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Analysis of Subsurface Structure of Sembalun Geothermal Prospect Area, East Lombok with 2D and 3D Gravity Modeling

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Abstract. The existence of Indonesian geothermal is estimated to be spread in 331 locations, one of which is Sembalun, East Lombok Regency. Therefore, this study was conducted to analyze the subsurface structure of geothermal prospect areas in the area using gravity methods. Gravity data used is satellite data as much as 4275 measurement points that have been corrected free air (FAA). The data processing stage resulted in a Complete Bouguer Anomaly (CBA) map with low anomaly values to be the target of research ranging from 58.9 – 115.7 mGal located in the east (Sembalun-Bumbung) and northeast (Sembalun-Lawang). The prospect of geothermal is controlled by Talaga fault and Pusuk fault on the caldera floor (Sembalun-Lawang). In addition, the Tanakiabang fault and the Orok fault are near the manifestation of Sebau Hot Springs and on the Caldera floor (Sembalun Bumbung). The results of 2D modeling correlated with 3D modeling conducted inversions showed geothermal sources are estimated to have a density of 2.68 gr/cc – 3 gr/cc consisting of hornblende andesite lava rocks with a depth of >2500, reservoir layer in the form of sand that has a density of 1.4 gr/cc - 1.72 gr/cc with a depth of 700 - 1200 m and a layer of hood in the form of alluvium rocks that have a density of 1.8 gr/cc - 2.2 gr/cc with a depth of 0 - 500 m.
Keywords: *gravity method, inversion method, geothermal.*

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INTRODUCTION

Indonesia is one of the three countries with the largest geothermal potential in the world. The existence of geothermal based on data from the Ministry of Energy and Mineral Resources in 2017 is found at 331 locations. The locations are scattered along volcanic paths ranging from Sumatra, Java, Bali, Nusa Tenggara and then veering to Maluku and Sulawesi. Geothermal sources in Indonesia are mostly produced from high and medium-temperature geothermal systems. The system is very suitable to be used as a source of power generation. The potential electricity generated for all these points is 28,579 MWe or equivalent to 14.47 % of all geothermal potential in the world. While its utilization has only reached 1,698.5 MW or about 5.94% of the potential nasional [1].

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Sembalun Geothermal Prospects

West Nusa Tenggara becomes a volcanic path of geothermal resources with one of its location points is in Sembalun, East Lombok Regency. East Lombok regency is a regency located at the eastern end of Lombok Island. Geographically the district is located between 8° LS – 9° LS and 116° BT – 117° BT with an area of 2,679.88 km^2 consisting of 1,605.55 km^2 landmasses and 1,074.33 km^2 oceans [2].

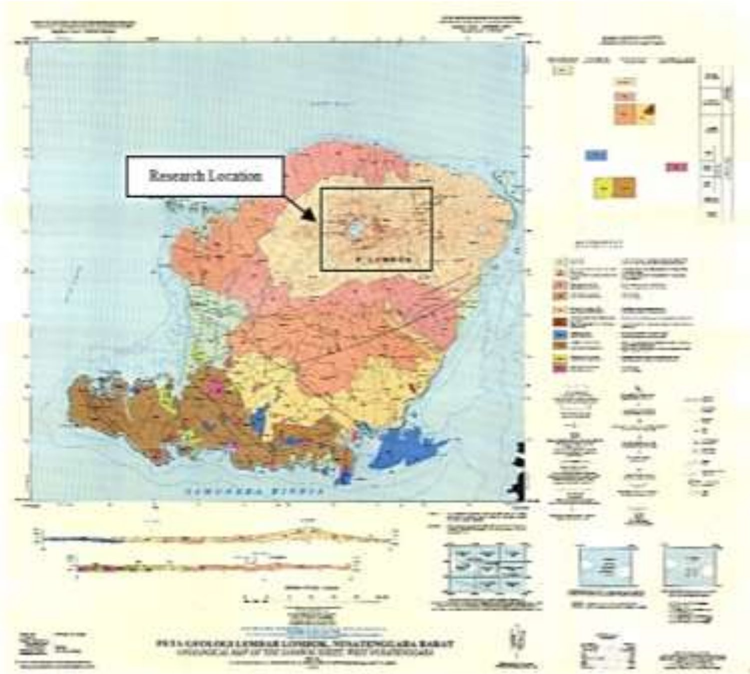


Figure 1. Geological Map of Lembar Lombok, West Nusa Tenggara [3].

In East Lombok area, there are several units of late Pleistocene to quarter volcano rocks composed by volcanic breccias, including Kalipalung formation, Kalibabak Formation, and Lekopiko Formation. Kalipalung Formation (TQp) consists of breccias gampingan and lava, Kalibabak Formation (TQb) consists of breccias and lava, while Lekopiko Formation (Qvl) consists of rocky tuf, lava breccias, and lava [4].

Sembalun area, East Lombok Regency located in the path of volcano is one of the areas that indicates the potential of geothermal with some symptoms of manifestations on the surface. The previous reference stated that in Sebau area there is an indication of geothermal potential in the form of hot springs and gas supply with a temperature of 36.50 °C dengan pH of 8.4 [5]. This manifestation is due to the research area located in the northeast at the foot of Mount Rinjani which is the second highest active mountain in Indonesia.

