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RESEARCH ARTICLE **Open Access**

Geocomputational Method to Determine the Effect of Serpentinized Ultramafic Rocks on Laterite Nickel Distribusion

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Abstract: Administratively, the study area is located in Wolo District, Kolaka Regency, Southeast Sulawesi Province. This research aims to assess the relationship between the serpentinization process and the grades and distribution of laterite nickel. The methods employed include data collection through drilling, which involves logging procedures and laboratory analyses such as petrographic and geochemical analyses (X-Ray Fluorescence). The geocomputational method, Inverse Distance Weighting (IDW), is subsequently applied to determine the distribution of laterite nickel. Observations indicate that the bedrock in the study area consists of ultramafic rock types, including Lherzolite, Olivine Websterite, and Serpentinite. Some of these rocks have undergone serpentinization, while others have not. The serpentinization levels in the study area are classified into three categories: weak serpentinization (≤15%), moderate serpentinization (35%-50%), and strong serpentinization (55%-75%). Nickel grades in strongly serpentinized rocks are 0.22%, in moderately serpentinized rocks 0.50%, in weakly serpentinized rocks 0.32%, and in rocks that have not undergone serpentinization 0.30%.

Keywords: Serpentinization; Ultramafic Rocks; Nickel Laterite; Geocomputation.

1. Introduction

Ultramafic rocks are igneous rocks that contains 45% or more ferromagnesian minerals and 0.3% or less nickel. Specific Ferromagnesian type minerals in ultramafic rocks are olivine (Mg_2SiO_4; Fe_2SiO_4), pyroxene ($CaSiO_3$; $MgSiO_3$; $FeSiO_3$), hornblende, mica, and biotite. The main source of nickel laterite deposits comes from ultramafic rocks in the Sorowako region (South Sulawesi Province) 3 [1][3][5][2]. Previous research showed that the chemical composition of Sorowako ultramafic rocks was also in accordance with ultramafic rocks in some other areas including the province of Southeast Sulawesi, Kalimantan Province, Papua Province and the international level in New Caledonia, and the Philippines.

Ultramafic rocks are generally found in the depths of Earth's layers, especially the oceanic crust. Through geological processes, these ultramafic rocks are brought into the Earth's surface and undergo fractional weathering of ferromagnesian minerals due to which they change into serpentinized ultramafic rocks. Serpentinization is a geological process that happens when ultramafic rocks become reactive to water and atmospheric gases, creating new minerals, including serpentine and magnesite [4]. This geochemical process is important as it can alter the rocks' physical and chemical properties, and the nickel content as well. When exposed to the surface, serpentinized ultramafic rocks are subject to lateritization, resulting in a kind of laterite deposits. Laterite is a product of weathered deposits and a rock that is metalliferous, containing certain metal minerals such as nickel and cobalt, and is naturally formed within the tropics [9].

Nickel ranks among the biggest mining commodities in the world. It is mined for the production of different types of products such as metal, refined nickel, powder, sponge, and more. Nickel laterite deposits are the primary source of nickel for global industry, as the high nickel content in laterite rocks allows for more efficient extraction of nickel in the mining industry. Thus, to optimize exploration strategies and resource utilization, knowledge of the distribution and geochemical characteristics of ultramafic and laterite rocks is important 3.

Geocomputation is a field of research that focuses on the application of programming and computational techniques to geospatial and geological data analysis. Machine technology has also revolutionized geospatial analysis as geocomputation has evolved quickly, becoming an essential aspect of geospatial analysis and an approach for GIS software that maps, analyzes, and models geological data. Geocomputation, as a field, offers a variety of branches that specialize in different aspects of geospatial data analysis, such as geostatistics and programming algorithms to predict metal distribution in rock [8][10]. Method widely used in geocomputation research is Inverse Distance Weighting (IDW) which is helpful to map the spatial distribution of nickel on laterite deposits. This method enables researchers to map where metals are located in the area by combining point data collected through drilling or field samples.

