*Journal Techno, Vol. 8, No.2, 2022, pp. 107 - 122*
*ISSN. 2461-1484*

# GEOLOGY AND GEOLOGICAL MODELS OF NICKEL LATERITE DEPOSIT GAG ISLAND, WEST WAIGEO DISTRICT, RAJA AMPAT REGENCY, WEST PAPUA PROVINCE

**Agus Harjanto[1], Bambang Kuncoro Prasongko[1], Joko Santoso[2], Waluyo Hadi[2], Nur Alif Yusuf Putra Karlina[3]**
[1]Geological Engineer, Teknologi Mineral Faculty, UPN "Veteran" Yogyakarta
[2]PT. Samudera Mulia Abadi
[3]Student of Geological Engineer, Teknologi Mineral Faculty, UPN "Veteran" Yogyakarta
**Corresponding author: aharjanto69@upnyk.ac.id*

## Abstract

*The location of the research is on Gag Island, West Waigeo District, Raja Ampat Regency, West Papua Province which is the area of PT. Nickel Gag. Based on the research flow chart, there are 3 main stages, namely data acquisition, data analysis, and synthesis. Physiography Gag Island is part of North Maluku (Northern Moluccas) which is included in the Raja Ampat Group. The drainage pattern found in the study area is the sub-dendritic alteration flow pattern (SDND). Geomorphology in the study area found denudational hills consisting of weak undulating hills D1, strong D2, and strongly eroded valleys D3. Lithology in the study area consists of 3 rock units, namely peridotite unit (Jp), dunite unit (Jd), and serpentinite unit (Js). The geological structure in the study area consists of the left horizontal fault of Gag 1 and 2, the right horizontal fault of Gag, paired joints, and veins. The geological model of Gag Island nickel laterite deposit consists of a bedrock model that affects the quality of nickel laterite deposits with a grade of 2-1.8% in harzburgite and dunite rocks; a slope model that affects laterite thickness with very gentle-slightly steep slopes >22 meters thick on harzburgite lithology; the geological structure model that influences the permeability of the bedrock with the presence of garnierite and chrysoprase mineralization in the fracture and help the leaching process. The exploration model is an application or application of a scientifically based geological model, besides that the exploration model is used as a command in finding exploration targets. Geological clues are used as an approach to search for nickel laterite deposits in the form of indications of flow patterns, geomorphology, lithology, geological structures, magmatogenic, and surrounding relationships.*

***Keyword:*** *The geological model, exploration, nickel laterite, Gag Island, Raja Ampat*

## INTRODUCTION

In Indonesia, the presence of nickel is dominated by laterite deposits (Mudd, 2014). Nickel laterite deposits known in Indonesia are found in the ophiolite belts of Southeast Sulawesi and Halmahera (Zhang, 2019). The islands of the Halmahera group are composed of bedrock in the form of ultramafic and alkaline rocks surrounded by deep-sea sedimentary rocks, one of which is Gag Island (Van Bemmelen, 1948). The enrichment of Ni in the profile is then controlled by several mutually influencing factors, such as the development of all pedolites, which include source rock, climate, chemistry/chemical weathering rate, channels, and tectonics according to several experts in (Marsh, Anderson, & Gray, 2013). In the search for mineral deposits, it is not possible to examine in detail every sq km in area or country. Knowing geological clues that can directly or indirectly indicate in the introduction what to look for. These clues must be distinguished from indications of mineralization - prospects that directly indicate the presence of ore (Kuzvart, 1986). Based on this, the author feels the need to conduct research to build a geological model of nickel laterite deposits on Gag Island which are included in this paper.

Administratively, the research area is located on Gag Island, West Waigeo, Raja Ampat Regency, West Papua Province which is the work area of PT. Gag Nickel (Figure 1) with a mapping area of 99 $km^2$.

The research method consists of 3 stages, namely acquisition, analysis, and synthesis. In the acquisition stage, initial data is taken in the form of primary data (geological mapping, observation of flow patterns and geomorphology, measured stratigraphic cross-section, and geological structure data collection) and secondary data (previous research). The analysis phase consists of flow pattern analysis, geomorphology, geological structure, petrography, mineragraphy, and geochemistry (assay) as well as nickel laterite deposit modeling. The stage of synthesis of geological information, geological models and exploration models as well as geological clues for nickel laterite deposits in the study area.

