

Applications of Geophysical Methods for Geothermal Exploration in Tarutung

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Abstract. Geothermal exploration in Tarutung uses geoelectric and geomagnetic methods to effectively map subsurface structures and identify geothermal systems. These systems are formed by the complex interaction of tectonic and volcanic activity that controls fluid migration and determines reservoir characteristics. Both methods are suitable for renewable energy development such as Tarutung. 2-D resistivity results show resistivity values ranging from 10 to 525 Ωm . Values between 10 and $-16.2 \Omega\text{m}$ indicate the presence of groundwater, values between 31.2 and $-74 \Omega\text{m}$ indicate denser rocks indicating a geothermal reservoir, while 112 – 525 Ωm usually indicates massive, dry rocks or dense sandstone that does not act as a reservoir. The magnetic residue map shows geomagnetic values between 14 and 30 nT, indicating a geothermal source, while susceptibility values ranging from 0.0013×10^{-3} to 0.0088×10^{-3} reflect limestone and sandstone rocks.

Keywords: Geothermal, Exploration, Geophysics, Tarutung.

1 Introduction

Geothermal energy is a natural resource produced through geological processes hundreds to millions of years ago and has been known in Indonesia [1]. The geothermal potential in Indonesia is very large, spread across the volcanic belt of Sumatra, Java, Bali, Kalimantan, Nusa Tenggara, Sulawesi, Maluku, and Papua, offering opportunities for renewable energy development [2]. According to data from the Ministry of Energy and Mineral Resources, Indonesia has geothermal potential of up to tens of thousands of Megawatts that can be utilized for power generation and other purposes [3]. Based on regional energy policies, Law no. 30/2009 prioritizes geothermal development as part of the national energy policy, where the utilization of this energy is expected to reduce pollution and replace fossil fuels [4].

Tarutung area, North Sumatra, is one of the areas that has prominent geothermal manifestations with the presence of Hutabarat, Sipoholon, and Panabungan hot springs as evidence of geothermal energy potential [5]. The study of the identification of subsurface structures in Tarutung using magnetic methods shows potential geological characters to support

geothermal systems in the area [6]. In addition, research on the geological structure of the Sarulla field describes the Tarutung area as being located between a tensile basin and a graben and supported by volcanic activity, which strengthens the prospects for geothermal development in this area [7].

Identification and mapping of geothermal energy potential in Tarutung is an important basis for planning and exploring sustainable energy sources for the future of the region. Volcanic activity in the Tarutung area and its surroundings is relatively high, marked by three volcanoes, namely Imun, Helatoba, and Dolok Martimbang, which are located close to the fault line. In addition, volcanic activity is also found in Sarulla, as indicated by the NIL dome and the Hopong caldera [7]. Volcanic activity and geological structures, such as faults, play an important role in the formation of the geothermal system in this area. The movement of tectonic plates in Sumatra has caused the formation of a large fault known as the Tarutung Basin. Within this basin, there are smaller faults, called normal faults. These normal faults provide a pathway for hot water from within the earth to rise to the surface. This is supported by modeling which shows that faults function as a pathway for heat transport from within the earth to the surface, which then emerges as hot springs [8].

Analysis of the Sipoholon and Sarulla basins reveals similarities in fault systems, particularly normal faults that cut through travertine deposits. These faults serve as the primary pathway for the outflow of geothermal fluids with significant temperatures and discharges, indicating a hydrothermal connection between the two basins. High-temperature hot water flows out at large discharges through these faults, cutting through horizontal travertine deposits. This hot water was recorded at a temperature of 64.9 °C and flowed at a rate of 6,000 liters per minute from various points near the faults. Studies conducted by Tampubolon [9,10,11,12] showed that Landsat satellite imagery can be used to calculate temperature changes in geothermal manifestations and their surrounding environment. High-temperature anomalies are distributed in the central part of the study area, namely a valley formed by the Sumatran Fault [13].

Previous research in the Tarutung area has shown that faults and volcanic activity play a significant role in the formation of geothermal systems. To obtain a clearer picture, the use of geophysical methods is necessary. This allows for optimal exploration of Tarutung's geothermal potential. This exploration involves collecting geological and geophysical data to determine the characteristics of the geothermal reservoir and its potential energy generation. The use of geophysical methods in geothermal energy exploration is crucial for understanding the subsurface structure and its geothermal potential [14,15,16].

2 Method

2.1 Research Location

This research was conducted in Tarutung, North Tapanuli Regency, North Sumatra Province. Tarutung has an area of 107.69 km², located between 1°54' - 02°07' North Latitude and 98°52' - 99°04' East Longitude.



