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Analysis of the Subsurface Structure of Mount Kerinci Based on Gravity Anomaly and 2-D Modelling

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Abstract
Mount Kerinci is a Type-A active volcano and the highest volcano in Southeast Asia, reaching an elevation of 3,805 m above sea level. This study aims to analyze gravity anomaly distribution and identify the subsurface structure of Mount Kerinci using the gravity method. Satellite gravity data from the Global Gravity Model Plus (GGMPlus) with a spatial resolution of approximately 220 m were processed through Complete Bouguer Anomaly (CBA) calculation, spectral analysis, regional–residual anomaly separation using upward continuation, and 2-D forward modeling of the residual anomalies. The CBA values range from 0 to 46 mGal, with low anomalies (0–14 mGal) occurring in the northern to northeastern part of the study area, moderate anomalies (15–30 mGal) dominating the volcanic edifice, and high anomalies (31–46 mGal) concentrated in the southwest. These variations indicate contrasts in subsurface rock density associated with lithological and geological structural variations. The 2-D forward modeling identified five subsurface density layers: 2.40 g/cm³, interpreted as Quaternary volcanic deposits; 2.20 g/cm³, interpreted as a hydrothermally altered and fractured zone; 2.55 g/cm³, interpreted as compact volcanic rocks forming the main volcanic edifice; 2.90 g/cm³, interpreted as a magmatic intrusion associated with the magma conduit system; and 3.40 g/cm³, interpreted as the regional basement. The resulting subsurface model is consistent with the observed gravity response and provides new insights into the volcanic structure of Mount Kerinci, supporting geothermal exploration and volcanic hazard assessment.

INTRODUCTION

Indonesia is located at the convergence of the Eurasian, Indo-Australian, and Pacific tectonic plates, placing the country within the Pacific Ring of Fire and making it one of the regions with the greatest number of active volcanoes in the world (Munir et al., 2024; Adri et al., 2021). A volcano is a fracture in the Earth's crust through which magma, volcanic gases, and other volcanic materials are released to the surface. Based on their activity, volcanoes in Indonesia are classified into Type A, Type B, and Type C, while their morphology and eruption characteristics are categorized as stratovolcanoes, shield volcanoes, and cinder cones (Azzahro & Permata, 2023; Singarimbun, 2024; Supriyadi et al., 2025)

There are 127 active volcanoes in Indonesia, one of which is Mount Kerinci, a Type A active stratovolcano located within Kerinci Seblat National Park (TNKS) in the Bukit Barisan Mountain Range, on the border between Jambi and West Sumatra provinces. With an elevation of 3,805 m above sea level, Mount Kerinci is the highest volcano in Indonesia and Southeast Asia (Oktariadi et al., 2024). As shown in Figure 1, the volcano exhibits a conical morphology formed by repeated explosive eruptions that have produced successive lava flows and pyroclastic deposits (Ashari & Purwantara, 2022).

According to records published by the Center for Volcanology and Geological Hazard Mitigation (PVMBG), Mount Kerinci experienced numerous eruptions between 1838 and 2023, including volcanic ash emissions, volcanic gas releases, and small- to moderate-scale explosive eruptions (Oktariadi et al., 2024). The last eruption in 2023 caused volcanic ash rain that covered approximately 10 hectares of agricultural land and several surrounding residential areas.

Figure 1. Mount Kerinci

In addition to being an active volcano, Mount Kerinci has significant geothermal potential, indicating the presence of hydrothermal and magmatic activity beneath the surface. This potential is supported by the existence of the Muaro Labuh Geothermal Power Plant (PLTP), which is associated with the Mount Kerinci volcanic system (Laboh, 2023). Furthermore, its volcanic activity poses various geological hazards. Therefore, understanding the subsurface structure is essential for geothermal exploration and volcanic hazard mitigation.

One of the most widely used geophysical methods for identifying subsurface structures is the gravity method, which utilizes variations in the gravitational field caused by differences in rock density (Telford et al., 1990). However, direct gravity surveys in the field require relatively high costs, time, and measurement precision, especially over large areas. Therefore, satellite-based gravity data serve as an efficient alternative because they can provide extensive coverage and preliminary information on subsurface conditions (Mazzaluna et al., 2024; Haning et al., 2022). One widely used dataset is the Global Gravity Model Plus (GGMPlus), which has a spatial resolution of approximately 200 m and can identify variations in lithology, geological structures, volcanic systems, and geothermal potential (Hofi et al., 2024; Wuletawu et al., 2024).

