Proceedings World Geothermal Congress 2000
Kyushu - Tohoku, Japan, May 28 - June 10, 2000

INTEGRATED GEOPHYSICAL STUDIES OF THE ULUBELU GEOTHERMAL FIELD, SOUTH SUMATERA, INDONESIA

Yunus Daud[1], Sayogi Sudarman[2], Keisuke Ushijima[1]
[1] Exploration Geophysics Lab., Fac. of Engineering, Kyushu University, 6-10-1 Hakozaki, Higashi-ku, Fukuoka, Japan 812-8581
[2] Geothermal Division, Pertamina, Gd. Kwarnas Pramuka 5th Floor
Jl.Merdeka Timur 6, Jakarta 10110, Indonesia

Key Words: geothermal, geophysical exploration, Ulubelu field

ABSTRACT

Ulubelu geothermal field is located in the southern part of Sumatra Island, Indonesia. Geophysical studies including gravity, electrical resistivity and self-potential methods have been carried out to explore promising geothermal reservoir conditions within the area. Integrated geophysical data interpretation supported by geology, geochemistry, remote sensing and drilling data has been synthesized to delineate the lateral extent of the reservoir, to assess hydrology within the area and to estimate the reserve potential of the geothermal reservoir. Geophysical studies suggest that the Ulubelu geothermal field could be associated with a graben structure as indicated by the residual gravity anomaly map of the area, supported by two-dimensional gravity modeling. The studies have also revealed two separate up-flow zones with different phase of the reservoir fluids covering a total of 25 km^2 and by an outflow zone in the southern area. The top of the main reservoir is probably 650 m below the surface, where the reservoir temperature is about 260^{0}C, as indicated by gas geothermometer and drilling data. The reserve potential of the geothermal reservoir was estimated to be about 100 MWe for 25 years of electric power generation. These studies have given a good understanding of the Ulubelu geothermal field as an attractive geothermal resource for the future development.

1. INTRODUCTION

The Ulubelu geothermal field is situated about 80 km west of Tanjungkarang in the Lampung Province, Sumatra, Indonesia (Figure 1). Reconnaissance surveys of the Ulubelu area, carried out by Geothermal Division, Pertamina (Indonesian State Oil and Gas Company), started in 1988 and including geological, geochemical and geophysical surveys. More detailed geophysical exploration consisting of Schlumberger electrical resistivity surveys (traversing and sounding), gravity surveys and self-potential surveys were carried out in 1991. Some research has also been carried out in this area (Sunaryo, 1993, Daud, 1995a and 1995b). Integrated interpretation of the existing geo-scientific data of the Ulubelu geothermal field has been very important for assessing the subsurface structures, hydrology and potential energy of the geothermal system. The results can be used to plan for the future development of the Ulubelu geothermal field, and are presented in this paper.

2. SURFACE GEOLOGY AND MANIFESTATIONS

The Ulubelu geothermal field is located in the southern part of the Sumatra Fault Zone (Semangko Fault System). Aerial photography and remote sensing data interpretations of the Ulubelu geothermal field indicate the morphological depression of a faulted graben between Mt Rendingan and Mt Kabawok (Figure 2). The normal faults found in the east, west and south of the area might be the boundaries of the graben structure. Another lineament indicated by the remote sensing data, but not evident from the aerial-photo or by field evidence seems to bound its northern side near the southern slope of Mt Rendingan. The local stratigraphy consists of andesitic and basaltic breccias, pyroclastics, tuffs and lavas (Figure 3). The main formations encountered in the Ulubelu geothermal field are the Mt Rendingan formation, the Mt Kukusan formation, the Mt Duduk formation and the Mt Sula formation. The Mt Rendingan formation is the youngest product and high standing (andesite). No active manifestations occur at the top of this mountain, but hot springs and alteration is encountered on the southern slope. The Mt Kukusan formation is low standing (basaltic) with some circular features. Active surface manifestations occur in this formation including fumaroles, boiling springs, and intensive clay alteration along fault lines. The Mt Duduk formation is sited in between old dacite plugs with hot spring occurrence and alterations. The Mt Sula formation is the oldest and believed to be the reservoir rocks in the Ulubelu field.

