

Ground-Penetrating Radar and Electrical Resistivity Tomography for Nickel Laterite Exploration: A Case Study in North Konawe, Indonesia

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Abstract. With the increasing demand of batteries for electrical vehicle in world, the interest of nickel laterite exploration and then its exploitation grow significantly. Nickel ore is one of the raw materials for making these batteries, which has high economic values, and is widely found in Indonesia. Therefore, extensive nickel exploration in Indonesia is highly required to obtain the estimation of its potential resources. Until now, data from boreholes near each other are used to calculate Nickel ore resources. To estimate the bedrock depth and horizontal variation between borehole data and therefore reducing operational costs, Ground-Penetrating Radar (GPR) and Electrical Resistivity Tomography (ERT) are the suitable methods for that purpose due to its cost and time effectiveness. In this research, we analyses several GPR profiles acquired with MALA Rough Terrain Antenna (RTA) 25 MHz antennas supported with ERT data in Antam exploration site in North Konawe, South-east Sulawesi. Radar attributes are assigned after applying conventional processing steps. From preliminary results and its comparison with ERT and borehole data as validation tool, we obtained interesting results about the boundaries of limonite, saprolite, and bedrocks.

Keywords: Nickel laterite; Ground-Penetrating Radar; MALA RTA; Electrical Resistivity Tomography; limonite; saprolite

1. Introduction

Nickel commodity nowadays is getting more labeled as the strategic commodity as it is highly demanded by electric vehicle companies to produce batteries. Besides that, nickel ores are commonly used for stainless steels, nickel-based alloys, and superalloys due to its resistance to corrosion. Indonesia becomes one of the biggest nickel ore producers in the world which is mainly produced from Sulawesi and Maluku (Zhou, 2017).

Generally, nickel ores come from two types of nickel deposits, namely laterite and sulphide nickel. 73% of the nickel resources in the world is dominantly produced from the nickel laterite deposit (Kim, 2010). Laterite is a term of the product of chemical and physical weathering process which is exposed to the surface, where the primary minerals become unstable due to the contact with ground water. The minerals will later dissolve and form secondary minerals in a more stable environment (Elias, 2002). The nickel laterite deposit is a weathering product of ultramafic rock (Marsh, 2011). The low exploration cost for nickel laterite deposits makes this business becomes more attractive than nickel sulfide deposit exploration (Farrokhpay, 2018).

The common geophysical methods to use in the nickel laterite deposit are Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR). The ERT method is a method which injects electric current with two electrodes and measures the electric potential difference that is produced due to differences in the resistivity values of rocks below the ground surface (Reynolds, 2011). On the other hand, GPR sends electromagnetic waves below the ground using a transmitter antenna and receives the reflected waves using a receiver antenna that moves along the surface of the measurement path. Even though these 2 methods have been commonly used for nickel laterite exploration, only few have measured both ERT and GPR in the same area. This research was conducted using both ERT and GPR methods in the same lines of measurement in Konawe Utara, South-east Sulawesi, Indonesia, which are

supported with borehole data to understand the correlation between ERT and GPR results to delineate the layer boundaries in nickel laterite deposit.

2. Nickel Laterite of North Konawe

The morphology of the research area consists of plateau (Plato block) and steep hills (Tanjung block). The research area still possesses a good potential of laterite deposit. Furthermore, the lithology found in the research area is the low-intensity altered harzburgite with main minerals such as olivine (60%), orthopyroxene (15%), chromite (2%), magnetite (1%) and few altered minerals such as actinolite, talc, magnesite, pentlandite, and pyrrhotite. On the other hand, the laterite composition found in the research area consists of topsoil, limonite, and bedrock.

- The topsoil has brown-red color with clay to medium-sand grain size. The mineral composition consists of 20-35% hematite, other minerals, humus, and tree roots. Furthermore, the outcrop is strongly weathered, with few boulder-sized ferricretes found in several area.
- The characteristic of limonite is brown-red, with clay to fine-sand grain size. The limonite consists of 20-45% hematite, 10% goethite, and other minerals. The outcrop is strongly weathered.
- The bedrock or boulder has blackish green to grayish green color, with the size of granule to boulder. The outcrops area is moderately weathered and located in the valley area. The composition of the bedrock is 55-90% olivine, 10-30% pyroxene, and 5-25% serpentine.