Although numerous studies on Mount Kerinci have investigated its volcanic activity, geological mapping, and geothermal manifestations, information on the subsurface density distribution and geological structure derived from high-resolution GGMPlus gravity data remains limited. A study by Larasati (2025) identified the subsurface rock density distribution and magmatic system beneath Mount Kerinci using 3-D inversion modeling. However, studies on the subsurface structure of Mount Kerinci that utilize Complete Bouguer Anomaly analysis and forward modeling 2-D for subsurface structural interpretation remain very limited. Therefore, this study aims to develop a subsurface structural model that describes the distribution of rock density, alteration and fracture zones, magmatic intrusive bodies, and the basement, thereby improving the understanding of the Mount Kerinci volcanic system.

METHOD

Research data

Data collection and processing in this study were conducted using MATLAB R2007b and Microsoft Excel, while mapping was performed using Surfer 16 and Global Mapper, and 2-D modelling was performed using Oasis Montaj 8.4. The data used in this study consisted of gravity anomaly data obtained from the Global Gravity Model Plus (GGMPlus) with a spatial resolution of 220 m, including Gravity Acceleration and Geoid data. In addition, Earth Relief Topography Model (ERTM2160) data with a spatial resolution of 220 m was used as a Digital Elevation Model (DEM) that provides topographic information for the study area. Both datasets were developed by Hirt et al., 2013 and can be accessed through : https://ddfe.curtin.edu.au/gravitymodels/. This data can represent the acceleration of gravity and the topography of the Earth's surface in land areas up to a geographical latitude of ±60°.

Research Location

This research was conducted in the area around Mount Kerinci, which is administratively located in Kerinci Seblat National Park (TNKS), Kerinci Regency, Jambi Province. The research area is located at coordinates 101°12′19.14" East Longitude to 101°20′02.84" East Longitude and 1°45′02.27" South Latitude to 1°37′13.37" South Latitude. Figure 2 shows the location of the study area, covering approximately 529 km² (23 km × 23 km) around Mount Kerinci. The study area extends from the foothills to the summit of the volcano. The study area was selected to encompass the entire Mount Kerinci volcanic edifice and the surrounding geological units that may influence the regional gravity response, thereby ensuring that gravity anomalies associated with the subsurface structure are adequately represented.

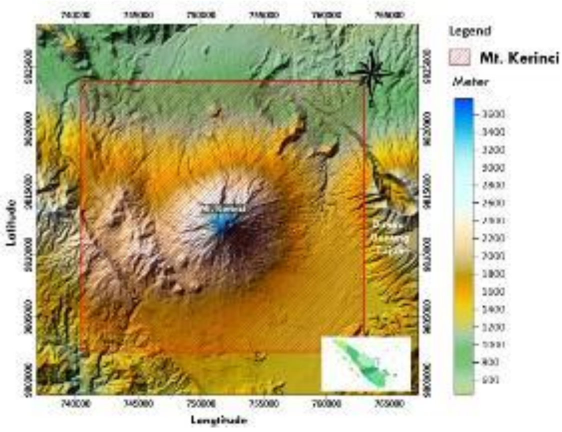

Figure 2. Study Area Location Map

Geological Settings

The geology of the Mount Kerinci area is composed of Paleozoic–Mesozoic rocks in the north, Tertiary rocks in the west, east, and south, and is dominated by Quaternary volcanic rocks resulting from Mount Kerinci's activity. Based on the Geological Map of the Painan Sheet and the Northeast Muarasiberut Sheet, the stratigraphy of this area includes the Asai Formation, Siulak Formation, Siguntur Formation, Peneta Formation, granitoid intrusions, and Quaternary volcanic products (Oktariadi et al., 2024).

