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Analysis of Subsurface Conditions of “X” Geothermal Field Based on Magnetic Data 3D Modelling

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Abstract

In the research area, there are indications of geothermal manifestations, which are indicated by the appearance of hot springs from the surface. This shows that in the research area there is a certain geological structure. This study uses a magnetic method to identify subsurface conditions in more detail. The magnetic method can measure variations in the distribution of objects on the earth’s surface due to variations in the distribution of magnetized objects below the earth’s surface. This study uses secondary data from the measurement method carried out by the Integrated Geophysical Research Team at the Bandung Coal and Geothermal Mineral Resources Center (PSDMBP) in 2009. Then daily corrections and IGRF corrections are carried out to obtain the total anomaly value. Next, an upward continuation filter is performed to obtain regional and residual anomaly values. After processing and analyzing the data, it was found that the density of the residual anomaly is -90 nT to 56 nT. Low anomalies (-90 nT to -5 nT) are sand and shale rock (around the manifestation), and reef limestone (southeast). Moderate anomalies (-5 nT to 4 nT) are sandstone and shale. High anomalies (4 nT to 56 nT) are indicated as compact sandstone and shale. The 3D inversion modeling carried out in this study resulted in the susceptibility valued to depth. The susceptibility value of the study area is -0.0035 SI to 0.0019 SI. It can be interpreted that the susceptibility values of -0.0035 SI to 0.0002 SI are reef limestones and values of 0.0002 SI to 0.0019 SI are sandstone and shale. The 3D model at a depth of 600 meters shows a fault structure in the north-south and southeast-northwest directions. The faults are thought to control the emergence of hot air manifestations in the study area.

Keywords: Upward continuation, Geothermal, Fault, Susceptibility

Introduction

The appearance of geothermal manifestations in the research area is the emergence of hot springs. The hot springs in the study area probably originate directly from the depths and have little influence from surface water or meteoric dilution (Tim Geologi dan Geokimia, 2009). One of the geophysical methods used to identify subsurface conditions is the magnetic method. The magnetic method is a geophysical method that is often used for preliminary surveys in geothermal exploration. The magnetic method is included in the passive geophysical method, where the source comes from within the earth which is used to measure variations in the magnetic field on the earth’s surface caused by variations in the distribution of magnetized objects below the earth’s surface.

Variations in the intensity of the magnetic field will be interpreted and then used as a basis for estimating geological conditions (Utama et al, 2016). This method utilizes the magnetic properties contained in rocks below the earth’s surface. Rocks in the earth contain minerals that also have magnetic properties. The mineral is induced by the earth’s magnetic field and creates a secondary magnetic field. This is the basis of the magnetic method. The magnetic method is based on measuring variations in magnetic intensity on the earth’s surface caused by variations in the distribution (anomalies) of magnetized objects below the earth’s surface (Sampurno, 2012).

Variations in the intensity of the magnetic field on different surfaces indicate a magnetic anomaly, where the magnetic anomaly is generally caused by differences in rock to be magnetized (susceptibility). Low magnetic anomaly values can interpret potential zones and geothermal sources (Chaerunnisah et al, 2016). This research was conducted to determine the value of the distribution of magnetic intensity and susceptibility of 3D modeling based on residual anomaly data as well as to analyze the subsurface conditions of hot water manifestations in the “X” Geothermal field.

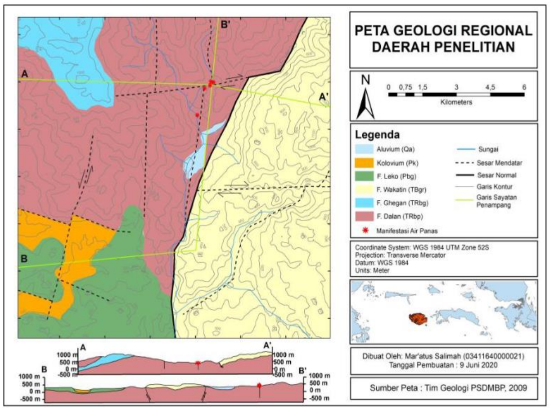

Figure 1. Geological map of the research area (modified from the Geology Team, 2009)

The study area is formed by two regional tectonic stresses consisting of a stress pattern which has pattern almost the same as the Sorong Fault Zone and the Molucca-Sorong Fault zone with a northeast-southeast compression force and a northwest-southeast extension, as well as a northwest-southeast strain stress pattern that produces normal west-east structure. The research location is in the Dalan Formation (TRbp) which is composed of shale sandstone, siltstone, and conglomerate; Wakatin Formation (TBgr); and alluvium (Qa) deposits (Tim Geologi dan Geokimia, 2009).

