RESISTIVITY ANOMALY AT MOUNT KABA, BENGKULU, INDONESIA, AS INFERRED FROM GEOELECTRICAL INVESTIGATION

ANOMALI TAHANAN JENIS DI GUNUNG BERAPI KABA, BENGKULU, INDONESIA, BERDASARKAN PENYELIDIKAN GEOLISTRIK

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ABSTRAK

Gunung berapi Kaba terletak di jalur magmatik Bukit Barisan di Curup, Kabupaten Rejang Lebong, Bengkulu, Indonesia. Dua manifestasi geotermal di permukaan dalam bentuk sumber air panas ditemukan di Suban Airpanas (50°C) dan Sindangjati (37°C). Survei geolistrik dengan konfigurasi Schlumberger dengan AB/2 sampai 2.000 m telah dilakukan pada tahun 2009–2011 di sekitar Gunung Kaba. Tujuan penyelidikan ini adalah menentukan distribusi batuan dengan anomali resistivitas (tahanan jenis) rendah karena perubahan fisis batuan bawah tanah akibat pengaruh fluida panas. Survei yang dilakukan menunjukkan bahwa batuan dengan tahanan jenis rendah (< 5 ohm-m) ditemukan di sebelah timur Gunung Kaba dengan kedalaman sekitar 400 m.

Kata kunci*: survei geolistrik, geotermal, tahanan jenis, gunung api Kaba*

ABSTRACT

Mount Kaba is a volcano located in the magmatic arc Bukit Barisan near the town of Curup, Rejang Lebong, Bengkulu, Indonesia. Two geothermal manifestations have been found in this region in form of hot springs at Suban Airpanas (50°C) and Sindangjati (37°C). Geoelectrical survey based on Schlumberger array up to AB/2 2,000 m was carried out in 2009–2011 in the surrounding area of Mt. Kaba. The aim of the investigation was to locate the distribution of low resistivity anomaly layer that may associate with hydrothermally altered subsurface rock in the area. It is estimated that the depth of low resistivity (< 5 ohm-m) found in the eastern part of Mt. Kaba is about 400 m.

Keywords*: geoelectrical* survey, geothermal, resistivity, Mt. Kaba

INTRODUCTION

Indonesian national energy sources are highly dependent on fossil fuel and its proven fossil fuel reserves are limited and declining. Currently, Indonesian energy demand is averaging at about 7% per year growth, which is faster than the growth of GDP per year of 5–6%.[1] Although Indonesia well possesses with energy resources, the proven fossil fuel reserves are limited and the production is now in decline. It is estimated that Indonesia energy mix is still dominated by oil at 52% and gas at 29%. Due to the decline in the fossil fuel production and limited proven reserve, it is essential for the government to find alternative energy. For this purpose, Indonesian government published "National Energy Policy (NEP)" in 2002, and set the target of supplying 5% or more of the primary energy by renewable energy by 2025.

Indonesian region is situated in the area of the three tectonic plate margins of the Indo-Australian, Eurasian, and Pacific plates. The interaction among these tectonic plates causes the generation of volcanisms and faulting along the boundary of these plates. These conditions have created the possibility for the vast geothermal prospect along the volcanic island arc. Identification of the geothermal prospect area is important for the future development of the prospect area used as the power generation. Successful development and utilization of the geothermal prospect for direct use of electric generation would facilitate the economic growth. Geothermal prospect at least needs four aspects to be considered for the development, which are heat sources, reservoir, cap rock characteristics, and hydrology characteristics.

Exploration for geothermal energy in Indonesia started to begin in 1970s along the volcanic chain from Sumatera, Java, Nusa Tenggara, and Sulawesi. As the results from those investigations, about 70 geothermal prospects have been identified and the combined potential could reach about 20 GW.[2,3] The first geothermal project started at Kamojang, Garut, West Java, in 1983 with 140 MW capacity.[4] Most geothermal potential can be found in Sumatera (13,800 MW), Java–Bali (9,250 MW), Sulawesi (2,000 MW), and about 964 MW have been developed, which are mainly located in Java and Bali.[1] Sumatera has large geothermal potential due to the volcanic mountain chain as a result of subduction between Indo–Australian and Eurasian tectonic plates.

