Berkala Fisika *ISSN : 1410 - 9662*
Vol.9, No.2, April 2006, hal 85-91

DETERMINATION ROCK DENSITIES OF ULUBELU GEOTHERMAL LAMPUNG BY USING GRAVITY METHOD COMBINED WITH BOREHOLE METHOD

SUHARNO[1] ,HERNOWO DANUSAPUTRO[2]
1) Physics Department the University of Lampung, Bandar Lampung
2) Physics Department the University Diponegoro, Semarang

ABSTRACT

The Ulubelu geothermal system is located within Tanggamus volcanism. Rock densities were measured from wells Rendingan (Rd), Kukusan I (Kk1), Kukusan II (Kk2), Ulubelu II (UBL2) and Ulubelu III (UBL3). A terrain density estimate was made across line GG' using the Nettleton method. The measured densities results, show values ranging between 2.60 x 10^3 kg m^{-3} and 2.70 x 10^3 kg m^{-3}. The density estimated profile is presented in Figure 2 shows the density of about 2.70 x 10^3 kg m^{-3}. Combined with the results from the laboratory measurements of borehole samples and density estimated, those suggest as the mean density of upper continental crust commonly used for the reduction of Bouguer anomalies (2.67 x 10^3 kg m^{-3}).

INTISARI

Sistem geothermal Ulubelu terletak di dalam volcanus Tangganus. Kerapatan batu karang diukur dari sumurRendingan, Kukusan I, Kukusan II, Ulubelu II dan Ulubelu III. Perkiraan kerapatan tanah dilakukan melalui garis GG menggunakan metode Neetleton. Hasil pengukuran massa jenis menunjukkan bahwa interval nilai terletak diantara 2.60 x 10^3 kg m^{-3} dan 2.70 x 10^3 kg m^{-3} Profil dari densitas yang ditampilkan pada gambar 2. menunjukkan bahwa densitas sekitar 2.70 x 10^3 kg m^{-3} Kombinasi dengan hasil-hasil pengukuran laboratorium menunjukkan bahwa densitas merata dari daerah kontinental bagian atas digunakan untuk mengurangi anomali Bouguer.

INTRODUCTION

The Ulubelu geothermal system is located in Tanggamus District, Lampung Province, and Southern of Sumatra, Indonesia. (Figure 1). The Ulubelu geothermal area is located among volcanoes such as Mt. Tanggamus, Mt. Kabawok, Mt. Kurupan, Mt. Rendingan, and Mt. Sula. Complex of Mt. Korupan pyroclastic lava is in northeastern. Mt. Rendingan pyroclastic and andesite lava complex are lied in north and northwestern. Mt. Sula complex is placed in west and southwestern. Mt. Kukusan basaltic andesite lava complex positioned in southern. Especially between Mt. Kukusan basaltic andesite lava and Mt. Sula andesite lave are lied the pumice tuff; and the Lake Ulubelu and Mt. Duduk dacite lava complex are seated in the middle of area.

The Ulubelu geothermal area has been surveyed by geophysical methods such as gravity. The precision data collecting and processing, the good density estimation is also important to assess before interpretation. It will be measured from some borehole samples and estimated by using both Nettleton methods on gravity calculation correlating with geological data (geological map and subsurface geology determination).

Rock densities were measured from 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 cuttings from wells ulubelu II (UBL2) and

Ulubelu III (UBL3) were measured. The results, 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 1). A terrain density estimate was made across line GG' (see Figure 1 for location) using the Nettleton method

BASIC THEORY

1. Density of Rocks

Density variations greatly influence gravity interpretations. Geothermal activity possibly causes a density change in the reservoir rocks. This may be a reduction, caused by leaching, or an increase, caused by deposition of hydrothermal minerals directly from solution,. Rock densities were measured from cuttings, and the surface densities were estimated by "regional" gravity data analysis using Nettleton method [1].

2. Density Measurements

Twenty sets of fine grain cuttings from wells Rd, Kukusan I (Kk1) and Kukusan II (Kk2) and 25 coarse cuttings from wells Ulubelu II (UBL2) and Ulubelu III (UBL3) (.1), were measured.

