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Analysis of The Subsurface Structure of the Geothermal Potential Area Based on Magnetic Data (Case Study in Blue Mountain-North Nevada)

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Abstract. Energy is an absolute necessity in human life and its availability has a significant influence on the progress of development. One of renewable energy sources exist all the time is geothermal. The magnetic method is one of the advanced exploration techniques in geothermal observations. Magnetic methods are used to determine the magnetic properties of rocks and subsurface geological structures based on magnetic field anomalies. Knowing the subsurface geological structure will be very helpful in interpreting the basic system and faults that may be used as a path for geothermal fluids to escape. This study is an analysis of the magnetization of the earth's surface from the acquisition of magnetic susceptibility values. Geothermal causes the value of the magnetic anomaly to be low because a demagnetization process removes the rock's magnetic properties. Mag2dc software is used to determine the earth's subsurface structure in 2 dimensions. In the modeling obtained, there is magnetic susceptibility contrast which is negative and that is at a depth close to the earth's core. This area indicates the existence of a geothermal source. In the modelling there are three types of rocks that make up the subsurface structure: granitic, volcanic, and sedimentary rocks.

Keywords: *geothermal; magnetic method; modeling; susceptibility.*

1 Introduction

Energy is an absolute necessity in human life, and its availability significantly influences the progress of development. Indonesia's energy needs have so far been supplied from fossil energy sources such as oil, gas and coal. This fossil energy source is not environmentally friendly because it produces pollution that increases global warming. Apart from being less friendly to the environment, the availability of fossil fuels will also gradually run out if they are continuously used. Therefore, geothermal energy is a renewable energy source that is widely available in Indonesia that can provide energy for all time. One of the most extensive renewable energies in Indonesia is geothermal. Geothermal is 40% of the contributors to geothermal potential worldwide, spread over 299 locations in Indonesia [1], (Sugiharta, et al. 2013). According to UU No. 27 of 2003 concerning geothermal energy, geothermal resources are thermal energy source contained in hot water, steam, and rocks along with other minerals and gases, all of which cannot be separated in a geothermal system.

Geothermal, which is widely spread in the territory of Indonesia, can be identified by several kinds of exploration activities carried out by researchers. Various type sort of method and geophysical surveys can be used in the search for potential geothermal areas, one of them is the magnetic method. Geophysical investigations apply the principles of applied physics to determine the structure and composition of layers within the earth to find potential geothermal sources in an area [2], (Sarkowi, 2010). This investigation is applied by knowing the physical properties of rocks below the surface. Anomalies found in the rocks can predict the potential of geothermal systems. One of the geophysical methods used to investigate the existence of a geothermal system is the magnetic method [3], (Loper, 2007).

The magnetic method is a method that uses the basis of measuring variations in the intensity of the magnetic field on the earth's surface caused by anomalies of magnetic objects (rocks) below the earth's surface. This research uses the magnetic method. The magnetic survey shows the various states of the magnetic field at the location to be measured. The magnetic method is often used in the field because it is cheaper and easier than other geophysical methods [4], (Telford, 1990).

This study uses the magnetic method. The research data processed is the data from a geophysical survey from the United States Geological Survey (USGS) in the Blue Mountain and Pumpernickel Valley north-central Nevada using the geomagnetic method. The field data collection took place in August 2012. The data were processed using the following software: Microsoft Excel, Surfer 20, Magpick, and Mag2dc to obtain anomalous object models.

2 Research Methodology

2.1 Measurement

Magnetic data were taken using two magnetometers (in this case, the Proton Procession Magnetometer) where had mapped one tool to measure the magnetic field at the Base Station (BS) for measuring the daily variations and another tool to measure the magnetic field in the field had been mapped in the form as grids. The frequency of the proton precession is directly proportional to the strength of the magnetic field ([5], Kearey et al. 2002 [6], Lowrie, 2007 [7], John et al. 2011).

Measurements in the field are carried out in several stages. First, the PPM instrument is calibrated. Then, daily magnetic field measurements in the Base Station are carried out every minute interval that is determined and adjusted to the needs of the measurements. Several corrections are made in measuring the magnetic field to determine the daily variation of the magnet, after obtaining the magnetic field data. In collecting data in the area, the data recorded is the magnetic field data listed on the tool, the position of the measurement point using GPS, and the time of measurement.

