

Advancing Geothermal Resource Assessment Using 3D Gravity Modeling: A Case Study from Kamojang, West Java

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ABSTRACT

The research was conducted using the gravity method in the Kamojang geothermal manifestation area, West Java. Data was obtained through the Topex website which contains information on latitude, longitude, elevation, and FAA value. The purpose of this research is to determine the density value of subsurface constituent rocks to determine the location of reservoirs and heat sources in the research area. The corrections made are Bouger correction and Terrain correction obtained from the CBA map which is sliced as many as 5 incisions. Calculation of subsurface average mass density using the Parasnis method obtained a density of 2.5882 mGal. Spectrum analysis was performed to determine the regional-residual depth using the moving average method. The regional anomaly contour map shows a range of 15 - 135 mGal. The residual anomaly contour map shows a range of -26 to +28 mGal with more complex results. Modeling results using Grav3D with a mesh value of 500 show a density range of 1.6752 - 3.1712 gr/cm³ with an altitude of 600 - 2000 m and a thickness of 1400 m. Zones with high density values between 2.9219 - 3.1712 gr/cm³ are indicated as heat source areas with volcanic rocks such as lava to basalt igneous rocks. Medium density values in the range of 2.4232 - 2.6722 gr/cm³ are indicated as boundary zones which are interpreted as basement in the caprock of the study area with igneous rocks surrounding the boundary zone. The low density zone with a value of 1.6752 - 2.1732 gr/cm³ is indicated as a reservoir zone with sedimentary rocks composed of pyroclastic rocks and breccias.

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INTRODUCTION

Indonesia has the largest geothermal resource in the world, with nearly 40 percent of the known global resource. It is estimated that Indonesia has an electricity potential of 27,000 Megawatts, almost equivalent to the current total national electricity supply (Meilani & Wuryandani, 2010). Rapid economic growth makes electricity demand rise rapidly, so increasing the use of geothermal is important. Therefore, the Indonesian government has made geothermal energy development a priority (Laksminingpuri & Martinus, 2013).

The potential for geothermal energy resources in Bandung Regency can be said to be very abundant because the geographical structure of the Bandung Regency area is surrounded by active volcanoes (Handayani & Singarimbun, 2016). Geothermal energy in Bandung Regency, one of which is in Kamojang. Kamojang geothermal energy source is the first geothermal energy source studied in Indonesia (Al Hakim et al., 2014). Geothermal exploration in Kamojang was first conducted by a Dutch scientist named J.B. van Dijk in 1918. However, the proposal was not immediately implemented, due to many obstacles and considerations from the Dutch East Indies government (Novita, 2018).

Mount Kamojang, widely known as Kawah Kamojang, is a geothermal resource in West Java, Indonesia. Historically, it was known as a volcano called Mount Guntur, but this crater is classified as an active volcano due to geothermal activity (Banu et al, 2013). One of the methods that can be used to determine the subsurface structure and reservoir is the gravity method. In this research, structural interpretation and 3D modeling of Kamojang area based on Bouguer anomaly will be conducted (Sihombing & Rustadi, 2018).

Kamojang geothermal field is the first geothermal field in Indonesia that has been developed and operated for 25 years from the exploration stage to electricity production (Mazaya & Kurniawan, 2022). The research area is located in the Kamojang geothermal manifestation area, West Java. Administratively, it is located in three sub-districts, namely Paseh District, Ibun District, and Majalaya District, Bandung Regency, West Java (Shidqi et al., 2018). Geographically, the study area is located at 799196.2518 mE - 826635.7439 mE and 9217254.69 mN - 9185970.885 mN (UTM zone 48 M) with altitudes varying from 600 meters to 2000 meters above sea level with a thickness of about 1400 meters.