The lithology of the research area is dominated by Quaternary volcanic rocks in the form of volcanic breccia, lava, tuff, ignimbrite, and lahar, which are classified into units Qv, Qyl, Qou, Qoa, and Qol. In addition, there are intrusive rocks as granite (Tgr), granodiorite (Tgdr), and granitic rocks (Kgr), as well as sedimentary and metamorphic rocks included in the Barisan Formation (Pb) and the Limestone Member of the Barisan Formation (Pbl). The youngest deposit is alluvium (Qal) comprising mud, sand, and gravel. Figure 3 shows the lithological diversity of the study area, which reflects variations in rock density that influence the gravity anomaly pattern in the Mount Kerinci region.

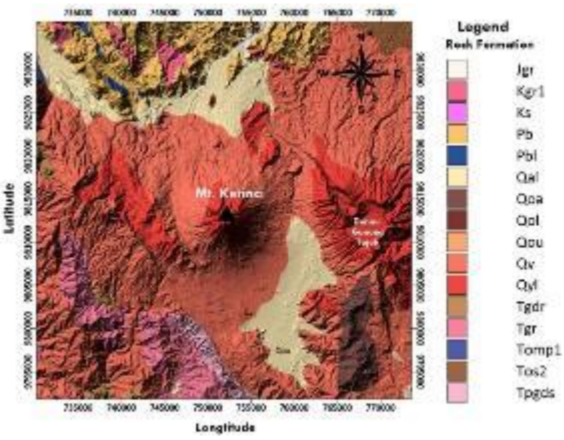

Figure 3. Geological Map of Mount Kerinci (Modified from Rosidi et al. 1996)

Data Processing

Parasnis Density

The method used to correct Bouguer for the average rock density is the Parasnis method. This method is used to determine rock density by plotting the difference between the Bouguer correction and the terrain correction against the free-air correction. Next, a straight line is drawn to obtain the gradient of the resulting curve, where the gradient value represents the average density of the study area. (Anggraeni et al., 2023).

Complete Bouguer Anomaly

The complete Bouguer anomaly is the sum of regional anomalies and residual anomalies, so the resulting value can still be influenced by various sources. This complete Bouguer anomaly has undergone corrections, including latitude correction, free-air correction, Bouguer correction, and terrain correction (Reynolds, 2011; Sanjaya et al., 2023). The complete Bouguer anomaly equation is as follows :

$$CBA = g_{obs} - g_n + \text{FAC} - \text{BC} + \text{TC}$$

With: CBA = Complete Bouguer Anomaly ($mGal$); g_{obs} = observed gravity ($mGal$); g_n = normal gravity ($mGal$); FAC = Free *Air Correction* ($mGal$); BC = Bouguer Correction ($mGal$); TC = Terrain correction ($mGal$). Based on the basic principle of gravity, the size of the anomaly is directly proportional to the density of the rock, where high anomalies indicate the presence of high-density material, while low anomalies reflect rocks with a lower density.

Spectrum Analysis

Spectral analysis is a Fourier transform-based method used to estimate the depth of subsurface anomaly sources and separate regional, residual, and noise components in complete Bouguer Anomaly (CBA) data. In this method, the gravity field is represented as a superposition of sinusoidal waves with a certain amplitude (A) and phase (Φ) (Telford et al., 1990). This conversion process is carried out using the Fast Fourier Transform (FFT) method using Oasis Montaj 8.4 software.

Separation Of Regional And Residual Anomaly

The upward continuation method was used in this study to separate regional and residual anomalies. This method transforms the potential field from the observation plane to a higher plane, thereby reducing the influence of shallow sources and noise. Thus, short-wavelength anomalies experience greater attenuation, while long-wavelength anomalies, representing the regional component, become more dominant (Telford et al., 1990). The upward continuation height was determined based on the spectral analysis results and the ability to effectively separate regional and residual anomalies while preserving significant geological features associated with the volcanic system (Kebede et al., 2020).

Forward Modelling

Forward modeling is a modeling method carried out by constructing a subsurface model based on geological parameters and the density distribution of rocks, then calculating the theoretical gravity response to obtain the best fit with the observed data (Telford et al., 1990). In this study, the density assigned to each layer of the subsurface model was determined based on the rock density ranges reported by Telford et al. (1990), as presented in Table 1, and subsequently adjusted to the regional geological conditions of Mount Kerinci. The modeling process was performed using Oasis Montaj 8.4 software. Profiles A–A' and B–B' were selected because they intersect the main gravity anomaly zones and traverse the volcanic edifice, enabling the interpretation of rock density variations, major geological structures, and the distribution of magmatic intrusive bodies beneath Mount Kerinci.

