Estimate the Location of Basaltic Intrusion in Karanglewas Village Jatilawang District Banyumas Regency Central Java Based on The Pseudogravity Anomaly Map

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Abstract

Estimation of the location of the basaltic intrusion in Karanglewas Village, Jatilawang District, Banyumas Regency has been carried out based on the pseudogravity anomaly map. The amount of data measured in the field is 239 data which stretches at 109.107222° – 109.134944° E and 7.561361° – 7.577306° S. After some corrections and reductions, local magnetic anomalies data were obtained with values of -2,961.11 – 1,516.31 nT. Then these data were transformed into pseudogravity anomalies data, with values ranging from -115.938 – 124.286 mGal. The transformation is carried out because the local magnetic anomaly map shows complex anomalies closures, making interpretation difficult. Based on the interpretation results of the pseudogravity anomaly contour map, basaltic rocks intrusion is interpreted to occur at the position of 109.131225° E and 7.569342° S in the form of a dyke structure. At this location point, the pseudogravity anomaly map shows the maximum value, i.e. 124.286 mGal. While to identify the distribution of basaltic intrusion on the surface, horizontal gradient analysis is applied to the pseudogravity anomalies data, so it can be obtained the basaltic rock distribution patterns oriented from west to east in accordance with the geological map of the research area.

Keywords
Basaltic intrusion, pseudogravity anomaly, horizontal gradient, Karanglewas, Jatilawang.

1. Introduction

Karanglewas is a village located in Jatilawang District, Banyumas Regency, Java, Indonesia. Geomorphologically, the research area is divided into two areas, i.e. the Karanglewas Anticline Ridge and the Jatilawang Alluvial Plateau. The stratigraphy of the study area is divided into five lithostratigraphic units, which are sandstones, claystones, tuffs, basalt, and alluvial deposits. The geological structure that develops in the research area is in the form of anticline folds that have a west-east direction and shear faults in a northwest-southeast direction. This shows that the stress that occurs in the research area has a north-south direction due to the subduction of the Indo-Australian Plate under the Java Island (Harsantosa 2013). The Karanglewas village has a large potential for subsurface natural resources, i.e. basaltic rock. Basaltic rock is extrusive igneous rock, that is volcanic rock formed due to freezing magma on the earth's surface with an alkaline composition. Basaltic rocks are generally relatively heavy, dark in color, contain lots of iron minerals, and a little silica mineral content. Basaltic rock is very well used for building materials because of its large density (Anonymous 2020). Figure 1 shows some basaltic rocks outcropped on the surface of Karanglewas Village, Jatilawang District, naturally and as a result of mining.

Figure 1 Basaltic rock outcrops in Karanglewas Village, Jatilawang District, Banyumas Regency, Central Java, Indonesia (personal documentation).

An effort to map the location and distribution of basaltic rocks intrusion in Karanglewas Village and surrounding is needed to formulate regulations governing rock mining because basaltic rock mining has begun to bloom in these areas. This mapping is also useful for localizing the distribution of basaltic rocks still very compact (high density), which can be used as a good building material. One of the geophysical techniques that can be applied for mapping basaltic rocks in an area is a magnetic survey (Adagunodo et.al. 2015). The magnetic survey has high sensitivity to identify and map basaltic rock distribution (Lino et al. 2018) so that basaltic rocks are easily detected, even though they are in the subsurface. This is related to the iron mineral content which tends to be ferromagnetic in the rock's bodies (Cyprian 2016). In processing and interpreting data, magnetic surveying has several advantages. One of the advantages is the presence of magnetic anomalies data filtering technique which are quite varied so that the magnetic anomalous sources in the subsurface that are the research targets can be interpreted easily either in qualitative and quantitative (Ansari and Alamdar 2009).

Based on the geological information as shown in Figure 2, basaltic intrusions were found in the form of dykes and sills in the research area (Asikin et.al. 1992). A dike is a sheet of rock that is formed in the fracture in a pre-existing rock body. Dike can be either magmatic or sedimentary in origin. Magmatic dikes are formed when magma intrudes into a crack then freezes in the form of a sheet intrusion, either cutting across layers of rock or through an unlayered mass of rock. While a sill is a tabular sheet intrusion that has intruded between older layers of sedimentary rock, beds of volcanic lava or tuff, or even along the direction of foliation in metamorphic rock. The basaltic intrusion spread pattern seen on the Geological Map indicates that this rock intrusion has appeared in the form of a dyke in the Karanglewas Village. Furthermore, the intrusions spread westward towards Pekuncen Village and its surroundings in the form of a sill. Therefore, this research purposes to estimate the location of basaltic intrusion in the form of dyke based on the interpretation results of the pseudogravity anomaly map and its distribution patterns based on the result of analysis of its horizontal gradient. One of the expected benefits of the research is to assist the local governments in drafting regulations related to rock mining activities, particularly the provision of research data.

