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Interpretation of gravity satellite data to delineate structural features connected to geothermal resources at Bur Ni Geureudong geothermal field

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Abstract. The gravity method is broadly used in analyzing potential geothermal studies. The method can be used for determining potential areas, reservoir locations, and geological structure investigation. In this paper, satellite gravity data was applied for better understand the geological conditions connected with the geothermal system of Bur Ni Geureudong geothermal field, Bener Meriah District, Aceh, Indonesia. Open access Free Air anomaly data were provided by satellite geodesy information with 1 minute-grid. The data were reduced to obtain Bouguer anomaly distribution in the study area. Tilt derivative (TDR) technique was applied to Bouguer anomaly to enhance linear trends of geological structures. The aim of this analytical technique is able to clearly display faults correlated with geothermal manifestations around the Bur Ni Geureudong geothermal field. The complete Bouguer anomaly range of 20 mGal up to 170 mGal covers Bur Ni Geureudong volcano complex. A low Bouguer anomaly is located in all summits of volcanoes that are included in Bur Ni Geureudong Volcano Complex; those are summits of Bur Geureudong volcano, Bur Ni Telong Volcano, Pepanji Mountain, and Salah Nama Mountain. The low Bouguer anomaly is associated with the andesitic flow and volcanic ashes. The higher Bouguer Anomaly is reflected in high-density basement rock in the west of Geureudong Volcano. Tilt derivative (TDR) shows geological structures more detail, particularly, the tilt derivative (TDR) clearly detects two fault structures over the study area presented by a tilt value of zero. The results will be useful as basic information in exploration study of Bur Ni Geureudong geothermal field.

1. Introductions

Bur Ni Geureudong Volcano complex is situated in the center of Aceh Province, Indonesia and the largest volcanic complex in Northwest Sumatra. This volcanic complex has four volcanic center over the area. The hugest volcano is an ancient Bur Ni Geureudong stratovolcano with a diameter of 18 Km and the other three are Bur Ni telong volcano, Mount Pepanji and Mt. Salah Nama. Recently, Bur Ni Telong volcano is the only active volcano in this volcanic region. According to Ref. [1], Bur Ni Geureudong Volcano estimately stores the potential of geothermal energy reaches 160 MWe. This

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potential energy is sufficient for the development of renewable energy in Indonesia, particularly in Aceh. Research related to geothermal systems in this region is poor. Several exploration studies have been carried out in the Bur Ni Geureudong geothermal field. Those studies concerned analysis of gravity and magnetic data to delineate local faults controlled by Bur Ni Geureudong Volcano [2], analysis of morphological based on fault and fracture density (FFD) mapping obtained from DEM and SRTM data [3]. Therefore, the geothermal potential of the Bur Ni Geureudong volcano requires for an exploration study as the beginning. Results of the exploratory studies will greatly assist the government in the process of developing this geothermal resource.

The presence of geothermal energy source in the Bur Ni Geureudong region is recognized by several surface manifestations, including hot springs and fumaroles. This surface manifestation is a scientific interest in geothermal studies. Hot spring and fumarole play a role as the discharge area of geothermal fluid, which depend on several interacting factors between geothermal reservoir, fluid, and permeable pathways [4]. In addition, faults and fractures have corresponded to reservoirs and geothermal fluids [5][6]. Therefore, investigation of fault structures is important to be analyzed for a better understanding of Bur Ni Geureudong geothermal field.

Mapping fault structure using the gravity method is broadly applied in geothermal exploration. Geothermal reservoir and fluid hence density contras with the ambient condition so that gravity response from subsurface can be revealed [6]. We use open access gravity satellite data to map geological structures controlled by geothermal systems. Satellite gravity data are now widely used in many explorations, like analyzing of geological structures in the oil and gas prospect area [7], aerogravity observation to map the distribution of iron deposits [8], and mapping the subsurface structure of Merapi-Merbabu Mountain, Java, Indonesia [9].

The interpretation of fault structures basically requires edge detection, which can be exposed certainly by several processing techniques. Tilt Derivative is a filter method for detecting the edge of a source that produces a sharp and detailed response to the edges of the source object [10]. Accordingly, we aim to use this processing technique on satellite gravity data to investigate structure features connected to the Bur Ni Geureudong geothermal field.

