Vol. 7, No. 1, January 2025: 48-59

Jambura Geoscience Review

p-ISSN 2623-0682 | e-ISSN 2656-0380

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Delineation of Nickel Laterite Based on Electrical Resistivity Tomography (ERT) Method at Kolaka Regency, Southeast Sulawesi

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ARTICLE INFO

Article history:
Received: 19-09-2023
Accepted: 27-01-2025
Published: 29-01-2025

Keywords:
Nickel Laterite Deposits; Electrical Resistivity Tomography; Wenner Configuration, Resistivity

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ABSTRACT

Fulfillment of nickel laterite needs for various industrial purposes has become a government plan that must be realized immediately. The sustainability of the nickel laterite supply is the main reason for increasing exploration activities in various nickel laterite-producing areas in Indonesia. Nickel laterite explorations have been carried out in several areas, one of which is in Pomalaa District, Kolaka Regency, Southeast Sulawesi. The ERT (Electrical Resistivity Tomography) method combined with drilling and geochemical data is very suitable for delineating nickel laterite in the subsurface in three blocks. The purpose of this study was to obtain the distribution of nickel laterite in the subsurface and analyze its characteristics. This study used the Wenner configuration and 19 exploration drill points with geochemical assay data. The results of the study showed that there were three zones based on their resistivity values, namely the saprolite zone with a low resistivity value (<35 Ωm), the saprolitic rock to boulder zone with a medium resistivity value (35 - 65) Ωm, and the bedrock zone in the form of peridotite rocks with a relatively high level of serpentinization, fracture and weathering, with a high resistivity value (> 65 Ωm). For characterization, the research area is divided into three blocks, namely West, Central and East Block. West block has low Ni content (<0.96%) for the saprolite zone and (0.32 - 1.27) % for the saprolitic rock zone, and high (1.65 - 3.24) % for the saprolite zone and (1.35 - 2.27) % for the saprolitic rock zone. In the Central block, the Ni content is low in the saprolite zone of (0.27 - 1.37) % and the saprolitic rock zone of (0.26 - 1.30) %. While in the East Block, the Ni content is low (0.48 - 1.25) % for the saprolite zone, (0.03 - 1.29) % for the saprolitic rock zone, and high (1.34 - 2.94) % for the saprolite zone and (1.31 - 2.84) % for the saprolitic rock zone.

How to cite: Arya, RN. (2025). Delineation of Nickel Laterite Based on Electrical Resistivity Tomography (ERT) Method at Kolaka Regency, Southeast Sulawesi. *Jambura Geoscience Review, 7*(1), 48-59. https://doi.org/10.37905/jgeosrev.v7i1.22109

1. INTRODUCTION (Calisto MT, 11pt)

The presence of electric vehicles in Indonesia has increased since 2020. Using electric vehicles provides various advantages, ranging from clean energy-based features, saving fuel costs, implementing an Intelligent Transport System (ITS) that guarantees safety while driving, and others (Colmenar-Santos, 2019). This is expected to be the first step in realizing net-zero emissions and reducing CO2 gas emissions gradually until 2050. Electric vehicles use the main energy source in the form of batteries composed of several elements and compounds, one of which is Nickel which is quite widespread in Indonesia. Indonesia is one of the countries with abundant natural resources and has the potential to improve the country's economy (Diantoro, 2017). The industry's need for nickel can be seen from the amount of Indonesian nickel exports. Based on data from the

Central Statistics Agency in 2018, the average amount of nickel exports from 2002 to 2014 reached 17,103,785 tons/year. Meanwhile, in terms of production, in 2021, it is estimated to reach 1 million MT or contribute 30.40% of the world's total production, making Indonesia the world's main producer of Nickel. On average, Indonesia's nickel product exports from March to September 2022 reached USD 542.81 million/month, with an average monthly growth trend of 2.84%. In Indonesia, Nickel is primarily found in laterite deposits, called Nickel Laterite Deposits. In addition to being used as a basic material for electric vehicle batteries, nickel laterite is also widely used in other heavy industries, such as electronic devices, and is used as a mixture for making stainless steel. Nickel laterite is one of the mineral metals produced from the chemical weathering process of ultramafic rocks that experience residual and secondary enrichment of Ni, Fe, Mn, and Co elements (Syafrizal, 2011; Burger, 1996). Nickel laterite deposits are usually characterized by the presence of reddish brown metal oxides, which are caused by the Ni and Fe content in them (Cahit et al., 2017). Nickel laterite deposits are formed due to several factors, including geological structure, climate, topography, chemical reagents, vegetation, time, original rocks, and high weathering, which greatly affect the sterilization process. The process of forming nickel laterite deposits begins with the weathering process on ultramafic rocks, which is quite intensive and lasts a very long time (Sundari and Woro, 2012). Then, there is a process of rainwater infiltration that enters the cracks in the rock which dissolves the minerals in the underlying rock into several elements. Elements with high density and immobile nature will be left on the surface and experience residual enrichment, such as Fe, Mn and Co. Meanwhile, elements that can move or are mobile will dissolve downward and form an accumulation zone through the supergene enrichment process, such as Ni, Ca, Mg, and Si (Golightly, 1979). In general, laterite nickel deposits are divided into several zones with varying thicknesses and element levels, such as overburden, limonite, saprolite, and bedrock. According to Robb (2004), the limonite zone is a layer under the overburdened or reddish brown to yellowish cover soil, soft and sticky in texture and rich in Fe (iron) alteration minerals. Meanwhile, the saprolite zone is the result of weathering, which generally still shows some of the textures of the original rock and is greenish to yellowish in color. In the saprolite zone, the nickel content varies, around 1 - 5%, and each region has different levels. The research location is located in Pomalaa District, Kolaka Regency, Southeast Sulawesi Province. In general, this area is composed of ultrabasic rocks that have undergone an obduction process so that they are exposed on the surface. The ultrabasic rocks that are formed then undergo chemical and mechanical weathering processes that cause the formation of laterite nickel deposits (Salsabila, 2021). The weathering process of the original rock and the high mineral content of each zone in the laterite nickel deposit can affect the physical parameters of the rock, one of which is resistivity. The research location is dominated by saprolitic rock in almost all areas. Basically, saprolitic rock still contains many bedrock components due to the very low level of weathering, so that it has a hard texture the same as the bedrock. In theory, the resistivity value of saprolitic rock will resemble the bedrock.

