Magnetic Survey for Qualitative Interpretation of Subsurface Andesites Rocks Distribution in Kutasari, Purbalingga Regency, Indonesia

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Abstract

A magnetic survey has been carried out in Kutasari District, Purbalingga Regency, Central Java, Indonesia in April 2019. The aim of this research is to interpret the distribution of subsurface andesite rocks qualitatively in the research area. The equipment used in this research are Proton Precession Magnetometer, Global Positioning System, compass, and other supporting tools. The final result is the local magnetic anomaly map with value of -1,238.13 – 1,892.40 nT. This local magnetic anomaly map show the anomalous sources distribution in the subsurface which is interpreted as andesite igneous rocks that dominate in the middle to northwestern of the research area. This result has been clarified by pseudogravity anomaly map and analysis of its horizontal gradient. The pseudogravity anomaly map which has value of -75.99 – 119.50 mGal represents the distribution of subsurface rocks density. Whereas the horizontal gradient map which has value of 0.0022 – 0.3305 mGal/m represents the subsurface rocks lithological boundaries. Both of them shows the distribution of subsurface anomalous sources which is interpreted as andesite rocks tends to be western of the research area.

Keywords:
Magnetic survey, local magnetic anomaly, andesite rocks, Purbalingga Regency

1. Introduction
1.1. Background

Andesites rocks are one of the natural resources that are often found in nature, especially in the area around volcanoes. These rocks are formed due to very high volcanic activity. Andesite rock has a strong resistance to weather and is durable. One of the results of technical testing shows that the andesite rock has an average uniaxial pressure (Unconfined Compression Strength) of about 410.93 kg/cm2, a broken resistance of about 22.6%, and an absorption of about 1.82%, so that andesite rock can be used as building foundation and building materials aggregate (Hardiyono, 2013). Andesites rocks not only "make" the structure of buildings become stronger, but also leave the cold impression which is strong enough and have very high aesthetic value.

One region in Central Java which has a large potential of andesite naturally is Kutasari District Purbalingga Regency especially Cendana, Candiwulan, Karangcegak, Bumisari, and Candinata Villages (Ariyanto, 2014). These villages are located below the southern slope of Slamet Volcano, Central Java. This volcano is located at geographical positions of 7°14′30″ S and 109°12′30″ E with altitude of 3,248 meters above mean sea level (Pratomo and Hendrasto, 2012). The community's knowledge of the presence of andesites rocks in these villages with a high selling value resulted in a traditional mining process of andesites. The andesites rocks mining business is often found in the lower slopes area of Slamet Volcano. The presence of andesites rocks in these areas is marked by rock outcrops that appear at some locations on the surface as shown in Figure 1. However the excavation activities of andesites rocks randomly, irregularly, and wildly can cause several negative impacts such as landslides, cliffs collapses, environmental damages, and others.

Figure 1. Outcrops of andesite lava rocks in Candiwulan and Karangcegak Villages, Kutasari District, Purbalingga Regency, Central Java.

There is a need for a regulation on mining activities in this region. Regulations are prepared based on the result of distribution and potential mapping of andesites rocks in the region. Through this regulation, the government can regulate and supervise the andesite rock mining activities, so that the negative impact can be minimalized and environmental sustainability can be maintained. One of the methods for mapping of andesite rocks distribution in the research area is by applying magnetic survey (Ahnin *et.al*., 2013). In exploration, magnetic surveys utilize the rock magnetic susceptibility value as an instrument to identify the subsurface rocks types and geological structures such as faults, igneous intrusions, groundwater aquifers, geothermal reservoirs (Mariita, 2007), iron ores (Sehah *et.al*., 2018), and others.

The magnetic survey has a high sensitivity to igneous rocks, so that igneous rocks are easily detected. This is related to the content of ferromagnetic minerals in those rocks (Vincent, 2013). Ferromagnetic material generally have a large magnetic susceptibility value, approximately a million times greater than paramagnetic or diamagnetic material (Imhmed, 2012). The magnetic susceptibility value of rock can be used as a basis for the modeling and interpretation to the local magnetic anomalies data which are obtained (Dai, 2014). Qualitative and quantitative interpretation of the local anomalies data modeling results were carried out to complement the distribution map of andesites rocks in the research area (Xiong *et.al*., 2016).

