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The Identification of the Existence of a Fault Structure on Gravity and Audio Magnetotulleric Data in the Area of Mount Kubing, Belitung

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Abstract

Mount Kubing holds significant potential as a tourist attraction, despite being situated in a tectonic zone prone to faults. Its size and attractions make it suitable for both travel and exploration. Hence, the study has been conducted to identify subsurface structures that can identify the structural fault lines when the mitigation occurred during an earthquake or landslide. The derivative analysis method is used to determine the type of structures. The results of the derivative analysis indicate the direction of the fault structure on a Northwest-Southeast, and Southwest - Northeast that is controlled by two different faults. The fault caused by depression from granitic body and silt with FHD and SVD gravity value around -3 mGal until 1 mGal that showing the indication of normal fault and reverse fault in the research location with depth estimation curve (RAPS) approximately 500 meters in the subsurface of the earth. Whereas in 2D Audio Magnetotelluric modelling, it is identified that the groundwater reservoir layer is at a depth of 70-85 meters below the surface which is recognized as a semi-stressed reservoir with a value of 20-27 mv/nT in complex silt and sandstone.

Keywords: *Derivative analysis; Audio Magnetotelutic; gravity method; Magnetotelluric, Reservoir*

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INTRODUCTION

The lithology of Bangka Regency is composed of schist units, sandstones, intrusions granite and alluvial deposits. Unit regional schists are included in the Old Pemali group Triassic, sandstone units, the Tanjung Genting Formation Late Triassic and intrusive granite, including Klabat granite Yura's age [1]. The rose diagram shows a dominant northwest-southeast trending,

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indicating the movement of layers. Additionally, an east sea-southwest contour and folded rocks, in Tanjung Formation Genting and Ranggam Formation, suggest significant tectonic activity. A significant slope ranging from 180 to 750 confirms the intense tectonic intensity. Furthermore, there is a north-south trending lineament, representing a fracture in its youngest phase, intersected by a horizontal fault [2]. Mount Kubing area is in the Perpat Village, Subdistrict of Membalong, Belitung District. This area harbored the potential of natural resources and a fascination with natural beauty caused by geological processes. Waterfalls are one of the hallmarks of a fault structure [3]. Fault structures are produced largely as a result of tectonic processes [4]. The island of Belitung underwent a lot of tectonism processes, thus producing faults on the island. Fault lines are often nonexistent on the surface.

This research focused on the gravity method, one of the commonly used geophysics methods alongside seismic methods. By measuring variations in the acceleration of the Earth, the gravity method determines density, a crucial physical parameter of rock. It is capable of identifying fault structures by examining changes in gravitational acceleration anomalies caused by density variations [5]. The method of gravity can identify a breaking structure by looking at increased gravitational velocity anomalies resulting from increased density [6]. The description of the geological structure of the rock types below the surface and its distribution both vertically and laterally is indicated by its density value. In the geothermal case, the difference in density becomes the reference in the gravity method investigation. The areas with heat sources and their accumulation below the surface cause differences in the density of the surrounding rock masses [7].

Lineament analysis can provide an overview of the geological structure on the surface. Furthermore, gravity analysis aims to provide a qualitative description of the type and depth of geological structures [8]. According to the Sukrisna, in 2004, Bangka Island and Belitung Island had limited groundwater potential. Investigations of groundwater reservoirs can use magnetotelluric, one of the geophysical methods. Magnetotelluric (MT) is an electromagnetic geophysical method that measures underwater electricity conductivity by measuring variations in the geomagnetic field and natural geoelectric on the earth's surface [9]. Applications of magnetotelluric methods can be used in hydrocarbon exploration (oil and gas), carbon absorption, geothermal exploration, mining exploration, and the monitoring of hydrocarbon and groundwater investigation [3].

METHOD

Based on the regional geological map of Belitung in Figure 1, it appears that the oldest granitic in the Triassic age spread across Northwest Belitung, including Tanjungtinggi beach, Kepayang Island, and Lengkuas Island. The outcrop appears with big consist that has bright gray deposits, crystallized rough to rough. This granite contained many cassiterite minerals. The absolute age is approximately 208 – 245 million (Triassic Era) [10].

The latest granite, known as the Burungmandi Granodiorite, can be found in the northeast region of Belitung. It extends from Burungmandi beach to Bolong - Tanjung Mountain. Additionally, there are limited occurrences of diorite quartz in Mount Batubesi and Dengong Water. The granite exhibits a darker color due to higher feldspar mineral content and has a medium, rather than coarse, texture. Its absolute age is estimated to be between 115-106 million years, dating back to the Cretaceous Era [10].