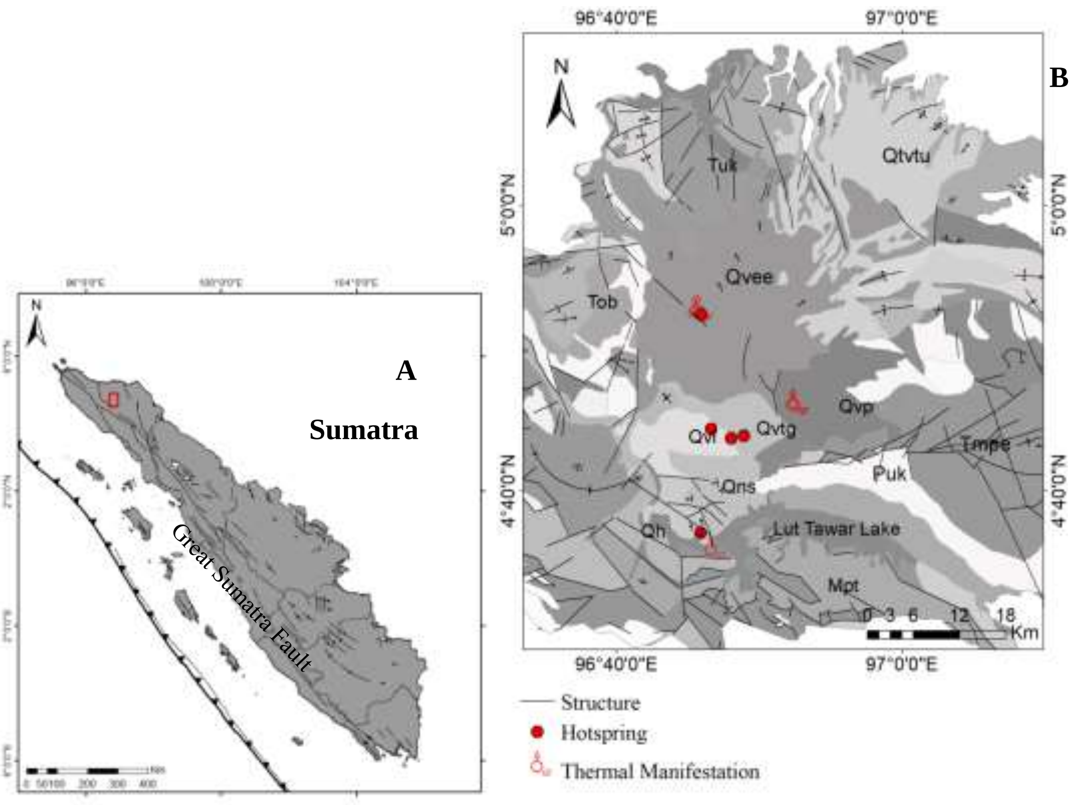

Figure 1. (A) Location of the study area is showed by red row near Great Sumatra Fault (B) Geological setting of Geureudong Volcanic Complex.

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2. Geologic settings

The study area covers Bur Ni Geureudong volcano complex located in the center of Aceh Province, Northwest Sumatra, Indonesia, and 50 km away from the north of the Great Sumatra Fault (Figure 1(A)). This volcano is the largest ancient volcanic complex in the North West of Sumatra with a width of 18 km, and the highest topography reaches 2624 m above sea level. This volcano has two parasite cones; Pepanji pyroclastic cones in the southeast and Bur Ni Telong lava dome in the Refs. [11][12] and Salah Nama Mountain in the south of Bur Ni Geureudong. The presence of geothermal energy in this region is manifested by hot springs, fumaroles, and solfatara over the volcano area (Figure 1(B)). The rocks in this region are dominated by andesitic volcanic sedimentary rocks originating from the Middle Pliocene to the Middle Holocene aged. In addition, there is basement rock from Paleozoic to late Miocene age near the volcano [13].

3. Data and method

3.1. Satellite gravity data

We used open-access satellite gravity data provided by Scripps Institution's Oceanography Topex Satellite website, University of California San Diego (UCSD) to investigate geological features over Bur Ni Geureudong. The data can be downloaded from Topex's website https://topex.ucsd.edu/WWW_html/mar_grav.html. The data covers the study area, which has a mountainous and densely vegetated area. Therefore, ground gravity acquisition is difficult to be done. Topex itself is a Geodesy Satellite launched by NASA in a 1-minute grid with a gravity data resolution of 1.5 km in 1 grid. The provided gravity data is already in free air anomaly, so we have to reduce the data by terrain correction to produce Bouguer anomaly. Correction of the terrain is based on topographic data which is also provided by Topex and assumes a standard rock density value of 2.67 g/cm^3. The result of the Bouguer anomaly map is displayed by overlaying with a hillside base map from processing DEM/SRTM data to display topographic effects.

