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THE EFFECT OF GEOCHEMICAL ELEMENTS ON RESISTIVITY VALUES IN NICKEL LATERITE PROFILES (CASE STUDY: AREA "YL", POMALAA DISTRICT, KOLAKAA REGENCY, SOUTHEAST SULAWESI

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SARI
Indonesia terletak pada zona pertemuan tiga lempeng besar dunia menyebabkan Indonesia termasuk wilayah dengan aktivitas tektonik yang tinggi. Salah satu produk dari kegiatas tersebut adalah banyaknya sumber daya mineral yang bernilai ekonomis di beberapa daerah di Indonesia, salah satunya adalah nikel. Indonesia merupakan salah satu produsen nikel tertinggi di dunia dengan produksi sumber daya bijih mencapai 11.887 ton. Tingkat permintaan nikel yang meningkat cukup pesat dalam beberapa tahun terakhir, sehingga mendorong kegiatan eksplorasi terus dilakukan. Zona nikel laterit menghasilkan beberapa endapan seperti *top soil*, limonit, saprolit dan batuan dasar. Dalam kegiatan eksplorasi, zona saprolit menjadi sasaran utama karena kandungan nikelnya yang tinggi. Tahap eksplorasi dilakukan dengan menerapkan salah satu metode geofisika yaitu metode *Electrical Resistivity Tomografi* (ERT). Penelitian ini menggunakan 4 (empat) jalur ERT sepanjang 300 meter dan konfigurasi Wenner, serta data bor dan geokimia untuk membantu proses analisis. Tujuan dari penelitian ini adalah untuk mengetahui karakteristik masing-masing zona endapan nikel laterit yang dikontrol oleh kadar unsur atau senyawa yang terkandung. Berdasarkan hasil penelitian, kisaran nilai resistivitas yang diperoleh cukup rendah, yaitu rendah (< 35 Ωm) merupakan zona saprolit, sedang (35 – 65) Ωm merupakan zona *saprock* yang didalamnya terdapat bongkahan batu dan tinggi (> 65 Ωm) merupakan zona batuan dasar berupa batuan Peridotit yang sebagian besar telah mengalami proses serpentinisasi dan pelapukan yang cukup intensif serta dipengaruhi oleh kadar unsur logam dan air (H_2O), terutama pada zona saprolit dan *saprock*. Hal ini dikontrol oleh morfologi dan pergerakan air di bawah permukaan, sehingga mempengaruhi proses pelapukan yang terjadi dan menyebabkan ketidakrataan ketebalan dan sebaran unsur dan senyawa pada setiap zona daerah penelitian.

Kata kunci: Endapan nikel laterit, *electrical resistivity tomography* (ERT), konfigurasi wenner, resistivitas, Daerah Pomalaa

ABSTRACT
Indonesia is located in the meeting zone of the world's three major plates, causing Indonesia to be an area with high tectonic activity. One of the products of this activity is the large number of economic mineral resources in several regions in Indonesia, one of which is nickel. Indonesia is one of the highest nickel producers in the world, with production reaching 11,887 tons of ore resources. The level of demand for nickel has increased quite rapidly in recent

years, thus encouraging exploration activities to continue. The nickel laterite zone produces several deposits, such as top soil, limonite, saprolite, and bedrock. In exploration activities, the saprolite zone is the main target due to its high nickel content. The exploration stage was carried out by applying one of the geophysical methods, namely the Electrical Resistivity Tomography (ERT) method. This research uses 4 (four) 300 meter ERT lines and wenner configuration, as well as drill and geochemical data to assist in the analysis process. The aim of this research is to determine the characteristics of each zone of nickel laterite deposits which are controlled by the levels of elements or compounds they contain. Based on the research results, the range of resistivity values obtained is quite low, namely low (< 35 Ωm) is the saprolite zone, medium (35 – 65) Ωm is the saprock zone which contains boulders in it, and high (> 65 Ωm) is the bedrock zone in the form of Peridotite rocks, most of which have undergone quite intensive serpentinization and weathering processes and are influenced by tectonic activity in the form of faults. Resistivity values are largely influenced by the levels of metal elements and water (H_2O), especially in the saprolite and saprock zones. This is controlled by the morphology and movement of water below the surface, thus influencing the weathering process that occurs, causing unevenness in the thickness and distribution of elements and compounds in each zone in the research area.

Keywords: *Nickel laterite deposits, electrical resistivity tomography (ERT), wenner configuration, resistivity, Pomalaa District*

INTRODUCTION

Indonesia is located in the meeting zone of the world's three large plates, namely the Indo-Australian, Eurasian, and Pacific Plates. This condition causes Indonesia to be included in areas with quite high tectonic activity, such as earthquakes, volcanic formation and geothermal activity. One of the products of this activity is the enrichment of economic mineral resources in several regions in Indonesia. One type of mineral resource that is currently widely used is nickel laterite (Suryawan et al., 2019). Nickel is an economical mineral with a fairly high consumption level. Indonesia has nickel ore resources of 13,955 tones (inferred 6,249 tones, indicated 4,535 million tones, measured 2,952 tones, mortgage 219 million tones) and nickel ore reserves of 4,380 million tones (proven 1,232 million and estimated 3,148 million tones (Lelono, 2020).

