



Identification of Alteration Zones Based on Resistivity and Induced Polarization Geoelectric Survey

Hana Raihana¹, Jesika Erni Elfrita Sinaga¹, Adinda Gusti Cahyani¹, Halauddin¹, Suhendra¹, Anggiat Hutauruk¹, Nanang Sugianto¹

¹Department Physics, Geophysics Study Program, University of Bengkulu

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Corresponding author:

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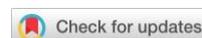
Email: nanang.s@unib.ac.id

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ABSTRACT



Air Putih, Lebong Regency's geothermal field, is near gold mining. The relationship between the two can be illustrated in the type of rock alteration. The study aims to identify the rock alteration zone caused by the Air Putih, Lebong Regency geothermal system. It was described by the correlation of rocks' resistivity and chargeability values based on geoelectric measurement. Two tracks spread along the Air Putih tour, with a track length of 240 meters, were used to see variations in resistivity and chargeability values and the depth of geothermal potential due to deeper current penetration to determine the alteration zone in the study area. The results of field measurements are in the form of 2D models processed with Res2DinvX64 software. According to analysis, the subsurface rock lithology in the research area is relatively the same because the location of the two measurement lines is still close together; namely, there are wet valley rocks and altered rock layers. Pores cause rock layers found in conductive areas in the rock filled with fluid or water at high temperatures. It is evidenced by the detection of manifestations on the surface in the form of warm soil, warm rocks, steamy soil, and small holes containing water grains. The higher the temperature and pressure, the lower the value of rock-specific resistance. At the Air Putih tourist area of Lebong Regency, it is found that it is a zone of prophylic alteration containing several minerals of andesite lava, breccia, tuff, and soil.

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1. INTRODUCTION

Indonesia is a location in the meeting zone of three major plates of the world, namely the Indo-Australian, Eurasian, and Pacific Plates, which play a role in forming volcanoes in Indonesia (Chaidir et al., 2021). The formation of volcanoes, intrusion, and the occurrence of fractures (faults) allows meteoric water to enter the pores of rocks or fractures around heat sources and can result in hydrothermal alteration and sulfide mineralization (Widodo & Noor, 1992). The presence of intrusion causes adjacent rocks to be altered. The presence of manifestations, such as hot springs, indicates geothermal potential. Hydrothermal alteration is a change in the mineral composition of a rock (mainly physical and chemical) caused by high-temperature hydrothermal solutions (Berger et al., 2008). These changes occur not only in the stone but also in the hydrothermal fluid as the fluid attempts to reach chemical equilibrium. Hydrothermal alteration converts a combination of minerals (Bateman, 2009). Geothermal areas can convert primary minerals into secondary minerals (hydrothermal alteration). Factors that

affect mineral alteration due to hydrothermal solutions are temperature, the composition of side rocks, chemical conditions of the solution, and solution concentration.

These hydrothermal are rich in relatively light metals and are the deposit formation process's largest source (90%). Hydrothermal processes under certain conditions produce mineral assemblages (Samuel & Lasky, 1947). The use of metallic minerals as raw materials is increasing. Therefore, Indonesia needs to increase metal mineral reserves for national and international needs by conducting maximum exploration. It can be done because the Indonesian region has several sizeable metallic mineral reserves. The mineral assemblages formed show various zonations in hydrothermal alteration: prophylic alteration zone, phyllic zone, argillic zone, and potassic zone. One area with a hydrothermal process in Bengkulu province is Air Putih, Lebong Regency. The appearance of geothermal heat on the surface is located on the hills of the Bukit Barisan range, where the Air Putih hot water manifestation is located (Purwanto, 2007). The manifestation in Air Putih village indicates the presence of a heat source that will affect the occurrence of hydrothermal processes in the rock above it. Manifestations are formed due to hydrothermal systems, where hydrothermal solutions circulate laterally and vertically at different temperatures and pressures.

