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Preliminary Study: Density Layer Values Estimation of Volcano Hosted Geothermal Area at Tiris Village, Probolinggo Regency, East Java, Indonesia

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Abstract

A preliminary study has been conducted using gravity method to estimate the volcano hosted geothermal system at Tiris, Probolinggo Regency, East Java. Gravimeter LaCoste & Romberg type G-1503 used for acquisition data which it collected in grid design with 100 meters per each datum. Complete Bouguer anomaly was obtained through gravity correction methods, then reduced into the flat plane and separated between regional anomalies and residual anomalies using upward continuation method. Complete Bouguer anomaly result had value ranged from 49–63 mGal and residual anomaly values ranged from -8.5–5.5 mGal. Subsurface structure identification for determining geothermal layer system was obtained by making three intersection lines (i.e A-A', B-B' and C-C') on the residual anomaly map and analyzing their cross-sections. Based on the modeling results of A-A', B-B' and C-C' cross-sections in terms of density values, it is estimated that the sub-surface rocks of the research area are composed by Lamongan volcano tuff-breccia rocks, Lamongan volcano breccia-lava rocks, Argopuro volcano andesitic-lava rocks, and old-Tengger andesitic-breccia rocks. The Argopuro volcano andesitic-lava rocks are suspected as the geothermal heat source because it volcanic activity is still detected. Furthermore, the Lamongan volcano breccia-lava suspected as the geothermal reservoir where they have large porosity so that the water passes and heated easily.

Keywords: Tiris, Bouguer anomaly, density, geothermal system, gravity.

INTRODUCTION

As one of alternative energy sources, geothermal energy continues to be studied and developed in Indonesia. Mostly, in Indonesia, the geothermal energy source has been identified as volcano hosted geothermal with a potential of around 29 GWe and its utilization is only about 5% of the total potential [1, 2, 3, 4, 5, 6, 7]. Specifically for East Java, there have been identified 14 geothermal locations that are not operational yet, with survey status up to the determination of mining working areas. Total geothermal potential in East Java is estimated at 1140 MWe [8].

One of the locations in East Java that potentially have geothermal is in Tiris Village, Probolinggo Regency. The visible manifestation is hot springs in Tiris that has the potential of geothermal that lies between Mount Lamongan and Mount Argopuro [9]. This potential is supported by the existence of 4 hot springs that come out on riverside of Pekalen River. The geothermal source of Tiris has a potential of 74 to 147 Mwe and has a surface temperature 37°C–46°C with an area of 11 km^2 [8, 10, 11]. The geothermal manifestation potentials in this area can be utilized as a source of energy, especially for alternative power plant. Thus, the existence of geothermal prospect in Tiris village needs to be investigated in order to obtain information related to geothermal reservoir rock layer. One step in the investigation of the existence of geothermal prospects in the region of Tiris is through a preliminary study.

Preliminary study that can be used to know the potential of geothermal is by geophysical survey. Geophysical surveys are used to view subsurface structures. One method that can be used to detect geothermal is by gravity method [8]. The gravity method is one of the geophysical exploration methods used to measure the variation of the earth's gravitational field due to the difference in density between rocks. In practice, this method studies the difference of gravitational field from one point to another. Therefore, that source which is a mass zone beneath the surface of the earth will cause a disturbance in the gravitational field called a gravitational anomaly [12].

The gravity method has an advantage that can provide enough detail information about the geological structure and contrast of rock density. In the case of geothermal, difference in rock density is a reference in the investigation of gravity methods. Meanwhile, the area of the heat source and its accumulation below the earth's surface can cause a density difference with the surrounding rock mass [13]. In addition, the gravity method can clearly record the value of the gravitational acceleration of a point under the influence of the geothermal indicated by the low value of the rock density in the zone. The use of the gravity method in analyzing rock density is considered appropriate since this method possesses an excellent response to the density of the subsurface rocks [14]. Focusing on the superiority of the gravity method in terms of subsurface estimation, this method is to reconcile the type of subsurface rocks under the geothermal region of Tiris Probolinggo, East Java.