1.2. Geological Settings

Geologically, the research area was dominated by igneous rock from andesite lava in the north and laharic deposits of Slamet Volcano in the south. The laharic deposits are laharic with boulder of rocks which composed of andesite and basalt in diameter of 10 – 50 centimeters resulting from the eruption of the old Slamet Volcano whose distribution covers relatively flat areas (Djuri *et.al*., 1996). The rocks group of old Slamet Volcano eruption consists of andesite lava and pyroclastic deposits that have undergone a hydrothermal change. The rocks group of young Slamet Volcano eruption that consisted of basaltic lava and falling pyroclastic which did not experience changes (Pratomo and Hendrasto, 2012). The geological map of the research area is shown in Figure 2. The research area is surrounded by various rocks formations; including of alluvium (Qa), laharic deposit of Slamet Volcano (Qls), andesite lava of Slamet Volcano (Qvls), clay member of Ligung formation (Qtlc), Kalibiuk formation (Tpb), Tapak formation (Tpt), Kumbang formation (Tmpk), and Halang formation (Tmph). The rocks stratigraphic order in the geological map has been sorted from young to old time. Based on the geological map, andesites rocks which are the target of mining are located in the uppermost stratigraphic, i.e. the Slamet volcanic lava formation (Qvls).

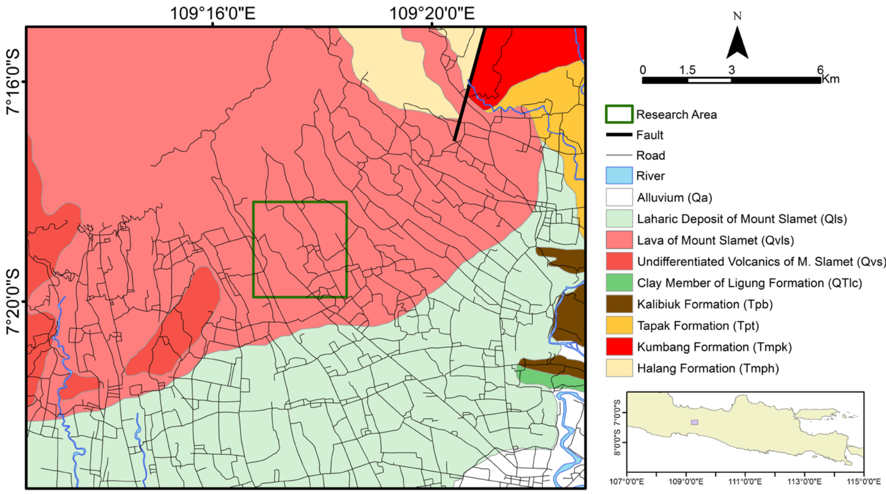

Figure 2. The geological map of the research area (Djuri et.al., 1996).

1.3. Magnetic Survey Theory

A volume of object (such as subsurface rock) consisting of magnetic materials or minerals can be considered as a magnetic dipole as shown in Figure 3. The magnetization which occurs in the object depends on its track record as long as it is in the main magnetic field of the earth, or in other words depends on the amount of magnetic induction that received from the main magnetic field of the earth. The magnetic potential contained at a point in the rock can be written with the equation (Telford *et.al*., 1990).

$$V = -C_m \vec{m} \cdot \nabla \left[\frac{1}{r}\right] = C_m \frac{m\cos\theta}{r^2} \tag{1}$$

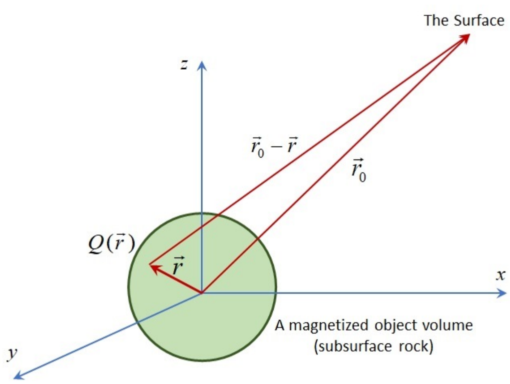

Figure 3. Description of magnetic anomaly from magnetized objects volume (Telford et.al., 1990).

