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DELINIATION SUB SURFACE STRUCTURE OF GANTIWARNO SUBDISTRICT, KLATEN DISTRICT USING GRADIENT AND EULER DECONVOLUTION ANALYSIS

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ABSTRACT

The earthquake that occurred in Yogyakarta and surrounding areas on May 27, 2006 killed thousands of people and caused a lot of damage. The earthquake was caused by an activated of the Opak Fault and the Dengkeng Fault. Previous research on Dengkeng Faults has not been well publicized. The Dengkeng Fault in the research area is in the northeast of the Opak Fault, which is located in the subdistrict of Gantiwarno and sorrounding in Klaten district. The existence of the Dengkeng Fault can be identified using geophysical methods, one of which is the gravity method. Gravity data used in this study are primary data with a distribution point of 94 field measurements with semi grid distribution. Data that has been obtained in the field needs to be corrected so that it becomes a complete bouguer anomaly data. Complete bouguer anomalies are then separated using upward continuation to obtain regional anomalies and local anomalies. The local anomaly is then analyzed using gradient analysis in the form of first horizontal derivative and second vertical derivative to determine the contact boundary position and direction of the fault. The depth of the fault can be estimated using euler deconvolution analysis. In this study, the results of the gradient analysis in the form of first horizontal derivatives and second vertical derivatives show that the fault is in the UTM coordinates of zone 49 S from 444500 meters and 9141000 meters to 456250 meters and 9139000 meters in the west to east direction. Modeling with euler deconvolution analysis shows that the estimated depth of the fault is between ± 400 meters to ± 800 meters.

Keywords: earthquake, fault, gravity method, gradient analysis, euler deconvolution.

1. INTRODUCTION

Indonesia has a high tectonic activity due to Indonesia's position in the area where three plates meet, namely the Indo-Australian plate, the Eurasian plate, and the Pacific Ocean plate (Katili, 1973). Indo-Australian plates that collide with Eurasian plates throughout Sumatra, Java, Bali and Nusa Tenggara. All three plates have the same converging boundary plane and form subduction zones. The subduction zone in the Indonesian ocean is the result of the interaction of the Indo-Australian plate which moves northeast with the Eurasian plate which moves relatively south-east and tends to be silent.

The movement of the subduction zone of the Java and Sumatra regions as a result of the collision of the Indo-Australian plate which struck the Eurasian plate can cause a large enough earthquake. One earthquake in Yogyakarta and its surroundings on May 27, 2006, at 05.54 West Indonesia Time with a magnitude of 6.4 SR at a depth of 11.8 km and the epicenter of the earthquake was at 8.03 LS-110.32 East (BMKG, 2006). The earthquake which lasted for 57 seconds resulted in 5,778 people died, 37,883 people were injured, tens or even hundreds of thousands of buildings were damaged (Bakornas PBP, 2006).

Abidin *et al*. (2009) concluded that the earthquake that occurred in the Yogyakarta Region was caused by the movement or activation of the Opak Fault which is a sinistral fault that extends from the Parangtritis beach area to Prambanan (Figure-1). Previous research on the Opak-Oyo Fault was conducted by Nurwidyanto et al. (2007, 20014) used the gravity method to model the fault zone, Fathonah *et al*. (2014) used magnetic field anomaly data to identify the Opak Fault pathway.

According to Natawijaya in Abidin (2007) the earthquake that occurred in Yogyakarta was contributed by the Dengkeng Fault which located at the northeastern end of the Opak Fault. The Dengkeng Fault is a strike sleep fault due to subduction of the Indo-Australian Plate and Eurasian plate under the island of Java. Research on the Dengkeng Fault has never been done by the gravity method using gradient analysis and euler deconvolution analysis. This research is expected to be a review of the existence of Dengkeng Fault which was activated at Yogyakarta earthquake in 27 Mei 2006.

2. THEORY

The geographical position of the research is at coordinates 110˚30 'BT - 110˚36' East and 7˚45'LS - 7˚51'LS (Figure-1). According to Surono (1992) in the northern part of the research area consists of lowlands that are occupied by volcanic deposits of volcanic products from Mount of Merapi. The southern part of the research area is the Baturagung Mountain, which is the Southern Mountains, extending in the east-west direction. Regional lithology from young to old is composed by Nglanggran Formation, Semilir Formation, and Kebobutak Formation. The rock formations are in Early Miocene to Oligocene age. The deformation process that formed the geological structure of the research area began in the Plistocene period. Samodra and Sutrisna (1997) added that many geological structures were found mainly in the form of faults trending east-west to north-south.

