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Research Paper

Utilizing geophysical methods for geothermal exploration

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ABSTRACT

Geothermal energy can be retrieved and simply generate energy on par with the out-turn of other types of energy fabrication such as nuclear reactors due to its abundancy. Geothermal reservoirs are one of a naturally occurring hydrothermal resources. In this study, three geophysical methods were used to Pole-dipole array with an electrode spacing of 5 m was used during the application of 2-D electrical method meanwhile for magnetic method a proton precession magnetometer device and Global Positioning System (GPS) navigation were used when the method performed. Total of four survey lines were conducted for 2-D electrical and magnetic method in which a data correlation between these two methods will then be used for data interpretation. Inversion of apparent resistivity data to a 2-D electrical model section was done using a RES2DINV software while for the magnetic data, Microsoft Excels and Surfer 10 software was used and presented in a form of contouring in which discovered the fault zone. Analytic signal map was produced from Surfer 10 and showing high magnetic value in geothermal locality which is about >10 nT while resistivity gives a low value of 10 Ωm and IP shows high chargeability value of 40 msec. Increasing of iron oxide causing the magnetic intensity to be high while increasing in temperature resulted in low resistivity value. Most of the fractures occurred at depth of 100 meters and above with size of approximately 20 meters. The presence of fractures is associated with the major fault in a geological map which occurred along the study area.

1. Introduction

Geothermal energy is characterized as heat produced from the Earth. It is a natural, renewable resource that offers worldwide electricity. It is called a renewable energy option because the heat generated within the interior of the Earth is virtually infinite. The heat streaming continuously from inside the earth is measured at 42 million megawatts of power. One megawatt is 1 million watts, and can fulfil around 1,000 people's power. The Earth's interior is predicted to continue incredibly hot over billions of years, maintaining an almost infinite heat flow. The following **Fig. 1** illustrates how far inside the crust of the earth increases, and the temperature will eventually increase too (Kagel, et al., 2007)

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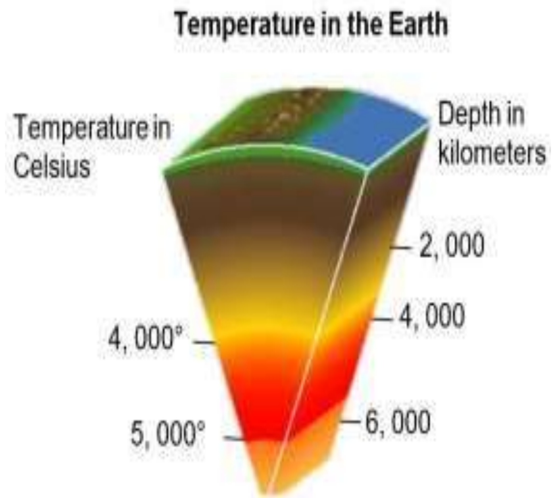

Fig. 1. The Earth's temperature (modified from Geothermal Energy Office).

The heat often hits the surface as lava or magma, but it usually stays under the earth's crust, boiling surrounding rock and water which can be as hot as hundred degrees Celsius. As water is heated by the heat of the planet, hot water or steam may be trapped underneath a layer of impermeable material which consist of permeable and porous rocks and create a geothermal reservoir. The hot geothermal water may appear on the surface as thermal springs or geysers, however largely remains underground deep, embedded in cracks and porous rock. Such underground hot water compilation is known as a reservoir of geothermal (Kana, et al., 2015).

Geophysical methods are one of the most prominent disciplines used on the surface for geothermal exploration (Kana, et al., 2015). The most significant geophysical methods of geothermal exploration are 2-D electrical and induced polarization (IP). This is because the resistivity is very susceptible to temperature and the alteration processes of geothermal and has a direct relation with reservoir characteristics. Rock's electrical resistivity is governed by significant geothermal criteria such as temperature, liquid form and salinity, porosity, rock structure and the existence of mineral alterations.

