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Department of Earth Science and Technology, Universitas Negeri Gorontalo

Delineation of Nickel Laterite Deposits in "DCV" Block Southeast Sulawesi Based on Data Analysis of Ground Penetrating Radar (GPR) Method

Getsimany Chrismast[1] , Y Yatini[1]

[1] *Department of Geophysical Engineering, Universitas Pembangunan Nasional Veteran Yogyakarta, Indonesia*

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Corresponding author:
Yatini
Email: jeng_tini@upnyk.ac.id

ABSTRACT

The need for nickel is very intensive in the development of industries, so domestic consumption of nickel ore will increase in the coming years. Therefore, domestic downstream is increasingly being improved. Facing the challenge of high nickel demand in Indonesia, exploration and exploitation are needed to support nickel downstream. Nickel laterite exploration can be accomplished with geophysical methods that aim to obtain subsurface data from nickel laterite deposits. The Ground Penetrating Radar (GPR) is one of the non-destructive methods that can determine the subsurface conditions of nickel laterite deposits based on physical properties in the form of dielectric constants, reflection patterns, and amplitude contrasts on radargrams. The nickel laterite deposits can be separated into 4 layers based on GPR data analysis: bedrock, saprolite, limonite, and topsoil. Based on GPR measurements, the top soil's average dielectric constant value is 6.8, the limonite layer is 10.87, the saprolite layer is 12.37, and the bedrock is 7.87. It is because the saprolite layer has a high conductivity so the dielectric constant value is also high; this is influenced by the very high nickel content in this layer. The depth of bedrock in the research area varies from 20-40 meters, the thickness of topsoil is dominated in the value range of 3.6-5 meters, while the thickness of the laterite layer, which is the main target of nickel laterite mining, includes saprolite and limonite layers which have varying values of 15-40 meters where the distribution of the thickness of this layer is in the eastern and central of the research area. The presence of targets scattered throughout the study area because it is a layer of.

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1. INTRODUCTION

The geological position makes Indonesia rich in mineral resources, including nickel laterite. Indonesia is one of the countries with the world's largest nickel ore reserves, around 23.7% of the country's nickel reserves. Sulawesi Island has the largest nickel potential in Indonesia with a total reserve of 2.6 billion tons of ore. The reserves are spread across Central Sulawesi, Southeast Sulawesi, and South Sulawesi (Wibowo, 2021). The need for nickel is very intensive in the development of upstream to downstream industries so that domestic consumption of nickel ore will increase in the coming years, therefore the downstream of domestic nickel laterite is increasingly being improved (Pandyaswargo, 2021).

Burger (1996) states that nickel laterite deposits are residual products of chemical weathering in ultramafic rocks. The sterilization process lasts for millions of years, starting when ultramafic rocks are exposed on the earth's surface until they produce nickel residues that are influenced by weathering rate factors, geological structure, climate, topography, chemical reagents and vegetation, and time. These factors are very influential in the formation of nickel laterite so that laterite nickel deposits in the form of topsoil, limonite, saprolite, and bedrock can be separated based on their physical parameters (Sukaesih, 2015).

One of the geophysical methods often used in nickel laterite exploration activities is the Ground Penetrating Radar (GPR) method, which is a non-destructive method that can be applied to determine the subsurface conditions of nickel laterite deposits based on physical properties in the form of dielectric constants and reflection patterns and amplitude contrasts produced on radargrams. Based on velocity analysis, the thickness of each zone can also be determined by travel time data from radar wave travel so that GPR data can be estimated from the distribution and depth of nickel laterite deposits (Jufri, 2015). The advantages of this method for nickel laterite exploration are the effectiveness during acquisition and this method is non-destructive and has high resolution (Knight, 2001), besides that this GPR method can describe the boundary between laterite and bedrock layers with high accuracy. The uses of the GPR method other than for nickel exploration include locating pipes, tanks, drums, concrete imaging, archaeological studies to detect possible underground water sources, studying soil layers, and so on (Oktafiani et al., 2017).

Research using the GPR method for nickel laterite exploration aims to obtain results in the form of radargram profiles which are then picked at the boundaries of each layer. These results can be used to determine the potential distribution of nickel laterite in the research area.

