

Subsurface Structure Identification Using Gravity Field Measurement Data Analysis in Songa Wayaua Geothermal Prospect Area

Andri Darmansyah Putra Perdana* ^{1,2}, Suryantini¹ & Tony Widiatmoro²

¹Master Program of Geothermal Engineering, Faculty of Mining and Petroleum Engineering, Bandung Institute of Technology, Jalan Ganesa 10, Bandung 40132, Indonesia

²PT PLN (Persero), Jalan Trunojoyo 135, Jakarta 12160, Indonesia
Email: *andri.darmansyah11@gmail.com

Abstract. Songa and Wayaua village which located in Bacan Island, North Maluku Province are one of several geothermal fields in Indonesia that developed by PT PLN (Persero). This geothermal field have a unique situation which some high temperature manifestations are found near coastal and also close to geological structure around the island. Prospective area needs to be analyzed using several techniques in terms of geological structure and its interconnection with subsurface structure. The structure can be hypothesized as the geothermal fluid path and become consideration of identification permeable zone that can produce large outcome of drilling results. Geological structure on Songa Wayaua geothermal field from previous research still unclear whether geological subsurface structure is related with its surface structure based on data observed. FHD and Euler deconvolution analysis done with a good result correlating subsurface feature with surface structure. FHD and Euler deconvolution result are mostly giving the same result based on horizontal anomaly interpretation. Tawa Fault, Banda-Hatuasa Fault, Sibela Fault and Bukit Bibino Fault are shows good correlation structure with anomaly majority occurred in 0 – 500 meters depth. Those structures probably are permeable structures that could control the existence of surface manifestation, both upflow and outflow.

Keywords: *Songa Wayaua, gravity, structure, FHD, Euler deconvolution.*

1 Introduction

Songa Wayaua geothermal field is located in Bacan Island, North Maluku Province, Indonesia. The field is identified have subsurface hydrothermal activity, characterized by surface manifestation features such as hot spring, steam vent and hydrothermal alteration rocks. Geothermal manifestations are found scattered along the coastal plains from the Songa area to Bukit Langsa, and a hot spring is also found on the Wayaua beach in the southern part.

Based on Geological Regional Map [2], volcanic breccia and andesite lava are the main components of the Sibela Metamorf complex as its oldest formation (Cretaceous age formed), along with interlayers of sandstone and claystone. This indicates underwater volcanic activity that occurred in the past. Geological structure based on previous study [3] consists of faults, extension joints, and conjugate joints. Extension joints are found as a set of parallel fractures. When the joints open, hydrothermal mineral deposits are often found in the fractures. Conjugate joints are found as a pair of fractures. As it stands, this structure can be hypothesized as the geothermal fluid path [1] and become consideration whether that area could yield the productive zone or not, which permeable zone identified can produce large outcome of drilling results.

Gravity measurements can be used to observe anomaly contrasts and the lateral extent of subsurface geological structures. The gravity data used for the analysis consists of Complete Bouguer Anomaly (CBA) gravity data obtained from previous acquisition by PT. PLN (Persero) in 2018 and data from the Geological Resources Center/PSDG in 2006. The gravity observation points during both observation periods total 372 points, with variative station interval range from 250 meters to 1 kilometer (Figure 1). The most recent field observations aimed to complement the data previously recorded by PSDG and to serve as calibration points during the observations. The processing of Complete Bouguer Anomaly data used a density value of 2.67 g/cm^3 , based on the calculation from the Parasnis method at all gravity points. In order to analyze geological structure interconnected with subsurface structure, First Horizontal Derivative (FHD) and Euler deconvolution technique are used to identified subsurface structure which related to permeable zone.