Conductivity, σ (Sm^{-1}) is the reciprocal dimension of resistivity (Flóvenz, et al., 2017). High levels of conductivity in geothermal systems typically are expected to correspond with low permeability, smectite-rich clay caps, with greater resistivity (> 100 Ohm m), high temperature and permeable reservoirs of hydrothermal (Cumming, 2009). In geothermal study, however, measurements of electrical or resistivity are a tradition (Flóvenz, et al., 2017). Ground magnetic methods also is important as it helps in identify the magnetic properties of the rock which is also one of the physical parameters and this method usually categorized as indirect method.

In magnetic experiments, spatial differences of the magnetic field strength of the Earth are calculated, either the survey is one on the ground or in aeromagnetic. The magnetic map resulting from the survey illustrates changes in the subsurface properties of magnetic. Magnetic maps for technical purposes, are utilized for identifying intrusive regions, dykes, faults, submerged lava and hydrothermally areas that has been altered. In general, the significance of the potential methods for exploration of geothermal is not big, mainly for geological structural details (Flóvenz, et al., 2017).

2. Methodology

1.1 Study area and geological setting

The study was conducted at Sungai Ber Hot Spring in which located at Lojing Highlands, Kelantan (**Fig. 2**). Lojing Highlands is sited adjacent to Cameron Highlands and located at the foot of the Main Range as shown in which is also known as Titiwangsa Range (**Fig. 3**). This mountain range have an elevation which is rarely less than 910 m and peaks over 2100m, extends from the southern part of Thailand in the north to Negeri Sembilan in the south. Granite with several enclaves of metasedimentary rocks are composed in this range (Raj, 2009). The west part of Kelantan, the Main Range granite stretching along western part of Kelantan up to Perak and Pahang's states boundary and Thailand's boundary (Nazaruddin, et al., 2015).

The Main Range Granite Province has a rock type from a coarse to very coarse grained megacrystic biotite granite. Common rocks are K-feldspar with large phenocrysts which is up to 7 cm long and usually demonstrate a distinctly megacrystic appearance in hand specimen. The study area consists of granite outcrops that can be found in large granite bodies and boulders which occurs mostly along the river.

Metamorphic and sedimentary rock are not found in the study area but Quartenary deposit specifically alluvium deposits or unconsolidated sediments are found covered the study area. The granitic bedrock was overlain by the sediment in which deposited mostly along the river (Azman Ghani, 2009).

The hot spring particularly the one in Sungai Ber (**Fig.3**) have a temperature of 72 °C. Silica minerals that was derived from an igneous rock making Lojing Hot Springs rich in silica content. It shows the resistivity is very susceptible to temperature and the alteration processes of geothermal and has a direct relation with reservoir characteristics. Rock's electrical resistivity is governed by significant geothermal criteria such as temperature, liquid form and salinity, porosity, rock structure and the existence of mineral alterations.

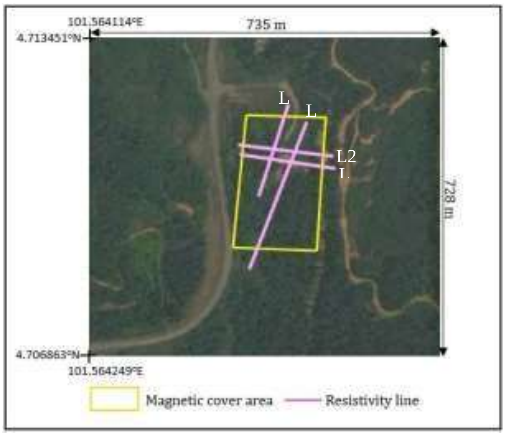

Fig. 2. Map of the study area.

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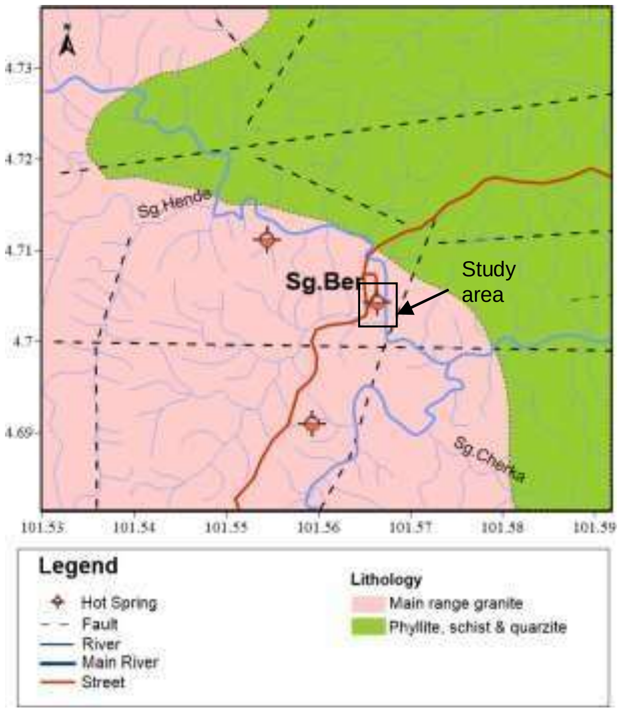


