



Subsurface density architecture and structural controls of the Dendang non-volcanic geothermal area, west Bangka, Indonesia

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ABSTRACT

The Dendang hot-spring area in West Bangka, Indonesia, represents a non-volcanic geothermal setting developed within a granitic geological environment. This study investigates the subsurface density architecture beneath the Dendang geothermal area using satellite-derived gravity data. Free-Air Anomaly and elevation data obtained from the TOPEX data portal were processed to construct the Complete Bouguer Anomaly, followed by spectral analysis, regional–residual anomaly separation, two-dimensional forward modelling, and three-dimensional gravity inversion. The Complete Bouguer Anomaly ranges from approximately 21.0 to 42.7 mGal, indicating substantial lateral variation in subsurface density. The gravity models reveal contrasting shallow low-density and deeper high-density domains. Based on comparison with the regional geological framework, the higher-density bodies are interpreted as being compatible with granitic and basement-related rocks, whereas lower-density zones are associated with shallower sedimentary and less consolidated materials. The three-dimensional model indicates that high-density domains remain significant to the maximum investigated depth of approximately 8.3 km, although their lithological identity is non-unique and should be interpreted cautiously. The spatial relationship between gravity gradients, mapped geological structures, and the Dendang hot-spring manifestation suggests that structural discontinuities may influence subsurface fluid circulation. The observed surface manifestation, with a temperature of approximately 49 °C, should be regarded as a discharge characteristic rather than a direct indicator of reservoir temperature.

1. Introduction

Non-volcanic geothermal systems represent an important but comparatively less explored geothermal resource because their thermal regimes are not directly associated with Quaternary volcanism. In such systems, heat may originate from deep crustal circulation, tectonic deformation, or radiogenic heat production within felsic and granitic rocks. Radiogenic geothermal systems are particularly relevant in granitic terrains enriched in heat-producing elements such as uranium (U), thorium (Th), and potassium (K), where long-term radioactive decay can contribute to elevated crustal temperatures. The development of exploitable geothermal circulation, however, also depends on subsurface permeability, structural discontinuities, groundwater recharge,

and the spatial relationship between the potential heat-producing rocks and overlying permeable units [1, 2].

Bangka Island, located within the Sunda Shelf, is characterized by extensive granitic plutons, metamorphic basement, sedimentary units, and structurally deformed rocks. The regional lithostratigraphy includes the Pemali Complex, Tanjung Genting Formation, Penyabung Diabase, Klabat Granite, Rangkam Formation, and younger alluvial deposits [3–5]. Granitic rocks are particularly widespread across Bangka and have been reported to contain elevated concentrations of radiogenic elements [6, 7]. Previous regional measurements cited in the original study indicate notable U, Th, and K concentrations in granites from different parts of Bangka, providing a geological basis for considering radiogenic heat production as a possible contributor to non-volcanic geothermal activity [8–10].

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The Dendang area in West Bangka is one of the localities where a surface thermal manifestation occurs within this granitic geological setting. The study area is underlain by several principal geological units, including Alluvium, the Pemali Complex, Penyabung Diabase, the Tanjung Genting Formation, and Klabat Granite [3, 11]. The Dendang manifestation has a reported surface temperature of approximately 49 °C, suggesting the presence of subsurface heat transport but not, by itself, defining the temperature or depth of the geothermal reservoir. The spatial distribution of granitic rocks and regional structures therefore provides an important framework for evaluating the subsurface architecture beneath the thermal manifestation.

Despite the geological evidence for granitic rocks and the occurrence of a thermal manifestation, the subsurface configuration beneath Dendang remains insufficiently constrained. Previous studies in other parts of Bangka have identified granitic subsurface bodies and have proposed links between granitic rocks, radiogenic elements, and non-volcanic geothermal activity. The original manuscript notes that detailed subsurface investigations specifically focused on Dendang remain limited and therefore relies partly on information from other geothermal localities in Bangka as regional analogues [12, 13]. Consequently, the depth distribution, lateral continuity, and structural relationships of subsurface density domains beneath Dendang remain important unresolved questions.

Gravity methods provide an effective approach for investigating such subsurface architecture because spatial variations in the gravitational field reflect contrasts in rock density. In granitic geothermal terrains, gravity data can help delineate broad high- and low-density domains, estimate characteristic source depths, identify lateral density boundaries, and constrain geometrically plausible subsurface models. Nevertheless, gravity interpretation is inherently non-unique: a given gravity anomaly may be reproduced by multiple combinations of density, depth, and geometry. Therefore, gravity-derived bodies should be interpreted together with regional geological information rather than treated as unique lithological determinations [6, 14, 15].

Satellite-derived gravity data offer particular value in areas where dense terrestrial gravity coverage is unavailable. In this study, Free-Air Anomaly and elevation data obtained from the TOPEX data portal are processed to construct the Complete Bouguer Anomaly and subsequently analyzed using spectral decomposition, regional-residual separation, two-dimensional forward modelling, and three-dimensional inversion. The original dataset covers approximately 1°38'–2°12' S and 105°05'–105°46' E in the Methods section, although the coordinate limits reported elsewhere in the original manuscript are inconsistent and should be standardized in the revised paper [4, 16].

Accordingly, this study aims to characterize the subsurface density architecture beneath the Dendang non-volcanic geothermal area using satellite-derived gravity data. Specifically, the study seeks to (1) characterize the spatial pattern of the Complete Bouguer Anomaly, (2) estimate the characteristic depths of regional and residual gravity sources using spectral analysis, (3) constrain subsurface density distributions through two-dimensional forward modelling and three-dimensional inversion, and (4) evaluate the spatial relationship between the gravity-derived structure, regional geology, and the Dendang thermal manifestation. The resulting models are used to develop a preliminary geophysical framework for the Dendang geothermal area, while interpretations concerning radiogenic heat production and subsurface fluid circulation are treated as geological hypotheses requiring independent thermal, geochemical, or borehole validation.

