Geohazard Identification Using 2-D Resistivity Imaging For Seulawah Agam Volcano, Indonesia

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Abstract. Common parameter used for delineating geothermal system is resistivity. Hydrothermal alteration of primary minerals depends on temperature distribution and forms various clay minerals with conductivity properties. Clay minerals formed at high temperatures are more resistant than lower temperature. Most geothermal systems within active volcanic regions show low resistivity (1-5 Ohm.m) surrounding an inner core of higher resistivity. 2-D resistivity study conducted at Seulawah Agam active volcano and its vicinity (Aceh) with geothermal sources (Herzt, Ie Jue and Ie Seu’m) flowing from south-east to north-west. Two lines, L1 and L2 were conducted crossing the suspected geothermal flow using ABEM SAS4000 system with 10 m minimum electrode spacing and Pole-Dipole array. Resistivity results indicated two main zones; (i) top layer, <100 m depth with resistivity value of >60 Ohm.m and (ii) cap-rock, 30-100 m depth with resistivity value of 6-50 Ohm.m. Few fractures and low resistivity regions (<5 Ohm.m) were identified in the cap-rock. Hot water and hot mud have low resistivity value; hence the low resistivity regions were interpreted as geothermal flow and it is convincingly suspected to be a geohazard zone. New extension of Seulawah Agam geothermal flow was identified by 2-D resistivity method.

1. Introduction

Resistivity is a common parameter used for delineating geothermal system since it is temperature dependent. Sounding methods (Schlumberger and TEM) are mostly used for shallow exploration, <1 km [1]. In volcanic regions, hydrothermal alteration of primary minerals depends on temperature distribution determined by heat convection (hydrothermal water) and forms various clay minerals (Figure 1). These clay minerals have varying electrical conductivity properties, thus becoming a significant factor in the search for geothermal heat source [2].
Temperature and pressure change an electrical resistivity, physical properties and other physical parameters of rocks due to changes in chemical reactions. Mineral alteration is a chemical reaction that depends on mineral content, pressure and temperature of hydrothermal fluid. Archie’s law is a formula that approximates the resistivity of rocks/formation:

\[ r = r_w a f^m \]

where:
- \( r \) = Bulk resistivity (measured)
- \( r_w \) = Resistivity of pore fluid
- \( f \) = Porosity of total volume of rocks/formation
- \( a \) and \( m \) = Empirical parameter (~1) and cementing factor (~2), respectively.

Rocks composed of minerals including water; carry mineral/chemical, physical and electrical properties. Electrical currents transfer in rocks as conduction, electrolytic and surface conductivity. Ionic conduction occurring in rocks contains free ionic exchange as rocks are filled with fluids in pore spaces. Rocks behave as semi-conductors if they contain minerals, which are electrically semi-conducting. Geothermal field is usually associated with volcanic or intrusive sources. The electrical conductivity is associated with electrolytic and surface electrical conduction of thermal water and the presence of clay minerals. Clay minerals formed at high temperatures are more resistant than clay minerals formed as alteration of rocks at a lower temperature. These properties are significant in the interpretation of electrical methods used for exploration of geothermal resources [3].

Most geothermal systems within the active volcanic regions, show common resistivity structure with low resistivity of 1-5 Ohm.m surrounding an inner core of higher resistivity. This increasing resistivity with depth is associated with a change in the conduction mechanism, from interface conduction to electrolyte conduction due to a change in alteration minerals at about 240°C [4]. Resistivity for geothermal area is substantially different and generally lower than the resistivity in areas with colder subsurface temperature [5]. Water penetration in Earth cracks produces a reduction of the bulk resistivity, and makes the fault easy to detect. Figure 2 shows a conceptual model of geothermal system [6].

The purpose of this paper is discussed the resistivity change towards temperature using 2-D resistivity imaging at geothermal fields of an active volcanic region (Seulawah Agam, Aceh, Indonesia), and to relate it and suspect it is a geohazard area, both due to volcanoes and faults in the study area. Most geothermal systems within the active volcanic regions, show common resistivity structure with low resistivity of 1-5 Ohm.m surrounding an inner core of higher resistivity. This increasing resistivity with depth is associated with a change in the conduction mechanism, from...
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Figure 2. Conceptual model of a geothermal field [6].

2. Geology Settings

Seulawah Agam volcano, one of three active stratovolcanoes in the Aceh province, is located at the northwest end of Sumatra (Figure 2). Seulawah Agam has two craters, van Heutsz (Heszt), the most active crater at an elevation of 714 m on the north side, and Simpago on the south side. The lithology of the study area is dominated by Lam Teuba volcanic composed of andesitic to dacitic volcanic, pumiceous breccia, tuffaceous, calcareous sometimes cross-bedded sandstones, conglomerates, agglomerate, minor mudstones and ash flows which intruded of the Seulimum formation. The Seulimeum formation is composed of tuffaceous and calcareous sandstones, conglomerates and minor mudstones [7]. The geological formation formed a topographic depression, occupied with alluvial flat and low flat-topped hills within Barisan Range. The adjacent Sumatra in the west coast constitutes volcanic arc with many Quaternary volcanoes such as Pulau Weh and Seulawah Agam.