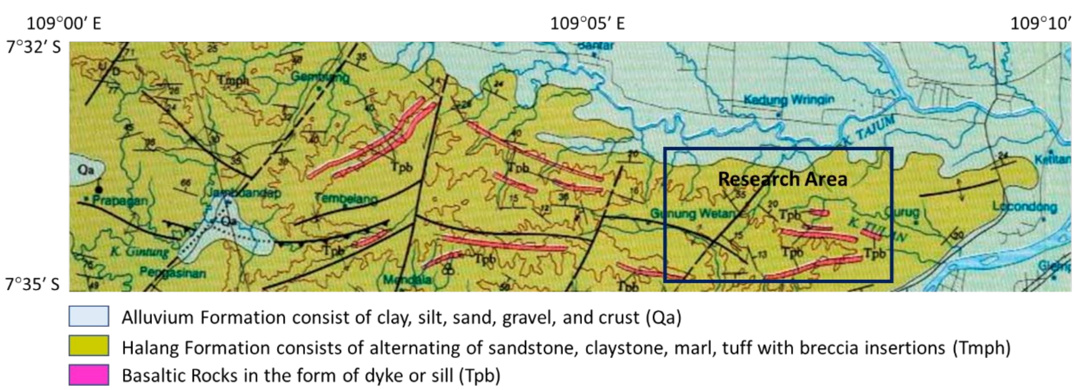

Figure 2 The geological map of the research area (Asikin et.al. 1992).

2. Literature Review

Magnetic anomaly is a magnetic field that comes from the distribution of magnetized subsurface rocks or magnetic minerals. A volume consisting of magnetic materials can be assumed as a magnetic dipole as shown in Figure 3. The magnetization that occurs in these materials depends on the magnetic induction that is received from the earth's main magnetic field (Telford et.al. 1990). The magnetic potential across the volume can be formulated by the equation:

$$V(\vec{r}_0) = -C_m M \frac{\partial}{\partial \alpha} \int \left[\frac{dV}{|\vec{r}_0 - \vec{r}|} \right] \quad (1)$$

M is the magnetic dipole moment per unit volume and C_m is a constant. The total magnetic induction of the rock can be formulated (Telford et.al. 1990):

$$\vec{B}(\vec{r}_0) = C_m \nabla \int_V \vec{M}(\vec{r}) \bullet \nabla \left[\frac{1}{|\vec{r}_0 - \vec{r}|} \right] dV \quad (2)$$

The total magnetic induction as referred to in equation (2) is referred to as a magnetic anomaly that superposes the main magnetic field of the earth (B_0) at all measurement points on the earth's surface. Thus, the actual total magnetic field measured in the apparatus at a given location is a combination of the earth's main magnetic field (B_0) and the magnetic field anomaly (B_{r0}) assuming that the external magnetic field value is negligible so that the equation can be stated:

$$\vec{B}_T = \vec{B}_0 + \vec{B}(\vec{r}_0) \quad (3)$$

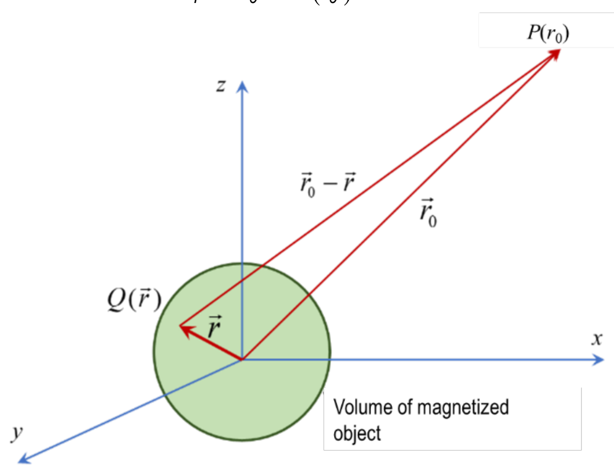

Figure 3 Magnetic anomalies from rocks or anomalous objects in the subsurface (Telford et.al. 1990).

In fact, to obtain the total magnetic anomaly data, it is necessary to make some corrections to the total magnetic field data measured at each location point on the earth's surface which includes daily correction (B_D) to eliminate the influence of the external magnetic fields and IGRF correction to eliminate the influence of the earth's main magnetic field (B_0). If the total magnetic anomaly can be symbolized by ΔB, then (Sehah et.al. 2020):

$$\Delta B = B_T - B_D - B_0 \quad (4)$$

IGRF is an abbreviation for the-International Geomagnetic Reference Field which is the earth's main magnetic field. The IGRF value at each location point is not fixed, but changes according to the geographical position of the latitude and time. However, changes in the IGRF value have been anticipated through updating and setting the IGRF value regularly; i.e. once every five years (Chambodut 2015).