GEOLOGICAL SETTING

Geothermal manifestations on Tiris Village (498 mdpl) is located in valley between Argopuro volcano and Lamongan volcano. The potential of geothermal energy is shown by the emergence of hot springs in Tiris village. The hot springs come out of the cracks in the andesite breccia [8]. The geological structures that developed in the study area were stocky and cesareanized. The faults develop in the Argopuro andesitic lava, Tengger andesitic lava and the morphological alignment of Argopuro pyroclastic flows. The presence of faults in this area is as hydrothermal fluid lane reaches on the surface. This affects the pattern of alteration distribution and the appearance of hot springs [15]. Volcano-stratigraphically, the region of Tiris has two eruptive centers of the development of volcanic activity taking place in this area. The assessed area has the geothermal prospect of being at the top of Mount Lamongan as an upflow characterized by the discovery of fumarole and rock alteration, while the outflow zone is estimated to lead northeast from Mount Lamongan [16].

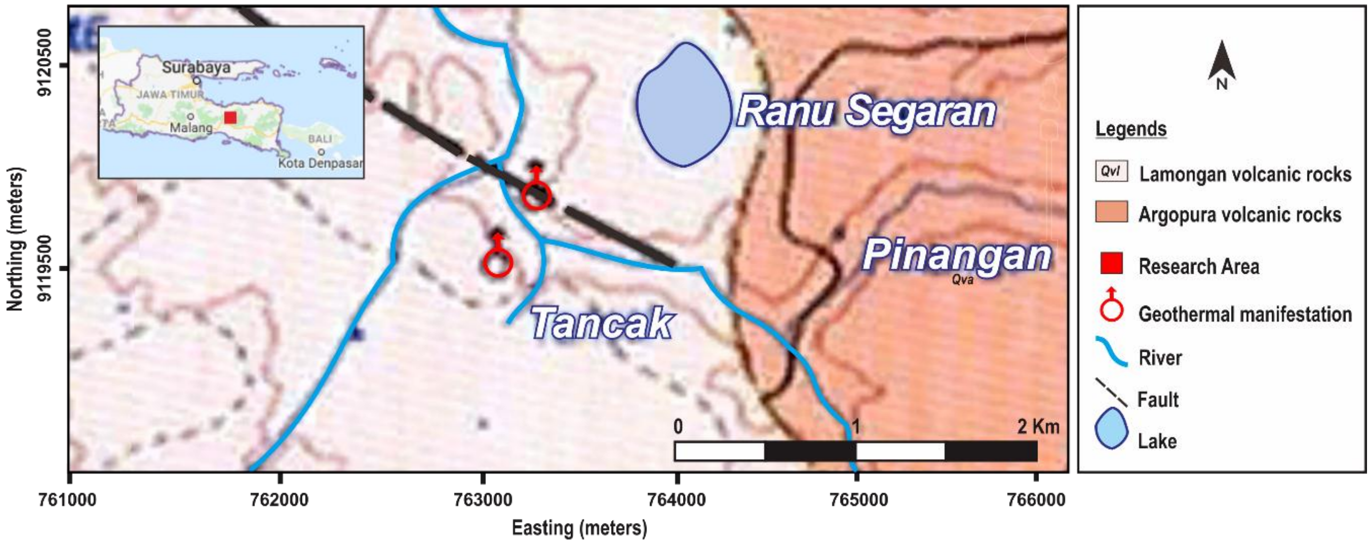


Figure 1. Geological map and tentative model of geothermal Tiris. Modified from Probolinggo geological map [11].

METHODS

Gravity measurements in Tiris were performed on 55 acquisition points (Figure 2) using Gravitymeter LaCoste & Romberg type G-1053 as acquisition devices. Gravitymeter type G-1053 is mechanical gravitymeter in which all errors data acquisition can be measured by the value of the calibration factor of the tool. Meanwhile, the distance between the acquisition points used in the survey design was 100 m. Base point used in the field was tied first with the first derived connective point in the Physics Building of Brawijaya University Malang.