Table 1. Rock Density (Telford et al., 1990)

Rock Type	Density Range(g/cm^3)	Average Density(g/cm^3)
Sediments wet		
Overburden		1.92
Soil	1.2-2.4	1.92
Clay	1.63-2.6	2.21
Gravel	1.7-2.4	2.0
Sand	1.7-2.3	2.0
Sandstone	1.61-2.76	2.35
Shale	1.77-3.2	2.40
Limestone	1.93-2.90	2.55
Dolomite	2.28-2.90	2.70
Sedimentaryrocks average		2.50
Igneous rocks		
Rhyolite	2.35-2.70	2.52
Andesite	2.4-2.8	2.61
Granite	2.50-2.81	2.64
Granodiorite	2.67-2.79	2.73
Porphyry	2.60-2.89	2.74
Quartz diorite	2.62-2.96	2.79
Diorite	2.72-2.99	2.85
Lavas	2.80-3.00	2.90
Diabase	2.50-3.20	2.91
Basalt	2.70-3.30	2.99
Gabbro	2.70-3.50	3.03
Peridotite	2.78-3.37	3.15
Acid igneous rocks	2.30-3.11	2.61
Basic igneous rocks	2.09-3.17	2.79
Metamorphic rocks		
Quartzite	2.5-2.70	2.60
Schists	2.39- 2.9	2.64
Graywacke	2.6-2.7	2.65
Marble	2.6-2.9	2.75
Serpentine	2.4-3.10	2.78
Slate	2.7-2.9	2.79
Gneiss	2.59-3.0	2.80
Amphibolite	2.90-3.04	2.96
Eclogite	3.2- 3.54	3.37
Metamorphic rocks	2.4-3.1	2.74

RESULT AND DISCUSSION

Parasnis Density

The results of the density analysis using the Parasnis method in Figure 4 produce a regression equation $FAA = 2.3262x + 11.862$ with an R^2 value of 0.9583. The regression slope value of $2.3262\ g/cm^3$ is interpreted as the average density of subsurface rocks in the study area. The high value of the coefficient of determination indicates a very strong relationship between the Free-Air Anomaly (FAA) and the Bouguer Correction without density, so that the density obtained is considered representative for use in calculating the complete Bouguer Anomaly. This density value is consistent with the regional geological setting of Mount Kerinci, which is dominated by Quaternary volcanic rocks, including volcanic breccia, lava, tuff, ignimbrite, and lahar deposits.

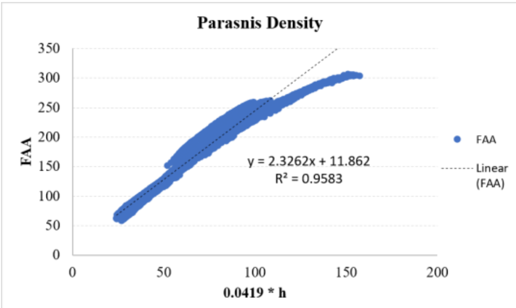

Figure 4. Parasnis Density

Complete Bouguer Anomaly

The complete Bouguer anomaly is a combination of regional and residual anomalies. According to Figure 5, the CBA values are between 0 and 46 mGal, showing differences in the density of rocks beneath Mount Kerinci. In the north to northeast, a low anomaly zone with values between 0–14 mGal is present, and moderate anomalies ranging from 15–30 mGal characterize the area surrounding the mountain peak. In the southwest, there is a high anomaly with values ranging from 31 to 46 mGal. According to gravity theory, these anomaly variations reflect differences in subsurface rock density. High-gravity anomaly zones are associated with relatively high-density rocks, such as granitic intrusions or basement rocks, which are consistent with the regional geological map. In contrast, low-gravity anomaly zones indicate lower-density materials that may be related to unconsolidated volcanic deposits or hydrothermally altered rocks (Pambudi et al., 2026). The spatial distribution of these anomalies reflects the influence of lithological variations, geological structures, and volcanic activity within the Mount Kerinci area, providing valuable information for delineating subsurface geological structures and serving as the basis for subsequent 2-D gravity modelling.

