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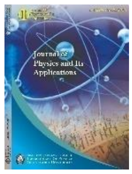

The Mass Distribution of Soputan Volcano Based on Gravity Data

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A R T I C L E I N F O

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A B S T R A C T

The gravity method is a passive method based on the density measurement among sediment. This method is usually applied to identify the condition of the earth's subsurface. Soputan Volcano is located in District Minahasa Tenggara. Soputan Volcano is included in type A Volcano or stratovolcano and it stands at 1783.7 MSL. This research aims to identify the distribution of subsurface mass (sediment density) of Soputan. The data used was Data from satellite GGmPlus and elevation data of ERTM which was corrected to ellipsoid reference. 3D inversion modeling applied Grablox software. The complete value of the Bouguer anomaly obtained was 110 – 162 mGal. The density result obtained from the inversion model was 2.3 g/cm³ to 2.95 g/cm³. The sediment that could be identified was andesite sediment and basalt sediment. Based on that result, the layer arranging Soputan Volcano consists of many variations of mass in each depth grouped into andesite, breccia, basalt, andesite-basaltic, lava, breccia, and tuff.

1. Introduction

Indonesia is one of the countries that lie in the ring of fire. The location of Indonesia could be seen from the area and geographical position where tectonic plates subduct so that Indonesia has many active volcanoes [1]. Soputan Volcano is one of 129 active volcanoes in Indonesia. It is located in Sulawesi Utara Province, 50 kilometers to the southwest of Manado [2]. Soputan Volcano is grouped in type A volcano or stratovolcano and it is 1783.7 MSL [3]. Based on the historical record from *Pusat Vukanologi dan Mitigasi Bencana Geologi* (Volcanology Center and Mitigation for Geology Disaster), Soputan Volcano exploded for the first time was in 1833 and its longest period of the explosion was 47 years while its shortest period was 1 year. The eruption characteristic of Soputan was that within one period of eruption, several eruptions occurred for several weeks to months. Soputan erupted in 1908, 1913, 1923, 1982, and 1984, 2000, and 2008.

One of the efforts to understand the behavior of the Soputan Volcano is by researching the structure beneath its surface. One of the geophysics methods, the gravity method is used to map the subsurface condition. The gravity method is a passive method based on measurement density variation of rock layering. This method is applied to identify the layering of the earth's subsurface before continuing with other geophysics methods. Generally, regional research (wide and deep) uses this method. The subsurface identification requires a subsurface model. The modeling would assist in the image of the subsurface structure related to the research purpose. One of the efforts to understand the behavior of the Soputan Volcano is by researching the structure underneath its surface. Research to determine the location of Soputan magma increased applied seismic data from 2013 to 2014. The result of the research revealed that the hypocenter was spread around the crater at the top and tended to lean to the southwest in the depth of 100 m to 8000 m beneath the dome of lava (2). They have not been many pieces of research dealing with Soputan Volcano therefore, Soputan Volcano's inversion modeling was conducted using satellite data. Other volcanic interpretations use GGmPlus data or satellite data already done in many volcanos, i.e Lamongan, Semarang, Lawu, Ungaran, etc. The satellite data is useful to use that will produce preliminary features of volcanic areas [4-9].

The use of GGmPlus for Soputan Volcano inversion modeling was conducted by modeling the local and its region. GGmPlus and ERTM Data are gravity satellite data and the current elevation has a grid of 220 m. This data is produced from the mathematical model and the existing observation data [10]. In this research, the modeling would be conducted using complete Bouguer anomaly data brought to the flat surface using Phyton programming. This research aims to obtain density variation pictures horizontally and vertically using local Bouguer anomaly data.

2. Theory

2.1. Geological of Research Area

Soputan volcano is located in Province Sulawesi Utara, 50 km to the southwest of Manado. Soputan Volcano is located in District Minahasa Tenggara and it takes place in 1783.7 MSL.

Geographically, it is located in 01°06'30 North Latitude and 124°43' East Longitude. According to the Center Volcanology and Mitigation, the geomorphological condition of Soputan Volcano and its surrounding could be categorized into three morphology units: volcano body morphology unit, hilly morphology unit, and land morphology unit [11].

