GEOTHERMAL EXPLORATION USING INTEGRATED GEOPHYSICAL AND GEOCHEMICAL METHODS IN NORTH SUMATERA, INDONESIA

MUHAMMAD KADRI

UNIVERSITI SAINS MALAYSIA

2022

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by

MUHAMMAD KADRI

Thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

November 2022

ACKNOWLEDGEMENT

I would like to take this opportunity to thank every ones who assisted me in finishing this thesis. First and foremost, I would like to thanks Allah the Almighty for His Most Gracious Kindness in allowing me to finish this work.I would like to express my deep gratitude to my supervisor Assoc. Prof. Dr. Nordiana Mohd Muztaza, my co supervisor Prof. Dr. Mohd Nawawi Mohd Nordin, and Prof. Khirudin Abdullah for introducing me the optimization strategies and for their guidance and support during the progress of this work. Also, their encouragement, valuable advice, help and kind supervision are highly appreciated. Special thanks to Research University grant entitle Integrated geophysical characterization of geothermal exploration and strategy for a sustainable use of geothermal resources" with account no. 1001/PFIZIK/8011110. May Allah Subhanahu Wa Ta„ala repay their kindness. My greatest thanks to my parents, May Allah bless them and put them to Jannah, to my wife Putri Sarah for her support, understanding and patience. Thanks also to my children Muhammad Ammar Yasir Adrisa, Zhufairah Khadijah Putri Adrisa and Nazhifa Aisyah Putri Adrisa for their understanding and patience.

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LIST OF SYMBOLS

°C	Celsius
I	Current
K	Geometric factor
km2	Square kilometer
m	Meter
mV	millivolts
p	Empirical parameter
ρ	Resistivity
ρa	Apparent resistivity
Ωm	Ohm Meter
V	Volts
θ	Angle
Å	Angstrom
pH	Power of Hydrogen

LIST OF ABBREVIATIONS

XRD	X-Ray diffraction
SEM	Scanning electron microscope
nm	Nanometer
μm	Micrometer
T	Temperature
mol	Mole
min	Minute
Res2Dinv	Resistivity 2-D inversion software
Surfer	2-D & 3-D mapping, modelling, and analysis software
RMS	Root of mean square
mg	Milligram
mL	Milliliter
ppm	parts per million
MW	Mega watt
2-D	Two dimension
SAS	Signal averaging system

LIST OF APPENDICES

PENEROKAAN GEOTERMA MENGGUNAKAN KAEDAH GEOFIZIK DAN GEOKIMIA BERSEPADU DI SUMATERA UTARA, INDONESIA

ABSTRAK

Sumatera Utara merupakan potensi geoterma bumi kedua terbesar di Indonesia. Oleh itu, ia diperlukan untuk meneroka tenaga berpotensi di kawasan ini. Penyelidikan ini telah dijalankan di lima kawasan (Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, dan Sibayak). Kajian geoterma telah dijalankan di Sibayak kajian. Walaubagaimanapun kajian ini tidak mengintegrasikan geokimia dan geofizik. Sementara itu, Siogung Ogung, Roburan Dolok, Penen, dan Silau Kahaean, masih kurang maklumat mengenai penerokaan geoterma. Oleh itu, kaedah geokimia, geofizik bersepadu (keberintangan 2-D dan geomagnetik) dan XRD telah dijalankan. Tinjauan geoterma di Sibayak merupakan lokasi yang baru yang tidak pernah ditinjau oleh penyelidik lain. Tujuan kajian ini adalah untuk mengenal pasti kawasan berpotensi, mencirikan potensi geoterma dan memetakan potensi sumber geoterma. Kajian penyelidikan dilakukan antara Januari 2018 hingga Jun 2019. Kaedah geokimia dilakukan dengan tiga ukuran kepekatan iaitu Geotermometer Silika, Geotermometer Na-K dan Geotermometer Na-K-Ca. Kaedah keberintangan 2- D telah dijalankan dengan sistem ABEM SAS4000 dengan susunan Wenner Schlumberger. Kaedah geomagnetik dilakukan dengan magnetometer precession proton. Semua kawasan terletak di kawasan batu gunung berapi. Takungan terendah adalah di Penen (324.58 ^{0}C) dengan nilai pH tertinggi (6.7) dan takungan tertinggi di Siogung Ogung (572.71 ^{0}C) dan nilai pH (6.0). Nilai kerintangan 2-D yang paling rendah adalah di Roburan Dolok (1 - 70 Ωm) menunjukkan takungan sumber geoterma manakala nilai

keberintangan 2-D tertinggi adalah di Sibayak dan Penen (1 - 4000 Ωm) yang ditunjukkan sebagai medium pemindahan haba. Nilai keberintangan 2-D yang tinggi mempengaruhi suhu kedua-dua kawasan ini sebagai suhu terendah. Geomagnetik menunjukkan nilai tertinggi ialah 420 nT terletak di Roburan Dolok, ia disebabkan oleh peningkatan batu kapur dan dolomit manakala nilai magnet terendah ialah 70 nT terletak di Silau Kahean yang ditunjukkan sebagai mendapan air panas. Kaedah XRD dilakukan di 3 kawasan (Roburan Dolok, Silau Kahean dan Penen) dan hasil kajian menunjukkan kawasan tersebut didominasi oleh kuarza, magnesium, kalsit dan gipsum. Siogung Ogung, Roburan Dolok, Silau Kahean dan Sibayak mempunyai potensi yang sangat tinggi, manakala Penen mempunyai potensi yang lebih rendah kerana nilai suhu rendah, kerintangan tinggi dan keputusan yang menujukkan adanya gipsum. Kajian ini memberi sumbangan yang besar dengan memberikan hasil tentang potensi geoterma di Sumatera Utara dan menunjukkan kawasan geoterma yang boleh digunakan sebagai tenaga alternatif dan menghasilkan peta geoterma di Sumatera Utara.