At least five morphological units can be distinguished from IFSAR images, namely in the form of mountains, high hills, low hills, plains, and karst. The research area is dominated by low hills morphological units consisting of small and low hills (less than 500 meters above sea level) with undulating morphology (Surono, 2013). The stratigraphy of Southeast Sulawesi from old to young consists of malachite rocks, Telugu formation, Kamakura formation, ophiolite complex, Mano formation, molas Sulawesi, and alluvium. According to the geological map of the Southeast Arm of Sulawesi (Rusmana et al 1993) Figure 1., the research area is dominated by ophiolite rock units in the form of mafic and ultramafic rocks such as peridotite, harzburgite, dunite, gabbro, and serpentinite. On the southeastern arm of Sulawesi, the main structures formed after the collision are dipping shear faults mainly consisting of the Lawanopo fault, Konaweha fault system (Lainea fault), Kolaka fault, and Matano fault and lineation. The faults and lineations show a pair of main directions southeast-northwest (332º), and northeast-southwest (42º). The southeast-northwest direction is the general direction of the south-eastern slab of Sulawesi's strike-slip faults.

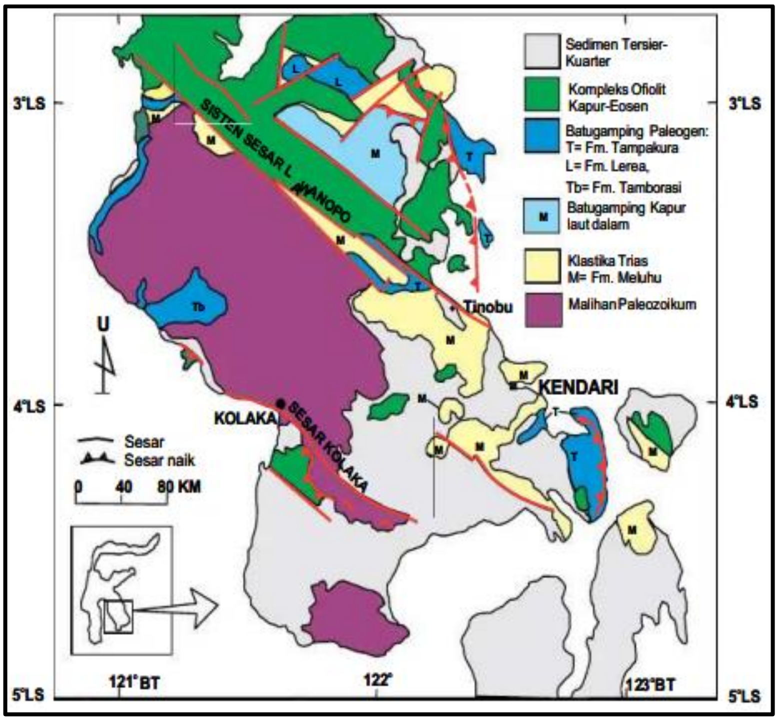

Figure 1. Geologic map of the Southeast Sulawesi (simplified and modified from Rusmana et al., 1993; Simandjuntak et al., 1993a, b, c).

