



Geological Structure Delineation Based on Forward Modeling and Inversion Using Gravity Methods at the Gemah Field, South Sumatra Basin

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ABSTRACT

The Gemah Field is one of the exploration areas located in the South Sumatra Basin, which exhibits complex geological structures resulting from regional tectonic activity and is one of Indonesia's key hydrocarbon-producing basins. This study aims to delineate subsurface structures and construct a geological model based on the analysis of gravity data using forward modeling and inversion methods. The data used consist of processed GGMPlus satellite gravity data to obtain Complete Bouguer Anomaly (CBA) values. The processing steps included Bouguer correction, rock density estimation, spectral analysis to estimate the depth of the anomaly source, separation of regional and residual anomalies, and the application of enhancement methods such as Total Horizontal Derivative (THD), Tilt Derivative (TDR), and Tilt Derivative of Horizontal Gradient (TDX) to clarify the boundaries of subsurface structures. The analysis results indicate that the gravity anomaly patterns in the study area are controlled by variations in rock density associated with the presence of geological structures such as faults and changes in subsurface stratigraphic configuration. Modeling results reveal a subsurface stratigraphic sequence consisting of Quaternary Volcanic Rocks, the Muara Enim Formation, the Air Benakat Formation, and the Gumai Formation. This research is recommended to support hydrocarbon exploration and identify optimal well locations. It addresses a gap in previous studies—which lacked a comprehensive integration of enhancement methods and spectral analysis—with the aim of providing a more accurate picture of subsurface conditions.

KEYWORDS: Gravitational Anomalies; South Sumatra Basin; Forward Modeling; Hydrocarbons; Gravitational Inversion

INTRODUCTION

The Gemah Field, operated by PetroChina International Jabung Ltd., is located in the Jabung Block, Jambi Province, and is part of the South Sumatra Basin, one of the largest hydrocarbon basins in Indonesia. This basin has a complex tectonic history that has given rise to various geological structures, such as faults and folds (Kausarian et al., 2023).

The gravity method is one of the most widely used passive geophysical methods for identifying variations in subsurface rock density associated with the presence of faults, folds, lithological contacts, and sedimentary basin configurations. The use of GGMplus gravity data can improve the accuracy of subsurface structure interpretation in sedimentary basins with high geological

complexity. The application of gradient-based enhancement methods, such as Total Horizontal Derivative (THD), Tilt Derivative (TDR), and Tilt Derivative of the Horizontal Gradient (TDX), has not yet been widely integrated with spectral analysis, forward modeling, and inversion in the interpretation of subsurface structures. These three methods are effective in clarifying the boundaries of anomaly sources, identifying fault zones, and delineating lithological contacts in potential field data (Pham, 2020).

This study builds upon the research of (Pirdaus) who modeled the subsurface structure at Lumbang Rarat, North Sumatra, and successfully identified three rock units along with the associated fault system using GGMplus data. Based on these findings, this study integrates GGMplus gravity data with spectral analysis, enhancement methods (SVD & FHD), as well as forward modeling and inversion to obtain an interpretation of subsurface structures.

This study builds upon previous research by updating the interpretation approach

through the application of enhancement techniques (THD, TDR, and TDX) to improve the accuracy of identifying and delineating subsurface structures. In addition, this study constructs a subsurface geological model using forward modeling and inversion, which is expected to provide more accurate information regarding the configuration of geological structures, support the evaluation of subsurface conditions, and facilitate hydrocarbon exploration activities in the Gemah Field, South Sumatra Basin.

Geologi Regional

Based on Figure 1. the Regional Geological Map of the South Sumatra Basin shows that it is one of the major sedimentary basins in Indonesia, formed as a back-arc basin as a result of the subduction of the Indo-Australian Plate beneath the Eurasian Plate. This basin extends in a northwest–southeast direction and is part of the regional tectonic system of the island of Sumatra (Kamila et al., 2023).

Regional Structure and Stratigraphy

The development of the regional

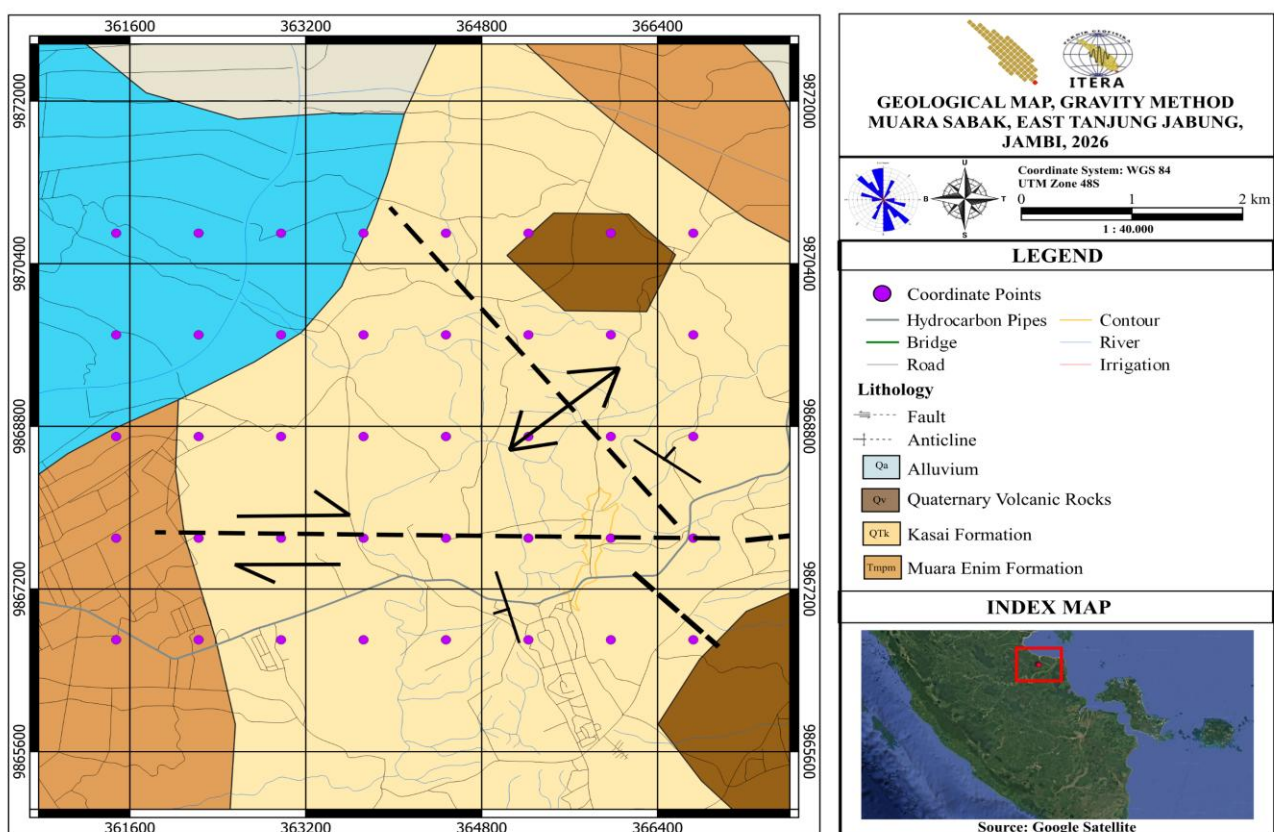


Figure 1. Regional geological map

geological structure of the South Sumatra Basin was controlled by three major tectonic phases. The first phase occurred from the Late Jurassic to the Early Cretaceous, resulting in strike-slip faults and initial deformation of the bedrock. The second phase took place from the Late Cretaceous to the Early Tertiary, leading to the formation of graben and half-graben structures that served as sedimentary basins. The third phase occurred from the Miocene to the present and was characterized by re-compression, which caused structural inversion and the formation of hydrocarbon traps. The combination of these three tectonic phases resulted in a complex structural system that plays a crucial role in the development of the petroleum system in the South Sumatra Basin (Syaifudin & Subroto, 2024).