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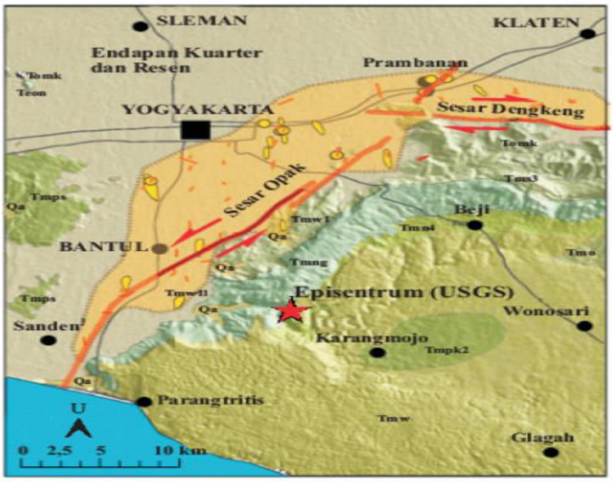

Figure-1. Opak Fault and Dengkeng Fault (Natawijaya dalam Abidin dkk.(2009).

Gravitational field theory is based on Newton's law of universal gravitational fields. Newton's law of gravitational field states that the force of attraction between two points of mass m_1 and m_2 which separated by r . The equation used to express the gravitational field theory is shown in equation (1), Telford *et al.* (1990)

$$\vec{F} = -G\frac{m_1.m_2}{\vec{r}^2}\,\hat{r} \qquad (1)$$

here $\vec{F}$ is the force experienced by an object (Newton) and G is the gravitational field constant (6.67×10^{-11} Nm^2 kg^{-2} or m^3 kg^{-1} s^{-2}), m_1 is the mass of object 1 (kg), m_2 is the mass of object 2 (kg) and $\vec{r}$ is the distance between the centers of mass(m).

Gravitational fields on the surface of the earth can be expressed by equation (2.2), Telford et al (1990).

$$\boldsymbol{g = G\frac{M}{r^2}} \qquad (2.2)$$

where g is the acceleration due to gravity on the surface of the earth, M is the mass of the earth and r is the distance of the point on the surface of the earth to the center of mass of the earth. Upward continuation is a method of upward continuity with the basic principle of highlighting regional and eliminating local effects. The upward continuity method is also one method that is often used as a filter to eliminate noise (Blakely, 1995).

Calculation of the potential field in the continuation yield field (z) can be done using equation (3), (Blakely, 1995).

$$\mathrm{U}(\mathrm{x},\mathrm{y},\mathrm{z}_0-\Delta\mathrm{z}) \qquad (3)$$
$$= \frac{\Delta z}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{\mathrm{U}(\mathrm{x}',\mathrm{y}',\mathrm{z}_0)}{[(\mathrm{x}-\mathrm{x}')^2+(\mathrm{y}-\mathrm{y}')^2+\Delta\mathrm{z}^2]^{3/2}}\mathrm{dx}'\mathrm{dy}'$$

where $U(x,y,z_0)$ the value of the potential field in the area of the product of continuity, Δz is the distance or height of upword.

Cordell (1979) revealed that the horizontal gradient used can be used to determine the location of horizontal contact boundaries as well as faults from gravity data. According to Svancara *et al.* (2008), the maximum value of the horizontal gradient that shows lateral direction contrast density was identified as a fault or lithological contact limit. The magnitude of the horizontal gradient (x, y) is defined by the gravity anomaly function bouguer g (x, y) where x, y are the horizontal coordinates, which are shown in equation (2.4) (Cordell, 1979).

$$(\boldsymbol{x},\boldsymbol{y}) = \sqrt{\left(\frac{\partial\Delta g(x,y)}{\partial x}\right)^2+\left(\frac{\partial\Delta g(x,y)}{\partial x}\right)^2} \qquad (4)$$

where Δg is the complete bouger anomaly value, ∂x is the x-axis derivative value, ∂y is the y-axis derivative value.

