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Imaging Reservoir Structure of Mt. Pancar Geothermal Prospect Using Audio-Frequency Magnetotelluric (AMT) and Gravity Technology

Yunus Daud[1,2], Syamsu Rosid[1,2], Wambra Aswo Nuqramadha[3], Fikri Fahmi[1,3], Anugrah Indah Lestari[3], Diajeng Liati[3], Adila Armando[1], Tri Widjaya Putranto[2], Fitriyani Mustika Ruslita[2]

[1]Master Program of Geothermal Exploration, Universitas Indonesia, Jakarta, Indonesia
[2]Geothermal Laboratory, Physics Department, Universitas Indonesia, Depok Campus, Indonesia
[3]PT NewQuest Geotechnology, Depok, Indonesia

ydaud@sci.ui.ac.id

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ABSTRACT

Mt. Pancar geothermal prospect area is located in Bogor district, West Java. The geological condition of the area is dominated by quaternary volcanic rock which probably associated with Mt. Pancar as a parasitic cone of Mt. Gede-Pangrango. Surface thermal manifestations that can be found in this area are altered rocks, warm grounds, and neutral pH hot springs with temperature range of 45 to 68^{o}C. The manifestations are distributed in the eastern and northern side of Mt. Pancar. However, there is no impressive manifestation found on the top of Mt. Pancar. It indicates that geothermal system in Mt. Pancar is classified as low to moderate temperature system. Based on Na/K geothermometry, the estimation of subsurface temperature in Mt. Pancar geothermal prospect is in the range of 140 to 180^{o}C. In order to develop conceptual model and understand the subsurface structure in the prospect area, geophysical methods including Audio-frequency Magnetotelluric (AMT) and Gravity were then conducted. To overcome the complex volcanic-tectonic structure, 3-D inversion of AMT data was performed using MT3DINV-X Software with frequency ranging from 1 Hz to 10 kHz. The results of 3-D AMT inversion show the presence of conductive layer. It is interpreted as clay cap distributed between Mt Pancar and Kawah Putih and between Mt Pancar and Kawah Merah. The conductive layer has value of less than 15 ohm-m with its thickness varies from 500 meters to 1500 meters. The up-dome shape was found beneath Mt Pancar and it was interpreted as upflow zone. The resistive layer found underlying clay cap layer with resistivity range of 20-100 ohm-m is indicated as reservoir zone. The highest resistivity layer (>100 ohm-m) is indicated as basement of Mt Pancar. The indication of geothermal reservoir obtained by AMT data is also indicated by gravity data. Complete bouguer anomaly (CBA) and residual anomaly data show that the region of Mt. Pancar is dominated by low gravity anomaly. Two-dimensional forward modeling result of gravity data also shows the indication of clay cap with low density layer. It supports the indication from AMT data. Therefore, integration of resistivity and density model supported by geological and geochemical data was used to develop conceptual model.

1. INTRODUCTION

Indonesia is a country blessed with huge geothermal resources potential. The geological setting of Indonesia may encourage various types of geothermal system. Based on the temperature, geothermal system in Indonesia can be classified as low-to-moderate and high temperature geothermal system. Nowadays, Indonesia has been developing high temperature geothermal systems intensively and for the next step the low to moderate geothermal systems will be utilized by applying the appropriate technology. One of the low-to-moderate temperature geothermal system in Indonesia is Mt. Pancar geothermal prospect.

Mt. Pancar geothermal prospect area is located in the Bogor district, West Java, Indonesia. Since 2009, Mt. Pancar has become the object of research by Geothermal Laboratory of the Department of Physics, Universitas Indonesia, through the Geophysics Field Camp Program (Daud et al, 2015). In 2014, at least 155 gravity stations and 18 Audio-magnetotelluric (AMT) stations have successfully measured. Additional gravity and AMT data acquisition were caried out in 2016 to complete the existing data in order to have better understanding of Mt. Pancar geothermal system.