Stratigraphy conditions based on the Geology Map of Soputan Volcano could be seen in Figure 1, arranged by: Kalelondeilava flows (KI), Lava sediment (Lh), Maniporoklava flows (MPl), Rindenganlava flows (RI), Sempupyroclastic flows (SEa), Soputanpyroclastic debris (Sj), Soputan Lava Flows (SOl), Silianlava flows (SNl), Soputanpyroclastic debris (SOj), Temboanpyroclastic flow (Ta), Miosenvolcanic sediment (Tmv), Tondanovolcanic sediment (TOv), and Watukolokpyroclastic flows (Wa) [11].

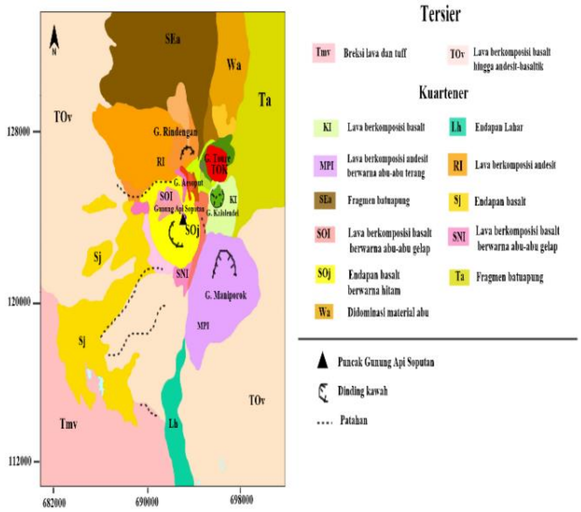

Fig.1: Geology Map of Soputan Volcano (Board of Geology)[8]

2.2. Basic Principle of Gravity Method

The basic principle of the gravity method is the law of the Newton gravity field. Newton's gravity field law explains about attracting force between 2 particles with mass and directly proportional with the result of mass and inversely proportional with the distance squared between both masses. An explanation about gravity field law could be seen in figure 2 [12].

Complete Bouguer Anomaly is the difference of observation result to its ideal model. The observation valueis the gravity field value obtained on the field, while its theoretical value is the mathematics value on the earth's homogeneous ellipsoid approach [21]. The difference from its ideal value is identified from the correction value produced. Correction value was obtained from the correction towards the latitude, topography, and the mass subsurface and around the observation point.

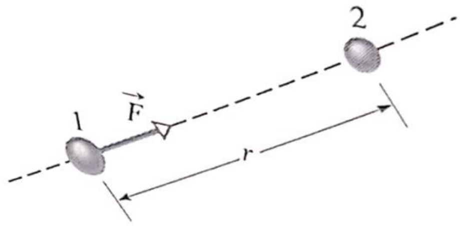

Fig.2: Attracting force between particle 1 and particle 2.

Mass is the main component of the gravity concept. Bouguer anomaly equation could be written as follows:

$$CBA = g\ obs - g\ teoritic \quad (1)$$

There is a simple Bouguer anomaly in the gravity method, also known as Free-Air Anomaly (FAA). Free Air Anomaly is an anomaly as the result of topography correction that has not accommodated the valueof subsurface mass density. Therefore, further correction is required to obtain a complete Bouguer anomaly valueas formulated by the following

$$CBA = FAA - BC + TC \quad (2)$$

CBA is Complete Bouguer Anomaly, BC is the Bouguer Correction and TC is Terrain Correction.

CBA value was the subsurface response presentation to identify the subsurface density distribution. Subsurface modeling could be done forwardly or inversely. Inversion modeling used mathematical calculation as the main process of modeling. The modeling that could be used consists of forwards modeling and inverse modeling, both in 2D and 3D. Forward modeling could be conducted using a trial-error technique that could be applied during the forward modeling to find the suitable response with the data on field or observation data. Inverse modeling could be said as the opposite of forwarding modeling since, in inverse modeling, the model parameter is obtained directly from the data [13-15]. Inverse modeling is one of the most common ways to identify subsurface density distribution. The objective of the inversion process was to estimate the physical parameter of sediment which was previously unknown [16].