Geocomputation in studies of geology can also show how rocks' physical characteristics relate to the presence of particular minerals in it so that more accurate predictions can be made about the potential of untapped natural resources. In this research, IDW is applied to model the distribution of laterite nickel in Sorowako and it could enhance exploration productivity as well as nickel resource utilization in this research area. Using this method, the researchers can get clearer insights into the difference in nickel concentrations around the study region, which helps in driving decisions in resources monitoring and development policies. Based on field observation data as Lherzolite, Olivine Websterite, and Serpentinite. Some of these rocks are serpentinized and some are not. The health and abundance of nickel in these rocks are influenced due to serpentinization. Highly serpentinized rocks are enriched in nickel compared with unmetamorphosed equivalents. Nickel in strongly serpentinized rocks is 0.22%, in moderately serpentinized rocks -- 0.50%, in weakly serpentinized rocks -- 0.32% Non-serpentinized rocks, on the other hand, demonstrate a nickel content of 0.30%.

2. Research Method

This study used a multidisciplinary approach of field, laboratory, and geospatial techniques applied to study the serpentinization process and nickel distribution within the scope of this work. To gain an understanding of the spatial distribution of nickel laterites, and the influence of factors causing their accumulation, a combination of methods was used. The first step in data collection involved drilling core samples at various locations in the study area. At carefully selected locations, we drilled to collect ultramafic rock samples from different depths. Geological characteristics (rock type, texture, and degree of alteration) were recorded for each core sample. The core samples were then carefully preserved and transported to the laboratory for further analysis. The core samples were analyzed petrographically by making thin sections. A petrographic microscope was used to study thin sections that can provide information about mineralogical processes by considering the presence and degree of serpentinization, which can be detected in thin sections. For example, petrographic analysis can be used to classify rocks based on several mineralogical compositions and identify serpentine minerals (e.g., chrysotile), which are important indicators of serpentinization. X-ray fluorescence (XRF) was used to perform geochemical analysis of the core samples. The elemental composition of the samples was determined by XRF, mainly nickel and trace elements. XRF analysis data are very important for determining the nickel content in ultramafic rocks and evaluating the effects of serpentinization on the distribution and concentration of nickel in the study area.

Geological mapping, nickel distribution, and serpentinization level were performed through ArcGIS 10.8 software, which is a key feature of the advanced Geographic Information System (GIS) tool. ArcGIS was used as a tool to input, sort, and map spatial data collected in the field through sampling, as well as samples processed in the laboratory that correspond to the geological characteristics of the area of interest. To depict the stratigraphy of the site, locate the lithological units and the main geological structures, a geological map was created. The map shows the distribution of nickel, visualizing the spatial variability of nickel content in the area. A serpentinization level map was then created by classifying the serpentinization level into weak, moderate, and strong according to the results obtained at the petrographic and geochemical levels. Through this map, the relationship between serpentinization and nickel mineralization can be better determined.

2D and 3D representations including Geocomputational techniques were used to process the field data. The 2D map generated in ArcGIS focuses on the spatial distribution of nickel and the serpentinization level in the study area. This map can show trends and anomalies in the data that can indicate greater mineralization potential. Geostatistical tools available in ArcGIS are used to generate 3D visualizations for more sophisticated data analysis. Global 3D Model Showing Variation in Nickel Grade & Serpentinization with Depth. Using inverse distance weighting (IDW) and other interpolation algorithms, this study produces a continuous surface model that represents the distribution of nickel and serpentinization in the study area. The 3D model of the mineral data can be used to evaluate how geological structures can be related to nickel deposition, and how favorable the area is for further nickel exploration.

In addition to IDW, there are other geostatistical techniques to represent spatial clustering of nickel and serpentinization. So, kriging is a common geostatistical interpolation method used to create a more accurate nickel model by examining spatial autocorrelation between samples. Kriging Method – Utilizes the correlation structure of nickel sample points to estimate nickel grade at unsampled points. This technique allows us to classify nickel concentrations in unsampled areas, thus taking our exploration strategy to the next level.

