

## Identification of subsurface structures in the geothermal manifestation area of mountain pusuk buhit samosir district, north Sumatra province using gravity method

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### Abstract

Mount Pusuk Buhit is an active volcano around Lake Toba which has a height of 1980 meters above sea level. On Mount Pusuk Buhit there are geothermal manifestations in the form of hot water flows and fumaroles. What was carried out in this research was the identification of subsurface structures in geothermal manifestation areas using the GGMPlus satellite image gravity method. GGMplus is a gravity data set based on GRACE satellite data, GOCE satellite, EGM2008 and topographic gravity. Based on the Sidikalang geological map sheet, in this study there are 5 types of rock formations, namely the Pusuk Buhit Formation (Qvpb), Kluet Formation (Puk), Kualu Formation (Mtk), Alluvium Formation (Qh) and Toba Tufa Formation (Qvt). Bouger anomaly values in this study ranged from -7.8 mGal to 6.0 mGal, low anomalies ranged from -7.8 mGal to -1.4 mGal. Moderate anomalies range from -1.0 mGal to 0.4 mGal. Meanwhile, the anomaly height in this study area ranges from 0.9 mGal to 6.0 mGal. The geothermal manifestation area of Mount Pusuk Buhit is located at a low anomaly. The depth of the residue map in this study is 520 meters while the regional depth is 1992 meters. From the results of this research, 22 faults were identified, namely 14 normal faults and 8 reverse faults.

**Keywords:** Gravity methods, satellite images, geothermal, geological structure

## 1 Introduction

Energy is one of the basic human needs, because with energy humans can do many things. As the population in Indonesia increases, energy needs also increase. Currently, most of Indonesia's needs are met from fossil fuels (oil and gas and coal). To be able to meet energy needs in the future, the government is developing several alternative energy sources, one of which is geothermal or geothermal heat (Utama et al., 2012). Geothermal energy itself is heat energy stored in rocks below the earth's surface and the fluids contained therein. The use of geothermal energy as an energy source began at the beginning of the 20th century, when electricity was first produced from geothermal steam in Larderello, Italy in 1904 (Gupta and Roy, 2007). Geothermal energy sources form naturally beneath the Earth's surface by heating subsurface water with hot igneous rock and magma. The important components in a geothermal system according to (Suharno, 2013) are: Heat source, Reservoir or porous rock where hot steam is trapped inside, Caprock or covering layer in the form of claycap (watertight rock), Geological structure (faults, fractures and unconformities), and water catchment areas or subsurface water flow (recharge areas).

Indonesia is a country that is included in the Pacific Ring of Fire, which is a circular area where plate boundaries meet, resulting in the formation of many volcanoes. Indonesia is located between the meeting of three large tectonic plates, namely the Indo-Australian Plate, the Eurasian Plate and the Pacific Plate. These three plates produce a row of volcanoes that stretches from west to east Indonesia. Indonesia's geothermal potential reaches 40% of the world's geothermal reserves. This is because Indonesia itself has 129 volcanoes which

have the potential to become geothermal development areas (Wismaya.YG, 2016).

Geothermal is a natural resource in the form of hot water and steam that is formed in the earth's reservoir through heating water below the surface by hot rocks (Winarsih, 2014). Based on the Ministry of Energy and Mineral Resources' program for 2020-2024 in an effort to increase the use of new, renewable energy by 23%, including the development of PLT (Geothermal Power Plant Center). In this case, the government will prepare 20 new Geothermal Mining Working Areas (WKP) with a total capacity of around 683 MW spread throughout Indonesia. West Java Province is the region with the largest geothermal potential in Indonesia. This province has a total resource potential of 2,159 MW with reserves of 3,765 MW (Gunawan et al, 2021).

