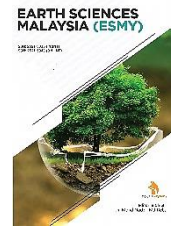


ZIBELINE INTERNATIONAL™
PUBLISHING

ISSN: 2521-5035 (Print)

ISSN: 2521-5043 (Online)

CODEN: ESMACU



RESEARCH ARTICLE

TWO-DIMENSIONAL MODELING OF MAGNETIC ANOMALY DATA REDUCED TO THE POLES IN THE ANDESITIC PROSPECT AREA OF THE SOUTHEAST SLOPE OF SLAMET VOLCANO, INDONESIA

Sehah, Urip Nurwijayanto Prabowo, Sukmaji Anom Raharjo, Rizky Intan Prasetya

Department of Physics, Jenderal Soedirman University, Street of Dr. Suparno No.61 Karangwangkal Purwokerto Central Java, Indonesia.

*Corresponding Author Email: sehah@unsoed.ac.id*This is an open access journal distributed under the Creative Commons Attribution License CC BY 4.0, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited*

ARTICLE DETAILS

Article History:

Received 18 January 2023

Revised 21 February 2023

Accepted 24 March 2023

Available online 28 March 2023

ABSTRACT

Reduction to the pole (RTP) is a magnetic anomaly data processing filter to remove the influence of the magnetic inclination angle. This filter is needed because of the magnetic dipole nature which complicates the interpretation process. The research aims to explore andesite rocks through the application of RTP to the local magnetic anomalies data in Kutasari District, Purbalingga Regency, Indonesia. The research procedures include data acquisition, processing, modeling, and interpretation. The 2D-modeling results on the local magnetic anomalies data have produced three layers of rock. Layer with a susceptibility value of 0.00291 cgs is interpreted as vesicular andesitic rocks, layer with a susceptibility value of 0.02307 cgs is interpreted as massive andesitic rocks, meanwhile layer with a susceptibility value of 0.00721 cgs is interpreted as undifferentiated volcanic rocks. The results showed that the west to northwest part of the study area is the most prospective area containing andesite rocks.

KEYWORDS

reduction to the pole, magnetic anomaly, massive andesite rocks, many fractures.

1. INTRODUCTION

Andesite rocks are often used as foundations for infrastructure buildings such as roads, bridges, irrigation canal, harbors, buildings, and various other buildings. Generally, andesite are used for infrastructure in the form of aggregates and was chosen because it has excellent durability strong to weather (Iqbal and Ratminah, 2018). Central Java is one of the provinces in Indonesia that has abundant andesite natural resource potential. The area in Central Java Province which is indicated to have quite abundant andesite natural resource potential is Purbalingga Regency, with one of its locations is Kutasari District and its surroundings (Ariyanto, 2014). Andesite is a type of igneous rock that comes from the eruption of volcanoes. The rock is formed from magma at temperatures ranging from 900°C – 1.100°C and crystallizes quickly. Andesite is a fine-grained rock and rich in plagioclase, feldspar, and amphibole minerals. Quartz and pyroxene minerals may be absent or present in small quantities, while small amounts of mica will be present as biotite or muscovite. Andesite usually does not contain olivine (Iqbal and Ratminah, 2018).

One of the method in the geophysical survey that can be applied for exploration and mapping of the subsurface structures or rocks including andesite rocks is magnetic survey (Akpa et al., 2023). The magnetic natures of andesite rocks are large, so that by applying magnetic method, it can identify large magnetic anomalous areas, that are thought to be related to the presence of andesite rocks in the subsurface (Lino, et al., 2018; Joshua et al., 2017; Keane and Gilstrap, 2012). Generally, the magnetic survey uses magnetic susceptibility as a tool to identify types of subsurface rocks and geological structures (Oladejo et al., 2019; Syukri et al., 2018). The magnetic susceptibility values are also utilized as a basis parameter for modeling and interpretation of magnetic anomalous sources in the subsurface (Dai, 2014; Li and Fu, 2019). Andesite rocks have

a magnetic susceptibility of 0.0025 – 0.0100 cgs and are thought to contain some ferromagnetic minerals, such as pyroxene and biotite, so they are easy to detect using the magnetic method (Zamora et al., 2015). In many cases this method is often utilized for initial mapping, that will be followed by a more detailed method for exploration.

The application of the reduction to the poles of magnetic anomaly data is commonly carried out. This operation transforms dipole (high and low) of magnetic anomalies data into monopole. The procedure is to change the actual inclination value to the inclination value that is directed vertically (as if done at the Earth's poles). This reduction to the poles technique is carried out to simplify the processes of modeling and interpreting magnetic data. The advantages of this method in magnetic surveying are magnetic anomalies data that have been reduced to the poles can be directly modeled and interpreted. For example, the modeling and interpretation of the subsurface rock structures in the area around an active volcano have been done based on magnetic anomaly data that has been reduced to the poles in Konga Bay, East Flores Indonesia (Laesanpura et al., 2017).

In addition, this technique has been also used to estimate gold mineralization based on the magnetic anomalies data that have been reduced to the poles in Nagari Lubuk Gadang, Solok, West Sumatra, Indonesia (Firmansyah and Budiman, 2019). In this study the use of the reduction to the poles is intended to facilitate the data modeling and interpretation, so that more logical and natural results are obtained, especially the model of subsurface andesitic rock layers. Anyway, the modeling and interpretation results without being reduced to the poles in the previous study have resulted in subsurface rock models that are relatively less logical and natural (Sehah et al., 2021).