3. GEOPHYSICAL DATA INTERPRETATION

3.1 Electrical Resistivity Traversing Data

Electrical resistivity traversing data measurements using Schlumberger configuration were carried out for AB/2 = 250 m, 500 m, 750 m and 1000 m at 137 stations covering almost 85 km^2. The objective of these measurements was to delineate the likely distribution of the geothermal reservoir in the study area. The Schlumberger electrical resistivity traversing data for AB/2 = 1000 meters (Figure 4) shows two separate low resistivity (10 Ohm-meter) anomalies. The first, a low resistivity anomaly (10 Ohm-meter) is distributed around Mt. Kukusan (Kukusan Block) from the central to the southern part of the Ulubelu area and covering 25 km^2. The low resistivity anomaly is associated with active surface thermal manifestations such as fumaroles, solfataras, steaming grounds, steam heated acid sulphate waters and mud pools. These active surface thermal manifestations are typical up-flow manifestations. The southern boundary of the low resistivity area is not clearly defined by the existing data. However, looking at the contour pattern, which is still open to the south, it is possible that the outflow zone occurs to the south of the study area. This interpretation is supported by the occurrence of neutral chloride springs around Mt Way Panas (Figure 2). The second, a low resistivity anomaly, occurs in the southern slope of Mt Rendingan (Rendingan Block) covering 3 km^2. This anomaly is supported by hot springs and alteration at the southern slope of Mt Rendingan. Careful inspection of the apparent resistivity map for AB/2 = 250 m and 500 m (Daud, 1995a) indicates that the low resistivity anomaly does not exist in the southern foothills of Mt.Rendingan. However, an indication of such a low resistivity anomaly first appears on the apparent resistivity map for AB/2 = 750 m. This indicates that its source is deeper.

3.2 Electrical Resistivity Sounding Data

The electrical resistivity sounding measurements were carried out at 21 stations using Schlumberger configuration. The maximum spacing of the electric current electrode from the measurement station, AB/2 is 2000 m. The objective of these measurements is to investigate the vertical distribution of resistivity in the study area, which is very useful in interpreting the existence of reservoir rocks as well as cap rocks. The electrical resistivity sounding (VES) data was interpreted in the one-dimensional approach proposed by Ghosh (1971) using Fortran Codes. In interpreting the resistivity curves, resolution and equivalence problems were taken into account. The problems of equivalent strata were overcome by comparing layer models from 1D interpretations of sounding curves, where the locations of the resistivity soundings in the field are close to each other. The preferred models taken in this interpretation are those which have a good correlation with other sounding interpretations.

Based on the one-dimensional interpretation, a true resistivity cross section was developed to improve understanding of subsurface conditions (Figure 5). Distribution of a conductive layer (true resistivity less than 10 Ohm-meter) extends along the whole section. The occurrence of the conductive layer is probably caused by strong hydrothermally altered rocks (cap rock) consistent with the presence of hydrothermally altered surface rock and hydrothermal manifestations scattered around Pagaralam and Gunung Tiga (see also Figure 2). A resistive substratum (32 Ohm-meter), which is usually correlated with reservoir rock was encountered at about 650 meter depth by the sounding station C-20. This resistive substratum was also indicated by the sounding stations D-05, E-45 and NW-80. However, such a resistive substratum was not detected beneath Pagaralam (station NW-70) nor beneath the southern slope of Mt Rendingan (stations I-53 and A-45). This is probably due to the thick conductive layer in the upper part of the reservoir, so that the injecting current produced during the Schlumberger measurement was only concentrated in the upper conductive layer. As a result the deep reservoir zone represented by the resistive substratum could not be detected by the measurements.

3.3 Gravity Data

Gravity measurements in the Ulubelu geothermal field were conducted at 400 stations. Data reduction and terrain correction were then applied to the observed gravity data to produce Bouguer gravity values. However, the Bouguer gravity values reflect a combination of local and regional subsurface effects. In order to get only local subsurface effects the regional effect was calculated and then subtracted from the Bouguer gravity values. In this study, the regional gravity values over the study area were assessed using low order polynomial fitting.

The residual gravity anomalies calculated are presented in Figure 6. The most obvious feature of the residual gravity anomalies is a broad negative anomaly (amplitude of –6 mgals and wavelength of more than 3 km), which occurs over the central part of the Ulubelu geothermal area (to the north of Pagaralam and Mt Duduk) indicating a concealed graben structure. The negative anomaly could be caused mainly by the negative density contrast between the graben structure infill (pyroclastics of Mt Rendingan) and the higher density of the surrounding rocks (i.e. andesitic lavas of Mt Rendingan in the north, andesitic lavas of Mt Sula in the west and basaltic andesite of Mt Kukusan in the south as indicated by result of geological survey).

