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2D Modeling of Subsurface Structures Based on Gravity Data of Mount Arjuno-Welirang

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ABSTRACT

Indonesia is a country that has volcanoes stretching from west to east from Sumatra, Java to Sulawesi. Mount Arjuno-Welirang is a stratovolcano type volcano with an altitude of about 3,339 m (10,955) for Mount Arjuno while for Welirang it is about 3,156. Mount Arjuno-Welirang and its surroundings are composed by rocks sourced from Anjasmoro Volcano (Early Plistocene), Ringgit-Pundak-Butak Volcano (Middle Plistocene), Arjuno-Welirang Twin Volcanoes I and II (Late Plistocene), and Penanggungan Volcano. This research includes data processing and interpretation of the results of data processing. This research was conducted using geophysical methods, namely the gravity method. The theoretical basis used is Newton's Law. Data in the form of gravity data that has been downloaded on the Land Gravity Data Website which is then processed using Surfer software, then the Magpick Software Upward Continuation process is carried out. After that, the slicing process is carried out on the residual anomaly, then the slicing results will be used to interpret using Grav2DC Software qualitatively based on the geological map as a reference. The interpretation results on the A-B and C-D tracks obtained 4 rock layers, namely volcanic breccia, lava, tuff breccia, and tuff rock. With an error value of 8.25% for incision A-B, and 3.63% for incision C-D.

Introduction

Indonesia is a country with socio-cultural and geographical diversity, each with its own unique characteristics. Indonesia is also home to numerous active and dormant volcanoes, both on land and offshore. These volcanoes stretch from west to east, from Sumatra and Java to Sulawesi. All of these mountains are part of a chain, so they likely share similar characteristics.

Each active mountain range contains geothermal resources, making Indonesia a country with significant geothermal potential (Hoerunisa & Sismanto, 2020). Indonesia currently has 129 active volcanoes, making it highly vulnerable to natural disasters. Understanding the behavior and activity of volcanoes is best understood through the volcanoes themselves (Chasanah et al., 2021).

The Greater Malang area, encompassing Malang City and Batu City, is surrounded by numerous volcanoes. One of the active volcanoes located to the west of this region is the Arjuna-Welirang Volcano. Mount Arjuno-Welirang is a stratovolcano with an elevation of approximately 3,339 m (10,955 m) for Arjuno and approximately 3,156 m for Welirang. The area surrounding the Arjuno-Welirang volcanoes is composed of rocks derived from the Anjasmoro Volcano (Early Pleistocene), the Ringgit-Pundak-Butak Volcano (Middle Pleistocene), the Arjuno-Welirang Twin Volcanoes I and II (Late Pleistocene), and the Penanggungan Volcano (Lestari & Jusfarida, 2021).

The geological structures surrounding the Arjuna-Welirang volcanic complex include normal faults, strike-slip faults, caldera rims, and subsidence faults.

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These faults cut along north-south, northwest-southeast, southwest-northeast, and west-east directions (Utama et al., 2016).

This research was conducted using geophysical methods, namely the gravity method. The basic principle of this method is to measure variations in the gravitational field caused by differences in rock mass density on the Earth's surface. The theoretical basis used is Newton's Law, which is mathematically written as the following equation (Supriyadi et al., 2020).

$$\bar{F} = -G\frac{Mm}{r^2}\hat{r}$$

The gravity method can provide a picture of the subsurface through differences in density between surrounding rocks (Kurniawan, 2023). In physics methods, the measured quantity is gravitational acceleration, whose value is directly proportional to the subsurface density. Therefore, variations in gravitational acceleration represent variations in mass density.

In the gravity method, subsurface geology is examined based on variations in rock density, which can generate different gravitational fields. Different gravity values result from rock units with different densities and additional mass, which can disrupt the gravitational field, commonly referred to as gravity anomalies (Watts, 1982).

