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APPLICATION OF INDUCED POLARIZATION (IP) METHOD FOR IDENTIFYING METALLIC MINERAL DISTRIBUTION IN THE LEON AREA

APLIKASI METODE INDUCED POLARIZATION (IP) *UNTUK MENGIDENTIFIKASI PENYEBARAN MINERAL LOGAM DI DAERAH LEON*

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ABSTRACT

The research was conducted in the Leon area to determine the presence and quantity of metallic mineral resources. The stratigraphy of the study area is composed of alluvium and coastal deposits, Molasa Sarasin Formation, Tinombo Formation, and Intrusion. Exploration was carried out in the Leon area using Induced Polarization Method with a dipole-dipole configuration with an area of 950 m^2. The length of the track is 580 meters with a North-South orientation. The number of tracks in this study was 15, with spacing electrodes as far as 20 meters and n = 1-10. The analysis showed that the distribution of resistivity values in the study area was from (13.6 to 1337) Ωm, while the chargeability values had a range of values (1.7 to 50.6) ms. The low resistivity values below 50 Ωm are interpreted as claystone to sandstone and the medium resistivity values between 50 Ωm - 500 Ωm are interpreted as compact sandstone to breccia. The resistivity values above 500 Ωm are interpreted as igneous rock. The presence of metallic minerals in the study area is characterized by changeability values above 22 ms in claystone, sandstone, breccia, and igneous rock. Calculating hypothetical resources was conducted the Block model method at Oasis Montaj that obtained 11.8 million tons of resources.

Keywords: chargeability, induced polarization, metallic minerals, resistivity.

ABSTRAK

Penelitian dilakukan di Daerah Leon untuk mengetahui keberadaan dan besarnya sumberda ya mineral logam. Stratigrafi daerah penelitian disusun oleh alluvium dan endapan pantai, Formasi Molasa Sarasin, Formasi Tinombo, dan Batuan Terobosan. Eksplorasi yang dilakukan di Daerah Leon menggunakan Metode Polarisasi Terimbas konfigurasi dwikutub dengan luas kavling 950 m^2. Panjang lintasan 580 meter dengan orientasi lintasan Utara-Selatan. Jumlah lintasan dalam penelitian ini sebanyak 15 dengan spasi antar elektroda sejauh 20 meter dan n=1-10. Hasil analisis didapatkan hasil persebaran nilai resistivitas daerah penelitian dari (13,6 – 1337) Ωm, sedangkan nilai ketermuatan memiliki rentang nilai (1,7 – 50,6) ms. Nilai resistivitas rendah dibawah 50 Ωm diinterpretasikan sebagai batulempung hingga batupasir Nilai resistivitas sedang antara 50 Ωm - 500 Ωm diinterpretasikan sebagai batupasir kompak hingga batubreksi. Nilai resistivitas tinggi di atas 500 Ωm diinterpretasikan sebagai batuan beku. Keberadaan mineral logam di daerah penelitian ditandai dengan nilai ketermuatan di atas 22 ms pada batulempung, batupasir, breksi, dan batubeku. Perhitungan sumberdaya hipotetik dilakukan dengan metode Block model pada Oasis Montaj diperoleh sumberdaya sebesar 11,8 juta ton.

Kata kunci: ketermuatan, polarisasi terimbas, mineral logam, resistivity.

INTRODUCTION

Indonesia is one of the countries in the world that is rich in natural resources, including metallic, non-metallic, and energy minerals (Ferial, Natalisanto and Lazar, 2019). Indonesia is located on three large active plates: the Indo-Australian Plate, the Eurasian

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Plate, and the Philippine Plate. A series of volcanoes in Indonesia, which are included in the Ring of Fire path, lead to the potential mineral resources in the form of mineral accumulations related to mineral deposits of volcanic or orogenic systems (Seizarsyah *et al.*, 2022). Tectonism and magmatism in Indonesia made Indonesia rich in mineral resources, and many companies used them. Minerals are formed through a long and lengthy process involving a large-scale process on the earth (Cahyono, 2020). Indonesia is a country with a very high mineral reserve potential. Mineral resources, as one of the natural resources, are a significant source to support the Indonesian economy (Safitri, 2019). Nickel minerals, for example, Indonesia occupies the top third position globally. In addition, Indonesia recorded a contribution of 39% for gold products, in second place after China. This makes Indonesia always in the top 10 in the world (Sony, 2019). Sulawesi is one of the areas known for its many mineral resources. Sulawesi is one of the big islands in Indonesia. It is a complex area because this island is the meeting place of three large plates: the Indo-Australian plate that moves northward; the Pacific plat which moves westward; and the Eurasian plate that moves south-southeast and a smaller plate, namely the Philippine plate (Sompotan, 2012). The industrial world's demand for metal minerals such as iron (Fe) has recently increased sharply, especially the steel industry supply to developed countries (Rauf, 2012). To meet the industrial needs, exploration is needed.