Fig. 1. Research Location

Tarutung is one of the areas with promising geothermal potential in North Sumatra. Located around the Tarutung Basin, south of Lake Toba, this area is part of a geothermal system closely linked to the seismically active Sumatran Fault. The geothermal potential in Tarutung is supported by the existence of several geothermal surface manifestations such as hot springs and fumaroles, as well as geological patterns that show fault and fracture structures that become paths for hot fluid flow.

2.2 Geoelectric Prosedure

The geoelectric data collection process begins by determining the line and position of the area using GPS, then selecting measurement points at the location to be studied. Next, the electrode spacing is determined for the survey area so that the electrodes are placed at the specified distance between points. The electrodes are then placed in the predetermined positions based on this spacing. Measurements are taken by injecting an electric current into the subsurface layer through the current electrode and the potential electrode. Data is collected using the ARES Geoelectric device along the predetermined route. During the measurement, the potential (V) and current (I) values are measured after the electric current is applied. Once data collection is complete, the data is downloaded from the ARES device and imported into Res2Dinv software for further processing. Using Res2Dinv, the data is processed to obtain a two-dimensional subsurface model along the survey line. The final stage is to analyze and interpret the data by looking at the color differences in the cross-sectional model, which reflect variations in resistivity in each subsurface section along the survey line.

2.3 Geomagnetic Prosedure

The survey process begins with direct observation at the location designated for the study. GPS is then used to determine the precise coordinates of the area. Measurements are conducted using Proton Procession Magnetometers (PPM) to obtain geomagnetic data. The geomagnetic data obtained is then systematically captured, followed by data processing to obtain more

detailed information. During the measurements, initial time observations are made at the base every five readings to ensure data accuracy. All measurement results are recorded in a structured table to facilitate further analysis. Data analysis and interpretation are performed using Mag2dc software, which allows for a deeper understanding of the distribution of susceptibility values. Susceptibility values are then differentiated based on anomalies and colors, making it easier to identify susceptibility variations in the study area.

2.4 Geoelectric Analysis

Data obtained from the ARES geoelectric tool was downloaded and first entered into a field data collection table before being further processed using Res2Dinv software. The data was then processed using the non-linear Least-Square optimization method to perform two-dimensional inversion. The 2-D inversion process produces cross-sectional images that represent the distribution of soil resistivity in the study area. With this survey, a cross-sectional image of the subsurface was obtained from each predetermined trajectory. Each resulting trajectory image was then analyzed and compared based on the distribution of resistivity values indicated by differences in color and depth of the soil or rock layers studied, and adjusted for the coordinate distance at the study location. From the two-dimensional cross-sectional images generated by the Res2Dinv software for each trajectory, a comparison was made with the location and depth of the identified geothermal reservoir in the study area.

2.5 Geomagnetic Analysis

After data processing is complete, the final result is a magnetic anomaly value, which is then plotted to see the susceptibility results. The technique is grinding, where the input is in the form of x and y point coordinates as well as magnetic anomaly data and external measurement points. Modeling is done with Mag2dc. Parameters used in the modeling include inclination, declination and IGRF values. So that the Mag2dc geomagnetic cross-section model is obtained which produces rock susceptibility values. Geothermal interpretation in the Mag2Dc geomagnetic cross-section model can be seen in each constituent rock that has a variation in susceptibility. The depth and distance of the constituent rock variations can be seen from the x and y coordinates. X is the depth of the constituent rock and Y is the distance.

