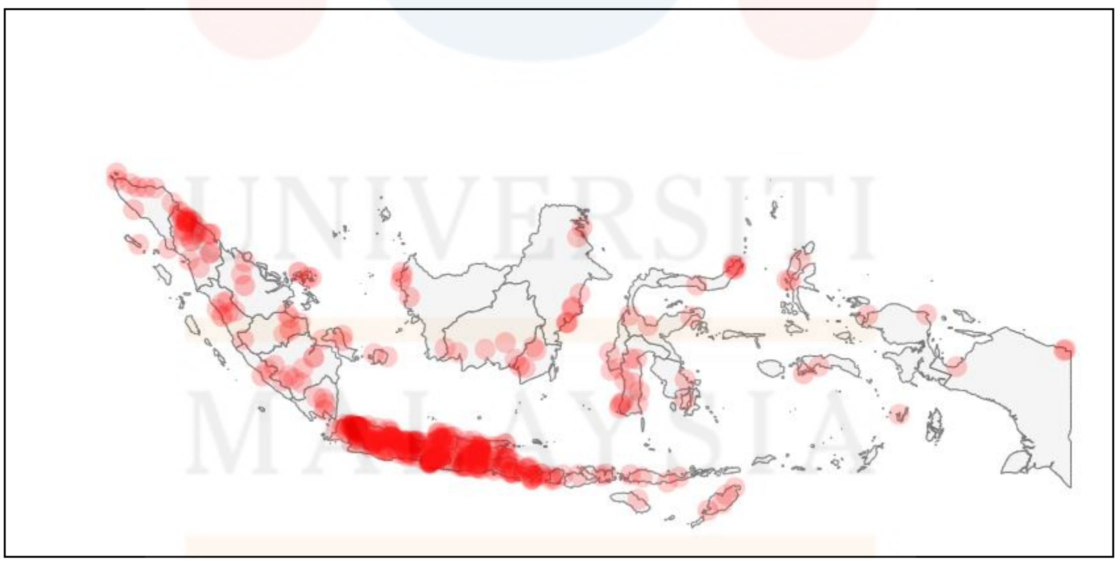


Figure 1.3 Indonesia population densities

1.2.3 Land use

In the study area, there are several types of land use that are include agriculture land use, tourism area, shops, small stall and residence area. Since Carita is one of tourism area, there are many main roads that make it easy to access. Since the study area is dominated by alluvium soil, rice field activities are active in that area.

1.2.4 Social Economic

The main incomes for Banten resident are from agriculture sector and tourism sector. Many residents are gains income by doing hospitality to the tourists that come almost every year.

1.3 Problem Statement

Geological map and geological hazard map is very important on the study area as it provide many detailed information. The database that been used in GIS software are not updated to the present, because there might have many change due to tectonic processes, geomorphological processes especially in coastal area which faced many weathering processes, and the geological aspects such as lithological development.

A detailed and specific information on geological structure and hazardous in the study area are important, but there is lack of research and information about Banten geological structure and tsunami hazards in this area. Although Banten area is near with Anak Krakatau Island, which is one of the causes of tsunami because of magma eruption, there is still least of information about this area. The geological map that provided only with scale of 1:100,000. Thus, the structural analysis and hazardous analysis of this area will provide narrower aspects of geological structure and tsunami hazard that caused the change of morphology of study area.

1.4 Objectives

The main objectives of this research that need to achieve are:

1) To produce geological map of the study area in a scale of 1:25,000
2) To produce tsunami hazard map of the study area in scale of 1:25,000.

1.5 Scope of Study

The scope of this research is to identify the general geology and tsunami hazard that consists of geomorphology, structural geology, stratigraphy and sedimentology of Banten area. The tsunami analysis is the analysis of tsunami wave in term of the analysis of seismic wave of tsunami wave, and the sedimentological and dynamic traces of recent tsunami as well as searching at the historical data to convert the information into tsunami hazards based of the characteristic of its scales of impacts and the areas that affected. Through that, the energy of the tsunami wave can be determined and indirectly can learn the movement of plate tectonic that generate tsunami.

1.6 Significance of Study

By conducting this research, the detailed analysis of tsunami hazard and geological structure of the study area can be useful as references to other geologists for further research. The geological map and tsunami hazard map in this research can be used for other agencies to develop and plan precautionary measures when tsunamis happen in future. The research also can be used as references to seismologist as they can determine how much of certain energy of waves can become dangerous enough for human. The geological structural analysis also can help in many directions for many agencies for developing and planning of urban area.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussing about the literature review of the study area that related with past research or any research that are associated with the scope of this study area research. Literature review is important to get the overview of study scope and give more information regarding the research that will be conducted.

2.2 Regional Geology Setting

Indonesia is located at the subduction zone which are one of the reasons why Indonesia have extreme seismicity and volcanism. Western Indonesia is predominantly underlain by continental crust while in eastern part of Indonesia is more are and ophiolithic crust, and some young ocean basins. Over the past 300 million years, the

Indonesian archipelago composed of fragments reassembled from the Gondwana supercontinent, which crossed the Eurasian subduction boundary (Holloway, 1883). Indonesia is a vast archipelago over than 17,00 islands and spreading almost 5000 km from east to west where its located at the three major plates bound which are Eurasia, Pacific-Philippine Sea and India-Australia.

The Indonesia's current geology is widely the byproduct of this margin's Cenozoic subduction and collision. Active deformation continues in the eastern part of Java within a complicated suture zone up to 2000 km broad, along with several small plates and several subduction zones; plate boundaries are trenches as well as another major strike-slip zone, the left-side Sorong Fault, which stretches from New Guinea to Sulawesi.

Sundaland, the Indonesia's interior, especially the Java Sea, Sunda Shelf, and adjacent evolving but topographically low areas of Sumatra and Kalimantan (Indonesian Borneo), is predominantly seismicity and volcanism. This geologically quiet area is component of the continental core of the Sundaland region (Holloway, 1883).

Indonesia is located at Pacific Ring of Fire. According to the United States, the Pacific Ring of Fire, technically called the Circum-Pacific belt, is the greatest earthquake belt in the world. Geological Survey (USGS), due to its series of fault lines extending 25,000 miles (40,000 kilometers) across Japan and Southeast Asia from Chile in the Western Hemisphere.

The peninsula can be simply divided into two major tectonic settings: western and eastern Indonesia separated by the Makassar Strait (Katili, 1971; Tjia, 1981). The western region, also known as the Sunda shelf or "Sundaland", occupies the partially submerged southeastern part of the Eurasian continental mass, the large islands Sumatera, Java and Kalimantan which share its continental shelf, the Java Sea and the southern part of the South China Sea. This region shows tectonic features including extinct and active subduction zones, volcanic arcs and volcanic plateaus, and foreland basins, all surrounding the continental mass. The major active volcanic arc now runs along the length of Sumatera and Java but continues eastward beyond west Indonesia, into Bali, Lombok, Sumbawa, Flores and small islands in the Banda Sea. Some back-arc basin extension due to subduction rollback has occurred in Sumatera, Java, South China and Kalimantan (Daly et al., 1991).

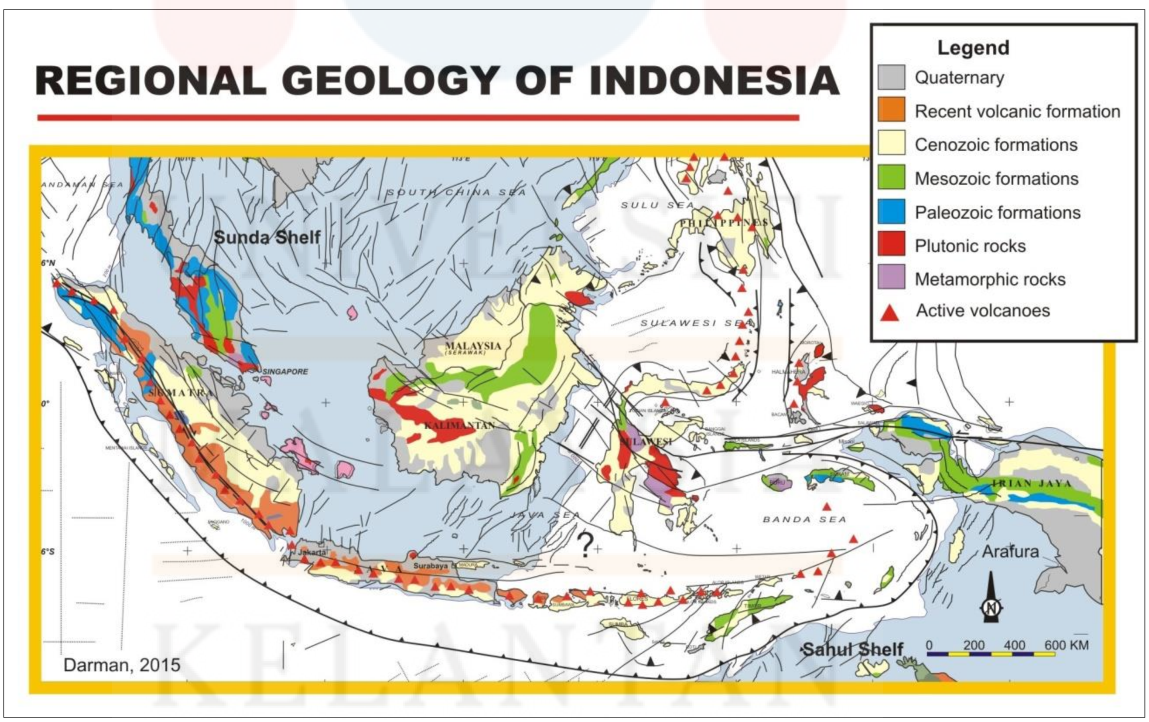


Figure 2.1 Regional map of Indonesia

The eastern region, also called the Sahul shelf, extends from Sulawesi through the east part of the archipelago including the Indian-Australian continental shelf, extends from Papua through the Arafura Sea and the southern part of Timor Sea.(Holloway, 1883)

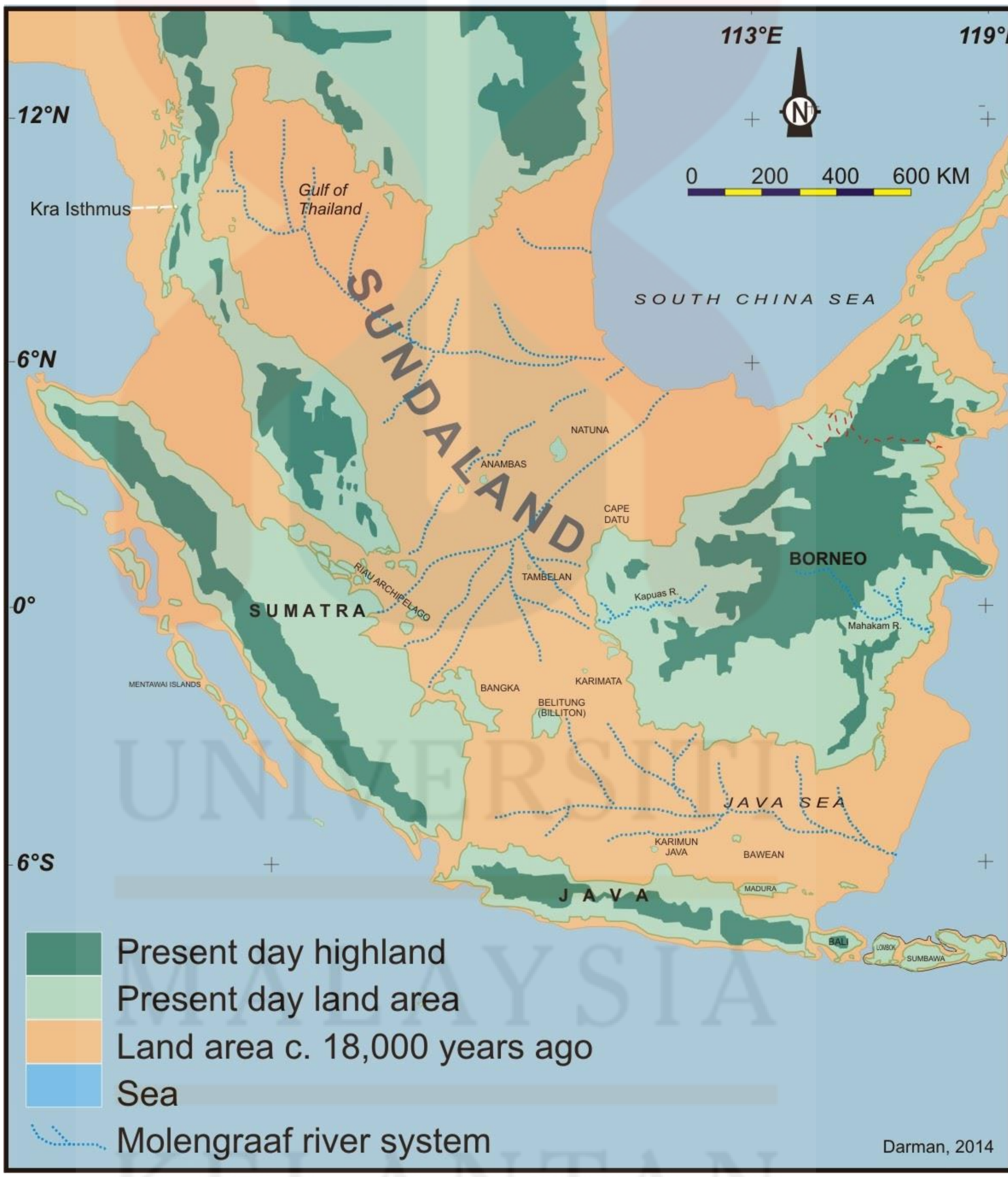


Figure 2.1 Map of Sundaland

Since it is a meeting point of several tectonic plates, the tectonics of Indonesia is very complex. Indonesia is located between two oceanic plates: The Philippine Sea Plate and Pacific Plateand between the Eurasian Plate (Sunda Plate) and Australian Plate (Sahul Shelf). The subduction of the Indian oceanic plate beneath the Eurasian continental plate formed the volcanic arc in western Indonesia, one of the most seismically active areas on the planet with a long history of powerful eruptions and earthquakes. This chain of active volcanoes formed Sumatra, Java, Bali, and Nusa Tenggara islands, most of which, particularly Java and Bali, emerged within the last 2–3 million years. The Pacific and Australian plate movements controlled the tectonics of the eastern portion of Indonesia. (Robert Hall)

The Sunda zone is the somewhat submerged south-eastern outgrowth of the Asiatic landmass, being associated with it by the Malay Peninsula and the Isthmus of Kra. The purported "Sunda Land" involves Malay Peninsula, Borneo, Java, Sumatra and the interjacent shallow oceans from which develops various littler islands.

2.3 Stratigraphy

The stratigraphy of the western part of Indonesia is dominated by Cenozoic age formations, ranging from Paleogene to Quaternary. Minor Mesozoic and Paleozoic formations were found in places. Devonian limestones were found in Telen River, East Kalimantan, as fragments within Paleogene clastic sediments.