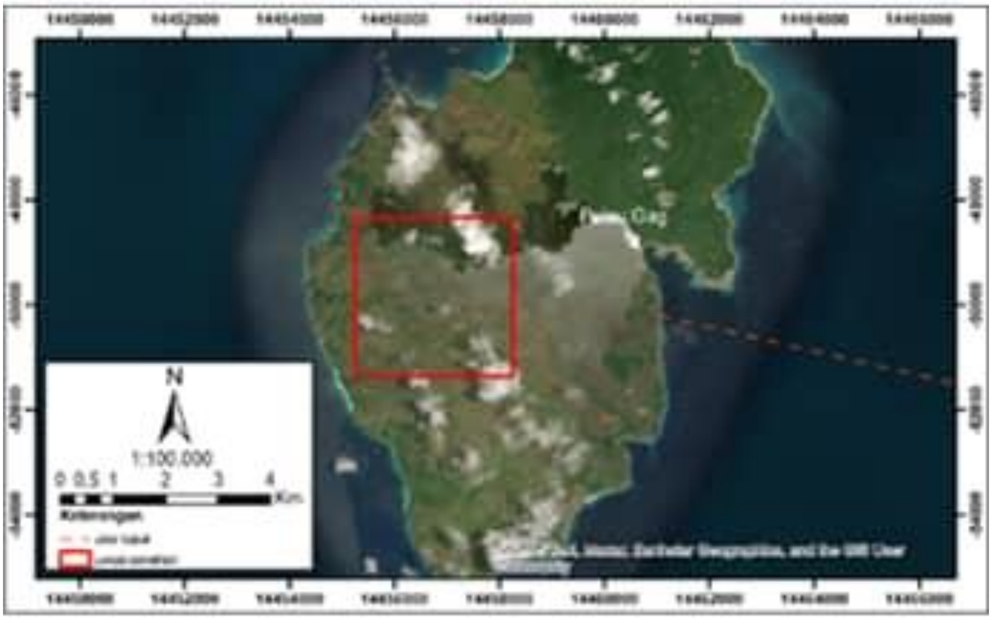


Figure 1. Location of research area

Physiography Gag Island is part of North Maluku (Northern Moluccas) which is included in the Raja Ampat Group (Bemmelen, 1948). The part of North Maluku, which connects the Philippines, New Guinea and Sulawesi, consists of a complex underwater ridge and plate that forms an archipelago and a series of small islands. The lithology is composed by a complex of bedrock in the form of mafic and ultramafic rocks with deep sea rocks being overlaid. Waigeo Island is part of the East Halmahera-Waigeo ophiolite plain, according to Ballantyne, 1990 the results of a detailed chemical and petrological study from East Halmahera ophiolite to Waigeo island which he interpreted to have formed in a supra-subduction zone (forearc) environment. According to (Sam Pemanadewi, 2017) the geological structure of Gag Island is controlled by the Sorong Fault and Halmahera Fault and forms a northwest-southeast direction.

## RESULT

### *Drainage Analysis*

Based on field observations, the drainage pattern found in the study area is sub-dendritic.

<u>Sub-dendritic Drainage Pattern</u>

Based on observations from the Gag Island base map and observations in the research area, the flow pattern in the study area is the result of wild flows, only when it rains the seasonal river body is filled with water. In contrast to the northern area of Gag Island, there is a river flowing by water throughout the year. Sub-dendritic flow patterns are interpreted as strong rock resistance, controlled by topography with slopes ranging from 18-33% (slightly steep). The flow texture is in the category of being interpreted that the lithology is rather difficult to pass water in the rock pores.

### *Geomorphology*

Based on observations from the topographic map of Gag Island and field observations in the research area, it was found that denudational hills consisting of weak undulating hills D1, strong undulating D2, and strong eroded valleys D3 were generally influenced by exogenous and endogenous processes. Exogenous processes in the research area are weathering, dissolving, leaching, and erosion. Endogenous processes in the study area consist of lifting, faulting, and jointing.

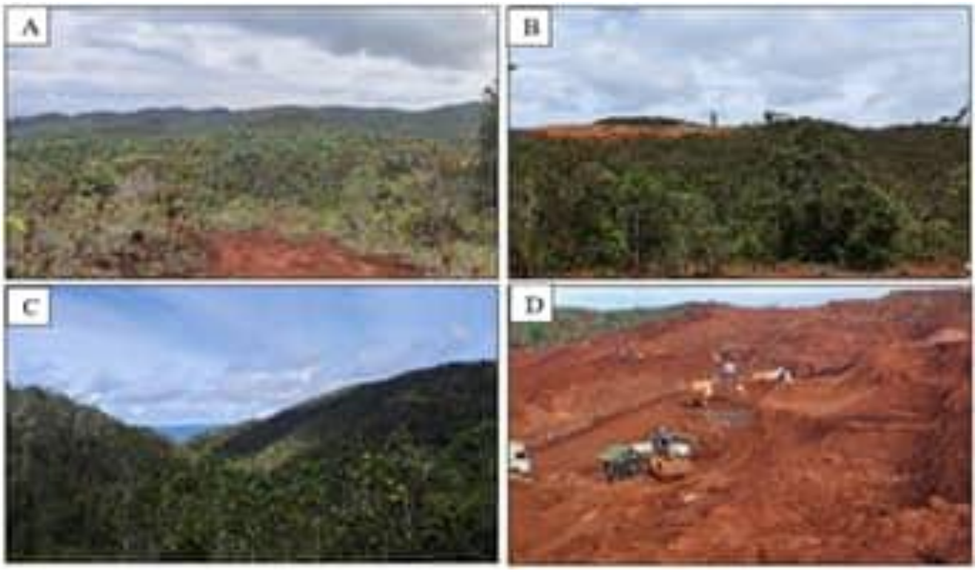


Figure 2. Landform of research area; A. Weak undulating hills (D1), B. strong undulating hills (D2), C. strong eroded valley (D3), D. mining area (A1)

***Stratigraphy***

Peridotite unit (Jp)

The peridotite unit, laterite was found with a reddish-brown color (Figure 3). Jurassic (148 million years ago) peridotite unit (S. Supriatna, 1995) consisting of harzburgite. Harzburgite in the study area has megascopic characteristics of fresh green-black color, holocrystalline degree of crystallinity, coarse-faneric phaneric granularity, euhedral crystal form, panidiomorphic granular equigranular relation, mineral composition of olivine (76%), pyroxene (19%) and serpentine (5%). The relationship between dunite units and peridotite units and serpentinite units is estimated to be graded. Some of the serpentine harzburgite has a selective pervasive pattern, weak intensity, characterized by the presence of serpentine minerals (antigorite?, lizardite?) that replace olivine (Figures 4 and 5).