2.2 Correction

The magnitude of the magnetic field measured at station point is the contribution of the earth's main magnetic field, the external magnetic field, and the anomalous magnetic field. To obtain the strength of the anomalous magnetic field generated by the rock under each surface measurement point, it is necessary to make corrections to the main magnetic field and the external magnetic field, which is also measured through PPM. The corrections made include the following;

1) Daily correction (diurnal correction) is a correction to remove the influence of the external magnetic field, especially from solar activity. The daily correction is obtained from the variation of the magnetic field strength over a spesific time interval at the base point corresponding to the measurement time of each station point. If there is a decrease in the strength of the magnetic field, it must be added for the reduction to the measurement result at the station point, and vice versa.
2) Topographic correction is a correction to eliminate the influence of the magnetic field due to topographic differences. There is no general rule in this correction, but if it is considered that there is no magnetization, the correction made only refers to the difference in elevation.
3) IGRF correction is a correction to eliminate the influence of the main magnetic field. This is necessary because the main magnetic field of the earth changes with time [8], (Broto, 2013).

The final result of the magnetic method is the strength of the magnetic field after correction. With the equation:

$$H_{daily} = \frac{(t_n - t_{in})}{(t_{fi} - t_{in})}\left(H_{fi} - H_{in}\right)$$

Where t represents time, H represents the measured magnetic field, index n represents the n^{th} data, index in represents the initial data at the base station, index fi represents the final data at the base station.

This daily correction (H_{daily}) can be positive or negative. If the value is positive (H_{daily}), subtract the value of the measured magnetic field (H_{tot}) at that time from this daily value. If the value is negative (H_{daily}), then add the measured magnetic field value (H_{tot}) at a certain time to this daily value. The corrected magnetic field (ΔH) can be written by the equation:

$$\Delta H = H_{tot} \pm \Delta H_{daily}$$

Susceptibility is the degree of magnetism of an object by the influence of a magnetic field. To calculate the magnetic susceptibility value at the measurement point, this can be obtained from the equation:

$$K = \frac{\Delta H}{H}$$

with,
K = Magnetic field susceptibility at the measuring point
ΔH = Magnetic field anomaly at the measurement point (nT)
H = Average magnetic field over the measuring area (nT)

The value of susceptibility is significant in looking for objects that have anomalies because of the variation in the characteristics of each type of mineral or mineral rock.

4) Upward continuation aims to eliminate local influences still present in the data and look for the effects of regional anomalies. The higher the data continuity, the more local information is lost, and regional information is more precise. Upward continuation should be manageable because it can reduce the local magnetic anomaly value from the magnetic source.

2.3 Data Interpretation

Data interpretation is carried out in two ways, that are quantitative interpretation and qualitative interpretation. Qualitative interpretation is based on regional anomaly contour map analysis, while quantitative interpretation is performed using Mag2dc software.

Qualitative interpretation aims to predict the presence of anomaly-causing objects and to localize areas that have anomalies. Quantitative interpretation aims to determine the shape and model and depth of anomalous objects or geological structures through mathematical modeling.

On the local contour map that has been obtained, a line is drawn that crosses the lowest anomaly and the highest anomaly (line section) on the contour map. This trajectory can be created using Surfer20 software. The trajectory data obtained is input data for the Mag2dc software as an anomaly cross-section. In Mag2dc, a match is made between the observed curve and the model curve in forming the subsurface layer with a forward modeling approach (matching the model profile with the field data profile) using the trial and error method. Magnetic susceptibility values for rock types are obtained by adding up the magnetic susceptibility contrast values for rock types obtained by adding up the magnetic susceptibility contrast values for rock types to the average magnetic susceptibility value.