The contact limits of rocks and faults in the study area can be identified using gradient analysis in the form of vertical gradients to reveal shallow anomaly sources (Sarkowi, 2014). Theoretically, this method is derived from Laplace's equation shown in equations (5) and (6).

$$\nabla^2\Delta g = 0 \qquad \ldots\ldots\ldots\ldots \quad (5)$$

$$\frac{\partial^2\Delta g}{\partial x^2}+\frac{\partial^2\Delta g}{\partial y^2}+\frac{\partial^2\Delta g}{\partial z^2}=0 \qquad \ldots\ldots\ldots\ldots (6)$$

The type of fault structure can be shown in equations (7), (8) and (9), (Sarkowi, 20015).

For sedimentary basins or broken faults apply:

$$\left(\frac{\delta^2\Delta g}{\delta x^2}\right)maks > \left|\left(\frac{\delta^2\Delta g}{\delta x^2}\right)min\right| \qquad (7)$$

For batolite / intrusion granite and rising faults apply:

$$\left(\frac{\delta^2\Delta g}{\delta x^2}\right)maks < \left|\left(\frac{\delta^2\Delta g}{\delta x^2}\right)min\right| \qquad (8)$$

For horizontal faults to apply (Sarkowi, 2010):

$$\left(\frac{\delta^2\Delta g}{\delta x^2}\right)maks = \left|\left(\frac{\delta^2\Delta g}{\delta x^2}\right)min\right| \qquad (9)$$

Euler deconvolution is a mathematical approach to estimating the depth of an object based on a three-way partial derivative (x, y, z) of a function. In general euler equations can be formulated with equation (10) as follows (Reid et al., 1990).

$$(\mathrm{x}-\mathrm{x}_0)\frac{\partial g(x,y,z)}{\partial x}+(\mathrm{y}-\mathrm{y}_0)\frac{\partial g(x,y,z)}{\partial y}+(\mathrm{z}-\mathrm{z}_0)\frac{\partial g(x,y,z)}{\partial z}=0 \quad (10)$$

where (x_0,y_0,z_0) is the position and depth of the gravity anomaly source detected from (x, y, z), $\frac{\partial g}{\partial x},\frac{\partial g}{\partial y},\frac{\partial g}{\partial z}$ is the data derivative gravity in the direction of x, y, z and N is an Index structure that describes the geometry of the source of the anomaly. The structure of objects causing anomalies for gravity data is explained in Table-1.

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Table-1. Structural refractive index values for gravity (Reid *et al*., 1990).

Source	Struktur Indeks
Ball / point	2
Sill/dike	1
Contact/Fault	0

3. MATERIAL AND METHODS

The geographical position of the study area is at coordinates 110˚30 'East - 110˚36' East and 7˚45'LS - 7˚51 'East which has 94 distribution points. The area of research is 11 kilometers x 10.5 kilometers. Measurement of gravity field data using a La-coste Romberg gravitymeter type G-1118 MVR, height measurements using Altus APS-3 GPS and location measurements using GPS Garmin III Plus.

The measurement data in this study need to be corrected with tool height correction, drift correction, tidal correction, latitude correction, free air correction, bouguer correction, terrain correction so that a complete bouguer anomaly (ABL) is obtained. Terrain correction is performed using SRTM maps which are processed using Global Mapper Software and Oasis Montaj. The complete Bouguer anomaly that has been obtained is then separated using upward continuation to obtain local anomalies and regional anomalies. The next process is to analyze local anomalies using gradient analysis and euler deconvolution analysis. Gradient analysis in the form of first horizontal derivative and vertical derivative is carried out to identify the location and boundary of rock contact, and the direction of the structure. Euler analysis was carried out to estimate the depth of the anomaly. Fault information according to Natawijaya (2007) and geological map of the study area are shown in Figure-2.

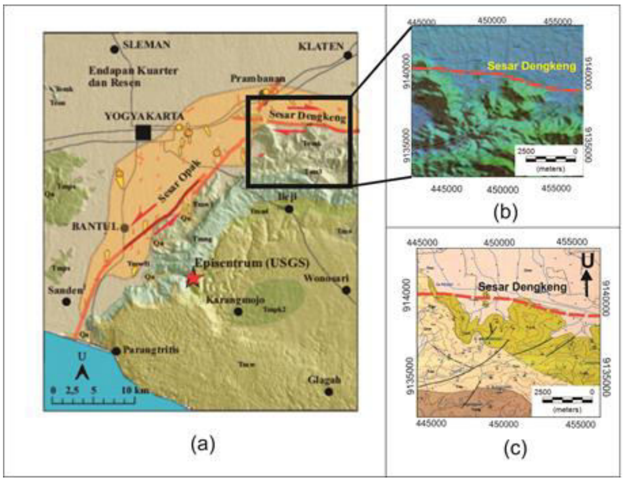

Figure-2. (a) Fault based on geological map according to Natawijaya (2007) (b) SRTM map of the study area (c) Geological map of the study area Surono *et al* (1995).