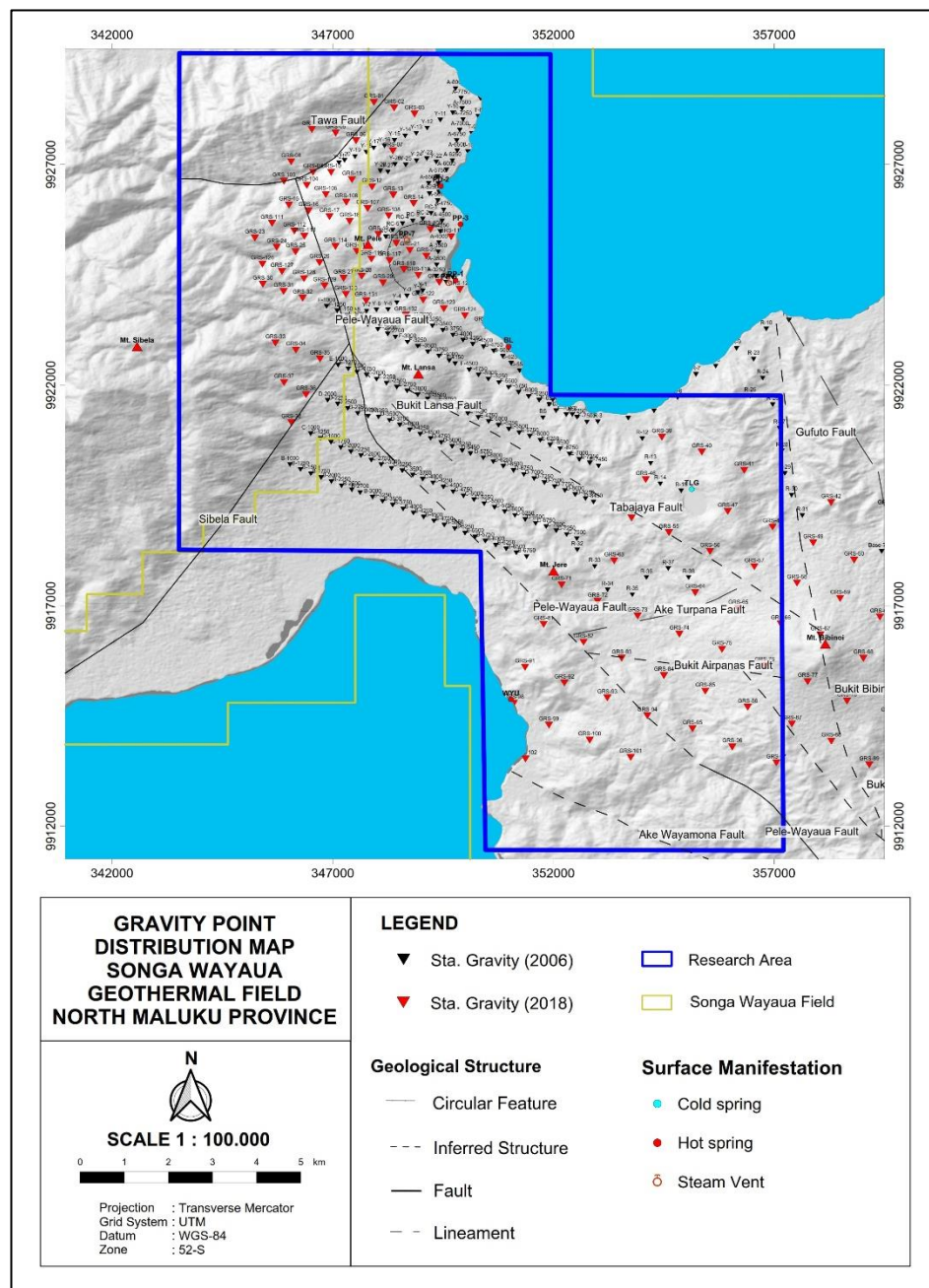