Geophysical method is a science that studies the earth based on physical properties; one geophysical method often used is the induced polarization method (Dakir *et al.*, 2019; Sidiq, Yatini and Fajrin, 2021). The Induced Polarization method is included in the geo-electric method; besides that, there is a resistivity method. According to Alpiandi (2021), the resistivity method is one of the geo-electrical methods used to investigate the subsurface structures based on the differences of rock resistivity. The basis of the resistivity method is Ohm's Law, which involves flowing current into the earth through the current electrodes and measuring the potential on the earth's surface using the potential electrodes (Santoso, Wijatmoko and Supriyana, 2017). The IP and the resistivity methods are geophysical methods that utilize electrical properties of rocks as a basis (Yuniarto, 2020).

Induced Polarization method, often abbreviated as IP, is, in principle, a method that detects the occurrence of electrical polarization on the surface of metallic minerals below the earth's surface and is an active geophysical method. The principle of the polarization induction method is to observe the polarization effect due to the induced current passing through it (Fajariyah and Supriyadi, 2014; Yatini *et al.*, 2022). The potential difference should be immediately zero when the current is cut off. Still, the potential difference in certain mediums does not immediately become zero because the medium is like a capacitor (stores electrical energy) (Revil, Florsch and Mao, 2015; Rahayu, Ribowo and Karlina, 2019). The potential difference, current strength, and chargeability values will be obtained in acquiring the IP method, which are then processed to get the actual resistivity and chargeability values. Chargeability is the ability of a rock to store an electric charge when the rock is electrified (Revil, Florsch and Mao, 2015; Srigutomo, Trimadona and Pratomo, 2016; Kim *et al.*, 2017; Antonelli *et al.*, 2019; Ferial, Natalisanto and Lazar, 2019).

According to Bodjawati, Heditama and Muttaqin (2020), the advantage of this method compared to other geophysical methods is its ability to detect the presence of disseminated and irregular minerals because the scattered minerals are more easily polarized due to the currents passing through them. The polarization effect occurs due to the rock media containing metallic minerals. According to Reynolds (2011), this method can be used for mapping the presence of scattered metal ores, searching for groundwater, and geothermal exploration, and is often used in the search for base metals.

This research was conducted to determine the distribution of resistivity and chargeability values that exists the research targets in the form of metallic minerals and the number of known metallic mineral resources. Some minerals have a specific resistivity value, and metallic minerals have a higher chargeability value than their surroundings. The configuration used in this research is dipole-dipole configuration. The dipole-dipole configuration is used because it can horizontally and vertically map subsurface conditions (Lowrie, 2007).

Geology Research Area

According to Rauf (2012), the physiography of the activity site is moderate to steep hills, with a slope of 20° to 70°. The lowest elevation is 126 m and the highest one is 456 m. The major river that passes through this location is Bangkalang Taipa River whose flow pattern is dendritic. Stratigraphy of this location is shown in Figure 1 that consists of the following lithological units:

- Alluvium and Beach Sediments, gravel, sand, and mud. Formed in a Holocene river, delta and coastal environtment;
- Molasa Sarasin, conglomerate, quartz sandstone, greek, claystone, shale, marl, and coral limestone. Weakly hardens with a slope of 00 – 100;
- The Tinombo Ahlburg Formation comprises of shale, sandstone, conglomerate, limestone, and volcanic rock and was deposited in the marine environment. This rock is found at a lower elevation on the flanks of both bunds, overlaps unconformably the Tinombo Formation with a metamorphic rock complex. It contains debris originating from older formations, and consists of conglomerate, sandstone, mudstone, coral-limestone, and marl. All just hardened weakly (Maskuri, 2010);
- Breakthrough rocks occur over some time. Andesite, diorite, sienite, and lamprofir are the oldest ones. It usually occurs as a volcanic channel within the Tinombo Formation.

The geological structure at this location is a fault with varying directions; in the northern part of this location, its direction is northwest-southeast and northeast-southwest. Meanwhile, the research location leads to the North–South and North East– Southwest (Rauf, 2012; Hasria, Idrus and Warmada, 2019). As a result of tectonic events, a fault structure is formed. The fault structure at the research site is towards Northsouth and – Southwest; this weak zone allows magmatism to occur, namely magma intrusion through the old rock. Breakthrough rocks, appearing in several periods, namely andesite, diorite, and sienite, are generally found as volcanic channels. As a result, there was a process of recrystallization, alteration, mineralization, and replacement in the contact section of the magma with the rock it breached, namely the Tinombo Formation, that is is composed of phyllite, slate, quartz sandstone, siltstone, marble, hornstone, red shale and red chert and volcanic rock. This change is caused by the heat and the liquid of the material (fluid) originating from the magma's activity. The process of penetrating magma in this weak zone until it freezes is generally accompanied by metamorphic contact. Metamorphic contact also involves the side rocks of the Tinombo Formation, giving rise to fluids such as magmatic and metamorphic fluids, which contain a lot of ore.