3 Result and Discussions

3.1 Geoelectric Interpretation

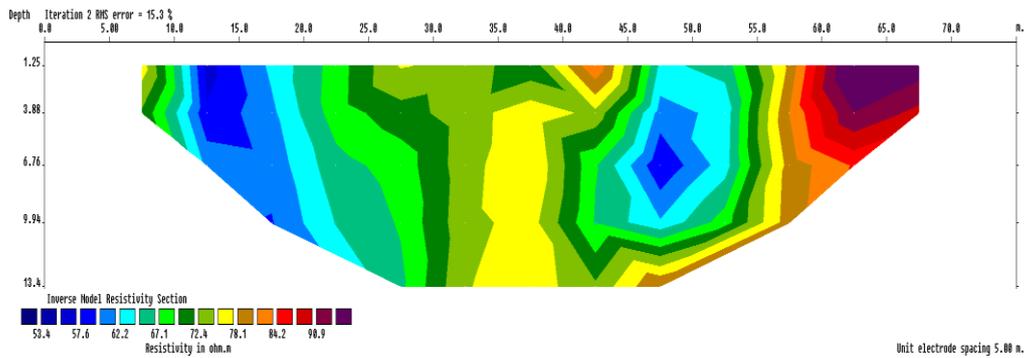


Fig. 2. Line 1 geothermal Tarutung

The image shows very low resistivity (blue, 10 Ωm). This zone usually indicates the presence of highly conductive hot water, a clay alteration zone (a zone of clay altered by hydrothermal fluids), or the accumulation of water with clay minerals. This zone is closely related to active geothermal systems. Moderate resistivity (green-yellow, 10-74 Ωm) indicates less intensively altered rocks, limestone, or permeable rock formations that conduct geothermal fluids. It can also be called a reservoir rock zone. High resistivity (red-purple, 74-88 Ωm) usually indicates an impermeable caprock layer (seal), a strong rock layer that inhibits fluid movement.

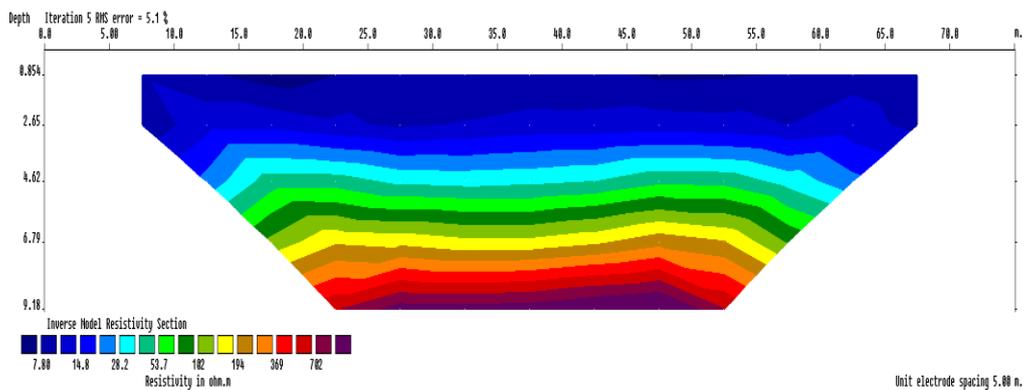


Fig. 3. Line 2 geothermal Tarutung

The image shows dark blue zones (low resistivity, around 8,43 – 16,2 Ωm) generally indicate the presence of water-saturated material, such as a hot spring aquifer. Light blue zones (medium resistivity, around 31.2 – 68.1 Ωm) indicate more compact rock layers, but still have the potential to act as reservoirs if there is sufficient porosity and permeability. Green to purple

zones (very high resistivity, 112 – 525 Ωm) usually indicate massive, dry rock or dense sandstone that does not act as a reservoir.

3.2 Geomagnetic Interpretation

Based on the results of observational data measurements, magnetic field anomalies were obtained and presented as a contour map using Surfer 13 software, as shown in Figure 3.

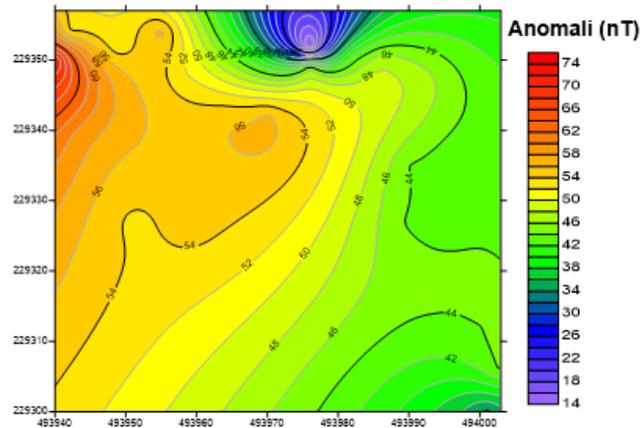


Fig. 4. Map of the distribution of magnetic anomalies

Figure 3 shows the magnetic field strength at the research location ranges from 14 nT to 74 nT. Low-intensity magnetic anomalies have a value of around 14 nT to 30 nT, which are visible in the section marked in bold blue. Moderate magnetic anomalies have a value of around 34 nT to 46 nT, as seen in the section marked in green. High magnetic anomalies have a value of around 50 nT to 74 nT, visible in the section marked with yellow to reddish color.

