Geothermal system characteristics on Northern Ternate region, Indonesia based on interpretation of magnetic anomalies

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Abstract. Geothermal resources can be indicated by surface manifestations such as hot springs, hot mud puddles, and geysers. In the Northern Ternate region, in the villages of Tobololo and Sulamadaha, the manifestation of hot springs is present. Therefore the purpose of this research is to study the geothermal characteristic in the Northern Ternate region, Indonesia, based on interpretation of magnetic anomalies in the hot surface temperature of hot springs. The method employed a fluxgate magnetometer to measure a sample of random temperature. Furthermore it examined for their chemical content to determine their resource type.

The results show that the magnetic anomalies value in the Northern Ternate region is of -3678.63 nT up to 2679.57 nT. The contour map is then developed by indicating three levels of magnetic anomalies; low, medium, and high. This is an indication that the area is of geothermal manifestation and it is classified as a hypothetical resource that could become an unexpected reserve. The temperature is measured at 50 cm depth and it shows of 27-38.50 °C. The result of the temperature anomaly in the Tobololo area is due to the flow of hot springs along the coastline. Meanwhile the Sulamadaha area has a smaller hot spring discharge, which is due to hydrothermal activity below the surface. Based on the the geochemistry assessments, both areas have alkali chloride water type.

Keyword: Geothermal; Ternate; Indonesia; geomagnetic; geophysical

1. Introduction

Indonesia has huge geothermal potential because the country is located in the fire ring of at volcano path. Approximately 28.91 GW of geothermal energy is spread across 312 locations on several islands such as Java, Sulawesi and Sumatra, Bali, Nusa Tenggara and Sulawesi [1]. The first indication that an area has geothermal resources are the surface manifestations that appear such as hot springs, hot mud puddles, and geysers. These manifestations are due to the heat propagation from the subsurface or fractures that allow geothermal fluids to flow to the surface.

In the Northern Ternate region, North Maluku (see Figure 1), geothermal manifestations in the form of hot springs can be seen in the village of Tobololo and Sulamadaha. This geothermal activity can be related to tectonic plates movements that led to the emergence of the Gamalama mountain with a height of 1715 meters above sea level. However, these resources have not been exploited yet. The temperature of the groundwater distribution in those two villages is quite high as compared to other areas. These high temperatures are the dominant parameters in geothermal regions as first indicator of potential geothermal resources.

By using the method of magnetic anomalies in hot spring water, the potency of geothermal resources in the Northern Ternate region can be observed. Then to determine the type of geothermal hot water within the area the chemical content is identified. Several researchers work in this method in several
resource [2–5], [6]. Therefore, the purpose of this research is to study the geothermal characteristic based on interpretation of magnetic anomaly and the temperature of hot springs water in the Northern Ternate region, Indonesia.

Figure 1. Geothermal power plant in Indonesia and potential in the Northern Ternate region [adapted from [1]]

2. Data and Research Methodology
2.1. Detail sites location
The research took place in the Northern Ternate region which is an area within Ternate Island, in the sub-district of Ternate located in the province of North Maluku as shown in Figure 2. North Maluku Province is located in the eastern part of Indonesia; it is divided into nine districts and cities: Ternate, Tidore Islands, West Halmahera, Central Halmahera, East Halmahera, North Halmahera, South Halmahera, Sula and Taliabu Islands, as well as Morotai. Furthermore in Ternate City consists of 8 islands ranging from small to large, namely Ternate, Hiri, Moti, Mayau, Tifure, Maka, Mano, and Gurida. Out of that number, as many as 5 islands have been inhabited, while the other 3 remain desolate. The total area of Ternate city reaches 5,709.58 km².

Figure 2. Map of Ternate city [7]

The research location is Sulamadaha and Tobolo which are located in the northern part of Ternate city. The location can be reached from the capital city of Indonesia, Jakarta which would take about 3.5 hours.
flight. The geographical position of Ternate city is at 0 ° - 2 ° North Latitude and 126 ° - 128 ° East Longitude, and all of its boundaries are surrounded by the sea; on the East side with Halmahera Strait and on the West side with Maluku Sea.

