GEOTHERMAL GEOPHYSICAL STUDY OF MT. PAPANDAYAN, GARUT DISTRICT, WEST JAVA INDONESIA

Asnawir Nasution[1], Djedi S. Widarto[2], Lambok Hutasoit[1], Dewi Yuliani[3], and Sumarwan Hadisoemarto[3]

[1] Department of Geology, Bandung Institute of Technology, Bandung 40132, Indonesia
[2] Research Ctr for Geotechnology – LIPI, Bandung 40135, Indonesia
(Presently at EP Technology Center, P.T. Pertamina, Jakarta 10110, Indonesia)
[3] Mining & Energy Agency, West Java Prov., Bandung, Indonesia

ABSTRACT

Papandayan volcanic complex (1,100 - 2,665 m asl) is dominated by young Quaterary andesitic rocks, showing cones, faults, dome and collapse structures. Extensive alteration of inner and outer volcanic flank with high tempearature fumaroles (80–150^{o}C), indicates that H_2S gases affect on fresh rocks. The gas geothermometry shows 250^{o}C or higher subsurface temperature, suggesting the low temperatur gas may take place below the older Tegal Alun-Alun volcanics. Magneto-telluric (MT) survey results for the north and north-east slopes of Papandayan indicates resistivity variations of conductive and resistive layers. Low frequency (<1 Hz) MT may be correlated to sub-surface hydrothermal processes. Two-dimensional inversion of the MT sections represent resistivity values of three layers. The upper layer has resistivity values of 80–300 Ohm-m, with a thickness of 500-1000 m. The second layer has low resistivity values of lower than 10 Ohm-m, which is 1000-3000 m thick, considered as a conductive layer related to condensated rocks. The resistive layer below the conductive zone may indicate a potential reservoir, at depths between 1,500 m and 3,000 m. At a deeper level (3,000 m to 5,000 m deep), a very high resistivity value (>1000 Ohm-m) presumably indicates deep hard rocks, as a part of heat source media.

INTRODUCTION

Geographically, Mt. Papandayan volcanic complex (1,100 – 2,665 m asl.) is located at 107^{o}44'00"E and 7^{o}19'00"S. It is between Bandung and Garut Districts, West Java Province, approximately 45 km to the south-east of Bandung and 20 km to the south of Garut. Volcanologically, Mt. Papandayan is an active volcano, having its last eruption in 2002. It produced phreatic products and volcanic debris.

The initial geothermal study consists of geological and geochemical methods, which were carried out at the end of 1990's. They include mapping of lithology distribution, alteration, and geologic structure, as well as locating, sampling, and analyzing fluid from surface features. The thermal features consist of fumaroles, solfatars, steaming ground, mud pools, hot springs and large alteration areas, with temperature between 55 – 150^{o}C, and most of them are SO_4 type water.

Fig.1 The location map of study area

Recent study in this area consists of gravity and magneto-telluric (MT) surveys. The survey is to define the subsurface structure over an interested area. The MT method is a technique used to investigate the electrical conductivity structure of the Earth to detect deep geological formations. It is increasingly used both in applied geophysics and in resources evaluation. Recently, it is one of effective geophysical methods and widely used for studies on subsurface geological structures. Many previous studies have applied this method, eg. Ross (1993) studied a subsurface geological structure; Berktold (1983); Benderitter and Gerard (1984) carried out hydrocarbon explorations; Mogi and Nakama (1993) and Widarto et al. (1997) used MT methods for geothermal exploration.

In this study, the survey was conducted with 16 MT station points at the east and north flank of Mt. Papandayan (Fig.1), with the objective is to understand resistivity value distribution of volcanic rocks, which are associated with hydrothermal process of geothermal potential beneath Papandayan volcanic complex. This paper describes the results of this geophysical study.

EQUIPMENTS AND FIELD METHOD

During data acquisition in the field, we used two units of MTU-5A Phoenix Geophysics System. Both of them were used to acquire data, but we employed cross-reference analyses to obtained better data quality. The source of electro-magnetic (EM) energy for MT survey was a natural source with frequency range from 320 Hz to 0.001 Hz. By this frequency range, the effective exploration depth of this MT survey is estimated to reach 5,000 to 6,000 meters deep. The measurement of EM wave field was carried out from 6 pm to 6 am, at about 12 hours per day in average. Due to low level of artificial noises, we set up our measurement from evening to morning of the next day. The time slot length or sampling rate used in this survey was 120 sec, thus we obtained lower frequency of EM wave.

