Research Paper

International Journal of Research and Review
[Indexed, Peer-Reviewed Journal]
Volume 12; Issue: 6; June 2025
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Subsurface Modeling Using Gravity Data in the Geureudong Volcano Geothermal Prospect Area

Muhammad Hanif Hafidh[1], Ahmad Ali Muckharom[1], Agus Setyawan[2], Fajar Arianto[2]

[1]Undergraduate Student, Department of Physics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Indonesia
[2]Department of Physics, Faculty of Science and Mathematics, Universitas Diponegoro, Semarang, Indonesia

Corresponding Author: Agus Setyawan

DOI: https://doi.org/10.52403/ijrr.20250631

ABSTRACT

Mount Geureudong is located in the Bukit Mulie area, Bener Meriah Regency, Aceh Province. This study aims to interpret the subsurface lithology of Mount Geureudong and develop a two-dimensional model. The data utilized in this research are secondary satellite data from GGMplus (gravity disturbance) and elevation data from ERTM2160. Inversion modeling was carried out using Grablox software, with residual anomaly data that had undergone flat-surface reduction. The inversion process resulted in 2D density cross-sections along the x, y, and z axes, visualized using Surfer software. The modeling suggests the possible presence of andesite rocks with densities of 2.4–2.8 g/cm³, lava at 2.9 g/cm³, pumice at 0.8–0.9 g/cm³, basalt at 3.1–3.3 g/cm³, sandstone at 2.0–2.3 g/cm³, soil at 1.3–1.8 g/cm³, and gabbro at 3.4–3.5 g/cm³. The 2D modeling of the Mount Geureudong study area indicates that andesite and sandstone are the dominant rock types, distributed across the region with density values ranging from 2.4 to 2.8 g/cm³.

Keywords: Mount Geureudong, Gravity, GGMPlus, Density, Inverse Modelling

INTRODUCTION

The Geureudong Mountain area in Central Aceh is known as a volcanic region with significant geothermal potential, marked by surface manifestations such as hot springs, fumaroles, and hydrothermally altered rocks [1], [2], [3]. With an estimated energy reserve of up to 160 MWe, the area is considered a prime candidate for the development of a Geothermal Power Plant (PLTP)[2]. However, intensive exploration efforts have been hindered by its remote geographic conditions and dense forest cover. As a result, previous studies have largely relied on remote sensing techniques, such as Land Surface Temperature (LST) analysis, the Normalized Difference Vegetation Index (NDVI), and the Normalized Difference Water Index (NDWI), to map potential distribution zones [3]. While these approaches have successfully identified prospect areas in the Pintu Rime Gayo and Wih Pesam sub-districts, they have yet to address subsurface characteristics, an essential factor in determining precise locations for exploration drilling [1].

Gravity data inversion modeling offers a strategic solution to overcome the limitations of field data. This method is capable of reconstructing subsurface structures through variations in rock density, identifying geothermal reservoirs, and mapping hot fluid systems [4], [5], [6]. Studies conducted in Mount Pandan [5] and Mount Ungaran [6] have demonstrated the effectiveness of 2D/3D inversion modeling in mapping

density anomalies associated with geothermal systems [7]. However, this methodology has not yet been applied to the Geureudong area, despite its potential to provide valuable quantitative data on reservoir depth and supporting geological structures.
Previous research in the Geureudong area has primarily focused on surface analysis, with little to no in-depth geophysical exploration. Studies by [1] and [2] were limited to reconnaissance surveys, while [2] highlighted the urgent need for more comprehensive investigations. The absence of subsurface inversion models has led to significant uncertainty in estimating geothermal reserve capacity and in optimizing the location of geothermal power plants (PLTP). In contrast, 3D gravity inversion has successfully guided the development of the Enhanced Geothermal System (EGS) at Utah FORGE with high resolution, demonstrating the potential for similar applications in the Geureudong region.
This study aims to perform 2D gravity data inversion modeling in the Geureudong area to identify the subsurface lithology of the Geureudong geothermal system. By applying kriging algorithms and spline interpolation to synthetic data, the model is capable of identifying fault structures, hydrothermal alteration zones, and geothermal reservoirs [4], [6], [8]. The results will serve as a scientific basis for further exploration planning and support the development of renewable energy in Aceh in line with the Sustainable Development Goals (SDGs).