Fig. 3. Geological map of Kelantan showing distribution rocks in the state (Dept. of Minerals and Geoscience Malaysia, 2003).

Ber hot spring has a highest flow rate (Table 1) and intense sulphur smell, according to Azmi et al. (1998). The emergence of the Kelantan hot spring is usually governed by the geological system and is closely linked to intrusion of granite and active magmatic activity in Malaysia. Most hot springs are situated near either granite or the major faults or areas of the joint (Kamal et al., 2001).

Table 1. Properties of Sungai Ber Hot Spring (Dony et al., 2015).

Measuring point	pH	Temp. (°C)	TDS (mg/L)	Conductivity (µS/cm)	DO (% Saturation)
The main vent	9.12	72.31	0.193	0.566	2.1
Pond 1	9.06	60.16	0.179	0.459	51.27
Pond 2	8.86	41.19	0.177	0.356	82.32
Pond 3	8.72	38.60	0.169	0.327	89.93
Pond 4	8.64	32.23	0.182	0.319	84.76

2.1 Field procedure of 2-D electrical

The 2-D electrical surveys are aimed to gather information about the physical properties of the subsurface. Different geological materials have different resistivity, and from the values it is possible to infer geological boundaries and structures (Loke, 2004). The 2-D electrical value obtained can differentiate the layering of rock, soil and water as the value is distinct from each other. Earth materials factors such as the degree of weathering, type of soil, porosity, grain size, chemical differences, permeability of rocks and volume of rock fracture filled with water greatly influences the differences in electrical resistivity value within the subsurface. Many geological parameters are included in the ground resistivity such as mineral and fluid content, porosity and degree of water saturation within the rock (Loke, 1999). Pole-dipole array was used in this survey as it can penetrate to the deeper depth and give a better resolution for interpretation. This array is commonly used in exploration of mineral and ore. A transmitting remote electrode need to be placed far away from the receiver dipole in which usually 10 times the survey area distance. in order to ensure that the remote electrode doesn't affect the instrument. Unlike other arrays, pole-dipole array has an asymmetrical arrangement as shown in **Fig. 4**.

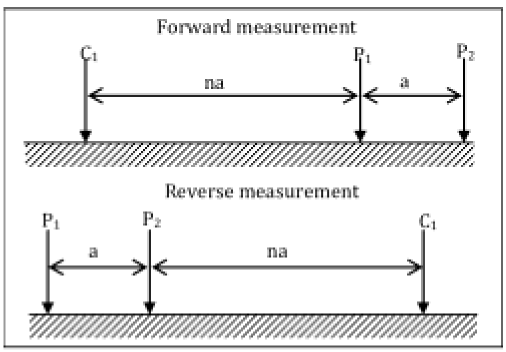


Fig. 4. Pole-dipole electrode array

The resistivities value of different geologic material vary greatly as shown in **Table 2**. Highest resistivity value always infers the value for igneous rock. More porous rock such as sedimentary rocks, can be expected to be some orders of magnitude lower. Lowest resistivity value represents unconsolidated soils. A high (saturated) porosity and clay content will significantly increase the conductivity of a soil (Loke, 2004). In addition to pores, crystalline rock that fractures occurred within it also can caused low resistivity if they are occupied with fluids. Clays have the capability to adsorb large amounts of ions, and even a small clay presence can lower the electrical resistivity of a soil significantly (Waxman 1968).