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Regional stratigraphy of the South Sumatra Basin shown in Figure 2 (Alfayed et

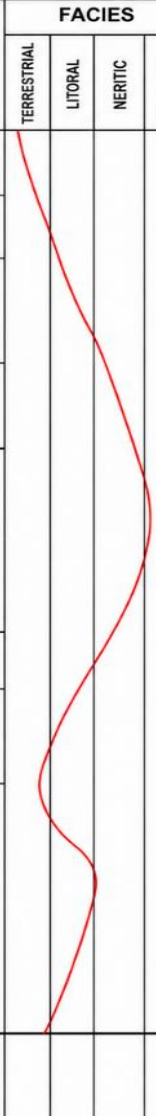
AGE		GROUP	FORMATION	THICKNESS (m)	LITHOLOGY	FACIES			
						TERRESTRIAL	LITORAL	NERITIC	NERITIC DEEP
Quaternary		ALLUVIUM			Sand, silt, clay, gravel, alluvial.				
Pliocene			Kasai		Gravel, tuffaceous sand, and conglomerate volcanic, tuff interbed.				
Early			Muara Enim	150 - 750	Clay, silty clay, sandstone, sand and thin coal intercalations.				
Miocene	Middle	Air Benakat		Silty clay and marl, glauconitic sand, interbedded with shale.					
	Lower	Gumai	2200	Marl, clay, silt, silty clay, shale, interbedded with thin sand and siltstone. Globigerina generally present.					
	Lower	Batu Raja	0 - 160	Marl, foraminiferal limestone and glauconitic limestone.					
Talangakar		0 - 1100	Sand, glauconitic sand, clay, silty clay, claystone, thin coal interbeds, fine sand in places.						
Oligocene	Early	LAF		0 - 300	Tuffaceous, green, red and gray tuff, tuffaceous sandstone, breccia and conglomerate.				
	Middle								
	Late								
Eocene	Early								
	Middle								
	Late								
Paleocene									
Pre-Tertiary		PRE-TERTIARY BASEMENT			Low grade metamorphic rocks and sedimentary rocks.				

Figure 2. Regional stratigraphy of the south

al., 2025). Stratigraphically, the South Sumatra Basin consists of Tertiary-aged sedimentary rocks deposited on top of pre-Tertiary basement rocks.

The Lahat Formation is the oldest unit, deposited in fluvial to lacustrine environments and serving as the source rock. Overlying it is the Talang Akar Formation, which reflects a shift in environment from fluvial to deltaic and serves as the primary hydrocarbon reservoir. Subsequently, the Baturaja Formation developed, consisting of carbonate rocks and serving as an additional reservoir. The Gumai Formation was deposited in a deep-sea environment and serves as a regional cap rock. (Alfayed et al., 2025).

The sedimentation cycle then continued with the Air Benakat Formation, the Muara Enim Formation, and the Kasai Formation, which reflect a shift in the depositional environment from marine to terrestrial due to regression processes (Alfayed et al., 2025).

RESEARCH METHODS

The Gravity Method

The gravity method is a passive geophysical method based on measurements of variations in the gravitational acceleration field at and below the Earth's surface. Gravity anomalies on the Earth's surface are influenced by complex geological factors beneath the surface, variations in surface relief caused by the Earth's non-spherical shape (ellipsoid), and the distribution of rock density, which is heterogeneous beneath the surface.

Gravity Data Corrections

Gravity data obtained from GGMPlus consist of free-air anomaly data (gravity disturbances). Therefore, corrections must be applied to eliminate the effects of mass that influence the gravity anomaly values; these are known as Bouguer corrections and terrain corrections. The Bouguer correction value can be expressed in Equation 1:

$$g_B = 2\pi G \rho h = 0,4192 \rho h \text{ g.u.} \quad (1)$$

where:

h = topographic height (m),

ρ = Bouguer slab density, using the average density of the Earth's crust of 2.67 kg/m³, and

G = universal gravitational constant.

Once the corrected Bouguer value has been obtained, the Simple Bouguer Anomaly (SBA) can be calculated using the following equation 2:

$$\Delta g_{bs} = g_d - g_b \quad (2)$$

where:

g_d = GGMPlus gravity disturbance anomaly value (mGal)

g_b = Bouguer correction value.

The next step is to calculate the Total Bouguer Anomaly (TBA) using the equation 3:

$$\Delta g_{bl} = \Delta g_{bs} + g_t \quad (3)$$

where:

Δg_{BS} = Simple Bouguer Anomaly value (mGal)

g_t = terrain correction value.

This research was conducted from February through mid-2026, encompassing the stages of literature review, data processing, analysis and interpretation, and report preparation. The following are the main stages of data processing:

1. Data Collection

The GGMplus data was downloaded from the [website](https://ddfe.curtin.edu.au/gravitymodels/GGMplus/data/) <https://ddfe.curtin.edu.au/gravitymodels/GGMplus/data/> and the SRTM2 DEM topographic and gravity data was downloaded from the website <https://tanahair.indonesia.go.id/portal-web/login?page=unduh/demnas> with the geometry tailored to the study area and the Gobs parameter selected as the primary data set.

2. Density Estimate

Rock density is a crucial physical parameter for gravity data processing, Bouguer correction, and subsurface modeling. Estimates using the parsnis method yield a density value of 2,67 gr/cm³.

3. Creating a Complete Bouguer Anomaly Map

GGMPlus data (coordinates, elevation, Gobs) were spatially corrected to obtain the Complete Bouguer Anomaly (CBA), then interpolated in Oasis Montaj to generate the CBA map.

4. Estimating Depth Based on Spectral

Analysis

Spectral analysis was performed using Oasis Montaj and Microsoft Excel, employing the Fourier transform to convert data from the time domain to the frequency domain.

5. Separation of Regional and Residual Anomalies

The anomalies were separated using a bandpass filter through a trial-and-error process. Regional anomalies are components of the gravity field originating from large-scale geological sources at relatively deep depths, whereas residual anomalies are components of the gravity field originating from smaller-scale geological sources at relatively shallow depths.

6. Data Enhancement Using TDH, TDR, and TDX

Regional anomaly maps were enhanced to improve the accuracy of interpretation and confirm the boundaries of subsurface geological structures. This study applied the Total Horizontal Derivative (THD), Tilt Derivative (TDR), and Tilt Derivative of the Horizontal Gradient (TDX) as the primary filters because they effectively highlight weak density contrast boundaries and reduce ambiguity in structural interpretation. All three methods were applied to the first derivatives of regional anomalies in the x, y, and z directions and then normalized using a tangent function to clarify structural responses.

The formula for TDR in equation 4:

$$TDR = \sqrt{\frac{\frac{\partial g}{\partial z}}{\sqrt{\left(\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2}\right)}} \quad (4)$$

The formula for TDX in equation 5:

$$TDX = \sqrt{\frac{\sqrt{\left(\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2\right)}}{\text{abs}\left(\frac{\partial g}{\partial z}\right)}} \quad (5)$$

7. Forward Modelling

This modeling was performed using Oasis Montaj by slicing regional maps along a (km) section. The model profile was

adjusted through trial and error until the error between the observed data and the calculated data was minimized, while determining the density of the rock formation.

8. 3D and Inversion Modelling

3D modeling and inversion were performed to visualize and estimate subsurface density distributions based on gravity anomaly data, thereby yielding a representative subsurface geological model.

9. Hydrocarbon Well Recommendations

This stage is conducted to identify prospective hydrocarbon zones as recommended locations for exploration wells; the determination of recommended locations for hydrocarbon wells is carried out through an analysis of hydrocarbon migration patterns.

Research Flowchart

The flowchart for this study shows the sequence of steps, from data processing to the systematic interpretation of results, as shown in Figure 3.