Geothermal systems in Indonesia are generally hydrothermal systems, namely geothermal systems whose reservoirs contain steam, water or a mixture of both. (Risdiyanto et al., 2015). Geothermal energy has good environmental properties (environmentally friendly) and can be used as an alternative energy to replace fossil fuels. Geothermal energy is useful for increasing energy stability and security and reducing greenhouse gas emissions (R. T. Mary & P. Studi, 2017). Based on their relationship to the geological setting, geothermal systems in Indonesia can be grouped into 3 types, namely volcanic systems, volcanotectonic systems and non-volcanic systems (Kasbani, 2010).

This research was conducted on Mount Pusuk Buhit, Samosir Regency, North Sumatra Province. At this research location there are geothermal manifestations that emerge to the surface

in the form of hot water flows and fumaroles. With the emergence of these manifestations, research was carried out using the GGMPlus satellite image gravity method to identify subsurface structures in the research area. Collecting gravity data is not only done directly in the field, but can be done using a satellite complete with the position of the data points on the earth's surface. One of the satellite data that can be used in gravity measurements is the Global Gravity Model Plus (GGMplus). GGMplus is a gravity model derived from space satellite measurements and terrestrial data. These space satellites include GRACE, GOCE, and EGM2008 with high-resolution SRTM topography data. Gravitational Model 2008 (EGM 2008) is a *spherical harmonic model* of the Earth's gravitational potential, which can be used to determine *geoid undulations* at a position. EGM 2008 is one solution for obtaining orthometric height data using the *GPS Leveling measurement method*. The GGMPlus gravity model is the result of research at Curtin University (Perth, Western Australia) and the

Technical University of Munich (Germany). GGMplus Gravity provides data grids for gravitational acceleration, gravitational perturbations, quasigeoid undulations, and North-South and West-East vertical component deflections. The advantage of GGMPlus data is that it has a spatial density of  $\pm 220\text{m}$ , and does not require costs like field measurements (NA Karimah & A. Suprianto, 2020). The most basic theory in the gravitational method is Newton's Law of the force of attraction between objects with a certain mass (RJ Blakely, 1995).

## 2 Research methodology

In this research, the geophysical method used is the GGMPlus (Global Gravity Model Plus) satellite image gravity method on Mount Pusuk Buhit, Samosir Regency, North Sumatra Province with topography ranging from 893-1956 meters. The gravity method is a geophysical method that can describe the shape or geology of the subsurface based on variations in the earth's gravitational field caused by differences in density or mass density between rocks.

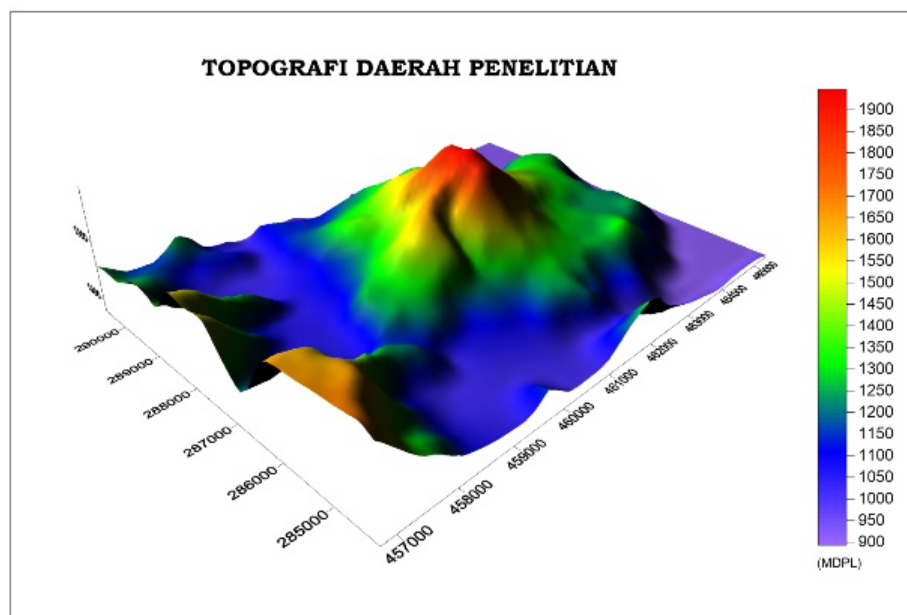


Figure 1. Topographic map of the research area.