The volcanic belt is extended along the tectonically weak SFS and this tectonic weakness is supposed to have triggered volcanism [8]. In the northern most Sumatra, the Sumatran Fault System (SFS) splits into two major dextral strike-slip faults which are the Seulimeum and the Aceh Fault [7]. Sumatran Fault system occurs from the Middle Miocene and the opening of the Andaman Sea. Pre-Tertiary basements rocks outcrop mainly along the central spine of the Barisan Mountains, which extend the length of the island parallel to the southwest cost.

The area from northeast and southwest is overlain by Tertiary sedimentary and volcanic rocks. From upstream of the Jantho region to downstream of Indrapuri, the Pleistocene coarse-grained partly volcanic sands and gravels form a prominent terrace surface on both sides of the Krueng Aceh. Downstream of Indrapuri, the alluvial deposits can be subdivided into a shallow aquifer system and a deep aquifer system. Upstream of Indrapuri, the alluvial sandy-gravelly deposits in the vicinity of the river courses, the older terrace sand-gravel deposits and the semi-consolidated sandstones are assumed to constitute the main aquifers of the upper part of the Krueng Aceh valley [9].
3. Study Area and Methods

2-D resistivity study was conducted at Seulawah Agam, Aceh, Indonesia and its vicinity. Seulawah Agam is an active volcano with geothermal sources such as Herzt, Ie Jue and Ie Seu’um. Flow of the geothermal is suspected from south-east to north-west from Seulawah Agam. Two survey lines, L1 and L2 were conducted crossing the suspected geothermal flow using ABEM SAS4000 system with 10 m minimum electrode spacing and Pole-Dipole array (Figure 4).

The data acquisition used roll along techniques which make a total length of the survey line is 1200 m. The data processed involve standard processing, standard processing with mathematical data extrapolation and modelled using RES2Dinv software. The data were then outputted into Surfer software for gridding, contouring and final presentation.
The 2-D electrical resistivity apply base on an injected electrical current (I) through two metallic electrodes and measuring the potential difference (V) between two other electrodes. The apparent resistivity ($\rho_a$) is given by:

$$\rho_a = k \frac{\Delta V}{I}$$

where k is geometric factor.

The measurements provide information about apparent resistivity for a medium whose volume is proportional to the electrode spacing. The data point corresponding to the investigated volume is conventionally represented on a section at a depth equals to the electrode spacing. The apparent resistivity is conventional: it consists of a pseudosection with x in abscissa and z in ordinate (not a real depth). Software such as Res2DInv [11] used to process the data for real resistivity inversion model interpretation.

4. Result and Discussions

2-D resistivity study was conducted at Seulawah Agam, Aceh, Indonesia and its vicinity. Seulawah Agam is an active volcano with geothermal sources such as Herzt, Ie Jue and Ie Seu’um. Flow of the geothermal is suspected from south-east to north-west from Seulawah Agam. Two survey lines, L1 and L2 were conducted crossing the suspected geothermal flow and faults area. Figure 5 and 6 show 2-D resistivity pseudosection of line L1 and L2. Generally, resistivity values of the study area is 0-500 Ohm.m and covered depth of up to 320 m from ground surface. The area is divided into two main zones;

(i) top layer with thickness up to 100 m and resistivity value of >60 Ohm.m and (ii) cap-rock with depth of 30-100 m and resistivity value of 6-50 Ohm.m. Few fractures and low resistivity regions (<5 Ohm.m) were identified in the cap-rock. Hot water and hot mud have low resistivity value; hence the low resistivity regions were interpreted as geothermal flow and it is convincingly suspected to be a geohazard zone. This shows that 2-D resistivity method can be used to identify geothermal flow and faults area as an identity of geohazard area, both volcanic and tectonic hazard. Figure 7 shows new extension of Seulawah Agam geothermal flow identified by 2-D resistivity method.
Figure 5. Resistivity pseudosection of line L1.

Figure 6. Resistivity pseudosection of line L2.

Figure 7. New geothermal flow of Seulawah Agam identified by 2-D resistivity method.
5. Conclusion
Generally the fractures and hydrothermal outflow regions were identified in the cap-rock, and it was detected at depth 50-120 m with resistivity value of <5 Ohm.m, and its identify as geohazard area, both volcanic and tectonic hazard. The fault was identified at distance 300-800 m, and it is suspected that the fault is >150 m deep. This shows that 2-D resistivity method can be used to identify the potential geohazard area. The resistivity profiles indicates the presence of several fracture in some geothermal spots at the study area. These results are also shown from the characteristics of the resulting resistivity values, which characterize the presence of fractures and hydrothermal outflow in the study sites. This can also be an implication of the presence of volcanic hazard in the region. The interpreted resistivity and geothermal data of the Seulawah Agam area have revealed new information and improved the knowledge about the internal structure beneath this area. Detail ground geophysical study such as 2-D resistivity, seismic, gravity is recommended for environmental and safety purposes.

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