Eastern Indonesia has generally older stratigraphy compared to the western part. The stratigraphy ranges from Permian to Tertiary. Ichthyosaur fossils were found in the mud volcanoes in Kai Island, indicating Mesozoic deposition in the subsurface (Charlton, 1992). Mesozoic macrofossils were studied in Misool Island by Fauzie Hasibuan (1996)

Based on Lumban and Poedjoprajitno (2012), the study area is built up of rocks; from oldest to youngest; Bojongmanik Formation which is the oldest rocks that consists of intercalation of sandstone and calcareous sandstone with marl, and clay intercalated with lignite and sandy tuff. This formation is overlain uncomfortably by alluvium deposits and Bojong Formation. Next is Cipacar Formation that composed of pisolitic pumice tuff, sandstone and claystone. This unit is unconformably overlain by Bojong Formation and coral limestone. Bojong Formation comprises marl, clay, limestone lenses, sandstone, and tuff. This unit is generally well bedded, having a thickness ranging from 100 - 300 m. This unit is overlain conformably by the Bojongmanik Formation and then overlain unconformably by Quaternary volcanic rocks or alluvium.

Next is Young Volcanic Rocks where it composed of volcanic breccias, lavas, tuffs, and lava flows. The young volcanic rocks were deposited on the continental environment of Holocene age, and unconformably overlie the older rock units, where the sources of these young volcanic rocks are from the eruption of Mount Asupan, Mount Tempo and Mount Pulasari. (U. & Soemantri, 2012)

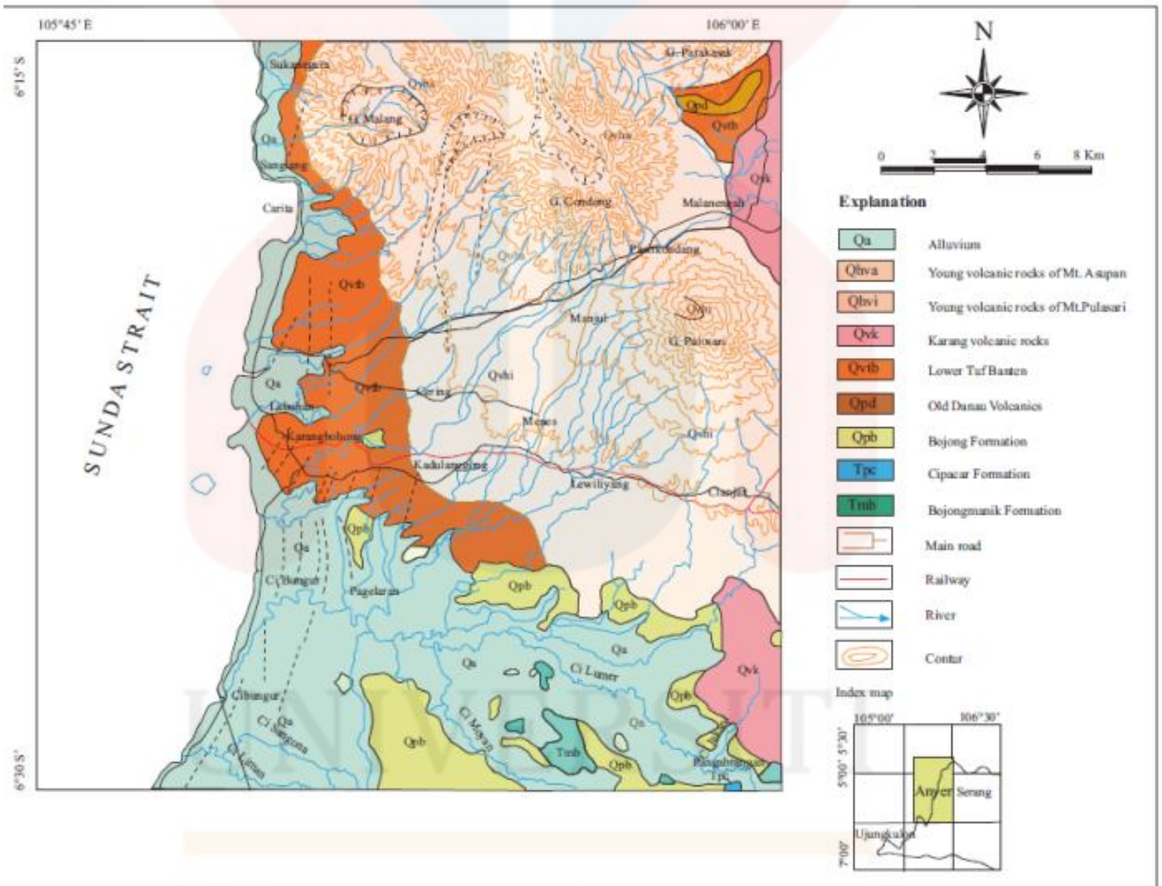


Figure 2.2 Geological map of Pandeglang, Banten, Indonesia (U. & Soemantri, 2012)

2.4 Geological Hazard

Geological hazards are mainly caused by plate the tectonic activities and become one of the most unpredictable hazards for human being. One of the deadliest geological hazards is tsunami which mainly triggered by earthquakes and volcanoes ("Tsunamis and Tsunami Hazards," n.d.). A tsunami is a large ocean wave that is caused by sudden motion on the ocean floor. Tsunami is the most catastrophic oceanic wave motion where that in result of shock waves that caused by the many processes such as submarine earthquakes, volcanic activity asteroid impacts (Shiki, Minoura, Tsuji, & Yamazaki, 2008)

Figure 2.3 Tsunami struck Japan in 2011

Geological Research on tsunami became very popular among geologist and seismologist since both parties are involved in very often in tsunami cases. Tsunami waves are unlike normal coastal waves. Tsunamis are more like a river in flood or a sloping mountain of water. They have no face for a surfboard to dig into and are usually filled with debris. Large tsunamis may reach heights of twenty to fifty feet along the coast and even higher in a few locales. The first tsunami surge is not the highest and the largest surge may occur hours after the first wave. It is not possible to predict how many surges or how much time will elapse between waves for a particular tsunami. The entire California Coast is vulnerable to tsunamis. The tsunami generated by the 2011 Tohoku earthquake off the coast of Japan caused damage to harbours and ports all along California's coast. A dozen people were killed in California following the 1964 Alaska

Figure 2.4 Alaska Tsunami 1964

earthquake. Tsunamis from local sources are also possible ("Indonesia's Explosive Geology Explained | Live Science," n.d.).

Based on D. Sugawara et al (2008), tsunamis are ephemeral wave motion in the oceans or enclosed basins that can be generated by many phenomena or sources such as earthquake and volcanic activity that force the water to move temporarily. The wave motion is the displacement of the water mass that propagates outwards. The behaviours of the wave are characterized by the wavelength, where it depends on the dimension of the wave sources that is proportional to the magnitude of the external force.

Earthquakes and slides are the major sources while volcanic activity and asteroid impacts are infrequent factors. Tsunamis are classified into four categories according to their causes. First, earthquake-induced tsunamis that are caused by plate tectonic activity. Convergent boundaries are the activities of plate tectonic where two plates are move toward each other and form subduction zone. This type of plate boundary is important from tsunami aspects. The Indian Ocean tsunami is the worst tsunami catastrophe in human history that occurred on 26th December 2004, where it triggered by the M9.3 Sumatra earthquake. The earthquake epicenter was placed on Sunda plate, where the Indian-Australian plate slides beneath the Eurasian plate ("Indonesia's Explosive Geology Explained | Live Science," n.d.).

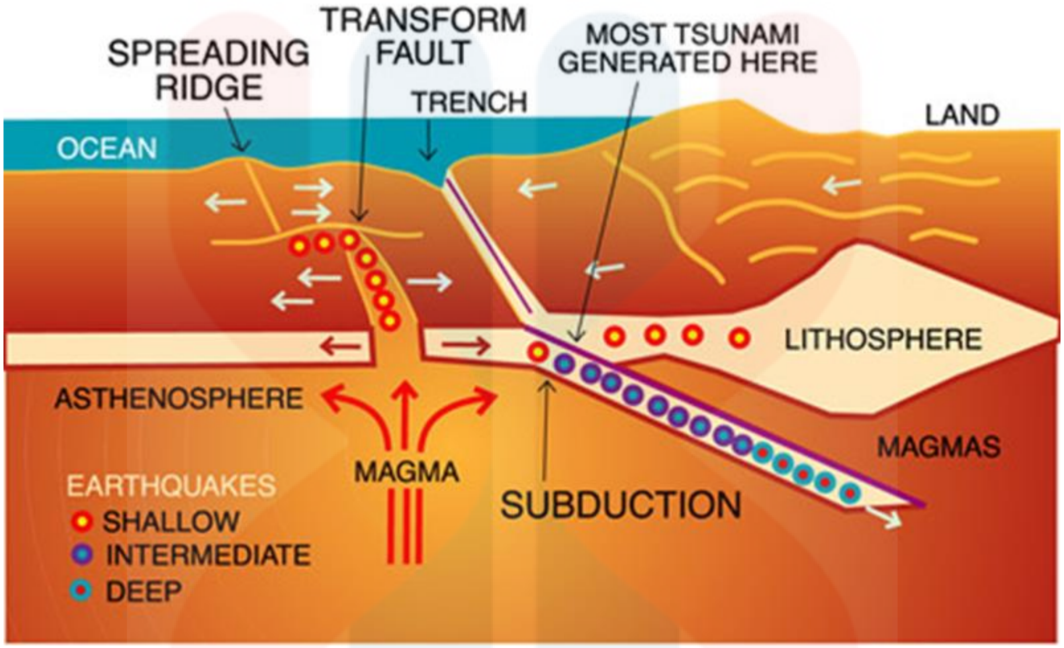


Figure 2.5 How earthquake triggered tsunami

7.7-Earthquake in magnitude that sparked a 10-foot (3-meter) tsunami, killing nearly 113 people, resulted when the Australian and Sunda plates struck the faces. Called thrust faulting, one mountainous plate subducted or dived below the other, leading to an earthquake. Other significant ruptures across the Sunda megathrust included the 2004 9.1-magnitude earthquake and tsunami in the Indian Ocean, and killed approximately 230,000 people in a few countries. Lots of shifting and colliding plates will expose a look underneath Indonesia.

Figure 2.6 Banda Aceh before and after tsunami 2004

The deadliest earthquake ever measured (magnitude 9.5) centered off the Chilean coast in 1960, causing a tsunami that killed almost 2,000 people in Chile, 61 people in Hawaii 15 hours later, and 122 people in Japan 22 hours later.(“Indonesia’s Explosive Geology Explained | Live Science,” n.d.)

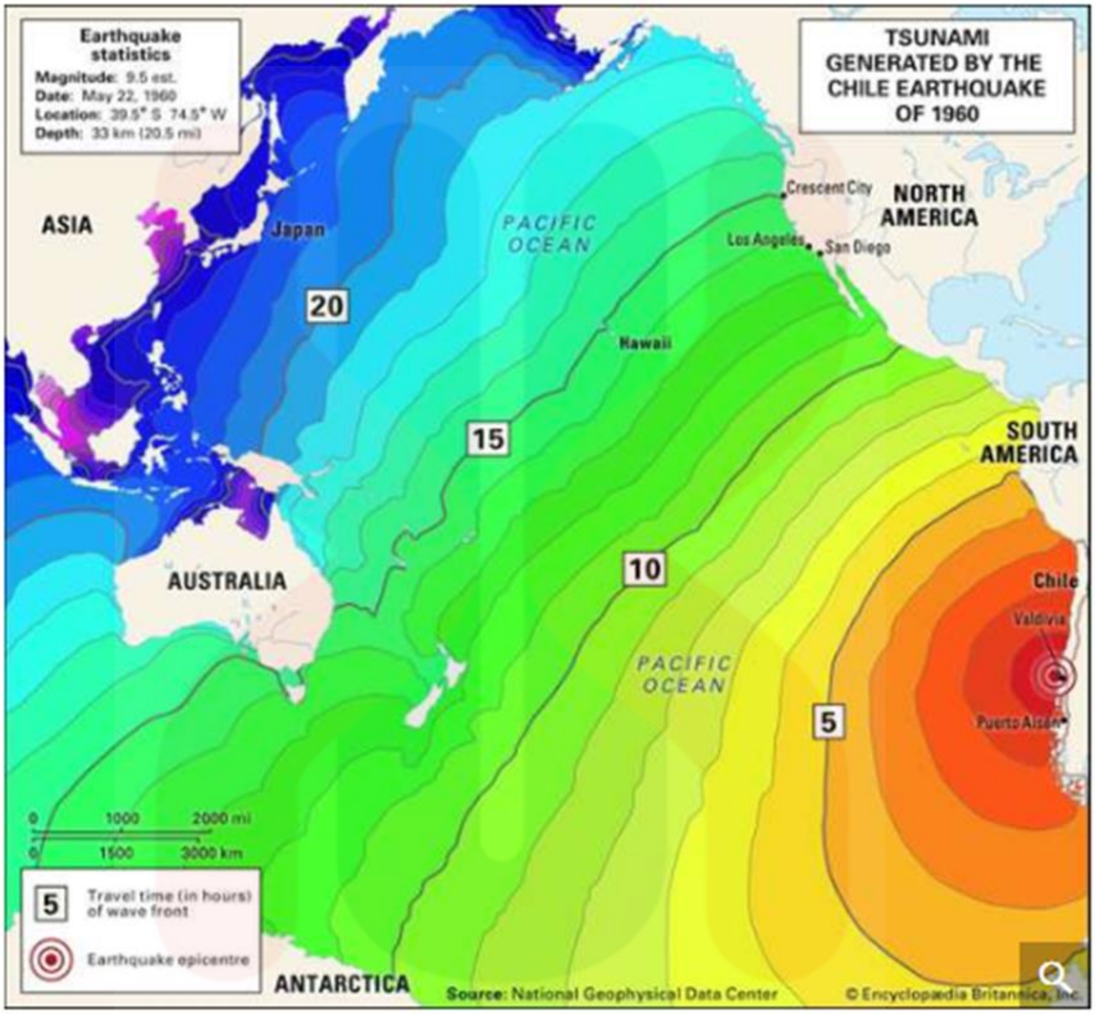


Figure 2.7 Chile tsunami wave travelled

Although fairly rare, vicious volcanic activity also portray reckless instabilities that can displace a massive volume of water in the immediate source area and create extremely destructive tsunami waves. Under this system, waves can be triggered by the rapid displacement of water induced by a volcanic explosion, a volcanic slope failure, or more likely by the volcanic magmatic chambers ' phreatomagmatic burst and crumble or engulfment (“Indian Ocean Tsunami Information Center | Tsunami Info | About Tsunami | What Causes Tsunami,” n.d.).

