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NICKEL LATERITE RESOURCES MODELING USING GEOLOGICAL DOMAIN ALGORITHM

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ABSTRACT: Laterization is one of the geological process of nickel ore formation. The mineral deposits genesis is important for the development of geological models. The development of geological domain in the laterite nickel ore deposits is determined through several aspects such as deposit boundary formation, geochemical data, and statistical test result. The objectives of this study are (a) characterization of laterite nickel through a weathering process study on horizontal and vertical stratigraphic conditions, (b) evaluation of the geochemical aspects, (c) development of geological modeling. The methodology consists of a literature study on the laterization process; identification of data based on geochemical analysis; statistical analysis based on histograms, scatter plots, ternary charts; and determination of the geological domain for nickel laterite. This research algorithm is used to create 3 (three) geological domains of nickel laterite, namely limonite zone, saprolite zone and bedrock zone. The result of this study shown that geological domain is adjacent with mineralization boundary. Henceforth, nickel grade estimation could be done through the characteristics of laterite nickel ore deposits**.**

Keywords: Nickel laterite, Domain, Limonite, Saprolite, Bedrock.

1. INTRODUCTION

Zonation on laterite nickel occupies at least 90% accuracy in resource modeling [1,2]. The suitability of the geological model results in the accuracy of resource grade estimation and a mathematical approach is required to prepare a suitable resource model [3-5]. The initial stage of resource modeling is to geological data input that leads to a better and more realistic model [6,7]. Correct identification of the distribution of the geochemical data population based on histogram graphs, scatter plots and terniary diagrams are media to facilitate and separate the laterite nickel domains.

The impact of domain generalization will provide an overview of the geological model based on the natural conditions of laterite nickel deposits. Thus, it will facilitate the process of estimating mineral resources based on zoning [8,9]. Understanding the weathering theory of laterite nickel deposits is a fundamental concept and complementary in the process of geological domain separation [10,11].

Mineral populations are strongly influenced by mineral formation genesis, lithology, deposit type, structural control, weathering, mineral formation and other factors that influence understanding, defining and limiting the mineralization zone [12,13]. Drilling data is a type of geochemical data that can be used to prepare laterite domains. The laterite domain is part of the exploratory data analysis (EDA) process. This process involves identifying the existence of several populations with a summary of different statistical information. The identification is based on an understanding from the statistical characteristics of the data, geological knowledge so that ore deposit data are grouped into domains. Defining domains depends on the availability of sufficient data, so that it will be easier to infer each statistical parameter from each of these domains. In addition, the domain must have predictability spatially and each domain does not overlap between one domain and another [14].

There are three zones in the nickel laterite profile: limonite, saprolite, and bedrock (Fig.1). The nickel laterite profile is affected from the solutability of mineral and groundwater flow [15].

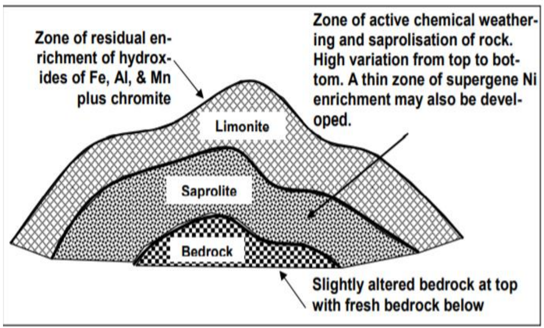

Fig. 1 Nickel laterite profile [16]

In the limonite zone there are residual concentrations of non-mobile chemical elements such as Fe, Al, Mn, while mobile elements such as Ca, Na, K, Mg, and Si are chemically leaching [17]. The upper part of this zone is yellow limonite which is rich in gutite, while the lower part is red limonite which is rich in hematite. Gutite can be remobilized under acidic conditions to form ironcap (Fe^{2+} to Fe^{3+}). Insoluble minerals such as spinel, magnetite, maghemite, and talc remain in this zone, not showing the structure and texture of the original rock. The base of the limonite zone is enriched by manganese, cobalt and asbolite or manganese lumps [18]. The density of limonite is greater than the saprolite zone due to FE mineral. The basis for the classification of the limonite zone based on chemical elements. The classification [19] is Fe (>25%), MgO (<5%), and Ni (<1.5%).