Mt. Kaba is part of Bukit Barisan, which is a volcanic chain along Sumatera, and located in the southern part of Sumatera (Figure 1). Mt. Kaba is identified as stratovolcano and has been active in the recent years. The activity of Mt. Kaba may indicate the occurrence of magma chamber in the shallow depth beneath the volcano. Magma chamber in shallow depth may create enough heat from the geothermal reservoir. Since the geothermal systems are complex, a single prospecting method cannot characterize them accurately; hence, it is necessary to combine techniques to be employed.[5]

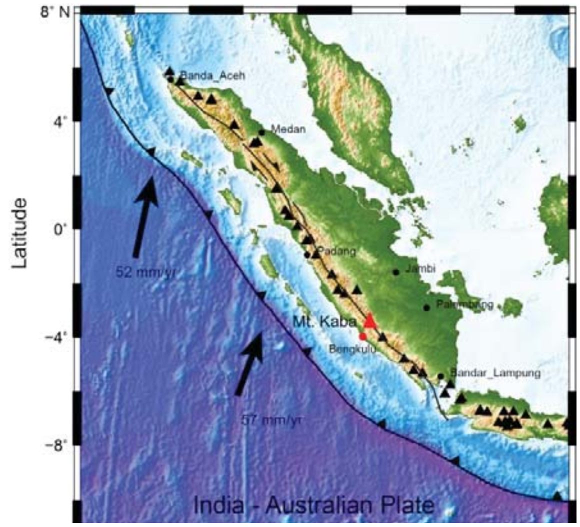


Figure 1. Map showing the location of Mt. Kaba (solid red triangle) on Sumatera Island within Bukit Barisan magmatic arc.

Geothermal exploration operation aims at locating geothermal field that can be developed economically. Geophysical methods play important role in the exploration particularly to detect temperature dependent parameters. The geophysical methods mainly aim at structure, trapping region of the hot fluid, or anomalies reflecting the properties of the hydrothermal fluid. The early steps on the geothermal exploration can reveal the depth, thickness and area of the reservoir. Geoelectrical survey that measures rock resistivity is an effective tool to observe resistivity anomaly to indicate the occurrence of an altered rock in the high thermal region. Due to high temperature and salinities, geothermal fluids are known to have much lower resistivity values than cold water in non-thermal ground. Previous studies showed that the resistivity of thermal ground in the geothermal field is very low (about 5 ohm-m) and contrasts sharply with much higher values (> 100 ohm-m) at area far from the field.[6,7,8] In this study we carried out geoelectrical survey in the area surrounding Mt. Kaba to determine the resistivity anomaly of the altered rock caused by hydrothermal alteration .

Mt. Kaba is located at Rejang Lebong Regency, Bengkulu, SW Sumatera is part of a magmatic arc Bukit Barisan.[9] The magmatic arc is basically controlled by subduction system of Indo-Australian and Eurasian plates at speed of about 7 cm/year.[10] Oblique subduction is created at angle of N27^{o}E.[11] The oblique subduction causes