This research was conducted to model the subsurface layers and determine the contrast of density variations in the Mount Arjuno-Welirang area using Surfer, Magpick, and Grav2DC software. The final analysis revealed that the Mount Arjuno-Welirang area exhibits granite and sedimentary rocks with density contrasts ranging from -0.060 g/cm³ to 0.0350 g/cm³.

Methods

The research location is administratively located on the border of Batu City, Pasuruan Regency, East Java, Indonesia, located at the geographical coordinates 7°42'02"S 112°34'29"E. This research includes data processing and interpretation. The method used is the gravity method, which can depict subsurface structures. The data, in the form of gravity data downloaded from the Land Gravity Data website, was then processed using Surfer software to display anomalies in the form of contour maps.

This research aims to study the structures closest to the surface. Therefore, an Upward Continuation process is necessary to separate residual anomalies from regional anomalies using Magpick software. The effects of subsurface structures are related to regional anomalies, while the effects of surface structures close to the surface are related to residual anomalies (Nafian et al., 2021).

Figure 1
Research Location

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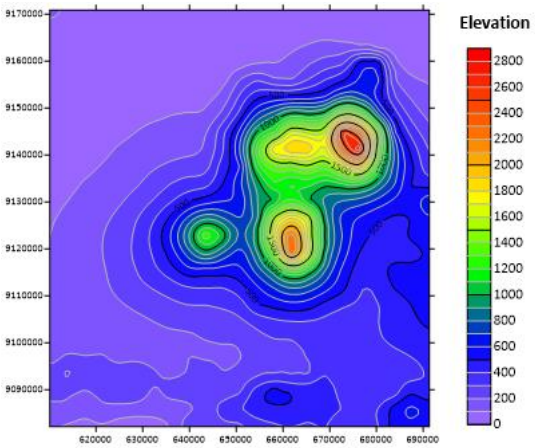
After separating the anomaly contours, the regional anomaly contour map is then sliced. The slicing results are then interpreted qualitatively using Grav2DC software based on the geological map of the study area as a reference (à Nyam et al., 2020).

Result and Discussions

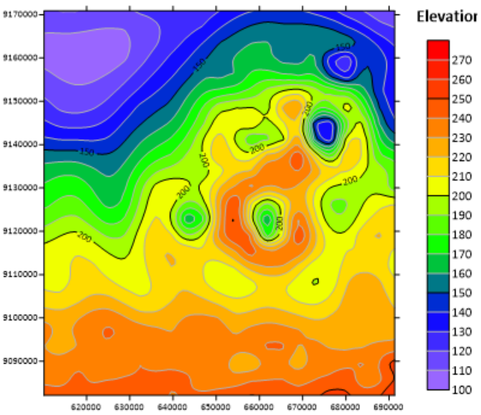
Based on the results of the simple Bouguer Anomaly correction, the Complete Bouguer Anomaly (ABL) value is obtained in the topography which will be used as a reference for interpreting the gravity data qualitatively and quantitatively. Figure 2 shows the contour of the topographic anomaly of the gravity field.

Figure 2
Topographic anomaly contour of the gravity field



The Complete Bouguer Anomaly gravity topography anomaly contour has the lowest value indicated by the purple area which has a value range of 0 mGal indicating lowland areas and the highest value indicated by the red area which has a value range of 2800 mGal indicating highland areas. Then there is the Bouguer anomaly contour value of the research area shown in Figure 3.

Figure 3
Bouguer anomaly contour of Mount Arjuno-Welirang



In Figure 3, the Bouguer Anomaly has a value between 100 and 270 mGal, and has 3 patterns, namely, areas with high elevations shown in the range between 190-270, areas with medium elevations shown in the range between 160-180, and areas with low elevations with a range between 100-150. This anomaly value is the total anomaly value caused by the influence of the mass density of the subsurface rock.

The anomaly response value must first be separated regionally and its residuals to clarify the form of anomalies near the surface and far from the earth's surface. To separate regional and residual anomalies, it is necessary to carry out upward continuation (upward lifting) which is a transformation carried out far upwards (altitude).