The negative anomaly is bounded by steep gravity gradients associated with faults trending NW-SE in the eastern and western boundaries and NE-SW in the northern and southern boundaries. Moreover, the residual gravity data has a good correlation with the remote sensing data interpretation (Figure 2). Therefore, this residual gravity data imaging of the subsurface structure in the study area can be used to assist quantitative interpretation. For this reason, a two-dimensional gravity forward modeling program based on Talwani's (1959) formulation was applied to the residual gravity data to get a better understanding of the subsurface structure in the study area (Figure 7). Based on the density estimations done using Nettleton's procedure with consideration of the geological conditions in the study area, densities of 2.20 and 2.70 g/cm^3 were used for modeling the graben structure infill (pyroclastics of Mt Rendingan) and the surrounding rocks (andesite), respectively. In interpreting the residual gravity data, the results of geoelectric sounding interpretations were used as a cross-check. From the modeling, the gross subsurface structures of the study area can be reconstructed for guiding the hydrology assessment.

3.4 Self-Potential Data

Self-Potential data can be used to assist interpretation of the possible up-flow and out-flow zones in a geothermal field (Corwin and Hoover, 1979; Ross et al.,1990). Total field self-potential data for line H and line NW of the Ulubelu geothermal field are combined as a contour map (Figure 8). It can be seen that a positive anomaly with an amplitude of about 70 mV and approximately 2.5 km wavelength occurrs in the central part of the study area. Since the positive anomaly has a good correlation with low resistivity anomaly (10 Ohm.meter) and the occurrence of acid sulphate hot springs in Pagaralam, it can be concluded that such an anomaly is probably caused by uprising fluids to the surface (up flow zone).

A negative anomaly with an amplitude of about 20 mV and wavelength of 1.5 to 3 km is also found in the western part of the study area. This anomaly may be caused by descending fluids through the Sula formation. These two anomalies (as a dipole of positive and negative anomalies) indicate a circulation of subsurface fluids in a closed path.

4. DRILLING DATA

Two holes have been drilled in the Kukusan Block and Rendingan Block in order to get subsurface information in the study area. An ultra slim hole drilled at the Kukusan Block indicates that the temperature of the reservoir is 220^{0}C at a depth of 800 to1200 m and that the reservoir is a two phase system (about 80 % steam fraction). A deep gradient hole (total depth = 600 m) drilled in the Rendingan Block indicates that the temperature gradient is higher than that encountered in the Kukusan Block's well. It is possibly associated with reservoir temperature of more than 260^{0}C as indicated by gas geothermometry (Sunaryo at al., 1993).

5. TENTATIVE GEOTHERMAL CONCEPTUAL MODEL

A tentative geothermal conceptual model of the Ulubelu field was developed on the basis of all the integrated studies. Figure 9 illustrates a tentative conceptual model map of the Ulubelu geothermal field. The geothermal system appears to be associated with the graben structure and fracturing zone. Two up-flow zones are indicated in the Ulubelu geothermal reservoir system separated by the Duduk formation. The first up-flow is located on the slopes of Mt Rendingan in the northern part of the Ulubelu area with the reservoir temperature of more than 260^{0}C associated with hot chloride water covering about 3 km^2. The top of the reservoir is located at about 2 km depth. The other up-flow zone is encountered around Mt Kukusan including Pagaralam and Gunung Tiga. This up-flow zone is associated with a two-phase system with temperatures of about 220^{0}C and covering about 22 km^2. The reservoir rocks appear to be composed of Sula formation, the oldest rocks in the Ulubelu area. The top of the reservoir is located at a depth of about 800 m. Clay cap (cap rock) is originated from Rendingan and Kukusan formation concealing the reservoir formation. This cap rock is clearly identified by the resistivity traversing and sounding data. The heat source, which is usually associated with a pluton is not recognized. A likely outflow zone occurs to the south of the study area, as indicated by the low resistivity contour that is still open to the south and supported by the occurrence of a chloride hot-spring around Mt Way Panas in the south. The total area of the Ulubelu geothermal prospect is assessed to be about 25 km^2. The reserve potential calculation based on the above information suggested that the Ulubelu geothermal field would be able to supply 100 MWe for 25 years of electric power generation. Based on these studies the Ulubelu geothermal area could be a promising field for future development for electrical power generation.