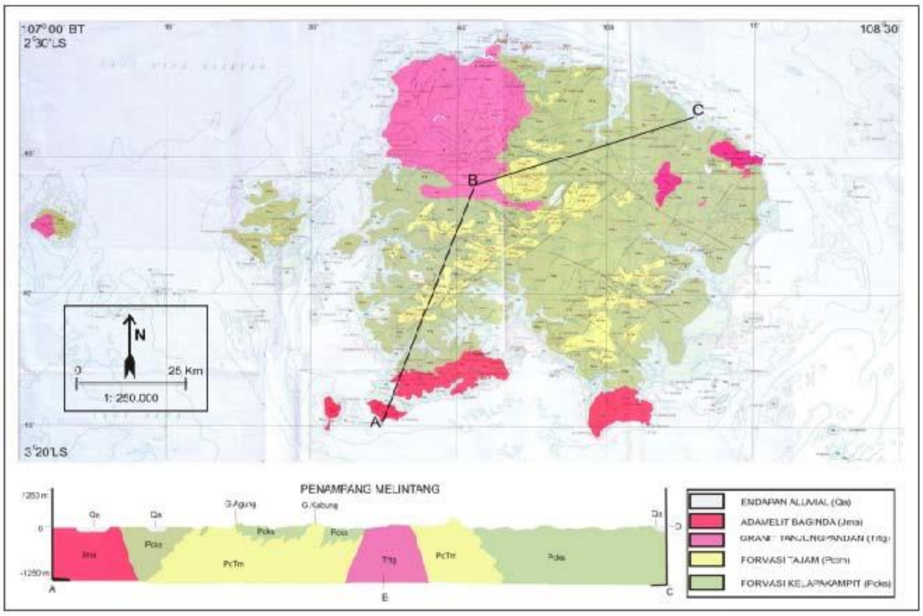

Figure 1. Regional Geological Mount Kubing [9]

This research focused on the District of Belitung with coordinate position 107°08' BT - 107°58' BT dan 02°30' LS - 03°15' LS. The magnetotelluric (Audio Magnetotelluric) primer data of Belitung Island was retrieved from the mountain. Meanwhile, the gravity data as secondary data is derived from a satellite. Processing gravity and Audio Magnetotelluric data were placed in the Central Laboratory of Syarif Hidayatullah State Islamic University Jakarta. The research location is in Mountain Kubing as geographically in Sub-District Membalong, District Belitung, Province of Bangka Belitung. The force of gravitation is expressed by Newton's law, the force between two particles of masses m_1 and m_2 is directly proportional to the product of the mass and inversely proportional to the square of the distance between the centers of masses [5].

The gravity method produces Complete Bouguer Anomaly (CBA) values. Gravity anomaly data refers to gravity measurements that have undergone corrections, including free air correction, field correction, and Bouguer correction. These corrections aim to account for the variation in rock mass within the Earth's crust, specifically between the spheroid plane and the measurement point. Gravity data processing will produce a complete Bouguer anomaly value. The complete Bouguer anomaly value consists of regional and residual anomalies, so it is necessary to separate the two anomalies [11]. It can be seen that the up-flow zone is located on Mount Hamidiing and can be seen the fault structure caused by the depression of the old Hamidiing caldera and local faults around Mount Dukono [12,13]. The physical parameters of rocks in the gravity method are density [14]. The local density shows the average density value of the subsurface constituent rocks in the study area. This local density value was obtained from field observation data using the Parasnis method. This method was based on the minimum correlation of the Bouguer gravity anomaly and Bouguer correction [15].

Free air correction is the effect of altitude on the Earth's gravitational field [16]. Bouguer correction is used to reduce the value of gravity due to the rock mass between the measurement point at a height of h meters and the Mean Sea Level. So that the measured gravity value is greater than the expected gravity value on the equipotential surface [17]. Terrain correction accounts for the influence of the surrounding material near the measurement point. To accurately assess the measurement terrain, topographic corrections are necessary, especially when dealing with irregular features like mountains or hills [17]. The First Horizontal Derivative, also referred to as Horizontal Gradient, represents a gravity anomaly resulting from an object that tends to manifest at the object's edges. This method utilizes the horizontal gradient technique to identify the boundaries of horizontal density contrast based on gravity data. The value of the First Horizontal Derivative can be calculated using equation 1 [18].

$$FHD = \frac{g_{(i+1)} - g_{(i)}}{\Delta x} \quad (1)$$

where g is anomaly value (mgal), x is the difference between the distance on the path (m), and FHD is First Horizontal Derivative.