Quick Response Code



Access this article online

Website:

www.earthsciencesmalaysia.com

DOI:

[10.26480/esmy.02.2023.75.82](https://doi.org/10.26480/esmy.02.2023.75.82)

2. LITERATURE REVIEW

2.1 Geological Setting

The study area is composed and surrounded by various rock formations such as laharic deposits of Slamet volcano (Qls), andesite lava deposits of Slamet volcano (Qvls), and undifferentiated igneous rocks of Slamet Volcano (Qvs) (Djuri et al., 1996). Laharic deposits of Slamet volcano consists of laharic with igneous rocks boulder of andesite-basaltic with 10 – 50 cm in diameter, that have been produced from the eruption of the Old Slamet Volcano. The laharic deposit outcrops appear to the south of the study area. The andesite lava rock deposits of the Slamet Volcano are in the form of andesites igneous rocks which have cavities, and are spread on the eastern slopes of Slamet Volcano including the study area and it's surroundings. While the undifferentiated igneous rocks of Slamet Volcano consists of several rocks as volcanic breccia, lava, and tuff. The spreading forms plains and hills. Outcrops of this formation are found in the western part of the study area.

Based on the geological map as shown in **Figure 1**, the andesite lava rocks that are the objective of this study have been outcropped on the uppermost stratigraphic in the study area. This rock deposits spread from the upper slope of Slamet Volcano to the study area which is located on the southeast downslope. This andesite lava consist of massive lava rocks with many fractures and vesicular lava rocks. The massive lava is dark gray, with layered structure, has many cracks, sometimes forming a flow structure, and is affanitic with the minerals size contained are very small. However there are some different phases of the lava flow formation to form the different layers, besides the cracks. While the vesicular lava rocks is dark gray colour with structure forming many holes or regularly have small cavities. The existence of cavities or holes in the rocks is thought to be caused by the release of volcanic gases from lava after reaching the surface. As magma rises to the surface, the pressure on it decreases. When this happens, the gases which dissolved in the magma are able to come out of solution, forming gas bubbles in the form of cavities. When the magma finally reaches the surface as lava and cools into rock, the rock solidifies around the gas bubbles and traps them inside, and preserving them as gas-filled holes (Iswahyudi et al., 2018).

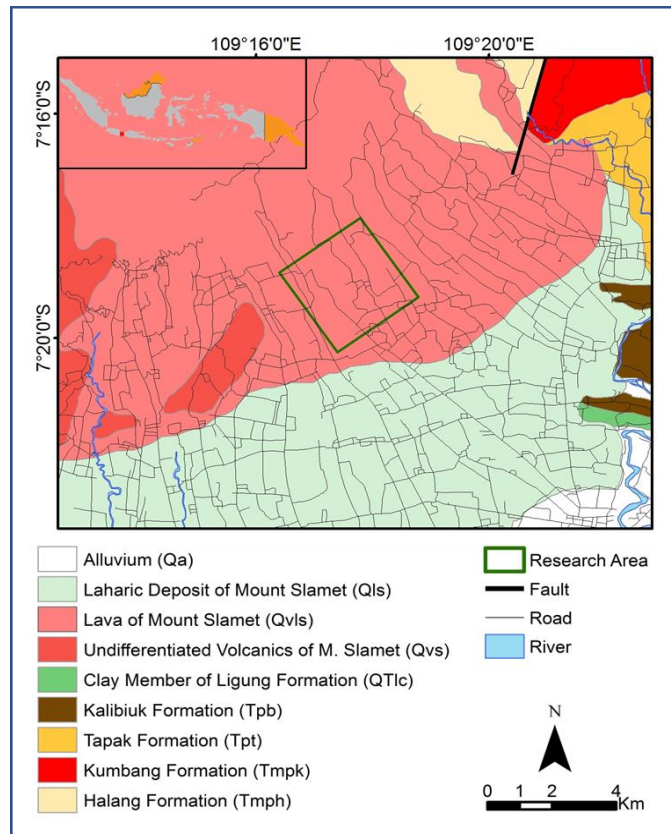


Figure 1: The geological map of the study area (Djuri et al., 1996).

2.2 Magnetic Method

A volume of object in the subsurface consisting of magnetic materials or minerals can be considered as a magnetic dipole as shown in **Figure 2**. The magnetization which occurs in the object depends on it's track record as long as it is in the Earth's main magnetic field, or in other words depends on the amount of magnetic induction 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):

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

By integrating the equation (1) and changing the variables slightly, then the magnetic potential for all object (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 M in equation (2) is a dipole moment per unit volume, while C_m is a constant. If M has a fixed value and direction, the magnetic induction of all rock volume can be calculated through an integration process which can

be expressed by the equation (Telford et al., 1990):

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

The magnetic induction field such as equation (3) is referred to as magnetic anomaly, where this value is superposed by the Earth's main magnetic field value (B_0) at all points on the Earth's surface. Thus, the total magnetic field value recorded by the magnetometer at a point on the Earth's surface is combination of the main magnetic field (B_0) and magnetic anomaly (B_{r0}) values, with assuming that the external magnetic field is ignored. Therefore, it can be expressed with simple equations:

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

In fact, to obtain magnetic anomaly values, it is necessary several corrections to the total magnetic field data which have measured at each point on the surface, which includes daily correction (B_D), and Earth's main magnetic field correction (B_0). Thus, the magnetic data correction can be written by (Sehah et al., 2021):

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

The Earth's main magnetic field value is stated in the-International Geomagnetic Reference Field (IGRF). IGRF is type of the mathematical model that expresses the geomagnetic field and its long-term changes in global distribution based on the Gaussian theory of the geomagnetism (Beggan, 2022).

2.3 Reduction to the Poles

In general, magnetic anomaly contour map shows complex dipole patterns, so that the processes of modeling and interpretation are very difficult. In addition, magnetic anomaly data obtained in the field often shows an asymmetrical pattern. One method to reduce the complexity in modeling and interpreting magnetic anomaly data is to apply Reduction to The Pole (RTP). Magnetic anomaly data which has been reduced to the poles tends to show monopole with a symmetrical pattern. Thus the subsurface anomalous object which is the target of study can be estimated precisely below the center of closure with the highest anomalous value, similar to

gravity anomaly closures (Ansari and Alamdar, 2009).

