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Gravity Interpretation of the RUW (Rendingan-Ulubelu-Waypanas) Geothermal System in Tanggamus Regency, Lampung, Indonesia

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ABSTRACT

Gravity interpretations have been done in the Rendingan-Ulubelu-Waypanas (RUW) geothermal system. A combination of both detailed data within the geothermal system and large-scale data from its surrounding, have been prepared by Pertamina, then processed and interpreted. Density determination is conducted by measuring the cores and cuttings and interpreted using the Nettleton method.

The gravity model shows the groups of volcanic lavas and pyroclastics occur across the RUW geothermal system. The basalt group of the Mt. Kukusan basaltic andesite lavas (KkBAl) in the southwest part of the study area, have average thickness is about 1000 m. The Mt. Rendingan andesite lavas (RdAl) in the northern part of the area with thickness about 1600 m underneath the Mt. Rendingan area, and 300 m within the Ulubelu caldera. The Mt. Rendingan pyroclastics (RdPr) in the north central area, the thickness is between 200 m and 300 m. The Mt. Duduk dacite lavas (DdDl) which occur in the north central area underneath the Mt. Rendingan pyroclastics, the thickness is between 800 m and 1000 m. The Mt. Sulah andesite lavas (SlAl) in the western part of the study area have thickness about 150 m.

1. INTRODUCTION

The Rendingan-Ulubelu-Waypanas (RUW) geothermal system is located in Tanggamus District, Lampung Province, Southern of Sumatra, Indonesia (Figure 1). It was formerly known as the Ulubelu prospect (Hochstein and Sudarman, 1993; Pertamina, 1993; Yunus, 1993). However, further publications Suharno (2003) suggested that the prospect extend to the north and southwest, therefore, called of the Rendingan-Ulubelu-Waypanas (RUW) geothermal system is a large system, covering an area of about 150 km^2. A gravity investigation was conducted to study the geological structures, distribution and dimensions of subsurface lithology of the RUW geothermal system. Interpretations of gravity data were constrained by drillhole data and density measurements made on rocks.

2. PREVIOUS INVESTIGATIONS

Several regional gravity surveys have been carried out in the RUW geothermal system. The gravity map of Kota Agung Quadrangle, scale 1: 250,000, was published by the Geological Survey of Indonesia in 1991 (Buyung et al., 1991). The regional gravity data over the whole of Southern Sumatra (Walker, 1993) indicates a shallowing of the pre-Tertiary basement southwards (Amin et al., 1994). The regional gravity background values are higher in the Lampung area than elsewhere in Southern Sumatra. Walker (1993) reported a much short wavelength of gravity signature in the southern part of Southern Sumatra indicating of the shallow metamorphic basement there. Amin et al. (1994) recognized a local gravity low in the RUW geothermal system and suggested that it is associated with a volcanic center. They also inferred the presence of several faults from the dominant northwest-southeast, northeast-southwest and north-south trends around the gravity low.

Figure 1 shows part of the Bouguer anomaly map of Kota Agung Quadrangle (Buyung et al., 1991) covering the RUW geothermal system. The Bouguer corrections were computed using a terrain density of 2.67 x 10^3 kg m^{-3}. The effects of topographic undulations (the terrain correction) were not all included in the reduction of these Bouguer anomalies in the map.

3. DENSITY OF ROCKS

Information about the density of rocks is necessary to interpret gravity data. Rock densities were measured from some borehole samples in the study area. A total of 20 samples of fine grained cuttings from the wells Rd, Kukusan I (Kk1) and Kukusan II (Kk2), and 25 samples of coarse cuttings from wells Ulubelu II (UBL2) and Ulubelu III (UBL3) were measured (Suharno, 2003). The result, show values ranging between 2.60 x 10^3 kg m^{-3} and 2.70 x 10^3 kg m^{-3}. Three of the wells, UBL2, Kk1 and Kk2, are located on Mt. Kukusan basaltic andesite lava (see Figure 5). The measured density values correlate with the rock types penetrated by these wells, described in Chapter III. Wells UBL2 and Kk1 are close to the boundary with Mt. Rendingan pyroclastics. The other two wells, UBL3 and Rd, are located within Mt. Rendingan pyroclastics. Well UBL3 is located in the middle section, but well Rd is close to its boundary with Mt. Rendingan andesite lava. The results show similar mean densities, about 2.67 x 10^3 kg m^{-3}, for wells Rd, UBL2 and UBL3. A lower mean density of about 2.63 x 10^3 kg m^{-3} is shown by samples from wells Kk1 and Kk2. These wells (Kk1 and Kk2) are located on exposures of Mt. Kukusan basaltic lavas but they penetrate less dense tuffs at depth.