The research area possesses a well-developed and interesting lateritization. Generally, this area is divided into 2 blocks, such as west Plato and Tanjung blocks. Generally, these 2 blocks have several significant differences which are summarized in Table 1 and visualized in Figure 1 below:

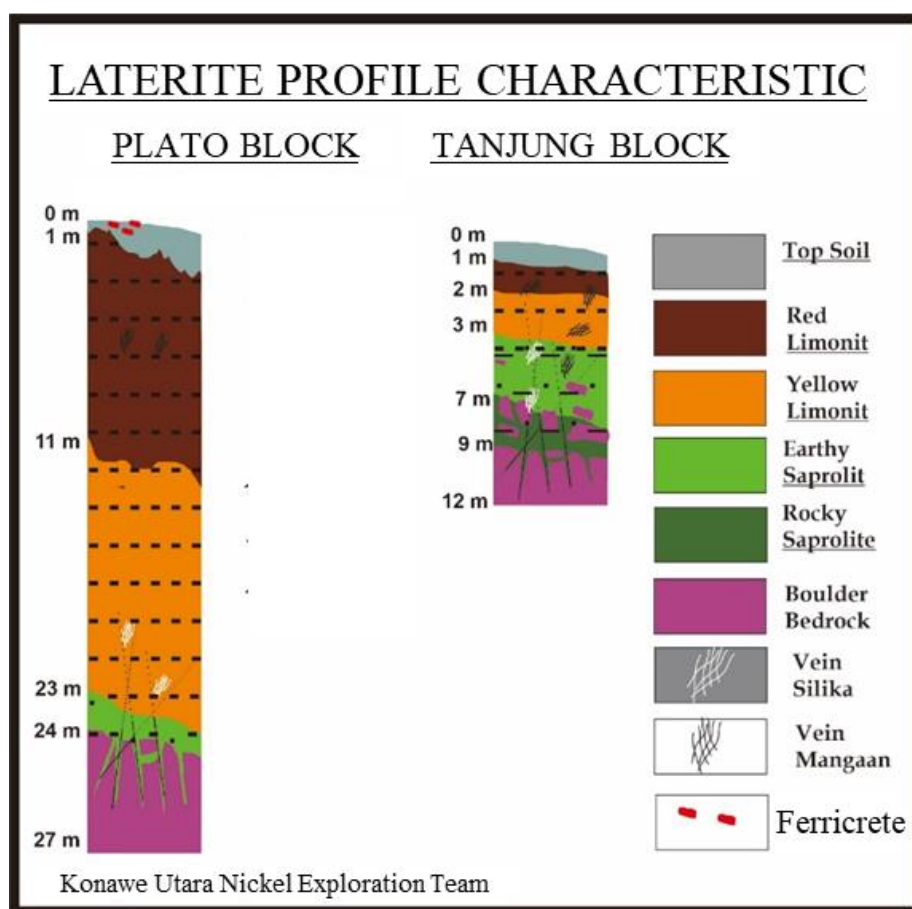


Figure 1. Laterite profile in research area consisting of Plato and Tanjung block.

Table 1. Laterite characteristic in the research area.

Parameter	West Plato	Tanjung
Top soil	Thick Peat	Thin peat
Limonite Thickness	2-35	1 meter -3 meter
Saprolite Thickness	1-10 meters	1 – 20 meters
Bedrock	Dunite in north-east, peridotite in south west	Dominated with peridotite, spotted dunite
Garnierite	Spotted in the east block	Spotted in several area with high intensity
Silica	Soft silica	Massive and boxwork silica
Ferricrete	Appear in the centre block, with boulder size	Absence

3. Data and Methodology

The research utilizes two geophysical methods to delineate the boundary of each nickel laterite layer, such as Electrical Resistivity Tomography (ERT) and Ground Penetrating Radar (GPR). The ERT data was measured using 1D Vertical Electrical Sounding (VES) method in which the VES data are combined to form 2D ERT raw data in each line. On the other hand, the GPR method utilizes 25 MHz unshielded antenna. These methods are measured in the same lines so that the geophysical data analysis can be more thorough by having 2 geophysical data in each line. Borehole data in each line are present to validate the geophysical data interpretation in delineating the laterite boundary.

As it is mentioned in chapter 2, the geophysical data are measured in two different area, such as Tanjung and Plato block. The characteristics of each block are different; hence the research could have wider scope of analysis to understand the geophysical response of nickel laterite exploration.

ERT Method

The 2D ERT data in the research area were obtained by having several 1D Vertical Electrical Sounding (VES) measurement with 25 meters spacing. The configuration used in the measurement was schlumberger configuration. The schlumberger configuration put a receiver electrode (electrode M and N) between the transmitter electrodes (electrode A and B). The transmitter electrodes inject electric current, while the receiver electrode records the potential difference resulted from the current injection.

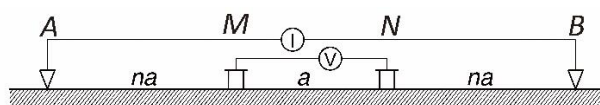


Figure 2. Schlumberger configuration

The 1D VES in each line is then combined to build a 2D ERT raw data. This 2D data would then be processed and inverted to get 2D inversed resistivity data. The result of the inversed 2D ERT data can be seen in Figure 3 and Figure 4.