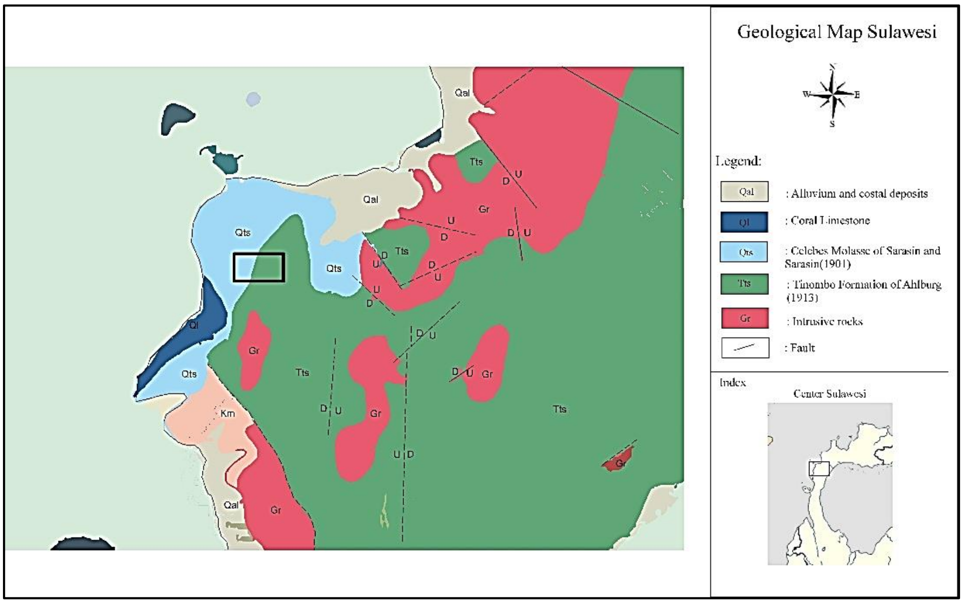


Figure 1. Geological map of Toli-Toli sheet (Ratman, 1976)

METHODOLOGY

Induced Polarization Method (IP)

Induced polarization method, according to Bodjawati, Heditama and Muttaqin (2020), is a geophysical method that can be used to study the subsurface geological conditions based on the ability of the rock/medium to store electric charges. This method is a development of the resistivity method with the addition of an electrical polarization parameter of a medium called chargeability (Mao, Revil and Hinton, 2016; Yatini, 2018).

The principle of time domain measurement is injected the electric current under the surface. Then, the current is turned off, causing the potential to fall but not immediately zero and decay slowly in a function of time (overvoltage decay). The measured chargeability value is apparent chargeability (apparent chargeability). Pseudo chargeability indicates how long it takes for the polarization effect to disappear as soon as the current is turned off. The obvious chargeability value is obtained by calculating the area under the decay curve and dividing it by the parental potential value (Sidiq, Yatini and Fajrin, 2021).

$$M_a=\frac{1}{V_o}\int_{t1}^{t2} V_p(t)dt \quad \text{......................................} \quad (1)$$

Where,

M_a : Apparent Chargeability
$V_p(t)$: Potential at time t (volt)
V_o : Potential Total (volt)
t_1, t_2 : Time Limit (millisecond)

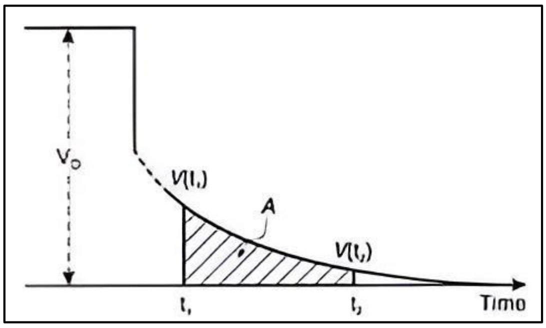


Figure 2. Potential decay (Reynolds, 2011)

Measurements were carried out in the "Leon" area using the Induced Polarization Time Domain Dipole-Dipole configuration method. The paths used are 15 tracks with a track length of 580 meters and a distance between electrodes of 20 meters with n = 10. The distance between the tracks is approximately 50 meters, and an area of 950 m^2 with a predominantly north-south orientation as shown in Figure 3.

