The Investigation of Hot Spring Flow Using Resistivity Method at Geothermal Field Ie-Seu'um, Aceh - Indonesia

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ABSTRACT

The study conducted at Ie-Seu'um geothermal field, Aceh Besar, Aceh (Indonesia), to investigate the flow of hot spring using 2-D resistivity method. Four survey lines using Pole-dipole array was design across the existing hot spring. The 2-D resistivity inversion models show the study area consists of saturated rock, surface water and rock area, which have very low resistivity value that is <5 Ohm.m and expected as hot spring. Hot water flow detected at line L1 and L2 with different depth and distance, and originated from the north part. The most possibility of hot spring flows in Ie-Seu'um are controlled by fault (Seulimuem segment) and expected at >40 m depth.

KEYWORDS: 2-D Resistivity, Hot Spring, Fault, Ie-Seu'um.

INTRODUCTION

There are many volcanoes in Indonesia because it is largely located in the ring of fire formed by subduction some tectonic plate. Aceh province is located on the westernmost of Sumatra island which has 4 active volcanoes, namely Burni Telong mountain, Peuet Sagoe mountain, Jaboi mountain and Seulawah Agam mountain. Seulawah (1.726 MSL) is the most active compared with other volcanoes. Manifestation of this active volcano is presence of two craters that are Van Heuzt and Simpago crater, steam, Fumaroles, mud pots and hot springs. One of the hot springs is coming from Seulawah Agam volcano which located at Ie-Seu'um region. Generally, Indonesian geothermal systems are dominated by high temperatures hydrothermal, 150-225 °C. The hot water/steam reservoirs are at shallow hydrothermal systems relatively less than 4 km (Subir, 2005). Another main feature of the Sumatran fault system is the collocation with the volcanic arc including calderas in direct proximity to the fault. In general, the position of the volcanic arcs correlates with the geometry of the subduction zone (Tatsumi, 1989). In Sumatra, the trench-parallel Sumatra fault is also collocated with arc volcanic centers; however, this might be pure coincidence (Sieh and Natawidjaja, 2000). Drilling is a direct method to obtain data but expensive. On the contrary, geophysical methods cover larger areas and are relatively inexpensive. Electrical and electromagnetic methods are frequently used in groundwater applications (Atekwana *et al*., 2000; Buselli and Lu, 2001; Yoon and Park, 2001; Inman *et al*., 2002; Rosqvist *et al*., 2003; De la Vega *et al*., 2003; Chandra *et al*., 2004; Corwin and Lesch, 2005 a, b; Owen *et al*., 2005; Bauer *et al*., 2006; Asfahani, 2007). The most important factors on electrical resistivity of rocks are the porosity, temperature, salinity and water-rock interaction. In geothermal areas, the rocks are water-saturated. Ionic conduction in the saturating fluid depends on the number and mobility of ions and the connectivity of flow paths through the rock matrix. Fluid flow and hydrologic cycle processes in geothermal systems originated from presence of water seeping into the ground through fractured rocks. Water absorption is very dependent on the type of rock. The presence of fault structures in geothermal field can create a wide fracture zone that can make ground water contact with hot rock is easier. The objective of this study is to investigate flow of hot water spring using 2-D resistivity method.

GENERAL GEOLOGY

Ie-Seu’um is located at the east of Banda Aceh. Geographically, Ie-Seu’um situated in Mesjid Raya sub-district, Aceh Besar regency and Aceh Province (Indonesia). Geologically, Ie-Seu’um was crossed by several local faults and Seulimuem segment (Figure 1). Field observations indicated an Ie-Seu'um geothermal was presence as a hot springs that occur continuously. Study area is situated about 17 km towards north of Seulawah Agam volcano which extremely prone areas by volcanic ash. Southwest of the Ie-Seu'um geothermal field to about 280 km, there is a Sunda trench, that a boundary of the Indo-Australian plate and Eurasian plate (Sieh and Natawidjaja, 2000). Ie-Seu'um is composed of volcanic rocks with stratovolcano and the most recent eruption is pleistocen. Even now, most of the area consists of the volcanic and andesitic rocks. The lithologies of Ie-Seu’um are andesitic to dasitic volcanic, tuffs, agglomerate and ash-flows (Bennett et al., 1981).

