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Integration of 3G Data (Geomagnetic, Gravity and Geology) to Identify Geothermal System Controlled by Geological Structure of Telomoyo Plateau (Study Case of Candi Umbul Area)

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ABSTRACT

As the technology development, there are more and more new innovations that utilize existing resources to support the energy needs and to fulfill the consumer needs. The energy source that is being discussed at this time is geothermal energy. Geothermal energy sources are considered effective because they are renewable and environmentally friendly when compared to other energies such as fossil energy. In Indonesia itself, geologically, it has a complex series of volcanoes that can be used as a heat source in this new energy innovation. One area that thought to have geothermal potential is the telomoyo mountain area, which is indicated by the manifestation of hot springs on the surface, precisely around Candi Umbul. However, it is necessary to conduct subsurface studies to identify the presence of subsurface structures such as faults or intrusions as heat sources, where this can be overcome using geophysical methods. This research was conducted using the integration of two geophysical methods, namely the geomagnetic method to determine the direction of the fault continuity and the gravity method to determine the regional heat source, and in the other side geological data as a reference for interpretation. From geomagnetic measurements, 163 rock magnetism data were obtained which indicated the existence of a fault continuity with northeast-southwest orientation in the direction of the river flow and cut the manifestation of hot springs. Meanwhile, from 176 gravity topex data, a high complete boguer anomaly value was obtained as an indication of an intrusion in the northeast that was cut by the fault recorded in the geomagnetic data. Based on geophysical data analysis and correlation with geological data from previous studies, it can be assumed that there is a geothermal system in the study area with andesitic intrusion as the heat source, fault structure with northeast-southwest orientation as a weak zone for meteoric water migration, andesite lava as caprock, unit tuff rock as a reservoir and the telomoyo plateau as a recharge area to supply meteoric water from the geothermal system.
Keywords: Geology, Geomagnetic, Geothermal, Gravity, Structure, Candi Umbul

I. INTRODUCTION

Along with the development of the times the need for energy is getting higher, while on the other hand the availability of main energy in the form of fossils is currently decreasing. Non-renewable fossil energy sources and complex prospecting areas encourage scientists to take advantage of existing technologies and resources.On the other hand, fossil-based energy is also not environmentally friendly because burning fossil fuels produces CO2 gas which can cause global warming (Jumina, & Wijaya, 2012). Responding to various problems in the energy industry, a new breakthrough is needed that can replace this energy and is environmentally friendly. Recently, a new and renewable energy source is known, namely geothermal energy. Geothermal energy is energy that utilizes geothermal heat to heat subsurface fluids and use it to drive turbines to generate electricity.

From a geological point of view, Indonesia is located at the confluence of three large plates (Eurasia, Indies-Australia and the Pacific) which causes Indonesia to have a complex tectonic setting. Subduction between continental and oceanic plates results in a magma smelting process in the form of partial melting. Mantle rock and magma undergo differentiation on their way to the surface. This process forms pockets of magma that play a role in the formation of volcanic pathways known as rings of fire. This has resulted in the emergence of a series of volcanoes in parts of Indonesia and their tectonic activities (Basid, A. 2014). This is certainly a very favorable condition for developing the geothermal energy industry as an environmentally friendly future energy source.

One of the areas in Indonesia that has geothermal energy potential is the Telomoyo area, Magelang, Central Java which is characterized by the manifestation of hot water on the surface. This is a topic that attracts geoscientists to conduct further research. One way that can be done in delineating the geothermal prospect zone is the geophysical method. The geophysical method itself has various methods that can identify the geological conditions of subsurface rocks, including the gravity method and the geomagnetic method. The gravity method utilizes variations in the density of subsurface rock and its distance to the surface which will affect instrument readings. The geomagnetic method is able to identify the distribution of the magnetic value of rocks which is influenced by various physical factors below the surface such as faults that cause the magnetism of subsurface rocks to decrease. Both of these methods can be integrated and linked with existing geological data so as to identify how the subsurface conditions are in analyzing geothermal systems such as heat sources and faults.