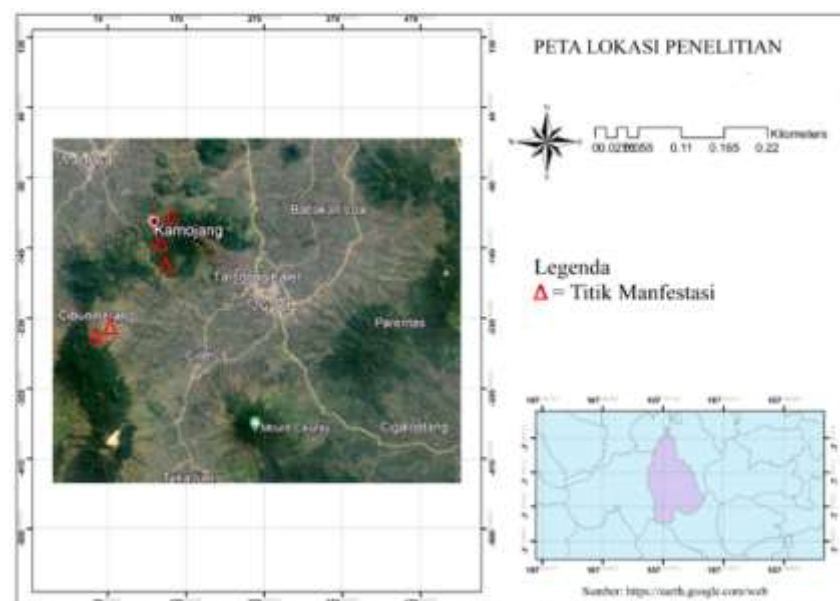


Figure 1. Map of Kamojang geothermal field measurement area

The gravity method is one of the geophysical methods often used in exploration activities, ranging from geothermal hydrocarbons, minerals, groundwater, to the study of crustal structure (Gaol et al., 2006). The principle of the method is based on gravity anomalies that arise due to the diversity of rock mass density in the subsurface. The diversity of mass density characterizes the existence of a geological structure or layer boundary, as well as the materials that make up the layer (Banu et al, 2013).

Gravity data processing which is often referred to as gravity data reduction can generally be separated into two types, namely the basic process and the advanced process (Hidayat & Basid, 2011). The basic process includes the entire process starting from the reading value of the field equipment until the Bouguer anomaly value is obtained at each point. The process includes the conversion of gravimeter readings to milligal (mgal) values, drift correction, tidal correction, latitude correction, free air correction, Bouguer correction and terrain correction (Jamil et al., 2014).

Geothermal exploration activities are carried out with the aim of knowing the presence of hot water or steam in a reservoir that has good permeability and support (Habibirahman et al., 2019). Exploration activities carried out can be in the form of geological, geochemical, geophysical investigations, test drilling, and exploration drilling with the aim of finding and estimating the geothermal potential of an area. Geophysical survey as a form of survey that utilizes physical principles to determine the state below the earth's surface, including geothermal systems (Basid et al., 2014).

METHODS OF RESEARCH

Data Acquisition

This data acquisition is the process of taking data in the field. This process is divided into several stages that must be carried out. Starting from knowing the information of the area to be measured and preparing the tools. Some of the tools are a set of gravimeters, GPS, geological maps and topographic maps, timers, stationery, cameras, gravimeter protectors, and several other supporting tools. However, due to limited tools, the data in this report is obtained from the opensource topex web which contains X coordinate, Y coordinate, elevation, and Free Air Anomaly (FAA) data.

Data Processing

Furthermore, after obtaining measurement data, data processing is carried out. This includes bouguer correction, terrain correction, calculation of parachute mass density, and 3D inversion modeling of gravity.

1. Bouguer Correction (BC)

In the free air correction, the calculation is done by calculating the difference between the height of the point and the datum without taking into account the mass between the points. For this reason, a correction is needed to eliminate the effect of mass from the datum to the height of the point. Bouguer correction is done to eliminate the effect of the gravity of the crustal mass plate above the measurement point so that if there is an anomaly towards it, it is an anomaly caused by the anomaly of the mass density below the surface at that point. The Bouguer correction value for the infinite slab model is given by Eq:

$$BC = 0.04193\rho\phi h \quad (1)$$

Where, ρ is the average surface density in gr/cc, ϕ is the porosity and h is the elevation of the measurement point in meters (Alsadi and Baban, 2014).

2. Terrain Correction (TC)

Terrain correction is performed to eliminate the effects caused by irregular topography around the observation point. Topographic conditions around the observation point are sometimes irregular such as the presence of valleys or hills which also affect the gravity value at the observation point. High elevations such as hills will minimize the acceleration of gravity. Therefore, terrain correction for this hill must be added which means that the valley around the observation point is considered to have rock mass (Sari, 2012). The calculation of the field correction value can be done using the Hammer Chart developed by Sigmund Hammer (Hidayat, 2011).