The geothermal type in the study area is a non-volcanic system. This type of system is geothermal that is not related to Quarternary volcanism activity, found in sedimentary, plutonic, and metamorphic environments associated with tectonic processes with manifestations characterized by the presence of hot springs (Kasbani, 2009). The appearance of geothermal symptoms in the research area is in the form of hot springs appearing in several locations. The formation of the geothermal system in the “X” area begins with surface water that seeps through the permeable zone in the form of fractures and intergrain spaces that enter the reservoir and then undergoes convective thermal heating from the heat sources. Hot springs appear in sedimentary rocks (shale-inserted sandstone) with temperatures ranging from 60° - 90°C with a neutral pH. The results of the geological mapping around the manifestation did not find any magmatism activity so the estimated heat source was the result of active tectonic activity from faults that developed in the investigation area or in intrusive rocks that did not appear on the surface such as in the “WS” geothermal area which is in the western part of the east volcano of the research area (Geology and Geochemistry Team, 2009).

Data and Method

The data used in this study is secondary data from the magnetic method measurements carried out by the Integrated Geophysical Research Team at the Bandung Coal and Geothermal Mineral Resources Center (PSDMBP) in 2009. Magnetic measurements were carried out using two sets of Proton Magnetometers type G-856, with an accuracy of 0.1 nT. Magnetic data contains several parameters, including coordinates, time, elevation, H value at the measurement point, and daily variation value (base). **Table 1** below is the result of susceptibility measurements on 5 rock samples.

Table 1. Rock sample susceptibility value
(for the sake of location privacy research, belongs to the company, the numbers are disguised for the coordinates)

No	X (m)	Y (m)	Susceptibility	Lithology
1	****88	*****97	0.0002	Sandstone
2	****86	*****95	0.0001	Sandstone
3	****20	*****75	0.00028	Limestone
4	****83	*****62	0.00001	Sandstone
5	****57	*****84	0.00002	Limestone

The research location is in the Maluku “X” Field with 91 points of magnetic method measurement consisting of 17 random points with 25-meter point intervals, and 74 points located on 4 tracks with intervals of 100-250 meters. The interval between the tracks is 500-1000 meters.

The data obtained from the results of measurements in the field is the total magnetic field data which is still influenced by the external magnetic field and the main magnetic field of the earth. Therefore, it is necessary to make daily (diurnal) corrections to eliminate the influence of the external magnetic field. Daily correction is done using the equation (1) below:

$$\Delta H = H_i \pm H_{kh} - H_{IGRF} \quad \text{.....................} (1)$$

After that, the IGRF correction was carried out to eliminate the influence of the main magnetic field. This correction is done by entering the inclination, declination, latitude, longitude, elevation, and measurement date values.

Total magnetic anomaly obtained after daily correction and IGRF correction. Magnetic anomaly value obtained by using equation (2) below:

$$U(x, y, z_0 - \Delta z) = \frac{|\Delta z|}{2\pi} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{U(x', y', z_0)}{R^3} dx' dy' \text{ ...}(2)$$

Furthermore, the gridding process was carried out to obtain a map of the distribution of the total magnetic anomaly. In this study, the type of grid used is kriging.

The separation of regional and residual anomalies is performed using an upward continuation filter. An upward continuation process was carried out to reduce the effects of local magnetic anomalies that are not related to the survey target and to amplify magnetic anomalies from deep sources. In this study, the upward continuation was varied from a height of 100m to 1000m to see the patterns of anomalies change at different heights. The upward continuation process is deemed sufficient if the anomaly pattern that is the target of the research is no longer influenced by shallow anomaly sources and changes in the anomaly contours seem to be stable.

The anomaly from the upward continuation describes a regional anomaly (Daud et al, 2017). Then the processing is continued to get the residual anomaly. This modeling is done by using the VOXI 3D feature. This 3D inversion process is carried out online by first signing in with a Geosoft ID. The data used in making the 3D model area Residual Anomaly Map, Elevation Map, and boundary polygon data of Residual

Anomaly Map. The following are the steps for creating a 3D model, including

a. Create a polygon

In this study, the selected model resolution is 200 m. Determination of model resolution will affect the number of initial model cells. The data collection location has an area of ± 4 x 6 km2 so that the number of cells or dimensions (x,y,z) obtained are 24, 33, and 30.

b. 3D Block

After creating a polygon, a 3D block will appear with the number of cells (x,y,z) namely 24, 33, and 30. The resulting 3D block is still empty.

c. Input Parameter

Data collection in the field was carried out on December 15, 2009, so that the field strength is 41847, the angle of inclination is -23.99°, and declination is 1.9°. After that, enter the settings of the 3D geometry. In this study, remove a linear trend background. According to the Geosoft Guidebook, this option will remove the linear trend from the observed data to eliminate long wavelengths.

d. Run Inversion

Run inversion is performed after parameter input. The run inversion process can be seen as shown in **Figure 2**. After that, the results of the 3D model will appear.