GEOLOGICAL METHOD

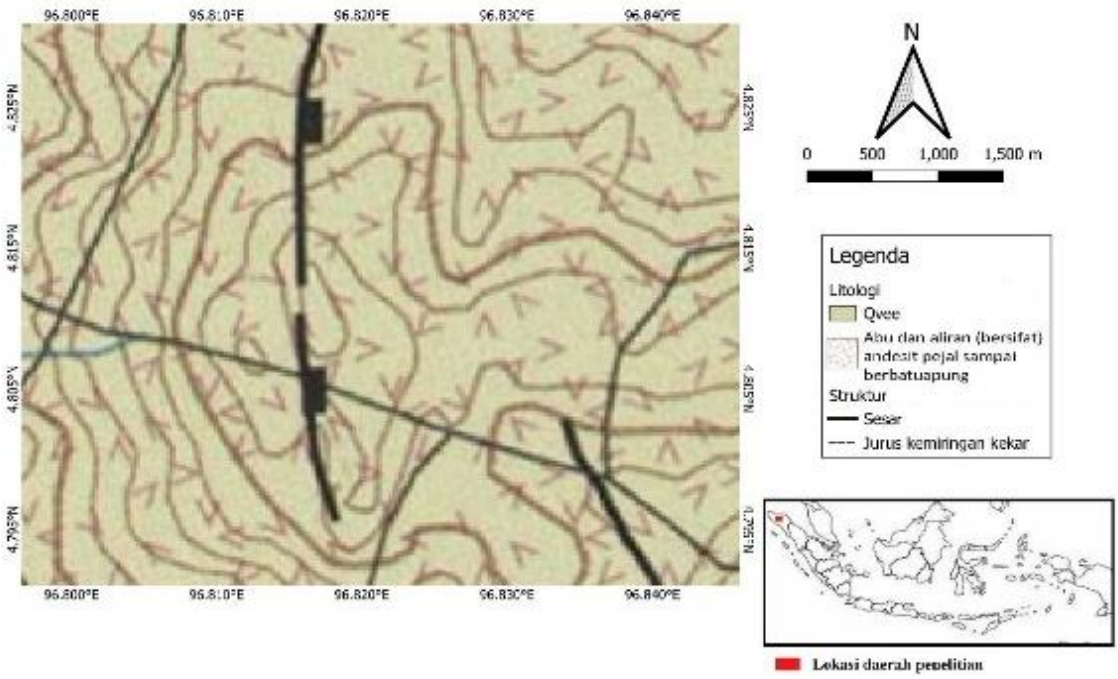


Figure 1. Geology of the research area

The geological diversity of the Mount Geureudong area is marked by the presence of the Enang-Enang Formation, which consists of volcanic ash and lava flows characterized by massive andesite to pumiceous rocks [9]. This is consistent with Mount Geureudong's classification as an inactive stratovolcano, where the volcanic materials reflect past eruptive phases. Additionally, the region is dominated by igneous rocks such as andesite, sandstone, soil, pumice, lava, basalt, and gabbro [10]. These igneous rocks were formed through the cooling of molten magma originating from within the Earth's crust, which underwent crystallization and solidification at varying rates.

According to petrology, all igneous rocks are the result of the solidification of extremely hot, molten silicate material known as magma. The cooling process of magma leads to the formation of various types of igneous rocks with different textures and mineral compositions, depending on environmental conditions such as depth and cooling rate. In the Mount Geureudong area, the presence of andesite and basalt indicates a complex volcanic history, in which magma experienced chemical and physical evolution before solidifying either at the surface or beneath the Earth's crust [9].

DATA & METHODS

The gravity method is a passive geophysical technique, meaning it is non-invasive and environmentally friendly. It measures variations in the Earth's gravitational field caused by differences in mass density among subsurface rock formations. This method is based on Newton's law of gravitation between two objects [11]. Gravity surveys are often used in preliminary exploration studies to provide information about subsurface rock densities, potential geothermal sources, and geological structures.

Geological structures are rock formations that result from geological processes and deformation events such as folding, faulting, and fracturing [12]. Faults represent a type of deformation caused by excessive stress acting on rocks [13].

Utilizing gravity data from the GGMplus satellite can serve as a cost-effective alternative for wide-area surveys [14]. However, GGMplus gravity data may still be influenced by external gravitational effects from surrounding topographical features, such as valleys or mountains. Therefore, several data corrections are required to improve measurement accuracy.

These include the Free Air Correction (FAC), which compensates for elevation differences to obtain the Free Air Anomaly (FAA) [15]; the Terrain Correction (TC), which adjusts for surface topography variations at the same elevation [16]; and the Bouguer Correction (BC), which reduces the gravitational effect of the mass between the measurement point and the Earth's center [17].