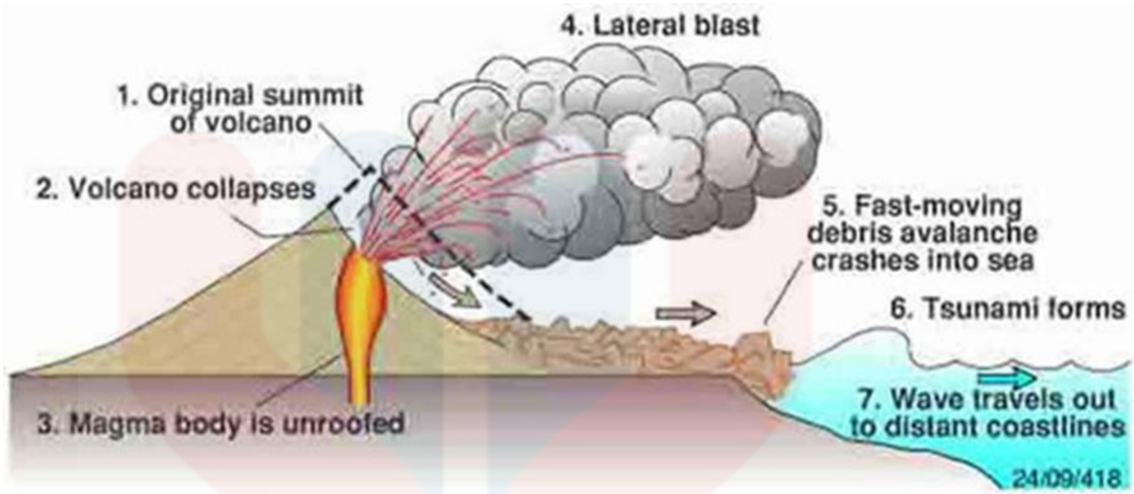


Figure 2.8 tsunami caused by volcano eruption

After the explosion and collapse of the Krakatoa (Krakatau) volcano in Indonesia, one of the largest and most destructive tsunamis ever recorded was generated on August 26, 1883 ("How Do Volcanic Eruptions Generate Tsunamis? - International Tsunami Information Center," n.d.). This eruption resulting in waves exceeding 135 feet, flooding coastal towns and villages along the Sunda Strait on both Java and Sumatra islands, killing 36,417 people. The collapse of the Minoan civilization in Greece is also thought to have been caused in 1490 B.C. The eruption of the Santorini volcano in the Aegean Sea. Tsunami tsunamis induced by submarine sliding where it happens together after an earthquake occurred. Even a small earthquake can generate slumping of a coastal landform and liquefaction of the sea bottom, and the indirect massive movement of sediment. When huge accumulations of unstable sediment intensify, the submarine slides can occur. An unusual change in sea-bottom topography also triggers a tsunami; so submarine slides are treated as one of the potential sources of several tsunami events.

2.4.1 Tsunami's Physical Characteristics

Tsunamis and all patterns of waves have a wave height, a wavelength, an amplitude, a velocity and a frequency or period ("TSUNAMIS," n.d.). Tsunami height is relating to the length between the through of the wave and the peak or crest of the wave ("Tsunami," n.d.). Tsunami is able to travel at over 800 kilometres per hour, but as it near the coast, the wave

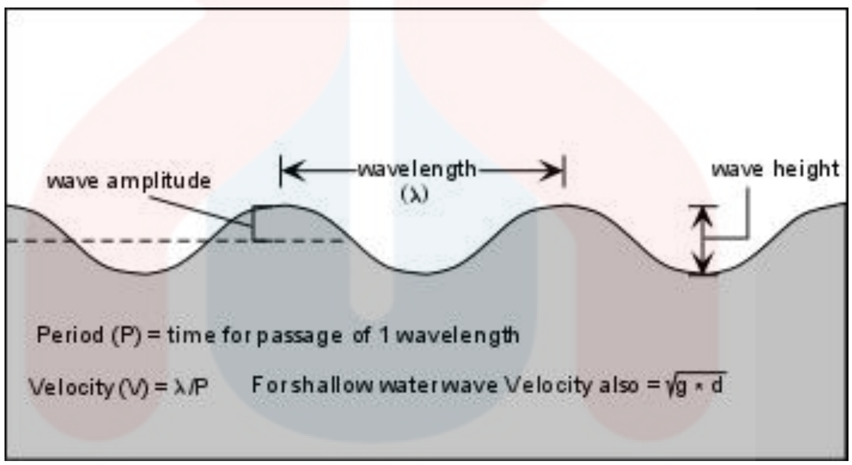


Figure 2.10 Physical characteristics of wave including tsunami (("TSUNAMIS," n.d.))

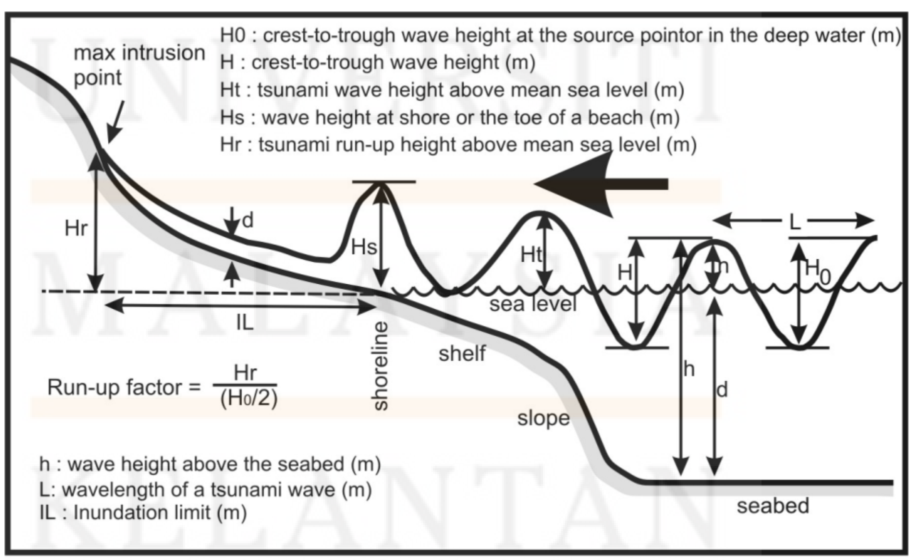


Figure 2.11 Graph explains terms used to express the wave height of a tsunami (Alpar, Alt, Gazio, & Yücel, 2003)

2.4.2 Stages in tsunami

i. Initiation

Earthquakes are frequently associated with ground shaking emerging from elastic waves that propagate through the solid earth. Near the source of deep sea earthquakes, however, the seafloor is "permanently" lifted up and down, pushing up and down the entire water column.

The potential energy that was generated from pushing water above mean sea level is then converted to the tsunami wave (kinetic energy) in horizontal propagation. For the above case, the rupture of the earthquake arisen in fairly deep water at the base of the continental slope. Situations could also emerge in which the rupture of the earthquake happens in much shallower water below the continental shelf.

Figure 2.9 Stage 1: Initiation

ii. Split

In the next few minutes of the earthquake, the first tsunami is categorized into a tsunami moving out to the deep ocean (desolate tsunami) and then another tsunami migrating to the nearby coastline (regional tsunami). The height of the two tsunamis moving in comparison above mean sea level is about half that of the initial tsunami. As the square root of the water depth, the speed at which both tsunamis travel. The deep-ocean tsunami, therefore, moves faster than the local coastal tsunami.

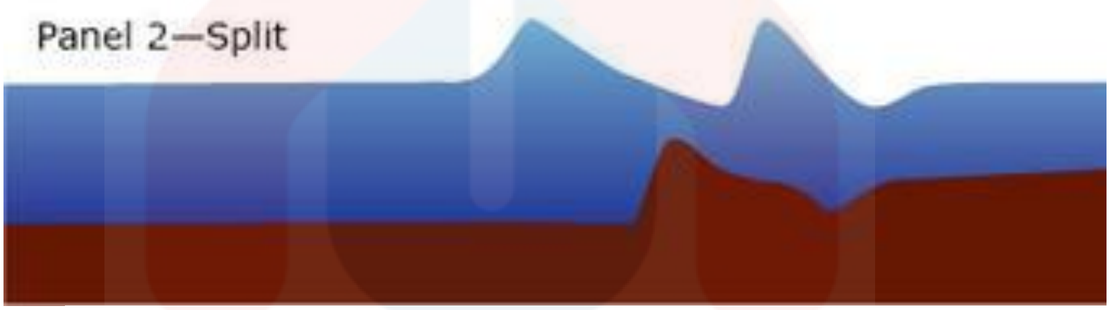


Figure 2.10 Stage 2: Split

iii. Amplification

As the local tsunami moves across the continental slope, various things happen. Quite significant, there was an increasing in amplitude but the wavelength of the wave is decreasing. This resulted in the steepening of the leading wave — a major influence of the inland wave run-up. Note that the very first segment of the wave that arrives the local shore is a trough that shows up as the sea further from the shore. That is a common sign of normal tsunamis notice. Note also that due to the higher propagation speed, the deep ocean tsunami has actually travelled much further than the local tsunami. As when the deep sea tsunami gets closer a distant shore, the wave will be intensified and shortened, which is shown above with the local tsunami.

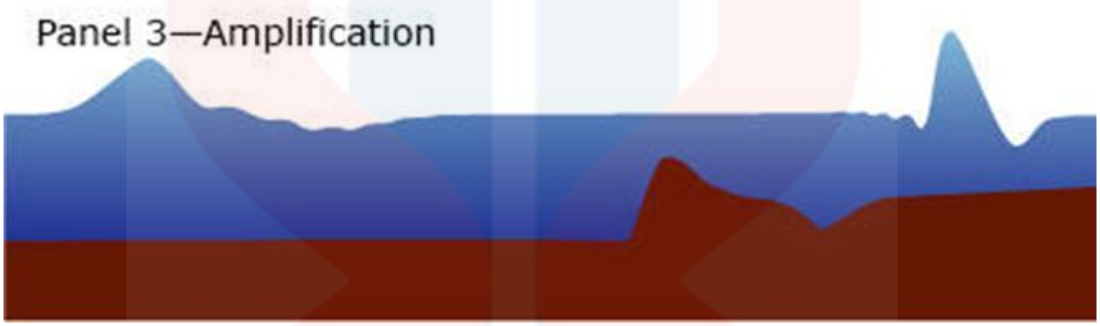


Figure 2.11 Stage 3: Amplification

iv. Run-Up

Tsunami run-up takes place once a tsunami waves peak travels to the shore from the near-shore region. Run-up is a representation of onshore water height measured above sea level of reference. Except for the greatest tsunamis, such as the 2004 Indian Ocean incident, most tsunamis do not lead in giant waves breaking (like normal beach surfing waves curling over as they encounter shore). Instead, they arrive in much like tides that are really strong and fast-moving (i.e., strong waves and rapid sea level changes). Much of the tsunami destruction is caused by massive currents and floating

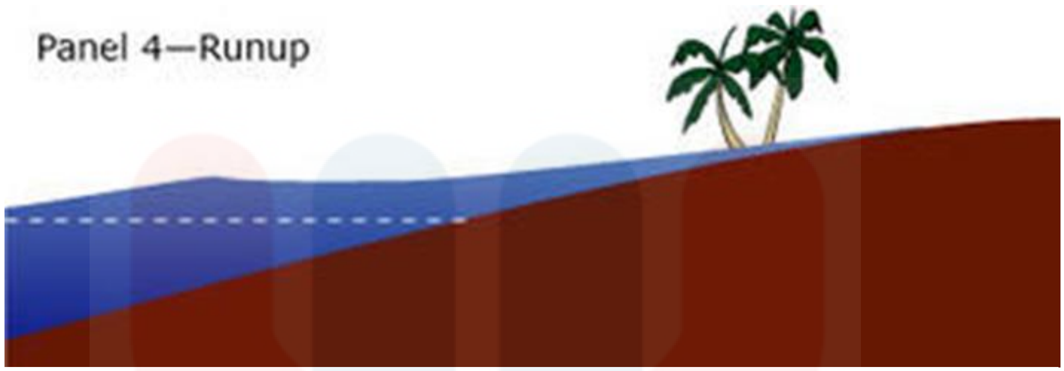


Figure 2.12 Stage 4: Run-up

2.4.3 History of Carita Tsunami

The tsunami that struck on 22nd December 2018 in Sunda Strait area is not the first time ever. Krakatau is very popular among volcanologist and geologist because of its disastrous on 27 August 1883, which are considered as one the largest incident in volcano activity. The eruption of Krakatau causes a tsunami with height between 30-40 meters along the west coast of Banten and south coast of Lampung. In that time, almost 295 small cities were washed and causes almost 36,271 deaths (Verbeek, 1885).

Tsunami in 1883 that arise at 10 am, 27 August came with two opinions which are; first is the tsunami is triggered by the Krakatau fallen body and pushed the sea water to became tidal wave. Second is the tsunami is caused by the erupted materials by the Krakatau itself. By the tsunami happen, all the coral in that area was destroyed by the huge wave. (*ANAK KRAKATAU PAK IGAN*, n.d.) Based on tsunami records, Sunda Strait has been struck by 11 tsunamis before this which take place in 416, October 1722, 24th August 1757, 4th May 1851, 9th January 1852, 27th August 1883, 10th October 1883, February 1884, August 1889, 26th March 1928 and 22nd April 1958 (Soloviev and Go, 1974 in Yudhicara and Budiono, 2008).

Table 2.1 The activities of Krakatau Volcano based on Igan S. Sutawidjaja

Time	Activity	Explanation
1927, 1963, 2006	Development period IV (G. Anak Krakatau)	1927-1963: Cinder Cone, 1963 – present: composite cone Composition: Basalt-andesite Basalt
1961	Development period III (G. Rakata, G. Danan, G. Perbuwatan	Composite cone, pyroclastic lava flow, basalt-andesite
1883	Destruction period III	Tuffaceous pumice, thick and the spread area is almost 18km^2 Dacite-rhyolite
1200	Destruction period II	Tuffaceous pumice was blasted Dacite-rhyolite
After 416	Development period II	Composite cone was disappearing Pyroclastic basalt scoria remnant found at the southeast part of Panjang Island and northeast of Rakata Island
416	Destruction period I	Tuffaceous pumice at Rakata Island
?	Development period I (Ancient Krakatau Volcano)	2000 m height from sea level Composite cone composed of lava, pyroclastic basalt-andesite

On 22 December 2018, the one that triggered the tsunami is also (GA) Anak Krakatau Volcano. The volcano causes a landslide by its own body and triggered a tsunami with height between 1.5 meters to 3 meters in west coast of Banten and south coast of Lampung (Pandeglang, 2018). The tsunami in Banten Province resulted in deaths and damage to inland infrastructure (roads, electricity networks, telecommunications networks, wave walls), damage to buildings, and scouring of beaches in Cimanggu and Sumur Pandeglang, based on field observations. According to BNPB data on 29 December 2018, the tsunami incident resulted in 431 deaths, 15 people missing, 7,200 people were injured and 46,646 people were evacuated (Junaedi, 2019).