Indonesia is one of the suppliers of nickel demand in the world. Thus, nickel plays an important role in industry, where its great potential needs to be developed sustainably. Products produced from the nickel laterite formation process are influenced by many elements or compounds, as well as with the altered product. The altered products referred to here are alteration minerals from several elements or compounds, such as Fe_2O_3, FeO, MgO, and others. All compounds produced have their respective levels in each zone. In exploration activities, the saprolite zone is the main target because its nickel content is quite high and suitable for exploitation. One of the areas with quite large potential for laterite nickel is Pomalaa District, Kolaka Regency, Southeast Sulawesi Province, where large-scale laterite nickel mining has been carried out in this area. Before mining or exploitation activities are carried out, of course they must go through an exploration stage which can be carried out by applying one of the geophysical methods, namely the resistivity method. Every element and compound in the nickel laterite profile will greatly influence the resistivity value, especially metal elements and water (H2O), so the resistivity method is very suitable in

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this research. Apart from that, drilling and geochemical data are also used to assist in the analysis process, so it is hoped that the use of all existing data can maximize the objectives of this research, namely to find out the response and influence of each geochemical element in the nickel laterite profile on the distribution of the resulting resistivity values.

GEOLOGICAL REVIEW

Geology of the Research Area

Pomalaa, which is the research area, is shown in Figure 1. It is included in the East Sulawesi Ophiolite Complex, which is composed of ultramafic rocks such as peridotite, harzburgite, dunite, wherlite, lherzolite, websterite, pyroxenite and serpentinite (Kusuma et al., 2015). These ultramafic rocks have gone through a weathering and serpentinization process to form laterite nickel deposits characterized by hydrous Mg silicate deposits, where ultramafic rocks are the main source of laterite formation and are quite often found in Pomalaa. Apart from that, the morphological type in Pomalaa is quite wavy and is controlled by the geological structure in the form of a left-slip fault with an azimuth of N 305° E, part of the Kolaka Fault. However, physiographically, the Pomalaa area is included in the lowland part of the Southeastern Arm of Sulawesi (Kamaruddin et al., 2018).

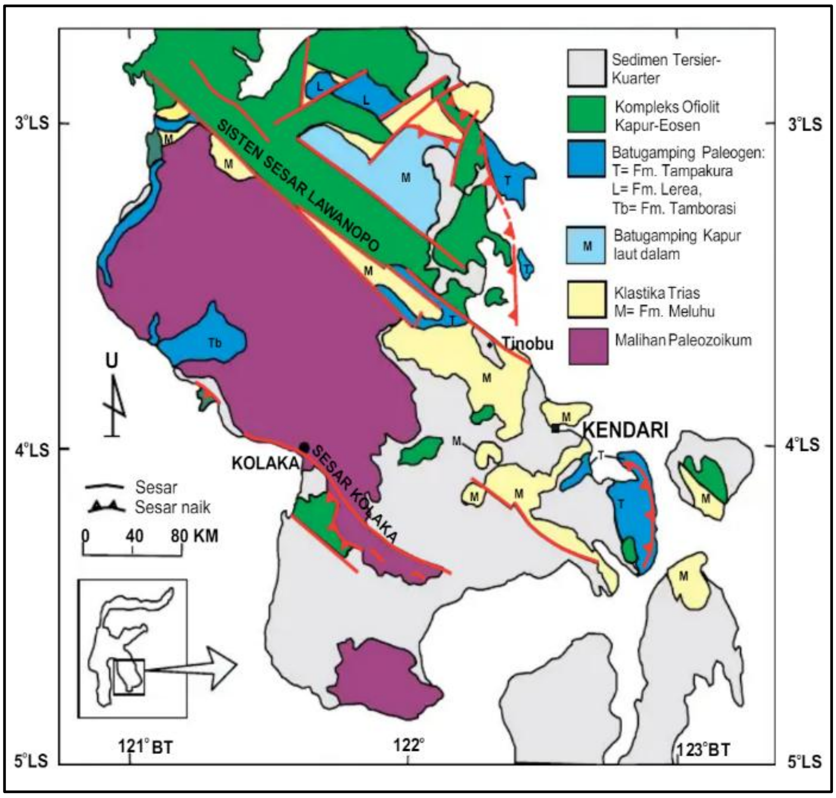
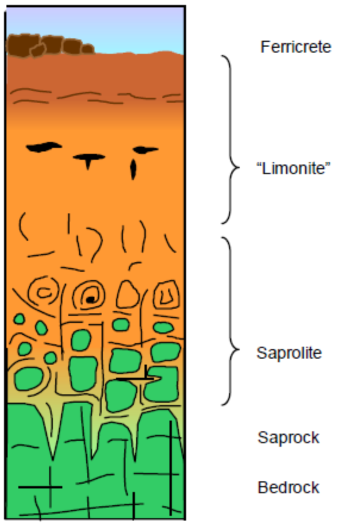


Figure 1. Geological map of southeast sulawesi (Rusmana et al., 2013), the black box shows the location of the research area

Nickel Laterite

Nickel laterite is a metal mineral product from the chemical weathering process of ultramafic rocks, which experience residual and secondary enrichment of the elements Ni, Fe, Mn, and Co (Burger, 1996; Syafrizal, 2011). Nickel laterite deposits result from further weathering of ultramafic rocks bearing Ni-Silicates, which are generally found in areas with tropical to subtropical climates. The influence of the tropical climate in Indonesia results in intensive weathering processes, so that several areas in eastern Indonesia have nickel laterite deposits. Ultramafic rocks have an average nickel content of 0.2%. Nickel laterite also has several zones or layers that form and form the profile shown in Figure 2.



