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GEOLOGY AND THE CORRELATION BETWEEN GEOLOGICAL CONTROL AND NICKEL QUALITY IN GAG ISLAND, RAJA AMPAT ISLANDS, WEST PAPUA

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Abstract

The geology of Gag Island, Raja Ampat Islands, West Papua Province is composed of volcanic rocks and ultramafic rocks as carriers of laterite nickel deposits (Supriatna, et al. 1995). The research was conducted by surface mapping supported by drill data, and drill geochemical data. Data collection by surface mapping aims to determine the relationship of geological control to the quality of laterite nickel. The characteristics of laterite nickel deposits are influenced by geological factors in the form of lithology, topography, Drainage drainage, tectonics, and geological structures (Elias, 2002), so that geological control of the quality of laterite nickel deposits needs to be studied further.
The research area found 3 rock units in the form of peridotite unit (harzburgite), serpentinite unit, and alluvial deposit unit. The data shows that the highest nickel content is in peridotite (harzburgite) units. In addition, the shape of the land based on the geomorphological aspect shows that in the form of weak wavy hills, laterite deposits are quite well developed and thick. The landform is supported by a relatively sloping slope (0-8 ^{o}) with an undulating morphology and a dendritic Drainage pattern with a content of > 1.5% Ni and a thickness of 9-16 meters, while levels of < 1.5% Ni reach a thickness of 5-22 meters. The geological structure in the morphology is only found in the form of paired joints and filled joints. These joints become an important component in the process of garnierite mineralization as a carrier of Ni.

Keyword: *geomorphology, grade, lithology, nickel laterite, Drainage pattern*

INTRODUCTION

Based on ESDM data (2020), Indonesia is one of the big countries that is rich in Ni resources and has large deposits of laterite which is well-known in the world. Indonesia has the largest nickel reserves in the world, which is 52% of world nickel reserves and 90% of nickel distribution in Indonesia is in Central Sulawesi, South Sulawesi, Southeast Sulawesi and North Maluku (ESDM, 2020). The distribution of nickel ore reserves in Indonesia reaches 4.5 billion tons and resources 11.7 billion tons. According to ESDM data (2020), nickel reserves in Indonesia are decreasing in 2025-2047 while production remains high, so it is necessary to control the quality of laterite nickel in order to maintain production every year. The geological characteristics of Ni-laterite soils over ultramafic rocks in Southeast Asia, particularly in Indonesia, have not been fully studied (Golightly, 1979, 1981; Sufriadin et al., 2011). The formation of laterite nickel in Eastern Indonesia, especially on Gag Island, is closely related to geological conditions and extreme weather conditions, resulting in a very strong weathering process, both physical and chemical (Sam Permanadewi et al, 2017).

The laterite profile is mostly due to the chemical weathering process by water. Chemical weathering of ultramafic rocks is accompanied by the fractionation of elements that become soluble with water and insoluble with water. The water-soluble elements are eventually leached out of the weathering system while the water-insoluble elements are left behind as enrichment residues. The chemical weathering process eventually results in the formation of a stratified laterite profile with the youngest laterite at the bottom and the oldest laterite at the top (Ahmad, 2008). Laterite nickel deposits can be classified mainly into three groups: (a) oxide or "limonite" deposits which are dominated by minerals such as goethite (FeOOH), (b) smectite or "clay minerals" deposits which are dominated by nickel clays such as smectite or nontronite and (c) hydrous Mg-Si-silicate deposits dominated by minerals such as talc and serpentine, collectively referred to as "garnierite" occurring in the saprolite zone of the yellow laterite profile (Konig W, 2021). Knowledge of the lateritization process related to the formation of Ni-laterite is still scarce because the geological characteristics vary from one to another (Golightly, 2010).

Nickel laterites are formed under humid tropical conditions during the weathering of serpentinites. Mineralogy and ore grades depend on the lithology and climate during deposit formation (Konig U, 2021). Identification of the control of geological factors that control the ore bed and variations in the distribution of ore grades becomes very important (Koike and Matsuda, 2006). It is clear that many of these climatic and geological factors are closely interrelated, and the profile characteristics in one place can be best explained as a result of the combined effects of all the individual factors acting over time (Elias M, 2002). Based on the size of laterite deposits, geomorphological factors are the most dominant, because they can affect other factors such as groundwater systems, weathering processes, and the role of geology in layer thickness in the limonite and saprolite zones above the bedrock (Asran Ilyas and Katsuaki Koike, 2012). Based on the explanation above, it is deemed necessary and important to conduct research on geology and the relationship between geological control and nickel quality on Gag Island, Raja Ampat Islands, West Papua.

METHOD STUDY

This research methodology uses several stages consisting of 3 parts, namely data acquisition, data analysis, and data synthesis.

A. Data acquisition

Data acquisition is the process of collecting data at the research site which is used to support and answer the problems of research. Data acquisition can be divided into 2 parts based on the processes, namely: a). Acquisition of secondary data in the form of regional geological map studies, literature reviews of previous researchers, and b) primary data acquisition in the form of field observations, geological mapping (making trajectories of research and observation locations, measuring geological structures, sampling, and measuring slope levels).

B. Data analysis

The data analysis of this research consisted of: a) geomorphological analysis, in the form of topographic map analysis and google earth-*google images* that produced maps of Drainage patterns and landforms, b) geological structure analysis, based on measurements of the position of geological structures in the field in the form of fault planes, breccias, gerus joint, tensile joint, and landscape photos, c) Petrographic analysis, obtained from observations in the field in the form of megascopic description, outcrop geometry, and rock sampling which will later be described microscopically using a polarizing microscope, and d) XRF analysis (*X-Ray Fluorence*), obtained from the preparation of laterite samples that have been dried and then inserted into the apparatus to measure the percentages of Ni, Fe, and SiO_2 as the dominant elements in laterite deposits.