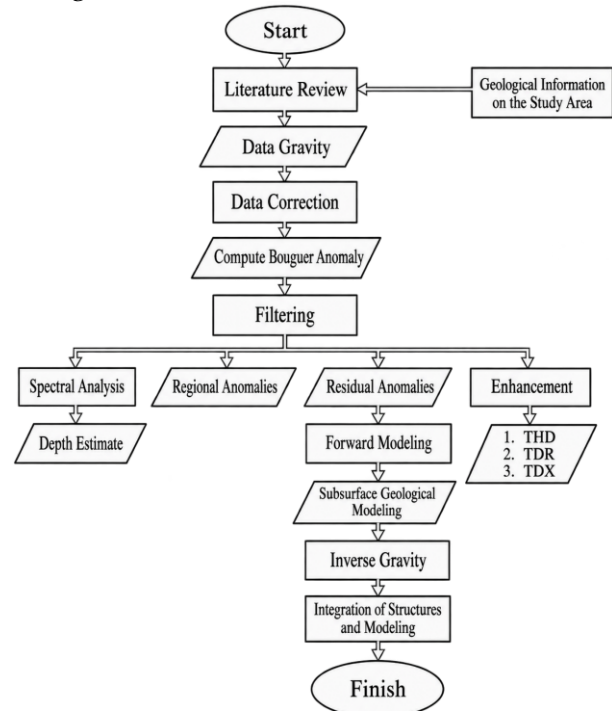


Figure 3. Data processing flowchart

RESULTS AND DISCUSSION

This study presents the results of GGMPplus gravity data processing that has

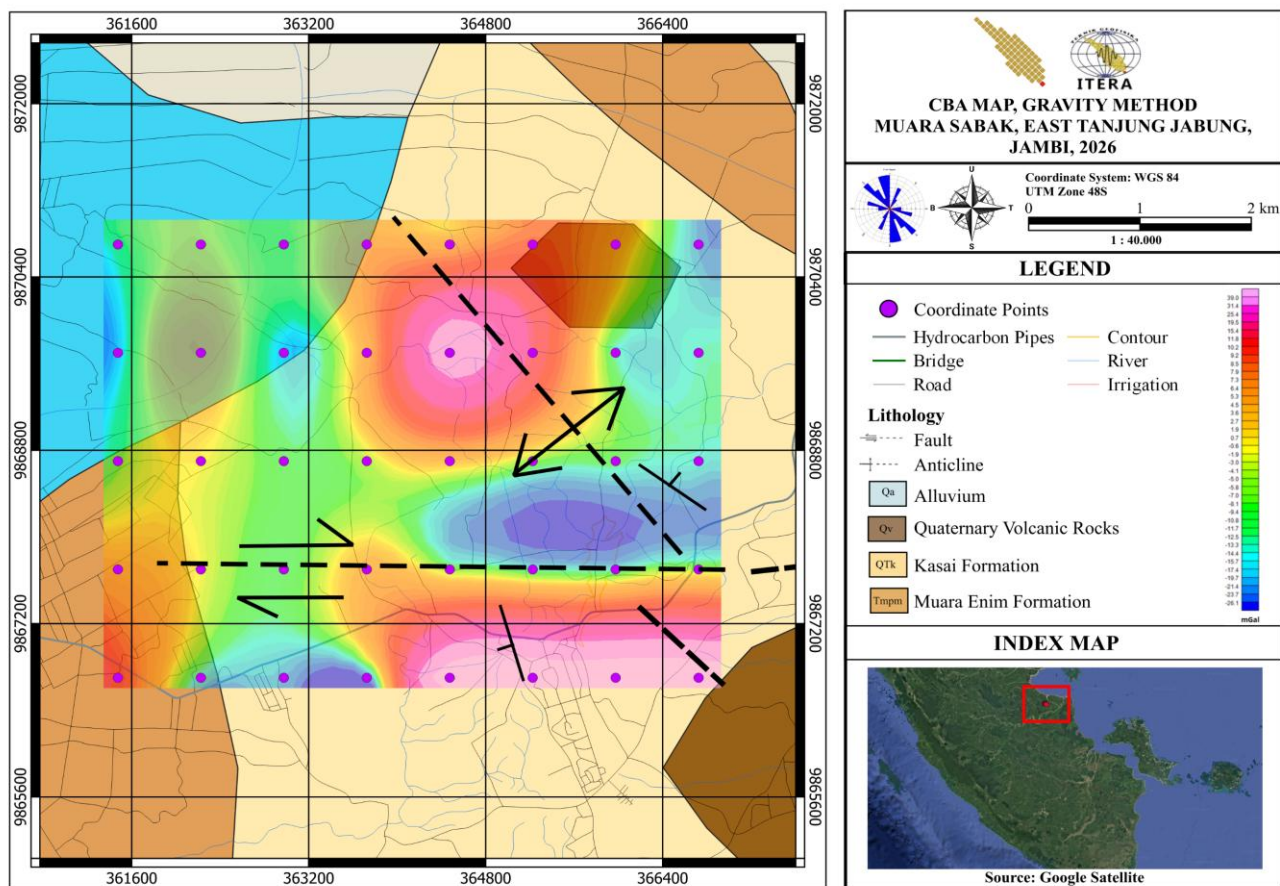


Figure 4. Complete anomali bouguer (CBA) map

undergone a series of correction steps—from correction, spectral analysis, and anomaly separation to appropriate modeling—thereby yielding mutually supportive information for interpreting subsurface conditions. The results obtained are as follows:

Complete Bouguer Anomaly (CBA) Map

Figure 4. Complete Bouguer Anomaly (CBA) map is the result of processing gravity data after all correction steps have been performed, thus reflecting the distribution of subsurface rock density variations.

As seen on the map, the area from the northeast to the center is a high-anomaly zone interpreted as rock with higher density associated with structural highs, relatively shallow bedrock, or rock that has undergone stronger compaction. Conversely, the low-anomaly zones in the eastern and southern parts indicate lower-density rocks, interpreted as sedimentary basins with greater thickness (Kausarian et al., 2023). The fairly contrasting changes in anomaly values in the central part of the map indicate the presence of a gravity

gradient, suggesting a lithological boundary or a geological structure in the form of a fault separating two rock blocks with different density characteristics (Hakim et al., 2023).

Overall, the CBA map provides an initial picture of the distribution of subsurface density contrasts; however, it is not yet capable of distinguishing between the effects of deep and shallow anomaly sources. Therefore, further analysis is needed to obtain a clearer and more representative delineation of subsurface structures.

Spectral Analysis

Spectral Analysis is required to determine the frequency cutoff (cut-off wavenumber) so that the separation of regional anomalies and residuals can be performed more objectively before interpreting subsurface structures shown in Figure 5 (Sarkowi et al., 2021). These results are consistent with (Zakaria, 2021), who stated that spectral analysis can be used to separate regional and residual anomalies by determining the cut-off wavenumber. In

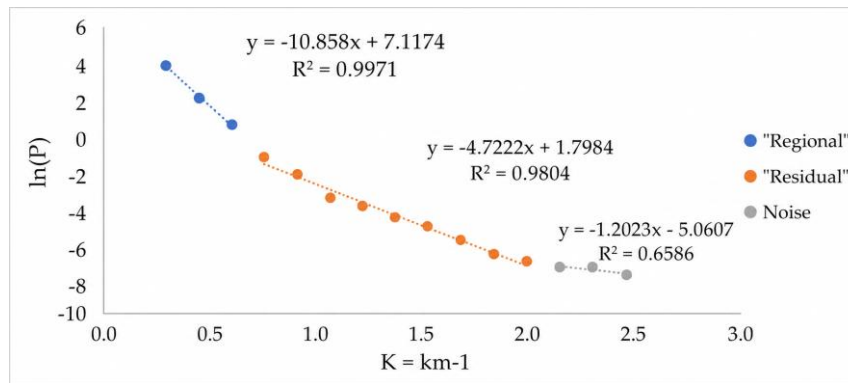


Figure 5. Gravity data spectral analysis

spectral analysis, the slope of the spectrum is related to the depth of the anomaly source, where a steeper slope generally indicates a deeper source, while a gentler slope indicates a shallower source. Accordingly, the estimated depths of 864.05 m for the regional anomaly and 375.78 m for the residual anomaly suggest that the anomaly sources are located at different depths. The regional anomaly source is interpreted to originate from a deeper subsurface level, whereas the residual anomaly source is associated with shallower geological features.

Based on these slope values, the depth of the anomaly sources was then calculated,

yielding an estimated regional depth of approximately 864.0522 meters, indicating a relatively deeper source compared to the residuals, and a residual depth of approximately 375.7807 meters, representing a shallower source. The spectral graph, a steep slope correlates with a deeper source depth, namely the regional anomaly. Meanwhile, a gentler slope indicates a shallower source depth, such as the residual anomaly.