The dominant topography is sloping and slightly steep with 3.361 ha (20.6%) and 3.323 ha (20.4%). It can’t be separated from the effects that the volcanic activity of the past has had in the formation of the land and its existent latitudes. Ternate Island has a height of 0 m dppl - 1700 m dppl; but only land with an altitude of 0 m dppl - 450 m asl is widely occupied by the community. The cause of such altitudes is traced to the aforementioned volcanic activity, and it’s estimated that the altitude will continue to change throughout time with the increase of eruptions.

![Figure 3. Topografi map of ternate island](Source: Office of City Planning and Garden City of Ternate, 2011)

### 2.2. Equipment

In this study, the equipment used is as follow:

- **For Field Survey:** To run the field survey a Flux Gate mobile Magnetometer was used as well as a Temperature sensor to calculate temperature. Garmin GPS was employed to note the coordinates of the positions that were later plotted in the map. Roll meters were used to measure water levels and the distance from the wells to the shoreline. In order to record the time, a stopwatch was used, and the process was all documented with the use of a camera.

- **For Lab Test:** In order to perform the lab tests, several utensils were used, such as: pH meter, sample bottles, Atomic Absorption Spectroscopy (AAS), HNO₃ solution, and pipette drops.

- **For Basic Mapping:** an Indonesia earth map of the scale 1:50.000 pieces of Ternate, a Geological Map of Ternate Sheet scale 1: 25.000 and a Topographic map scale 1:25.000 were used in order to create the mapping, as well as software Surfer 11 and Coordinate Transformation Version 1.01 [8]
2.3. **Research Procedures**
The procedures undertaken are divided into three stages, namely: data collection, processing and analysis.

### 2.3.1. **Data Collection Method**
The geothermal exploration location was examined by using the magnetic method. It controlled by a lot of important structural concepts, which are: a) geothermal system in sedimentary and large faults, both presumably related to basement tectonic, b) secondary fissures and minor faults at shallow depths must be tapped for exploitation, c) geothermal systems in volcanic environment are associated with non-magnetic volcanic rocks [9]. Magnetic measurements are often used for the investigation of high-temperature geothermal systems derived from young volcanic rocks (quarter) [10]. Magnetic measurements are made by using the grid method at several points in the manifestation and its surroundings. The fluxgate magnetometer measurements were made in an area of the size of $± 100 \times 100 \text{ m}^2$ to obtain the magnetic anomaly values. In this study, about 181 magnetic measurements were obtained.

The temperature measurements of the hot springs are conducted randomly in order to create a map of the temperature anomalies. The purpose of this measurement is to identify the distribution of heat around the hot springs associated with the hydrothermal alteration of the rocks exposed on the surface. Water samples are taken by using the purposive sampling method. Furthermore it was examined in the laboratory to identify the chemical elements. These water samples were taken from both sites with two replicates and the addition of HNO$_3$ at 0.1% to preserve the volume of the sample.

**Figure 4.** Research procedure including data collection, processing and analysis

### 2.3.2. **Data processing**
The purpose of data processing was to contour a map of the value of magnetic and temperature anomalies using the software Surfer 11. For the measurement of surface temperature, the first thing to be completed is calibration of the thermometer and sensor to reduce the measurement error. This includes the conversion from mV to Celcius. The result of chemical element measurement, is then to be averaged from replication at both locations, to know the chemical content.

### 2.3.3. **Data analysis**
Data analysis is determined by using qualitative interpretation. The data results of the two fields are compared to determine the characteristics of the geothermal system and its characteristics based on the interpretation of magnetic anomalies. The chemical element used to classify the type of geothermal hot water resources.

3. **Results and Discussions**

### 3.1. **Magnetic Data**
Before interpreting the magnetic anomaly data obtained from the field work, it will first be processed by performing corrections, i.e. daily variation correction, IGRF correction, drift correction and regional and residual anomaly separation correction. The function of the separation of the anomaly to obtain the value of residual magnetic anomalies is to eliminate the effects of broader regional anomalies.