2.4 Research Flow Chart

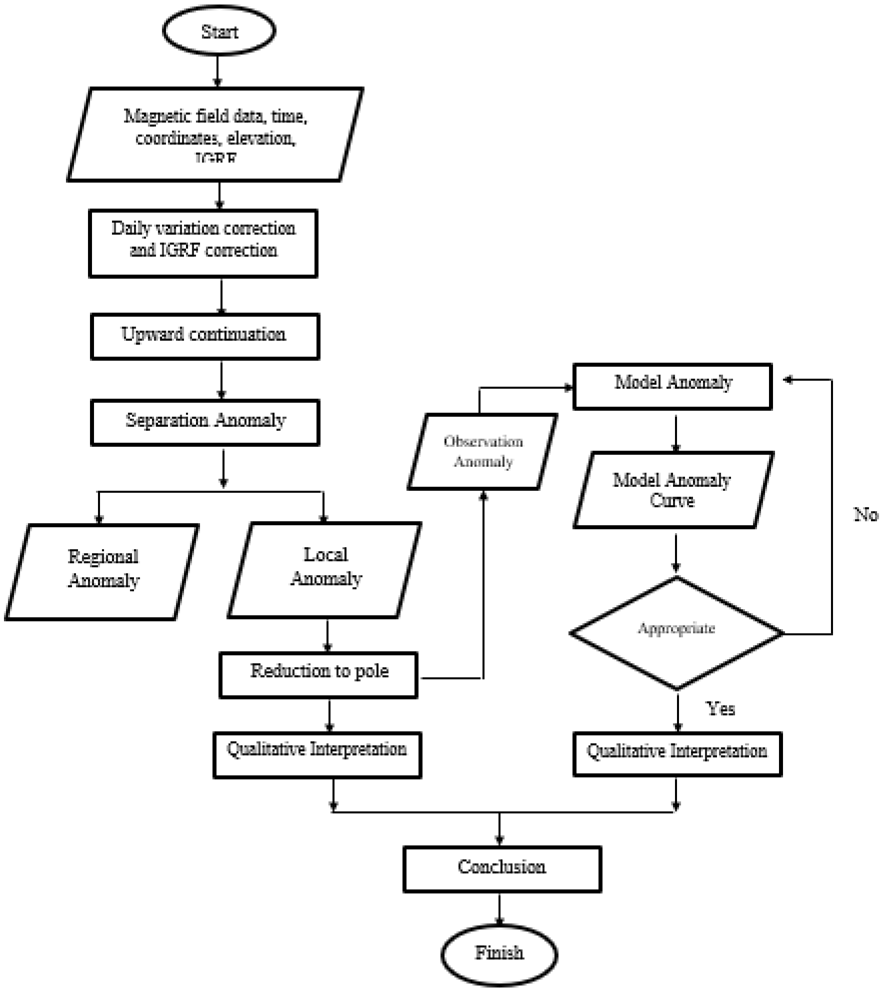

Figure 1. Research Flow Chart

3 Result and Discussion

3.1 Magnetic Anomaly Distribution

The data obtained from the research area are in the form of latitude and longitude coordinates in the decimal degree coordinate system, as well as the total magnetic anomaly value resulting from daily (diurnal) and IGRF corrections. So, before carrying out further data processing, the decimal degree coordinate system is converted to Universal Transfer Mercator (UTM), namely easting and northing coordinates in meters. The aim is to make it easier to read the contour map maker software. In Figure 2, the contours of the total magnetic field show variations of different magnetic field anomalies based on the color scale. This anomaly value describes the difference in the susceptibility of rock layers beneath the surface of the area. Thus, the contrasting magnetic anomaly on the contour map indicates the possibility of a potential geothermal source below the surface so that it can continue that data processing. Anomaly values are grouped into three groups, namely: high anomaly shown in yellow to red (-6 to 14 nT), moderate anomaly shown in light blue to light green (-26 to -10 nT) and low anomaly depicted in color purple to blue (-46 to -30 nT).