Geological mapping of Mt. Papandayan was conducted to understand the volcanic rock distribution, stratigraphy and volcanic structures. It is based on an aerial photo interpretation and field survey. Field sampling of fresh volcanic rocks and thermal features are mostly carried out at the lava flow outcrops along valleys and volcanic cones.

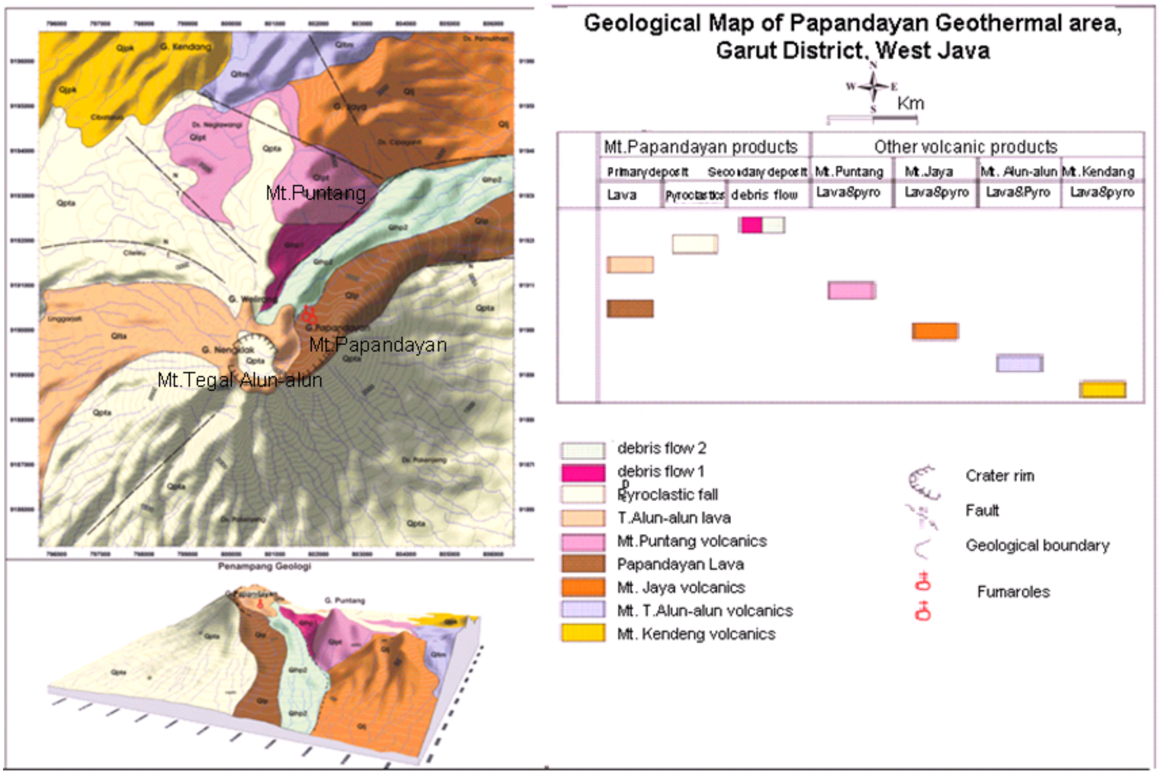

Fig.2 Geological map of Papandayan volcanic complex

RESULT AND DISCUSSION

The geothermal geology is shown by a volcanic rock distribution, stratigraphy and volcanic structures as illustrated in Fig. 2. In this survey, we carried out MT measurement at 16 points, as distributed in 3 irregular lines with a spacing of 500 m, located to the north-east and north-west of Mt. Pandandayan. They composed of Line 1, 2 and line 3 (Fig. 3). The Line-1 consist of PAP 1 to PAP 6, the Line 2 consists of PAP 201 to PAP 207, and the Line-3 consists of PAP 6 to PAP 10. Quality of the data was mostly good, particularly for frequency higher than 1 Hz. However, for frequency below 1 Hz, the data have intermediate quality (Fig. 4).