The RTP is needed to eliminate the influence of the inclination angle of the Earth's magnetic field, because the inclination vector of the induction magnetic field and the external magnetic field produces a dipole pattern on the magnetic data. Magnetic anomalies that have been reduced to the poles can have high or low values, according to the magnetic material distribution burried in the Earth's subsurface (Hiskiawan, 2016). Magnetic anomalies which are reduced to the poles provide information about the existence of the subsurface anomalous objects as shown in **Figure 3** (Ravat, 2007). The RTP function is affected by the value of the inclination and declination angles based on equation (Blakely, 1995):

$$A_{pole}(s, \theta) = \frac{1}{(j \cos I \sin(\delta + \theta) - \gamma)(j \cos I_0 \sin(\delta_0 + \theta) - \gamma_0)} \quad (6)$$

δ_0 is the angle of declination and I_0 is the angle of inclination of the magnetization vector; while δ is the angle of declination and I is the angle of inclination of the Earth's magnetic field vector.

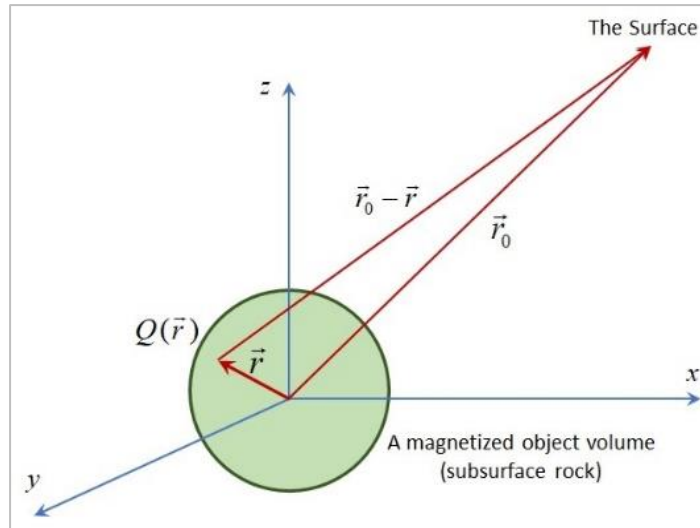


Figure 2: Description of magnetic anomaly from magnetized objects or subsurface rock volume (Telford et al., 1990).

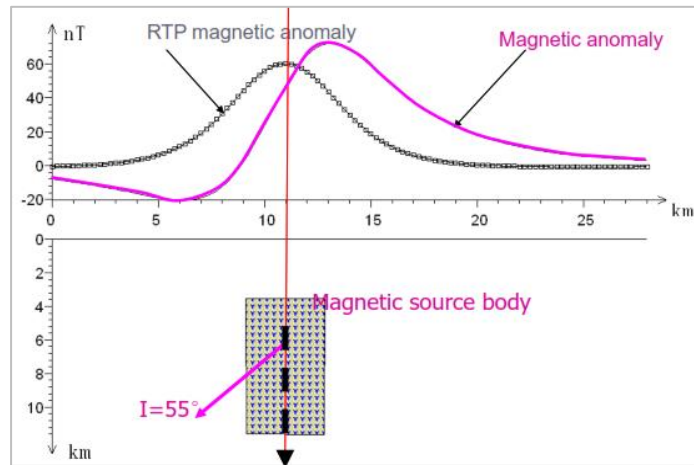


Figure 3: Illustration of the reduction process to the poles of magnetic anomaly data

3. RESEARCH METHOD

3.1 Location and Research Equipment

The magnetic data acquisition was carried out in Candiwulan and Karangcegak Villages, District of Kutasari, Purbalingga Regency, Central Java, Indonesia. Whereas the magnetic data processing and modeling was carried out at the Geophysics Laboratory, Faculty of Mathematic and Natural Sciences, University of Jenderal Soedirman. The equipments used in the data acquisition consisted of a Proton Precession Magnetometer, a Global Positioning System, a Google Earth application, compass, worksheet and several other supporting softwares and equipments.

3.2 Research Procedure

The data obtained from the acquisition in the field is the total magnetic field strength data which are distributed on the location points. In order to

get total magnetic anomalies data, then the data are corrected, including daily and IGRF corrections. The IGRF value refers to the value of the Earth's main magnetic field strength. After applying the corrections, the total magnetic anomalies data are obtained. The total magnetic anomalies data are distributed on the topographic surface, so they are function of longitude (x), latitude (y), and altitude (h). Therefore the magnetic anomalies data must be reduced to horizontal surface; in this study using the Taylor series approximation, which can be written as equation (Blakely, 1995):

$$\Delta H(x, y, h_0)^{[l+1]} = \Delta H(x, y, h) - \sum_{n=0}^{\infty} \frac{(h - h_0)^n}{n!} \frac{\partial^n}{\partial z^n} \Delta H(x, y, h_0)^{[l]} \quad (7)$$

where $\Delta H(x,y,h)$ is anomalies data which are still distributed on the topographic surface, $\Delta H(x,y,h_0)$ is anomalies data that have been distributed on a horizontal surface, h is the elevation of each data, and h_0

is the average topography elevation.

After the magnetic anomalies data are distributed on a horizontal surface, the magnetic anomalies data are corrected by the regional magnetic data to obtain the local magnetic anomalies data with the equation:

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

$\Delta H(x', y', h_0 + \Delta h)$ are regional anomalies data. The regional magnetic anomalies data can be obtained through an upward continuation process using the equation (Blakely, 1995):

$$\Delta H(x', y', h_0 + \Delta h) = \frac{\Delta h}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{\Delta B(x, y, h_0)}{\sqrt{((x'-x)^2 + (y'-y)^2 + \Delta h^2)^{3/2}}} dx dy \quad (9)$$

In Equation (8), the first term on the right side represents the total magnetic anomalies data on a horizontal surface (h_0), whereas the second term represents the regional magnetic anomalies data resulting from upward continuation at elevation of Δh . Further, the local magnetic anomalies data obtained represent local geological conditions or subsurface rocks (Sehah et al., 2020).

