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THE EFFECT OF GRAVITY MEASUREMENT DISTRIBUTION POINTS ON INTERPRETATION OF GRAVITY DATA IN THE GUNUNG ENDUT GEOTHERMAL PROSPECT AREA, INDONESIA

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ABSTRACT: The geothermal prospect located at Gunung Endut was investigated in 1980s based on reconnaissance surveys, primarily on geological and geochemical aspects. Then in 2006 a gravity measurement with 247 stations was carried out. However, due to the distribution of the gravity station was less than optimal, interpretation of gravity data was not suitable with the geological situation that support geothermal system. To ensure this, we have carried out a new gravity survey with 134 random stations distribution but remained concentrated on hot spring locations. Data from both measurements were processed by the same treatment starting from pre-processing with some standar corrections to obtain complete Bouguer anomaly, then continue by filtering process to separate regional and residual gravity anomaly using Butterworth filter in a wavenumber domain. Residual gravity anomaly map obtained by random position of stations is more resemble to the geological features developed in the prospect area. The contrast boundaries of the residual gravity anomaly value coincide with the fault-line structures recorded in the surface geological data. This result is better when compared with previous measurements. This study shows that there is a significant influence of the distribution pattern of the gravity stations which affects the conformity with the geological data. Based on the new interpretation result, the structural features in the prospect area are characterized by the complex fault structures that intersected each other mainly close to the surface manifestations. This intersection area is expected to be an enhanced permeability zone so that the hydrothermal fluid can flow to the surface. The interpretation of new gravity data combined with the results of geochemical analysis can be used for more understanding of the geothermal system beneath Gunung Endut prospect area.

Keywords: Geothermal, Gravity, Endut, Indonesia

1. INTRODUCTION

Renewable energy, especially from geothermal, is going to increase in future years. The demand is increasing rapidly. Indonesia has tremendous geothermal energy resources distributed along its main islands. The generation of electric power from geothermal energy plays an important role in maintaining balance between energy supply and demand in Indonesia.

One of the prospective areas for producing electricity from geothermal energy is Gunung Endut located in Banten province, Indonesia. The prospect area is about 70 km south-west of Jakarta, as shown in Fig. 1. According to Hochstein, the subsurface geothermal system of the area has not been identified. The surface manifestation are minor. Hot springs (T≤84 ºC) and altered rocks associated with a diorite intrusion were found during the first exploration stage by Pertamina in the 1980s [1]. Pertamina returned most licenses of their volcanic geothermal prospects to the Ministry of Energy and Mineral Resources (MEMR) in 2000.

A preliminary study of the Endut geothermal prospect area has been performed based on geological, geochemistry and geophysical data in 2006 by MEMR. Regarding to geophysical data, a total of 247 stations for gravity survey were carried out on the area. However, due to the distribution of the gravity station is not optimal, the interpretation of gravity data is not suitable with the geological situation [2].

To ensure this, we conducted a new gravity survey at 134 randomly distributed stations concentrated on hot spring locations. This study shows that there is significant influence of the distribution pattern of gravity stations on the variation of gravity residual anomaly value which affects the conformity between gravity data interpretation and surface geology data.