Regional Anomaly Map

Regional Anomaly Map illustrates regional-scale geological conditions related to basement configuration, sediment thickness, and general basin geometry shown in Figure 6

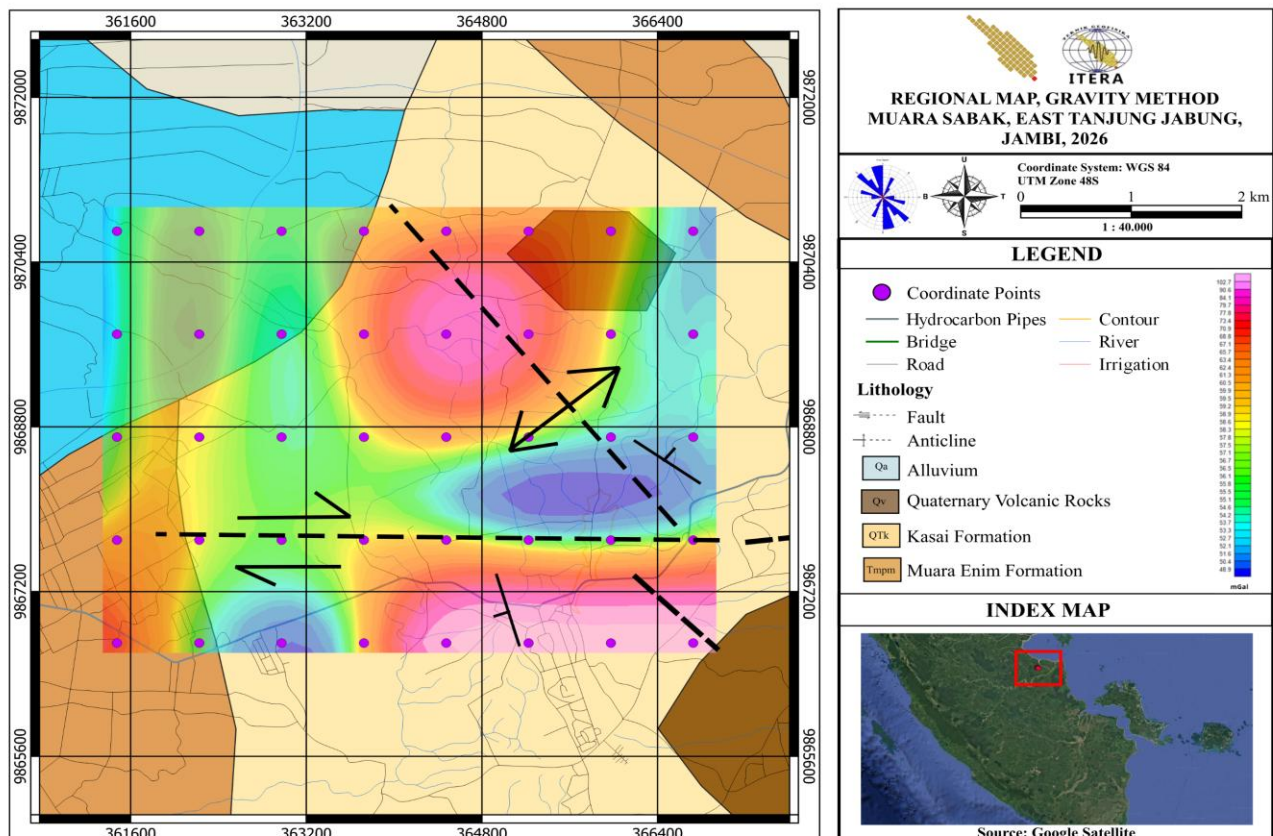


Figure 6. Regional anomaly map

(Sarkowi et al., 2021).

The high-anomaly zones (pink–purple) extending from the central to southern parts indicate the presence of high-density rocks or a basement high, while the low-anomaly zones (blue–green) in the western, eastern, and parts of the central regions indicate sedimentary basins with lower density. In the geological context of the South Sumatra Basin, this response is likely related to a basement high or a part of the basin with thinner sediment thickness, causing high-density rocks to lie closer to the surface compared to the surrounding areas.

Northwest–southeast and west–east trending strike-slip faults appear to control the distribution of anomalies and form complex structural intersection zones, while the presence of anticlines indicates the potential for structural traps. In terms of lithology, high anomalies are thought to be associated with Quaternary volcanic rocks or basement rocks, while low anomalies are associated with sedimentary deposits.

Residual Anomaly Map

The Residual Anomaly Map shows variations in subsurface rock density associated with local geological structures after regional influences have been removed shown in Figure 7. The high-anomaly zones, shown in shades of pink to purple in the central and southern parts, indicate the presence of denser rocks or elevated subsurface structures, while the low-anomaly zones, colored blue to dark purple in the western, southeastern, and parts of the southern regions, indicate lower-density rocks that have the potential to serve as reservoir zones.

The residual anomaly pattern also reveals a dominant northwest–southeast structural trend that aligns with the direction of regional faults in the South Sumatra Basin. This indicates that tectonic activity has a strong influence on the formation of reservoir geometry in the Gemah Field. After obtaining a residual anomaly map representing rock density variations at shallow depths, the next step is to perform edge detection analysis to clarify the boundaries of subsurface geological structures. The edge detection method is a transformation of potential field data aimed at

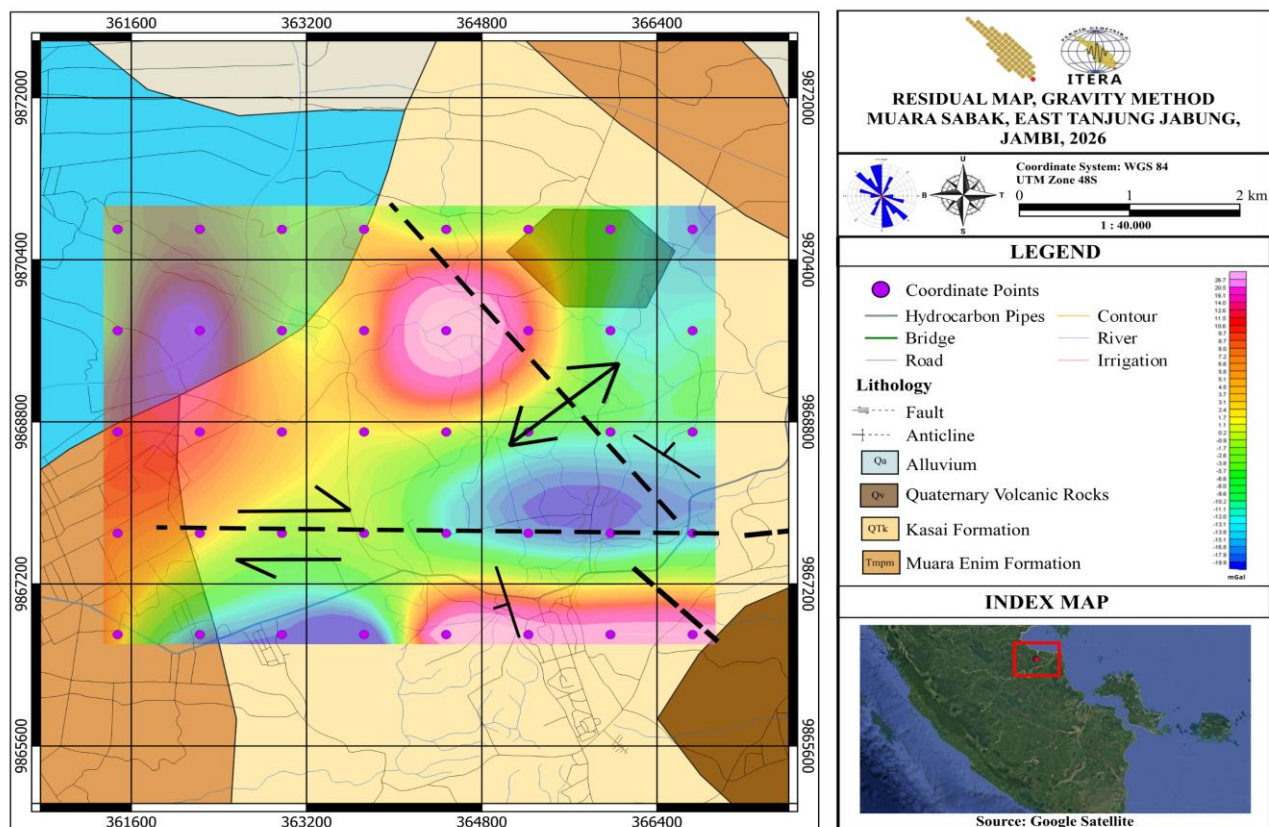


Figure 7. Residual anomaly map

enhancing the response in areas experiencing significant changes in density, so that structural boundaries such as faults, lithological contacts, and folds can be identified more clearly than when using residual anomaly maps directly (Cooper & Cowan, 2006).

Application of the Total Horizontal Derivative (THD)

Total Horizontal Derivative (THD) map, high THD values generally appear in areas with sudden changes in rock density, and are therefore often interpreted as lithological boundaries, faults, or contacts between rock units shown in Figure 8 (Pham, 2020).