In nickel laterite exploration activities, an appropriate method is needed to be able to map and determine the ideal boundaries of each zone found in the laterite nickel deposit.

The method used in this study is one of the geophysical methods, namely the geoelectric method. The geoelectric method is a method that utilizes the electrical properties below the surface, by injecting electric current into the subsurface to then measure the potential (Telford et al., 1990). More specifically, this study used the Wenner configuration Electrical Resistivity Tomography (ERT) method, which is a modified result of the resistivity mapping method measurement with Vertical Electrical Resistivity (VES). The Wenner configuration is intended to obtain variations in resistivity values based on lateral and depth (vertical) differences. This modification can be done only by using a tool with a multi-channel system so that measurements can be carried out quickly to obtain large amounts of data. However, the resulting data can be processed in 2D with the hope of being able to provide results with good vertical and horizontal resolution. Thus, this ERT method can be said to be a resistivity mapping method. The processing results are correlated with supporting data (drill data and geochemical assay) so that analysis can be carried out to map and determine the ideal boundaries of each zone in laterite nickel deposits. This study also conducted characterization based on the distribution of chemical elements and resistivity values at each depth.

The results are used to determine the characteristics, volume size, and geoelectrical layer modeling of laterite nickel deposits in the research area.

2. Geological Review

2.1. Geology of the Pomalaa Region

Sulawesi Island is located at the meeting point of three tectonic plates, namely the Eurasian Continental Plate to the west, the Australian Continental Plate to the east, and the Pacific Ocean Plate to the northeast. Thus, Sulawesi Island has a tectonic condition that is quite complex, reflected in the morphological form, geological structure, lithology of the constituent rocks, and stratigraphy (Surono, 2013). Van Bemmelen (1949) divided Sulawesi Island into the North Arm, South Arm, Southeast Arm, and East Arm. Pomalaa District, Kolaka Regency, is included in the Southeast Arm of Sulawesi. Regarding tectonics, Sulawesi Island is separated from the Sunda Shelf to the west by the Makassar Strait, which was formed due to the expansion of the sea during the Miocene (Katili, 1979 & 1989; Hamilton, 1979). To the north, there is the North Sulawesi Trench, which stretches west-east, while to the east, there is the Tolo Thrust Fault, which connects it to the North Sulawesi Trench and continues with the Matano Fault (Silver et al., 1983a; b).

In general, the regional structures that developed on Sulawesi Island (Figure 1) include:

1) North Sulawesi Trench. This structure extends west-east or is commonly called the Beniof Zone, which is where the Sulawesi Sea Crust began to subduct under the North Sulawesi Arm at the end of the Paleogene (Fitch, 1970; Katili, 1971; Cardwell et al., 1978; Hamilton, 1979; McCaffrey et al., 1983).
2) Palu-Koro Fault System. The name of this fault was first proposed by Sarasin in 1901 and then repeated or continued by Rutten in 1927. This fault system cuts from the northern tip of South Makassar, through Palu City and continues to Bone Bay. The results of geological mapping conducted by the Geological Research and Development Center show that this fault system is also related to the Matano Fault and Lawanopo Fault (Simandjuntak et al., 1993a, b, c; Rusmana et al., 1993; Sukamto, 1975).
3) Batui Thrust Fault. This fault is the result of a collision between the Banggai-Sula Continental Plate and the East Sulawesi Ophiolite Strip, where the Continental Plate rises against the Ophiolite Strip, so it is called a Thrust Fault. This fault cuts the tip of the East Sulawesi Arm to Tolo Bay and meets the extension of the Matano Fault, which was named the Manui Fault by Gerrard et al. (1988). This fault is also cut by several shear faults that appeared after it, including the Toili Fault, Ampana Fault and Wekuli Fault (Simandjuntak, 1986; Rusmana et al., 1993).
4) Poso Thrust Fault. This fault extends from north to south, starting from Tanjung Peindilisa in Tomini Bay to Masamba on the north coast of Bone Bay (Sukamto, 1975a; Simandjuntak et al., 1993b). This fault separates the Central Sulawesi Shifting Zone in the east from the West Sulawesi Volcanic Zone in the west.
5) Walanae Fault. This fault is trending almost north to south, incising the South Arm of Sulawesi and continuing to cut Selayar Island which is located to the south (Sukamto, 1975a; Sukamto, 1982). Darman & Sidi (2000) suspect that this fault continues to the south until it meets the Flores Thrust Fault to the north of Flores Island. While to the north, the fault may continue to the Makassar Strait and unite with the Paternoster-Lupar suture. This fault was reactivated in the Quaternary, thus forming the extensive Walanae Depression.
6) Expansion of the Makassar Strait. This strait is thought to have formed due to expansion that was almost north-south in direction (Katili, 1979). Situmorang (1982) suspected that the expansion of the Makassar Strait began in the Neogene. This is based on the similarity of the Cretaceous bedrock and the Eocene-Oligocene sedimentary cover sequence in southern-eastern Kalimantan and the South Arm of western Sulawesi (Hamilton, 1979).