6. CONCLUSIONS

Integrated geophysical studies of the Ulubelu geothermal field have revealed that the field has two separate up-flow blocks (Rendingan and Kukusan) with different phases of the reservoir fluids covering a total of 3 km^2. The Rendingan block is a deep hot water system with a temperature of 260^{0}C covering 10 km^2, while the Kukusan block is a two-phase system with 80 % steam fraction and temperature of more than 220^{0}C covering 22 km^2. Our present study suggests that the Ulubelu geothermal field is a very promising prospect for future development for the electrical power generation. Additional exploration and drilling of wells to further delineate the characteristics and capacity of the reservoir are highly recommended.

ACKNOWLEDGEMENTS

The authors wish to thank the management of Pertamina (Indonesian State Oil and Gas Company) for their permission to publish this paper. The first author gratefully acknowledges the Hitachi Scholarship Foundation in Tokyo for providing financial support for postgraduate study. Finally, special thanks to the two anonymous reviewers for reviewing this paper.

REFERENCES

Corwin, R.F. and Hoover, D.B. (1979). The self-potential method in geothermal exploration. *Geophysics*, Vol. 44, pp.226-145.

Daud, Y. (1995 a). Resistivity and Gravity Study of the Ulubelu Geothermal Area, South Lampung, Indonesia. *Unpublished Geothermal Project Report No.95.07*, Geothermal Institute, University of Auckland, New Zealand.

--------- (1995 b). Interpretation of Gravity, Magnetic and Self-Potential Data over the Ulubelu Geothermal Area, South Lampung, Indonesia. *Unpublished NZMFAT Research Fellowship Report in Geothermal Energy Technology*, Geothermal Institute, University of Auckland, New Zealand.

Ghosh, D.P. (1971). The application of linear filter theory to the direct interpretation of geoelectrical resistivity sounding measurements. *Geophysical Prospecting*, Vol. 19, pp.769-775.

Masdjuk, Muchsin (1989). Geology of the Ulubelu Geothermal Area, South Lampung, Indonesia. *Unpublished Internal Report,* Geothermal Division, Pertamina.

Ross, H.P., Blackett, R.E., Shubat, M.A. and Mackelprang, C.E. (1990). Delineation of fluid upflow and outflow plume with electrical resistivity and self-potential data, Newcastle geothermal area, Utah. *Geothermal Resources Council Transactions*, Vol.14, pp.1531-1536.

Sunaryo, Hantono, D., Ganda, S. and Nugroho (1993). Exploration Results of the Ulubelu Geothermal Prospects, South Sumatera, Indonesia. *Proceedings 15th New Zealand Geothermal Workshop 1993*, University of Auckland, pp. 103-106.

Talwani, M., Warzel, J.J., and Landisman, M. (1959). Rapid gravity computations for two-dimensional bodies with application to the Mendocino submarine fracture zone. *Journal of Geophysical Research*, Vol. 64, pp. 49-59