Based on the geological map of the Sidikalang sheet, the research area consists of the Pusuk Buhit Formation (Qvpb) with Dacite and/or rhyolite rock types, the Toba Tufa Formation (QVT), the Kluet Formation (Puk) with metaquartz sandstone. rock types,

metalake, shale and phyllite, Kualu Formation (Mtk), Sibaganding Limestone member: Biocalcilitite, and Alluvium Formation (Qh) with rock types of gravel, sand, mud, fan glomerate, diatomaceous earth, coral.

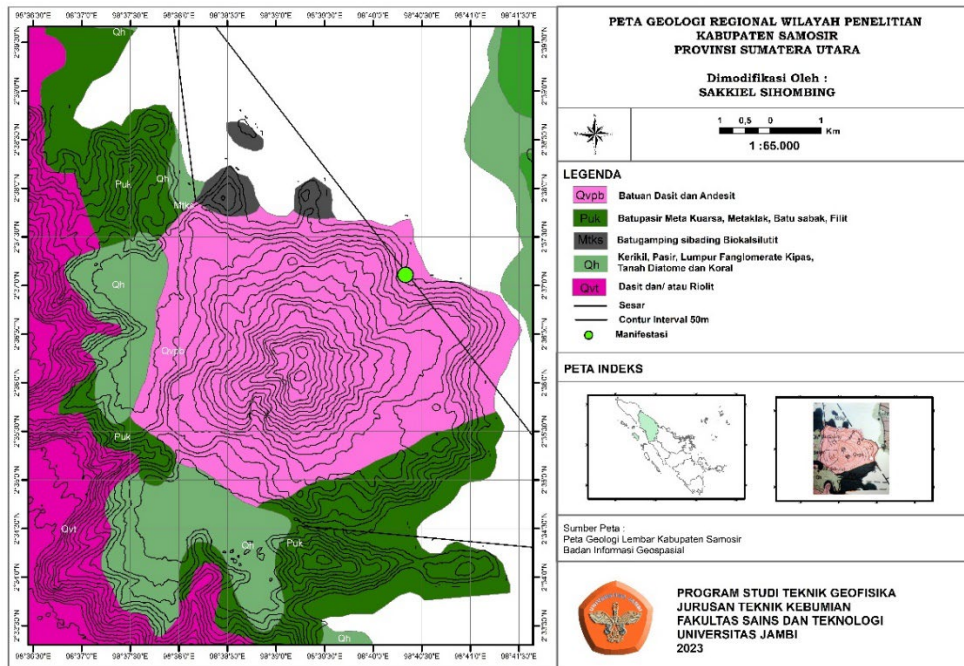


Figure 2. Regional Geological Map.

### 3 Measurement

This research was conducted on Mount Pusuk Buhit, Samosir Regency, North Sumatra Province. Gravity data collection in this study used satellite

imagery with an area of 56 km<sup>2</sup> and obtained 1200 research data points.

In this research, the first step taken was to extract GGMPPlus gravity data from the page

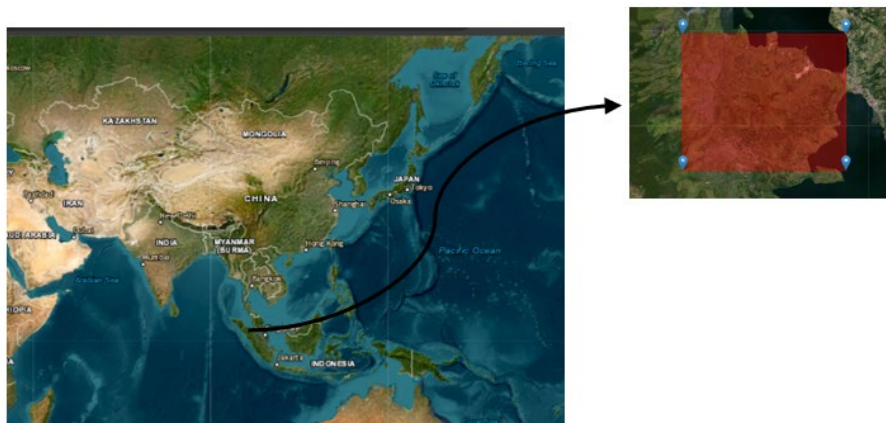


Figure 3. Research area (source: <https://earthexplorer.usgs.gov/>).

