Modelling of Heat Source in the Geothermal field based on Euler Deconvolution and Occam Inversion using GGMPlus Gravity data

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Abstract. The component of the geothermal system that plays an important role is a heat source. Heat sources can be a magma intrusion from volcanic activity or a geothermal gradient from sedimentation. Identification of heat source can be conducted using gravity anomaly modeling in the Sumbersari Geothermal Field, Southeast Sulawesi. In this study, inversion modeling was undertaken using the occam approach. The input data, Complete Bouguer Anomaly (CBA), was acquired from satellite data processing (GGM Plus). The estimation of heat source depth was established through spectral analysis of CBA data, to obtain regional and residual anomalies, as well as estimates of rock density in the study area. The geometry of the rock body in the inversion process uses a rectangular prism arrangement in the form of a 3D regular grid which represents the distribution of subsurface density. This inversion process uses ZondGM2D software. To improve the subsurface model of the inversion process, data enhancement was also carried out. Fault structure analysis based on geological data and Horizontal Gradient Magnitude (HGM) enhancement data on gravity anomalies was used as a reference for the initial model of subsurface conditions in inversion modeling. Not only horizontal gradient magnitude, but Euler Deconvolution is also carried out to determine the lineament of the geological structure in the study area. Based on the CBA map, low anomalies are associated with sedimentary rock and high anomalies are metamorphic rock with NW-SE and NE-SW trends. The presence of high and low anomalous contrasts in the CBA data indicates the presence of faults that control the geothermal system in the Sumbersari potential area. This is in accordance with the findings of manifestations in the study area which are correlated with geological structures. In addition, the high anomalous contrast resulting from the occam inversion also indicates the presence of altered rock, which is considered as heat source with an estimated very deep heat source. Thus, the results of this 3D gravity inversion can provide comprehensive information and are expected to be a reference in the development of the Sumbersari geothermal field, Southeast Sulawesi.
Keywords: Euler Deconvolution, Geothermal, Heat source, Horizontal Gradient Magnitude, Occam Inversion

1. Introduction

Sumbersari is a non-volcanic geothermal field located in South Konawe, Southeast Sulawesi. This field be composed of pre-tertiary metamorphic rocks and tertiary sedimentary rocks which are the lithology that builds the reservoir [1] with a water-dominated system. The fluid flow occurs by convection from the heat source to the sedimentary metamorphic reservoir through geological structures such as fractures. For identifying geothermal fields, discovering the heat source's exact position is deemed to be essential activity. The existence of this heat source is generally associated with the presence of manifestations on the surface. Nonetheless, the location of the heat source cannot be determined directly based on the manifestation. As one of the vital attempts to ascertain the heat source spot, in particular, taking the integration of geophysical methods and supporting information as well as geological data is a reasonable way and will give prominent merits for newly interpreting subsurface conditions in geothermal areas.

The study of geophysical methods has been widely used to develop a geothermal field. To illustrate, inversion modeling using gravity data has been effectually implemented to establish subsurface density models, among them conducted by Tian et al [2] and Witter et al [3]. 3D inversion modeling was constructed by Didas et al [4] to detect regional thermal anomalies for exploring geothermal potential zones. Several approaches have been done in the Sumbersari field, one of them was accomplished by Aprilia et al [5] on geothermal systems based on geochemical analysis. Besides, another research was carried out by the Ministry of Energy and Mineral Resources [1] using gravity and AMT methods to investigate the lithology and structure that developed in this geothermal site.

In this study, we performed an inversion modeling on the gravity data obtained from GGM Plus in the form of FAA. Anomaly separation is conducted to pursue the gravitational response from the rock body near the surface namely local anomaly. This local anomaly is used for subsurface modeling using the inversion method and data enhancements such as Euler deconvolution and Horizontal Gradient (HGM) are carried out to perceive the boundaries of the rock body that causes the anomaly. Afterwards, the results of modeling and anomalous boundary maps as well as geological supporting data are used for the interpretation of the structure and heat source positions. The interpretation results of the heat source position from this research are conceivably used to be a consideration for the development of the Sumbersari geothermal potential area. Additionally, the outcome of this research is perchance to be used for supporting further study reference.

2. Geological Setting

The area of identification, approximately 59 km from South Konawe, is a non-volcanic geothermal system. A glance at Fig. 1 provided reveals the lithological units overlying the area which are composed of 20 lithological units. Afterward, choit rock is also generating the formation units of this investigation area which consists of metamorphic sandstone covered in Kolono, Lainea, and Laeva. Lastly, metamorphic limestone was distributed along Moramo, North Moramo, Kolono, Lainea, and Laeya, then, it is also in Palanga, and South [6, 7]. This research focuses more on metamorphic rock and significantly apply to the geothermal occurences in the surface of Sumbersari to the south-eastward.