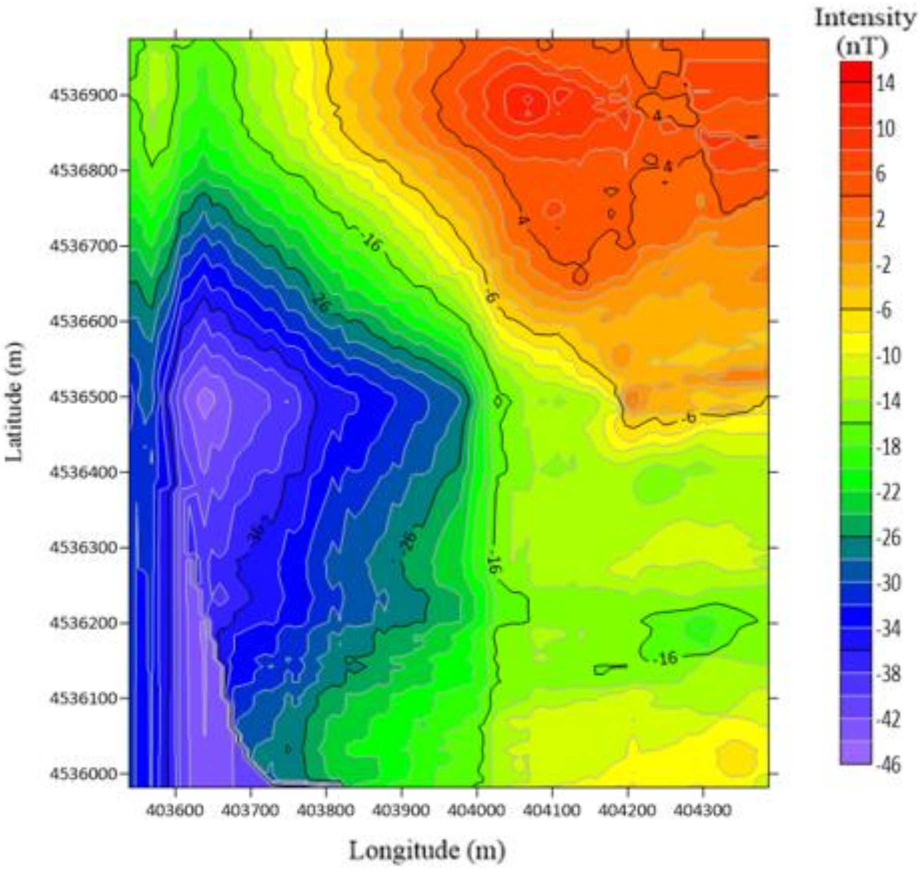

Figure 2. Total anomalous magnetic field.

3.2 Magnetic Data Interpretation

Based on the magnetic anomaly and rock susceptibility obtained, magnetic anomaly modeling is made to interpret the subsurface structure. The initial modeling step is in the form of 7 lines sections in Figure 3, representing all anomaly contours.