A terrain density estimate was made across line GG’ (see Figure 5 for location) using the Nettleton method (Dobrin and Savit, 1988). The density estimated profile is presented in Suharno (2003) which showed that he correlation of gravity with topography along this line can be matched by a value for terrain density of about 2.70 x 10^3 kg m^{-3}. Combined with the results from the laboratory measurements of borehole samples, this suggests that the overall mean density of rocks in the study area is close to 2.67 x 10^3 kg m^{-3}. This is also the mean density of upper continental crust commonly used for the reduction of Bouguer anomalies (Dobrin and Savit, 1988).

4. DATA ACQUISITION AND PROCESSING

The gravity data used were collected by Pertamina (1991/92) from about 500 gravity stations established over the RUW geothermal prospect. These stations were located along several lines at about 250 meters spacing. Pertamina also conducted a larger scale gravity survey covering the area surrounding the Rendingan-Ulubelu-Waypanas (RUW) geothermal system.

The gravity measurements were conducted using a La Coste-Romberg Gravitymeter type G 655, which has a sensitivity of about 0.2-0.4 $\mu N\ kg^{-1}$. Other characteristics of this gravitymeter are given in most standard geophysical textbooks (e.g. Parasnis, 1997). During the RUW survey, the measurement drifts of the gravitymeter were linearly interpolated (with respect to time) from the differences of readings made at the same base station.

The Bouguer anomalies were reduced using a Bouguer density of 2.67×10^3 kg m^{-3}. The terrain corrections were adopted from the values given by Rahman et al. (1991/1992). Recalculations of some of the highest and lowest terrain effects using the Hammer (1939) method produced very similar results. The reduction of a Bouguer anomaly is presented as a contour map on Figure 2. Another contour map (Figure 3) was based on only the Bouguer anomaly data from the large-scale survey.

The Bouguer anomalies computed for this study (Figure 2) are compatible with those of the previous investigations (Figure 1) only in the eastern part of the area. In the western part, these two maps differ, mostly because of incomplete station coverage of the previous investigations (see Figure 1), as topographic effects were not removed during the reduction of Bouguer anomalies by Buyung et al. (1991). Overall, the Bouguer anomalies obtained for this study are of a much better quality than those obtained from the previous investigations. Hence, only the data shown in Figure 4 are used for the gravity interpretations made in this paper.

5. SEPARATION OF RESIDUAL AND REGIONAL ANOMALIES

To identity residual anomalies it is necessary to remove regional trends caused by deeper, larger scale density variations. The regional gravity field over the RUW geothermal system was determined using the Bouguer anomalies from the large-scale survey (Figure 3) which used values measured at stations close to exposures of the local basement, the Hulusimpang Formation. Figure 3 shows that the inferred regional field (interpolated by kriging using the Surfer program of the Golden Software Inc.) has a nearly uniform gradient across the research area.

Figure 4 is a map of residual Bouguer anomalies in the study area obtained by subtracting the regional field, represented by the data in Figure 3, from the Bouguer anomalies shown in Figure 2. Figure 4 shows that the exposures of Hulusimpang Formation in the northwest and southeast are associated with the near zero contours, indicating that the residual anomalies reflect mostly density variations above this local basement. Figure 5 is the superimposed contours of residual Bouguer anomalies over the geological map of the RUW geothermal system. Its shows the relationships between gravity and geology.

