Further Gravity Data Process to Estimate Geological Structure in Tulehu Geothermal Field, Ambon Island

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Abstract
Tulehu geothermal field in Central Maluku, managed by PT PLN since 1997, is targeted for a 20 MW power plant by 2025/2026. Initial exploration, including five wells drilled from 2011 to 2018, yielded unsatisfactory results. This study revisits gravity survey data from 2010 and process additional 2019 gravity data focused on the Banda and Banda Hatuasa Faults to refine the structural understanding of the field. Gravity data processing involved complete bouguer anomaly (CBA) mapping and spatial derivatives. The analysis indicates a gravity anomaly pattern decreasing from SW to NE, suggesting a basement elevation drop across the field. First Horizontal Derivative (FHD) emphasize fault boundaries, and Euler Deconvolution points to structural dip directions. Results confirm the Banda Fault as the primary control for geothermal fluid flow, although it appears slightly southward of prior interpretations. The Banda Hatuasa Fault, contrary to earlier assumptions, is identified as a distinct structure north of the Banda Fault. These findings provide essential insights for targeting faults in future drilling plans, enhancing geothermal resource development in Tulehu.

Keywords: *Tulehu; gravity; CBA; FHD; fault.*

Introduction

Tulehu geothermal field is located in Salahutu District, Central Maluku Regency, Maluku Province. This field is located on the eastern part of Ambon Island. Currently, Tulehu geothermal field is managed by PT PLN (Persero) through an assignment from the Government since 1997 and has been included in the RUPTL (Electricity Supply Business Plan) 2021-2030 which is planned for COD in 2025/2026 with a capacity of 2x10 MW.

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Figure 1 Location of Tulehu Geothermal Field (https://geoportal.esdm.go.id/ebtke)

Pre-Feasibility Study has been carried out by PLN in 2010 to prepare the drilling of exploration wells. One exploration well was drilled in 2011, namely TLU-01 with a depth of 932 m (PLN-JICA-WestJEC, 2011). Then in 2017-2018 an additional four exploration wells were drilled, namely TLU-D1, TLU-B1, TLU-C1 and TLU-B2 with a depth of 1700-1900 m. However, from the results of drilling the five wells, satisfactory results have not been obtained for the development of building geothermal power plants.

One of the surveys that has been carried out by PLN, namely the gravity survey in 2010, covers an area of 25 km2 as many as 247 points with distances between stations ranging from 300 to 600 m (PLN Geothermal-GeoAce, 2010). The results of the survey processed and produced a map of the Bouguer anomaly in 2010, which was then interpreted as a geological object, i.e. a straightness correlated as a fault or lithological contact, depicted with the GL1-GL5 line. The thing of concern in the map below is the main fault that controls the outflow of geothermal fluids and the fault that is the target of drilling exploration wells, namely the Banda Fault and the Banda Hatuasa Fault are not identified by the GL1-GL5 line.