Fe	MgO	Ni	Co
>50%	<0.5%	<0.6%	<0.1%
40-50%	0.5-5%	0.8-1.5%	0.1-0.2%
10-25%	15-35%	1.5-3%	0.02-0.1%
5%	35-45%	0.3%	0.01%

Figure 2. Profile of nickel laterite deposits (Elias, 2002)

METHODS

The research location is located in Pomalaa District, Kolaka Regency, Southeast Sulawesi Province, where the data used is the Electrical Resistivity Tomography (ERT) method with Wenner configuration data, with a total of 4 (four) 300-meter-long ERT lines oriented west–east, where the distance between the line is 100 meters long and the electrode spacing is 10 – 60 meters, but only 1 (one) line will be discussed in this research. The data was processed using Res2Dinv software, and data quality control was carried out before processing. The research area is divided into 2 (two) different hills or blocks, marked with a red line for the first hill and yellow for the second hill. For drill data, there are 5 (five) drill points for the first block and 7 (seven) drill points for the second block. All drill points are marked with the code "YL". The design survey map of the ERT method and drill points is shown in Figure 3.

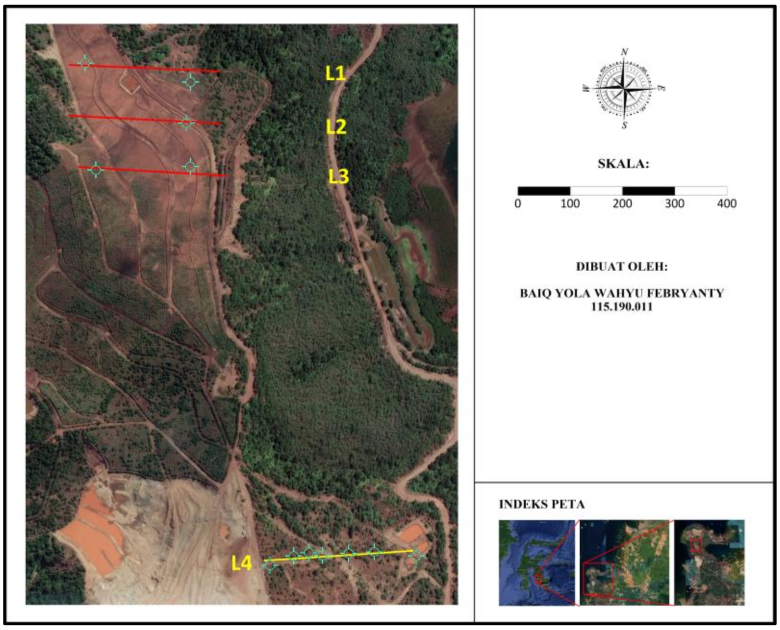


Figure 3. ERT and drill method design survey map

The geoelectric method is a geophysical method that studies conditions below the earth's surface using a physical parameter approach in the form of the electrical properties of a rock, rock formation or part of a rock formation. The working principle of this geoelectric method is to measure the resistivity of rocks by passing an electric current through a current electrode, where the current will then be received by a potential electrode using the assumption that the earth is a resistor (Susanti, 2020). The main aim of a survey using the geoelectric method is to determine subsurface resistivity distribution by taking measurements on the ground surface. From these measurements, the actual resistivity beneath the earth's surface can be estimated. The relationship between resistivity and the current sent and the potential is expressed by following:

$$V = IR \quad (1)$$

Where R is the resistance of a material in units of ohms or Ω, the electric current strength is symbolized by I , and V. symbolizes the potential difference or voltage The ERT method measurements in this research use one configuration to map the subsurface, namely the Wenner configuration as shown by Figure 4.

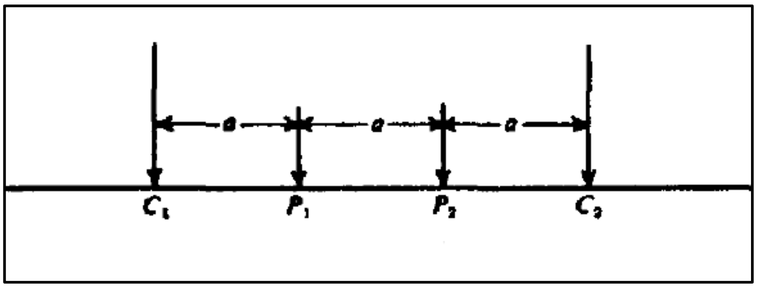


Figure 4. Susunan konfigurasi wenner

The electrode arrangement in the Wenner configuration is placed uniformly in one line on a measurement path, with the arrangement $r_1 = r_4 = a$ dan $r_2 = r_3 = 2a$. In the Wenner configuration, the resistivity can be described using the following equation, where $2\pi a$ is the configuration factor (Telford et al., 1990):

$$\rho = 2\pi a \frac{\Delta V}{I} \quad (2)$$

RESULTS AND DISCUSSION

The distribution of the range of resistivity values resulting from the interpretation is shown in Table 1, where the resulting resistivity values are quite low. Resistivity values below 35 Ωm are the saprolite zone, medium (35 – 65 Ωm) is the saprock zone, which contains boulders in it, and high (above 65 Ωm), is the bedrock zone in the form of peridotite rock, which is included in the Ophiolite Complex formation of East Sulawesi on the Southeast Arm of Sulawesi. Most of these rocks have undergone quite intensive serpentinization and weathering processes, and are influenced by tectonic activity in the form of a left-slip fault (azimuth N305°E) which is part of the Kolaka Fault.