2. METHOD

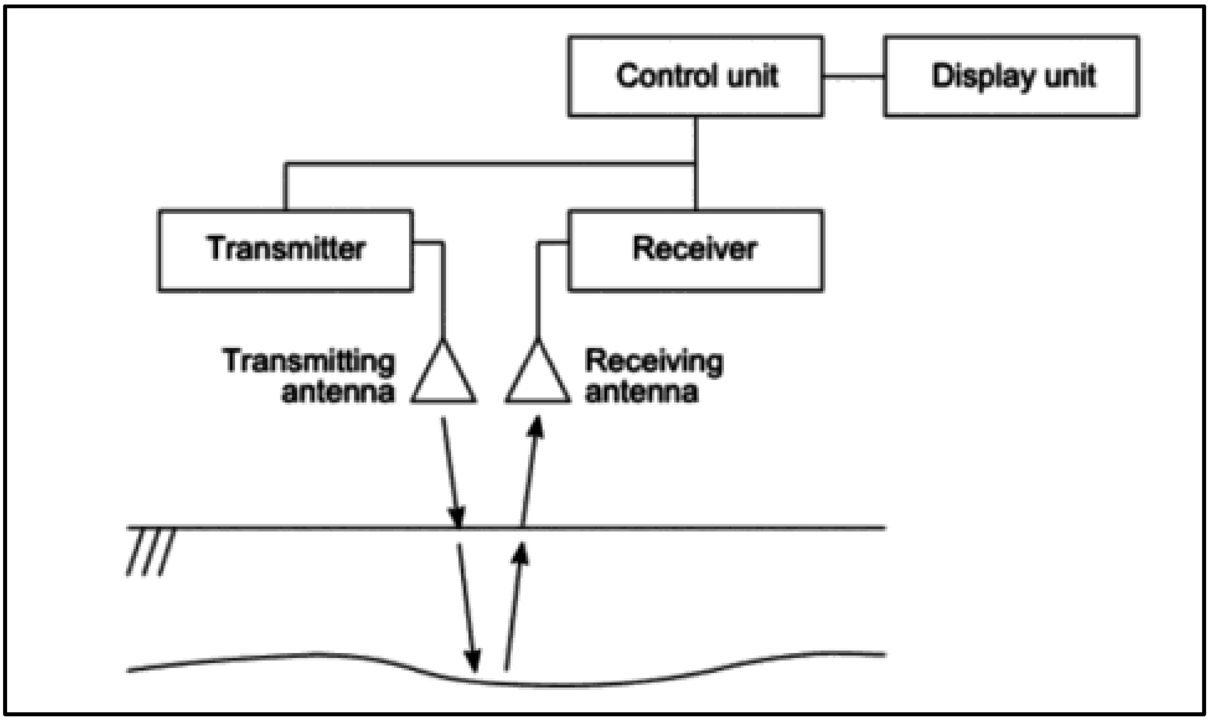

Figure 2. Basic Principles of the GPR Method (Takahashi et al, 2013)

The Ground Penetrating Radar (GPR) method utilizes electromagnetic waves designed to detect subsurface objects and evaluate the depth of these objects without drilling or digging the ground. The technique of using GPR method is the Electromagnetic Subsurface Profiling (ESP) system, by utilizing electromagnetic waves emitted through the ground surface with an antenna (Heteren et al., 1998).

The electromagnetic waves used in the GPR method use the principle of reflection and are similar to the principle of the seismic method (Chen and Sidney, 1997). The GPR unit consists of transmitting and receiving antennas, a control unit, and a monitor. A transmitting antenna generates short pulses of EM waves that penetrate the substrate below the time surface. The reflection is caused by the boundary of two different materials with contrasting dielectric permittivity. The strength of the reflected signal is affected by various dielectric constants and conductivities of the two substrates (Neal, 2004). The basic principle of the GPR method is shown in Figure 2.

The electromagnetic wave equation in Ground Penetrating Radar is based on Maxwell's equations. Maxwell's equations consist of four differential equations that express the relationship between electric and magnetic fields, which also express the direction of propagation, transmission, reflection and diffraction of electromagnetic waves. The velocity of electromagnetic waves in the medium is given by equation (5) (Musset and Khan, 1993):

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{1}$$

and the wavelength of the signal can be determined from

$$\lambda = \frac{v}{f} \tag{2}$$

where: v is velocity of electromagnetic energy in the material (m/s); c is velocity of light (2.997 924 58 x 108 m/s); εr is Relative permittivity or Dielectric constant; λ is wavelength (m); f is frequency (Hz).

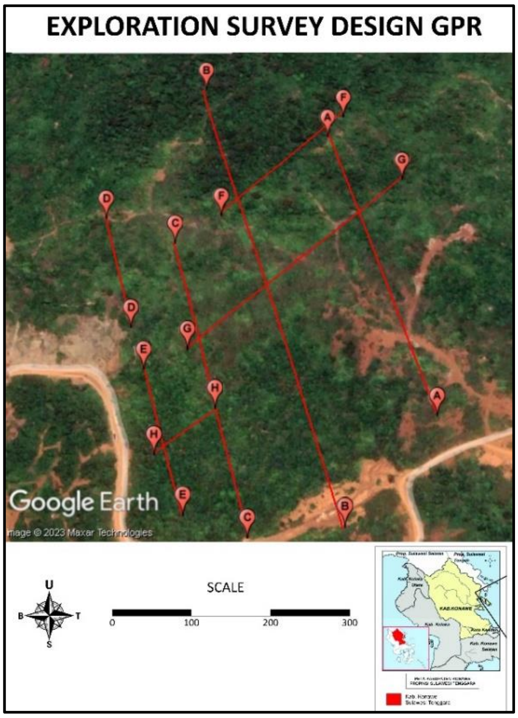

Figure 3. Survey Design of Ground Penetrating Radar for Exploration Nickel Laterite in "DCV" Block Sulawesi

GPR survey was fielded in Block "DCV" of North Konawe, Southeast Sulawesi using MALA Rough Terrain Antenna instrument with a frequency of 25 MHz with maximum depth penetration of 35-60 meters. Data acquisition was carried out on a 400 x 500-meter lot consisting of 8 lines with a variation in line length of 100-660 meters. The survey design of the GPR measurement method is shown in Figure 3.