The topography of the research area is shown in Figure-3. The elevation values range from 100 meters to 600 meters. Low topography is located in the northern part of the research area which is shown in dark blue. High topography is in the south, northwest, east, and the central part of the research area which is a mountainous path. On the south side of the research area there is Mount Blencong, on the east side there is Mount Jogotamu, on the northwest side there is Mount Pegat, and on the middle side of the research area there is Mount Mintorogo.

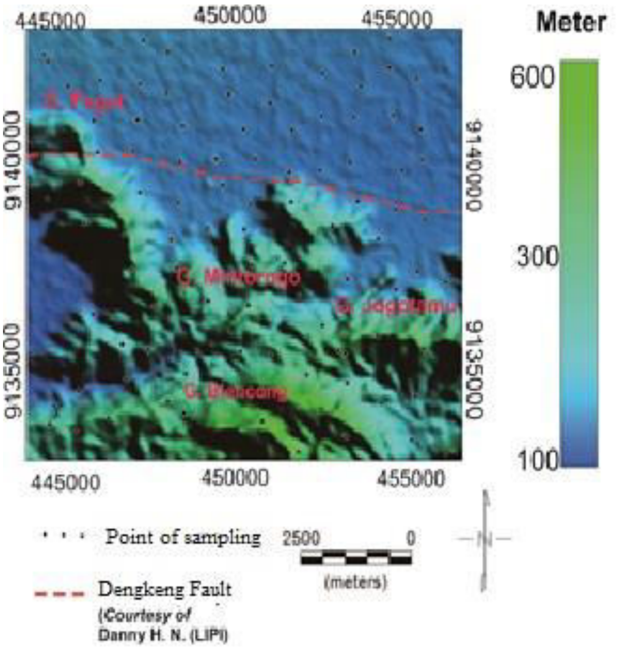

Figure-3. Topography of Research arrea.

The observed gravity value at each measurement point in the field is shown in Figure-4.

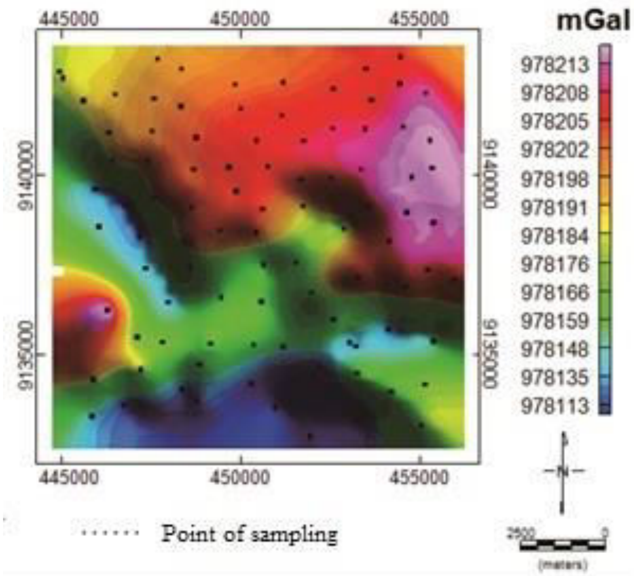

Figure-4. Gravity Observe of Research area.

The distribution of the observed gravitational field values in the research area are 978113 mGal to

978213 mGal. The topographic contour patterns and gravitational fields shown in Figure-3 and Figure-4. In Figure-3 and Figure-4, we can sees that in the south, east, and northwest regions of the study area on low-value observational gravity fields, while in the topographic contours in the south, east, and northwest regions the research area has a high value, this corresponds to the theory of the gravitational field, the higher the topography of an area, the smaller the gravitational field of observation will be, and vice versa.

The complete bouguer anomaly in the study area ranges from 121 mGal to 176 mGal which can be seen in Figure-5.

