The Study of Fault Lineament Pattern of the Lamongan Volcanic Field Using Gravity Data

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Abstract. Lamongan Volcano located in Tiris, East Java, possesses geothermal potential energy. The geothermal potential was indicated by the presence of geothermal manifestations such as hot springs. We used secondary gravity data from GGMplus. The result of gravity anomaly map shows that there is the lowest gravity anomaly in the center of the study area coinciding with the hot spring location. Gravity data were analyzed using SVD method to identify fault structures. It controls the geothermal fluid pathways. The result of this research shows that the type of fault in hot springs is a normal fault with direction NW-SE. The fault lineament pattern along maar is NW-SE. Maar indicates anormal fault. As the result we know that gravity data from GGMplus which analyzed with SVD can be used to determine the type and trend of fault.

1. Introduction
Indonesia is located between three tectonic plates, i.e. the Eurasian, the Indo-Australian, and the Pacific Plates [1]. These plates formed convergent plate margin namely subduction zone. Consequently, Indonesia has many active volcanoes [2]. Active volcanism in convergent margin becomes a potential target for geothermal explorations. These geothermal potentials are indicated by manifestations such as hot springs [3].

The Lamongan Volcano is one of the 76 active volcanoes in Indonesia [4]. The Lamongan Volcano, which is stratovolcano type, is located in 7.983°S and 113.342°E [5]. It is also situated in the Sunda arc and in between three volcanic complexes, that is Bromo, Semeru, and Argopuro volcano, as shown in Figure 1 [6]. Moreover, the Lamongan Volcano has 61 basaltic cinder or spatter cones and 29 maars [4, 7]. Tiris, a village located on the eastern of Lamongan Volcano, has a geothermal potential characterized by hot springs, with temperatures between 35°C and 45°C. There are also zeolite veins on rocks, indicating a boiling zone along the hydrothermal outflow zone [3].

Gravity method was conducted to identify subsurface structures in Lamongan Volcano. The basic principle of the gravity method was to measure the difference value of the gravitational field due to variations in rocks density [8]. In this research, we used gravity method to identify fault structures that controlling geothermal fluid pathways using Second Vertical Derivative (SVD) [9]. We used secondary gravity data from Global Gravity Model Plus (GGMPlus).
Figure 1. East Java map shows the location of the research area. There are 3 major towns around, i.e. Probolinggo, Lumajang, and Jember. Four volcanoes i.e. Bromo, Semeru, Argopuro, and Lamongan showed by a red triangle. The fault on hot springs shown by the black line [10, 11]

2. Materials and Methods

In this research, gravity data was obtained from GGMPflus in radial derivative of disturbing potential form. Gravity data satellite was downloaded from http://ddfe.curtin.edu.au/gravitymodels/GGMplus. GGMPlus provides gravity data covering all continents and coastal zones with a total of 3 billion points data. Gravity data was available in grid form with space between points ~200 m [12]. The coordinates of this research in the 49S UTM zone elongated from 681731 m to 806625 m and 9085476 m to 9137909 m.

The data obtained from GGMPlus was available in the form of 5°x5° areas, so we have to select data according to the research area [12]. The utilized GGMPlus data was the gravity anomaly. Gravity anomaly was subsequently separated into regional anomaly using upward continuation and subtracted to produce the residual anomaly. The residual anomaly was analyzed with SVD to generate SVD anomaly.

Structural analysis was conducted by slicing SVD anomaly. SVD was used to delineate the contact of lithology with contrast density and enhancing local anomaly and to identify the types of fault and the estimated dipping fault [13, 14]. The slice was made by cross-section of the fault boundary. The fault boundary was classified by a zero value of SVD anomaly [15]. The slice on the contour anomaly of SVD resulted in a curve which then analyzed to determine the type of fault in the area. There were criteria used to determine the type of faults, as follows [14, 16]

\[
\left| \frac{\partial^2 U}{\partial z^2} \right|_{\text{max}} \left( \frac{\partial^2 U}{\partial z^2} \right)_{\text{min}} > 1
\]

(1)

For normal faults, and

\[
\left| \frac{\partial^2 U}{\partial z^2} \right|_{\text{max}} \left( \frac{\partial^2 U}{\partial z^2} \right)_{\text{min}} < 1
\]

(2)

For thrust faults
3. Results and Discussion
Gravity anomaly response was obtained from GGMplus gravity data. The gravity anomaly ranges from -20 mGal to 380 mGal (shown in Figure 2).

Figure 2. Contour map of gravity anomaly in the study area was obtained from GGMplus and overlaid with fault, lineament, and hot springs. The focus of our study shown by the black rectangular and will be explained further in Figure 3.

Figure 2 shows the response of gravity anomaly in the research area affected by variations of rock density. The contour of gravity anomaly shows that highest anomaly associated by the Bromo, the Semeru, and Argopuro volcano, while lowest anomaly conformed to the length of the northern-southern in center of the study area. The results show that there is the lowest gravity anomaly in the center of the study area coinciding with the hot spring location.

Figure 3. Contour map of SVD anomaly surrounds Lamongan Volcanic Field. The line A-A’, B-B’, C-C’, and D-D’ show position of slice. The east of Lamongan Volcano is dominated by highest and lowest anomaly. The black line and green line show the position of fault and lineament based on geological data.
Contour map of SVD anomaly (Figure 3) shows anomaly value between -0.00032 mGal/m² to 0.00028 mGal/m². East side was dominated by highest and lowest anomaly which corresponds with Argopuro Volcano. In the north-west of Lamongan, there is low anomaly that located in the center area and the high anomaly was located around the center. This result corresponds with maar (blue circle) [4, 7]. The trend of fault lineament pattern directed in NW-SE. This direction indicates weak zone which was assumed as the fluid pathways from the body of volcano to the surface. This weak zone can be defined as a maar. The fault lineament was known from the pattern of maar distribution. In the north-east of Lamongan Volcano, zero value of SVD anomaly indicates the contact boundary of the fault plane. It is shown in Figure 3 that the trend of fault lineament pattern was directed NW-SE. This direction corresponds to the geological data which also displayed NW-SE. In addition, the fault in an area that located in north-east of Lamongan Volcano coinciding with hot springs location.

Overall from this curve, the value of SVD anomaly is ranged between -0.000053 mGal/m² to 0.000084 mGal/m². The value of SVD anomaly of slice A-A’, B-B’ and C-C’ has formed the curve with the maximum amplitude which is higher than minimum amplitude. Based on the value of SVD anomaly and equation 1 and 2, the result can be classified as normal fault. This normal fault has a coinciding with hot springs location.

4. Conclusion
From SVD anomaly contour map and curve profile of slicing result, we can conclude that there are two faults. The type of fault which corresponds with hot springs is anormal fault with trend direction NW-SE. Moreover, the trend of fault lineament pattern along maar can be indicated by normal fault. This lineament trends in NW-SE.

5. Acknowledgements
We would like to thank to “Kementerian Riset, Teknologi, dan Pendidikan Tinggi” for the PUPT funding no. 2452/UN1.P.3/DT-LIT/LT/2017. We are grateful to Western Australian Geodesy Group, Curtin University for data providing the gravity data used in this study. We would like to thank the anonymous reviewers for important suggestions and comments.
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