The Second Vertical Derivative (SVD) is used for the interpretation of the type of Bouguer anomaly data structure caused by a down or up fault structure. The SVD acts as a high pass filter to describe residual anomalies associated with shallow structures that can be used to identify the type of down or up fault. [19] This method is derived from the Laplace equation. The second derivative can be used to determine the SVD value with equation 2.

$$SVD = \frac{g_{(i+1)} - 2g_{(i)} + g_{(i+1)}}{\Delta x^2} \quad (2)$$

Objects that have low emissivity, low heat capacity, and high thermal conductivity will experience an increase in surface temperature. On the contrary, it will experience a decrease in surface temperature so as to determine the spatial distribution of areas that affect the increase in soil surface temperature [20] the corrected Ts emissivity is calculated as equation 3.

$$Ts = \frac{BT}{\{1 + [\left(\frac{\lambda BT}{\rho}\right) \ln \lambda]\}} \quad (3)$$

where Ts is the Land surface temperature in Celsius, BT on the BT sensor (°C) is the emitted emission wavelength (where the peak and average response of the wave boundary (λ = 10,895 [21] will be used)), is the emissivity based on calculations by Weng et al [22].

When conducting absolute gravity measurements, the availability and accessibility of equipment must be considered. Absolute gravimeters, due to their heavy and bulky nature, are not suitable for measuring remote or challenging sites. In such cases, a slimmer relative gravimeter is preferred to ensure comprehensive survey coverage. Recently, an advanced approach known as the combined absolute and relative gravimeter method has emerged, which is now being employed for geothermal monitoring purposes. This method involves utilizing a portable absolute gravimeter as a reference for other relative measurements, a technique referred to as hybrid gravity measurement, as introduced by Okubo et al [17]. In order to interpret the results of a gravity survey accurately, it is essential to correct for any variations in the Earth's gravitational field that are not caused by differences in density within the underlying rocks [23].

The gravity data obtained comes from satellite data, which is then processed to generate the first horizontal model for faults analysis and interpretation. Similarly, audio magnetotelluric data serves as primary data, which is then processed to create models to identify groundwater reservoirs and subsequently interpreted (see Figure 2).

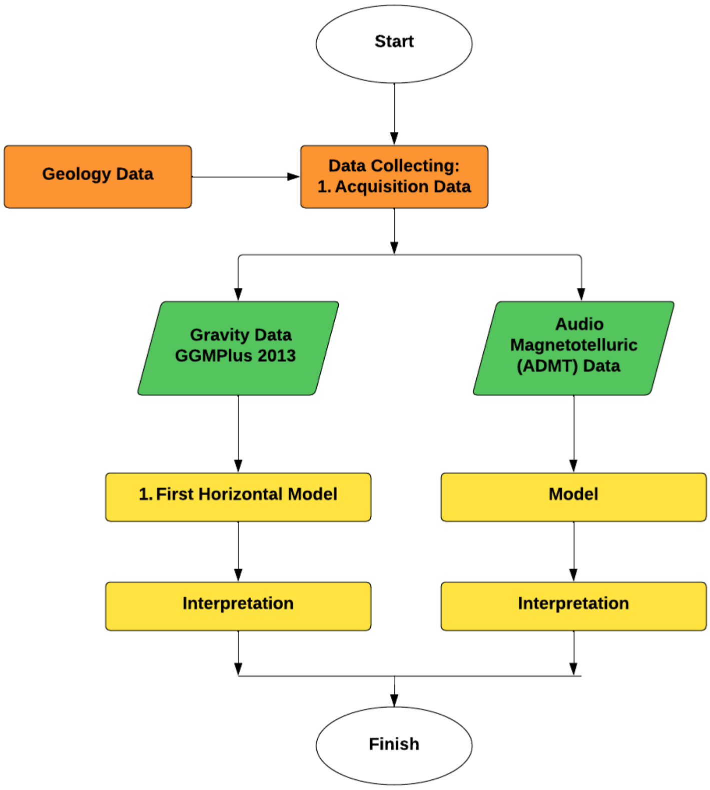

Figure 2. Research Flowchart

RESULTS AND DISCUSSION

The resulting Bouguer anomaly map of the study area illustrates the subsurface structure and tectonic trends that generate potential heat sources. The gravity inversion revealed a good correlation between areas of high temperature gradients, high heat flow, and positive gravity anomalies [24,25]. After applying corrections such as free air correction, Bouguer correction, and terrain correction, a Complete Bouguer Anomaly (CBA) is obtained. The CBA represents the diverse gravity anomalies and density contrasts of the rock in the research location of Mount Kubing, as observed in Figure 3.

Visible on the CBA map, the value of the gravitational anomalies in the research area is between 46.2 – 108.6 mgal, where the value of a low anomaly (dark blue-blue) ranges from 39.4 – 42.3 mgal, the value of a moderate anomaly (dark green) ranges from 81.4 – 114.6 mgal and the value of the high anomaly (orange-purple) ranges between 46.5 – 48.8. From the fragmentary anomalies visible on the CBA map, it is clear that two anomalies look very unique, showing that the current anomaly surrounded by high anomalies is the perp at the research location, the Subdistrict of Mambalong, the island of Belitung (the white circle).