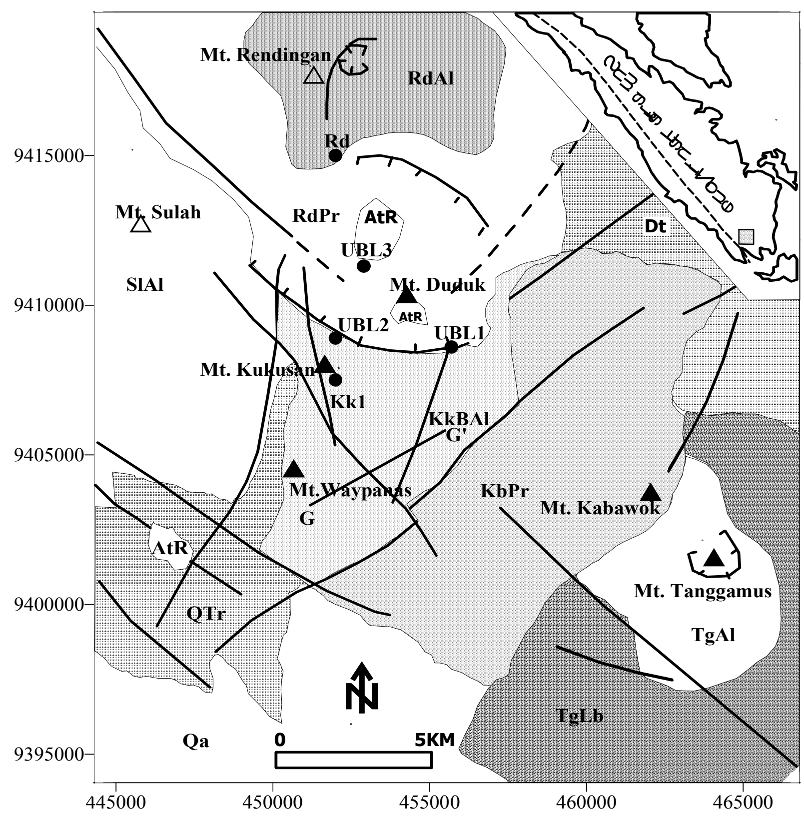

Figure 1. Location of the Ulubelu geothermal system. Qa: Alluvium, AtR: Altered rocks, TgAl: Tanggamus andesite lavas, KrRl: Kurupan rhyolite lavas, Dt: Dacite tuff, RdAl: Rendingan andesite lavas, RdPr: Rendingan pyroclastics, TgLb: Tanggamus laharic breccia, KbPr: Kabawok pyroclastics, DdDl: Duduk Dacite lavas, KkBAl: Kukusan basaltic andesite lavas, SlAl: Sulah andesite lavas, QTr: Pumiceous tuff (Ranau Formation), Tmgr: Granodiorite, Tomh: Hulusimpang Formation. Filled circles (Kk1): bore holes; triangles: summits of mountains; Full and dashed lines are confirmed and inferred faults, respectively. The coordinates are given in terms of the Indonesian map (m) standard metric grid referred to as Dittop TNI-AD [2].

2.1 Fine grained cuttings

The cuttings were oven-dried at about 60^o C for almost 66 hours. The weights of a container M (c) and a pycnometer M (p) were measured by electronic scale in air. The weights of the container and rocks M (c+m), the pycnometer and water M (p+w), and the weight of pycnometer plus rocks plus water M (p+m+w-sw) were measured on the same scale. The weight of spilled water from the pycnometer M (sw) yield from dropping a sample into the full water pycnometer. The volume of the sample in the pycnometer is equal to the volume of the water which spilled out from the pycnometer.

2.2.2 Coarse cuttings

First the cuttings were oven-dried at about 60^o C for almost 66 hours. The weight of a sample (m_d) was measured in the air by electronic scale. The samples were then saturated in water under vacuum for about 66 hours. They were then dried directly using tissues to remove the water on the outside. This is called a saturated sample. The saturated sample weights (m_s) were measured in air by an electronic scale. The weights of a pycnometer filled with water (m_w) and filled with water plus saturated sample (m_{wp}) were measured on the same scale.