2. Method

2.1. Study area and gravity dataset

The study was conducted in the Dendang geothermal area, Kelapa District, West Bangka Regency, Bangka Belitung Islands, Indonesia. The study area is located approximately between 1°38'–2°12' S and 105°05'–105°46' E, as reported in the original methodological description. Gravity-data processing was conducted between November 2021 and March 2022. The geological setting and location of the Dendang hot spring are shown in Fig. 1.

The study used secondary Free-Air Anomaly (FAA) and elevation data obtained from the TOPEX data portal on 10 November 2021. The downloaded dataset consisted of longitude, latitude, elevation, and FAA values for regularly distributed observation points. Additional topographic data from the Shuttle Radar Topography Mission (SRTM) were used to calculate terrain corrections. For spatial processing and interpretation, geographic coordinates were transformed into the UTM Zone 48S coordinate system. The overall workflow (Fig. 2) consisted of gravity-data preparation, Bouguer and terrain corrections, Complete Bouguer Anomaly construction, spectral analysis, regional-residual separation, two-dimensional forward modelling, three-dimensional inversion, and geological interpretation [17, 18].

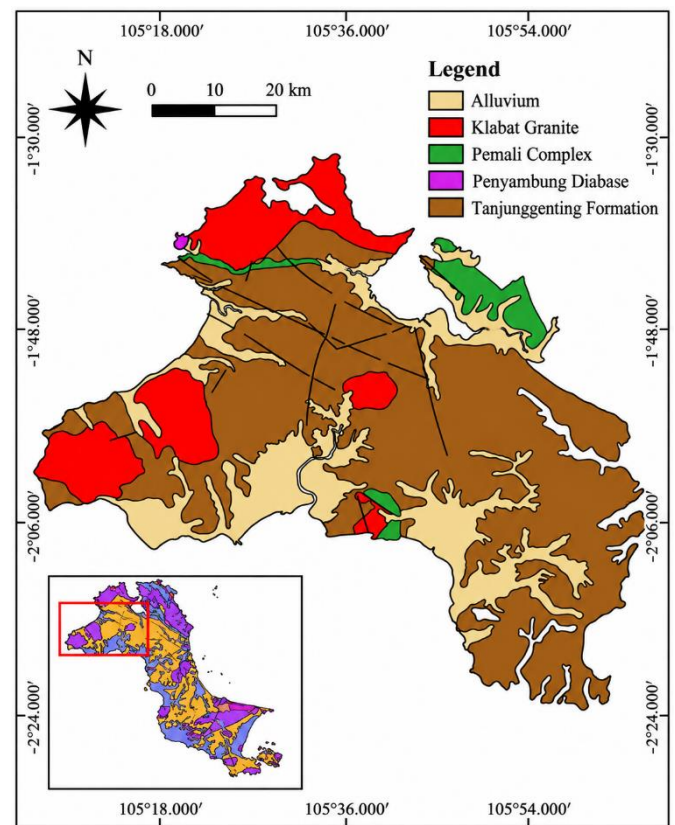


Fig. 1. Geological map of the Dendang geothermal area, West Bangka, showing the distribution of the principal lithological units, including Alluvium, Klabat Granite, Pemali Complex, Penyabung Diabase, and the Tanjung Genting Formation. The inset map indicates the regional location of the study area within Bangka Island. Major structural lineaments interpreted from the geological framework are also shown..

2.2. Bouguer reduction density and complete bouguer anomaly

The FAA data were first corrected for the gravitational effect of material between the observation elevation and the reference

datum. A correlation-based approach was used to estimate the Bouguer reduction density. Trial densities ranging from approximately 1.7 to 2.3 g/cm³ were evaluated by examining the relationship between Simple Bouguer Anomaly and elevation. For each trial density, the Simple Bouguer Anomaly was calculated as Equation (1):

$$\Delta g_{(\rho)} = FAA - 0.04193\rho h \quad \dots (1)$$

where FAA is the Free-Air Anomaly, ρ is the Bouguer reduction density in g/cm³, and h is elevation in metres. The correlation coefficient between Bouguer anomaly and elevation was subsequently evaluated for each assumed density, and a linear relationship between correlation coefficient and density was used to determine the reduction density. The original calculation yielded a reduction density of 1.38 g/cm³ [1].

Because this value is unusually low relative to typical densities of the geological units reported for the study area, the reduction-density calculation should be independently verified before the final gravity model is accepted. The Bouguer correction was calculated using the standard slab approximation in Equation (2):

$$BC = 0.04193\rho h \quad \dots (2)$$

and the Simple Bouguer Anomaly was obtained by subtracting the Bouguer correction from the FAA. Terrain correction was calculated using SRTM topographic data processed through Global Mapper and Oasis Montaj. The Complete Bouguer Anomaly (CBA) was then calculated after application of the terrain correction. The theoretical section of the original manuscript gives terrain correction as an additive term in the CBA equation, whereas the processing section states was calculated in Equation (3):