3. RESULTS AND DISCUSSION

3.1. Radargram Profile of Nickel Laterite Deposits

The results of GPR data processing in the form of radargram profiles show that in the research area, there are 4 layers: bedrock, saprolite, limonite, and topsoil. The determination of layer differences is based on the amplitude contrast response on the radargram cross section and the range of physical parameter values of the research area material in the form of dielectric constant values, and wave propagation velocities (Yelfm, 2007), as shown in Table 1.

Table 1. Electromagnetic Wave Velocity and Dielectric Constant of the Entire Lines in "DCV" Block

Line	Electromagnetic Velocity (m/µs)				Dielectric Constant (mS/m)			
	Top Soil	Limonite	Saprolite	Bedrock	Top Soil	Limonite	Saprolite	Bedrock
A	127	98	91	106	5,57	9,35	10,85	7,99
B	119	96	87	106	6,34	9,75	11,87	7,99
C	121	88	81	106	6,13	11,60	13,69	7,99
D	115	84	81	108	6,79	12,73	13,69	7,70
E	111	88	82	101	7,29	11,60	13,36	8,81
F	104	98	95	121	8,30	9,35	9,95	6,13
G	112	83	81	101	7,16	13,04	13,69	8,81
H	115	97	87	109	6,79	9,55	11,87	7,56
Average	111,5	91,5	85,6	107,25	6,80	10,87	12,37	7,87

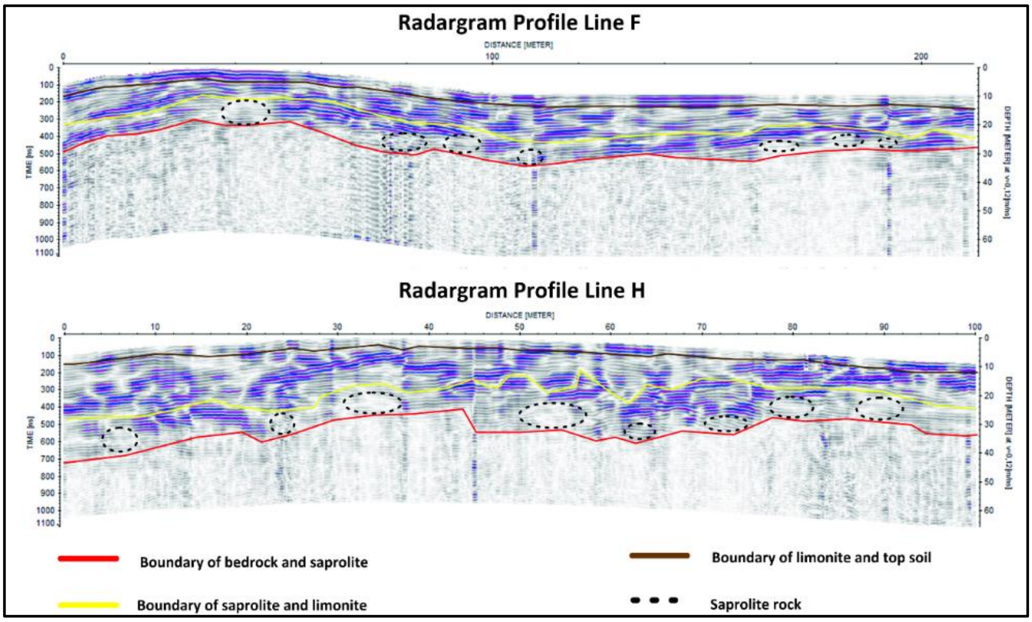

Figure 4. Radargram Profiles of Line F and H

The dielectric constant value of the material has a relationship with the electromagnetic wave propagation speed of the material according to equation (5) where both have inversely proportional properties. Material with a high dielectric constant value has a high electromagnetic wave propagation speed value, vice versa, but the dielectric constant value is directly proportional to the conductivity value. The higher the conductivity value, the higher the dielectric constant value, and vice versa. Materials with high dielectric constant values will produce high amplitude values, while materials with low dielectric constant values will produce low amplitude values (Luga, 2019).