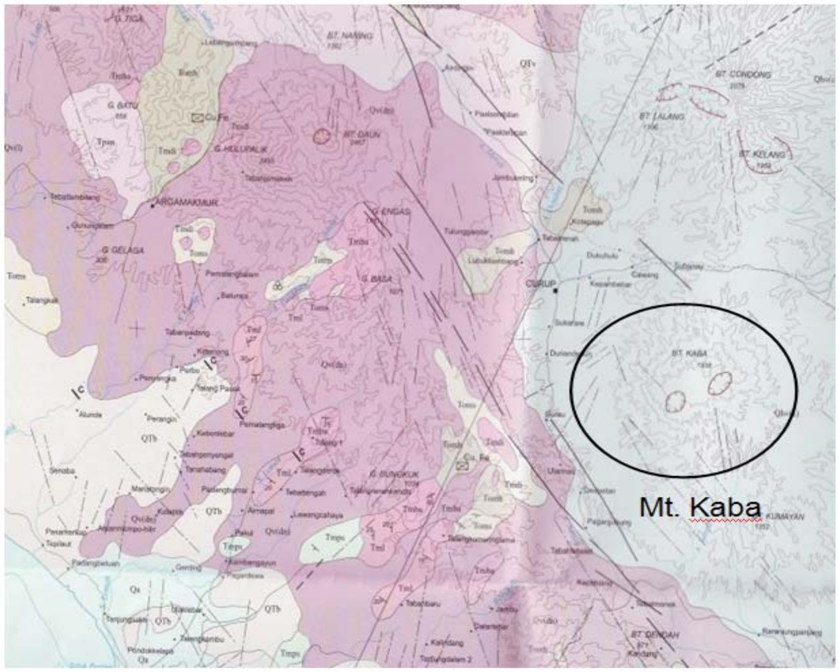


Figure 2. A geologic map of surrounding area of Mt. Kaba (scale 1:100,000). Circle indicates the location of Bukit Kaba, the highest peak at Mt. Kaba. Qhv: quaternary breccias; Qvi: quaternary andesitic-basalt; QTv: quaternary andesitic; Tomh: tertiary lava; Tmba: tertiary breccias.

two phenomena along Sumatera, which are the Bukit Barisan magmatic arc and Great Sumatera Fault Zone. The Bukit Barisan magmatic arc is characterized with lava flow, volcanic breccia, and tuff.

Mt. Kaba surrounding area is mostly covered by volcanic deposits from quaternary period with breccias and andesitic–basalt lava.[12] Figure 2 shows a geologic map at Rejang Lebong Regency adopted from Gafoer.[13] The summit area of Mt. Kaba contains two peaks, which are Bukit Kaba (1,938 m) and Bukit Item (1,893 m). The summit crater complex is dominated by two large craters, and the largest crater called Kawah Lama is located in the southwestern part of the Mt. Kaba, while a smaller crater is called Kawah Baru. Most historical eruption occurred mostly in the summit area of the volcano.

Surface manifestations of geothermal system are found at Suban Airpanas and Sindangjati. Water discharge with temperature of about 50^{o}C (pH 8) is found at Suban Airpanas, which is located near Curup. Although the hot water is found in this region, the altered rock zone is not found. It is likely that the how water is associated with the Ketaun-Tes fault with northwest–southeast orientation. At Sindangjati, hot water discharge is found with temperature of about 37^{o}C. At this location, the water discharge is likely to be associated with the Despetah fault. Another manifestation is found in the summit area of the volcano. Kawah Baru crater shows volcanic activity as characterized by fumaroles.

METHODS

Rock resistivity characterizes how strongly a rock medium opposes the flow of electric current. It depends on a number of parameters, such as porosity, salinity of fluid, and temperature. The effect of temperature change is the greatest especially at low temperature (< 100^{o}C) and becomes small for temperature > 200^{o}C.[14] In deeper parts of a hydrothermal system, the resistivity is more affected by porosity and salinity than by variations in temperature, where the effect is more easily observed in horizontal profiling where lateral variations in resistivity are mapped.[14] Therefore, Schlumberger vertical electrical sounding has been applied at the surrounding region of Mt. Kaba for mapping the vertical and horizontal variations in resistivity.[15]

Figure 3 shows the map area of the geoelectrical survey conducted in three years (2009–2011). A total of fifty geoelectrical surveys were carried out in the area surrounding Mt.

Kaba. The location of the geoelectrical survey was selected at distant of about 2 km to cover as much as possible or whenever the topographic conditions permitted to conduct the survey. Most of the geoelectrical surveys were carried out with maximum AB/2 1,000 m, the geoelectrical surveys conducted in 2011 were mostly carried out with maximum AB/2 2,000 m. Two traverse lines in the northeastern part of Mt. Kaba were carried out in 2011 to image the cross-section in the subsurface. The two traverse lines, which were chosen based on the interpretation of the results from 2009 and 2010 surveys, were selected to be perpendicular with maximum AB/2 of 2,000 m. The surveys were carried out with Martiel Geophysics resistivity meter MGG 1,260 type. Data were processed and analyzed with RESOMA software.