$$ABL = SBA - TC \quad \dots (3)$$

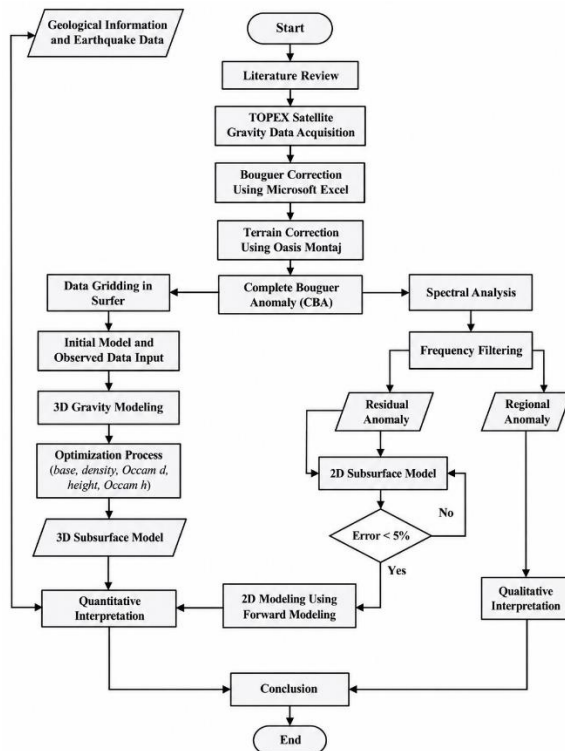


Fig. 2. Workflow of gravity-data processing and subsurface interpretation applied in the Dendang geothermal area. The procedure includes acquisition of TOPEX gravity data, Bouguer and terrain corrections to derive the Complete Bouguer Anomaly (CBA), spectral analysis and frequency filtering for regional–residual separation, two-dimensional forward modelling, three-dimensional gravity modelling and optimization, and subsequent qualitative and quantitative geological interpretation. The modelling workflow was iteratively evaluated using a target misfit of less than 5%.

2.3. Spectral analysis and source-depth estimation

Spectral analysis was applied to the Complete Bouguer Anomaly to estimate the characteristic depths of gravity sources and to determine suitable cutoff wavenumbers for regional–residual separation [19–21]. The CBA data were transformed from the spatial domain into the wavenumber domain using the Fourier transform in Equation (4):

$$F(k) = \int_{-\infty}^{\infty} f(x)e^{-ikx} dx \quad \dots (4)$$

where $F(k)$ represents the gravity signal in the wavenumber domain, $f(x)$ is the spatial gravity signal, and k is the wavenumber. The radially averaged power spectrum was examined using a plot of logarithmic spectral amplitude against wavenumber. Linear segments were interpreted as representing different depth domains, including deeper regional sources, shallower residual sources, and high-frequency noise. Characteristic source depths were estimated from the slopes of the fitted spectral segments. The corresponding cutoff wavenumbers were subsequently used to define the regional and residual wavelength domains [3, 6, 16].

For reproducibility, the final manuscript should explicitly report:

- the unit of k ;
- regression equations;
- regression slopes;
- R^2 values;
- cutoff wavenumbers;
- depth-conversion equation.

2.4. Regional–residual anomaly separation

The Complete Bouguer Anomaly contains responses from gravity sources occurring at different depths. Frequency-domain filtering was therefore applied to separate the deeper regional component from shallower residual anomalies. A low-pass filter was used to preserve the low-wavenumber, long-wavelength component associated with deeper regional sources, whereas a band-pass filter was used to isolate intermediate-to-higher-wavenumber anomalies associated with shallower residual sources [6, 14, 15]. Accordingly,

- the regional anomaly represents broader and deeper density variations; and
- the residual anomaly emphasizes relatively shallow and localized density contrasts.

The selected filter boundaries were derived from spectral-analysis results.

2.5. Two-dimensional gravity forward modelling

Two-dimensional forward modelling was performed using the Complete Bouguer Anomaly to investigate the subsurface density distribution along a representative profile crossing the Dendang geothermal area. The profile was selected to intersect contrasting gravity-anomaly domains and the geothermal manifestation. Forward modelling was performed iteratively by modifying the geometry and density of subsurface bodies until the calculated gravity response approximated the observed anomaly. The original modelling procedure used a trial-and-error approach and adopted a target misfit of less than 5% [3, 6, 16].

Initial density constraints were derived from regional geological information and published rock-density ranges. The resulting model was interpreted with reference to the principal geological units occurring in the Dendang area, including Alluvium, Tanjung Genting Formation, Klabat Granite, and basement-related rocks. Because gravity forward modelling is non-unique, the resulting geometry was treated as one geologically plausible density model rather than a unique reconstruction of subsurface lithology [19–21].

2.6. Three-dimensional gravity inversion

Three-dimensional gravity modelling was performed using Grablox 1.6e, with subsequent visualization using Bloxer 1.6e. The input dataset consisted of gridded Complete Bouguer Anomaly

values. The modelling workflow comprised two stages: 1). construction of an initial forward block model; and 2). inverse modelling through iterative optimization.

The inversion procedure included sequential optimization of:

- base level,
- density,
- Occam density,
- model height,
- Occam height.

These steps were used to reduce the difference between observed and calculated gravity responses [19–21]. The model was subdivided into a three-dimensional block system extending across the study area and to the maximum investigated depth. Density constraints used in the 3D inversion were informed by the 2D modelling results and geological information. The inversion results were analyzed using both perspective views and horizontal depth slices to evaluate the lateral and vertical continuity of contrasting density domains. Because gravity inversion is inherently non-unique, model fit was not considered equivalent to geological certainty. The recovered density domains were therefore interpreted together with the geological framework shown in Fig. 1.

