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Magnetic Method Interpretation to Determine Subsurface Structure Around Kelud Volcano

KEYWORDS: total magnetic anomalies, kelud mountain, subsurface structure and rocks susceptibilities, grinding

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ABSTRACT *Measurements have been performed using magnetic method to determine the structure of the subsurface in the vicinity of Mount kelud. Data collection is conducted at random in an area of 0.6 km x 1 km with the amount of points gained 244 points of measurement. Acquisition process is performed using the Proton Magnetometer ENVI SCINTREX. Data processing begins with a correction IGRF and daily variation correction to get the total magnetic field anomalies. Then the reduction of flat areas, the upward continuation at a height of 100 feet to 400 feet above the sferoida reference and the result is used for the separation of local and regional anomaly. A qualitative interpretation of the results shows that there is a magnetic dipole anomalies in the East which stretches from the Northwest to the southeast of-2125 nT until 1863 nT. Talwani method of 2-D is used for quantitative interpretation. The resulting geological model is fracturing fault plane. The value of magnetic suseptibilitas under the dome of the volcano mount Kelud to Lirang (k = 0,0124 emu/g) is dominated by basalt rocks and mount Sumbing (k = 0,0234 emu/g - 0,0239 emu/g) which is dominated by andesite.*

1. Introduction

Any magmatic event of Mount Kelud in 2007 that formed the mountain child is a deformation of the body of volcanic activity report. The events of this deformation can be either inflation or deflation. Deformation in the form of inflation generally occur because the process of the movement of the magma is intruding to the soil surface. In this case the maximum deformation is usually observed shortly before the eruption of volcanic activity report. While the deformation of deflation generally occurs during or after the event

Changes to the structure under Earth's surface occurs due to changes in the load mass of soil and rocks both in the surface of the Earth or in the Earth, in the event of the discharge of magma of Mount Kelud. To identify the structure beneath the surface as a result of such events, a number of geophysical methods can be used. Geohysical methods are often used to investigate the structure of the subsurface, among others: resistivity method, gravity method, seismic method and geomagnetic method. This research uses a magnetic method because it has been widely used in the exploration of minerals and rocks. Magnetic methods can be used to determine the geological structure of the subsurface such as faults, folds, igneous intrusion or geothermal reservoirs and salt domes. Magnetic method can be used to determine the depth and surface structures, measurements can be retrieved easily for local and regional studies. Working method of magnetic are based on the measurement of small variations in the intensity of the magnetic field at the Earth's surface. This variation is caused by the contrast between the magnetization properties of rocks in the Earth's crust, so that raises the Earth's magnetic field which is not homogeneous, it can be referred to as a magnetic anomaly.

2. Theory

2.1 The Morphology of Research Area

Kelud (70.56' S and 112.019' E) is one of the quarter volcano in East Java. Kelud is surrounded by some of the older volcanoes, such as mount Kawi and mount Butak on the East, as well as Mount Anjasmara in Northeast. These mountains form a rugged morphology with the Hill, a steep ravine and in the Northeast and on the slopes of Mount Kelud. According to morphology, Kelud can be divided into 5 units, namely the Summit and crater of Kelud, Kelud, Kelud parasitik basin, the legs and the plains of Kelud. Mount Kelud has a height of more than 129 meters above sea level, and has an irregular morphology. This is due to the presence of an explosive eruption that followed the formation of lava domes.

Stratigraphy of the rock units of Kelud is comprised of a wide variety of lava flows, pyroclastic flows and lava domes and pyroclastic deposits. Rocks of pre-kelud consists of volcanic rocks from South Mountain, Mount Anjasmara, Mount Butak and Gunung Kawi. The secondary heap consists of cold lava and kolovium.

2.2 Geological Structure of Research Area

Geological structure of Kelud consists of several crater (Lir... and
Rh...

Th... jest
an... ock-
wi... ally
de... anic
ro... rom
K... to
61... anic
ea... tor-
in... (VK
=... S-
wa... out
3... ose
en...