By integrating the equation (1) and changing the variables slightly, then the magnetic potential quantity for all rock volumes can be calculated using the equation (Telford et.al., 1990):

$$V(\vec{r}_0) = -C_m \int \vec{M}(\vec{r}) \cdot \nabla \left[\frac{1}{|\vec{r}_0 - \vec{r}|}\right] dv \tag{2}$$

where $\vec{M}(\vec{r})$ in equation (2) is a dipole moment per unit volume, while C_m is a constant. If $\vec{M}(\vec{r})$ has a fixed value and has a fixed direction, then the magnetic induction of all rock volumes can be calculated through an integration process which can be expressed by the equation

$$\vec{B}(\vec{r}_0) = C_m \nabla \int_V \vec{M}(\vec{r}) \cdot \nabla \left[\frac{1}{|\vec{r}_0 - \vec{r}|}\right] dV \tag{3}$$

The magnetic induction field such shown as equation (3) is referred to as magnetic anomaly, where the value is superposed by the earth's main magnetic field value (B_0) at all points on the surface. Thus, the total magnetic field value recorded in the magnetometer apparatus at a point on the surface is combination of the main magnetic field and magnetic anomaly (Br_0) value with assuming that the external magnetic field is ignored. This formula can be expressed with simple equations

$$\vec{B}_T = \vec{B}_0 + \vec{B}(\vec{r}_0) \quad (4)$$

But in reality to get the magnetic anomaly value, it is necessary correction to the total magnetic field data which have measured at each point on the surface, which includes daily correction (B_D), and earth main magnetic field correction (B_0). Thus, the magnetic data correction equation can be expressed by

$$\vec{B}(r_0) = \vec{B}_T - \vec{B}_D - \vec{B}_0 \quad (5)$$

The earth main magnetic field value (B_0) is stated in the-International Geomagnetic Reference Field (IGRF). The IGRF is the mathematical model that expresses the geomagnetic field and its long-term changes in global distribution based on the gaussian theory of geomagnetism (Deng *et.al*., 2017). The IGRF value is not constant, but changes according to latitude position and time. The effect of the earth's magnetic field value variations in the IGRF has been anticipated by updating and setting the IGRF values every 5 years by The International Association of Geomagnetism and Aeronomy (IAGA) (Macmillan and Maus, 2005).

2. Research Methodology

2.1. Procedure

Magnetic survey for interpretation of the andesites rocks distribution in Kutasari District Purbalingga Regency Central Java Indonesia has been carried out in April 2019. The acquisition of magnetic data which area equipped with geographical position data has been conducted covering the area with the position of 109.2788° – 109.3072° E and 7.3032° – 7.3319° S. The research begin with magnetic data acquisition, so that the total magnetic field strength data are obtained. Further, several corrections including the daily correction and the IGRF correction are applied as shown in Equation (5), so that the total magnetic field anomalies data is obtained. This magnetic anomalies data are distributed on the topographic surface, so it is a function of longitude (x), latitude (y), and altitude (h). The magnetic anomalies data must be transformed to horizontal surface; using the Taylor series approximation (Blakely, 1995) which can be written as Equation (6). It is because the data cannot be processed in the next stage, if it is not be distributed on the horizontal surface. If the magnetic anomaly can be written as ΔB, then:

$$\Delta B(x, y, h_0)^{[i+1]} = \Delta B(x, y, h) - \sum_{n=0}^{\infty} \frac{(h-h_0)^n}{n!} \frac{\partial^n}{\partial z^n} \Delta B(x, y, h_0)^{[i]} \quad (6)$$

Equation (6) is written in an iterative form, where $\Delta B(x,y,h_0)$ are magnetic anomalies data distributed in a horizontal surface which estimated through an approach; i.e. $\Delta B(x,y,h_0)$ that obtained from i-th iterations can be used to obtain the value of $\Delta B(x,y,h_0)$ in the $(i + 1)$-th iteration. The iteration process is done sufficiently to obtain convergent values. For the initial guess before the iteration, the value of $\Delta B(x,y,h_0)$ on the right side can be filled with $\Delta B(x,y,h)$.