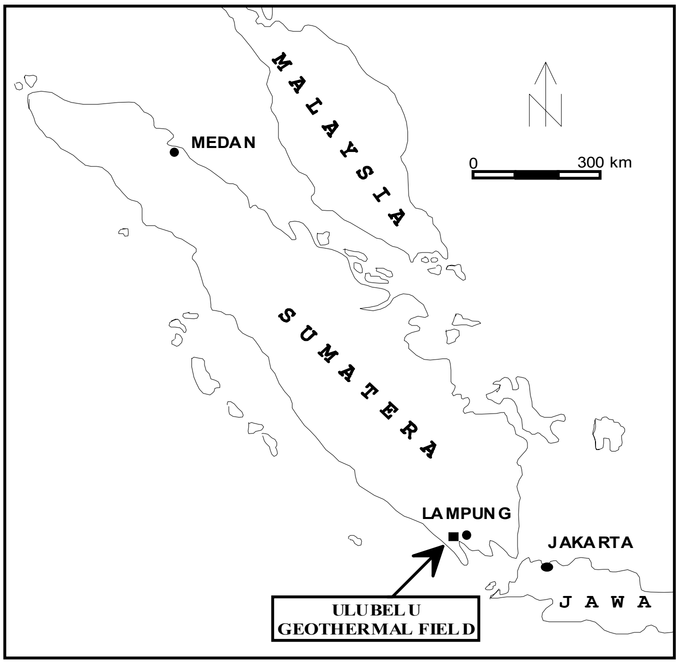

Figure 1. Location of the Ulubelu Geothermal Field, Indonesia

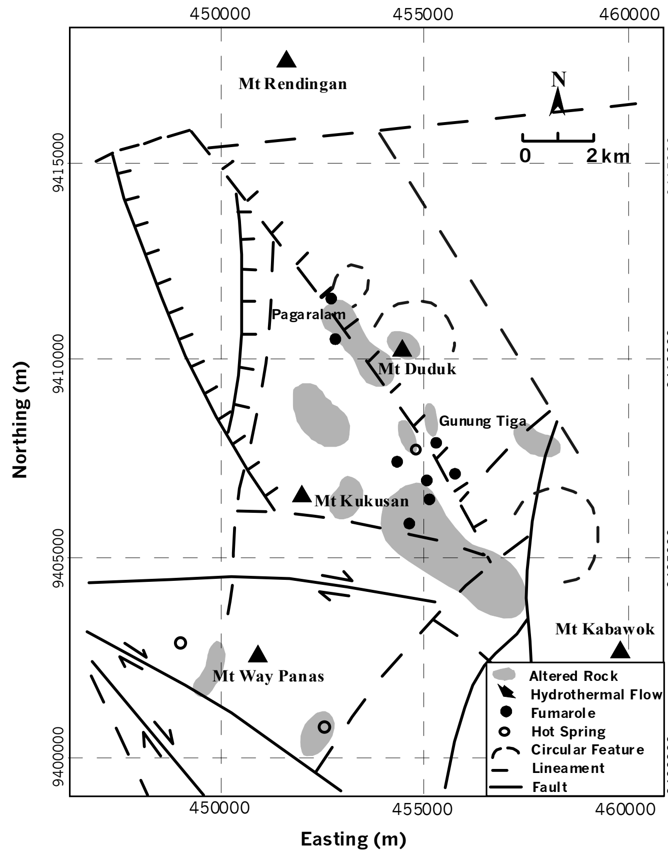

Figure 2. Remote Sensing Data Interpretation of the Ulubelu Geothermal Field

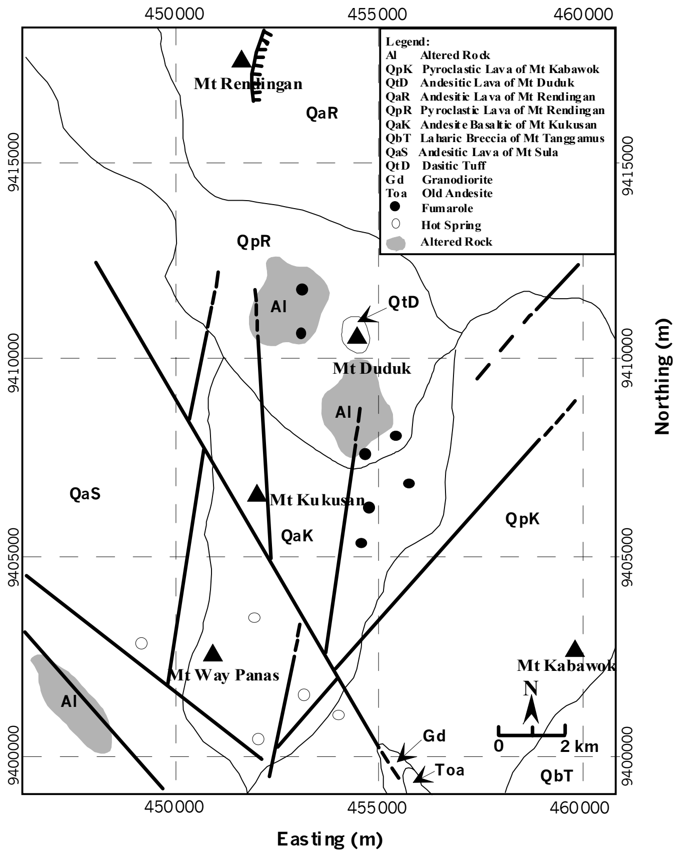

Figure 3. Surface Geology of the Ulubelu Geothermal Field (modified from Masdjuk, 1989)