6. GRAVITY INTERPRETATION

6.1 Qualitative interpretation

The residual anomalies (Figure 4) are negative in the northwestern but positive in the southwestern parts of the study area. This indicates that, in general, rocks surrounding Mts. Kukusan and Waypanas are denser than those in the area near Mts. Duduk and Rendingan. Low Bouguer anomalies around Mt. Duduk have been described by Suharno (2000) as due to the Ulubelu caldera (Figure 5) being filled with low-density volcanic rocks. This study investigates a larger area covering Rendingan-Ulubelu-Waypanas, as well as Ulubelu.

Across this larger area, negative residual anomalies extend towards the northwest and central east. The negative anomalies are mostly associated with exposures of Mt. Rendingan andesite lava, Mt. Rendingan pyroclastics and Mt. Kabawok pyroclastics. The negative anomalies also correlate with altered rocks and possibly alluvial deposits around Mt. Duduk (Figure 5).

The presence of broad negative residual anomalies in the northwest covering Mt. Rendingan lavas and pyroclastics suggests that these rocks have negative density contrasts with respect to the reference density of 2.67×10^3 kg m^{-3}. The Mt. Rendingan pyroclastics consist of rhyolitic tuff seen in thin section. Negative anomalies also cover Mt. Kabawok pyroclastics, which mainly consist of andesite and dacite tuffs. The lowest parts of the negative anomalies occur where faults F5 and F8 merge, probably creating a zone of intensified fracturing.

The positive residual anomalies in the southwestern sector appear to be related to the Mt. Kukusan basaltic andesite lavas. The highest anomaly, over Mt. Waypanas, is possibly associated with blocks of lava that accumulated around this mountain. The steep gradient of the anomalies on the exposure of low density Ranau formation (QTr) suggests that it is probably only a thin layer overlying the Mt Kukusan lavas (see Figure 5).

6.2 Gravity Modeling

Quantitative interpretations of the gravity data over the RUW geothermal system were made using two-dimensional gravity modeling because of the simple patterns of residual anomalies shown in Figure 5. The modeling was conducted using Grv2D-Win code written by S. Soengkono at the Geothermal Institute, Auckland University. Two-dimensional interpretations were conducted along lines AA', BB' and CC', shown in Figure 5. The Quantitative interpretations has done by Suharno (2003)

Mt. Rendingan pyroclastics (RdPr) around the summit of Mt. Duduk are about 300 m thick. These pyroclastics occur between wells Rd and Kk2, and are covered by a thin layer of Mt. Kukusan basaltic lava near Mt. Kukusan; they also extend towards well Kk2. Mt. Rendingan pyroclastics (RdPr) occurs close to fault F4, about 1800 m from the end of section BB'. The RdPr is shown in section CC' extending from near fault F1 to the end of this section. These rocks also occur underneath Mt. Kukusan basaltic lavas (KkBAl) between well Kk2 and fault F1.

Mt. Rendingan andesite lavas (RdAl) occur from the south end of section AA' north into well Kk2. The lavas are overlain by the Mt. Rendingan pyroclastics between well Rd and well Kk2. However, RdAl is buried beneath andesite breccia near well UBL2 In section BB' RdAl occurs from near fault F4 through to the end of this section.

It is covered by pyroclastic produce Mt Rendingan (RdPr) from near fault F4 to beyond well Rd. Section CC' shows RdAl covered by RdPr from near drillhole Kk2 to end of this section.

Mt. Duduk dacite lavas (DdDl) occur underneath Mt. Rendingan andesite lavas (RdAl), as shown by well UBL3 The drilled interval in UBL3 without samples is assumed to be occupied by DdDl. Mt. Duduk dacite lavas also shown in section CC' between faults F1 and the end of this section. It is buried by RdAl which, in turn, is covered by RdPr.

A block of Mt. Kukusan basaltic lavas (KkBAl) occurs at the south end of section AA'. KkBAl is exposed at the surface from near Mt. Kukusan to the end of this section. It is thin (less than 100 m), near Mt. Kukusan and extends to well Kk2. In section CC', KkBAl occurs from the southwest until fault F1. It is thin (less than 100 m) between well Kk2 and fault F1 and thicker (about 1000 m), in the southwest section CC', underneath rocks of Ranau Formation (QTr).