The residual magnetic anomaly value is then processed to produce a contour mapping using the Surfer
The basis for contouring the residual magnetic anomaly is made up of 3 variables, namely latitude, longitude and the value of residual magnetic anomaly. The magnetic anomalies are interpreted in a qualitative manner rather than by geometry and depth. The geological data of the study area is also required in this interpretation. The results of the contour maps of residual magnetic anomalies in the villages of Sulamadaha and Tobololo, are featured below (see Figure 5).

As seen in Figure 5, the residual magnetic anomaly values are about -3678.63 nT up to 2679.57 nT where the magnetic anomaly contour maps can be divided into 3 parts: low, medium and high magnetic anomalies. Low Anomalies under 2.200 nT are depicted in light blue, while the medium anomalies that show values between $-2.200$ and 200 nT are depicted in blue and green. Finally, high anomalies greater than 200 nT are depicted using the color range from yellow to deep red. Negative magnetic anomalies are associated with geothermal manifestations on the surface whereas positive anomalies are not associated with thermal activity. Areas with negative magnetization may have presented hydrothermal alteration [11]. Sulamadaha and Tobololo are dominated by moderate to low magnetic anomalies, which are indicated by the emergence of hot springs.

The pattern of investigated magnetic anomalies, structural lineament identification and characteristics of magnetic sources clearly describe sedimentation associated with tectonic plates [12]. The result of the positioning of magnetic anomalies is related to the geological condition, which indicates that the area is a geothermal manifestation resources. This is made clear by the emergence of hot water in the surface. If we take a look at the geology of Ternate Island it is dominated by Holocene volcano rocks such as andesite breccia, andesite-basalt lava and tuff. Sulamadaha and Tobololo areas are dominated by surface deposits of lava andesite blocks of the types 2 and 3. Hydrogeology also plays an important role to understand the flow of ground water in the areas of Sulamadaha and Tobololo.

Geothermal location are predominantly by the fluid due to the hydrothermal processes that convert magnetite and titmagnetite into almost non-magnetic minerals, such as pyrite, leukoxin, or hematite [13]. Changes from hydrothermal roses caused some or all of the volcanic rocks to be demagnetized and there were visible significant differences in magnetization between reservoir rocks and the unaltered volcanic rocks outside of it [14]. The distribution of hot water in the northern part of Ternate Island is uneven due to the high-low anomaly seizure pattern and the rocks show a medium to high susceptibility. These rocks are lava andesite-basalt, and some are even exposed to the surface. Medium to low magnetic anomalies
are spread in coastal areas, and they can be interpreted as low magnetic to non-magnetic rocks [15]

Figure 6. Map of the Combined Contour of Magnetic Anomalies in Sulamadaha and Tobololo areas

The results of data processing in the Center for Volcanology and Geological Hazard Mitigation in Bandung shows an indication of the faults that direct the flow of hot water toward the coast. Differences in the level of susceptibility are not caused by differences in the type of lithology, but rather by changes in the physical properties that occur due to faults. As a result of this process, the materials will undergo changes in their physical properties that will directly or indirectly lead to changes in the level of magnetic susceptibility. The direction of relative magnification is to the east-west and southwest-northeast. Increased fault blocks have a higher magnetic anomaly value compared to falling fault blocks [15].

3.2. Surface temperature data

The heat flow in the medium caused by the difference in conductivity is mathematically the same as the magnetic induction caused by an object having the same size in a uniform field. Based on these similarities the method of magnetic interpretation can be applied to the interpretation of temperature anomalies [16]. This research shows the qualitative interpretation of the mapping of temperature anomalies in order to study the distribution of heat around hot springs. This is related to the distribution of hydrothermal alteration rocks exposed on the surface. The appearance of geothermal manifestation in hot springs is strongly influenced by the condition of the area. The Northern Ternate region includes the Sulamadaha and Tobololo areas, have a magnetization structure and this is influenced by the magnetic anomaly values in the physic changes of rocks.

