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Utilizing of Geophysical Method for Geothermal Exploration In Aceh Besar (Indonesia)

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Abstract - *Magnetic and 2-D resistivity imaging method were widely used in geothermal exploration. In this study geophysical method were conducted in two different locality situated in Ie-Seu 'Um and Iejue area. The purpose of this study to identify the geothermal environment and subsurface characteristics. Magnetic method was performed with proton precession magnetometer device and Global Positioning System (GPS) navigation for real-time measurements while 2-D resistivity imaging method were conducted with ABEM SAS4000 system with pole-dipole array. Two survey lines were conducted for each locality with 2 m electrode spacing for Ie-Seu 'Um area while 10 m electrode spacing for Iejue area. The magnetic data were processed using Surfer10 software for contouring to produce magnetic residual map while resistivity data were processed using Res2Dinv software. The magnetic residual map shows high magnetic value in geothermal area which is about >60 nT while resistivity give low values <7 Ωm. High magnetic intensity for geothermal area were caused due to increasing of iron oxide while low in resistivity are causes due to increasing the temperature as the depth increase. Low in resistivity <7 Ωm were suspected as hot water with composition of sulphur and clays.*

***Key Words*: Magnetic, 2-D resistivity imaging, Seulimeum fault**

1.INTRODUCTION

Geothermal described as heat contained within the earth. Geothermal system can be located in the region with normal or slightly above normal geothermal gradient and the region around plate margin where geothermal gradient higher than the average values. A volcanoes, hotsprings, and other thermal geological phenomena is a part from the geothermal system. The characteristic of geothermal system consist of the heat sources, reservoirs, a fluid which carries and transfer the heat, and recharge area [1]. The heat source can be either a very high temperature (>600 °C) magmatic intrusion that reached shallow depths (5-10 km) or in certain low temperature as it increase with depth. The reservoir refer as a volume of hot permeable rocks from which the circulating fluids extract a heat and normally consists of hot fluids, vapors and gases depending on its temperature and pressure. The reservoir is surrounded by a cover of impermeable rocks and connected to recharge area where water (fluids) flows into the reservoir due the buoyancy forces. Geophysical technique such as resistivity and magnetic are widely successfully used in identifying and delineating the geothermal system. In resistivity exploration the parameter of interest is electrical resistivity of the rocks which reflects the properties of geothermal system. Resistivity is highly sensitive to temperature and geothermal alteration process and controlled by several important geothermal parameter such as temperature, fluid type and salinity, porosity, composition of the rocks, and also the presence of alteration minerals [2]. In a geothermal environment, the resistivity value decrease as a result increasing in temperature and salt concentration in geothermal reservoir [3] and almost volcanic rocks a magnetic due to presence of small amount of primary magnetic minerals (magnetite and titanomagnetite). Magnetic exploration in geothermal are important to identify the potential area of reducing magnetization due thermal activity [4]. Induced magnetization depends on the magnetic susceptibility of rocks and the magnitude of earth magnetizing field. The present of ferrimagnetic minerals such as magnetite and titanomagnetite in significant amount contributes a high values of magnetic susceptibility of volcanic rocks. The magnetic susceptibility in geothermal environment depends on the temperature and type of rocks in the environment it is in. Normally, in geothermal environment the heated rocks increase the bulk susceptibility due to growth of iron oxides ([5];[6]). Figure 1 shows the idealized model of geothermal system.

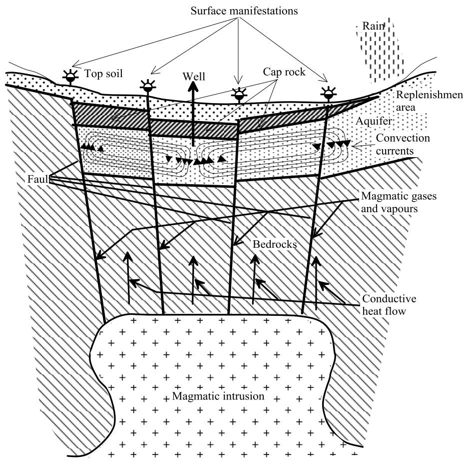


Fig -1: Idealized model of geothermal system [7].