Table 2. Resistivity values of rocks and soil (Keller & Frischknecht, 1966)

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

The induced polarization (IP) method is a method that is almost the same as resistivity method. IP has higher sensitivity to noise and needs stronger currents than resistivity surveying but has seen increasing use due to upgraded instruments and its capability to notice certain minerals and contaminants that resistivity measurements cannot (Loke, 2004). This method has been mainly used for mineral exploration since the first half of the 20th century and recently it has been implemented for extensive range of uses such as mapping groundwater contamination plumes, landslides and structurally sensitive clays and the recognition of buried landfills. **Table 3** shows the chargeability values of Earth materials.

Table 3. Chargeability (IP) of various Earth materials (Telford et.al., 1990)

Material Type	Chargeability (msec)
Groundwater	0
Alluvium	1-4
Clay	3-7
Gravel	3-9
Schist	5-20
Granite	10-50

Ground magnetic survey are used upon measuring the effects of magnetic formed by different concentrations of ferromagnetic minerals for an example magnetite. This method uses the contrast in subsurface rocks magnetization and has been extensively used in geothermal exploration for structural and lithologic mapping as well. A remnant magnetization which indicate as magnetization that left behind after removing an external magnetic field, will produced when a magnet undergo magnetization. Magnetic susceptibility of the material and magnitude and direction of ambient magnetic field controlled induced magnetization meanwhile, the previous past of magnetic history of the material is reflected by the remnant magnetization (William et.al, 2013). **Table 4** shows the value of magnetic susceptibility in common rocks and ores.

Table 4. Magnetic susceptibility in common rocks and ores

Rock Type	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}

3. Results and Discussions

Fig. 5 shows the analytic signal map of Sungai Ber Hot Spring area. The magnetic value ranges from -6.336 nT to 10.473 nT. High magnetic value mostly occurred nearly to the hot spring area as shown in **Fig. 5** with the value ranging from 0 nT to 10.473 nT. This analytic signal map showing the edge of magnetic body which assembles the geothermal bodies lies underneath the study area. The suspected fracture zone is represented by the contrast zone as shown in the analytic signal map that gives rises to thermal springs. The black rectangle area shows the hot spring point with magnetic values ranging from 1.934 nT to 10.473 nT.