2.7. Geological interpretation

Interpretation of the gravity results was conducted at two levels. 1). Qualitative interpretation was based on the spatial distribution of Complete Bouguer, regional, and residual anomalies and their relationships with known geology and the Dendang hot-spring manifestation; and 2). Quantitative interpretation was based on the density geometries derived from the 2D forward model and 3D inversion. The original study describes this combined qualitative and quantitative interpretation framework explicitly. High-density domains were interpreted as being compatible with granitic and basement-related rocks, whereas lower-density domains were associated with relatively lower-density sedimentary or altered materials. Lithological assignments were considered interpretations rather than unique identifications because different rock types can exhibit overlapping densities.

2.8. Methodological limitations and uncertainty

Several sources of uncertainty should be considered when interpreting the results. First, satellite-derived gravity data have lower spatial resolution than dense terrestrial gravity surveys and therefore primarily constrain relatively broad subsurface structures. Second, gravity modelling is inherently non-unique, meaning that different combinations of body geometry, depth, and density may produce similar gravity responses. Third, uncertainty in Bouguer reduction density, terrain correction, spectral cutoff selection, and inversion density bounds propagates into the resulting models [14, 22, 23].

Consequently, the models presented in this study are used to characterize subsurface density architecture rather than to uniquely determine lithology, geothermal reservoir properties, or heat-production mechanisms. Interpretations related to radiogenic heating and geothermal-fluid circulation require independent validation using geochemical, thermal, electrical, magnetic, petrophysical, or borehole observations.

3. Results and discussion

3.1. Complete bouguer anomaly characteristics

The Complete Bouguer Anomaly (CBA) of the Dendang geothermal area ranges from approximately 21.0 to 42.7 mGal. The anomaly distribution shows a broad contrast between relatively high values in the western part of the study area and lower values toward the eastern sector. The CBA distribution is presented in Fig. 3. The higher anomaly domain, approximately 30.5–42.7 mGal, indicates the presence of comparatively denser subsurface material, whereas lower values of approximately 21.0–30.2 mGal indicate relatively lower-density domains. The

original interpretation associates the low-anomaly area with the vicinity of the Dendang thermal manifestation and proposes that the reduced gravity response may be influenced by less compact rocks, enhanced fracturing, felsic material, porosity, and hydrothermal alteration [24].

However, a gravity low cannot uniquely be attributed to geothermal activity. Similar responses may result from sedimentary units, weathering, altered rocks, fracture zones, or variations in basement depth. Therefore, the low anomaly surrounding the thermal manifestation is more conservatively interpreted as a relatively low-density subsurface domain whose spatial relationship with the hot spring warrants structural interpretation.

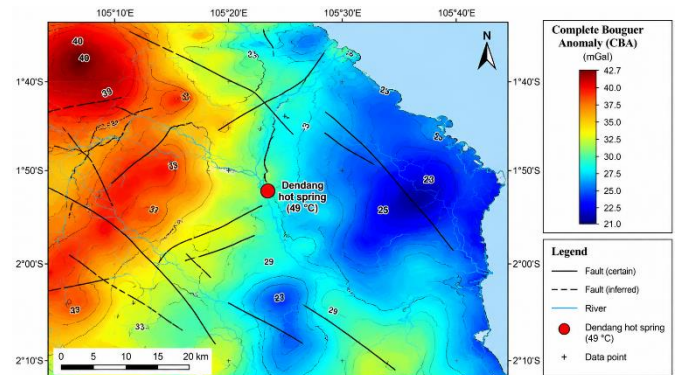


Fig 3. Complete Bouguer Anomaly (CBA) map of the Dendang geothermal area, West Bangka. The CBA values range from approximately 21.0 to 42.7 mGal. The red circle marks the Dendang hot spring with a reported surface temperature of approximately 49 °C. Solid and dashed black lines indicate mapped and inferred faults, respectively, while the blue lines represent drainage features.

Conversely, the broad high-anomaly region is compatible with denser basement or intrusive material. Considering the geological framework in Fig. 1, these high-density domains may be associated with Klabat Granite and/or other basement-related rocks. Such lithological assignments remain interpretative because gravity data directly constrain density contrasts rather than rock type.

3.2. Spectral analysis and estimated source depths

Spectral analysis was applied to the CBA to distinguish gravity responses associated with deeper regional sources from shallower residual sources. The original analysis identifies a regional characteristic depth of approximately 4.77 km using a cutoff wavenumber of approximately 0.074, while the residual component is reported within an approximate depth interval of 3.75–4.77 km, associated with a cutoff wavenumber of approximately 0.1904 [20, 21, 25]. The spectral results can be seen in Fig. 4.

The deeper spectral component is interpreted to represent broad, long-wavelength density variations associated with regional basement architecture, whereas the higher-wavenumber component reflects shallower and more localized density heterogeneities. These depths should not be interpreted as exact lithological boundaries. Spectral analysis provides an estimate of the average or characteristic depth of ensembles of gravity sources, and the calculated values depend on the selected spectral windows, wavenumber definition, and regression slopes. Accordingly, the approximately 4.77 km depth is interpreted as a characteristic depth scale of the deeper gravity sources rather than a uniquely defined geological interface.

3.3. Regional and residual gravity anomalies

Frequency-domain filtering separates the CBA into regional and

residual components. The regional anomaly ranges from approximately 20.7 to 42.8 mGal and shows a broad west-to-east decrease in gravity values. The residual anomaly ranges from approximately -1.9 to 2.4 mGal, with negative-to-low values between approximately -1.9 and 0.2 mGal and positive anomalies between approximately 0.2 and 2.4 mGal (Fig. 5).

The regional anomaly reflects long-wavelength density variations and therefore provides information on the deeper crustal architecture. The predominantly high regional response in the western sector is consistent with the presence of denser basement or intrusive rocks. In contrast, lower regional values toward the east may indicate relatively lower-density crustal material or greater thickness of lower-density overlying units [16, 26, 27].