Previous research has been conducted by Maskuri (2003) on hydrothermal alteration study of the Karangbolong area, Kebumen Regency, West Java, using drilling. This study showed two hydrothermal alteration zones: quartz-sericite/illite-pyrite zone (argillic type) and Chlorite-Carbonate-epidote Zone (prophylic type). Several researchers have analyzed the geological structure of rocks in the form of faults and fractures. However, so far, only utilizing 2D images to identify the presence of faults or fractures. Anas et al. (2020) used the resistivity geoelectric method to identify subsurface structures in the form of fractures that resulted in the emergence of geothermal manifestations in Reatoa, South Sulawesi. In addition, Irjan's (2012) research using the resistivity geoelectric method in surveying the hydrothermal potential of Kasinan Pesangrahan shows that hot water comes to the surface due to rock fractures below the surface. Mende et al. (2017) research to identify Manado faults with the Schlumberger configuration geoelectric method in Manado City. The results showed that lower resistivity values than other layers characterize the weak plane layer. It is suspected to be a fractured field because the layer at this point is a hollow layer filled with deposits of rubble from above the surface and fluid, which results in a decrease in resistivity value.

Fajri et al. (2021) researched the characteristics of hydrothermal alteration in the AN-1 well, geothermal prospect area Candi Umbul-Telomoyo Semarang Regency, Central Java Province, using drill cuttings samples with petrographic analysis, Analytical Spectral Device (ASD), and X-Ray Diffraction (XRD). The results show hydrothermal alteration occurs due to replacing plagioclase and pyroxene and direct deposition in veins/veins and voids/vuggy. Based on Sianturi (2018), identifying geothermal distribution in Air Putih Village with the geoelectric method of specific resistance shows that the research only focuses on hydrothermal distribution, and the presence of hydrothermal alteration rocks has yet to be discovered. Although the TDIP method provides information on the physical properties of rocks or minerals seen from their electrical and polarization properties, this method can also determine the resistivity (ρ) and chargeability (M) values of the alteration zone in the hydrothermal area (Harjo et al., 2017). It is known that hydrothermal alteration areas have low resistivity and high chargeability (conductive zone). High chargeability is an indication of the presence of metallic minerals. These metallic minerals are the target of exploration using the IP method. Therefore, it is necessary to research to determine the hydrothermal alteration zone using the Time Domain Induced Polarization method and dipole-dipole configuration. This method effectively determines the hydrothermal alteration zone area because the minerals are disseminated (Slater & Lesmes, 1966).

In geothermal reservoirs, fractures are considered very important because of their ability to transport water vapour. Hydrothermal systems can change rock's physical properties, leading to an area of potential gold resources. The geothermal field, Air Putih at Lebong Regency, is close to the gold mining area. These two are certainly interrelated, so we must know about them. So, this research aims to map and identify rock alteration zones caused by geothermal systems based on resistivity, chargeability, and their correlation from geoelectric measurements. One geophysical method that is good enough to map subsurface conditions to determine geothermal

manifestations' alteration zone is the 2-Dimensional Geoelectric method using the Dipole-Dipole configuration. This research obtained resistivity (ρ) and chargeability (M) values. This research is expected to be able to model in 2 dimensions the alteration zone of hydrothermal manifestations with data processing using Res2dinvx64. A focus on the type of alteration zone is also needed if the government wants to drill for geothermal exploitation. Therefore, further research is needed to see the type of alteration zone in the potential geothermal area of Air Putih Tourism, Lebong Regency.

2. REGIONAL GEOLOGY

Based on the Regional Physiography of Sumatra Island, according to Van Bammelan (1949), this area is included in the zone of the Barisan range, in which, in the core, there are granite rocks that indicate the presence of magma activity in the study area. The granite igneous rocks of the study area are included in the Breakthrough Rock (tmgr), which has tertiary elements. According to Gafoer et al. (2007) in the Geological Map of Bengkulu Sheet (Figure 1). Based on the results of a particular study of Petrogenesis analysis of granite rocks in the Lebong Regency area and its surroundings, it can be concluded that granite rocks are formed at an average temperature of 400–800 °C pragmatic-pneumatolytic phase, with acidic magma types with calcite-Alkali magma series. The geological structure in the study area occurred at the time of the late Miocene main force direction or relatively north-south. The study area is tectonically located in the fore-arc basin of the Bengkulu Basin. In this research area, there are several types of rock formations, including :

1. Hulusimpang Formation: The Hulusimpang Formation is composed of lava, altered tuff, and volcanic breccia and is composed of andesite to basalt rocks. The formation unit was deposited around the late Oligocene - Early Miocene in the land-shallow sea transition area.
2. Seblat Formation: The Seblat Formation is of the late Oligocene - Middle Miocene age. The lower part of the unit consists of sandstone, partly a carbonate component, and the middle part consists of limestone and claystone. The upper part comprises claystone shale, conglomerate, tuff, and marl.