Figure 3. Peridotite unit outcrops

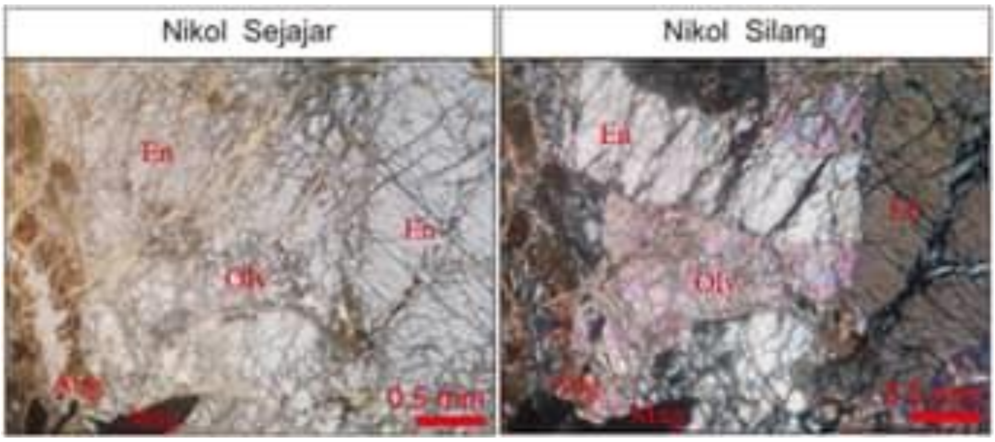


Figure 4. Microscopic photo of harzburgite with olivine and enstatite textured mesh structure

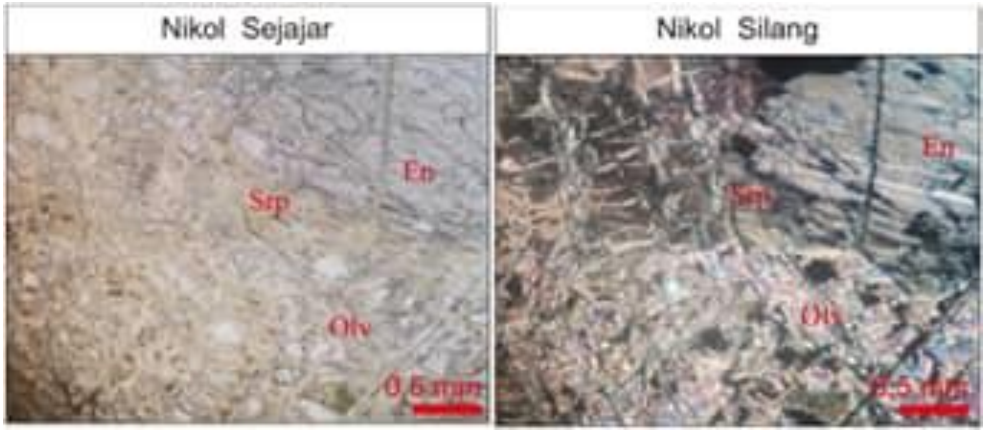


Figure 5. Microscopic photo of serpentinized harzburgite the presence of serpentine which altered enstatite and olivine

<u>Dunite unit (Jd)</u>

The appearance in the field is in the form of fresh rock in channel (Figure 6). The dunite unit was formed simultaneously with the peridotite unit in the Jurassic period (148 million years ago) (S. Supriatna, 1995). The dunite in the study area has megascopic characteristics of dark green-green fresh color, holocrystalline crystallinity, medium-coarse phaneric granularity, euhedral crystal form, equigranular panidiomorphic granular relations, mineral composition of olivine (95%) and pyroxene (5%). The relationship between dunite units and peridotite units and serpentinite units is estimated to be graded. Microscopically, the dunites in Figure 7 are peach to colorless, the degree of crystallinity is holocrystalline, the degree of granularity is coarse-faneric medium, euhedral-subhedal crystal form, equigranular panidiomorphic granular relation, with a mesh structure texture, mineral composition of olivine (92%), enstatite (5%), and Augit (3%).

Figure 6. Dunit unit outcrops

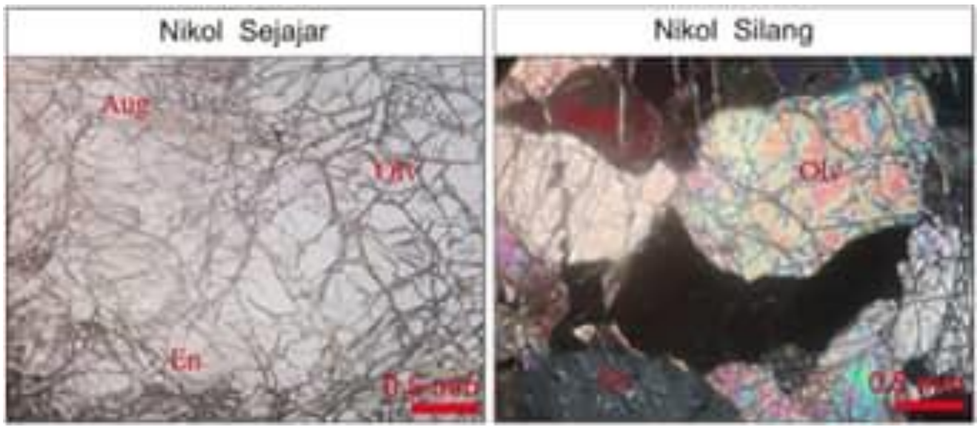


Figure 7. The microscopic photo of dunite is dominated by olivine and pyroxene minerals with a mesh structure texture

<u>Serpentinite unit (Ts)</u>

The appearance in the field is in the form of fresh rock and laterite. Laterite is reddish brown in color (Figure 8). Serpentinite units formed in the Jurassic Period along with the formation of dunites and peridotites (148 million years ago) (S. Supriatna, 1995). The serpentinite unit is composed of serpentinite and strongly serpentine harzburgite. Serpentinite in the study area has a yellowish green color, linear structure, with nematoblastic critaloblastic texture, mineral composition is dominated by stress minerals in the form of serpentine (80%) (lizardite? and antigorite?), pyroxene (10%), olivine (10%). Microscopically, serpentinite in Figure 9 is peach to colorless, linearly nonfoliated structure, nematoblastic texture with a special mesh structure, stress mineral composition is serpentine (84%), enstatite (11%), and magnetite (5%).