<http://ddfe.curtin.edu.au/gravitymodels/GGMplus/>. The data obtained from the Matlab extract is in the form of latitude-longitude coordinates, FAA (Free Air Anomaly) values and altitude. The data will later be transferred to Microsoft Excel, where processing will be carried out until the Bouger Correction (BC), Terrain Correction (TC), Simple Bouger Anomaly (SBA), Complete Bouger Anomaly (CBA) values are obtained. After processing in Microsoft Excel, processing is then carried out in Oasis Montaj software. The first processing carried out in the Oasis Montaj software is the Complete Bouger Anomaly (CBA) map.

## 4 Results and Discussion

### 4.1 Fault Analysis

After the CBA Map is carried out, the next step is anomaly separation

regional and residual. After that, subsurface structure analysis is carried out, namely by FHD (First Horizontal Derivative) and SVD (Second Vertical Derivative) analysis. In determining the type of fault, SVD can be used because SVD acts as a highpass filter, so it can describe residual anomalies associated with shallow structures which can be used to identify the type of descending or ascending fault (Hartati, 2012). . In determining the type of fault, the

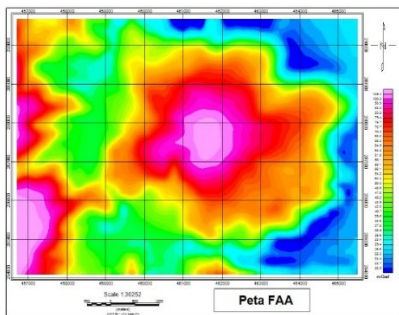


Figure 4. FAA Map (Free Air Anomaly).

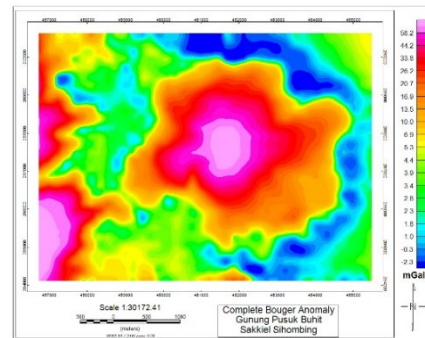


Figure 5. CBA (Complete Bouger Anomaly) map.

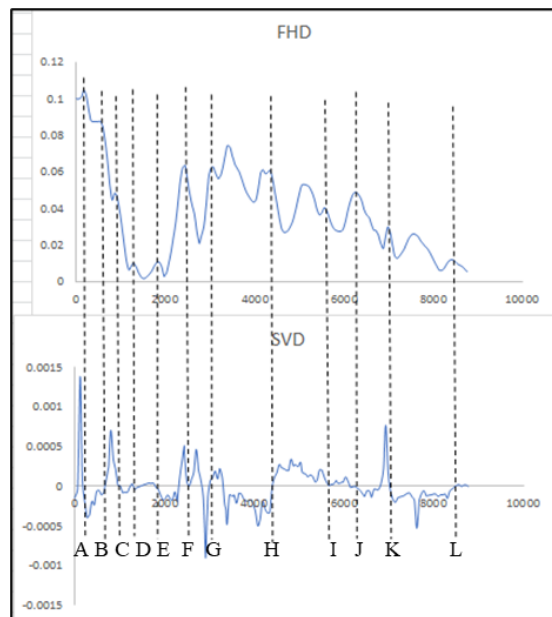


Figure 6. FHD and SVD curves of line A.