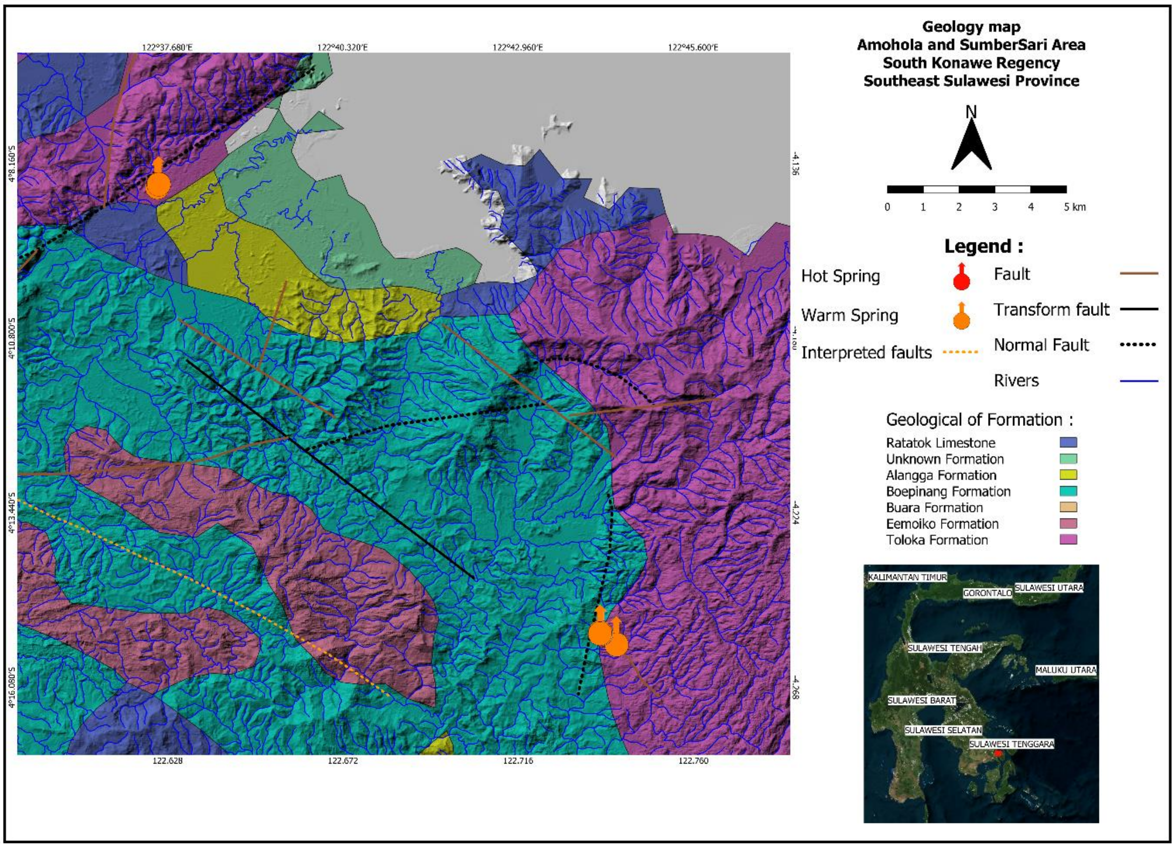

Figure 1. Geological map of Amohola-Sumbersari geothermal field (modified from Simandjuntak et al., 1993 [7])

The Late Pliocene tension mechanism established the uplift area in the fractured rock formation that permeable zone eventually formed. Thus, this location was verified as a magma accumulation zone. In this area of investigation, the tectonic process is a heat source in this geothermal component. The NW-SE sinistral Faults evolved as a dominant controlling structure, followed by two other major faults, NE-SW and N-S, respectively [1]. Consequently, hydrothermal fluids move to the earth's surface due to permeability which is enhanced by geological structures such as faults and fractures. Fluid movement is not only accomplished by normal fault, but it is also influenced by tear fault. The reservoir rock is presumably produced by high temperature and pressure that work on the sedimentary rocks. This scheme was also constructing the fractures and permeable properties of the reservoir rock. On the other hand, an impermeable zone is found in clay mineral-rich sediment which is hereinafter referred to as clay cap.