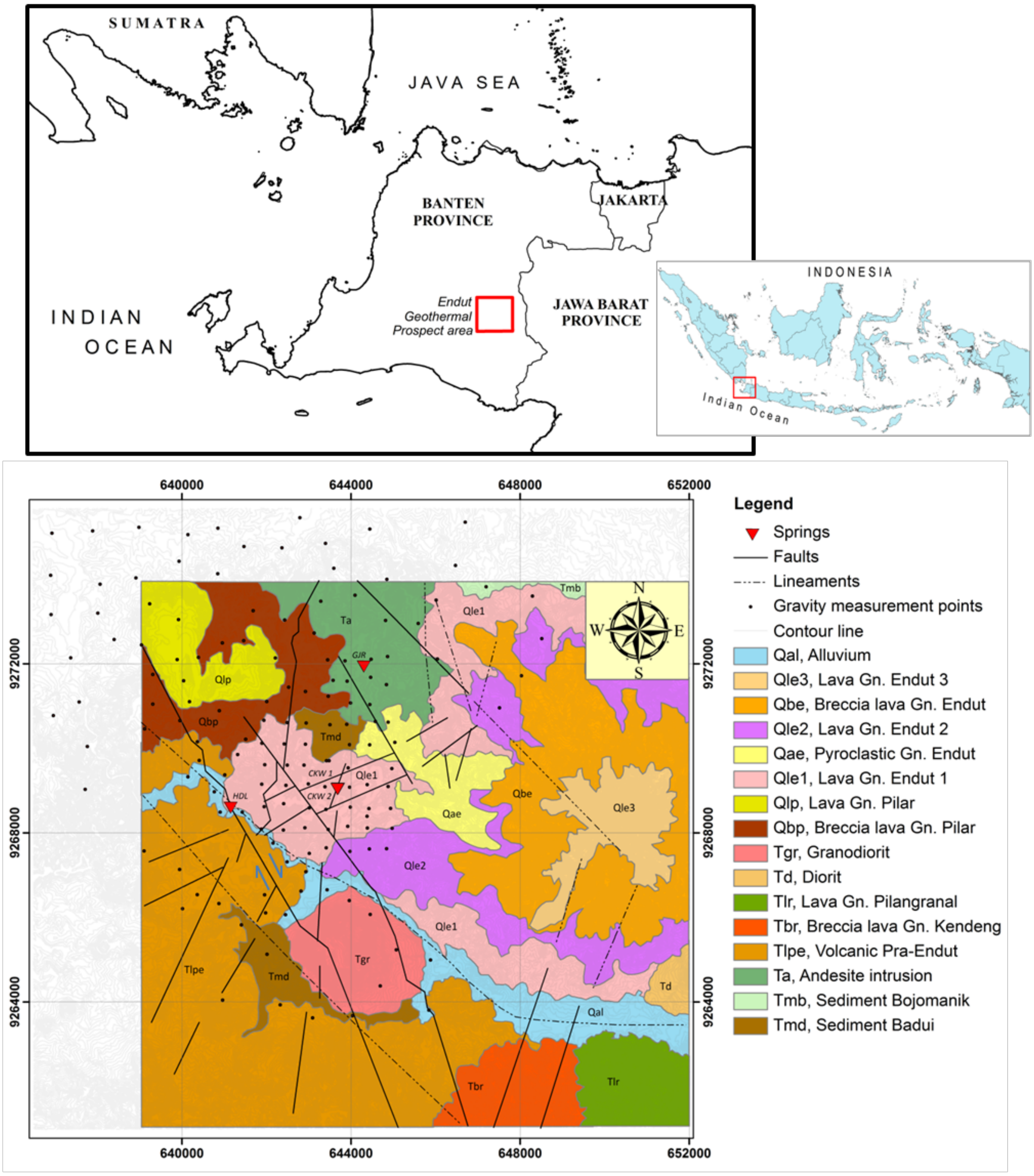

Fig. 1 Location of Gunung Endut geothermal prospect area and its geological map including new distribution of gravity measurement points

2. GUNUNG ENDUT PROSPECT AREA

2.1 Geological setting

Indonesian active volcanic arcs along Sumatra to Flores islands can be interpreted as the result of sub-crustal melting induced by subducted lithosphere plates [3][4]. It is easy to recognize that the Gunung Endut prospect area is located on a geologically active zone together with several active volcanoes.

Fig. 1 shows the geological map of the Gunung Endut geothermal prospect area. The dimension of the area is about 13x13 km^2 located on the UTM coordinates range between 9261000-9274000 N and 639000-652000 E. The highest elevation point, measured by the height above sea level is the Gunung Endut summit, with an altitude of 1.193 meters. The altitudes of the prospecting area where surface manifestations exist vary between 300 to 500 meters above sea level. Geomorphology of the area highly varied with fluvial valleys and hills and complicated by lava flows.