RESULTS AND DISCUSSIONS

Geoelectrical surveys at the surrounding region of Mt. Kaba show spatial distribution of rock resistivity about 5 ohm-meter up to about 3,500 ohm-meter. High resistivity is usually observed at shallow depth up to a few tens meter; while low resistivity is observed at deeper part. Apparent resistivity distribution at AB/2 1,200 m is shown in Figure 4. High resistivity is observed at area around SGL-03 while low resistivity is observed in the west direction (GL 37 and GL-40). Geoelectrical surveys up to AB/2 1,200 m do not reveal apparent resistivity < 10 ohm-meter that associates with clay or geothermal reservoir cap rock.

Spatial distributions of apparent resistivity using AB/2 1,600 m and 2,000 m are shown in Figure 5. Similar characteristics of resistivity distribution at AB/2 1,200 m are also observed using AB/2 1,600 m (Figure 5a). High resistivity is observed at region around SGL-03 and low resistivity is observed at area of GB-53 and SGL-01. However, apparent resistivity < 10 ohm-m is still not observed at the AB/2 1,600 m. Apparent resistivity at AB/2 2,000 has similar characteristic of resistivity distribution of AB/2 1,600 m (Figure 5b). We suggest that low resistivity may be localized beneath the area of GB-53 and SGL-01. Low resistivity is also observed in the eastern

Sindangjati

Suban Airpanas

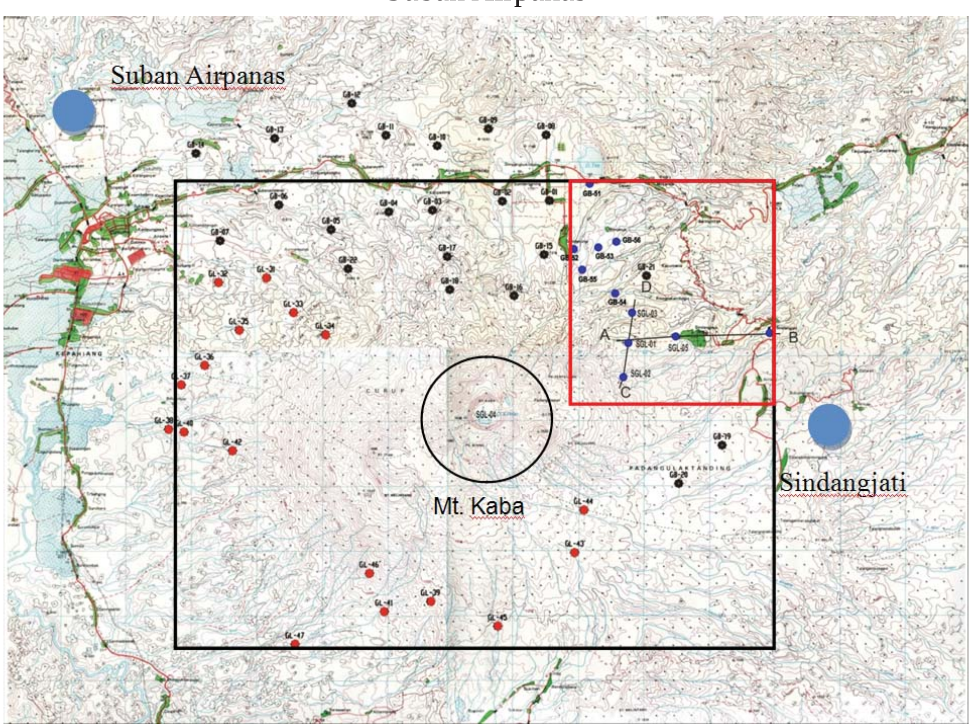


Figure 3. Locations of geoelectrical survey surrounding of Mt. Kaba (scale 1:100,000). Solid black, red, and blue circles represent the locations of the survey conducted in 2009, 2010, and 2011, respectively. Two traverses lines AB and CD are also shown. Black square indicates the area used for resistivity contour with AB/2 1,200 m. Red square indicates the area used for resistivity contour with AB/2 1,600 m and 2,000 m.