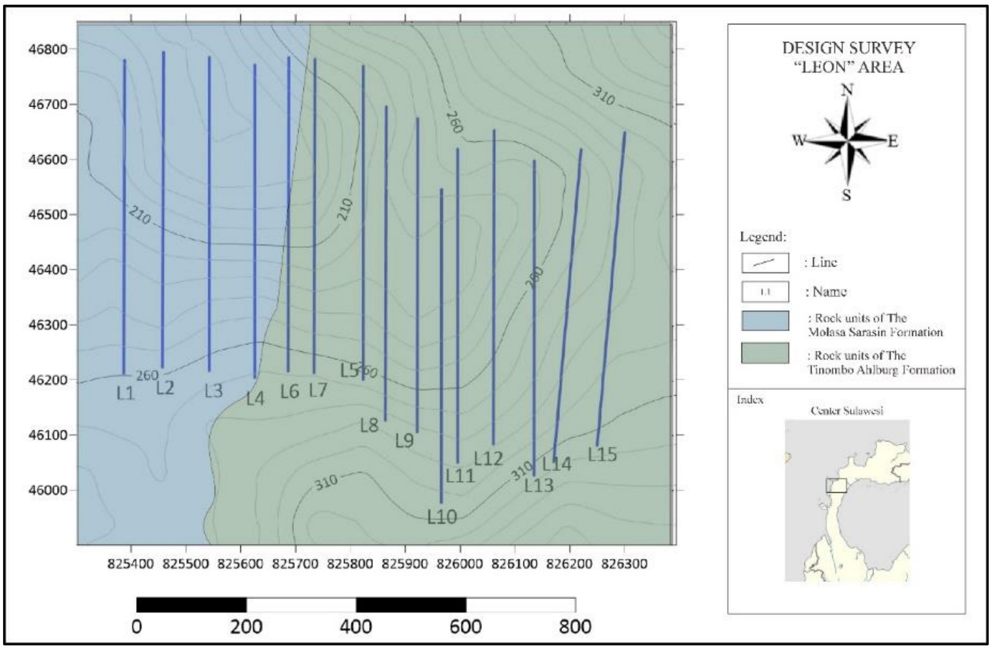
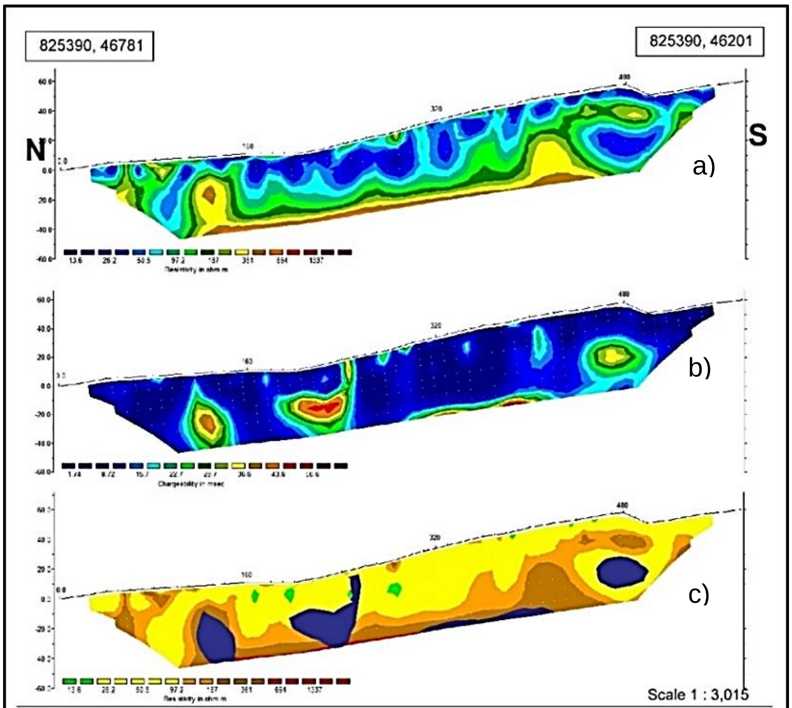


Figure 3. Design survey for data collecting induced polarization method in Leon area, L1 to L15 IP track data.

RESULTS

Research conducted in the Leon area aims to determine the distribution of metallic minerals by analyzing the resistivity and chargeability values. The response of the chargeability value of metallic minerals tends to be high, and the resistivity value will be by the rock associated with the metallic mineral (Yatini, 2018). Metallic minerals can be formed due to the magmatism, hydrothermal processes, weathering, etc. The metallic minerals, in general, are in the form of compounds, for example, sulfide compounds, which have a high conductivity contrast and are ionic conductors. Hence, minerals from sulfide compounds quickly cause IP symptoms (Umroh, 2018).

The stratigraphy of the study area comprises Tinombo Formation, Molasa Celebes Sarasin Formation, Alluvium deposits, and intrusions. The Tinombo Ahlburg Formation comprises shale, sandstone, conglomerate, limestone, and volcanic rock deposited in the marine environment. This rock is found at a lower elevation on both sides of the embankment, unconformably overlaps the Tinombo Formation with a metamorphic rock complex, contains debris originating from older formations, and consists of conglomerate, sandstone, mudstone, coral-limestone, and marl, all of which only hardens weakly (Maskuri, 2010). Molasa Celebes Sarasin consists of conglomerate, quartz sandstone, claystone, shale, marl, and coral limestone.