C. Data Synthesis

The data synthesis is the result of data collection and analyzes that have been carried out in the form of: a) differences in the characteristics of nickel laterite in the study area, b) the influence of geomorphology in the study area through topographic maps and *google earth images* , as well as direct observations in the field on the characteristics of nickel laterite, c) the stratigraphy of the research area is explained in geological history through literature review and field sampling, d) the geological structure is generated in the general direction of the dominant stress controlling the study area, e) the geological model of laterite nickel deposits in the study area is realized in the form of drawings or tables based on parameters geology such as lithology, geomorphology, Drainage patterns, and geological structures.

GEOLOGY RESEARCH AREA

A. Drainage Pattern Research Area

On area The study found seasonal rivers with a relatively southeast-northwest direction (Figure 1) and relative river branches trending north-south and northeast-southwest. Based on the classification according to Howard (1967), the drainage pattern in the study area is divided into 3 drainage patterns, namely *dendritic drainage* patterns, drainage patterns and *sub-parallel alteration drainage patterns*.

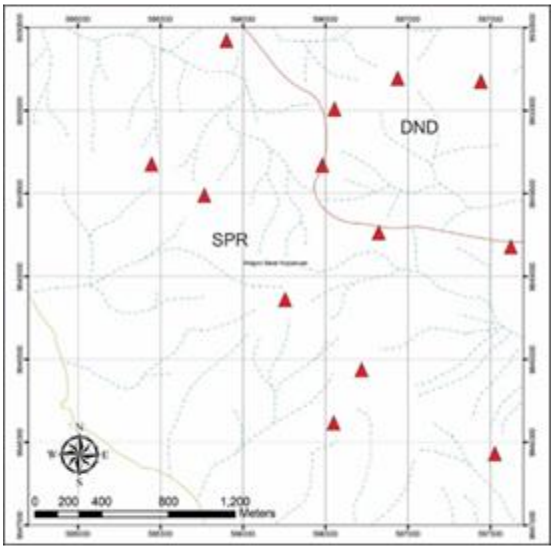

Figure 1. Regional Drainage Pattern Study

a. Dendritic Drainage Pattern

According to Howard (1967), the pattern of dendritic drainage is characterized by a Drainage pattern such as a series of "roots" that merge into the main river with a small angle in the direction of the Drainage influenced by impermeable lithology and fine texture. In addition, the geological processes that take place in the research area are mentioned as follows:

1) The dendritic Drainage pattern in the study area has a general direction of northwest-southeast Drainage, which is interpreted as having non-resistant rock resistance due to the development of geological structures in the form of joints.
2) Drainages in *the bedrock stream* which shows the lithology of igneous rocks in the form of peridotite.
3) The river branches are U-shaped with gentle slopes on the river walls and the riverbed is relatively flat (Figure 2).

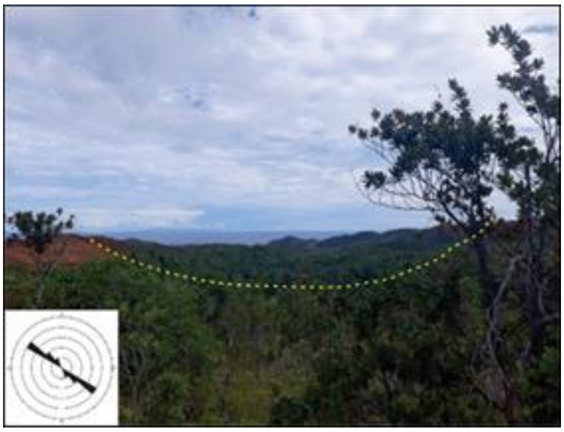
Figure 2. Sloping U-shaped valley

4) Controlled by a slope of 0-8 degrees.

b. Sub-Parallel Stream Pattern

Based on the results of observations in the field, the parallel Drainage pattern in the research area has the following characteristics:

1. The sub-parallel Drainage pattern is spread in the southeast and south, which is characterized by parallel Drainage patterns, but some streams show anomalies of different Drainage directions.
2. The texture of this Drainage is moderate to fine which characterizes the non-resistant lithology.
3. This drainage pattern is found on very steep slopes in the form of a steep V on river walls and on hillsides (Figure 3).

Figure 3. Steep V valley shape

4. The riverbed is overgrown with dense vegetation and sloping slopes.

B. Geomorphology Research Area

Based on the topographic map analysis of the original form classification according to Van Zuidam (1983), the research area consists of denudational, structural, and *marine origins*. According to Verstappen (1983) by considering anthropogenic aspects, the research area consists of an anthropogenic origin in the form of a *pit* (Figure 4).

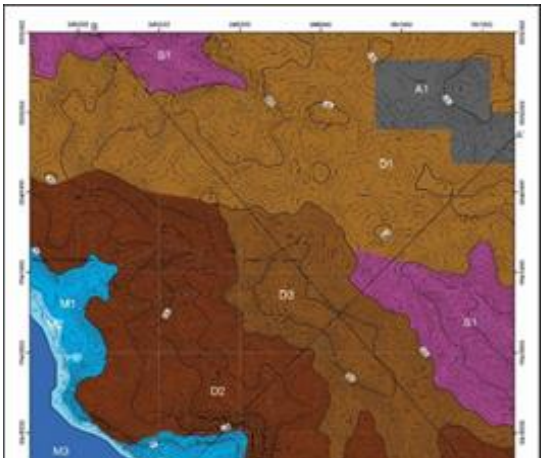

Figure 4. Geomorphology of the Research Area

Anthropogenic landforms are landforms that occur as a result of human activities. Human activity causes the original form that is formed naturally can no longer be seen because it is covered by the results of human activities. Anthropogenic landforms in the study area are *pit* (A1).

The original structural form is an original form caused by tectonic activities such as faults, faults, uplift, and folding. In addition, this original form characterizes morphology which is actively influenced by geological structures so that it can show symptoms of geological structures in the field. The research area consists of 1 landform, namely the structural valley (S1).