3.2. Tilt derivative (TDR)

Edge detection on gravity data is a common technique in geophysical interpretation, which is able to detect faults through significant density contrast. Tilt derivative (TDR) is a potential field data processing technique which is adequate to detect edges of structural bodies by edge enhancement. We applied this tilt derivative filter to localize faults structure over Bur Ni Geureudong geothermal field. TDR is obtained from the ratio of the vertical gradient of the field to the absolute horizontal gradient, which is defined in equation (1) and (2) [14].

$$TDR = arctan\left[\frac{\left(\partial f/_{\partial z}\right)}{\left(\partial f/_{\partial h}\right)}\right] \tag{1}$$

$$\frac{\partial f}{\partial h} = \sqrt{\left(\partial f/_{\partial x}\right)^2 + \left(\partial f/_{\partial y}\right)^2} \tag{2}$$

where $\partial f/\partial z$ is the first vertical derivative of the potential field and $\partial f/\partial h$ is the horizontal gradient of the field.

4. Result and discussion

Bouguer anomaly map has been produced based on gravity satellite data obtained from the topex's website. The map is considerably good with sharp and clear contras. We overlayed the Bouguer anomaly map with the geological structure of the area based on a geological map produced by Ref. [13]. The structures were used to analyze the Bouguer Anomaly responses with geological structures like faults and rocks beneath the surface. Figure 2 shows the complete Bouguer anomaly distribution over Bur Ni Geureudong Area. Based on the result, Bouguer anomaly over the study area ranges 20 mGal up to 170 mGal. The Bouguer anomaly is affected by regional trends. It is seen that Bouguer anomaly highly responses to the presence of deep and large structures [6]. Low Bouguer anomaly response is obtained in several place of the area. The summits of the volcanoes i.e Bur Ni Geureudong Volcano, Bur Ni Telong Volcano, Mount Pepanji and Mount Salah Nama show a low response. Thus, in geothermal exploration, usually low gravity anomalies are associated with geothermal reservoirs [6]. Bouguer's anomaly is able to represent the discontinuity of rock lithology [15]. Apparently, the summit of Bur Ni Geureudong is covered by andesitic flow that has low Bouguer Anomaly. the buttom slope of Bur Ni Geureudong area is assosiated with volcaniclastic sedimentary rock. Bouguer anomaly in this area is moderate about 90 mGal – 130 mGal that is influenced by deep bodies and more dense than the andesitic rock. Whereas at the western of Mount Bur Ni Geureudong, it has a high Bouguer anomaly that is probably reflected by high-density basement rock. Bouguer anomaly is moderate in geothermal manifestation area, and the anomaly does not show some specific response to the manifestation. Bouguer anomaly is also found in the NE of the Bur Ni Geureudong volcano which was thought to be a fault structure (Redline on Figure 2). This assumption is based on the presence of density contrast which indicates the existence of a fault.

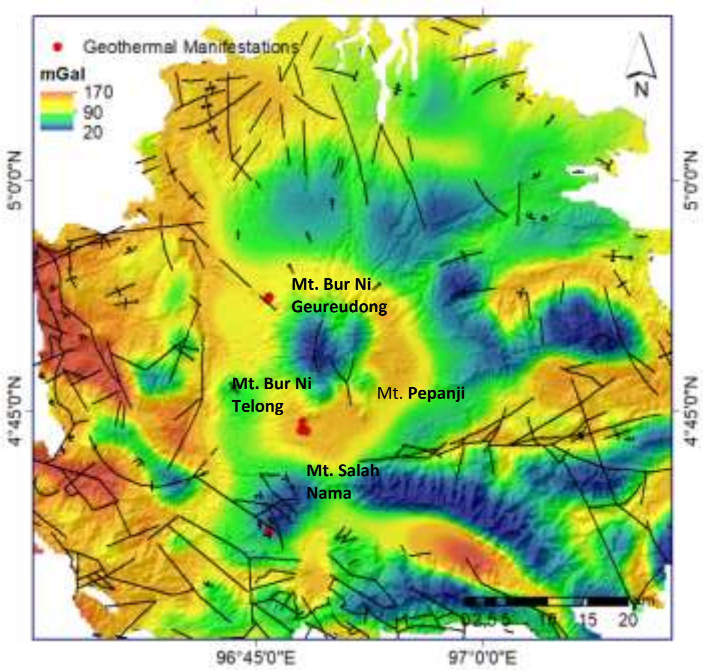

Figure 2. The complete bouguer anomaly of study area. Read circles represend geothermal manifestations and black lines are lineament fault structure.