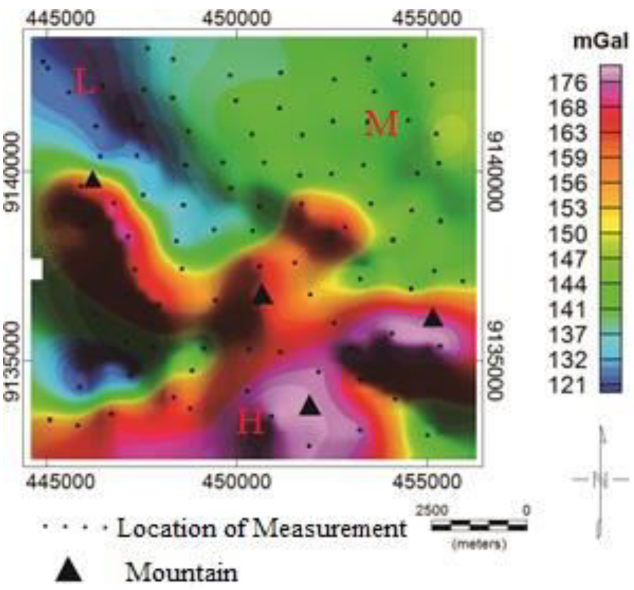

Figure-5. Complete Bouguer Anomaly (CBA).

The complete bouguer anomaly contour pattern in the research area has a low, medium, and high value distribution. Low values are marked with the letter L which is indicated by a blue contour with a value of 121 mGal to 140 mGal, the area has a Semilir Formation consisting of tuffs, breccias, dacitic pumice, tuffaceous sandstone, and shale which have low density values. The distribution of complete bouguer anomaly in medium values is on the northeast side of the study area which is marked with the letter M with green to yellow contours with a value distribution between 142 mGal to 158 mGal. The area contains of alluvial Merapi volcano rocks that have medium density. Distribution of high value bouguer complete anomaly values found in the south, southeast, and east areas indicated by the letter H which has a value distribution of 159 mGal to 176 mGal. The area is a high density mountain range consisting of four mountains namely Mount Pegat, Mount Mintorogo, Mount Blencong and Mount Jogotamu. The southern part is the Blencong Mountain which is mainly composed of rocks from the Nglanggran Formation. The formation is composed of several rocks which have a high density because it consists of volcanic breccias, agglomerates, lava, andesite-basalt and tuff. The northwestern part of the research area is Mount Pegat composed of Semilir Formations. The formation is composed of tuff, titanic pumice breccia, tuff sandstone, and shale. The southeast and center of the research area are Mount Jogotamu and Mount Mintorogo, which are composed of rocks from the Kebobutak Formation. The Kebobutak Formation is the oldest rock in the research area. The top of the Kebobutak Formation consists of sandstone, a thin layer of acid tuff and clay stone. The lower part of the Kebobutak Formation consists of sandstone, siltstone, clay stone, shale, and agglomerate. Upward Continuation is carried out to separate regional anomalies and residual anomalies in complete bouguer anomalies. Regional anomalies in the study were carried out using upward continuation to a height of 4000 meters. The results of the upward continuation process are regional anomaly and residual anomalies which shown in Figure-6 and Figure-7.

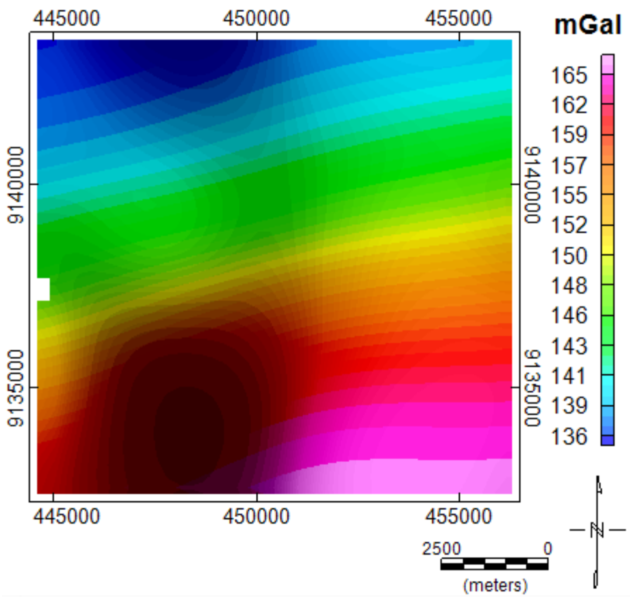

Figure-6. Regional Anomaly.