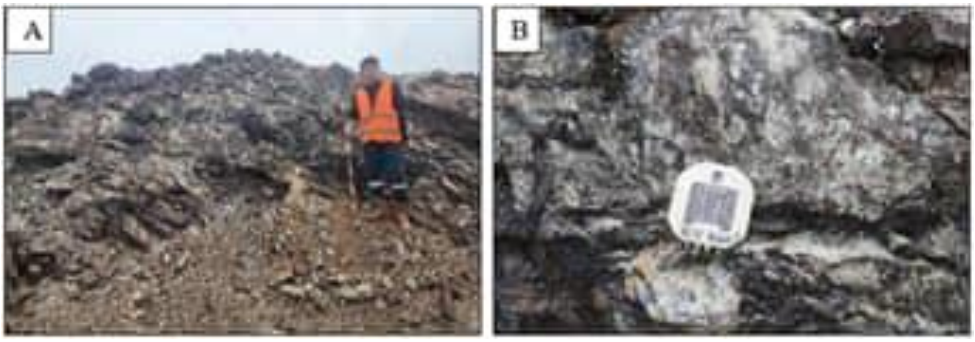


Figure 8. Serpentinite unit outcrops

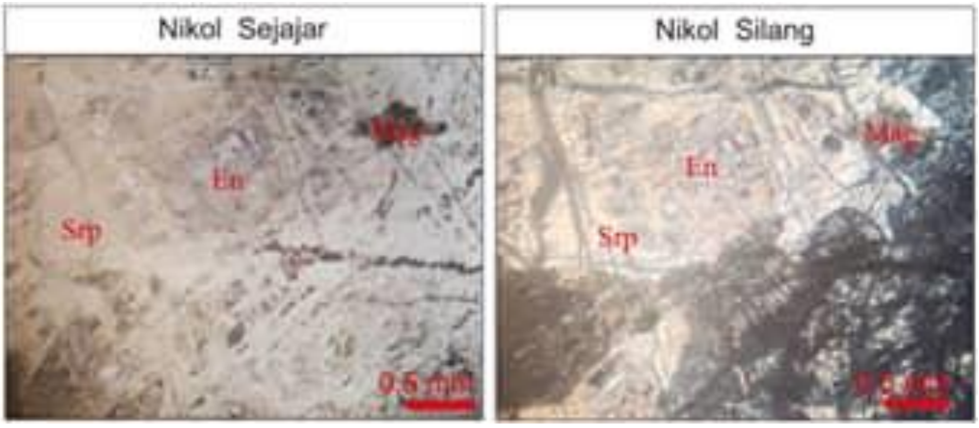


Figure 9. Microscopic photo of serpentinite the presence of serpentine which altered enstatite and olivine

***Geological Structure***

The geological structure that develops in the study area is influenced by the sliding fault system. Based on the evidence found in the field at several locations of observation of geological structures that developed in the research area in the form of joint structures and faults. Geological structure analysis was carried out using the stereographic method after obtaining data in the field. The geological structure is a left slip fault of Gag 1 which has a strike and dip N090°E/75° and a left slip fault of Gag 2 with a strike and dip N271°E/80° in a west-east direction, a right horizontal fault of Gag in a southwest-northeast direction and a srike and dip N050°E/73°, and pairs of shear joint and tensile joints that have the main stress from the southwest-northeast direction (Figure 10).

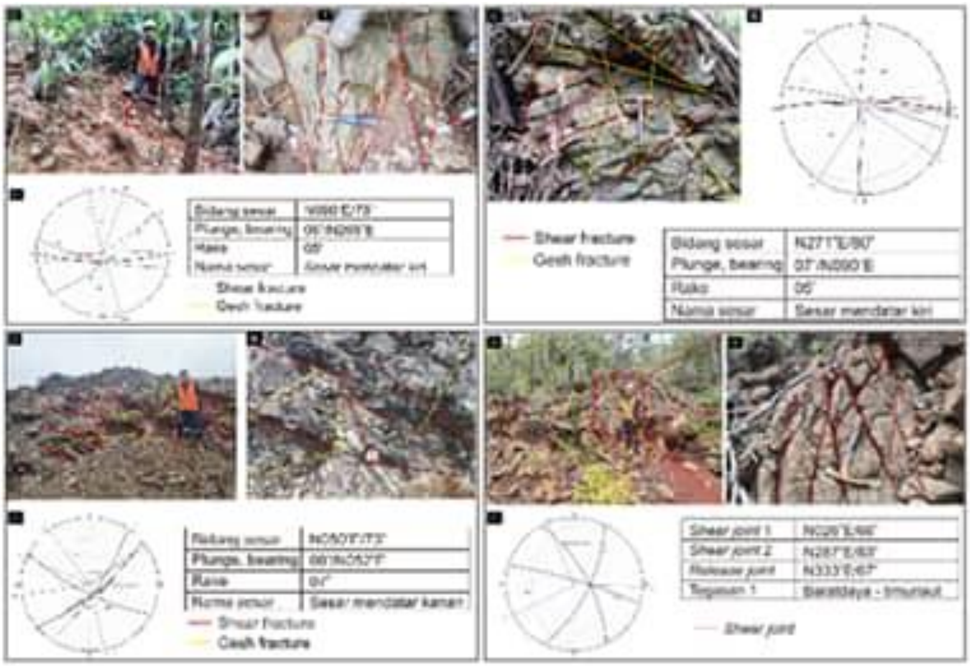


Figure 10. Geological structure in research area

There is a geological map of the research area (Figure 11).