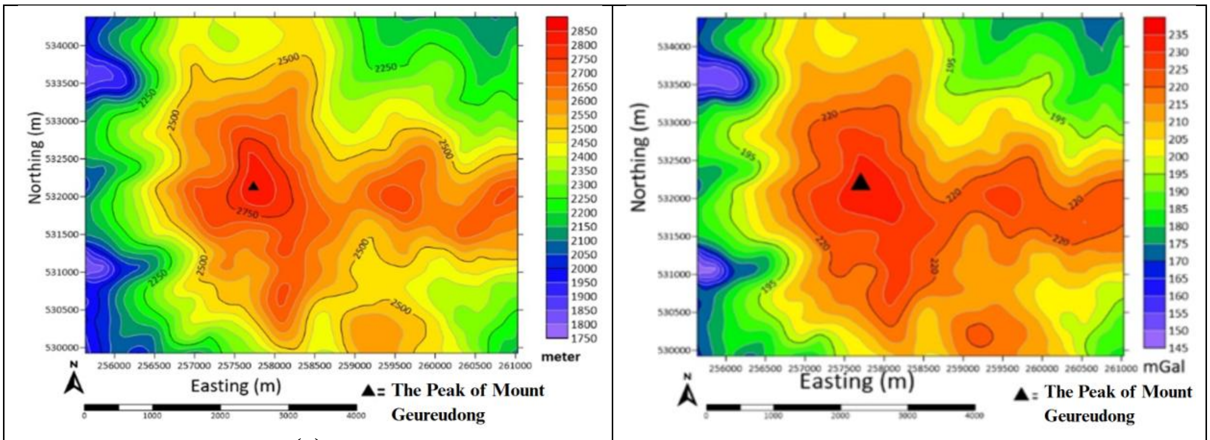
$$CBA = FAA - BC + TC \qquad (1)$$

After applying gravity corrections, the resulting anomaly values are referred to as the Complete Bouguer Anomaly (CBA). CBA represents the difference between the observed gravity value and the theoretical Earth's gravity at a specific observation point [18]. This value reflects variations in mass density within a given area. CBA encompasses both regional and residual anomalies, which are associated with differences in rock mass density. The upward continuation method is used to distinguish between regional and residual anomalies.

In inversion modeling, model parameters are directly derived from observational data, providing a straightforward approach to interpreting subsurface properties. The accuracy of the subsurface model depends on the degree of fit between the inversion results and the observed data. Variations in the subsurface model are influenced by this fit. The presence or absence of data, acquisition errors, and the characteristics of the geological phenomena under investigation significantly affect this outcome [19]. The inversion modeling will be presented as 2D slices using Grablox and Bloxer software, while Surfer will be used to generate grid-based subsurface maps. By utilizing residual anomalies, researchers can more accurately focus on localized features related to potential coal deposits and identify underlying subsurface structures.

RESULT AND DISCUSSION

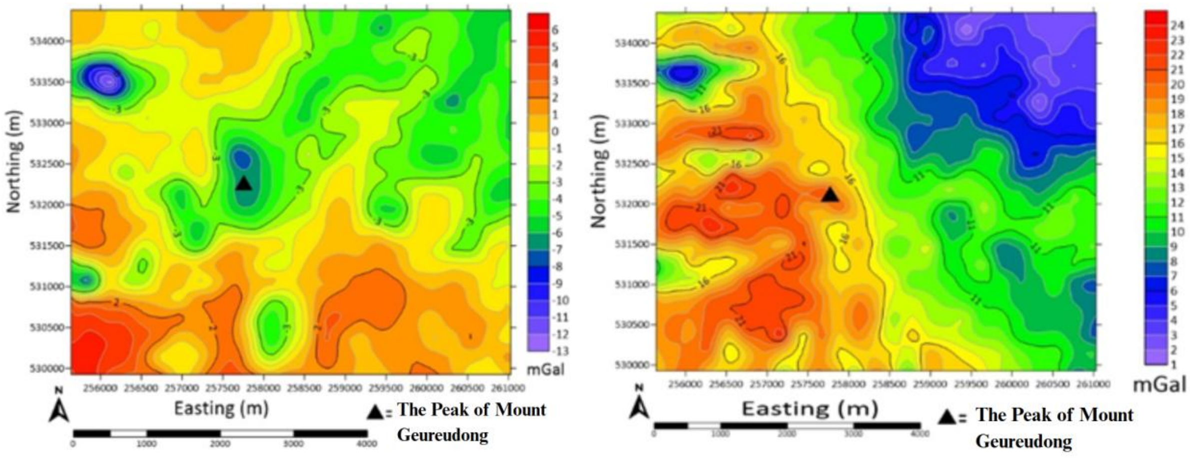
The topography of the study area, obtained from ERTM2160 data, was mapped using Surfer software based on UTM coordinates, as shown in Figure 2(a). According to the topographic contour map, the lowest elevation in the area is approximately 1,750 meters. Low-elevation zones are represented by bluish-purple to dark blue colors. Areas with moderate elevation are illustrated in shades ranging from blue-green to yellow-green, while high-elevation regions are shown in yellow-orange to red hues. The highest elevation in the study area reaches around 2,850 meters. The red-colored region, which marks the highest topography, is presumed to be the summit of Mount Geureudong, whereas the lower elevation areas, indicated in darker blue, represent the mountain's foothills.