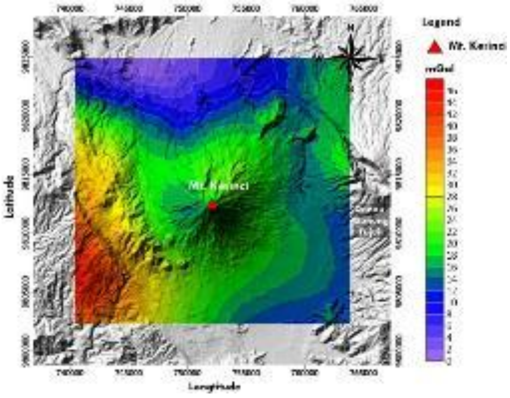

Figure 5. complete Bouguer Anomaly Map

Spectrum Analysis

Based on the results of the spectrum analysis in Figure 6 and Table 2, two anomaly components were identified, namely regional and residual anomalies. The regional component has a cut-off wavenumber (Kc) of 0.54 rad/km, a wavelength of 11.64 km, and an average source depth of 1.337 km with an R^2 value of 0.77.

Meanwhile, the residual component has a Kc of 5.63 rad/km, a wavelength of 1.12 km, and an average source depth of 0.165 km with an R^2 value of 0.99. In spectrum analysis, longer wavelengths are associated with deeper sources, whereas shorter wavelengths indicate shallower sources (Armi et al., 2025). Therefore, the regional anomaly is interpreted to originate from deeper geological structures, while the residual anomaly is related to shallow volcanic structures and lithological variations around Mount Kerinci. These results indicate anomaly source depths of approximately 1.34 km for the regional component and 165 m for the residual component.

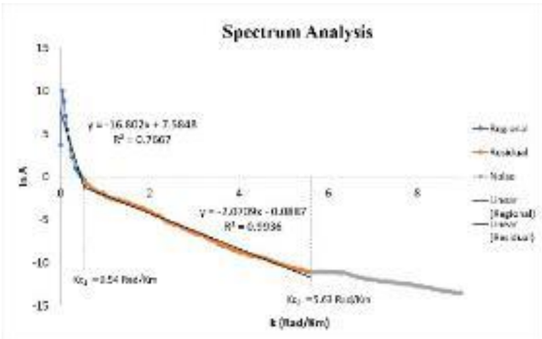

Figure 6. Spectrum Analysis Graph

Table 2. Spectrum Analysis Results

No	Slice	Depth (Km)	R	Kc (Rad/ Km)	λ (Km)
1	Regional	1.337	0.77	0.54	11.64
2	Residual	0.165	0.99	5.63	1.12

Separation Of Regional And Residual Anomaly

The results of the anomaly separation based on the spectrum analysis produce regional anomalies and residual anomalies in Figure 7. Regional anomalies have a value range of approximately 4–42 mGal with a relatively smooth pattern, thus reflecting the influence of deeper and larger-scale geological structures. In contrast, residual anomalies have a value range of approximately −9 to 8 mGal with a more complex pattern, indicating the influence of shallow anomaly sources. At Mount Kerinci, low anomalies that develop around the summit indicate the presence of relatively low-density material. Thus, regional anomalies represent density variations at greater depths, while residual anomalies describe shallow geological conditions.