Legend

Lithology	Colour	Resistivity (Ohm.Meter)
Claystone		< 10
Sandy Claystone		10 - 15
Sandstone		15 - 50
Compact Sandstone		50 - 100
Sandbrecciastone		100- 200
Breccia		200 - 500
Igneousrock		> 500

Description	Chargeabiliity (ms)
Not Mineralized - Low Mineralized	0 - 22
Medium Mineralized (Dark Blue)	22 - 50
High Mineralized (Dark Blue)	> 50

Figure 4. Resistivity section L1 result of inversion modeling, a) resistivity section, b) chargeability section, c) lithological interpretation and metallic mineral presence zone

Interpretation

The cross-section resulted from the inversion has a resistivity value of 13.6 m to 1337 m and a chargeability value from 1.7 to 50.6 msec. The resulting cross-section is then interpreted as in Table 2 and 3. Section C is a combined section of Sections A and B, describing the lithology and metallic mineral presence. Claystone is depicted in green with a resistivity value of less than 15 m. Sandstones are yellow with resistivity values of 15 to 200 m. The breccias are brown with resistivity values of 200 to 500 m. Igneous rock is red with a resistivity value of >500 m. Metallic minerals are depicted in dark blue with a value of >22m. This study has 15 tracks and discussed 2 tracks, namely Track 1 and 7.

The distribution of medium to high chargeability and high resistivity values in the L1 section shown in Figure 4 is found at 100 to 140 meters, 290 to 410 meters, and 180 to 250 meters are identified as the presence of metallic minerals characterized by propylitic alteration. The propylitic alteration has a chargeability value response that tends to be moderate to high and has an average resistivity value. This propylitic alteration occurs in compact sandstone to igneous rock. Other moderate to high chargeability values were found in 440 to 500 meters and identified the presence of metallic minerals that is characterized by argillic alteration. Argillic alteration is an alteration in clay-sized minerals with a low resistivity value response and moderate to high chargeability. This argillic alteration occurs in clay rocks to sandstones.

Table 1. Resistivity value (Santoso, 2016)

Lithology	Resistivity Value(Ωm)
Clay	<10
Sandy claystone	10-15
Clay sandstone	15-20
aquifer	20-50
Compact sandstone	50-100
Breccia sandstone	100-200
Breccia	200-1000
Igneous rocks	>1000

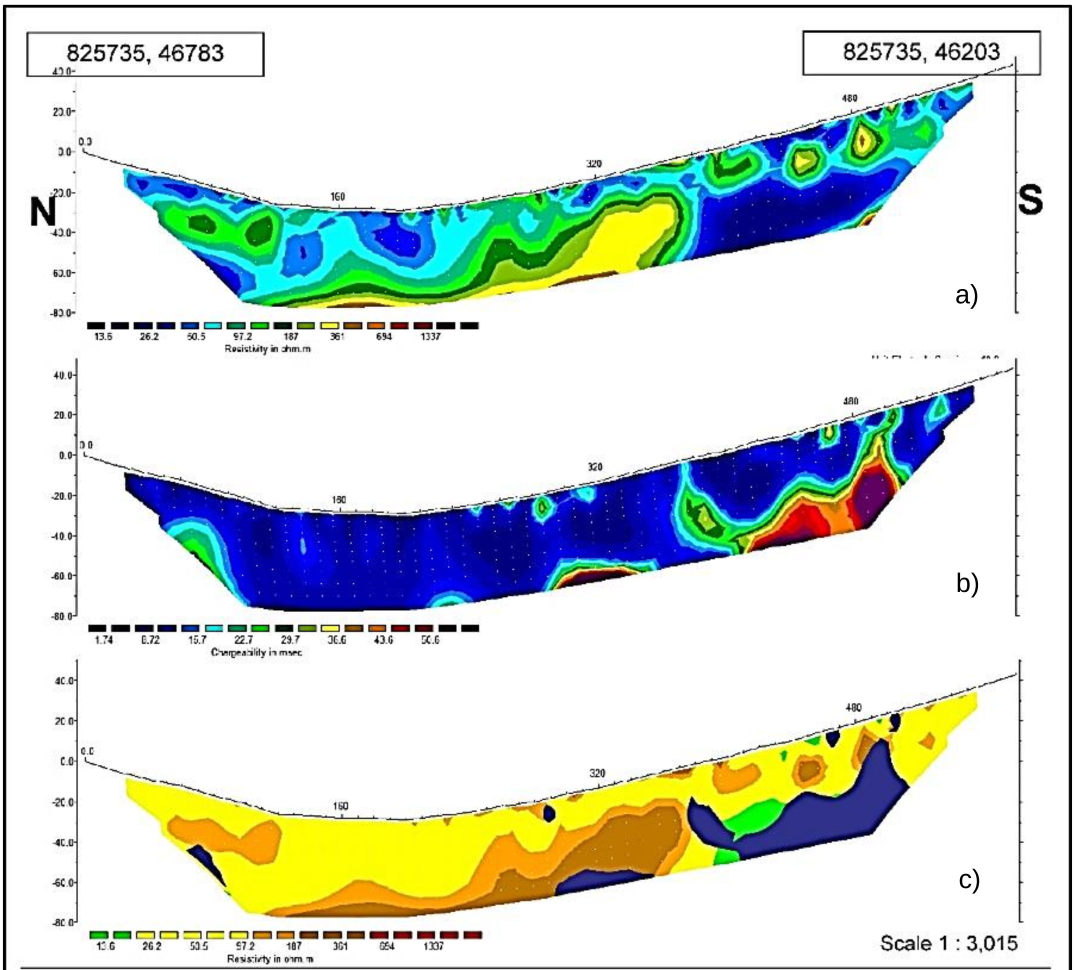
Table 2. Classification of resistivity and chargeability values of the study area table classification (Waskito, 2020)