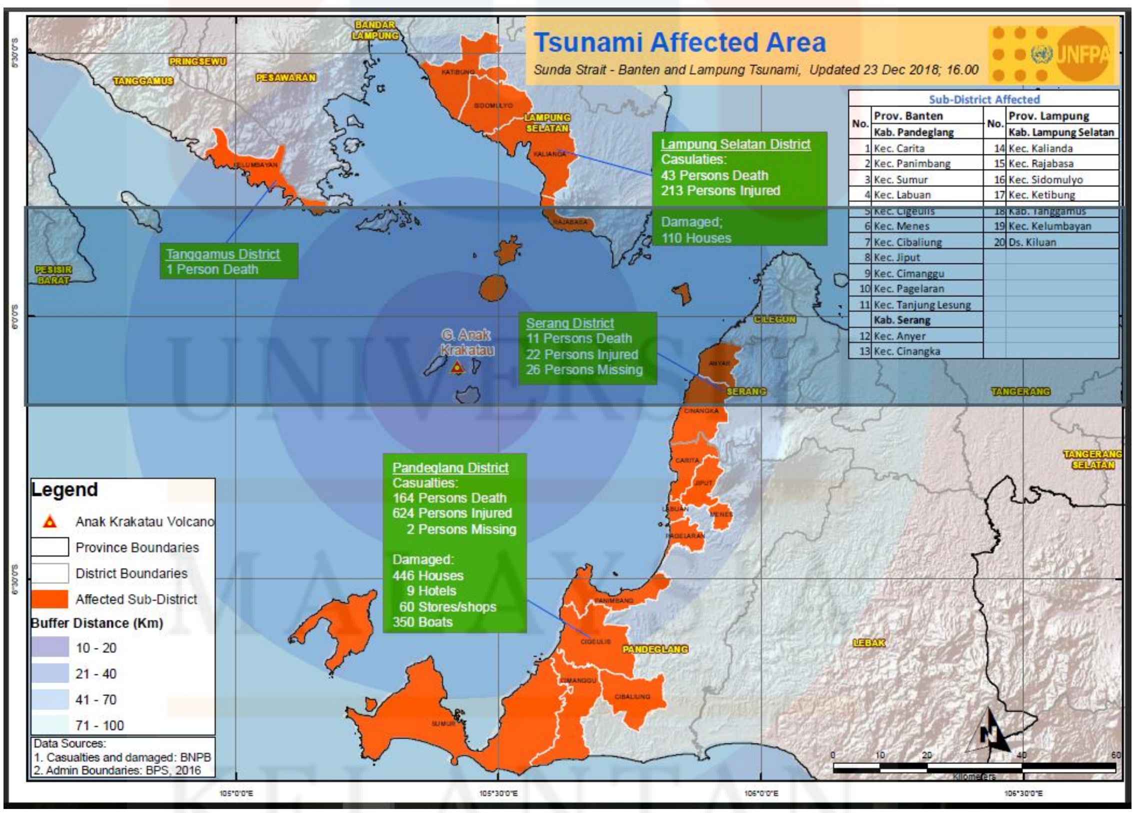


Figure 2.16 tsunami affected area

CHAPTER 3

MATERIALS AND METHODOLOGIES

3.1 Introduction

This chapter discussing about the materials and methodologies that will be used in order to achieve this research objective. Figure () shows the flow chart of the method that used in conducting this research.

3.2 Materials

3.2.1 Materials for Geological Mapping

The materials that used for geological mapping are includes raw base maps and geological tools like geological hammer, hand lens, compass, Global Positioning System (GPS), hydrochloric acid (HCl) and measuring tape.

a. Maps

A base maps is access by composing the map using GIS software. In the base map, include the important features such as contour, rivers, streets, and town to be use as a reference during mapping. Any preceding geological map is also important as the references about the study area.

b. Geological Hammer

Geological hammer is basic tool in field mapping and very important to collect fresh sample in study area. It will be use to break the rock to sampling and for further data analysis.

c. Compass

Compass is useful to get dip and strike reading of the feature structure of surface such as bedding plane, foliation, fault plane etc.

d. Global Positioning System (GPS)

GPS is the most accurate and global navigation system ever built. GPS can give people the exact position on Earth, how faster the user movement, how far and where the user traverse and so on. GPS also can be used to get the elevation of the study area and marking the localities of sampling stations.

e. Measuring Tape

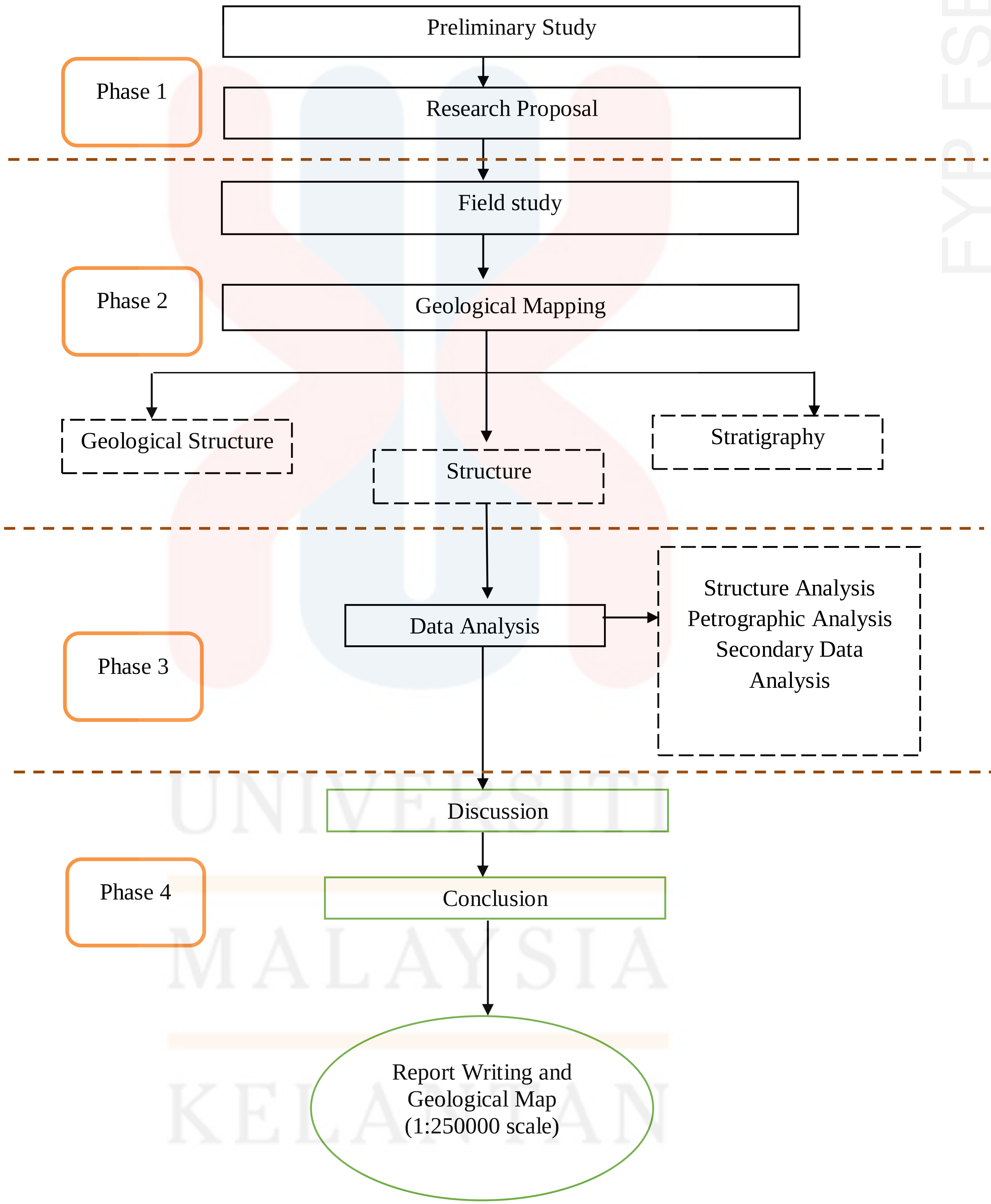
The measuring tape is important to get the actual measurement of outcrops. For an outcrop that has bedding lithology, it's very important to take the thickness of each layering that will be used to make a stratigraphy correlation with other formation.

f. Hand Lens

Hand lens is to make the first assumption and analysis of rock sample in the field. Hand lens is important to determine the mineral composition in the rock especially for fine grain rock that can be seen with naked eyes.

g. Hydrochloric Acid (HCl)

HCl are used to see the reaction of rocks towards acid which it will produce gas bubbles. Rocks such as limestone, dolomite marble and more that contain carbonate are mostly will reacts with HCl.


Preliminary Study
Phase 1
Research Proposal
Field study
Phase 2
Geological Mapping
Geological Structure
Structure
Stratigraphy
Structure Analysis
Petrographic Analysis
Secondary Data
Analysis
Data Analysis
Phase 3
Discussion
Phase 4
Conclusion
Report Writing and
Geological Map
(1:250000 scale)

3.3 Methodology

3.3.1 Preliminary Research

Before doing a research, an initial knowledge is important to study the problem statement or collecting the idea for the study area. The data collection would cover from many aspects like lithology, stratigraphy, sedimentology geomorphology, sediment structure and paleontology data that can help researcher to understand the theory behind the study area.

3.3.2 Field Study

Field study is the main resources for collecting of field data. Geological field mapping is a process to collect and identify all the geological structures that exist in the study area and to gain a detailed and precise data for geological data. Data that collected in the field includes the geological structure, stratigraphy and sedimentology of the study area. Field study is the most important phase for this research because field data can help much to provide an updated geological map.

a. Traversing

Traversing method is important to collect data in the study area. By traversing, the data collection become more precise and detail. Traverse is a surveying method to cover all the study area in collecting geological data. A plan must be planned carefully for entire study area in order to collect and gather data also to mapping rock types, which need to cover the entire study area. By studying the topographic maps will help in avoiding any areas that cannot be traversed by food or areas that can be accessed without permission.

b. Sampling

During the geological mapping, sample of fresh rocks will be taken from the outcrop of different and many localities to be analyzed in laboratory. Fresh rock sampling is important because weathered rocks maybe altered in mineral composition. The size of the rock sample is depending on its intended use such as for lithological analysis or petrographic analysis.

c. Surveying

Surveying is one of the simplest ways in collecting data. The survey that be conducted will discuss with the people that are expert in geological tsunami hazard in term of seismography to get the actual ideas about the tsunami. There are many researchers that involved in tsunami research which consist of geologists, universities' lecturers, and also coastal engineers. Data that collected from the tsunami events are important to become references to the next researcher. So, by surveying a certain person that experts in this field, the data collection can be more precise and more detailed about the hazards.

3.3.3 Laboratory Work

The laboratory work is done to prepare thin section for the rock samples, to determine the mineral composition and mineral properties of the rocks. A thin sliver of rock is cut from the sample with a diamond saw and ground optically flat. It is then mounted on a glass slide and then ground smooth using progressively finer abrasive grit until the sample is only 30 μm thick.

3.3.4 Data Analysis and Interpretation

a. Tsunami Data Analysis

The data collection is mostly from PVMBG Indonesia since the detail data are not published on website. PVMBG is the centre for geological hazard data such as earthquakes, tsunami, volcano and more hazards that related to geology. The data that collected then will be digitised in ArcGis to produce hazards map by plotting the coordinate of the data given.

b. Petrographic Analysis

The rock samples that are take in the field studies are determined by thin section in laboratory. Petrographic analysis is an important method to determine the mineral composition of the rocks. This analysis is done to precisely determine the rock types and the mineral composition of the rocks.

3.3.5 Final Report Writing

All the findings are written in a report that must consist of geological map. After the data is analyzed and discussed, this research is concluded and recommendations are given for further research.

CHAPTER 4

GENERAL GEOLOGY

4.1 Introduction

4.1.1 Accessibility

Carita, Pandeglang, Banten is located between Serang and Labuhan which makes it easy to access by Jalan Ciateri where Jalan Ciateri is highway that connect Serang and Labuhan. Mostly in the study area is easy to access, but there are some places such as in nouth-eastern part of the study area that is hard to access because of heavy forest and some places is need permission to access. While the other part can be accessed by vehicle because of agriculture activities and heavy settlement.

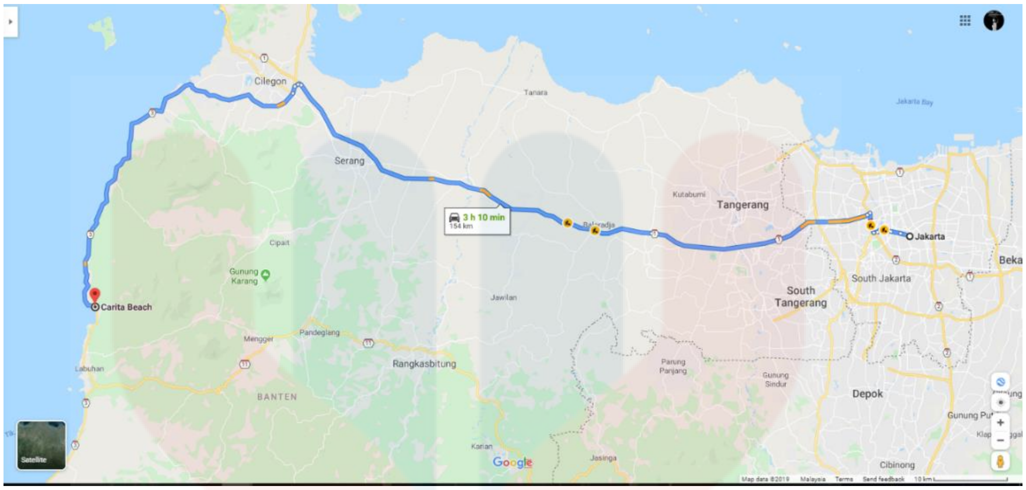


Figure 4.1 Accessibility from Jakarta to Carita, Banten

Figure 4.2 Ciater Highway

Figure 4.3 Accessibility inside the study area. Mostly of the road in the study area are unpaved road

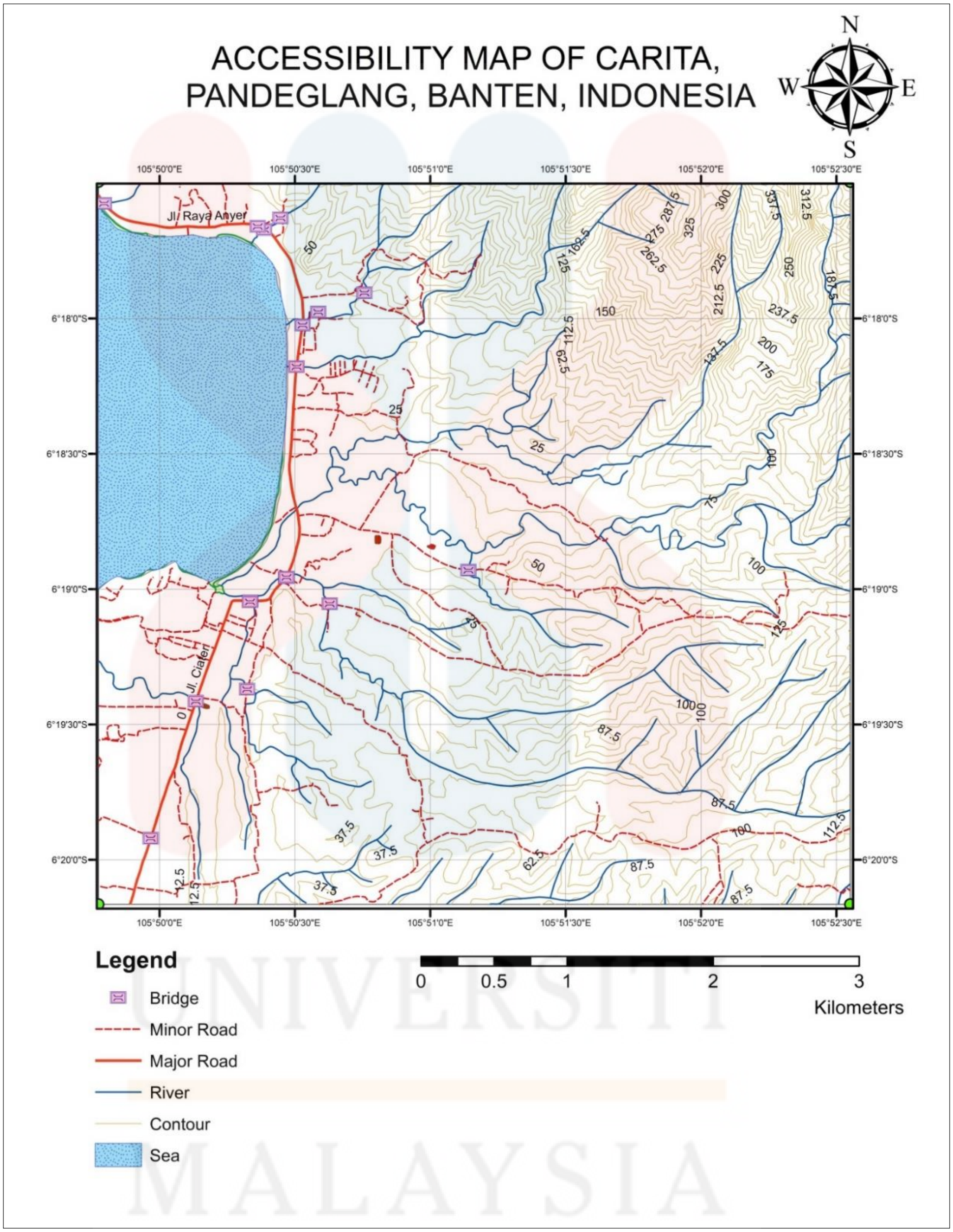


Figure 4.4 Accessibility map in study area

4.1.2 Settlement

Carita area is largely dominated by citizen area. There are many small villages that live by the locals and they do their own agriculture for daily living and mostly the village is located near the coastal area. Carita also have many chalet, apartment and hotels for tourism purpose since Carita is a tourism spot. Others than resident's area, there also have school, mosque, police station and many small shop such as Indomaret, Alfamart, workshop and more. Figure 13 and 14 shows the apartment and small shop in the study area.

