Identification of igneous rock distribution in Kalisonggo area using geomagnetic method

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Abstract. Shallow intrusions of igneous rocks are often found in the Kalisonggo area and form a columnar joint. The presence of shallow intrusions of igneous rocks in the study area is closely related to Mount Mujil as an ancient volcanic system. This study aims to prove the existence of igneous intrusion and subsurface conditions using the geomagnetic method. First Horizontal Derivative (FHD) is used to determine the edge boundaries of the anomalous source of the rock's magnetic field. Quantitative interpretation is done by using 2.5 D modeling to determine the distribution of igneous intrusion in the study area. The results of data processing show the total anomaly value in the study area has a range of values ranging from \(-400\) nT to \(600\) nT. Whereas the local anomaly value that has been reduced to the equator has a range of values between \(350\) nT and the lowest \(-400\) nT with a closed contour closure pattern between the high anomaly and the low anomaly. Based on the cross-section results of 2.5 D incision 1 and 2, there are 3 layers of rock in the presence of boulder lava andesite. The andesite lava has a susceptibility value of 0.00004 SI which penetrates the bedding above it. The top layer is soil with a susceptibility value of 0.00001 SI. The next layer is the andesite breccia rocks with a susceptibility value of 0.00003 SI. The third layer is sandstone with a susceptibility value of 0.000005 SI. The model shows that the andesitic lava lumps did not break through the basement, this is following Van Bemmelen's opinion that igneous rock in Kalisonggo is an avalanche.

1. Introduction
In the Kalisonggo area can be found igneous rock intrusion outcrops. At one of the observation sites, the igneous intrusion outcrops form poles that can be found in lava flows and also basalt lava, but not all lava can produce columnar joints [1, 2]. Sill and dyke are part of an igneous intrusion system. Sill is an intrusion of igneous rock which is parallel to the structure of the bedding through it. While dyke is one of the intrusion rocks as a sheet with both sides parallel, cutting the structure (bedding) of the rock that has been broken through[3, 4, 5].

The presence of igneous rock outcrops in the study area is closely related to the existence of Mount Mujil as an ancient volcanic system. There are two conflicting opinions regarding the presence of Mount Mujil namely Van Bammelen stated that Mount Mujil was an avalanche [6], while Hartono and Pambudi stated that Mount Mujil was the remainder of the intrusion body [7]. The opinion expressed by Hartono and Pambudi refers to the landscape and rocks found around Mount Mujil. Based on the landscape, it is estimated that Mount Mujil has erupted weakly. The weak eruption correlates with the composition of
rocks that make up cracks and fragments of andesite breccia to basal andesite. These cracks are found around Mujil, and then some of them develop into columnar joints.

This research aims to prove the existence of igneous intrusion and subsurface conditions using the geomagnetic method. The geomagnetic method is one of the oldest geophysical methods that can detect the presence of an igneous rock intrusion by utilizing the magnetic properties of rocks [8, 9, 10]. This method is based on measuring the intensity of the magnetic field on rocks that arise due to the influence of the earth's magnetic field when the rock is formed. The ability of a rock to be magnetized is strongly influenced by the value of rock susceptibility [11]. The susceptibility of rocks is influenced by the type of minerals contained in these rocks.

2. Geologic Setting
Based on the Peta Geologi Lembar Yogyakarta compiled by Raharjo, et al., the Kulonprogo regional stratigraphy is based on the oldest to the youngest according to the following: 1). Nanggulan Formation, this formation is a formation taken from regional research. 2). The Kebobutak Formation or Old Andesite Formation (OAF), this formation contains constituent rocks consisting of andesite breccias, lapilli tuffs, tuffs, lapilli breccias, agglomerates, and lava flows and volcanic sandstone exposed in the Kulonprogo area. This formation is the focus of this research. 3). Jonggrangan Formation, this formation has a constituent stone consisting of tuff, napal, breccia, clay stone with lignite inserts in it. 4). Sentolo Formation, this formation has a constituent rock consisting of napalan sandstone and limestone, and at the bottom consists of napal tuffan. 5). Sediment Merapi Muda, this formation has a composition consisting of tuff, ash, breccias, agglomerates and inseparable melt lava. 6). Koluvium, Composed of an inseparable form of the Kebobutak or Old Andesite Formation (OAF) formation [12]. At the research area, several outcrop were found, including Andesite Lava and Andesite Breccia, which are part of the Kebobutak Formation, while Sandstone and Napal are part of the Nanggulan Formation (figure 1).