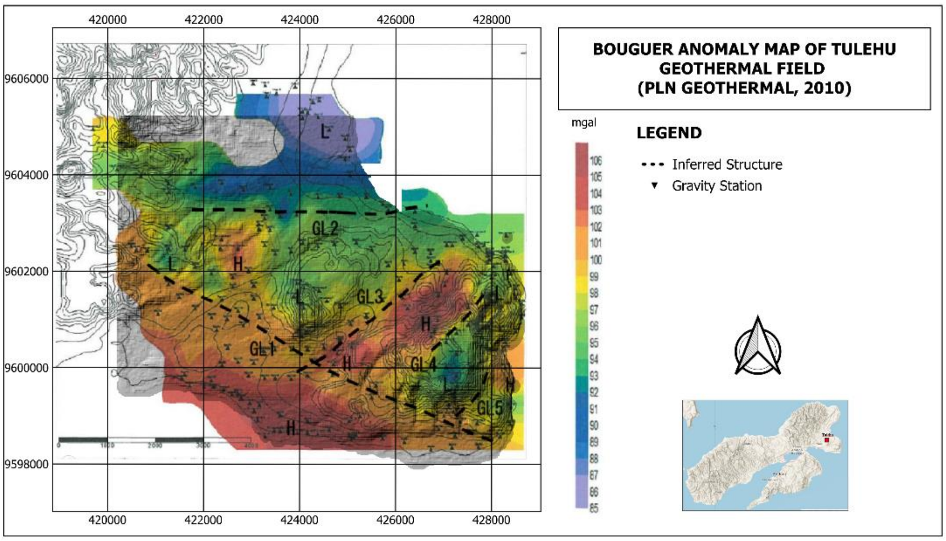

Figure 2 Bouguer Anomaly Map (PLN Geothermal, 2010)

Tectonic Setting

The Ambon and Seram regions are tectonically included in the Eastern Indonesia region which is influenced by the interaction of three main plates: Eurasia, Australia, and the Pacific. Since the Late Oligocene, these three plates have been active in forming regions, including the Banda Arc which has a distinctive 180° curve of the Sunda Arc to the west. Current tectonic activity around Seram and Ambon involves the convergence of Seram Island with the Papuan "Bird's Head", which is moving towards the Seram Trough at about 20 mm/year.

There is a difference of opinion regarding the geometry of the curved Banda Arc, where some researchers argue that this region is not included in the volcanic path. However, Pownall et al. (2017) stated that Seram and Ambon are at the end of the volcanic path due to the subduction of the Australian Plate. The epicenter in southwest Seram showed activity up to a depth of 300 km, with the dominance of upward fault movement, accompanied by shear faults and normal faults.

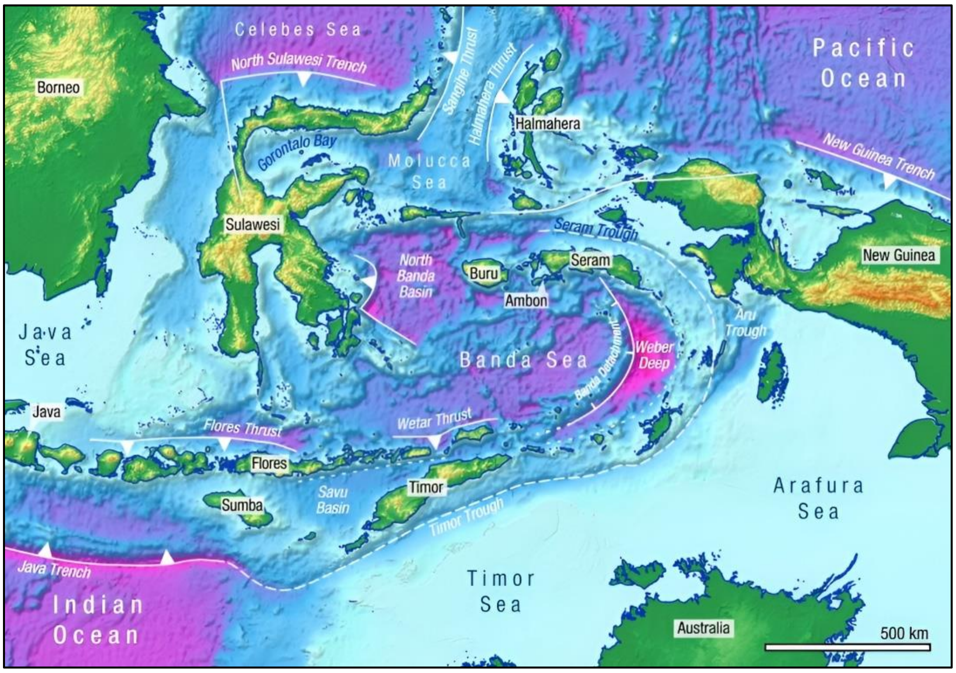

Figure 3 Eastern Indonesia Tectonic Order (Pownall et al., 2017)

Seram Island is often interpreted as part of a thrust-fault-belt system, with a geological structure that develops through several phases: a normal fault in the direction of NNE-SSW, followed by left shear fault (WNW-ESE) in the Kawa Shear Zone, and a normal fault that cuts through other structures. Pownall et al. (2017) also mentioned the existence of episodes of high-temperature extension and strike-slip faulting in the west of Seram, showing a pattern of deformation and fault distribution oriented northeast-southwest.