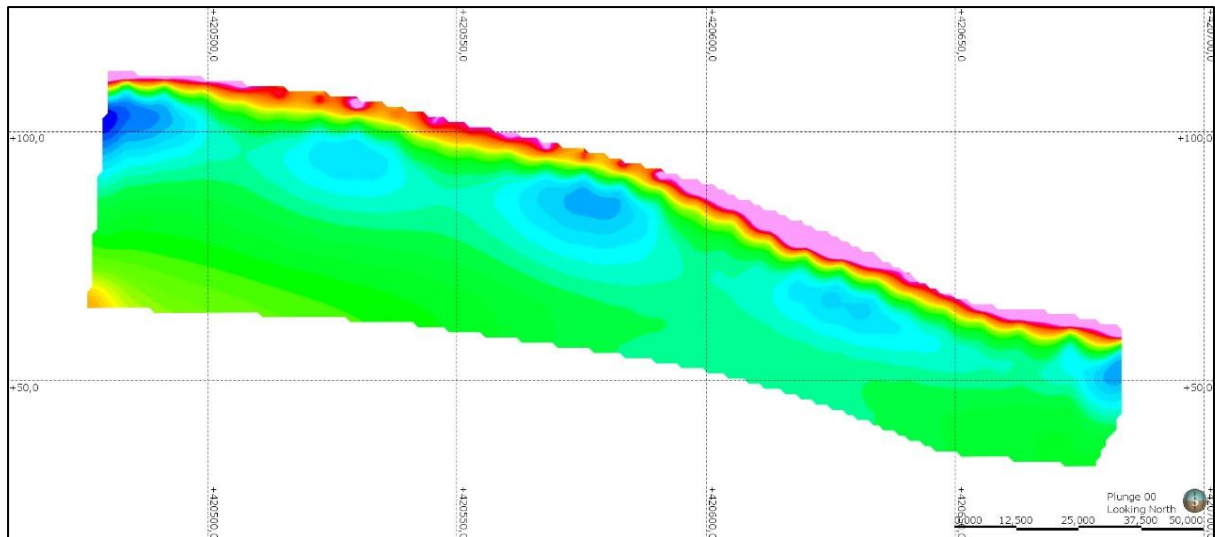


Figure 3. Inversed ERT data in Tanjung block.

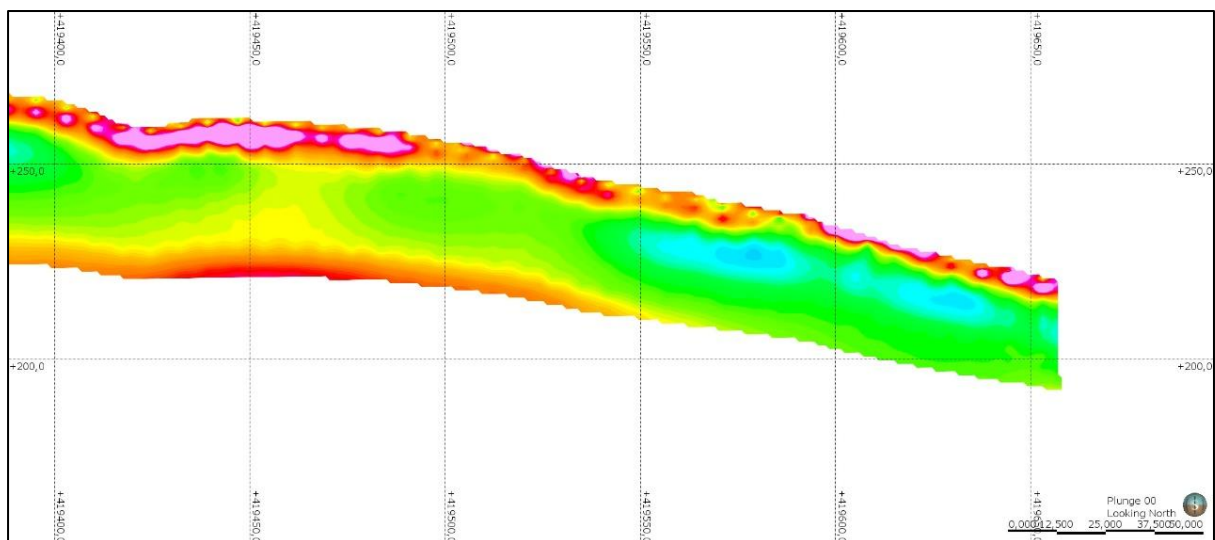


Figure 4. Inversed ERT data in Plato block.

Ground Penetrating Radar (GPR) Method

Ground Penetrating Radar (GPR) utilizes radio waves to investigate the subsurface at specific maximum depth depending on the frequency used. The reflected waves observed in the GPR profile are the result of electromagnetic properties contrast between two layers. In nickel laterite area, each layer such as limonite, saprolite, and bedrock has its own electromagnetic properties. For example, limonite layer has soft texture and moderate amount of water content. The response of the GPR in this layer will be different compared to the saprolite layer which has low porosity with relatively high-water content. Hence, it is expected that the GPR measurement will show different reflection between limonite, saprolite, and bedrock.