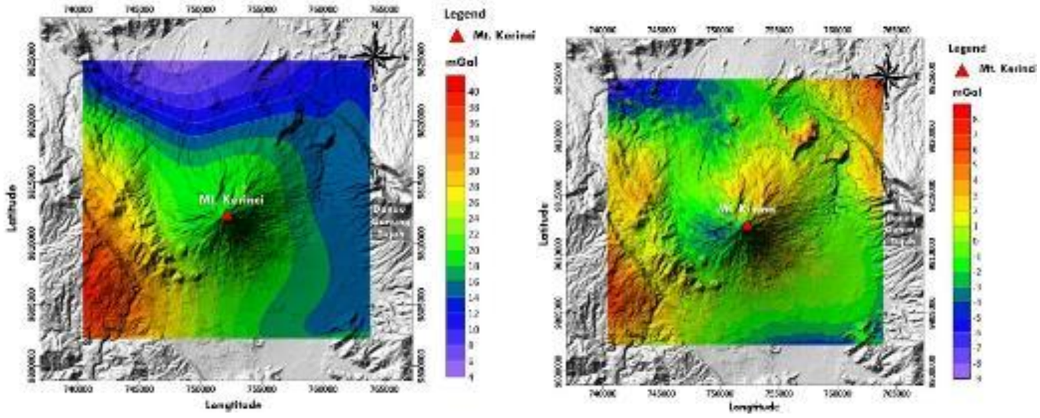

Figure 7. (a) Regional Map and (b) Residual Map

Forwad Modelling

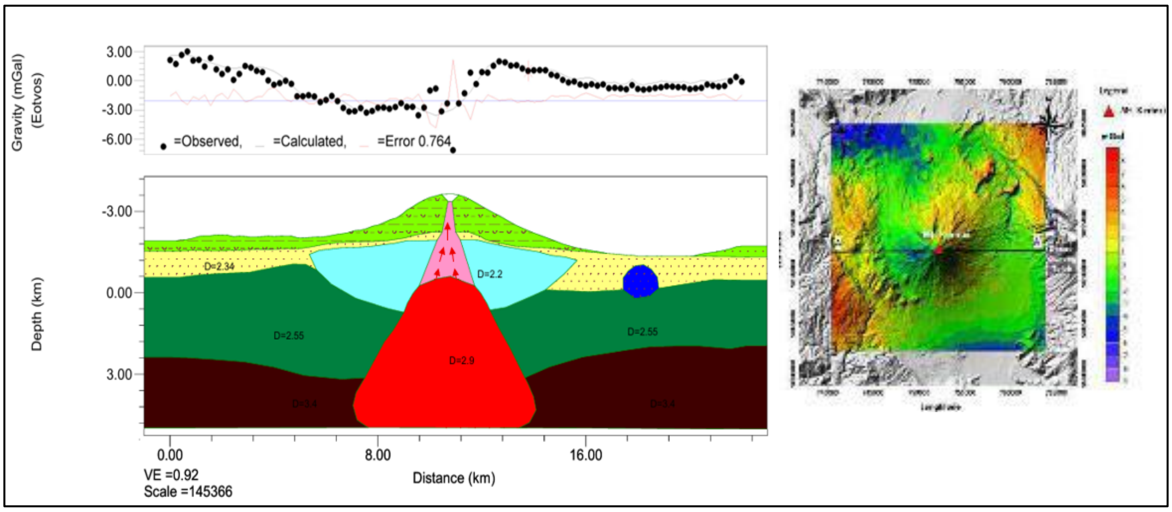

Figure 8. 2-D Modelling results of slice A-A'

The 2-D forward model along profile A–A′ shows good agreement between the observed and calculated gravity anomalies, with a misfit value of 0.764 mGal as shown in Figure 8. This result indicates that the estimated subsurface density model adequately represents the gravity response beneath Mount Kerinci. The model consists of five density layers that are consistent with the regional geological setting. The layer with a density of 2.4 g/cm³ is estimated to represent Quaternary volcanic deposits comprising volcanic breccia, tuff, lahar, and weathered volcanic materials. The layer with a density of 2.20 g/cm³ is estimated to represent a hydrothermally altered and fractured zone, where hydrothermal alteration and fracturing have reduced the density of the volcanic rocks. This zone is surrounded by volcanic rocks with a density of 2.55 g/cm³, which are estimated to constitute the main body of Mount Kerinci. The layer with a density of 2.90 g/cm³ is estimated to represent a magmatic intrusion associated with the volcanic magma conduit system, whereas the layer with a density of 3.40 g/cm³ is estimated to represent the regional basement that forms the structural foundation beneath Mount Kerinci.