The magnetic anomalies data that have been spread in the horizontal surface are still affected by the effects of regional magnetic anomalies sources. Therefore the regional magnetic anomalies effect must be reduced because target of this research is local geological structure like andesites rocks. The regional magnetic anomalies data were obtained through upward continuation process of magnetic anomalies data which have spread on the horizontal surface (Stella and David, 2015) using equation of the 2nd-Green identity (Telford et.al., 1990):

$$\Delta B(x', y', h_0 + \Delta h) = \frac{\Delta h}{2\pi} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta B(x, y, h_0)}{\sqrt{\left((x'-x)^2 + (y'-y)^2 + \Delta h^2\right)^{3/2}}} dx\, dy \quad (7)$$

$\Delta B(x',y',h_0+\Delta h)$ are the regional magnetic anomalies data, that is then corrected to the magnetic anomalies data which have distributed in the horizontal surface using the following equation

$$\Delta B(x, y, h_0)_{Local} = \Delta B(x, y, h_0) - \Delta B(x', y', h_0 + \Delta h) \quad (8)$$

The obtained local magnetic anomalies data are magnetic anomalies data which represents the subsurface conditions of the research area in the crust near surface (Li and Oldenburg, 1998), such as andesites rocks in the research area.

2.2. Equipments

Several equipment which is used for magnetic surveying in the field consists of Google Earth application for plotting survey points in the field and making survey design, Proton Precession Magnetometer (PPM) to measure the total magnetic field, Global Positioning System (GPS) to measure the geographic position of entire measured point, Compass to direct the PPM sensors to the north, and notebook to record data of measurement results. Several of the equipment used for laboratory work is a personal computer (PC) equipped with various necessary software such as Microsoft Excel application, Fortran 77, and Surfer 7.

3. Results and Discussion

3.1. Results of Total Magnetic Anomalies Data Mapping

Acquisition of the magnetic field data have been carried out in the Kutasari District, Purbalingga Regency, Central Java, Indonesia covering the area in the geographical position of 109.2788° – 109.3072° E and 7.3032° – 7.3319° S. The results which obtained are total magnetic field strength data at each measurement point with values ranging of 43,467.99 – 46,888.65 nT. Further, to get the total magnetic anomalies data, then several corrections and reduction were carried out as has been explained in the Research Method section. The data corrections which have been done include the daily correction and the IGRF correction. After apply several corrections, the total magnetic anomalies data are obtained. The total magnetic anomalies data are spread on the topography with values ranging of -1,376.79 – 2,037.26 nT. The total magnetic field strength map and total magnetic anomaly map of the research area are shown in Figure 4. The total magnetic anomaly map shows that the magnetic anomalies closures are relatively spread in the middle to northwest of the research area.

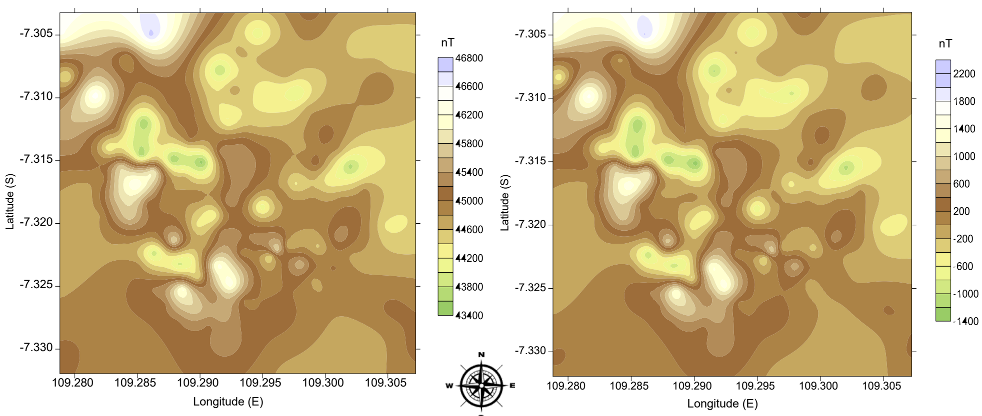

Figure 4. The maps of total magnetic field strength (left) and total magnetic anomaly (right) which still distributed on the topographic surface of the research area.

3.2. Results of Local Magnetic Anomalies Data Mapping

The magnetic anomalies data are reduced from the topographic to the horizontal surface using Taylor Series approximation like equation (6), so the anomalies data can be processed in the next. The horizontal surface has been chosen at the height of average topographic, i.e. 438.04 m above a reference spheroid. The magnetic anomalies data obtained from this calculation process have value range of -1,148.59 – 1,982.00 nT with contour map can be seen in Figure 5. The range between maximum and minimum anomalies data is relatively smaller than the range of data when still above the topography surface, i.e. -1,376.79 – 2,037.26 nT. This shows the iteration process in the Taylor Series calculations has reached convergency, so that anomalies data which obtained is considered to have been distributed on the horizontal surface (Blakely, 1995).