![Figure 1. Geological Map of the research area (modified from [12]).](image)

3. Methods
3.1 Correction of magnetic field value
Initial corrections made to the value of field measurements are corrections to the IGRF (International Geomagnetic Reference Field) and correction of daily variations. Daily variation correction (diurnal
correction) aims to eliminate the effect of the measured external magnetic field due to the presence of solar activity, namely sunspots which can cause solar storms that affect the earth's magnetic field [13]. While the IGRF correction aims to eliminate the influence of the Earth's main magnetic field [14]. IGRF or International Geomagnetic References Field values are obtained from international agreements based on mathematical models of the main magnetic fields of the earth by entering the position of latitude, longitude, elevation and measurement time [13][15]. Correction of daily variations is obtained from daily measurements on a base during measurements in the field.

3.2 Reduksi of flat field
The total magnetic anomaly field value obtained is still influenced by the topography of the undulating study area. The anomaly data that is still in the topography is then transformed on a flat plane using Taylor series suppressors. Flat plane transformation aims to raise the total magnetic field anomaly data that is still in the topography of a flat field with the same height.

3.3 Reduction to the equator (RTE)
The purpose of this RTE is that the total magnetic field anomaly which is still a magnetic dipole is transformed into a monopole, so that interpretation is easier.

3.4 Upward continuation
The continuation to the top is intended to separate regional and local anomalies (residuals).

3.5 First Horizontal Derivative (FHD)
Based on this analysis, it is expected to delineate areas thought to be igneous rock intrusion.

4. Results and Discussion
4.1 Total magnetic field anomaly
The measurement data in the field in the form of observation magnetic field was then corrected by IGRF and daily variations, so that the total anomaly was obtained. The data is then interpolated so as to obtain a map of the total magnetic field anomaly that has been corrected. The range of values of this total magnetic field anomaly ranges from -400 nT to 600 nT.

4.2 Total magnetic field anomaly on the flat field
The total magnetic field anomaly obtained after daily correction and IGRF correction is an anomaly that is still on an uneven or undulation topography. This reduction to the plane uses the Taylor series approach. The method of approximation of the Taylor series by carrying data at the height of the middle between the lowest measurement point with the highest measurement point of the average sea level.

4.3 Upward continuation
Separation of local and regional anomalies is carried out using the upward continuation method. The continuation process is carried out to clarify the regional anomaly and eliminate local effects. Lifting the data is tried at an altitude of 50 m to 500 m. Continuation is used at an altitude of 400 m, assuming that from 400 to altitude 500 m the contour closure pattern and its value have not changed again.

4.4 Reduction to the Equator (RTE)
The nature of the magnetic dipole geomagnetic method still gives ambiguity to the position of the source of the anomaly, so RTE is needed. RTE is carried out to bring the anomaly peak directly above the source of the anomaly object (figure 2).

4.5 First Horizontal Derivative (FHD).
Determiniation of the border of the anomalous source in the study area is used derivative analysis in the form of First Horizontal Derivative (FHD). FHD is a magnetic field anomaly changes the magnetic
anomaly from one point to another horizontally at a certain distance, which can be used to determine the edge of the source of the anomaly[16].

Figure 3 below shows that the source of the anomaly was split into 2 scales, namely high and low. High anomaly sources are symbolized in red and low anomaly symbols in blue. White symbol is present between white and red, as delineation or border between high and low anomaly sources.

Figure 2. Map of a local anomaly in reduction to the equator

Figure 3. Map of first horizontal derivative (FHD)
4.6 Discussion

Based on the geological condition, the presence of columnar joints and intrusion of igneous rocks in the study area is a manifestation of ancient volcanic activities that occurred in the Kulonprogo area. The igneous intrusion is included in the Old Andesite Formation (OAF). In some places, the intrusion develops as a stocks and column structure. The results of data processing shown on local anomalies that are reduced to the equator show closed magnetic contour closures. The highest magnetic field value is 350 nT and the lowest is -400 nT. Contour closure patterns are formed, where high anomaly values have a Northwest to Southeast distribution pattern. The low anomaly on this map lies between the high anomaly contour closure patterns.