The resistivity cross-section on path four is shown in Figure 5, where iterations have been carried out five times with a final RMS error value of 5.2%. Low resistivity values (below 35 Ωm) are interpreted in the resulting cross-section as the saprolite zone. In the saprock zone, there is a part that extends close to the surface, which is thought to be part of bedrock that has not undergone a weathering process, which is then called peridotite boulder. A high resistivity value (above 65 Ωm) is a bedrock zone in the form of peridotite rock with a relatively high fracture content, with a layer thickness of up to 50 meters.

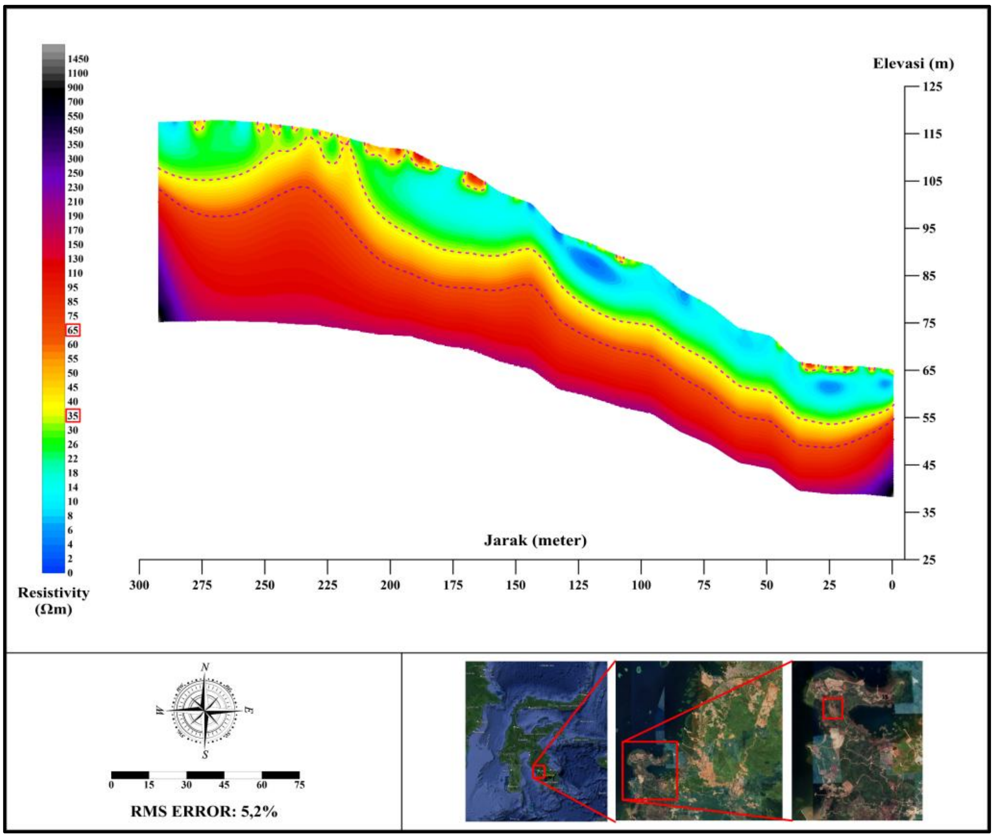


Figure 5. Resistivity cross section line 4

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Table 1. Classification of resistivity values and interpretations.

Category	Resistivity (Ωm)	Interpretation
Low	<35	Saprolite
Medium	35 – 65	Saprock/Boulder
High	>65	Bedrock (Peridotite – East Ofiolit Complex formation)

Each zone is influenced by many elements and compounds, so the resulting resistivity value is quite low. Figure 6. is the correlation result for the Ni element content from each drill point, where each drill point has a fairly good correlation, starting from point YL-11 in the west to YL-7 in the east. Points YL-11 to YL-12 in the west and YL-6 to YL-7 in the east have a relatively high Ni element content at the top (above 1.3%), while for YL-8, the Ni element tends to be quite low from top to bottom. The Ni element (metal) can reduce the resulting resistivity value, so the Ni element in this path significantly affects the low resistivity value, as evidenced by the high levels of Ni elements at the top of the drill point profile. To see how the Ni element influences the research area, a comparison graph is displayed between the Ni element and the resistivity value on the entire path shown in Figure 7.