Based on the map, zones with high THD values are concentrated in the central to southern parts of the study area. These zones indicate significant changes in density and are therefore interpreted as lithological boundaries or fault zones. The anomaly patterns show a dominant northwest–southeast orientation, which is interpreted as the main structure controlling subsurface conditions. In addition, there are several northeast–southwest-

trending lines that intersect the main structure and are interpreted as secondary structures. The presence of these two orientations indicates that the structural system in the study area is complex, although it remains dominated by the northwest–southeast trend. Therefore, the THD map is effective in delineating structural boundaries that could potentially influence the distribution of reservoirs and cap rocks.

Zones with high THD values form a linear pattern extending along the northwest–southeast direction, reflecting strong density boundaries and indicating the presence of faults or lithological contacts. The concentration of THD anomalies in the central part of the study area further reinforces the interpretation of a major structure that could potentially serve as a hydrocarbon migration pathway toward geological traps.

Application of the Tilt Derivative (TDR)

The Tilt Derivative (TDR) map is used to clarify the boundaries of anomaly sources, particularly in areas with low to moderate density contrast. The map shows a clear

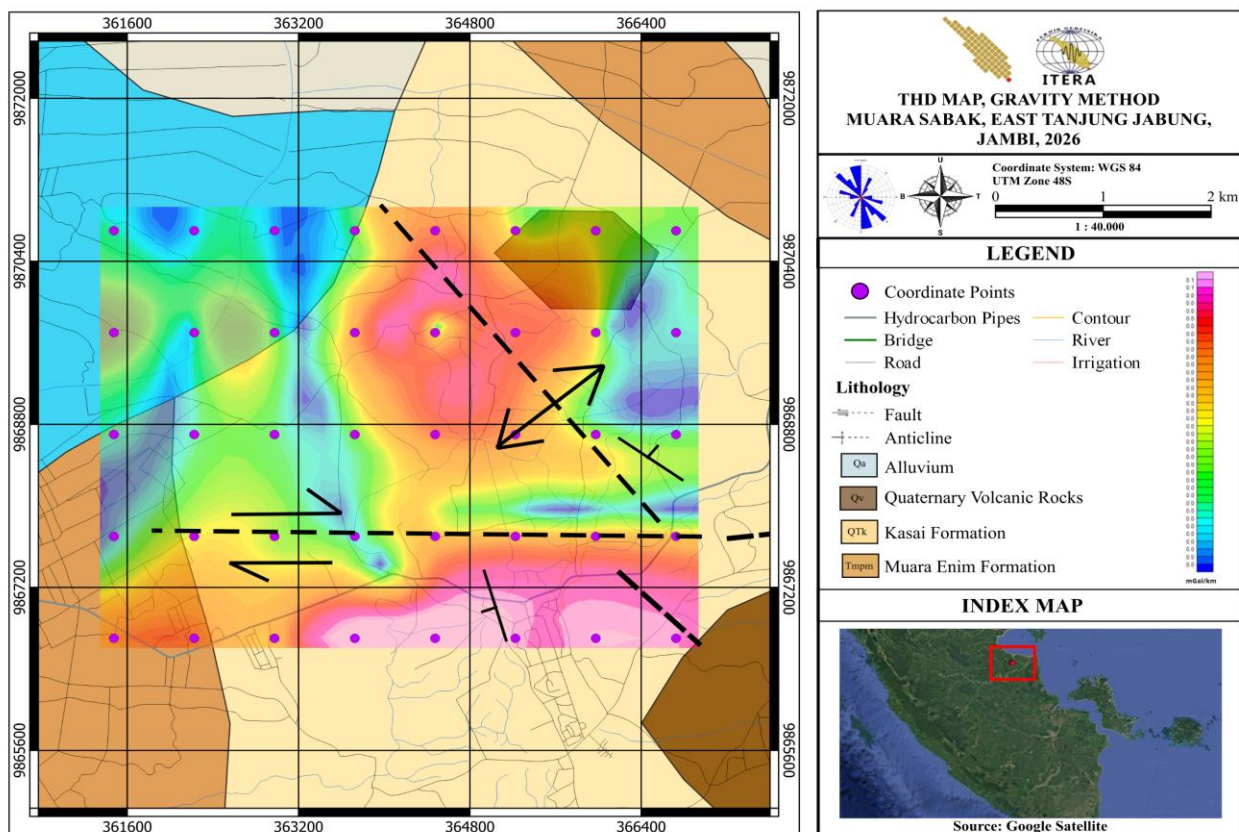


Figure 8. Total horizontal derivative (THD) map

transition zone between positive and negative values, indicated by a contrasting color change shown in Figure 9.

This transition boundary is interpreted as a lithological contact or fault plane that separates rock units with different density characteristics. The linear patterns appearing on the TDR map have a direction that is relatively consistent with the THD interpretation results, thereby reinforcing indications of the presence of major geological structures in the study area. The advantage of this method is its ability to clarify structural boundaries that are less visible in the initial gravity data.

The map shows fairly contrasting color changes forming a linear pattern-oriented northwest–southeast. This transition zone is interpreted as the boundary of a major fault cutting across the study area. A key advantage of TDR is its ability to detect structures in both strong and weak anomalies. Consequently, some structures that are less distinct on the residual map appear more clearly defined on the TDR map. These results indicate that the

Gemah Field has a relatively complex fault system with the potential to form reservoir compartments.

THD identifies the location of the maximum gradient marking a change in density, whereas TDR helps determine the position of structural boundaries through the transition from positive to negative values. The combination of these two methods yields a more reliable interpretation because they complement each other in determining the presence of subsurface structures (Cooper & Cowan, 2006).

Application of the Tilt Derivative of the Horizontal Gradient (TDX)

The Tilt Derivative of the Horizontal Gradient (TDX) map provides higher resolution in identifying the edges of anomaly sources compared to previous methods shown in Figure 10.

The TDX map reveals more distinct anomaly patterns concentrated in specific zones, particularly in the central to southern parts of the study area. The linear patterns appearing on this map are consistent with the structures previously identified on the THD and TDR