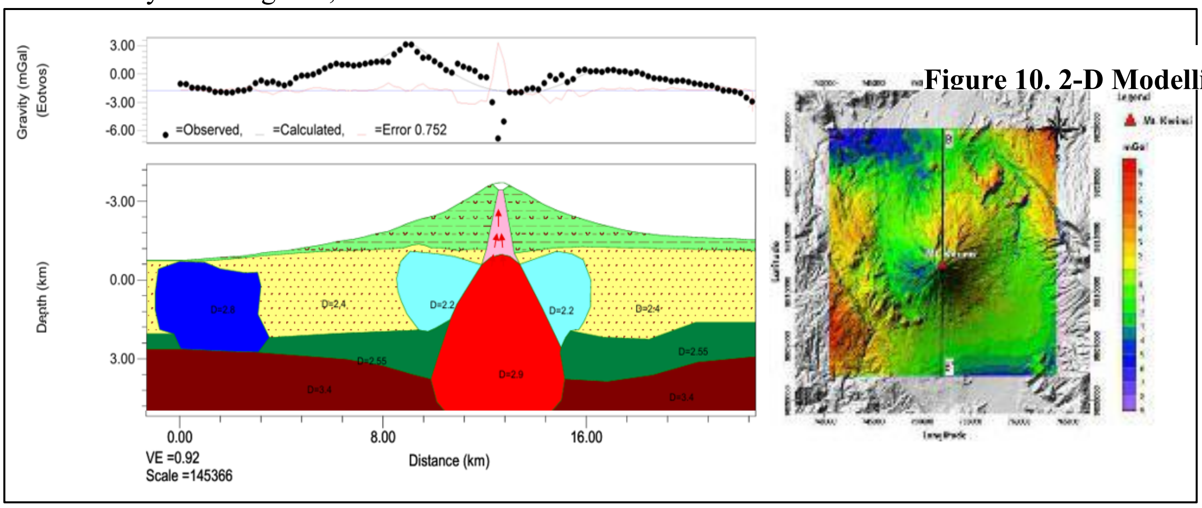

Figure 10. 2-D Modelling Results of

Based on 2-D gravity modelling on the B–B' trajectory with a misfit of 0.752 mGal as shown in Figure 10, the subsurface structure of Mount Kerinci is composed of Quaternary volcanic rocks (ρ = 2.40–2.55 g/cm³), alteration and fracture zones beneath the summit (ρ = 2.20 g/cm³), magmatic intrusions or magmatic conduits (ρ = 2.90 g/cm³), and high-density basement rocks (ρ = 3.40 g/cm³). In addition, a body with a density of 2.80 g/cm³ in the western part of the trajectory is interpreted as a granite–granodiorite intrusion that corresponds to the presence of Tgr, Tgdr, and Kgr units on the geological map. This interpretation indicates that low anomalies are controlled by alteration and fracture zones, while high anomalies are related to magmatic intrusions and denser basement rocks.

Overall, the density distribution indicates that the subsurface beneath Mount Kerinci consists of Quaternary volcanic deposits, hydrothermally altered and fractured zones, compact volcanic rocks, a magmatic intrusion, and the regional basement. The comparison between profiles A–A′ and B–B′ suggests lateral variations in the distribution of low-density rocks. Profile A–A′ indicates the presence of a low-density body on the eastern side of the volcanic edifice, whereas profile B–B′ reveals a similar low-density body on the western side. These results suggest that hydrothermal alteration and fracturing are distributed around the volcanic edifice rather than being confined to the summit area.

CONCLUSION

Based on the results of this study, the Complete Bouguer Anomaly (CBA) in the Mount Kerinci area ranges from approximately 0 to 46 mGal. Low gravity anomalies are predominantly distributed in the northern to northeastern part of the study area and are estimated to be associated with low-density rocks, whereas high gravity anomalies are concentrated in the southwestern part and are estimated to be associated with high-density rocks. The results of the spectral analysis and upward continuation indicate that the regional anomaly represents deeper anomaly sources, whereas the residual anomaly reflects shallow subsurface density variations associated with the volcanic system of Mount Kerinci. The 2-D forward modelling of the residual gravity anomaly produced a subsurface structural model of Mount Kerinci comprising a density layer of 2.4 g/cm³, estimated to represent Quaternary volcanic deposits; a density layer of 2.20 g/cm³, estimated to represent a hydrothermally altered and fractured zone; a density layer of 2.55 g/cm³, estimated to represent compact volcanic rocks forming the main volcanic edifice of Mount Kerinci; a density layer of 2.90 g/cm³, estimated to represent a magmatic intrusion associated with the volcanic magma conduit system; and a density layer of 3.40 g/cm³, estimated to represent the regional basement. The resulting model reveals the spatial relationship among the rock density distribution, the hydrothermally altered and fractured zone, the magmatic intrusion, and the regional basement, thereby providing a more comprehensive understanding of the subsurface structure and volcanic system beneath Mount Kerinci.

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