II. METHODS

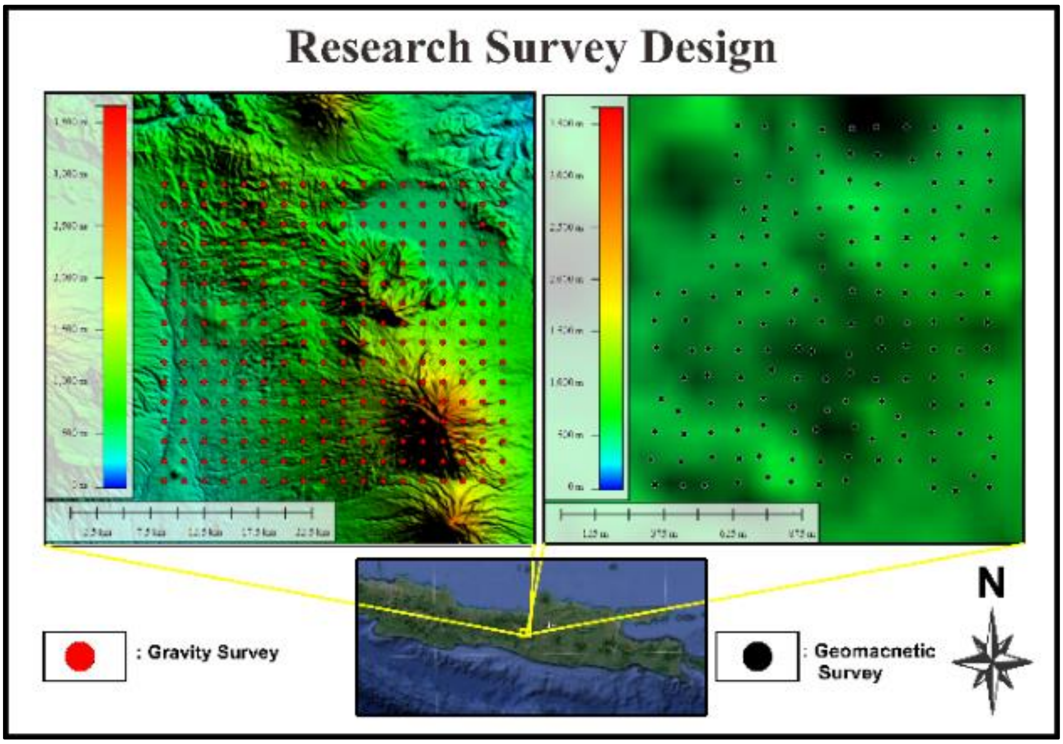

Figure 1. Reaserch survey design

The picture above is a geomagnetic survey design map using the gridding method which was carried out in the Candi Umbul Area, Grabag, Magelang, Central Java with a total of 164 measurement points. This research was conductedon the 12th and 13th of March 2022. The area of the research plot based on the survey design is 3.75 km2 with a length of 1.5 km and a width of 1.5 km. There are 14 measurement paths with a total of 14 acquisition points per trajectory. Measurement activities are carried out with the base rover concept using 3 PPM tools of the G-857 type where there is one tool that stays at a point (base) which is considered to have the least noise for correction of daily magnetic field variations later and one other tool moves according to the location of the measurement point.

In addition to the geomagnetic method, research is also carried out using the gravity method obtained from TOPEX satellite data. The TOPEX data obtained are in the form of elevation data and free air anomaly (FAA) values. TOPEX data acquisition reaches an area of 30 Km by 30 Km with the number of measurement points reaching 288 points with a space between points as far as 1800 meters. These two methods are then supported by geological data based on previous research.