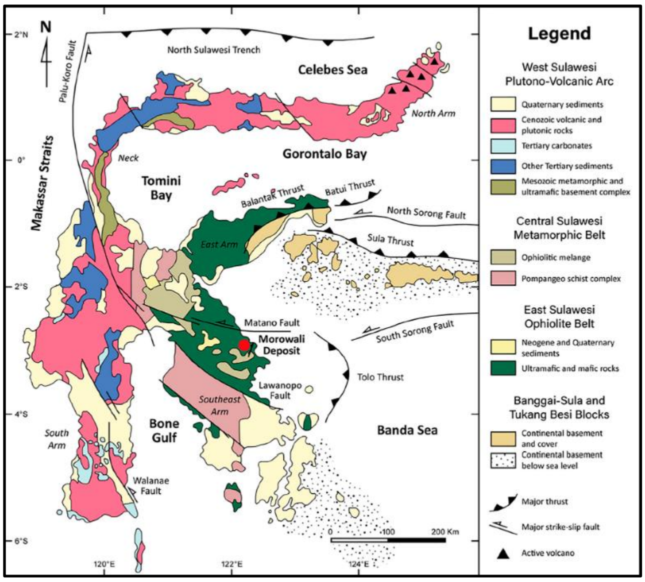


Figure 1. Tectonic and Geological Setting of Sulawesi Island (Choi et al., 2021; modified from Hamilton, 1979 in Hall & Wilson, 2000).

The geological map of Southeast Sulawesi, where a black box shows the research area (Figure 2). Pomalaa is part of the ultramafic rocks of the East Sulawesi Ophiolite Complex in the Southeast Arm of Sulawesi, with the dominance of ultramafic rocks in this area including peridotite, harzburgite, dunite, wherlite, lherzolite, websterite, pyroxenite and serpentinite (Kusuma et al., 2015). In this area, nickel laterite deposits are also formed, resulting from the weathering of ultramafic rocks dominated by serpentinized peridotite (harzburgite or dunite), a hydrous Mg silicate deposit. These ultramafic rocks are the main source of laterite formation, as is often found in the Pomalaa area. The mineral composition of the peridotite rock itself is dominated by olivine, clinopyroxene, and orthopyroxene, and some are accompanied by chromite. The olivine mineral composition in serpentinized harzburgite is an excellent source for forming nickel laterite deposits, of which there are quite a lot in the Pomalaa area. Apart from that, almost all rocks in the Pomalaa area have experienced lateralization, which is followed by a wavy morphology which is controlled by the geological structure in the form of a left shear fault with an azimuth of N 305° E, which is part of the Kolaka Fault.

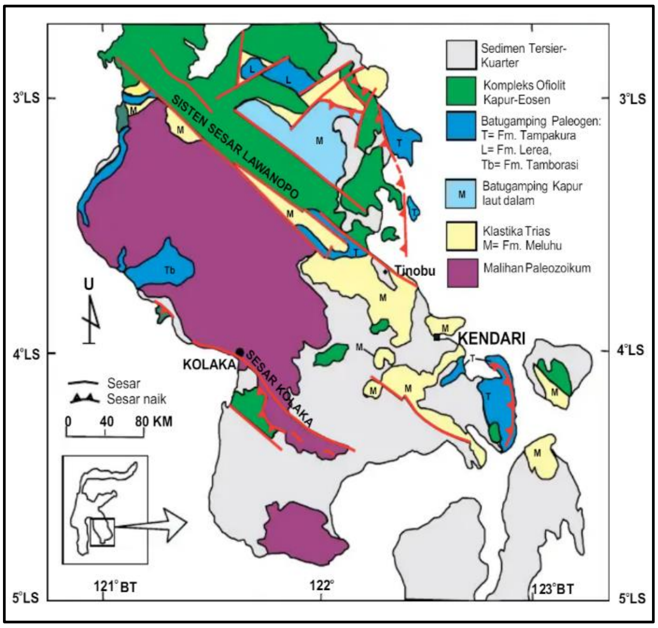
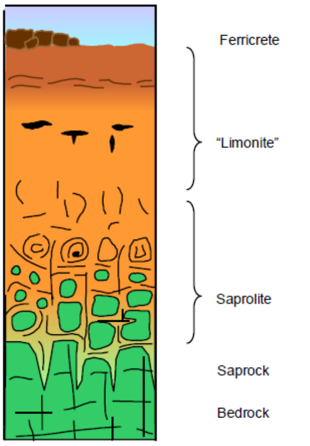


Figure 2. Geological Map of Southeast Sulawesi (Rusmana et al,, 2013).