Magnetotelluric (MT) method is the most cost-effective geophysical method which can be applied for geothermal exploration. The MT method has ability for detecting the conductive altered rock formed at temperature range of 70^{o}C to 200^{o}C. The cause of this has been linked with the type of clay alteration that occurs in this temperature range (Ussher et al, 2000). In this reasearch, we have conducted AMT method, a high-frequency MT technique. The method is applied in the frequency range from 0.1 Hz to 10 kHz. The Gravity method has been also performed to support the AMT data. 3-D inversion approach is selected to get more realistic resistivity structure over the complex geological structure of the Mt. Pancar geothermal prospect. Whereas the gravity method is used to give an understanding of subsurface structures that control geothermal system in Mt. Pancar. Gravity method has been widely used in several geothermal prospects such as in Sibayak Geothermal Field (Daud et.al., 2001). The study shows that gravity anomaly has good correlation with the subsurface geological condition. It can also support MT data for giving geological structure which control the reservoir geometry (Daud et al, 2002). Two-dimensional gravity forward modeling was then conducted to describe the geothermal subsurface structures in Mt. Pancar. It is also cross checked by 3-D inversion result of AMT data.

2. GEOLOGICAL SETTING AND SURFACE MANIFESTATIONS

Mt. Pancar geothermal prospect area is located on 871 m elevation above sea level. Based on regional geological map of the Bogor Quadrangle Java, the Bojongmanik formation consist of tertiary sedimentary rocks. The presence of sedimentary rock found as claystone outcrop around Mt. Pancar during geological field checking. In the southen part, there is a quaternary volcanic formation of Mt. Panisan formation as a basement (Figure 1). The regional and local structures surrounding Mt. Pancar area are dominated by northeast-southwest and northwest-southeast structure orientation.

The surface thermal manifestations found in Mt. Pancar geothermal area are hot springs, warm grounds, and altered rocks. The manifestations are distributed in the eastern and northern side of Mt. Pancar. However, there is no impressive manifestations in Mt. Pancar Summit. Three hotsprings found in the lower vicinities of Mt Pancar area are Kawah Merah (T = 68.4°C), Kawah Hitam (T = 58.1°C), and Kawah Putih (T = 47 °C). The whole hotsprings are classified as neutral hotsprings with pH range of 6.4 to 7.7. Water chemical analysis shows high chloride content in the Kawah Merah (about 1000 ppm). Based on Na/K geothermometry, the estimation of the subsurface temperature in Mt. Pancar geothermal prospect is in the range of 140 to 180°C.

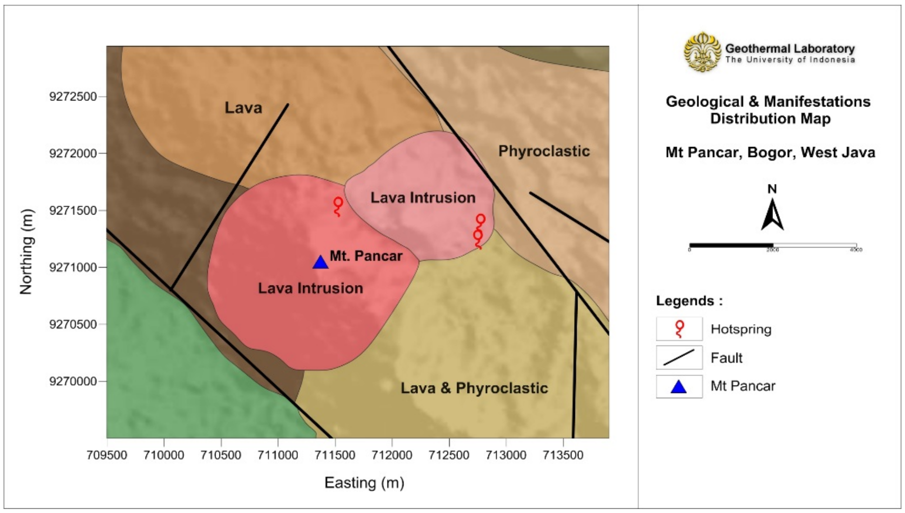

Figure 1: Geological and Manifestations Distribution Map

3. AMT AND GRAVITY SURVEY

AMT and gravity method were conducted in Mt Pancar to develop the conceptual model of Mt Pancar Prospect Area . The AMT survey has carried out using Phoenix equipment system in 2013, 2014, and 2016. The total AMT stations that had been successfully measured until 2016 are 32 stations covered the andesitic intrusive body and the manifestations around Mt. Pancar (Figure 2). The duration of AMT measurement was about 2 hours per station and it could obtain the data with frequency range of 0.1 Hz to 10 kHz.

The gravity survey in Mt. Pancar geothermal area has carried out since 2009 using Scintrex Gravimeter CG-5. The total gravity stations already measured until 2016 were 236 stations. The gravity station was distributed in a grid survey design with spacing is about 250 m (Figure 3).