GEOTHERMAL EXPLORATION USING INTEGRATED GEOPHYSICAL AND GEOCHEMICAL METHODS IN NORTH SUMATERA, INDONESIA

ABSTRACT

North Sumatera is the second largest geothermal potential in Indonesia. This research was conducted in five areas (Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and Sibayak). Geothermal research has been carried out in Sibayak. However, this study have not integrated geochemistry and geophysics. Meanwhile, Siogung Ogung, Roburan Dolok, Penen, and Silau Kahaean, there is still a lack of information regarding geothermal exploration. Therefore, geochemistry, integrated geophysical (2-D resistivity and geomagnetic) and XRD method were conducted. The geothermal survey at Sibayak was conducted in a completely new location that has never been surveyed by other researchers. The purposes of these studies are to identify the prospective area, to characterize the potential geothermal and to map potential geothermal source. The research study was done between January 2018 until June 2019. Geochemical method was performed with three concentration measurement which are Geotermometer Silica, Geotermometer Na-K and Geotermometer Na-K-Ca. 2-D resistivity method were conducted with ABEM SAS4000 system with Wenner Schlumberger array. Geomagnetic method was performed with proton precession magnetometer. All areas are located in volcanic rock areas. The lowest reservoir is in Penen (324.58 ^{0}C) with the highest pH value (6.7) and the highest reservoir in Siogung Ogung (572.71 ^{0}C) and pH value (6.0). The lowest 2-D resistivity value is in Roburan Dolok (1 - 70 Ωm) indicates as a reservoir of geothermal resources while the highest 2-D resistivity value is in Sibayak and Penen (1 - 4000 Ωm) which indicated as a heat

transfer medium. The high value of 2- D resistivity affects the temperature of these two areas being the lowest temperature. The geomagnetic shows the highest value is 420 nT located in Roburan Dolok, its due to the increasing of limestone and dolomite while the lowest magnetic value is 70 nT located in Silau Kahean indicated as hot water deposits. XRD method were done in 3 areas (Roburan Dolok, Silau Kahean and Penen) and the result shows that the area is dominated by quartz, magnesium, calcite and gypsum. Siogung Ogung, Roburan Dolok, Silau Kahean and Sibayak have very high potential, while Penen has a lower potential due to low temperature values, high resistivity and dominated by gypsum. This study makes a significant contribution by providing results on geothermal potential in North Sumatera and showing geothermal areas that can be used as alternative energy and produce geothermal maps in North Sumatera.

CHAPTER I

INTRODUCTION

1.1 Background of Study

Indonesia's electricity consumption reached 1,064 kilowatt hours (kWh) per capita in 2018. Currently, the Indonesian government is only able to meet 75 percent of its people's electricity needs. One of the areas experiencing an electricity crisis is the province of North Sumatera (Sumut). Currently, North Sumatera's electricity needs are 1,700 MW (megawatts), while the supply shortage is around 330 MW. The need for electrical energy is increasing every year, in 2014 in Indonesia it reached 31,550.95 MW, while the electrical energy needed by Indonesia was 50,000 MW (Budiyanti, 2014). The huge energy use is causing an increase in energy demand. Meanwhile, the amount of energy that has been consumed and is derived from non-renewable sources is diminishing. If this mismatch persists, an energy crisis is expected to erupt in every part of the globe. As a result of this threat, governments around the world require alternative energy to meet their local and international needs.

Indonesia is one of the countries that has pushed to seek alternative energy to meet energy needs. Moreover, domestic energy is always in deficite due to the growing population of Indonesia. Indonesia's geographic location, which is located between three tectonic plates, namely the Indies-Australia, Eurasia, and Pacific plates, it makes Indonesia becoming as a disaster-prone country. In addition, Indonesia has a large amount of energy potential, both fossil energy which has been explored for a third of a century and coal and geothermal energy derived from volcanic activities (Asrillah et.al, 2014).

Geothermal is a natural heat resource, the result of interaction between heat emitted by hot rock (magma) and ground water that is nearby, where heated fluid will be trapped in rocks located near the surface so that it can be economically utilized (Armstead, 1983). Geothermal energy is clean, renewable and sustainable energy that does not increase world emissions.

Geothermal potential in Indonesia is very abundant, because it is located in the collision zone between the Eurasian plate and the Indo-Australian plate, so far 256 geothermal prospect areas have been identified in Indonesia, (Figure 1.1.). It is 138 locations (52.07%) are still at the speculative level investigation stage, 24 locations (9.05%) are still in the hypothetical level investigation stage, 88 locations (33.21%) have potential as geothermal reserves, 8 locations (3.01%) are ready to be developed into geothermal potential, 7 locations (2.64) %) has been used for geothermal power plants (Badan Geologi, 2009).

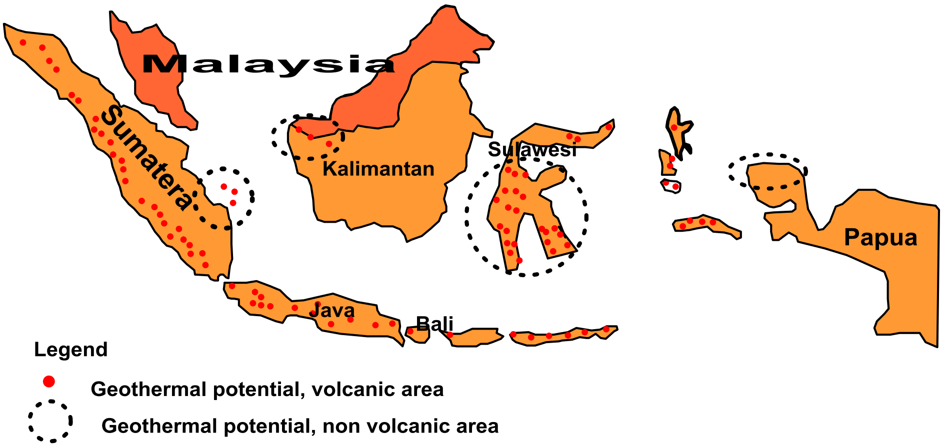

Figure 1.1 Geothermal potential distribution map of Indonesia.

So far, geothermal exploration is still being carried out in several regions in Indonesia. In North Sumatera itself, which is the largest geothermal potential area in Indonesia after West Java. Geothermal potential in North Sumatera is in six areas, namely Tanah Karo, North Tapanuli, South Tapanuli, Padang Lawas, Simalungun, and Mandailing Natal. Geothermal research has been carried out in the Sibayak and in the Sorik Marapi, however the research has not integrates between geochemistry, geophysical research and geological maps of geothermal potential areas in North Sumatera. Therefore, further surveys are needed to explore geothermal energy in North Sumatera, both in areas that have been explored but have not conducted integration research between geochemical and geophysics, as well as in areas that have not been explored.