The distribution of regional anomaly values in the research area ranges from 138 mGal to 165 mGal. These anomalies are a general description of low anomalies and high anomalies. Low anomaly values are scattered in the northern part of the research area consisting of rocks with low density, such as sandstones and shales. The high anomaly is in the southern part of the research area, because the area compose by the Kebobutak Formation and the Nglanggran Formation.

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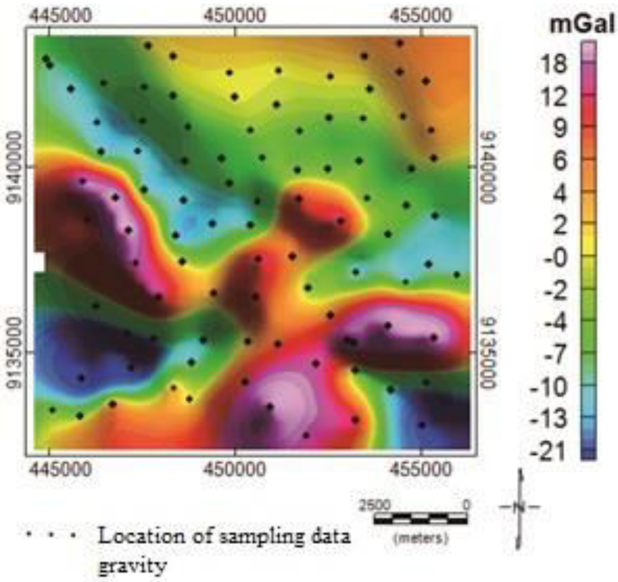

Figure-7. Residual Anomali.

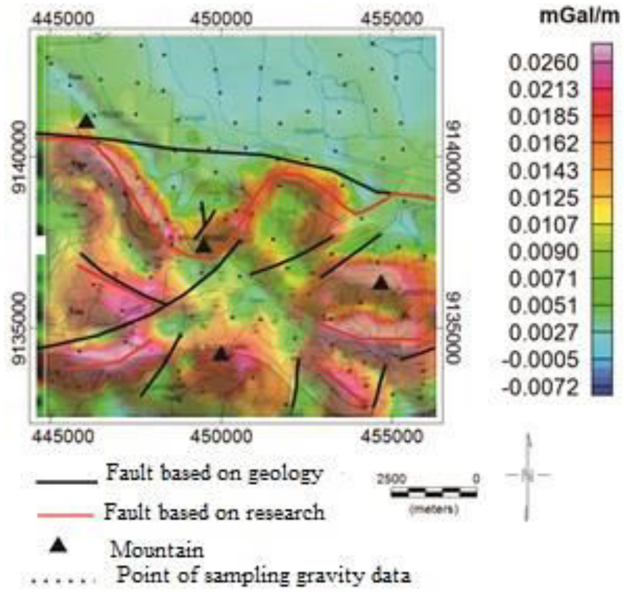

Figure-8. Contour of the first horizontal derivative of the research area whcich overlay in a geological map.

Residual anomaly in the research area has a value between -21 mGal to 18 mGal. Variations in residual anomalies have decreased significantly, positive and negative values. The anomaly value can be caused by the density and size of the rock body that affect the value of an anomaly. Negative values are interpreted as at least anomalous differences due to shallow residual effects, based on the results of upward continuation process, the depth of the residual effect and the contact limits of rocks occur at a depth of 4000 meters.

Rock contact boundary identified as faults can be determined by using gradient analysis in the form of first horizontal derivatives and second vertical derivatives. The area identified as a fault according to the analysis of the first horizontal derivative is an area that has a maximum value, because the maximum value indicates the lateral views that are suspected as faults. The results of the first horizontal derivative analysis can be seen in Figure-8.

The value of the first horizontal derivative in the study area ranged from -0.0072 mGal / m to 0.026 mGal / m. Analysis using the first horizontal derivative is done by overlaying the first horizontal derivative data with the geological map of the study area. The Dengkeng Fault is based on a geological map according to Danny in Abidin (2009) in the northernmost section has a east-west direction.

Dengkeng Fault results of analysis using the first horizontal derivative east-west direction but curved in the middle. The fault passes through the Pegat Mountain route in the west and passes Mount Mintorogo then returns straight along the Dengkeng Fault route based on the geological map to the east. The fault line based on the analysis of the first horizontal derivative is in a Semilir Formation through the Kebobutak Formation and Merapi volcano rocks.