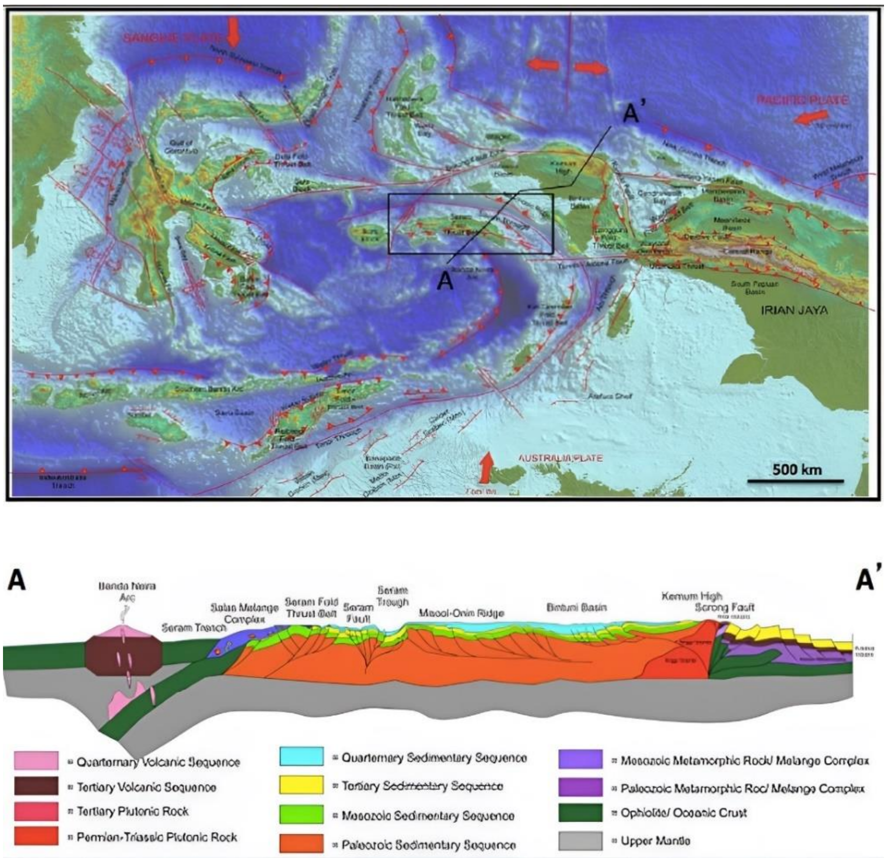

Figure 4 Eastern Indonesia's tectonic order influenced by the Plate Australia, the Eurasian Plate, and the Pacific Plate. (Hadiana, 2014).

Geological Structure

Based on the PLN-JICA-WestJEC report in 2011, there are eight large faults in Tulehu in the direction of NE-SW and NW-SE.

NE-SW directional fault

1. Wairutung Normal Fault cuts through most of the rock. The southeastern part of this fault is relatively lower than the northwest part.
2. Huwe Normal Fault separates G. Eriwakang and G. Terang Alam (G. Huwe). The northwestern part of this fault is relatively lower than the southeast. The Huwe Fault and the Wairutung Fault form the Eriwakang Graben Zone which controls the formation of the Banda and Banda-Hatuasa Faults, and the activity of G. Eriwakang. PLN (2010) stated that the formation of graben is influenced by tectonic activity of Pre-Tertiary

to Tertiary age. Although the Huwe Fault is said to have cut limestone, it is possible that this fault has been reactivated. This fault has a plane of N56°E/80° NW.