The dipole nature of the magnetic field causes the magnetic anomalous contour map to have many interpretations, so the interpretation process is sometimes difficult, especially for areas that are in low latitude zone such as Indonesia. Therefore, a data processing method is needed to reduce the effect of magnetic field dipoles, thereby facilitating the interpretation of magnetic anomaly data. One method that can be used for this purpose is pseudogravity method (Yolanda et al. 2018). The basic principle of the pseudogravity transformation can be stated in the Poisson relation. Based on equation (5), the Poisson relation shows that the magnetic potential V and the gravitational potential U originating from an object that has the same density and magnetization, which have a relationship (Blakely 1995):

$$V = -\frac{C_m}{\gamma}\frac{M}{\rho}\,\hat{m}\bullet\nabla_P U = -\frac{C_m}{\gamma}\frac{M}{\rho}\,g_m \tag{5}$$

where ρ is the density, M is the intensity of the magnetization, $\hat{m}$ is the unit vector in the direction of magnetization and g_m is the component of the gravitational field in the direction of magnetization. To obtain a Poisson relation, it is assumed that M and ρ are constant (Blakely 1995).

The transformed pseudogravity anomaly map from magnetic anomaly data is relatively clear in showing the location of subsurface sources anomalous targets. However, to clarify the lithological contact boundaries of the anomalous sources in the subsurface, the horizontal gradient analysis can be applied to the pseudogravity anomaly data. The maximum horizontal gradient value will indicate a sudden lateral change in the direction of magnetization. Then the value of the horizontal gradient from the pseudogravity anomaly data can be stated as follows (Blakely 1995):

$$h(x,y) = \left[\left(\frac{\partial g_z(x,y)}{\partial x}\right)^2 + \left(\frac{\partial g_z(x,y)}{\partial y}\right)^2\right] \tag{6}$$

When applied to two-dimensional data interpretation, the horizontal gradient tends to occupy a narrow ridge above a sudden change in magnetization or density, as can be seen in Figure 4. This can be utilized to locate the lithological contact boundary of the source of an anomaly to its environment based on changes in density or magnetization which suddenly changes in a lateral direction.

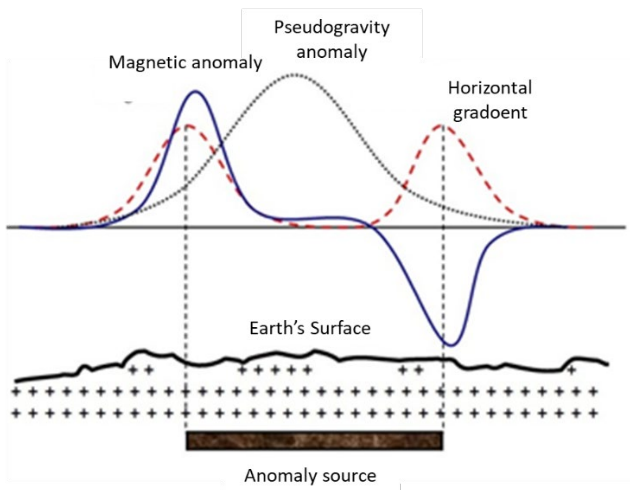

Figure 4 Magnetic anomaly, pseudogravity anomaly, and horizontal gradient curves models over a slab-shaped anomaly source in subsurface (Blakely 1995).

3. Methods

Magnetic data acquisition has been carried out in Karanglewas Village and it′s surrounding, District of Jatilawang, Regency of Banyumas as shown in Figure 5. Magnetic data processing has been carried out at the Geophysical Laboratory, Faculty of Mathematics and Natural Sciences, Jenderal Soedirman University. The equipment used for data acquisition includes Proton Precession Magnetometer (PPM), Global Positioning System (GPS), compass, and several other supporting tools. The equipment used in the laboratory consists of a personal computer be equipped with various software. The data obtained from the acquisition in the field are the total magnetic field data which are distributed over all the location points. To obtain total magnetic anomalies data, some corrections are applied which include daily and IGRF corrections. The data obtained after corrections are total magnetic anomalies data which are distributed on the topographical surface. Therefore, these data are transformed into a horizontal surface using the Taylor Series approximation (Blakely 1995):

$$\Delta B(\lambda,\vartheta,h_0)^{[i+1]} = \Delta B(\lambda,\vartheta,h) - \sum_{n=0}^{\infty}\frac{(h-h_0)^n}{n!}\frac{\partial^n}{\partial z^n}\Delta B(\lambda,\vartheta,h_0)^{[i]} \tag{7}$$

where $\Delta B(\lambda,\vartheta,h)$ is anomalies data which is still distributed on the topographic surface, $\Delta B(\lambda,\vartheta,h_0)$ is anomalies data which has been distributed on a horizontal surface, h is the height of the data elevation, and h_0 is the average height of the topographical surface. After the total magnetic anomalies data are distributed on the horizontal surface, then the regional magnetic anomalies data are reduced from these data to obtain the local magnetic anomalies data, with the equation (Telford *et.al*. 1990):

$$\Delta B_{Lokal} = \Delta B(\lambda, \vartheta, h_0) - \frac{\Delta h}{2\pi} \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} \frac{\Delta B(\lambda, \vartheta, h_0)}{\sqrt{\left((\lambda' - \lambda)^2 + (\vartheta' - \vartheta)^2 + \Delta h^2\right)^{3/2}}} d\lambda\, d\vartheta \tag{8}$$