2.2. Nickel Laterite Deposit

Nickel laterite deposits are a metal product from the chemical weathering process of ultramafic rocks, which experience residual and secondary enrichment of the elements Ni, Fe, Mn and Co (Syafrizal, 2011; Burger, 1996). Nickel laterite is usually characterized by reddish-brown metal oxide caused by its Ni and Fe content (Cahit et al., 2017). Nickel laterite deposits result from further weathering ultramafic rocks bearing Ni-Silicates, generally found in tropical and subtropical climates. The influence of the tropical climate in Indonesia results in intensive weathering processes, so several areas in eastern Indonesia have nickel laterite deposits. Due to substitution for Fe and Mg atoms, the nickel element is found in the crystal lattice of olivine and pyroxene minerals. The serpentinization process that occurs in ultramafic rocks due to the influence of hydrothermal solutions will change the rock into serpentinite rock or peridotite serpentinite rock. Meanwhile, the chemical and physical processes of air, water, and continuous changes of heat and cold cause the disintegration and decomposition of the parent rock. The nickel laterite profile is divided into several zones, such as limonite, saprolite, and bedrock, where each zone has its own element and compound content. The profile is shown in Figure 3.



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 3. Nickel Laterite Profiles (Elias, 2002).

3. METHOD

3.1. Electrical Resistivity Tomography (ERT) Method

The ERT method, better known as the geoelectric or resistivity method, is a geophysical method that studies the nature of electric currents beneath the earth's surface and how to detect them on the earth's surface. The basic principle of the resistivity method is to utilize the propagation properties of electric current, which is injected below the earth's surface through two current electrodes, then measure the value of the potential difference that occurs using two potential electrodes so that the resistivity value of the rock below the surface can be determined. The geoelectric method is divided into 2 (two) types based on the energy source it requires, namely the passive method, which requires a natural current source such as Self Potential (SP), and the active method, which requires an artificial source in the form of injecting electric current into the subsurface, such as the resistivity method and induced polarization (Telford et al., 1990). This method is based on Ohm's Law, where the following equation 1 expresses this linear relationship:

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

Where R is the resistance of a material (in this case, a conductor, with units of ohms or Ω), the electric current is symbolized by I, and the potential difference is symbolized by V. The ERT method measurement, in this research, uses one configuration to map the subsurface. laterally, namely the Wenner configuration, as shown in Figure 4.

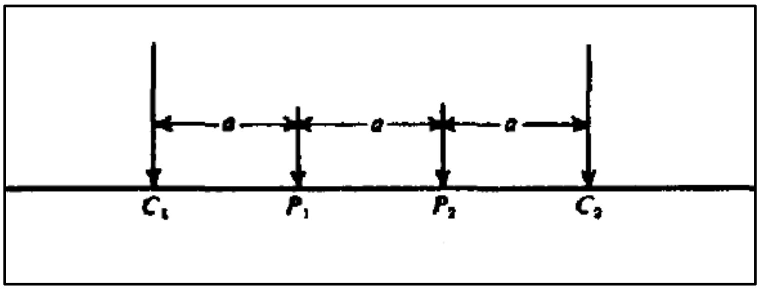


Figure 4. Wenner Configuration Arrangement (Telford et al., 1990).

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 and r_2=r_3=2a. In the Wenner configuration, the resistivity (ρ) can be described using the following equation 2, where 2πa is the configuration factor (Telford et al., 1990).

$$\rho = 2\pi a \frac{\Delta V}{I} \tag{2}$$

3.2. Desain Survey , Data Processing and Interpretation

The acquisition map of the geophysical measurement and drilling trajectory based on satellite imagery in the South Block, Pomalaa District, Kolaka Regency, Southeast Sulawesi, is shown in Figure 5. The measurement method of ERT uses the Wenner configuration. The total area of the measurement area located right in the middle of the South Block is ±110.47 km2. A total of five ERT lines are oriented west-east; each line is 300 meters long, the distance between lines is ±100 meters, the furthest spacing between electrodes is 60 meters, and a total of 25 sounding points. The research area is divided into two different blocks, marked with a blue line for the first block and yellow for the second block.