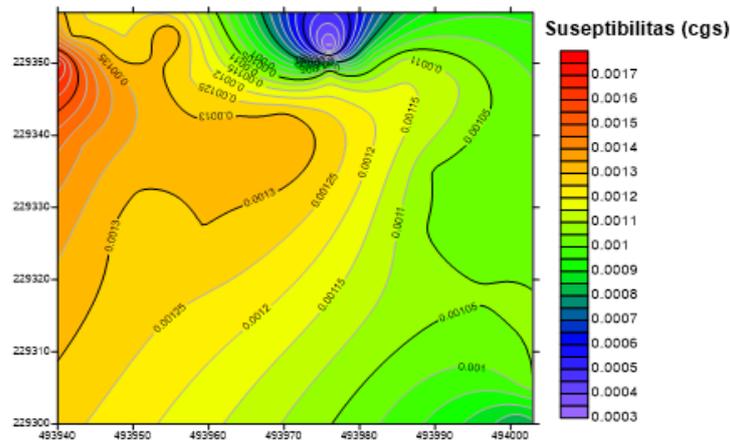


Fig. 5. Susceptibility counter map at the research site

Magnetic susceptibility is a measure of how much a rock can be magnetized by the Earth's magnetic field. Susceptibility measurements are carried out at each survey point to understand the magnetic characteristics of the rocks in the study area, as shown in the contour map in Figure 4. The survey results in Tarutung show susceptibility values ranging from 0.3×10^{-3} nT to 1.7×10^{-3} nT. These values help identify the types of rocks beneath the surface. In geothermal surveys, areas with low susceptibility are often the main targets because hydrothermal alteration processes can change magnetic minerals into less magnetic minerals (paramagnetic or diamagnetic), indicating the presence of potential geothermal resources.

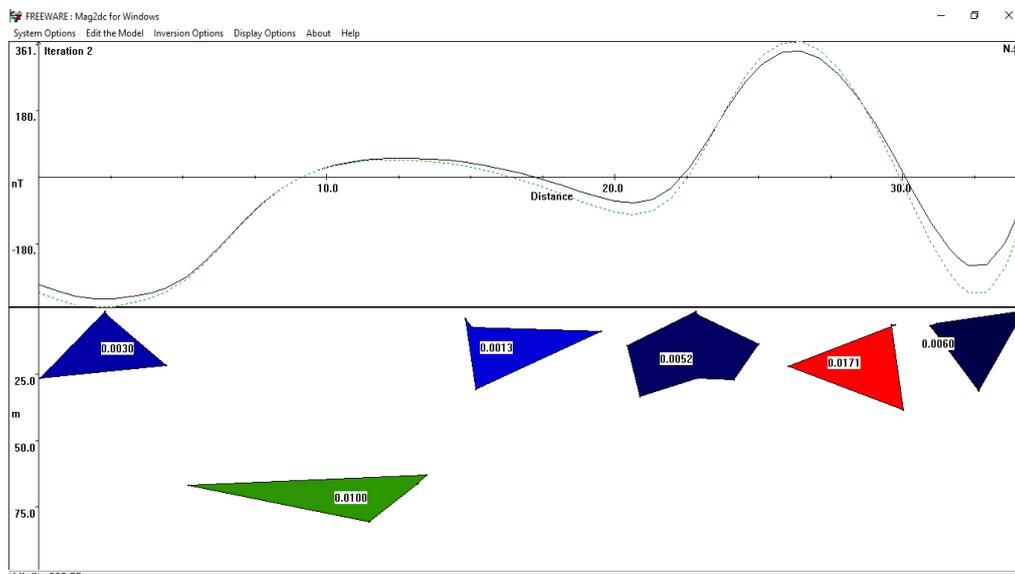


Fig. 6. Model Magnetic

Based on the results of the susceptibility value model obtained, the research location consists of sandstone with a susceptibility value of 0.01 to 0.03 cgs at a depth of 25 to 75 meters and limestone with a susceptibility value between 0.0013 to 0.006 cgs at a depth of about 25 meters with a distance of 15 to 35 meters. The presence of sandstone as a permeable rock has the potential to become a reservoir zone that can accommodate and flow geothermal fluids, while limestone found at that depth can function as a cover layer or impermeable caprock so as to maintain pressure stability and prevent the release of geothermal fluids. This combination of characteristics indicates conditions that support the formation of an effective geothermal system.

4 Conclusion

Geophysical methods play a crucial role in identifying the geothermal potential in Tarutung. eksplorasi such as geoelectric and geomagnetic have helped delineate subsurface structures, reservoir, and heat sources that control the geothermal system in the area. The presence of active fault systems and fractures allows the movement of geothermal fluids and

heat transport, making Tarutung a favorable site for geothermal energy development. Therefore, Tarutung is recognized as an area with abundant and accessible geothermal resources that can be sustainably harnessed for renewable energy.