The research target are near surface objects, i.e. andesites rocks, so that magnetic effects from deep and wide sources must be reduced. This magnetic effect is called as regional magnetic anomaly. The regional magnetic anomalies data were obtained through upward continuation process of the total magnetic anomalies data which distributed on the horizontal surface to a certain height, then the ranging of anomalies data has shown a very small value and it´s map tends to remain (Ilahude, 2012). The upward continuation process of magnetic anomalies data is carried out step by step; where for each step is equipped with it´s anomaly contour image. Visual observation was done to determine; whether anomaly contour pattern has shown regional anomaly pattern. Based on this criteria, the anomaly contour as shown in Figure 5 is designated as the regional magnetic anomaly contour, because it has shows very fine pattern (Ganiyu et.al., 2013). This contour has been obtained through upward continuation process at a height of 5,000 m above the reference spheroid surface.

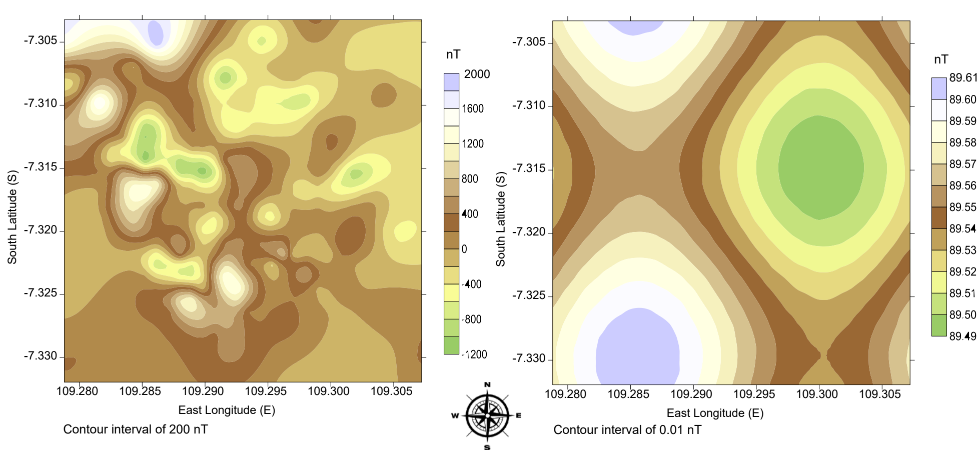

Figure 5. The total magnetic anomaly map which is distributed on the horizontal surfaces; i.e. at the topographic average height of 438.04 m (left) and the regional magnetic anomaly map resulting from upward continuation process of magnetic anomalies data at a height of 5,000 m (right)

The regional magnetic anomalies data which obtained, then corrected to the total magnetic anomalies data which has distributed above the horizontal surface, so that the local magnetic anomalies data are obtained. This anomalies data have ranging values of -1,238.13 – 1,892.40 nT and represent the geological condition near surface, including andesites rocks distribution in the research area. Based on the analysis results to the magnetic anomaly contour map, some pairs of magnetic anomalies closures are found relatively in middle to northwest. This closures are the magnetic effect that comes from subsurface magnetic objects. The distribution of subsurface magnetic objects are interpreted to be found in this area. Based on the interval of local magnetic anomalies values which is obtained, the research area was dominated by the high anomalies closures. This shows that the subsurface magnetic objects which are the anomalous sources are thought to contain ferromagnetic minerals (Joshua et.al., 2017). Then the local magnetic anomaly contour map of the research area can be seen in Figure 6.