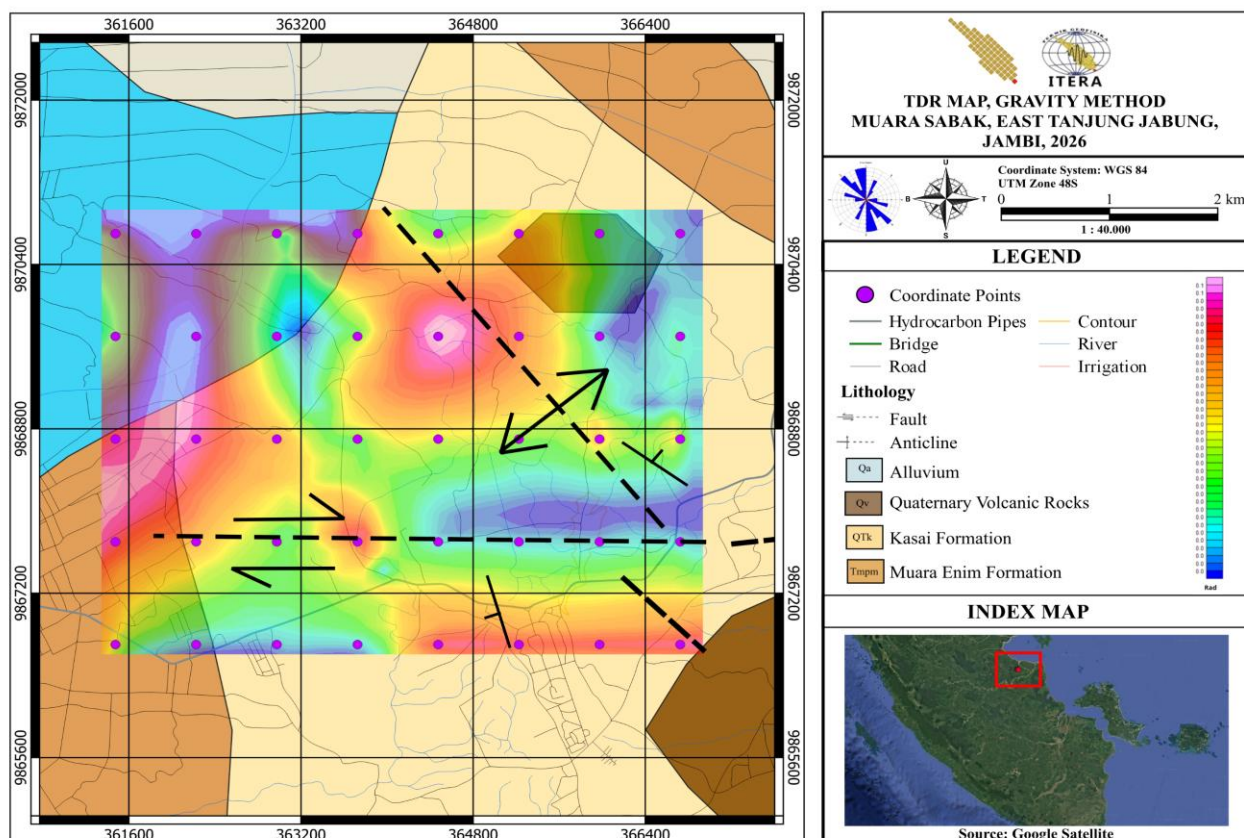


Figure 9. Tilt derivative (TDR) map

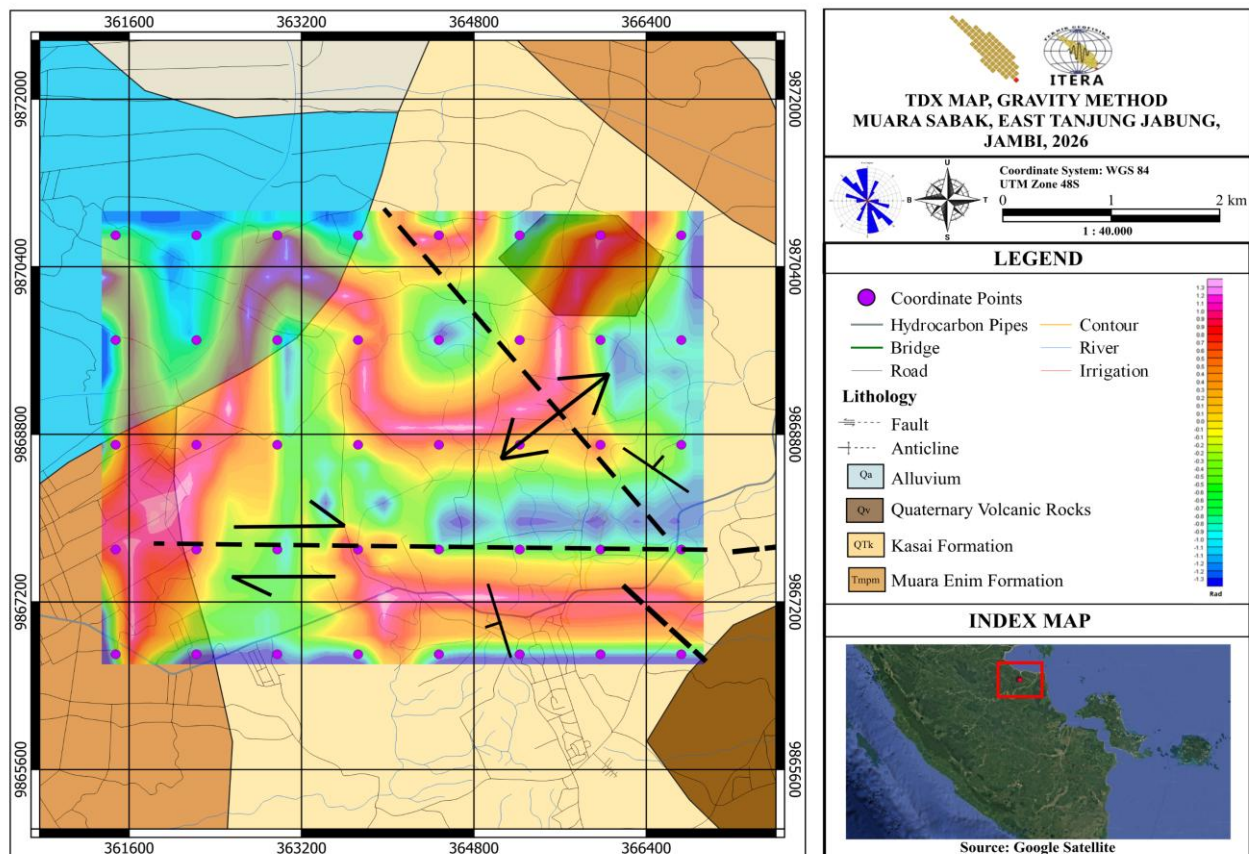


Figure 10. Tilt derivative of the horizontal gradient (TDX) map

maps. With the sharpness of the response it produces, the TDX map is able to clarify the geometry of subsurface structures that have the potential to form geological traps for accumulation.

The map shows high-anomaly zones forming linear and circular patterns around the central part of the study area. These patterns indicate the presence of structural boundaries that are more complex than those visible on the residual map. Several TDX anomalies coincide with previously interpreted fault intersections. These intersection zones are particularly important because they often serve as sites for fluid accumulation due to the formation of structural traps. Additionally, the TDX indicates that the main structures have a dominant northwest–southeast orientation.

Forward Modelling

Based on the results of the data processing that has been conducted, Figure 11. Forward Modelling shows the results of 2D forward modeling, which illustrates the subsurface density distribution based on the match between the observed gravity data and

the response of the constructed model. An RMS value of 0.612 mGal indicates that the model exhibits a good level of agreement with the observational data and can therefore be used to represent subsurface geological conditions (Adhani et al., 2022).

The model consists of several layers with density values of 2.15 g/cc, 2.47 g/cc, 2.64 g/cc, and 2.73 g/cc, which are interpreted as Quaternary Volcanic Rocks, the Muara Enim Formation, the Air Benakat Formation, and the Gumai Formation. These density variations indicate differences in the physical properties of the rocks, while the increase in density toward the lower depths suggests that the rocks become increasingly compact due to compaction processes during deposition (Ramadhani et al., 2021).

The modeling results show that deformation developed in the 2.73 g/cm³ density layer of the Gumai Formation, while the overlying layer experienced relatively little displacement. These conditions indicate that the structure is a basement fault that formed during the early extension phase of the South