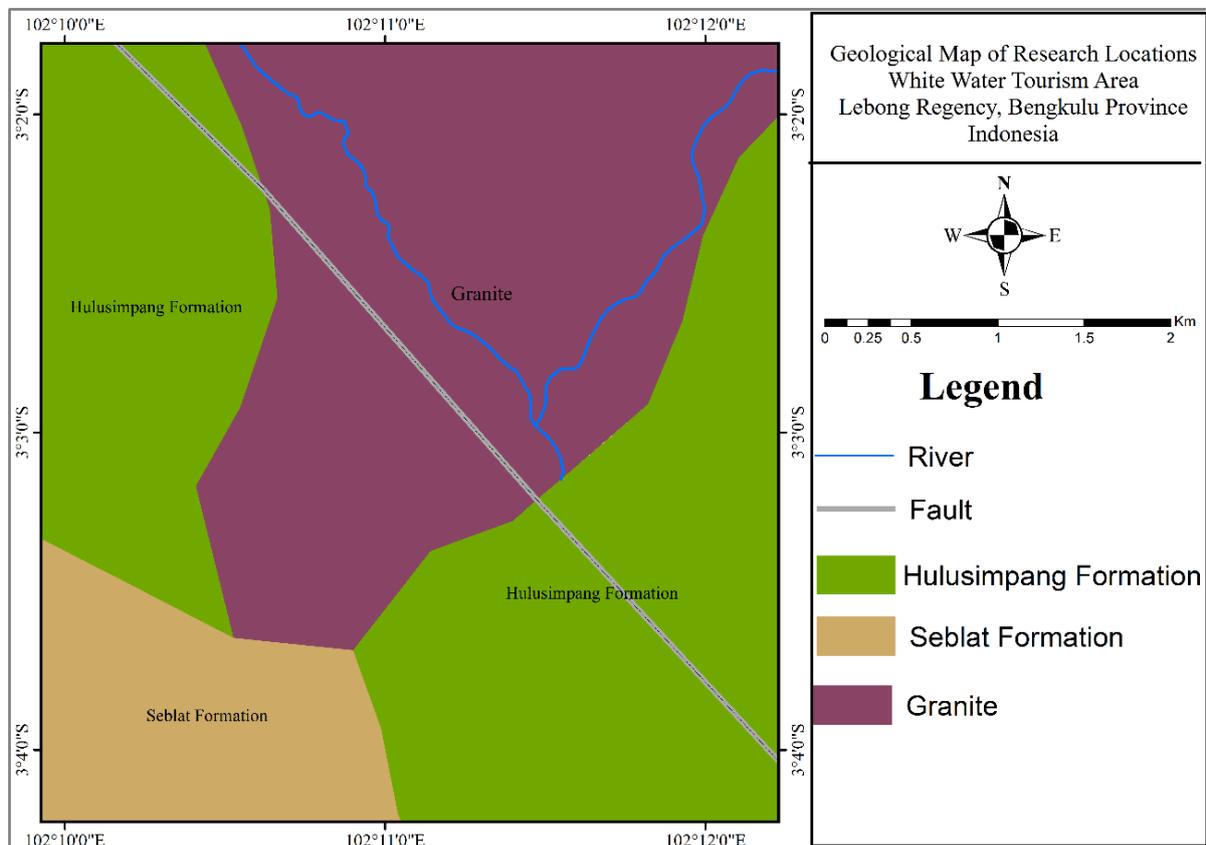


Figure 1. Geological map of research locations Lebong Regency

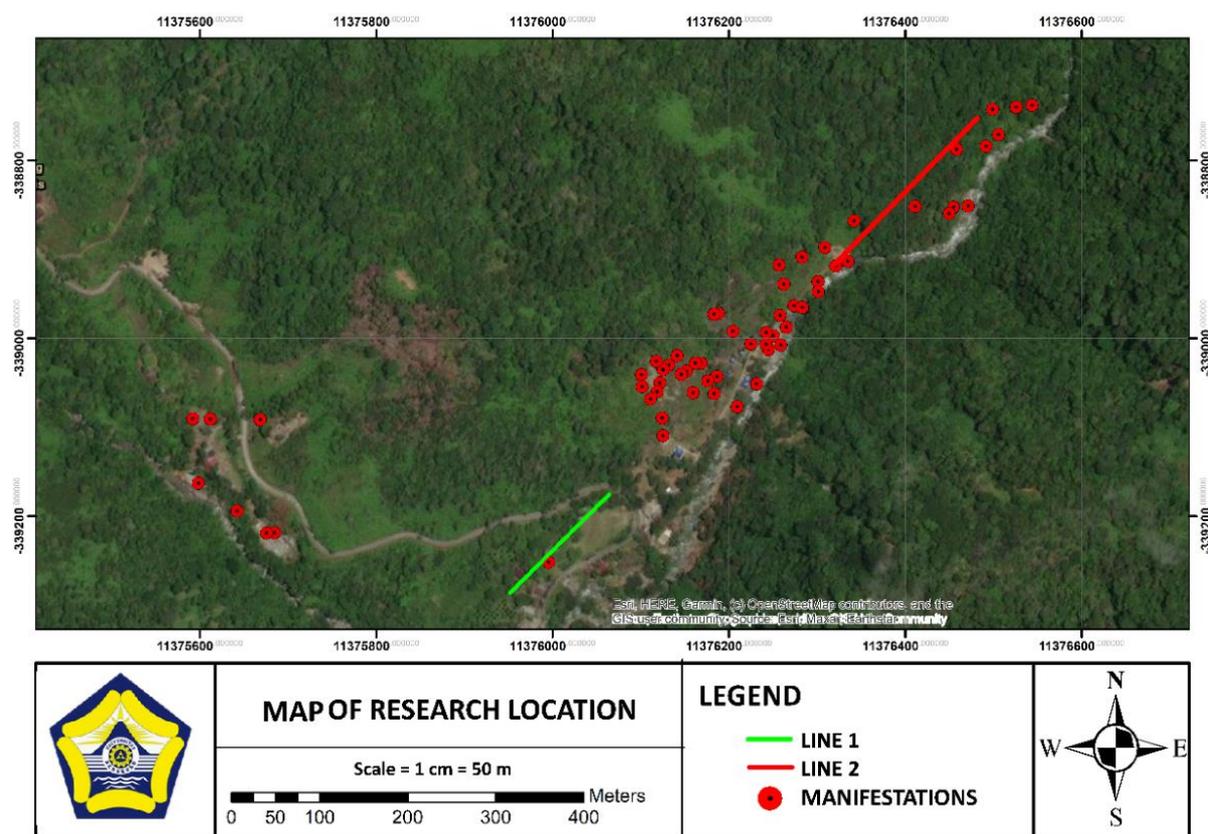


Figure 2. Resistivity and IP trajectory survey design and location of thermal manifestations in the study area

3. Lemau Formation: The Lemau Formation comprises breccia with tuffaceous sandstone inserts with mollusc components on the lower side. The upper side consists of sandstone and tuffaceous sandstone with inserts of claystone and limestone. The formation unit was deposited in a shallow marine area in the Middle Miocene-Late Miocene.
4. Bintunan Formation: The Bintunan Formation consists of conglomerate, breccia, and tuffaceous claystone with a thin lignite layer. Based on the stratigraphic unit, the rock formation was deposited in a brackish water transition area in the Plio-Pleistocene.
5. Simpangaur Formation: Simpangaur Formation contains breccia and conglomerate with sandstone and coal inserts on the lower side. The upper side is siltstone and claystone, which contains freshwater molluscs. The rock formation unit is of Late Miocene-Early Miocene age (Gafoer et al., 2007).

3. METHOD

This research uses the MAE X612-EM Geoelectric tool in Air Putih Tourism, Lebong Regency. Field measurements were carried out in October 2022, with two tracks spread along the Air Putih tour, with a track length of 240 meters. The 240-meter track length was used to see variations in resistivity and chargeability values and the depth of geothermal potential due to deeper current penetration to determine the alteration zone in the study area. This research area is located at latitude-longitude coordinates ($3^{\circ}02'43.25''\text{LS}$ and $102^{\circ}11'36.57''\text{BT}$); this area manifests hot springs (Figure 2). The results of field measurements are in the form of 2D models processed with Res2DinvX64 software.