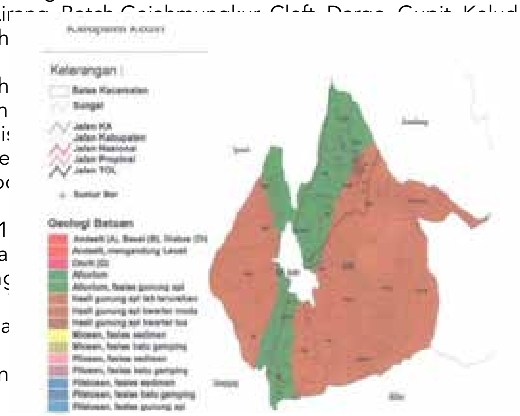

Figure 2.1 Kediri Geological Map

2.3 Magnetic Field

The magnetic field of the Earth is characterized by physical parameters or also called the elements of the Earth's magnetic field, which can be measured, i.e. include the direction and magnetic intensity of. Physical parameters including:

- Declination (D), the angle between the magnetic north and the horizontal components are calculated from North to East
- Inclination (I), the angle between the magnetic field to the total horizontal field with the calculated from the horizontal plane to the vertical plane down.
- The Horizontal Intensity (H), which is the magnitude of total magnetic field on horizontal space.
- The total magnetic field (F), which is the magnitude of

total magnetic field vector.

The main magnetic field of the Earth has changed over time. To uniform the main values the Earth's magnetic field, the default value is made is referred to as International Geomagnetics Reference Field (IGRF) which are updated every five years. The IGRF values retrieved from the average measurement results on the total area of about 1 million km2 which is carried out within a year. The magnetic field of the Earth is composed of 3 parts:

- **Main Magnetic Field**

The main magnetic field can be defined as the average field measurement results in a longer time period long enough to cover an area more than 10^6 km2.

- **External Magnetic Field**

The influence of external magnetic field comes from outside of the Earth that is the result of ionization in the atmosphere caused by the ultraviolet rays of the Sun. Because the source is associated with an electric current that flows in the ionized layers in the atmosphere, then changes of this field with respect to time is much faster.

- **Anomalous Magnetic Field**

Magnetic anomaly is often also called the local magnetic field (crustal field). The magnetic field is produced by rocks containing magnetic minerals such as magnetite, titanomagnetite and others who are in the Earth's crust.

In the survey of magnetic method the target of measurement is a variation of the magnetic field measured at the surface (the magnetic anomaly). The anomalous magnetic field caused by the remanen magnetic field and induced magnetic field. Remanen magnetic field has a great role to the magnetization of rocks in magnitude and direction and relating to earlier magnetic events so it is very complicated to be observed. Anomalies obtained from the survey is the result of the combined magnetic field induction and remanen, when the direction of the magnetic field of remanen is the same as the direction of the magnetic field induction, then the anomaly gets larger. And vice versa. In the survey, the effect of magnetic field remanen will be ignored when the anomalous magnetic field less than 25% of the Earth's main magnetic field (Telford, 1976).

2.4 Geomagnetik Method

In the geomagnetic measurements, major equipment used is the magnetometer. This equipment is used to measure the strong magnetic field at the location of the survey. One kind is the Proton Precission Magnetometer (PPM) which is used to measure the total magnetic field strength values. Other equipment which is supporting in the magnetic survey is Global Positioning System (GPS). This equipment is used to measure the position of the point of measurement which include longitude, latitude, altitude, and time. GPS determine the position of a point location using satellite aid. It uses satellite signals due to reach areas that are very broad and are not disrupted by mountains, hills, valleys and canyons.

Some other supporting equipment is often used in magnetic surveys, among others (Sehan, 2001):

- Geological compass, to know the south and north direction of the magnetic field.
- Topographical map, to determine measurement route and location of measurement point.
- Transportation means,
- Workbook, to record the data during measurement
- PC or laptop with software such as Surfer, Matlab, Mag-2DC, etc.

Measurement of magnetic field data in the field is carried out using the PPM, which is a portable magnetometer. Data recorded during the process of measurement is the day, date, time, strong magnetic field, the weather conditions and the environment.