3. Normal Banda Fault is a fault that slopes to the northwest. This fault splits the central part of Tulehu. Around the manifestation of the Hatuing fault, this fault forms a splay fault of the Banda-Hatuasa Fault. This fault has a plane of N53°E/85°W in the northern part and N 69° E/80° NW in the southern part.
4. Banda-Hatuasa Normal Fault also has a slope to the northwest. The Banda and Banda-Hatuasa faults form a depression zone in the central part of Tulehu. These two faults control the exit of geothermal manifestations in Hatuing, Banda, Sila, Telaga Biru and Hatuasa. The slope of the two faults is also confirmed in the report, namely with the N46°E/80° plane.
5. Kadera Normal Fault is located south of G. Salahutu. This fault is west-east and turns northeast-southwest. This fault has a slope towards the south.

NW-SE directional fault

1. Waiyari Right Horizontal Fault which has an S plane of 62° E/85° NE
2. Horizontal right fault of the Descent.
3. The Normal Tulehu Fault is located along the east coast of Tulehu. This fault has a northeasterly slope (S 65° E/80° NE) and controls the exit of manifestations in Batulompa, Batukuda and Tulehu.

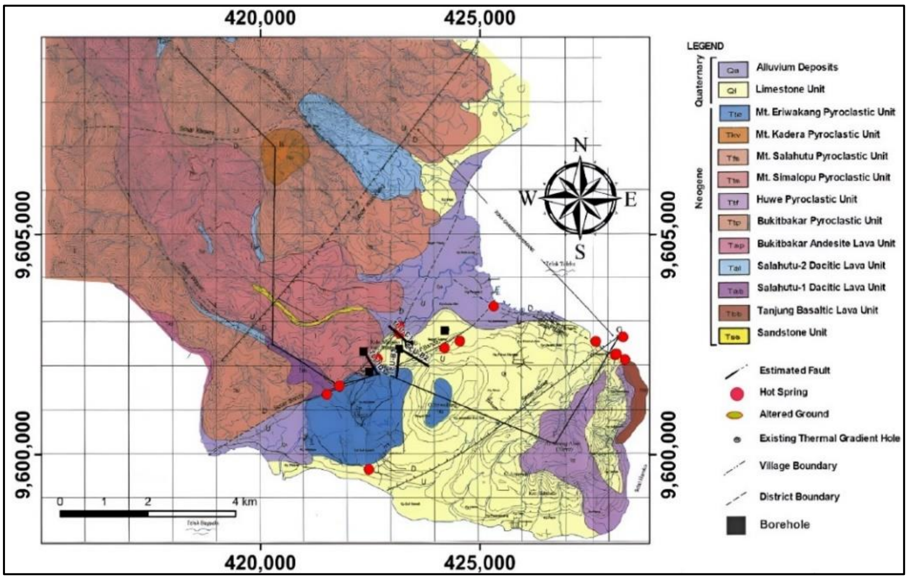

Figure 5 Geological Map of Tulehu (PLN, 2018)

Gravity Data Processing

In 2019, PLN acquired gravity data at 123 points focusing on the main structural areas, namely the Banda Fault and the Banda Hatuasa Fault.