Table 1. Classifications of resistivity and chargeability value

Class	Resistivity (ohm.m)	Chargeability (ms)
Low	0 - 100	0 - 100
Intermediate	100 - 700	100 - 300
High	>700	>300

Source: Manrulu et al. (2018)

Table 2. Interpretation according to resistivity and chargeability correlation

Resistivity (ohm.m)	Chargeability	Interpretation
Low	Low	Soil, Water Saturated
Intermediate	Low	Lava andesite, breccia, tuff, soil
High	Low	Lava andesite, breccia, tuff, soil still compact and fresh
Low	Intermediate-high	Zone of Potassic Alteration
Intermediate	Intermediate-high	Zone of Silicification Alteration
High	Intermediate	Zone of Propylitic Alteration
High	High	Au mineralization zone on silica

Source: Nurfaq et al. (2018)

4. RESULTS AND DISCUSSION

The measurement results of this study using the TDIP method in 2 dimensions in white water tourism carried out two passes with the Induced Polarization (IP) geoelectric method dipole-dipole configuration. This research analyzed current (I) and potential difference (V) data from each measurement point. The electric chargeability cross section is obtained from processing induced polarization (IP) geoelectric data from the field using Res2dinv software. TDIP and type resistance geoelectric method dipole-dipole configuration obtained subsurface cross section in 2 dimensions: resistivity (Figure 3 and Figure 4) and chargeability cross-section on each line. The subsurface rock lithology in the research area is relatively the same because the location of the two measurement lines is still close together; namely, there are wet valley rocks and altered rock layers. Pores cause rock layers found in conductive areas in the rock filled with fluid or water at high temperatures. It is evidenced by the detection of manifestations on the surface in the form of warm soil, warm rocks, steamy soil, and small holes containing water grains; the higher the temperature and pressure, the lower the value of rock-specific resistance. The 2-Dimensional resistivity and induced polarization (IP) models can also display topographic data used to identify alteration zones.

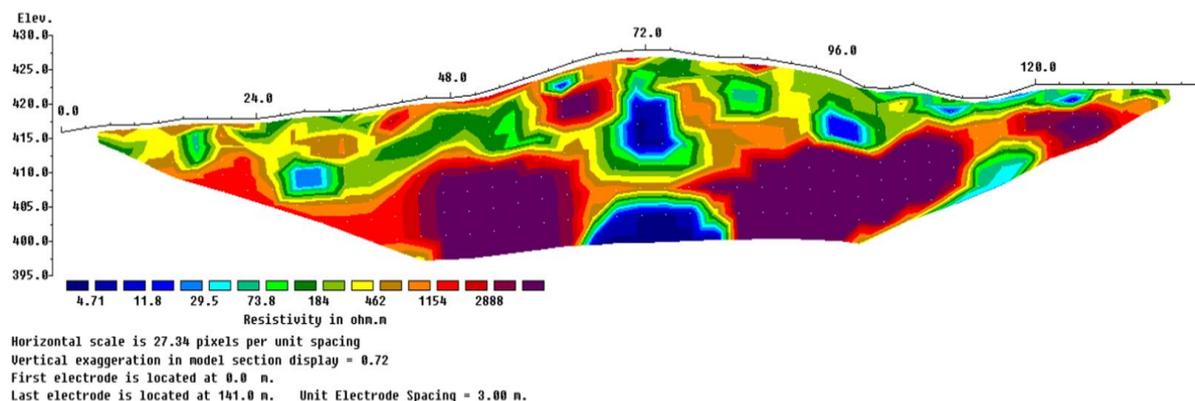
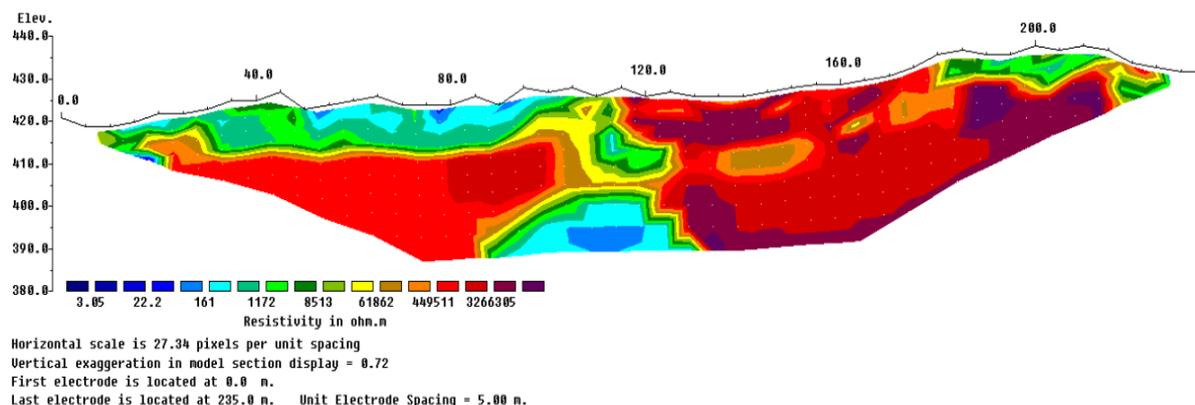
**Figure 3.** Geoelectric data processing results in line 1**Figure 4.** Geoelectric data processing results in line 2