Volcanic and tectonic processes mainly control the geological structures in the Gunung Endut area. The zone is dominated by a quaternary volcanic formation as a product of Gunung Endut. There are four hot springs i.e. Cikawah-1 (CKW-1), Cikawah-2 (CKW-2), Handeuleum (HDL) and Gajrug (GJR) as geothermal surface manifestations where located approximately 6–8 km from the Gunung Endut summit. The tertiary granodiorit and diorit intrusions are encountered in the southern part of the area, developing over a considerable period of time before Gunung Endut activity was started. It had intruded through the basement tertiary sediment of Badui formations. The Badui sedimentary formation, as outcropped to the southwest of Mt Endut, is predominantly sandstone and limestone. As mentioned in the internal report of MEMR, the result of the geological survey shows that the Endut area could be categorized into 16 geological units. These geological units are written sequentially from the youngest to the oldest, as shown on Fig. 1 [5].

The NW-SE strike-slip fault structures are recognized as responsible for tertiary intrusions and quaternary Endut volcano activities. A younger NE-SW normal fault is suggested to control thermal features of Cikawah hot springs (CKW-1) and CKW-2) about 6 km west from the summit of Gunung Endut. The surface rock alteration i.e. silicified brecciated andesite and argilic clay with rich content of opaline silica mineral exist close to the Cikawah hot spring. Other NW-SE normal fault is suggested to control thermal features of Handeuleum hot spring (HDL) located about 8 km to the west of Gunung Endut summit. The existence of Gajrug hot springs (GJR) is suspected as a result of another NW-SE strike fault.

2.2 Geochemical overview

Geochemistry plays a key role in geothermal exploration. Geochemical analysis can estimate the reservoir temperature and hydrothermal fluid flow whether up flow or out flow. Geochemical analysis of geothermal exploration has been undertaken by many previous researchers [6-8].

Sample of water was taken by MEMR from some springs located at Cikawah (CKW-1 and CKW-2), Handeuleum (HDL) and Gajrug (GJR). As shown in Table 1, the highest temperature is water sampled from CKW 1, while all the other water sample have neutral pH.

Table 1 Temperature and pH of water sample from spring

Spring	Temp	pH	IB%
CKW 1	88°C	7.98	0.2
CKW 2	53°C	7.74	-1.1
HDL	57°C	7.70	-0.6
GJR	61.5°C	6.74	-3.4