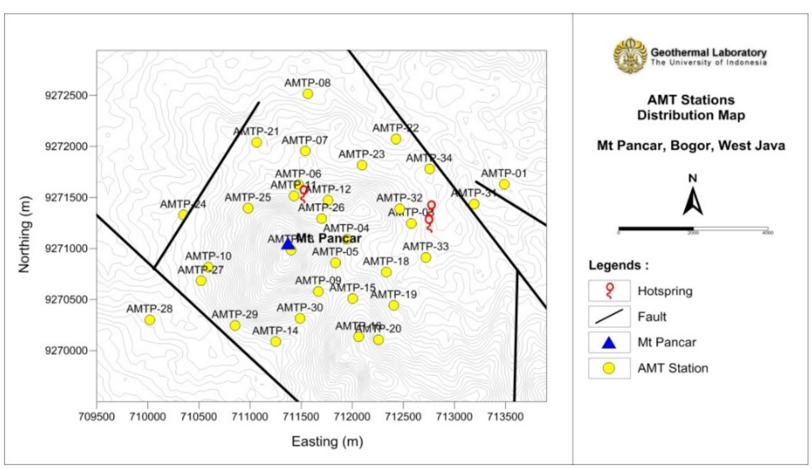

Figure 2: AMT Stations Distribution Map

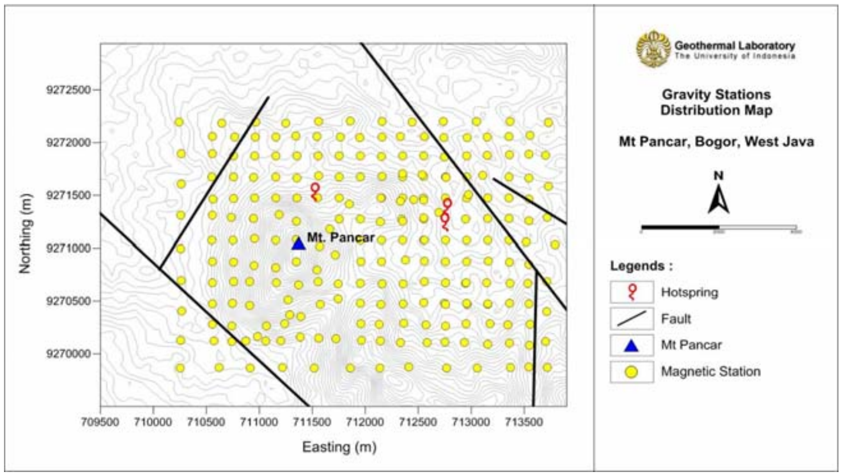

Figure 3: Gravity Stations Distribution Map

4. 3-D INVERSION OF AMT DATA

3-D inversion has been performed to 32 AMT data. The AMT data quality can be accepted to be calculated in 3-D inversion. The 3-D inversion process has done using MT3DINV-X Software (Daud et al, 2012). The software was built using occam's inversion and data space algorithm which has developed by Siripunvaraporn (2011).

The initial model within a meshgrid form is needed as input for running 3-D inversion process. The block size was set 150 m along x and y axis and 20 m along z axis, the next block is multiplied by 1.5 so the block size would increase gradually. The total blocks of x, y, and z axis are 36, 32, and 22 blocks. Whereas the total block of the whole meshgrid are 25344 blocks. The initial resistivity model used is 100 ohm.m homogenous resistivity.

Full tensor data had been performed in the inversion process. All of the impedance tensor components were used (Zxx, Zxy, Zyx, Zyy) with 8 sampling period from each AMT data (frequency range of 0.3 Hz to 10 kHz). Error floor magnitude were restricted to 5% to minimize RMS error value. The inversion process produced model data in (x, y, z) format. The 3-D inversion result was then visualized using GeoSlicer-X software (Daud and Saputra, 2010).

5. GRAVITY PROCESSING AND 2-D GRAVITY MODELING

Gravity data acquired from the acquisition process are relative gravity value and the time of measurement. Those data are converted into absolute data or Gobs. Several reduction have been applied towards Gobs data to produce Complete Bouger Anomaly (CBA) data.

Firstly, the gravity relative data were corrected by drift correction. The drift correction were done by dividing the total gravity drift into every stations proportional to time. The largest drift correction of overall data is 2.6. The corrected relative data from drift correction were then converted into absolut gravity data (Gobs) by using basecamp absolute gravity.