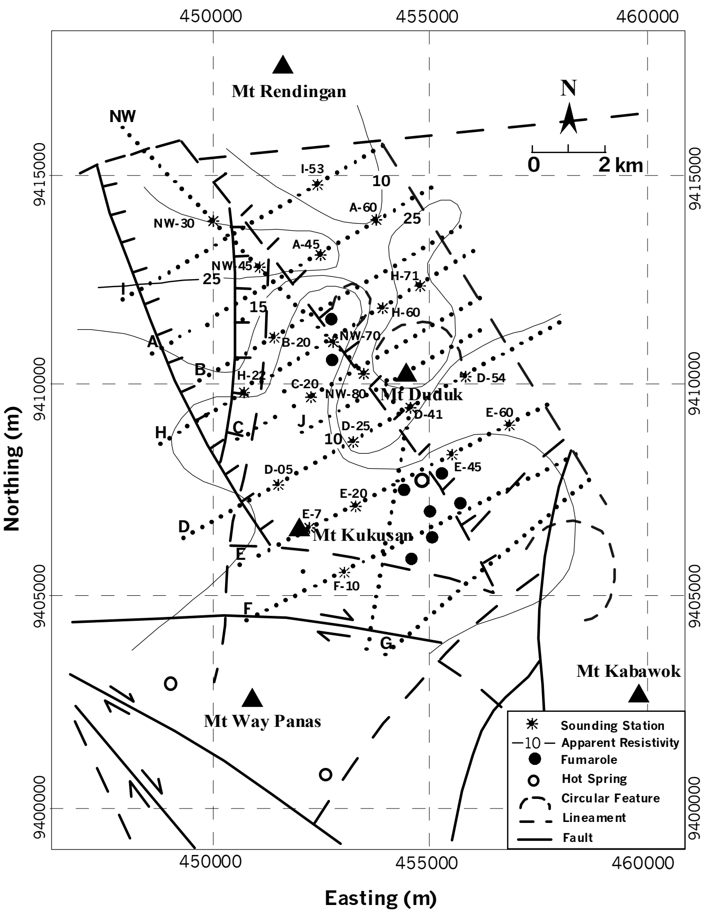

Figure 4. Resistivity Traversing Map for AB/2 = 1000m

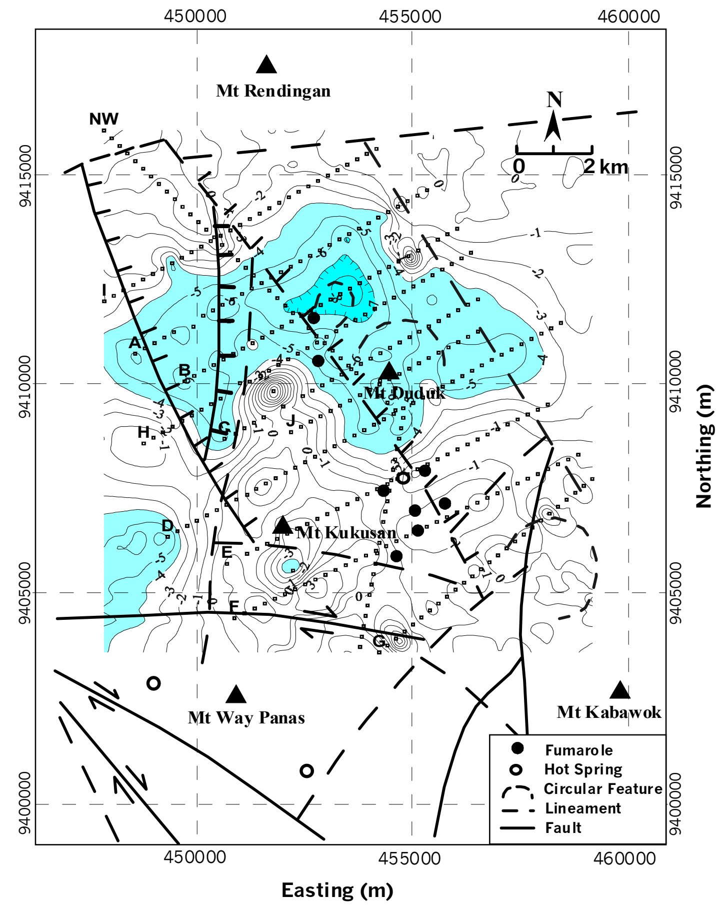

Figure 6. Residual Gravity Anomaly of the Ulubelu Geothermal Field