**Table 1.** Fault analysis based on anomaly response on Line A.

Titik	SVDmax	SVDmin	SVDmax & SVD min	Jenis Patahan
A	0.0013460	0.0003980	SVDmax > SVDmin	Normal Fault
B	0.0007021	0.0000540	SVDmax > SVDmin	Normal Fault
C	0.0003493	0.0000783	SVDmax > SVDmin	Normal Fault
D	0.0000355	0.0000082	SVDmax > SVDmin	Normal Fault
E	0.0000321	0.0001733	SVDmax < SVDmin	Reverse Fault
F	0.0005063	0.0000023	SVDmax > SVDmin	Normal Fault
G	0.0001706	0.0008963	SVDmax < SVDmin	Reverse Fault
H	0.0003367	0.0002703	SVDmax > SVDmin	Normal Fault
I	0.0001797	0.0000272	SVDmax > SVDmin	Normal Fault
J	0.0001143	0.0001286	SVDmax < SVDmin	Reverse Fault
K	0.0001547	0.0002040	SVDmax < SVDmin	Reverse Fault
L	0.0000056	0.0001004	SVDmax < SVDmin	Reverse Fault

following provisions can be seen:

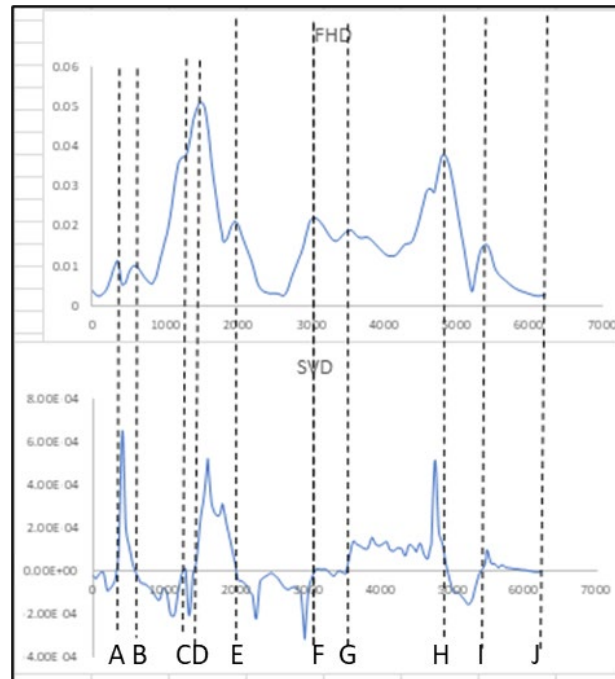
$|SVD|_{min} < |SVD|_{max}$  = Normal Fracture

$|SVD|_{min} > |SVD|_{max}$  = Fault Rise

$|SVD|_{min} = |SVD|_{max}$  = Handline Fault

The aim of cutting Line A is to cut Mount Pusuk Buhit perpendicularly from low anomaly to high anomaly and stop at the low anomaly in the area. manifestation. In section A there are 12

fault zones with minimum SVD and maximum SVD above 0. Based on the SVD parameters, in section A points A, B, C, D, F, H, and I are normal faults. because the SVDmax value is greater than the SVDmin value, and points E, G, J, K, and L are reverse disturbances because SVDmax is smaller than the SVDmin value.



**Figure 7.** FHD and SVD line B curves.

**Table 2.** Fault analysis based on anomaly response on Line B.

Titik	SVDmax	SVDmin	SVDmax & SVD min	Jenis Patahan
A	0.0006403	0.0000800	SVDmax > SVDmin	Normal Fault
B	0.0004576	0.0001181	SVDmax > SVDmin	Normal Fault
C	0.0000103	0.0002005	SVDmax < SVDmin	Reverse Fault
D	0.0005219	0.0002074	SVDmax > SVDmin	Normal Fault
E	0.0002919	0.0002223	SVDmax > SVDmin	Normal Fault
F	0.0000059	0.0003050	SVDmax < SVDmin	Reverse Fault
G	0.0001369	0.0000120	SVDmax > SVDmin	Normal Fault
H	0.0005162	0.0001128	SVDmax > SVDmin	Normal Fault
I	0.0000990	0.0001354	SVDmax < SVDmin	Reverse Fault
J	0.0000487	0.0000030	SVDmax > SVDmin	Normal Fault