The geochemical and geophysics integrated research is very important to see the geothermal potential area comprehensively. The geochemical survey was carried out by conducting a chemical test of the water contained in the manifestation of areas with geothermal potential. geochemical methods are used to measure and determine geothermal reservoir temperature based on the chemical elements contained in it. In this case the chemical elements that are usually contained in hot water include pH, potassium (K), calsium(Ca^{+2}), natrium(Na), mercury, cloride (Cl), silica (SiO_2), sulfat (SO_4), magnesium (Mg), and bicarbonate (HCO_3). While the geophysical reseach was carried out by the 2-D resistivity, geomagnetic and XRD test. The 2-D resistivity is a geophysical exploration method utilized for exploration of mining, water supplies for consumption and geothermal exploration. The 2-D resistivity is designed and utilized to supply the information regarding the electrical conductivity anomalies from rock, soil and subsurface formations. 2-D resistivity method can be used to map sediment content in the early stages of petroleum and geothermal exploration. In geothermal exploration, 2-D resistivity method is used to determine the prospect of geothermal areas, namely studying the properties of electricity flow in rocks below the earth's surface. While geomagnetic methods are used to determine the depth and surface structure, measurements can be obtained easily for local and regional studies. The geomagnetic method works based on measuring some variations in the intensity of the magnetic field at the earth's surface. This variation is caused by the contrasting magnetic properties of the rocks in the earth's crust, causing the geomagnetic field to be inhomogeneous, which can also be called a magnetic anomaly, where the rocks in the geothermal system generally have a lower magnetization than the surrounding rocks. The low magnetic value can interpret the potential zones as reservoirs and heat sources. The magnetic method can be used to determine geothermal potential in an area so that it can be used as geothermal energy as a substitute for the energy crisis that has occurred (Santosa et. al, 2007). An accurate way to identify mineral rocks that make up geothermal rocks is to use X-Ray diffraction analysis. XRD analysis is a method that can provide information about the types of minerals that exist in a rock. XRD data were analyzed to determine the characteristics of each mineral, mineral percentage, and mineral crystallinity level.

The results of this research are expected to be utilized by the Indonesian government and the Indonesian people as an alternative energy source and no less important and to facilitate the search for areas that have the potential for hot water resources in North Sumatera especially Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and also in Sibayak that has been carried out the research but the research has not integrates between geophysical and geochemical research.

Based on the above problems, it is necessary to carry out comprehensive geothermal research using geochemical and geophysical integration methods as an alternative energy and to map the geothermal area in the province of North Sumatera, Indonesia.

1.2 Problem Statement

North Sumatera will have a plenty electricity sources if its geothermal potential is completely utilized. Furthermore, if the area has been adequately mapped based on this research, geothermal can be utilized as a source of energy and a source of income in North Sumatera. North Sumatera has developed geothermal energy, particularly Sibayak and Sorik Marapi geothermal. However, there are still many areas in North Sumatera that have not been developed and result in insufficient electrical energy. Therefore, it is very important to study and develop geothermal sites in North Sumatera that have the potential to contribute to geothermal energy for North Sumatera particularly and for Indonesia. Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and Sibayak are some areas that have the potential for geothermal exploration which are characterized by the presence of geothermal manifestations in this area, and also no geothermal survey in this area which is usefully when it developed more deep. Although Sibayak has been the subject of many geothermal surveys, this research in Sibayak will be conducted in site that has never been done by other researchers and the significant difference is that this research uses an integrated method. Geochemistry and geophysical approaches are used to conduct the research. 2-D resistivity and geomagnetic approximation were used as geophysical methods. An additional method, the XRD method, was applied in Roburan Dolok and Silau Kahean, and Penen. This is done to add material available to compare geochemical and geophysical data. This research is expected to show more specific and new results.

1.3 Research Objectives

The purpose of this investigation are:

i. To identify the prospective area, of geothermal energy in North Sumatera province with 2-D resistivity and geomagnetic method.

ii. To characterize the potential geothermal prospect with integrated geochemical and geophysics.

1.4 Novelty of Study

This geothermal survey was conducted using an integrative strategy that includes geochemistry, geophysical (2-D resistivity and geomagnetic) analysis and XRD. This study provides a significant contribution by showing the large geothermal potential that exists in five areas in North Sumatera (Siogung Ogung, Roburan Dolok, Silau Kahean, Penen and Sibayak) and also shows geothermal characteristics in each research area. This study also displays a map of geothermal potential in North Sumatera and a comparison of the results of geothermal potential in terms of geochemistry and geophysics. From the results obtained, it can make it easier for the government to find alternative energy sources and geothermal tourism areas which will certainly provide income for the government.

1.5 Scope of study

The focuses in this research on geothermal exploration in 5 areas (Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and Sibayak) that have geothermal potential using geochemistry, 2-D resistivity, geomagnetic and XRD methods. All of the research areas are located in North Sumatera, Indonesia. While specifically in 3 areas (Roburan Dolok and Silau Kahean, and Penen) the XRD method was applied. The geochemical survey will focus on measuring surface temperature, concentration measurement, pH measurement, reservoir temperature data and type of water. 2-D resistivity surveys were carried out at all locations using the Wenner Schlumberger configuration method. The purpose of the 2-D resistivity survey is to determine the value of the subsurface resistance. The resistance value obtained will provide the interpretation of subsurface of the research area. Geomagnetic surveys were carried out at all locations and uses proton precession magnetometer device and Global Positioning System (GPS) navigation. The purpose of geomagnetic survey is to determine the value of the magnetic and subsurface anomalies. XRD survey was only conducted in Roburan dolok, Silau Kahean and Penen. The variables tested were crystal structure, parameter cells, density, and field index.

1.6 Layout of thesis

Chapter 1 focuses on Indonesia's geothermal potential, particularly in the province of North Sumatera, which has great geothermal potential but has not been fully exploited. Either using geothermal energy as an alternate energy source for power or using geothermal energy as a tourist attraction to boost regional revenue. As a result, utilizing geochemical and geophysical approaches is one of the ways to explore geothermal potential and map the area (2-D resistivity and geomagnetic). The study area is located in five differents areas: Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and Sibayak. There is an area of research that has generally been carried out by other researchers, namely in Sibayak, but this research was carried out entirely at a site that had never been investigated before.