The rightmost term in equation (8) is an upward continuation process that produces regional anomaly data (Telford *et.al*. 1990). The local anomalies data obtained represents local geological structure or subsurface rock conditions in the research area (Sehah *et.al*. 2020).

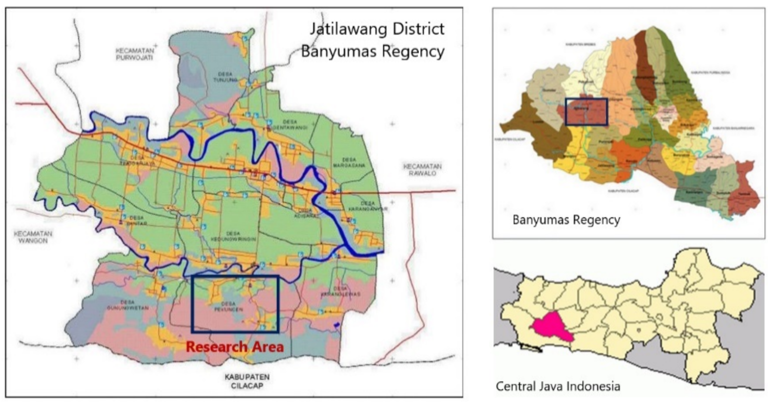

Figure 5 Research location; Karanglewas Village, Jatilawang District, Banyumas Regency and it′s surrounding.

Further, the local magnetic anomalies data are then transformed into pseudogravity anomalies data, as described in the Literature Review section. Pseudogravity anomalous map associated with rock density is used to localize the basaltic rock zone in the research area (Pratt and Shi 2004). While horizontal gradient analysis can be applied to the pseudogravity anomalies data to clarify the location of the lithological contact boundaries of the subsurface rocks to the surrounding environment (Kusumah et.al. 2010). The lithological contact boundaries between several rocks are usually in the form of faults or boundaries between igneous rocks intrusions and surrounding sediment rocks. The equation for the horizontal gradient has been described in the Literature Review. The results can be used to interpret the spread pattern of basaltic rock intrusions in the research area.

4. Data Collection

Data acquisition of total magnetic field strength in the research area is carried out on February 28 – March 6, 2020, at predetermined points with the same distance from one point to another. In the data acquisition, several data recorded include geographical position of the measuring points, measuring time, magnetic field strength, and environmental condition. Data measurement of the magnetic field strength has been carried out together with the geographical position data measurement of the measuring points using the Global Positioning System (GPS). The number of the total magnetic field strength data which have been successfully measured in the fields were 239 data stretching at the positions of 109.107222° – 109.134944° E and 7.561361° – 7.577306° S. The total magnetic field strength valuesobtained from measurements in the fields ranged of 41,804.58 – 46,719.76 nT. While the topography of the research area has an elevation ranging from 29.0 m – 232.0 m, with an average value of 102,69 m. Visually, the contour map of the topography of the research area which is overlaid with the position of the measuring points and the total magnetic field strength contour map can be seen in Figure 6. The total magnetic field strength data which are obtained from measurements in the field are a combination of the earth's main magnetic field, the external magnetic field, and the magnetic field originating from anomalous sources in the earth's crust. In magnetic surveying, magnetic anomalous sources are generally the target of research.