Category	Resistivity (Ωm)	Chargeability (msec)
Low	<50	< 22
Medium	50-500	22 – 50
High	>500	>50

The value of medium to high chargeability and high resistivity in the L7 cross-section shown in Figure 5 is found at the depth of 280 to 320 meters identified as metallic minerals that is characterized by propylitic alteration. Other moderate to high chargeability values were found at depths of 60 to 90 meters. Depth of 370 to 510 meters identified the presence of metallic minerals that is characterized by argillic alteration.

Table 3. Interpretation of subsurface lithology based on resistivity, chargeability values of the study area, and table classification (Waskito, 2020)

Resistivity (Ωm)	Chargeability (msec)	Interpretation
Low	Low	Claystone and sandstones in Tinombo Ahlburg Formation
	Medium - High	Claystone and sandstones in Tinombo Ahlburg Formation contain metallic minerals.
Medium	Low	Breccian sandstones and breccias in Tinombo Ahlburg Formation
	Medium - High	Breccia sandstones and breccias in Tinombo Ahlburg Formation contains metallic minerals
High	Low	Igneous Rock on intrusion
	Medium - High	Igneous rocks on intrusion that contains metallic minerals.



Legend

Lithology	Colour	Resistivity (Ohm.Meter)
Claystone		< 10
Sandy Claystone		10 - 15
Sandstone		15 - 50
Compact Sandstone		50 - 100
Sandbrecciastone		100- 200
Breccia		200 - 500
Igneousrock		> 500

Description	Chargeabillity (ms)
Not Mineralized - Low Mineralized	0 - 22
Medium Mineralized (Dark Blue)	22 - 50
High Mineralized (Dark Blue)	> 50

Figure 5. Resistivity section L7 result of inversion modeling, a) resistivity section, b) chargeability section, c) lithological interpretation and metallic mineral presence zone

Correlation and Stacking

The correlation in Figure 6 and stacking in Figure 7 is used to determine the continuity of metallic minerals. In correlation and stacking, it can be seen that the high resistivity value is in the eastern part of the study area, and the deeper it is, the higher the distribution of the resistivity value. The continuity of metallic minerals looks more profound and more east, and the distribution is more comprehensive. In correlation, the distribution of metallic minerals is divided into 2 parts, namely in the north and south, where the south has a broader distribution of metallic minerals. At elevation 160, the metallic minerals are more widely found, and it is estimated that they are getting deeper and wider.