For 2-D inversion, data from three sections were used, which pass through geothermal prospective areas. The first section, it passes through six MT points, PAP-101, PAP-102, PAP-103,PAP-104, PAP-105 and PAP-106. The second section pass through four MT points, which are PAP201, PAP202, PAP203 and PAP204. The third section pass through seven MT points, consistig of PAP110, PAP109, PAP108, PAP107, PAP106, PAP207, and PAP205 (see Fig. 5a and 5b).

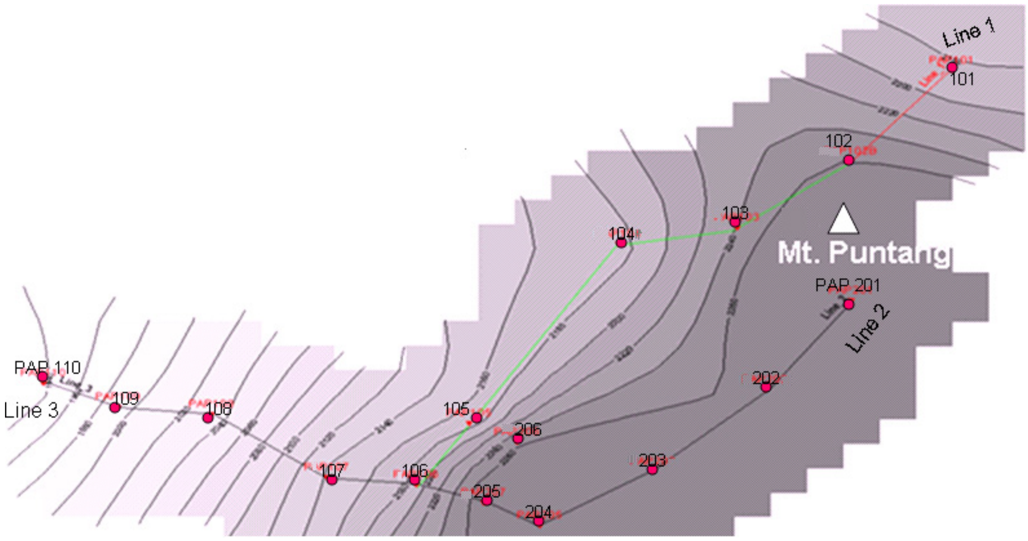

Fig. 3 The distribution of MT measurement sites

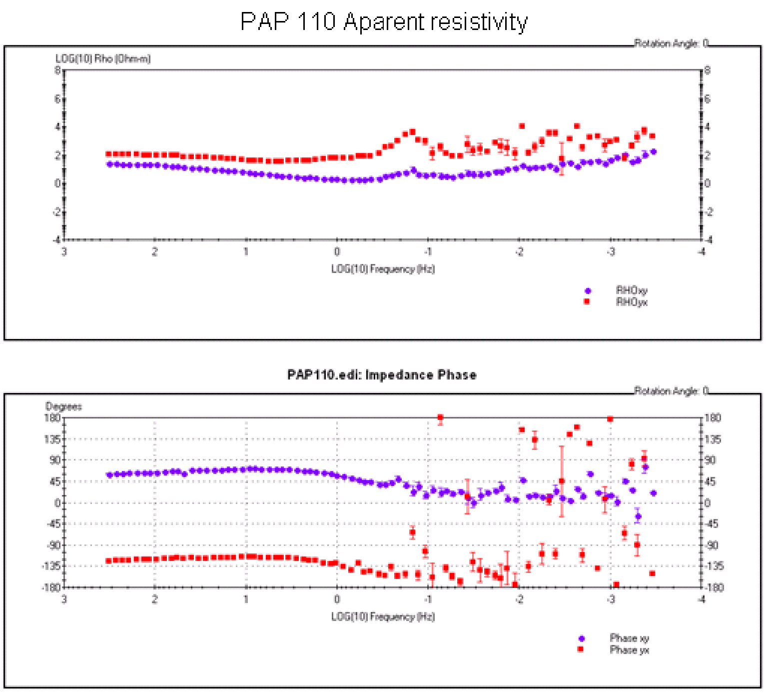

Fig. 4 Aparent resistivity and phase different values vs measuring frequencies of point PAP 110 at Line 3

In general, 2-D inversion results for the three sections show a similar vertical resistivity distributions, from the upper to the lower layers. The upper layer has resistive values of 80 – 300 Ohm-m, which may be related to overburden, consisting of fresh materials of lava and pyroclastic materials. The thickness of upper layer is ranging between 500 to 1,000 meters.