Data processing from the two methods was carried out using Microsoft Excel and Oasis Montaj software. especially gravity data, processing is carried out through global mapper software to make field corrections after boguer corrections are carried out so that ABL values are obtained which can be further processed with Ipward, THD and TDR filters. Meanwhile, the obtained geomagnetic acquisition data is processed to obtain the value of Ha or the value of the magnetic intensity which is then performed with a Reduce to Pole (RTP) filter to obtain an RTP map that has been corrected for the influence of the main magnetic field from the earth which is dipole. RTP values that have been obtained can be further processed in the form of Lowpass, RTP and THD filters. Each value obtained from the gravity and geimagnetic methods is made into a map to facilitate the interpretation stage.

III. RESULTS AND DISCUSSION

3.1. Basic Theory Of Gravity

In 1687, Newton published Philosophiae Naturalis Principia Mathematica, which, among other things, stated Newton's law of gravitational attraction, where the magnitude of the gravitational force between two masses is proportional to each mass and inversely proportional to the square of their distance. In Cartesian coordinates, it can be displayed as shown below (Blakely et al, 1995).

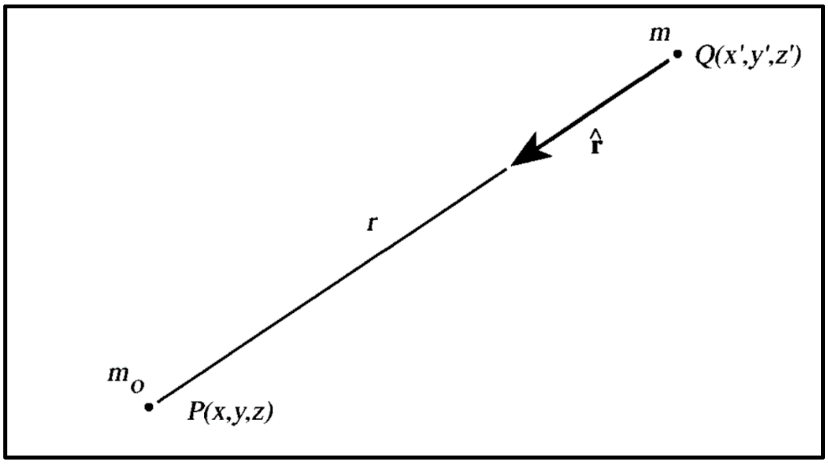

Figure 2. The masses m and mo experience a mutual gravitational force. By convention, the unit vector r is directed from the gravity source to the observation point, which in this case is located at the test mass m_0. (Blakely et al, 1995).

Theoretically, the magnitude of the force that works is formulated as follows;

$$\vec{F} = -G\,\frac{m_0\, m}{r^2}\hat{r} \qquad (1)$$

Where :

F ⃗ = F between Object 1 and Object 2 (Newton)
m_0 = Mass of object 1
m_ = Massa of object 2
G = Gravitational Constant (6,672 x 10 -11 Nm / kg)
r = Distance between object 1 and object 2 (m)
r ̂ = Unit vector from direction m to m0

3.2. Identification Of Fault Structures

One of the components in the geothermal system is a fault. Faults found below the surface, either normal faults or rising faults, can be a path for subsurface fluid migration from the surface to the heat source, or from the reservoir to the surface as a manifestation. Faults under the earth's surface are difficult to identify because not all of them are exposed on the surface. However, in this study, the presence of subsurface faults was identified using the geomagnetic method in the Candi Umbul area. Geomagnetic data survey was carried out in this area due to the presence of two manifestation points in the form of hot springs that were found and of course caused by the presence of a fault.