The process of inversion modeling is to find model parameters resulting in a suitable response to the data observed, therefore, inverse modeling is frequently called data fitting. 3D models produced could be displayed as 2D or 3D [17-19]. Software Grablox combines two inversion methods: Singular Value Decomposition Inversion (SVD) and Occam Inversion processed at the same time [20]. Occam Method is a method to overcome non-linear issues using a linear approach. Occam Method is the result of the development of the Lavenberg-Marquardt method by adding a delta parameter for smoothing. The Occam equation could be seen in equation 3.

$$L = \begin{bmatrix} 0 & 0 & \\ -1 & 1 & \vdots \\ & \cdots -1 & 1 \end{bmatrix} \quad (3)$$

Equation 3 could be used to calculate the model parameter on equations 4 and 5.

$$\hat{d} = d - g(m_n) + J_n m_n \quad (4)$$

$$m_{n+1} = [J_n^T J_n + \alpha^2 L^T L]^{-1} J_n^T \hat{d} \quad (5)$$

With d is data, m is model, g (m) is the result of data forward modeling, J is Jacobi matrix, α is smoothing factor, and L is order 1 Tikhonov regulation [17].

3. Methods

Data used in this research was secondary data in the form of satellite data GGMPlus consisted of longitude data, latitude data, and Free Air Anomaly data. The border of the research area was 682000 to 702000 E and 112000 to 132000 S. This data had 9500 observation points with the width of the research area of 20 km x 20 km. Elevation data used was ERTM data which was converted to elevation data for ellipsoid reference. The average density value used was 2.67 gr/cc. 2.67 gr/cc was the value used in GGmPlus mathematical calculation. The application used in this research was Ms. Excel 2013, Google Earth Pro, Ms. Visio 2013, Global Mapper 18, Oasis Montaj, Surfer 11, Phyton, Grablox, and Bloxer. Qualitative interpretation of complete Bouguer anomaly data was conducted in this research. The model of density value distribution uses the inversion model which is then sliced into a 2-dimensional surface (2D).

3. Results and Discussion

4.1. Complete Bouguer Anomaly

The result of data processing produced a complete Bouguer anomaly value mapped in figure 3.

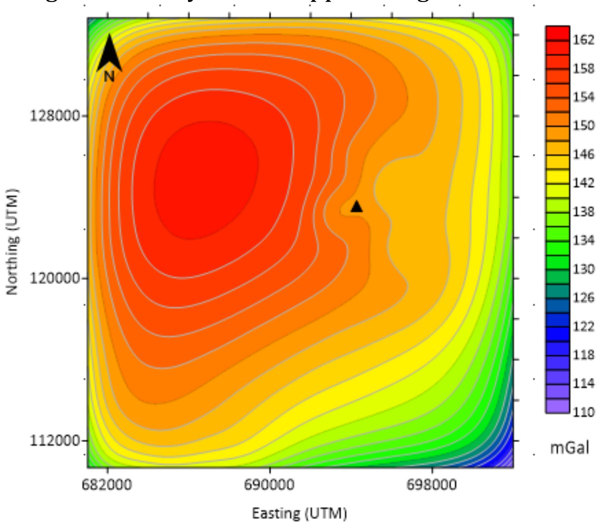

Fig. 3: Complete Bouguer Anomaly in Flat Surface.

Bouguer anomaly value in the flat surface was around 110 mGal to 162 mGal Bouguer anomaly value in the flat surface was around 110 mGal to 162 mGal. The distribution of the Bouguer anomaly value consisted of a high, medium, and low Bouguer anomaly score. The high Bouguer anomaly value stretched that its scope was quite wide in the north, west, and southwest parts of the research area. Medium Bouguer anomaly value distribution was signed by the color yellow to green. Low Bouguer anomaly value distribution has a tiny part of the scope since the color blue was only seen in the southeast part of the research location. Soputan Volcano area is located in a medium to high anomaly area. High anomaly area in volcanic areas is commonly a response of medium density sediments such as andesite-basaltic and high-density such basalt and basalt-based lava [2,6,8,19,21-22].

4.2. Quantitative Interpretation

The result of subsurface mass distribution modeling using software Grablox and Bloxer applied complete Bouguer anomaly data on a flat surface.