The layer closest to the surface is the top soil layer which has a low average dielectric constant value of 6.80 and a high value of electromagnetic wave propagation speed of 111.5 m/μs resulting in low amplitude contrast, it is characterized by a weak color intensity dominant white. Limonite and saprolite layers are the main targets of laterite nickel mining because they have greater nickel content than other layers, this layer is conductive and has a high dielectric constant value of 10.87 for limonite and 12.37 for saprolite while the electromagnetic wave velocity is low, namely 91.5 m/μs for limonite and 85.6 m/μs for saprolite so that the resulting amplitude contrast is of high value, characterized by a strong color intensity dominated by blue and red intersections. The bedrock is an ultramafic rock forming nickel laterite that is resistive, the dielectric constant value in this layer is low at 7.87 while the electromagnetic wave velocity is high at 107.25 m/μs. This layer has a chaotic response and weak color intensity characterized by the dominance of white on the radargram.

The metal mineral content contained in each layer can affect the dielectric constant value. The higher the metal mineral content in a layer, the higher the dielectric constant value, this is because the dielectric constant value is directly proportional to the conductivity value where the higher the metal content in a layer, the more conductive the material is. It can be seen that the limonite and saprolite layers have high dielectric constant values because the metal content in these layers is high compared to the topsoil and bedrock layers. Although not significant, the saprolite layer has a higher dielectric constant value than the limonite layer because the Ni content in the saprolite layer is higher so it is more conductive than the limonite layer. The dotted black circle is interpreted in the saprolite layer as saprolite rock (saprock) which is bedrock that has not been completely weathered so that it is still in the form of boulders in the layer above (saprolite).

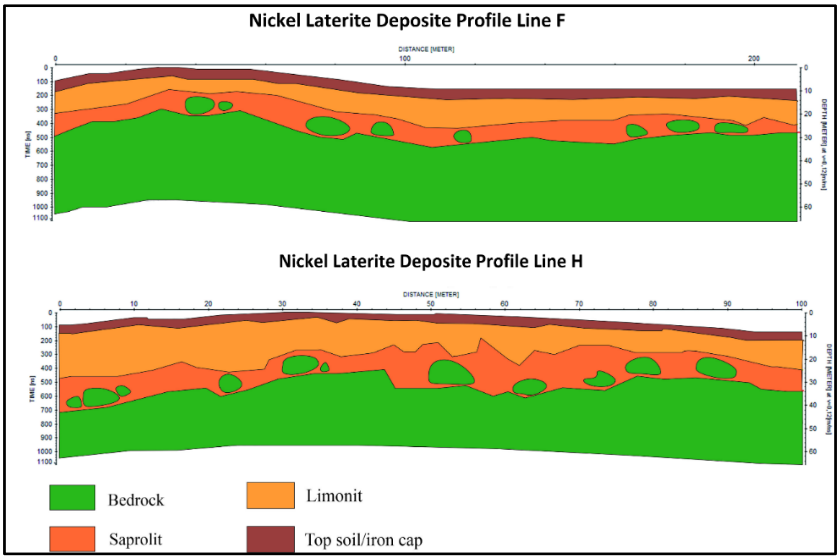

Figure 5. Nickel Laterite Profiles of Line F and H

The thickness of the topsoil in this layer is an average of 4 meters from the surface, this layer is an oxidized residual soil consisting of hematite, goethite, and limonite. The iron content contained in this layer is very high with a very low abundance of Ni. Limonite thickness is below the topsoil by 6 - 20 meters, this layer is an iron-rich layer with 40% - 50% levels that cover the entire area and has a nickel content of 0.8% - 1.5%. The thickness of saprolite under the limonite layer is 6 - 15 meters, this layer is a mixture of rock debris, passive, formed from a transition zone from limonite to bedrock with a nickel content of 1.5% - 4% while the iron content is 10% - 25%. In the saprolite layer there are boulders of bedrock that have not been completely weathered at the bottom of this layer can be referred to as saprolite rock (caprock). The thickness of the bedrock which is the deepest layer of nickel laterite deposits has a thickness of more than 20 meters, this layer is a host rock that generally does not contain economic minerals (the levels are close to or equal to the bedrock), namely nickel content of 0.3% and iron content of 35% - 45% (Ahmad, 2006). The profile of nickel laterite in the F and H passes is shown in Figure 5.