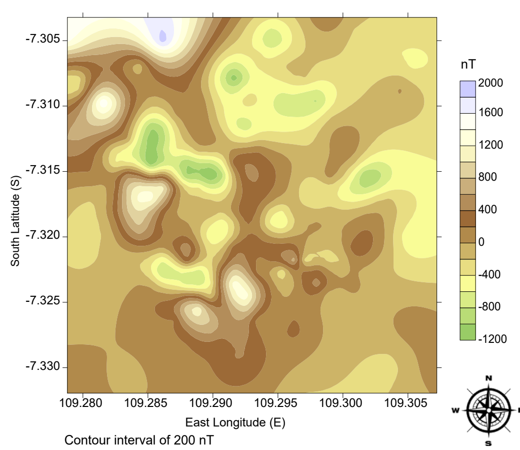

Figure 6. The Local magnetic anomaly map which distributed at the average height of topography, i.e. 438.04 m

3.3. Results of Pseudogravity and Horizontal Gradient Mapping

The local magnetic anomaly map still show several complexity of anomalous pattern. This can complicate the modeling process which aims to interpret the subsurface anomalous objects and geological structures which are the target of research. To obtain the survey target clearly, so the subsurface anomalous sources can be localized through pseudogravity transformation process. This transformation works by changing the local magnetic anomalies data into the pseudogravity anomalies data. The pseudogravity uses the Poisson relations in it´s working principles. In the Poisson relations shown that the magnetic potential value (V) and gravitational potential value (U) originating from a homogeneous density and an uniformly magnetized objects are related to the equation (Blakely, 1995)

$$V = -\frac{C_m}{\gamma}\frac{M}{\rho}\hat{m}\bullet\nabla_P U = -\frac{C_m}{\gamma}\frac{M}{\rho} g_m \qquad (9)$$

where ρ is density of subsurface object, M is intensity of the magnetization of object, $\hat{m}$ is magnetization direction and g_m is a component of earth's gravitational field in accordance with the direction of magnetization. The anomaly map resulting from the pseudogravity transformation is shown in Figure 7.

Although the pseudogravity anomaly contour map is relatively clearer in indicating the target location of the subsurface anomalous sources, but to clarify the lithological boundaries that show the edges of objects or rocks, it can be conducted using the horizontal gradient. The horizontal gradient calculations are performed on pseudogravity anomalies data. This method has been used extensively to locate the boundaries of density contrast from gravity data or pseudogravity data (Setyawan et.al., 2015). The maximum horizontal gradient value which is originated from the plate-shaped anomaly object tend to be present at the boundaries or edges of the subsurface object and will be localized directly at the edge of the subsurface object (Alamdar et.al., 2009). The working principle of maximum horizontal gradient is to place change in the density value of the subsurface object suddenly in the lateral direction based on the gravity or pseudogravity anomalies data. This case of maximum horizontal gradient also reflects lateral change suddenly in the direction of magnetization. Then the amplitude of the horizontal gradient is expressed as equation

$$h(x,y) = \left[\left(\frac{\partial g_z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial g_z(x,y)}{\partial y}\right)^2\right] \qquad (10)$$

where ($\partial g/\partial x$) and ($\partial g/\partial y$) are the horizontal derivatives of the pseudogravity field in the x and y direction (Cordell and Grauch, 1987). The contour map of the horizontal gradient analysis result of pseudogravity anomalies data has shown in Figure 7. Thus, the horizontal gradient method can be used to approximate horizontal edges location and estimate minimum and maximum source depths.

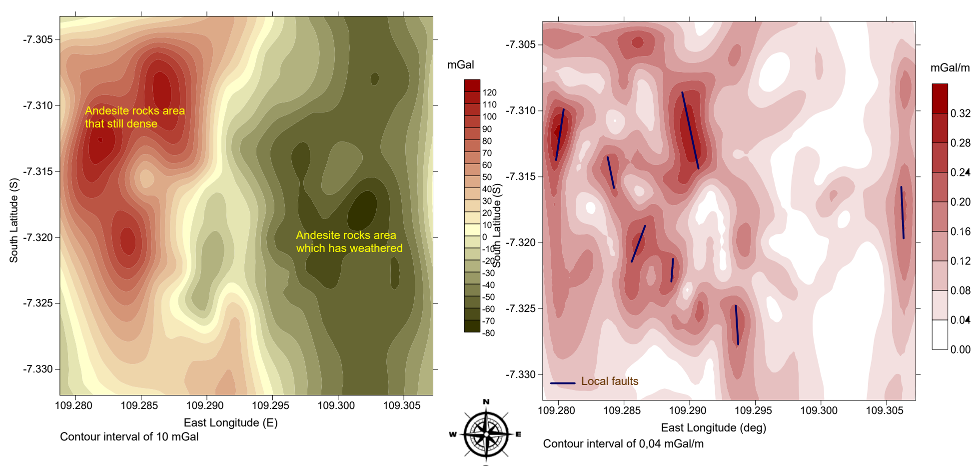

Figure 7. The pseudogravity anomaly contour map of the research area and the it's horizontal gradient map. The spread of high density andesites rocks is indicated by red contour in the pseudogravity contour map, whereas the red closures in the horizontal gradient contour map show the lithological contact boundaries between rocks (likely local faults).