Figure 4.5 Apartment along the beach area

Figure 4.6 Mini market in study area

4.1.3 Forestry and Landuse

In Carita area, there are many agriculture areas which is the main agriculture activity is rice crop (paddy field). The resident there still using old methods in paddy agriculture such as using cattle to plowing the land. Most of the plantation is privately own by the residents itself. Almost three quarter of the study area is covered by agriculture area.

But, in the north-eastern part of the study area, there is a heavy forest which is own by WISATA, the government forestry agency. It hard to access since the visitors need to have a permission from the government or have someone to guide that tracks.

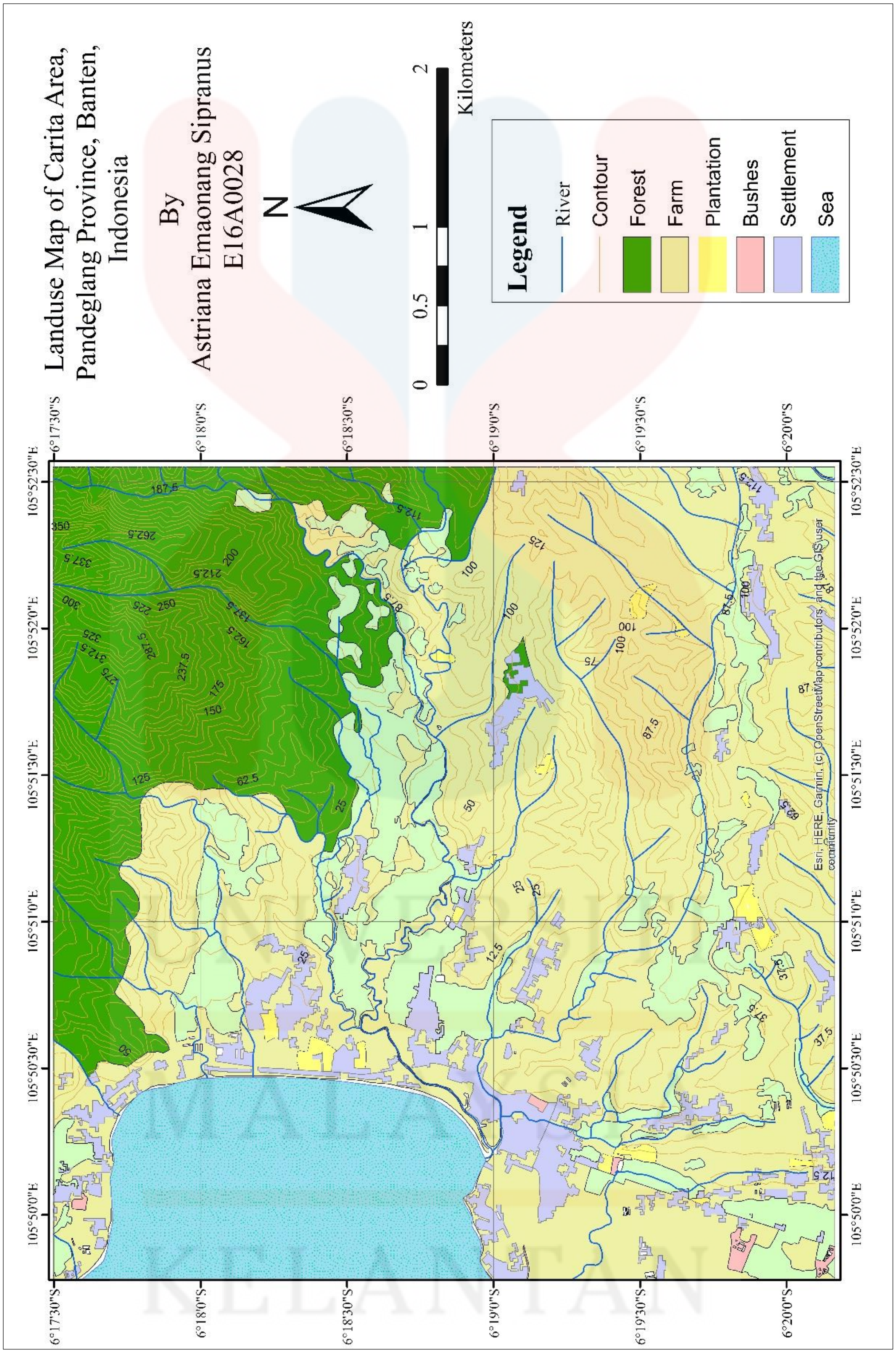


Figure 4.6 Landuse map in study area

Figure 4.8 Paddy field in the study area

4.1.4 Traverse and Observation

Traverse is a method of surveying the study area to collect geological field data and make sure that the study area is fully covered. All station or checkpoint to collect data is divided by the activities distribution in the study area. The checkpoints are including rock sampling, geomorphological observation, structural measurement.

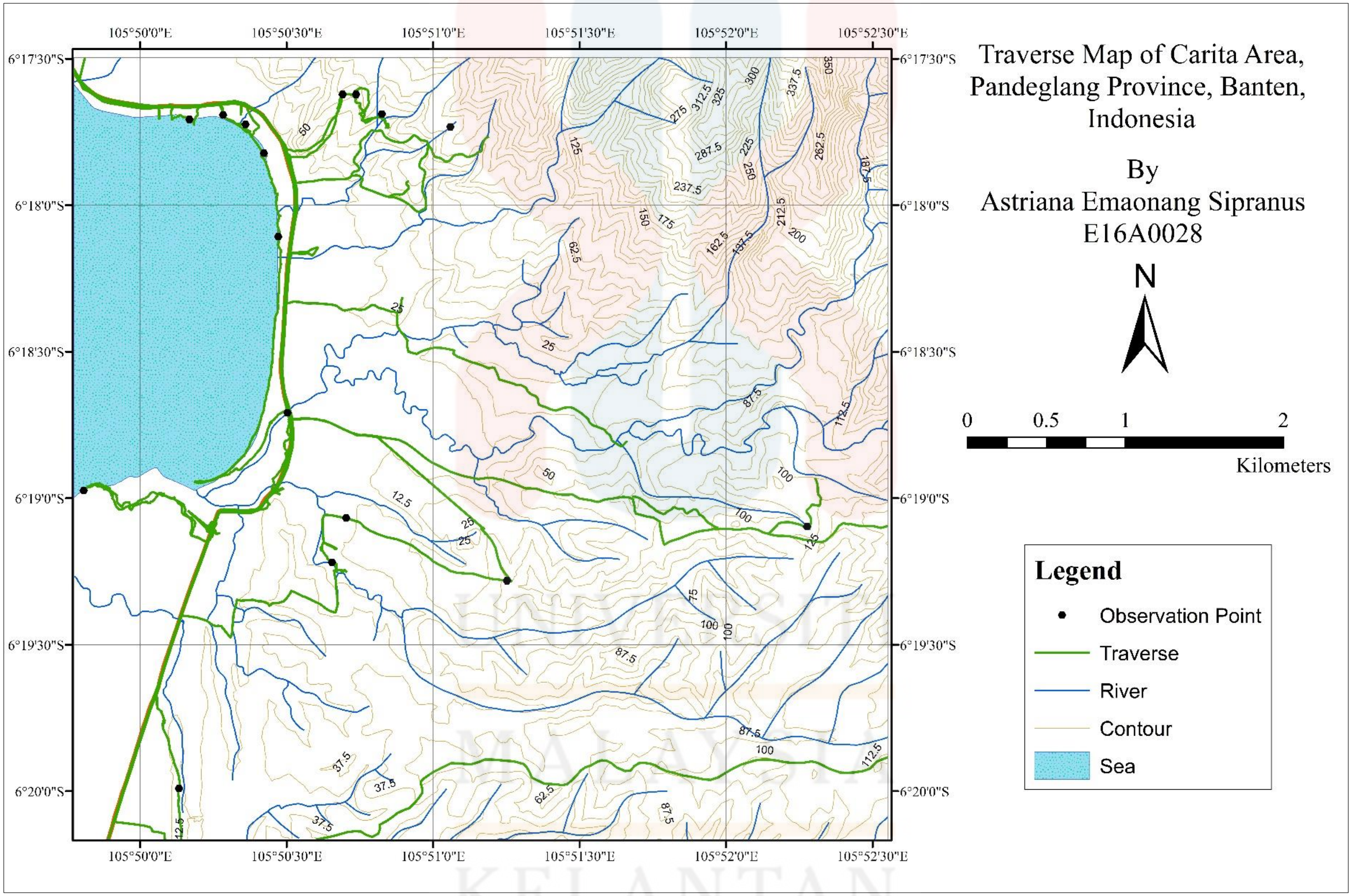


Figure 4.9 Traverse map in study area

4.2 Geomorphology

Geomorphology is a study that related to the Earth' surface landforms. Geomorphology is sit between the natural environment's study; the physical geography, and the study of solid Earth; geology. The geomorphology study is associated with other environmental systems; hydrology, climatology, and pedology (soil science). Geomorphology also related geology's sub-disciplines, mostly with tectonics activity and

4.2.1 Geomorphological Classification

The geomorphology of the study area based on the topography map is classified into rolling to undulating landforms; near with the beach. The classification of the topographic unit is based on the difference in mean elevation that can be distinguished according to five broad topographic units (Table 4.2).

Table 4.1 Classification of topographic unit

Classification	Topographic unit	Mean Elevation
1	Low lying	<14
2	Rolling	15 – 30
3	Undulating	31 – 75
4	Hilly	76 – 300
5	Mountainous	>301

(Source: Hutchison and Tan, 2009)

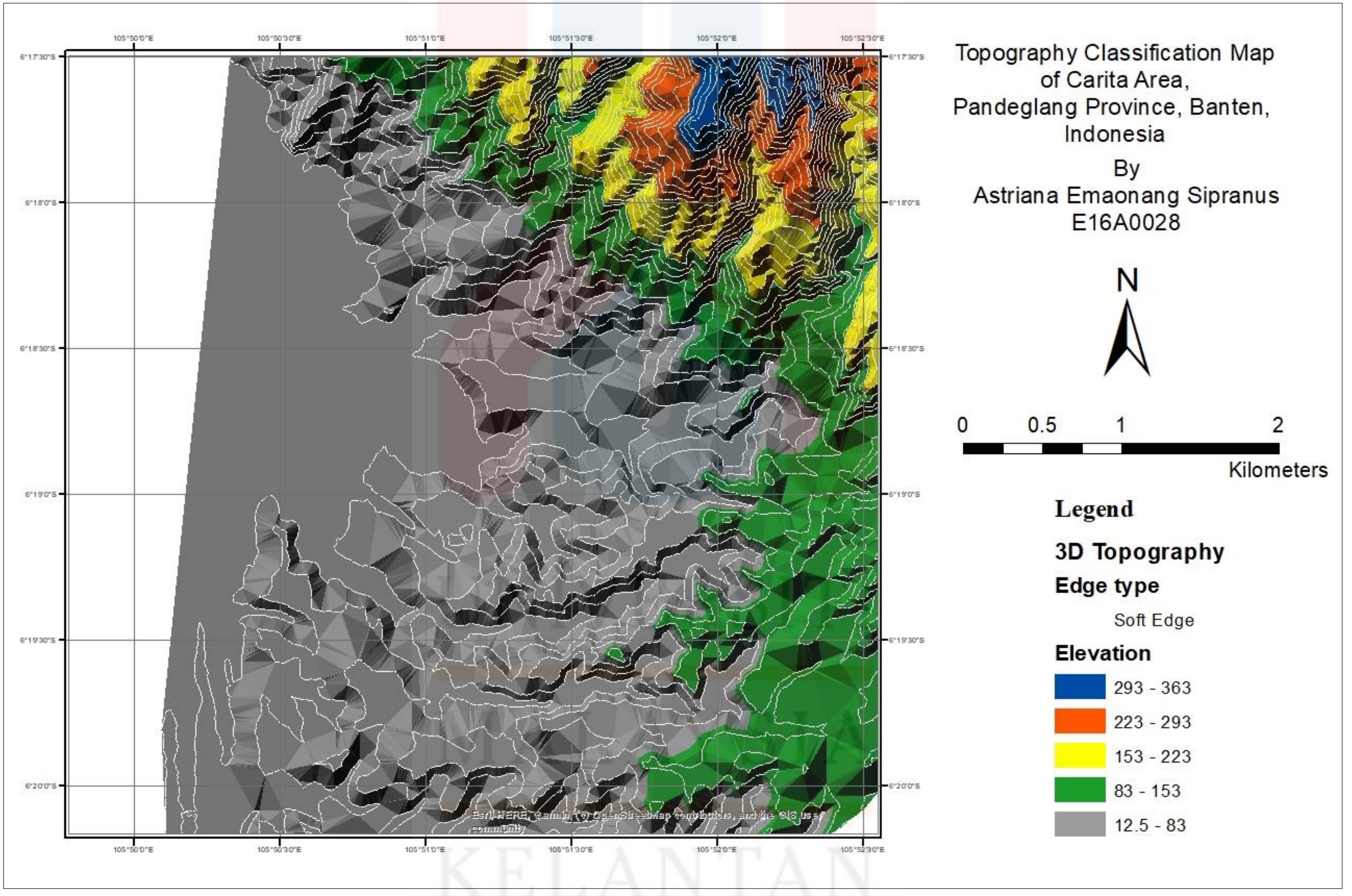


Figure 4.10 Topography map in study area

4.2.2 Drainage Pattern

A stream is a source of flowing surface water of any length, varying from a small trickle to a mighty river. It is regarded as its drainage basin as the area from which the water flows to form a channel ("13.2 Drainage Basins – Physical Geology," n.d.). Drainage pattern is the pattern generated by rivers, streams and lakes in a specific drainage basin which are controlled by the land topography, whether a specific area is controlled by hard or soft rocks, and the behaviour of bedrock structures ("Types of Drainage Patterns," n.d.). There are several forms of drainage pattern which are dendritic, trellis, parallel, radial, rectangular, centripetal, and angular pattern.