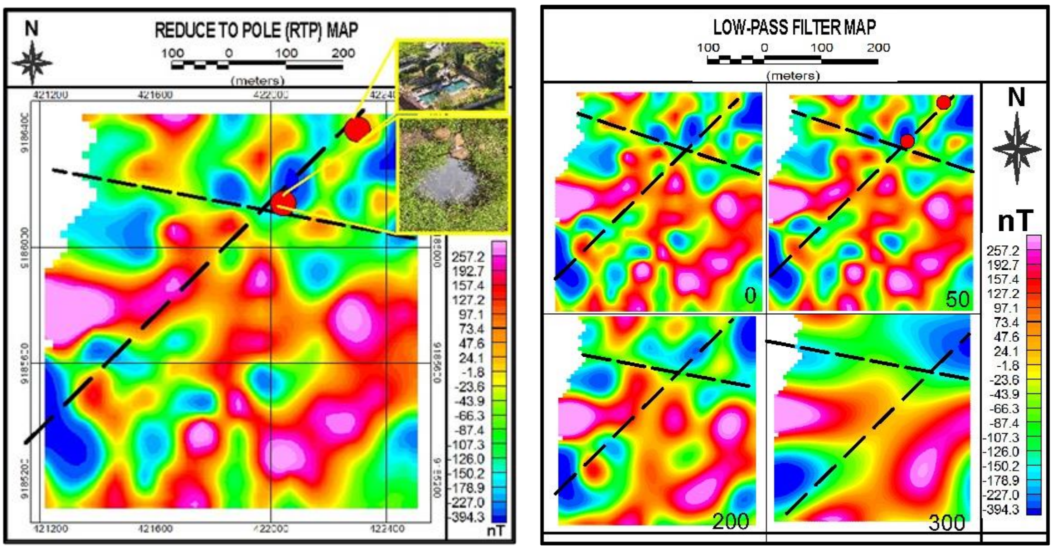

Figure 3. Reduce to pole map (top) and Low-pass filter map (buttom).

In the measurement of geomagnetic data in the field, the anomaly value obtained is the magnetic anomaly value in the research area. magnetic field (HA) which is then processed to produce a magnetic value that has been removed from the influence of the earth's dipole properties by using a reduce to pole filter. This filter causes the magnetic properties to become monopole so that the magnetic field displayed is the value of the magnetism that is right below it. On the RTP map, it can be seen that there are suspected faults with NE-SW and EW directions which are characterized by low and continuous anomalies. In addition to separating local and regional anomalies from the obtained magnetic values, use a low pass filter. This filter only captures low-frequency values so that it gives the results of the response of rocks that are far from the surface. The lowpass filter map also shows the alleged presence of a fault with the same direction as the previous assumption. This shows that the fault structure in the study area is a regional fault as well.

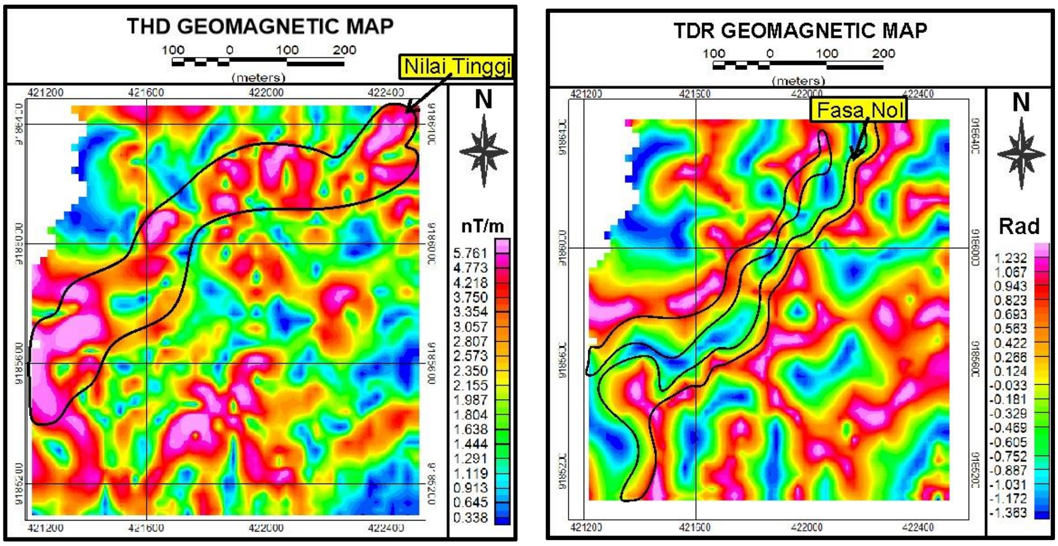

Figure 4. THD geomacnetic map (top) and TDR geomacnetic map (bottom).