The original denudational form is a morphological form caused by weathering, erosion, rock mass movement (*mass wasting*), and depositional processes due to aggradation and degradation where the degradation process causes a decrease in the earth's surface, while the agradation process causes an increase in the earth's surface. The form of denudational origin in the study area consists of 3 landforms, namely weak undulating hills (D1), Gawir (D2), and strong undulating hills (D3).

Marine origin is a morphological form caused by hydraulic processes. In this original form, there are processes of traction, saltation, suspension, solution, and buoyancy. The *marine* origin in the study area consists of 3 landforms, namely coastal terraces (M1), beach (M2), and sea (M3).

C. Regional Stratigraphy Study

The stratigraphy of the research area was compiled based on outcrop observations and profile trajectories. The determination of rock units is based on the unity of lithological characteristics in the form of physical appearance, structure, texture, and rock composition. The research area is composed of 3 rock units, namely the peridotite rock unit and the peridotite rock unit aged late jurassic, serpentinite rock unit aged late jurassic, and alluvial deposit unit aged quarter).

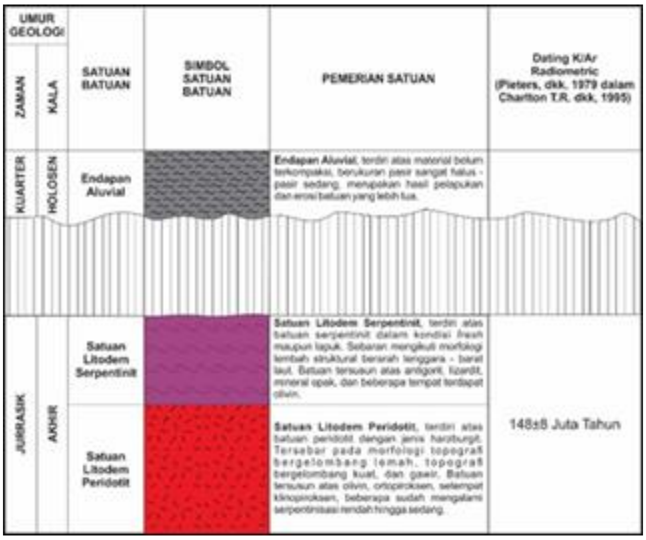

Figure 5. Local Stratigraphy Research Area.

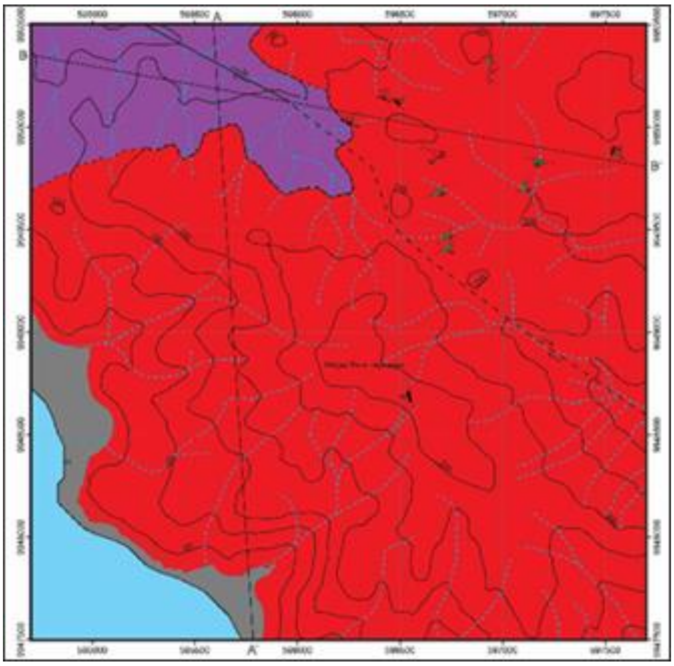

Figure 6. Distribution of Rocks in the Research Area.

D. Regional Geological Structure Study

Geological structure describes the results of changes or deformation of rock structures in certain areas. The geological structure of the study area consists of joints and faults in *bedrock*. The existence of these geological structures has no effect on rock deformation, but can affect the results of laterite and laterite quality in the study area.

The research area found a fault data that developed in the form of a right horizontal fault with a southeast-northwest direction. Based on its morphology, this fault produces a steep V-shaped valley. (Figure 7). In addition, other geological structures were found in the form of paired joints and filled joints.

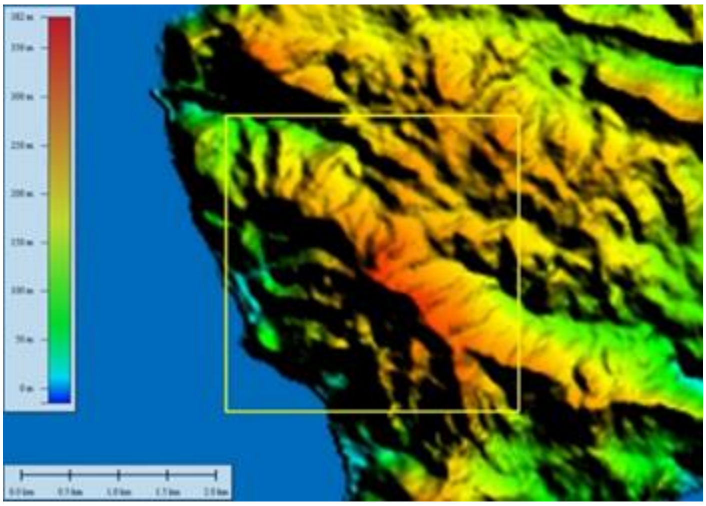

Figure 7. The morphology of the USGS DEM satellite image shows an offset of valley morphology in the study area.