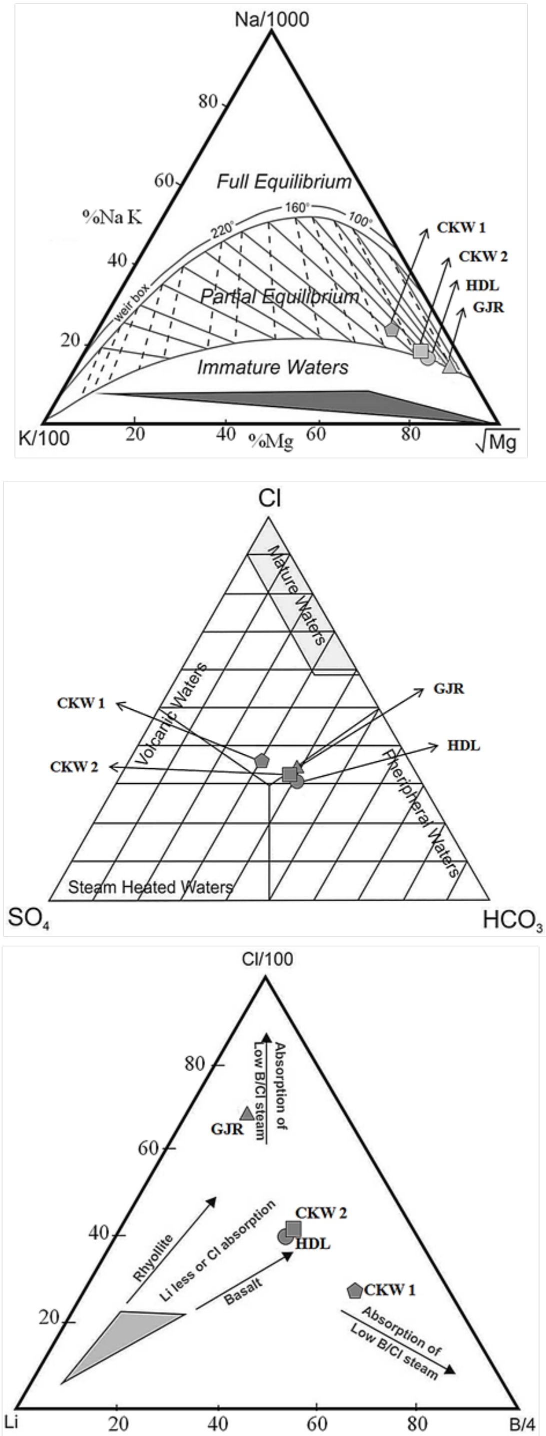

Fig. 2 Ternary diagram obtained from the hot springs water sample

The hot water sample taken from CKW-1 has more total cation than total anion with IB (Ion Balance) = 0.2%, while the hot water from CKW2, HDL and GJR has IB-1.1%, -0.6%, and -3.4% respectively. The four samples showed excellent quality with IB less than 5% [9].

We have performed a geochemical data analysis to estimate reservoir temperature and characteristic of water sample using method that proposed by Giggenbach [10]. The ternary diagram of Na-K-Mg (Fig. 2) shows that the hot springs CKW-1 is located on a partial equilibrium. It indicates the occurrence of hot fluid interaction with the rock prior to the formation of hot springs on the surface. The reservoir temperature estimation based on Na-K geothermometers is between 160ºC to 180ºC.

Fig. 2 also shows the water compositions that are ploted on the center of Cl, SO_4 and HCO_3 triangular diagram. It could be infered that all the water are mixing-water as a result of reservoir water and rock interaction. It means that all the springs are located far enough from the geothermal reservoir.

The Cl, Li, B ternary diagram, as shown in Fig. 2, indicate that the two hot spring i.e. CKW-2 and HDL possibly come from same reservoir. The most interesting thing is although the hot springs location of CKW-1 and CKW-2 are close enough, but it is suspected that the water come from different reservoirs. This assumption is also supported by the significant difference of their water surface temperature shown in Table 1.