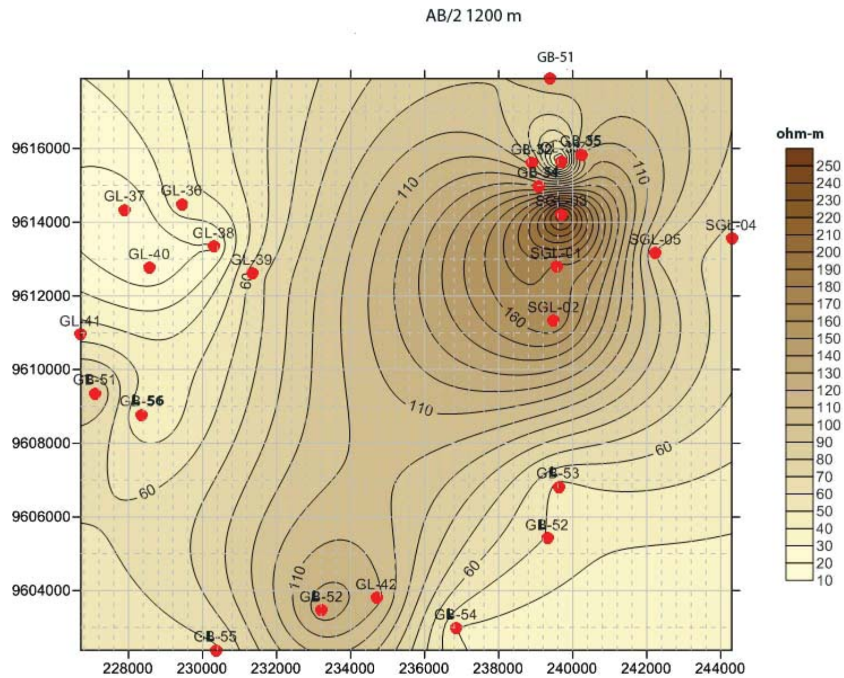
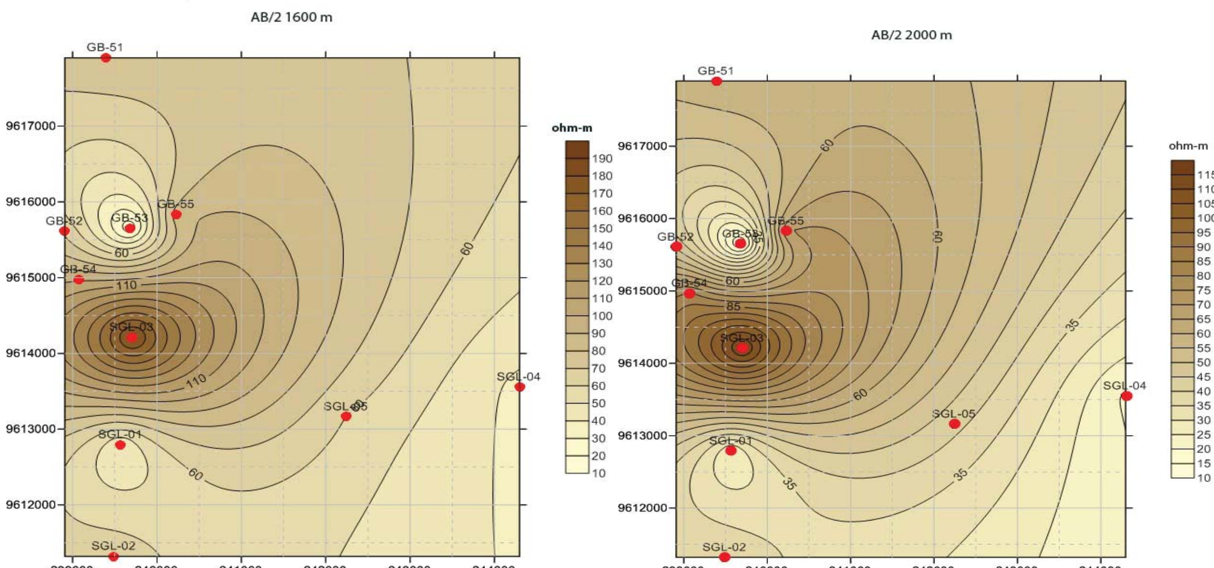


Figure 4. Spatial distribution of apparent resistivity at AB/2 1,200 m.



(a) (b)

Figure 5. Spatial distribution of apparent resistivity at AB/2 (a) 1,600 m and (b) 2,000 m.

direction from Mt. Kaba, which associates with the geothermal fluid at Sindangjati.