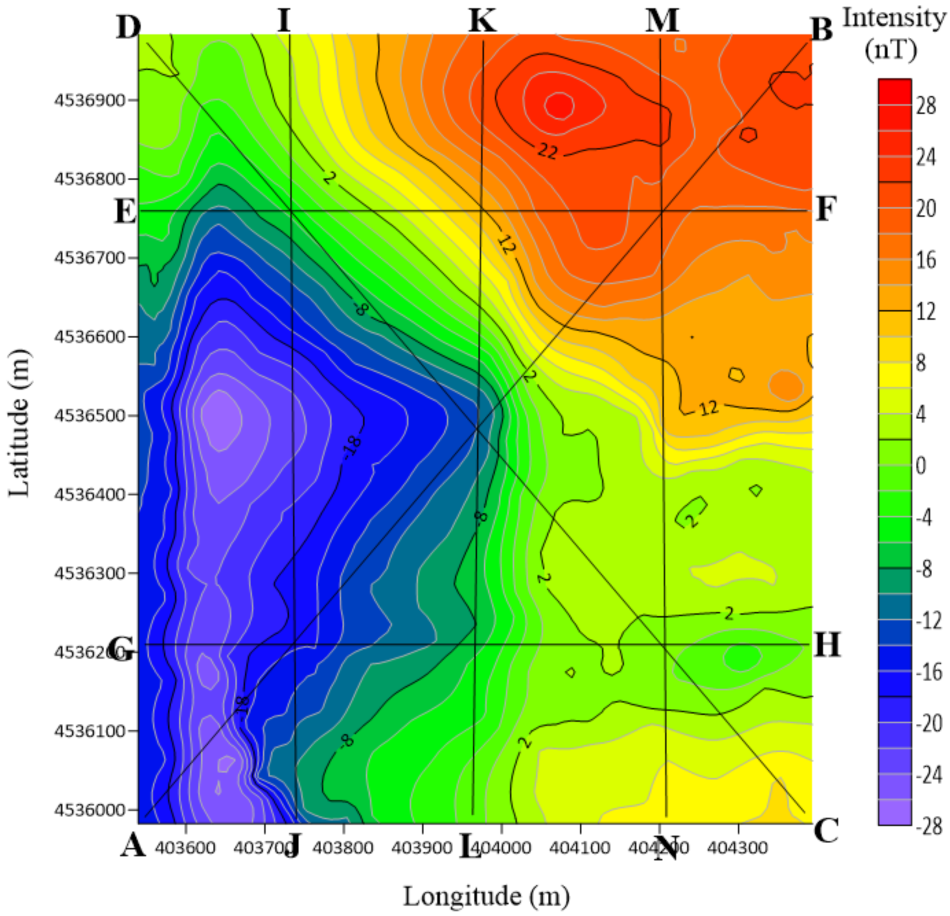

Figure 3. Modeling trajectory on local anomaly contour area

3.2.1 Magnetic Anomaly Modeling

Quantitative interpretation is needed to describe the subsurface structure from the measured data. Quantitative interpretation aims to determine the lithology of the research area. Interpretation is carried out by making a geomagnetic cross-sectional model using Mag2dc software by inputting data in table 4.1 so that Figure 4.4 will be obtained, which has a translation in the form of an image showing the susceptibility and color values based on rock layers. In conducting numerical modeling, several parameters of the earth's magnetic field are required in the study area, which include the IGRF value (51,722 nT), declination angle (64.5°), inclination angle (-14.5°), as well as several modeling parameters. Look at the picture below.

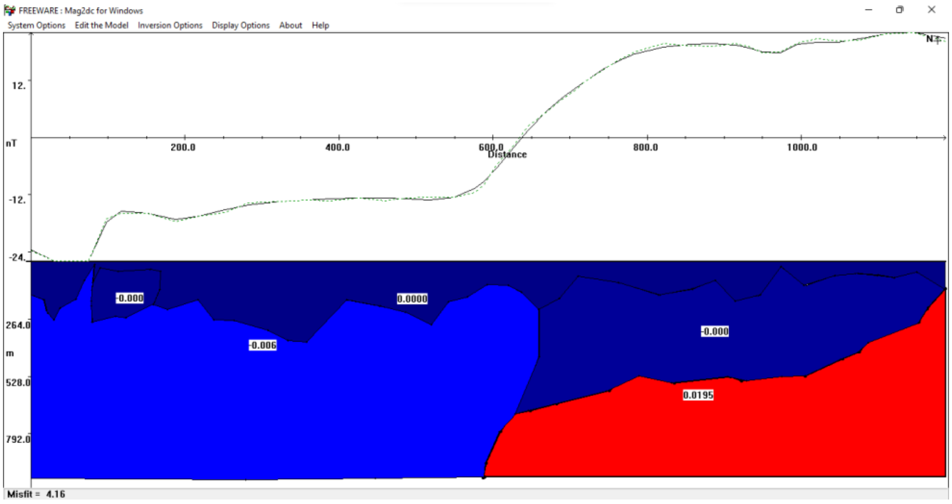

Figure 4. A-B Path Modeling

Based on the results of subsurface geological modeling of A-B slices and actual regional geological information in Figure 4, rocks with a susceptibility range of 0.0000 to 0.000, which are blue, are suspected of sedimentary rocks such as argillite, mudstone, metasediment, and slate types. Rock layers with red susceptibility 0.0195 are considered gabbro or diorite rock types. At a depth of 100 meters down to 1000 meters, the susceptibility values of several layers show negative values of -0.000 and -0.006. It is caused because the rock is demagnetized. Rocks with a negative susceptibility value are suspected as rocks with geothermal potential, which is indicated as a path passed by the hot fluid flow underneath.