The study area is dominated by the dendritic type of drainage pattern where dendritic drainage pattern is the most frequent patterns found. The dendritic pattern is formed in areas where the rock (or unconsolidated material) underneath the stream does not have any specific fabric or structure and can be stripped away in all directions fairly easily. Dendritic drainage patterns appear like tree branches with lots of twigs, formed in areas such as sandstone or shale with flat and uniform bedrock. There is no significant influence over the course of the tributaries since the underground geology has similar weather resistance ("Drainage Patterns," 2012.)

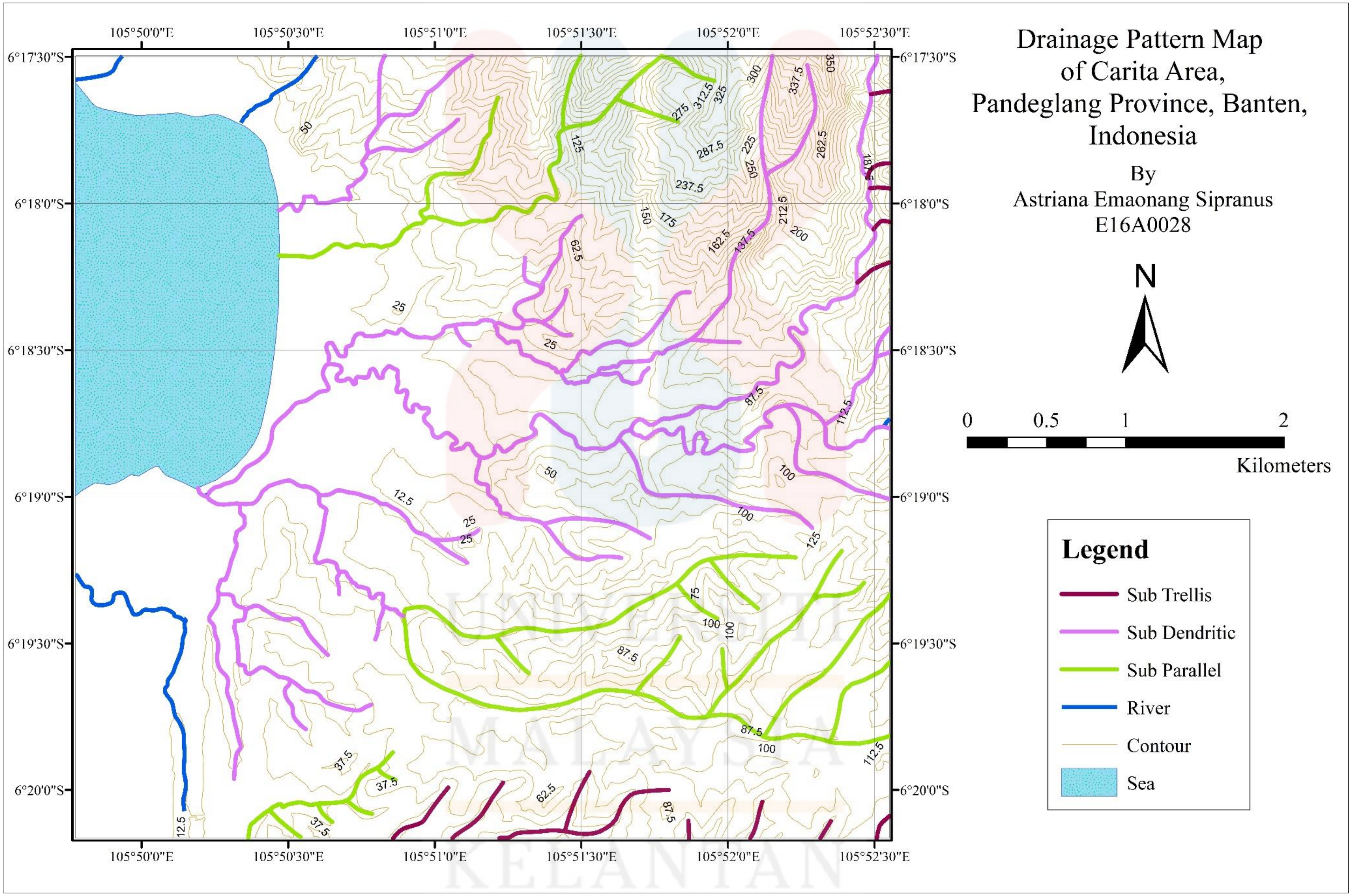


Figure 4.11 Drainage pattern map

4.2.3 Weathering

a) Physical Weathering

The physical weathering or mostly known as mechanical weathering is geological process that involved breaking rocks apart without any changing in chemical content of the rocks. The rock is breaking apart as a result from the mechanical or physical forces that act on the rocks such as pressure and temperature.

In the study area, this is one of the common weathering type that can be found on the rock. The basalt outcrop in figure 1 shows the mechanical weathering that formed due to change in pressure and temperature that act on the rock. This processes cause the rock from the parent rock fell and from boulders.

Figure 4.12 Basalt boulders

b) Chemical weathering

The chemical weathering is a geological process of disintegration of rock materials that involve the changing of chemical content to break apart the rock into smaller pieces by chemical mechanism. The disintegration of the rock is generally through oxidation, hydrolysis and solution. The chemical weathering in study area is in high rate due to the location is near with the ocean. The wind itself contain salt (sodium chloride) that can react with the rocks that presence. ("Geological Society - Chemical Weathering," n.d.)

Figure 2 shows the chemical weathering between the basalt boulders and the water (hydrolysis). Water causes both chemical weathering and physical weathering. The chemical weathering take place when the water is dissolving the minerals content in a rock and form new compounds. This chemical reaction is known as hydrolysis.

Figure 4.13 Chemical weathering. Interaction between water and rock (hydrolysis)

c) Biological weathering

Biological weathering is referring to the disintegration of rock or breaking rock into small materials by the activity of plants, animals and microorganisms. The rocks receive pressure and stress by the growing plants roots. The penetrating and contracting force of the plant roots in cracks, fractures, pores and other discontinuities might cause the rock to crack and disaggregate if favorable conditions and the rock strength is lower than was enforced by the plant roots (de Oliveira Frascá & Del Lama, 2018).

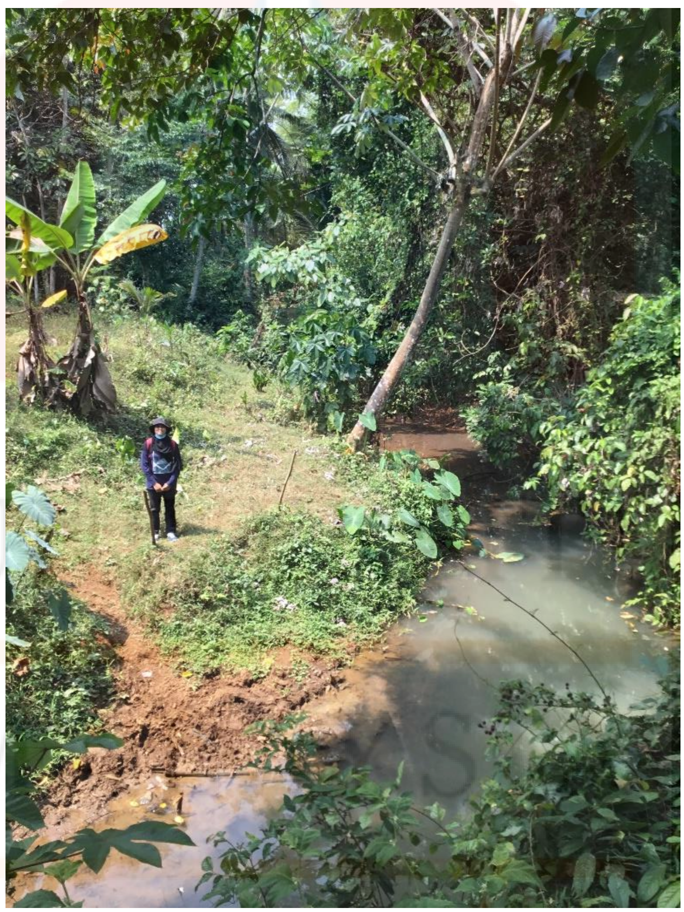


Figure 4.14 Biological weathering

4.3 Lithostratigraphy

Stratigraphy is a scientific study of geology that are related to the strata (rock layers) and the explanation of rock succession and their analysis in term of general time scale. It is mainly used in the sedimentary and layered volcanic rocks study. Based on Boggs, 2011, stratigraphy is a science of study of or study of sedimentary rock strata (layers).

4.3.1 Stratigraphic Position

The stratigraphic position is arranged from the oldest to the youngest for the lithology unit in the study area which is basalt, alluvium and beach alluvium respectively. All the lithology are from Holocene age, with the formation of Young Volcanic Rocks (Qhv) and Alluvial and Beach Sediments (Qa) (U. & Soemantri, 2012).

The oldest lithology is basalt unit that from Young Volcanic Rocks Formation, then followed by alluvium and beach alluvium in Alluvial and Beach Sediments Unit. The stratigraphic column is shown in table 3 for the lithology found in the study area.

Table 4.2 Stratigraphic column

<table>
<tr><th>Rock Unit</th><th colspan="2">Age</th><th colspan="2">Lithology</th><th>Description</th></tr>
<tr><td>Alluvium</td><td rowspan="2">Quaternary</td><td rowspan="2">Holocene</td><td>Alluvium Beach</td><td>Alluvium Soil</td><td>Consist of marine sediment and alluvial.</td></tr>
<tr><td>Basalt</td><td colspan="2">Basalt</td><td>Volcanic rocks that found is basalt with rounded shape along the low slope are of Gunung Malang</td></tr>
</table>

4.3.2 Unit Explanation

The study area is composed of two main lithology units which are Young Volcanic Rock and Alluvial and Beach Sediments. Young Volcanic Rock is consisting of basalt while Alluvial and Beach Sediments consist of alluvial soil and marine sediment. Alluvial are the one who dominating the lithology in the study area.

a) Basalt

The outcrop is located at foot slope of Mount Malang where it's found at northeast part of the study area. The outcrop is found in boulders type and scattered around the foot slope. Based on the observation, the boulders are falling from the upper part of the Mount Malang which are believe to be an ancient caldera. The landform around the outcrop is mostly hilly landform and the outcrop is covered by some vegetation.

Figure 4.15 Basalt in the study area

Basalt is a dark-coloured, fine-grained, igneous rock composed mainly of plagioclase and pyroxene minerals. It most commonly forms as an extrusive rock, such as a lava flow, but can also form in small intrusive bodies, such as an igneous dike or a thin sill.

Figure 4.16 Hand Specimen of Basalt

From the hand specimen in figure 7, the texture if the rock is had a fine grain size but still can be seen by naked eyes and this rock is igneous rock; the hardness is quite hard. This is mainly composed of pyroxene and plagioclase minerals. the colour is dark-coloured and the outside part of the rock has brownish colour that show the oxidation occurred (chemical weathering).

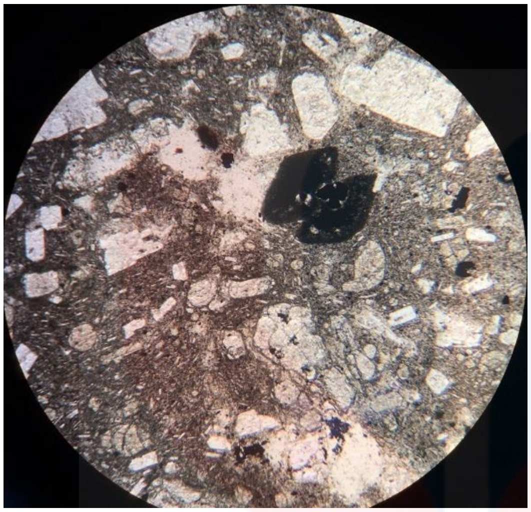


Figure 4.17 Plane polarized basalt

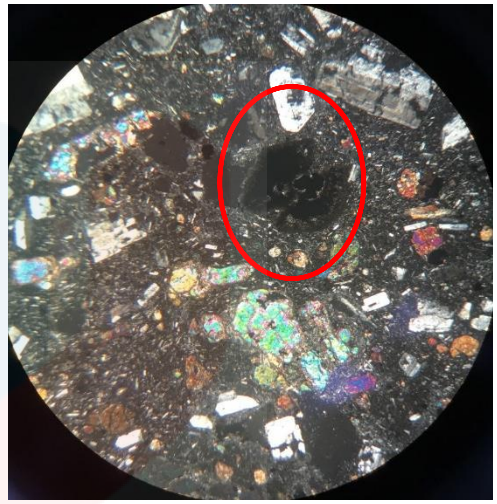


Figure 4.18 Cross polarized basalt

Based on microscope analysis, this rock is dominated by pyroxene and plagioclase. The texture of this rock is aphanitic since the mineral can be seen by naked eye. In Figure 35 and 36, the petrographic analysis of volcanic basalt show the mineral was compacted. The rock is heterogeneous mixture of glass and crystal fragments. The one with red circle is opaque mineral which it is maybe a metal mineral.

A basalt is a fine-grained basic igneous rock containing essential calcic plagioclase feldspar and pyroxene, with or without olivine. Basalts can also contain quartz, hornblende, biotite, hypersthene (an orthopyroxene) and feldspathoids. Basalts are often porphyritic and can contain mantle xenoliths. As basic rocks they contain between 45-50% silica, abundant Fe, Mg and Ca, and little Na and K.

b) Alluvial

The study area is mostly covered by alluvial soil which most half of the study area are alluvial soil. Active agriculture activities in the study area is shown that most of the area is alluvial soil. the Alluvial soil is materials of loose sediments that transported by water and wind that consists of clay, silt, sand, gravel or other unconsolidated material that deposited during recent geologic time.

Figure 4.19 Alluvium that deposited along the river

c) Beach Alluvium

Beach and alluvial sediments (Qa) are distributed along the west coast of the studied area, where the lithology consists of gravel, gravelly sand, silt and clay, mud, and gravel pumice beaches locally mixed with pieces of mollusc shells. Also, along the beach in the study area, the sand has black colour sediments.

Based on XRF (X-ray fluorescence) analysis, the beach alluvial in study area consists of 64.49% of hematite (Fe_2O_3), 18.08% of titanium dioxide (TiO_2), 6.7% of silicon dioxide, 3.60% of aluminium oxide (Al_2O_3), 3.09% of magnesium oxide (MgO) and others are calcium oxide, manganese oxide, phosphorus pentoxide, sulphur trioxide and potassium oxide. Figure 4.20 shows the magnetic reaction of beach alluvium to an IPad.