2. General Geology

Aceh province is located on the western Sumatra island with consist of four active major volcanoes mountains namely as Burni Telong mountain, Peuet Sagoe mountain, Jaboi mountain, and Seulawah Agam mountain which are more active compare from others. Generally, high temperature of 150-225 °C dominated for this geothermal environment in Indonesia region [8]. 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. Rock unit of all ages are transacted by Sumatra fault which follow the NW-SE trend [9]. The geology of Banda Aceh Quadrangle has been mapped (figure 2) [11]. The lithology of the study area, Ieju is dominated by Lam Tuba volcanic which is composed of andesitic to dacitic volcanic, pumiceous breccia, tuffs, agglomerate and ash flows with composition of tuffaceous and calcareous sandstones, conglomerates and mudstones [10]. The geological formation formed a topographic depression, occupied with alluvial flat and low flat-topped hills within Barisan Range ([11]; [12]).

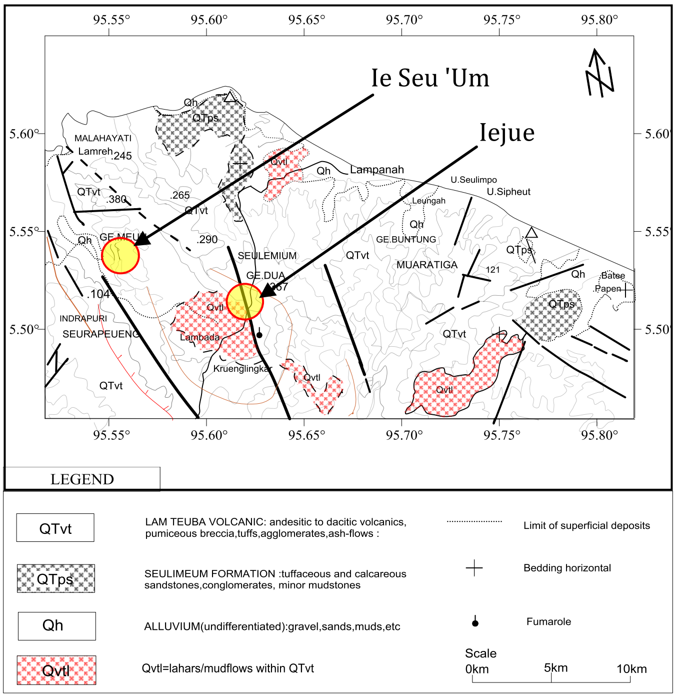


Fig -2: Geological Map of Banda Aceh Quadrangle, Sumatra [11].

3. Theory

2-D resistivity imaging technique utilize direct current to investigate the electrical properties of the subsurface. The resistivity method basically measures the resistivity distribution of the overburden materials. Electrical resistivity in the earth depends on a combination of ohmic and dielectric effects related to lithology of subsurface [13].

The apparent resistivity, ρ_a are calculated based on equation 1.1.

$$\rho_a = k\frac{V}{I} \qquad (1.1)$$

where;

V: voltage (V)
I : current (A) or (mA)
k : geometric factor depends on electrode arrangement

In resistivity survey, the value *k* plays an important role, the depth of penetration of resistivity sounding depends on spacing of electrode which is refer to value of *k.* For this survey pole-dipole electrode array was chosen based on the deepest depth penetration beside provide a good resolution. Pole-dipole array is an asymmetrical arrangement which influence the anomalies by giving asymmetrical apparent resistivity in 2-D inversion model. To eliminate this asymmetry affect, the electrode are arrange in reverse manner as shown in figure 3 below.

