Identification of the geological structure on the NPR Geothermal Area based on 3D Modeling Gravity Data

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Abstract. This research does to know the geological structure of the NPR geothermal area. We applied a gradient analysis and 3D modelling of gravity data based on bouguer anomaly, the additional method of euler deconvolution analysis to estimate the depth of the geological structure. The data consist of 325 points which was measured by PSDMBP team, Bandung. Based on the the result of horizontal gradien which is located at the maximum value and controlled by of vertical derivative which is located is at zero, we interpret that the appearance of a goethermal manifestation such as fumarole and hot spring controlled by the presence of fault. The average depth fault of Euler Deconvolution is < 288.5 meters to >480.2 meters. 3D modelling results indicates volcanic breksi stone, lava andesit and tuff and the presence of fault with some changing significantly rocks densities in the southwest and northwest to southeast research area.

1. Introduction
In geothermal cases the difference in rock density is a basic principle in gravity investigation where heat sources and areas of accumulation below the earth's surface can cause differences in density between the surrounding rocks[2]. The NPR area is one of the volcanic areas in Indonesia that has discovered geothermal manifestations. NPR geothermal areas have geothermal manifestations in the form of fumaroles and the appearance of warm soil. The previous investigation by Hadiwidjojo (1998) states that the NPR geothermal area consists of Qhvb, Qpbb, and Qvbb rocks. Research was carried out using gravity methods and 3D modeling of subsurface structures in NPR geothermalareas.

2. Theory
2.1. The concept of gravity method
Gravity method is one of the geophysical methods based on variations in the earth's gravitational field. This gravitational field variation is a homogeneous density distribution in the earth's constituent rocks. Inhomogeneous density distribution characterizes the existence of a geological structure under the earth's surface[1].

2.2. Research Area Geology
The geology of the survey area is dominated by volcanic rocks with andesite-basalt lava types, pyroclastic flows and tertiary pyroclastic falls to date. The pattern of stress of the main fault that develops in the Caldera area is northwest-southeast, with this pattern controlling the formation of magma and the formation of volcanoes. The NPR geothermal area is composed of 3 volcanic rock formations consisting of Qhvb, Qpbb, Qvbb, each of which has regional structural contact[4].
1. Qhvb, buyan-bratan volcanic rocks andbatur are mainly tuffs andlava.
2. Qvbb, ancient buyan-bratan volcanic rock group: mainly volcanic breccia and lava, locally tuff.
3. Qhvb, volcanic rocks: especially agglomerates, lava and tuffs; a little lava and ignimbrit, produced by mountains that are still active.

![Geological map of NPR Geothermal Area](image)

**Figure 1.** Geological map of NPR Geothermal Area

2.3. Gradient analysis

Gradient analysis with 4 methods, namely First Horizontal Gradient, Second Horizontal Gradient, First Vertical Derivative, Second Vertical Derivative [9]. Horizontal Gradient is used to emphasize the high anomalies contained in gravity data, because the maximum values that show lateral density in contrast are indicated as faults.

\[
HG_x = \frac{\partial \Delta g}{\partial x} = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2}
\]

\[
HG_y = \frac{\partial \Delta g}{\partial y} = \sqrt{\left(\frac{\partial g}{\partial y}\right)^2}
\]

\[
HG(x, y) = \sqrt{\left(\frac{\partial \Delta g(x)}{\partial x}\right)^2 + \left(\frac{\partial \Delta g(y)}{\partial y}\right)^2}
\]

The Vertical Derivative can be used to interpret the type of structure against Bouguer anomaly data caused by the existence of a downward fault structure or a rising fault [9].

\[
\nabla^2 U = 0
\]

\[
\nabla^2 \Delta g = 0
\]

\[
\frac{\delta^2 \Delta g}{\delta x^2} + \frac{\delta^2 \Delta g}{\delta y^2} + \frac{\delta^2 \Delta g}{\delta z^2} = 0
\]

\[
\frac{\delta^2 \Delta g}{\delta z^2} = -\left(\frac{\delta^2 \Delta g}{\delta x^2} + \frac{\delta^2 \Delta g}{\delta y^2}\right)
\]
2.4. Euler Deconvolution

Euler Deconvolution is one of the interpretation methods in geophysical exploration that is used to estimate the position and depth of anomalous objects from a gravitational potential field patented by Thompson which is applied to 2D magnetic anomalies [5]. Then, Reid applied this method to 3D grid data. This method refers to the Euler homogeneity equation which is written mathematically in equation 8. The use of large SI values in the Euler equation is shown in Table 2.1[7].