III. CALCULATIONS

3.1. Fine grained cuttings

When the weights of M(c), M (c+m), M (p), M (p+w), and M (p+m+w-sw) were known the weights of the rock samples M (m), water M (w), spilled water M (sw) and the rock density ρ (m) were then calculated. They were calculated using Equations (1), (2), (3) and (4),

$$M(m) = M(c+m) - M(c) \quad \ldots\ldots(1)$$

$$M(w) = M(p+w) - M(p) \quad \ldots\ldots(2)$$

$$M(sw) = M(p+w) + M(m) - M(p+m+w-sw) \quad \ldots\ldots(3)$$

The density of the rocks were determined using the mass of the samples divided by their volume, i.e. equivalent to the mass of spilled water.

$$\rho(m) = M(m) / M(sw) \quad \ldots\ldots(4)$$

3.2. Coarse cuttings

The weights (m_d), (m_s), (m_w) and (m_{wp}) were measured. The volume (V) and particle density (ρ_p) were calculated. The weight of the water (m_f) can be calculated from:

$$m_f = m_s + m_w - m_{wp} \quad \ldots\ldots(5)$$

So, the volume of the sample is:

$$V_x = m_f \, \rho_f = (m_s + m_w - m_{wp}) \, \rho_f \quad \ldots\ldots(6)$$

where ρ_f is the density of water. The dry and saturated densities can by calculated from

$$\rho_d = m_d / V \quad \ldots\ldots(7)$$

$$\rho_w = m_s / V \quad \ldots\ldots(8)$$

The particle density can be computed by equation:

$$\rho_p = \rho_d / (1 - \phi) \quad \ldots\ldots(9)$$

where $\phi = (\rho_w - \rho_d) / \rho_f$

IV. RESULT

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. The results, 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 1). The measured density values correlate with the rock types penetrated by these wells. 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.

V. ESTIMATION OF DENSITY FROM GRAVITY MEASUREMENT

A terrain density estimate was made across line GG' (see Figure 1 for location) using the Nettleton method [3]. The density estimated profile is presented in Figure 2 which shows that the 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}.

Based on this estimation density using Nettleton methods and compare with some literature such as (Telford et al., 1976)[6] choose the most representative the surface density as described bellow. Alluvial Ulubelu River is closed to 1.7 x 10^3 kg m^{-3}. Both Mts. Rendingan pyroclastics and andesite lava, respectively 2.1 x 10^3 kg m^{-3} and 2.6 x 10^3 kg m^{-3}. Mt. Korupan pyroclastic, Mt. Kabawok pyroclastic and the pumice tuff rocks are undefined. Mt. Duduk dacite lava may be 2.8 x 10^3 kg m^{-3}. Finally, Mt. Kukusan basaltic lava and Mt. Sula andesite lava respectively 2.8 x 10^3 kg m^{-3} and 2.6 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 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.