The heat released by geothermal fluid is due to the two volcano-tectonic depressions. This is controlled very well by the depths of the magma-ambient zones, and the depth to which the groundwater convection cells can penetrate [17]. As seen from contours based on geological information the data of temperature anomaly shows heat position and distribution. At each point of measurements, the temperature values of fluid and rocks can reach depths of 50 cm below the surface. The measured temperature mapping is 27 – 38.50 °C.

In the temperature mapping shown in Figure 7, the value spread throughout the study area. The temperature anomaly of the map shown in the Sulamadaha and Tobololo is too large towards the coast.
The temperature reach 38.30 °C for the Sulamadaha and of 38.50 °C for the Tobololo. Moreover in the Tobololo an anomalous temperature indicating the flow of hot springs is present along the coastline. Meanwhile in the Sulamadaha there is a hot spring discharge smaller than in Tobololo, this is because the hydrothermal activity below the surface of the Sulamadaha is smaller than the Tobololo.

![Map Temperature 50 cm below the surface of the hot springs in Sulamadaha and Tobololo](image)

**Figure 7.** Map Temperature 50 cm below the surface of the hot springs in Sulamadaha and Tobololo

As seen in Figure 7 at the Contour closures map show that the temperature anomalies near the hot springs are high, but they remain once it measured far away from it. Although surface temperature anomalies are present in this area, hot springs may actually be present in other areas. This is because hot fluids are able to flow through the existing fault structures and form new hot springs.

### 3.3. Geochemical Data

The analysis of the chemical elements of the water from the geothermal system in each region has shown that the water has the properties and intensity of the various hot rocks. This causes the characteristics of each region to be different, such as the type of surface manifestations, reservoir characteristics and chemical composition of the water [18]. In this research, four hot water samples from two different locations in Sulamadaha and Tobololo were obtained. Temperature and pH were measured in site by using a portable instrument. Demagnetization of volcanic rock by fluid or rock interaction is a complex process that depends on the parameters that control the stability of primary magnetic minerals, such as pH and fluid temperature [5].

Laboratory analysis was performed to determine the chemical composition in order to determine hot water type. Table 1 shows the chemical element of the hot water sample of the hot spring. Generally both springs have relatively neutral water with a pH of 7.435-7.745; pH In Sulamadaha is higher (7.745) than in Tobololo (7.435). The pH indicates that the water in both areas is in a neutral condition. Hot springs with this condition indicate that there is no sulfuric acid, sulfate chloride or carbonate present. This neutral pH will prevent the occurrence of heavy metal dissolution.

Chemical content is dominated by chloride (Cl); the sample taken at Tobololo shows a higher level at 917 ppm while in Sulamadaha has 872 ppm. In contrast, the higher SO\(_4\) content at Sulamadaha's location is of 798.5 ppm, whereas in Tobololo is 503.5 ppm. The highest Na content is found in the Tobololo area (743.919 ppm), while Sulamadaha reaches 596.647 ppm. There was no significant difference of SiO\(_2\) in both areas; in Sulamadaha the SiO\(_2\) content was of 150.522 ppm and in Tobololo it was of 149.082 ppm. The lowest chemical content is HCO\(_3\) at Sulamadaha location with 27.852 ppm. No Fe was found in the water sample.
Table 1. Chemical content of research area

| No | Sample | pH  | Cl   | SO₄   | Ca   | SiO₂ | Na  | K    | HCO₃ | Mg  | Remarks        |
|----|--------|-----|------|-------|------|------|-----|------|------|-----|----------------|
|    |        |     | Ppm  | Ppm   | Ppm  | Ppm  | Ppm | Ppm  | Ppm  | Ppm |                |
| 1  | T1     | 7.42| 590  | 501   | 30.199| 151.9627| 764.629| 55.548| 38.679| 73.353| alkali chloride |
| 2  | T2     | 7.45| 1244 | 506   | 28.993| 146.201| 723.208| 54.710| 35.541| 74.024|                |
|    | Average| 7.435| 917  | 503.5 | 29.596| 149.0818| 743.919| 55.129| 37.110| 73.689|                |
| 3  | S1     | 7.72| 870  | 761   | 37.191| 149.802| 589.743| 49.689| 28.401| 44.018| alkali chloride |
| 4  | S2     | 7.77| 874  | 836   | 38.075| 151.2423| 603.550| 49.857| 27.303| 47.601|                |
|    | Average| 7.745| 872  | 798.5 | 37.633| 150.5222| 596.647| 49.773| 27.852| 45.809|                |