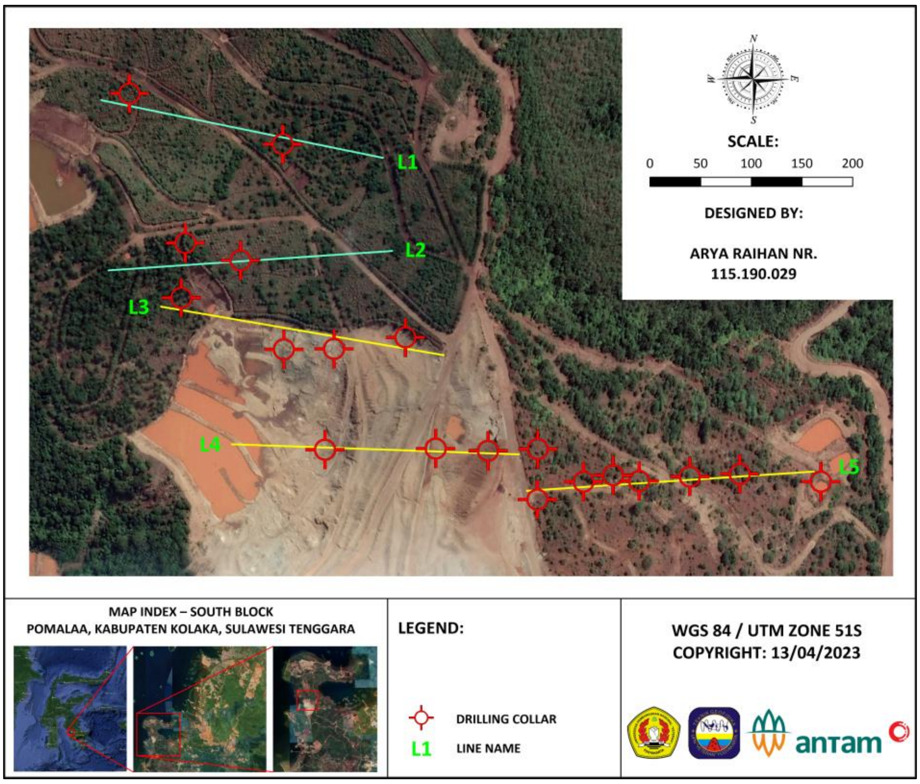


Figure 5. Design map of ERT method survey and exploration drilling in the research area, with a total of five ERT lines and 19 exploration drilling points.

ERT data processing uses Res2DInv software. The inversion process to obtain measured apparent resistivity values uses the least-squares inversion method (Loke et.al., 2013). The inversion method will provide a subsurface cross-sectional model with the minimum possible RMS (Root Mean Square) error value. The data resulting from the inversion process can be interpreted based on the distribution of resistivity values.

Drilling activities aim to take rock samples in the subsurface (core), which is part of advanced exploration activities and is carried out after geological exploration activities. This activity is divided into several stages, namely regional, semi-detailed, to detailed exploration drilling. This activity is carried out before or after geophysical method measurement activities. On rock samples, chemical analysis is carried out in the laboratory, where the final product in drilling activities is geochemical assay data. All drilling and geochemical assay data are analyzed and integrated with ERT method data. In addition, there are core photos to strengthen the analysis results. In addition to containing various geological information from a drill point, information is also obtained regarding the content of elements or compounds (geochemical assay) in the rock. This study only focuses on the elements Ni, Fe, Mg (MgO compounds), Si (SiO2 compounds) and MC (Moisture Content or Water Content, in this case the H2O compound).

Qualitative and quantitative data interpretation was carried out in this study. The qualitative interpretation stage was performed by classifying the resistivity values obtained in the 2D resistivity processing, with quality control of regional geological data in the research area. The resistivity values obtained were influenced by several factors, including the porosity and permeability properties, compactness, and mineral content of a rock. In addition, there are other important factors that always affect the resistivity value, namely water content. Water is a conductive material so if a rock is filled with water, it has a low resistivity value. This quantitative interpretation stage was carried out by utilizing the drill data and the geochemical assay obtained. The resistivity values obtained were the sampling results on drill data and geochemical assays, then correlated with ERT method data using Geosoft Oasis Montaj software. In addition, at the time of the ERT method measurement, the research area was an active mining area, where the topsoil to limonite layers had been completely peeled off and only left the saprolite to bedrock layers.

4. RESULTS AND DISCUSSION

4.1. Drilling and Range Resistivity Result

Table 1. Classification of drilling and geochemical assay data with a coverage of 17 exploration drill points spread around the ERT lines. The classification is divided into five, i.e., from very low to very high, which is determined based on the geochemical assay data obtained.

Classification	Ni (%)	Fe (%)	MgO (%)	SiO2 (%)	H2O (%)
Very Low	<0,6	<5	<10	<15	<5
Low	0,6 – 1,3	5 – 10	10 – 20	15 – 20	5 – 10
Medium	1,3 – 1,5	10 – 15	20 – 25	20 – 30	10 – 15
High	1,5 – 1,8	15 – 20	25 – 30	30 – 35	15 – 20
Very High	>1,8	>20	>30	>35	>20

Classification for each element and compound content is presented in Table 1., where this section only focuses on the elements Ni, Fe, Mg (MgO compound), Si (SiO2 compound), and water content (H2O compound). In addition, the drilling data also presents geological information in the form of serpentinization levels, rock hardness, weathering, and fractures, and is equipped with core photos for every 1 (one) meter of drilling. In addition to containing various geological information from a drill point, information is also presented on the content of elements or compounds (geochemical assay) in the rock. The classification in Table 1. is determined statistically, where the limits of each range are determined based on the pattern of numbers or values that appear from each geochemical assay data. Meanwhile, the Ni element content is determined based on the Cut of Grade (COG). COG from Nickel Laterite is divided into three levels, i.e., High-Grade Ore Saprolite (HGSO) with a Ni content above 1.8 %, Low-Grade Ore Saprolite (LGSO) with Ni content of (1.5 – 1.79) %, and Limonite Ore Saprolite with Ni content of (1.3 – 1.5) %. Based on the processing results, geological information is divided into three classifications: low, medium, and high, respectively. Meanwhile, the classification of geochemical content is divided into five classifications, i.e., very low, low, medium, high, and very high.