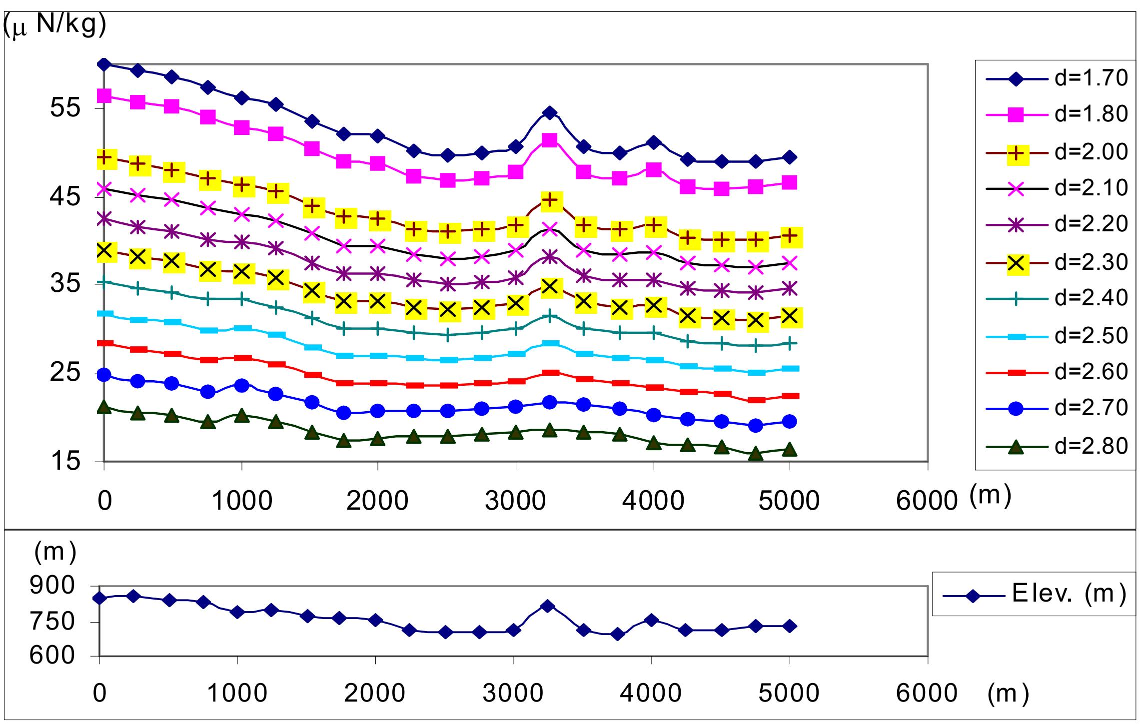

Figure 2. Density profile along section GG' showing its relationship with topography, calculated using the Nettleton method, d x 10^3 kg m^{-3} is a density value [4].

DISCUSION

The Ulubelu geothermal area has been surveyed by geophysical methods such as gravity, magnetic and resistivity in 1991, and also microseismic in 1992. Interpretations using gravity and seismic are influenced strongly by density of rocks near surface and/or the underneath. As well as both the precision data collecting and processing, the good density estimation is also important to assess before interpretation. It will be estimated by using both Nettleton method on gravity calculation correlating with geological data (geological map and subsurface geology determination).

The Ulubelu geothermal area is located among volcanoes such as Mt. Tanggamus, Mt. Kabawok, Mt. Kurupan, Mt. Rindingan, and Mt. Sula. Masdjuk, 1997 [5] has classified the local lithology into any stratigraphic units. The main stratigraphic was produced by volcanic activity. Complex of granodiorit, old andesite and Mt. Kabawok pyroclastic are located in southeastern. Complex of Mt. Korupan pyroclastic lava is in northeastern. Mt. Rindingan pyroclastic and andesite lava complex are lied in north and northwestern. Mt. Sula complex is placed in west and southwestern. Mt. Kukusan basaltic andesite lava complex positioned in southern. Especially between Mt. Kukusan basaltic andesite lava and Mt. Sula andesite lave are lied the pumice tuff; and the Lake Ulubelu and Mt. Duduk dacite lava complex are seated in the middle of area [6].

The variation of stratigraphic units can be associated with variation of density. The density variation would influence the gravity and seismic interpretations. We tried to estimate the density variation in this area using the Nettleton method based on gravity observation. This method is suitable for estimation of the near surface density.. The Nettleton method may be obtained from a representative gravity profile over the observation area. The field readings are reduced to produce Bouguer gravity profiles, assuming several different values of density (σ) for the Bouguer and terrain corrections. The Nettleton method is suitable for a high gradient topographic profile, because of the smoothest of these profiles, that is, the one that reflects the topography least, is the one with the correct density. The Parasnis method is an analytical method approach somewhat similar to Nettleton method, it has been developed by Parasnis. Since we are attempting to determine an average bulk density over the survey area, the Bouguer anomaly is considered to be a random error of mean value zero. For example, in single profile resembles a straight line of the form $y = a + bx$. The slope will be density if we plot (g_{obs} - $g_r \pm dg_L + 0.094\ h$) versus ($0.01277\ h - T$) and draw the best straight line through the points and through the origin. This research uses least square method in this case.

Pertamina in 1991 has conducted gravity measurements in the Ulubelu geothermal area. There are 10 lines of gravity measurements running cross Mt. Rindingan pyroclastic and andesite lava, Mt. Sula andesite lava, Mt. Kukusan basaltic andesite lava, pumice tuff, Mt. Duduk dacite lava, altered rocks and aluvially Ulubelu river (Figure 1).

Gravity calculation base on the assuming that the correct and precision data reading including terrain reading and calculating. The terrain corrections listed on the data from Pertamina were checked by recalculated the highest and lowest values. The Nettleton method was conducted along high gradients of terrain, where significant relationship between gravity measurements and topography can be expected Bouguer profiles reduces using a series of density values were compared with topographic profiles and reduction density which gave a minimum correction between the two was selected. The method provided estimates of the local density. In addition a modified technique by plotting was also applied to improve the validity of density estimation. We compare result from the Parasnis and the original Nettleton methods to get the representative value of local density along the profiles.

Figures 2 is the example that it delineated Nettleton method in order to determine the best surface density of the Ulubelu geothermal area that it represent of the general bulk density in this area. Based on Nettleton method (Figure 2) that the best density may approximate 2.7 x 10^3 kg m^{-3} or 2.8 x 10^3 kg m^{-3}.