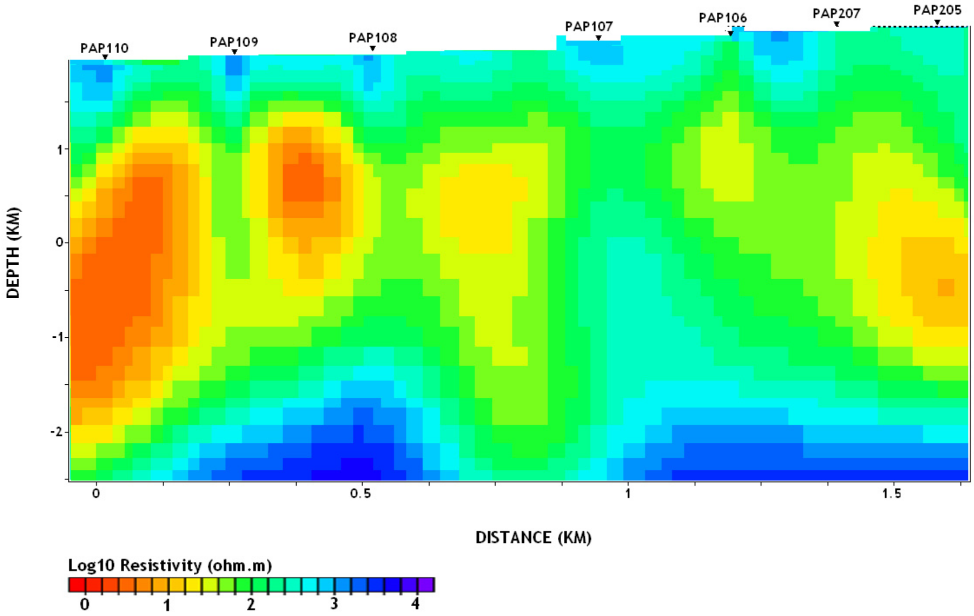

Fig 5a Cross section of MT resistivity layer at PAP 110 – PAP 205

The second layer has low resistivity values lower than 10 Ohm-m with a thickness of 1,000-3,000 meter. Presumably, the low resistivity derives from a combination of cap rocks, which are rich in conducting minerals as known as conductive layer, and hydrothermal layers containing electrolite of hot water. Both components cause the second layers as conductive one.

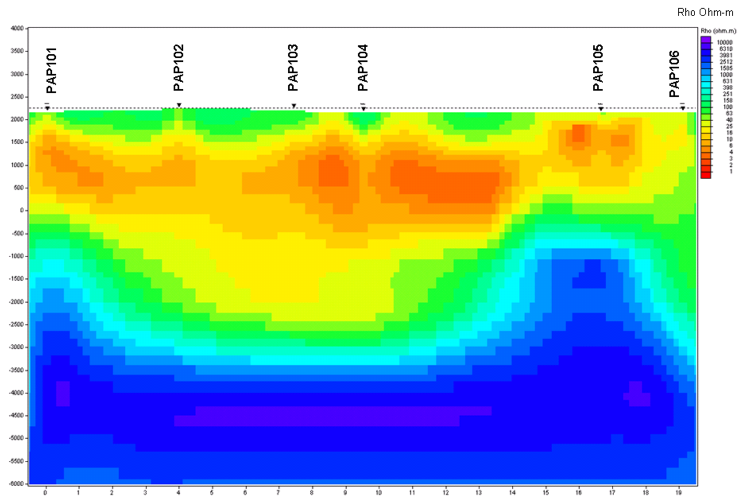

Fig. 5.b Cross section of MT resistivity layer at PAP 101 – PAP 106

Below the conductive layers, resistive rocks which range from 15 – 40 Ohm-m take place, which is 1,500 – 3,000 meter deep. At this depth, a high seismicity is identified by seismometer monitoring at the observatory of Volcanological Survey of Indonesia. Therefore, this zone is assumed as a convection current area, propose to be a reservoir geothermal location.