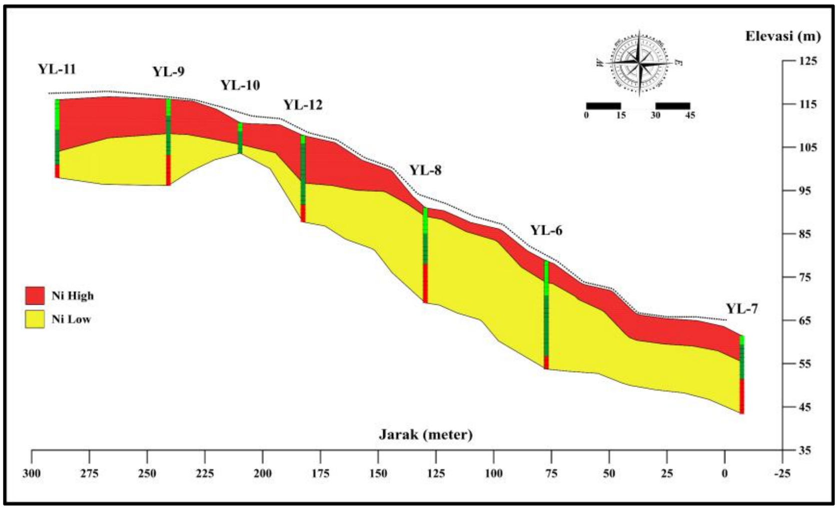

Figure 6. Ni element correlation line 4

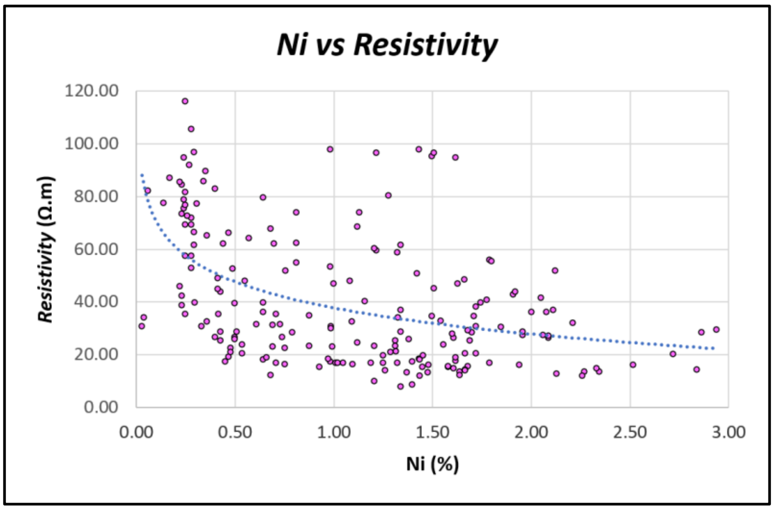

Figure 7. Comparison graph of Ni element and resistivity values

The graph shows that the Ni element's distribution relative to its resistivity value is quite varied, with a range of Ni element levels between 0 and 3% and resistivity values between 0 and 120 Ωm. However, it can be seen that the higher the Ni element content, the relatively lower the resistivity value, and the lower the Ni element content, the relatively higher the resistivity value. As previously explained, the Ni element (metal) can reduce the resulting resistivity value. However, there is also some distribution of the Ni element with relatively low levels with high resistivity values, and vice versa. This is thought to be caused by the influence of the content of other elements and compounds found in each zone, so that the resistivity value becomes lower or higher. However, in general, the Ni element has a quite significant influence on the resistivity value as evidenced by the lower resistivity value as the Ni element content increases in each zone.

The Fe element is also a metal element that can influence resistivity values, where the correlation results are shown in Figure 8. Each drill point has a fairly good correlation, starting from point YL-11 in the west to YL-7 in the east. Points YL-11 in the west and YL-12 to YL-7 in the east have a relatively moderate Fe element content at the top (above 10%), where in particular, point YL-12 has a moderate distribution of Fe elements in thickness, which is relatively thicker compared to other drill points. At point YL-9, the Fe element tends to be quite low from top to bottom; likewise, at point YL-10 the Fe element tends to be very low from top to bottom. With quite varying percentage levels in each zone, the Fe element significantly influences the resistivity value. To see how the Ni element influences the research area, a comparison graph is displayed between the Ni element and the resistivity value on the entire path shown in Figure 9 .

