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Submission date: 30-Nov-2021 04:51PM (UTC+1100)

Submission ID: 1716095229

File name: Geology_and_2D_modelling_of_magnetic_data_to.pdf (3.94M)

Word count: 4085

Character count: 22032

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To cite this article: I N Manyoe *et al* 2020 *IOP Conf. Ser.: Earth Environ. Sci.* **589** 012002

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Geology and 2D modelling of magnetic data to evaluate surface and subsurface setting in Bongongoayu geothermal area, Gorontalo

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Abstract. Bongongoayu is one of the regions in Indonesia that has geothermal potential. Bongongoayu requires surface and subsurface data to support the preliminary data. This research aims to determine surface and subsurface data conducted by geology and magnetic method. The surface data, including geomorphology, lithology, hydrology and manifestation. The subsurface data have taken by the magnetic method. The result showed that the geothermal manifestation of Bongongoayu is a hot pool. The surface temperature is 43 to 59 °C. The geomorphology units is composed of volcanic hills unit and lake plains unit. The lithology of the research area is composed of granite and alluvial deposits. Based on petrographic analysis, the level of alteration in granite rocks is 65% and is classified as moderate alteration. The recharge area is in the north and southwest of the research area. Discharge area is in the central area. Based on 2D magnetic modeling, there are two subsurface layers. The first layer is alluvial and the second layer is granite. Rocks that are under the alluvial layer and have been altered are interpreted as a cap rock. 2D magnetic models show normal faults in the research area as a controlling factor for geothermal fluid.

1. Introduction

Indonesia affected by three major plates, i.e. SE-Asian Plate, the Indo-Australian Plate, and the Pacific Plate [1,2]. Sulawesi is formed in the convergence zone of the Eurasian, Pacific, Australian plate complexes [3] and affected by Philippines plate [4]. Northern part of the North Arm Sulawesi is the Sulawesi Sea Subduction. Sulawesi Sea Subduction was thought to have been active since the Early Tertiary and produced Tertiary volcanic arcs that stretch from around Toli-Toli to Manado [5].

The reconstruction in Sulawesi Sea shows that the volcanic arc system surrounding the Sulawesi Sea has been established since the Late Miocene [6]. Volcanism on North Arm Sulawesi is related to



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Sulawesi Sea Subduction [3]. Geothermal associated with an area of active volcanic [7]. Besides being associated with active volcanoes, geothermal is also associated with faults [8,9] and intrusions [10].

The volcano-tectonic conditions of Indonesia cause Indonesia, especially the North Arm of Sulawesi, to have big geothermal potential. This big geothermal potential is being developed by the government to support national energy. Based on a recent survey from the Geological Agency, the Ministry of Energy and Mineral Resources [10], there are 331 potential areas that have been identified consisting of 11,073 MW of resources and 17,506 MW of reserves spread across 30 provinces.

Areas identified as having geothermal potential will be explored through scientific survey methods. The scientific survey method can be in the form of geological and geochemical studies. In addition to more detailed geological and geochemical studies, various geophysical techniques can be used, including geomagnetic methods [11].

Geological surveys are preliminary surveys carried out in geothermal exploration by analyzing rocks, determining morphological characteristics, hydrological conditions, and geothermal systems. Geophysical survey in the form of magnetic, electrical and other subsurface surveys.

The geomagnetic method utilizes the contrast magnetization of subsurface rocks [12]. In geothermal areas, geothermal fluids can cause massive changes in the chemical and physical properties of subsurface rocks. Another change is the magnetic properties of rocks will be down or lost due to heat generated [13].

Geological surveys have been conducted in several geothermal areas in Gorontalo, one of which is in the Lombongo geothermal area [14]. Surveys that have been conducted in Bongongoayu are electrical [15] and magnetic [16] surveys, except that they have not provided surface geology and subsurface magnetic models. Based on the explanation above, it is very interesting to study the Bongongoayu geothermal area. This study aims to determine the characteristics of surface and subsurface in the Bongongoayu geothermal area based on geological and magnetic data.