The measured gravity data in the field was first converted into gravity unit miliGal and then applied corrections to the gravity data. The corrections were tidal correction, drift correction, normal gravity correction, free air correction, Bouguer correction and terrain correction. Various data correction was performed to reduce the unknown factors that exist beneath the surface to change the value of gravity to obtain the value of gravity anomaly (Bouguer anomaly). Bouguer anomaly is simply the difference between the observation gravity value and the theoretical gravity value in a particular reference plane in a measurement point. This anomaly arises because the earth's interior density is not homogeneous [17] and the anomaly value is obtained by the following equation [15, 18]:

$$\Delta g = g_{obs} - g_{\phi corrected} \quad (1)$$

$$g_{\phi corrested} = g_{\phi} - FAC + BC - TC \quad (2)$$

Hence obtained:

$$\Delta g = g_{obs} - g_{\phi} + FAC - BC + TC \quad (3)$$

Where, Δg is the complete Bouguer anomaly (mGal), g_{obs} is the accidents of gravity corrected with tidal and drift (mGal), g_{φ} is the normal gravity value at the point of measurement (mGal), *FAC* is free air correction (mGal), *BC* is Bouguer correction (mGal), and *TC* are Terrain correction (mGal). Normal gravity correction (g_{ϕ}), *FAC*, *BC* and *TC* are theoretical values of gravity [18].

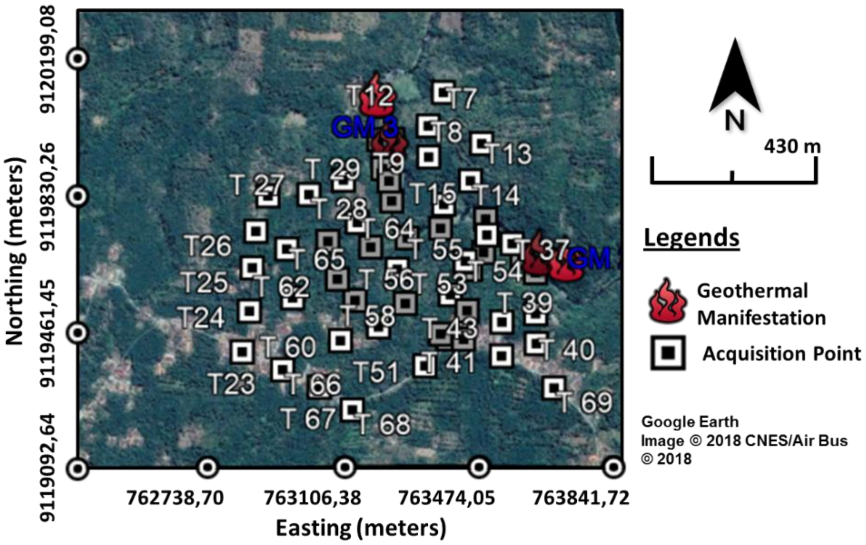


Figure 2. Map of gravity acquisitions based on Google Earth.

Complete Bouguer anomaly values obtained were still at their respective topographic heights then projected into a plane at the same height. This projection result was used as an initial data of upward continuity process in which this process was used to separate complete Bouguer anomaly into regional anomaly and residual anomaly. Regional anomaly is isostatic compensation based on regional topographic loads that can be correlated with the presence of basement. Meanwhile, residual anomaly can be correlated with more shallow geological structures [18, 19]. Therefore, a quantitative and qualitative analysis of residual anomaly is required in estimating the geothermal reservoir structure of Tiris village.