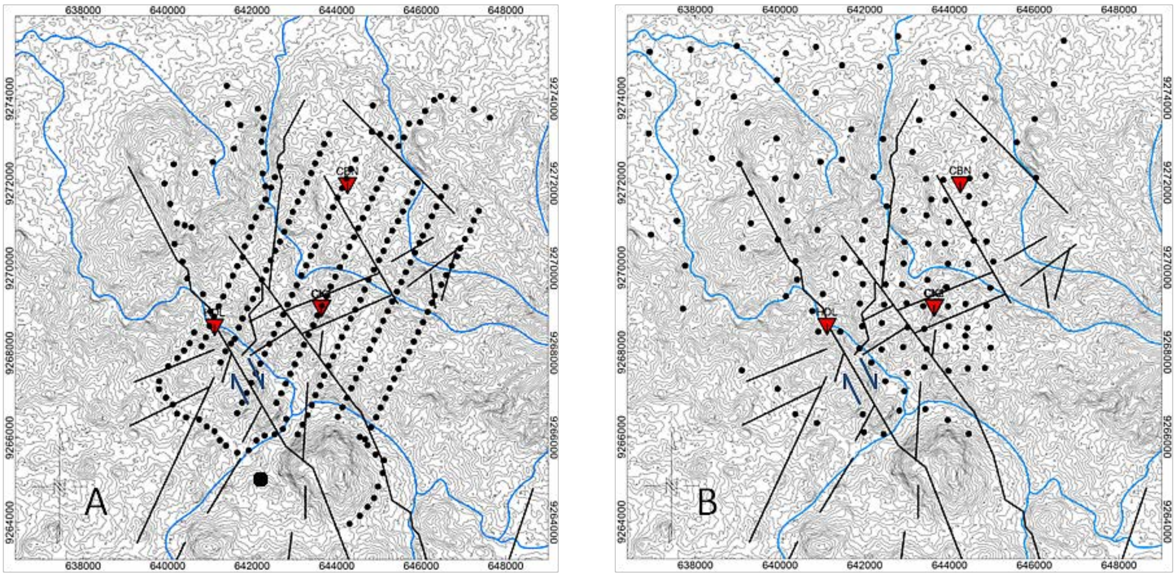

Fig. 3 Distribution of gravity measurement points that were measured in 2006(A) and in 2014 (B)

3. GRAVITY MEASUREMENT

Gravity is a convenient geophysical method for identifying lateral differences in the densities of subsurface rocks [11]. It is therefore useful for finding buried geological objects and structures, such as igneous intrusions as a heat source of geothermal system; and some faults that usually control the existance of geothermal manifestation [12-14]. The measurement of gravity on land and in the air using airborne gravity for geothermal exploration has rapidly grown [15]. However, the clarity of the appearance of those geological features is largely determined by the distribution of gravity measurement points.

Ideally, the distribution of gravity measurement points forms a grid with a specified interval spacing point distance. However, situations and field survey condition are often not possible to make grid measurements. In such situations, it is recommended that the measurements be made with random measuring point but still concentrated on the main target of the measurement. This study shows significant differences in the results of the analysis due to differences in the distribution of gravity measurements in study area.

A total of 247 stations, as shown inf Fig. 3A, for gravity survey in the Gunung Endut geothermal prospect area were carried out by MEMR in 2006 using A Lacoste Romberg gravity-meter (type D-114) with an accuracy of 0.01 mgal. Fig. 3A shows the distribution of gravity measurement points that make up the 7 main lines. The distance between the measuring point in a line is of 200 m, while the distance between the line is about 500 m. Fig. 3B shows the distribution of 134 gravity measurement points with randomly positions that carried out in 2014 using the same equipment. Both measurements are centered around hot springs in order to investigate the fault structures that control the presence of hot springs.

As a part of the gravity data pre-processing, latitude, free-air, Bouguer and terrain corrections were then applied to the measured gravity data. Density was measured on samples from selected outcrops in the study area and used as a control of average surface density calculated using Parasnis' method. The obtained average density of 2.66 g/cm^3 reflects the average density in the near-surface where the Quaternary volcanic units in the study area are scattered. This density was then used for calculation complete Bouguer anomaly

(CBA).

The CBA obtained after various corrections represent the combined responses of various masses lying at depths below the Gunung Endut geothermal prospect area. On the analysis stage we separate the effects local or residual gravity anomaly which are likely to be associated with the geological features that support the geothermal system from the rest of the response. From the spectral analysis of the CBA, regional and local gravity anomaly energy is mainly concentrated in the frequency band (0–0.86 rad/km). The regional gravity anomaly is dominated in the low frequency band (0–0.18 rad/km), while the local gravity anomaly is dominated in the mid-high frequency band (above 0.18 rad/km). To obtain the residual gravity anomaly we used a Butterworth bandpass filter in a wavenumber domain with the low cut-off about 0.18 rad/km and high cut-off of 0.86 rad/km.