Geoelectrical surveys up to AB/2 2,000 m at the region in the eastern part of Mt. Kaba reveal the occurrence of low resistivity zone at depth of about 400 m. The values of low resistivity (< 5 ohm-m) agree with the low values of thermal ground in the geothermal field.[6,8,16] The anomalously low resistivity shown in the eastern part of Mt. Kaba may suggest the presence of hydrothermally altered subsurface rocks.

From both geoelectrical traverse lines AB and CD, the low resistivity region becomes shallow in the southern and eastern part from the Mt. Kaba (Figure 6). We suggest that the low resistivity layer coincides with the location of the hot water springs at Sindangjati, which may strongly associates with the geothermal reservoir. From section AB, we interpret that the depth of anomalously low resistivity layer is about 400 m beneath point SGL-01. At point SGL-04, we suggest that the anomalously low resistivity layer is located at about 200 m depth. Relatively high resistive body seems to intrude the anomalously low resistivity beneath point SGL-05 (Figure 6a). In section CD, we interpret that the anomalously low resistivity layer is about 400 m depth beneath points SGL-02 and SGL-01 (Figure 6b). However, the low resistivity layer dips northwardly reaching greeter depth below point SGL-03.

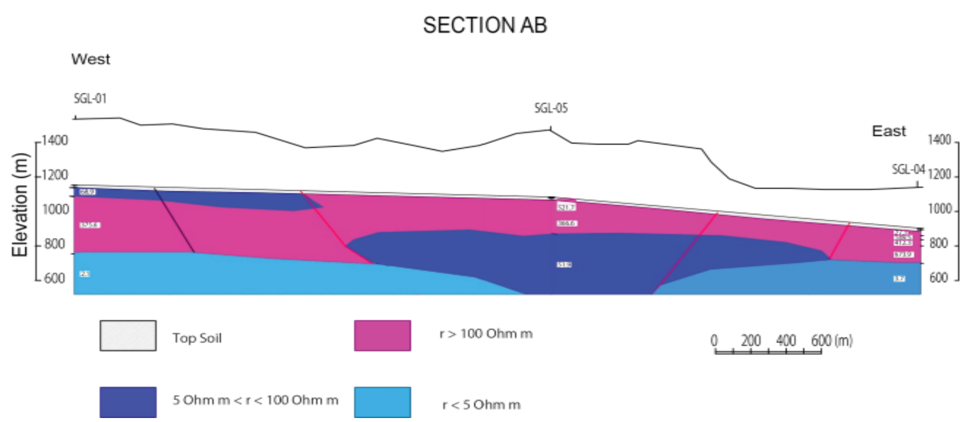
CONCLUSIONS

Geologically, geothermal prospect at Mt. Kaba is possible. However, geothermal manifestation such as hot spring is quite rare so that it is quite difficult to estimate the potential only based on surface manifestations. Two hot springs found at Suban Airpanas and Sindangjati may associate with the Ketaun-Tes and Despetah faults.

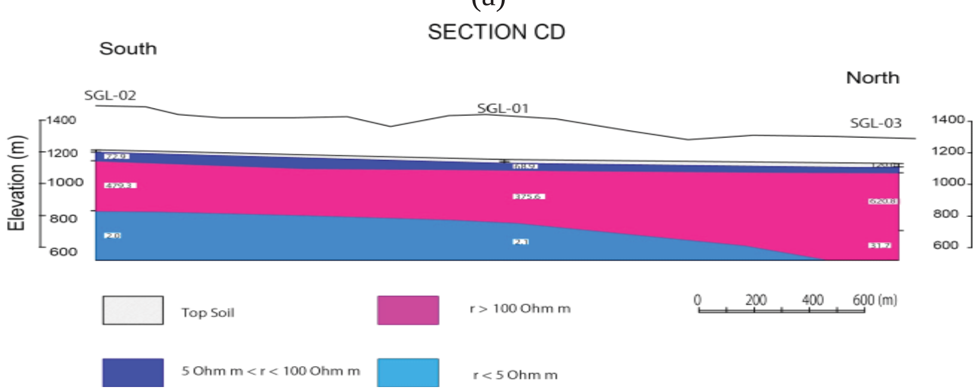
From geoelectrical prospecting using Schlumberger array with AB/2 up to 2,000 m, we suggest the existence of anomalously low resistivity (high conductivity) less than 5 ohm-m in the eastern part of Mt. Kaba. These low resistivity layer is located close to Sindangjati hot spring. We suggest the low resistivity layer is associated with the conductive impermeable cap rock found in the geothermal system. The depth of the anomalously low resistivity layer is estimated to be about 300–400 m from the surface.