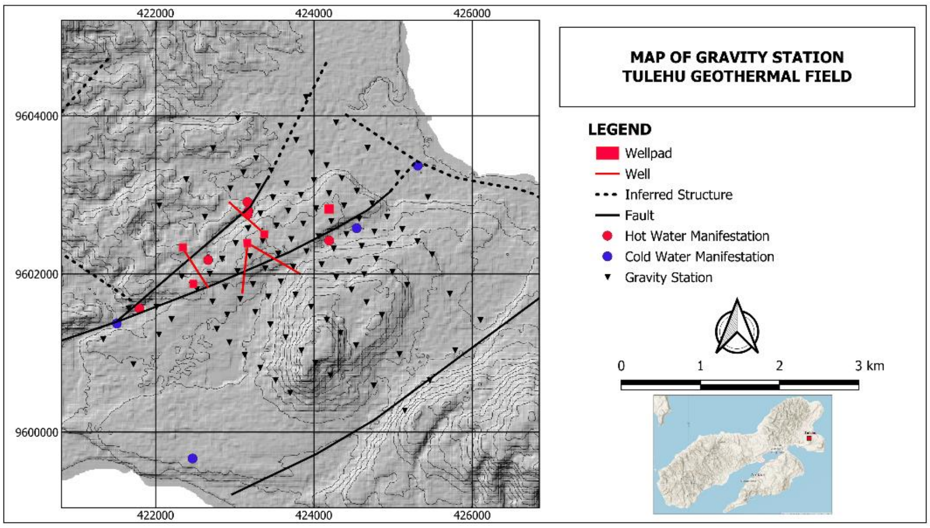

Figure 6 Gravity Station Distribution

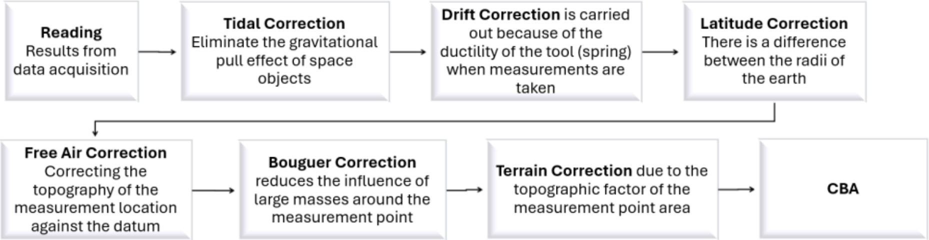

Figure 7 Gravity Data Processing Process Flow

The gravity value at each point which is the result of measuring the equipment in the field, several corrections are calculated using various formulas, such as tidal correction, drift, latitude, free air and bouguer correction. These corrections can be made using Microsoft Excel, while terrain corrections are obtained from the Oasis Montaj software.

The complete bouguer anomaly (CBA) value that has been obtained from the results of gravity field data processing, is then used as a processing input using software. The software used in this research is Oasis Montaj. The maps generated from the software are CBA maps, regional anomaly maps, residual anomaly maps, first horizontal derivative maps and euler deconvolution maps.