The theory of geothermal and geothermal potential in Indonesia and North Sumatera is discussed in Chapter 2. This chapter covered the methods for studying geothermal with geochemical and geophysical approaches, such as 2-D resistivity and geomagnetic methods. It also explains past geothermal exploration research conducted by a number of researchers.

The methods employed in geothermal exploration are discussed in Chapter 3, followed by an explanation of the research framework, study area, data collecting, and data processing.

Chapter 4 explains the results of the research and discussion.

Chater 5 discusses the conclusions and future recommendation of the research.

CHAPTER 2

LITERATURE REVIEW

2.1. Geothermal

The geothermal and other supporting information utilized in this investigation will be discussed in this chapter. In this chapter, past researchers' geochemical, geophysical (2-D resistivity, and geomagnetic) theories, as well as numerous applications utilized to investigate geothermal resources, will be presented. Geothermal energy is a renewable and ecologically favorable source of energy. According to the national energy policy of Indonesia goverment (Indonesia presidential order no. 5 of 2006), the contribution of geothermal energy is targeted in the renewal of national energy by 5% of the total potential geothermal energy by 2025 or estimated around 9500 Megawatt. To reach this result, a road map for geothermal energy development has been created, which includes a timeline for completion. The existence of this legislation must be accompanied by technical efforts, such as the preparation of geothermal data obtained through survey or exploration activities, which will subsequently be utilized to prepare geothermal mining operating zones (Kasbani, 2009).

Since the process of geothermal energy creation is constant as long as the environmental conditions, both geologically and hydrologically, can be kept in balance, geothermal energy sources are unlikely to be exhausted. Because geothermal energy cannot be exported, it can only be used to meet domestic energy requirements. As a result, geothermal energy will become a cornerstone and crucial energy source for Indonesia, as it can decrease the country's reliance on finite fossil fuels (Asrillah et al., 2014). Geothermal energy can be used as an alternative energy source because it offers several benefits (Setyaningsih, 2011). These benefits include:

i. Indigeneous: the source of geothermal energy can be used directly or it can be used through one process.

ii. Renewable: the source of geothermal can be renewed by maintaining water reserves that enter the geothermal system in order that the process of evaporation of water by heat sources continues.

iii. Suistanable: the source of geothermal can be used continuously because it can be renewed in a relatively short period of time.

iv. Economic: construction of geothermal power plants requires a smaller area and the cost of using geothermal energy is cheaper than fossil fuels.

v. Environmentally friendly: Unlike fossil fuel exhaust gases, which cause global warming and ozone depletion, geothermal energy exhaust gases are safer because the majority of the exhaust gas (96 percent) is in the form of CO^2, which can be used as an additional material.

Geothermal energy is defined as heat stored in rocks beneath the subsurface, as well as the fluid contained inside (Suhartono, 2012). Geothermal energy is natural heat energy that is transmitted to the subsurface by conduction or convection from deep within the earth. The geothermal system is a natural heat transfer in a specific volume from a heat source in the earth's crust to a heat release point, which is usually the ground surface. The majority of geothermal systems in Indonesia are found in high-altitude locations, underground reservoirs with depths of 1-3 km, complicated structures hidden in dense woods, and some fields with lengthy and deep outflows (Daud, 2010).

Geothermal energy, like solar energy, is dispersed throughout the earth's interior, making it difficult to master. However, it can be discovered in dissolving corals in some spots (magma). Magma is forced upward to form volcanoes, or magma is restricted at the subsurface, according to the earth's structure. This contained magma produces hot water or hot water vapor, which can be used for a variety of energy applications (Suhartono, 2012).

Geothermal energy is a type of energy that has the potential to promote the development of locations with geothermal resources, both for power generation and other purposes (Setyaningsih, 2011). However, not all heat sources may be classified as geothermal (Figure 2.1). According to Suhartono (2012), there are six requirements under which heat sources can be classified as geothermal energy:

i. The existence of geothermal rock in the form of magma.
ii. There is an adequate supply of groundwater which is circulating close to the magma source so that hot water vapor can be formed.
iii. The existence of reservoir rocks that can store steam and hot water.
iv. The presence of hard rock that resists the loss of steam and hot water (cap rock).
v. There are tectonic symptoms, where cracks can form in the earth's crust that give way to steam and hot water moving to the earth's surface.
vi. The heat must reach a certain minimum temperature of about 180° - 250 °C.

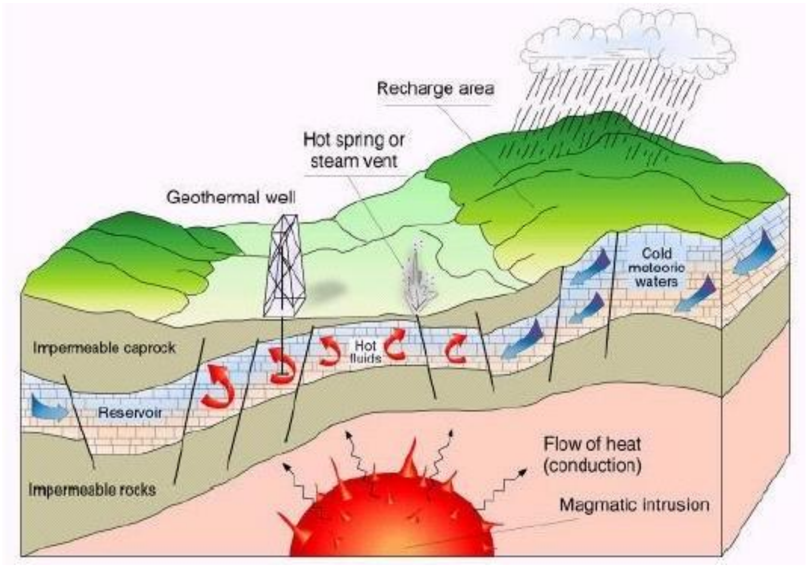

Figure 2.1 Geothermal cross section Suhartono (2012).