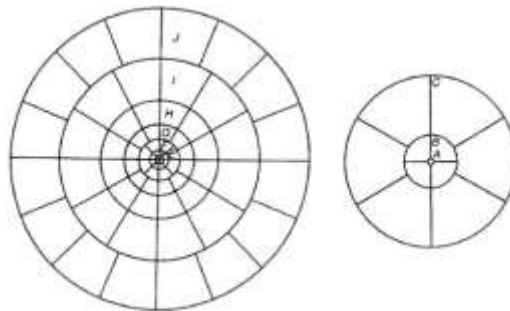


Figure 2. Hammer Chart (Reynolds, 1997)

Terrain correction can be calculated using the following equation.

$$TC = 2\pi\gamma\rho \left[r^2 - r^1 + \sqrt{r_1^2 + z^2} - \sqrt{r_2^2 + z^2} \right] \quad (2)$$

Or

$$TC = 0.04191 \frac{\rho}{n} r^2 - r^1 + \sqrt{r_1^2 + z^2} - \sqrt{r_2^2 + z^2} \quad (3)$$

Where TC is the terrain correction, ρ is the density of the rock mass, n is the number of segments in the zone, r_1 is the radius of the inner circle, r_2 is the radius of the outer circle and z is the hill height or valley depth.

3. Calculation of Parasnis Mass Density

Calculation using parasitics has the aim of obtaining the mass density value of the subsurface anomaly. This determination is made by preparing the gravity data to be calculated, the BC (Bouguer Correction) value that has been obtained is assumed to be the axis and the FAA (Free Air Correction) value obtained from TOPEX, then making a BC (Bouguer Correction) relationship graph as the x-axis and FAA (Free Air Correction) as the y-axis. Calculate the gradient of the graph that has been obtained and the surface density value is the gradient of the graph.

4. Spectrum Analysis

The spectrum analysis process is usually done in one dimension. In spectrum analysis, a fourier transform is performed to convert a signal into the sum of several signals, the fourier transform process converts the time or spatial domain to the frequency domain or wave number (k). Through the analysis of wave number (k) and amplitude (A), the estimated depth of regional and residual

anomalies can be estimated and the width of the filter window can be found from the calculation of the cut off frequency from spectrum analysis.

5. 3D Inversion Modeling

Inverse modeling is frequently described as the converse of forward modeling since, in inverse modeling, the model parameters are directly derived from the data. Inversion theory consists of a collection of mathematical and statistical techniques used to extract valuable information. The physical system in question is the phoneme we are looking at, the observations of the system are the data while the information to be obtained from the data is the model or model parameters. Grav-3D software is used in performing 3D inversion modeling.

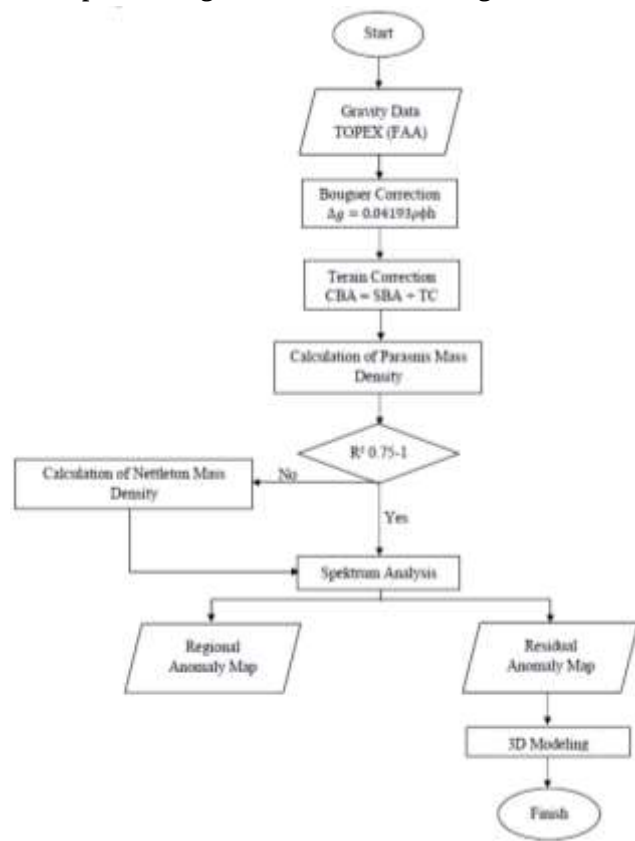


Figure 2. Flow Chart

RESULT AND DISCUSSION

The study area is located in Kamojang, West Java, Indonesia. 3D modeling using Grav3D software, calculations using the Parasnis method, then spectrum analysis to determine regional-residual depth.