This study also utilizes remote sensing and satellite imagery to complement field and laboratory data. We examined surface features seen in high-resolution satellite imagery that may be related to the distribution of ultramafic and lateritic rocks. The Martian surface was imaged in color, and image processing techniques such as spectral analysis were used to identify different rock types and alterations. This makes satellite imagery useful in identifying areas of surface exposure with more extreme serpentinization that can guide future field sampling and drilling efforts. Data Integration and Modeling: The final phase of this research involved bringing together all of our data from the field, lab, and geospatial maps into a single model. This model was used to interpret the relationship between serpentinization and nickel grade, with an emphasis on evaluating areas of high exploration potential. QRMIQ has outputs for seismic data interpolation that can be enhanced by combining multiple data sources; integrating multiple data sources through GIS and geocomputational methods helps create a simple, dynamic model that can inform future exploration activities.

3. Result and Discussion

3.1 Results

3.1.1 Morphology

The morphology of the study area has a topography that is generally composed of peridotite ultrabasic rocks. The topography of the research area is a hilly area with an average altitude of 50-200 meters above sea level [1]. Microscopically composed of lherzolite, olivine websterite, and serpentinite lithology.

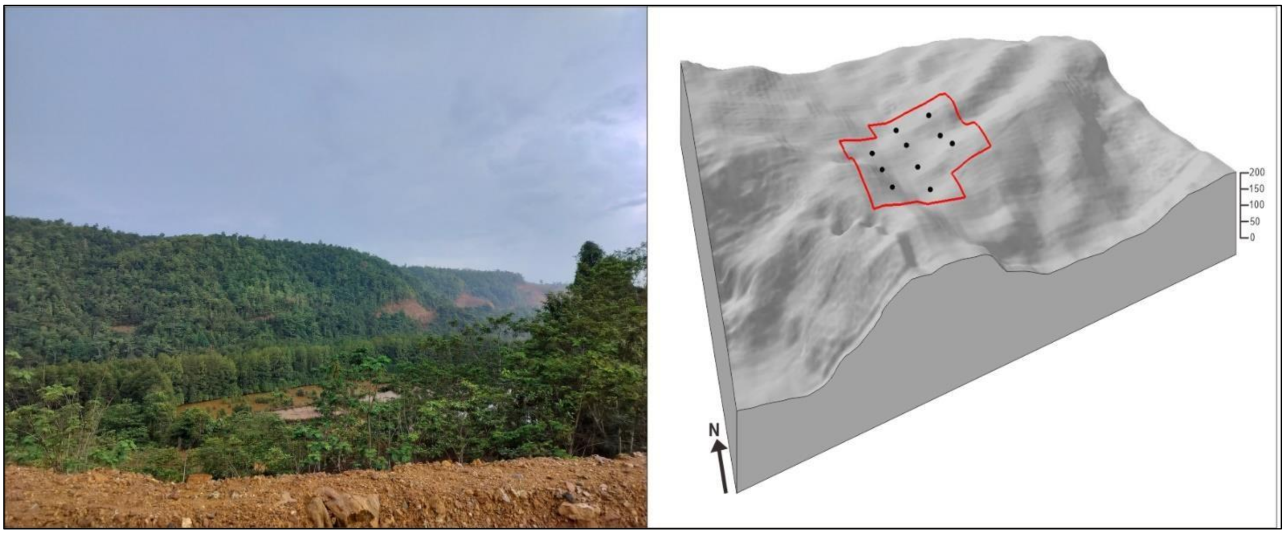


Figure 1. Appearance of Denudational Hills Geomorphology Unit (Photo direction N61o E)

3.1.2 Lithology

Figure 2 Appearance of Denudational Hills Geomorphology Unit (Photo direction N61o E). minerals. Based the field data, the unit is composed of peridotite lithology. Megascopic characteristics have physical characteristics of blackish brown weathered color, blackish gray fresh appearance, holocrystalline crystalline texture, faneritic granularity, euhedral-subhedral mineral shape. Massive structure with mineral composition consisting of olivine, pyroxine and serpentine minerals.