3. Data and Methodology

In this research, we used GGMPlus Gravity Data at Sumbersari Region, South Konawe obtained from http://murray-lab.caltech.edu/GGMplus/index.html. The DEMNAS data has extracted to establish terrain correction used with FAA for generating Complete Bouguer Anomaly (CBA) that can be shown at Fig. 2 (left). The CBA value ranges from 35 to 95 mGal.

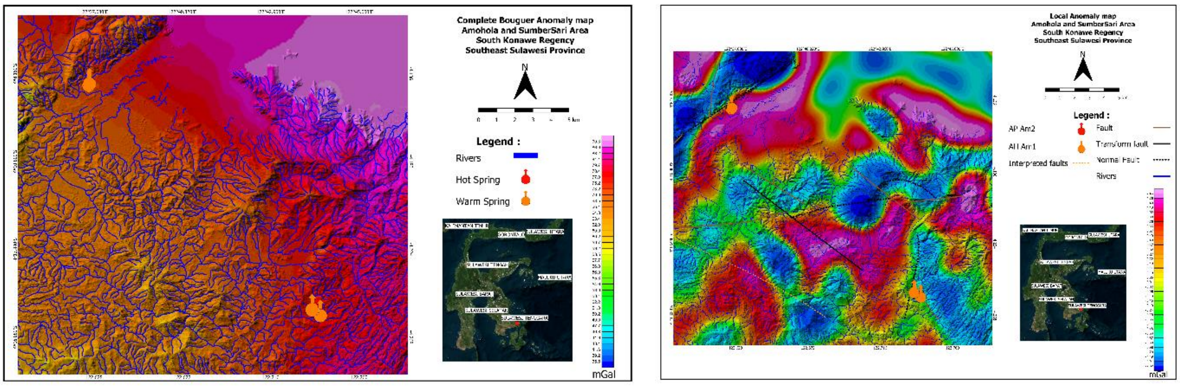

Figure 2. Complete Bouguer Anomaly Map (left) and Local Anomaly Map (right) of Amohola-Sumbersari geothermal field

The regional effect has reduced by implementing anomaly separation to conduct the local anomaly. The outcome of this process is used to identify the anomaly body distribution. Low anomaly is interpreted as sediment, alluvium, and unconsolidated rock. A high anomaly is a metamorphic rock within schist, phyllite gneiss that is exposed on the surface (Fig. 2 right).

Next, various filters such as Horizontal Gradient Magnitude (HGM) and Euler Deconvolution have been applied in the CBA map to enhance the anomaly response from the rock body. The HGM filter helps in sharpening anomalous effects based on lateral density contrast discontinuities that the result shown in Fig. 3 and formulated as follows [8]:

$$HG(x,y) = \sqrt{\left(\frac{\partial g}{\partial x}\right)^2 + \left(\frac{\partial g}{\partial y}\right)^2} \quad (1)$$

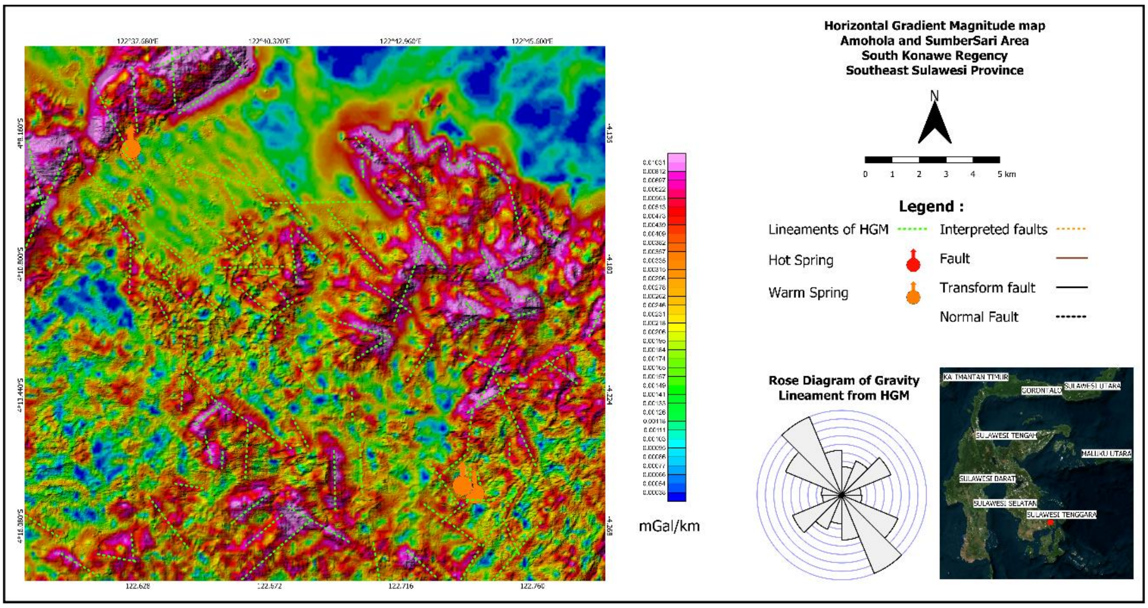

Figure 3. Horizontal Gradient Magnitude or HGM Map of Amohola-Sumbersari geothermal field