The GPR measurement utilizes MALA RTA 25 MHz unshielded antenna. The measurement setup uses continuous mode; hence it covers the whole measurement lines. After the GPR data has been measured, it is processed through several processing stages such as dewow, static correction, gain, bandpass frequency filter, background removal, and F-K filter, while the processed GPR sections from both Tanjung and Plato block can be seen in Figure 5 and Figure 6.

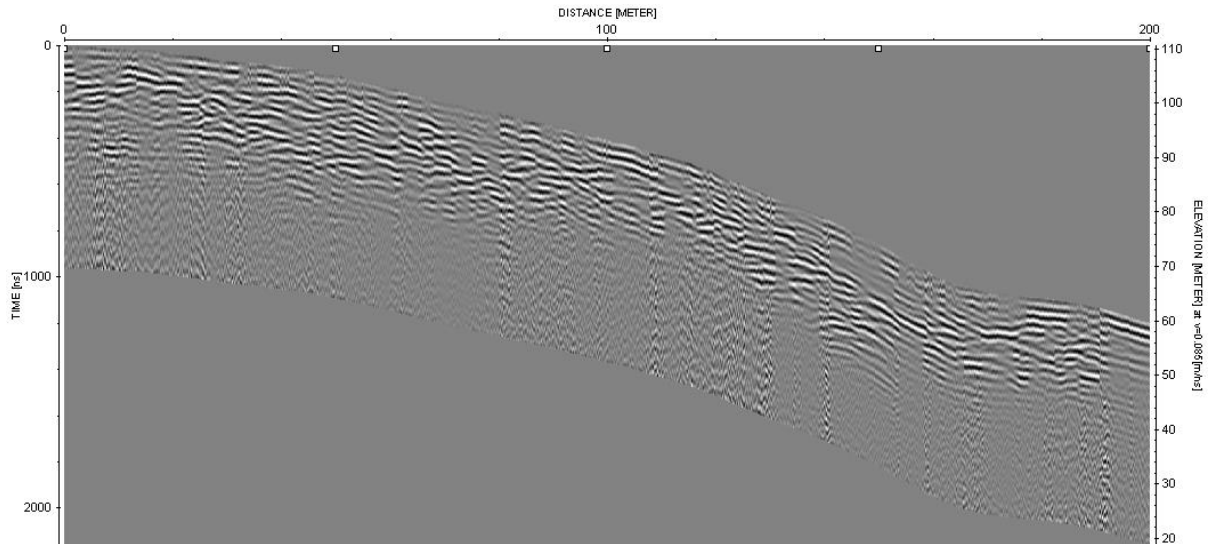


Figure 5. Filtered GPR Section in Tanjung block.

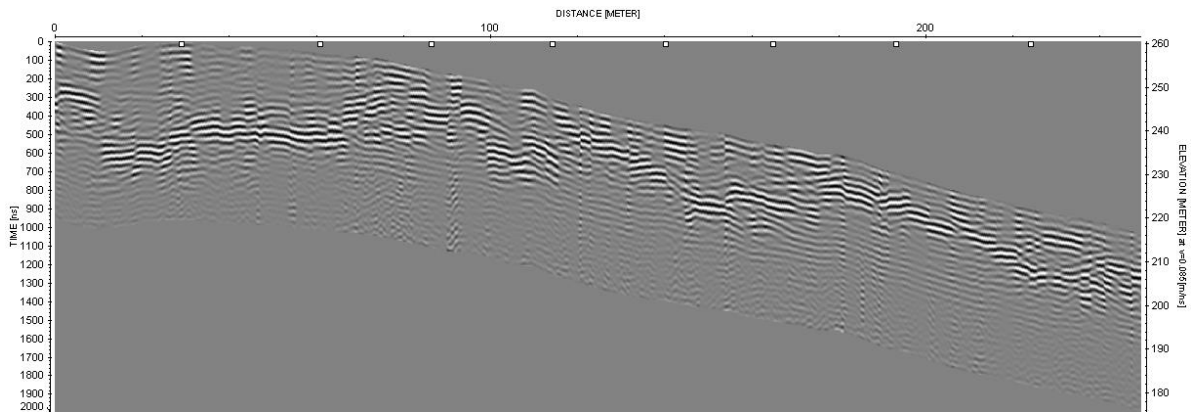


Figure 6. Filtered GPR Section in Plato block.