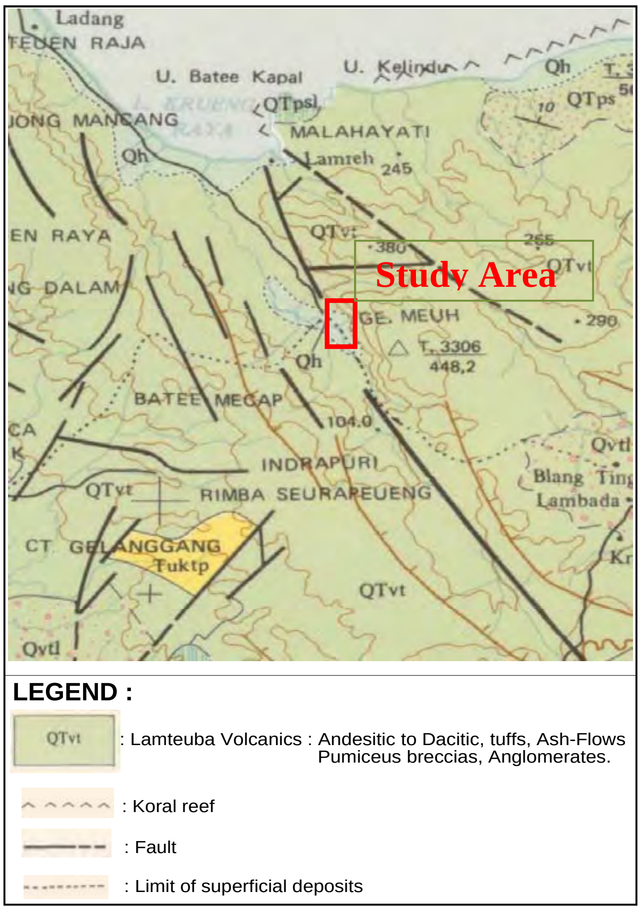

Figure 1: Geology map of the study area (Bennet et al., 1981)

STUDY AREA

The study area was located at Ie-Seu’um village, Aceh, Indonesia (Figure 2). Four (4) resistivity survey lines trending from North to South are perpendicular to the sea. The first and second line with length of 80 m each and elevation of first line is 87-98 m and second line 89-99 m. The third and fourth line with length of 200 m each and elevation of third line is 97-109 m and fourth line is 97-105 m.