4. RESULTS AND DISCUSSION

4.1 Results of Processing Data

The magnetic field data obtained in the field is the total magnetic field strength data distributed over the topographical surface of the study area. After daily and IGRF corrections were applied, the total magnetic anomalies data are obtained with values ranging from -618.8 – 1572.4 nT. As explained in Research Method, the anomalies data are reduced to a horizontal surface using the Taylor series. The surface chosen is the average elevation of the study area topography (i.e. 436.68 m), so that the iteration process in equation (7) quickly reaches convergence (Blakely, 1995). The total magnetic anomalies data which have been distributed on a horizontal surface, are then separated from the regional anomalies data

(Guo et al., 2013).

The separation is done using the upward continuation technique as shown in Equation (9). The upward continuation result that shows a regional anomaly pattern is obtained at an altitude of 5000 m above the reference spheroid. The resulting contour map pattern tends to be fixed and smooth with very small value intervals (Sehah et al., 2021). Further, the regional anomalies data are corrected using Equation (8), so that the local magnetic anomalies data are obtained with values of -589,8 – 1209,9 nT. Visually, the local magnetic anomaly contour map is shown in **Figure 4**.

4.2 Results of Reduction to the Poles

The local magnetic anomalous contour map has a relatively complicated closure pattern. It makes the modeling process difficult, since the position of subsurface anomalous objects is difficult to predict (Rajagopalan, 2003). One solution is to apply reduction to the poles. The reduction to the poles is carried out to change the direction of the magnetization of the Earth's main magnetic field that was originally influenced by the declination and inclination angles to be directed vertically like at the poles. Therefore, this process is carried out by changing the inclination of -31.3201° and declination of 0.717985° to 90° and 0° as written in Equation (6). The reduction to the poles filter changes the magnetic field asymmetry pattern to a symmetrical pattern.

This symmetry pattern can be used as an indication of the presence of bodies or anomaly sources, such as gravity field anomaly data. Hence, the position of the anomaly sources can be estimated to be right under the curve peak or the anomaly closures center. Further, the local magnetic anomalies data that have been reduced to the poles have values ranging from -1084.1 – 2038.2 nT. This shows that the magnetic anomaly has increased in value after reduction to the poles (Keating and Zerbo, 1996). High anomaly values are interpreted to originate from andesite rocks intrusion in the subsurface. The existence of these andesite rocks is exposed a lot on the surface. The local magnetic anomaly contour map which has been reduced to the poles, visually can be shown in **Figure 5**.

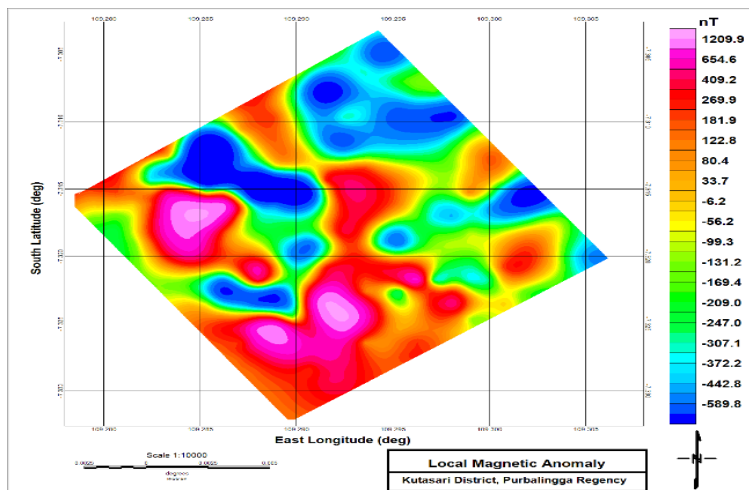


Figure 4: The local magnetic anomaly contour map of study area; Paningkaban, Gumelar, Banyumas.

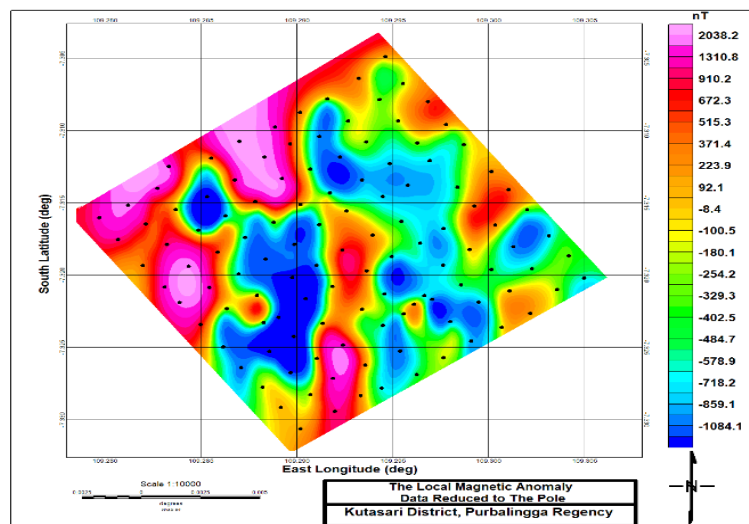


Figure 5: The local magnetic anomaly map which has been reduced to the poles.