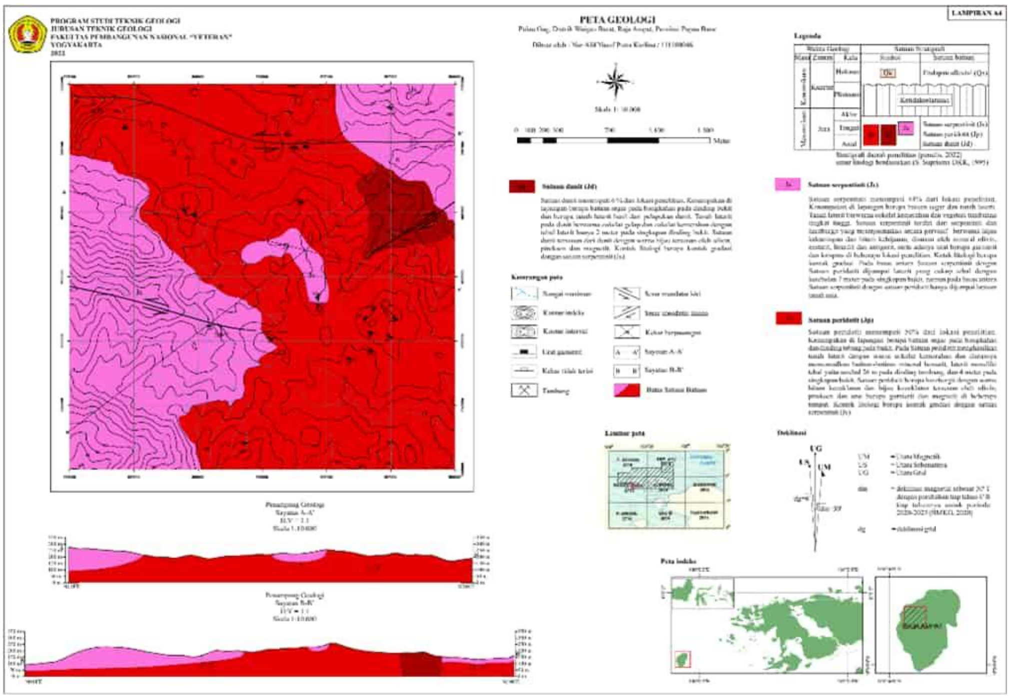


Figure 11. Geological map of research area

## DISCUSSION

Based on field observations, the authors found differences between lithology, geomorphology, and geological structures that influenced the development of nickel laterite deposits in the working area of P.T. Gag Nickel, Gag Island. Building a geological model of nickel laterite deposits begins with making a descriptive model, then interpreting it according to the geologist's beliefs which will later become a geological model. The geological model created is used to anticipate the exploration model and determine the exploration model. The exploration model will later be revealed as geological clues to search for nickel laterite deposits.

***Descriptive Model***

Based on field observations, a descriptive model was made to build the basis of nickel laterite deposits in the study area. The descriptive model table for nickel laterite deposits can be seen in Table 1.

Table 1. Descriptive model of Gag Island nickel laterite deposit.

| No | Geological environtment | Description |
|---|---|---|
| 1. | Drainage | **Sub dendritic,** has:<br>a. The medium flow texture indicates that the lithology is rather difficult to pass water in the pores of the rock.<br>b. The deviation of the flow pattern that forms an angle of 88o – 85o with a relatively uniform flow direction in the direction of the slope can be interpreted as the influence of faults and joints.<br>c. The V-shaped valley is steep and V-shaped |
| 2. | Geomorphology | **Weak undulating hill landform**, has:<br>a. Morphography in the form of hills<br>b. b. Slope 3.20% - 20.64% (very gentle),<br>c. c. Relief in the form of undulating - sloping undulating,<br>d. d. In particular, it forms a land form in the form of a dissected plateau.<br>**Strong undulating hill landform**, has:<br>a. Morphography in the form of hills<br>b. Slope 15.20% - 32.26% (slightly steep – steep)<br>c. Relief in the form of rolling hill – step hilly<br>d. In particular, it forms land forms in the form of rolling hills and step hills. |
| 3. | Lithology | Serpentinized harzburgite, harzburgite, dunite and serpentine. |
| 4. | Age | Jurassic bedrock, probably weathered in the Cenozoic. |
| 5. | Laterite texture | Fine grained (fine clay-sand) with a medium-soft texture in the limonite-saprolite zone.<br>The minerals garnierite and chrysoprase are textured in-filling in rock fractures and covered by silica. |
| 6. | Mineralogy | Hematit + Goetit + Limonit + Nodul mangan dioksida + Silika + Garnierit + Krisopras + Sepentin (lizardit + antigorite) |
| 7. | Geological structure | **Joint,** the joints found are joints that control the lateriation process, namely: |

| No | Geological environtment | Description |
|---|---|---|
| | | 1. Tensile joints filled with minerals garnierite, chrysoprase, and magnetite.<br>2. Paired crushing joints that are not filled with minerals.<br>**Fault,** faults that control the laterization process, namely:<br>1. Right slip fault<br>2. Left slip fault |
| 8. | Alteration | Serpentinization in harzburgite |
| 9. | Ore control | The limonite zone contains 0.4-1.5% Ni, 0.2-0.01% Co, and 54.97-24.35% Fe in iron oxide minerals.<br>The saprolite zone contains 1.6-2.41% Ni, 0.02-0.001% Co, and 23%-5.20% Fe in hydrosilicate minerals and iron oxide minerals.<br>Laterite thickness varies from the outcrop of 2 meters to 22 meters. |
| 10. | Characteristic geochemistry | Enrichment of Co, and Fe in the limonite zone, and Ni in the saprolite zone. The deeper you go, the richer the MgO. |
| 11. | Tectonic setting | *Island arc* |

***Geological Model***

The nickel laterite deposit geological model was built from a descriptive model and then interpreted based on the beliefs of a geologist. The geological model of nickel laterite deposits on Gag Island was built based on data on geomorphology (slope), lithology (bedrock), and geological structures.