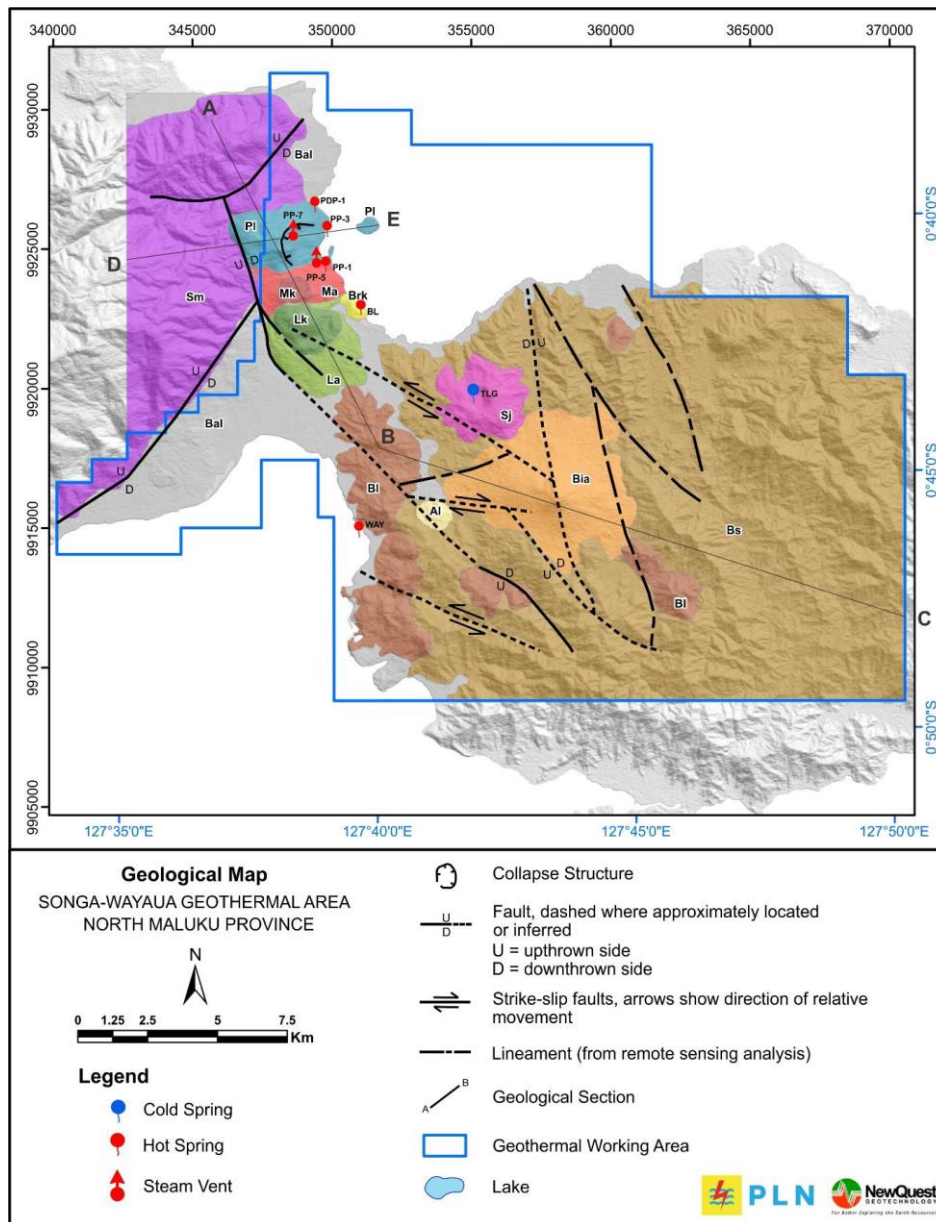