Table 2.1 SI values Euler Deconvolution (Reid et al. 2014).

| Sumber       | Struktur Indeks |
|--------------|-----------------|
| Bola/titik   | 2               |
| Sesar        | 1               |
| Lapisan tipishorisontal | 0               |

Euler homogeneity equation which is written mathematically in equation 8[7].

\[
(\chi - \chi_0) \frac{\Delta A_{\text{lok}}}{\Delta x} + z_0 \frac{\Delta A_{\text{lok}}}{\Delta z} = -N_{\text{lok}} \quad (8)
\]

correction of the position and depth of the anomalous source. The first horizontal gradient contour results are then overlaid with the results of the ed analysis. ABL is also used to do 3D modeling using Grablox. The contour results from anomalous separation, gradient analysis, eulerdeconvolution analysis, and 3D modeling results are then interpreted together with geological information to find outsubsurface structure of NPR geothermal energy.

4. Results

4.1. Topography of the research area

This research area has a topography ranging from 963.2 m to 1688 m above sea level. The low topographic area is located to the east extending to the southeast. Areas with medium topographic values are areas that have lowlands. The high topographic area lies in the northwest and in the center of the study is the mountain in the research area.
4.2. Complete Bouguer Anomaly
The Complete Bouguer Anomaly contour which shows the range of anomalies between 155.89 to 218.6 mGal. With this range anomalies are grouped into low anomalies, medium anomalies and high anomalies. Spectrum analysis is performed to estimate the depth of a gravity anomaly object below the surface so that it will help in the modeling that will be carried out.

4.3. Moving Average
The separation in ABL is done to determine the distribution of anomalies that dominate in the study area. In this study is used, moving average. The width of the window used in this study is 31 x 31. Regional Anomaly values have a range of 161.49 mGal to 210.1 mGal. Reisudal anomaly have a range of values of -24.7 mGal to 22.6 mGal.
4.4 Gradient analysis

Horizontal Gradient can be used to emphasize high anomalies, this maximum value indicates lateral density in contrast. First Horizontal Gradient results obtained maximum value in the more dominant research area located spread around from the Northeast towards the Southeast. Distribution of First Horizontal Gradient values between 0.001 mGal/m to 0.020 mGal/m. The results of Second Horizontal Gradient are obtained from the maximum value are more dominant in the study area which spreads circularly from the South towards the Southeast. The distribution of Second Horizontal Gradient value in the area of the study which has a value distribution between 0.000001 mGal/m to 0.000042 mGal/m.

Figure 4. Regional anomaly of the NPR area.

Figure 5. Residual anomaly of the NPR area.

Figure 6. First horizontal gradient NPR area.

Figure 7. Second horizontal gradient NPR area.
Vertical Gradient can be used to identify rock contacts or lithological limits if they are 0. The distribution of Second Vertical Derivative values is between 0.019 mGal/m to 0.017 mGal/m. The distribution of the Second Vertical Derivative value between -0.000051 mGal/m to 0.000022 mGal/m. It has been found the fault location based on the results of the svd interpretation which is shown by the distribution of values that are 0 mGal/m indicated that it detects the boundary of the mountain in the area as the analysis of First Vertical Derivative but on First Vertical Derivative the boundary of the mountain in the area is quite clear compared to the results of the analysis Second Vertical Derivative.

Figure 8. First vertical derivative NPR area.

Figure 9. Second vertical derivative NPR area.

4.5. Euler Deconvolution

Euler Deconvolution is one method of interpretation in Geophysics that is used to estimate the position and depth of anomalous objects (Kahar, 2016). Besides being used to estimate position and depth, Euler Deconvolution can also represent the lithology boundary of the research area. The results of Standard Euler Deconvolution are form of points that estimate the depth. The results of the Standard Euler Deconvolution calculation have varying depth values from <288.5 m to 480.2 m.

Figure 10. Euler deconvolution NPR area.

Figure 11. Overlay euler deconvolution and fhg.
4.6. 3D modeling.
Subterranean modeling is performed using 7 incision paths in Bouguer anomalies.

Figure 12. Complete Bouguer Anomaly using 7 slice of the NPR area

X-axis incision.