Advanced analysis of gravity data acquired in 2006 also has already done using integrated gradient analysis [2]. Although the measurement design is less than optimal, the results of the analysis show that all geothermal manifestations on the prospect area is structurally controlled by faults system.

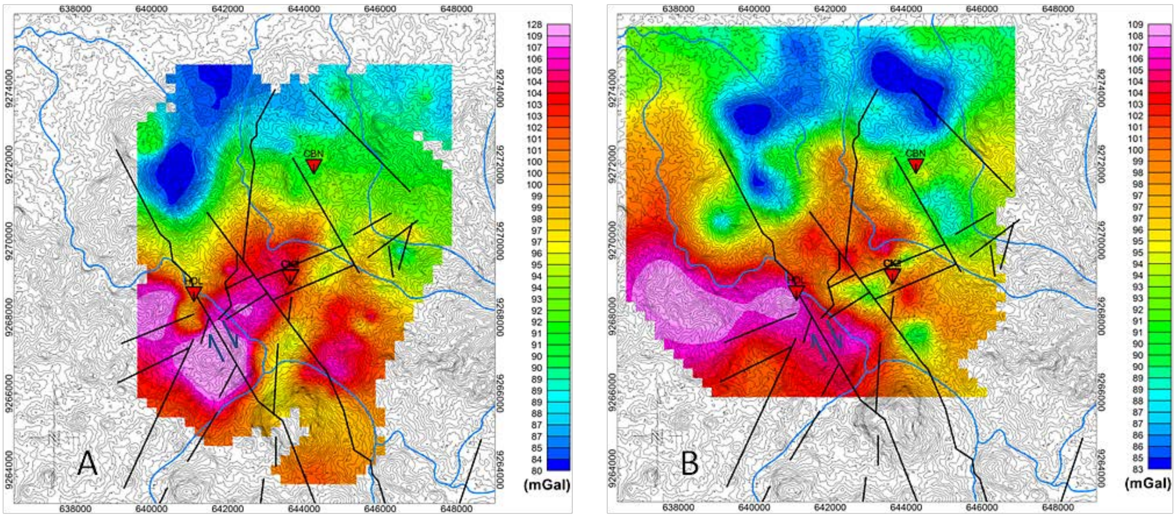

Fig. 4 The complete Bouguer anomalies of gravity data that were measured in 2006 (A) and in 2014 (B)

4. DISCUSSION

Map of complete Bouguer anomalies in Fig. 4A shows a variation in values between 80 mgal to 128 mgal, while in Fig. 4B variations of values between 83 mgal to 109 mgal. In Fig. 3A, high-value anomaly (> 100 mgal) is in the southwest of the prospect area. The medium anomaly (90 mgal - 95 mgal) spread from east to west through Gajrug spring (GJR). Low anomaly (<90 mgal) dominates the northwest area.

In Fig. 4B, the high anomaly (> 100 mgal) dominates the western region and lowers to the south. Medium anomalies (90 mgal - 95 mgal) are uniformly distributed in all directions except the southwest region.The low anomaly (<90 mgal) lies to the north of the Gajrug hot spring (GJR) and is bounded by by north-south trending fault structures and northwest-southeast fault.

In general, the low Bouguer anomalies distribution is encountered in the northern part of prospect area. While high Bouguer anomalies values are observed in the southern part of study area. It should be emphasized that the Bouguer gravity anomalies pattern obtained from both measurements exhibit a regional trend, with gravity decreasing from the SW to the NE.

However, if we look in more detail it is seen that the NW-SE strike-slip fault pattern that passes through the HDL hot springs appears more clearly shown in Fig. 4B than Fig. 4A. Moreover, in Fig. 4B, the variation of complete Bouguer anomaly between high and low in the southern part is clearly bordered by the river path. This may indicate that there are different lithology that are bordered by the river path. This can be proven on the geological map in Fig. 1. This condition is less visible in Fig. 4A.