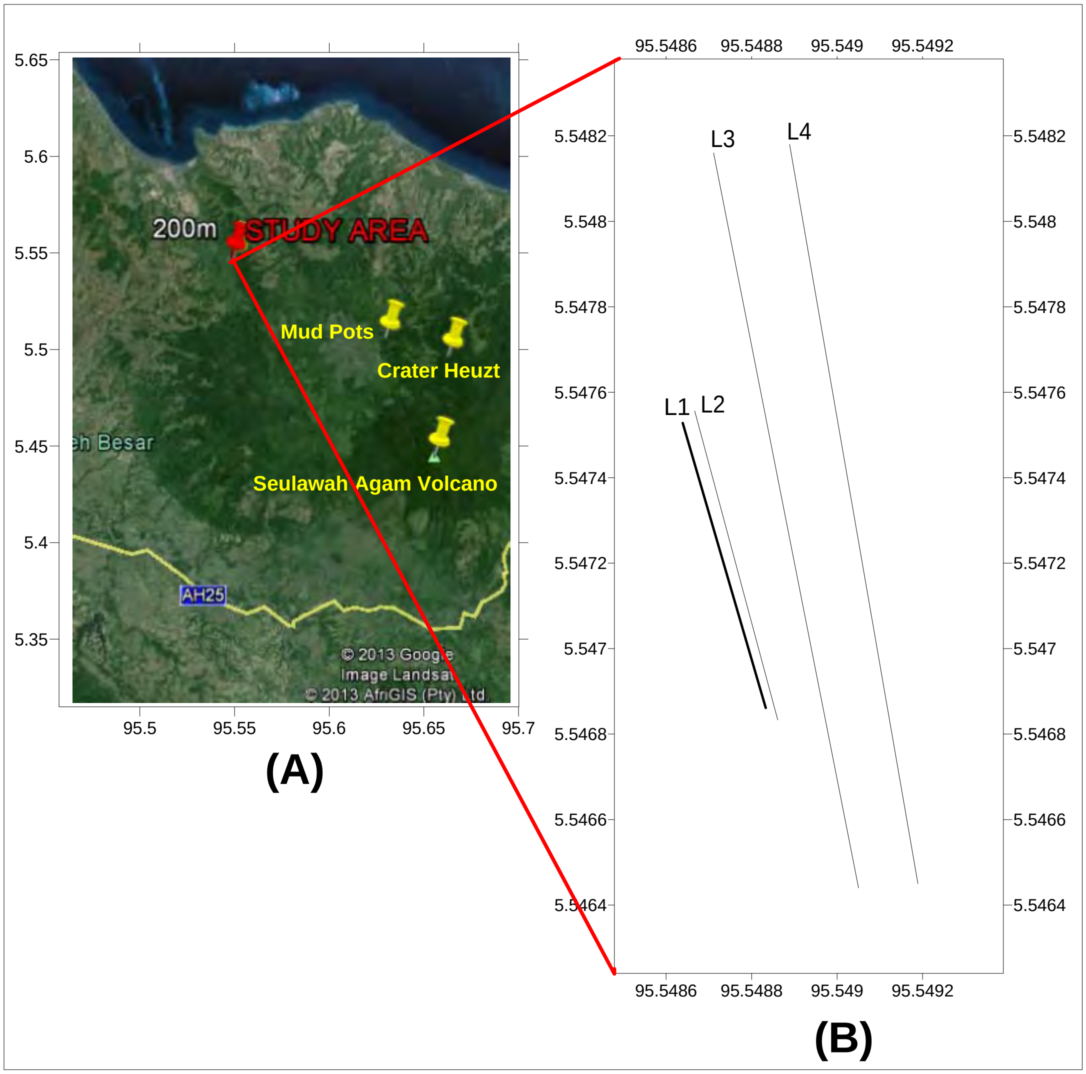

Figure 2: (A) Study area (Google Earth, 2010); (B) Four resistivity survey lines

THEORY OF 2-D RESISTIVITY METHOD

The ground resistivity is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation soil/rock. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels (Loke, 1994). The main parameter measured from 2-D resistivity is resistance of rocks or minerals. The resistivity of material is defined as the resistance (ohms) between the opposite faces of a unit cube of the material (Kearey *et al.*, 2002). The Pole-dipole array has relatively good horizontal coverage, but it has a significantly higher signal strength compared with the dipole-dipole array and it is not as sensitive to telluric noise as the Pole-pole array. Unlike the other common arrays, the Pole-dipole array is an asymmetrical array (Figure 3). Over symmetrical structures, the apparent resistivity anomalies in the pseudosection are asymmetrical (Loke, 1994). The resistivity method measures the resistivity distribution of the subsurface materials.