2. Data and Method

The study area is located at coordinates 0.6230 – 0.7890 N and 122.6940 – 122.4510 E, administratively included in the Bongongoayu area (also known as Diloniyohu area), Boliyohuto District, Gorontalo Regency, Indonesia (Figure 1). The research area is located in a depressed area that extends in the central part of Gorontalo.

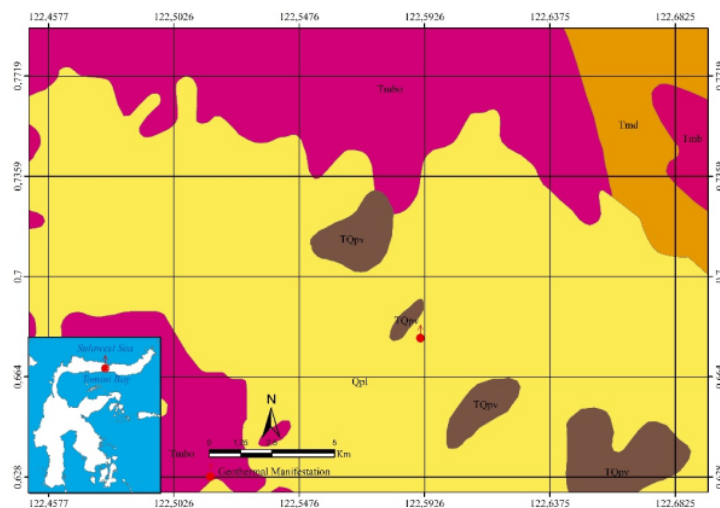


Figure 1. Geologic map of research area [17].

The instruments used in the study are GPS receivers, Proton Precession Magnetometer GSM 19-T v7.0, Nikon ci-POL Microscope, infrared thermometer, geological hammer and geological compass. The GPS receiver is to determine the location of base station, mobile stations and observation stations. One set of Proton Precession Magnetometer GSM 19-T v7.0 is to measure and determine the distribution of magnetic anomalies. Nikon ci-POL Microscope is to determine mineral composition of rocks. Infrared thermometer to measure the temperature of geothermal manifestation. Geological hammer is to take rock samples and a geological compass is to determine direction.

2.1 Data collection and acquisition

Based on the regional geological map, rocks formation in the research area are composed of Bone Diorite (Tmb), Boliyohuto Diorite (Tmbo), Dolokapa Formation (Tmd), Pinogu Volcanics (Tqp), and the Lake Deposit (Qpl). The hot pool is located in the Lake Deposit (Figure 1). The geological data collection is carried out to determine rock units in the research area. Rock samples were taken in the research area with the aim to determine the composition of rock minerals. the geological data collection was also carried out to determine the geomorphological and hydrological data of the research area. Determination of geomorphological units by conducting field surveys of landforms.

The acquisition data of magnetic is carried out to obtain primary data. A set of Proton Precession Magnetometer GSM 19-T v7.0 is used for measurements the magnetic observation data of base station and mobile stations. Acquisition data of magnetic is carried out with a closed loop system (A, B, A), i.e. measurements always start and end at the same point.

2.2 Processing, analysis and interpretation data

Thin section of rock samples was analyzed in a laboratory using a Nikon Ci-POL Microscope. Analysis petrography using IUGS (1979) classification. Geomorphology data analysis using Van Zuidam classification (1985). Hydrological analysis of the research area was conducted to determine the recharge area and discharge area. This analysis, using field data, topographic data, and lithology.

Magnetic data processing begins by correcting the measurement data in base station and mobile stations with diurnal variation and International Geomagnetic Reference Field (IGRF) correction. Magnetic modeling of subsurface data is carried out after data correction. Modeling of subsurface magnetic data is a continuation of magnetic studies that were not carried out in previous studies [16]. Previous studies have only mapped total magnetic field anomalies without subsurface modeling. Interpretation of magnetic data uses rock susceptibility values as provided by Telford (1990).

3. Result and Discussion

3.1. Geomorphology

Geomorphological studies in a geothermal field are intended to systematically organize landforms. Based on Van Zuidam classification [18], the Bongongoayu geothermal area is separated into two geomorphological units. Two geomorphological units in the Bongongoayu geothermal area are volcanic hills (Figure 2) and lake plain (Figure 3).