3.4. Discussion

The local magnetic anomalies data are magnetic anomalies data which represents the geological conditions or distribution of subsurface magnetic objects that originating from the local anomalous sources. One of the dominant subsurface anomalous sources in the research area is andesite rock (Djuri et.al., 1996). The local magnetic anomalies data has been obtained through some stages as has been described in the Research Methodology. The obtained data have ranging values of -1,238.13 – 1,892.40 nT. This value interval is relatively very large, i.e. 3,130.53 nT. The very large magnetic anomaly interval value is related to the magnetic susceptibility of the subsurface anomalous sources which can be interpreted as andesites rocks. Generally, andesites rocks have higher magnetic susceptibility value compared to other types of igneous rocks, i.e. about 0.170 SI units (Hunt et.al., 1995). Therefore several closure pairs of magnetic anomalies which appear relatively in the middle to northwest on the local magnetic anomalous contour map can be interpreted as subsurface andesites rocks. This is in accordance with the geological map of the research area (Djuri et.al., 1996) and direct visual observation in the field as shown in Figure 1.

The pseudogravity anomaly and horizontal gradient contours maps reinforce the indications that there are some subsurface anomalous sources which are interpreted to be in the northwest of the research area. The gravity anomaly data including the pseudogravity anomaly data is generally associated with density of subsurface rocks (Omosanya et.al., 2012), where almost overall igneous rocks including andesites have high density (Ekinci and Yiğitbaş, 2015). Therefore, the pseudogravity anomalies data can be associated with the presence of subsurface igneous rocks in this research area. Based on Figure 7, many high pseudogravity anomalous closures dominate in the northwest, whereas low anomalous closures dominate in the middle to east. This is interpreted that the subsurface rocks in the northwest area are dominated by dense igneous rocks, especially massive andesite rocks (according to the geological map). Whereas in the east area, although vesicular andesite rocks outcrops are still found on the surface, but these rocks may have weathered or are being weathered.

The horizontal gradient method was used extensively to locate the boundaries of density contrast from gravity or pseudogravity data. The red closure that stands out on the horizontal gradient map indicates the maximum (steep) gradient, which is usually associated with contact or lithological fracture (Setyawan et.al., 2015), as shown in Figure 7 (right). Local faults that are mostly found on the horizontal gradient contour map are thought to be fracture in the andesite rocks. Based on the geological information, this andesite rocks consist of massive lava rocks with many fractures and vesicular lava rocks (Iswahyudi et.al., 2018). The massive lava is dark gray, with layered structure, has many cracks, sometimes forming a flow structure, and are affanitic with the minerals size contained are very small. However there are several different phases of the lava flow formation to form the different layers, besides the cracks (Iswahyudi et.al., 2018). Local faults in the form of fractures are found in the northwest region of the research area, which indicates that the igneous rock is localized in the area.

4. Conclusion

Magnetic survey with magnetic method for qualitative interpretation of andesite igneous rocks distribution in the subsurface has been done in Kutasari District, Purbalingga Regency, Central Java, Indonesia in April 2019. The research area is the lower southern slope of Slamet Volcano, Central Java. Geologically, the dominant rocks in the research area surface are andesite rocks. The local magnetic anomaly map that represent distribution of subsurface anomalous sources has values ranging of -1,238.13 – 1,892.40 nT. This value interval which relatively very large is associated to the magnetic susceptibility quantity of the subsurface magnetic object which interpreted as andesites igneous rocks. These rocks have dominate in the western to northwest of the research area. This fact is reinforced by pseudogravity anomaly and it′s horizontal gradient maps. The pseudogravity anomaly map represents distribution of subsurface rocks density, where almost all over igneous rocks including andesites have high density. Whereas the horizontal gradient contour map represents the lithological contact boundaries of subsurface rocks. Both of them show that the subsurface anomalous sources distribution interpreted as andesite igneous rocks are in the western of the research area.

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