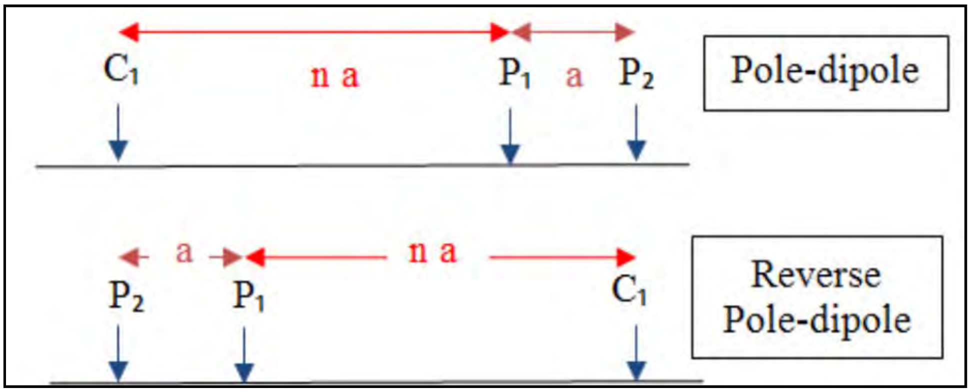

Figure 3: The forward and reverse pole-dipole array

Pole-dipole configuration is different with another configuration due to the current source (C2) is not inline, placed at infinity and perpendicular to the survey line. Distance of the remote electrode wills inference the penetration depth. Types of water and material have each resistivity value. Table 1 and 2 show the resistivity values of some type of waters and rocks.

Table 1: Resistivity values of some types of waters (Telford, 1990).

Type Of Water	*Resistivity (Ωm)*
Precipitation	30 – 1000
Surface water, in areas of igneous rock	30 – 500
Surface water, in areas of sedimentary rock	10 – 100
Groundwater, in areas of igneous rock	30 – 150
Groundwater, in areas of sedimentary rock	>1
Sea water	≈ 0.2
Drinking water (Max. salt content 0.25%)	>1.8
Water for irrigation and stock watering (Max. salt content 0.25%)	>0.65

Table 2: Resistivity values of common rocks and soil materials in survey area (Telford, 1990).

Materials	*Resistivity (Ωm)*
Alluvium	10 - 800
Sand	60 - 1000
Clay	1 - 100
Groundwater(Fresh)	10 - 100
Sandstone	8 - 4 x 103
Andesite	4.5 x 10^4(wet) – 1.7 x10^2 (dry)
Dacite	2 x 10^4
Tuffs	20-10^3(wet) - 10^5 (dry)
Sulphur	1 x 10^{16}

METHODOLOGY

2-D resistivity survey lines R1-R4 were conducted around the hot spring spot area using Pole-dipole array using two cables with minimum electrode spacing of 2 m for line L1 & L2 and 5 m for line L3 & L4. Terrameter ABEM SAS4000 system was used to collect the data with ES10-64C selector. A least-squares inversion of the resistivity data was conducted using a finite element mesh with surface topography to generate a 2-D model of resistivity versus depth/ elevation. Field resistivity structures of 2-D resistivity data was processed using RES2Dinv software (Loke and Barker, 1996).

RESULTS AND DISCUSSION

Figure 4 shows the results of inversion models for L1-L4. Line L1 with penetration depth of 30 m shows a low resistivity value of ≤ 120 Ohm.m. There are 4 (four) spots of very low resistivity values with 3-5 Ohm.m at depth of 10-20 m interpreted saturated rock. Line L2 shows the two layers of rock that have different resistivity values. The first layer with thickness of 7 m is interpreted as andesite with resistivity values of 300-800 Ohm.m. The second layer with thickness of 16 m and resistivity value of <10 Ohm.m interpreted saturated rock. The third line, L3 shows a two-layer case. The first layer with a depth of 20 m and resistivity value of 300-800 Ohm.m interpreted as andesite rock. The second layer with resistivity value of 40-120 Ohm.m is interpreted as saturated rock. The fourth line L4 shows the layer that is dominated an andesite rock that has resistivity values of 500-800 Ohm.m.