4. Results and Discussion

GPR Data Result

The interpreted GPR section in Plato block can be seen in Figure 7. There is a low-amplitude zone in the near-surface area of the GPR section. This zone is interpreted as the limonite zone, with the yellow line as the bottom of the limonite layer (limonite bottom). The interpretation is based on the limonite characteristic which has uniform soil-like properties (Francké, 2015), hence the layer does not produce strong reflections. In the middle part of the sections, the moderate-strong reflection zone reflects the saprolite zone, with red-marked line as the bottom part of the saprolite (saprolite bottom). This zone has stronger reflections compared to those in limonite due to the grain variety inside the saprolite zone. A saprolite zone could consist of a very soft layer to rocky layer which is called rocky saprolite. However, it is quite difficult to define the saprolite bottom. This is due to the saprolite characteristic which gets more compact as it goes deeper. There is only slight difference between saprolite rock with fresh bedrock, hence it cannot be clearly separated using the GPR data.

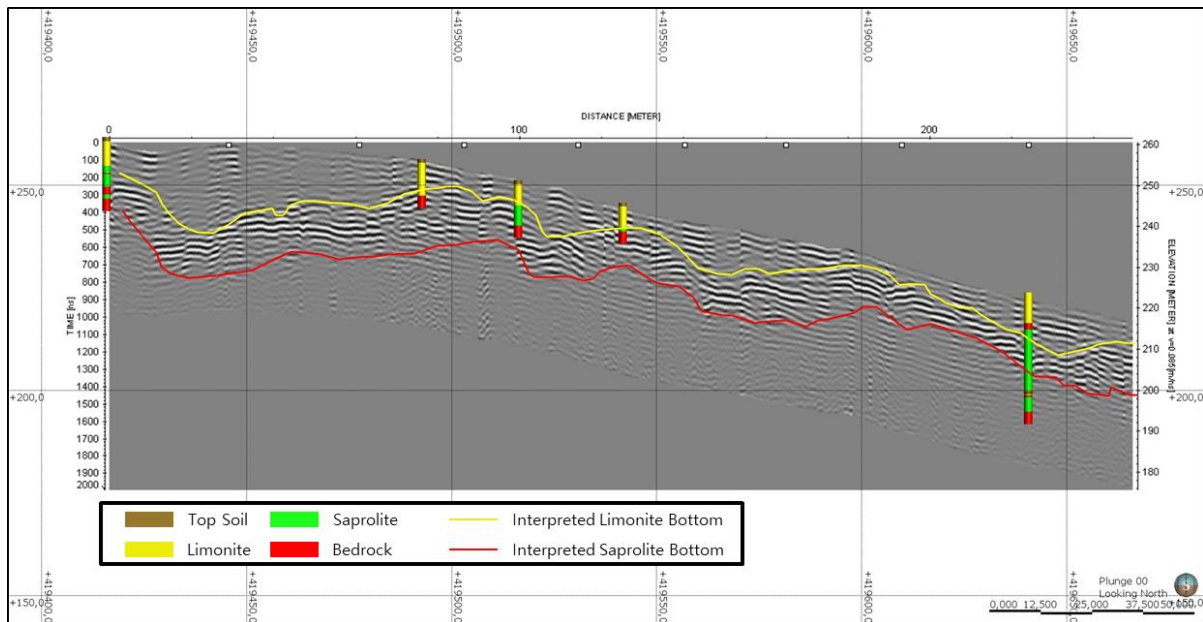


Figure 7. Interpreted GPR section in Plato block.

The same interpretation procedure is implemented in the GPR section of Tanjung block, which can be seen in Figure 8. The interpreted limonite bottom from the GPR data shows a good match with the limonite bottom from the borehole data. Furthermore, the interpreted saprolite bottom in this block also has a good quality compared to the borehole data, except the eastern part of the borehole which has more than 20-meter saprolite layer. Similar to the interpretation of saprolite bottom in Plato block, there are also difficulties in defining the saprolite bottom in this block. In some spots, the gradual change of saprolite into bedrock does not give a strong reflection, therefore the boundary could not be clearly defined.