Previous research on the investigation of geothermal areas Sembalun, East Lombok Regency, West Nusa Tenggara has been conducted by the Geological Resource Center in 2007 using geoelectric methods, and geomagnetic methods in the Proceedings International Conference on Science and Technology (ICST) in 2020. To find out more accurate information, therefore this study was conducted with the aim to analyze the subsurface structure of the geothermal prospect area of Sembalun, East Lombok using gravity methods.

Gravity Method

Gravity method is one of the geophysical methods that application by measuring the gravitational field and utilizing variations in density values that have been distributed below the earth's surface. Gravity methods are used in regional characterization of the earth, determining the structure of the Earth's crust, and identifying regions or regions for resource exploration [6].

The higher gravitational anomaly value of the surrounding area indicates a higher density as well. The method of gravity works based on Newton's Law of Gravity which states that the force working between two m-mass objects separated at a distance of r will be directly proportional to the multiplication of the mass of the two objects and inversely proportional to the squared distance of the two centers of mass of the object [7].

$$F = G \frac{M\, m}{r^2} \quad (1)$$

where F is the gravitational force (N), G is the universal gravitational constant (6,672 × 10^{-11} Nm^2/kg^2), M is the mass of particles or objects (kg), m is the mass of particles or objects (kg), and r is the distance between the two centers of mass (m).

The method of gravity is processed to produce the Complete Bouguer Anomaly (CBA) value, the gravitational anomaly data obtained from the satellite is the corrected gravitational anomaly data to free air correction (FAA), so that the correction required is only terrain correction and Bouguer correction that aims to reduce the mass of rocks in the Earth's crust that are between the spheroid plane and the measurement point.

Terrain Correction is performed due to irregular topographic conditions around the measuring point. Measurements in hilly areas will result in a different measuring value to measurements made in flat areas. The influence of topography with elevation differences such as data surfaces or valleys from the surroundings can be eliminated by terrain correction[8]. Field correction can be formulated as follows:

$$TC = \frac{2\pi Gp}{n} (r_L - r_D) + (\sqrt{r_L{}^2\, z^2}) - (\sqrt{r_D{}^2\, z^2}) \text{ mGal} \quad (2)$$

where r_L and r_D are the outer radius and inner radius of the compartment, z is the difference in the average elevation of the compartment, and n is the number of segments in the zone.

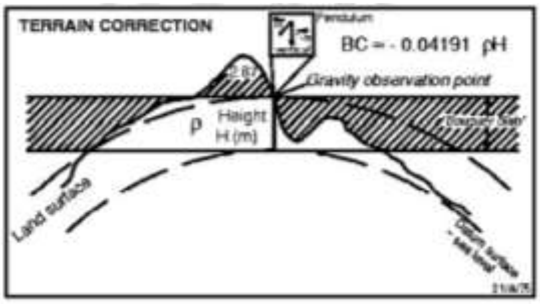


Figure 2. Correction of The Field against Gravity [8].

While Bouguer correction is taken into account because there is a pull effect of the rock mass located in the station and datum plane assuming it has infinite radius with h (meter) thickness and density of ρ (gr/cc). Bouguer's correction value can be searched by equation [9]:

$$BC = 2\pi g\rho h \tag{3}$$

Inversion Modeling

Inversion modeling is often said to be the "opposite" of forward modeling because in inversion modeling is obtained directly from the data. Menke (1984) defines inversion theory as a whole of mathematical and statistical techniques or methods to obtain useful information about a physical system based on observations of the system. The physics system in question is a phenomenon that we review, the observation of the system is data while the information that wants to be obtained from the data is the model or parameters of the model [10].

In the process of inversion is usually done analysis of field data by matching curves (curve fittings) between field data and mathematical models. The purpose of the inversion method is to estimate the physic parameters of subsurface conditions that were not previously known. Inversion modeling techniques for gravitational anomaly data have been widely performed both against the corrected primary data of Earth's gravitational anomalies as well as to regional and residual gravitational anomaly data as well as complete Bouguer anomalous secondary data [11]. This is why this study used inversion methods to model it.

RESEARCH METHODS

The research location in the geothermal area of Sembalun is within the area of Suela and Aikmal Subdistricts, East Lombok Regency, West Nusa Tenggara Province. Located at coordinates between 116° 30' 00" – 116° 35' 00" BT and 8° 20' 30" – 8° 30' 00" LS (Figure 3). [12] The study, conducted on 1–6 July 2021, used gravity methods to analyze the subsurface structure of the geothermal prospect area.

Figure 3. Research Area Map.

The gravitational data used is satellite data from TOPEX as many as 4275 measurement points that have been corrected free air (FAA). Software used to support the data processing stage include: Ms. Excel, Notepad, Google Earth Pro, Global Mapper, Surfer, Oasis Montaj, Voxler, Bloxer, ZondGM2D, and Grablox. From the ten software produced modeling images of the structure below the surface of geothermal in 2D and 3D by means of data processing that can be seen from the flow chart below.