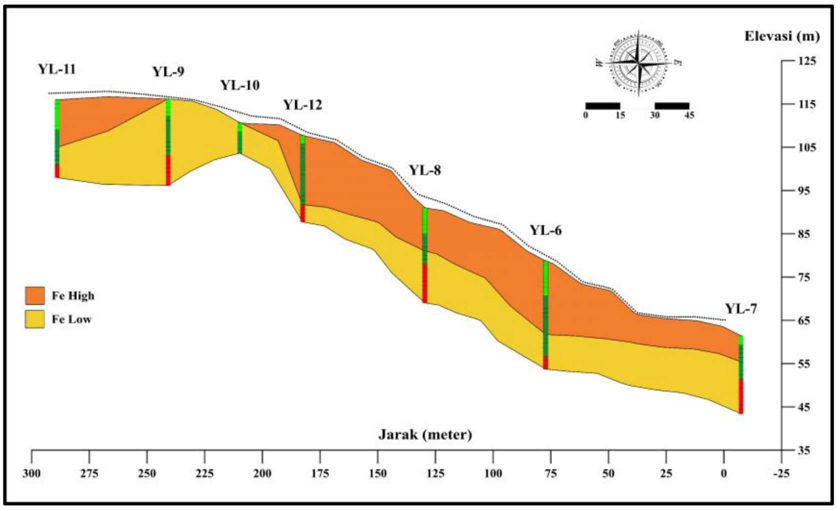

Figure 8. Fe element correlation line 4

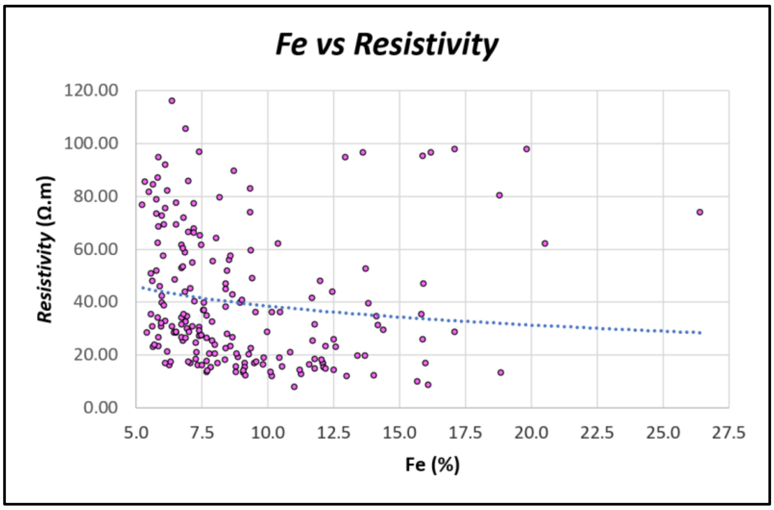

Figure 9. Comparison graph of Fe element and resistivity values

In the graph, it can be seen that the distribution of the Fe element in terms of resistivity values is quite varied, with a range of Fe element levels between 5 and 27.5% and resistivity values between 0 and 120 Ωm. Based on the graph, you can see the distribution of the Fe element at lower or higher levels with the same resistivity value, so that no limits can be determined regarding the influence of the Fe element on the resistivity value. As previously explained, the Fe element (metal) can reduce the resulting resistivity value. However, it can be seen that the higher the Fe element content, the resistivity value tends to be lower, likewise, with the lower Fe element content, the resistivity value is relatively higher. However, some Fe elements are distributed with relatively low levels with high resistivity values, and vice versa. This is thought to be caused by the influence of the content of other elements and compounds found in each zone so that the resistivity value becomes lower or higher. With quite varying percentage levels in each zone, the Fe element has quite a significant influence on the resistivity value as evidenced by the lower resistivity value as the Fe element content increases in each zone.

Water is one of the compounds that can influence resistivity values, where the correlation results are shown in Figure 10. Each drill point has a fairly good correlation, starting from point YL-11 in the west to YL-7 in the east. Points YL-11 to YL-9 in the west and YL-12 to YL-7 in the east have relatively high water content from the middle to the top (above 15%), where at points YL-12, YL-8 , and YL-6 in the eastern area has a distribution of high water content with a thickness that is relatively thicker than other drill points. At the YL-10 point, the water content tends to be very low from top to bottom. In general, water content also has a significant influence on the resistivity value as evidenced by the high water content at the top of the drill point profile. To see how the water content affects the research area, a comparison graph between the water content and the resistivity value on the entire track is displayed as shown in Figure 11.

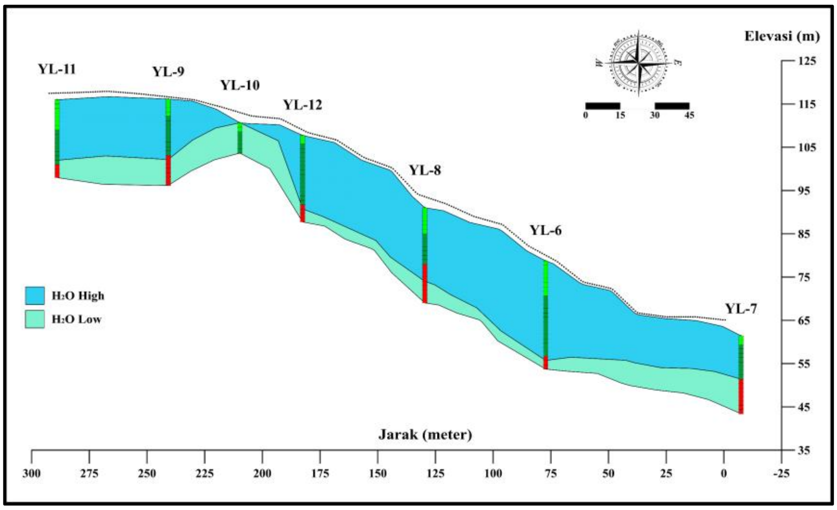

Figure 10. Water content correlation line 4

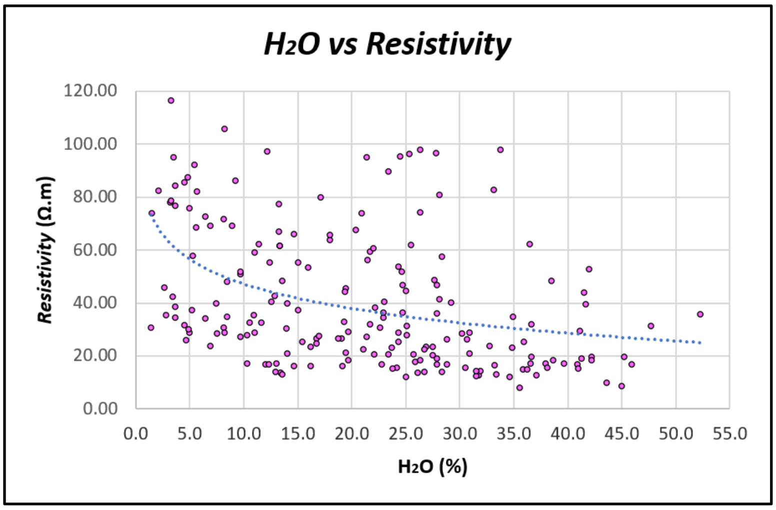

Figure 11. Comparison graph of water contentand resistivity values

Apart from the elements Ni, Fe, and water content, the elements Mg and Si were also analyzed. To see the influence of the Mg element on the research area, a comparison graph between the Mg element and the resistivity value on the entire path is displayed as shown in Figure 12.