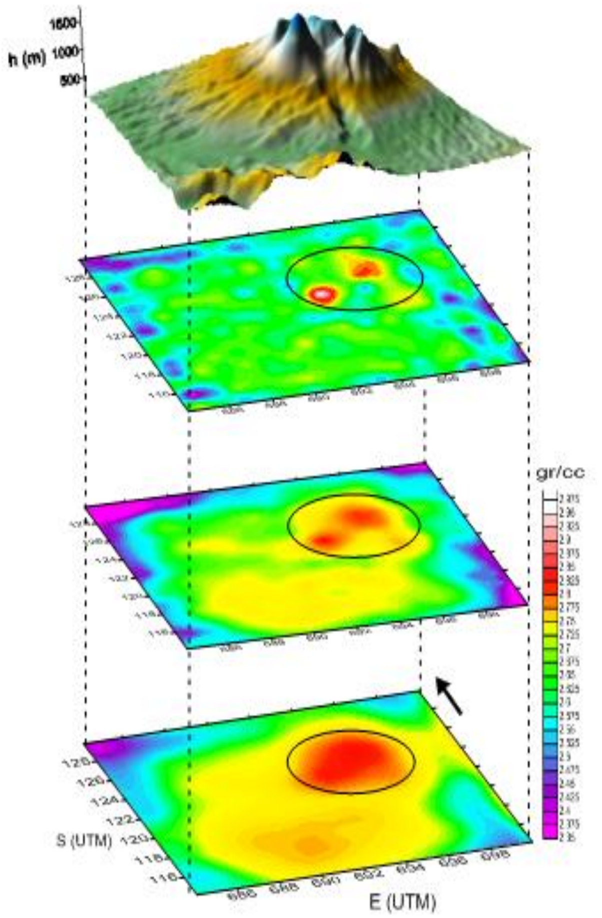

Fig. 4: Mass distribution on horizontal layer on depth 1000 m, 2000 m, and 3000 m.

The mass distribution model in the depth of 1000 m, 2000 m, and 3000 m produced 2.00 g/cc to 2.85 g/cc density as seen in Figure 4. The 3-dimensional model on the horizontal slice in 1000m depth produced the layer arranging the Soputan Volcano shown with color red yellow with the range of value 2.55 g/cm³ to 2.85 g/cm³ could be suspected as andesite sediment as the compiler. Andesite sediment has a density valueof 2.40 g/cm³ – 2.80 g/cm³. In 2000 m depth, the layers compiling Soputan Volcano are shown with the color yellow, green, and red with a range of valuefrom 2.49 g/cm3 to 2.9 g/cm3 was suspected as andesite and andesite-basaltic sediment. In 3000m depth, the layer compiling Soputan Volcano has the colors green-yellow and red. The color yellow red seems to be wider than in 2000 m depth. The compiling sediment in 3000 m is basalt sediment of Soputan Volcano. The distribution of sediment in the southern part was Tondano sediment formation. Tondano formation sediment consists of Tondano Volcanic sediment (Tov), pyroclastic Soputan debris (Sj), Silian lava flows (SNI) and Maniporok lava flows (MPI). Tondano volcanic sediment is the basic sediment of volcanism activity whose composition consists of basalt-composed lava, andesite, and basalt sediment. Andesite sediment has a density value of 2.40 g/cm³ to 2.80 g/cm³. Basalt sediment has a density value of 2.70 g/cm³ to 2.90 g/cm³. Basalt sediment with the color yellow to red starts to dominate at the depth of 2,000 m and lower. The peak area is dominated by lava sediment starting from 1,000 m and lower. Density is getting bigger as it goes deeper [2,6,8,19,21-23].

The result of modeling produced a relatively high density since the formation of its compiler sediment has a high density. Reviewing back on the contour of its Bouguer anomaly which was dominated by a high anomaly value then it could be seen the suitability between the density model and the gravity anomaly response. An object with high density would provide a bigger gravity field response than an object with low density. The response of sediment with higher density becomes more dominant than the sediment layer that becomes the compiler of the layer above it [23,24]. The width of the high-density area related to the volcanic activity had already been seen in the depth of 3000 m to the surface. The presence of a high-density zone is closely related to the presence of the crater of Maniporok and Kalelondoi.

4. Conclusion

The result of subsurface modeling of the complex area of Soputan Volcano with the density starts from 2.3 g/cm³ to 2.95 g/cm³. The result of such density value equals the geology information on the research area containing andesite sediment with the density range of 2.4 g/cm³ – 2.8 g/cm³, basalt sediment with the density range of 2.7 g/cm³ – 3.3 g/cm³, breccia sediment with the density range of 2.6 g/cm³ – 2.8 g/cm³, lava with the density range 2.8 g/cm³, and tuff with the density range 2,3 g/cm³ – 2.5 g/cm³. Grablox modeling result by marking with the density contrast from the density with a medium valueso that the density could have a lower score. Besides, the result of modeling could identify two craters of the volcano; Maniporok volcano, and Kalelondei. Based on the result, the layer compiling Soputan Volcano is andesite sediment, breccia sediment, basalt sediment, and andesite-basaltic

5. Conflict of Interest

The authors declare that they have no conflict of interest.

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