Saprolite zone is yellowish brown, greenish brown, greenish yellow. Saprolite is a strongly altered zone where the active chemical weathering occurs [20]. The chemical weathering occurs along fractures, cleavages, and fractures in rocks as well as micro-fractures in crystals. The original rock texture and structure are still visible, most of the original rock minerals are still the same. This zone consists of the original rock fragments, silica, and garnierite which are formed by re-deposition. In the unserpentinized peridotite the saprolite formation process is limited to the rock surface because water is difficult to penetrate the rock. Henceforth, the nickel is barely found in the rock chunks. In the serpentinized peridotite, the rock becomes softer and allows water to enter so that the saprolite formation process can occur throughout the rock mass. Rock chunks in the saprolite zone contain significant amounts of Ni. The grain size gradation is increasing to coarser size along the depth. Intense fracture condition is usually filled with silica minerals such as garnierite and crysopras. The basis for the classification of saprolite zones based on chemical elements [20], namely Fe (<25%), MgO (> 5%), and Ni (> 1.5%).

Zone bedrock has grayish black, greenish black color or depends on the rock composition. The composition consists of the original rock (Dunit, Peridotite, or other Ultrabasic rocks). This zone does not contain any economic minerals anymore. Fracture zone at the top is filled with silicate minerals such as Garnierite, Serpentin, Crysopras or other silicate minerals. This fracture is thought to be the cause of the root zone, namely the high-grade Ni zone, but its position is hidden. Generally, fresh, and massive bedrock can be found at the bottom with zone fracturing.

The implementation of domain analysis may lead to a wireframe construction process [21]. Wireframe is a three-dimensional framework covering a domain. Wireframing can be constructed in many ways, but usually the process is to interpret domain boundaries in parts and then tie the interpreted polygons together [2].

In determining the process, it depends on the software. In the end, the volume of the blocks in wireframing reflects the volume of the wireframing. The polygon method is an estimation method with the characteristic concept of a deposit in an area represented by a certain point. Along with the development of technology, various methods of estimating the grade of mineral resources use software [22-24] Sense of geology is the background for conducting research on domains and calculating wireframe volumes using software applications [25].

2. RESEARCH METHOD

The research methodology includes identifying the geochemical domain of laterite deposits with exploratory data analysis (EDA), checking the number of errors in the value of geochemical data elements (assay) on the overall geochemical data on laterite nickel deposits is QAQC ≤1% of the total. Make sure there is no duplication of geochemical data (assay) which is indicated by the presence of the same drilling point number (holes ID). Make sure the generalization of the geological stratigraphic domain starts from the bottom, namely the bedrock layer, then the saprolite layer and at the top is the limonite layer.

Data identification is based on statistical analysis for Ni, Fe, Co SiO_2, MgO, Cr, Al, Mn and Ca on each laterite layer. The results of statistical analysis displayed in a histogram, a scatter plot and a ternary diagram. The histogram is a graphical display of the frequency tabs as a manifestation of binning data. Scatter plot shows the correlation between two variables and shows the closeness of the relationship between the two variables which is often manifested as a correlation coefficient. Ternary diagram is a triangular diagram where each side corresponds to an individual binary system. Identification of data based on the distribution of the ternary diagram on the oxide values of Fe, MgO and SiO_2. When the laterite domain process will be carried out, another important aspect of the distribution of geochemical data is that the geochemical data column with a value of 0 or -999 must be left blank.

Analysis at the drill point aims to obtain data of the physical characteristics from each layer in the laterite profile such as limonite, saprolite, and bedrock. This layer can be evaluated based on differences in material composition, color and chemical elements. Analysis on drill data includes a XRF (X-Ray Fluorescence Analysis) analysis on the chemical elements such as Ni, Co, MgO, Fe, and SiO_2.

The zoning of laterite nickel is based on physical characteristics found in the field including color and grain size. Fig. 2 shows a photo of the core from the drill. Zone limonite is red limonite (red line in Fig. 2) and yellow limonite (yellow line in Fig. 2), has red-brown-orange characteristics, with fine-clay grain size, soft hardness, and the mineral hematite. Saprolite zone (green line in Fig. 2) has a yellowish brown color with a grain size of sand - lumps, soft hardness and mineral garnierite. Bedrock (blue line in Fig. 2) is blackish gray, has a massive structure, the minerals found are olivine and pyroxine.

Fig.2 Core photograph

Table 1 shows the chemical analysis to determine the limonite, saprolite and bedrock categories.