Cross section BB' shows Mt. Sulah andesite lavas (SlAl) occurs in the southwest (left side of the section). This occur at the surface (Figure 5) in the southwest of section CC', but the profile does not include this exposure. However, SlAl in Figure 5 is contiguous with Ranau Formation rocks (QTr), so in section CC' it is interpreted as buried Ranau Formation rocks (QTr).

The gravity interpretation is consistent with the faults mapped in the study area. It also helped to reveal the sub-surface distribution and dimension of volcanic rocks across the Rendingan-Ulubelu-Waypanas (RUW) geothermal system.

The lowest density body shown near well Rd possibly represents a fracture zone (Pbr) within the Mt. Rendingan andesite lavas and pyroclastics. Such a fracture zone (Pbr) is inferred to be related to micro-earthquake swarm.

7. SUMMARY

The gravity model shows volcanic lavas and pyroclastics occur across the Rendingan-Ulubelu-Waypanas (RUW) geothermal system. A fracture zone can be inferred within the Mt Rendingan andesite lavas in the northern part of the RUW geothermal system.

The groups of volcanic rocks indicated by the gravity data are:

- The basalt group of the Mt. Kukusan basaltic andesite lavas (KkBAl) are indicated by the gravity model in the southwest part of the study area (Figure 5), which is underneath the Mt. Waypanas area. The average thickness of this group is about 1000 m.

- The Mt. Rendingan andesite lavas (RdAl) in the northern part of the area have a maximum thickness of about 1600 m underneath the Mt. Rendingan area. Their average thickness within the Ulubelu caldera is about 300 m.

- The Mt. Rendingan pyroclastics (RdPr) in the north central area range in thickness between 200 m and 300 m. The Mt. Duduk dacite lavas (DdDl) occur in the north central area underneath the Mt. Rendingan pyroclastics. This group ranges in thickness between 800 m and 1000 m.

- The Mt. Sulah andesite lavas (SlAl) lie in the western part of the study area. Their average thickness is about 150 m.

8. ACKNOWLEDGEMENTS

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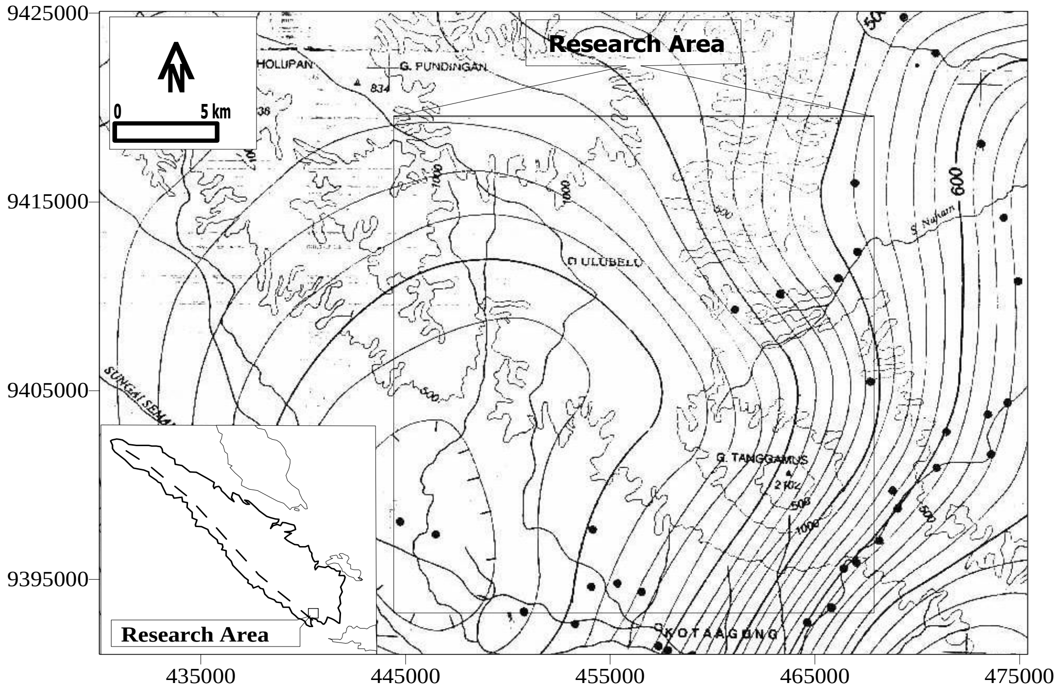

Figure 1. Bouguer anomaly map surrounding of the area Rendingan-Ulubelu-Waypanas (RUW) geothermal system made from previous investigations (modified from Buyung et al., 1991). Measurement sites are indicated by solid circles. The contour interval is 20 μN kg^{-1}. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980).