(a) (b)

Figure 2. Topographic Map (a) and Free Air Anomaly Map (b)

The lowest values on the free-air anomaly (Figure 2(b)), contour map of the Mount Geureudong area are represented by bluish-purple to blue-green colors, ranging from 145 to 175 mGal. Moderate values are indicated by blue-green to yellowish-green and yellow shades, ranging from 175 to 200 mGal, as shown in Figure 6. Higher values are displayed in orange to red tones, with anomaly values between 205 and 235 mGal. The influence of mass excess and deficiency still affects the free-air anomaly map due to topographic variations within the study area.



(a) (b)

Figure 3. Simple Bouguer Anomaly Map (a) and Complete Bouguer Anomaly Map (b)

Bouguer correction was applied to minimize the influence of topographic effects on the gravity anomaly values in the study area. This correction involves calculating the mass effect by considering both the rock density and the elevation of the measurement points relative to gravity values. The Bouguer correction was performed using Microsoft Excel. As a result, a simple Bouguer anomaly map was produced, as shown in Figure 3(a). On the simple Bouguer anomaly contour map, the topographic effects begin to diminish. The low anomaly values range from approximately -13 to -8 mGal, medium anomalies range from -7 to -1 mGal, and high anomalies range from 0 to 6 mGal. However, the simple Bouguer anomalies are still influenced by regional field effects in the study area, indicating the need for subsequent terrain correction.

The terrain correction is performed to account for the influence of irregular mass distribution around the measurement points. This correction was initially carried out using Global Mapper and then refined with Oasis Montaj. After applying the terrain correction, a complete Bouguer anomaly was produced, as shown in Figure 3(b). The complete Bouguer anomaly is obtained by combining the terrain correction with the simple Bouguer anomaly.

The complete Bouguer anomaly consists of both regional and residual components. Regional anomalies tend to have smoother textures because they originate from deeper subsurface rock formations, resulting in a more uniform distribution of gravity anomalies at the surface. In contrast, residual anomalies are associated with shallower rock structures located closer to the surface, leading to a more heterogeneous pattern in gravity anomaly distribution.

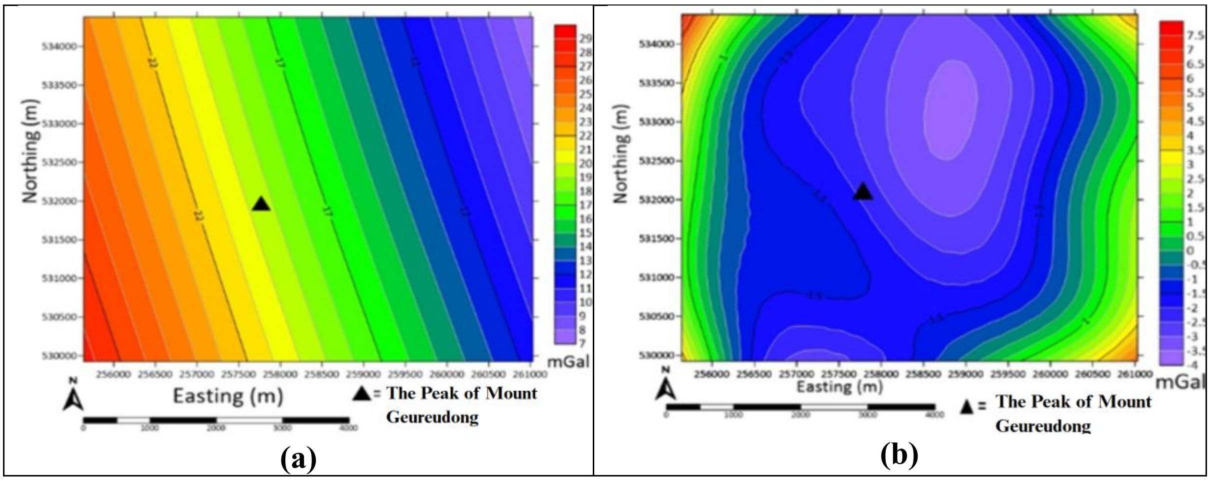


Figure 4. Regional Map (a) and Residual Map (b)

Quantitative interpretation was carried out to analyze the subsurface model through inversion, resulting in a density cross-sectional model. The two-dimensional modeling was performed using Grablox software. Subsurface modeling involved creating five cross-section lines based on the residual gravity anomalies. For the X-axis interpretation in the study area, three vertical cross-sections were created, stretching from south to north, labeled as sections A–A', B–B', and C–C'. The following is the interpretation of the inversion modeling results using Grablox and Surfer software.