Average Surface Density

Determination of the average surface density value is required to determine the density value to be used in the Bouguer correction. The determination of the average surface density is done by the Parasnis and Nettleton methods. The Parasnis method determines the surface density by plotting the Bouguer correction value minus the field correction against the free air anomaly

(FAA) value. The Parasnis method density curve is shown in Figure 3, where the average surface density obtained from the curve gradient is 2.5882 g/cm³.

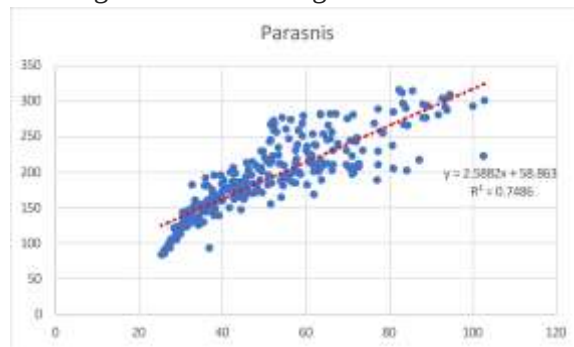


Figure 3. Average Density Curve of Parasnis Method

Based on the regional geological map of the Kamojang area, it is found that most of the area is composed of andesite rocks. Andesite itself has an average density value of 2.61 gr/cm³, so there is no need to find the density value by Neettleton because the average density value obtained through Parasnis with the actual average density value is close.

Complete Bouguer Anomaly

The complete Bouguer gravity anomaly is a map of gravity anomalies that have undergone various reduction processes so that the variation in the value of the resulting gravity acceleration anomaly is only influenced by variations in the mass density of the subsurface relief. This research aims to determine the distribution of Bouguer anomaly of gravity data in the geothermal system of Kamojang area, West Java, Indonesia.

On the Bouguer anomaly map there are geothermal areas such as Figure 4. With values between 10-140 mGal. The difference in value is caused by variations in the denistas below the earth's surface and the location and depth of the rock below the surface. Based on these values can be grouped into low, medium and high anomalies. Low anomalies have a value range of 10 mGal to 55 mGal. Medium anomalies have a value range of 60 mGal to 100 mGal. Then the high anomaly is 105 mGal to 140 mGal.

The results of data processing using Surfer software, obtained different Bouguer anomaly values shown in Figure 4. To facilitate the interpretation of gravity anomaly values, they are grouped into high, medium and low anomalies. The variation in anomaly values is caused by variations in rock density, location, and depth of subsurface rocks.

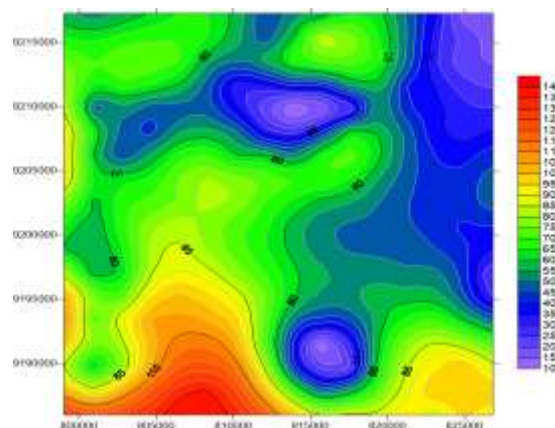


Figure 4. Complete Bouguer Anomaly processing map

Spectrum Analysis to Determine the Depth to the Regional-Residual

Gravity anomaly data is generated from regional anomalies, residuals, and noise so it needs to be sorted. The separation of regional-residual anomalies is done using spectrum analysis. Spectrum analysis is performed by Fourier transforming the selected trajectory on the CBA map. Before the regional-residual anomaly separation process is carried out, a regular grid is first made on the Bouguer anomaly contour map. After that, the area is sliced at least 5 to determine the window width value in the data. The determination of the window width itself uses Numeri software to Fourier transform the existing data, then the window width of each slice is summed and then averaged. In this processing, the window width obtained is 17 x 17. Furthermore, the separation of regional anomalies with residual anomalies is carried out using the moving average method which produces output in the form of regional anomalies. To get the residual value, the Math feature is needed, which will subtract the total CBA value from the processed regional anomaly value.