Shallow anomaly sources can be clarified using second vertical derivative analysis. According to Sarkowi (2014) the area identified as fault structure and rock contact boundary can be determined by second vertical derivative analysis which is zero value. The contours of the second vertical derivative in the research area are shown in Figure-9.

Second vertical derivative analysis in the study area has a range of values between -0.0000577 mGal/ m^2 to 0.0000324 mGal / m^2. The analysis was carried out by overlaying the second vertical derivative data with the geological map of the study area. Areas that are identified as faults and rock contact boundaries are areas that have zero values. On faults based on geological maps, the Dengkeng Fault has a northwestern direction. Dengkeng Fault results from the analysis of the second vertical derivative trending east-west but curved in the middle. The Dengkeng Fault line results from the interpretation of the second vertical derivative starting from the Mount Pegat route, passing Mount Mintorogo to the east. The results of the second vertical derivative analysis of the study area can also be used to determine the contact limits of mountain rocks shown by the dark blue dashed line. The study area contained 4 contact limits for rocks thought to be the body of Mount Pegat in the northwest, the body of Mount Mintorogo in the middle, the body of Mount Jogotamu in the east, and the body of Mount Blencong in the south.

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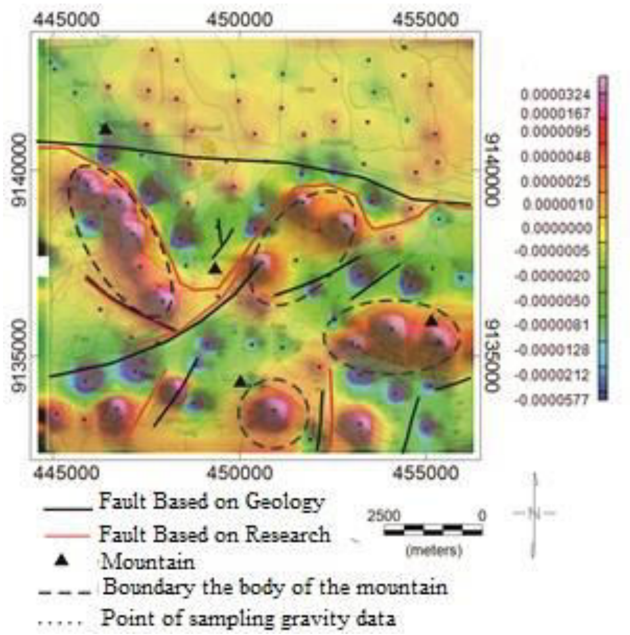

Figure-9. Contours of the second derivative overlaid with the geological map of the study area.

Fault location estimation is done by gradient analysis, namely first horizontal derivative and second vertical derivative. The area identified as a fault is at the maximum first horizontal derivative value, while in the second vertical derivative analysis that is identified as a fault is at zero (Reynold, 1990). To find out the type of fault, an SVD value profile was created. The maximum value and minimum value on the second vertical derivative profile curve are the same, so that the type of fault in the research area is estimated to be the type of strike sleep fault. From the FHD and SVD analysis the location of the Dengkeng Fault in the research area can be estimated to be in the UTM zone 49 S from 44,4500 meters and 914,000 meters to 456250 meters and 9139,000 in the west to east direction with the Strike-Slip movement.

Euler deconvolution analysis can be used to estimate the depth of the gravitational anomaly below the surface using the principle of euler homogeneity. The results of the Euler deconvolution analysis in the study area are shown in Figure-10.

Euler Deconvolution Analysis is in the form of depth points which estimate the depth of the study area and then overlaid with a contour map of the results of the second vertical derivative analysis, because the dengkeng fault is a shallow fault so the vertical second derivative method has good values and contours that are good and clear in identifying faults. Overlay analysis of euler deconvolution with second vertical derivative analysis is shown in Figure-11.