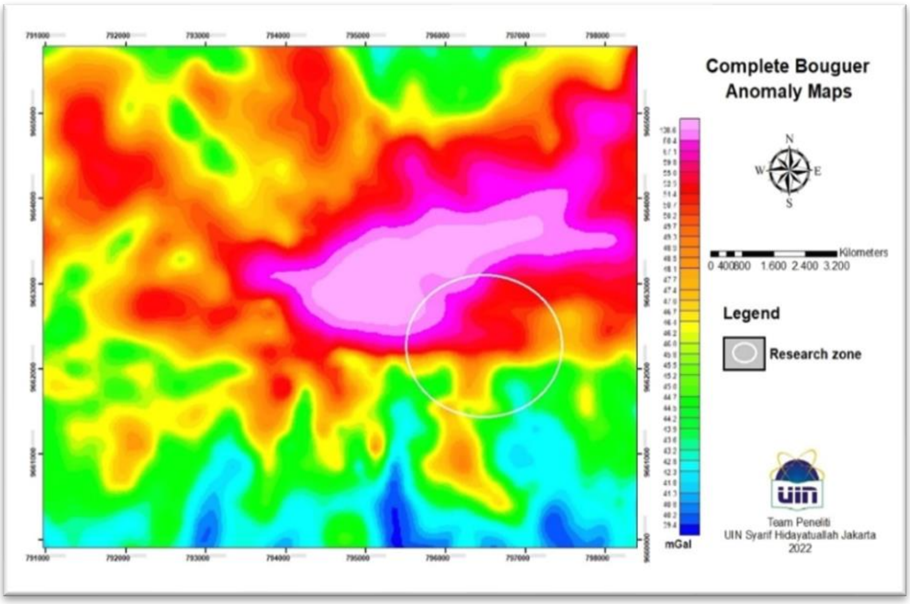

Figure 3. Complete Bouguer Anomaly Maps (CBA)

The research indicates a depth estimation of approximately 3 km from the measurement point, as shown in Figure 4.

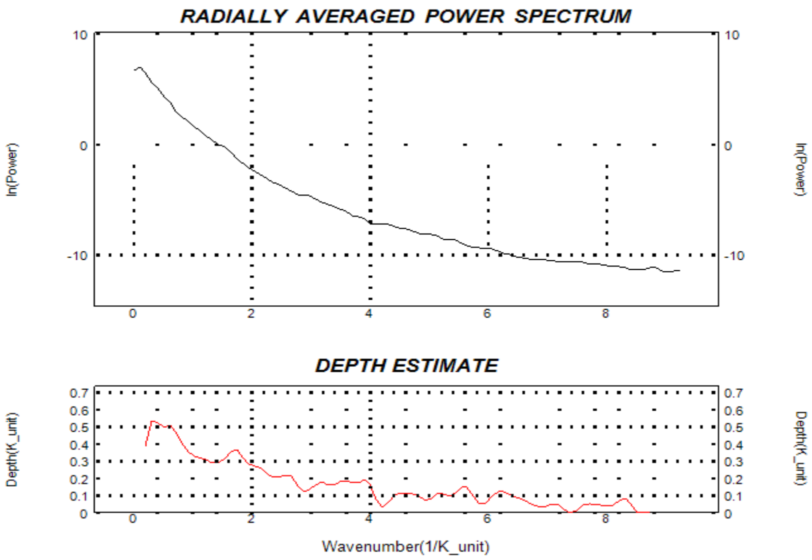

Figure 4. Depth Estimate Curves

The depth estimation is derived from the analysis of the RAPS (radially average power spectrum) curve. The RAPS curve exhibits a deceleration indicating two distinct zones: the regional zone with a steep gradient and the residual zone. The depth used for the regional zone is 2 km from the measurement point. The residual anomalies are identified through Butterworth filtration of the CBA, analyzing residual maps obtained from areas with depth estimates on the RAPS chart below 500 meters. The Butterworth filter is effective in performing highpass and lowpass filtering on data with a fixed wavelength [26].