The ERT inversion results on all lines show a resistivity range varying from 1 to 1100 Ohm-m, which is divided into three classifications, namely low, medium, and high resistivity. The classification with the resistivity value range and its lithology interpretation is shown in Table 2.

Table 2. Classification of Resistivity Values and Interpretations

Classification	Resistivity (Ωm)	Interpretation
Low	<35	Saprolite
Medium	35 – 65	Saprolite rock – Boulder
High	>65	Bedrock (Peridotite, from East Ofiolit Complex formation)

Based on Table 2, the range of resistivity values obtained is very low, especially for bedrock. Low resistivity values (below 35 Ωm) are interpreted as saprolite zones. The low resistivity value is strongly suspected to be caused by its high porosity nature due to weathering processes involving water, so this zone has a relatively high water content. The saprolite zone also has a relatively high Ni element content. The relatively high content of water and Ni elements significantly affects the resulting resistivity value, whereas metal elements such as Ni and water have conductive properties, so they will produce relatively low resistivity values. Medium resistivity values (35 – 65) Ωm are interpreted as a zone of saprolite rock to (and/or containing) boulders. This zone is a transition area from the saprolite to the bedrock zone, so most of it will have partial properties, meaning that the saprolite rock zone has the properties of the saprolite and bedrock zones simultaneously. This zone contains many boulders, even experiencing enrichment of the Ni element in most of the boulders, and is still considered quite economical to mine. Boulders in this zone are part of bedrock that have not experienced complete weathering but can still and/or do not experience chemical element enrichment at all, as evidenced by the presence of boulders exposed on the surface in most of the research area, coupled with the high content of the Si element, which can influence rock properties, where rocks with a high Si content have relatively high hardness. High resistivity values (above 65 Ωm) are interpreted as bedrock zones in the form of peridotite rocks. The resulting resistivity value is very low for the bedrock zone, which is thought to be caused by many factors, one of which is water. Water is an important parameter in the weathering process and serpentinization, as well as the relatively high fracture rate in the bedrock zone as evidenced by the geological structure in the form of a left-slip fault with an azimuth of N305°E, which is part of the Kolaka Fault. A high fracture level will also provide space for water and other conductive chemical elements to fill the fracture. This is the main factor in the low resistivity values produced in the bedrock zone. Figure 6. is the result of implementing the range of resistivity values that have been determined on the 2D resistivity cross-section.

4.2. Inversion result

The length of line 5 is 300 meters with a northeast-southwest direction, with an azimuth of ±N266.16°E (Figure 6). The boundaries of each zone (dotted lines) are determined based on the range of resistivity values produced. High resistivity values (> 65 Ωm) are interpreted as bedrock zones that have a fairly small thickness compared to other lines, especially on lines 4 which is located right next to lines 5. This high resistivity is located at a distance of (200 - 250) meters. While low resistivity values (< 35 Ωm), which are interpreted as saprolite zones, are relatively thick and spread out at the top of the profile. Saprolite zones with a thickness of approximately 20 meters are located at a distance of 0 - 200 and 250 - 300 meters. While for thicknesses less than 5 meters, they are located at a distance of 225 - 250 meters. In addition, for relatively high resistivity values (35 - 65) Ωm, it is part of the bedrock that has not experienced perfect weathering, so it has characteristics that are almost similar to bedrock. This zone is then referred to as saprolitic rock, with a relatively high boulder content. In the resulting 2D resistivity cross-section, the lateralization process that occurs can be analyzed well, which is mainly caused by the relatively steep and wavy morphological form. This morphological form affects the movement of water flowing below the surface, especially since the research area is located right on the sea's edge. So, the water will