The residual anomaly emphasizes shallower density variations and is therefore more relevant for evaluating local structures near the Dendang manifestation. Local residual lows may reflect weathered, fractured, altered, or sedimentary materials, whereas residual highs indicate comparatively denser shallow bodies. The original manuscript relates residual gravity directly to topographic elevation. This interpretation should be avoided because topographic effects should already have been largely accounted for by the Free-Air, Bouguer, and terrain corrections. A persistent relationship between residual anomaly and topography would instead require verification of the reduction density and terrain correction.

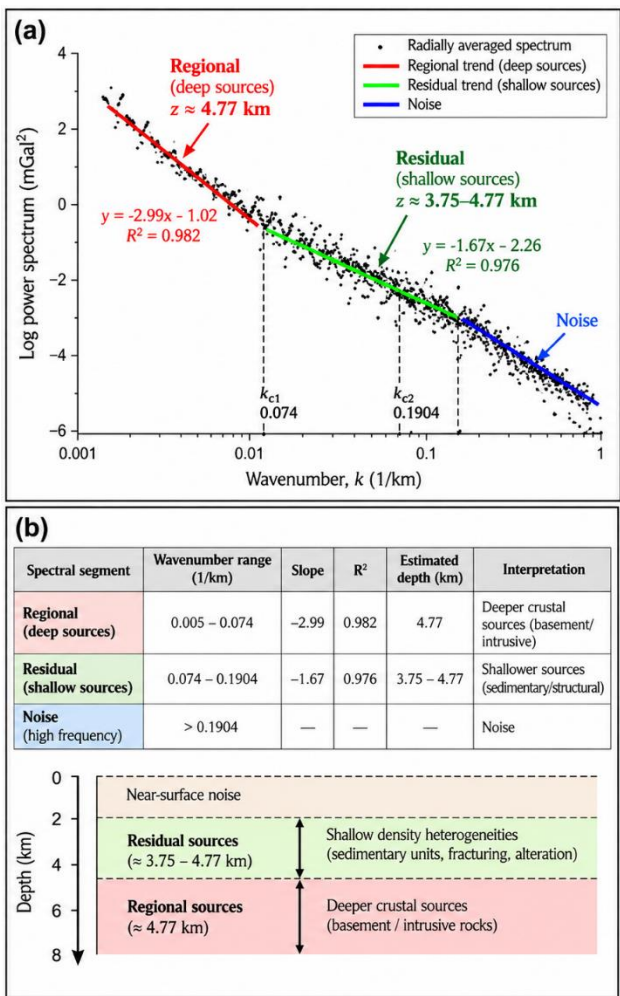


Fig 4. Spectral analysis of the Complete Bouguer Anomaly (CBA) in the Dendang geothermal area. **(a)** Radially averaged power spectrum showing the regional, residual, and noise components together with their corresponding linear trends and cutoff wavenumbers. **(b)** Summary of the characteristic source depths and their geological interpretation. The regional component indicates a characteristic depth of approximately 4.77 km, whereas the residual component represents shallower sources within an approximate depth range of 3.75–4.77 km.

3.4. Two-dimensional gravity modelling

A 2D forward model was constructed along profile A–A', which extends for approximately 60 km and intersects the Dendang thermal manifestation and nearby mapped structural features. The profile location and corresponding model can be presented as Fig. 6, respectively. The calculated gravity response reproduces the observed anomaly with a reported model misfit of approximately 1.117%. A low numerical misfit indicates good agreement between calculated and observed gravity responses; however, it does not demonstrate that the resulting geological geometry is unique [20, 21, 25].

The original model contains four principal density domains interpreted as the Tanjung Genting Formation, Alluvium, Pemali Complex, and Klabat Granite. Reported densities are approximately 1.9 g/cm³ for Alluvium, 2.1 g/cm³ for the Tanjung Genting Formation, 2.5 g/cm³ for the Pemali Complex, and 2.85 g/cm³ for the deepest high-density body interpreted as Klabat Granite. The relatively low-density shallow domains are consistent with unconsolidated and sedimentary materials. The deeper high-density body is interpreted as being compatible with granitic or basement-related material on the basis of the regional geological framework [16, 26, 27].