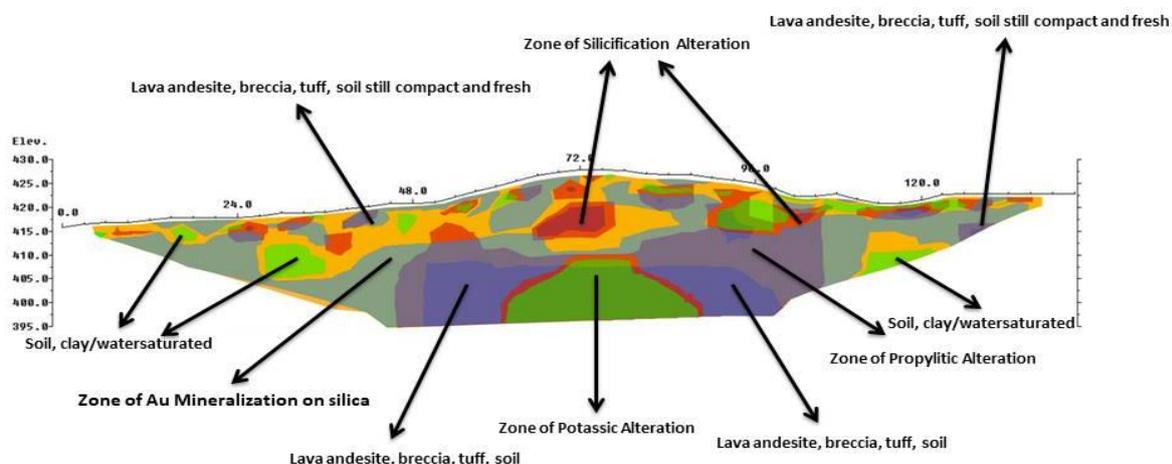
Table 3. Colour scale of resistivity and chargeability values

Line	Resistivity	Chargeability
Line 1	High: Blue	High: Yellow
	Intermediate: Orange	Intermediate: Red
	Low: Light Green	Low: Purple
Line 2	High: Light Blue	High: Dark Green
	Intermediate: Brown	Intermediate: Bright Red
	Low: Light Green	Low: Pink

In the first line, data has been combined between resistivity and chargeability value according to Table 1 and Table 2, so the classification of rock into low, intermediate, and high categories. The interpretation of line 1 is based on resistivity and chargeability correlation. After identification in line 1, there are several types of rocks, such as andesite lava, breccia, and tuff. Soil is still compact and fresh, and several types of saturated soil rocks have weathered. The results of data processing to obtain rock types that have been combined between resistivity and chargeability values by identifying with colours according to Table 3.

On line 1, several alteration zones were found: the silicification alteration zone, the potassic alteration zone, and the propylitic alteration zone (Figure 5). The silicification alteration zone has the characteristics of silicification outcrops in the field and is relatively parallel to the direction of mineralization veins; this is because the hydrothermal fluid that forms the silicification alteration type in the area intensively works to break through the primary permeability of rocks and secondary permeability with the presence of quartz veins (veinlets) that fill the fractures in the field. The formation of this type of silicified alteration is interpreted as the result of the devitrification of volcanic glass during the cooling of silica-saturated hydrothermal fluids. The distinctive alteration texture in the form of vuggy silica zones in the silicification zone is caused by dissolution by acidic fluids that leave silica pits. The remnants of this dissolution recrystallize into quartz/silica. Quartz and pyrite mineral assemblages characterize silicification zones. The potassic alteration zone is located in the inner part of a hydrothermal system with varying depths. Alteration minerals in the form of secondary biotite, K Feldspar, quartz, sericite, and magnetite characterize this zone. The zone is formed by adding potassium in the metasomatic process and is accompanied by more or less calcium and sodium in rocks rich in aluminosilicate minerals. The propylitic alteration zone is characterized by chlorite and some epidote, illite/sericite, calcite, albitite, and anhydrite minerals and formed at temperatures of 200-300 °C at various salinities near-neutral pH generally in areas of low permeability (Gafoer et al., 2007).