At deeper level (3,000 to 5,000 m deep), a very high resistivity layer is found. The resistivity values are mostly higher than 1,000 Ohm-m, that is of deep basement rocks, which is considered as a part of heat source.

Geology

The geology of study area is characterized by a Quaternary Papandayan volcanic complex, and Mt. Puntang and Tegal Alun-alun volcanics, which are close to the main cone. The products mostly consist of andesitic rock with calc alkaline suite, while hydrothermal or phreatic eruption occurred at a main crater. The structures, which pass through the volcanic complex, are associated with active thermal features indicating of young volcanic activities. It suggests the existent of prospective heat source of Papandayan geothermal system. Quaternary volcanic activity of study area was started by Puntang, Tegal Alun-Alun affect and young Papandayan volcanics, indicating a shallow cooling magma chamber, as was shown for Otake and Matsukawa geothermal fields. The thermal features of Papadayan are composed of SO_4 type water. Gas geothermometry represents the subsurface tempeature betwen 300-500^oC.

Reservoir parameter and cap rocks are usually represented by a stratigraphy of altered lavas and pyroclastics materials, which are caused by hydrothermal processes. When altered rocks change to hydrothermal clay below the surface, they may become a cap rock layer of geothermal system. This system is clearly recognized from a low resistivity anomaly of MT result (<10 Ohm-m) to medium resistivity (15 -40 Ohm-m) Papandayan geothermal system.

Several faults and volcanic structures are well recognized. They may be showing a heat transfer medium from a cooling magma to the surface, and a migration channel system to the shallow level, where a convective heat may occur below Puntang, Tegal Alun-Alun and Papandayan complex. Structure and fracture zones are recognized as productive zones. Therefore, Papandayan area presumably has a completed parameter for a geothermal system.

Electrical resistivity and MT mappings

Schlumberger resistivity and MT survey are very successful in identifying the extent of the alteration halo overlying active geothermal systems, which represent by an electrically conductive clay. The low resistivity zones are found out at the shallow and deeper levels, particularly at below 300 to 1 km depth which are shown at the flank of Puntang and northern flank of Tegal Alun-Alun volcanics (Fig. 5a and 5b). The low resistivity zone has values smaller than 10 Ohm-m. These values clearly represent a low tempeature of gases (< 400^oC) that may affect condensated layer at lower part at the surrounding of Papandayan complex.

Below the condensated layer, a zone of low resistivity values (15-40 Ohm-m) may occur, and usually associated with a vapor zone (Hochstein,1975). Based on these values, Papandayan geothermal complex probably may be associated with a vapor geothermal system. Therefore, one detailed exploration well is recommended to be drilled at the survey point of PAP 10 to north flank of Tegal Alun-Alun area (Fig. 3).

The results of vertical electrical sounding (VES) showed resistivity variation from deep volcanic rock layers that it may indicate condensated zones. This zone is affected by SO_4 type water, containing hydrated alteration minerals. These values may be associated with altered pyroclastic materials at the depth, representing a cap rock as a self-sealing process. At some places, alteration processes may occurred toward the surface layers, as shown at the flank of Papandayan crater (see Fig.5a and 5b).

The model of resistivity layers may give a better structural configuration at the sub-surface (Fig. 6). It shows also flow of the geothermal fluids in reservoir. Therefore, these models may be used for the future exploration target.