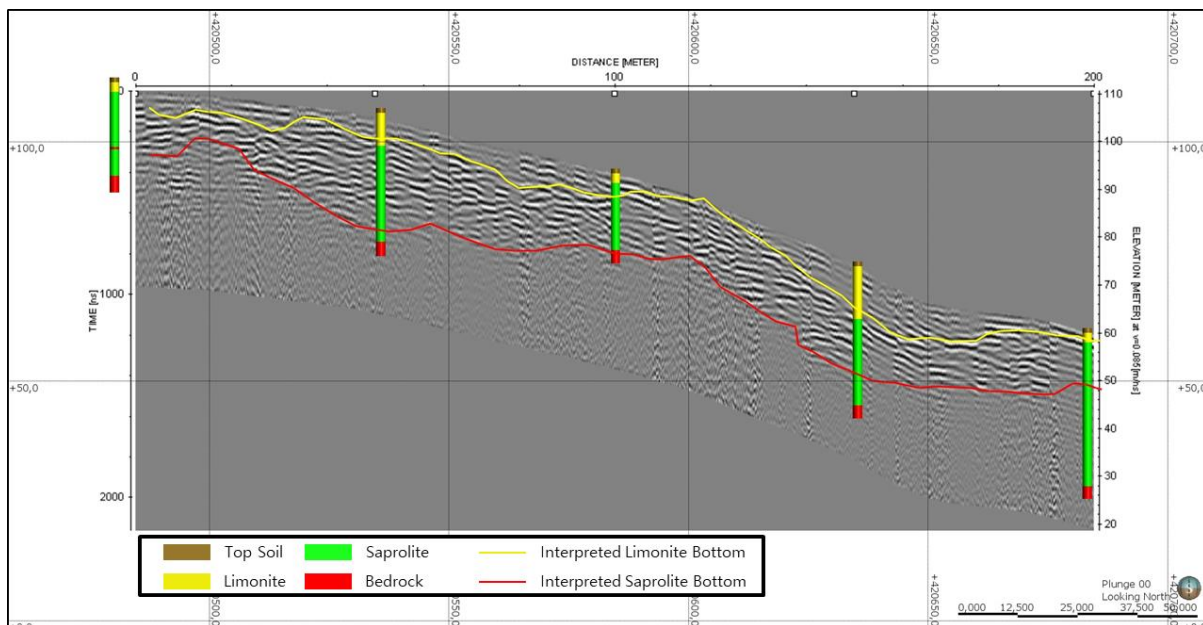


Figure 8. Interpreted GPR section in Tanjung block.

ERT Data Result

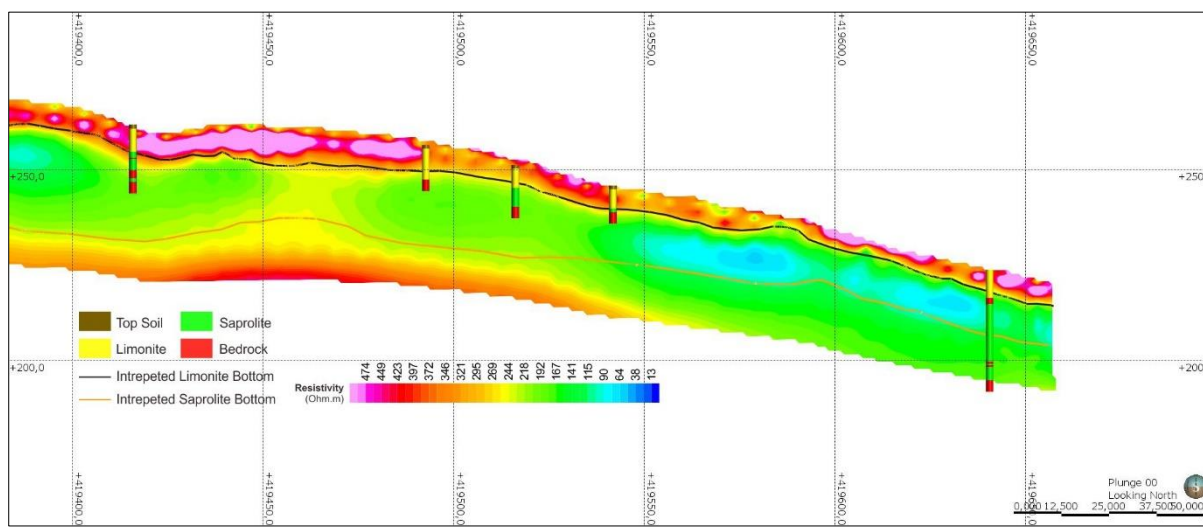


Figure 9. Interpreted ERT section in Plato block.

The interpretation of ERT section in Plato block can be seen Figure 9. The ERT section shows 3 resistivity zones ranging from 10 – 500 Ohm.m. In the near surface area, the ERT data shows high resistivity zone with resistivity of 300-500 Ohm.m, which is interpreted as limonite layer. Just below the limonite layer is the low-medium resistivity zone ranging from 10-300 Ohm.m. This layer is interpreted as saprolite zone. The low resistivity value in this layer is due to the high mineralization intensity and water content in this zone (Aswad, et.al., 2015). The saprolite bottom is interpreted with orange line, while the limonite bottom is interpreted with black line.

The ERT data was validated using 5 borehole data in Plato block. Based on the ERT interpretation, the interpreted limonite bottom (black line) correlate well with the borehole data which indicate limonite zone. The ERT section is able to show lateral variation of limonite depth which cannot be covered by borehole data. However, the interpreted saprolite bottom (orange line) does not show a good match with the borehole data. Several boreholes only show a thin layer of saprolite before it reaches bedrock layer. The low accuracy of saprolite bottom interpretation may be due to the unclear boundary between saprolite and bedrock. Based on the laterite profile in Figure 1, saprolite can still be presence in the bedrock fractures. The gradual change from saprolite to bedrock makes it difficult for the ERT data to define the exact boundary of the saprolite bottom layer.