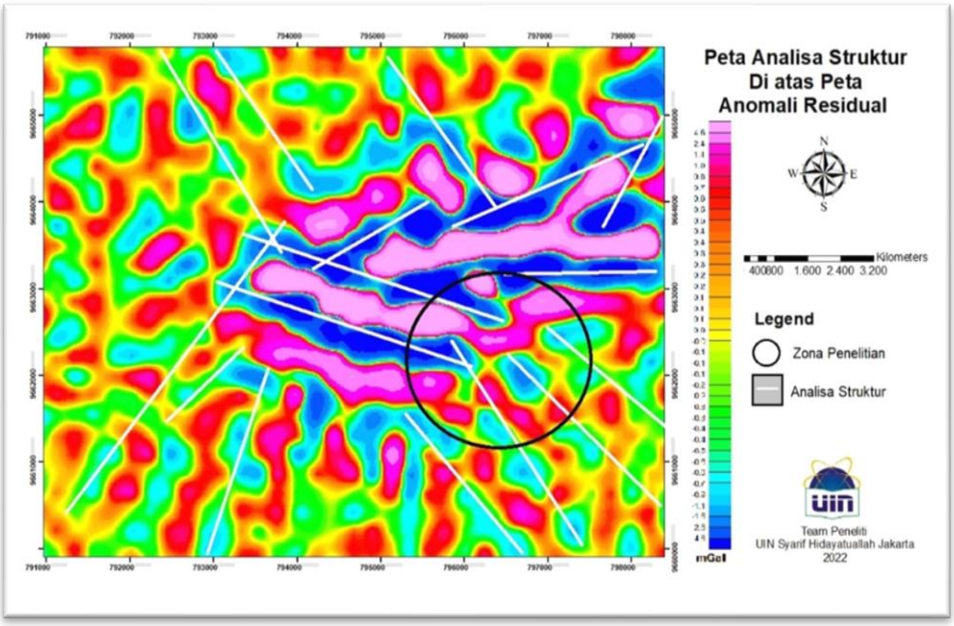

Figure 5. Structural Identification Map

Figure 5 displays the identification of structures (white line) on the residual anomaly map. These structures indicate areas of discontinuity in the relative gravitational anomalies within the research area. They suggest potential rock movement patterns that could lead to natural disasters. This is further supported by observed features at the research site, such as caves, waterfalls, and a heterogeneous lithological pattern.

In Figure 6, the residual anomaly map reveals the presence of a primary southeast-oriented research structure and a conjugate northeast-oriented structure. This interpretation confirms the existence of shallow bone deposits, which can be further identified through derivative analysis. Additionally, the topography maps provide an overview of the altitude of Mount Kubing and its surrounding area.

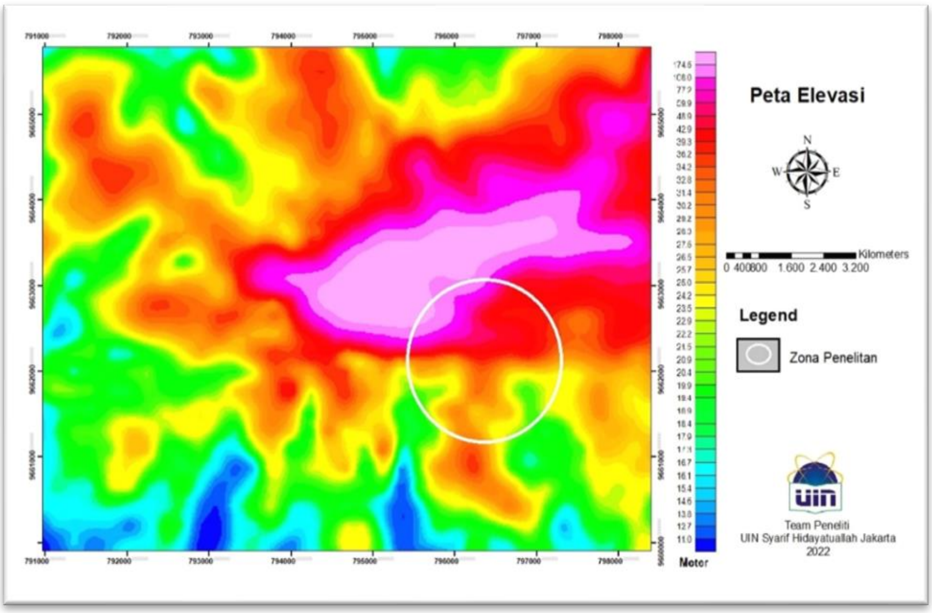

Figure 6. Digital Elevation Model Maps (DEM)

Topographic maps indicate that the altitude of the study area varied from about -21.6 – 870 mdpl (3,316 ft) in value. Topographic maps validate whether the value of Complete Bouguer Anomaly was complete or not. In recent research, the validity of the Complete Bouguer Anomaly value is confirmed. This is due to the relationship between the rate of elevation and the inverted rate of gravity acceleration in the formulation of gravity value. It is observed that higher rates of gravitational anomalies result in smaller and reverse values [27,28].

The evidence of structure identification was made to identify potential structures and determine their types within the research area. This was achieved through an analysis of the correlation between the First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD), as depicted in Figure 8. The FHD analysis enabled the identification of geological structure boundaries impacting the anomaly, while the SVD analysis focused on detecting shallow effects influenced by the regional influence and determining the specific structure types present in the research site. Figure 7 shows the presence of a structure at Mount Kubing, as evidenced by the high anomaly observed in the FHD maps. Additionally, the SVD map indicates a depression zone in the vicinity of Mount Kubing.