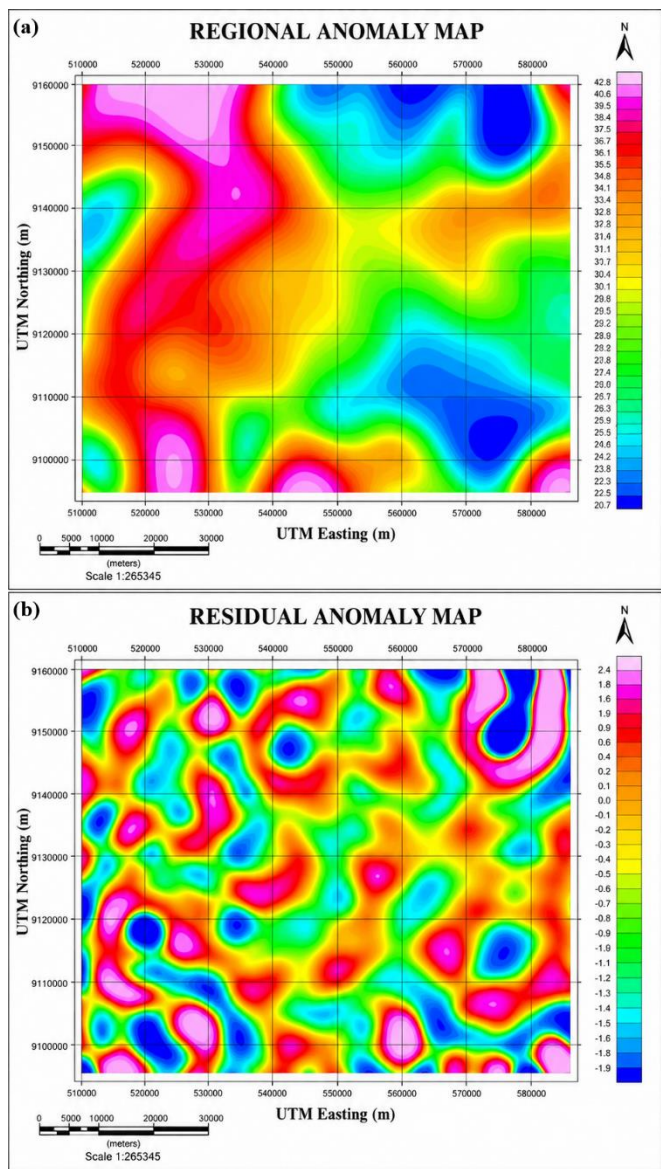


Fig. 5. Regional and residual gravity anomaly maps of the Dendang geothermal area. **(a)** Regional anomaly obtained from low-wavenumber filtering, with values ranging from approximately 20.7 to 42.8 mGal. **(b)** Residual anomaly representing relatively shallower density variations, with values ranging from -1.9 to 2.4 mGal.

ranging from approximately -1.9 to 2.4 mGal. The red circle indicates the Dendang hot spring, while solid and dashed black lines represent mapped and inferred faults, respectively.

The value of 2.85 g/cm^3 assigned to Klabat Granite is higher than the typical granite density range presented elsewhere in the original manuscript. Therefore, this value should be treated as a model parameter rather than a direct measurement of local granite density unless independent petrophysical data are available.

Abrupt lateral changes in modelled density near the Dendang manifestation are spatially associated with mapped structural features. These discontinuities may represent structurally controlled contacts or fault zones. Nevertheless, because the faults are primarily constrained by geological information rather than gravity-gradient analysis, the gravity model should be described as consistent with mapped structures, rather than as independently proving active faults [16, 26, 27].

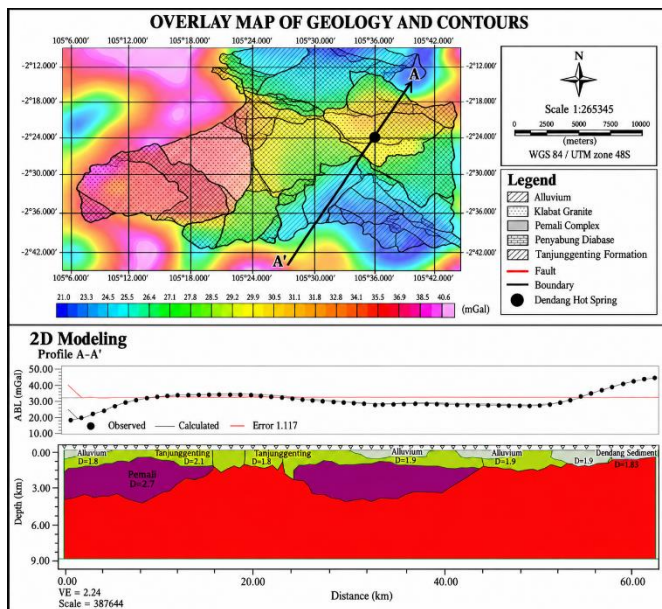


Fig 6. Geological overlay and two-dimensional gravity forward model along profile A–A' across the Dendang geothermal area. The upper panel shows the geological units superimposed on the Complete Bouguer Anomaly (CBA) map together with mapped faults, the study-area boundary, the location of the Dendang hot spring, and the A–A' modelling profile. The lower panel presents the observed and calculated gravity responses and the corresponding subsurface density model, including the interpreted Alluvium, Tanjung Gending Formation, Pemali Complex, Klabat Granite, and shallow sedimentary units. The reported model misfit is approximately 1.117%.

3.5. Three-dimensional density architecture

The 3D model covers approximately 76.009 km in the x direction and 62.616 km in the y direction. Each horizontal layer contains 20×20 cells, and eight vertical layers extend to a maximum model depth of approximately 8.3 km, resulting in 3200 model blocks. The initial inversion allowed model densities of approximately $1\text{--}3 \text{ g/cm}^3$. Sequential optimization of the base level, density, Occam density, block height, and Occam height produced reported numerical misfits of approximately 0.243%, 0.546%, 0.4291%, 0.5891%, and 0.443%, respectively (Fig. 7).

The 3D model shows substantial lateral and vertical variations in density. Higher-density domains become particularly prominent at depth and are spatially compatible with the occurrence of granitic and basement rocks mapped regionally. Lower-density bodies occur locally within the model and may reflect sedimentary, fractured, altered, or otherwise less dense materials. The extremely small numerical inversion errors should be interpreted only as measures of data fit. They do not eliminate the inherent non-uniqueness of gravity inversion, and

therefore should not be used as evidence that the recovered density model represents the exact subsurface geometry.

3.6. Depth evolution of the 3d density model

Two representative depth intervals from the original model provide useful information on the vertical evolution of the density structure. At approximately 4.0–5.5 km depth, the original model reports densities of approximately $1.0\text{--}2.07 \text{ g/cm}^3$. At approximately 6.3–8.3 km depth, the reported density range increases to approximately $1.0\text{--}2.85 \text{ g/cm}^3$, and the deeper model is dominated by higher-density material (Fig. 8).