Table 1. Determination of limonite, saprolite and bedrock categories

	Limonite	Saprolite	Bedrock
Ni	0.4-3	0.3-3	0.26-1
Co	0.03-0.28	0.001-0.3	0.001-0.03
Fe	33-53.71	5-40	5-10
SiO_2	1-25	12.78-50	28-50
MgO	0.5-5	5-40	19-45

Statistical data processing used histograms, scatter plots and ternary diagrams. Statistical analysis for skewness parameters on grades Ni, Co, SiO_2, MgO is required for the determination of limonite, saprolite and bedrock categories The scatter plot (XY-plot) shows possible bias in the correlation of two chemical elements [12,24]. Population trends using ternary diagram determine limonite, saprolite, and bedrock zones.

3. RESULTS AND DISCUSSION

3.1. Determination of laterite nickel zones

Core photos and chemical element validation criterion are used for validation. Zoning of laterite nickel per borehole (Fig. 3). At a depth of 1-3 m a limonite zone was determined based on chemical element validation (Table 1) and physical appearance (Fig. 3). At a depth of 3-8 m a saprolite zone was determined based on chemical element validation (Table 1) and physical appearance (Fig. 3). At a depth of 9-10 m, the bedrock zone was determined based on chemical element validation (Table 1) and physical appearance (Fig. 4).

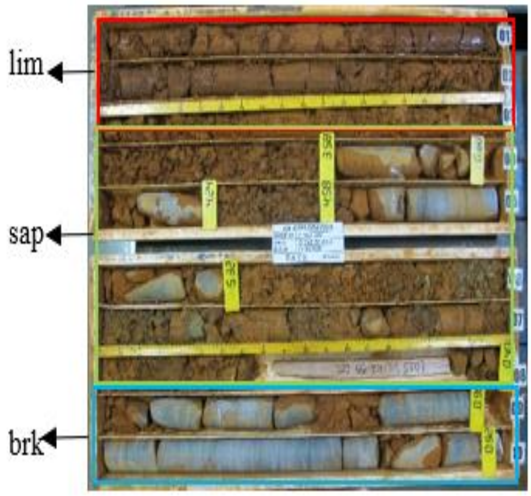

Fig. 3 Physical appearance of core photo

3.2. Nickel Laterite Histogram

The geological domain is used as a geological process illustration. The validation of chemical elements in the study area showed a single population for each domain.

Based on the population geochemical characteristics of grades Ni, Co, SiO_2, MgO, the histogram graph shows a positive skew and a negative skew of the chemical element Fe. Fe value 4.5–27% indicates the presence of boulder, recovery ≤15% in the limonite zone and domaining is generalized as a limonite layer (Fig. 4).

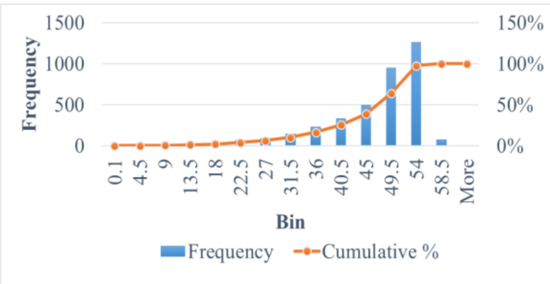

Fig. 4 Histogram of chemical elements Fe in the limonite zone

The chemical elements Ni, Co, Fe show positive skew, while SiO_2 and MgO are normal distribution. The value of 40-50% Fe indicates the proportion of soil material (soft material), recovery ≤15% in the saprolite zone and the domaining is generalized as a saprolite layer (Fig. 5).

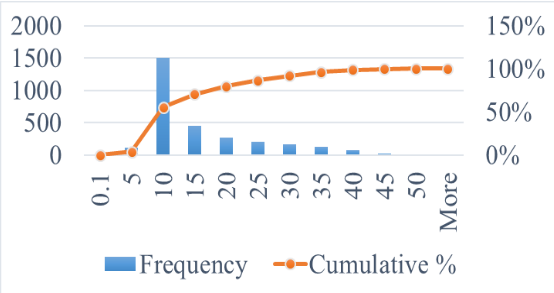

Fig. 5 Histogram of the chemical elements Fe of the saprolite zone

The histogram of the chemical elements Ni, Co, Fe, SiO_2 in the bedrock shows a positive skew while MgO is a negative skew. SiO_2 values ranged from 4.5 - 29% indicating the proportion of soft material, recovery ≤15% was in the bedrock zone so that the domain was generalized as a bedrock zone (Fig. 6).