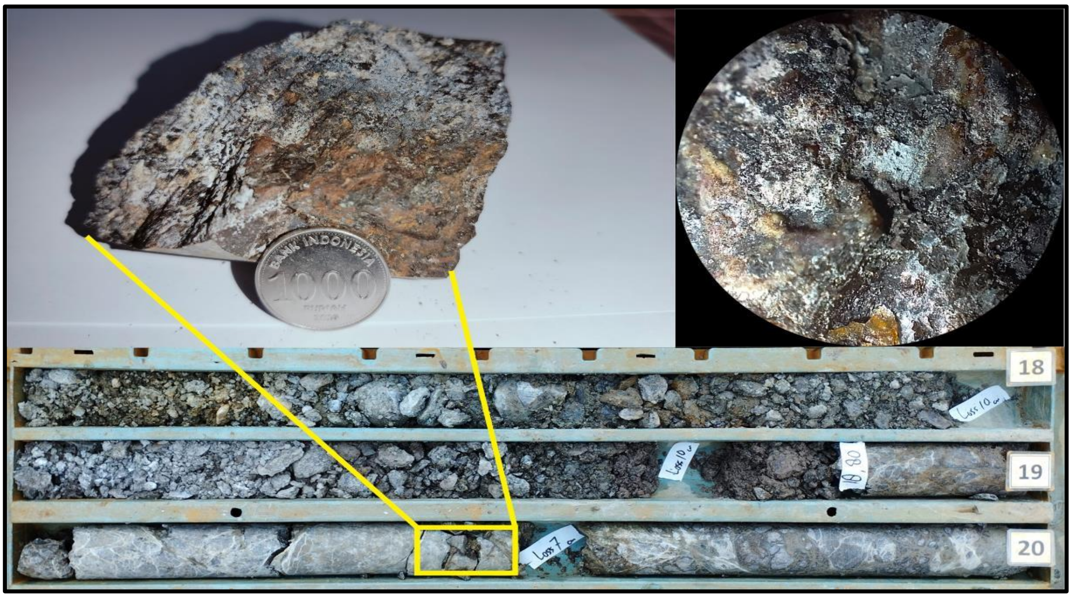


Figure 2. Rock coring results of peridotite

1) Lherzolite
   Petrographically, the absorption color ranges from colorless to brownish, with an interference color of grayish-brown. The texture is crystalloblastic, and the structure is non-foliated, specifically granulose. It is composed of primary minerals: olivine (14-45%), orthopyroxene (6-40%), clinopyroxene (5-20%), spinel (4-10%), and serpentine (0-35%).

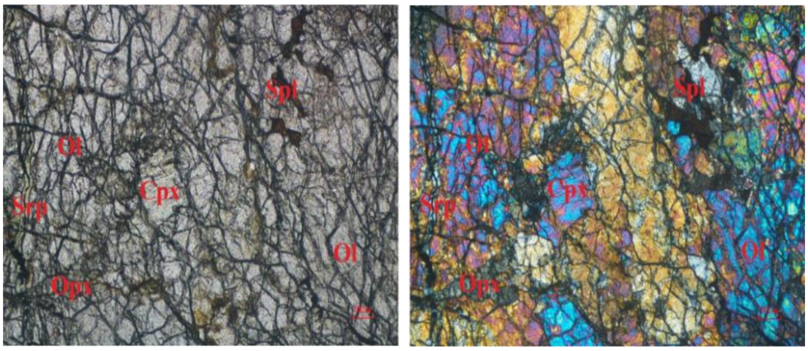


Figure 3. Petrographic appearance of incision DPA0106 showing mineral composed of Olivine (Ol), Orthopyroxin (Opx), Clinopiroxine (Cpx), Spinel (Spl), Serpentinite (Spt)

2) Olivine Websterite
Petrographically, the absorption color ranges from light brown to blackish, with varied interference colors (corresponding to the mineral colors). The texture is holocrystalline, with a phaneritic granular texture, and the mineral shapes are anhedral to subhedral. It is composed of olivine (35%), orthopyroxene (33%), clinopyroxene (20%), spinel (10%), and opaque minerals (2%).