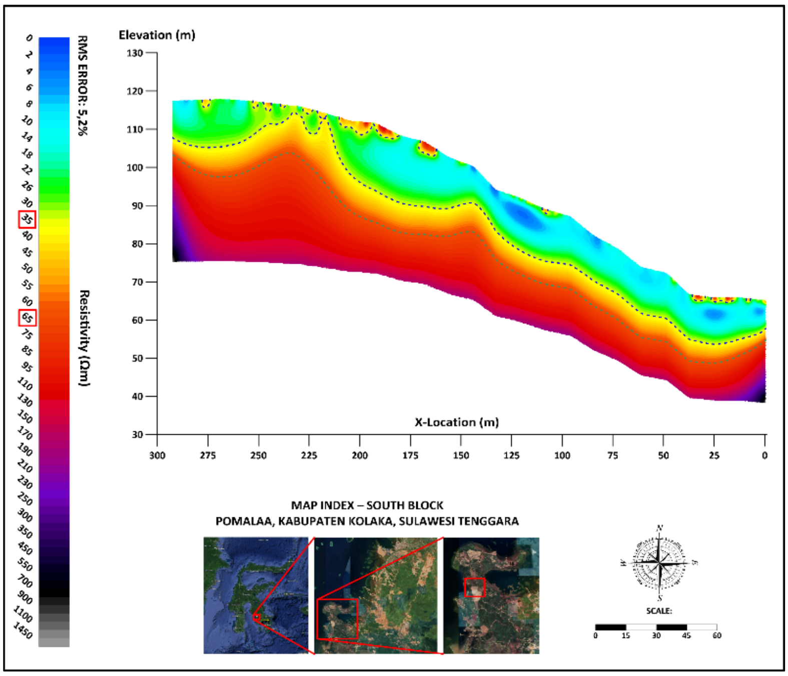


Figure 6. 2D Inversion Modeling for Line 5.

relatively move or flow directly towards the sea following the morphological form and does not have enough time to weather the rocks below the surface. In the relatively thick saprolite zone, the water below the surface has a longer time to soak and weather the rocks better so that the lateritization process can occur more perfectly. Meanwhile, for high resistivity values (> 65 Ωm) it is interpreted as a bedrock zone in the form of peridotite rocks, with high fracture content as a fractured peridotite/bedrock zone. This zone has a relatively very large thickness, ranging from (15 - 35) meters. Very high resistivity values (indicated by purplish to black colors) are interpreted as peridotite rocks that are still classified as massive and have not undergone a weathering process. Furthermore, the cross-section was "lithological reconstruction" to provide a clearer picture of the lithology on line 5, as shown in Figure 7.

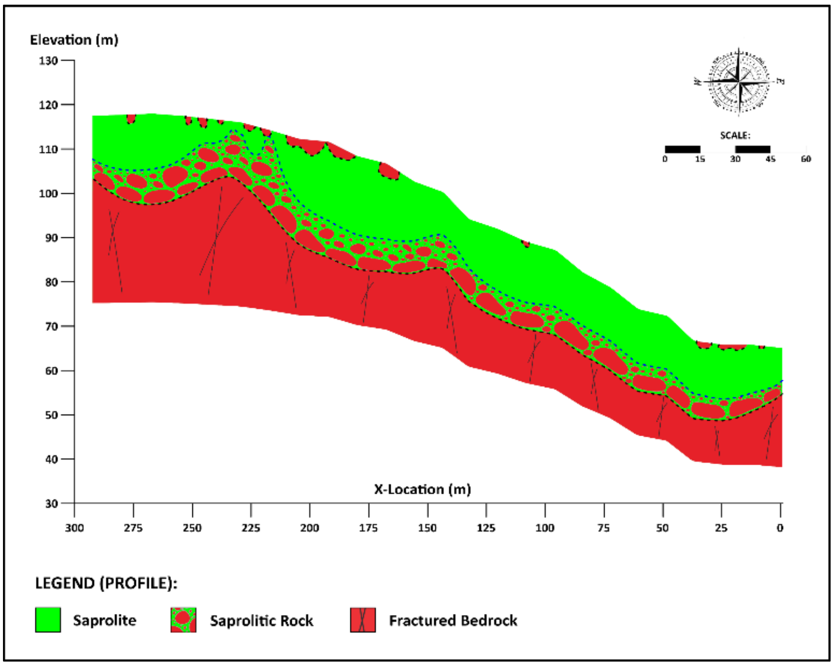


Figure 7. Interpretation of 2D Resistivity Cross Sections for Line 5.

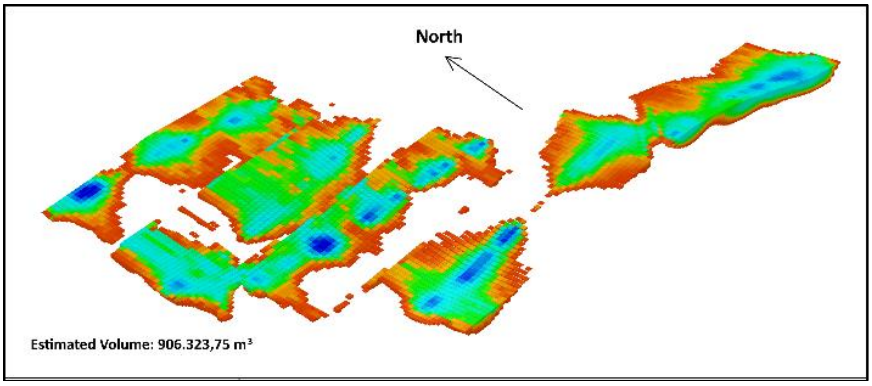


Figure 8. 3D Resistivity Modeling Results from the Saprolite & Saprolite Rock Zone.

In general, the enrichment of the Ni element in the research area is found in the saprolite and saprolite rock zones. 3D modeling based on resistivity data was carried out to see the distribution pattern, as well as estimate the volume size based on the resistivity value of each zone. Based on Figure 8, it can be seen that the saprolite and saprolite rock zones are spread quite evenly throughout the research area, with resistivity values below 65 Ωm. The estimated volume results for the two zones are 906,323.75 m^3.