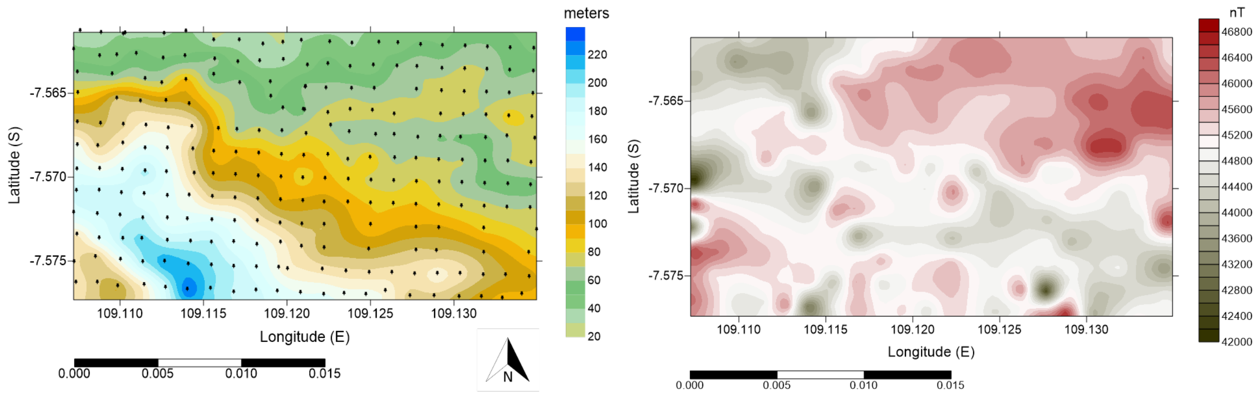

Figure 6 The topography of the research area contour map which overlaid with the position of the measuring points and the total magnetic field strength contour map.

5. Results and Discussion

The total magnetic field strength data are corrected by daily and IGRF corrections as described in the previous. After some corrections were applied, the total magnetic anomalies data were obtained with values ranging from -3,175.12 – 1,773.76 nT. The total magnetic anomalies data are still distributed on the topographic surface, so the data cannot be processed mathematically at the next stage, because the data must be spread on a horizontal surface (Blakely 1995). One method that can be used to reduce the anomalies data from an uneven surface to a horizontal surface is through the Taylor Series approximation, as explained in the previous (Blakely 1995). Based on these data, it is known that the total magnetic anomalies data resulting from reduction to the horizontal surface are relatively more convergent than when the anomalies data are still distributed on the topography surface, with anomaly values ranging from -2.830, 23 – 1,647.24 nT. Visually, the total magnetic anomaly contour map that is still spread on the topographic surface and has been spread on the horizontal surface (average topographic height) can be seen in Figure 7.

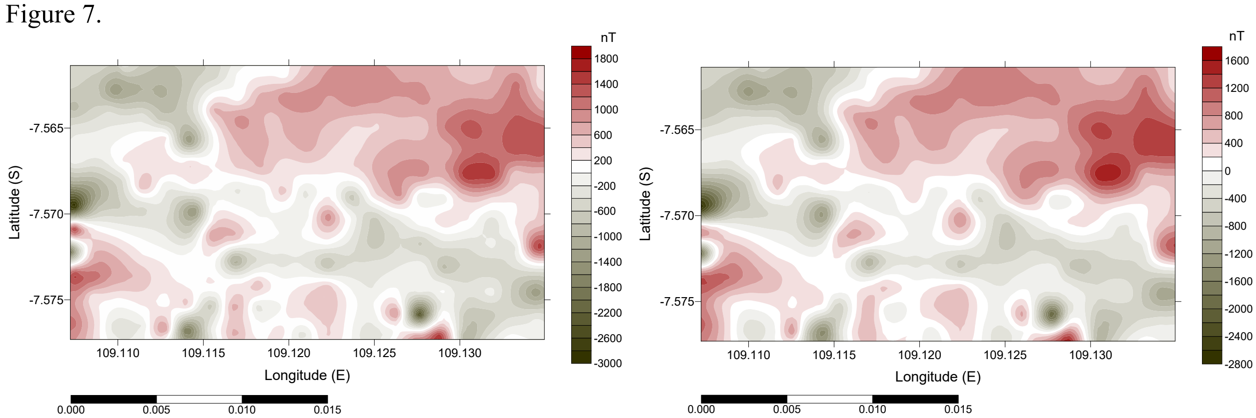

Figure 7 The total magnetic anomalous contour map that still spread on the topographic surface and has been spread on the horizontal surface (average topographic height).

The total magnetic anomaly data which has been distributed in the horizontal surface still superpose to the magnetic anomaly originating from very deep and wide sources, which are called the regional magnetic anomaly. Therefore the regional anomaly data must be reduced because the research target is local anomalous sources, i.e. basaltic rock intrusions. The regional magnetic anomalies can be obtained through an upward continuation of the total magnetic anomalies data which have been distributed on a horizontal surface up to a certain height. Upward continuation of anomalies data has been carried out until the anomaly contour pattern has shown a relatively constant or not change (Ilapadila et.al. 2019). Analysis result of the anomalous contour pattern after upward continuation shows that the magnetic anomaly contour map at a height of 3,500 m has shown a smooth pattern with a very small interval value, so that is stated as a regional magnetic anomaly. Visually, the magnetic anomalous contours patterns resulting from the upward continuation process from a height of 1,000 m to 3,500 m are shown in Figure 8.