Figure 4.20 beach sand with black coloured that attached to an IPad

Figure 4.21 Beach area with black sand

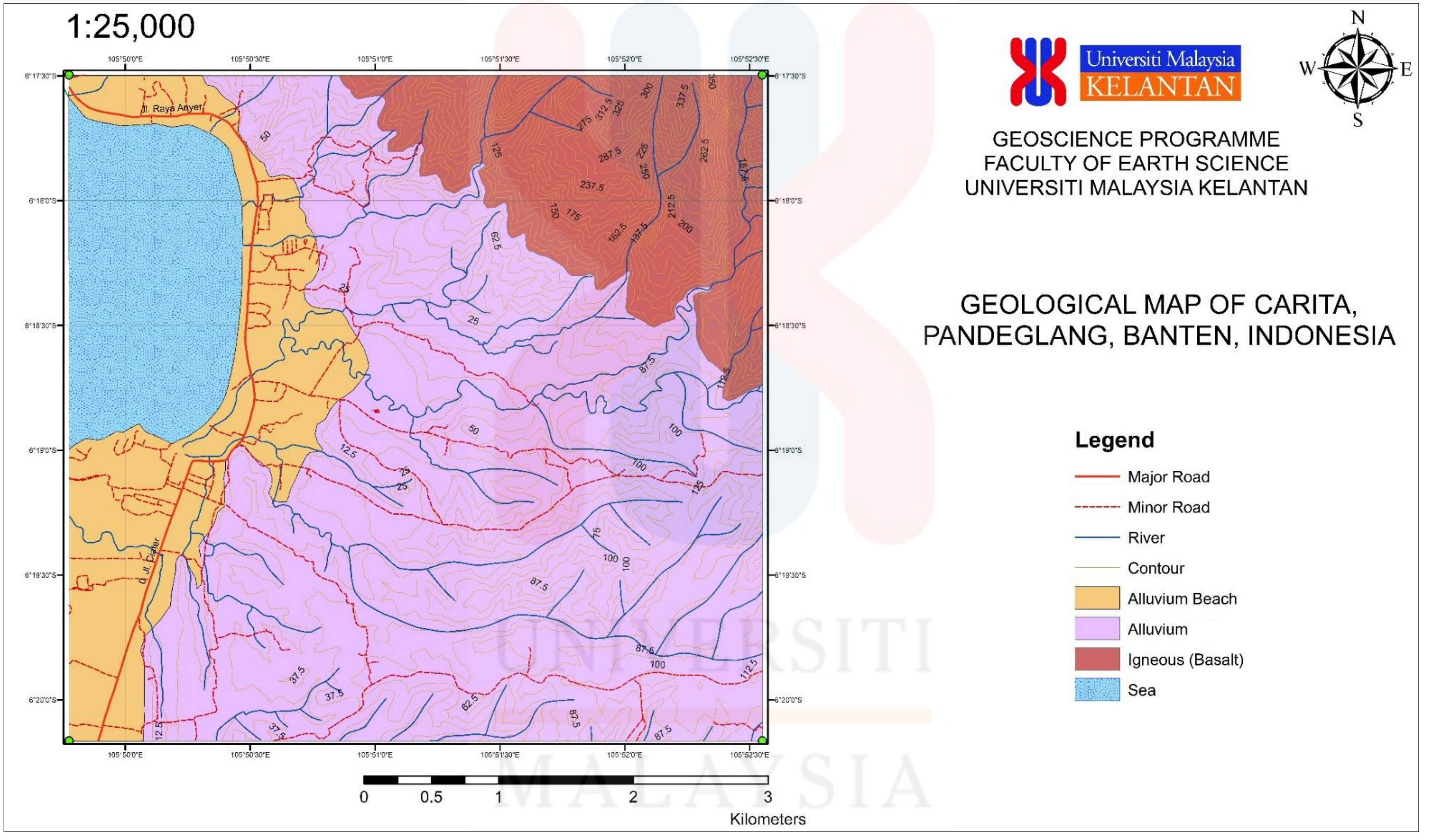


Figure 4.22 Lithology map

4.3.3 Historical Geology

The geological formation of the study area is consisting of Young Volcanic Rock which are from Mt Asupan with age from Holocene age and it overlies unconformably the older rock. The geological structure in the study area is hard to find since almost all the area was excavated for agriculture purpose.

But from the past research, the study area; to be more specific, the coastal line has this characteristics: slope less than 10° and the difference in height between the land and sea level is less than 3 m. The study area also consists of Lower Tuff Banten, but due to excavation, the outcrop was difficult to found.

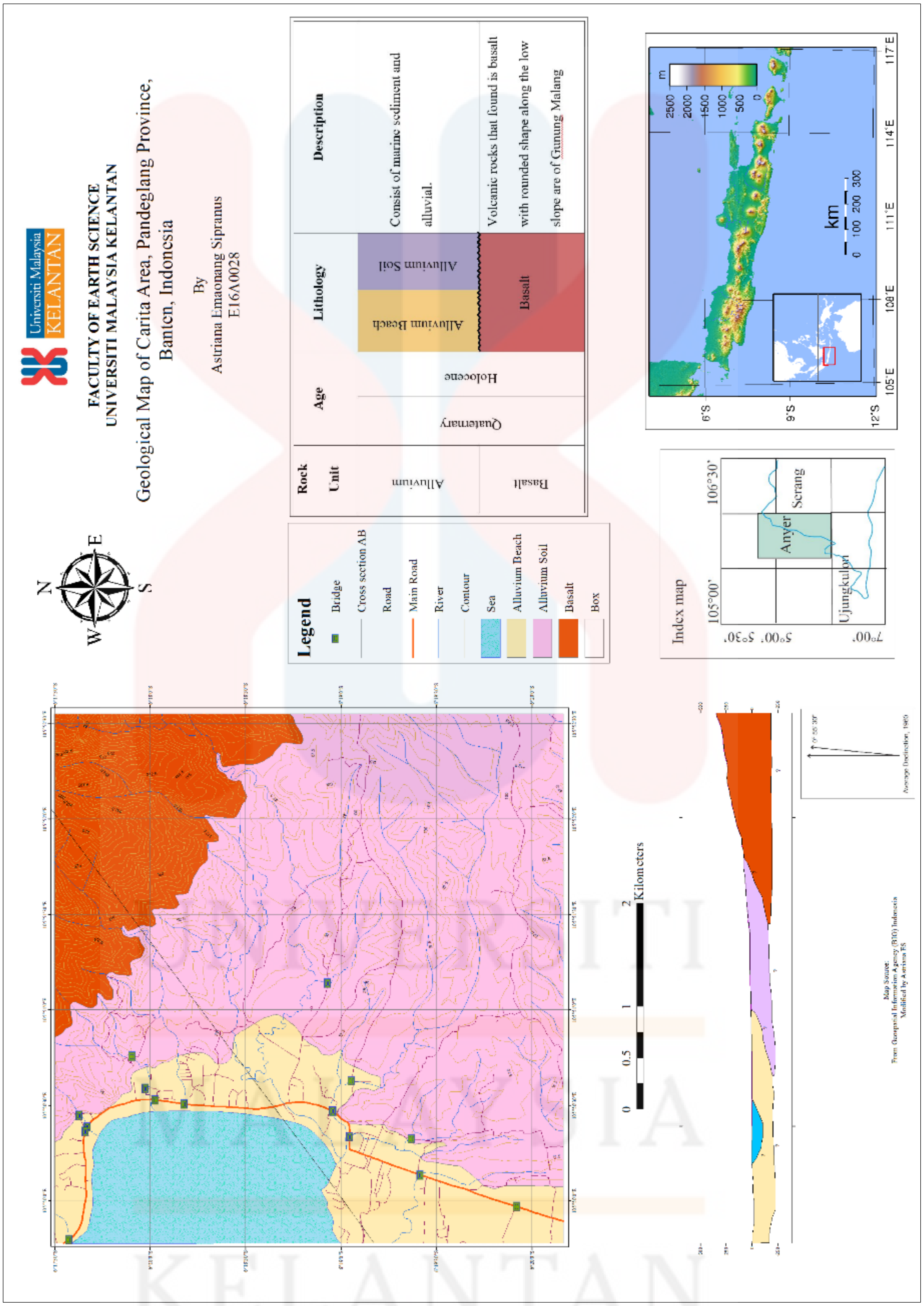


Figure 4.23 Geological map of study area

CHAPTER 5

TSUNAMI ANALYSIS

5.1 Introduction

This chapter will cover the tsunami analysis including Carita tsunami history, the chronology and tsunami characteristics which as include flow depth, tsunami height, run-up distance and tsunami historical data in Carita area, Banten, Indonesia. Tsunami analysis is done to regulate the characteristic of the tsunami that occurred in December 2018.

5.2 Chronology of Tsunami Sunda Strait 22 December 2018

5.3.1 Tsunami Cause Analysis

Before the tsunami took place, (GA) Anak Krakatau Volcano was erupted continuously since June 2018 and fluctuated but there was no significant in intensity. Tsunami that occurred on 22nd December 2018, was triggered by a landslide or flank collapse of GA Anak Krakatau specially in south and southwest zone.

5.3.2 Anak Krakatau Volcano Chronology

i. 21 December 2018

- there is movement solid mass in which showed with recorded volcanic tremor with over scale.

Figure 5.1 Volcanic tremor 21 December 2108. Source PGA GAK Pasauran post

ii. 22 December 2018

- dense masses breaking the body of the south-western mountain resulted in avalanches of his body and pressured sea water to cause a tsunami followed by a directed blast.

Figure 5.2 Phreatomagmatic eruption on 23 December 2018, continues towards the **southwest**
Source TNI AL crew

iii. 4 January 2019

- vertical eruption that destroy volcanic body eastern part and north and column ruins smoke towards Panjang Island to scorch all over trees in that island.

Figure 5.3 Vertical eruption
Source; Oystein

iv. 9 January 2019

- Phreatomagmatic eruption is weak and continues to weaken until now and returns to normal.

Figure 5.4 Phreatomagmatic eruption
Photo source: Daniel Moyano

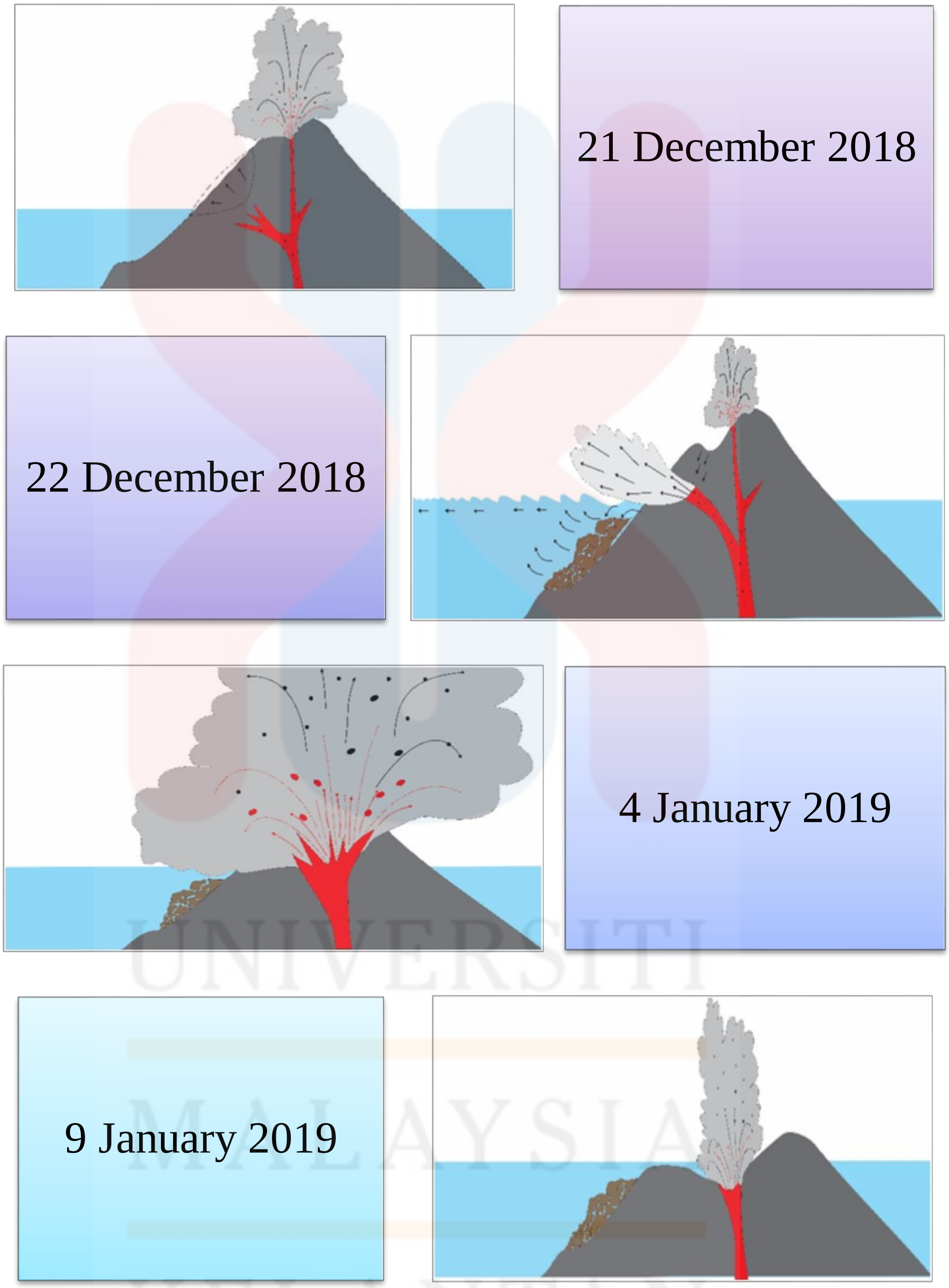


Figure 5.5 Anak Krakatau Volcano Chronology

5.3.3 Carita Tsunami Chronology

On 22nd December 2018, around 21:30 WIB, the Sunda Strait area was struck by a tsunami that cause severe casualty in Banten and Lampung provinces. 431 lives, 7,200 injured and 46,646 was claimed by the tsunami based on the data from BNPB. Based on the tidal station of Geospatial Information Agency (BIG), the information of the first wave's time and the first tsunami height are:

i. Marina Jambu Station (Desa Bulakan, Cinangka District, Serang Regency, Banten) arrived at 21:27 WIB with height 1.4 m.
ii. Banten Station (Ciwandan Port, Kota Cilegon, Banten) arrive at 21:40 WIB with height 0.27 m.
iii. Kota Agung Station (Kota Agung District, Tanggamus Regency, Lampung) reached at 21:35 WIB with height 0.31 m
iv. Panjang Station (Panjang Port, Lampung City, Lampung) reached at 21:27 WIB with height of 0.36 m.

5.3 Tsunami Data Collection

Tsunami inundation is the tsunami's final and most harmful stage. Tsunami inundation refers to the inland range that a tsunami waves scatters and changes for each tsunami-affected shore or harbour. Due to the complex variables associated with varying bathymetry, topography and elevation along coastlines, simulation of this process is very difficult.

The measurement is recorded after the tsunami occurred in December 2018 by Emergency Response Team (TTD) of Geology Department (Badan Geologi, BG) with Energy and Mineral Resources Province Banten team. This team record that the flow depth (FD) after the tsunami is between 10 cm to 390 cm, where the highest flow depth;390 cm is at Kg. Sumur, Sumberjaya, Sumur District, Pandeglang Regency. The tsunami height (TH) from the coastline is range from 100 cm to 562 cm. the run up distance (RD) is range from 6 m to 274 m. The furthest RD; 274 m is located at Desa Banyuasih, Cigeulis District, Pandeglang District. The condition that happened is because of the shore has sloping characteristic, low vegetation and also lack of coastal embankment where mostly, the coastal embankment was damaged by the tsunami.

Based on Figure 5.9, tsunami zonation map, the region with red colour indicates the most damage area that was struck by tsunami with the highest flow depth is up to 330 cm and the run up distance is in range to 175 m from the coastline with highest destruction. The zonation is done by plotting the coordinates for every flow depth and run-up distance.