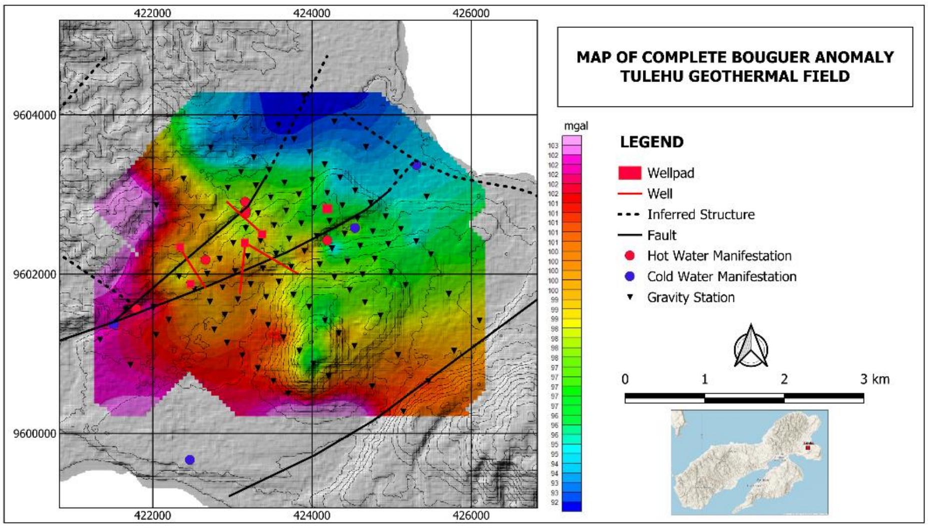

Figure 8 Map of Complete Bouguer Anomaly

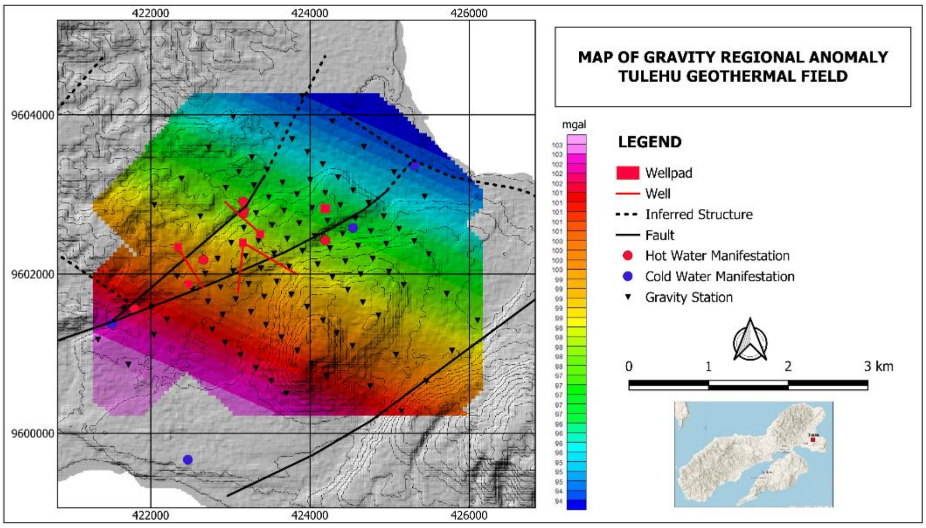

Figure 9 Map of Gravity Regional Anomaly

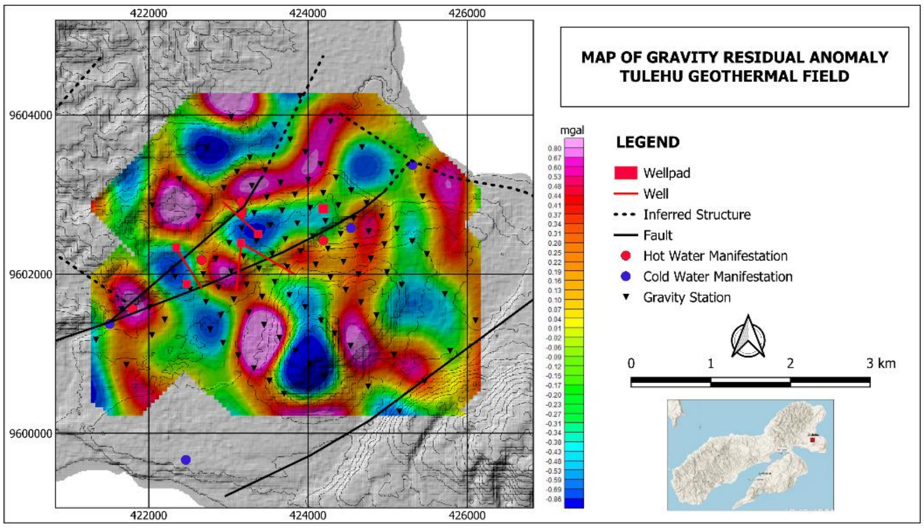

Figure 10 Map of Gravity Residual Anomaly

The CBA map depicts the variation in total gravity on the earth's surface after removing the effects of gravity from the topography and thickness of the earth's crust. The CBA value is measured in milligals (mGal) and can provide information about the mass distribution below the surface. Regional anomaly maps have low frequencies and are associated with deep subsurface. This map highlights a wider variation in gravity, usually caused by large geological structures such as tectonic plates, basins, or mountains. Regional anomalies can help identify deeper geological features. Maps of residual anomalies have a high frequency and are located on shallower surfaces. This map illustrates the difference between anomalies and regional gravity. Residual anomalies can reveal geological features that are closer to the surface.