Acquired Gobs are reduced into complete bouguer anomaly. There are several corrections applied towards the data. The corrections are latitude correction, free air correction, bouguer correction, and terrain correction. The overall reduction processes are shown by the following equation :

$$CBA = Gobs - Gn + 0.3086h - 0.04193\boldsymbol{\rho}h + TC$$

Where CBA is complete bouguer anomaly, Gobs is station absolute gravity, Gn is latitude correction, and TC is terrain correction. Bouguer density was acquired by using Parasnis technique and the Bouguer density value was 2.56 g/cm3. Those density value was used in Bouguer correction and terrain correction calculation. Terrain correction was done using elevation data which were acquired from ASTER DEM. Complete bouguer anomaly was separated into regional and residual anomaly data by utilizing Trend Surface Analysis method toward CBA data. Then residual anomaly data were used to develop 2-D forward model.

6. INTEGRATED INTERPRETATION AND CONCEPTUAL MODEL OF MT PANCAR GEOTHERMAL SYSTEM

6.1 AMT Result

The 3-D AMT inversion results are shown in the resistivity section of north-south and west-east profiles crossing Mt Pancar (Figure 4 and 5). The resistivity sections show the presence of conductive layer which has value less than 15 ohm-m. The conductive layer is interpreted as the clay cap. It is distributed between Mt Pancar and Kawah Putih and also between Mt Pancar and Kawah Merah. The thickness of the conductive layer varies from 500 meters to 1000 meters. The resistivity sections of line 1 and line 2 show the up-dome shape of conductive layer beneath Mt Pancar. It usually indicates an upflow zone. The clay cap layer seems thickening toward the Kawah Merah hotsprings and the Kawah Putih hotsprings. It could be an indication of lower temperature zone, probably associated with the outflow zone. The resistive layer also found underlying clay cap layer with resistivity range of 20 to 100 ohm-m which is interpreted as a reservoir zone. The most resistive layer (>100 ohm-m) is indicated as basement of Mt Pancar geothermal area.