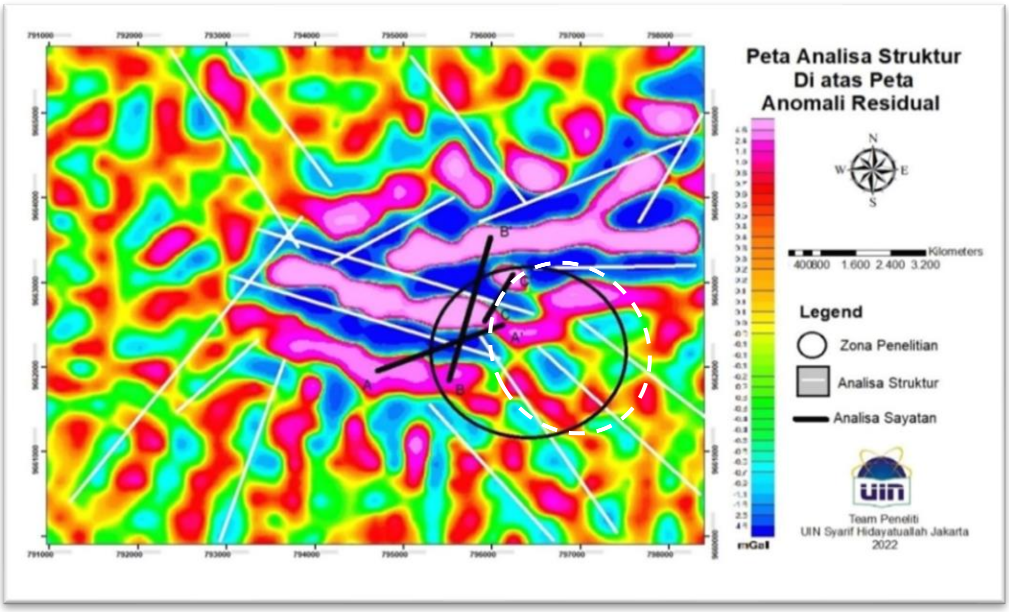

Figure 7. Slicing Residual Maps

The FHD method was employed to detect faults in the subsurface, while the SVD method was utilized to classify the type of fault. In the case of reverse faults, the SVD value exhibits the lowest absolute value from the minimum SVD value. Conversely, for normal faults, the maximum SVD value exceeds the minimum SVD value [29]. The geological structure in the research site is intersected by five fault lines, and the fault type can be determined based on the SVD method.

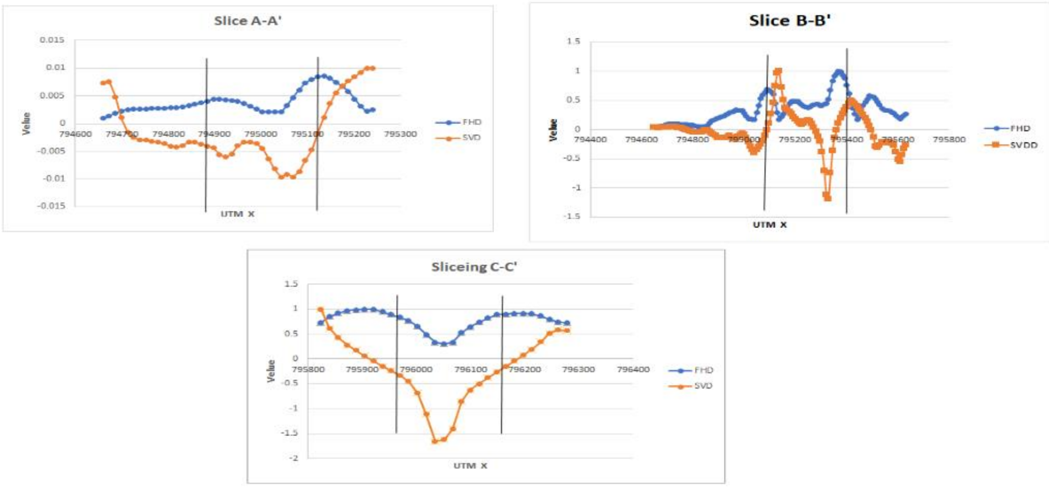

Figure 8. Slicing Curve

Figure 8 displays the FHD curve, depicting maximum and minimum values that indicate the boundaries of contact areas. On the other hand, the SVD analysis reveals a zero-value incision profile, serving as a marker for the boundaries of geological characteristics and indicating the locations of geological structures [29]. On the FHD and SVD maps, there is a close curve at line B-B′ with a maximum value on the FHD analysis and a minimum value on the SVD analysis. It indicates the potential of structure or fault in the subsurface of the research site as a focus. The analysis of FHD and SVD derivatives on the residual maps provides consistent indications of secondary structures in the research area, confirming the presence of a reverse fault. Slicing of the FHD and SVD maps further supports this identification. Correlating the SVD map with the geological map reveals a northwest-to-southeast fault in the study area, passing through a dense rock body near the geothermal manifestations. However, the continuity of the fault is not well-defined as it intersects the high-density rock body along the Tancak River lane [30].