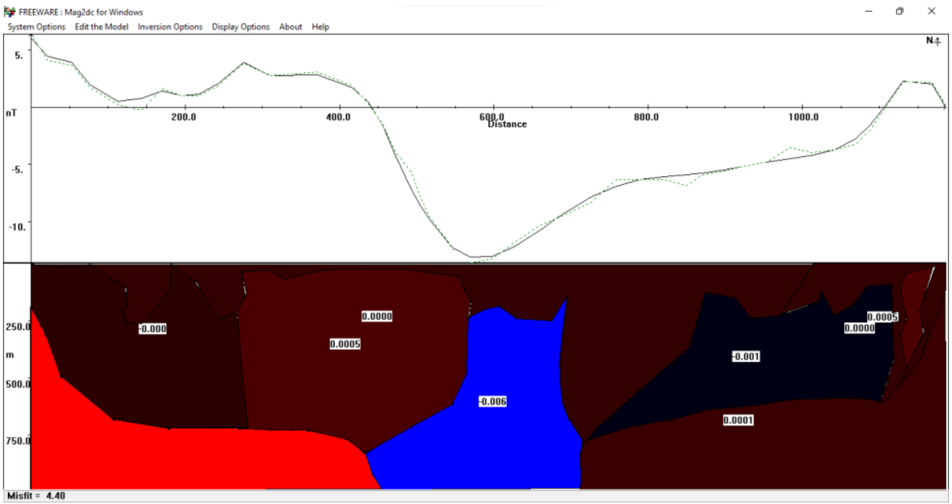

Figure 5. C-D Path Modeling

From the results of the C-D modeling and based on the basic geological information of the area in Figure 5, the red, blue and brown rock layers with a susceptibility 0.0000, 0.000, 0.0001, and 0.0005 are presumed as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.001 is presumed as volcanic rock which is basalt rock types. The rock with susceptibility 0.006 is presumed as granitic rock which is gabbro or diorite rock types. In rock layers with negative susceptibility values, namely -0.000, -0.001 and -0.006, it indicates that the rock is demagnetized. This rock layer is marked as a path of hot fluid under the surface of an area with geothermal potential.

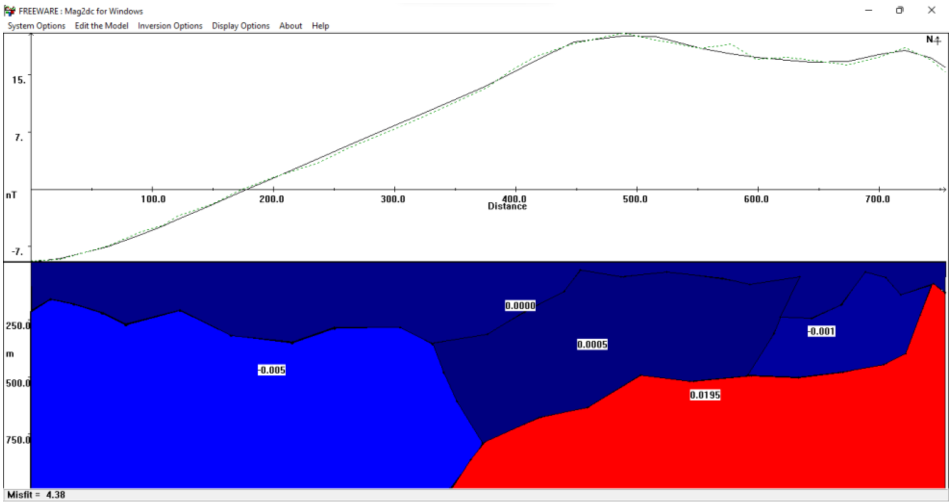

Figure 6. E-F Path Modeling

From the results of the E-F modeling and based on the basic geological information of the area in Figure 6, the red rock layer with a susceptibility of 0.0195 is suspected as a type of gabbro or diorite rock. Blue rock layers with a susceptibility range of 0.0000 and 0.0005 are presumed as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.001 is presumed as volcanic rock which is basalt rock types. The rock with susceptibility 0.005 is presumed as granitic rock which is granite rock types. Rock layers with negative susceptibility, namely -0.001 and -0.005 indicate that the rock is demagnetized. This rock layer is marked as a path of hot fluid under the surface of an area with geothermal potential.