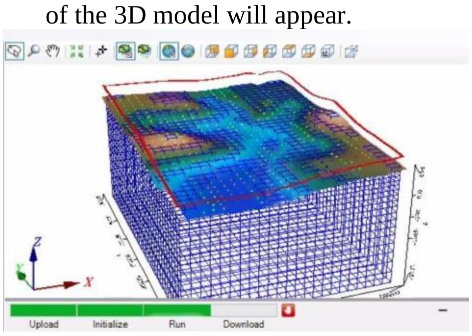

Figure 2. Run inversion process online

Next, 2D modeling with incisions is made on the results of the 3D inversion. In this study, a 1-pass incision was made that passed through the manifestation of hot water as shown in Figure 3.

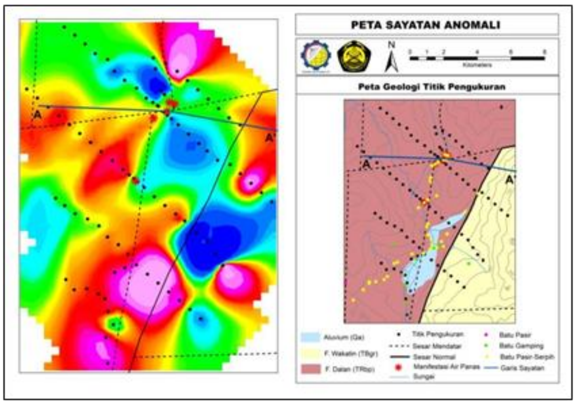

Figure 3. Anomaly incision map

In this study, the work steps performed are shown in the following flowchart in **Figure 4.**

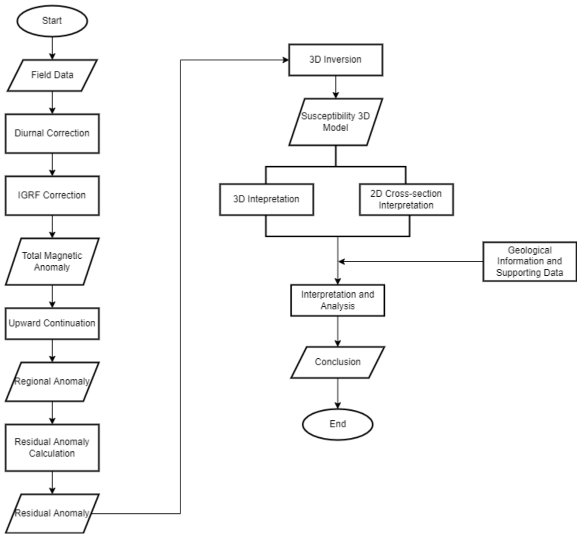

Figure 4. Research flowchart

Result and Discussion

Magnetic anomaly obtained after daily correction and IGRF correction. The value of the magnetic anomaly intensity in the study area is -206 nT to -37 nT. Low anomalies in the range of -206 nT to -102 nT are interpreted as limestone. Moderate anomalies in the range of -120 nT to -90 nT are interpreted as sandstone and shale. Meanwhile, the high anomaly in the range of -90 nT to -37 nT is interpreted as compact sand and shale.

The upward continuation process was carried out with variations of 100m, 300m, 500m, 600m, 800m, and 1000m. The result of upward continuation considered the most optimum is at an altitude of 600m because there are no local anomalies. Meanwhile, at an altitude of 800 meters, a new anomaly appears in the northwest part. And at an altitude of 1000 meters, the new anomaly looks clear, and more information is lost. The intensity value of the regional anomaly is -113 nT to -91 nT. A low anomaly with an intensity value of -113 nT to -106 nT is limestone. Moderate anomalies with intensity value -106 nT to -101 nT are suspected as rocks undergoing a demagnetization due to hydrothermal activity. The high anomaly with an intensity value of -101 nT to -91 nT in the south is sandstone and shale. Whereas in the southeast it is thought to be partially filled with limestone. The low anomaly bordering the high anomaly in the east is believed to be a fault structure trending northwest southeast.

The intensity value of the residual anomaly is -90 nT to 56 nT with a more diverse anomaly pattern. A residual anomaly shows a low anomaly with a value of -90 nT to -5 nT around the hot spring manifestation, indicated as sand and shale. Moderate anomalies with values of -5 nT to 4 nT are suspected as sandstone and shale. The high anomaly with a range of 4 nT to 56 nT is indicated as compact sandstone and shale. The low anomaly which is bordered by the high anomaly in the north indicates a fault structure with an almost north-south trend.

The input data used in the inversion process is the residual anomaly map. In the initial model, the number of cells or blocks on the X-axis is 24, the Y-axis is 33, and the Z-axis is 30. So, the number of blocks in the initial model is 23760. The error value used in this 3D modeling is 5% of the standard deviation value. The standard deviation value in statistical data is 18.993, so the error value is 0.95%. Iterations are carried out until the data fit value is close to 1. In this inversion, iteration is carried out 4 times.