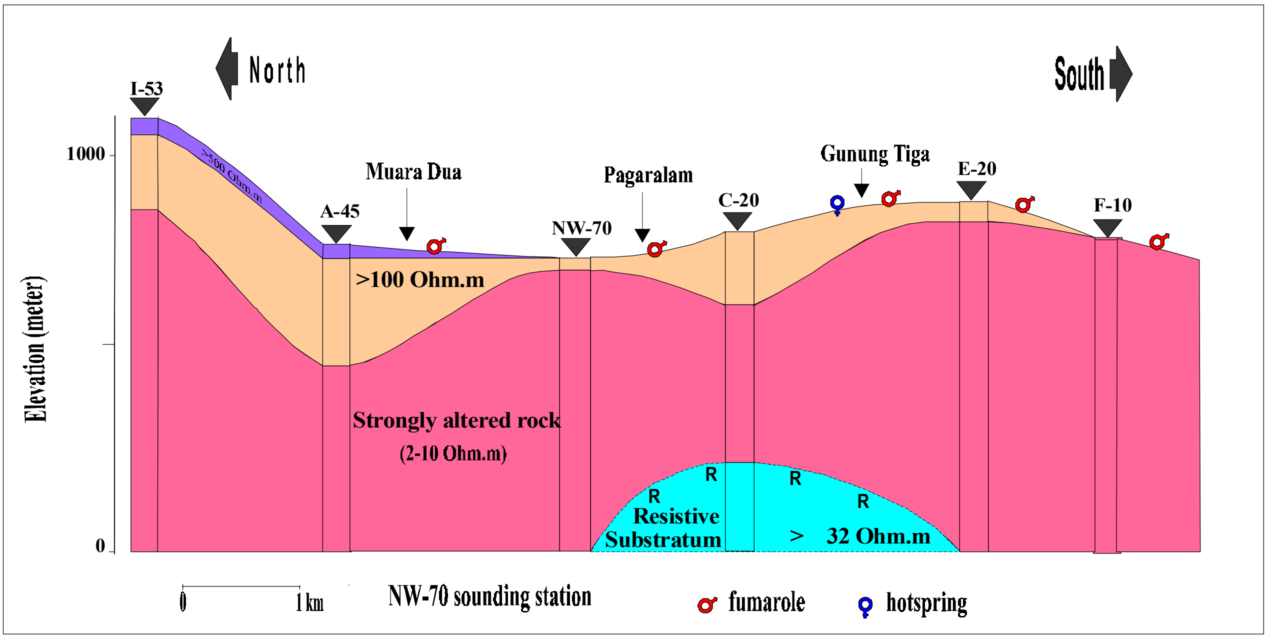

Figure 5. True-Resistivity Sounding Section along the Line North-South

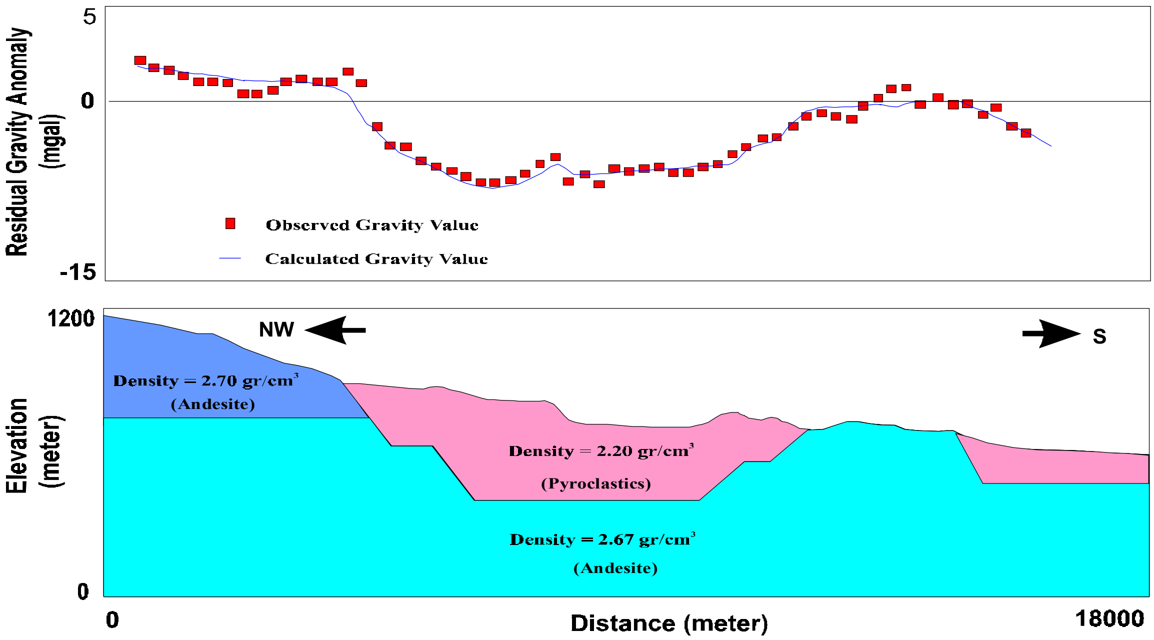

Figure 7 Gravity Model of the Ulubelu Geothermal Field along the Line NW