The upward continuation process is carried out at several continuity heights with the aim of determining the optimum regional anomaly value. Upward continuation is carried out with a range of 500 m starting from 1000 m to 6000 m (Setiadi, Purwanto, Kusnida, & Firdaus, 2019). The optimum regional value taken is 6000 m, to ensure more accurate results. The following is an image of the residual anomaly countermeasure performed with the optimum value, shown in Figure 4.

Based on Figure 4, the residual anomaly value at an altitude of 6000 m has an elevation value between -55, indicating a lowland area, to 45 mGal, indicating a highland area. Then, the Bouguer anomaly map was subjected to an upward continuation process to obtain the optimum regional anomaly contour, as shown in Figure 5.

Figure 4
Residual anomaly contour of Mount Arjuno-Welirang

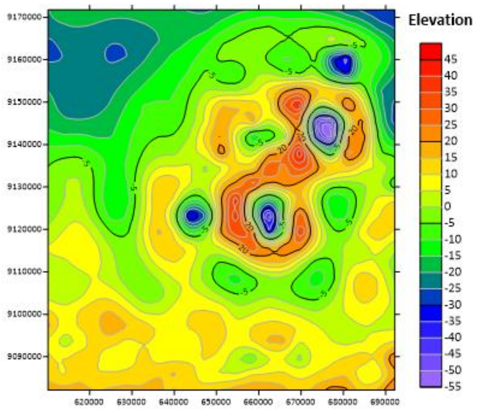


Figure 5
Regional Anomaly Contour of Mount Arjuno-Welirang

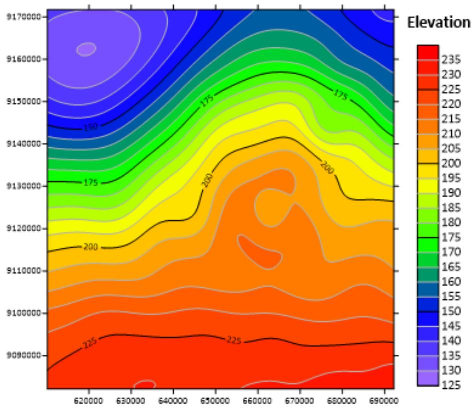


Figure 5 shows the regional anomaly values for the study area at an elevation of 6,000 m, with elevation values ranging from 125 mGal, indicating a lowland area, to 235 mGal, indicating a lowland area.

This study also created sections AB and CD, as shown in Figure 6. These sections were then interpreted in 2 dimensions using grav2dc, as shown in Figure 7.

The slicing results produced output data, which was then processed using grav2dc software. In this process, the sliced data was processed using forward modeling to obtain a 2-dimensional gravity model (Pratikno, Jamaluddin, Ryka, & Prabowo, 2020).

Figure 7 shows the results of modeling regional anomaly contours using an A-B section. Based on the Malang Geological Map, the Mount Arjuno-Welirang area is dominated by rocks resulting from eruptions of the Middle Quaternary Ringgit volcano (Qv-r), the Old Anjasmoro volcano (Qpat), and the Arjuna-Welirang volcano. The surface is dominated by volcanic breccia, tuff, tuffaceous breccia, lava, agglomerate, and volcanic breccia.