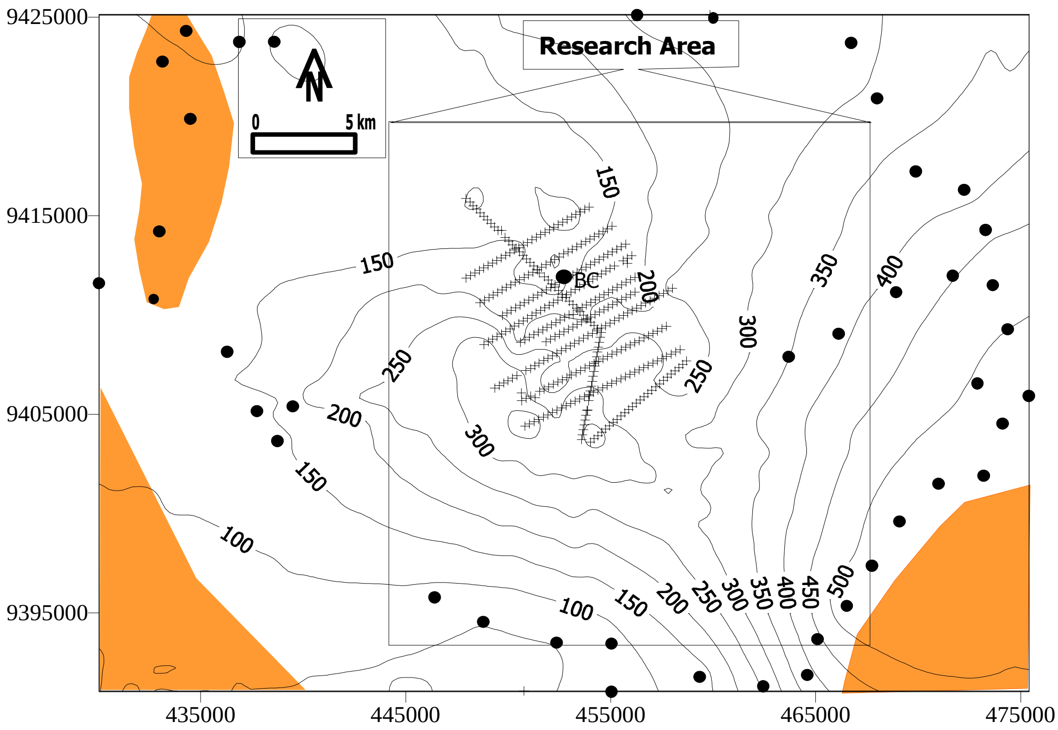

Figure 2. Contour map of Bouguer anomalies over the Rendingan-Ulubelu-Waypanas (RUW) geothermal system obtained for this study. Contour values are in μN kg^{-1}. Gravity measurement stations are shown by solid circles (large-scale survey) and crosses (detailed survey over the RUW geothermal prospect). Surface exposures of the rocks the Hulusimpang Formations are shaded. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980).