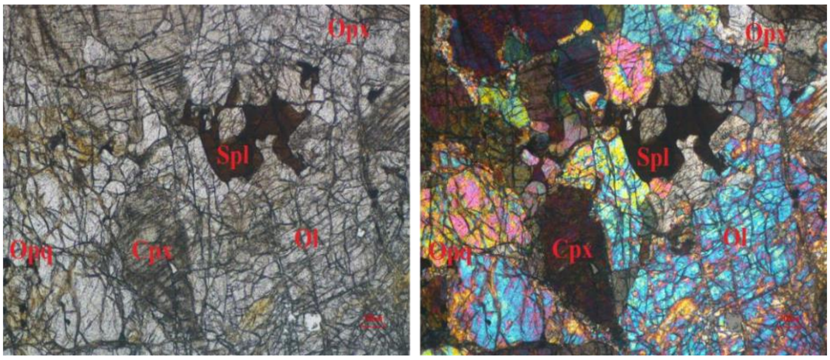


Figure 4. Petrographic view of incision DPA0106 showing mineral composed consisting of Olivine (Ol), Orthopyroxine (Opx), Clinopiroxine (Cpx), Spinel (Spl), Opaq (Opq)

3) Serpentinit
Petrographically, the absorption color is light to brown, with varied interference colors (matching the mineral colors). The texture is holocrystalline, with a phaneritic granular texture, and the mineral shapes are anhedral to subhedral. It is composed of olivine (6-8%), serpentine (90-92%), and spinel (2%).

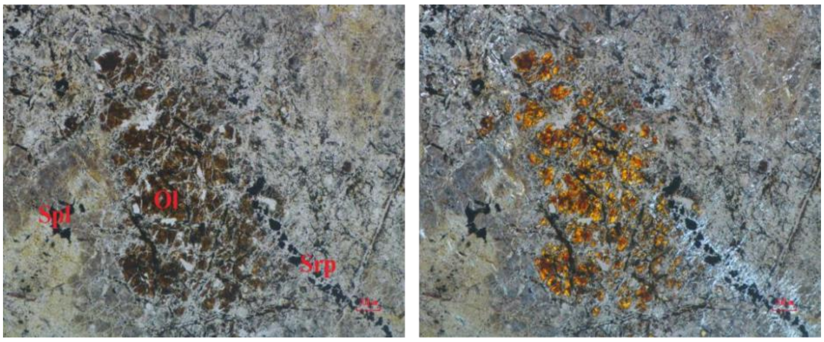


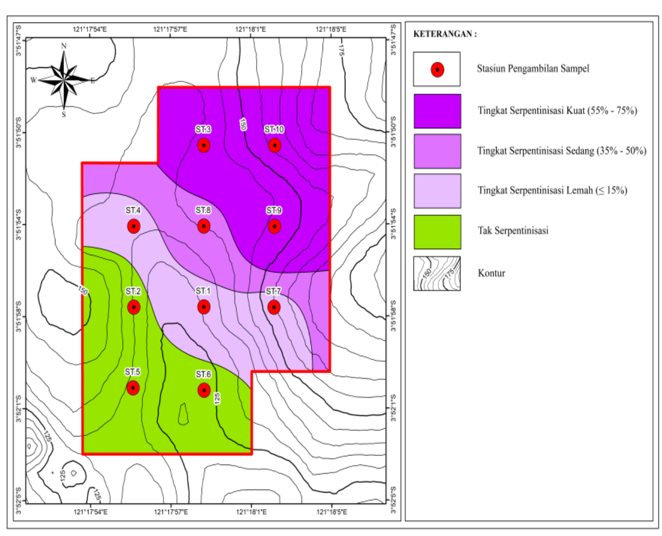
Figure 5. Petrographic of incision DPA0106 showing mineral composed consisting of Olivine (Ol), Spinel (Spl), Serpentinite (Spt).

3.1.3 Serpentinization Level

The degree of serpentinization in the research area can be divided into 3 (three) levels of serpentinization. Olivine and pyroxene minerals that transforma into the serpentine mineral group, with a percentage of 55% - 75%, are classified as strong serpentinization. Olivine and pyroxene minerals that transform into the serpentine mineral group, with a percentage of 35% - 50%, are classified as moderate serpentinization. Olivine and pyroxene minerals that transform into the serpentine mineral group, with a percentage of ⩽ 15%, are classified as weak serpentinization.

