Geological structure identification in Tulehu geothermal prospect area using gravity data analysis

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Abstract. Tulehu is one of geothermal prospect areas located in east Indonesia, which is in Maluku Province. The geological condition of the area is dominated by quaternary volcanic rocks like lava flow, lava dome, and pyroclastic flow, which probably associated with Mt. Eriwakang and Mt. Huwe. But the area is mostly covered by limestone, especially in the southern part of the area. The geothermal prospect of Tulehu is indicated by the occurrence of hot springs spotted along Banda Fault, Banda-Hautusa Fault, and Huwe Fault in the southern part of Tulehu. In order to understand the subsurface geological structure and its correlation to Tulehu geothermal system, gravity survey was conducted. Gravity survey was carried out using Scintrex CG-5 gravimeter with total of 130 stations were measured with 500 m spacing. The result of CBA and residual gravity indicated the existence of low gravity anomaly at the Mount Eriwakang, while the high gravity anomaly found around several structures obtained from Remote Sensing. Several structures were detected by FHD method, those are Huwe Fault, Banda Fault, Tulehu Fault, and Wayari Fault. Based on SVD method, the type of faults are identified. These structures also supported through 2-D gravity forward modeling. The 2-D gravity modeling results several layers that build the geothermal system of Tulehu, those are Limestone with density of 1.79 g/cc, Pyroclastic with density of 2.67 g/cc, Andesitic Lava with density of 2.6 g/cc, claycap with density of 2.2 g/cc, and Basement with density of 2.81 g/cc.

Keywords: Gravity, geothermal, fault, derivative analysis, 2-D forward modelling

1. Introduction

Recently, Indonesia government through PT. PLN has concern about the utilization of geothermal energy. The energy is developed to fulfill the increase in electricity demands in Indonesia. Especially in eastern Indonesia, including Ambon Island and the/its surrounding area.

Ambon Island is blessed by a geothermal energy resource which is located at Tulehu district area. The presence of geothermal energy resources in this area is indicated by several geothermal manifestations, such hot springs and also altered rocks. The geothermal manifestations are aligned along several major faults in the area.

Previous exploration works include 3G (geology, geochemistry, and geophysics) surveys and exploration well drilling had been done as attempt to delineate the geothermal system in Tulehu.
Exploration drillings were conducted based on 3G study. Unfortunately, drilling results from several existing wells show that the temperature in the bottom hole is less than 200 °C on average. Effective structure identification must be done for further identification of this geothermal system. Thus, gravity survey was carried out in this study. Gravity method has been widely used in several geothermal prospects such as in Sibayak Geothermal Field [1]. The study shows that gravity anomaly has good correlation with the subsurface geological condition.

In this research, 2-D forward modeling of recent gravity data was applied to re-evaluate the geological structure that may controlled the geothermal system in the area.

2. Experimental

2.1. Geological setting and surface manifestations
Tulehu geothermal prospect is located in the eastern part of Ambon Island, in the northern part of Banda arc. Interaction of the Australian, Pacific-Philippine and Eurasian plates from the Late Miocene until the present strongly influences the tectonic of Seram- Ambon Series [2]. Pleistocene volcanic complex on Ambon islands is caused by the subduction of Australian plate beneath Seram Trough which has 20–30 km crust thickness.

Tulehu area is composed of alluvium in the northern part, the Quarternary volcanic around Mt. Eriwakang, Tertiary volcanic from Mt. Salahutu and Mt. Huwe, and Tertiary Metamorphic rocks as the oldest unit of this area. There is also quaternary limestone which is mostly distributed in the southern area. The Eriwakang volcanic is covered by limestone, which is probably derived from marine environment. The limestone is 30–50 m thick and very porous because of intense weathering influence.

Several geological structures are detected from remote sensing such as Banda Fault, Banda-Hatuasa Fault, Huwe Fault, Wayari Fault, and Tulehu fault as shown in figure 1. These faults might act as a channel or pathways for manifestation to appear at the surface. This is supported by the occurrence of several thermal activities spotted along Banda Fault, Banda-Hatuasa Fault, and Huwe Fault in the eastern part of Tulehu. The type of these manifestations is hot spring which categorized as outflow manifestations [3].

2.2. Gravity data acquisition and processing
Gravity survey was conducted in Tulehu geothermal prospect area in 2019 to get better understanding of the subsurface geological structure and the correlation with the geothermal system. The survey area extends from North West area of Eriwakang Mountain up to Mount Huwe in South East area. 130 gravity stations were measured and evenly distributed around the area. Each station were separated by 500 m distance.

Gravity survey was carried out by utilizing Scintrex CG-5 gravimeter. The gravimeter measured relative gravity value in mgal. The data were corrected with drift correction and converted into absolute gravity value. Absolute gravity value at gravity Base Station in BMKG Pattimura Meteorological Station, near Pattimura International Airport, was used as reference.

Absolute gravity data were corrected with several reduction to produce complete bouguer anomaly. The corrections were consisted of latitude correction, free-air correction, bouguer correction, and terrain correction. All of the corrections can be explained by the equation below:

\[ CBA = Gobs - Gn + 0.3086h - 0.04193ph + TC \]

where, CBA is complete Bouguer anomaly, Gobs is station absolute gravity, Gn is latitude correction and TC is terrain correction [4].
Figure 1. Geological setting of Tulehu geothermal prospect area.