In doing the magnetic data acquisition first is determine the base station and make the stations measurements (try forming a grid). The size of the grid is adjusted with the extent of the measurement location, then magnetic field measurements conducted at measurement stations in each trajectory, while at the same time also conducted measurements of daily variations in the base station.

2.5 Geomagnetic Data Processing

To obtain the desired value of the magnetic field anomalies, a correction to the data the total magnetic field measurement results at every point of the location or the measurement station is then made, which includes daily corrections, IGRF and topography.

2.5.1 Diurnal Correction

Diurnal correction is the correction of deviation of the value of the Earth's magnetic field due to the time difference and the effect of solar radiation in a single day. The time that is intended to be referred to or in accordance with the measurement data to a magnetic field at any point location (measurement station) which will be corrected. If the value of the daily variation is negative, then the daily corrections done by adding recorded daily variation value to the magnetic field data that will be corrected. Otherwise, once the daily variation is positive, then the correction done by subtracting the value of the daily variation of at a certain time, the equations are:

$$\Delta H = H_{total} \pm \Delta Daily \qquad (2.1)$$

2.5.2. IGRF Correction

Measurement data outcome of magnetic field is essentially the contribution of three basic components, namely, the Earth's main magnetic field, magnetic field and field anomalies. The value of the main magnetic field is none other than IGRF value. If the value of the main magnetic field removed with daily correction, then the main magnetic field contributions removed with correction IGRF. IGRF correction can be done by subtracting the value of the IGRF to the total magnetic field has been corrected daily at each measurement point on the appropriate geographical position. The correction equation (after corrected daily) can be written as follows:

$$\Delta H = H_{total} \pm \Delta H_{daily} \pm H0$$

Where H0 = IGRF

2.5.3. Topographical Correction

Topographic correction is conducted if the influence of topography in the survey megnetik very strong. Correction of topography in the geomagnetic survey did not have clear rules. One method to determine the value of the correction is by building a model of topography using modeling some prisma quadrilateral (Suryanto, 1988). When doing modeling, magnetic suseptibilitas value (k) Rock topography must be known, so that the model topography created, generating a magnetic field anomalies (ΔH_{top}) in accordance with the facts. Furthermore the correction equation (after done daily and koreski IGRF) can be written as:

$$\Delta H = H_{total} \pm \Delta Daily - H0\ \Delta h_{top} \qquad (2.2)$$

After all the corrections imposed on magnetic field data, then the data anomalies in total magnetic field topography is retrieved. To know the pattern of anomalies obtained, which will be used as the basis for the prediction model of the geological structures beneath the surface that may be anomalous, then the data should be presented in the form of contour maps. Map contours consist of contour lines connect the dots the same anomaly that has value, as measured from a certain comparison field.

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2.6 Reduction to Flat Plane

To ease the processing and data interpretation of magnetic data, then the total magnetic field that is still scattered around the topography should be reduced or brought to the flat areas. The process of transformation is must be committed, because the next data processing requires input of a distributed magnetic field anomalies on the mast. Some techniques to transform data into magnetic field anomalies flat areas, among others: source equivalent (equivalent source), a layer of equivalent (equivalent layer) and the Taylor series approximation (Taylor series approximaion), where each technique has its advantages and disadvantages (Blakely, 1995).

2.7. Upward Continuation

Upward continuation is the process of data transformation from a potential field of flat areas to other flat areas is higher. On geomagnetic data processing, this process can serve as a filter to filter low, namely to remove the effects of the reduction of a local magnetic field emanating from a variety of sources of magnetic objects scattered on the surface topography is not associated with the survey. The process of adoption should not be too high, as this can reduce local magnetic anomalies sourced from magnetic objects or geological structures that become the targets of this magnetic surveys.

2.8. Correction of Regional Effects

In many cases, the magnetic field anomaly data always mixed in with other magnetic anomalies that are derived from sources which are very deep and wide below the surface of the Earth. The magnetic anomaly is referred to as a regional magnetic anomalies (Breiner, 1973). To interpret the anomalous magnetic field which became the target of the survey, then regional effects corrections is conducted, which aims to eliminate the effects of magnetic anomaly data of regioanl anomalous magnetic field measurement results.