Figure 1 SONGA WAYAU Gravity Points Distribution Map

2 Problem Statement and Related Works

Interconnected structure between surface and subsurface geological structures are controlling the permeable zone of geothermal field. The main problem is geological structure on Songa Wayaua geothermal field from previous research still unclear whether geological subsurface structure is related with its surface structure based on data observed. This study using FHD and Euler deconvolution analysis, which hopefully yields the subsurface structure that correlated with geological structure in surface.

Previous geological study in this geothermal field done by PT PLN (Persero) in 2020. The study performs geological site investigation to identify lithology formation start from the oldest to youngest are Sibela formation (Cretaceous age), Bacan formation (tertiary age), and the others from quarter age such as: Pele formation, Ake Songa formation, Lansa formation, Bibinoi formation, Bakor-bakor formation, Songa formation, Mangga formation and Bacan Alluvium formation. Geological structure found by site investigation around 8 from 13 lineament studied by remote sensing analysis. The structures found such as faults, extension joint and conjugate joint. Lithology formation and structures found from previous study shown by Geological Map in Figure 2.



AGE		ACTIVITY PERIOD	VOLCANOSTRATIGRAPHIC UNITS				ERUPTION CENTER	Rock Unit																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								
Relative	Absolute (ka)		Super Brigade	Brigade	Crown	Hummock		Primary Rocks/Deposits							Secondary Rocks/Deposits			Flank Eruption		Sedimentary Deposits	Metamorphic Rocks																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
								Lava Dome	Lava Flows	Pyroclastic Fall	Pyroclastic Flows	Pyroclastic Surge	Explosion Lahar	Phreatomagmatic Explosion	Volcanoclastic Deposits	Rain-Generated Lahar	Phreatic Explosion	Lava Dome	Lava Flows																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																													
QUATERNARY		0,72	The birth of Mangga volcano					CENTRAL																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																								

Figure 2. Geological Map from previous study [3]

3 Methodology

3.1 Complete Bouguer Anomaly (CBA) Gravity

The gravity data used was acquired by PT PLN (Persero) in 2020. The surface rock density calculated in previous research using the Parasnis method showed a value of 2.67 g/cm³. In this study, the surface rock density from the previous research will be used for recalculating the gravity survey data.

Before the gravity survey data can be interpreted, gravity reduction is required to correct for various gravitational field variations. The corrections applied, as shown in Eq. (1) and Eq. (2), include tidal correction, drift correction, latitude correction, free-air correction, Bouguer correction, and terrain correction [4].

$$g_{\phi} = 978031.846 (1 + 0.005278895 \sin^2 \theta - 0.000023462 \sin^2 2\theta) \quad (1)$$

$$g_{CBA} = g_{obs} + tidal_{obs} - drift_n - g_{\phi} + 0.3086h - 0.04193rh + TC \quad (2)$$

Descriptions: g_{obs} = gravity field observed value (mGal)
 $tidal_{obs}$ = tidal correction
 $drift_n$ = drift correction
 g_{ϕ} = latitude correction

θ	= latitude at observation point
0.3086h	= free-air correction
0.04193rh	= Bouguer correction
TC	= Terrain Correction

3.2 First Horizontal Derivative (FHD)

FHD technique used to delineate geological structure boundary using horizontal derivative from CBA gravity results. Most of these methods are high-pass filters based on the horizontal derivatives ($\partial g/\partial x$) and ($\partial g/\partial y$) of the gravity anomaly [Saibi dkk]. The First Horizontal Derivative (FHD) maximizes any change of density. The equation is given below:

$$\text{FHD} = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \quad (3)$$

FHD technique is that it is least susceptible to noise in the data because it requires only the calculation of the two first-order horizontal derivatives of the field. The location of maximum FHD may be used as an indicator of the fault location.

3.3 Euler Deconvolution

Euler deconvolution used to estimate anomaly structure depth beneath the surface. The Euler depth solution is not only estimating the depth (z_0) but also delineate the horizontal boundaries as well as the interpretation of fault using FHD technique [5]. Position of the causative body based on a gravity field measurement analysis involved and the field gradients also some constraint on earth geometry body. Structural index (SI) must be selected in order to interpret as purposed (Table 1). Fault identification using gravity data using SI value equals to 0 (zero). The 3D equation of Euler deconvolution is given below:

$$(x - x_0) \frac{\partial g}{\partial x} + (y - y_0) \frac{\partial g}{\partial y} + (z - z_0) \frac{\partial g}{\partial z} = \eta (\beta - g) \quad (3)$$

Descriptions:	(x_0, y_0, z_0)	= Source position of total gravity
	$\frac{\partial g}{\partial x}, \frac{\partial g}{\partial y}$	= Horizontal derivative gravity
	$\frac{\partial g}{\partial z}$	= Vertical derivative gravity
	η	= Structural Index (SI)
	β	= Regional gravity value

Table 1 Structural Index (SI) value with Structure Anomaly [1].