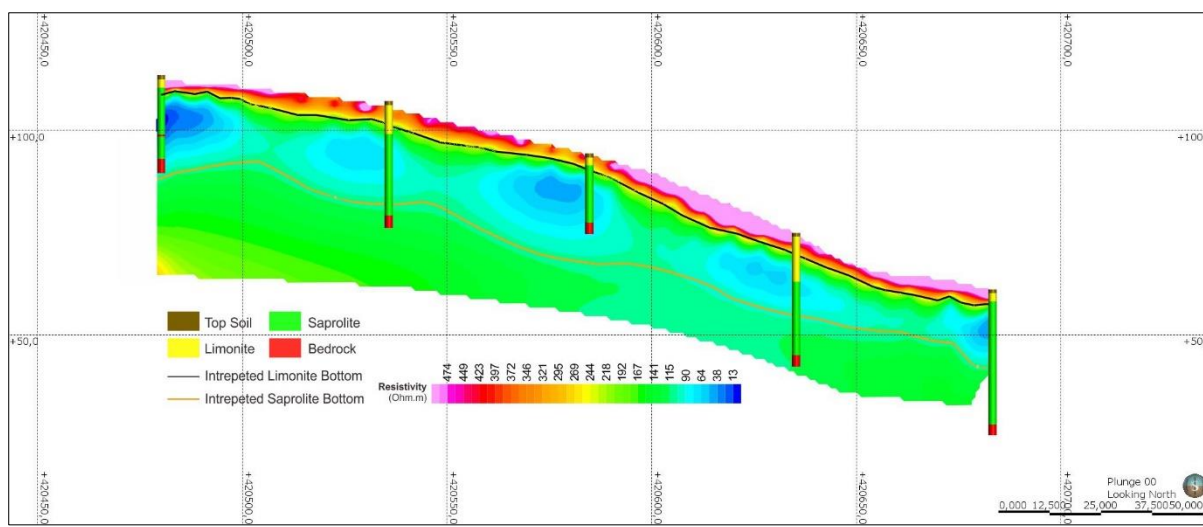


Figure 10. Interpreted ERT section in Tanjung block.

The same interpretation technique was also done in ERT section at Tanjung block, which can be seen in Figure 10. The interpreted limonite bottom (black line) has a good match when it is validated with limonite bottom (yellow bar) from borehole data. The interpreted saprolite bottom (orange line) from ERT data in Tanjung block has a better match with borehole data compared to those in the Plato block. The different matching rate between ERT data in Tanjung block and Plato block indicates that each area is unique: every hill or region of nickel laterite deposit may have different resistivity values for limonite, saprolite, and bedrock which cannot be used in other region.

GPR & ERT Data Analysis

The combination of GPR and ERT data interpretation can be seen in Figure 11 and Figure 12 for Plato block and Tanjung block, consecutively. Besides that, the depth differences between limonite and saprolite bottom from borehole data and those interpreted by GPR and ERT data are summarized in Table 2. In the interpretation of limonite bottom, both GPR and ERT data show a satisfying match with the limonite bottom in the borehole data. Based on the data on Table 2, The average depth difference of interpreted limonite bottom between the geophysical methods compared to the borehole data is less than 2 meters.

The saprolite bottom interpretation also gives a good result in Tanjung block. However, the geophysical data in the Plato block still needs improvement due to the differences in the saprolite bottom interpretation. Based on Table 2, only 4 out of 9 boreholes which shows a good match with the GPR and ERT data. For the ERT method, it is assumed that the resistivity standard for limonite, saprolite, and bedrock needs to be re-evaluated specifically for Plato block.

In terms of the layer boundaries between boreholes, in both Plato and Tanjung block, the interpreted saprolite zone (limonite bottom to saprolite bottom) from GPR data is inside the interpreted saprolite zone from ERT data. Hence, the limonite and saprolite bottom that is utilized is the zone from GPR data, because it covers both interpretation of GPR and ERT data.