Based on figure 4, it can be seen that the contour closure pattern with a low value is interpreted as igneous intrusion, corresponding to the rock outcrop. The minus (low) value of this anomaly is caused by the rock formation process and its remanence. The process of formation of igneous rock that occurred in the study area begins with the release of lava in the fractures that are on the surface. Lava then breaks through the cracks. Lava liquid then fills the existing fracture. Due to high temperatures and limited space occupied and due to strong pressure, the cooling lava forms igneous rocks with small magnetic remanent properties (low). Because it only fills these fissures is one of the causes of igneous intrusion found in the study area is insitu.

The outcrops of the pillar found in the study area are more northwestward, the more difficult to find in the form of a pillar but in the form of a heft column (figure 4). This is caused by the difference in lava viscosity, the thicker (the higher the viscosity), the lava is relatively difficult to move. The northwestern direction of this outcrop is interpreted as the center of igneous intrusion from the columnar joint.

FHD map analysis is intended to determine the edge boundaries of magnetic field anomalies. Anomaly borders are marked with a value of 0. On the FHD map can be seen patterns with high closure and low closure. This closure pattern is then overlayed with outcrops of rocks in the research area (figure 5).

Based on figure 5 can delineate rock types based on the boundaries formed by FHD. The results obtained in figure 4 are then checked directly in the field, apparently in accordance with the geological conditions of the study area.

![Figure 4](image_url)

**Figure 4.** The local anomaly map after reduction to the equator that overlay with the columnar joint outcrops.
The next step is modelling the 2.5D anomaly by making 2 incisions on the map of the total magnetic field anomaly (figure 6). The making of this incision is based on qualitative interpretation of the position of the object causing anomalies, rock outcrops, and geological information in the study area.

Based on the cross section results of 2.5 D, the first slice and the second slice (figure 7 and figure 8), there are 3 layers of rock in the presence of andesite lava blocks. Andesite lava has a susceptibility
value of 0.00004 SI which penetrates the bedding above it. The top layer is soil with a susceptibility value of 0.00001 SI. The next layer is the andesite breccia rocks which are part of the OAF Formation with a susceptibility value of 0.00003 SI. The third layer is sandstone which is part of the Nanggulan Formation with a susceptibility value of 0.000005 SI. The Nanggulan Formation is known as the oldest rock making up the Kulon Progo Mountains.

Based on subsurface models created using magnetic and gravity data, it can be seen the presence of andesite lava lumps in the study area not continuously or penetrating from the rock basement. This lack of continuity to the basement indicates the presence of andesite lava in the study area in accordance with Van Bemmelen's opinion which states igneous rock in Kalisonggo is an avalanche [6]. However, the opinion of Pambudi and Hartono who stated the andesite lava as intrusion can also be justified, because the source of the andesite lava could be outside the area of measurement, so as to ensure that magnetic and gravitational data are needed that covers Mount Mujil and Kalisonggo.

Figure 7. Profile model 1

Figure 8. Profile model 2
5. Conclusion
The total anomaly value in the study area has a range of values ranging from -400 nT to 600 nT, with a high anomaly distribution pattern in the North-West direction. While the value of local anomalies that have been reduced to the equator has a range of values range between 350 nT and the lowest -400 nT with closure contour pattern closing between high anomalies and low anomalies. Based on the result of the 2.5 D cross section of 1 and 2, there are 3 layers of rock in the presence of andesite lava block. The lump of andesite has a value of 0.00004 SI susceptibil that penetrates the layer above it. The top layer is soil with a value of 0.00001 SI susceptibilitas. The next layer is an andesite breccia with a value of 0.00003 SI susceptibilitas. The third layer is sandstone with a susceptibility value of 0.000005 SI. From the model obtained showing the andesite lava does not break through the basement, this is in accordance with the opinion of Van Bemmelen that the igneous rocks in Kalisonggo as an avalanche.

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