One of the methods that can be used to obtain regional anomalies is upward continuation to certain altitudes, where the resulting anomaly contour maps already tend to be fixed and do not change the pattern again when done for a higher appointment.

2.9. Geomagnetic Data Interpretation

In general, the geomagnetic data interpretation is divided into two, namely the interpretation of qualitative and quantitative. A qualitative interpretation is based on the pattern of magnetic field anomaly contours which came from the distribution of magnetized objects or geological structures beneath the Earth's surface. Next the pattern generated from magnetic field anomaly is interpreted based on the local geological information in the form of the distribution of the magnetic geologic structures or objects, which are the basic foundation of the prediction of the actual geological conditions.

Quantitative interpretation aims to define a shape or model and depth of anomalies or geological structure objects through mathematical modeling. To perform a quantitative interpretation, there are several ways in which between one another may differ, depending on the form of anomalies obtained, the targets are achieved and the accuracy of measurement results.

3. Software

The equipment used in the processing of this data is microsoft excel software, surfer9, MagPick, and GravMag.

4. Processing Method

Data that is used are from a thesis of Zainul Musafak a graduate students in the Department of physics at ITS. From the data obtained from the thesis then reprocessed using the above mentioned software. The first data on the attachment on the insert in microsoft excel software to the revamped format. xcel works. Then with Surfer9 data is opened and processed in order to get surfers and surfer grid plot. After a subsequent Surfer9 MagPick software is used to obtain the plane. From MagPick data opened with NotePad and saved in .txt file type. The last one is by processing data with GravMag to get 2D cross section with the approach.

5. Discussion

Data from the thesis is inserted in microsoft excel software. So come by the following data:

X	y	T (nT)
643400	9122101	161,1691
643391	9122114	352,0875
643385	9122122	528,8004
643377	9122129	708,0386
643370	9122138	911,0859
643366	9122145	1103,77
643360	9122153	1326,173
643350	9122161	1444,265
643344	9122171	1450,644
643332	9122186	1417,193
643321	9122198	1361,005
643313	9122207	1263,195
643307	9122215	1091,799
643296	9122226	897,3988
643282	9122245	747,46
643271	9122257	593,484
643259	9122272	411,6147
643246	9122286	215,178
643238	9122295	-228,394
643233	9122299	-671,851
643229	9122309	-899,867
643221	9122318	-997,513
643221	9122324	-1060,14
643221	9122336	-1093,59
643221	9122347	-1116,46
643221	9122351	*-1233,4*
643221	9122355	-1335,8
643221	9122363	-1254,77
643221	9122373	-800,11
643221	9122385	-497,943
643221	9122397	-386,946
643221	9122406	-278,416
643221	9122421	-130,741
643221	9122429	-35,9591
643221	9122438	8,7042

Figure 5.1 data .xls

The data above, was then processed using Surfer9 software to obtain the following .grid data,

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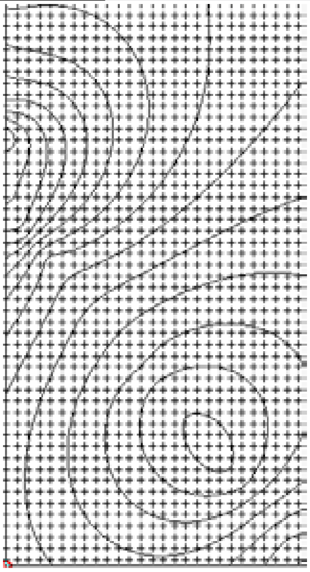

Figure 5.2 .grid data

From the .grid data, it further processed using MagPick and plot data of 45 picking point is obtained. All 45 picking point is then further processed using GravMag , which result in this,