Figure 13. Slice A-A’ modeling (a), Slice B-B’ modeling (b), and Slice C-C’ modeling (c)

The results of the slice A-A’ modeling with the grablox software. obtained high density values have a range of values of 2.75 g/cc to 3 g/cc is lava rock, and volcanic breccia. Low density values have a range of 2.05 g/cc to 2.35 g/cc which is the dominance of the tuff layer. There are indications of subsurface faults that can be seen clearly in the 3D model that controls the appearance of M1 and M2 manifestations. The subsurface modeling results at the slice B-B’ have a low subsurface density value with arrange of 2.05 g/cc to 2.35 g/cc which is suspected to be volcanic rock produced by volcanoes that are still active. There are several indications of subsurface faults. The fault is identified as a normal fault which is directed to the Southwest to Northeast of the study area which controls the
appearance of M3 and M4 manifestations. The presence of M3 and M4 manifestations is in medium
density to high density rocks with a range of 2.4 g/cc to 2.65 g/cc and manifestations appear close to
the presence of cesarean. The results of the slice C-C' modeling has Low rock density values are
obtained with a range of 2.05 g/cc to 2.35 g/cc which is indicated by the dominance of tuff rock. The
emergence of high value rock density values with a range of 2.7 g/cc to 2.95 g/cc is andesite lava rock,
a little lava, and volcanic breccia produced by volcanoes that are still active. From the results of these
models there are some indications of subsurface faults located in the Northwest to Southeastern area of
the study indicated by faults formed due to the volcanic process of the NPR mountain, this fault
indication can also be seen from the results of gradient analysis.

Y-axis incision.

Figure 14. Slice D-D’ modeling (a), Slice E-E’ modeling (b), Slice F-F’ modeling (c), and Slice G-G’
modeling (d)

The results of the slice D-D’ modeling has Low rock density values with a range of 2.05 g/cc t 2.35
g/cc are rocks produced by volcanic changes. Indications of faults are found in the Northwest to
Southeastern area of the study which can be seen on regional geological maps. There are indications of
faults extending from the west to the east of the study area. Another indication of a fault located
southwest of the research area. The results of the slice E-E’ modeling. There are several indications
of subsurface faults located in the Northwest to Southeast direction and indications of faults located in
the Northwest direction of the study area that controls the manifestation exit. And there are results of
indications of faults based on edand ag which extend from the direction of the West to the East of the
study area. High value density values ranging from 2.75 g/cc to 3 g/cc indicated as walls of the NPR
mountain and the caldera that surrounds the NPR mountain. The results of the slice F-F’ modeling
has Low density values with a range of 1.95 g/cc to 2.35 g/cc are volcanic alteration rocks which have
low density values filled with tuff rocks from batur volcanic unit formations. Some indications of
subsurface faults are located in the northwest direction to the southeast of the study area. These
indications are the emergence of high value density values with a range of 2.95 g/cc to 3.3 g/cc which
are thought to be in the form of andesite lava, volcanic breccia, indications of other faults in the
Northwest. The existence of manifestations is in rocks with a moderate density value with a range of
2.45 g/cc to 2.7 g/c at a depth of 1 km to 2 km. There are indications of faults extending from the west
to the east of the research area which can be seen clearly in the 3D model. The results of the slice G-
**G’ modeling** has the high density value, which has a range of 2.05 g/cc to 2.95 g/cc which is the dominance of andesite lava rock and volcanic breccia. The results of low to medium density values with a range of 2.4 g/cc to 2.7 g/cc are rocks produced by volcanic changes. From the results of the model, there are several indications of subsurface faults. The fault was identified as a normal fault that traversed Northwest to Southeast and the Southwest direction to the Northeast of the study area. Indications of other faults in the center of the study area can be seen clearly in the 3D model.

5. **Conclusion.**
Gradient analysis interprets the presence of faults that are scattered in several points of the study area. Geothermal manifestations are located at the maximum value of horizontal gradient value, and 0 is the value of vertical derivative, so its presence is controlled by fault structures. The results of Euler deconvolution overlay with first horizontal gradient indicate the geological structure in the form of faults which are in the west direction extending eastward, then in the Northwest direction the position also occupies a fault position based on first horizontal gradient analysis. This indication of fault can be seen clearly in 3D modeling results. Sed results show that the visible structure has an average depth of < 288.5 m to > 480.2 m. The results of the subsurface model illustrate the geological structure of the research area with the Grablox software consisting of low density values ranging from 1.95 g/cc to 2.5 g/cc estimated volcanic alteration rocks. The middle area of the study was obtained from the caldera formed by the collapse of the top wall of the shelf with a density of 1.95 g/cc to 2.5 g/cc. High density values are indicated as intrusive rocks which have a value range of 2.95 g/cc to 3.35 g/cc. The indications for faults were found in the presence of several rock densities that changed significantly in the Southwest to Northeast and Northwest directions to the Southeast research area.

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