The fault geological structure data were found in observation point 50, and observation point 52 in the form of *shear fracture* and *gash fracture data* in bedrock. On observation point 50, data obtained for *shear fracture* with position N284° E/81° and *gash fracture* with position N182° E/81° and straightness direction N290° E (Figure 8). From the results of the stereonet analysis, it was found that the movement of the fault was in the form of a *lag right slip fault* (Rickard, 1972). Meanwhile, on the observation point 52 fault, we found *shear fracture data* with a position of N286° E/83° and *gash fracture data* N201° E/71° and river lineaments in the direction of N298° E. The results of stereonet analysis showed that the fault movement was a *lag right slip fault* (Rickard, 1972). The role of geological structures in the study area is interpreted as the presence of fractures that can assist the laterization process in the study area.

The joint data found in the field showed paired joints. The joint data were found at 3 observation locations, namely observation point 70, observation point 50, and observation point 140. The results of the joint analysis resulted in the direction of stress 1, stress 2, stress 3, *release joint*, and *extension joint*. Emphasis 1 on the joint shows east – west and northeast – southwest directions (Table 1 and Figure 8).

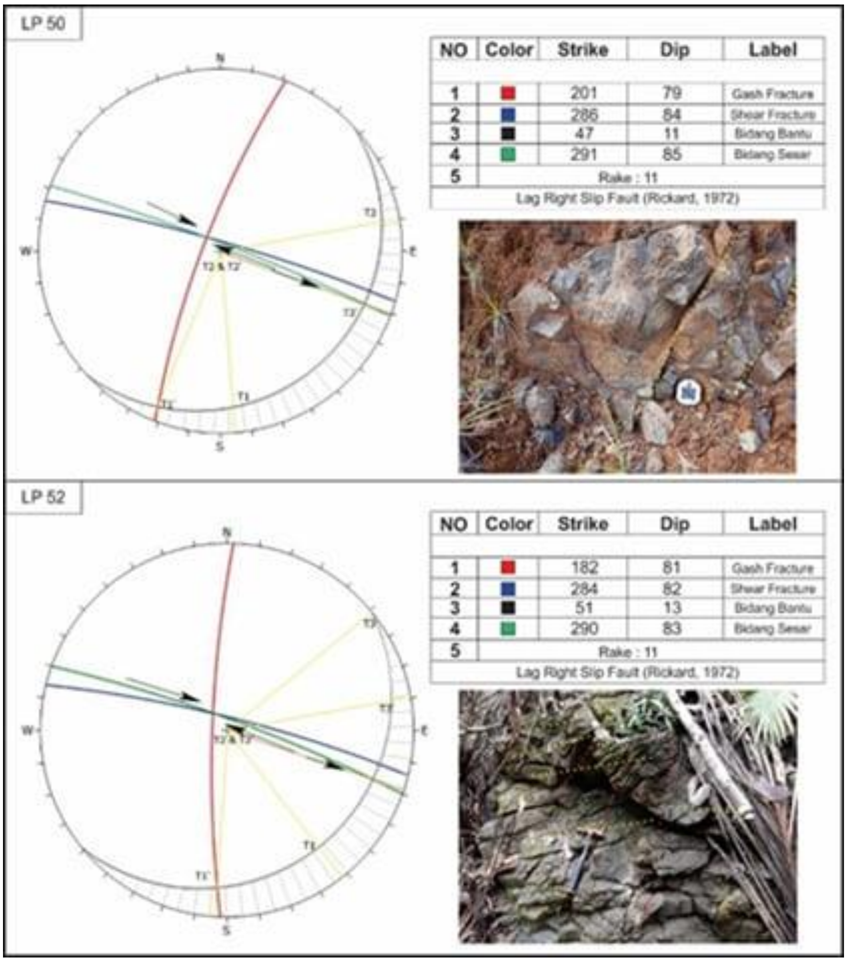

Figure 8. Observation point 50 & observation point 52 fault stereonet analysis.

Table 1. The results of the analysis of paired joint stress observation point 70.

Results	LP 70	LP 50	LP 140
σ 1	24°, N 104° E	01°, N 061° E	24°, N 104° E
σ 2	45°, N 223° E	85°, N 165° E	45°, N223°E
σ 3	34°, N 356° E	4°, N 332° E	34°, N356°E
Extension Joint	N062° E / 85°	N088°E / 82°	N086° E / 5°
Release Joint	N153°E / 88 °	N 178° E / 80°	N 194° E / 64°

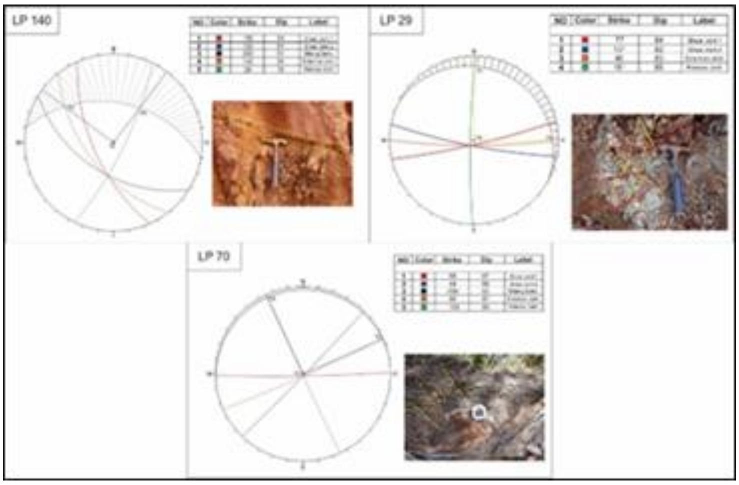

Figure 9. Research Area Linearity .