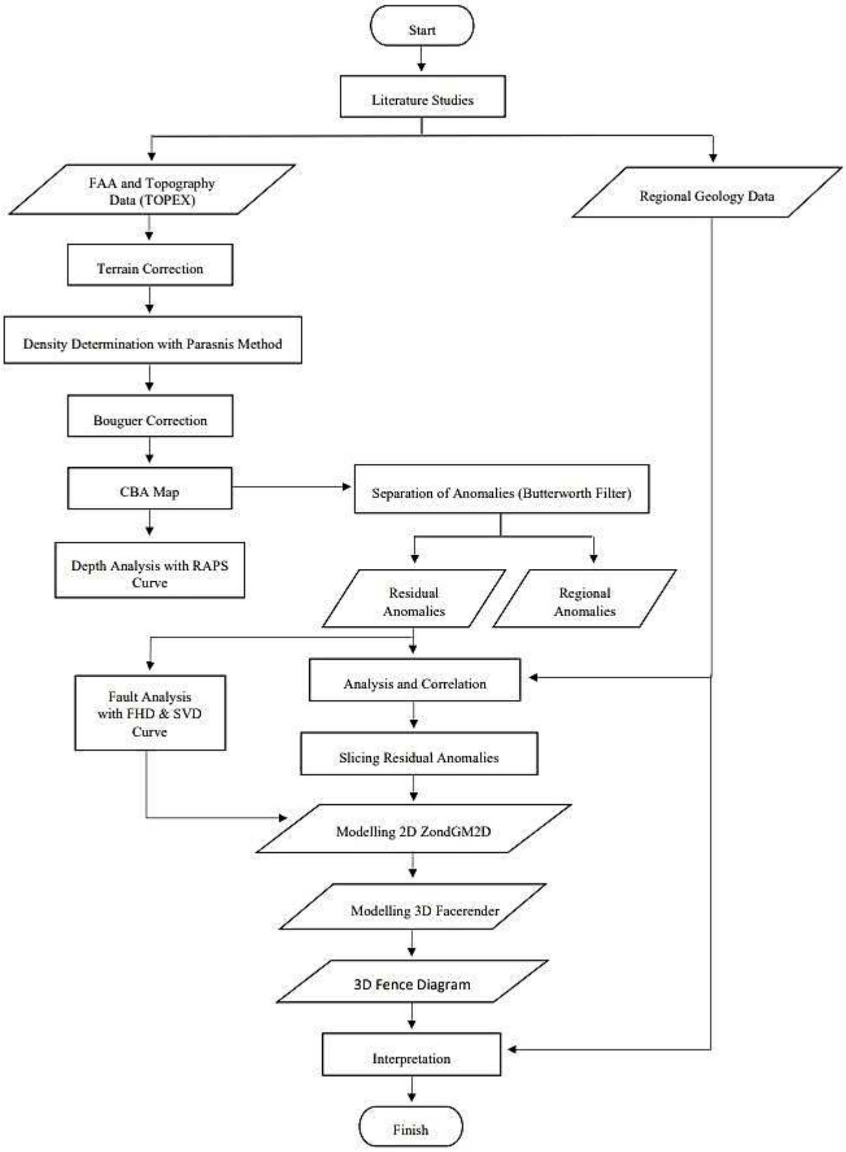


Figure 4. Research Flow Chart

RESULTS AND DISCUSSION

Complete Bouguer Anomaly (CBA)

After the FAA data is done correction Bouguer and field correction then obtained the results of Complete Bouguer Anomaly (CBA) which presents the distribution of gravitational anomalies and contrast of rock density in the research area that is Sembalun area due to differences in density below the surface (Figure 5).

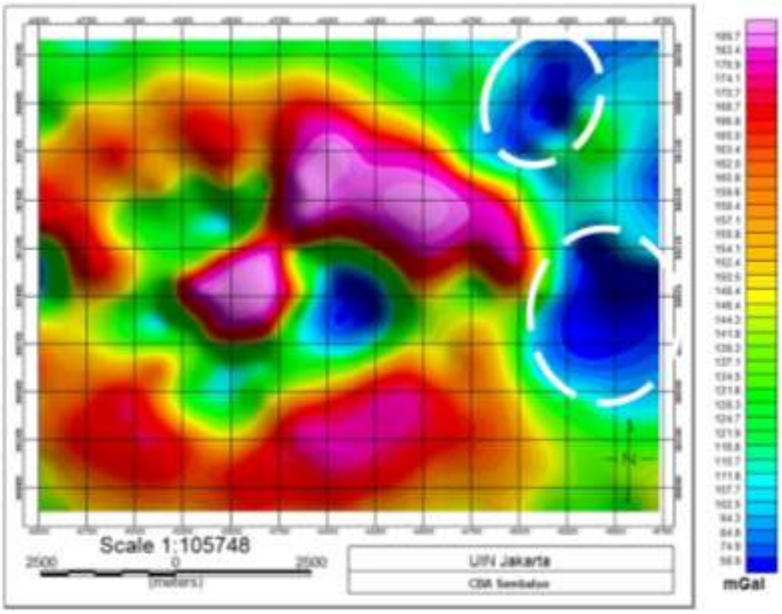


Figure 5. Map of Complete Bouguer Anomaly (CBA).