The CBA value has a range of 12 mgal with values ranging from 90,645 to 102,446 mgal, with variations in values that are decreasing towards NE. Likewise, regional gravitational anomalies have high values in the SW part and are getting lower towards NE. Meanwhile, the resulting residual gravity anomalies show a varied pattern, in the northern part in the direction of NE-SW and in the eastern part relatively in the direction of N-S.

Tulehu gravity anomaly map shows a simple pattern, namely a decrease in the value of gravity anomalies from SW to NE of the study area. The anomaly pattern can represent the source of the anomaly at a deeper depth that correlates with the geometry of the basement in the study area. This can indicate that at the depth of the basement, there is a decrease in elevation from east to west of the study area.

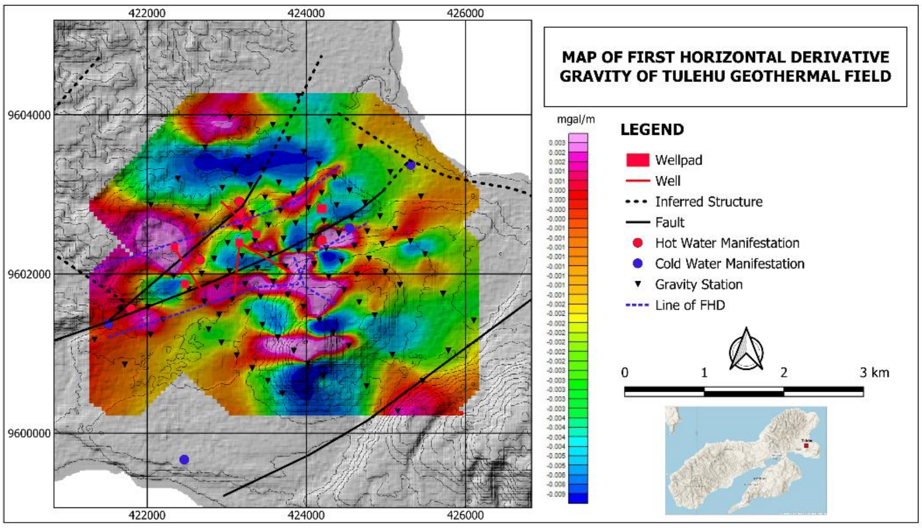

Figure 11 Map of First Horizontal Derivative (Axis Y)

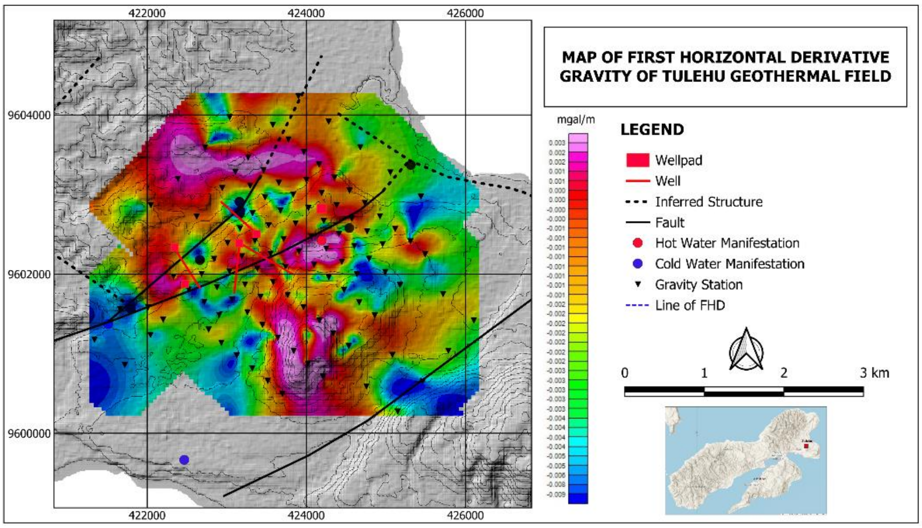

Figure 12 Map of First Horizontal Derivative (Axis XY)