4.3 Results of Modeling dan Interpretation

2D-modeling has been carried out by making line sections or trajectories in the certain areas on the local anomaly contour map that has been reduced to the poles. The determination of the trajectories must be in accordance with the target of the study, especially the andesite rock complexes. Further, a number of the local magnetic anomalies data that have been reduced to the poles are extracted along the trajectories. These anomalies data are utilized as input for modeling of subsurface rocks (Quesnel et al., 2008). The positions of the three trajectories on the local magnetic anomaly map that have been reduced to the poles are shown in **Figure 6**. The modeling results for subsurface rocks on trajectories of AA', BB', and CC' can be seen in **Figure 7**, **Figure 8**, and **Figure 9**.

While the results of the interpretation of the modeling results are shown in **Table 1**, **Table 2**, and **Table 3**. Based on the geological map (as **Figure 1**), the research area is not traversed by structures in the form of faults and folds, thus the patterns of andesitic lava spread on the three trajectories are not much different (Djuri et al., 1996). The modeling results show that massive andesite rocks have the potential to be found in the west to the northwest of the research area. This can be seen in **Figure 7** that shows that the thickness of massive andesite rocks is greater than vesicular andesite rocks. It is in accordance with the appearance of the local magnetic anomaly pattern that has been reduced to the poles, where in the area is interpreted to be dominated by high magnetic anomaly.

Based on the information of the geological map, the study area which is located in the southeast of the slopes of Slamet Volcano has andesitic lava lithology from the formation of Slamet Volcano Lava (Djuri et al., 1996). The lava is estimated to be the results of the eruption of the young Slamet Volcano (Iswahyudi et al., 2018). The andesite lava rocks consist of vesicular andesite lava rocks with many cavities, and massive lava rocks with many fractures. The local magnetic anomalies data that have been reduced to the poles with high values are interpreted to originate from massive andesite lava rocks which are located relatively near to the surface. These magnetic anomalies are spread over the study area; mostly in the west to the northwest, some in the south, and a small part in the center and east.

Based on the 2D-modeling results as can be seen in **Figure 7**, **Figure 8**, and **Figure 9**, the massive andesite lava rock has a magnetic susceptibility value of 0.02307 in cgs units. The rock is located in the second layer, under the vesicular andesite lava deposit. Further, the results of the lithology interpretation of the modeling results are shown in **Table 1**, **Table 2**, and **Table 3**. The modeling and interpretation results show the potential for massive andesite rocks which have prospects for mining is located in the west to the northwest of the study area. In this area, the massive boulder of andesite rocks are often found on the surface. The outcrops of the massive andesite rocks with some fractures that have partially weathered are shown in **Figure 10** (left).

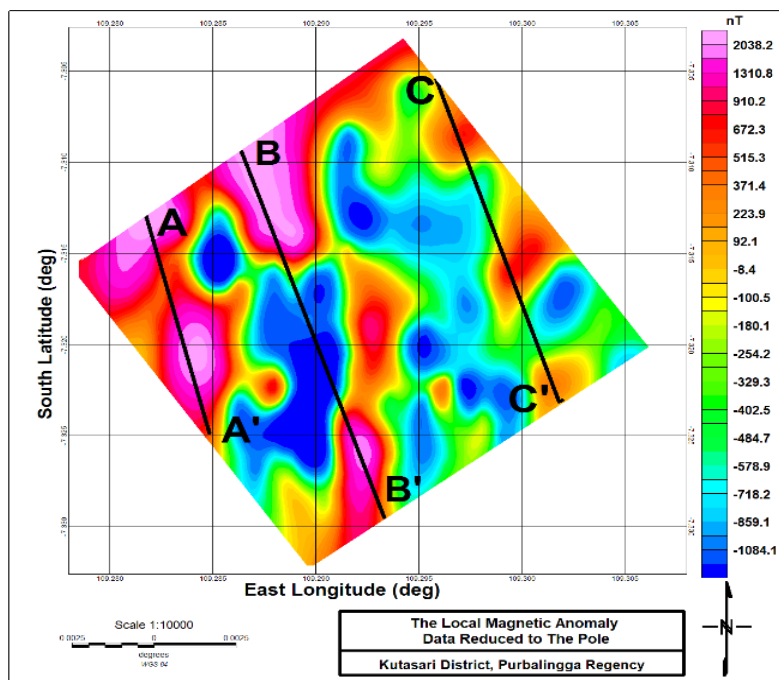


Figure 6: The local magnetic anomaly map which has been reduced to the poles.

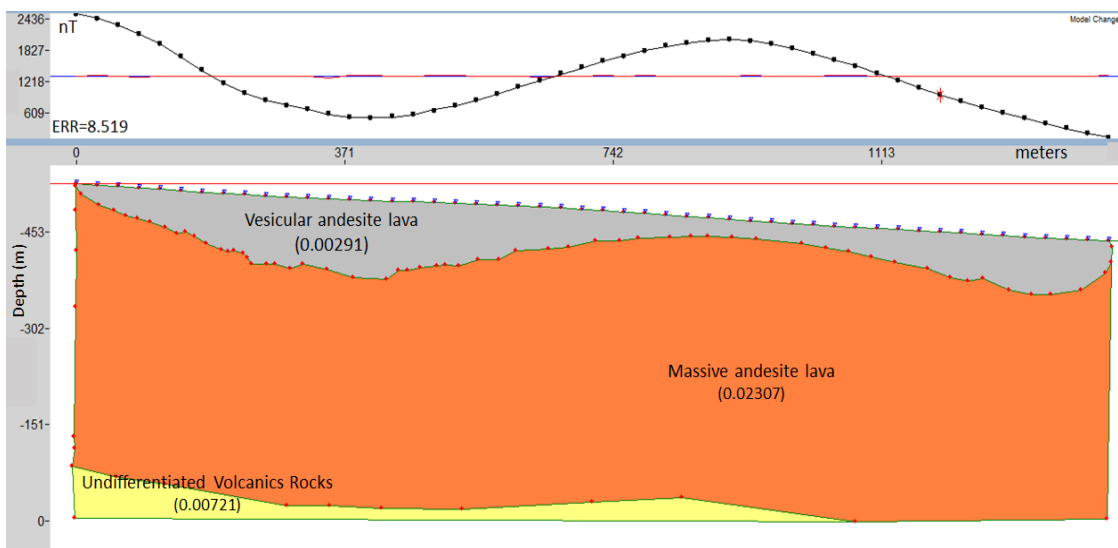


Figure 7: The results of 2D-modeling of subsurface anomalous sources based on the local magnetic anomalies data that have been reduced to the poles along the AA' trajectory.