E. Laterite Research Area

The laterization process in the study area develops in almost all of the study area with varying thickness of laterite. Laterite distribution is characterized by red clay-sized soils as a result of Fe elements remaining at the top of the laterite profile. Laterite outcrops found in the field consisted of limonite zones scattered in almost the entire study area and local saprolite zones in the study area. The difference between the two zones is characterized by the mineralogy of each zone. The limonite zone in the study area is dominated by local compositions of hematite, Fe concretion, manganese oxide, and goethite. In addition, the limonite zone can also be recognized from the texture of the fine-sized soil or clay. While the saprolite zone is recognized by its composition in the form of hematite, goethite, manganese oxide, manganese, *boxwork silica* at the top and chunks of bedrock. Based on the texture, the saprolite zone is characterized by a sandy texture (Figure 10).

Figure 10. Laterite outcrop in the study area.

CORRELATION BETWEEN GEOLOGICAL CONTROL AND NICKEL QUALITY

1) Geological Control

The factors causing the quality of nickel deposits need to be carried out based on geological aspects. The analysis of these aspects that affect the quality consists of Drainage patterns, geomorphology, lithology, stratigraphy, and geological structures.

a. Drainage Pattern Aspect
   i. Nickel quality in dendritic drainage pattern with a gentle U-valley shape and *bedrock stream*.
   ii. Nickel quality in parallel Drainage pattern with steep V valley shape and *bedrock stream*.
   iii. Nickel quality in sub-parallel Drainage pattern with steep V valley shape and *bedrock stream*.
b. Geomorphological aspects
   i. Nickel quality in mining landform units (flat – sloping or 0^o – 8^o) with a process that has been dominated by human activities.
   ii. Nickel quality in hilly landform units is weak (flat – slightly steep or 0^o – 16^o) with a process dominated by weathering and erosion.
   iii. Nickel quality in escarpmental landforms (slightly steep – very steep or 8^o – 40^o) with a process dominated by weathering and erosion.
   iv. Nickel quality in hilly landform units is strongly undulating (sloping – steep or 4^o – 30^o) with a process dominated by weathering and erosion.
   v. Nickel quality in coastal terrace landforms (slightly sloping or 2^o – 8^o) with a process dominated by tides.
   vi. Nickel quality in coastal landform units (flat – slightly sloping or 0^o – 3^o) with a process dominated by tides.

vii. Nickel quality in marine land forms (flat or 0°) with a process dominated by tides.
viii. Nickel quality in structural valley landform units (slightly sloping – steep or 2° – 20°) with processes dominated by geological structures.

c. Lithological and stratigraphic aspects
   i. The quality of nickel in the alluvial deposit unit which is composed of non-compact and easily separated material.
   ii. Nickel quality in serpentinite rock units which are composed of serpentine minerals which are more resistant to weathering and are not easily weathered.
   iii. The quality of nickel in peridotite rock units composed of olivine, pyroxene, and serpentine minerals which are easily weathered and not resistant to weathering.
d. Aspects of geological structure
   i. Nickel quality in the fault zone with right horizontal fault movement.

Some of the geological aspects above will be used as a reference for the analysis of geological control of nickel quality in the study area.

2) Quality Nickel Laterite

Quality is defined as any physical or chemical measurement of the characteristics of the desired material in the sample or product (KCMI Code, 2011). According to Elias (2002), the quality of the ore for laterite nickel deposits depends on several factors:

a. Grade

   Possibly the highest *grades* of Ni and secondary products especially Co can improve plant utilization efficiency and reduce the effects of internal wastes included in the ore stream.

b. Consistency

   Continuity and consistency in grades and other physical and chemical properties allow for less variability in the composition of materials delivered to the factory.

c. *overburden* thickness

   Ore thickness and *overburden* increase *stripping ratio overburden* to ore.

d. Mineralogy

   In *smelting*, the Si:Mg ratio is very important to control the temperature and the reactivity and viscosity of the *slag*. The ratio is strongly influenced by mineralogy, especially the formation of serpentine.

e. Missing element

   Mg and Al are strong acid consumers and high levels of Al (in *overburden*) can lead to alunite formation in *autoclaves*.

Geological control is closely related to *grade* or grade, thickness of ore and *overburden zones*, and mineralogy of laterite nickel deposits. In this study, data collection of elemental consistency in the percentage of missing elements in determining the quality of nickel deposits in the study area was not carried out with limited data obtained so that in determining the quality of nickel deposits in the study area based on 3 parameters, namely grade, thickness of the ore zone and *overburden*, and mineralogy.

3) Quality Nickel Based on Drainage Pattern Aspect

a. Drainage Pattern Dendritic

The laterization process in the dendritic drainage pattern area develops optimally. The pattern of dendritic drainage in the study area is characterized by relatively sloping valley slopes and valley walls with non-resistant lithology. Lithology that is not resistant to this Drainage pattern is interpreted as the influence of fracture structures so that the rock has a gap for water to enter the rock. In addition, non-resistant lithology can be a factor in the formation of laterite.

The study area found laterite with a thickness of ± 5 meters to 20 meters based on outcrops and mine walls in dendritic Drainage patterns. The characteristics of laterite in this drainage pattern are very fine textured – clay on the limonite and an Fe concretion zone is formed on the top of the limonite. In addition, garnierite mineralization was found at several observation sites. In general, the garnierite mineralization found at the study site is in the form of *veins* that are present with silica or quartz and some places are also found along with the presence of manganese oxide (Figure 11).

Figure 11. Laterite outcrop (top) and mineralization (bottom) in a dendritic Drainage pattern

b. Sub-Parallel Stream Pattern

The sub-parallel Drainage pattern in the study area is characterized by relatively parallel river branch patterns, resistant lithology, relatively steep valley slopes and valley walls, as well as Drainage deviations due to geological structures. In this drainage pattern, laterite outcrops are found which are quite developed locally with the characteristics of laterite fragments, and laterite thickness ranges from ±1 meter to 3 meters based on the outcrop. In addition, at observation point 68 and observation point 70, *vein* garnierite mineralization was found along with the presence of manganese oxide (Figure 13) and garnierite mineralization in rock fragments locally and their presence was very small. At observation point 42 found laterite with a thickness of 1 meter and the presence of garnierite in rock fragments (Figure 12).