3.2. Bedrock Depth and Laterite Thickness of "DCV" Block

The depth of bedrock needs to be known as the determination of nickel laterite mining boundaries, the bedrock depth value is obtained from the picking results on the radargram profile. The bedrock depth distribution map shows the variation in the depth of the bedrock layer boundary indicated by the colored pattern, the color difference on this map indicates the bedrock depth value from the surface of the research area in meters. The range of bedrock depth values in the research area is classified into three groups, namely shallow, medium, and deep. Shallow depths are marked with purple to blue colors worth 18-27 meters, medium depths are marked with green to yellow colors worth 27-36 meters, while deep depths are marked with orange to red colors worth 36-44 meters.

Mapping the distribution of laterite layer thickness which includes saprolite and limonite layers needs to be done in order to determine the potential for laterite nickel mining at the research site. The color differences found on the laterite layer thickness distribution map in Figure 6b. show the variation in thickness values in the research area. Purple to blue colors show low thickness values with a thickness of 15-23 meters, green to yellow colors show medium thickness values with a thickness of 23-30 meters, while orange to red colors show high thickness values with a thickness of 30-40 meters. This map shows that laterite nickel mining has more potential in areas with high laterite layer thickness values, namely in the eastern and central parts of the research area marked with orange to red colors. The southern part and a little in the north have low values, which shows that the thickness of the laterite layer in the area is thinner than other parts of the research area, even so it will still have the potential for mining even though the amount is not as much as areas that have thick laterite layers. The bedrock depth map is shown in Figure 6a and the laterite layer thickness map is shown in Figure 6b.