Can be seen on the CBA map, gravitational anomaly values in the research area ranged from 58.9 – 189.7 mGal, where the value of low anomaly (dark blue – light blue) ranges from 58.9 – 115.7 mGal, the medium anomaly value (dark green – yellow) ranges from 118.8 – 146.4 mGal and the high anomaly value (orange – purple) ranges from 148.4 – 189.7 mGal. From some literature, the low anomaly value on the CBA map in the east and northeast is thought to be the Sembalun geothermal prospect area. Low anomalies are associated with low density owned by geothermal fluids that are usually hot water, hot steam or a mixture of water and hot steam contained in reservoir rocks.

Figure 6. Map of Complete Bouguer Anomaly (CBA).

If overlay on regional geological map and CBA map (Figure 6) area that has geothermal prospects can be divided into two areas, first the area located in the northeast is Sembalun-Lawang area which is on the caldera floor and Mount Prigi area. Then the second area is in the Sembalun-Bumbung area which is on the caldera floor and around the Sebau hot spring manifestation area.

Topographic Map

On the topographic map, it appears that the height in the area of Mount Rinjani, Mount Anakdare, Mount Prigi and Caldera Sembalun (Figure 7).

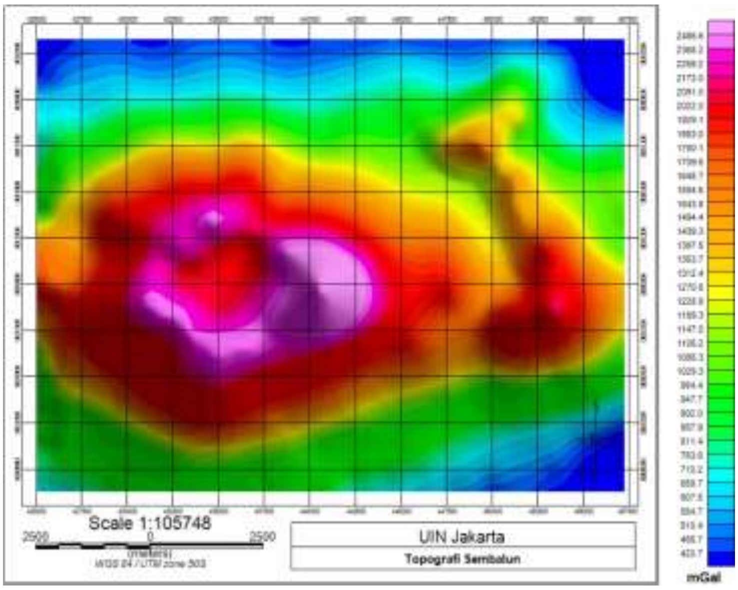
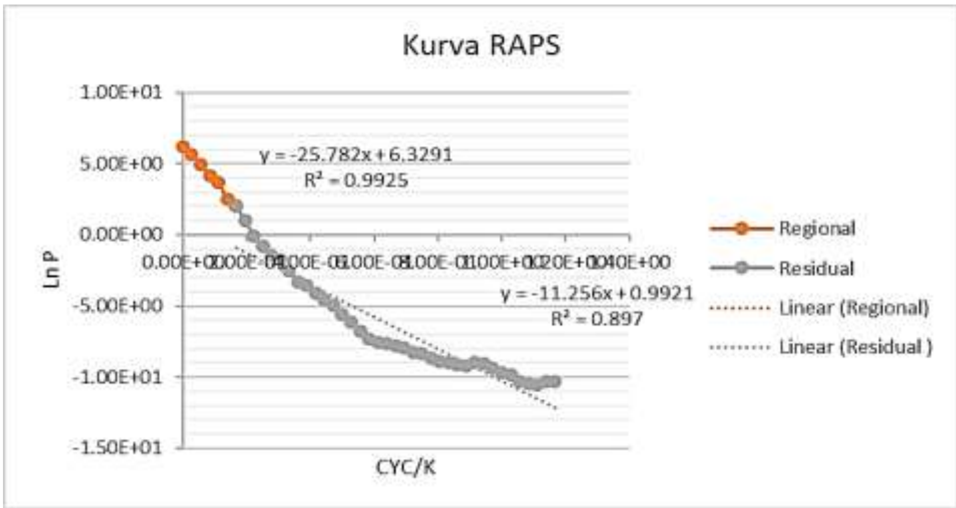


Figure 7. Topographic Map.

On the topographic map, the height of the research area varies with a value of about 420.7 – 2486.6 meters above sea level. Topographic maps have one function to validate whether the Complete Bouguer Anomaly value is true or not. In this study the value of Complete Bouguer Anomalies is valid because in the formulation of gravitational values, the value of height is inversely proportional to the value of gravitational acceleration, the higher the surface, the smaller the value of gravitational anomalies and vice versa.

Analisa Kurva Radially Average Power Spectrum (RAPS)

In the process of analyzing the RAPS curve aims to estimate the depth value of residual and regional anomalies which then this depth information will be used to create depth limits for both 2D and 3D conceptual models (Figure 8).