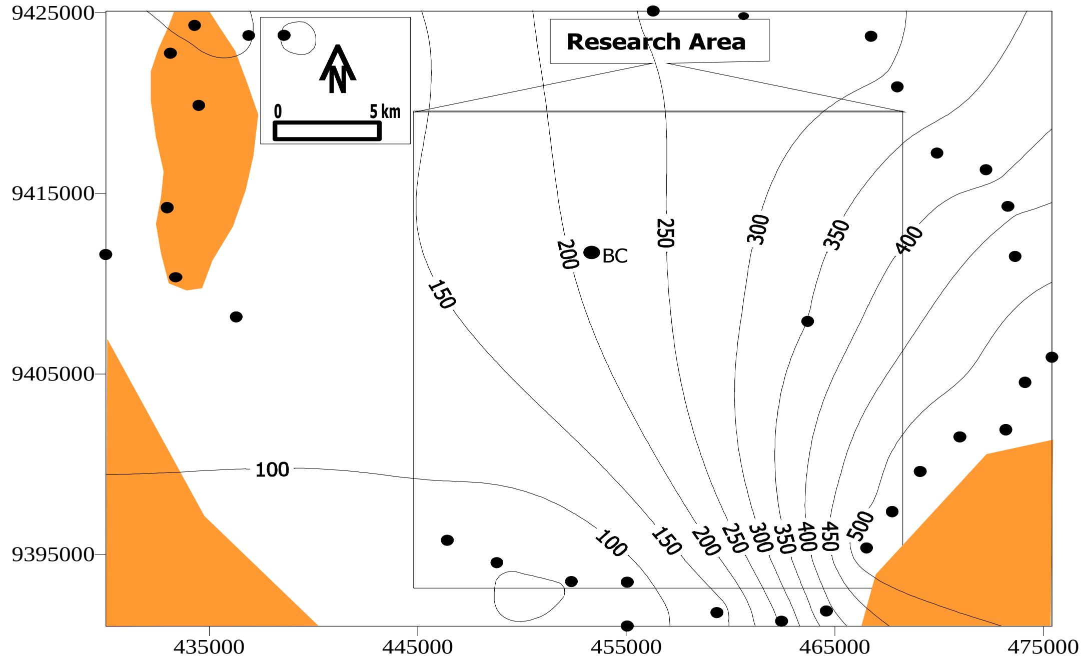

Figure 3. Bouguer anomalies from the large-scale survey over the Rendingan-Ulubelu-Waypanas (RUW) geothermal system. Contours values are in μN kg^{-1}. Surface exposures of Hulusimpang Formation, the local basement rocks, are shaded. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980).