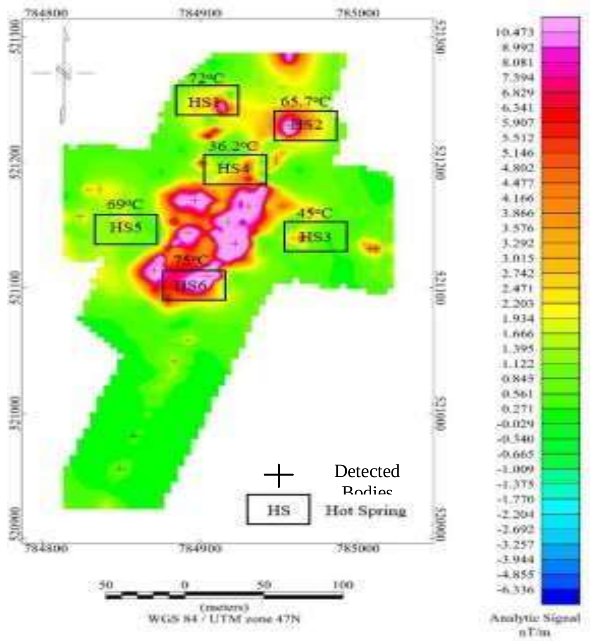
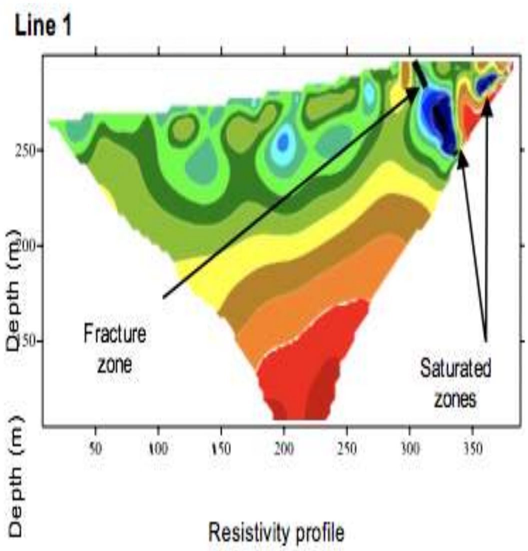
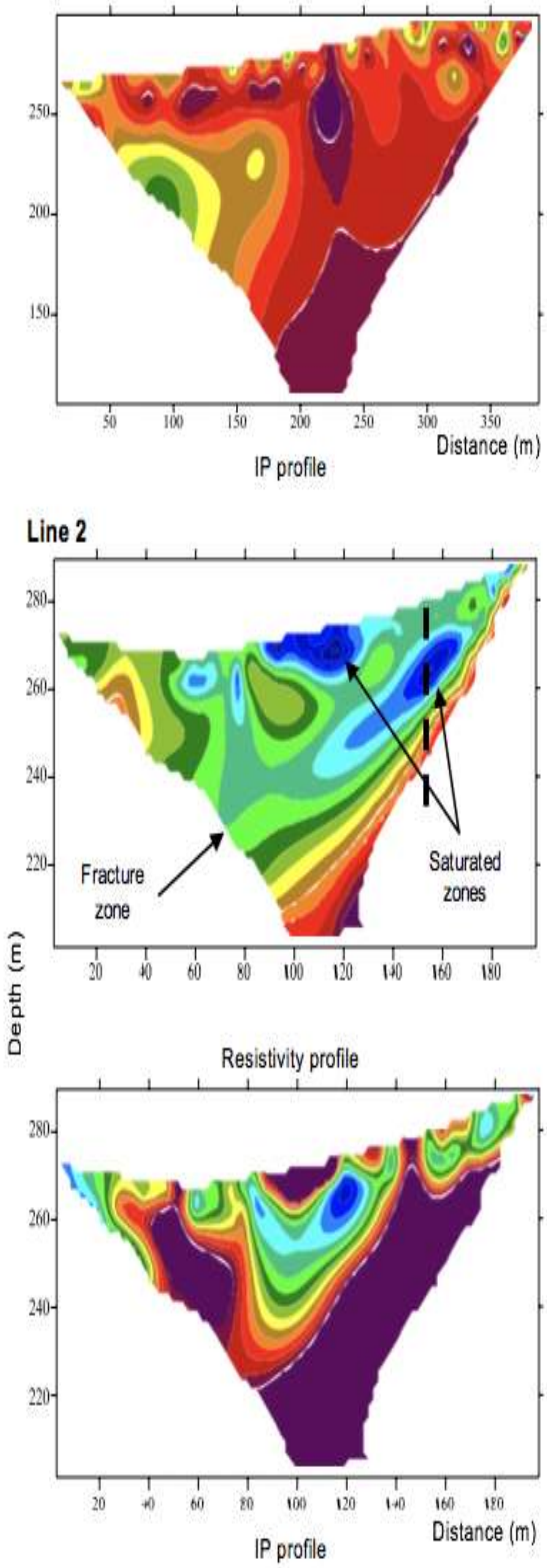


Fig. 5. Analytic signal map of Sungai Ber Hot Spring.

Fig. 6 shows the 2-D inversion models of resistivity and induced polarization (IP) for L1-L4 in Sungai Ber Hot Spring area. Low resistivity value <50 Ωm and higher chargeability >15 msec indicate the fracture zone consist with geothermal fluid that mixed with the sulphur minerals as well. As the study area does not compose of mud, so there are no big changes in the induced polarization (IP) value. The occurrence of the fracture was indicated by the resistivity value of 0 – 100 Ωm and chargeability (IP) value of 15 – 40 msec which fall in range of granitic rock. Resistivity values >800 Ωm as shown in line 4 may indicate the presence of granite bedrock as the vicinity of the study area are dominated with granite with several enclaves of metasedimetary rocks (Raj, 2009). A resistivity <50 Ωm indicate the saturated zone for this area.