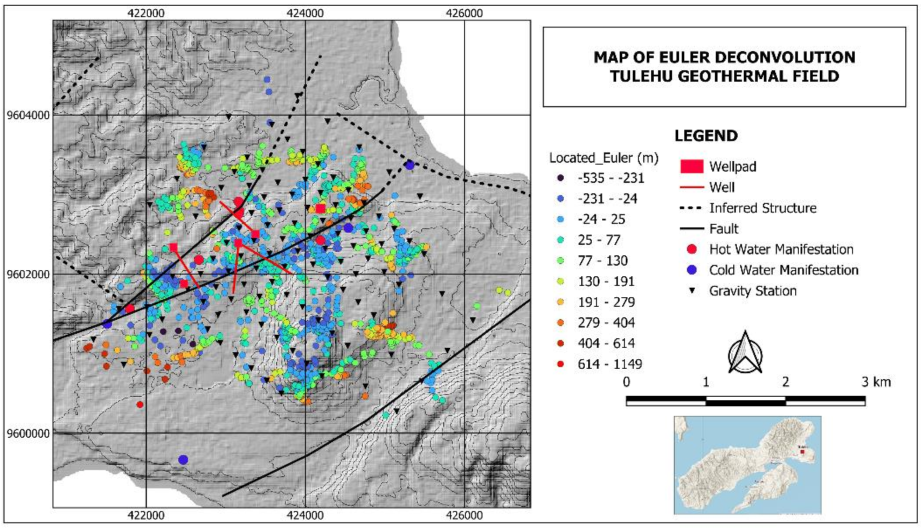

Figure 13 Map of Euler Deconvolution

Gradients or derivatives of gravity values spatially (horizontally) in gravity data are additional data processing techniques that aim to sharpen data and delineate the source of subsurface anomalies (Cooper et al., 2003). The horizontal gradient of the Y-axis is the change in the value of gravity towards the north, and the horizontal gradient of the direction of the X-axis is the change in the value of gravity towards the east; both use the unit of mGal/meter. The limit of an anomaly on a horizontal gradient is indicated by the value of the peak gradient, which is the maximum and minimum values (Saad, 2006).

FHD maps emphasize the boundaries of gravitational anomalies, helping to identify geological features more clearly, including structures such as faults, dikes, or rock boundaries that may be pathways for geothermal fluids.

The y-directional horizontal gradient value pattern shows the boundary pattern of anomalies in the direction of E-W and NE-SW separated by a straightness pattern in the direction of NNW-SSE. The interpretation of the FHD map above is seen from the high mgal/m value which illustrates the Banda fault which shifts slightly to the south from the interpretation of geological studies. Then, the Banda Hatuasa fault, which is a splay fault of the Banda fault, is not visible, but the Banda Hatuasa fault is a separate fault located in the north of the Banda fault. Then, the total FHD map (x and y directions) can be used better in identifying radial features that can be related to heat sources below the surface, in this case Mount Eriwakang which is located south of the Banda fault. High mgal values on the residual anomaly map and high mgal/m values on the total FHD map on Mount Eriwakang can be suspected as heat sources.

In the Euler Deconvolution map above, the dots in the map legend indicate the depth (m), so if you look at the distribution of points based on the color that has a depth function, these points can show the dip direction of the geological structure below the surface, where the direction is seen from the low Euler value and continuously to the higher Euler value. In addition, the relatively same distribution of Euler point colors can be interpreted as a geological structure. The purple and blue dots are quite evenly distributed along the Banda fault line and north of Mount Eriwakang which can be interpreted for the existence of subsurface structures. This supports the interpretation of the FHD map regarding the existence of the Banda fault as the main fault.

Conclusion

Based on the results of gravity data processing analysis, the Banda fault, which is the main fault, can be identified, especially through FHD and Euler analysis. However, the position has shifted slightly to the south compared to the interpretation of the Banda fault in previous studies. The Banda Hatuasa Fault is not a splay fault of the Banda fault, but a separate fault located north of the Banda fault. For the next drilling plan, the Banda fault can still be considered as the main target of drilling as a geological structure that controls the outflow of geothermal fluids.

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