Table 1. Fault Type Based on FHD SVD Analysis

Slice Profile	FHD	SVD	Nilai Curve SVD	Fault Type
A-A′	Minimum	0	Max < Min Normal	Normal Fault
B-B′	Maximum	0	Max < Min Reverse	Reverse Fault
C-C′	Minimum	0	Max > Min Normal	Normal Fault

The slicing profiles (A, B, and C) on the FHD and SVD maps, which intersected the previously identified structure using the gravity method, provide a consistent indication of a fault structure. The slicing curves of FHD and SVD confirm that the fault structure observed on the surface extends into the subsurface. At the slicing curves A-A′ and C-C′, FHD shows the maximum and minimum values showing the boundaries of the rock. Whereas in the SVD analysis, the slicing profile shows a zero value which means it is a boundary of geological characteristics and identifies where the geological structures are.

Hydrogeological investigations to delineate zones of high groundwater potential in five selected communities in the Agona East District of Ghana have been successfully carried out using the magnetotelluric geophysical technique. The technique has successfully been applied to delineate potential zones of high groundwater in terms of location and depth-to-aquifer zones.

The study has revealed that the apparent electrical resistivity of the subsurface of the study area to a depth of 300 m displays the stratigraphic layers of different resistivities [31].

The magnetic anomaly map shows that the Bangka Belitung waters are characterized by a pair of high and low long-wave amplitude anomaly values of -200 nT—500 nT. While the distribution map of magnetic susceptibility in Belitung shows a limited range of magnetic susceptibility values, ranging from 0.001 cgs units to 0.003 cgs units, indicating areas of relatively high magnetic susceptibility. The presence of positive anomalies of low magnetic susceptibility values, ranging from 0.001 to 0.003 cgs units, suggests the presence of submerged intrusive rock bodies, specifically granitic plutons of the granite biotite type. These granitic plutons are associated with cassiterite mineralization. It is worth noting that similar granitic plutons are found in the mainland island of Belitung, which is known for its tin deposits [31].

The Audio Magnetotelluric track map shows that the Mount Kubing area, Belitung Island, and its surroundings have a surface whose contours rise to a height of nearly 200m on the DEM map (Figure 8). In details, as indicated, track 1 is red, track 2 is yellow, track 3 is blue, tracks 4, 5, and 6 are white. Each channel has the same length of 100 meters with tracks 1, 2 and 3 as the main lines for analyzing the reservoir zone of the research area, while tracks 4, 5 and 6 as cross-section lines for depth data correlation.

Figure 9. The Audio Magnetotelutic Track Map

In the sub-study focused on aquifer exploration in the Mount Kubing area of Belitung Island, a confined aquifer was identified with a resistivity value ranging from 20 to 27 mV/nT. A confined aquifer refers to an aquifer that is fully bounded by impermeable layers both above and below, and it has a pressure higher than atmospheric pressure. This confined aquifer is situated within a hard rocky formation composed of quartz rock, which is metamorphic in nature, and is interbedded with silt. Additionally, the aquifer contains sand inserts in the yellow area.

The study area exhibits potential indications of aquifers, which are associated with the presence of fault zones observed in the gravity data and the geological conditions of the rocks visible in outcrops. These conditions provide favorable spaces or chambers for the development of confined aquifers at a depth ranging from 70 to 80 meters.