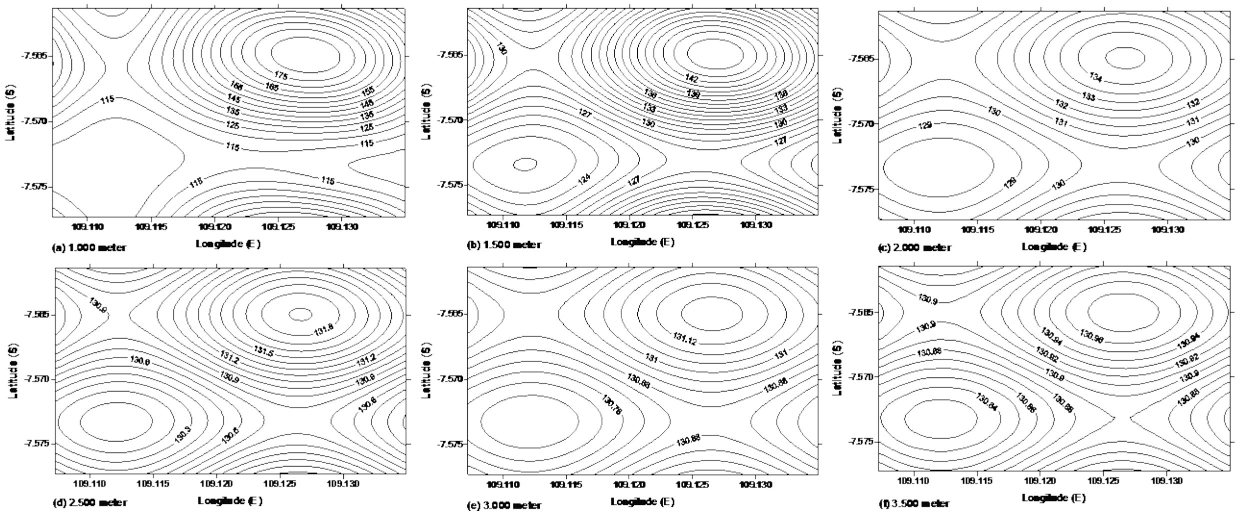

Figure 8 The magnetic anomalous contours maps resulting from upward continuation, where the magnetic anomaly contour map at a height of 3,500 m is stated as a regional anomaly.

Considering that the target of this research is to identify the location of basaltic intrusion and it′s distribution in the research area, then the contribution of the regional magnetic anomalies data must be reduced from the total magnetic anomalies data as described in the previous; because the target is assumed to be part of the local anomalous sources. The technique is the total magnetic anomalies data that have been distributed on the horizontal surface are corrected by the regional magnetic anomalies data. The data generated from this correction is referred to as the local magnetic anomalies data, with the contour map shown in Figure 9. The local magnetic anomalies data are at the same height as the total magnetic anomalies data on the horizontal surface; i.e. the average topographic height (102,69 m). The local magnetic anomalies data have values ranging from -2,961.11 – 1,516.31 nT, with data interval is relatively large. This can be attributed to a large number of basaltic intrusions in the subsurface (Quesnel et.al. 2008). Basaltic rocks have a large mineral composition, such as pyroxene, olivine, magnetite, ilmenite, plagioclase feldspar, and other minerals (The University of Auckland 2005). The presence of magnetite in the basaltic rocks is estimated to have contributed greatly to the high interval of the local magnetic anomaly value.

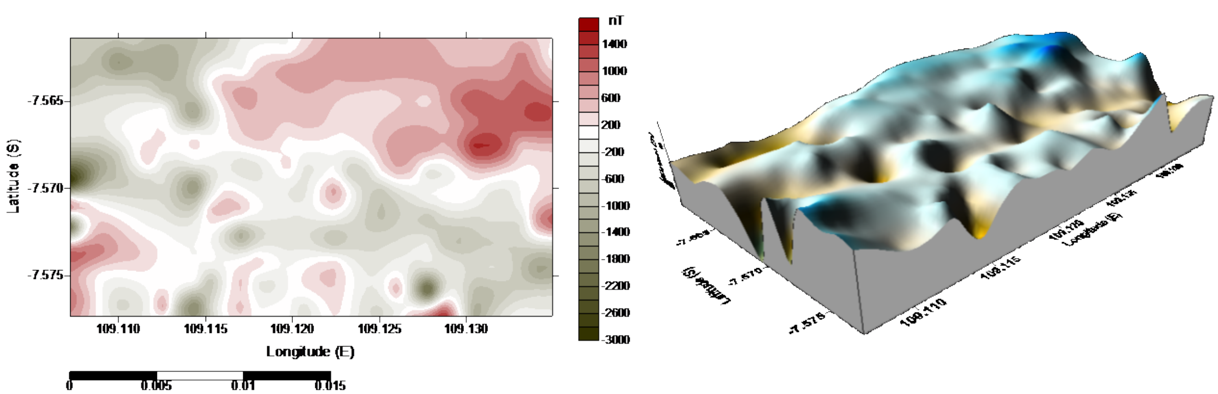

Figure 9 The 2D and 3D local magnetic anomalous contour maps of the research area are estimated to be directly associated with local anomalous sources in the subsurface.