Volcanic hills units occupy the northern and southwestern part of the research area. The elevation of the volcanic hills unit is 28 to 687.5 meters above sea level. The hills which are located in the north are part of the north mountain which consists of Mount Tamboo, Mount Dolokapa and Mount Boliyohuto. The hills in the southwest are part of the Loba Mountains. This geomorphological unit consists of granite, diorite and soil. On the lower slopes, local people use it as an agricultural area.

**Figure 2.** Volcanic hills unit.**Figure 3.** Lake plain unit.

The geomorphological unit of the lake plain is composed of alluvial. This unit occupies the central to southern part of the research area. The elevation of the lake plain unit is about 25 meters above sea level. Lake plain is part of the depression that stretches from east to west Gorontalo. The unit of landform of the lake deposit is located in the western part of the depression. Land use in this unit is for settlement, agriculture/plantation and fisheries.

3.2. Lithology

Bongongoayu geothermal manifestations are hot pool, found in alluvial units. Alluvial units are located in the southern part of the research area. Alluvial is concentrated around geothermal manifestations extending to the south, east and west of geothermal manifestations. The color of alluvial deposits in the research area is blackish brown. The northern part and southwestern part of the research area is composed of granite units. Granite units are composed of granite and diorite.

Granite is located in the northern part and southwestern part of the research area (Figure 4). Rock texture is holocrystalline and composed of orthoclase, quartz and plagioclase. Secondary minerals found in granite rocks are quartz, clay minerals and opaque minerals. The mineral form is anhedral to subhedral.

**Figure 4.** Granite (photo direction N 70° E).**Figure 5.** Carbonate vein in diorite (photo direction N 40° E).

Diorite is located in the northern part of the research area on volcanic hills units. Rock texture is holocrystalline and composed of orthoclase and quartz. Secondary minerals found in diorite are clay minerals and opaque minerals. The form of minerals is anhedral and subhedral. Vein Carbonate is found in diorite (Figure 5).

Microscopic analysis of rock samples in the study area shows that rock samples are alteration igneous rocks. Rock structure type is massive. Rocks in the study area are granite based on petrographic analysis of rock samples in the research area.

The mineral composition of rocks in the research area is shown in Table 1. Microscopic analysis of rock samples in the study area showed that the secondary mineral composition was at least 45% and the

highest was 65%. Primary mineral forming rocks in the study area are orthoclase, quartz, and plagioclase. Secondary minerals found in rocks are quartz, clay minerals and opaque minerals.

Table 1. The mineral composition of the rocks in the Bongongoayu geothermal area.

Station	Rocks	Mineral Composition (%)					
		Primary Mineral			Secondary Mineral		
		Ort	Qz	Pl	Qz	Cl	Opq
SR.a	Granite	20	10	10	35	15	10
SR.b	Granite	20	10	15	25	15	15
SR.c	Granite	10	20	25	30	10	5
SR.d	Granite	20	15	10	35	15	5
SR.e	Granite	10	25	-	45	15	5
SR.f	Granite	20	10	10	35	15	10

Note: Ort = Orthoclase; Qz = Quartz; Pl = Plagioclase; Cl = Clay Mineral; Opq = Opaque Mineral.

The composition of primary minerals at SR.a is 40%, while the secondary mineral composition is 60%. Primary mineral composition at SR.b is 45%, while secondary mineral composition is 55%. SR.c has 55% of primary minerals while secondary minerals are 45%. SR.d primary mineral composition is 45%, while secondary minerals 55%. SR.e primary mineral composition is 35%, while secondary minerals 65%. SR.f shows the composition of primary minerals is 40%, while secondary minerals is 60%.