The assumption of the existence of this fault is reinforced by data from the THD and TDR filters which can be seen on the THD and TDR maps. The THD value is obtained from the derivation of the RTP value. in principle, the THD value will be high at the boundaries of the anomaly, so this filter can be applied to the determination of fault boundaries in the study area. On the THD map it can be seen that the previously predicted fault position has a high value along its side. On the map obtained, it can be seen that the fault structure with a NE-SW direction shows high values as indicated by the white line. Meanwhile, a high THD value is also shown in the fault in the EW direction. Unlike the THD filter, the TDR filter has the principle that the anomaly value will be zero when it is at the anomaly boundary. on the map it can be seen that the position of the alleged fault gives an anomalous response with a value of zero which is continuous along the side of the fault. this indicates that the zero anomaly value indicated by the white line in the figure is the boundary of the fault. The sharpening of this anomaly strengthens the assumption that the fault has a NE-SW direction and a NW direction.

The identification of the next fault structure can be seen from the boundary of the anomaly and the body of the fault. Where to see the section, the Total Horizontal Derrivative (THD) and Tilt Derrivative (TDR) filters are used to identify the presence of the structure by looking at the boundaries and body of the fault. In the **Figure 3.** the map on the top is the result of the Total Horizontal Derrivative (THD) filter and the Tilt Derrivative (TDR) filter on the buttom. Conceptually, the THD filter is a combination of the X and Y orientation First Horizontal Derivative analysis, where this filter raises the value at the anomaly boundary. While the TDR filter is a filter that is used to see the anomalous boundaries along with their geometric shapes and directions. If seen on the THD map, the boundaries of the anomalies indicated as structures in the form of northeast-southwest trending faults, the majority show high values along their continuity. Likewise with several minor faults that appear in a northwest-southeast direction, the boundaries of each fault line can be seen.

To see another form of the fault, it can be seen on the TDR map where the TDR map clarifies the boundary of the anomaly by looking at phase 0 on the entire map. Phase 0 here is shown in the yellow shutter where the orientation direction and geometric shape of the fault can be determined with this TDR map. It can be seen that the majority of phase 0 directions are in the northeast – southwest which describes the orientation direction of the northeast – southwest major fault. While a small part of phase 0 with a northwest-southeast orientation describes a minor fault formed in the study area.

With the support of the control structure in the form of a fault that appears on the RTP map and all of its filters (Lowpass, TDR, and THD) and based on the geological map data of the telomoyo area which shows the direction of the slump of the fault zones that cause geothermal manifestations, the structural aspect Geothermal control in the Telomoyo area is considered a prospect and is one aspect of the geothermal system that has been fulfilled.

Based on the geological data that has been obtained, the main lineage in the study area has an east-west orientation. This lineament is a characteristic of the Java structure that occurs due to the subduction of the Indo-Australian plate which moves towards the Eurasian plate to the north. On the other hand, there is also a fault structure that dominates the study area which is continuous in the NE-SW direction. This northeast-southwest pattern is indicated as a result of the formation of the Soropati mountain caldera. The direction of the continuity of the structure obtained can also be observed in the DEM data and the pattern of river water continuity on the surface. In addition, two points of manifestation in the form of hot springs that are connected also form a NE-SW orientation. this shows similar results to the obtained geomagnetic data. On the map, it can be seen that the east-west orientation lineage pattern in the north and the NE-SW pattern are shown by low anomalies. The type of fault that developed in the study area is a normal fault. This fault cuts the subsurface rock that acts as a reservoir and caprock so that the fluid comes to the surface as a manifestation in the form of hot springs as an outflow zone.