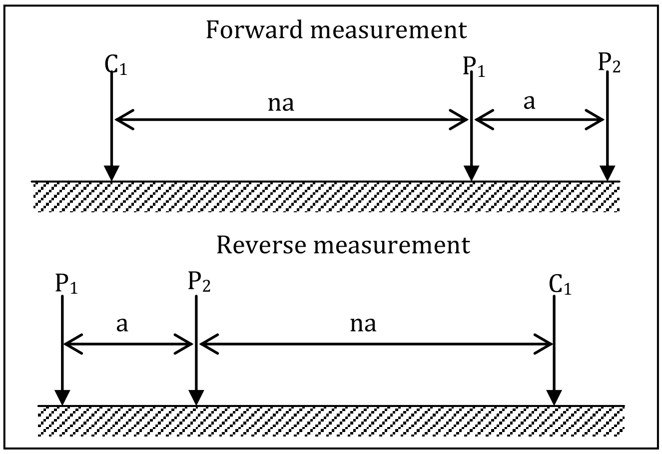


Fig -3: Pole-dipole electrode array.

The resistivity method basically measures the resistivity distribution of the subsurface material. Rock types such as igneous and metamorphic typically have high resistivity values. Variations in electrical resistivity may indicate changes in composition, layer or contaminant levels [14]. The resistivity of these rocks is mainly dependent on the degree of fracturing. High fracturing of rocks will result a lower resistivity values. Table 1 shows the resistivity values of rocks and soil types [15].

Table -1: Resistivity values of rocks and soil [15].

Material	Resistivity (Ωm)
Alluvium	10 - 800
Sand	60 - 1000
Clay	1 - 100
Groundwater (fresh)	10 - 100
Sandstone	8 - 4x10^3
Shale	20 - 2x10^3
Limestone	50 - 4x10^3
Granite	5x10^3 - 1x10^6

Magnetic survey measure the magnitude and the orientation of the Earth's magnetic field intensity. The purpose of magnetic survey is to identify the subsurface geology on the basis of the anomalies in the earth's magnetic field due to magnetic properties of underlying rock [16]. When a magnet undergo magnetization it will have a remanent that refer to magnetization left behind after an external magnetic field is removed. It also refer as magnetic memory in magnetic storage and source of information on the past Earth's field in paleomagnetism [17]. Induced magnetization depends on the magnetic susceptibility of the material and magnitude and direction of ambient magnetic field while remanent magnetization reflects the previous past of magnetic history of the material [18]. Table 2 shows the general magnetic susceptibility value in common rocks and ores. The magnetic properties of highly magnetic rocks tend to be extremely variable and their magnetization is not directly proportional to the applied field [19].

Table -2: Magnetic susceptibility in common rocks and ores.

Rock types	Susceptibility (k)
Altered ultra basics	10^{-4} to 10^{-2}
Basalt	10^{-4}
Gabbro	10^{-4} to 10^{-3}
Granite	10^{-5} to 10^{-3}
Andesite	10^{-4}
Rhyolite	10^{-5} to 10^{-4}
Metamorphic rocks	10^{-4} to 10^{-6}
Most sedimentary rocks	10^{-6} to 10^{-5}
Limestone and chert	10^{-6}
Shale	10^{-5} to 10^{-4}

4. METHODOLOGY

Two survey area which is Ie-Seu 'Um and Iejue locality are choose for this study. Ie-Seu 'Um locality are famous established hotspring area used for eco-tourism purpose while Iejue area are located about 10 km from Ie-Seu 'Um hotspring. A magnetic survey was conducted surrounding the Ie-Seu 'Um hotspring area. Data was measured randomly by proton magnetometer with 20 m interval spacing for each station (rover) while 2-D resistivity survey line was conducted near the hotspring area with ABEM SAS 4000 system. Pole-dipole array were selected for this survey with electrode spacing of 2 m. In Iejue area three magnetic survey lines were conducted with distance of 50 m distance interval for each magnetic station while two resistivity survey line are conducted with electrode spacing of 10 m (Figure 4). The magnetic were processed using Surfer10 software to produced full magnetic residual map. Resistivity data processing involve standard processing and model resistivity using Res2Dinv software. The data were then outputted into Surfer10 software for contouring and final presentation.