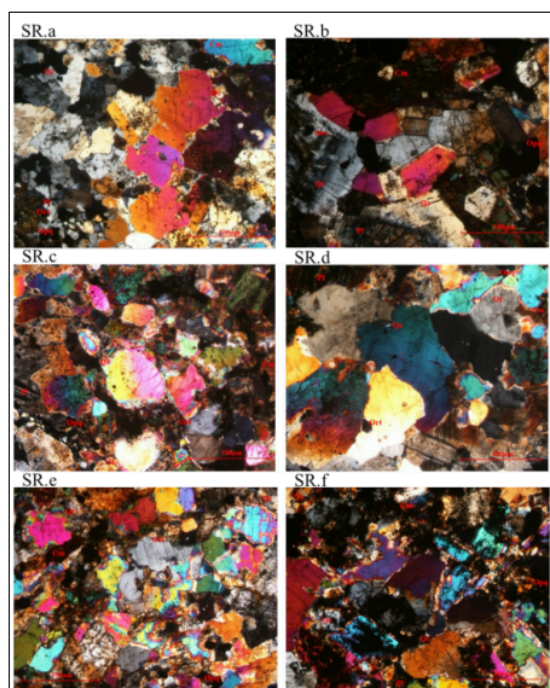


Figure 6. Photomicrograph of sample in the study area. Sample SR.a up to SR.f are granite.

Alteration intensity is defined as the level change based on the percentage of secondary minerals. Morrison [19] provides alteration intensity based on the percentage of secondary minerals. Not altered, if no secondary mineral. Weak altered if secondary mineral is 25%. Moderate altered if the secondary mineral percentage is about 25 to 75% and strong altered if secondary mineral is >75%.

If all primary minerals are altered (except quartz, zircon and apatite) but the primary texture is still visible, the intensity of the altered is called intense altered intensity. The total altered intensity is all primary minerals are changed (except quartz, zircon and apatite) and the primary texture is not visible. Microscopic analysis of samples in the research area showed that the secondary mineral composition was at least 45% and the highest was 65% (Figure 6). Based on the classification given by Morrison [19] the intensity of rock altered in the study area is moderate altered.

3.3. Hydrology

Annual rainfall in the research area ranges from 1244 to 2311 mm per year. The highest monthly rainfall in eight years generally occurs in May and the lowest monthly rainfall generally occurs in August. Cumulative rainfall a month with rainfall 90 mm occurred in August and September while the cumulative monthly rainfall >100 mm occurred in October – July [20]. The level of rainfall can affect the height of the water table [21]. Thus, high rainfall in the research area can affect groundwater availability.

The northern part of the Bongongoayu geothermal area is a protected forest area, production forest and Nantu reserved forest [22]. Vegetation in the forest can accelerate the process of rainwater infiltration. Plant roots forest vegetation opens the way for rainwater to be infiltrated. The infiltration process is one of the determinants of water availability.

The next determining factor is the shape of the landscape and permeability. According to Noor [23], water will flow faster on steep slopes than moderate sloping. It means that the rainwater infiltration process takes place in the northern part of the study area. The nature of rock that can carry water is another determining factor for infiltration. The fractures in the rocks in the northern part of the Bongongoayu geothermal area [17] are potential infiltrations. Rainwater infiltrates into the soil through fractures in rocks.

According to Rezky et al. [24] shallow groundwater conditions can be seen from the presence of large and watery rivers throughout the year. The rivers surrounding the Bongongoayu geothermal area are the Bongo River, Diloniyohu River, Buliya River and Paguyaman River. Bongo River, Diloniyohu River and Buliya River are watery rivers throughout the year and head into the Paguyaman River.

Recharge areas in the Bongongoayu geothermal area are in the northern part of the Bongongoayu geothermal area which has moderate slopes and rocks that have fractures. Discharge area is located in the central part, which is located in the lake plain unit. The hydrological conditions in the research area have caused a large amount of surface and groundwater reserves in the Bongongoayu geothermal area.

According to Marshak [21] on a local scale, a recharge area occurred at the top of a hill and discharge area in the valley. This means that on a local scale, the recharge area in the research area is on volcanic hill near from hot pool. Discharge area is in the valley where geothermal manifestations occur.

3.4. Geothermal manifestation

Geothermal manifestation in the Bongongoayu area is hot pool (Figure 7). The hot pool is located at coordinates 0.67785 N and 122.5911 E. The hot pool is located at an altitude of 24 meters above sea level.