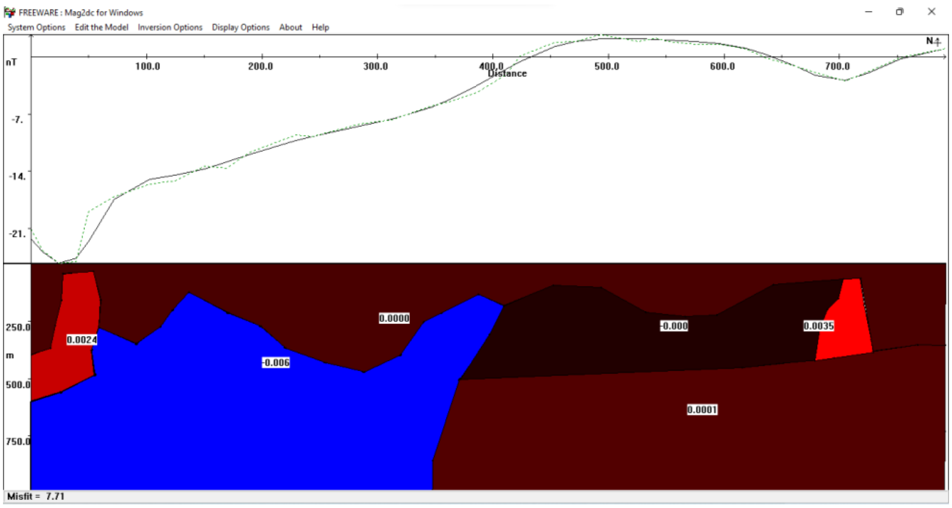

Figure 7. G-H Path Modeling

Based on basic regional geological information, the G-H modeling results in Figure 7 show that rock layers with a susceptibility 0.0000, 0.000, 0.0001 in brown are suspected as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.0024 in red is presumed as volcanic rock which is basalt rock types. The rock with susceptibility 0.006 in blue is presumed as granitic rock which is granite rock types. The rock with susceptibility 0.0035 is presumed as granitic rock which is granodiorite rock types. Rock layers with a depth of 100 meters to 1000 meters with a negative susceptibility of -0.000 and -0.006 indicate that the rock is demagnetized. This rock layer is marked as a path of hot fluid under the surface of an area with geothermal potential.

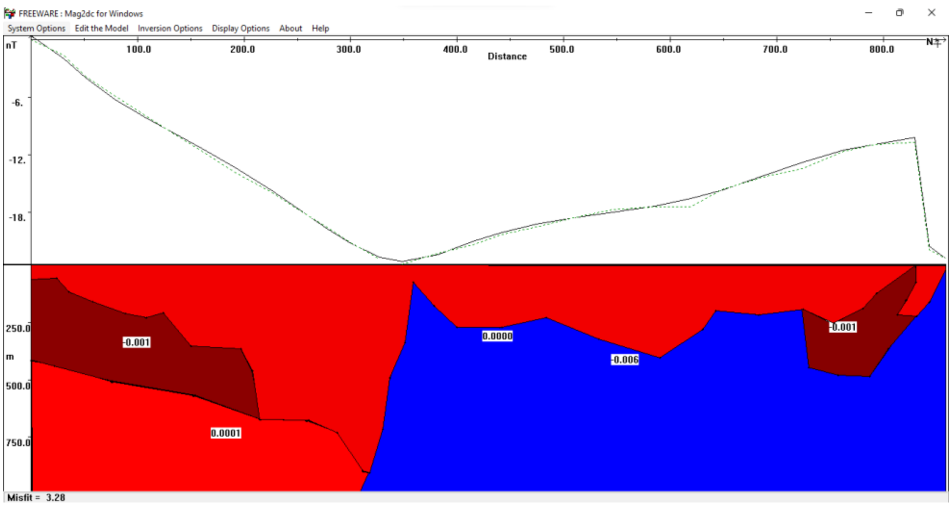

Figure 8. I-J Path Modeling

From Figure 8, the results of the I-J modeling and based on actual regional geological information, the blue layers with a susceptibility 0.0001, 0.00000 are suspected as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.001 in red is presumed as volcanic rock which is basalt rock types. The rock with susceptibility 0.006 in blue is presumed as granitic rock which is granite rock types. In rocks with negative susceptibility, namely -0.001 and -0.006, it indicates that the rock is demagnetized and is a path for the geothermal fluid underneath.

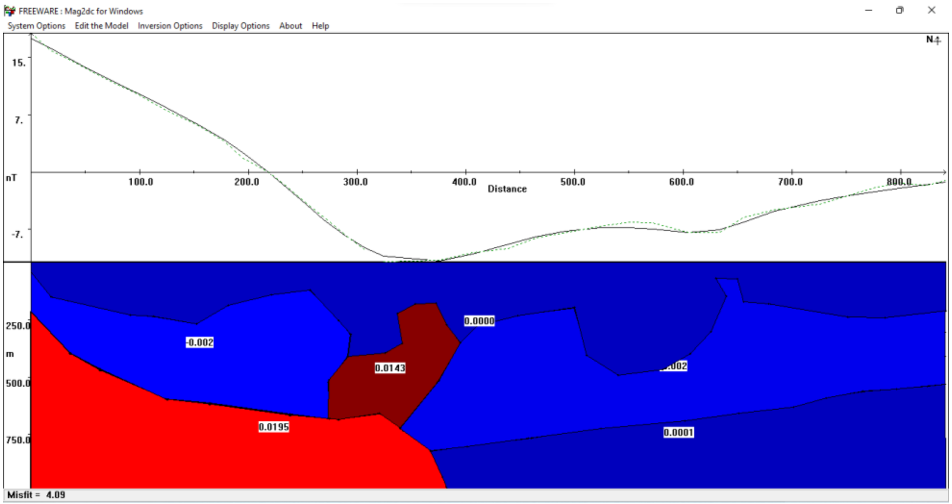

Figure 9. K-L Path Modeling.