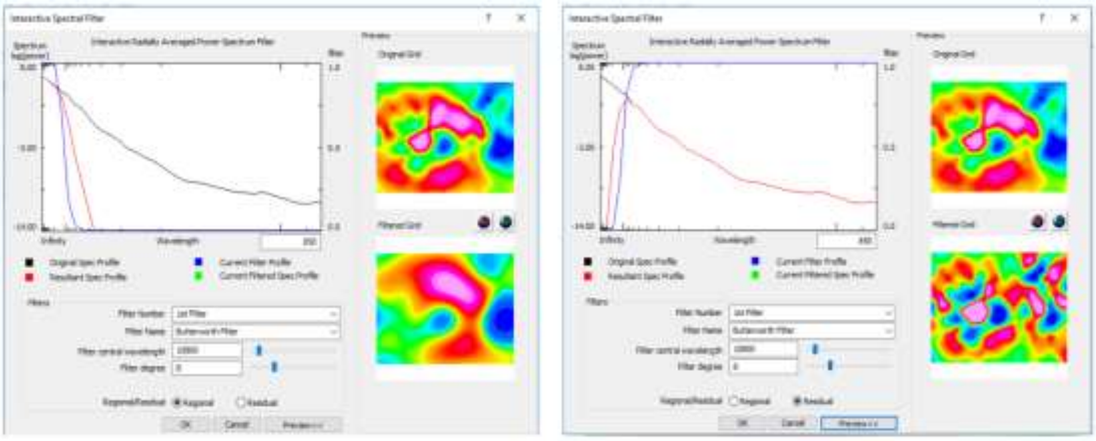


Gambar 8. Curve Radially Average Power Spectrum (RAPS).

From the RAPS curve, the gradient of residual zones and regional zones, residual and regional depths can be calculated by formulating gradient values divided by 4 times π (3.14), regional depth of 2.051666371 km and residual depth of 0.89572402 km. From the depth of each of these zones can be concluded that the creation of a conceptual model has a depth of about 2.05 km from the ground.

Anomaly Separation (Butterworth Filter)

The anomalous separation is done using Butterworth filter, where the selection of cut off zone between zoa residual and regional zone is at 10800 in central wavelength filter and 8 on degree filter (Figure 9).

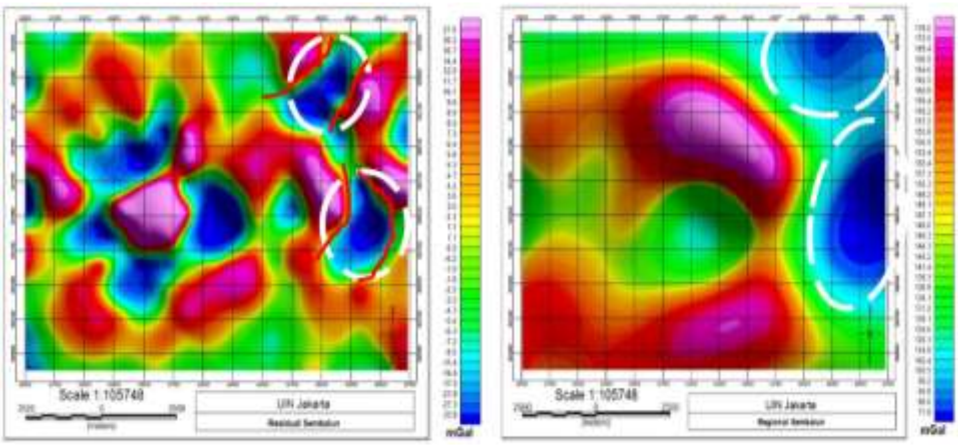


(a) (b)

Figure 9. Determination of Cut Off Value of Butterworth Filter (a) Residual (b) Regional.

Regional Anomalies and Residual Anomalies

After the separation of anomalies using Butterworth filter will be produced residual anomalies (shallow anomalies) and regional anomalies (anomalies in) (Figure10).



(a) (b)

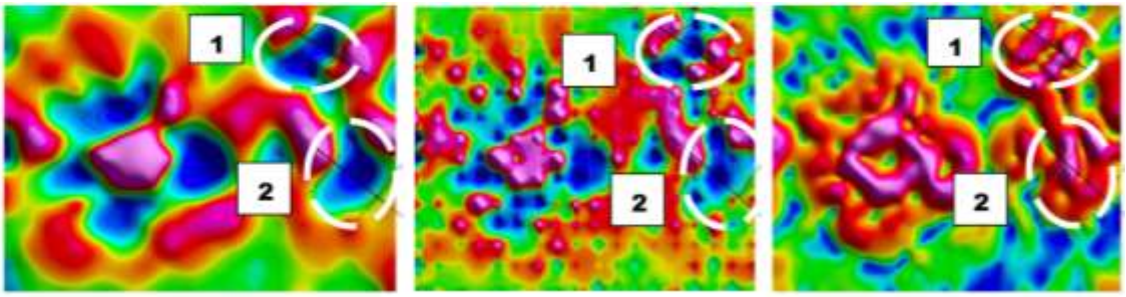
Figure 10. (a) Residual Anomalies, (b) Regional Anomalies

Can be seen on the map of residual anomalies (Figure 10.a), the distribution of gravitational anomalies is very visible heterogeneity on the surface because these anomalies are shallow caused by rocks or layers near the surface. Residual anomaly values in the research area ranged from -33.8 – 27 mGal, where low anomaly values ranged from -33.8 – (-7.2) mGal to target studies marked in blue. On the residual anomaly map it appears that the geothermal prospect area is controlled by minor faults found in areas that have low anomalous values that are around Mount Prigi and the manifestation of Sebau Hot Springs.