No	SI	Magnetic Field	Gravity Field
1	0	Contact	Sill/dyke/step
2	0.5	Thick step	Ribbon
3	1	Sill/dyke	Pipe
4	2	Pipe	Sphere
5	3	Sphere	-

4 Result and Analysis

4.1 FHD Analysis

FHD value of research area shows the range value between 0.00012 to 0.2 mGal/m. The FHD map can be seen in Figure 3. The presence of fault identified by high FHD value (represented with white and blue-light dashed line area), within range 0.03 - 0.2 mGal. White dashed area shown by Figure 3 are the surface structure correlated with subsurface structure. Trend of subsurface structure related with surface structure are vary, NW-SE and NE-SW. Tawa Fault, Banda-Hatuasa Fault, Sibela Fault and Bukit Bibino Fault recognized have good interconnected structure between surface and subsurface based on FHD map superimposed by geological structure based on previous research. Area (1) and (2) that represented with blue-light dash area are anomaly with no faults and joint occurrence based on geological observation. These two areas possibly lead to younger subsurface zone than the other areas that have good interconnection structure between surface and subsurface.

4.2 Euler Deconvolution Analysis

Euler deconvolution solution has been done using structural index equals to 0 (zero) with 20% maximum depth uncertainty value and windows size 20. The euler solution in research area mostly dominated with depth 0 – 500 meters as shown by Figure 4. Structural interpretation from Euler deconvolution mostly is not further away than FHD interpretation result. Tawa Fault, Banda-Hatuasa Fault, Sibela Fault and Bukit Bibino Fault have the same result with FHD analysis. Euler deconvolution with straight and continuous pattern shown by white and blue-light dashed line area. White dashed line area as shown by Figure 4 are the surface structure correlated with subsurface structure, while blue-light dashed are not correlated. This phenomenon is almost in the same area with FHD interpretation result. Euler deconvolution can indicate density contact, as shown by circular feature in the eastern side of Mount Pele (area 2).