Line 2 also found several alteration zones, such as line 1, including the silicification and propylitic alteration zones (Figure 6). It can be seen that the alteration zone has the same characteristics as line 1. It is possible because line 2 parallels the distribution of hydrothermal manifestations in the Air Putih tourist area of Lebong Regency. Line 2 has a rock structure of andesite lava, breccia, tuff, and soil that is still compact and fresh.

**Figure 5.** Combining resistivity and chargeability data on line 1

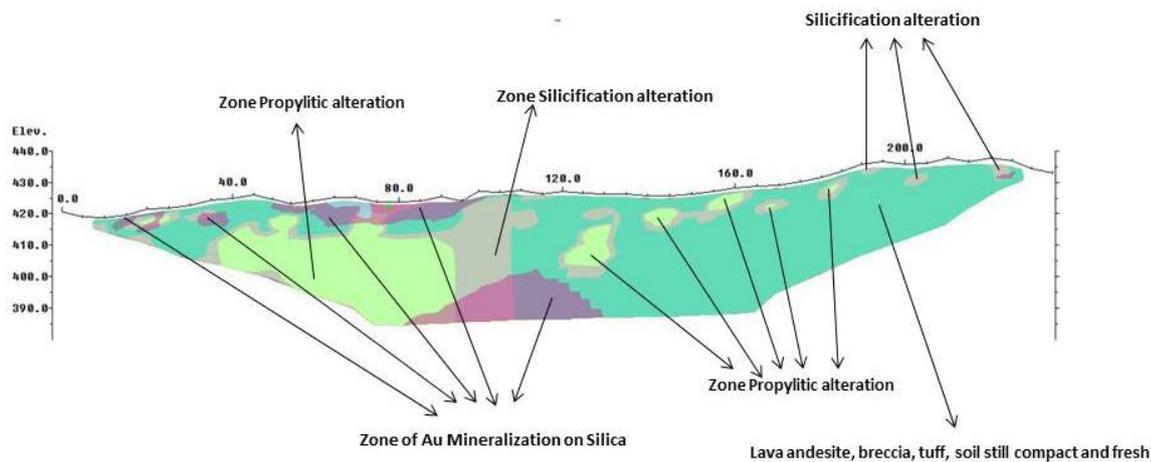


Figure 6. Merging of resistivity and chargeability data on line 2

From the results of zone modelling on line 1 and line 2, it is suspected that it is closely related to the presence of gold minerals in Tambang Sawah (a village at Lebong Regency). The location of traditional gold mining in Desa Tambang Sawah is near the research site, so it is strongly suspected that the presence of gold minerals around there is influenced by hydrothermal alteration processes such as those on line 1 and line 2. This alteration process forms the gold (Au) mineralization zone in the Air Putih Tourism Area of Lebong Regency. It is undoubtedly exciting if geoelectric research can be continued in the gold mining area around the geothermal area in Air Putih Tourism, Lebong. The types of hydrothermal alteration in traditional gold mining can be mapped to illustrate the distribution of gold potential in Tambang Sawah (a village at Lebong Regency).

5. CONCLUSIONS

Based on the measurement results using the Time Domain Induced Polarization (TDIP) geoelectrical method, the subsurface structure is obtained from resistivity and chargeability cross-sections in 2 dimensions. The characteristics of hydrothermal alteration in the study area are visible: the potassic alteration zone, silicification alteration zone, and propylitic alteration zone. The minerals in line 1 are andesite lava, breccia, tuff, and clay/water-saturated; the soil is still compact and fresh. In line 1, several types of rocks, such as andesite lava, breccia, and tuff. Soil is still compact and fresh, and several types of saturated soil rock have weathered.

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