Table 1: The results of lithology interpretation of subsurface anomalous bodies on the AA' trajectory

No	Legend	Depth Estimation (m)	Magnetic Susceptibility	Lithological Interpretation
1		0 – 174 m	0.00291	Vesicular andesite lava of Slamet volcano which has many small cavities
2		0 – 528 m	0.02307	Massive andesite lava of Slamet volcano which has many cracks and fractures
3		443 – 528 m	0.00721	Undifferentiated volcanics rocks; volcanic breccia, lava, and tuff

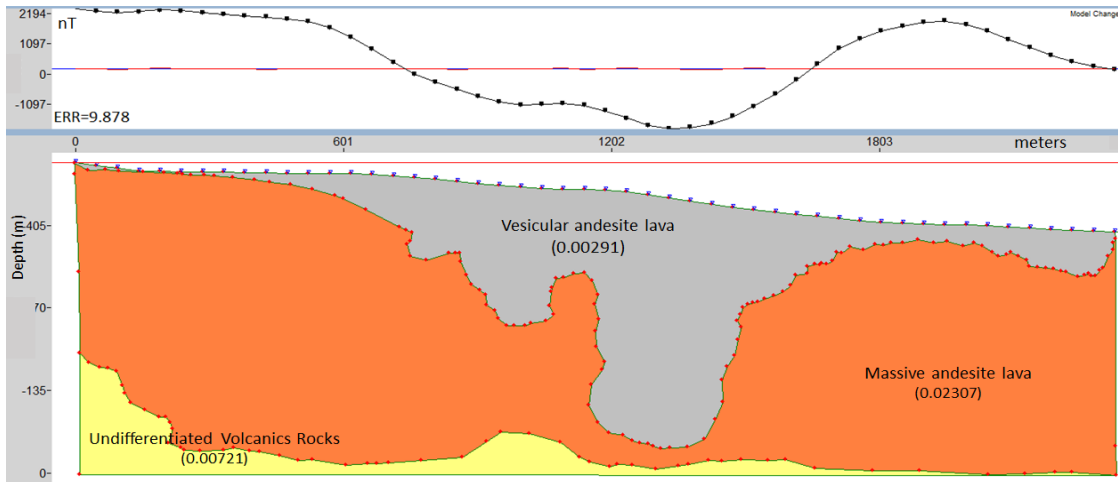


Figure 8: The results of 2D-modeling of subsurface anomalous sources based on the local magnetic anomalies data that have been reduced to the poles along the AA' trajectory.

Table 2: The results of lithology interpretation of subsurface anomalous bodies on the BB' trajectory

No	Legend	Depth Estimation (m)	Magnetic Susceptibility	Lithological Interpretation
1		0 – 468 m	0.00291	Vesicular andesite lava of Slamet volcano which has many small cavities
2		0 – 508 m	0.02307	Massive andesite lava of Slamet volcano which has many cracks and fractures
3		311 – 508 m	0.00721	Undifferentiated volcanics rocks; volcanic breccia, lava, and tuff

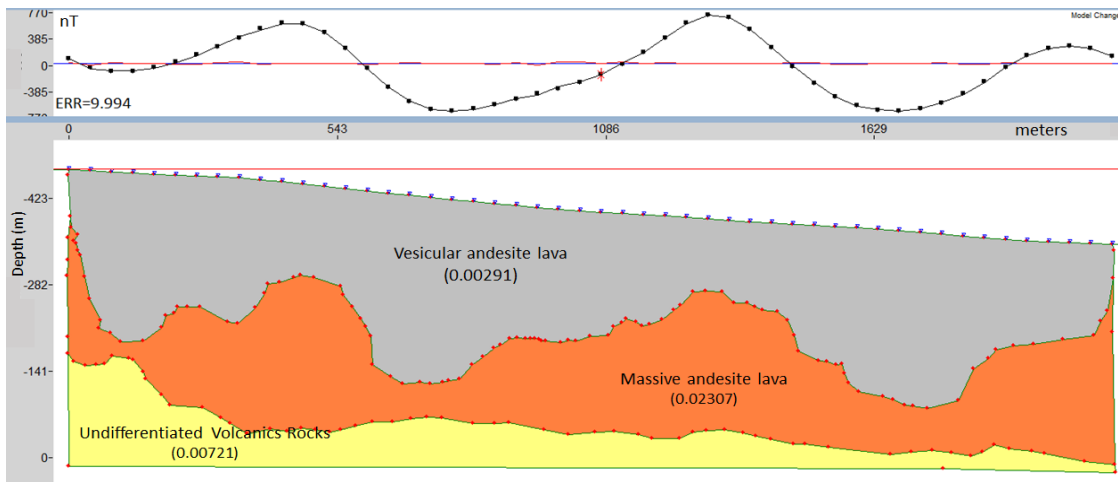


Figure 9: The results of 2D-modeling of subsurface anomalous sources based on the local magnetic anomalies data that have been reduced to the poles along the BB' trajectory.