3.3. Heat Source Analysis

Apart from the manifestation of hot water and existing structures, other components in the geothermal system are heat sources or heat sources. The heat source of a hydrothermal system is generally in the form of an intrusion body or magma from volcanic activity. However, there are also sources of hydrothermal heat that are not derived from igneous rock but are generated from the uplift basement rock which is still hot or it can also come from tectonic activity in the form of faults and folds so that the rock circulation warms up. This difference in heat sources will have implications for differences in geothermal reservoir temperatures in general, will also have implications for differences in geothermal systems (Goff & Janik 2000). Apart from that, in general, the heat source must have a high density so that it gives a high gravity anomaly value as well.

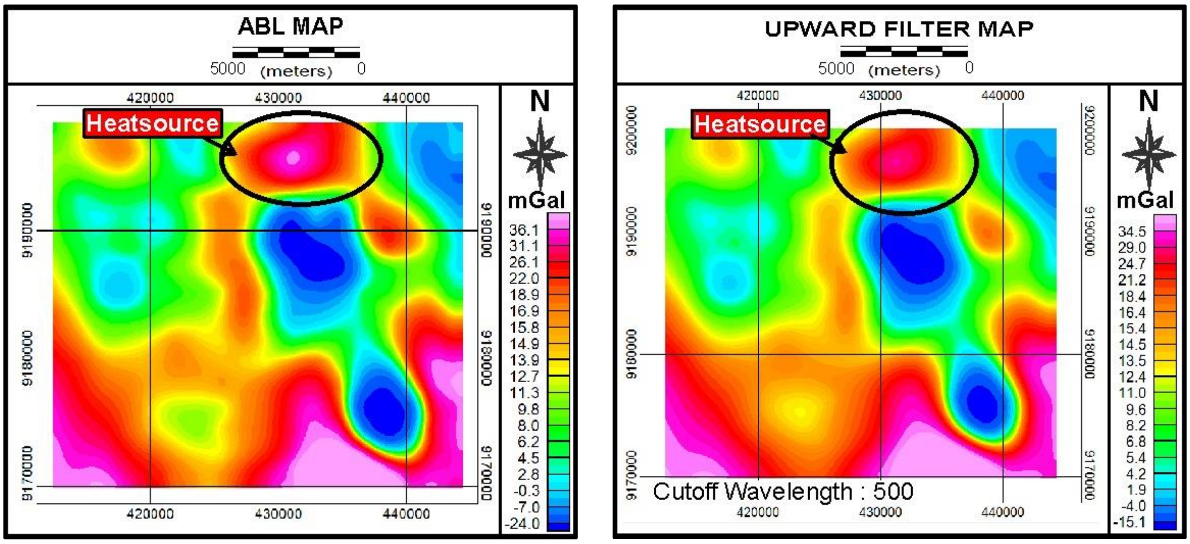

Figure 5. ABL map (top) and Upward filter map (buttom).

Based on the gravity data obtained, the distribution of the value of the gravity anomaly is influenced by the density factor and the distance between the subsurface formation and the surface. The picture above is a complete Boguer Anomaly (ABL) map (left) and an upward continuation filter map with a cut of wavelength value of 500. The ABL map can obtain information in the form of the distribution of subsurface gravity anomaly values at a point that has been corrected for factors affecting acceleration. gravity such as elevation, average density, latitude position, tides, high gravity anomaly value of the study area is in the southern part of the study which is indicated by red to ung with values of 10 mGal to 30 mGal which can be seen on the scale bar. However, there is also a high anomaly value in the northern part which forms a circular closure which is suspected as a heat source in the study area. the location of this intrusion is in the northern part of the caldera of Mount Soropati.