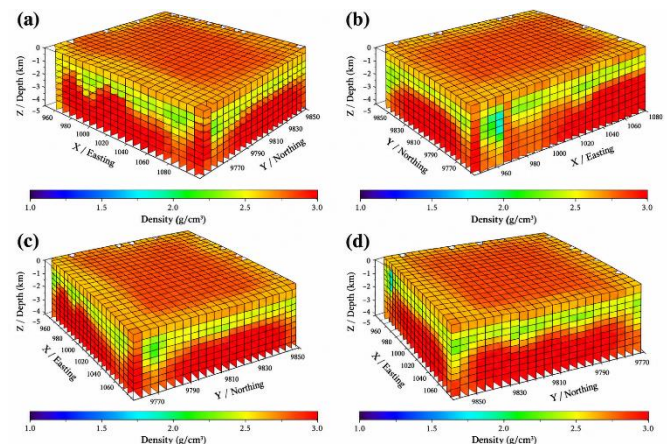


Fig. 7. Three-dimensional gravity inversion model of the Dendang geothermal area shown from four viewing perspectives: (a) southwest–northeast oblique view, (b) southeast–northwest oblique view, (c) northwest–southeast oblique view, and (d) northeast–southwest oblique view. The voxel model illustrates the lateral and vertical variation of subsurface density from approximately 1.0 to 3.0 g/cm^3 , with warmer colors representing relatively higher-density domains and cooler colors indicating lower-density zones. The model extends to a maximum investigated depth of approximately 8.3 km and is used to evaluate the three-dimensional distribution and continuity of contrasting subsurface density bodies beneath the Dendang geothermal area.

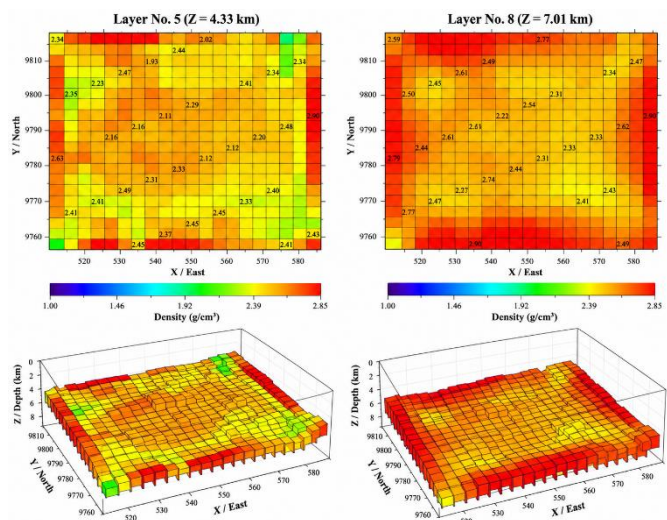


Fig. 8. Representative depth slices and corresponding three-dimensional density distributions from the gravity inversion model of the Dendang geothermal area. The left panels show Layer 5 at approximately 4.33 km depth, whereas the right panels show Layer 8 at approximately 7.01 km depth. The upper panels display plan-view density distributions, and the lower panels present the corresponding three-dimensional block models. Density values range from approximately 1.0 to 2.85 g/cm^3 , with warmer colors indicating relatively higher-density domains and cooler colors representing lower-

density zones. The deeper layer is characterized by a broader distribution of high-density material, consistent with an increasingly basement-dominated subsurface.

The dominance of higher-density material at greater depth is broadly consistent with a granitic or basement-dominated subsurface. However, the original interpretation of granite in the 4.0–5.5 km slice requires caution because its reported maximum density is only approximately 2.07 g/cm³, substantially lower than the value assigned to granite in the 2D model. Similarly, interpreting very low-density zones at depths of 6–8 km as Alluvium is not geologically plausible. Holocene alluvium should be restricted to shallow near-surface deposits. Deeper low-density domains are more appropriately interpreted as lower-density sedimentary/metasedimentary, fractured, or altered materials unless independent geological constraints indicate otherwise. Thus, the 3D inversion supports a heterogeneous subsurface with increasingly prominent high-density domains at depth, but individual lithologies should not be assigned solely from inversion density.

3.7. Structural controls and geothermal implications

The Dendang hot spring occurs near mapped structural discontinuities and local changes in the gravity field. The original model interprets faults near the manifestation as pathways linking deeper granitic rocks with the surface. The spatial association between the hot spring, mapped faults, and contrasting density domains suggests that structural discontinuities may influence subsurface fluid migration. Faulting and fracturing can enhance permeability and provide preferential pathways for circulation, but the present gravity dataset does not directly demonstrate active fluid transport.

Accordingly, the structural relationship is better expressed as: *"mapped faults and density boundaries are spatially consistent with possible fluid pathways beneath the Dendang manifestation"*. Confirmation would require additional constraints such as electrical resistivity, structural mapping, hydrochemistry, isotopes, temperature gradients, or borehole information.

3.8. Implications for a possible radiogenic geothermal system

The geological framework of West Bangka provides a basis for considering radiogenic heating as one possible mechanism contributing to the Dendang geothermal system. Previous studies cited in the original manuscript report U, Th, and K enrichment in Bangka granitic rocks. The original study also cites granite samples containing Th concentrations of approximately 32–241 ppm and U concentrations of approximately 25–142 ppm. These regional geochemical observations support the possibility that granitic rocks in Bangka may produce radiogenic heat. However, they should not be interpreted as direct measurements of radiogenic heat production beneath Dendang.