The maximum values that are suspected can identify the presence of the structure. The maximum value is powerful to enhance the edge detection of geological structures such as fault and NW-SE lineament of HGM in accordance with the trend direction of the regional structure of the Southeast Sulawesi region.

Euler Deconvolution is one of the methods for detecting the depth and position variable in the lateral direction (x_0 and z_0) from the body that causes anomaly with produce the specific trend based on [9, 10]:

$$(x - x_0)\frac{\partial G}{\partial x} + (y - y_0)\frac{\partial G}{\partial y} + (z - z_0)\frac{\partial G}{\partial z} = -N(U - G) \quad (2)$$

This equation reveals that gravity anomaly object located in x_0, y_0, z_0 relative to z positive downward. The total gravity field is detected in x, y, and z while the regional value is described by U. The subsurface anomaly body is determined by the structural index that is represented by the N variable [10]. The outcome of this process is exhibited in Fig 4. The Euler Deconvolution of the GGMPlus gravity data finding ranges in depth from less than 50 m until more than 2000 m. The structural index utilized in this work was 0 for the model of lithological contact in gravitation objects. Gravitational anomaly is the window box cell in the box with the chosen window size of 3 x 3.

The occam inversion method optimizes the match between the measurement and calculated data. Finally, inversion modelling was performed on CBA data using zondGM2D software based on the occam algorithm. Basically, the occam inversion method optimizes the match between the measurement results and the calculated data that based on three block parameters i.e. occam density, occam heights and occam h+d (heights and density) for each layer [11]. The outcome of the whole process establishes heat source model of Sumbersari Field.

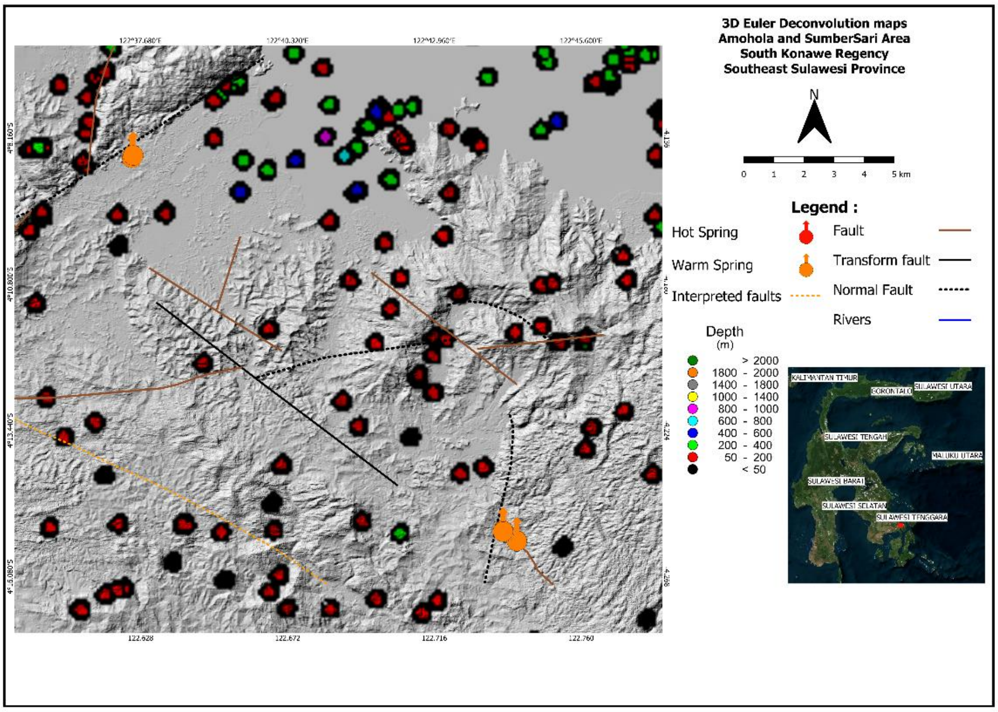

Figure 4. 3D Euler Deconvolution Map (left) of Amohola-Sumbersari geothermal field