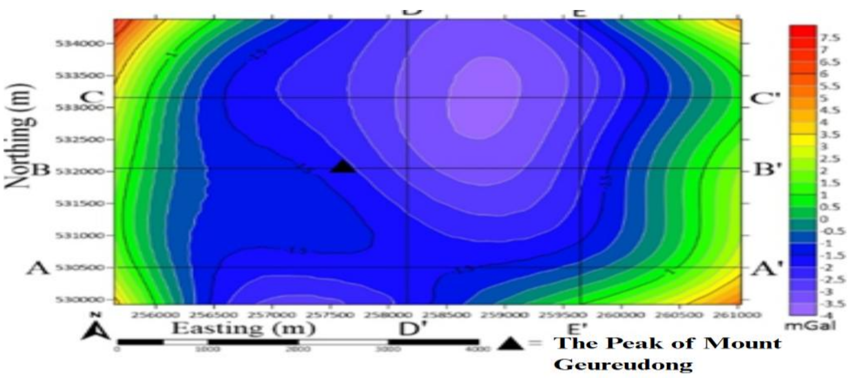


Figure 5. Cross Section Inverse Modelling

The modeling revealed rock formations belonging to the Enang-Enang Formation of Mount Geureudong. The interpreted lithological contacts indicate rocks with varying density values—low, medium, and high. Low-density rocks, represented by blue coloring, include pumice and soil. Medium-density rocks, shown in green, consist mainly of sandstone. High-density rocks are indicated by yellow to red colors and include andesite, lava, basalt, and gabbro.