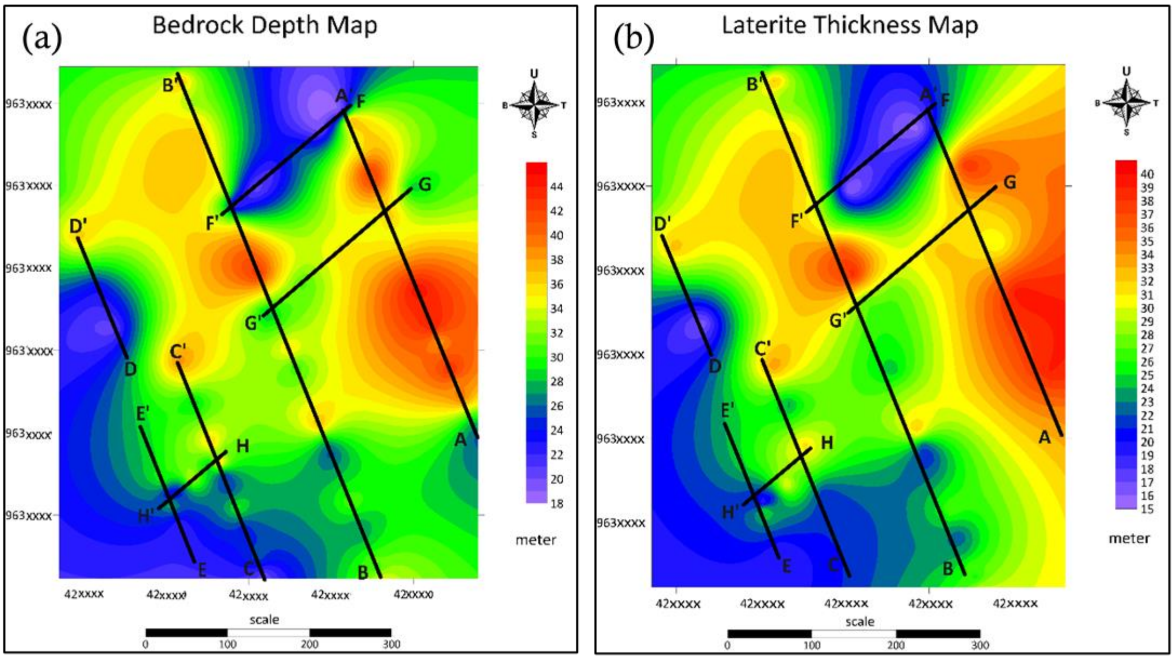

Figure 6. (a) Bedrock Depth Map; (b) Laterite Thickness Map

3.3. D Model of Nickel Laterite Deposits Block "DCV"

The 3D model of nickel laterite deposits in the "DCV" block is the result of Ground Penetrating Radar (GPR) for all lines data modeling which is weighted based on the type of layer so that a representative geological model is obtained. Figure 7 (a) is a 3D model of the laterite nickel deposit as a whole, Figure 7 (b) is a 3D model of the limonite layer, while Figure 7 (c) is a 3D model of the saprolite layer. By knowing the horizontal boundaries in the form of upper and lower boundaries and each layer, the distribution of laterite thickness in the "DCV" block can be known, the limonite and saprolite laterite layers are thicker in the eastern part of the research area which is at 200 meters from the easternmost to the west of the study area, so that the potential resources in the area are higher and have more economic value.

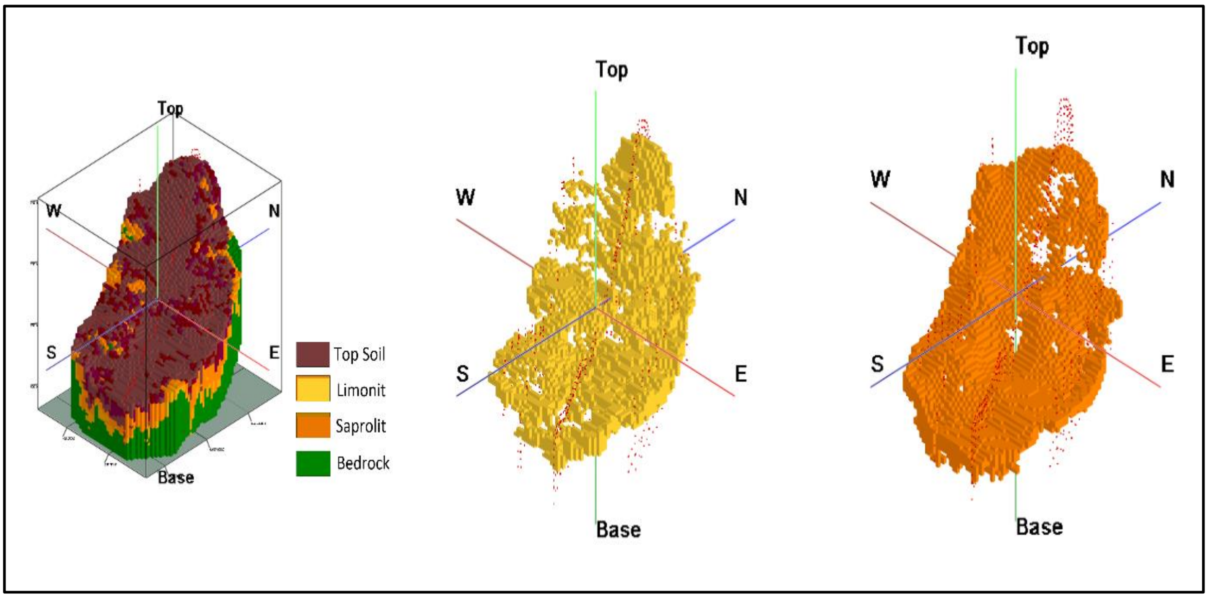

Figure 7. 3D Model of (a) Nickel Laterite Deposits (b) Limonite Layers (c) Saprolite Layers

4. CONCLUSIONS

Research using the GPR method on nickel laterite deposits obtained subsurface profile results of bedrock, saprolite, limonite, and topsoil. The average dielectric constant value in the topsoil layer is 6.80 mS/m, in the limonite layer is 10.87 mS/m, in the saprolite layer is 12.37 mS/m, while in the bedrock is 7.87 mS/m. It can be seen that the layer with the highest nickel content is in the saprolite layer with the highest dielectric constant value. The depth of the bedrock is at a depth of 20 - 44 meters from the surface, the depth of the bedrock is in the eastern and central parts of the research location. The topsoil thickness is 4 meters from the surface. The thickness of the laterite layer which is the main target of laterite nickel exploration has a value variation of 15 - 40 meters, the thickness of the laterite which is of high value is in the eastern and central parts of the research location.

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