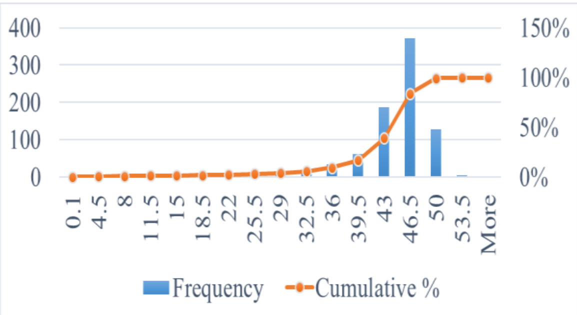

Fig. 6 Histogram of chemical elements MgO in the bedrock zone

3.3. Nickel Laterite Scatter Plot

The scatter plot Ni of the chemical element Co in the limonite zone is normal, the Co element is enriched in the transition zone or limonite zone (Fig. 7). Based on the Fe and MgO values on 4.0-15% Fe and 28-47% MgO, the presence of a boulder fraction in the fine (soft material) or natural fraction that has not been completely weathered (Fig. 8).

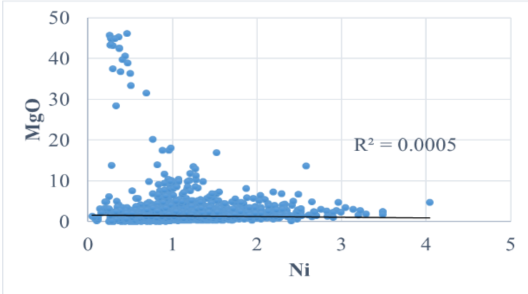

Fig. 7 Scatter plot Ni vs MgO of limonite zone

Fig. 8 Generalize soft materials as limonite domains mixed with boulder and which have not undergone complete weathering

The scatter plot of Co element in the saprolite zone is normal and unbiased. The element Co undergoes enrichment in the transition zone or limonite zone. While the Fe element in the saprolite zone generally has a high population distribution, normal or unbiased ranges. MgO compounds are normal and unbiased (Fig. 9). MgO grade 35–52% is caused by the presence of a coarse fraction (boulder) in the fine fraction (soft material) which has not been completely weathered. In the saprolite zone, the SiO_2 grade has a high variation (Fig. 10).

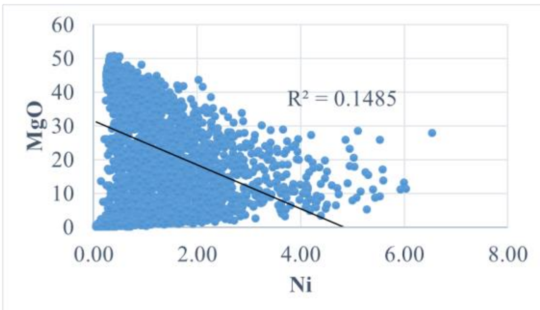

Fig. 9 Scatter plot Ni vs MgO in saprolite zone

Fig. 10 Generalize soft material as saprolite domain mixed with boulder which has not undergone a complete weathering process

The scatter plot Ni of chemical elements Co in the bedrock zone is normal and unbiased. The Co element is not enriched in the bedrock zone (Fig. 11). Grades of Fe, MgO and SiO_2 are relatively normal or unbiased. Grade MgO <19% was caused by the presence of a fine fraction (soft material) in the core data which was generalized as zone bedrock (Fig. 12).

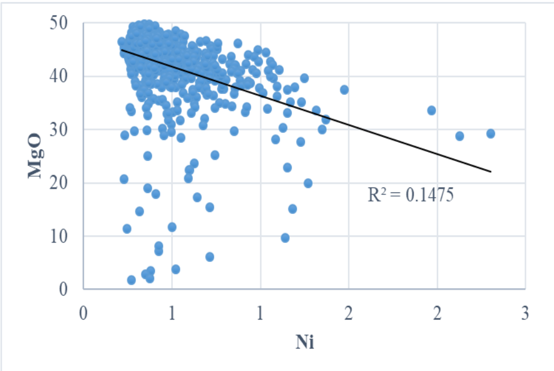

Fig. 11 Scatter plot Ni vs MgO in bedrock zone

Fig. 12 Generalize soft material as the bedrock domain

3.4. Ternary Diagram Plot of Nikel Laterite

The evaluation of the grade distribution of total oxide, total MgO and total SiO_2 was based on the ternary pattern plot diagram on nickel laterite. The limonite zone has a population trend on the right side of the ternary plot diagram. The dark circles indicate the presence of separate populations in the limonite zone due to the high silica content in this zone (Fig. 13).