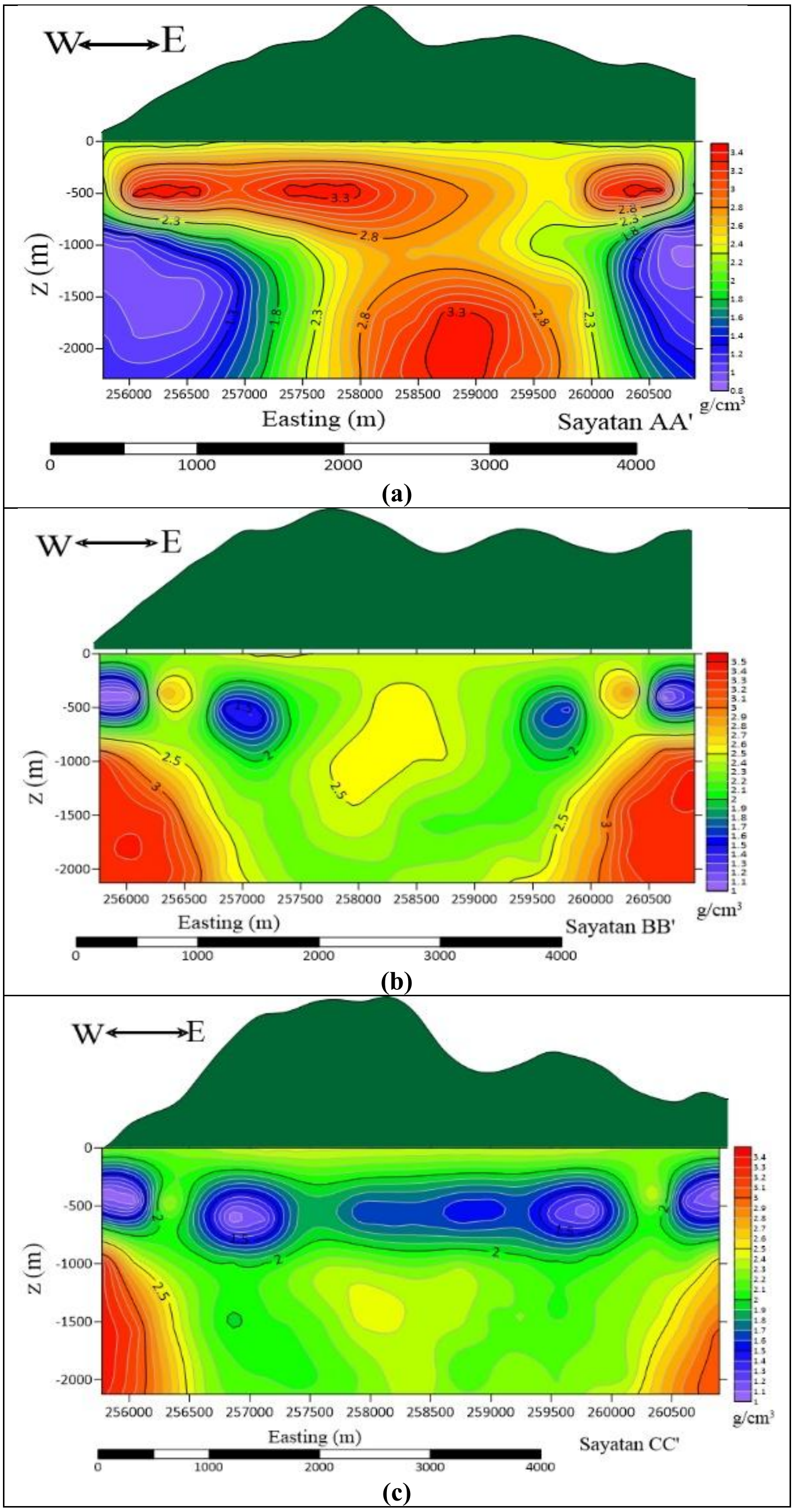


Figure 7. Cross Section A-A' (a), B-B' (b), and C-C' (c)

Quantitative interpretation along the X-axis of the study area was carried out through three horizontal cross-sections running from west to east, identified as sections D–D' and E–E'. The interpretation is based on the results of inversion modeling using Grablox and Surfer software. The subsurface is composed of rock formations belonging to the Enang-Enang Formation of Mount Geureudong. The lithological contacts were interpreted based on variations in density, ranging from low to high. Low-density zones, indicated by blue, represent pumice and soil; medium-density areas, shown in green, correspond to sandstone; while high-density regions, represented by yellow to red, indicate the presence of andesite, lava, basalt, and gabbro.

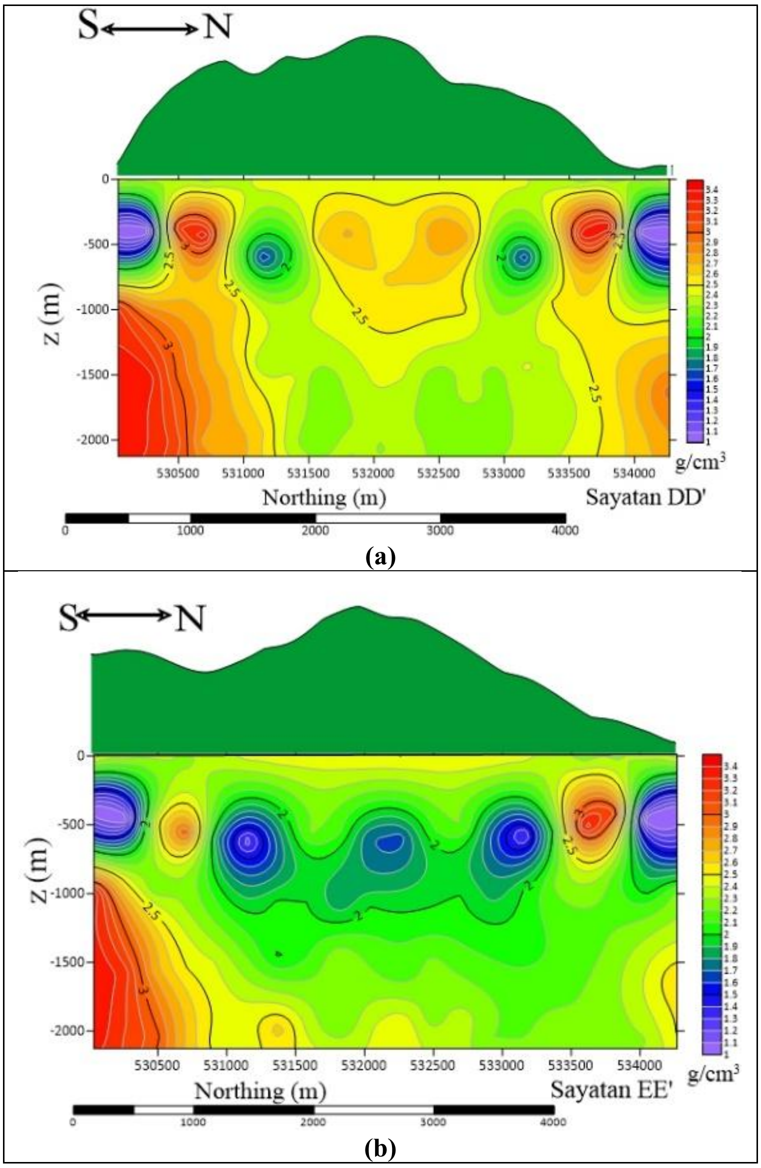


Figure 8. Cross Section D-D' (a) and E-E' (b)