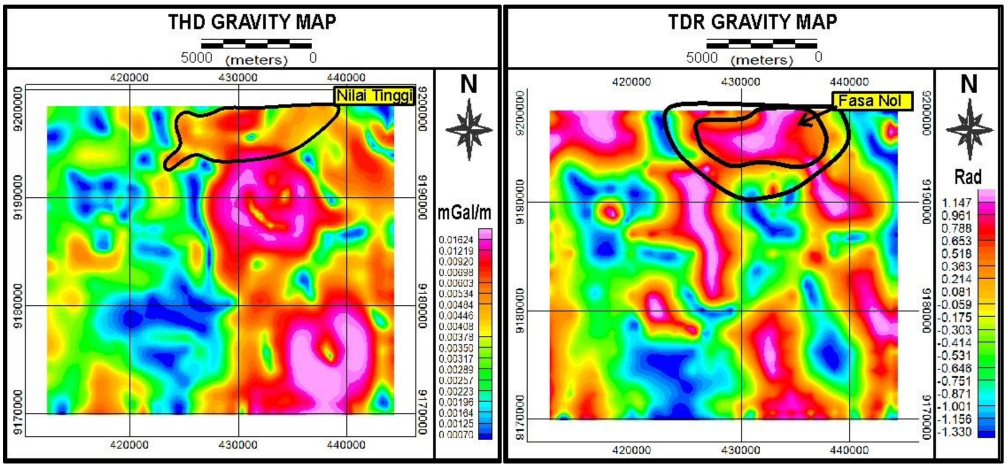

Figure 6. THD gravity map (top) and TDR gravity map (buttom).

The ABL value that has been obtained is then amplified by amplifying the signal through the Total Horizontal Derivative (THD) and Tilt Derrivative (TDR) filters. The THD map will elevate the boundaries of the anomaly. On the map we can see that the low and high anomaly boundaries that we have obtained previously produce high values on this THD map. The position of the previously suspected heatsource is further strengthened by the limits that can be seen with the THD value reaching 0.0164 mGal/m. however, the map tends to strengthen the low anomaly which is suspected to be the reservoir of the geothermal system. Unlike the TDR map, the boundaries of the anomaly will be shown with a value of zero. the anomalous boundaries on this map appear to be rounded and surround the predicted intrusion and reservoir locations.

From the geological data obtained, the rocks that make up the study area are dominated by volcanic rocks with heat source sourced from andesite-basaltic magma under the surface resulting from the vulcanization process of the Telomoyo volcano. This intrusion provides heat to the subsurface rock which is then in contact with the fluid in the reservoir so as to produce a fluid that has heat which then exits to the surface through a weak zone in the form of a normal fault that has been previously delineated.