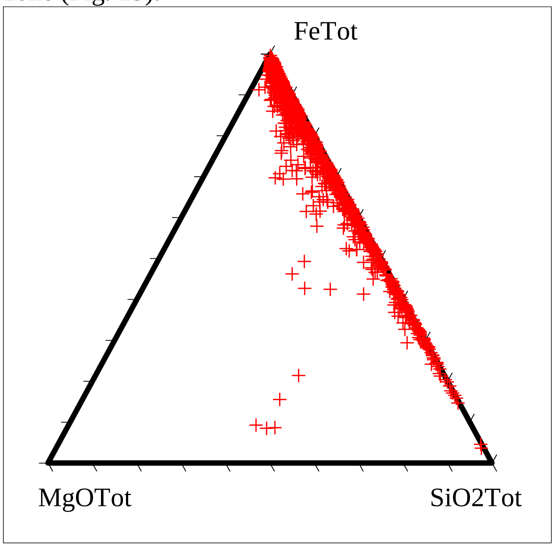

Fig. 13 Diagram showing the chemical element statistics for total Fe, total SiO_2 and total MgO in the limonite zone

While the ternary plot diagram in the saprolite zone is on the right and bottom right of the ternary plot diagram. The population distribution is normal, there is no bias and reflects the total typical elements of Fe, and oxides of MgO and SiO_2 in the saprolite zone (Fig. 14).

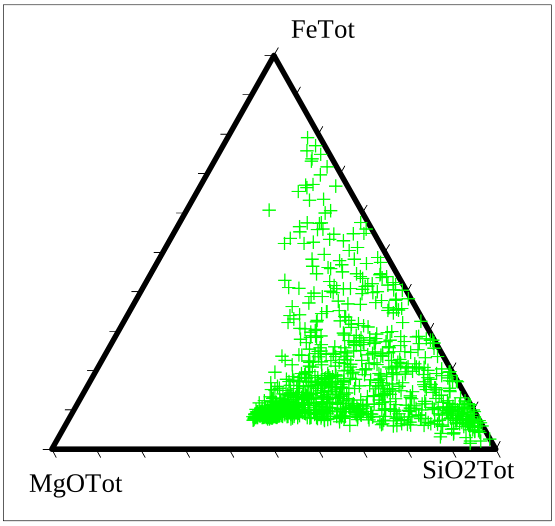

Fig. 14 Diagram showing chemical element statistics of total Fe, SiO_2 and MgO in saprolite zone

The ternary pattern in the bedrock zone has a population trend at the bottom of the diagram. The emergence of a separate population (red circle) is a population of fine fraction (soft material) or soil with ≤50% recovery which is generalized as zone bedrock (Fig. 15).

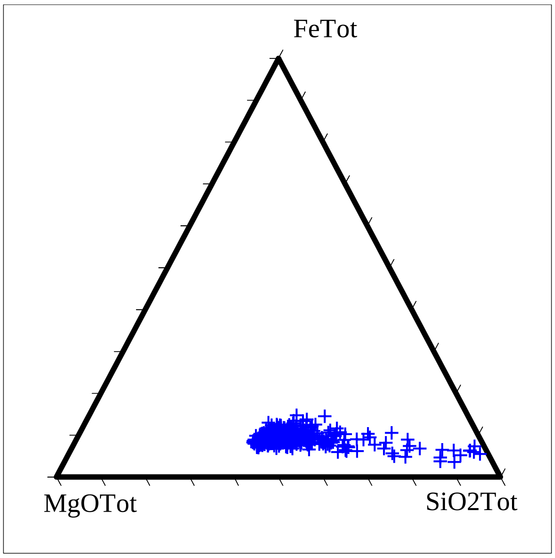

Fig. 15 Diagram showing the statistics of the element total Fe, total oxide SiO_2 and total MgO in the bedrock zone

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3.5. Nickel laterite profile

Based on the results of chemical element data processing in the study area, it illustrates that the correlation between Ni and Co elements is directly proportional. Ni and Co grades has positive correlation with the saprolite layer depth; but it has negative correlation with the bedrock layer (Fig. 16). This is phenomenon happens because the bedrock layer does not undergo a chemical weathering process and a supergen enrichment process. Therefore, the Ni and Co grades in this zone are very-low, compared to the limonite and saprolite layers which have undergone a weathering and Ni enrichment process (Fig. 16).