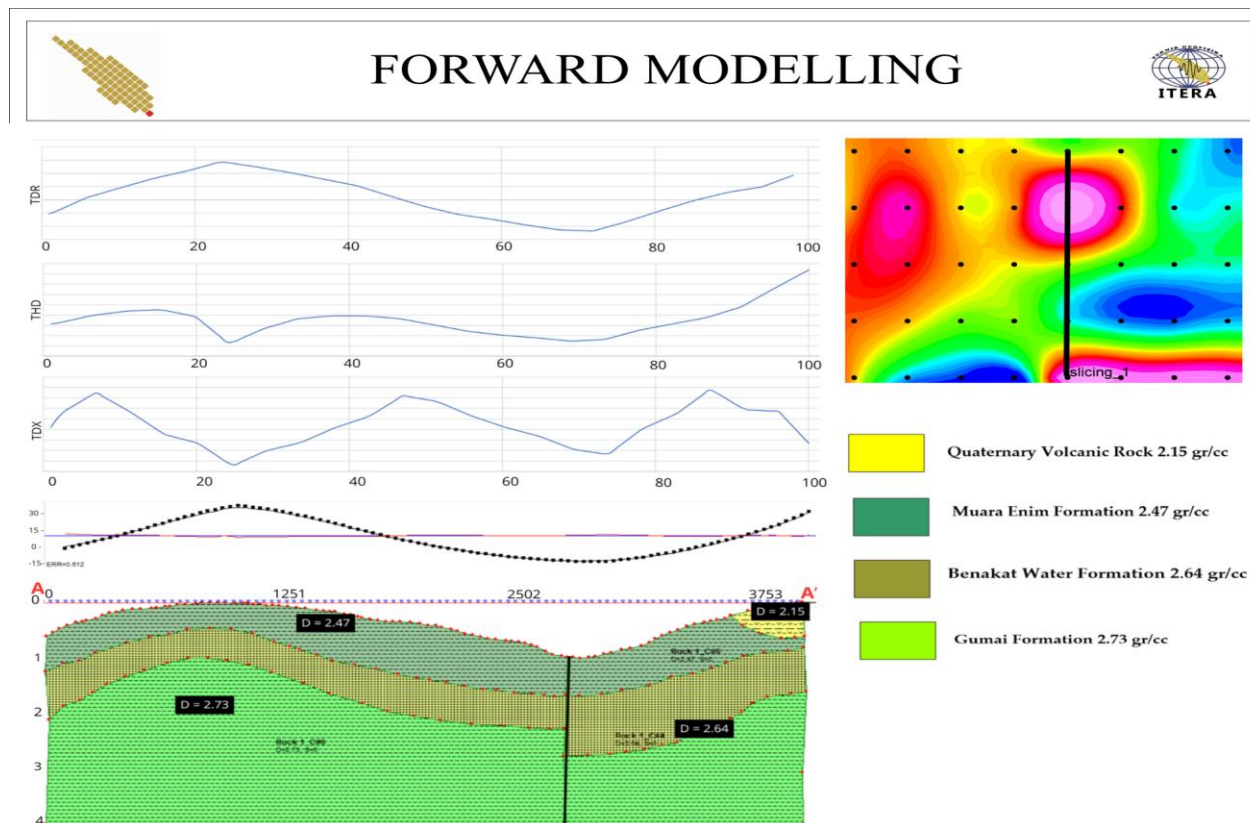


Figure 11. Gravity data forward modelling

Sumatra Basin's formation. Fault activity created an accommodation space that was subsequently filled by younger sedimentary deposits, so that the lower-density layer did not exhibit significant deformation. This basement fault acts as the primary controller of subsurface structural configuration, sediment thickness, and hydrocarbon migration pathways in the Gemah Field.

The central part of the profile, a change in layer geometry is observed in the form of a downward-sloping rock block bounded by a nearly vertical structural plane. This structure is interpreted as a normal fault that forms a depression zone (graben), thereby controlling changes in stratum thickness and rock density distribution. The density contrast in this zone also indicates the presence of a lithological boundary influenced by tectonic activity, as is commonly observed in the interpretation of gravity data using forward modeling (Rinanda, 2024).

3D Modelling

3D Modeling Results, the 3D inversion modeling results consist of 3,200 blocks (voxels) obtained by dividing the model into 20

blocks along the X-axis, 20 blocks along the Y-axis, and 8 blocks along the Z-axis shown in Figure 12. The inversion model was constructed using an area of 5.40 km in the X direction (East), 4.14 km in the Y direction (North), and a model thickness of 0.376 km (376 m) in the Z direction, with each voxel measuring approximately 0.27 km × 0.207 km × 0.047 km (270 m × 207 m × 47 m).

Voxel-based inversion methods, the subsurface volume is divided into small cells, each with a specific density value, allowing the rock density distribution to be reconstructed in three dimensions. The greater the number of voxels used, the higher the model resolution, as density variations can be depicted in greater detail. However, the number of parameters to be calculated also increases, making the inversion process more complex and potentially increasing solution ambiguity. Therefore, the number of voxels must be selected by balancing model resolution and the stability of the inversion results (Darmawati & Setiawan, 2021).

The layer shown is the uppermost layer (Z = 0 m). In this layer, low-density zones—

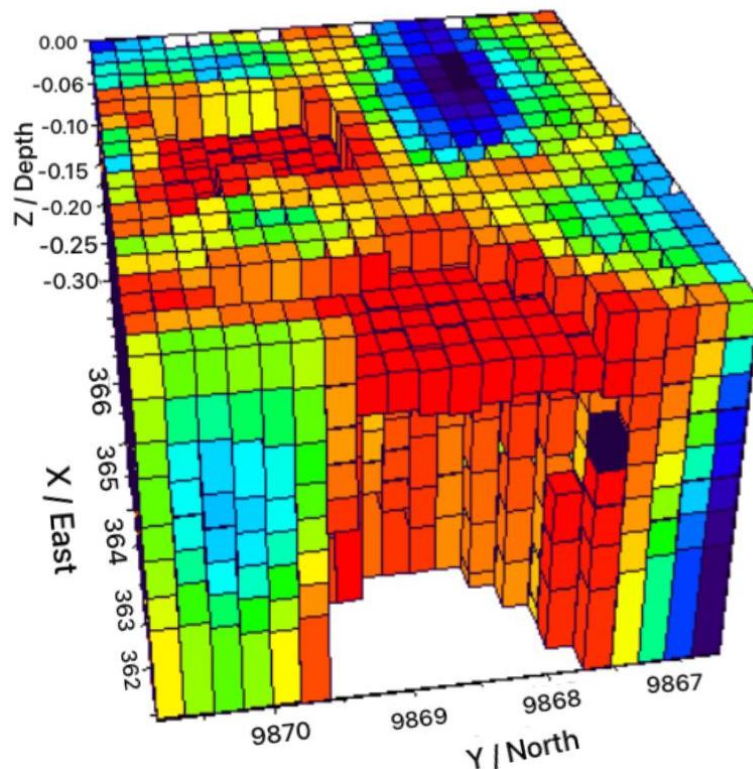


Figure 12. Gravity data 3d modelling

indicated by blue—and high-density zones—indicated by red to orange—are visible. Density values in the surface layer range from 2.13 to 2.78 g/cm³, indicating variations in the physical properties of the rocks in the study area. The relatively sharp density contrast indicates the presence of lithological boundaries and geological structures that control the distribution of rock density. In 3D gravity inversion modeling, changes in density that form linear patterns are generally interpreted as indications of the presence of faults or fracture zones that separate rock blocks with different physical characteristics (Sudrajad et al., 2024).

Based on the density distribution of the inversion results, there are high-density zones associated with structural highs and low-density zones interpreted as parts of a basin or a down-dip block. This pattern indicates the presence of fault structures. The presence of these faults causes variations in the thickness of the Muara Enim Formation, the Air Benakat Formation, and the Gumai Formation, as seen in both the forward modeling and inversion results (Sudrajad et al., 2024). With a model size of 5.40 km × 4.14 km × 0.376 km and a

resolution of 20 × 20 × 8 voxels, the inversion model is capable of representatively depicting the subsurface density distribution and provides sufficient spatial resolution to identify lithological variations and major geological structures in the Gemah Field.

Comparison of Forward and Inversion Modeling

After forward modeling is completed, the next step is inversion modeling to obtain the subsurface density distribution based on gravity anomaly data. Unlike forward modeling, which produces a model through a trial-and-error process, the results of inversion modeling present a more continuous subsurface density distribution, allowing changes in lithology and boundaries between layers to be observed more clearly (Zhong et al., 2022). Based on Figure 13. Comparison of Forward and Inversion Modeling shows a subsurface density distribution consistent with the forward modeling results.

The inversion reveals a more gradual change in density with a wider distribution of the Air Benakat Formation. These differing patterns indicate that the development of geological structures in the study area is not