2.1.1. The occurrence of Geothermal Process.

A lithosphere made up of a number of thin and unyielding plates exists within the earth's crust. The listosphere consists of 64 until 145 km thick sections of rock that float above the asthenosphere. Slowly and steadily, these plates move. As seen in Figure 2.2, the plates move apart in some locations while pushing against each other in others, causing one to stick under the other (Suhartono, 2012).

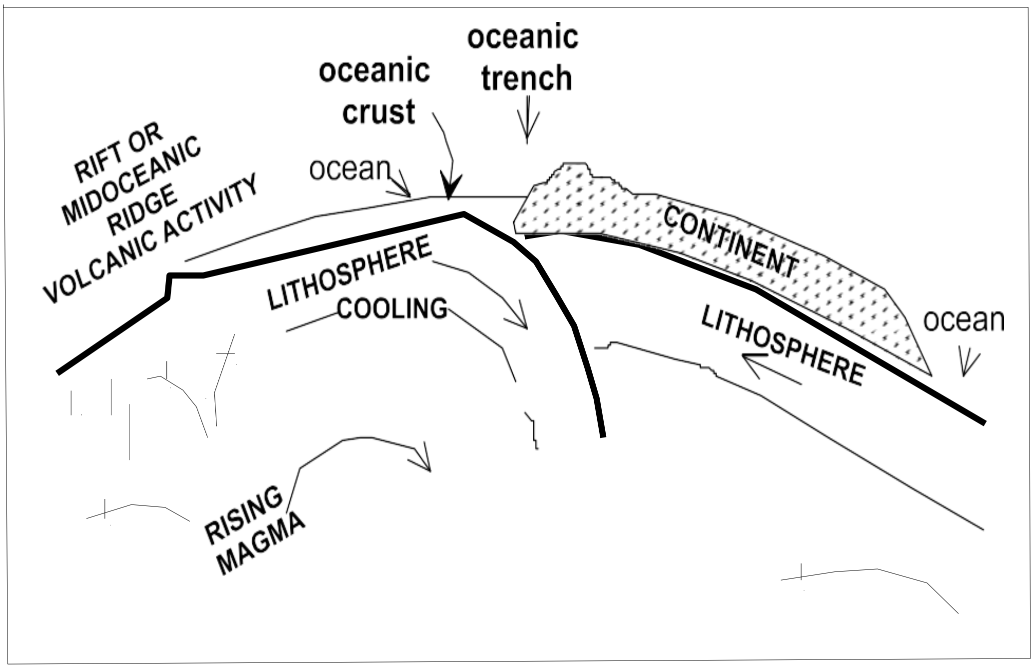

Figure 2.2 Movement of tectonic plates (Suhartono, 2012).

The heat in the asthenosphere, along with heat generated by friction, causes the plate's edge to melt and reach a high temperature (magmatization process). A flow of heat from the heat source to the surface is caused by the presence of hot material thousands of kilometers beneath the subsurface. This results in a temperature difference from below to above, with an average temperature gradient of 300 ^{0}C per km (Sumotarto, 2017).

The geothermal system is generated as a result of heat transfer from a heat source that occurs via conduction or convection around it (Figure 2.3). Conduction heat transfer happens via rocks, whereas convection heat transfer occurs when water and a heat source come into contact. Water has a natural inclination to sink due to gravity, but if it comes into contact with a heat source, there will be a heat transfer, causing the water temperature to rise and the water to become lighter. Warmer water rises and colder water sinks as a result of this scenario, resulting in water circulation or convection currents (Sumotarto, 2017).

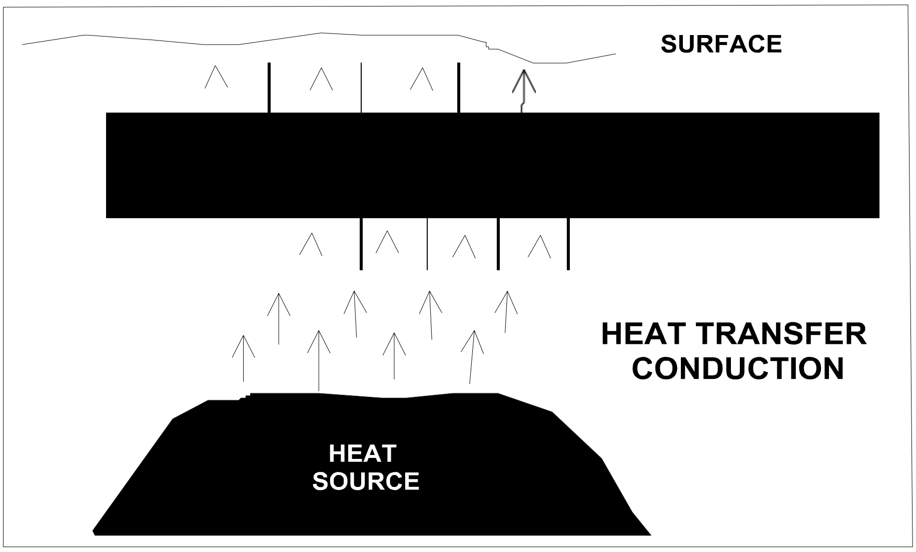

Figure 2.3 Heat transfer beneath the earth (Suhartono, 2012).

Earth energy, hot dry rock energy, magma energy, geopressured energy, and hydrothermal energy are the five categories of geothermal energy (Suhartono, 2012).

The majority of geothermal energy used across the world is energy collected from hydrothermal systems (Figure 2.4). In the active plate boundary zone, where there is a lot of heat flux, the hydrothermal system is closely linked to volcanic systems and the production of volcanoes (Hadi, 2008).

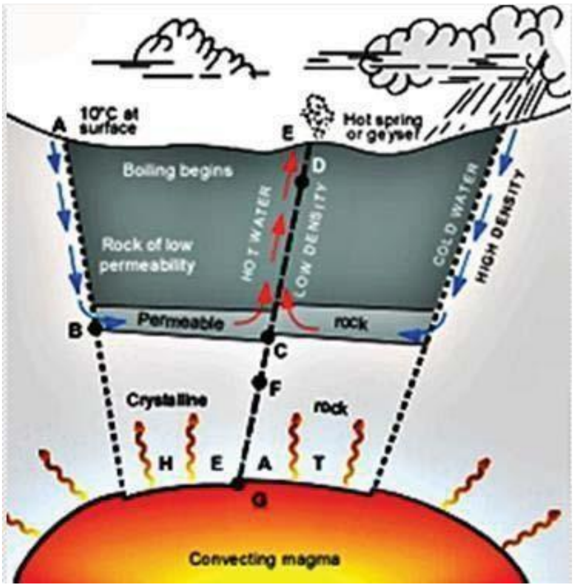

Figure 2.4. Hydrotermal system (Suhartono, 2012).