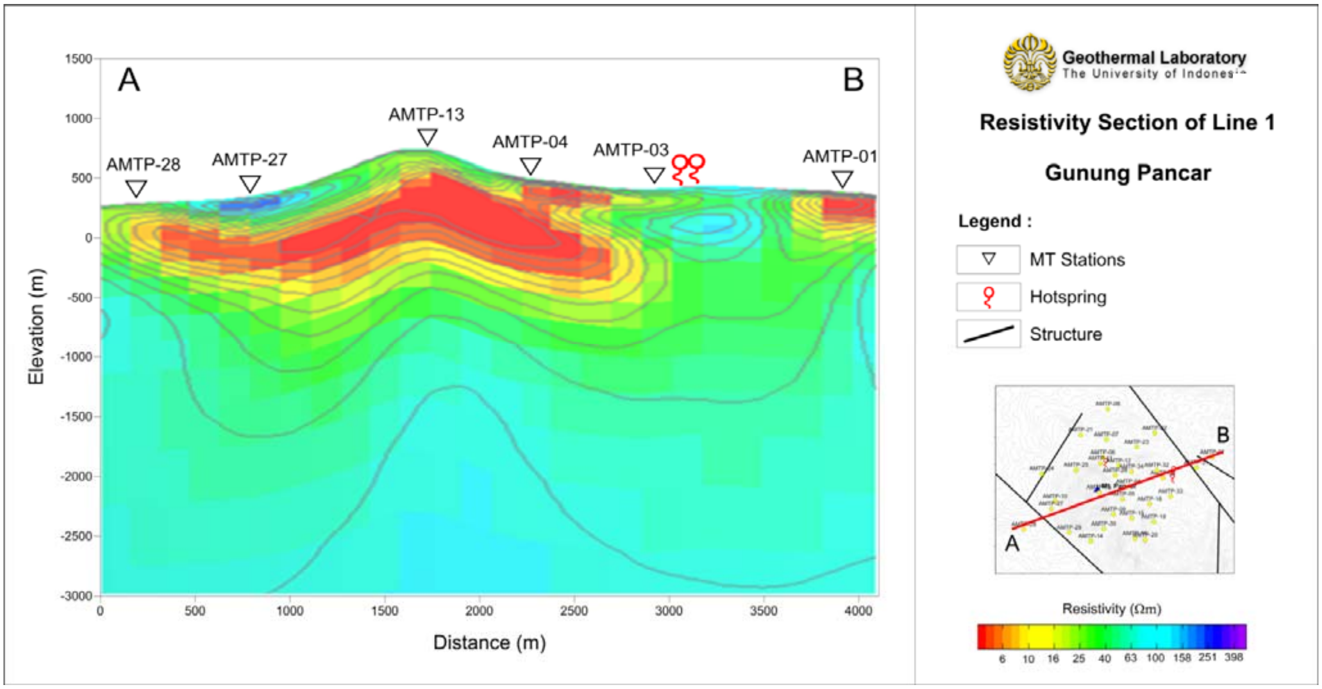

Figure 4: Resistivity Section of Line 1

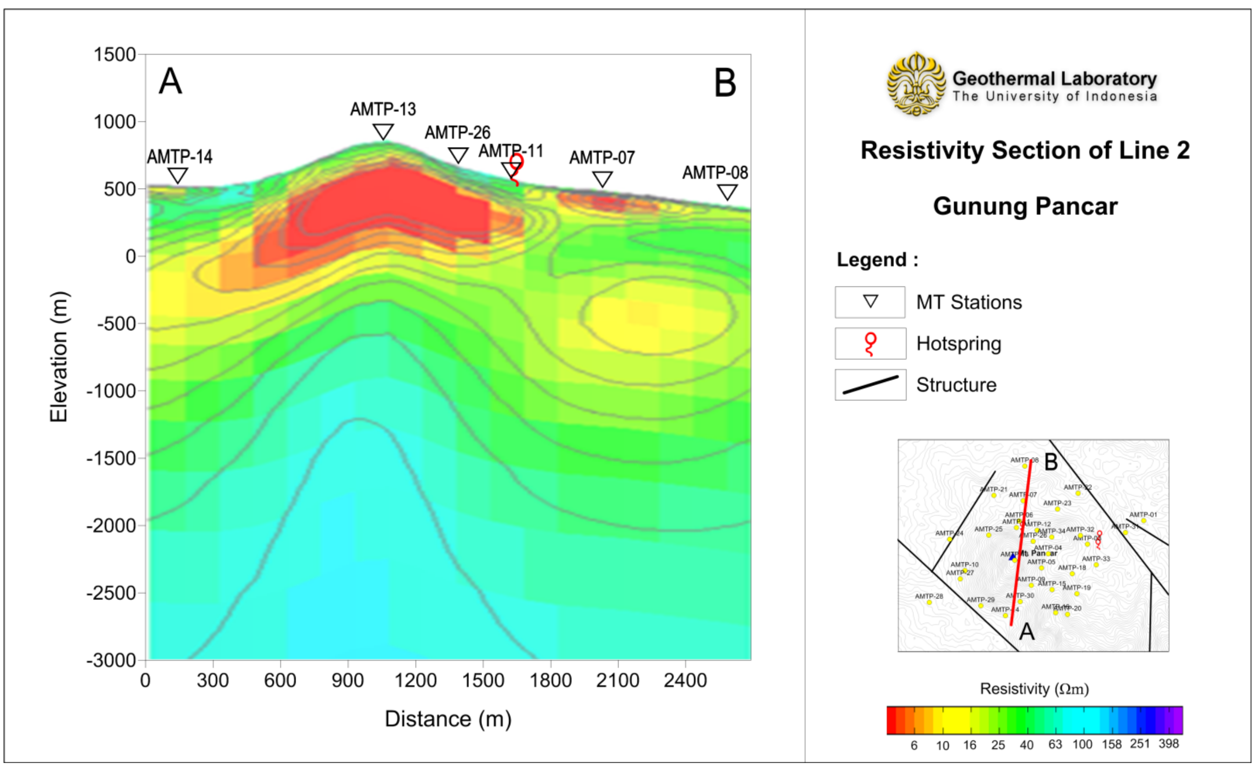

Figure 5: Resistivity Section of Line 2

6.2 Gravity Result

CBA Map shows the distribution of low gravity anomaly at the surrounding of the Mount Pancar (Figure 6). The pattern is also seen in the residual gravity anomaly map, with a value of less than -3 mgal (Figure 7). It is surrounded by high gravity anomalies that have higher value than 1.5 mgal. The low anomaly pattern is represented by the occurrence of low density clay cap surrounding the Mt Pancar – Kawah Putih – Kawah Merah. It also supports the appearance of conductive layer as indicated by the AMT data. 2-D Gravity model also supports the indication of clay cap in vertical distribution (Figure 8). The model is also tied by the AMT result. The pattern of low gravity anomaly is bounded high gravity anomaly. It seems like graben structure in the prospect area.