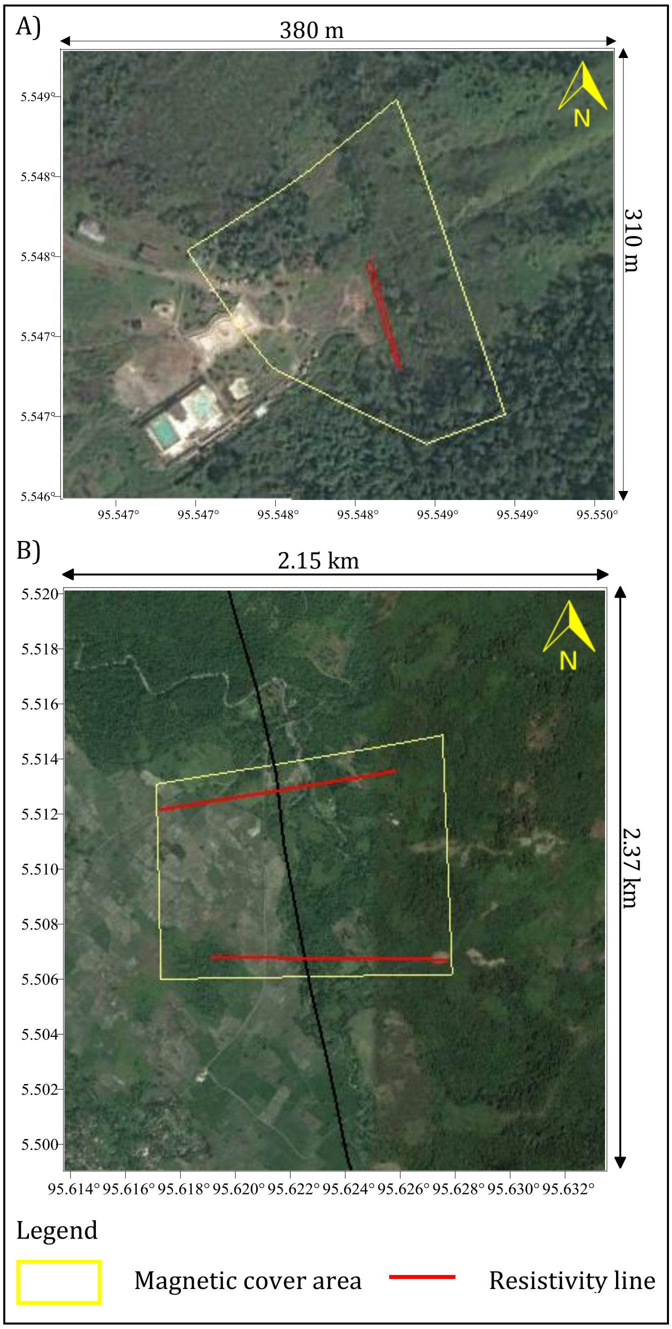


Fig -4: Study area; Ie-Seu 'Um (A) and Iejue (B).

5. RESULTS AND DISCUSSIONS

Figure 5 shows the magnetic residual of Ie-Seu 'Um area. The magnetic value cover from -240 nT to 220 nT. High magnetic value from range of 0 nT to 220 nT assembles at western part while low magnetic value from range -180 nT to 0 nT dominated the eastern part of the map. The contrast zone of this magnetic map suspected a presence of fault zone. The black rectangle area shows the hotspring point with magnetic values covers from 60-120 nT.