However, when viewed on the regional anomaly map (Figure 10.b) it appears that the distribution of gravitational anomalies is very little heterogeneous on the surface because these anomalies are deep caused by rocks or layers deep within the earth's surface. Regional anomaly values in the research area ranged from 71.8 – 178 mGal, where low anomalous values ranged from 71.8 – 120.3 mGal to be the target of research marked in blue.

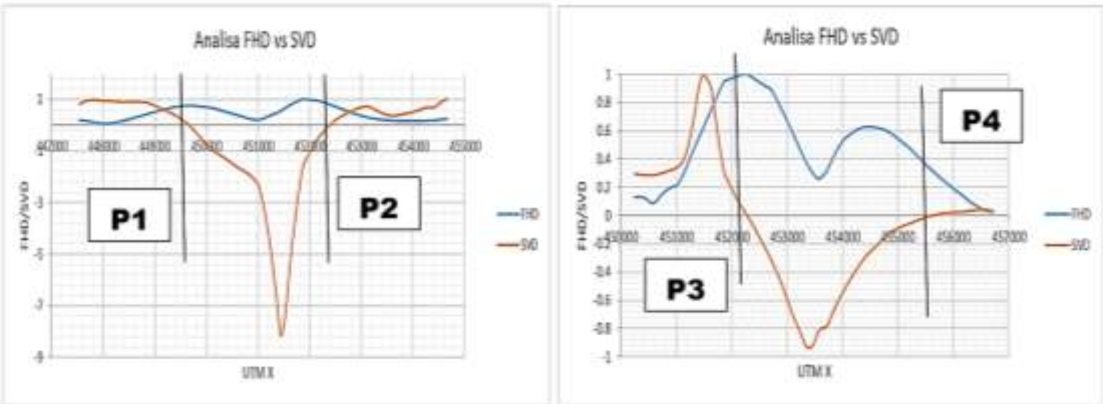
Validation Analysis and Fault Type

Validation analysis and type of fault is done to find out if in the research area there is a fault and what type of fault, this analysis is done using the method of correlation graph between First Horizontal Derivative (FHD) and Second Vertical Derivative (SVD) (Figure 12), FHD is done to determine the boundary of geological structure that causes anomalies and SVD is done to bring up the superficial effect of regional influence or to determine the type of fault in the research area.



(a) (b) (c)

Figure 11. Fault Indication Area (a) Residual Anomaly, (b) SVD, (c) FHD



(a) (b)

Figure12. Graph Correlation Analysis FHD vs SVD (a) Region 1, (b) Region 2.

From the correlation between FHD and SVD graphs, it is seen that there are two faults in area 1 and two faults in area 2. According to the analysis of faults in area 1, the first fault (P1) has the characteristic of an up fault due to the value of SVD min > the svd max value where the SVD min value is -8.15 and the SVD max value is 0.875, this fault is the Talaga fault that is heading west to east which is near Mount Prigi. The second fault (P2) has the characteristic of an up fault due to the SVD min value > the SVD max value where the SVD min value is -8.15 and the SVD max value is 0.7, the fault is the Pusuk fault, these two faults control the geothermal system located on the caldera floor (Sembalun-Lawang).

According to the analysis of faults in area 2, the third fault (P3) has normal fault characteristics because the value SVD min = SVD max value where the value of SVD min and SVD max is 1, this fault is a fault Tanakiabang heading southwest to northeast which is near the manifestation of Sebau Hot Springs. The fourth fault (P4) has the characteristic of an up fault due to the SVD min value > the SVD max value where the SVD min value is -1 and the SVD max value is 0.03, this fault is the Orok fault located near the manifestation of Sebau Hot Springs. These two faults control the geothermal system located near the manifestation of Sebau Hot Spring and on the caldera floor (Sembalun Bumbung).

2D Inversion Modeling

In this 2D inversion modeling, two slicings are performed on the residual anomalous map, the first slicing is directed from northwest to southeast (NW - SE) and the second slicing is northeast to southwest (NE – SW).

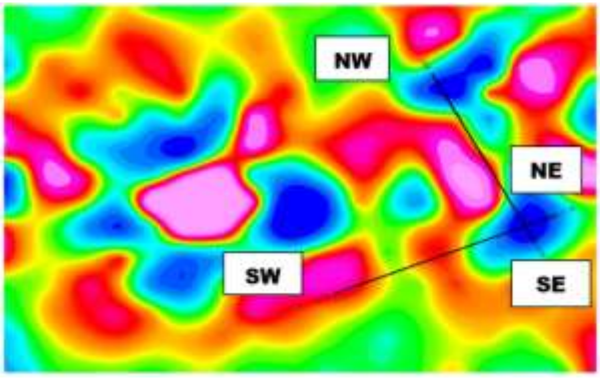


Figure13. Slicing On Residual Anomaly Map.