L4 shows higher resistivity value > 800 Ωm and low IP value from 0-2 msec. Tirana (2014) has stated that, in geothermal studies the low chargeability values can be described with the lack of formation of the chargeability effect of the first kind which is known as metal-electrolyte or second kind which is known as membrane IP due to the high ion mobility in this environment. Anion and cations are blocked from naturally linking with reciprocal charges of the rock-solid phases due to the high thermal energy, therefore no double electric layer can be formed, which is responsible for the IP effect (Tirana, 2014). Other than granitic rocks, the study area is also covered by the Quaternary deposits which are alluvium deposits or unconsolidated sediments (Nazaruddin et.al., 2015). Line 4 shows higher value of resistivity 600 – 800 Ωm and low in chargeability < 4 msec value due to the presence of the alluvium deposit in the study area.





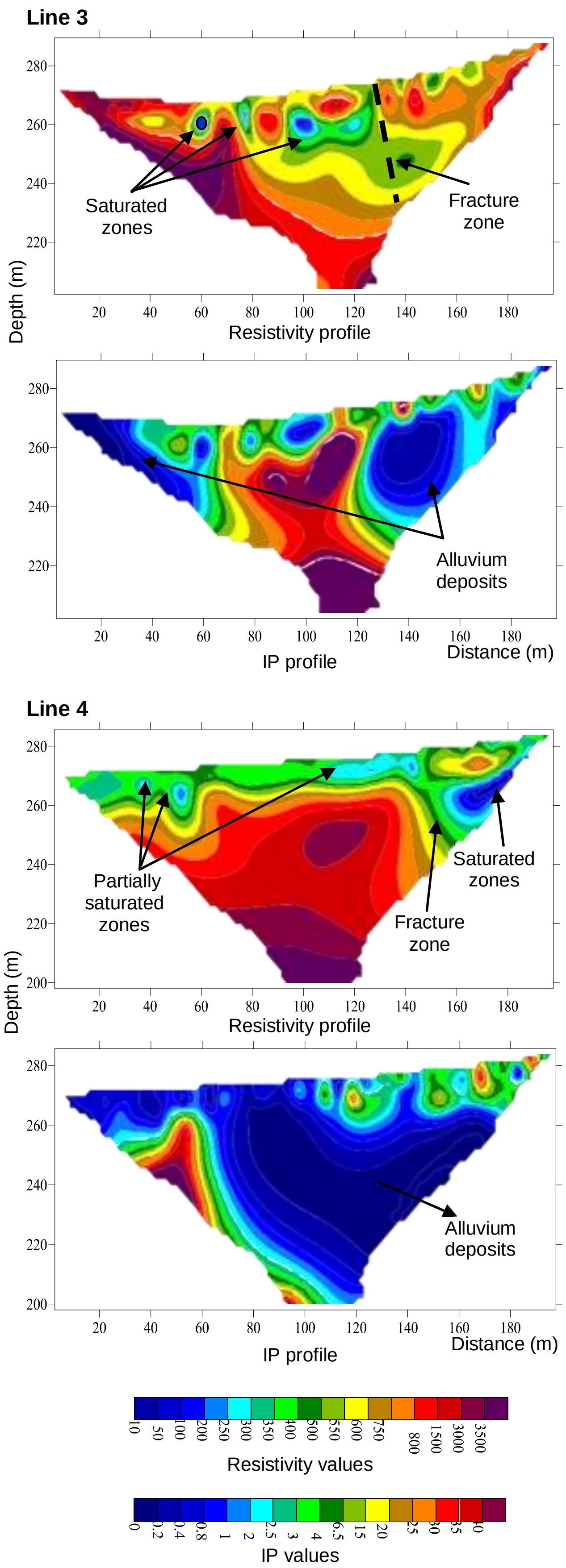


Fig. 6. 2-D electrical profile for Line 1 – Line 4.

4. Conclusion

The 2-D electrical, induced polarization (IP) and ground magnetic methods are extensively used in this study as it helps in portray the fracture which is one of the subsurface structures that correlate with geothermal exploration. Increase in magnetic value >1.934 nT and decrease in resistivity value of 0-10 Ωm indicate the presence of fracture that gives rise to thermal springs. The growth of iron oxide gives rise to higher in magnetic values meanwhile, increase in depth gives rise to increase in resistivity values.

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Symbols and abbreviations

2-D	Two-dimensional
Ωm	Ohm.meter
<	less than
>	greater than
m	meter
km	kilometer
nT	nanotesla