Figure 12. Laterite outcrop (left) and the presence of the mineral garnierite (right) at observation point 42

Figure 13. Laterite outcrops (left) and mineralization (right) at observation point 68 (top) and observation point 70 (bottom)

4) *Quality Nickel Based on Aspect Geomorphology*

a. Mine landform

Mining land forms are land forms that have been altered due to human activities. This landform is associated with a weak undulating hilly landform. Based on the geomorphological aspect, the shape of the mining area can be known to be related to nickel quality, namely:

i. Based on morphography, the distribution of laterite is found in plain morphography with a laterite thickness of up to 20 meters and a clay texture in the limonite zone and sandy in the saprolite zone.
ii. Based on the morphometry, the distribution of laterite is found on the sloping morphometry (0^o-8^o) with a thickness of 5 meters - 20 meters.
iii. Based on the morphostructure of the sand, the distribution of laterite is found in the form of loose material due to mining results.
iv. Based on morphodynamics, the distribution of laterite is found due to the erosion process and mining activities.

Figure 14. Outcrop laterite in landform mine

b. Wavy Weak Hills Landform

Based on the geomorphological aspect, the form of weak undulating hills can be seen in relation to nickel quality as follows:

i. Based on morphography, laterite distribution is found in hilly plain morphography with laterite thickness reaching 20 meters. Laterite textured clay in the limonite zone and sandy in the saprolite zone. Garnierite mineralization is often found in *vein outcrops* and is present together with silica and manganese oxides.
ii. Based on morphometry, the distribution of laterite is found in very gentle – rather steep morphometry (2^o-15^o).
iii. Based on sand morphostructure, laterite distribution is found in lithology that has undergone >75% weathering in the form of peridotite rocks.
iv. Based on morphodynamics, the distribution of laterite is found because it is dominated by weathering and erosion processes.

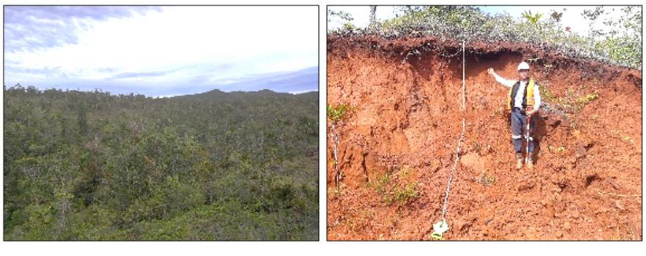

Figure 15. Forms hills wavy weak (left) and outcrop laterite (right)

c. Escarp Landform

Based on the geomorphological aspect, the shape of the escarpment can be seen in relation to nickel quality as follows:

i. Based on morphography, slope morphography did not find laterite outcrops.
ii. Based on morphometry, the slope is steep – very steep (16^o-45^o).
iii. Based on the morphostructure of the sand, it was found that the lithology had weathered 25% and had not yet formed laterite.
iv. Based on morphodynamics, laterite distribution was not found because it was dominated by physical weathering processes.

d. Wavy Strong Hills Landform

Based on the geomorphological aspect, the strongly undulating hilly landforms can be related to nickel quality as follows:

i. Based on morphography, laterite distribution is often found in hilly plain morphography with a laterite thickness of 1 meter - 2 meters. Laterite has fragmented clay texture in the limonite zone and lumps in the saprolite zone. Garnierite mineralization is often found in *vein outcrops* and is present together with silica and manganese oxides.
ii. Based on morphometry, the distribution of laterite is found in very steep slopes (7^o - 35^o).
iii. Based on the morphostructure of the sand, the distribution of laterite is found in the lithology that has undergone >75% weathering in the form of peridotite rocks.
iv. Based on morphodynamics, the distribution of laterite is found because it is dominated by weathering and erosion processes.

e. Beach, Beach, and Sea Terrace Landform

Based on the geomorphological aspect, the shape of the coastal, coastal, and marine terraces can be seen in relation to nickel quality as follows:

i. Based on morphography, laterite distribution is not found in plain morphography.
ii. Based on morphometry, the distribution of laterite was not found in the flat-sloping morphometry (0^o – 5^o).
iii. Based on the sand morphostructure, the distribution of laterite is not found in alluvial deposits.
iv. Based on morphodynamics, the distribution of laterite is not found because it is dominated by tidal processes.

Figure 16. The landforms of beach, beach, and sea terraces (left) and outcrops sediment alluvial (right)

f. Structural Valley Landform

Based on the geomorphological aspect, structural valley landforms can be related to nickel quality as follows:

i. Based on morphography, laterite distribution is not found in valley morphography.
ii. Based on the morphometry, the distribution of laterite was not found in the sloping-steep morphometry (8^{o} – 35^{o}).
iii. Based on the active morphostructure, the distribution of laterite is influenced by faults or faults.
iv. Based on the sand morphostructure, the distribution of laterite is found in lithology that has undergone weathering >75% and is fractured.
v. Based on morphodynamics, laterite distribution was found because it was dominated by weathering and faulting processes.