The BB' line cuts the high to low anomaly, namely in the manifestation area. The results of the BB' section show 10 fault zones with minimum SVD and maximum SVD above 0. Based on the SVD parameter, on line B, points C, F and I are reverse faults because the SVDmax value is smaller than the SVDmin value, and points A, B, D, E, G, H, and J are normal disturbances because SVDmax is greater than the SVDmin value.

Based on these two trajectories, the identification of faults in this study area is dominated by descending faults, where from slice A and slice B there are 14 normal faults and 8 reverse faults. From each slice, faults are cut that are visible on the surface according to the geological map. Wedge A extends from southwest to northeast and cuts the southeast-northwest trending fault and intersects right around its manifestation. With faults visible on the surface according to the geological map, geothermal manifestations appear on the surface. Meanwhile, slice B extends from south-southwest - north-northeast

and cuts 2 faults visible on the surface, precisely in the southern part which trends east to west and the second fault trends southeast - northwest.

#### 4.2 2D Inversion Modeling

2D modeling is carried out based on residual maps. The residual anomaly map is obtained based on the reduction between the *Complete Bouger Anomaly* (CBA) map and the regional map. 2D modeling using ZondGM2D software. In this research, 2D inversion modeling was carried out on 2 tracks and cutting the manifestation area with the aim of seeing the presence of faults around the research area and determining the estimated reservoir zone. The first area has trajectory A in a northwest to northeast direction and the second region has trajectory B in a south-southwest – north-northeast direction. Path selection for the slicing process is carried out in the same direction as the slicing on the FHD and SVD maps. This aims to correlate the location of the fault with the modeling results.

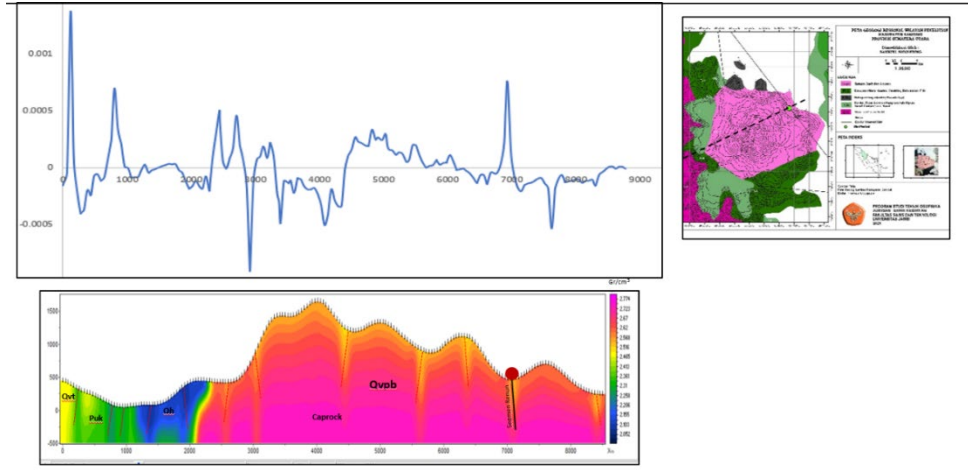


Figure 8. 2D Modeling of Line A.