RESULT AND DISCUSSION

Based on the results of data processing, the complete Bouguer anomaly value obtained ranged from 49-63 mGal and after upward continuous, residual anomaly value was obtained between -8.5–5.5 mGal (Figure 3). Qualitatively it was interpreted that residual anomaly had value ranged from -8.5 to 5.5 mGal because it was influenced by the effects of surface geology. Based on the residual anomaly map (Figure 4), the spread of positive to negative anomaly values occured from the sides to the middle and only in some places where the changes were significant.

Negative contour area visible on the residual anomaly map may be indicated as area that had changed due to a geothermal system. If the negative contour area was overlaid with a regional geological map it was seen that the area was affected by a normal fault (Figure 4). The fault spread along the east-west direction with the negative contour area of the residual anomaly. According to Figure 4, there was also a hot spring affecting the negative contour pattern of residual anomaly. A low residual anomaly pattern can be indicated that the rocks that fill the area were rocks with a lower density contrast value than the surrounding density value of the rock.

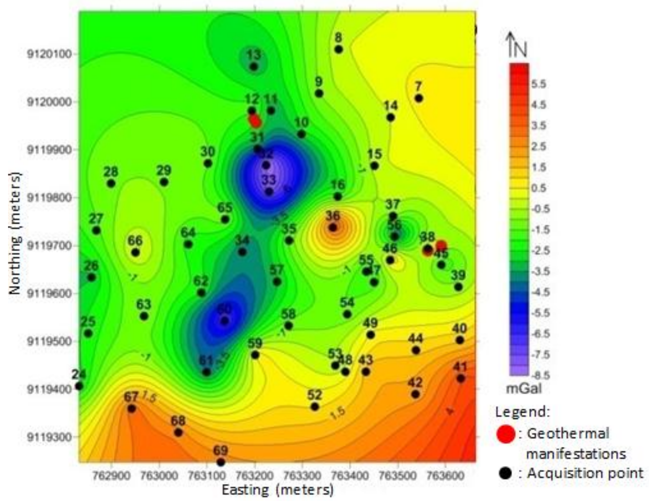


Figure 3. Contour map of residual anomaly.

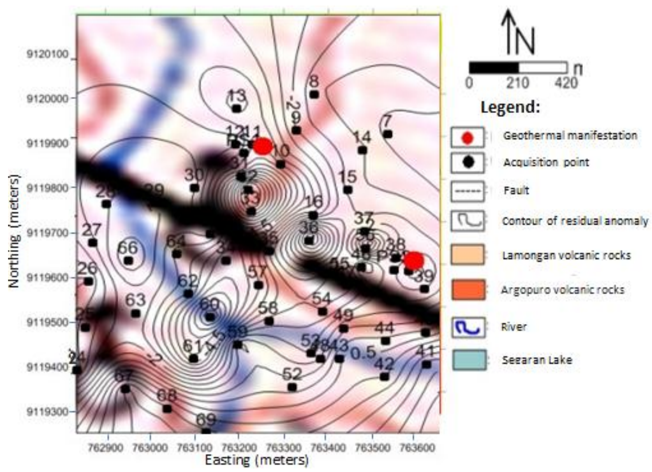


Figure 4. Map overlay of residual anomalies with regional geology.

It was interpreted that the low anomaly pattern was composed of rocks that had undergone alteration due to hydrothermal, and could serve as a way out for the geothermal heat fluid to get out to the surface.