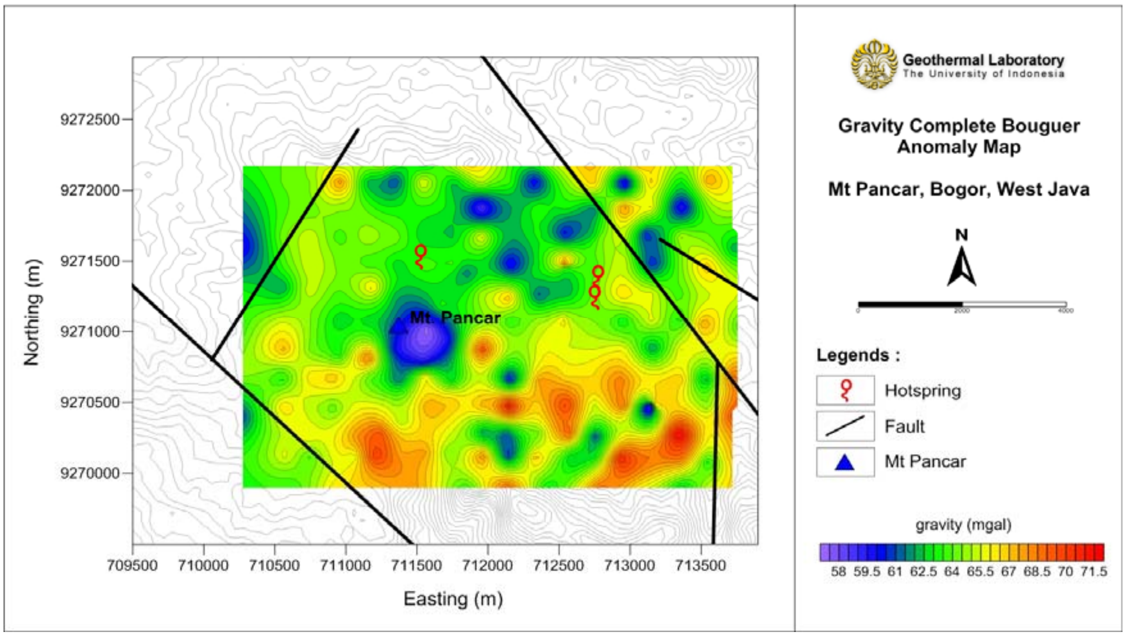

Figure 6: Gravity complete bouger anomaly map

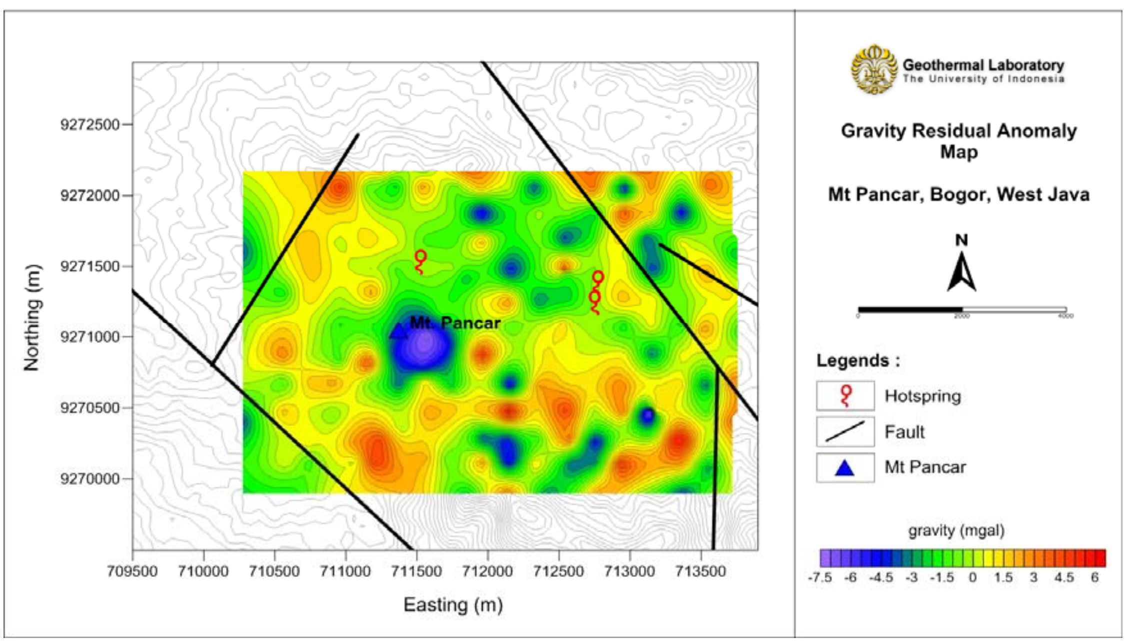

Figure 7: Gravity residual anomaly map

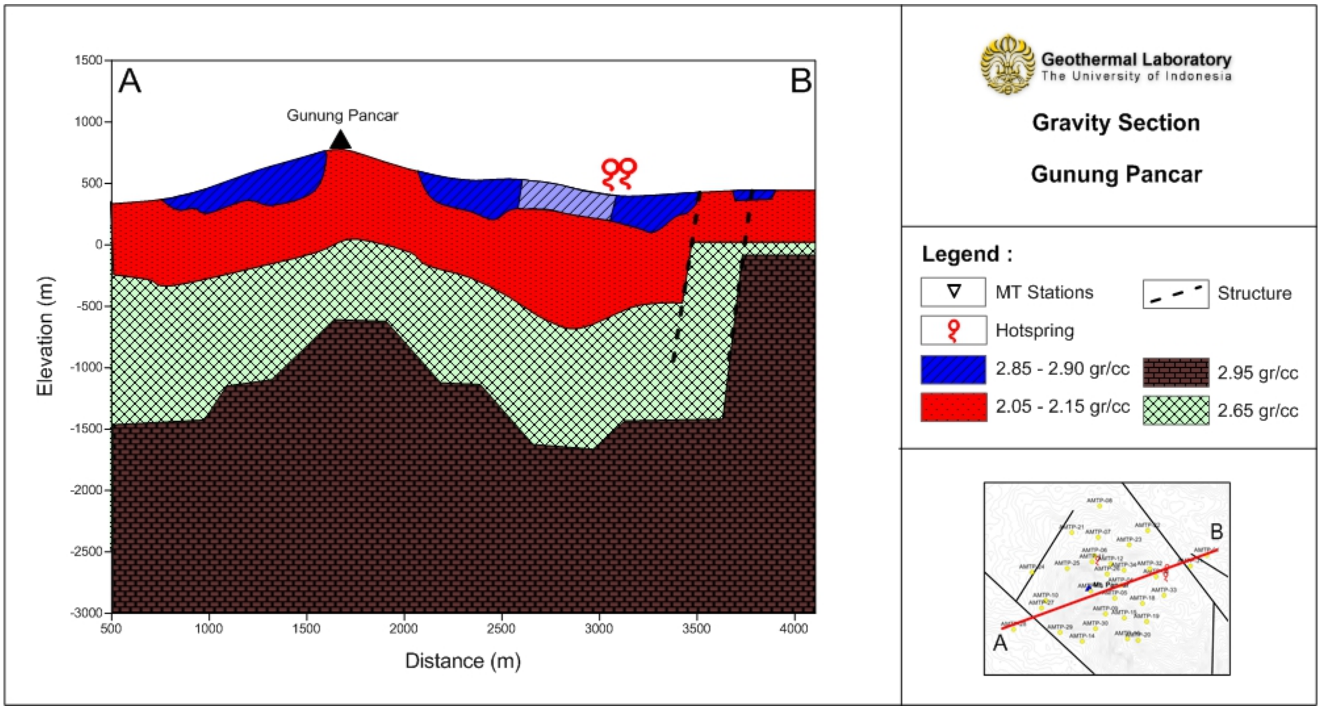

Figure 8: 2-D Gravity model of Mt Pancar Gravity Data along Line AB.

6.3 Conceptual Model of Mt. Pancar Geothermal System

Geologically, the occurrence of geothermal system in Mt Pancar geothermal prospect is probably controlled by a pair of NW-SE geological structure located at the western and the eastern part of Mt Pancar. The appearance of surface manifestations, especially Kawah Merah, is probably also associated with the structures. Based on integrated interpretation result of geoscientific data, the possible upflow is located below the Mt Pancar, while the outflow seems toward Kawah Merah and Kawah Hitam (Figure 9). The indication of the upflow zone is supported by up-dome shape of resistivity structure derived from 3-D inversion of AMT data. The conductive layer, as an indication of clay cap is distributed in the surrounding of Mt Pancar and the manifestations. It is also strengthened by low density layer from 2-D model of Gravity data. Unfortunately, there is no surface manifestation on the top of Mt Pancar. However, resistivity distribution in the subsurface has correlation with the temperature (Ussher et al, 2000). The correlation has also been proved by the other study in Blawan-Ijen geothermal area (Daud et al, 2017). Accordingly, the existence of geothermal reservoir in Mt Pancar geothermal prospect could be identified based on the study result. The assessment of Kawah Merah and Kawah Hitam as the outflow of the geothermal system is supported by chemical analysis result. Kawah Merah has neutral fluid with high concentration of Chloride (1039-1172 ppm).