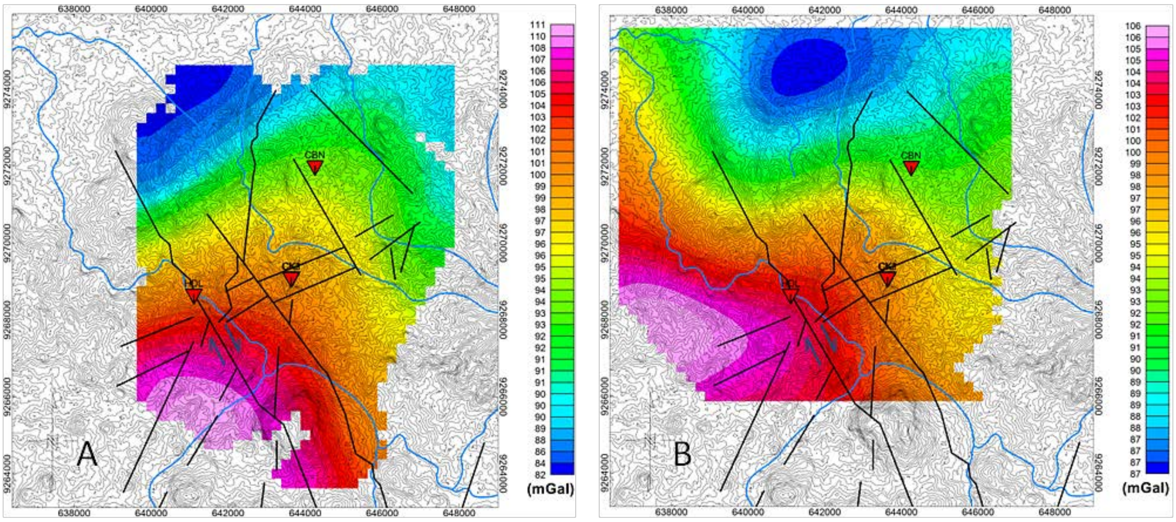

Fig. 5 The regional anomalies of gravity data that were measured in 2006 (A) and in 2014 (B)

Both regional anomaly map is made with a density correction of 2.66 gram/cm^3. The map is shown in Fig. 5. The regional anomalies do not show suitability with surface fault structures as indicated by geological maps Fig. 1. Therefore the alignments emerging from the map of regional anomalies can be interpreted with large and deep structures occurring in the southwest and central regions of investigations in the direction of almost southwest - northeast.

From this regional anomaly it is clear that the separation of low anomalies, moderate anomalies, and high anomalies. Area with low anomalous values (80-90 mgal) in the northern part of prospect area is reflecting the presence of sedimentary rocks of Baduy Formation in depth. While those with medium values (90-95 mgal) are thought to be occupied by andesite, breccia and pyroclastic product deposits of Gunung Endut eruption. Then a high regional anomaly (95-130 mgal) occupies the southwestern region to the center reflecting the presence of high density rocks, which are thought to be andesitic rocks and granodiorit that have been unified and mineralized.