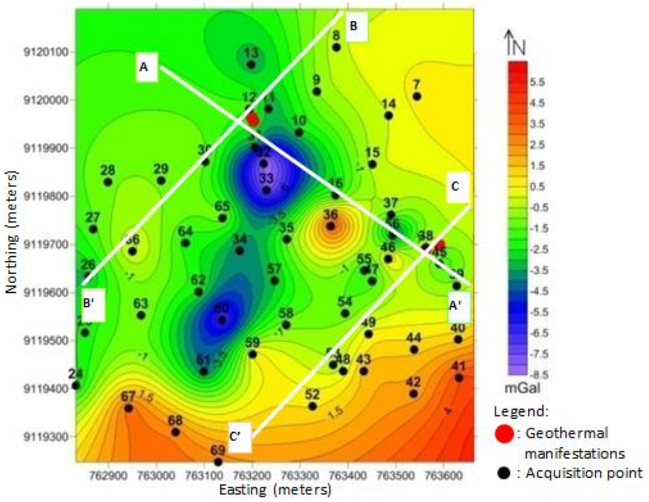


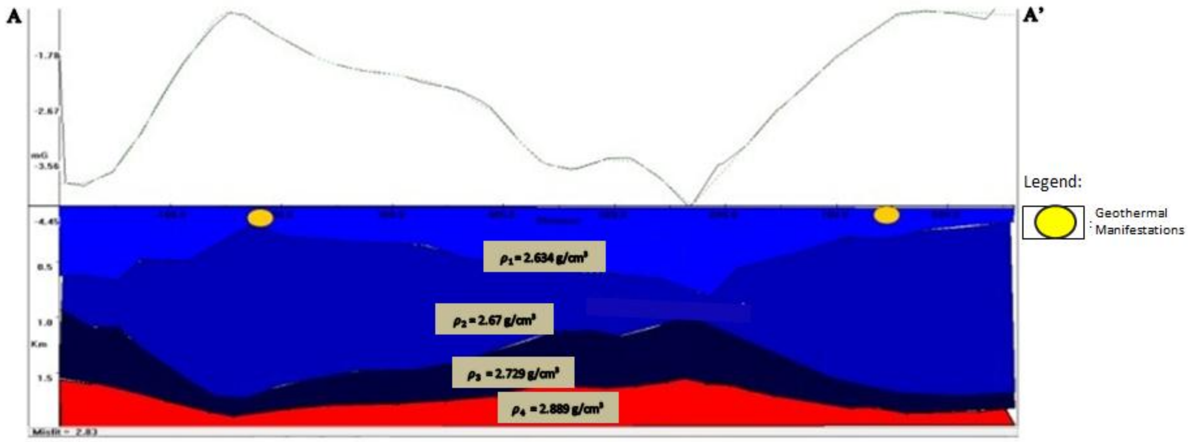
Figure 5. Cross-sectional lines of A-A', B-B', and C-C'.

Quantitative interpretation was performed by modeling the cross-section of the subsurface structure of the residual anomaly map. The cross-section model was obtained from the digitized incision on 3 lines (Figure 5). Based on Figure 5, line A-A' was made crossline B-B' and line C-C'. Every line had various distance, with line A-A' was 866 meters, line B-B' was 878 meters and line C-C' was 665 meters. Something that must be noticed when conducting modelling, each incision must overleap an anomaly point that is negative and positive. The modeling of each incision was performed by inversion technique to know the density value and the matching curve technique to approximate the potential field graph of the forward modeling result to the graph of the result of digitized residual anomaly. During this process the error value was controlled so that the result of the cross-sectional model approached the profile according to the regional lithology where the smaller error value signified that the model made was more accurate [18].