Based on the local magnetic anomaly contour map as shown in Figure 9, the local magnetic anomalous sources tend to be scattered in the eastern of the research area; where the contour pattern shows strong positive and negative anomalous closures pairs. While in the west of this area there are also positive and negative anomalous closures pairs, but the closures are cut off by the boundaries of the research area, so they are not optimal in showing the sources of the subsurface anomalous. Around the magnetic anomalous closures pairs, there are generally anomalous sources in the subsurface. Based on the geological information (**Figure 2**), the rock formations in the research area are dominated by the Halang Formation which is composed of alternating sandstones, claystones, marl, tuff with breccias (Asikin and Handoyo 1992). Therefore, the basaltic rock intrusion in the research area can be considered as a very strong anomaly source in the sedimentary rock area of the Halang formation and will be detected easily in the local magnetic anomaly contour map (Sehah et al. 2020).

The local magnetic anomaly maps such as Figure 9 show complicated closures patterns, so that can complicate the interpretation of anomalies data. Meanwhile, the pseudogravity transformation has the characteristic of reducing shallow magnetic anomaly data and eliminating the polarity effect in magnetic data, thereby reducing the difficulty of the interpretation process. This technique is a qualitative interpretation method for determining subsurface targets (Yolanda et.al. 2018). The magnetic anomalies data that has been transformed into pseudogravity anomalies data show monopole-shaped closures with symmetrical patterns, i.e. a half-wave curve. The anomalous sources in the subsurface are considered to be right below the crest of the wave with the highest amplitude, similar to the gravity anomaly curve (Limbong et.al. 2018). Based on the results of the transformation calculation, the pseudogravity anomaly contour map obtained has values ranging from -115,938 – 124,286 mGal. The pseudogravity anomaly map looks simpler and more informative than the local magnetic anomaly map as shown in Figure 10. Based on this figure, the highest pseudogravity anomaly value is 124.29 mGal, which is located at 109.131225° E and 7.569342° S. This location is estimated to be the center of basaltic intrusion which is very compact in the form of a dyke structure, according to geological information (Asikin and Handoyo 1992). The high anomaly in the east area indicates that the intrusion of compact basaltic rocks is near the surface, whereas the low anomaly in the west area indicates the dominance of sedimentary rocks near the surface with low density.

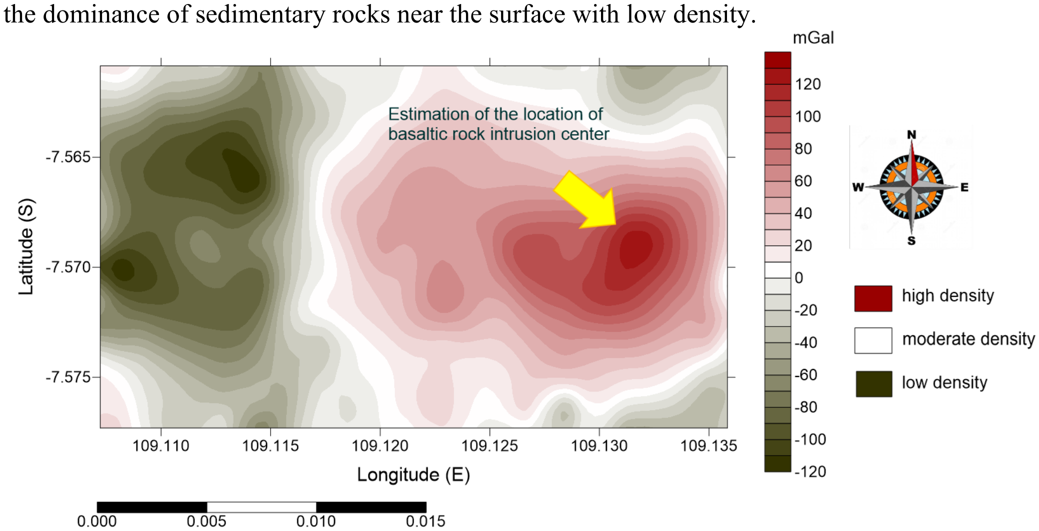

Figure 10 The pseudogravity anomaly contour map of the research area; the maximum value represents the location of basaltic rock intrusion center which is very compact (high density).