In the graph, it can be seen that the distribution of the Mg element in terms of resistivity values is quite varied, with a range of Mg element levels between 7.5 to 37.5% and resistivity values between 0 and 120 Ωm. Based on the graph, you can see the distribution of the Mg element at lower or higher levels with the same resistivity value, so that no limits can be determined regarding the influence of the Mg element on the resistivity value. As previously explained, the element Mg (metal) can reduce the resulting resistivity value. However, it can be seen that the higher the Mg element content, the relatively lower the resistivity value for each value, but there are also relatively high resistivity values. However, there is also some distribution of the Mg element with relatively low levels with high resistivity values, and vice versa. This is thought to be caused by the influence of the content of other elements and compounds found in each zone, so that the resistivity value becomes lower or higher. With quite varying percentage levels in each zone, the Mg element significantly influences the resistivity value as evidenced by the quite low resistivity value along with increasing levels of the Mg element in each zone.

Apart from the Mg element, to see how the Si element influences the research area, a comparison graph between the Si element and the resistivity value on the entire path is displayed (Figure 13).

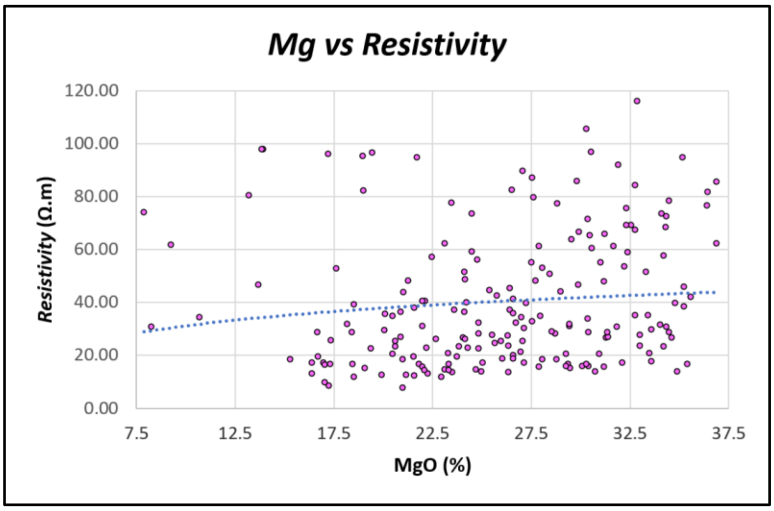

Figure 12. Comparison graph of Mg element and resistivity values

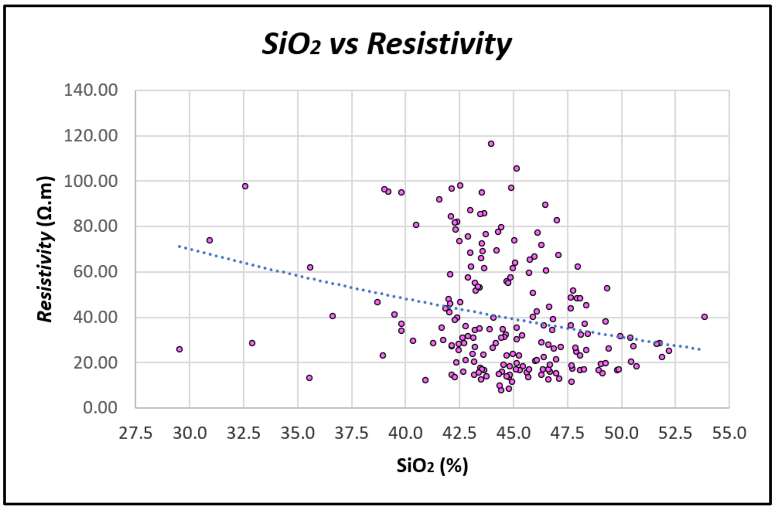

Figure 13. Comparison graph of Si element and resistivity values

3D modeling was also carried out to see distribution patterns and estimate the volume of each zone, in this case the saprolite and saprock zones which contain the economically valuable Ni element. The enrichment of the Ni element is controlled by the morphological forms that develop in the research area, as well as other chemical elements. The results of 3D modeling of the saprolite and saprock zones based on resistivity values are shown in Figure 14 :

Based on Figure 14 and Figure 15, it can be seen that the saprock zone has a relatively larger volume compared to the saprolite zone based on the results of 3D resistivity modeling. The estimated volume for the saprolite zone is 256,548.8 m³ with a majority distribution pattern in the central part of the research area, while for the saprock zone it is 532,227.2 m³ with a larger majority distribution pattern, with a thicker section in the central part of the research area. . This uneven distribution in each zone is controlled by the morphological form and due to the weathering process, that occurs during the lateritization process. This is largely influenced by the movement of water below the surface, which is also indirectly influenced by the morphological form. Water does not have sufficient time to soak and weather the rocks because the water will move relatively down the slope, causing unevenness in the thickness of each zone in the research area. Apart from that, these factors also influence the distribution of chemical elements such as Ni. Based on the 3D results, it can be concluded that volume estimation can be done quite well by utilizing resistivity data, although several parts experience an extrapolation process due to the asymmetric ERT trajectory. However, the 3D modeling results are still quite representative for estimating the economic volume of ore, namely the saprolite and saprock zones based on resistivity values.