Based on the laterite profile physically, laterite found in harzburgite lithology, and dunite contains garnierite and chrysoprase minerals geochemically, Ni content ranges from 2-1.8% in these two rocks, in contrast to laterite found in serpentinite lithology does not contain garnierite and chrysoprase minerals. , geochemically the levels of Ni ranged from 0.6-1.3%. Nickel laterite deposits vary in thickness vertically at 19 meters thick harzburgite, 2 meters thick dunite, and 5 meters thick serpentinite, but horizontally laterite is only spread over harzburgite, dunite and slightly on serpentinite Figure 12-14.

Figure 12. The harzburgite lithology model of the Gag Island nickel laterite deposit.

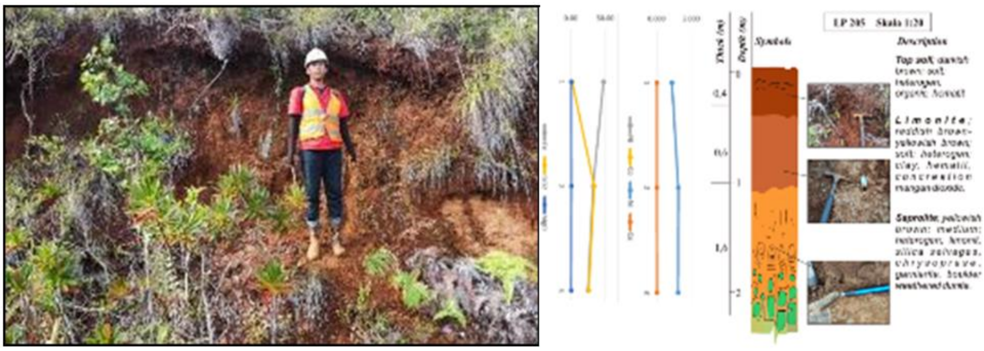

Figure 13. The dunite lithology model of the Gag Island nickel laterite deposit

Figure 14. The serpentinite lithology model of the Gag Island nickel laterite deposit

Based on field facts, the slope is very gentle (3-10%) with thick harzburgite lithology laterite in the cliff outcrop having a thickness of 4 meters this can be even thicker, as evidenced in the mine area where the slope is initially gentle-rather steep (18-32%) which is 19 meters thick and the presence of garnierite minerals, the quality of Ni ranges from 2-1.8%. On slightly steep slopes (18-32%) with thick dunite lithology laterite in the cliff outcrop has a thickness of 2 meters and this can be even thicker and on serpentinite lithology 4 meters thick laterite but there is no garnierite mineral. On very gentle to slightly steep slopes, water infiltration is more dominant than run off water, causing the leaching process to take place well. In strongly eroded valleys with steep slopes (25-32%) only 1 meter thick top soil is formed, this is because water is dominantly run off rather than water infiltration, causing the leaching process to take place less well (Figure 15).

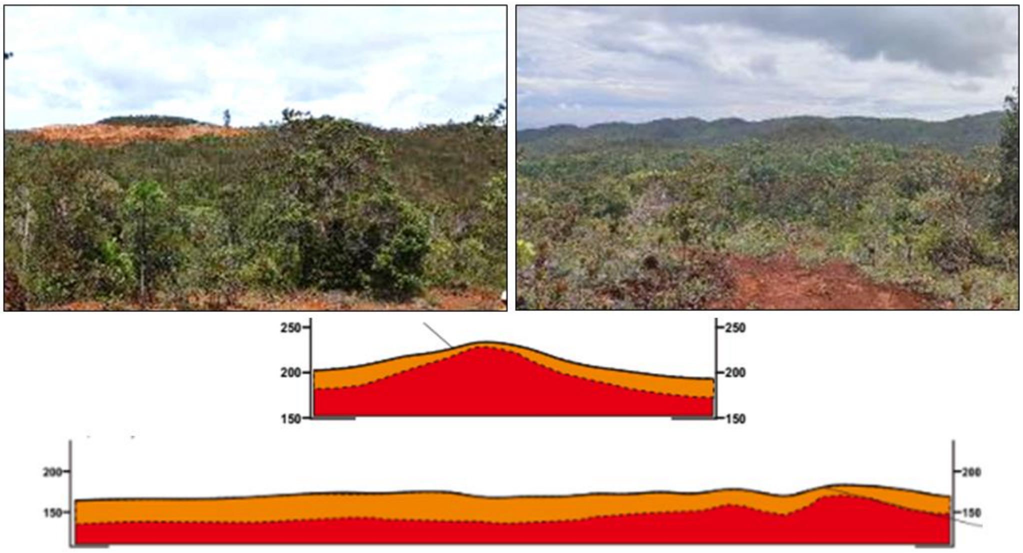


Figure 15. Gag Island lateritic nickel deposit slope model

Based on field observations of the faults that control laterization in the southwest part of the research location in the form of a left horizontal fault with Fe pisolite found on the laterite surface, this could happen because water infiltration into the rock through fractures in the rock is more dominant than run off water. Mineralization in nickel laterite deposits is found in fractures filled with garnierite and chrysoprase minerals. Both minerals are very high levels (> 2). However, in the western valley, laterite is not formed due to the steep slope, so that water is dominantly run off rather than infiltration into fractures in the rock (Figure 16).