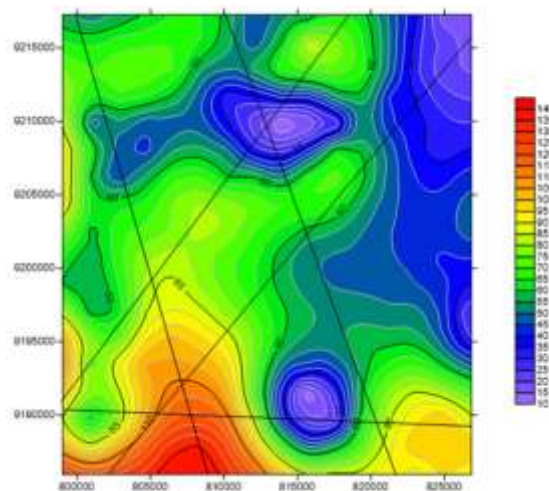


Figure 5. Areas to be analyzed with the spectrum

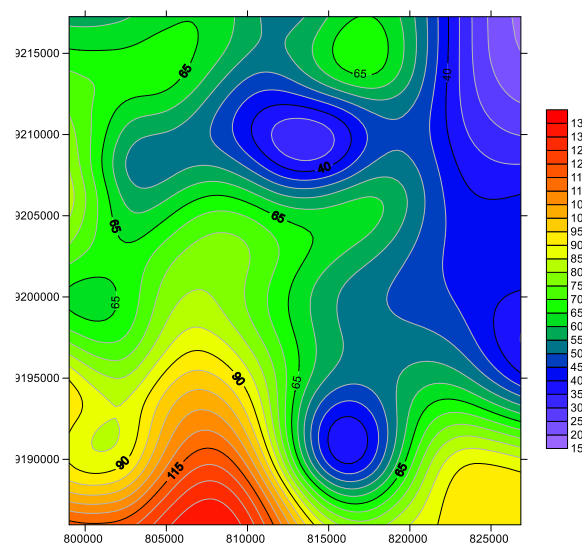


Figure 6. Regional anomaly contour map

The regional anomaly contour pattern in Figure 5 shows a depth range between 15 mGal - 135mGal. The low anomaly value is 15 mGal - 45 mGal. While for medium depth there is a depth of 50 mGal - 95 mGal. The high anomaly variation is found at a depth of 100 mGal - 135 mGal.

In Figure 6 the residual anomaly contour map shows an oriented contour pattern with residual anomaly values between -26 mGal to +28 mGal. The residual anomaly map shows a more complex anomaly pattern.

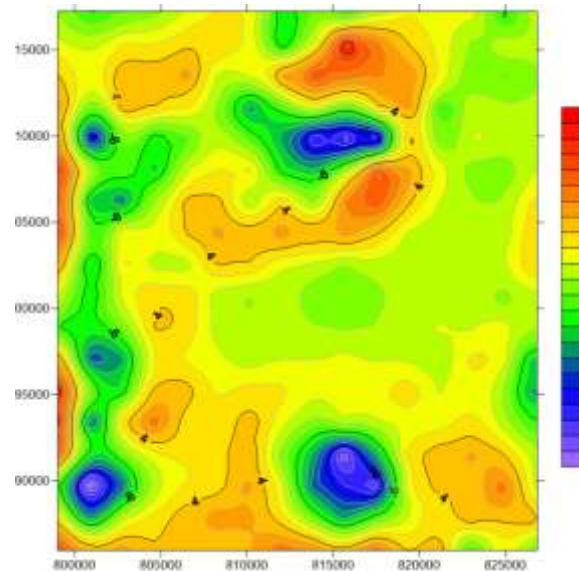


Figure 6. Residual anomaly contour map

In Figure 7 3D modeling with a mesh of 500 above, it can be seen that the research area has a range of density values between -0.913 gr/cm^3 to 0.583 gr/cm^3 , or if summed up with the average density value, it is between 1.6752 gr/cm^3 to 3.1712 gr/cm^3 with heights varying from 600 meters to 2000 meters above sea level with a thickness of about 1400 meters. We can divide the 3D modeling into 3 zones where the zone with a density value of 1.6752 gr/cm^3 to 2.1732 gr/cm^3 represented by dark blue to light blue can be called a low density zone, then the zone with a density value of 2.4232 gr/cm^3 to 2.6722 gr/cm^3 represented by green to yellow colors can be called the medium density zone, then the zone with a density value of 2.9212 gr/cm^3 to 3.1712 gr/cm^3 represented by orange to light purple colors can be called the high density zone.