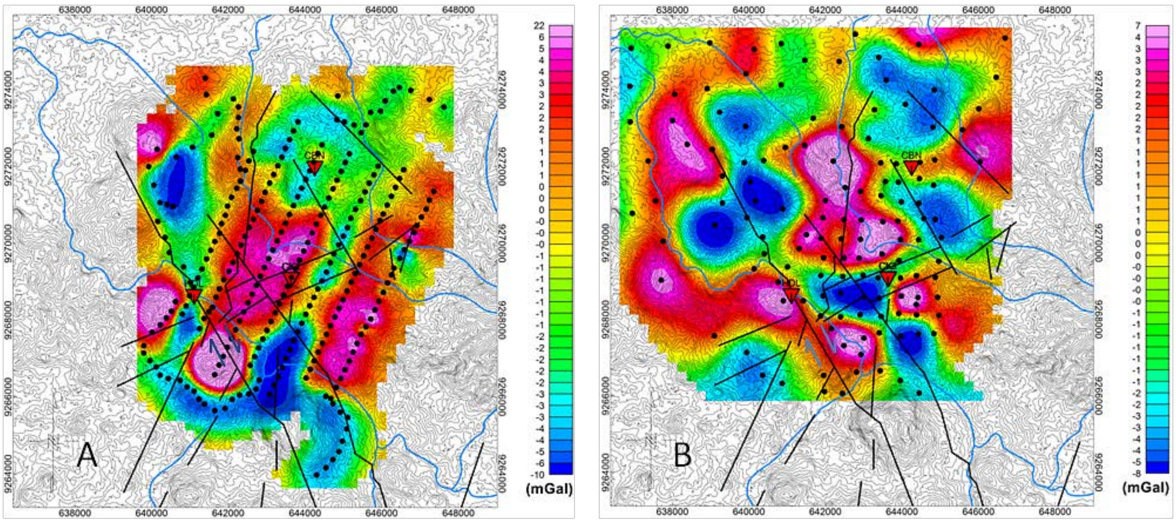

Fig. 6 The residual anomalies of gravity data that were measured in 2006 (A) and in 2014 (B)

The results of regional anomalies are aimed for extracting shallow information from Bouguer anomalies with the intention of obtaining localized gravity anomalies, called residual anomalies. The residual gravity anomaly map is a gravitational response that is affected only by rock variations from shallow depths to the surface. Therefore, the gravitational response to residual anomalies usually corresponds to geological data, particularly fault structures. In general, the residual anomaly map of Fig. 6A and Fig. 6B appears to be different.

The residual anomaly map obtained by random spacing of measurement points (Fig. 3B) actually shows better conformity with geological data. The existence of the strike-slip fault NW-SE oriented that passes through HDL hot springs is clearly indicated by the position of two high anomalies that appear to be shifted according to the strike-slip fault orientation. The river channel also explicitly divides the high anomalous and low anomalous values that can be interpreted as the boundary between two different rock types as seen on the geological map Fig. 1. The low anomalies between CKW hot springs and HDL hot spring are probably caused by the interconnecting of fault structures resulting in a decrease in overall density due to the number of fractures. Even the presence of CBN hot springs is more easily explained from the results of Fig. 6B where there is an anomalous contrast near the CBN hot springs suspected to be the fault that controls the CBN hot springs, as shown in Fig. 1. In fact, the things that have been described are hard to be explained from Fig. 3A.

5. CONCLUSION

Ideally, the distribution of gravity measurement points forms a grid with specified interval spacing point distance. However, field conditions are often not possible to make grid measurements. In such situations, random or arbitrary measuring points should be performed surrounding the main target of the measurement. This study shows significant differences in the results of the analysis due to differences in the distribution of gravity measurements in Gunung Endut geothermal prospect area. Residual gravity anomaly map obtained by random position of gravity stations is more suitable to the geological structure conditions developed in the prospect area. The contrast boundaries of the residual gravity anomaly value coincide with the fault-line structures including NW-SE strike-slip fault recorded in the surface geological data. This result is better when compared with previous measurements that show less conformity with geological structure. Based on the new gravity data interpretation result, the structural features in the prospect area are characterized by the complex fault structures that intersected each other mainly close to the hot springs. This intersection area is expected to be an enhanced permeability zone so that the hydrothermal fluid can rise up to the surface. These analysis conclude that all geothermal manifestations on the prospect area is structurally controlled by faults system. Meanwhile, according to Cl-Li-B ternary diagram, it could be concluded that the two hot spring i.e. CKW-2 and HDL possibly come from same reservoir. In contrast, the CKW-1 and CKW-2, even they are close enough, it might be suspected that their water come from different reservoirs. The interpretation of new gravity data combined with the results of geochemical analysis can be used for more understanding of the geothermal system beneath Gunung Endut prospect area.

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