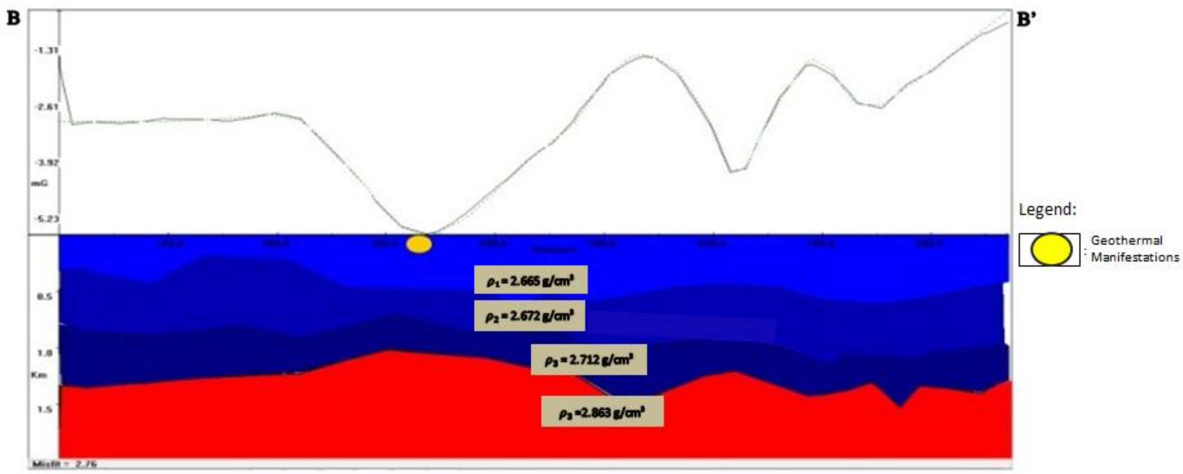
The residual anomaly cross-sectional graph of lines A-A', B-B' and C-C' (Figure 6) consists of the *x*-axis representing the line distance (meters), the positive *y*-axis is the residual anomaly digitized (mGal), and negative *y*-axis is value of estimated depth (meter or km) in which the study used a maximum depth of 2 km. Based on Figures 6a, 6b, and 6c it appears that the results of the A-A', B-B', and C-C' cross-sectional models have 4 types of layers with different density values. Each layer of each cross-section represents a notably different density value. Estimated density values of four types of layers, where in the first layer density (ρ_1) is 2.623 – 2.665 g/cm^3, the second layer density (ρ_2) is 2.670 – 2.672 g/cm^3, the third layer density (ρ_3) is 2.675 – 2.729 g/cm^3, and the fourth layer density (ρ_4) is 2,732 – 2,889 g/cm^3.

Sequentially, the four ranges of density values in terms of the lithology of the regional geological map are Lamongan volcano tuff-breccia rocks (ρ_1), Lamongan volcano breccia-lava rock (ρ_2), Argopuro volcanolava-andesitic rocks (ρ_3), and old-Tengger volcano breccia-andesitic rocks (ρ_4) [16]. The cross-section of A-A'is dominated by a layer of ρ_2 with depth ranging from 0 to -1000 m a.s.l and suspected as Lamongan breccia-lava rocks. The cross-sectional model of B-B' and C-C' is more dominated by layers of ρ_4 in depth -1000 to -2000 m a.s.l and suspected as old-Tengger deposit of breccia-andesite rocks.

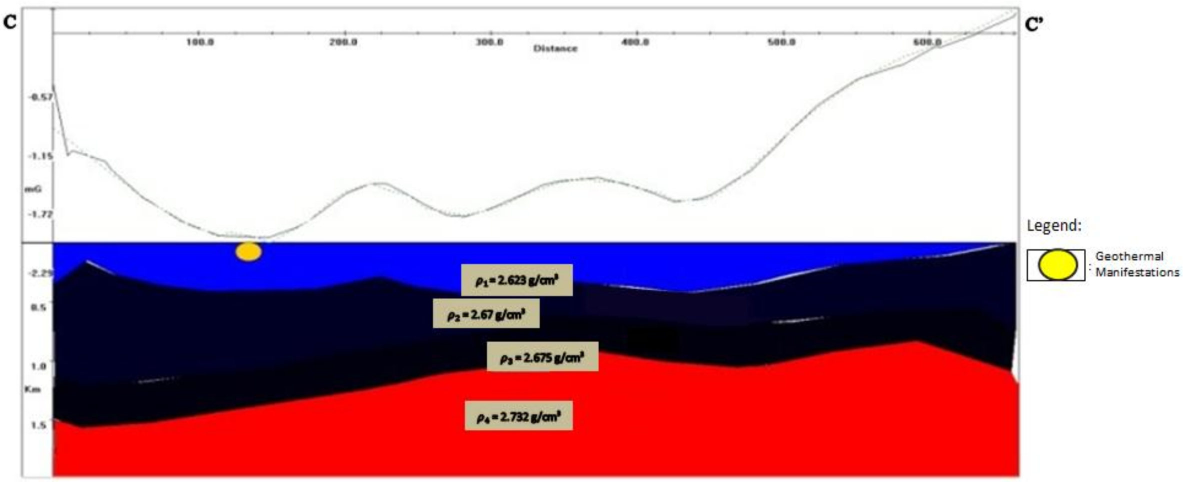
Argopuro andesitic-lava rock layer is estimated as a source of heat because it volanicactivity is still detected. Layers of breccia-lava of Lamonganvolcano that lies above the andesitic-lava rock layer of Argopuro volcano is estimated as a reservoir rock from the heat of the Tirisvillage. Thesubsurface river water is allegedly passed through this reservoir layer through the crevices of the breccia-lava rock layer so that the water gets heat contact directly from the layer below it. In addition through the cracks of breccia, the fractures caused by the normal fault in the study area become the hydrothermal transfer lane to the surface.