Table 1. Serpentinization Level Based on Percentage of Serpentine Mineral

Station	Lithology	Mineral Serpentine	Serpentinisasi Level
DPA0101	Lherzolite	75%	Strong
DPA0102	Serpentinit	90%	Strong
DPA0103	Lherzolite	10%	Weak
DPA0104	Lherzolite	35%	Medium
DPA0105	Serpentinit	92%	Strong
DPA0106	Olivine Websterite	-	-
DPA0107	Lherzolite	10%	Weak
DPA0108	Lherzolite	10%	Weak
DPA0109	Lherzolite	-	-
DPA0110	Lherzolite	-	-



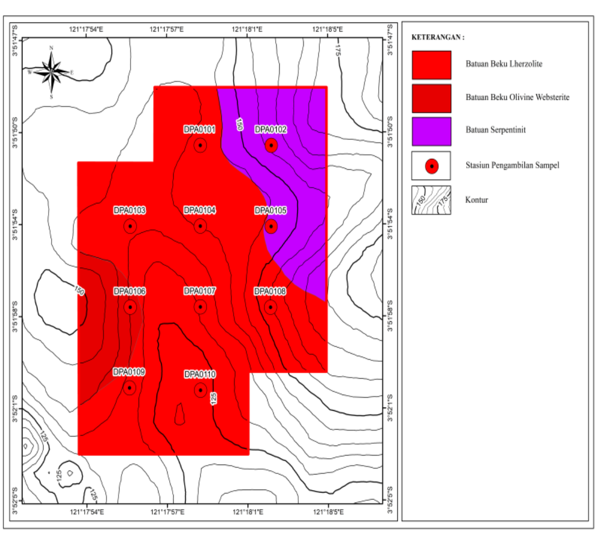


Figure 6. Serpentinization Level Figure 7 Geological Map

3.1.4 Correlation Serpentinization with Ni sof Laterite

Geochemical analysis at 10 stations uses the X-Ray Fluorescene method, where the chemical data obtained are the main elements, namely Ni, Co, Fe, SiO2, CaO, MgO, Cr2O3, Al2O3. Chemical element samples that have been analyzed are rocks resulting from drilling conducted in the study area.

1) Ultramafic Type on Ni Composed

a) Lherzolite, consisting of 7 stations, namely at Station 1 (DPA0101), Station 3 (DPA0103), Station 4 (DPA0104), Station 7 (DPA0107), Station 8 (DPA0108), Station 9 (DPA0109), and Station 10 (DPA0110). In the limonite zone, Ni levels at station 1 amounted to (1.19%), station 3 amounted to (0.91%), station 4 amounted to (1.26%), station 7 amounted to (0.91%). (1.13%), station 8 by (1.11%), station 9 by (1.16%), station 10 by (0.95%). In the saprolite zone Ni at station 1 was (1.19%), station 3 was (0.10%), station 4 was (1.82%), station 7 was (0.89%), station 8 by (0.91%), station 9 by (0.67%), station 10 by (1.06%). In the bedrock zone Ni levels at station 1 by (0.22%), station 3 by (0.36%), station 4 by (0.50%), station 7 by (0.36%), station 8 by (0.26%), station 9 by (0.23%), station 10 by (0.36%).

b) Olivine Websterite Oivine websterite rock at station 6 with drill point (DPA0106). The limonite zone has a Ni composed of (1.00%), the saprolite zone is (0.86%), and the bedrock zone is (0.33%).

c) Serpentinite Serpentinite rocks were found at station 2 (DPA0102) and station 5 (DPA0105). In the limonite zone, the Ni composed at station 2 is (1.04%) and at station 5 has a Ni composed of (0.78%). In the saprolite zone, station 2 Ni composed is (1.18%) and at station 5 it is (0.75%). In the bedrock zone, the Ni composed at station 2 was (0.20%) and at station 5 was (0.24%).