Although the pseudogravity anomaly contour map is relatively more informative in showing the subsurface anomaly sources location; but to clarify the lithological contact boundaries, so horizontal gradient calculations can be applied. The maximum horizontal gradient of pseudogravity anomalies data originating from subsurface objects or rocks tends to be at the edge of the object so that the maximum gradient will be localized directly at the edge of the object as shown in Figure 4 (Blakely 1995). This can be applied to identify the contact boundaries of the basaltic lithology to the surrounding rocks by observing the rock density which changes suddenly in a lateral direction (Nurdiyanto et.al. 2004). The horizontal gradient contour is shown in Figure 11 with values ranging from 0.003 – 0.553 mGal per m. These lithological contact boundaries represent the distribution pattern of the basaltic intrusion in the research area. In general, the distribution pattern of basaltic rocks is in accordance with the geological map as has been shown in **Figure 2**, although there are slight differences. This difference is understandable because the horizontal gradient map depicts the distribution pattern of basaltic intrusion on the surface and subsurface (Blakely 1995); meanwhile, the geological map only shows the distribution of basaltic rocks exposed on the surface. In addition to penetrating from below, this basaltic rock intrusion also breaks parallel to the surrounding sediment rock layers. Based on the appearance in the field, these rock units form a sill structure, which is an intrusion of igneous rock that is parallel to the plane of rock layers with an elongated flat shape (Sembiring et.al. 2016) as seen in Figure 12.

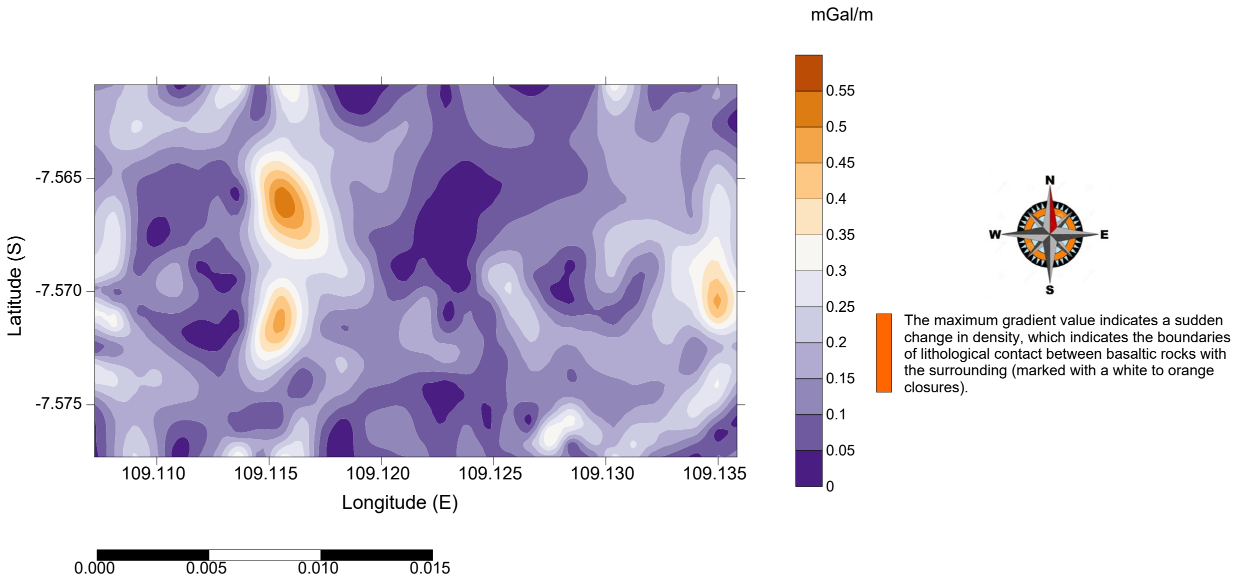

Figure 11 Horizontal gradient contour map showing the suitability of basaltic rock distribution with the geological map of the research area.

Figure 12 Photo of basaltic intrusion outcrop that parallels to the alternating area of sandstone and claystone at the research area.

6. Conclusion

The magnetic survey has been carried out in Karanglewas Village and the surrounding, District of Jatilawang, Regency of Banyumas, Central Java, Indonesia to identify the location of basaltic intrusion and its distribution patterns. The research area stretches on the position of 109.107222° – 109.134944° E and 7.561361° – 7.577306° S with an elevation ranging from 29.0 – 232.0 m. The total magnetic field strength data obtained in the field are in the range of 41.804.58 – 46.719.76 nT. After some corrections and reductions were applied, then the local magnetic anomalies data can be obtained with values ranging from -2,961.11 – 1,516.31 nT. The obtained local magnetic anomaly map still shows complicated closures, so making interpretation difficult. The pseudogravity transformation has been applied to reduce the complexity of the magnetic anomaly contour map and the difficulty of interpretation. The pseudogravity anomaly map acquired looks more informative with values ranging from -115.94 – 124.29 mGal. The highest value of the pseudogravity anomalies data is 124.29 mGal located at the positions of 109.131225° E and 7.569342° S; and interpreted as the location of a very compact basaltic rock intrusion. To clarify the lithological contact boundaries of the basaltic rock intrusion to the surrounding rocks and its distribution pattern, the calculation of the horizontal gradient has been applied to the pseudogravity anomalies data. The horizontal gradient contour map acquired has values ranging from 0.003 – 0.553 mGal/m. The direction of spread of the basaltic intrusion has been shown on the horizontal gradient contour map and is in accordance with the geological map of the research area, which is oriented relatively from the east to the west.

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