Table 3: The results of lithology interpretation of subsurface anomalous bodies on the CC' trajectory

No	Legend	Depth Estimation (m)	Magnetic Susceptibility	Lithological Interpretation
1		0 – 416 m	0.00291	Vesicular andesite lava of Slamet volcano which has many small cavities
2		113 – 501 m	0.02307	Massive andesite lava of Slamet volcano which has many cracks and fractures
3		326 – 509 m	0.00721	Undifferentiated volcanics rocks; volcanic breccia, lava, and tuff

The results of modeling on the three trajectories show that the upper rocks of the study area are dominated by vesicular andesite lava rocks with a magnetic susceptibility value of 0.00291 in cgs units. These lava rocks are andesite lava that have many cavities (Djuri et al., 1996). These rocks are dark gray with structure which forms many small regular cavities. The existence of the cavities is related to volcanic gases released from molten lava after reaching the surface. When the lava flows out towards the surface, the temperature and pressure of the volcano liquid lava decreases drastically, which causes the gases contained in the lava to come out. After the lava cools quickly on the surface, the gases that have come out leave marks or traces in the form of small cavities in the rocks as shown in **Figure 10** (right) (Iswahyudi et al., 2018). Several of the vesicular andesite rocks located in the upper of the study area have experienced slow weathering and erosion. The resulting material then settles somewhere into sandstone and other small grained rocks that are mining commodities in the area.



Figure 10: Outcrops of massive andesitic lava rocks with many fractures and vesicular lava rocks with many cavities.

This study has advantages compared to previous study (Sehah et al., 2021). The advantage of this study is that the modeling is carried out on three trajectories, so the interpretation results obtained represent the geological conditions and spread of subsurface rocks in the study area more broadly. The modeling in previous study was only carried out on one trajectory. In addition, the use of the reduction to the poles filter greatly facilitates the modeling process, so the interpretation results are more logical, natural, and closer to the geological information of research area. While the weakness of this study is the exploration method of andesite rocks which is applied only magnetic method, so that other geophysical methods are needed as a comparison. However, the magnetic method (as with other geophysical methods) only measures physical quantities on the Earth's surface, so that comparisons with other methods are very needed to increase the validity of study results. Hence, the next recommended study is exploration using gravity and 2D-resistivity methods.

5. CONCLUSION

Two-dimensional modeling of the local magnetic anomalies data that have been reduced to the poles has been carried out in the andesite prospect area of the southeast slope of Slamet Volcano, District of Kutasari, Purbalingga Regency, Central Java, Indonesia with the following results:

1. The local magnetic anomalies data of the study area which have been reduced to the poles have values ranging from -1084.1 – 2038.2 nT, with a relatively simple and symmetrical patterns.
2. The local magnetic anomaly map that has been reduced to the poles shows the distribution of high values in the west to northwest and a small part in the south, east and northeast of the study area. The high magnetic anomalies distribution indicates the existence of the anomaly sources which are interpreted as massive andesite rocks in the subsurface.
3. 2D-modeling of the local magnetic anomalies data that have been reduced to the poles in the AA', BB', and CC' trajectories has resulted in three subsurface rock layers, covering vesicular andesite rocks (0.00291 cgs), massive andesite rocks (0.02307 cgs), undifferentiated volcanic rocks (0.00721 cgs).
4. The results of the 2D-modeling for all of these trajectories show that the west to the northwest part of the study area is the area with the most prospects for having andesite rock resources, especially massive andesite rocks, so it has the potential to be mined.

The results of interpretation indicate that andesite rocks are spread in the study area evenly. This can be observed on the local magnetic anomaly map that has been reduced to the poles; where the pink anomalous closures (high anomaly) indicate the presence of massive andesite rocks, whereas the blue anomalous closures (low anomaly) indicate the presence of vesicular andesite rocks. Both the rock types appear on the surface of the study area in the form of outcrops in several locations, as can be seen in **Figure 10**. Actually, the locations are the location of the andesite rock mining activities, mainly in the outcrop area of the massive andesite rocks. The massive andesite rocks are affanitic, dark gray, have a layered structure, many cracks, and sometimes forming a flow structure with very small mineral sizes. Administratively, the areas of andesite mining activities are often found in Candiwulan and Karangcegak Villages, District of Kutasari, Purbalingga Regency, Central Java, Indonesia. The results of the interpretation are in accordance with the geological information of the study area (Djuri et al., 1996).

ACKNOWLEDGMENT

The authors would like to thank the Rector and Chairman of Research and Community Service Institute of Jenderal Soedirman University for the research funding provided. We also would like to express gratitude to the research teams, especially students in magnetic data acquisition in the field and collaboration in the research.

REFERENCES

- Akpa, C., Nnabo, P.N., Ani, C.C., Obasi, I.A., Obasi, P.N., Nworie, D.C., 2023. Application of Ground Magnetic Method for Delineation Subsurface Structural Control on Sulphide Ore Deposit in Benue Trough; A Case Study of Ikenyi Izzi. *Earth Sciences Malaysia*, 7 (1), Pp. 7-19.
- Ansari, A.H., and Alamdar, K., 2009. Reduction to the Pole of Magnetic Anomalies Using Analytic Signal. *World Applied Sciences Journal*, 7 (4), Pp. 405 – 409.
- Ariyanto, 2014. Determination of Licensing Zones of Andesite, Sand and Stone (Sirtu), and Tras Minings in Purbalingga Regency, Central Java. Thesis. Faculty of Technique, Science, dan Mathematic. National Development University (UPN) "Veteran", Yogyakarta.
- Beggan, C.D., 2022. Evidence-based Uncertainty Estimates for the International Geomagnetic Reference Field. *Earth, Planets and Space*, 74, Pp. 17.
- Blakely R.J., 1995. *Potential Theory in Gravity and Magnetic Applications*. Cambridge University Press. USA. Pp. 464.
- Dai, B.N., Dong, X.C., Xiang, K., Trong, L.T., Akhter, Q.J., Lei, L.S., 2014. Magnetic Method Surveying and Its Application for the Concealed Ore-Bodies Prospecting of Laba Porphyry Molybdenum Ore Field in Shangri-La, Northwestern Yunnan Province, China. *Journal of Geoscience and Environment Protection*, 2 (1), Pp. 46-53.
- Djuri, M., Samodra, H., Gafner, S., 1996. *Geological Map of The Purwokerto and Tegal Quadrangles, Java, Scale 1:100,000*. Geological Research and Development Center. Bandung. Indonesia.
- Firmansyah, F., and Budiman, A., 2019. Estimation of Gold Mineralization Using the Magnetic Method in Nagari Lubuk Gadang, Sangir District, South Solok, West Sumatra. *Jurnal Fisika Unand*, 8 (1), Pp. 77 – 83.