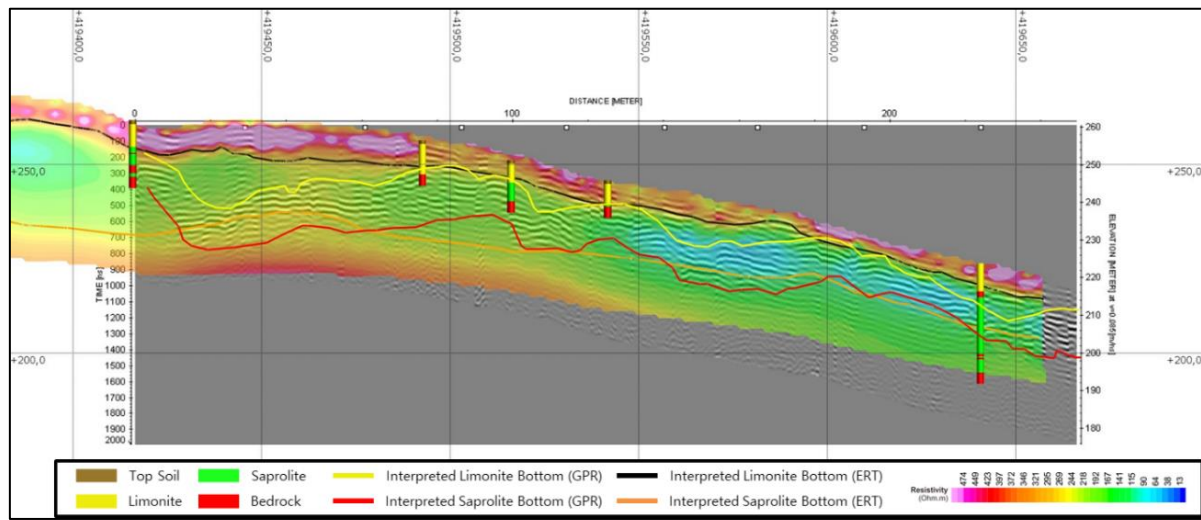


Figure 11. Interpreted GPR and ERT section in Plato block.

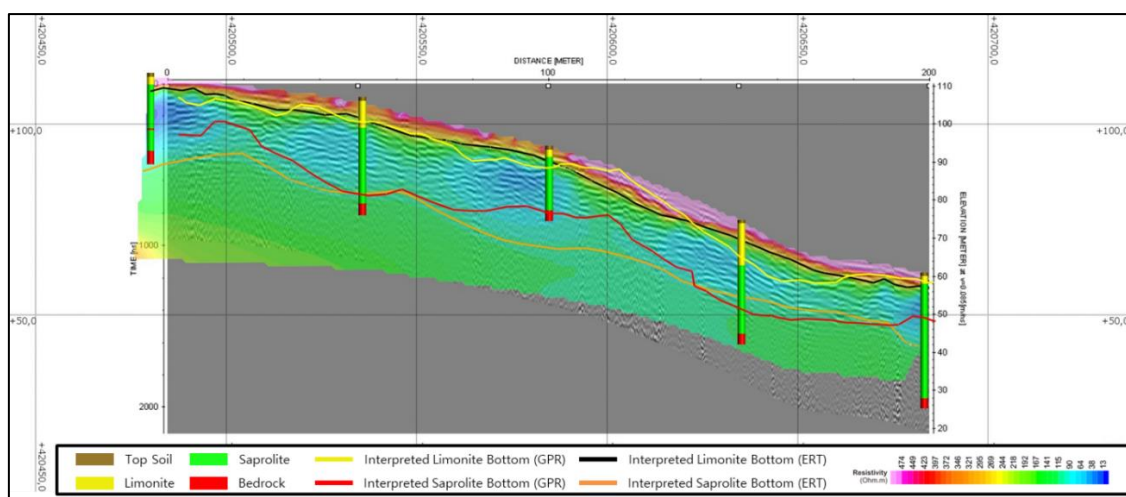


Figure 12. Interpreted GPR and ERT section in Tanjung block.

Table 2. Difference value between limonite and saprolite depth from borehole against the interpreted depth from GPR and ERT methods.

Block	BHID	Limonite Bottom		Saprolite Bottom	
		GPR	ERT	GPR	ERT
Plato	TPK0598	0.35	2.60	0.64	15.10
Plato	TPK0646	1.58	2.23	13.31	17.40
Plato	TPK0704	0.23	1.47	6.21	13.10
Plato	TPK0692	0.36	0.11	8.51	13.30
Plato	TPK0632	3.96	1.69	9.33	12.00
Tanjung	TPK1012	1.58	2.27	2.30	2.30
Tanjung	TPK0871	2.59	0.14	0.95	0.80
Tanjung	TPK0870	1.76	7.00	0.79	9.40
Tanjung	TPK0912	0.48	0.47	14.39	12.70

Difference Level	
	< 2 meters
	< 5 meters
	> 5 meters

5. Conclusions

GPR and ERT data were measured in two different blocks of Konawe Utara area, South-east Sulawesi. To summarize, the ERT and GPR data are able to provide the lateral variation of the laterites between the boreholes. Based on the research result, both GPR and ERT measurement can define the limonite bottom satisfyingly in Plato and Tanjung blocks.

These geophysical methods also show a good result in comparing the saprolite bottom from the GPR with the saprolite bottom from the borehole data in Tanjung block. In case of the Plato block, the resistivity range for limonite, saprolite, and bedrock need to be re-evaluated to produce a specific resistivity values for Plato block, hence the accuracy will be improved. It is also suggested that 2D ERT measurement is to be conducted to give a lot more data between the boreholes, which can improve the ERT data accuracy.

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