Based on the results of the subsurface modeling (Figures 7 and 8), several distinct lithological units were identified within the study area. Andesite rocks were observed with density values ranging from 2.4 to 2.8 g/cm³, indicating the presence of volcanic rock commonly associated with geothermal systems. Lava flows were characterized by a slightly higher density of approximately 2.9 g/cm³, suggesting solidified magma deposits at shallow to moderate depths. Sandstone formations were also identified, with density values between 1.9 and 2.3 g/cm³, reflecting sedimentary processes and the potential for porous rock layers that could influence fluid movement in geothermal reservoirs.

In the near-surface layers, soil was found with density values ranging from 1.1 to 1.6 g/cm³, likely corresponding to weathered materials and unconsolidated sediments. Additionally, pumice was detected, exhibiting very low densities between 0.8 and 0.9 g/cm³, consistent with its highly vesicular volcanic origin. Denser igneous rocks, including basalt with densities of 3.0 to 3.3 g/cm³ and gabbro with densities ranging from 3.4 to 3.5 g/cm³, were identified at greater depths.

The 2D inversion modeling results indicate that andesite and sandstone are the dominant lithologies within the Mount Geureudong geothermal prospect area, extending laterally across much of the modeled section. At depths ranging from 1 km to 2 km, the presence of high-density igneous rocks such as lava, basalt, and gabbro was confirmed, suggesting the existence of a more solidified and thermally active geothermal system in the deeper subsurface.

CONCLUSION

The modeling results reveal various subsurface lithologies in the Mount Geureudong area. Andesite and sandstone are the dominant rocks, with densities ranging from 2.4 to 2.8 g/cm³ and 1.9 to 2.3 g/cm³, respectively. Lava flows have a density of about 2.9 g/cm³, while soil and pumice show lower densities between 1.1–1.6 g/cm³ and 0.8–0.9 g/cm³. Denser igneous rocks like basalt (3.0–3.3 g/cm³) and gabbro (3.4–3.5 g/cm³) occur at depths between 1 and 2 km. These findings indicate a layered subsurface structure with volcanic and sedimentary rocks dominating the upper layers and high-density igneous formations present deeper, consistent with an active geothermal system.

Declaration by Authors

Acknowledgement: None

Source of Funding: None

Conflict of Interest: No conflicts of interest declared.

REFERENCES

1. L. C. A. Nurlaila, R. Dewi, And A. Salsabila, “Identifikasi Potensi Panas Bumi Kawasan Gunung Geureudong Menggunakan Landsat 8 Oli Serta Rekomendasi Lokasi Pembangkit Listrik Panas Bumi,” Jurnal Ilmiah Penalaran Dan Penelitian Mahasiswa, Vol. 6, No. 2, 2022.
2. D. R. Putri, N. Ismail, R. Idroes, S. Rizal, S. Nur, And M. Nanda, “Analysis Of Land Surface Temperature (Lst) In Bur Ni Geureudong Geothermal Field, Aceh, Indonesia Using Landsat 8 Oli / Tirs Images,” Chiang Mai University Journal Of Natural Sciences, Vol. 20, No. 4, Pp. 1–13, Oct. 2021, Doi: 10.12982/Cmujns.2021.084.
3. M. Isa, Z. Zulfadhli, C. F. Thahul, And D. P. Cesarian, “Geothermal Distribution Analysis Of Geureudong Volcano Based On Satellite Data And Fault Fracture Density (Ffd),” Elkawnie, Vol. 7, No. 2, P. 354, Jan. 2022, Doi: 10.22373/Ekw.V7i2.9728.
4. A. Zewge, E. Lewi, And D. Midekso, “Design And Implementation Of Forward And Inverse Gravity Modeling Tool,” East African Journal Of Sciences, Vol. 5, No. 2, Pp. 83–88, 2011.
5. T. Any Spryany Panggabean And D. Ahmad Zaky, “Analysis And Modelling Of Subsurface Structures With 3d Inversion Of Gravity Data Using Simpeg Open Source Framework Analisis Dan Pemodelan Struktur Bawah Permukaan Dengan Inversi 3d Daat Gayaberat Menggunakan Framework Open Source Simpeg Abstrak,” 2024.
6. Agus Setyawan, Muhammad Faris Nadhila, Jatmiko Endro Suseno, And Rina Dwi Indriana, “2d Sparse Inversion Gravity Method For Subsurface Interpretation By Simpeg: A Case Study Of Ungaran Volcano,” Journal Of Southwest Jiaotong University, Vol. 59, No. 3, 2024, Doi: 10.35741/Issn.0258-2724.59.3.36.
7. A. Widya Permatasari, D. Santoso, And Setianingsih, “Subsurface Modeling Based On Gravity Data Of Rendingan-Ulubelu-Waypanas (Ruw) Geothermal Field, Lampung, Indonesia,” In Iop Conference Series: Earth And Environmental Science, Institute Of Physics Publishing, Aug. 2019. Doi: 10.1088/1755-1315/318/1/012002.
8. X. Tu, A. Schultz, And Q. Di, “Integrated Mt, Gravity, And Seismic Inversion and Interpretation for Improved Subsurface