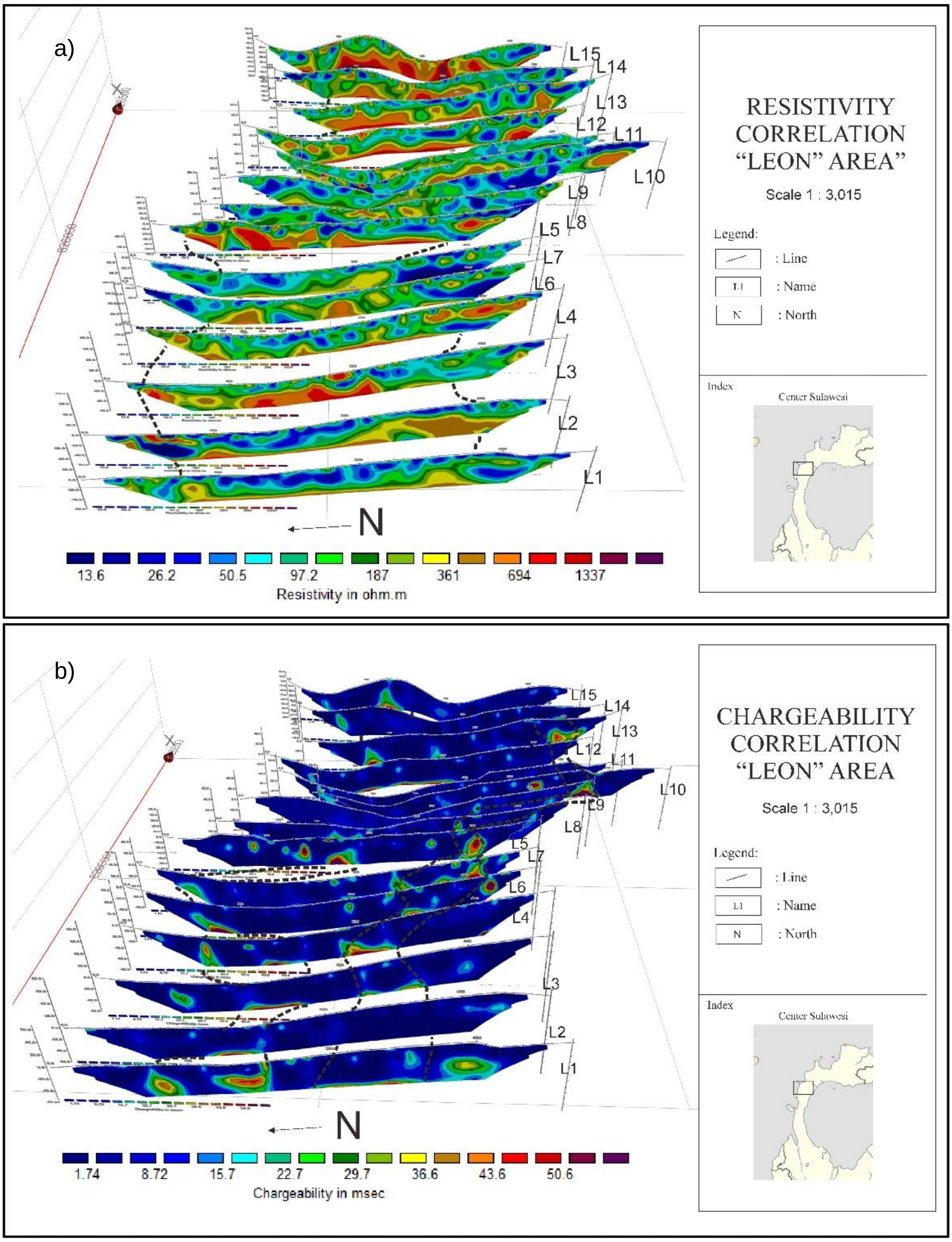


Figure 6. Correlation of resistivity (a) and chargeability (b) Leon area

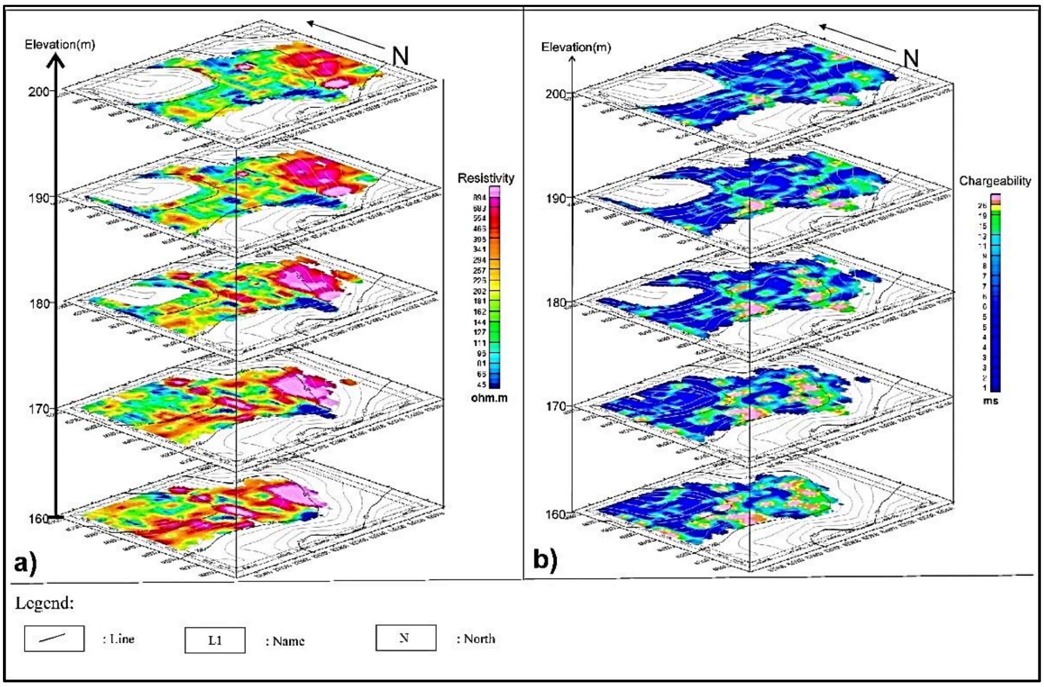


Figure 7. Results of distribution stacking values: resistivity (a) and chargeability (b) at elevation 160 meters to 200 meters in Leon area