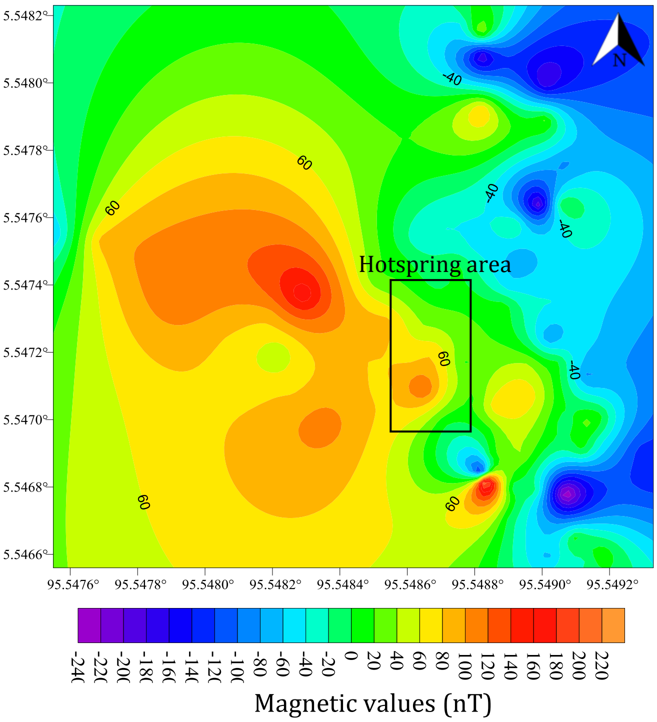
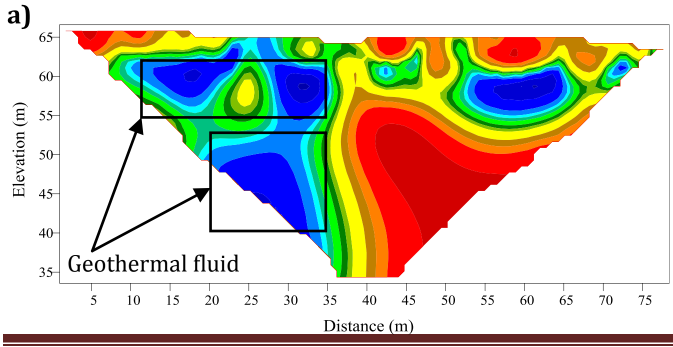


Fig -5 : Magnetic residual map of Ie-Seu 'Um locality.

Figure 6 (a and b) shows the 2-D inversion model of resistivity line 1 and 2 in Ie-Seu 'Um area. The resistivity values covers from 0-1800 Ωm with exploration depth up to 30 m. High resistivity values >200 Ωm may indicate the presence of volcanic tuff and rocks. A resistivity <50 Ωm indicate the saturated zone for this area. Low resistivity values <0-3.5 Ωm indicates the geothermal fluid consist of hot water with composition of sulphur and clays.

Line 1

a)



Line 2

b)

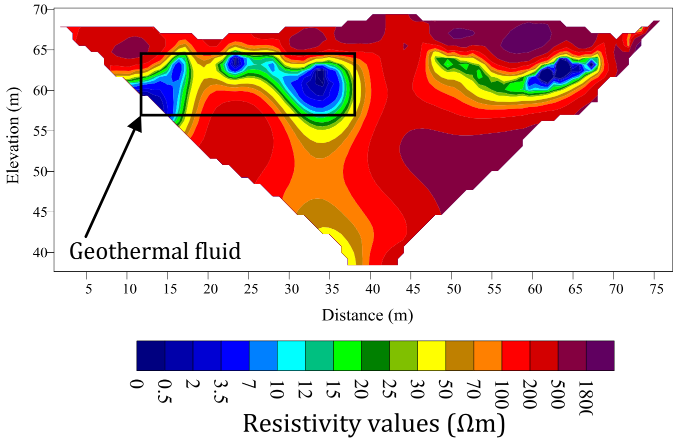


Fig -6: 2-D inversion model resistivity line 1(a)and line 2(b).

Figure 7 shows the magnetic residual map of Iejue area. The magnetic values covers from -150 nT to 550 nT. From this map a low magnetic values <-50 nT assembles at western part while high magnetic values >100 nT assemble at eastern part of the map. The highly contrast of magnetic zone may indicate the presence of fault zone. High magnetic value (>100 nT) are indicated as the presence of geothermal fluid which flow from northwest to southeast direction.