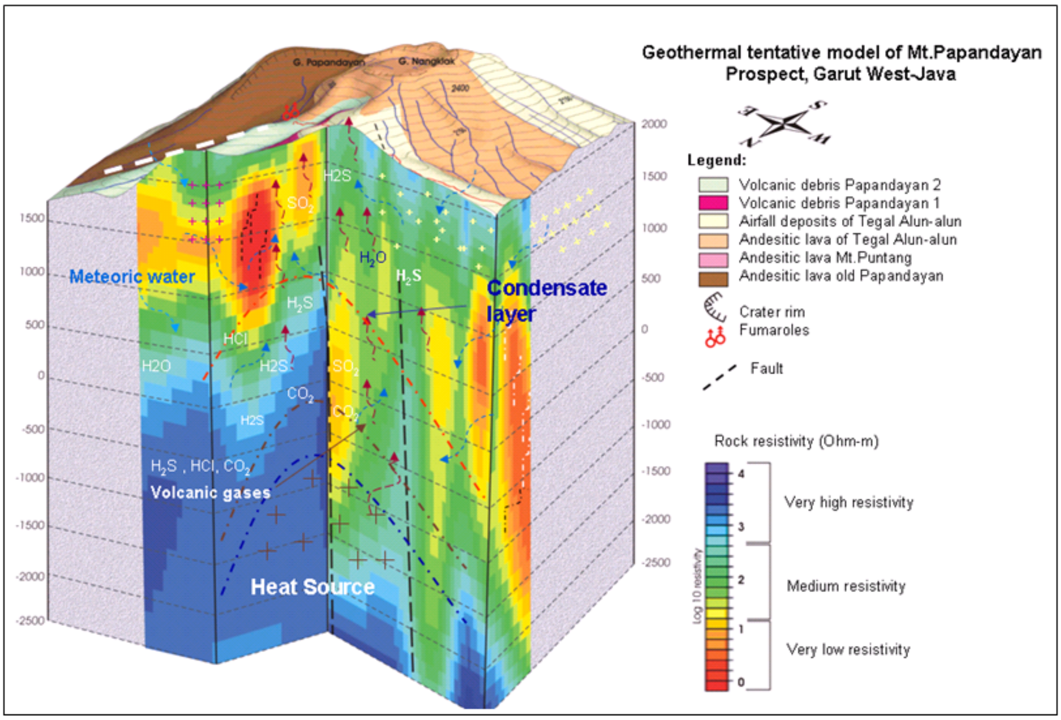

Fig. 6 The resistivity model based on MT survey of Papandayan complex

CONCLUDING REMARKS

The young Quaterary volcanic of Mt. Papandayan is one of a newly geothermal prospect area in West Java Province. This area is characterized by an extensive alteration as distributed in the inner and outer volcanic flank indicating H_2S gases is intensively affecting the fresh rocks.

MT survey results indicate a resistivity variation of conductive and resistive layers. Two-dimensional inversion result shows that upper layer has 80 – 300 Ohm-m, which may be related to pyroclastic and blocky materials, with a thickness of 500-1000 m. The second layer has resistivity lower than10 Ohm-m, which is 1000-3000 m thick, may be associated with a conductive formation, and it represents a fluid flow from deeper level. A potential reservoir is assumed at the depth of 1500 m to 3000 m, indicated by resistivity values of 15- 40 Ohm-m. A very high resistivity value (>1000 Ohm-m) at a deeper level (3000 m to 5000 m deep) may be related to dioritic (basement) rock.

REFERENCES

Benderitter,Y. and A. Gerard, 1984. Geothermal study of Re-union island: Audio-magnetotelluric survey, *J. Volcanol. Geoth. Res.*, 20, p. 311-322.

Berktold, A., 1983. Electromagnetic studies in geothermal regions, *Geophys. Surv.*, 6, p. 173-200.

Hochstein, M.P., Geophysical Exploration at Kawah Kamojang Geothermal Field (West Java), Second United Nation Symposium on Dev. & Use of Geoth.Res.Calif., 1975.

Mogi, T. And S. Nakama, 1993. Magnetotelluric interpretation of the geothermal system of the Kuju volcano, southwest Japan, *J. Volcanol. Geoth. Res.*, 56, p. 297-308.

Ross, L., 1993. Evolution of structure models of two anticlines in the Papua thrust belt by application of magnetotellurics. Petroleum Exploration and Development in Papua New Guinea, *Proc. 2nd PNG*

Petroleum Convention, Port Moresby, p. 351-370.

Widarto, D.S., E.M. Arsadi, E.P. Utomo, dan S. Kesumadharma, 1997. Two-dimensional resitivity imaging across Liwa area, Sumatra, based on audio-frequency magnetotelluric data, J. Physics TELAAH, Res. Ctr Physics – Indonesian Inst. Sci., V. XVIII no. 2, p. 10-18 (in Indonesian with English abstract).