Imaging," Mar. 18, 2025. Doi: 10.5194/Egusphere-Egu25-2763.
9. Reza, "Geologi Gunung Geureudong," Scribd.
10. F. Yolanda, N. Ismail, And D. Gunawati, "Transformasi Pseudogravitasi Data Anomali Medan Magnetik Total Pada Kawasan Bur Ni Geureudong, Bener Meriah Pseudogravity Transformation of Total Magnetic Field Anomaly Data in Bur Ni Geureudong, Bener Meriah," J. Aceh Phys. Soc, Vol. 7, No. 3, Pp. 110–113, 2018, [Online]. Available: Http://Www.Jurnal.Unsyiah.Ac.Id/Jacps
11. P. B. Imran, E. Fernanda, And S. D. Sudrazat, "Pengolahan Data Landsat Dan Gravitasi Sebagai Indikasi Panasbumi Daerah Rana Kulan, Ntt," Jge (Jurnal Geofisika Eksplorasi), Vol. 7, No. 1, Pp. 41–51, Mar. 2021, Doi: 10.23960/Jge.V7i1.108.
12. N. Anivatul Karimah, S. Supriyadi, And A. Suprianto, "Korelasi Data Gravitasi Satelit Pada Daerah Panas Bumi Blawan-Ijen," Jurnal Sains Dasar, Vol. 9, No. 1, Pp. 11–15, Feb. 2021, Doi: 10.21831/Jsd.V9i1.26431.
13. H. S. Yasmin Et Al., "2d Geological Structure Identification in Mount Ciremai Geothermal Area Using the Ggmplus Data.," In Iop Conference Series: Earth and Environmental Science, Institute of Physics, 2024. Doi: 10.1088/1755-1315/1344/1/012017.
14. N. Satria Putra, Y. Arman, Z. Prodi Geofisika Jurusan Fisika, And F. Universitas Tanjungpura, "Identifikasi Struktur Bawah Permukaan Daerah Potensi Panas Bumi Pada Lembar Kota Agung Menggunakan Data Global Gravity Model Plus (Ggmplus)," Vol. 9, No. 2, Pp. 183–189, 2021, [Online]. Available: Http://Ddfe.Curtin.Edu.Au/Gravitymodels/Ggmplus/
15. Reynolds J M, An Introduction to Applied and Environmental Geophysics. John Wiley And Sons Ltd, 1997.
16. Lowrie W, Fundamentals of Geophysics, Second Edition. 2007.
17. B. M. Kearey P And Hill I, An Introduction to Geophysical Exploration, Third Edition. Blackwell Science, 2009.
18. R. J. Blakely, Potential Theory in Gravity and Magnetic Applications. Cambridge University Press, Cambridge Core, 1995.
19. I. Muttaqien and J. Nerjaman, "Two-Dimensional Inversion Modeling Og Magnetotelluric (Mt) Synthetic Data of a Graben Structure Using Simpeg," Riset Geologi Dan Pertambangan Indonesian Journal of Geology and Mining, Vol. 31(1), Pp. 1–12, 2021.

How to cite this article: Muhammad Hanif Hafidh, Ahmad Ali Muckharom, Agus Setyawan, Fajar Arianto. Subsurface modeling using gravity data in the Geureudong volcano geothermal prospect area. *International Journal of Research and Review*. 2025; 12(6): 261-269. DOI: *https://doi.org/10.52403/ijrr.20250631*

******