From Figure 9, the K-L modeling is the point of intersection of the locations of the sections AB, CD, and KL so that at the end of the meeting of the three tracks, they are in the exact location and show the same rock structure. In the blue rock layers with a susceptibility 0.0000, 0.0001 are suspected as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.002 in blue is presumed as volcanic rock which is basalt rock types. The rock layer with a red color with a susceptibility of 0.0195 and 0.0143 is a type of granitic rock which is gabbro or diorite rock types. Rocks with negative exposure is -0.002 demagnetized rock and is indicated as a path for geothermal fluid flow.

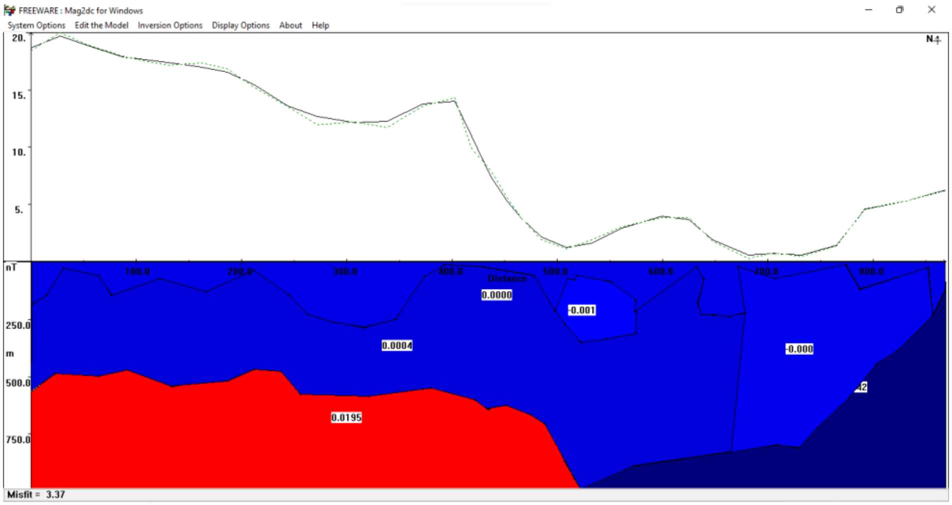

Figure 10. M-N Path Modeling

In Figure 10, based on the M-N modeling results and actual regional geological information, blue rock layers with a susceptibility 0.0000, 0.000, 0.0004 are suspected as sedimentary rocks such as argillite, mudstone, metasediment, and slate rock types. The rock with susceptibility 0.001 is presumed as volcanic rock which is basalt rock types. The rock with susceptibility 0.006 in blue is presumed as granitic rock which is granite rock types. The rock with susceptibility 0.0035 is presumed as granitic rock which is granodiorite rock types.are suspected of argillite, mudstone, and sandstone types. In the red rock layer with a susceptibility of 0.0195, it is supposed that it is a type of gabbro rock. The rock with susceptibility 0.00422 is presumed as granitic rock which is granodiorite rock types. Rocks with negative susceptibility, namely -0.000 and -0.001, are demagnetized rocks and are geothermal fluid flow paths.

4 Conclusion

Based on the results of data processing using the magnetic method of magnetic field anomalies on the surface of the Blue Mountain and Pumpernickel Valley area of north-central Nevada, it can be concluded that there is a magnetic anomaly with a maximum magnetic value (positive value) and a minimum magnetic field value (negative value) indicating there is geothermal potential underneath. Through forward modeling carried out with Surfer 20, Magpick, and Mag2dc software, it can be found that there are rock layers below the surface of the area in the form of argillite, mudstone, sandstone, and gabbro which is the rock which has been altered due to high temperatures resulting in a decrease in the value of the magnetic susceptibility of rocks, and sedimentary rocks of shales or shales.

Acknowledgement

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