A geothermal system with a single heat source, reservoir, and cap rock is known as a hydrothermal geothermal system. A geothermal field will produce geothermal fluids in the form of steam, hot water or a mixture of steam and hot water in this system (Kasbani, 2012). If the reservoir temperature is less than the saturation or boiling point temperature of water at the reservoir pressure, the fluid will only have one phase water. If the temperature is higher than the saturation or boiling point temperature of water at the reservoir pressure, the fluid only has one phase steam. The fluid consists of two phases, namely a mixture of steam and water, if the reservoir pressure and temperature are the same as the water saturation pressure and temperature (Saptadji, 2009).

The occurrence of geothermal surface manifestations such as hot springs, mud pools, geysers, and other geothermal manifestations indicates the presence of a hydrothermal system under the surface. The propagation of heat from subsurface or the fractures that allow geothermal fluids (steam and hot water) to flow to the top are hypothesized to create geothermal manifestations (Figure 2.5) on the surface (Suhartono, 2012).

(a) (b) (c)

Figure 2.5 Geothermal manifestations on the surface (a) hot springs, (b) mud puddles, and (c) geysers (Suhartono, 2012).

2.1.2. Geothermal manifestation

The appearance of manifestations on the surface, which show that hydrothermal fluid originating from the reservoir has come out through the rock crack, indicates the presence of geothermal activity.

In regions with heat sources on the surface, geothermal manifestations can be discovered. Hot soils, steamy earth, hot pools, hot mud pools, hot springs, fumaroles, and geysers are only a few of the manifestations that can be found in geothermal areas (Broto et al., 2011).

Since it reveals that there is heat on the surface, the survey regions Siogung Ogung, Roburan Dolok, Silau Kahean, Penen, and Sibayak were categorised in this study. Fumaroles, hot springs, hot soil, and changed rock are all part of this expression.

Fumarole is a type of hot steam (vapor) that contains water particles and contains SO^2 and CO^2. It comes out of rock fractures. Hot springs are formed when groundwater is discharged from the earth's crust after being heated by geothermal energy. The hot rock surface heats water seeping into the earth's crust, and the heated water emerges as hot springs. The presence of soil with a temperature higher than the surrounding soil temperature suggests the presence of geothermal sources under the surface, which can be detected by the presence of soil with a temperature higher than the surrounding soil temperature.

This occurs due to the conduction of heat transfer from subsurface rocks to surface rocks. As for alteration rock, it is a rock that has changed because alteration means changing rock minerals. The old minerals that are formed turn into new minerals because there have been changes in conditions. These changes can be caused by changes in temperature, pressure, chemical conditions or a combination thereof. Hydrothermal alteration is a mineralogical change as a result of the interaction of rocks with hot fluid, which is called hydrothermal.

This geothermal manifestation is formed due to steam activity, namely fumaroles and several steaming ground.

2.1.3. Geothermal utilization

Geothermal energy is used in two purposes, for electricity generation (geothermal power plants) and for non-electric purposes (geothermal direct usage) or direct consumption. The use of geothermal energy for both power generation and direct use has the advantages of being clean, sustainable, and renewable.

Hot water or hot steam generated by fumaroles and hot springs in geothermal areas can be used immediately for hot springs, swimming pools, agricultural drying, and room heating.

The North Sumatera region has considerable energy potential. North Sumatera is one of the provinces with the biggest geothermal energy potential, with 1.857.00 MW. This enormous potential has not been fully realized; while certain places have been examined, many others have gone undetected. Geothermal energy may be converted into electricity and used as hot water baths. If handled effectively, geothermal energy can provide revenue for the government in the region. Then, by optimizing regional potential and charting hot prospective places on the globe, it can be used for other things like educational parks.

Geothermal extraction is only possible in particular places, such as those with geothermal manifestations visible on the surface.

2.2. Indonesia geothermal system

Indonesia, a country made up of more than 13.000 islands, is an archipelago country. The Indonesian archipelago is situated at the meeting point of three tectonic plates (Indies-Australia, Eurasia and the Pacific). As a result, Indonesia's tectonic sequence is complicated. The melting of magma in the form of partial melting of mantle rock occurs as a result of subduction between continental and oceanic plates. When magma flows to the surface, it differentiates into magma pockets (silisic or basaltic), resulting in the construction of volcanic routes known as ring of fire. A conceptual model of Indonesia's geothermal system is based on the eruption of a sequence of Pacific volcanoes in portions of Indonesia and their tectonic activity (Kasbani, 2009).

There are 251 geothermal hotspots in Indonesia, with a total potential of roughly 27 Giga Watt, dispersed along the volcanic pathway that spans from Sumatera to Java, Nusa Tenggara, Sulawesi, Maluku, and Papua (Figure 2.6).

Indonesia is home to the world's biggest geothermal energy potential. The quantity of geothermal field potential reserves that can be characterized by multiple reservoir parameters such as temperature, pressure, and enthalpy, which indicate the thermal energy contained in the reservoir fluid (Singarimbun, 2011). In Indonesia, geothermal energy has a wide range of enthalpies, with some having a high enthalpy (temperature > 200ºC) and others having a medium to low enthalpy (temperature <200ºC) (Hasan, 2009).

No	Province	Locations	No	Province	Locations	No	Province	Locations
1	**Aceh**	**17**	9.	**Banten**	**5**	18.	**South Sulawesi**	**16**
2	**North Sumatra**	**16**	10	**West Java**	**40**	19.	**Southeast Sulawesi**	**13**
3	**West Sumatra**	**16**	11.	**Central Java**	**14**	20.	**Central Sulawesi**	**14**
4	**Riau**	**1**	12.	**Yogyakarta**	**1**	21.	**North Sulawesi**	**5**
5	**Jambi**	**8**	13.	**East Java**	**11**	22.	**Maluku**	**15**
6	**Bengkulu**	**6**	14.	**Bali**	**5**	23.	**Gorontalo**	**2**
7	**South Sumatra**	**8**	15.	**West Nusa Tenggara**	**3**	24.	**Papua**	**2**
8	**Lampung**	**13**	16.	**East Nusa Tenggara**	**18**	25.	**Kalimantan**	**3**

Total : 252 Locations

Figure 2.6. Indonesia geothermal potential.