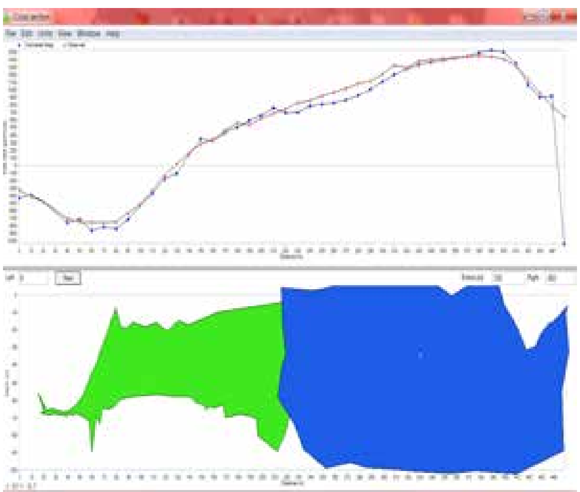

Figure 5.3 GravMag result

Based on figure 5.3, subsurface interpretation is conducted on the location.

In Figure 5.3 above, the anomaly occurs at a distance of 328,933 metres from point E, on the 27th data and reside on the x axis 643191, y axis 9122355 with magnetic field of 1335,8-nT.

Based on the results of the GravMag model, it can be noted that, the magnetic anomalies on the incision E-F. Anomaly near Kelud crater dome that is caused of faulting. This fault, in the form of magnetic anomalies have different susceptibility values. The value of magnetic susceptibility under the dome of the volcano Kelud Mountain to the Lirang is lower than on the hillside of Mount Sumbing. In General, a fracturing of rocks having the same susceptibility value. This susceptibility difference, allegedly as a result of rock demagnetization that occur under Mount Lirang. This demagnetization happens as a result of rocks subjected to heat up to a temperature above the Curie. Based on the results of data modeling incision E-F, it is known that the susceptibility value under magnetic mount Sumbing of 0,0234-0,0239 emu/g, whereas the magnetic susceptibility value under Mount Lirang is 0,0124 emu/g. The value of rocks susceptibility are thought to be basalt and andesite. This is supported by the geological condition of Kelud which is dominated by basalt and andesite.

Next, an analysis of the intersection between the incision E-F is performed located on the x axis 643233 and y axis 9122315. These positions, on the incision E-F is blue, with a value of the same susceptibility i.e. 0,0124 emu/g. This results compared with results of data analysis by using vertical gradio, vertical x-axis horizontal gradio, y-axis horizontal gradio and reduction to the pole. All of the analysis, confirm the existence of alleged supply of lava from Mount Lirang into the Kelud crater.

Modeling of the EF incision shows a fault, so different susceptibility value is obtained, the green plate has the susceptibility value of 0,0239 emu/g, 200 m wide and 30 m depth below the surface to the lower limit of 85 m. The blue plate has the susceptibility value of 0,0124 emu/g, 190 m in width and depth 25 m below the surface to the lower limit of 90 m. Blue Plate has lower susceptibility value, this is due to the warming at the crater of kelud.

6. Conclusion

After the acquisition, processing and interpretation of data then it can be concluded that:

1. On the contour of the total magnetic field corrected using IGRF and daily variations retrieved dipole magnet that shows the existence of anomalies in the area of research. Total magnetic field anomalies on the contour closure couples shows positive and negative, with a large magnetic field strength on positive closure around 1851 nT and magnetic closure negatively about -2178 nT.
2. From the gradiomagnetic contour map and the reduction to the pole it can be known that magnetic anomaly extends from Mount sumbing and mount Lirang towards the crater of the Kelud in the form of magma volcano.
3. Quantitative interpretation method using 2D talwani by utilizing software GRAVMAG, incision on E-F anomalies occur at a distance of 328,933 metres from point E, on datum to 27 and is located on the x axis 643191, y axis 9122355 with magnetic field of -1335,8 nT.
4. Quantitative interpretation method using 2D talwani by utilizing software GRAVMAG, the incision the EF produces two geometry prediction objects below the surface with error rate 0.85%. Anomalous objects I with value suseptibilitas 0,0239 emu/g is located at a depth of 30 m and the lower limit of 85 m. Anomalous Objects II with the value suseptibilitas 0,0124 emu/g, is the depth of 25 m and the lower limit of 90 m.

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