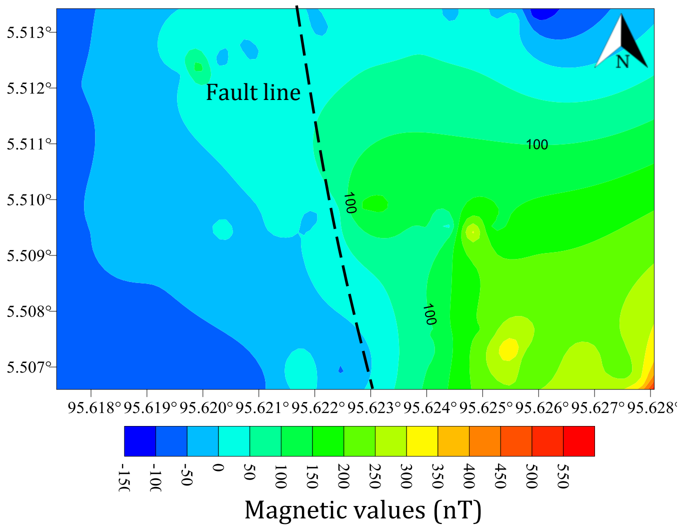


Fig -7: Magnetic residual map of Iejue area.

Figure 8 shows 2-D inversion model resistivity of line 1 and line 2 in Iejue area. Low in resistivity value at range of 0-3.5 Ωm interpreted as geothermal fluid which consist of hot water and hot mud with composition of sulphur and clays. Low in resistivity value due to increase in temperature as it is increase with depth. From this result, two main zone are identify which are a top layer with thickness of 120 m at resistivity of >50 Ωm. The second layer are identify at resistivity value of 5-50 Ωm that interpreted as a cap layer for a geothermal system.

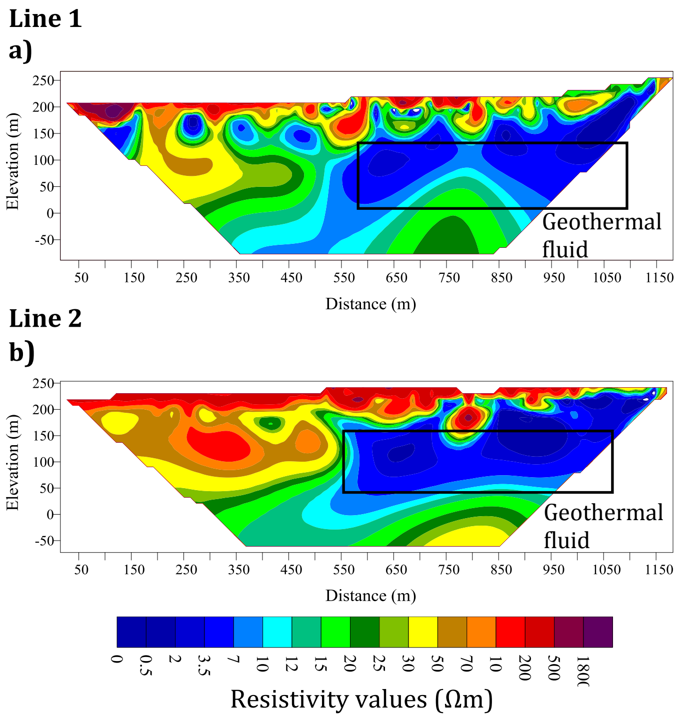


Fig -8: 2-D inversion model resistivity of line 1(a) and line 2(b) in Iejue area.

6. CONCLUSIONS

Magnetic and 2-D resistivity imaging technique capable in delineating the geothermal system. High magnetic value >100 nT and low in resistivity value of 0-3.5 Ωm indicate the presence of geothermal fluid. High magnetic values in geothermal system are causes due to growth in iron oxide while low in resistivity value causes by increasing temperature as it increase in depth.

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