To avoid bias, geological data were not considered during the estimation of density. The result indicated that Mt. Rendingan pyroclastic has a bulk density of 2.1 x 10^3 kg m^{-3} where the aluvially Ulubelu River has a density 1.7 x 10^3 kg m^{-3}. The result also suggested different density value of andesite basaltic lava unit of Mt. Kukusan is 2.8 x 10^3 kg m^{-3}, Mt. Sula andesite lava (2.7 x 10^3 kg m^{-3} and Mt. Rendingan andesite lava (2.6 x 10^3 kg m^{-3}). And the most fantastic is The altered rocks within the vicinity of well UBL1 appear have rather high density (2.8 x 10^3 kg m^{-3}).

Some density determination should be true and some is unrepresentative. The aluvially density may be true because some data found in this area, but may not because the data found in the law and relative flatly terrain. Nevertheless, suggest that density of alluvium sediments and alluvium sedimentary rocks respectively in range (1.5 - 1.6) x 10^3 kg m^{-3} and (1.96 - 2.0) x 10^3 kg m^{-3}. Mt Kukusan basaltic lava looks very low density, it may untrue density determination because the Bouguer anomaly data are lied on moderate topography and the Nettleton method is more accurate in the high topographic gradient. Beside the range of basaltic lava density is 2.7 x 10^3 kg m^{-3} to 3.3 x 10^3 kgm^{-3}. The density of Mt. Sula andesite lava is unsatisfactory because it only a less data located in the corner area. The altered rocks closed to well UBL1 appear have rather high density (2.8 x 10^3 kg m^{-3}). It may be caused by the altered rocks are abundant with epidote [7][8], but it should be inaccurate density determination because the altered rocks are generally located in the lowest situation and the relative flatly zone area. The high density probably associated with buried Mt Duduk dacite lava. It is possible that the density dacite rocks closed to 2.8 x 10^3 kg/m^3. The other high density value (2.6 x 10^3 kg m^{-3}) also presents to the NE of well UBL3 suggesting that the Mt. Rendingan pyroclastic lava appeared on the surface is thin, and the Mt. Rendingan andesite lava believably buried underneath. It is possible that some andesite lava with average density 2.61 x 10^3 kg/m^3 covered by Mt. Rendingan pyroclastic [9].

ACKNOWLEDGMENTS

I would like to thank to Pertamina who prepared the gravity and drilling data and gave consent to publish this are gratefully acknowledged.

REFERENCES

[1]. Browne, P.R.L., 1998. Hydrothermal alteration lecture notes, Geothermal Institute, the University of Auckland, New Zealand, pp. 70.

[2]. Dittop, 1980. Topographic map of Kota Agung. Directorate Topography TNI-AD, Jakarta.

[3]. Dobrin, M.B. and Savit, C.H., 1988. Introduction to geophysical Prospecting. Mc Graw-Hill International, 867 pp.

[4] Rahman, A., Fuad, D., Hutabarat, H. and Nasrun, 1991/1992. Provisional report survai kombinasi geofisika (Tahanan-Jenis, Head On, CES, Gravitasi, Magnetik & SP) daerah Ulubelu Lampung, Pertamina, Jakarta.

[5] Masdjuk, M., 1997. Laporan geology detil daerah Ulubelu, Lampung, Pertamina, Jakarta.
[6] Kemah, M.Y. and Yunis, 1997. Evaluasi geologi-geokimia pemboran sumur Ulubelu Lampung, Pertamina, Jakarta.
[7] Siahaan, E.E., 1997. Hydrothermal alteration and fluid inclusion geothermometry of cores and cuttings from well UBL-1, Ulubelu geothermal field Lampung, Sumatera, Indonesia. 97.22, Geothermal Institute, the University of Auckland, Auckland.
[8] Silaban, M.S.P., 1998. Hydrothermal alteration and fluid inclusion study of cores and cuttings from well # 03, Ulubelu, Sumatera, Indonesia. 98.21, Geothermal Institute, the University of Auckland, Auckland.
[9] Suharno, 2003. Geophysical, Geological and Paleohydrological Studies of the Rendingan-Ulubelu-Waypanas (RUW) geothermal system, Lampung, Indonesia. PhD Thesis, The University of Auckland, Auckland, 204 pp