- Guo, L., Meng, X., Chen, Z., Li, S., and Zheng, Y., 2013. Preferential Filtering for Gravity Anomaly Separation. *Computers and Geosciences*, 51, Pp. 247-254.
- Hiskiawan, P., 2016. Effect of Upward Continuation Contour Patterns on Geomagnetic Data of Interpretation of Reduction to the Poles. *Saintifika*, 18 (1), Pp. 18 – 26.
- Iqbal, M.F., and Wawong, D.R., 2018. Balance Sheet and Potential of Andesite Rock Resources in Singkawang City, West Kalimantan Province. *Proceedings of the National Seminar on Engineering Technology and Information XIII*, Pp. 108-116.
- Iswahyudi, S., Jati, I.P., and Setijadi, R., 2018. Preliminary Study of the Geology of Tirta Marta Lake, Purbalingga, Central Java. *Jurnal Ilmiah Dinamika Rekayasa*, 14 (2), Pp. 86-91.
- Joshua, E.O., Layade, G.O., Akinboboye, V.B., and Adeyemi, S.A., 2017. Magnetic Mineral Exploration Using Ground Magnetic Survey Data of Tajimi Area, Lokoja. *Global Journal of Pure and Applied Sciences*, 23 (1), Pp. 301-310.
- Keane J., and Gilstrap, T., 2012. Delineation of Mafic Intrusions near Bedford (Virginia, USA) Using Geological and Geophysical Methods. *Environ Earth Sci*, 66, Pp. 1393–1402.
- Keating, P., and Zerbo, L., 1996. An Improved Technique for Reduction to The Pole at Low Latitudes. *Geophysics*, 61 (01), Pp. 131 – 137.
- Laesanpura, A., Dahrin, D., Nurseptian, I., 2017. Preliminary Study on Ground-Magnetic Data Near the Active Volcanoes in Konga Bay, East Flores Indonesia. *Southeast Asian Conference on Geophysics. IOP Conf. Series: Earth and Environmental Science*, 62, Pp. 012037.
- Li, Z., and Fu, G., 2018. Application of Magnetic Susceptibility Parameters in Research of Igneous Rock in Chepaizi. *IOP Conf. Series: Journal of Physics: Conf. Series*, 1176, Pp. 042068.
- Lino, L.M., Cavallaro, F.D.A., Vlach, S.R.D.F., and Coelho, D.C., 2018. 2D-Magnetometric Modeling of a Basic – Intermediate Intrusion Geometry: Geophysical and Geological Approaches Applied to the Limeira Intrusion, Paraná Magmatic Province (SP, Brazil). *Brazilian Journal of Geology*, 48 (2), Pp. 305-15.
- Oladejo, O.P., Adagunodo, T.A., Sunmonu, L.A., Adabanija, L.A., Olasunkanmi, N.K., Omeje, M., Babarimisa, L.O., and Bility, H., 2019. Structural Analysis of Subsurface Stability Using Aeromagnetic Data: A Case of Ibadan, Southwestern Nigeria. *3rd International Conference on Science and Sustainable Development (ICSSD 2019). IOP Conf. Series: Journal of Physics Conf. Series*, 1299, Pp. 012083.
- Quesnel, Y., Langlais, B., Sotin, C., Galdeano, A., 2008. Modelling and Inversion of Local Magnetic Anomalies. *Journal of Geophysical Engineering*, 5, Pp. 387–400.
- Rajagopalan, S., 2003. Analytic Signal versus Reduction to Pole: Solutions for Low Magnetic Latitudes. *Exploration Geophysics*, 34 (4), Pp. 257-262.
- Ravat, D., 2007. Reduction to The Pole. In book: *Encyclopedia of Solid Earth Geophysics*, D. Gubbins and E. Herrero-Bervera (editors). Springer, Pp. 856 – 857.
- Sehah, R.S.A., Prabowo, U.N., Sutanto, D.S., 2021. Interpretation of Magnetic Anomaly Data in the Andesitic Rock Prospect Area of Kutasari Subregency, Purbalingga Regency, Central Java, Indonesia. *Indonesian Journal on Geoscience*, 8 (3), Pp. 345-357.
- Sehah, Raharjo, S.A., Risyad, A., 2020. A Geophysical Survey with Magnetic Method for Interpretation of Iron Ore Deposits in the Eastern Nusawungu Coastal, Cilacap Regency Central Java Indonesia. *Journal of Geoscience Engineering, Environment, and Technology (JGEET)*, 5 (1), Pp. 47-55.
- Syukri, M., Saad R., Marwan, Tarmizi, Fadhli, Z., Safitri, R., 2018. Volcanic Hazard Implication Based on Magnetic Signatures Study of Seulawah Agam Geothermal System, Indonesia. *The 8th International Conference on Theoretical and Applied Physics. IOP Conf. Series: Journal of Physics: Conf. Series* 1120, Pp. 012028.
- Telford, W.M., Gedaart, L.P., and Sheriff, R.E., 1990. *Applied Geophysics*. Cambridge. New York. 744pp.
- Zamora, M.A.A., Enriquez, JOC., Elguera, JGR., Garcia, L.P., Flores, R.M., Bacerra, E.F., 2015. Chapala Half-Graben Structure Inferred; A Magnetometric Study. *Geofísica Internacional*, 54 (4), Pp. 323-342.