Figure 6
Contour of residual anomaly by performing A-B and C-D sections

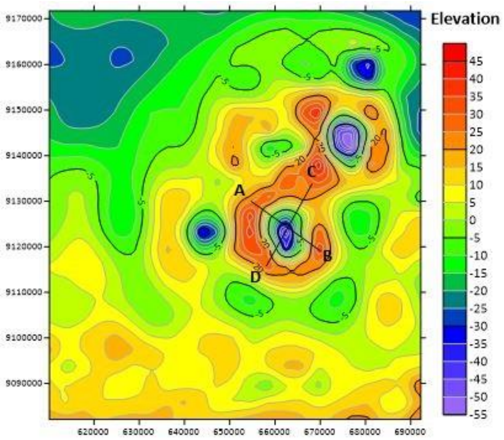
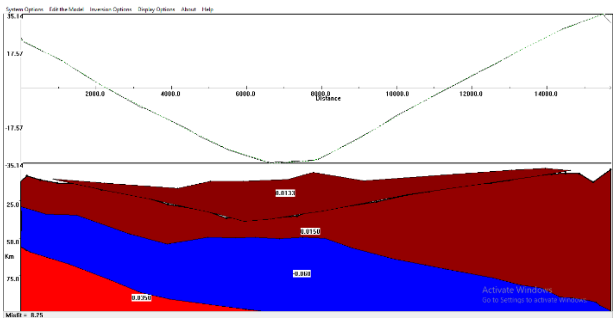
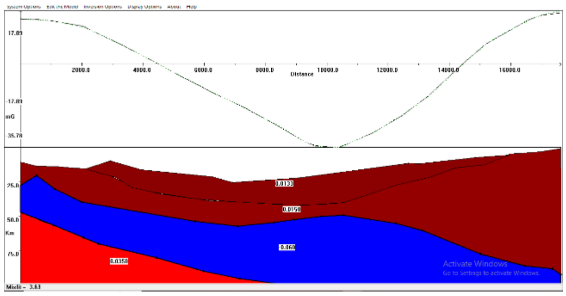


Figure 7
Modeling Results on Section A-B



In the first layer of the A-B model, it is suspected to be volcanic breccia with a density value of 2.88 gr/cm3 and a density contrast of 0.0350 gr/cm3 (in SI), the second layer is suspected to be lava with a density value of 2.68 gr/cm3 and a density contrast of -0.060 gr/cm3 (in SI), the third layer is suspected to be tuff breccia with a density value of 2.38 gr/cm3 and a density contrast of 0.0150 gr/cm3 (in SI), and the fourth layer is suspected to be tuff rock with a density value of 2.15 gr/cm3 and a density contrast of 0.0133 gr/cm3 (in SI). The error value of the modeling on the A-B section is 8.25%. This error value is the difference between the observation anomaly value (residual anomaly value) and the modeling result value.
Figure 8 is the result of modeling the regional anomaly contour by performing an A-B section. The first layer of the C-D model is suspected to be volcanic breccia with a density value of 2.88 gr/cm3 and a density contrast of 0.0350 gr/cm3 (in SI), the second layer is suspected to be lava with a density value of 2.68 gr/cm3 and a density contrast of -0.060 gr/cm3 (in SI), the third layer is suspected to be tuff breccia with a density value of 2.38 gr/cm3 and a density contrast of 0.0150 gr/cm3 (in SI), and the fourth layer is suspected to be tuff rock with a density value of 2.15 gr/cm3 and a density contrast of 0.0133 gr/cm3 (in SI). The error value of the modeling on the A-B section is 3.63%. This error value is the difference between the observation anomaly value (residual anomaly value) and the value of the modeling results.

Figure 8
Modeling Results on Section C-D



Conclusions

Based on the results of research conducted in the Mount Arjuno-Welirang area, it can be concluded that the interpretation of the Bouguer contour pattern in the research area has a value between 100 and 270 mGal and has 3 patterns, namely, high with a range between 190-270, medium with a range between 160-180, and low with a range between 100-150. Upward continuation is carried out with a range of 500 m, starting from 1000 m to 6000 m. The optimum regional value taken is 6000 m. Based on the results of the interpretation of the A-B and C-D trajectories, 4 layers of rock are obtained, namely volcanic breccia, lava, tuff breccia, and tuff. With an error value of 8.25% for the A-B section, and 3.63% for the C-D section. The modeling results of the two sections that have been carried out can be observed that the types of rocks on Mount Arjuno-Welirang are the same.

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