3D inversion modeling of magnetic intensity inversion results in susceptibility values. This model aims to model the distribution of susceptibility in the research area.

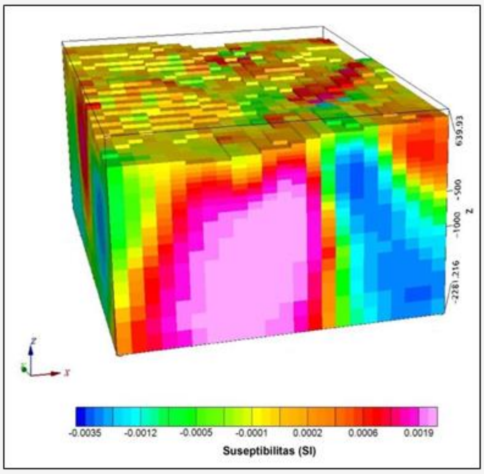

Figure 5. 3D susceptibility model

The 3D susceptibility model is shown in **Figure 5**. The susceptibility values obtained were -0.0035 SI to 0.0019 SI. The depth obtained is 2281 meters. Low susceptibility values of -0.0035 SI to 0.0002 SI are reef limestones, while values of 0.0002 SI to 0.0019 SI are sandstone and shale.

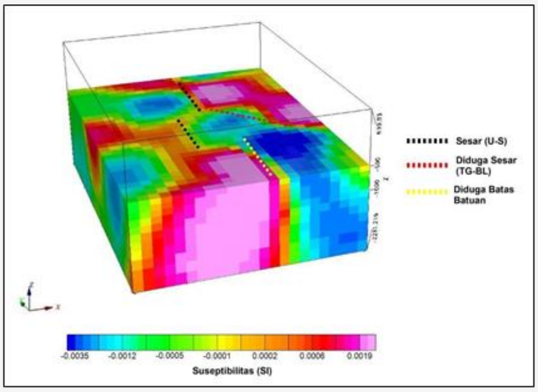

Figure 6. 3D model interpretation

Figure 6 shows a 3D model where at a depth of 600 meters there is a contrasting susceptibility. The susceptibility contrast marked by the black line is a horizontal fault with a north-south direction. The contrast anomaly marked with a red line is thought to be a fault with a southeast-northwest direction. Meanwhile, the contrast of susceptibility visible in the southeast is thought to be the boundary between sandstone and limestone. The western part is sandstone (Dalan Formation) and the eastern part is reef limestone (Wakatin Formation). After that, an incision is made to see a 2D cross-section.

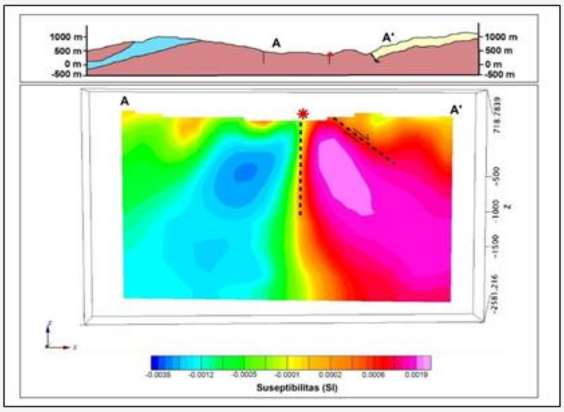

Figure 7. 2D cross-section

The results of the 2D cross-section on the A-A' trajectory are shown in **Figure 7**. The contrast of the susceptibility anomaly in the middle shows a horizontal fault structure with a north-south direction. This fault is thought to be the control of the manifestation of hot water discharge in the study area. While the contrast anomaly in the east is a normal fault structure.

Conclusions

The conclusions that can be drawn based on the result of the study are:

1. Low anomalies with values of -90 nT to -5 nT are sandstone and shale (around the manifestation) and reef limestone (southeast).
2. Moderate anomalies with values of -5 nT to 4 nT are sandstone and shale.
3. High anomalies with values of 4 nT to 56 nT are located in the south with anomalies centering the section indicated as compact sandstone and shale.
4. The susceptibility value of the study area is -0.0035 SI to 0.0019 SI. Low susceptibility with a value of -0.0035 SI to 0.0002 SI is reef limestone, while values from 0.0002 SI to 0.0019 SI are sandstone and shale.
5. In the 3D model, there is a fault structure with a north-south direction and southeast-northwest, these faults are thought to be the emergence control hot water manifestation.

Based on the results of processing and analysis in this study, the authors have suggestions for the next step, namely to carry out a second vertical derivative to further analyze the fault structure.

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