The content of SiO_2 compounds is directly proportional to MgO in the limonite layer, such as in Ni and Co grades. In limonite layer, grade SiO_2 is directly proportional to MgO while in the saprolite grade zone it becomes high up to the bedrock layer. The phenomenon happens due to the element content of SiO_2 and MgO is abundant as constituent elements of bedrock. Meanwhile, the low-grade of the limonite layer is caused by the decomposition of the element. This process is caused by weathering which is higher in the limonite zone than in the saprolite and bedrock zones (Fig. 16).

Fe grade is inversely proportional to the elements Ni, Co, and oxides such as SiO_2, and MgO. Fe grade in the limonite layer was high with an average value of 44.29%, then in the saprolite layer it was getting lower with an average value of 13.23% and very-low in the bedrock layer with an average grade of 6.77%. Elemental Fe is formed as the result of the oxidation process. The highest Fe content is found in the limonite zone due to the very-high level of chemical weathering and the nature of Fe which is not easily mobilized by water media.

This study shows that some drill data in the limonite zone have low Fe grade but high MgO grade. This is due to the presence of boulders in the limonite zone.

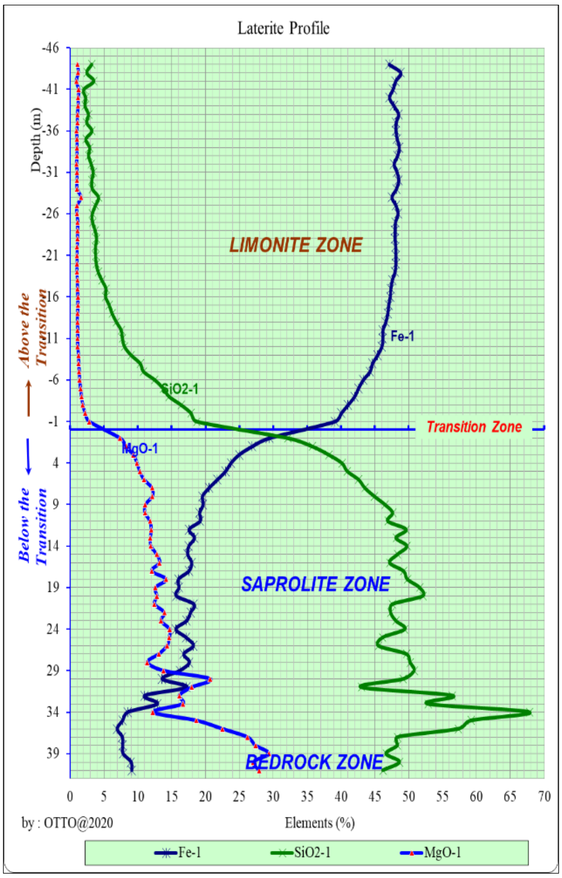

Fig. 16 Nickel laterite profile

3.6. Wireframe

Wireframe construction resulting in volume of each zones (limonite, saprolite, and bedrock). The result of wireframe modelling and construction.

The density used for volume calculation was obtained from limonite and saprolite namely 1.6 ton/m^3 and the bedrock density of 3.2 ton/m^3. The estimated volume of limonite and saprolite layers are 28,000,000 m^3; and 30,000,000 m^3. The saprolite zone has a larger total nickel ore volume compared to the total nickel ore volume in the limonite zone. While the bedrock zone with a volume of 33,000,000 m^3 is greater than the saprolite layer.

4. CONCLUSION

Geological domain algorithm used in this study has shown its capability for resources modeling. The important parameters of this methodology are understanding nickel laterite deposits, data analysis using statistical methods, and data validation based on the core photos. Based on histogram analysis, each element of Ni, Co, and Fe on each layer has positive skew while SiO_2 and MgO has normal distribution. Based on the scatter plot, each element a relatively low coefficient of correlation. Based on ternary diagram, Fe and SiO_2 are dominant element that associated with Ni. This method also has proven to illustrate the nickel laterite profile based on several chemical elements of Ni, Co, and oxides elements such as SiO_2 and MgO. As a final result, total resources volume is estimated using wireframe modeling. The application of geostatistical methods such as nearest neighbor polygon and kriging could be investigated in further research of nickel grade estimation in this study area.

5. ACKNOWLEDGMENTS

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