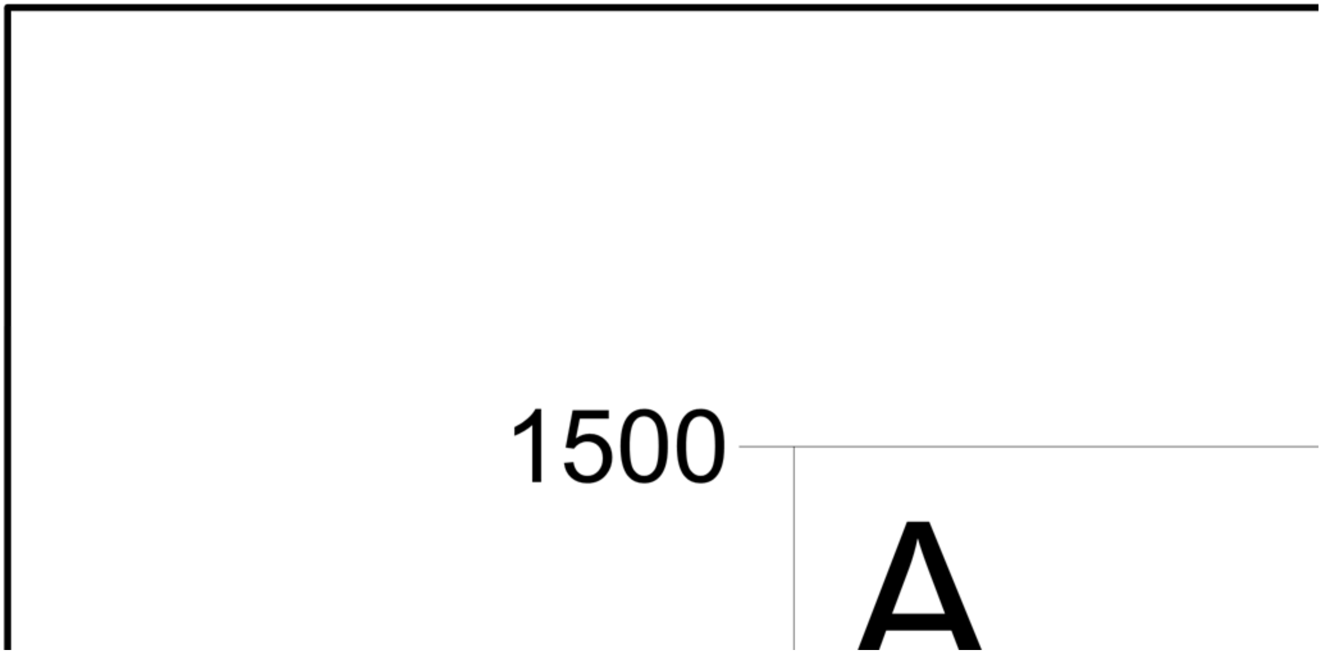

Figure 9: Conceptual model of geothermal system in Mt Pancar.

7. CONCLUSION

Mt Pancar geothermal prospect is located in Bogor district, West Java, Indonesia. The occurrence of geothermal system is probably associated with volcanic product of Mt Pancar. Unfortunately, there is no impressive surface manifestations found on the top of Mt Pancar. However, the existence of altered rock, warm ground as well as neutral pH hotsprings in the surrounding of Mt Pancar indicate possibility of geothermal resource in the subsurface.

Based on the integration of geological, geochemical and geophysical data analysis, the geothermal system in Mt Pancar is probably controlled by a pair of NW-SE geological structure. The structure is located at the western and eastern side of Mt Pancar. The upflow zone of the system is indicated by up-dome resistivity structure derived from 3-D inversion of AMT data. It is discovered below the Mt Pancar. Meanwhile, the outflow of the system seems toward Kawah Merah and Kawah Hitam. The chemical content of Kawah Merah support the indication. Kawah Merah has neutral fluid with high concentration of Chloride (1039-1172 ppm). Furthermore, to confirm the subsurface temperature, it can be recommended to drill a temperature gradient.

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