Figure 17. Structural valley view (top left), laterite outcrop (top right) and bedrock outcrop at the bottom of the valley (bottom)

5) Quality Nickel Based on Aspect Lithology and Stratigraphy

Based on field observations, it is known that the nickel quality is based on lithology and stratigraphy. Lithological differences cause differences in the characteristics of nickel deposits and affect nickel quality.

a. Quality Nickel Based on Unit precipitate alluvial

The alluvial deposit unit is scattered in the alluvial deposit unit characterized by non-compact or loose material. The following are the characteristics of nickel deposits based on alluvial deposits in the study area.

i. Laterite deposits are not found in alluvial sediment units because there is no original rock as a carrier of Ni.
ii. Laterite deposits take a long time to form. Meanwhile, alluvial deposits are deposits whose formation process is still ongoing.

b. Quality Nickel Based on Serpentinite Rock Unit

Serpentinite rock units are characterized by rocks dominated by serpentine minerals. Serpentine minerals are included in the mineral alteration of olivine minerals which can form laterite nickel deposits. The following are the characteristics of nickel deposits based on serpentinite rock units in the study area.

i. Laterite nickel deposits are found in serpentinite lithology with laterite thicknesses ranging from 1 meter to 3 meters.
ii. Garnierite mineralization in serpentinite units was not found.
iii. The characteristics of the laterite formed are fragmented in the limonite zone to bedrock.
iv. Serpentinite units are influenced by faults in the study area so that water infiltration does not take place optimally.

c. Quality Nickel Based on Peridotite Rock Unit

Peridotite rock units are characterized by rocks dominated by olivine, pyroxene, and local serpentine minerals. The mineral olivine is the mineral that carries the most Ni, and will decrease with changes to pyroxene, amphibole, and biotite minerals (Ahmad, 2008). The following are the characteristics of laterite nickel deposits based on peridotite rock units.

i. Laterite nickel deposits are found in peridotite lithology with a thickness of 5 meters to 20 meters.
ii. Most of the peridotite units in the study area have undergone weathering up to >75%.
iii. Garnierite mineralization is often found in peridotite units in *veins*, and is present together with silica and manganese oxide *veins.*
iv. The characteristics of the limonite zone are clay-textured and thick, locally there is *saprolite rock*. While the characteristics of the saprolite zone have a sandy clay texture.
v. Ni content based on geochemical data shows an average amount of > 1.5% Ni.

d. Quality Nickel Based on Aspect Structure Geology

Geological structure can influence the development of laterite deposits. The geological structure in the study area is a right horizontal fault and paired joint. The following are the characteristics of laterite nickel deposits based on the geological structure.

i. The right horizontal fault in the study area is trending relatively southeast – northwest which causes the formation of a steep V valley morphology in the same direction. The steep V valley is a destruction zone so that laterite outcrops are not found.
ii. The area to the northeast of the fault is a *hanging wall block* characterized by a more varied morphology and more intensely fractured lithology. In addition, the direction of garnierite mineralization found is relatively northeast-southwest due to the direction of the *extension joint* due to fault movement.
iii. In the northeastern area, there are many thick to thin laterizations.
iv. The area in the southwest of the fault is a footwall block *characterized* by more massive rock and not intensely fractured so that laterite is not well developed and mineralization is not found.

DEPOSIT MODEL OF NICKEL LATERITE.

Term “model” in the context of geoscience gives rise to various images, ranging from a physical reflection of a subject's form, to a unifying concept that explains or describes complex phenomena. While the mineral deposit model is information that is systematically arranged that describes the important attributes (properties) of the mineral deposit class (Cox, et al. 1963). The model can be empirical (descriptive), where various objects are considered important even though the relationship is unknown or a theoretical (genetic) model, where the attributes are interrelated through some fundamental concepts. In this study using a descriptive model approach and a genetic model Cox, et al. 1963).

a. Descriptive Model precipitate Nickel Laterite Gag Island

According to Cox and Singer (1963), the descriptive model has 2 parts, namely:

i. Geological Environment, describes the depositional environment found which includes the type and texture of rocks and ages that refer to tectonic settings related to additional conditions from the model described.
ii. Description of the deposit, describing the identifying characteristics of the deposit itself, especially emphasizing aspects of the deposit that can be identified through its geochemical and geophysical anomalies.

Referring to the explanation above, the descriptive model of laterite nickel deposits in the study area can be described in the form of a table as follows.

Table 2. Description model of laterite nickel deposits in the study area (Inspired by Donald A. Singer, 1963)

MODEL DESCRIPTION OF GAG ISLAND LATERITE NICKEL DEPOSIT			
Geological Environment		Description of Sediment	
Rock Type	Ultramafic Rocks such as: Serpentinized Peridotite, Harzburgite and Serpentinite)	Mineralogy	Garnierite, clay minerals, quartz, hematite, goethite, local cobalt.
Age Range	The bedrock is late Jurassic (Supriatna, et al. 1995). Weathering age of early - late paleocene (based on the Lamlam Formation of early - late paleocene age containing ultramafic rock breccias.	Texture/ structure	The soil is reddish brown in color, some places are dominated by bedrock fragments, locally found *silica boxworks*.
Depositional Environment	The intensity of chemical weathering is high and the intensity of physical weathering is low.	Alteration	Red and yellow limonite, soft saprolite under limonite, then hard saprolite, until peridotite is *fresh*.
Tectonic Settings	Convergent settings	Ore Control	Limonite contains an average Ni 0.8%Ni – 1.5%Ni, saprolite contains an average Ni> 1.5%Ni.
Associated Precipitation Type	Not identified	Weathering	Reddish-brown residual soil characterizes the product of chemical weathering of ultramafic rocks.
		Main Commodity	Rich in Ni and Fe.

b. Genetic Model precipitate Nickel Laterite Gag Island

A genetic model is a collection of related sediment group traits for which a particular object reason is useful if identified. As the object of the model becomes understood in a genetic sense, the descriptive model can develop into a genetic model and thus the descriptive model is developed into a genetic model so that it becomes much more flexible and powerful (Cox, et al. 1963).

Based on the explanation above, the following is a genetic model of laterite nickel deposits in the study area which can be seen in Appendix 1

c. Correlation Geological Control to Quality Nickel Laterite Deposit.

On the explanation of the sub-chapter above, it is known that the relationship of geological control to the quality of nickel deposits is interrelated. It is based that geological aspects such as Drainage patterns, geomorphology, lithology, and geological structures are aspects that are directly related to the formation process (genetic). So that the quality of laterite nickel deposits can be known based on genetics.

CONCLUSION

After research using the *mapping method surface*, then some conclusions can be drawn as follows.