3. Results and Discussion

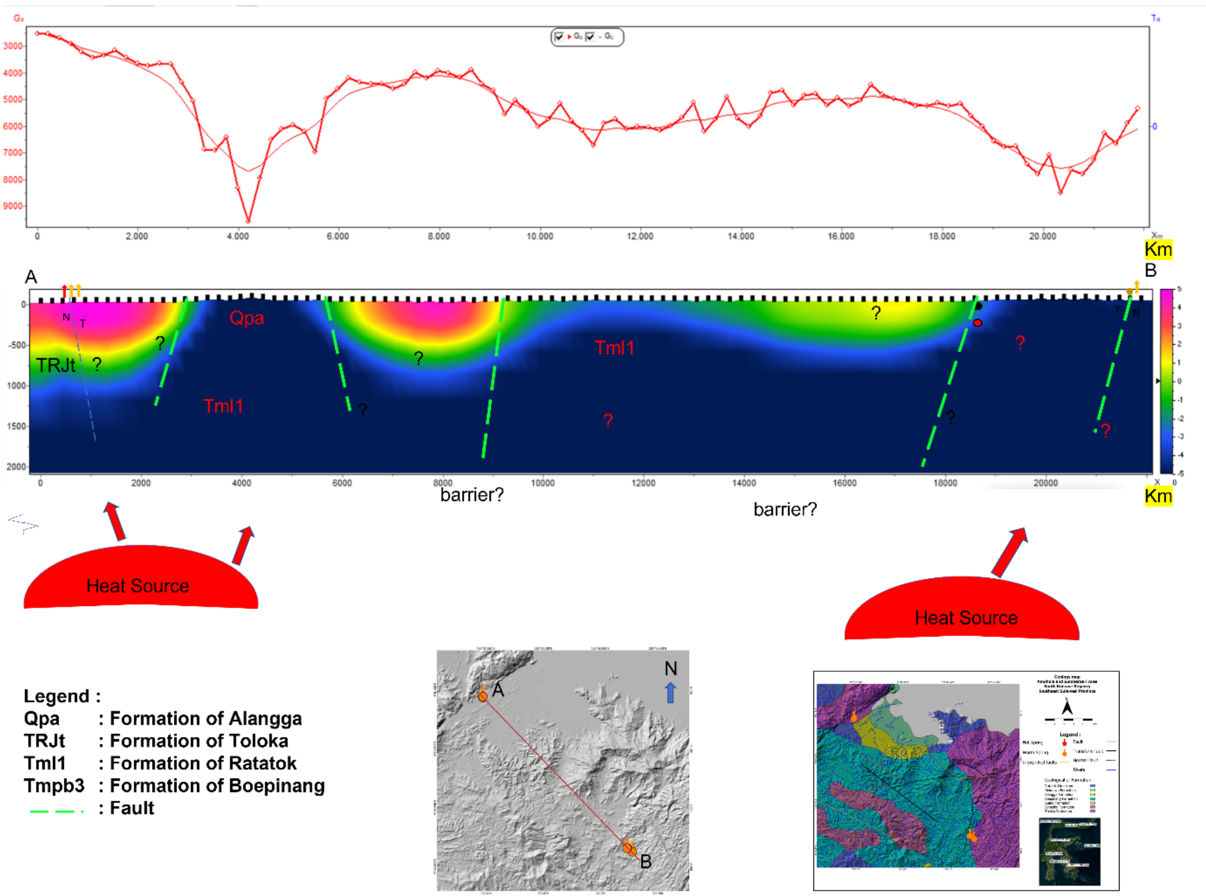

Figure 4. Heat Source Model of Amohola-Sumbersari geothermal field based on Inversion Method using Gravity Data

The geothermal manifestation that lies from Amohola to Sumbersari is used as a cross-section. Inversion modeling does not penetrate the depth of the heat source; thus, we assume that the heat source is very deep below the surface. One of the pieces of evidence is that previous studies such as geochemistry shows the manifestation appearance with low temperature, less flow rate, and the absence of magmatic gases [13].

4. Conclusions

The integration of GGMPlus data using local anomaly interpretation, HGM, euler deconvolution and 2D inversion modeling shows that the Sumbersari heat source is located deeper than the basement rock controlled heatflowly by fault. Thus, the geothermal system in Sumbersari is a medium enthalpy 'Heat Sweep' system.

Acknowledgments

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