The two zones are separated by applying boundaries based on previously determined resistivity values, where the appearance of the 3D modeling for the saprolite zone is shown in Figure 9. The saprolite zone has a relatively small distribution area in the research area, with resistivity values below 35 Ωm and an estimated volume of 215,370 m3. Apart from that, the western part shows that the distribution of the saprolite zone looks larger and more even than in the eastern part. Meanwhile, the appearance of the 3D modeling for the saprolite rock zone is shown in Figure 9. The saprolite rock zone has a relatively larger distribution area compared to the saprolite zone, with a resistivity value range of (35 – 65) Ωm and an estimated volume of 215,370 m3. Apart from that, the western part shows that the distribution of the saprolite zone looks larger and more even than in the eastern part. The distribution pattern and differences in layer thickness of each zone are caused by the relatively wavy morphology in the study area. The morphological form also

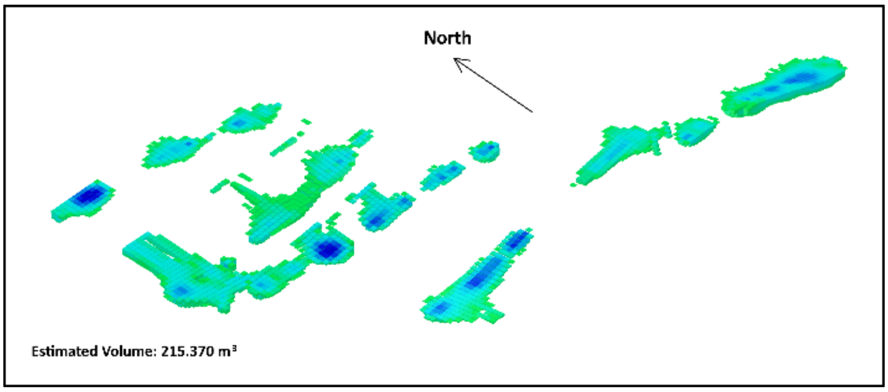


Figure 9. 3D Resistivity Modeling Results from the Saprolite Zone.

influences the lateritization process that occurs, thereby influencing the transportation or distribution process of each element and compound during the lateritization process. Apart from that, mining activities that had been carried out previously also had a significant influence, where the saprolite zone (including the saprolite rock zone), had mostly been taken or mined before ERT measurements and exploration drilling were carried out. It can be said that the 3D modeling process is effective enough to carry out, although the pattern of the entire ERT trajectory is not symmetrical, so many points or parts have to go through an extrapolation process. However, in general, the 3D modeling results are representative enough to support the research objectives, namely estimating the volume of economic ore, in this case, the saprolite and saprolite rock zones, where the Ni element experiences quite significant enrichment.

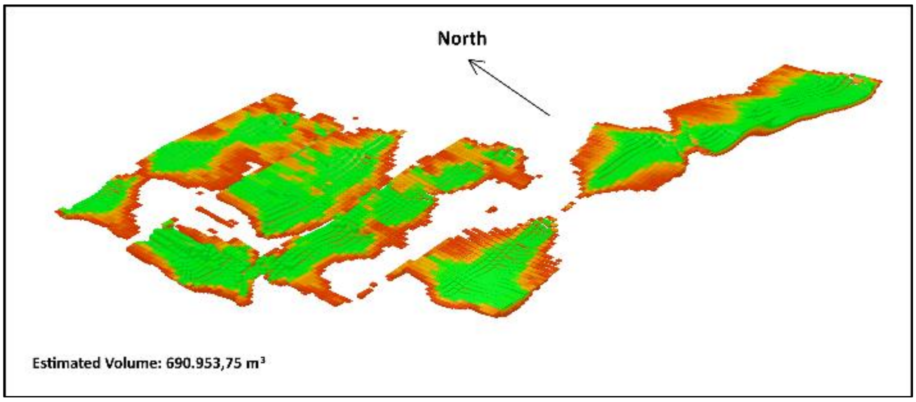


Figure 10. 3D Resistivity Modeling Results from the Saprolite Rock Zone.

5. CONCLUSIONS

The profile of laterite nickel deposits in the research area is divided into three classifications based on resistivity values, namely saprolite, saprolitic rock, and bedrock zones. The saprolite zone has a low resistivity value (<35 Ωm), and saprolitic rock-to-boulder zones have medium resistivity values (35 - 65) Ωm. The bedrock zone is in the form of peridotite rocks with relatively high levels of serpentinization, fractures, and weathering, with high resistivity values (> 65 Ωm). Based on the characteristics of the Nickel content in the three blocks, the West Block has a low Ni element content below 0.96% for the saprolite zone and (0.32 - 1.27)% for the saprolitic rock zone and high (1.65 - 3.24)% for the saprolite zone and (1.35 - 2.27)% for the saprolitic rock zone. Central Block with low Ni content in the saprolite zone of (0.27 – 1.37) % and the saprolitic rock zone of (0.26 – 1.30) %, and East Block with low Ni content, (0.48 – 1.25) % for the saprolite zone and (0.03 – 1.29) % for the saprolitic rock zone and high (1.34 – 2.94) % for the saprolite zone and (1.31 – 2.84) % for the saprolitic rock zone.

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