References

- [1] Ahmad, F. A. (2021). Potensi Panas Bumi dan Kaitannya Dengan Pengembangan Energi di Indonesia
- [2] Hakim, A. F., Krismadiana, K., Sholihah, F., Ismawati, R., & Dewantari, N. (2023). Potensi dan Pemanfaatan Energi Panas Bumi di Indonesia. *Indonesian Journal of Conservation*, 11(2), 71-77.
- [3] Nurwahyudin, D. S., & Harmoko, U. (2020). Pemanfaatan dan Arah Kebijakan Perencanaan Energi Panas Bumi di Indonesia Sebagai Keberlanjutan Maksimalisasi Energi Baru Terbarukan. *Jurnal Energi Baru Dan Terbarukan*, 1(3), 111-123.
- [4] Meilani, H., & Wuryandani, D. (2010). Potensi panas bumi sebagai energi alternatif pengganti bahan bakar fosil untuk pembangkit tenaga listrik di Indonesia. *Jurnal Ekonomi Dan Kebijakan Publik*, 1(1), 47-74.
- [5] Mardiyati, D., Utama, P. P., & Apriyanti, D. (2022). Penggunaan Citra Landsat untuk Pendeteksian Anomali Suhu Permukaan Sebagai Indikasi Keberadaan Manifestasi Panas Bumi. Studi Kasus: Sipoholon, Indonesia. *Jurnal Ilmiah Geomatika*, 2(2), 1-12.
- [6] Hidayati, N., Arman, Y., & Zulfian, Z. (2022). Identifikasi Struktur Bawah Permukaan Daerah Panas Bumi dengan Metode Magnetik di Daerah Tarutung Bagian Selatan dan Sekitarnya, Provinsi Sumatera Utara. *Prisma Fisika*, 10(2), 206-213.
- [7] Wahyuningrum, C., Kevin, K., & Badruzzaman, F. (2023). Analisa Geologi Struktur Lapangan Geothermal Sarulla. *Jurnal Ilmiah Teknik Informatika dan Komunikasi*, 3(2), 174-188.
- [8] Hasan, R., Setiadarma, Risdianto, D., & Supardi, K., 2005, Geologi Daerah Panas Bumi Sipoholon-Tarutung Kabupaten Tapanuli Utara Sumatera Utara, Pemaparan Hasil Kegiatan Lapangan Subdit Panas Bumi, 7:1-7.
- [9] Tampubolon, T., Hutahaean J., Juliani, R., & Panggabean, Y. (2019). Identification of Geothermal Environments by Using Landsat Imagery at PLTP Sarulla unit I, Pahae Jae Subdistrict, North Tapanuli. *Journal of Physics: Conference Series*, 1245/012030.
- [10] Tampubolon, T., Hutahaean J., & Siregar S. N. J. (2018). Subsurface Structure Determination of Geothermal Area in Siogung-ogung Samosir District by Using Magnetic Method. *Journal of Physics: Conference Series* 970/012002.
- [11] Tampubolon, J., Juliani, R., Hutahaean J. & Widiyanti, S. (2018). Identification of Magnetic Anomaly at Geothermal Subsurface Area PLTP Sarulla Unit I Pahae Jae, North Sumatera, Indonesia. *Journal of Physics: Conference Series*, 1120/012045.
- [12] Tampubolon, T., & Yanti, J. (2017). Satellite Landsat for eruption of Mt. Sinabung. *AIP Conference Proceedings* 1857/070002.
- [13] Tampubolon, T., Yanti, J., Juliani, R., & Hutahaean J. (2023). The influence of Mount Sinabung eruption on the geothermal in Tinggi Raja Simalungun. *Physics and Chemistry of the Earth*, 2023, 129.
- [14] Kadri, M., Tampubolon, T., Hutahaean, J., Muztaza, N. M., & Nordin, M. N. M. (2025). Utilizing of Geophysical Methods for Geothermal Exploration at Guru Kinayan Village, Tanah Karo Regency. *Jurnal Penelitian Pendidikan IPA*, 11(1), 367-373.
- [15] Kadri, M., Muztaza, N. M., Nordin, M. N. M., Zakaria, M. T., Rosli, F. N., Mohammed, M. A., & Zulaika, S. (2023). Integrated geophysical methods used to explore geothermal potential areas in Siogung-Ogung, North Sumatera, Indonesia.
- [16] Kadri, M., & Nordiana, M. M. (2021, March). Geothermal Fluid Identification at Geothermal Area Sorik Marapi using 2d Resistivity Imaging. In *Journal of Physics: Conference Series* (Vol. 1819, No. 1, p. 012067). IOP Publishing.