1) Laterite deposits develop well in dendritic Drainage patterns, hilly plain morphology and the dominant process in the form of weathering and erosion, weathered lithology in the form of peridotite, and is located in the *hanging wall block* of faults trending southeast – northwest.
2) Characteristics of well-developed laterite deposits with clay texture in the limonite zone, local *rocky saprlite found*, with mineral assemblages in the form of hematite, goethite, silica, local garnierite, and manganese oxide. While the saprolite zone has a sandy clay texture, locally found chunks of bedrock, and the mineral assemblage consists of hematite, goethite, garnierite, and silica.
3) Ni levels reach an average of > 1.5% with a thickness of 5 meters to 20 meters located in peridotite lithology, hilly terrain with weak waves, dendritic drainage patterns, and located in the *hanging wall block of* faults trending southeast – northwest.
4) Based on geomorphology, laterite develops well in flat – slightly steep morphography (0^{o}-16^{o}).
5) The general trend of garnierite mineralization is relatively northeast – southwest due to garnierite mineral filling at the *extension joint* due to fault movement.
6) The relationship between geological control and nickel quality based on the results of the analysis in the studio and in the field shows that there is a bound relationship between geological control and nickel quality because it is genetically related to the formation of nickel laterite deposits.

REFERENCES

Ali Jason R, Hall Robert. 1995. Evolution of The Boundary Between The Philippine Sea Plate And Australia: Paleomagnetic Evidence From Eastern Indonesia. *Techtonophysics* 251 (1995) 251-275.

Anbiyak Nur, Cahyaningrum Tyas. 2020. Identification of Cobalt Rich Zones in Laterite Nickel Deposits in Indonesia**.** *Indonesian Mining Professionals Journal, Volume* 2, Number 2, November 2020: 103 – 110.

Butt, C. Cluzel, D. 2013. Nickel Laterite Ore Deposits: Weathered Serpentinits. Article in *Elements*, April 2013.

Charlton TR, Hall Robert, Partoyo E. 1991. The Geology and Tectonic Evolution of Waigeo Island, NE Indonesia. *Journal of Southeast Asian Earth Science*, Vol.6, No.3/4, pp.289-297, 1991.

Cox, DP and Singer, DA 1986: *The Mineral Deposit Model*. USGS. United States.

Edwards, R. and Atkinson, K. 1986: *Ore Deposit Geology and Its Influence on Mineral Exploration,* London-New York. Chapman and Hall.

Ministry of Energy and Resources Mineral Power. 2020. Opportunity Investation Indonesian Nickel. Ministry of Energy and Resources Mineral Resources of the Republic of Indonesia.

Golightly, JP 2010. *Progress in Understanding the Evolution of Nickel Laterites*. Society of Economic Geologists Special Publication, v. 15.

Howard AD 1967. Drainage Analysis In Geologic Interpretation: A Summation. *The American Association of Petroleum Geologists Bulletin*. V.51, No.11 (November 1967), P. 2246-2259. 4 Figs., 1 Table.

Huggett, R. 2007. *Fundamentals of Geomorphology Second Edition,* Routledge. London.

Ilyas Asran, Koki Kashiwaya, Koike Katsuaki. 2016. Ni grade distribution in laterite characterized from geostatistics, topography and the paleo-groundwater system in Sorowako, Indonesia. *Journal of Geochemical Exploration*. doi: 10.1016/j.gexplo.2016.03.002.

Ilyas Asran, Koike Katsuaki. 2012. Geostatistical Modeling of Ore Grade Distribution from Geomorphic Characterization in a Laterite Nickel Deposit. *Natural Resources Research,* Vol. 21, No. 2, June 2012.

Marsh Erin, Anderson Eric, Gray Floyd. 2010. *Nickel-Cobalt Laterites A Deposit Model*. Virginia. USGS.

Milsom J, Parson L, Masson D, Nichols G, Sikumbang N, Dwiyanto B. 1996. Tectonic of The Palau – Halmahera – Waigeo Triangle. *AAPG Bulletin; Circum-Pacific Council for Energy and Mineral Resources* 2009.

Parvis Merle. 1950. Drainage Pattern Significance in Airphoto Identification of Soils and Bedrock. *Highway Research Board*.

Indonesian Mineral Reserve Committee. 2011. Indonesian Exploration Results Reporting Code, Mineral Resources and Ore Reserves; Code-KCMI 2011. PERHAPI and IAGI.

Revuelta MB 2018. Mineral Resources From Exploration to Sustainability Assessment. Spanish. *Springer*.

Sam Permanadewi, Joko Wahyudiono, Armin Tampubolon. 2017. Laterite Nickel Deposits on Gag Island, Raja Ampat Regency, West Papua Province. *Geological Resources Bulletin* Volume 12 Number 1 – 2017: 55 – 70.

Supriatna, S., Hakim AS and Apandi, T. (1995), Geological Map of Waigeo Sheet, Irian Jaya, Research and Development Center Geology, Bandung.

USGS. 2011. *Ni-Co Laterites – A Deposit Model.* US Geological Survey, Reston, Virginia.

Van Zuidam , RA (1983). *Guide to Geomorphology Aerial Photographic Interpretation and Mapping*. ITC, Enschede, The Netherlands, 324 pp.

Verstappen, HT (1983). *Applied Geomorphology, Geomorphological Surveys for Environmental Development.* Amsterdam: Elsevier, 437 pp.

Waheed, A. 2018. *Nickel Laterite: Fundamentals Of Chemistry, Mineralogy Weathering Processes, Formation And Exploration*. Sorowako.

Zhengwei Zhang, Shu Qiao, Yang Xiaoyong, Wu Chengquan, Zheng Chaofei, Xu Jinhong. 2019. Review on The Tectonic Terraces Associated With Metallogenic Zone in Southeast Asia. *Journal of Earth Science, Vol. 30, No.1, P 1-9, February 2019.* https://doi.org/ 10.1007/s1258 3-019-0858-0.