(a)



(b)



(c)

Figure 6. Cross-section models for line (a) A-A', (b) B-B' and (c) C-C'. The cross-sections consist of four-density value layers i.e. $\boldsymbol{\rho_1}$ is 2.623 – 2.665 g/cm^3,$\boldsymbol{\rho_2}$ is 2.670 – 2.672 g/cm^3, $\boldsymbol{\rho_3}$ is 2.675 – 2.729 g/cm^3, and $\boldsymbol{\rho_4}$ is 2,732 – 2,889 g/cm^3.

CONCLUSIONS

The complete Bouguer anomaly value in research area has range from 49 to 63 mGal. Separation of regional anomaly and residual anomaly from complete Bouguer anomaly using upward continuation obtained residual anomaly value ranged from -8.5 - 5.5 mGal. Correlation of residual anomaly with geological map shows that negative contour of residual anomaly is representation the normal fracture that located at research area.The result of cross-section model in lines A-A', B-B', and C-C'derived from inversion analysis of regional anomaly which theyhave influenced by 4 layers density. All four rocks layers are tuff of Lamongan volcano have density value 2.634-2.665 g/cm^3, breccia-lava of Lamongan volcano have density value 2.67-2.672 g/cm^3, andesitic-lava of Argopuro volcano have density value 2.712 -2.729 g/cm^3, and breccia-andesite of Tengger old volcano have density value 2.863-2.889 g/cm^3.Lamongan breccia-lava rocks is estimated as reservoir, while Argopuro lava-andesite rocks is estimated as geothermal heat source at Tiris village. Layers of lava-breccia rocks with large porosities that is affected by fracture causing hydrothermal fluids to pass into the soil surface.However, as a preliminary study, this research shall be developed to establish the direction of hydrothermal fluids distributionand Tiris geothermal system itself in detail.

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REFERENCES

[1] Zarkasyi A., 2015, Geothermal Research Handbook, Geology Agency and Ministry of Energy and Mineral Resources, Bandung, Indonesia.

[2] Governor of East Java, 2016, Environmental Management Performance Information of East Java Province Year, Surabaya, Indonesia.

[3] Maryanto, S., Arisalwadi, M., Syahra, V., & Triastuty, H. 2017. Polarization of Volcanic Tremor Recorded at Bromo Volcano, East Java, Indonesia. International Journal of Applied Environmental Sciences 12 (11): 1993-2005.

[4] Maryanto S., Wicaksono A., Azhari A. P., Dewi C. N., Foster J., Nadhir A., and Abdurrouf (2015). Multi Geophysical Observations at Blawan-Ijen Volcano Geothermal Complex for Regional Development. J. of Env. Eng. & Sus. Tech. 2(2): 105-113.