The geothermal system of Indonesia is linked to magmatism. The magma that pierces the earth's crust cools and forms a hot intrusive igneous rock mass. Following that, the intrusive igneous rock is transported to the surrounding rocks. Groundwater stored in porous and permeable reservoir rock is heated by the intrusive rock body in acceptable geological conditions. Reservoir rocks are frequently capped by impermeable cap rocks that act as reservoir fluid traps. The fissures in the cap rocks act as a conduit for steam or hot water, resulting in geothermal energy manifestations such as hot springs (Utami, 1998).

The geothermal system in Indonesia is generally specified as hydrothermal system that has a high temperature (> 225ºC). Only a few of the geothermal system Indonesia have moderate temperatures (125 - 225ºC). This condition is very potential if the geothermal system used to generate electricity in Indonesia (Saptadji, 2009).

Geothermal systems are often formed from moderate volcanic rock (andesite-basaltic) to acid, with a reservoir characteristic of approximately 1.5 km and a high reservoir temperature (250 °C – 370 °C). Active volcanic sites typically have relatively young rock ages, extremely high temperatures and a lot of magmatic gas. Since tectonic activity factors are not sufficiently dominating to generate extensive fissures as reservoir rocks, the gap between rocks (permeability) is relatively limited. Inactive volcanic areas are often older in age and have been characterized by intense tectonic activity, which has resulted in the formation of rock permeability through extensive fractures and common fractures. Medium-high temperatures are frequently created under these conditions, with lower magmatic gas concentrations.

Recently, Indonesia's geothermal system has primarily been a hydrothermal geothermal system. The presence of the surface manifestations such as hot water, a sulfur-containing gas, can simply establish the existence of geothermal resources. Leaks from geothermal enclaves or underground reservoirs might be thought of as surface manifestations.

One of the island that has a great geothermal potential in Indonesia is Sumatera island. Sumatera island is part of an oblique subduction zone between the Indian-Australian Oceanic Plate and the Eurasian Plate, according to the report. The horizontal fault movement that resulted in the Sumateran major fault system, which axially divides the island, released the associated tensions (Rock et al, 1983). Furthermore, magma movement associated with subduction influences the rise of the Sumateran volcanic arc, which stretches almost the entire length of Sumatera, as well as volcanic activity along the Sumateran fault system, indicating the potential for shallow magmatic heat sources and permeability zones. Sumatera was formed by recent extensive volcanism that was relatively thin, overlaying folded and fractured Neogene strata as well as unconformably overlying Pre-Tertiary basements.

Indonesian state oil company (Pertamina) began an assessment of Sumatera's geothermal potential in the early 1970's. There are currently around 200 geothermal opportunities in the Indonesian arc, with 70 of these fields being identified as possible high temperature systems, with about half of these being found on Sumatera. In year 2008, the installed capacity from seven fields had reached 1000 MWe (Hochstein et. al, 2008).

The Sumateran fault system runs across the producing wells in the Sarulla geothermal field in North Sumatera and the Ulubelu geothermal field in Lampung province in Sumatera island (Gunderson et al, 1995). In the Sarulla geothermal field, several attempts have been undertaken to determine the fault growth mechanism and its impact on subsurface fluid flow and geothermal activity (Gunderson et al, 1995) and (Hickman et al, 2004).

2.3. Geological method

Regional and thorough geological map analysis is the geological method used. Regional geological maps depict the area's regional geological order, whereas comprehensive geological maps contain information on the study area's structure and stratigraphic structure, which can be used to estimate and predicted the presence of geothermal systems.

The heat source, reservoir, cap rock, fluid source, and hydrological cycle are all components of the geothermal system. This system is closely related to the mechanisms of magma generation and volcanisme. As a result, this system's existence has a specific location, such as along ridge volcanic zones, continental splitting, above subduction zones, and plate melting anomalies.

Based on reservoir temperatures, a geothermal system's temperature is divided into three categories (Hochstein et al., 2008):

i. High (reservoir temperature more than 225 °C).
ii. Moderate (reservoir temperature 125 °C to 225 °C)
iii. Low (reservoir temperature smaller than 125 °C).

The geothermal system in Indonesia can be classified into three groups based on the geological order: volcanic, volcanic-tectonic, and non-volcanic. The volcanic geothermal system is a geothermal system connected with quaternary volcanoes that range from Sumatera through Java, Bali, Nusa Tenggara, and parts of Maluku and North Sulawesi. The geothermal system's formation is often formed of intermediate (andesite-basaltic) to acidic volcanic rock, and it has the features of a 1.5 kilometer long reservoir with a high reservoir temperature of 250 to 370 ^{0}C. The volcanic tectonic geothermal system is a collection of graben structures and volcanic cones that can be found along the Sumatera fault system in the Sumatera area.

Non volcanic geothermal systems are those that are not directly tied to volcanism and are found outside of the quaternary volcanic period. Because the area is dominated by rocks that make up the Asian continent's crust, such as metamorphic and sedimentary rocks, the non volcanic environment in western Indonesia is often spread in the eastern portion of the Sunda land (the Sunda Shelf). The non volcanic environment in eastern Indonesia is characterized by granitic, metamorphic, and marine sedimentary rocks in Sulawesi and Maluku islands until Papua islands (Kasbani, 2012).

The oblique subduction between the Oceanic India-Australia plate and the Eurasia plate currently includes Sumatera Island. The forces that resulted from it were released by strike slip fault movements, resulting in the major Sumatera fault system, which bisects the island axially (Rock et al., 1983). Apart from the rising of the Sumatera volcanic arc, which stretches nearly the entire length of Sumatera, and the occurrence of volcanic activity along this Sumatera fault system, suggesting the potential for a shallow magmatic heat source and zone of permeability, magma movement associated with subduction has also affected the rising of the Sumatera volcanic arc, which stretches virtually the entire length of Sumatera. The Sumatera was formed by relatively thin extensive recent volcanism, which is overlie folded and fractured Neogen sediments, which also unconformably overlie Pre-Tertiary basements.