In the first slicing model directed from northwest to southeast (NW - SE) (Figure 14) it can be seen that the low anomaly (dark blue - light blue) which is thought to be a reservoir layer with a density value of about 1.4 gr/cc - 1.72 gr/cc which is estimated to be a layer of sand with high permeability controlled by 4 minor faults (black lines) which is the gap in the entry of meteoric water into the reservoir layer. This fault is close to Mount Prigi and near the manifestation of Sebau Hot Spring which has a depth of almost the same which is about 700 - 2500 m and a thickness of about 1800 m. In addition, this fault also controls the geothermal system located near the manifestation of Sebau Hot Spring and on the caldera floor (Sembalun Bumbung). Geothermal sources (white circles) in this cross-section are characterized by high anomalies (red - purple) with an estimated density of about 2.68 gr/cc – 3 gr/cc in the form of intrusion rocks of magma residual products that are young magma lava rocks that stretch along the caldera floor (Sembalun Lawang - Sembalun Bumbung) with a depth of > 2500 m. And the last layer is a thin layer of hood (red circle) which is suspected as an alluvium layer with a density value of about 1.8 gr/cc - 2.2 gr/cc with a depth of about 0 - 500 m.

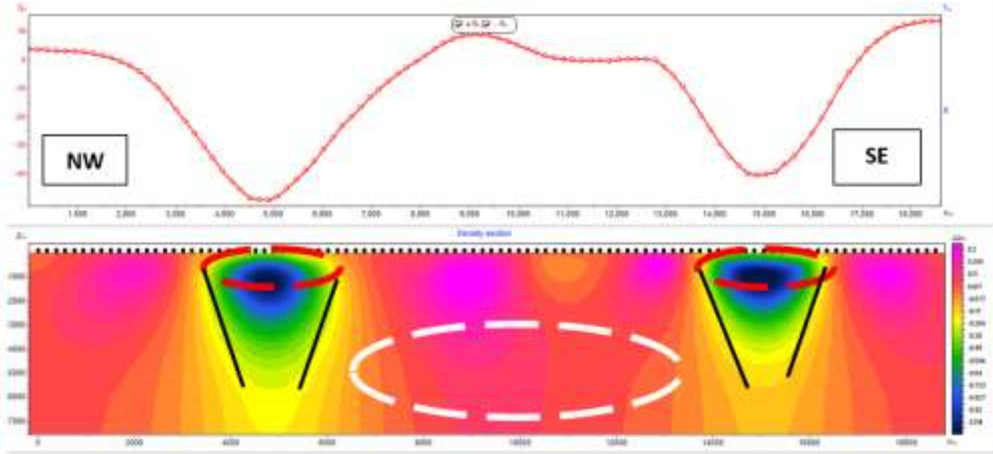


Figure 14. 2D Modeling Northwest to Southeast (NW - SE).

In the second slicing model directed northeast to southwest (NE - SW) (Figure 15) it can be seen that the low anomaly (dark blue - light blue) which is thought to be a reservoir layer with a density value of about 1.4 gr/cc – 1.72 gr/cc is estimated to be a layer of sand with high permeability controlled by 2 minor faults (black lines) which is a meteoric water gap into the reservoir layer. This fault is estimated to be near the manifestation of Sebau Hot Spring which has a depth of almost the same which is about 700 - 2500 m and a thickness of about 1800 m. Geothermal sources (white circles) in this cross-section are characterized by high anomalies (red - purple) with an estimated density of about 2.68 gr/cc - 3 gr/cc in the form of intrusion rocks magma residual products that are young andesite lava rocks hornblende, estimated to be near the caldera of Mount Rinjani which has a depth of > 2500 m. And the last layer is a thin layer of hood (red circle) which is suspected as an alluvium layer with a density value of about 1.8 gr/cc - 2.2 gr/cc with a depth of about 0 - 500 m.

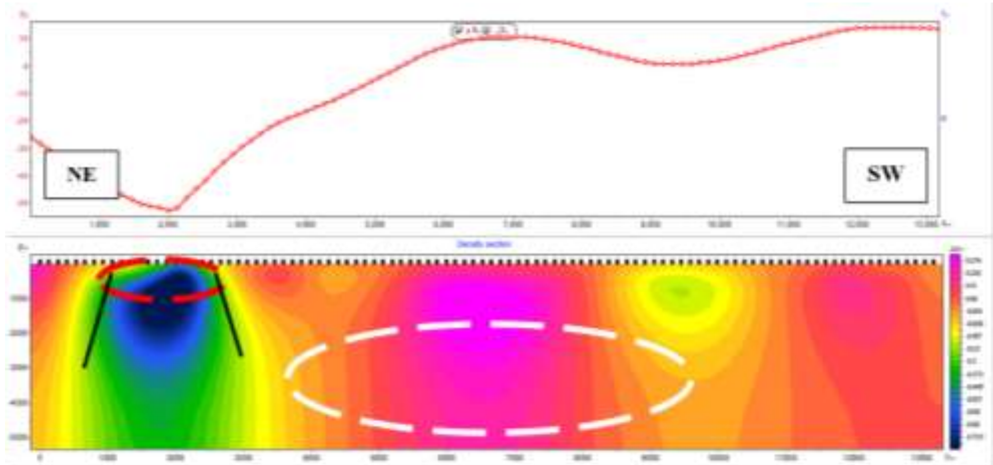


Figure 15. 2D Modeling Northeast to Southwest (NE - SW).