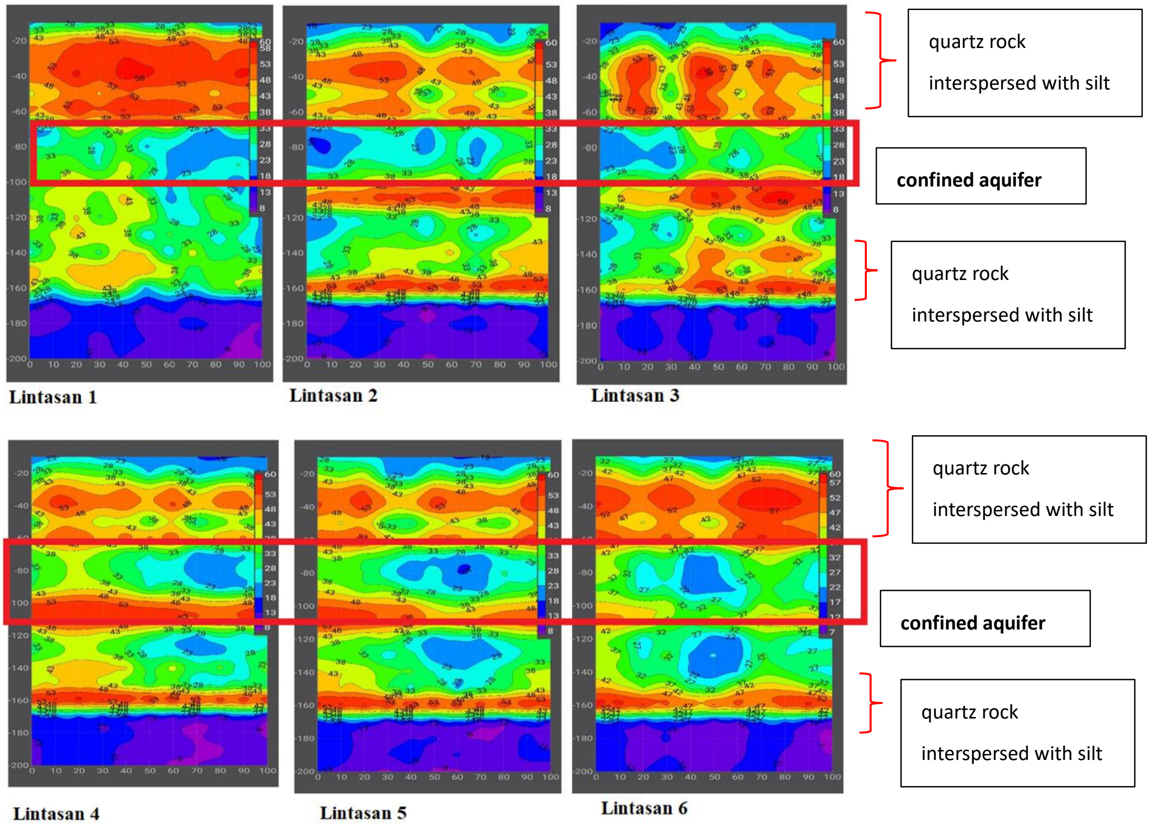

Figure 10. The Supporting Lines or Cross Sections

The research location consists of main lines (1, 2, and 3) and supporting lines (4, 5, and 6) that provide cross-sectional insights. The groundwater reservoir zone is identified along the long red line, situated at a depth of 70 to 85 meters. This zone serves as a source of confined groundwater, occurring beneath hard rocks (blue) with a resistivity value of 20-27 mV/nT. Metamorphic rocks (red) with resistivity values of 50-60 mV/nT are characterized by silt-inserted quartz. The yellow-colored area represents a siltstone complex with sand inserts and a resistivity value of 28-33 mV/nT. Finally, the green-colored section corresponds to a complex sedimentary rock, specifically white-green, dense, fine-grained sandstone.

The research has certain limitations that should be considered. Firstly, the correlation between gravity satellite data and the original field data may be affected by the Earth's non-uniform shape, leading to variations in gravitational velocity force in different zones. This could introduce discrepancies between the satellite data and the actual field measurements. Additionally, the use of ADMT (Audio Magnetotelluric) as a portable wireless device for data acquisition introduces sensitivity to noise. It is important to exercise caution during field observations, considering natural conditions such as rain, lightning, and proximity to rivers, as these factors can cause frequency disturbances that may affect the data received by devices like smartphones and mean units, leading to potential data acquisition failures. The research aims to determine changes in the resistivity of rock layers beneath the soil surface. Its impact lies in assisting the local government in understanding, maintaining, and making informed decisions regarding the zones indicated by faults on the Mount Kubing Geosite in Belitung Island. This knowledge can be valuable in the future development of facilities and infrastructure in the area.

CONCLUSION

Based on the results of research that have been carried out with gravity data and identification of groundwater reservoirs based on Audio Magnetotelutic data around Mount Kubing, it is concluded that the identification of fault structures using FHD and SVD on the latest residual data suggested that the fault is located between the bare- southeast with its eastern and southern regions. Furthermore, the SVD analysis, including the SVD minimum and maximum value parameters, indicates that the errors are within normal limits. The research also confirms the presence of a groundwater reservoir zone along the long red line at a depth of 70 to 85 meters.

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AUTHOR CONTRIBUTIONS

Edi Sanjaya: supervision, validation, review, editing and manuscript finalisation. Muhammad Nafian: Magnetotulleric Audio data acquisition and gravity, conceptualisation, methodology, and analysis and manuscript drafting. Suwondo : supervision, validation, review. M Hasnan Fadhilah: Magnetotulleric Audio data acquisition and gravity, data processing. All authors have read and agreed to the published version of this manuscript.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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