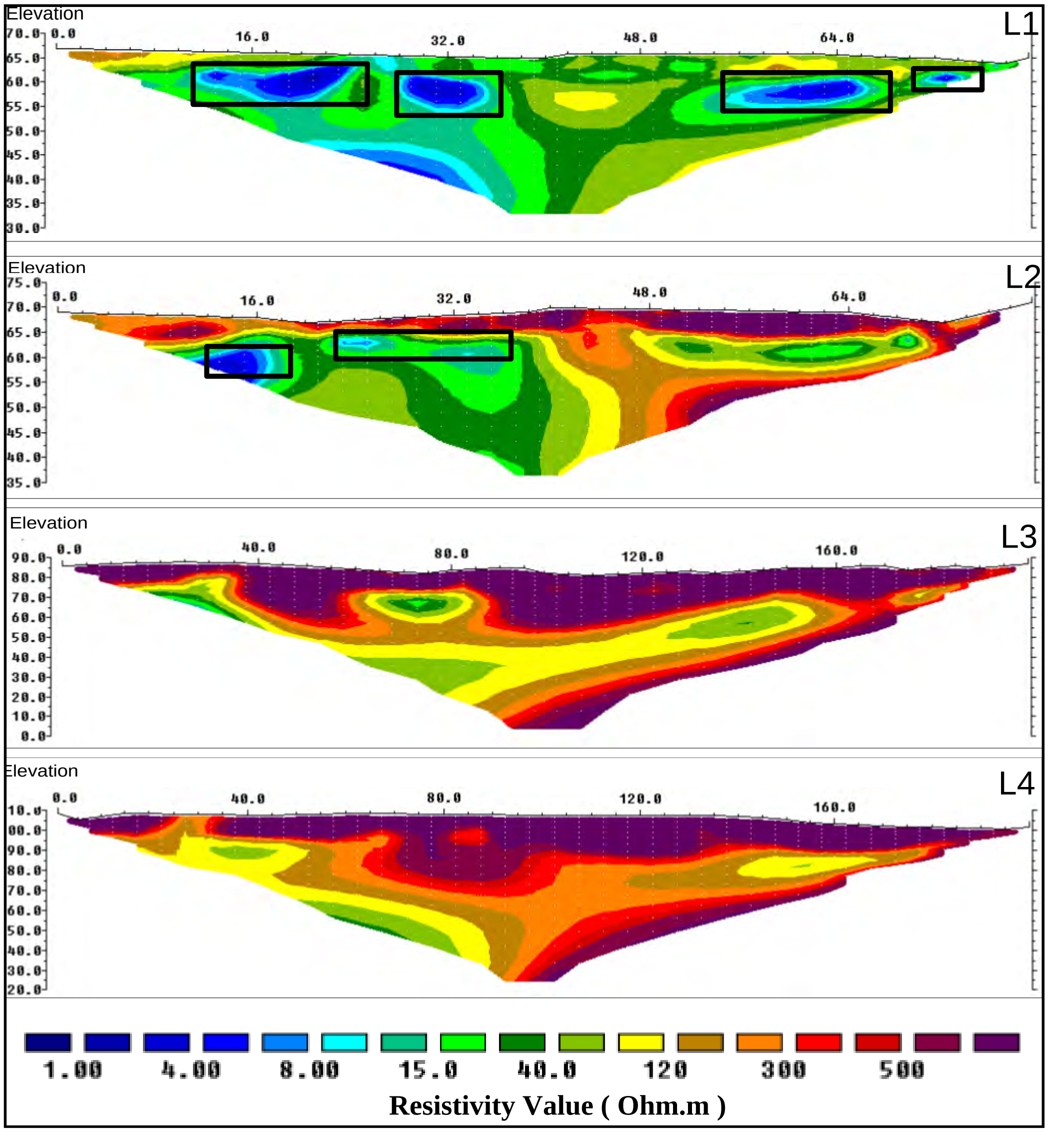

Figure 4: 2-D resistivity inversion model of L1 – L4.

CONCLUSION

The 2-D resistivity method successfully detected saturated rock, surface water and rock area, which have very low resistivity value and expected as hot spring. The resistivity value of the saturated rock is <5 Ohm.m due to the water content (Sulfite, clay, etc). Hot water flow detected at line L1 and L2 with different depth and distance, and originated from the north part. The most possibility of hot spring flows in Ie-Seu'um are controlled by fault (Seulimuem segment) and expected at >40 m depth.

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