3.4. Geothermal System Analysis

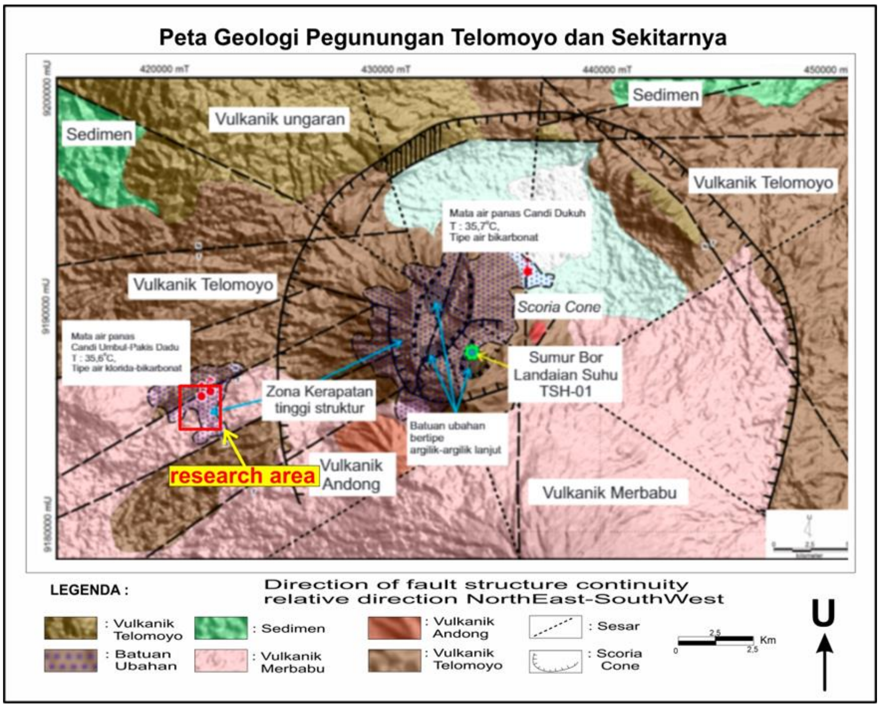

Figure 7. THD gravity map (top) and TDR gravity map (buttom).

Based on the analysis of research data that has been carried out and correlated with geological data from previous studies, information on geothermal systems is obtained which includes heat sources, reservoirs, overburden, faults and recharge areas. A geothermal field will not be able to stand if one of these components is not met. The components of the geothermal system that are the focus of this research are the presence of heat sources and fault structures as fluid migration paths in the Candi Umbul geothermal system.

From the data that obtained, the geothermal system in the area of Candi Umbul is a volcanic geothermal system consisting of a heat source component in the form of andesite magma intrusion, tuff as a reservoir, massive andesite lava as cap rock and the telomoyo mountains as a recharge area. Meteoric water enters the subsurface in the caldera of Mount Seropati through existing fractures to the reservoir in the form of tuff rock with good porosity and permeability values. The fluid is then heated by the andesite intrusion by conduction through the heated subsurface rock. Fluids that have experienced an increase in temperature are transported back to the surface through weak zones such as fractures and faults. In this condition, Fluid transport takes place through the Java fault with an east-west orientation and a normal fault caused by the Telomoyo volcanic activity in a NE-SW direction. The temperature and pressure in the reservoir are maintained due to the presence of overburden or clay cap in the form of andesite lava rock near the surface. In some locations, the fault cuts the claycap so that manifestations arise in the form of hot springs, and one of them is in the area of the Candi Umbul. From the various components that interact with each other in the research area, it is suspected that the Candi Umbul area has geothermal potential which can be developed into a source of electricity generation as an environmentally friendly and sustainable future energy defense effort. The temperature and pressure in the reservoir are maintained due to the presence of overburden or clay cap in the form of andesite lava rock near the surface. In some locations, the fault cuts the claycap so that manifestations arise in the form of hot springs, and one of them is in the area of the Candi Umbul. From the various components that interact with each other in the research area, it is suspected that the Candi Umbul area has geothermal potential which can be developed into a source of electricity generation as an environmentally friendly and sustainable future energy defense effort. The temperature and pressure in the reservoir are maintained due to the presence of overburden or clay cap in the form of andesite lava rock near the surface. In some locations, the fault cuts the claycap so that manifestations arise in the form of hot springs, and one of them is in the area of the Candi Umbul. From the various components that interact with each other in the research area, it is suspected that the Candi Umbul area has geothermal potential which can be developed into a source of electricity generation as an environmentally friendly and sustainable future energy defense effort.

IV. CONCLUSION

Based on the research that has been done, several conclusions were obtained as follows;
1. Variations in susceptibility values from the obtained geomagnetic data indicate a low and continuous magnetic field anomaly which indicates a structure in the form of a fault reinforced by a high value THD value and a zero phase TDR value with a NE-SW direction and an EW direction.
2. Complete Boguer Anomaly (ABL) data shows a suspected heat source in the Northeast of the study area which is indicated by high anomaly values and reinforced by THD maps with high values and TDR with zero phase values.
3. Geological data on the surface is in line with subsurface data in identifying components of the geothermal system which includes the heatsource in the northeast which is cut by a fault in the NE-SW direction which intersects two manifestations of hot water and is in the direction of river water flow. Other components of the geothermal system consist of andesite lava as caprock, andesite intrusion as heat source, tuff rock unit as reservoir and there is a normal fault structure as a weak zone for fluid migration as well as a recharge area zone from the telomoyo mountains.

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