The two sample sites contain Cl, Ca, SiO₂, Na, K, Mg and HCO₃, but no Fe content. Both locations also have relatively clear water and it’s odorless too. The high content of Cl, reaching levels of 400-1800 ppm, and neutral pH indicates that this spring is of the alkaline chloride type, although it has high sulfate content. In the water sample no Fe content was found, so there are no sulfuric acid springs in either location. In addition to high chloride, high Na and SiO₂ content, low Ca and SO₄, HCO₃ and Mg findings indicate that both sample sites have an alkaline chloride (Alkali Chloride Water) water type.

Figure 8. Comparison of chemical elements of the study area

The two sample sites contain Cl, Ca, SiO₂, Na, K, Mg and HCO₃, but no Fe content. Both locations also have relatively clear water and it’s odorless too. The high content of Cl, reaching levels of 400-1800 ppm, and neutral pH indicates that this spring is of the alkaline chloride type, although it has high sulfate content. In the water sample no Fe content was found, so there are no sulfuric acid springs in either location. In addition to high chloride, high Na and SiO₂ content, low Ca and SO₄, HCO₃ and Mg findings indicate that both sample sites have an alkaline chloride (Alkali Chloride Water) water type.

The Cl element (chloride) is not soluble in steam at temperatures below 300° [19]. The sample test results showed high levels of Cl, so it is concluded that the geothermal hot water dominated the water springs. The neutral heating of the spring water indicates a water-dominated system, indicated by a high Cl content.

The dominant presence of chloride can be due either to the direct access flow of geothermal water or to the mixing of seawater with thermal water. High levels of Cl will cause corrosion in the pipes of the hot water supply system. At research sites that have high Cl content, the water sample is quite salty and therefore not fit for consumption, because it will lead to dehydration. In addition, it is not recommended to use iron pipes for hot water flow because of the high corrosion risk. Cl can also be used in the
disinfection process, but if it’s mixed with HC it can cause the formation of hydrocarbon halogen (Cl-HC). This halogen is carcinogenic.

The presence of SO_4 is quite high. Sulfate is irritant to the gastro-intestinal tract when mixed with magnesium (Mg) or sodium (Na), and in this region the Na content is quite high. Small amounts of MgSO_4 can cause diarrhea. Therefore it is not recommended to be used as a source of drinking water. Furthermore SO_4, Na content are also quite high. Na content in the form of NaCl is required by the body in the form of salt, but in the form of NaOH it will be very corrosive.

The presence of Ca and Mg is relatively low in both sites. They are both derived from lime. Therefore it’s concluded that there’s no lime in this area. High Ca and Mg content will cause the water to be contained and detergent properties to be lost, which makes washing very difficult. High Ca and CO_3 content will cause the formation CaCO_3 deposits in the form of crust on the pipe wall.

4. Conclusions
This research was conducted to observe the geothermal resources in the Northern Ternate region, North Maluku, eastern Indonesia, by doing several measurements in the villages of Tobololo and Sulamadaha. The method used is magnetic anomalies by employing the fluxgate magnetometer and random temperature sampling. The results of the research shows several conclusions:

1. A magnetic anomaly value of about -3678.63 nT up to 2679.57 nT was obtained, and it indicates that the area is a geothermal manifestation area and it’s classified as a hypothetical resource that can be an unexpected reserve.
2. Mapping the anomalies of fluid and rock temperatures to a depth of 50 m below the measured surface of the value 27 – 38.50 °C Is leads to the coast.
3. The spring water resistance in the Sulamadaha area is smaller than in the Tobololo. This is due to hydrothermal activity occurring below the surface.
4. Based on the results of geochemistry, it is known that the sample location has a type of alkaline chloride water.

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