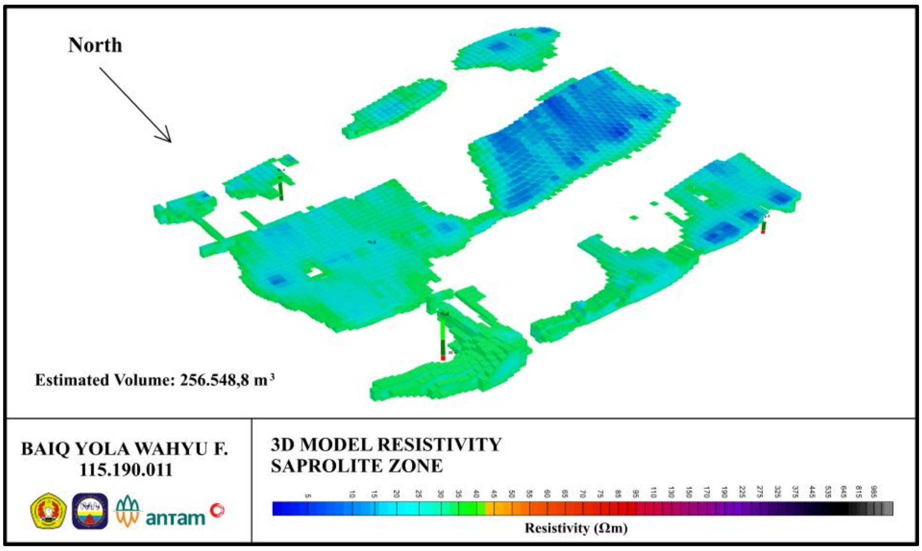

Figure 14. 3D modeling results for the saprolite zone

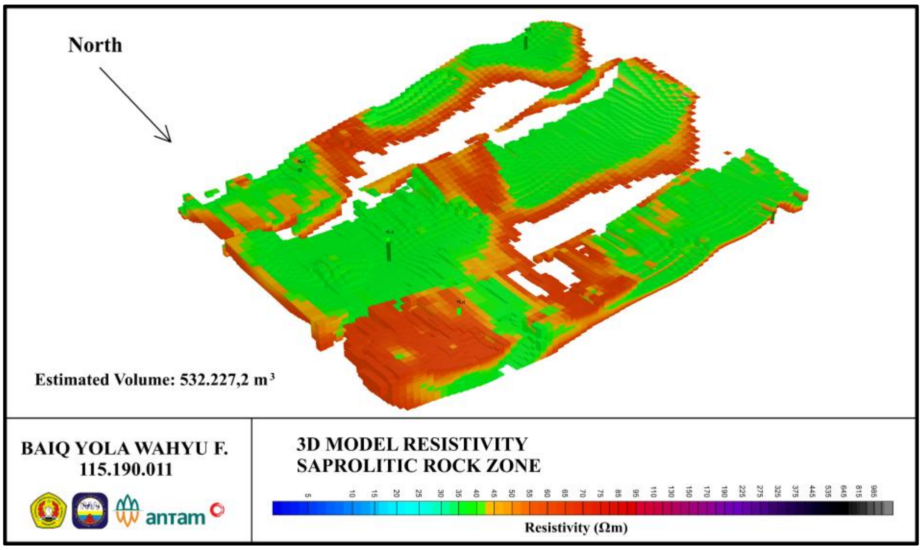

Figure 15. 3D modeling results for the saprock zone

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CONCLUSIONS

In the research area, a fairly low range of resistivity values was obtained, namely low (< 35 Ωm) is the saprolite zone, medium (35–65) Ωm is the saprock zone which contains boulders in it, and high (> 65 Ωm) is the Bedrock is in the form of peridotite rock, most of which has undergone quite intensive serpentinization and weathering processes and is influenced by tectonic activity in the form of faults. Resistivity values are largely influenced by the levels of metal elements such as Ni, Fe and Mg, as well as water content (H_2O), especially in the saprolite and saprock zones. This is proven by the higher the levels of metal elements and water, the resistivity value tends to be lower. Meanwhile, for the Si element, even though its presence is quite abundant (high levels), the influence it has on the resistivity value is much lower compared to other elements and compounds that are more conductive. The saprolite and saprock zones, which are economic ores in laterite nickel deposits, have an uneven distribution pattern, but the majority are thicker in the central part of the study area. larger, with a thicker section in the center of the study area. This is controlled by the morphology and movement of water below the surface, thus influencing the weathering process that occurs. Thus, this causes unevenness in the thickness and distribution of elements and compounds in each zone in the research area.

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