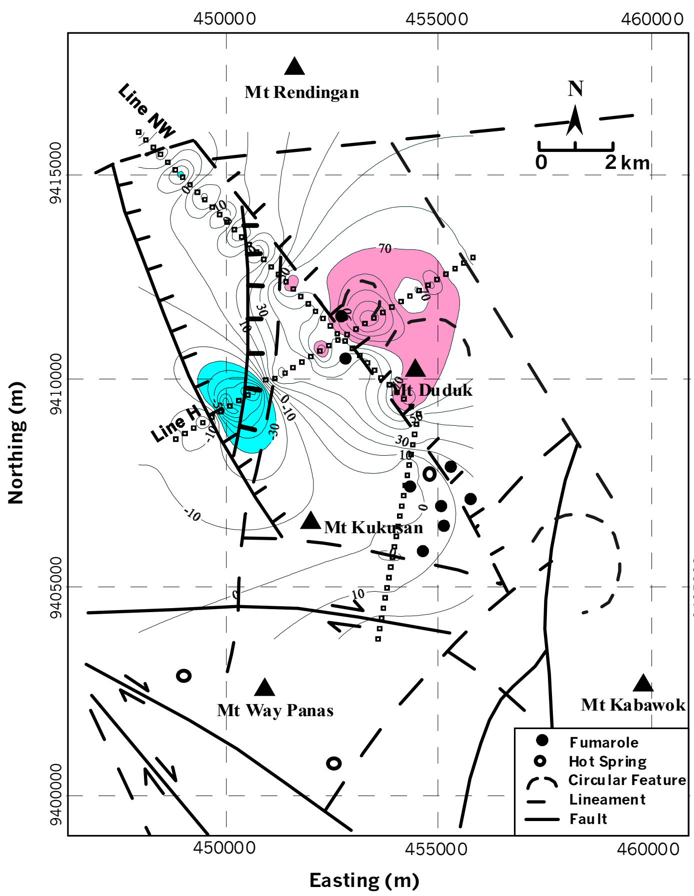

Figure 8. Self-Potential Anomaly of the Ulubelu Geothermal Field

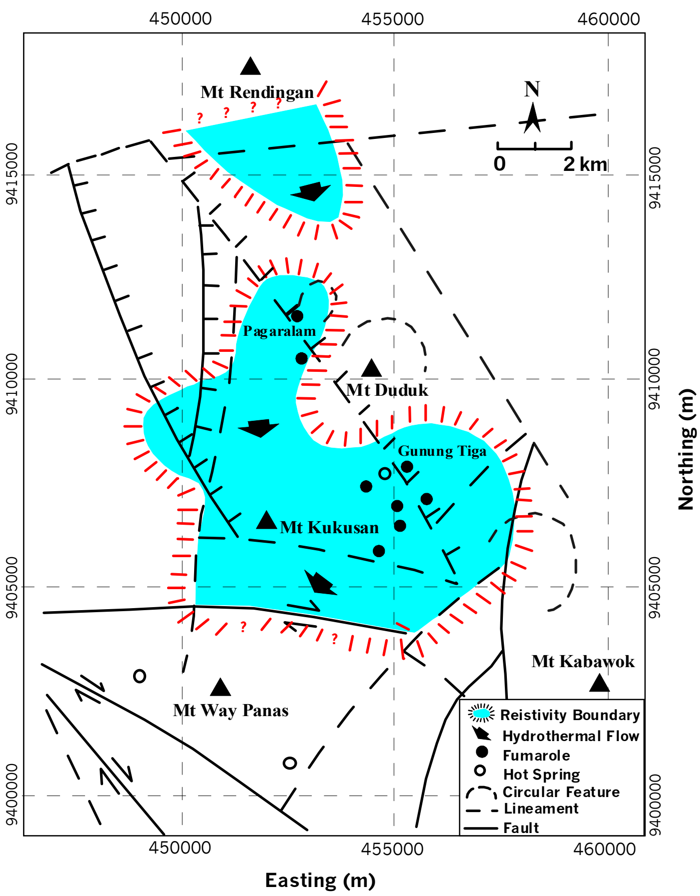

Figure 9. Tentative Conceptual Model of the Ulubelu Geothermal Field