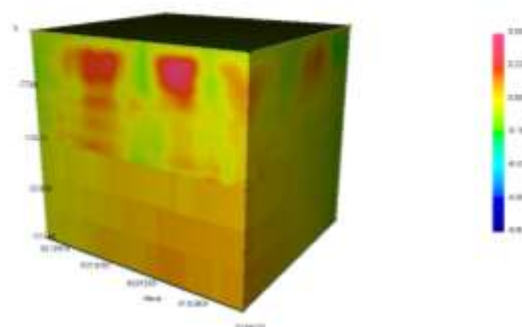


Figure 7. 3D modeling with 500 mesh

In zones with high density values, it can be indicated as a heat source area, with volcanic rocks as the constituent rocks. It is known that the Kamojang geothermal area is composed of andesite dust lithology, andesite lava, andesite breccia, and andesite tuff. It can be assumed that the area shown in red to purple is a geothermal resource area composed of mostly igneous rocks, which have a higher density value than other rocks. When referring to the Telford table, density values in the range of 2.9212 gr/cm³ to 3.1712 gr/cm³ are lava to basalt igneous rocks, which are quite compatible with the lithology of the Kamojang geothermal area. So, it can be concluded that this research area has several heat source areas quite a lot, which are evenly distributed.

The low density zone, which is located in the west and center of the research location, can be interpreted as the reservoir zone of the geothermal research area, which is located at a depth of 500m. The low zone is composed of sedimentary rocks, which is supported by density values in the range of 1.6752 gr/cm³ to 2.1732 gr/cm³. It can be assumed that the reservoir zone of this geothermal system is composed of pyroclastic rocks and breccias.

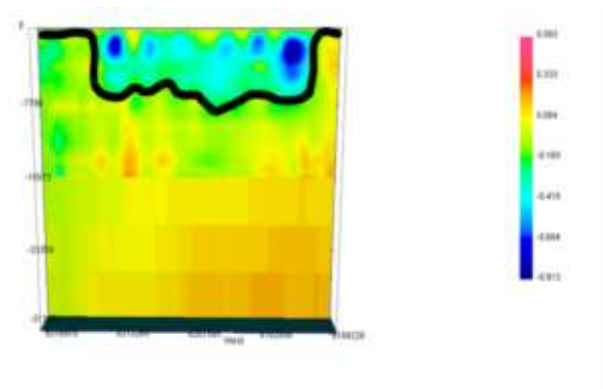


Figure 8. 3D modeling with 500 mesh

By knowing the heat source and reservoir zones of a geothermal system, the boundary of the target heat source and reservoir zones can also be determined, where the boundary of the target zone is a medium density zone that can be interpreted as the basement of the target zone. The basement or caprock (if located at the top) is thought to be the volcanic igneous rock surrounding the heat source and reservoir target zones, judging by their density values. This zone is represented by medium density values ranging from 2.4232 gr/cm³ to 2.6722 gr/cm³ and is categorized as igneous rock when referring to the Telford table.

CONCLUSION

Based on the results of research on the Kamojang earth area, West Java where the area can be estimated as a geothermal manifestation area. The height of the area varies between 600 meters to 2000 meters above sea level with a thickness of about 1400 meters. In the regional anomaly contour pattern, it can be seen that the depth range is between 15 mGal - 135mGal. The low anomaly value is 15 mGal - 45 mGal. As for the medium depth, it is found at a depth of 50 mGal - 95 mGal. The high anomaly variation is found at a depth of 100 mGal - 135 mGal. Then the results on the residual anomaly contour map show an oriented contour pattern with residual anomaly values between -26 mGal to +28 mGal.

From the 3D modeling results, it can be divided into 3 zones, each of which has a density value of 1.6752 gr / cm³ to 2.1732 gr / cm³ which is represented by dark blue to light blue, we can call it a low density zone, then a zone with a density value of 2.4232 gr/cm³ to 2.6722 gr/cm³ represented by green to yellow colors can be called the medium density zone, then the zone with a density value of 2.9212 gr/cm³ to 3.1712 gr/cm³ represented by orange to light purple colors can be called the high density zone. When referring to the Telford table, then the density value in the range of 2.9212 gr/cm³ to 3.1712 gr/cm³ is lava to basalt type igneous rock, which is quite compatible with the lithology of the Kamojang geothermal area.

Based on the geological model of the Kamojang geothermal field, it can be seen that one of the sedimentary layers covering the volcanic rocks is pyroclastic rocks and breccias. Therefore, it can be assumed that the reservoir zone of this geothermal system is composed of pyroclastic rocks and breccias.

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