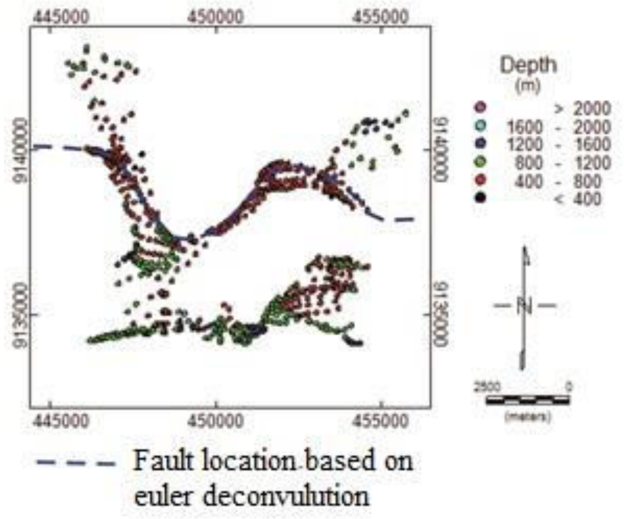

Figure-10. Map of fault lines resulting from Euler Deconvolution Interpretation.

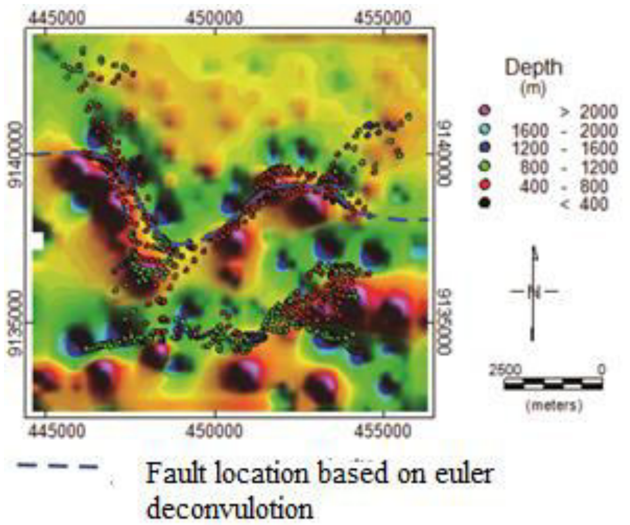

Figure-11. Fault path map resulting from Euler Deconvolution Interpretation in the overlay of the second vertical derivative contour.

Euler deconvolution analysis of the study area shows that the estimated fault depth ranges from 400 meters to 800 meters. Euler deconvolution analysis has the results of a fault which is almost the same as the results of the analysis of the second vertical derivative that is west to east.

The results of the gradient analysis and euler deconvolution analysis are overlaid into a geological map to find indications of faults. Image overlay gradient analysis and euler analysis can be seen in Figure-12.

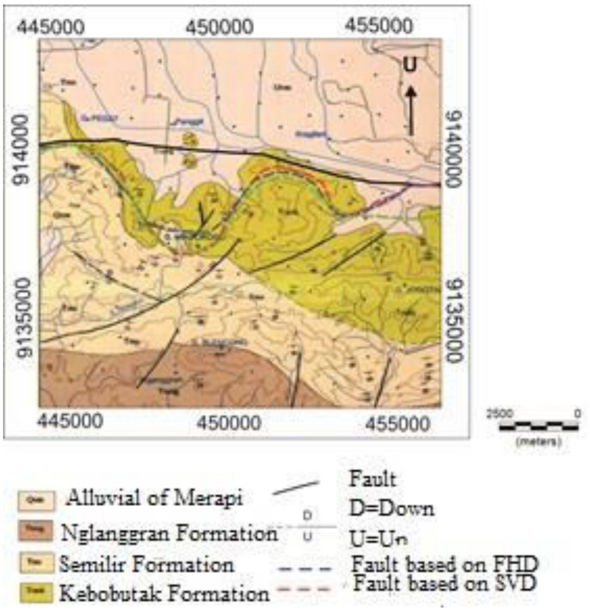

Figure-12. Interpretation of fault based on the results of the analysis of first horizontal derivatives, second vertical derivatives and Euler Deconvolution.

4. CONCLUSIONS

From the results of the research conducted, it can be concluded that the subsurface structure in the form of Dengal Fault in the study area is carried out using gradient analysis, namely first horizontal derivative and second vertical derivative. The fault is located in the UTM coordinates zone 49 S from Easting 444500 meters and Northing 9141000 meters to Easting 456250 meters and Northing 9139000 with west to east directions. The depth of the structure of the peak of Dengkeng Fault based on euler deconvoluton analysis is estimated to be at a depth of ± 400 meters to ± 800 meters below the surface.

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