The research area consists of granite units and alluvial units. Granite and diorite are included in granite units. Hot springs are located in alluvial units. The northern part of the hot pool is the granite and diorite volcanic hills. The wide area of a hot pool is $\pm 600 \text{ m}^2$.

Measurement of surface temperature in hot pool using an infrared thermometer. The surface temperature of the hot pool ranges from 43 to 59 °C. Physical conditions of hot pool are tasteless and odorless. The appearance of the color of hot water is clear with a neutral pH 6.



Figure 7. Hot pool as a geothermal manifestation in research area.

3.5. Magnetic model

The 2D modelling of magnetic data is shown in Figure 8 and Figure 9. The first model is in the Northeast part of the research area stretching from Northwest-Southeast. The second model is in the Southwestern part of the research area stretching from Northeast-Southwest.

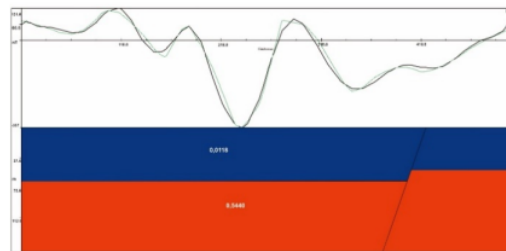


Figure 8. 2D modelling of first anomaly.

There are two layers in the first model consisting of alluvial and granite. The total layer depth in the model is 62.5 m. The first layer has 0.0118 susceptibility value. The first layer is at a depth of 0 to 62.5 m. Based on the value of susceptibility, the first layer is interpreted as alluvial. The second layer has 0.5440 susceptibility value. The second layers are at a depth ranging from 62.5 m. Based on the value of susceptibility, the second layer is interpreted as granite.

In the second model, there are two layers. The first layer has a value of 0.0118 susceptibility value. The first layer is at a depth from 0 to 43.75 m. Based on the value of susceptibility, the first layer is interpreted as alluvial. The second layer has a value of 0.5440 susceptibility value. The depth of the

second layer starts at a depth of 43.75 m. Based on the value of susceptibility, the second layer is interpreted as granite. Lithology and susceptibility value refer to Telford et al. [25].

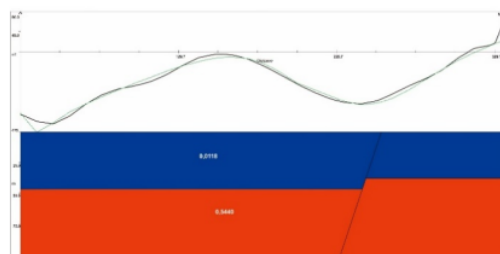


Figure 9. 2D modeling of second anomaly.

2D magnetic models show that alluvial deposits are surface layers. The layers beneath the alluvial are granite. Some minerals in granite rocks have been altered. The altered part of Granite just below the alluvial layer is interpreted as a cap rock. 2D magnetic models also show the geological structure. Magnetic modeling show that the structure contained in the study area is a normal fault. Geothermal fluids from reservoirs exposed to the surface are controlled by this fault.

4. Conclusion

Geomorphology of the research area is volcanic hills and lake plains. The lithology of the study area is composed of alluvial and granite. The alteration intensity in the research area is included in moderate rock alteration intensity. Recharge area is located in the northern part, while the discharge area is in the valley. The valley is located in the central part of the research area, where hot pool appears. The surface temperature of hot pool ranges from 43 to 59 °C. The physical condition of water in a hot pool is tasteless and odorless. The color appearance of hot pool is clear with neutral pH 6. Based on the 2D model, there are two layers, alluvial with susceptibility value 0.0118 and granite with susceptibility value 0.5440. 2D models show that the normal fault in the research area is a controlling factor for geothermal fluids.

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Acknowledgments

We would like to express our deep gratitude to KEMENRISTEKDIKTI for the research fund. We would like to extend our thanks to the staff of the Geological Engineering Laboratory and Geography Laboratory of Universitas Negeri Gorontalo for their help in acquisition data of magnetic.

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