In the first inversion modeling, slicing is carried out in a northwest to northeast direction covering the area of geothermal manifestation in the research area. From the results of 2D modeling, it has a depth of 520 meters and a track length of 8.5 km with several rock layers. The first layer with alluvium formation (Qh) is marked in dark blue with a thickness of 500 meters consisting of gravel, sand, mud, fan glomerate, diatomaceous earth and coral. This is the youngest unit exposed in regional geology with an average density value of 2.1 gr/cc. Furthermore, at the western end there is the Toba tufa formation (Qvt) marked yellow which has a depth of 520 meters

consisting of rhyodacite tuff material which has an average density of 2.4 gr/cc. Then, the Pusuk Buhit Formation (Qvpb), which is the main constituent of Mount Pusuk Buhit, has a depth of up to 520 meters and a height of 1,800 meters. The Pusuk Buhit Formation (Qvpb) consists of dacite and andesite material with an average density of 2.65 gr/cc. Finally, the bedrock that makes up the research area is the kluet (Puk) formation ranging from a depth of 0 – 520 meters consisting of metaquartz sandstone, metalake, shale and phyllite with an average rock density of 2.35 gr/cc. The modeling results show 12 faults marked with red dotted lines.

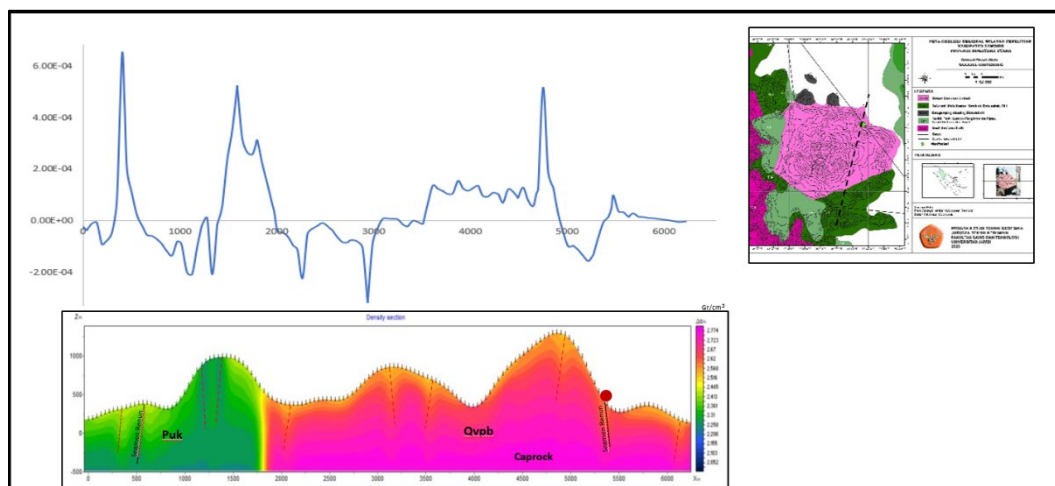


Figure 9. 2D Modeling of Line B.

In the first inversion modeling, slicing B was carried out in a northwest to northeast direction covering the geothermal manifestation area in the research area. From the results of 2D modeling, it has a depth of 520 meters and a track length of 6.5 km with several rock layers. The first layer of the Pusuk Buhit Formation (Qvpb), which is the main constituent of Mount Pusuk Buhit, has a depth of up to 520 meters and a height of 1400 meters. The Pusuk Buhit Formation (Qvpb) consists of dacite and andesite material with an average density of 2.65 gr/cc. Finally, the bedrock that makes up the research area is the Kluet (Puk) formation ranging from a depth of 0 – 520 meters consisting of metaquartz sandstone, metalake, shale and phyllite with an average rock density of 2.35 gr/cc. The modeling results show 10 faults marked with red dotted lines.

## 5 Conclusion

The conclusions of this research are as follows:

1. Analysis and interpretation of fault structures in the research area based on the Second Vertical Derivative (SVD) Anomaly map is to identify the presence of fault geological structures around its manifestation.
2. Inversion modeling in the research area contains 4 rock layers. The first layer is the Pusuk Buhit Formation (Qvpb) with a density of 2.65 gr/cc which is the rock that makes up Mount Pusuk Buhit. The second is alluvium formation (Qh) with a density of 2.1 gr/cc. The Toba Tuf Formation (Qvt) with a density of 2.4 gr/cc and the Kluet Formation (Puk) with a density of 2.35 gr/cc. Caprock is defined as the Pusuk Buhit (Qvpb) formation, namely andesite and dacite rocks.

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