Tilt Derivative (TDR) filtering is used to Bouguer anomaly in order to detect the edge of the geological structures over the study area (Figure 3). Based on Figure 3, the distribution of derivative tilt values ranges from -1.4 mGal up to 1.4 mGal/m. TDR value is positive for the source, zero value for the edge next to the source vertical, and negative value for the other responses [14] where the edge of the source can be assumed as fault, dip, and rock density contrast.

Figure 3 shows that the TDR enhancement technique is able to investigate fault structures clearly and sharply through edge detection. The dashed red lines represent the probable faults which are interpreted based on the lineament patterns shown by tilt value of 0. The fault structure 1 is recognized as Nisam Segment, and fault 2 probably is an extension of the Samalanga Segment, both are mentioned by Ref. [16]. However, the determination of the location of the fault structure is not accessible due to the effects of interference from regional sources, especially from deep fault structures. The TDR technique sharpens the peak of gravity anomalies signal and widens weak anomalies signal, so it is effective in localizing the deep source. However, the TDR technique is very sensitive to noise, but this noise effect can be reduced through upward continuation in processing gravity data [9].

The TDR pattern is also consistent with geological features over the area. For example, in geothermal manifestations near Salah Nama Mountain, the tilt value is zero, which is estimated because of fault or fracture responses. In geothermal systems, faults or fractures area support fluid circulation, allowing for infiltration and then moving fluid to the surface. Areas that cross fault systems have good permeability as the pathway for hot fluids to up flow as a hot spring [15].

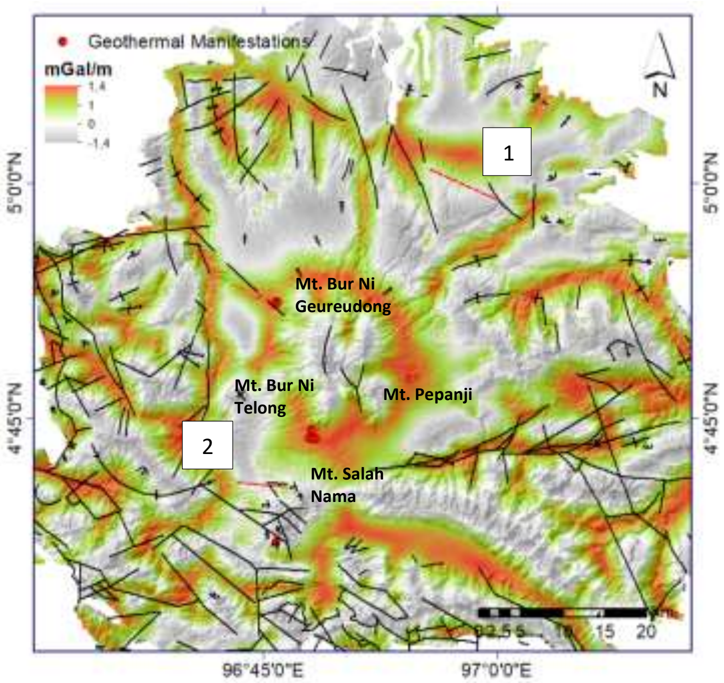

Figure 3. Tilt Derivative (TDR) map can recognize edges of rock bodies. Dashed red lines ares estimated fault detecting by TDR.

5. Conclusion

Gravity data interpretation was presented in Bur Ni Geureudong geothermal field to delineate structure features. The 1.5 km resolution of airborne gravity data is adequate to present Bouguer Anomaly of the area. However, the response of Bouguer anomaly to geothermal manifestations is inadequate. Therefore, regional and residual analysis is needed to be done in order to observe Bouguer anomaly from both deep and shallow sources. Tilt derivative (TDR) method revealed from the data also successfully detects fault structures clearly. Some faults are detected crossing Geureudong geothermal field including faults located near the geothermal manifestation. The fault can be suspected as the circulation of geothermal fluid up flows to the surface.

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