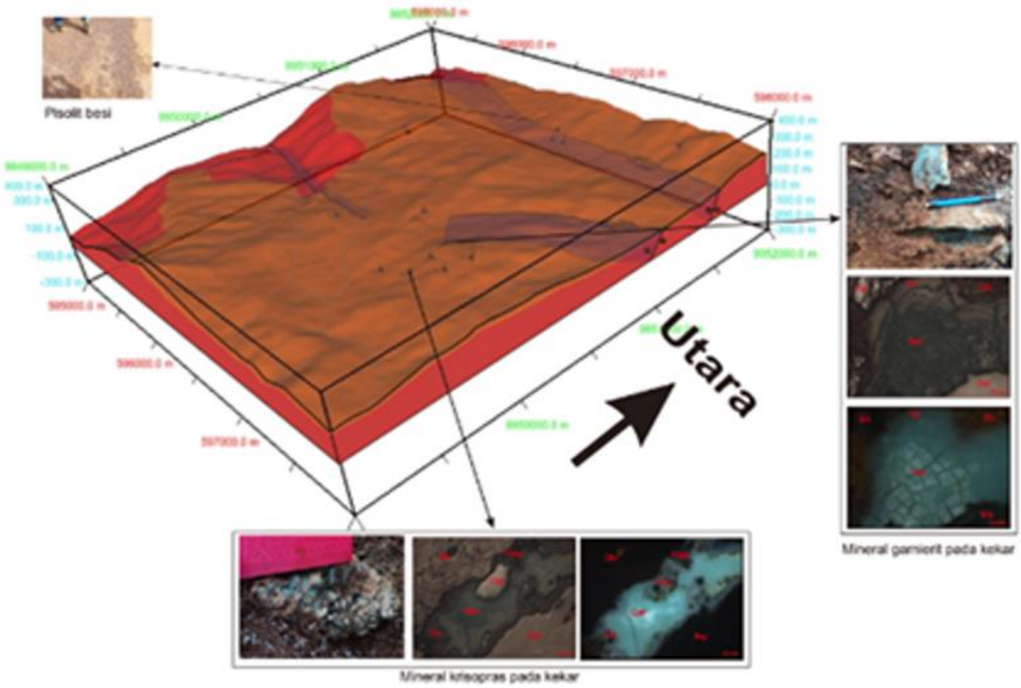


Figure 16. Geological structure model of the Gag Island Nickel laterite deposit

***Exploration Model***

According to (Corbet & Leach, 1997) the exploration model is derived from interpretation, with a focus on the characteristics of the deposit model that helps the discovery of ore deposits with certain characteristics. The exploration model is the application or application of a scientifically based geological model, besides that the exploration model is used as a command in finding exploration targets with several methods, namely geological methods such as characteristics of flow patterns, geomorphology, lithology, geological structures etc., geophysical methods carried out by other parties. Such as the GPR method, and geoelectric; and finally the geochemical method for Gag Island nickel laterite deposits as shown in Figure 17.

***Geological Clue***

Based on the exploration model for nickel laterite deposits, geological clues regarding nickel laterite deposits can be derived in Figure 17. Geological clues are used as an approach to find the geological object.

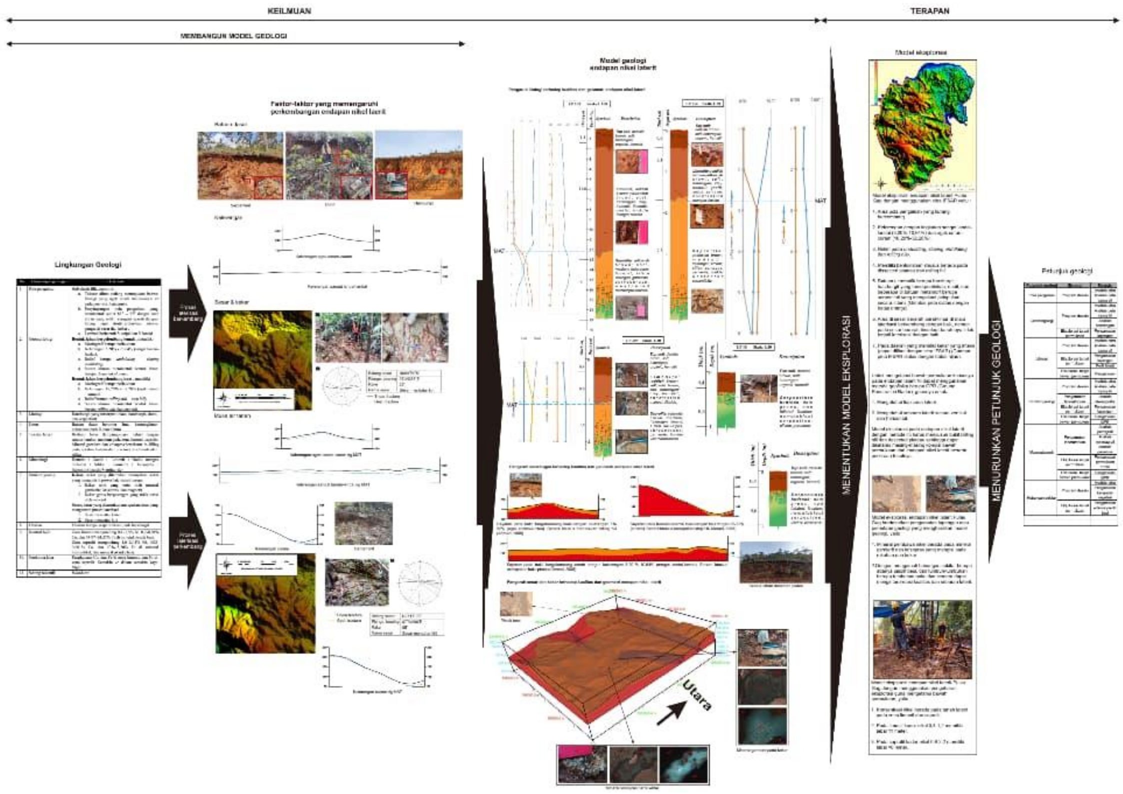


Figure 17. Geological models of laterite nickle deposit in Gag Island

**CONCLUSION**

From the results of the research that has been done, it can be concluded:

1. The geology of the study area consists of subdendritic drainage patterns; landforms of weak undulating hills, strong undulating hills, strongly eroded valleys, and mining areas; the lithology consists of dunite units, peridotite units, and serpentinite units in the Jurassic ultramafic complex and recent

alluvial deposits; geological structures that developed in the form of left horizontal faults Gag 1 and 2 and right horizontal faults Gag; The research area has three original forms, namely Structural Origin Form Units consisting of Structural Slope Land Forms (S1), Structural Hills (S2), and Structural Valleys (Structural Valleys). S3). The Fluvial Origin Form Unit consists of the River Body Land Form (F1).