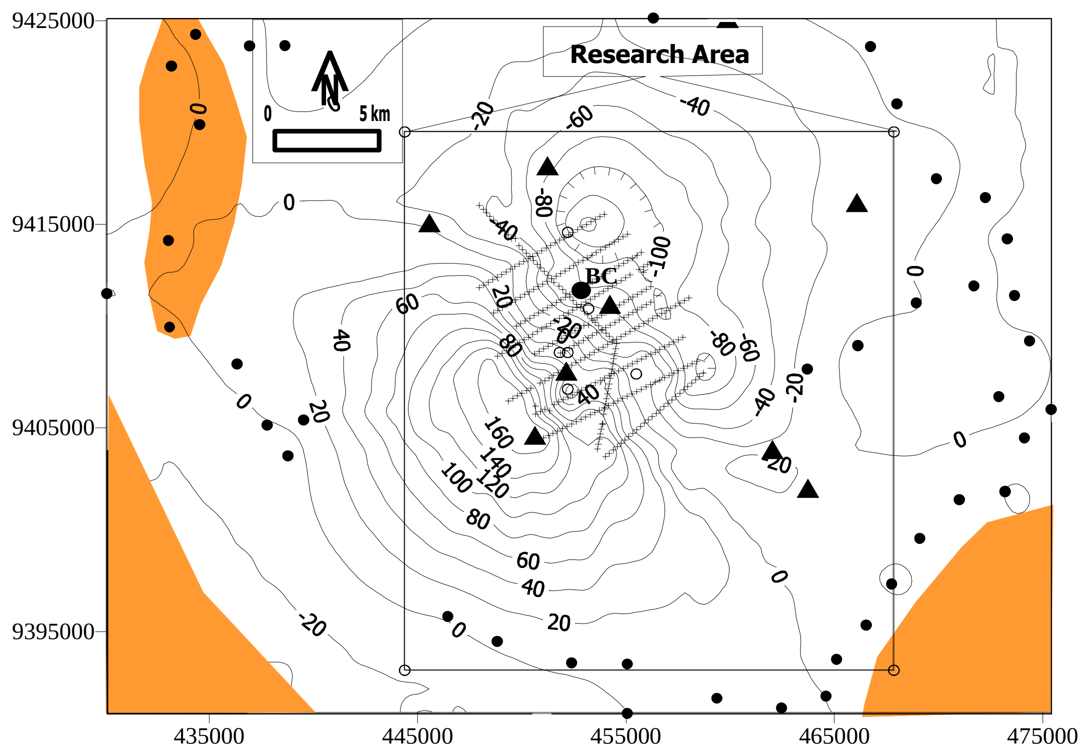

Figure 4. Residual Bouguer anomaly over the Rendingan-Ulubelu-Waypanas (RUW) geothermal system. Contour values are in μN kg^{-1}. Shaded areas show exposures of the inferred local basement of the Hulusimpang Formation. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980).

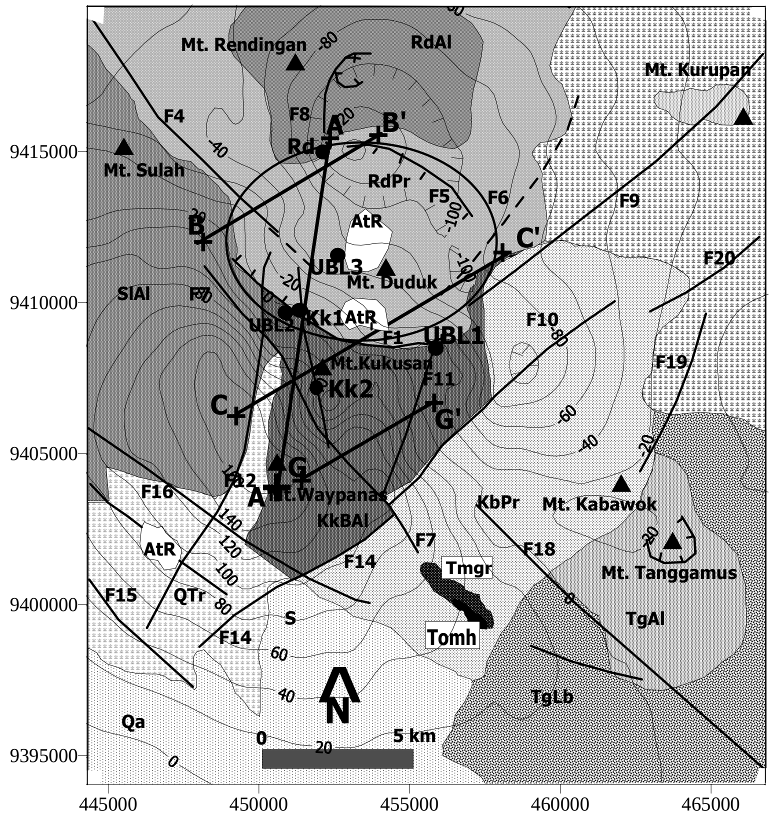

Figure 5. **Residual Bouguer anomalies superimposed over the geological map of the Rendingan-Ulubelu-Waypanas (RUW) geothermal system showing localities of 2-D interpretation profiles AA', BB' and CC'. The contour interval is 20 μ N kg^{-1}. Full line ellipse is Ulubelu caldera marked by F1 and F5. Qa: Alluvium, AtR: Altered rocks, TgAl: Tanggamus andesite lavas, KrRl: Kurupan rhyolite lavas, Dt: Dacite tuff, RdAl: Rendingan andesite lavas, RdPr: Rendingan pyroclastics, TgLb: Tanggamus laharic breccia, KbPr: Kabawok pyroclastics, DdDl: Duduk Dacite lavas, KkBAl: Kukusan basaltic andesite lavas, SlAl: Sulah andesite lavas, QTr: Pumiceous tuff (Ranau Formation), Tmgr: Granodiorite, Tomh: Hulusimpang Formation. Solid circles are wells. Triangles represent topographic summits. Broken and solid lines are inferred and confirmed faults, respectively. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD (1980).**