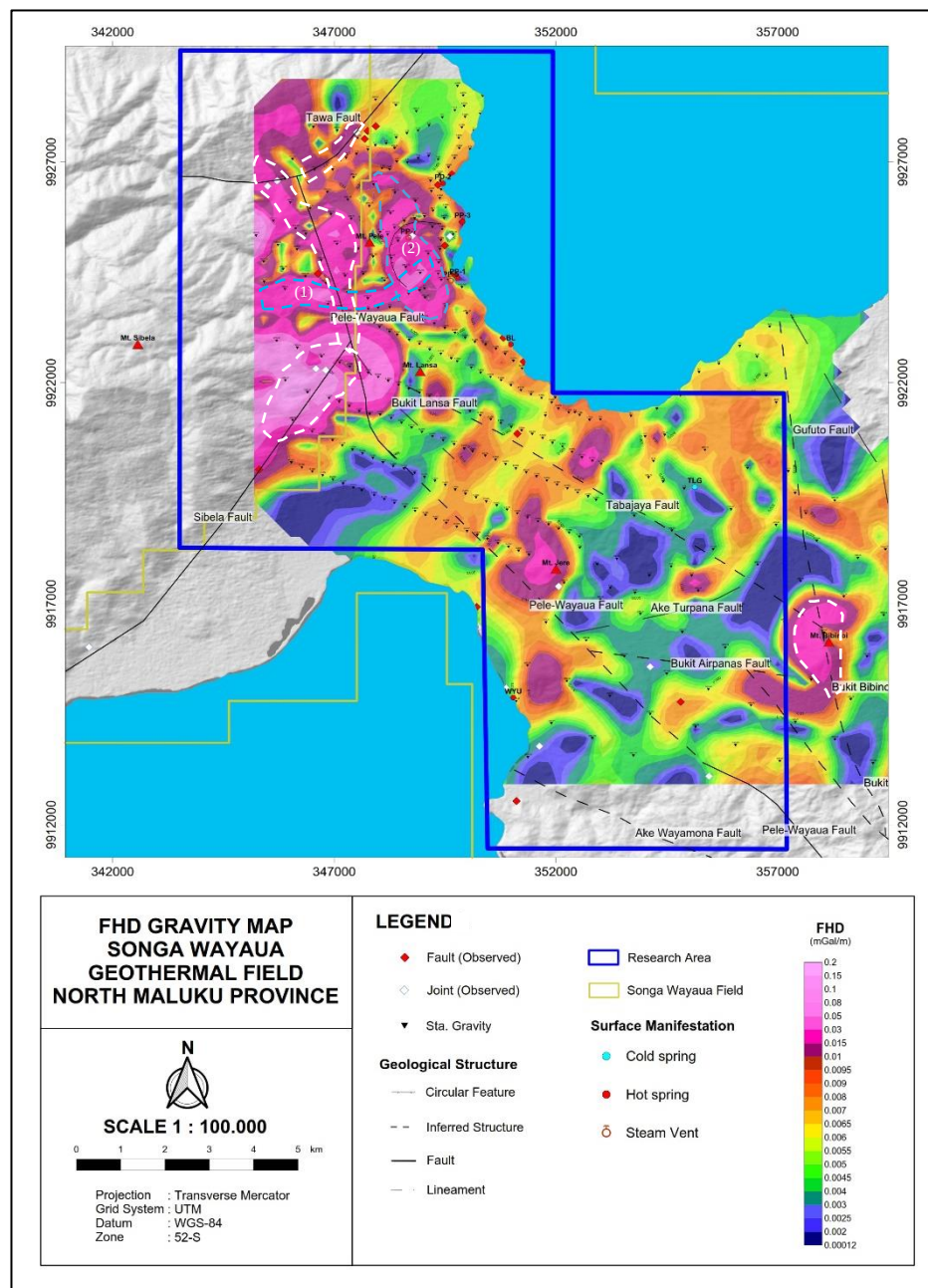


Figure 3. FHD Gravity Map Songa Wayaua Geothermal Field

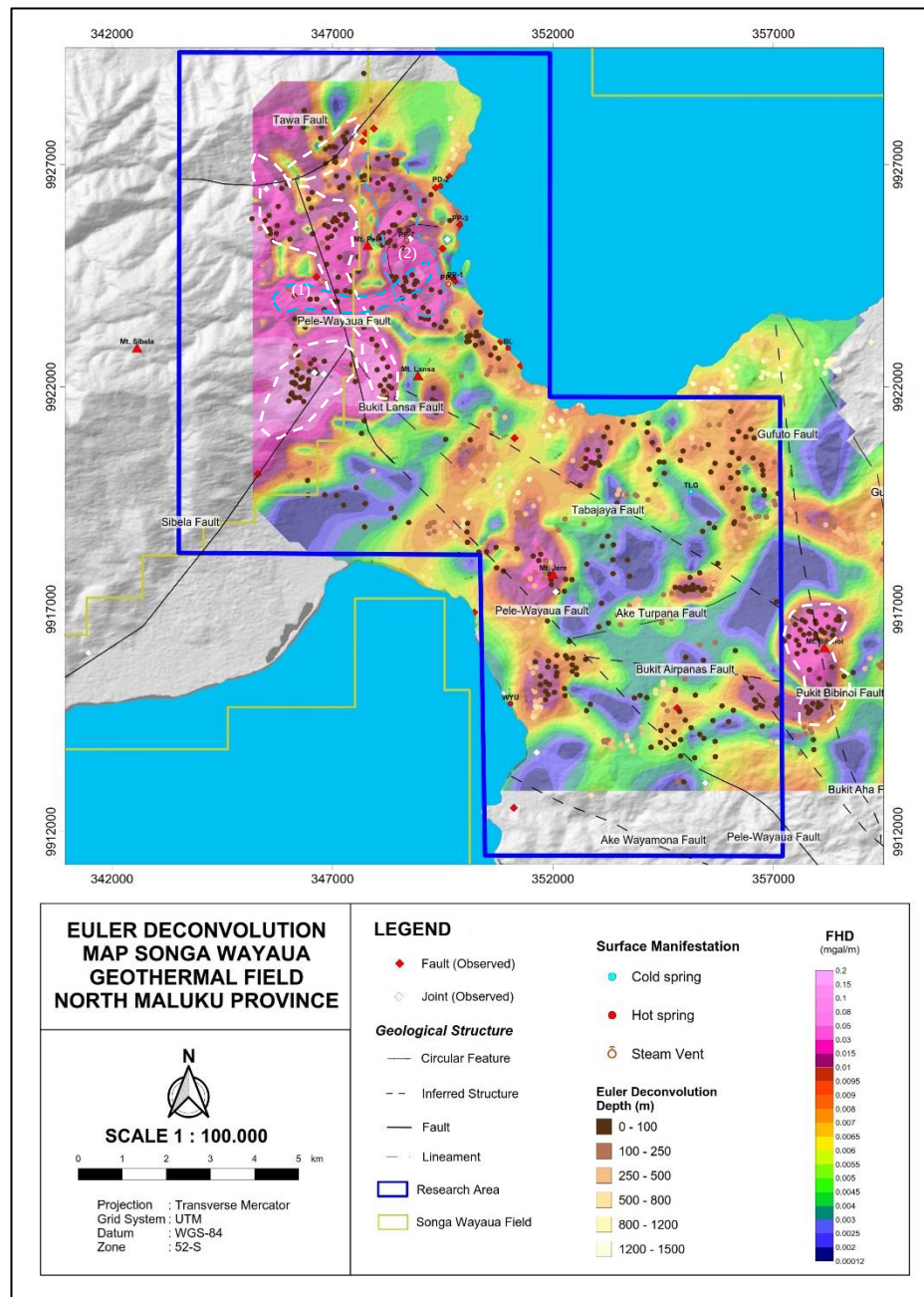


Figure 4. Euler Deconvolution Map Songa Wayau Geothermal Field

5 Conclusion

Based on gravity field measurement data, FHD and Euler deconvolution analysis have been done with a good result in terms of correlating subsurface feature with geological surface structure. This indication done with FHD map and Euler deconvolution map within research area superimposed by geological structure based on previous research. FHD and Euler deconvolution result are mostly giving the same result based on horizontal anomaly interpretation. Tawa Fault, Banda-Hatuasa Fault, Sibela Fault and Bukit Bibino Fault are shows good correlation between surface and subsurface with anomaly occurred in 0 – 500 meters depth. Those structures probably are permeable structures that could control the existence of surface manifestation, both upflow and outflow.

References

- [1] A. Armando, Y. Daud, and J. P. Atmojo, "Structure Zone Identification as a Geothermal Fluid Path using Gravity Euler Deconvolution-Case Study on Geothermal Area AA," IOP Conf Ser Earth Environ Sci, vol. 187, no. 1, p. 012081, 2018, doi: 10.1088/1755-1315/187/1/012081.
- [2] A. Yasin, "Peta Geologi Lembar Bacan, Maluku Utara," 1980.
- [3] PT PLN (Persero), "Final Report Pre-Feasibility Study of Songa Wayaua Geothermal Working Area, unpublished," 2020.
- [4] J. Domra Kana, N. Djongyang, Danwe Raïdandi, P. Njandjock Nouck, and Abdouramani Dadjé, "A review of geophysical methods for geothermal exploration," Renewable and Sustainable Energy Reviews, vol. 44, pp. 87–95, 2015, doi: <https://doi.org/10.1016/j.rser.2014.12.026>.
- [5] Y. Daud et al., "First horizontal derivative and Euler Deconvolution in application for reconstructing structural signature over the Blawan-Ijen Geothermal area," IOP Conf Ser Earth Environ Sci, vol. 254, p. 012008, Apr. 2019, doi: 10.1088/1755-1315/254/1/012008.