[5] Maryanto S., Suciningtyas I., Dewi C. N., and Rachmansyah A (2016). Integrated Resistivity and Ground Penetrating Rada Observations of Underground Seepage of Hot Water at Blawan-Ijen Geothermal Field. Intl. J. of Geophys. 2016: 23-37. http://dx.doi.org/10.115/2016/6034740.

[6] Maryanto, S.; Dewi, C.N.; Syahra, V.; Rachmansyah, A.; Foster, J.; Nadhir, A.; Santoso, D.R. Magnetotelluric-Geochemistry Investigations of Blawan Geothermal Field, East Java, Indonesia. Geosciences 2017, 7, 41.

[7] Maryanto, S., Santosa, D. R., Mulyana, I., & Hendrasto, M. 2011. Fractal and chaos properties of explosion earthquakes followed by harmonic tremor at Semeru volcano East Java, Indonesia. International Journal of Scientific & Engineering Research, 02(07): 1-7.

[8] Directorate of Geothermal, Directorate General of EBTKE Center for Mineral, Coal and Geothermal Resources, and Geological Agency, 2017, "Potential Geothermal Indonesia," Ministry of Energy and Mineral Resources, Jakarta, Indonesia, Vol. 1.

[9] Suprianto, A., Wahyudi, W., Suryanto, and Subekti, A., 2015, "Modeling of Seismic Wave Propagation at Tiris Geothermal Area Using 2D Spectral Element Method (SEM)," Appl. Mech. Mater., 771, pp. 257–260.

[10] Jaya, M., Jousset, P., Deon, F., Gassner, A., Putriatni, D, Supoyo, Suprianto, A., Putra, T., and Erbas, K., 2013, "Passive Seismic Monitoring Studies at Tiris Geothermal Field in East Java, Indonesia," Proc. EGU General Assembly 2013, Vienna, Austria, p. 13637.

[11] Suprianto, A., Supriyadi, Priyantari, N., Pujiastutik, R., Suryanto, W., and Wahyudi, 2017, "Magnetotelluric Responses at Tiris Geothermal Area Based on One-Dimensional Recursive Forward Modeling Method," IOSR-J. App. Geol. & Geophy., 5(5), pp. 37–42.

[12] Hidayat, N., and Basid, A., 2011, "Gravity Anomaly Analysis as Reference in the Determination of Geological Structure Under Surface and Geothermal Potential (Study Case: Songgoriti, Batu City)," J. Neutrino, 4(1), pp. 35–47.

[13] Raehanayati, Rachmansyah, A., and Maryanto, S., 2013, "Study of Geothermal Energy Potential of Blawan-Ijen, East Java Based on Gravity Method," J. Neutrino, 6(1), pp. 31–39.

[14] Lowrie, W., 2007, Fundamentals of Geophysics 2nd Ed., Cambridge University Press, Cambridge, United Kingdom, Chap. 2.

[15] Telford, W. M., Geldart, L. P., and Sheriff, R. E., 1991, Applied Geophysics 2nd Ed., Cambridge University Press, Melbourne, Australia, Chap. 2.

[16] Suharsono and Surwati, T., 1992, "Geological Map of The Probolinggo Quadrangle, Jawa (1:100.000)," Geological Research and Development Centre, Bandung, Indonesia.

[17] Handayani, L., and Wardhana, D. D., 2017, "Gravity Exploration for Groundwater and Bedrock Topography in Serang, Banten," Ris. Geol. dan Pertamb., 27(2), pp. 157–167.

[18] Purnomo, J., Koesuma, S., and Yunianto, M., 2013, "Separation of Regional-Residual Anomaly on Gravity Method Using Moving Average, Polynomial and Inversion," Indones. J. Appl. Phys., 3(1), pp. 10–20.

[19] Ilmi, S., Harmoko, U., and Widada, S., 2014, "Interpretation of Geothermal Subsurface Systems at Diwak and Derekan Based on Gravity Data," Youngster Phys. J., 3(2), pp. 165–170.