The majority of Indonesia's geothermal potential are connected with quartenary arc volcanism, as well as beneath the slopes of active or dormant stratovolcanoes (Hochstein et al., 2008). Active geothermal surface manifestations, steaming ground with acid fluids, fumaroles, hot pools, tiny geysers, and travertines define these fields. The first four sorts of manifestation are common in high-temperature settings. Boiling water and a high chloride content are two prominent signs of a high temperature (Hochstein et al., 2008). The wells mainly reached volcanic rock reservoirs, such as andesite, as well as small dioritic and basaltic rocks (Hochstein et al., 2008).

Sumatera is part of the Eurasian continent's southwest-southwest edge, which interacts with the Indian-Australian ocean plate, which flows north-northeast (Figure 2.7). The magnitude of the interaction angle and the speed of plate convergence determine the interaction of the two plates. Subduction and horizontal dextral faults have formed as a result of the movement. The formation of a magma arc path, the Bukit Barisan Mountains, resulted from the sharpening that occurred during the Tertiary to Resen under the island of Sumatera.

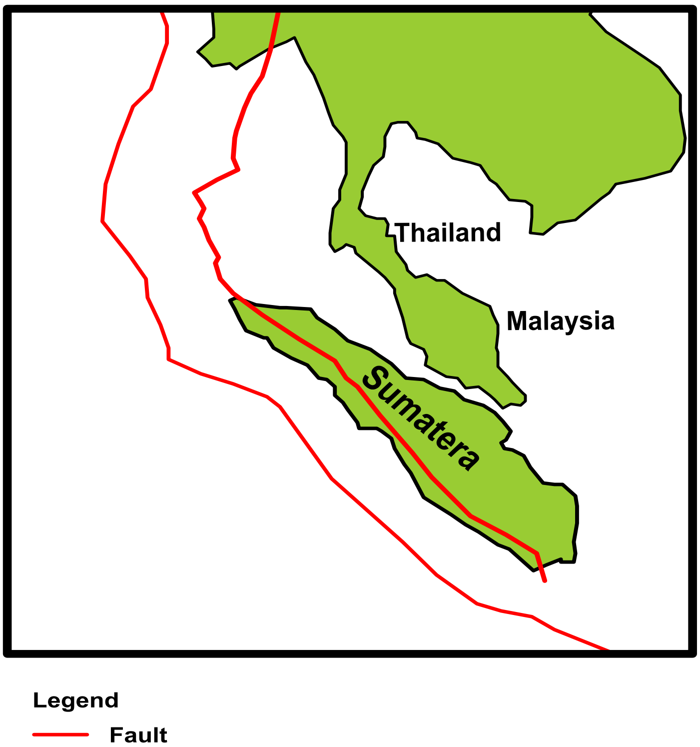

Figure 2.7. Sumatera's physiography and tectonic setting.

The geology of the tertiary and quaternary periods on the island of Sumatera reflects natural motion. The dextral fault known as the Semangko fault or the Sumateran fault cuts through much of the island of Sumatera from North Sumatera to south Sumatera, forming magmatic bows and arc back basins. The nature of the interaction between the Indies-Australian plate and the divergent Sundanese Micro

Plate resulted in the formation of this horizontal fissure. Because it serves as a tectonic barrier between the Sunda microplate and the Indian-Australian plate to the west, this fault has a significant tectonic significance. As a result, the development of tertiary tectonics from the Sunda micro padal is likewise the development of tertiary tectonics from the area of Sumatera lying east of the Sumateran fault. The rocks in the research region are Paleozoic-Cenozoic in age and include volcanic rocks, breakthrough rocks, sediments, and sedimentary metale.

Geothermal potential can be categorized into three, namely small, medium and large energy potentials. Geothermal with reservoir temperature < 200 °C has an energy potential about 50 MW. Geothermal with a temperature of 200 – 250 °C has an energy potential 50 – 100 MW. Meanwhile, geothermal with a temperature > 250 °C has an energy potential of > 100 MW.

2.4. Basic Applications of Geochemistry method

In utilizing geothermal energy resources, it is important to know the understanding of the chemical properties of the geothermal system, namely various rocks, fluids and other constituents. Because the formation of a geothermal system is a process that is not only dominated by changes in physical aspects, but also chemical and even radioactive activities have also taken place during the making of geothermal systems that are formed in nature. Chemical activities that occur during the formation of the geothermal system must be understood not only in terms of what happens in the rocks that make up the geothermal system, but also in terms of the chemical aspects (composition, reactions, and changes) that occur in the geothermal fluid in order to predict the geothermal energy potential.

Chemical aspects and activities that occur in geothermal rocks and fluids are commonly understood as geothermal geochemical which need to be known in detail during the development of geothermal energy resources. Geochemical of geothermal not only analyzes the formation and changes of minerals that make up rocks, but also the chemical properties of fluids that can be used for temperature predictions, known as the branch of geothermometer.

Geochemical observation activities are especially important for the assessment of geothermal resources in the early stages of exploration. Prior to drilling, a chemical geothermometer can provide the only information about the potential temperature of a geothermal reservoir. Similarly, geochemistry studies can also be important to track the extent of geothermal areas prior to geophysical resistivity surveys.

2.4.1. Geochemical of geothermal

Chemical activities that occur in the process of forming a geothermal system not only explain what happens in the rocks that make up the geothermal system, but also explain the chemical aspects that exist in the geothermal area. The aspects of geothermal chemistry in the form of composition, reactions, and changes that take place in geothermal fluids must be able to predict the existing geothermal energy potential. In addition, geothermal geochemistry can also analyze the formation and changes of minerals that make up rocks, and also the chemical properties of fluids used for temperature prediction, which is known as the geothermometer. In geothermal exploration the surface fluids (liquid solutions and gas mixtures) reflect the chemical-physical and thermal conditions in the reservoir. Geochemical studies of geothermal fluids in principle involve three stages, namely sampling, data analysis, and data interpretation (Sumotarto, 2015).

The purpose of geochemical methods used in geothermal exploration research is to assess the possibility of developing geothermal resources. Data that are often used in geochemical methods are data on the manifestation of hot water and gas, as