Figure 5.6 Tsunami sediments deposits used to measure the RD

Figure 5.7 Water mark for FD measurement

Table 2.1 the data that collected by BG and TTD

No	Location measured	Longitude	Latitude	FD (cm)	TH (cm)	RD (m)	Explanation
1	Kasepan, Sukajadi, Carita	105° 51' 15.68"	6° 9' 45.89"			107	
2	Kasepan, Sukajadi, Carita	105° 50' 29.49"	6° 18' 39.07"	54			FD: 93 m from shore
3	Kasepan, Sukajadi, Carita	105° 50' 27.34"	6° 18' 40.68"	176			FD: 46 m from shore
4	Cibenda, Sukarame, Carita	105° 49' 37.01"	6° 17' 17.32"	330			FD: 60 m from shore
5	Cibenda, Sukarame, Carita	105° 49' 36.24"	6° 17' 16.05"	310			FD: 37 m from shore
6	Cibenda, Sukarame, Carita	105° 49' 40.944"	6° 17' 18.564"			137	
7	Cibenda, Sukarame, Carita	105° 49' 37.84"	6° 17' 19.083"	80			FD: 39 m from shore
8	Dukuh, Sukanegara, Carita	105° 49' 37.06"	6° 14' 41.35"	275			FD: 48 m from shore
9	Dukuh, Sukanegara, Carita	105° 49' 41.45"	6° 14' 44.57"			157	
10	BTS Smartfren, Carita	105° 49' 43.82"	6° 15' 42.12"		526		
11	Bts Smartfren, Carita	105° 49' 44.11"	6° 15' 42.59"	315			FD: 8 m from shore
12	Bts Smartfren, Carita	105° 49' 47.49"	6° 15' 43.32"			191	

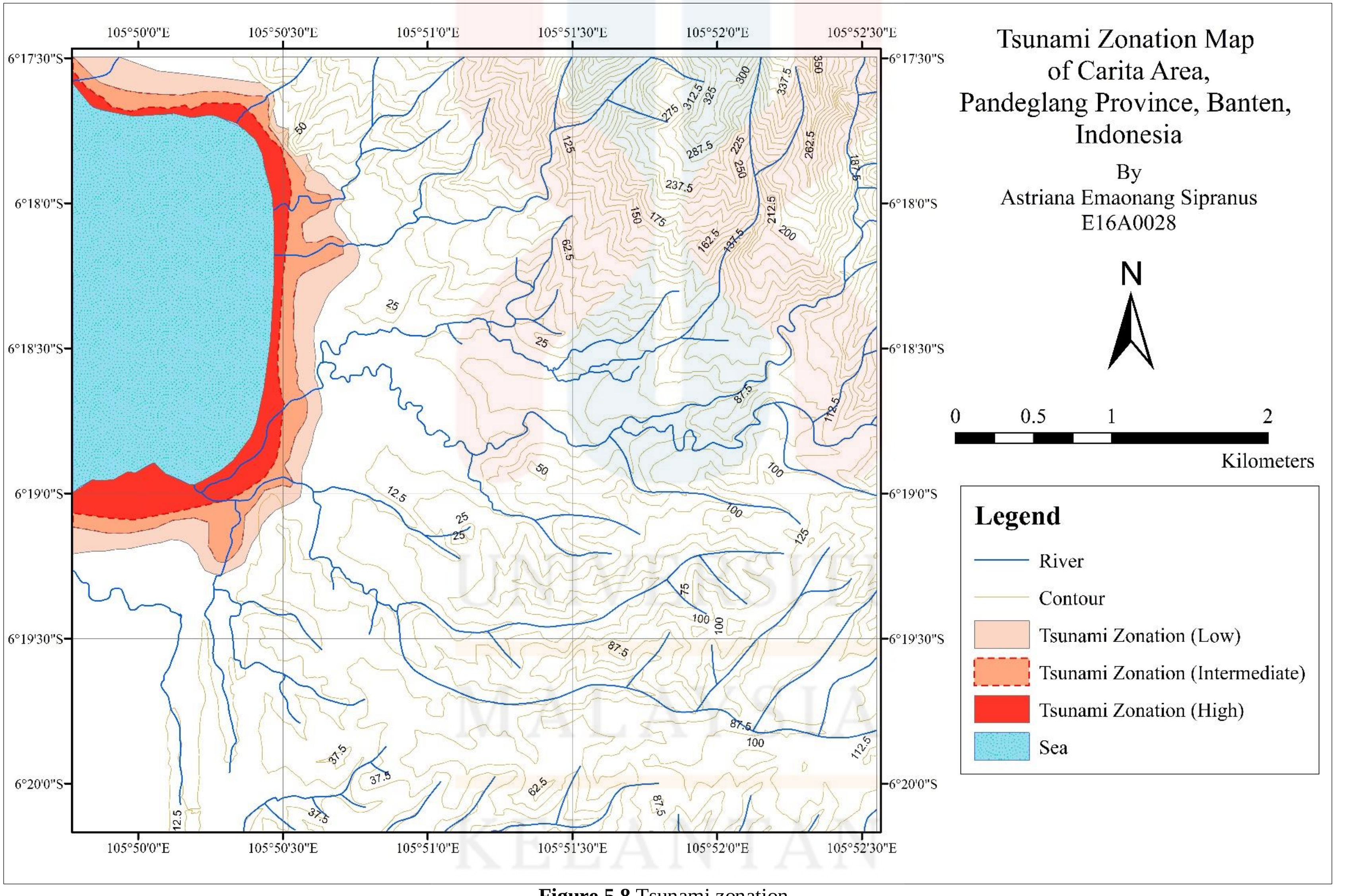


Figure 5.8 Tsunami zonation

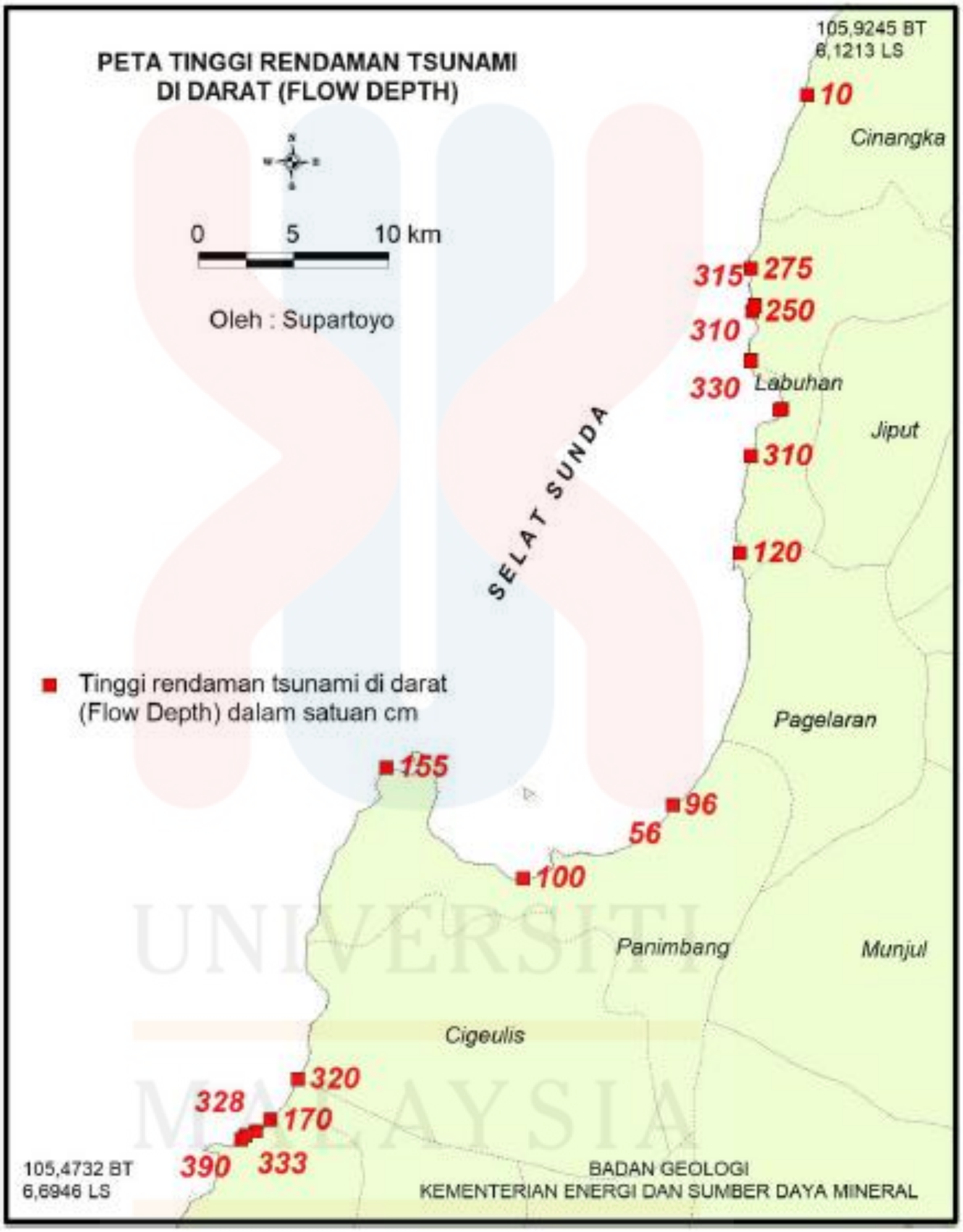


Figure 5.9 Flow depth map. Source from PVMBG

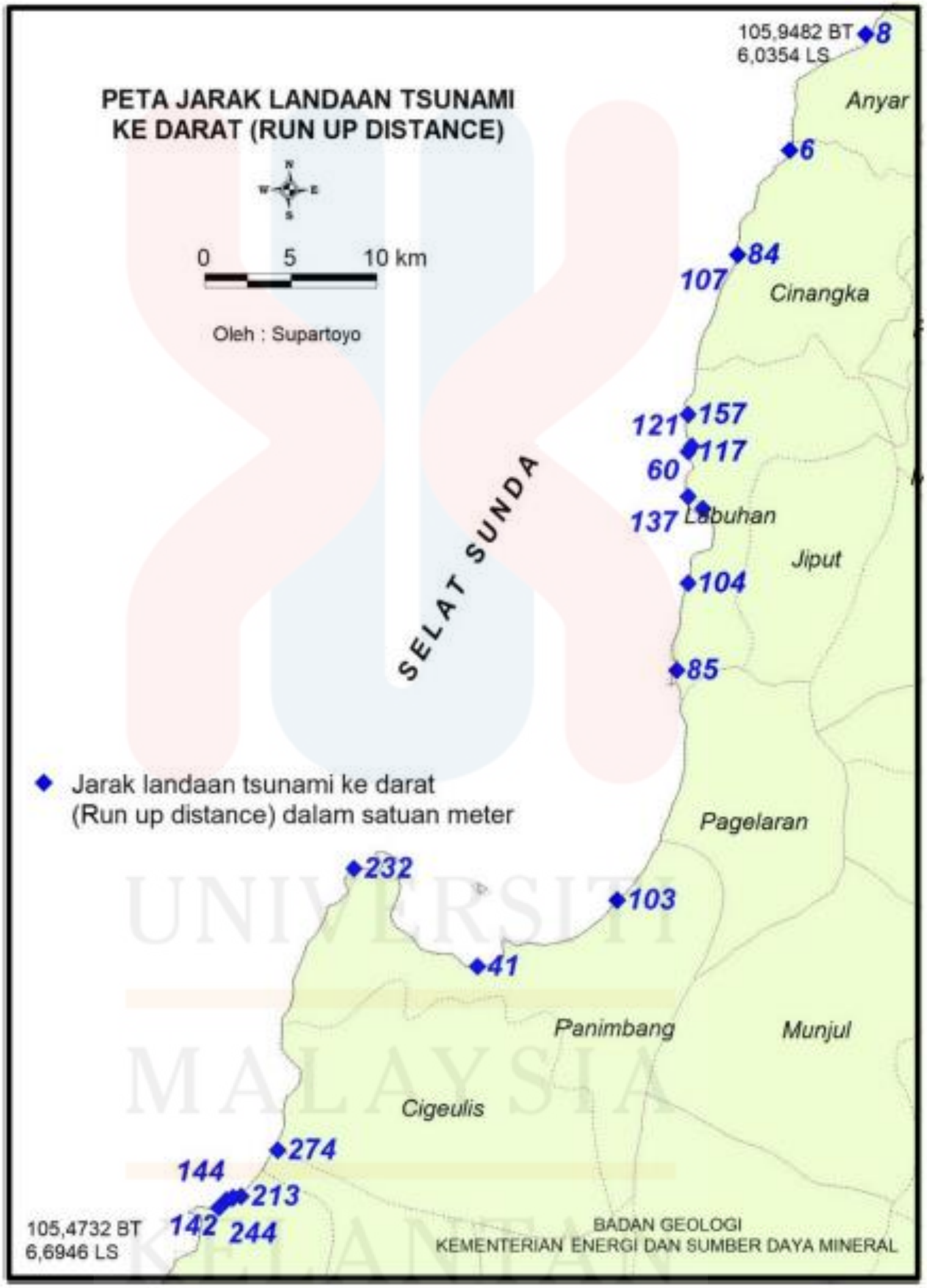


Figure 5.10 Run Up Distance map. Source PVMBG

CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Conclusion

In conclusion, the aims of this thesis have been accomplished, which the main objectives for this thesis to be achieved are to update the geological map of the study area with a scale of 1: 25,000 and also to evaluate the tsunami risk to generate the study area's tsunami hazard map.

Roughly, the main objective of this research is achieved by producing geological map of the study area, which is in Carita area, Banten, Indonesia. From the geological map, there are two units that can be found which are young volcanic rock unit, alluvial and beach sediments unit. Young volcanic rock unit was composed by basalt while alluvial and beach sediments unit is composed of soil alluvium and beach alluvium. The age for both units is from Holocene.

As for the next aims, the geological hazard analysis that occurred in study area can be determined only in secondary data since the tsunami's evidence already disappear because of cleaning process by rain and also the citizen doing. But, the tsunami geological hazard map can be produced by using secondary data that collected after the tsunami struck.

6.2 Recommendation

Recommendation is quiet important in order to improve the quality of the data or outcome in the future. As for the geological mapping, the methods to be used must be more advanced than normal geological mapping. Since the study area is dominantly covered by alluvium soil, the rock is already buried beneath it. So it to better use drilling or borehole in order to get the more accurate data.

APPENDIX

Kode sampel (*sample code*)	: AES-P4D7	Tanggal diterima (*received date*)	: 3 September 2019
Kode lab. (*lab. code*)	: 118/2.2/19/0652	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
Fe2O3	64.49	0.24	Fe	45.10	0.17
TiO2	18.08	0.19	Ti	10.84	0.12
SiO2	6.70	0.13	Si	3.13	0.06
Al2O3	3.60	0.09	Al	1.91	0.05
MgO	3.09	0.09	Mg	1.86	0.05
CaO	2.35	0.08	Ca	1.68	0.05
MnO	0.618	0.031	Mn	0.479	0.024
P2O5	0.0674	0.0034	Px	0.0294	0.0015
SO3	0.0341	0.0017	Sx	0.0137	0.0007
K2O	0.0132	0.0008	K	0.0110	0.0007

Figure 7.1 XRF data for beach sediment

Figure 7.1 Damage that caused by tsunami (source PVMBG)

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