ACKNOWLEDGEMENT

This study was supported by Ministry of Research and Technology through Program Peningkatan Kemampuan Peneliti dan Perekayasa. We thank Dinas Energi dan Sumber Daya Mineral of Rejang Lebong, Bengkulu, for their assistance during the geoelectrical survey for three years.



(a)



(b)

Figure 6. True resistivity observed at sections (a) AB and (b) CD. Low resistivity less than 5 ohm-m is observed at about 400 m depth from the surface.

REFERENCES

[1]International Energy Agency. 2008. *Energy policy review of Indonesia*. France: IEA. 236 pages.

[2]Rachman, A. et al. 1995. Geothermal prospect in Indonesia–Prospect status and development opportunity. *Proceeding of the World Geothermal Congress*, Florence, Italy, 1525–1529.

[3]Fauzi, A., Bahri, S., and Auanbantin, H. 2000. Geothermal development in Indonesia: an overview of industry status and future growth. *Proceeding of the World Geothermal Congress*, Kyushu – Tohoku, Japan, 1109–1114.

[4]Radja, V.T. 1995. The role of geothermal energy in the context of the future electric power supply in Indonesia. *Proceedings of the World Geothermal Congress*, Florence, Italy, 173–189.

[5]Armstead, H.C.H. 1982. A proposal for accelerating geothermal power development: especially in small systems. *Geothermal Resource Council Bulletin*, 11 (8), 4–8.

[6]Hatherton, T., Macdonald, W. J. P., Thompson, G. E. K. 1966. Geophysical methods in geothermal prospecting in New Zealand. *Bulletin Volcanologique*, 29, 485–298.

[7]Abiye, T. A. and Haile, T. 2000. Geophysical exploration of the Boku geothermal area Central Ethiopian Rift, *Geothermics*, 57, 586–596.

[8]Hunt, T. M. et al. 2009. Geophysical investigations of the Wairakei Field, *Geothermics*, 28, 85–97.

[9]Pardede, R., and Gafoer, S. 1992. *Geologic Map of Bengkulu Quadrangle, Sumatera*, Geologic Survey Institute, Bandung.

[10]Barber, A.J. 2000. The origin of the Woyla Terranes in Sumatra and the Late Mesozoic evolution of the Sundaland margin. *Journal of Asian Earth Sciences*, 18, 713–738.

[11]Newcomb, K. R. and McCann, W. R. 1987. Seismic history and seismotectonics of the Sunda Arc. *Journal of Geophysical Research*, 92 (B1), 421–439.

[12]Natawidjaja, D. H. and Ruslan, M. 1994. Kondisi tektonik serta hubungannya dengan kegempaan dan aktivitas gunung api di daerah Rejang Lebong, Bengkulu, *Prosiding hasil-hasil penelitian Puslitbang Geoteknologi, Bandung*, 47–64.

[13]Gafoer, S, 2007, *Geologic Map of Bengkulu Quadrangle, Sumatera*, Geologic Survey Institute, Bandung.

[14]Haile, T., Alemayehu, T., and Ranieri, G. 2000. Geophysical, geological and hydrogeological investigations of Boku thermal field, Nazareth, Ethiopia. *Proceeding Twenty-Fifth Workshop on Geothermal Reservoir Engineering*, Stanford, California, SGP–TR–165.

[15]Telford, W. M., Geldart, L. P., and Sheriff, R. E. 1990. *Applied geophysics*. Cambridge: Cambridge University Press. 770 pages.

[16]Thanassoulas, C., Tselentis, G.-A, and Kolios, N. 1986. Geothermal prospecting by geoelectrical sounding in NE Greece. *Geophysical Prospecting*, 34, 83–97.