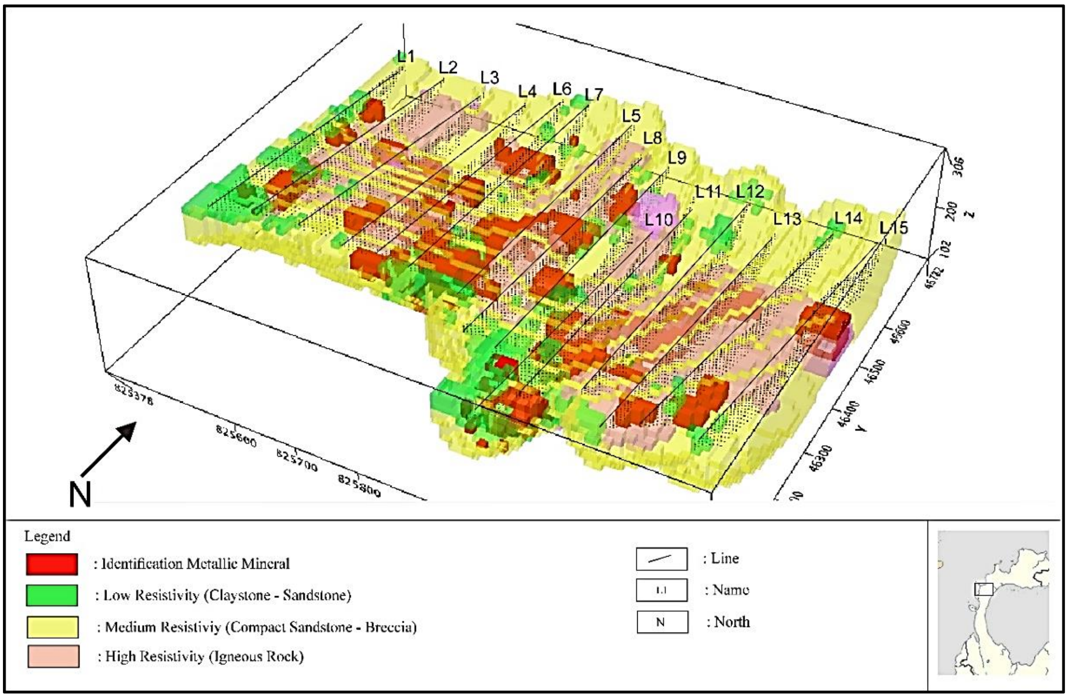


Figure 8. 3-Dimensional model of resistivity and chargeability value distribution

The formation of minerals in the study area is related to the presence of tectonic events before the occurrence of mineralization. Faults and faults formed in the study area will be weak zones. This weak zone allows magma to break through, and intrusion events occur. According to Rauf (2012) explained that as a result of this magmatic contact, there was a process of recrystallization, alteration, mineralization, and replacement in the magma contact section with the penetrated rock, namely Tinombo Formation, which is composed of phyllite, slate, quartz sandstone, siltstone, marble, rock horns, red shale, red chert, and volcanic rock. This change is caused by heat and liquid material originating from magma activity. The process of penetrating the magma in this weak zone until it freezes is generally accompanied by the metamorphic contact. Metamorphic contact also involves the side rocks of the Tinombo Formation, giving rise to liquid materials such as magmatic and metamorphic fluids that contain a lot of ore.

3-D Model of Resistivity and Chargeability

The 3D model was created using the Oasis Montage software shown in Figure 8. This model describes the distribution of resistivity values combined with moderate to high chargeability values that was identified as metallic minerals. In the 3D model, the research area is dominated by rocks with average resistivity values. Some parts of the rocks have low resistivity values. Hight resistivity value occurs at the bottom of the 3D model indicates that the lower the distribution of the high resistivity value, the more widespread the high resistivity value in the eastern and southern parts of the study area. The presence of metallic minerals is identified in red color. In the 3D model, the metallic minerals are distributed in the south and east of the study area. The presence of metallic minerals is getting deeper and broader, so it is identified that the presence of metallic minerals expands as it gets deeper and gets wider to the further south.

Resource Calculation

The amount of metallic mineral resources in the study area can be calculated using the block model method found in Oasis Montaj. A 3D model is made based on the chargeability value response to determine the volume of metallic minerals due to mineralization. Then, the chargeability value, suspected of containing metallic minerals based on Tables 2 and 3 is 22 ms so a volume of 3.6 million m^3 is obtained. According to the study area, a massive sulfide density is 4 g/cm^3 (Syafrizal, 2013), so the hypothetical amount of metallic mineral resources is 11.8 million tons.

CONCLUSION

Rocks containing metallic minerals are formed in sandstone with resistivity value of 15 to 200 Ωm, breccia 200 to 500 Ωm, igneous rock with a value greater of 500 Ωm. The continuity of metallic minerals shows that they are mainly located at the bottom, namely at elevation of 160 meters, and tend to be the south and east of the study area. In contrast, in the eastern part of the study area, they tend to be composed of rocks with high resistivity values from their surroundings. Based on the calculation results, metallic mineral hypothetical resources of 11.8 million tons were obtained.

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