3D Inversion Modeling

In 3D inversion modeling, 3D fence diagrams and 3D face renders are created to be able to see the spread of subsurface density in 3D or evenly. On the 3D face render model can be seen 3D models below the surface solidly, it is seen that in 3D face render the result is correlated with the 2D inversion model (Figure 16), but in this 3D inversion is only done setting the depth up to 2 km in accordance with the analysis of the RAPS curve. Can be seen intrusion rocks (white circles) namely hornblende andesite lava rocks clearly at a depth of 1 km - 2 km located along the caldera floor (Sembalun Lawang - Sembalun Bumbung).

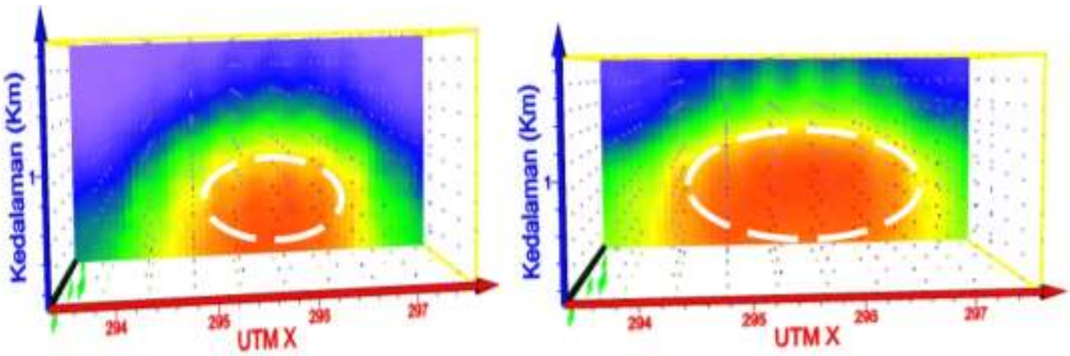


Figure 16. Face render 3D Modeling.

In the 3D fence diagram model can be seen subsurface 3D model in section, it appears that in 3D fence diagram the result is correlated with the 2D inversion model (Figure 17), but in this 3D inversion is only done setting depth up to 2 km in accordance with the analysis of the RAPS curve. Can be seen intrusion rocks (white circles) namely hornblende andesite lava rocks clearly at a depth of 1 km - 2 km located along the caldera floor (Sembalun Lawang - Sembalun Bumbung).

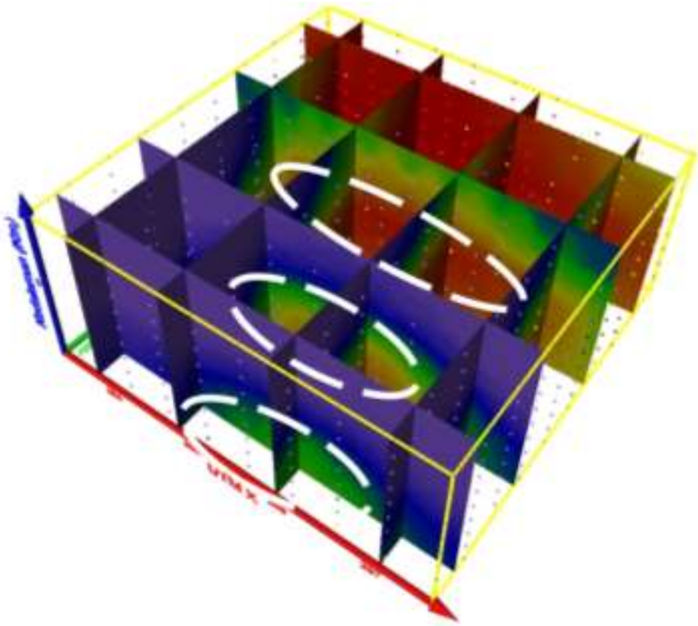


Figure 17. Modeling 3D Fence Diagram.

CONCLUSION

Based on the results of research conducted by gravity method in Sembalun area, East Lombok, West Nusa Tenggara, it can be concluded that:

1. Anomaly low value on the CBA map became the target of research as a geothermal prospect with a value between 58.9 – 115.7 mGal located in the east (Sembalun-Bumbung) and northeast (Sembalun-Lawang).

2. The prospect of geothermal Sembalun is controlled by the Talaga fault and Pusuk fault on the caldera floor (Sembalun-Lawang). Meanwhile, Tanakiabang fault and Orok fault that control the prospect of geothermal near the manifestation of Sebau Hot Spring and on the caldera floor (Sembalun Bumbung).
3. 2D modeling correlates with 3D modeling where geothermal sources are estimated to have a density of 2.68 gr/cc – 3 gr/cc consisting of hornblende andesite lava with a depth of > 2500 m, reservoir layer that is suspected sand layer has a density of 1.4 gr/cc - 1.72 gr/cc with a depth of 700 - 1200 m and a thin layer of hood that is suspected alluvium layer has a density of 1.8 gr/cc - 2.2 gr/cc with a depth of 0 - 500 m.

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