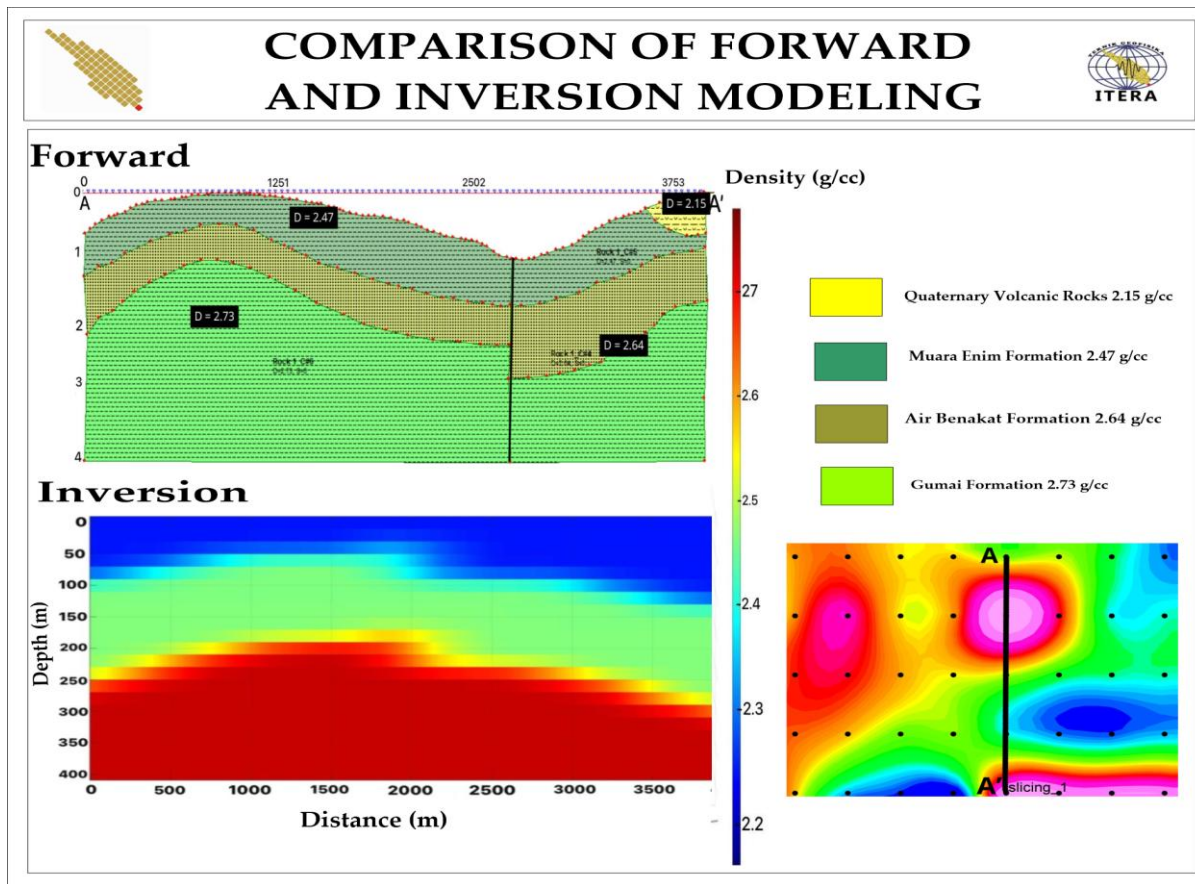


Figure 13. Comparison of forward and inversion modeling

uniform and affects the thickness and lateral distribution of each formation (Elhussein, 2021).

Based on the inversion map, low-density zones (blue to green) dominate the near-surface section, while higher-density zones (yellow to red) develop at greater depths. This pattern indicates an increase in density with depth due to rock compaction processes. Additionally, the density distribution is laterally non-uniform, particularly in the central part of the survey line, which shows changes in density contrast, thus indicating the influence of geological structures that control the distribution of rock layers (Liu et al., 2025). The agreement between the forward modeling and inversion results indicates that the constructed model is capable of accurately representing subsurface conditions, while the inversion results provide a more continuous density distribution, allowing lithological boundaries and geological structures to be interpreted more clearly (Coelho, 2021).

When compared with the results of forward modeling, the inversion model shows smoother boundaries between layers and a more continuous density distribution (Minakov & Gaina, 2021). This indicates that the forward model that was constructed has been able to accurately represent subsurface geological conditions, while the inversion results provide refinements in the form of a more realistic density distribution, thereby making the interpretations of lithology and structure more reliable (Roy, 2021).

Map of Recommended Hydrocarbon Wells and Hydrocarbon Migration Patterns

Based on Figure 14. Map of Recommended Hydrocarbon Wells and Hydrocarbon Migration Patterns Based on Residual Maps, the geological structures shown indicate that the study area is influenced by structural elements such as faults and anticlines.

The presence of these structures plays a crucial role as they can serve as fluid migration pathways or hydrocarbon traps. The fault

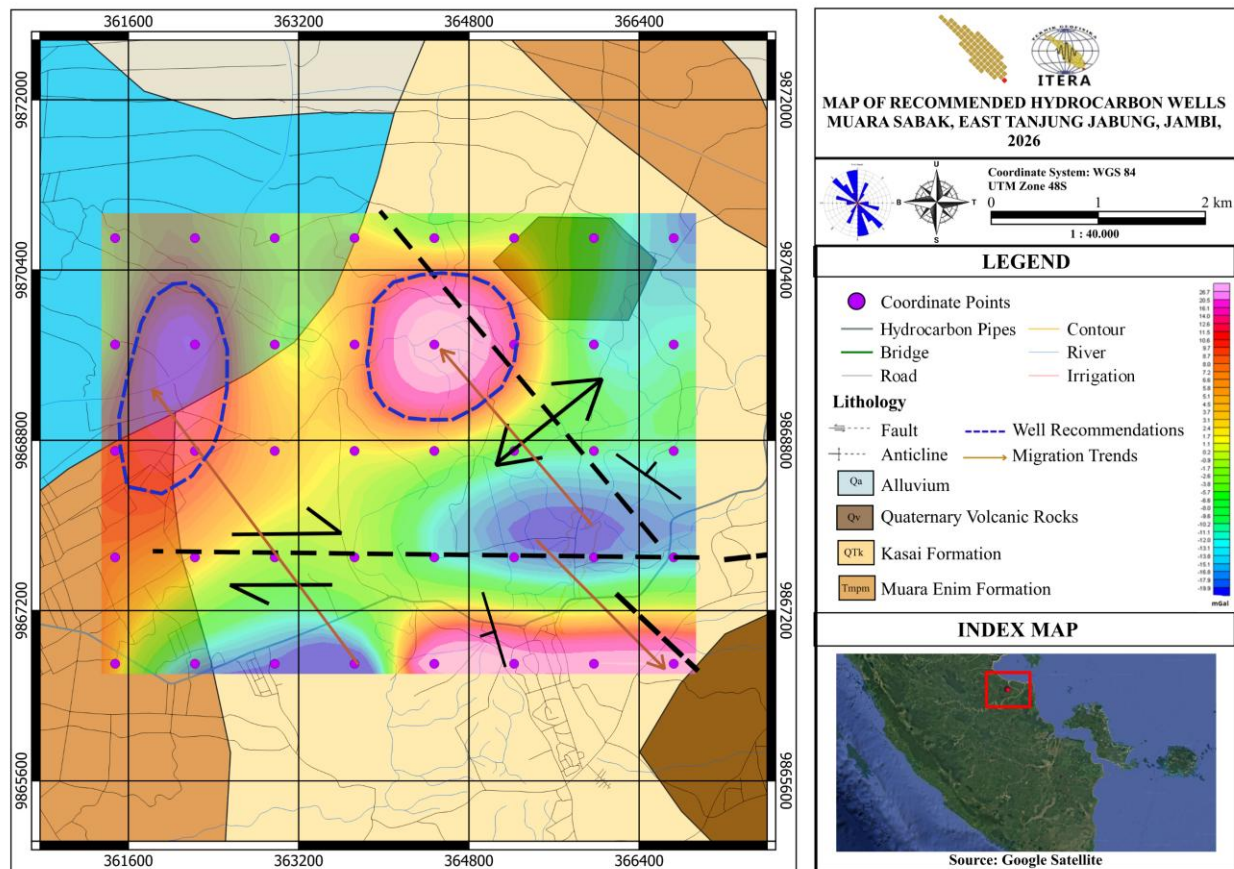


Figure 14. Map of recommended hydrocarbon wells and hydrocarbon migration patterns based on residual maps

structures observed cutting across the anomaly zone indicate the potential presence of fracture pathways. Meanwhile, the anticline structures in the study area have the potential to act as structural traps.

Based on the map, there are two main prospect zones marked with orange dashed lines. These zones are located in areas exhibiting higher anomaly responses compared to the surrounding regions and are correlated with subsurface structural patterns. These conditions indicate that these zones likely contain rocks with density contrasts associated with lithological changes or geological structures that are the targets of exploration.

Based on the direction of the migration arrows, hydrocarbon fluids are expected to move along structural weaknesses, such as faults, toward areas with geological conditions more conducive to accumulation. Recommended well sites located at the intersection of migration paths and trap structures are the most promising locations for

drilling, as they offer a higher probability of encountering hydrocarbon-filled reservoir zones.

CONCLUSION

This study successfully delineated the subsurface structure of the Gemah Field using GGMPPlus gravity data through spectral analysis, enhancement methods (THD, TDR, and TDX), as well as forward modeling and inversion. Spectral analysis estimated the depth of the regional anomaly source at approximately 864.05 m and the residual at approximately 375.78 m. The interpretation results indicate the presence of a fault structure that controls the subsurface configuration, while forward modeling and inversion identified four rock units: Quaternary Volcanic Rocks, the Muara Enim Formation, the Air Benakat Formation, and the Gumai Formation, with a density range of 2.15–2.73 g/cm³. The 3D inversion model clarifies lithological boundaries and hydrocarbon prospect zones as a basis for recommendations for further exploration.

The integration of gravity analysis, enhancement methods, and forward and inversion modeling has proven to improve the reliability of subsurface structure interpretation in the Gemah Field. However, since this study used only gravity data, future research is recommended to integrate seismic data, well data, and petrophysical logs to obtain a more accurate geological model.

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