2. The geological model of Gag Island nickel laterite deposit consists of a bedrock model that affects the quality of nickel laterite deposits with a grade of 2-1.8% in harzburgite and dunite rocks; a slope model that affects laterite thickness with very gentle-slightly steep slopes >22 meters thick on harzburgite lithology; the geological structure model that influences the permeability of the bedrock with the presence of garnierite and chrysoprase mineralization in the fracture and helps the leaching process.
3. The lateritic nickel deposit exploration model on Gag Island must follow areas that (1) have less developed flow patterns. (2) Slopes are very gentle-slightly steep, (3) Relief undulating, sloping undulating, and rolling hilly. (4) In the form of dissected plateau and rolling hill. (5) In harzburgite, serpentine harzburgite, dunite, and some serpentinites. (6) In the west-east trending fault area in the north. (7) has intense stockings. (8) Mineralization of garnierite and chrysoprase in fractures and joints. (9) Ni is concentrated in the limonite and saprolite zones. (10) The highest levels were in the saprolite zone 2.2% and the limonite zone 1.2%. (11) On the surface there are iron pisolites and ferns and cypresses.
4. Geological clues that can be derived from the exploration model are (1) indications of flow patterns. (2) Geomorphological clues (3) Lithological clues. (4) Guidance of geological structure. (5) Magmatogenic Hints. (6) Hints of approx. relationship.

## REFERENCES

Ahmad, W. (2008). Nickel Laterites. VALE Inco-VTSL.

Arifudin Idrus, D. (2007). Eksplorasi Sumberdaya Mineral. Yogyakarta: Universitas Gajah Mada.

Babcock, J. W. (1984). Introduction to Geologic Ore Deposite Modeling. Journal Mining Engineering.

Ballantyne, P. (1991). Petrological Constraints Upon The Provenance and Genesis of The East Halmahera Ophiolite. Journal of Shoutheast Asian Earth Science Vol. 6, 259-269.

Bemmelen, V. (1948). The Geology of Indonesia Vol. 1A. General Geology of Indonesia and Adjacent Archipelagoes. Batavia: Former Member of The Netherlands Indies Geological Survey and Head of The Netherlands Indies Volcanological Survey.

Brand, N. W., Butt, C. R., & Elias, M. (1998). Nickel laterites: Classification and Features. AGSO Journal of Australian Geology & Geophysics, 81-88.

Charles J. Moon, M. K. (2006). Introduction to Mineral Exploration Seconf Edition. Leichester: Blackwell.

Corbett, G. J., & Leach, T. (1997). Short Course Manual: Southwest Pacific Rim Gold Copper System: Structure, Alteration and Mineralization.

Cox, D. P., & Singer, D. A. (1992). Mineral Deposit Models. Denver: USGS.

Hall, R. (2014). Indonesian Tectonics : Subduction, Extension, Provenance and More. Proceedings, Indonesian Petroleum Association.

Hamilton, W. (1979). Tectonic of the Indonesian Region. Washington : Departement of Interior U.S.

Howard, A. D. (1967). Drainage Analysis in Geologic Interpretation a Summation. The AAPG Bulletin, 2246-2259.

Hugget, R. J. (2007). Fundamentals of Geomorphology Second Edition. Poynton: Routledge .

IAGI. (1996). Sandi Stratigrafi Indonesia. Jakarta: Pengurus Pusat IAGI 1995-1996.

Kuzvart, Milos., & Bohmer, Miloslav. (1986). Prospecting and Ecploration of Mineral Deposits. Prague: Elsevier.

Marsh, E., Anderson, E., & Gray, F. (2013). Nickel-Cobalt Laterite-A Deposit Model. Reston, Virginia: U.S. Geological Survey.

Mudd, G. M. (2014). A Detailed Assessment of Global Nickel Resource Trends and Endowments. Economic Geology, 1813-1841.

Pirajno, F. (2009). Hydrothermal Processes and Mineral System. Perth: Springer.

Revuelta, M. B. (2018). Mienral Resources From Exploration to Sustainability Assesment. Madrid: Springer.

Rickard, M. J. (1972). Fault Classification: Discussion. Geological Society of America Bulletin, 2545-2546.

Robert Hall, G. N. (1991). The Character and Significance of Basement Rock of The Southern Molucca Sea Region. Journal of Southeast Asian Earth Science, Vol. 6, No3/4, 249-258.

S. Supriatna, A. H. (1995). Peta Geologi Lembar Waigeo, Irian Jaya. Bandung.

Sam Pemanadewi, J. W. (2017). Cebakan Nikel Laterit di Pulau Gag, Kabupaten Raja Ampat, Provinsi Papua Barat. Buletin Sumber Daya Geologi Vol. 12, 55-70.

Selley, R. C., Cocks, L. M., & Plimer, I. R. (2005). Encyclopedia of Geology. London: Elsevier Academic Press.

T. R. Charlton, R. H. (1991). The Geology and Tectonic Evolution pf Waigeo Island, NE Indonesia. Journal of Seoutheast Asian Earth Sciences, Vol. 6, No. 3/4, 289-297.

Vestrappen, T. H. (1970). Introduction to the ITC - System of Geomorphology Survey. KNAG Geografisch T.