The gravity results independently indicate extensive density domains that are compatible with granitic and basement material. Combining these results with previous radioactive-element measurements leads to a conceptual model in which:

- meteoric water infiltrates through permeable near-surface units and fractures;
- circulation may extend downward along structurally weakened zones;
- water interacts thermally with deeper granitic and basement rocks;
- faults and fractures may facilitate upward migration;
- heated water ultimately discharges at the Dendang hot spring.

This conceptual model can be illustrated as Fig. 9. The reported 49 °C temperature represents the surface thermal manifestation and should not be interpreted as the reservoir temperature. Cooling, mixing with shallow groundwater, and conductive heat loss may significantly modify the fluid temperature during ascent.

Similarly, the Tanjung Genteng Formation should not be identified definitively as a geothermal reservoir from gravity data alone. A more defensible interpretation is that it may represent a possible permeable host unit above the deeper high-density basement [16].

The combined gravity results indicate a heterogeneous subsurface

architecture beneath Dendang, characterized by shallow relatively low-density materials and deeper high-density domains. The broad gravity pattern, 2D forward model, and 3D inversion are generally consistent with a basement architecture involving granitic and related rocks beneath sedimentary and unconsolidated units. The interpretation can therefore be summarized at three levels. Directly constrained by the gravity analysis:

- CBA of approximately 21.0–42.7 mGal;
- regional and residual anomaly patterns;
- characteristic spectral source depths;
- modelled lateral and vertical density contrasts;
- a deeper high-density domain extending through much of the model.

Geologically interpreted:

- probable granitic or basement-related high-density bodies;
- shallower sedimentary and unconsolidated units;
- structural boundaries associated with mapped faults.

Conceptually inferred:

- radiogenic heat production;
- deep meteoric-water circulation;
- fault-controlled fluid ascent;
- development of the Dendang non-volcanic geothermal system.

This hierarchy is important because the gravity data provide robust constraints on density architecture, whereas geothermal heat production and hydrological connectivity require additional independent evidence [28, 29].

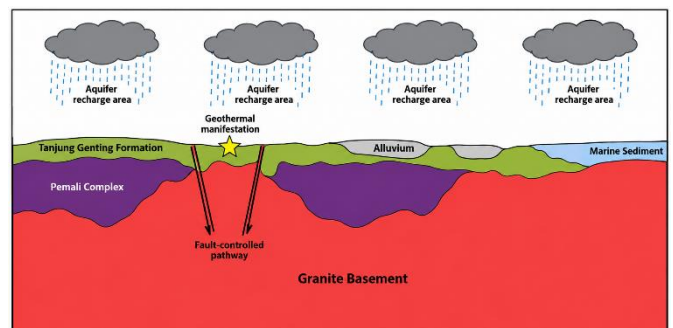


Fig. 9. Conceptual hydrogeological model of the Dendang non-volcanic geothermal system, illustrating meteoric recharge, shallow permeable units, major subsurface lithological domains, and possible fault-controlled pathways for geothermal fluid circulation. The Tanjung Genteng Formation and Alluvium represent shallow recharge and permeable zones, whereas the Pemali Complex overlies the deeper granitic basement. The Dendang thermal manifestation is spatially associated with interpreted fault structures that may provide pathways for upward fluid migration. The granite basement is considered a possible heat-source domain, although its radiogenic contribution requires independent geochemical and thermal validation.

4. Conclusion

The gravity analysis reveals a heterogeneous subsurface density architecture beneath the Dendang non-volcanic geothermal area. The Complete Bouguer Anomaly ranges from approximately 21.0 to 42.7 mGal, with higher values concentrated mainly in the western part of the study area and lower values toward the eastern sector. Spectral analysis indicates a characteristic regional source depth of approximately 4.77 km, while the residual component reflects shallower gravity sources within an approximate depth range of 3.75–4.77 km. The regional and residual anomaly patterns therefore indicate that both deep and shallow density contrasts contribute to the observed gravity field. The two-dimensional forward model along profile A–A' reproduces the observed gravity response with a reported misfit of approximately 1.11% and indicates contrasting shallow low-density and deeper high-density domains. These density domains

are interpreted, in accordance with the regional geological framework, as being associated with the Tanjung Genting Formation, Alluvium, Pemali Complex, and deeper granitic or basement-related rocks. The three-dimensional inversion further indicates that relatively high-density material becomes increasingly prominent at depth and remains significant within the model down to approximately 8.3 km. The spatial association between the Dendang hot spring, mapped structural discontinuities, and lateral density contrasts suggests that faults and fractures may influence subsurface fluid circulation. However, the gravity data constrain density distribution and subsurface geometry rather than directly demonstrating permeability or active fluid flow. Similarly, although previous studies report elevated U and Th concentrations in Bangka granitic rocks, the present gravity results do not independently quantify radiogenic heat production. The granitic basement should therefore be regarded as a possible radiogenic heat-source domain, consistent with the regional geological context, rather than as a heat source proven directly by gravity data. Overall, this study provides a gravity-based framework for understanding the subsurface architecture and possible structural controls of the Dendang geothermal area. The results support a conceptual model involving meteoric recharge, circulation through permeable and fractured zones, thermal interaction with deeper granitic basement, and structurally influenced upward discharge at the Dendang hot spring. Further integration with geochemical and isotopic tracers, heat-flow measurements, electrical or electromagnetic surveys, petrophysical measurements, and borehole data is required to constrain the heat-production mechanism, fluid pathways, and reservoir properties more robustly.

CRedit authorship contribution statement

Nur Ramadhani: Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation. **Korhan Cengiz:** Writing – review & editing.

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.

Data availability

Data will be made available on request.

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