Bouguer density is a constant for bouguer correction and terrain correction calculation. The density was calculated by using parasnis method [5] and obtained a value of 2.1618 g/cm$^3$. As for terrain correction, elevation data around the survey area were also needed. DEM data from DEMNAS were used as elevation data.

Residual anomaly was extracted from CBA by subtracting the anomaly with regional anomaly. Regional anomaly was calculated with the first order of Trend Surface Analysis (TSA). 2-D forward of gravity data were then applied toward the residual anomaly, in order to generate the subsurface density model which may represent the subsurface geological condition in Tulehu geothermal prospect area.

3. Results and discussion

3.1. Complete bouguer anomaly and residual anomaly

The complete Bouguer anomaly (CBA) is shown in the figure 2, where the value ranging from 87.95 to 120.03 mgal. Based on CBA Map, the estimated prospect zone is located around Mt. Eriwakang which has medium anomaly value while the surrounding area has high anomaly value. Thick and wide limestone distribution at the mountain peak causes the medium anomaly. The limestone has low density and high porosity because of intense weathering.

CBA Map also shows the distribution of low gravity anomaly in the northern part of the area. The low anomaly correlates with the geology condition. The lithology is alluvium which lower density than other rocks.

High gravity anomaly is spotted between Mount Eriwakang and Mount Huwe. The anomaly indicates the existence of Huwe Fault. Furthermore, This fault probably controls the occurrence of hot springs as it is coincided with the location of the hot springs. However, the indication is not clear enough since fault contact should be located at high contrast of high and low gravity anomaly.
Residual anomaly was separated using the first order of TSA. The anomaly indicates shallow anomaly in the study area. Generally, the pattern of residual gravity anomaly is mostly similar to the CBA (figure 3). The anomaly has a value ranging from -9 to 21 mgal.

Residual anomaly shows higher anomaly contrast compared to CBA. Especially, anomaly around Huwe fault and Banda Fault show higher contrast. High gravity anomaly assembles on northwest side of Banda fault while low gravity anomaly is shown on the other side. As for Huwe Fault, high gravity anomaly gathers on northern side of the fault, while low gravity anomaly gathers on the other side.

First horizontal derivative (FHD) and second vertical derivative (SVD). FHD or First Horizontal Derivative map is shown in figure 4. Presence of geological structure is indicated by maximum gradient value. Fortunately, maximum gradient anomaly in the area have coincided with the presence of the geological structures obtained from RS analysis and geological study. The structures are Banda Fault, Banda-Hatuasa Fault, and a fault between these faults at the middle of Tulehu area (Line A-A’), Huwe Fault in the southern part of this area (Line B-B’), Wayari Fault at the western part, and Tulehu Fault at the eastern part of the area.

Figure 2. CBA map of Tulehu geothermal prospect.

Figure 3. Residual anomaly map of Tulehu geothermal prospect.
Furthermore, SVD is used to identify the type of the faults (figure 5). In general, fault contact is located at 0 SVD anomaly value between maximum and minimum SVD anomaly value. Normal fault is indicated by higher SVD maximum value than absolute of SVD minimum value. Thrust fault is indicated by lower SVD maximum value than absolute value of SVD minimum anomaly [4].

FHD and SVD value of Line A-A’ and line B-B’ were plotted to identify the presence and the type of these faults. The results are shown in FHD and SVD curve for line A-A’ and line B-B’ (figure 6 and figure 7).

Based on FHD and SVD curves, there are three faults identified in line A-A’, shown by red lines. The faults contact is located near the peak of FHD value and 0 value of SVD. In figure 5, 0 value is shown by white line which is the boundary between blue and green colour. All of the three faults are interpreted as normal fault. In the curve, maximum SVD anomalies always have a higher value than the absolute value of SVD minimum anomaly. The interpreted faults location are corresponding with Banda Hatuasa Fault, unnamed fault, and Banda Fault respectively, which are based on geological data.

FHD and SVD curve of line B-B’ indicates the presence of a normal fault. The fault contact is shown by the red line which is located near FHD peak curve. Maximum SVD value on the right side
of the line is higher than absolute of SVD minimum value on the other side. The fault is interpreted as Huwe Fault.

2-D forward modeling of gravity data. 2-D forward model has five layers, which are consisted of Limestone with density of 1.79 g/cc, Pyroclastic with density of 2.67 g/cc, Andesitic Lava with density of 2.6 g/cc, Clay Cap with density of 2.2 g/cc, and Basement with density of 2.81 g/cc (figure 8). Several fault features are presented in the model. The fault location is determined based on FHD and SVD analysis, while the fault type and direction is modeled through 2D forward modelling. Two faults on the right side form a graben structure. The faults are interpreted as geological structure that control the geothermal system.

![Figure 6. SVD and FHD curves line A-A’.](image)

![Figure 7. SVD and FHD curves line B-B’.](image)
4. Conclusion
A gravity study has delineated the major geological structure features of Tulehu geothermal prospect area. The indications are shown in CBA map by high contrast of high and low gravity anomaly. The presence of these structures also indicated by FHD and are suitable (good correlation) with structures from geological data interpretation. Banda Fault, Banda-Hatuasa Fault, and a fault between these faults at the middle of Tulehu area is detected at Line A-A’. Huwe Fault is indicated from Line B-B’ FHD curve. Based on SVD method, the type of Banda Faults, Banda-Hatuasa Fault, a Fault between these two faults, and Huwe Fault is a normal fault. These faults strengthened from the 2-D gravity modeling result. 2-D forward model of gravity data also can show the distribution of several structures and rock layers.

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