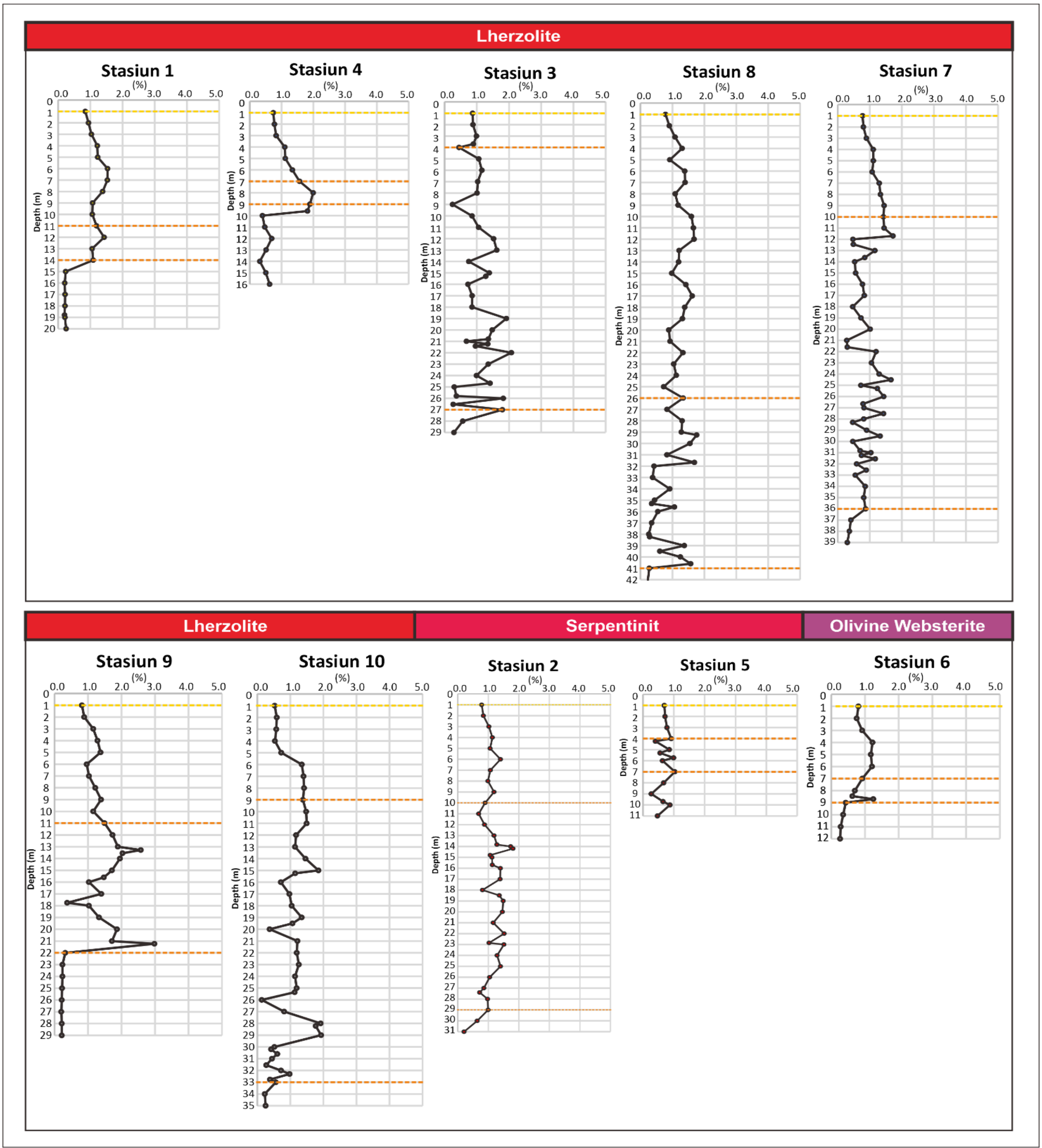


Figure 7. Ni element in nickel laterite profiles in lherzolite, serpentinite and olivine websterite rocks

The correlation of Ni with the elements Fe, SiO2, and MgO in the limonite zone and saprolite zone. The correlation of Ni with Fe in the limonite zone is inversely proportional with a moderate level of correlation, R2 = 0.328, in the saprolite zone it is directly proportional with a very strong correlation. The correlation of Ni with SiO2 in the limonite zone is directly proportional, with a very weak correlation of R2 = 0.0029, in the saprolite zone it has an inverse correlation with a very strong correlation with an R2 value of 0.725. The correlation of Ni with MgO in the limonite zone is directly proportional with a very weak correlation of R2 = 0.3313, in the saprolite zone it has an inverse correlation with a moderate level of correlation with an R2 value of 0.2955.

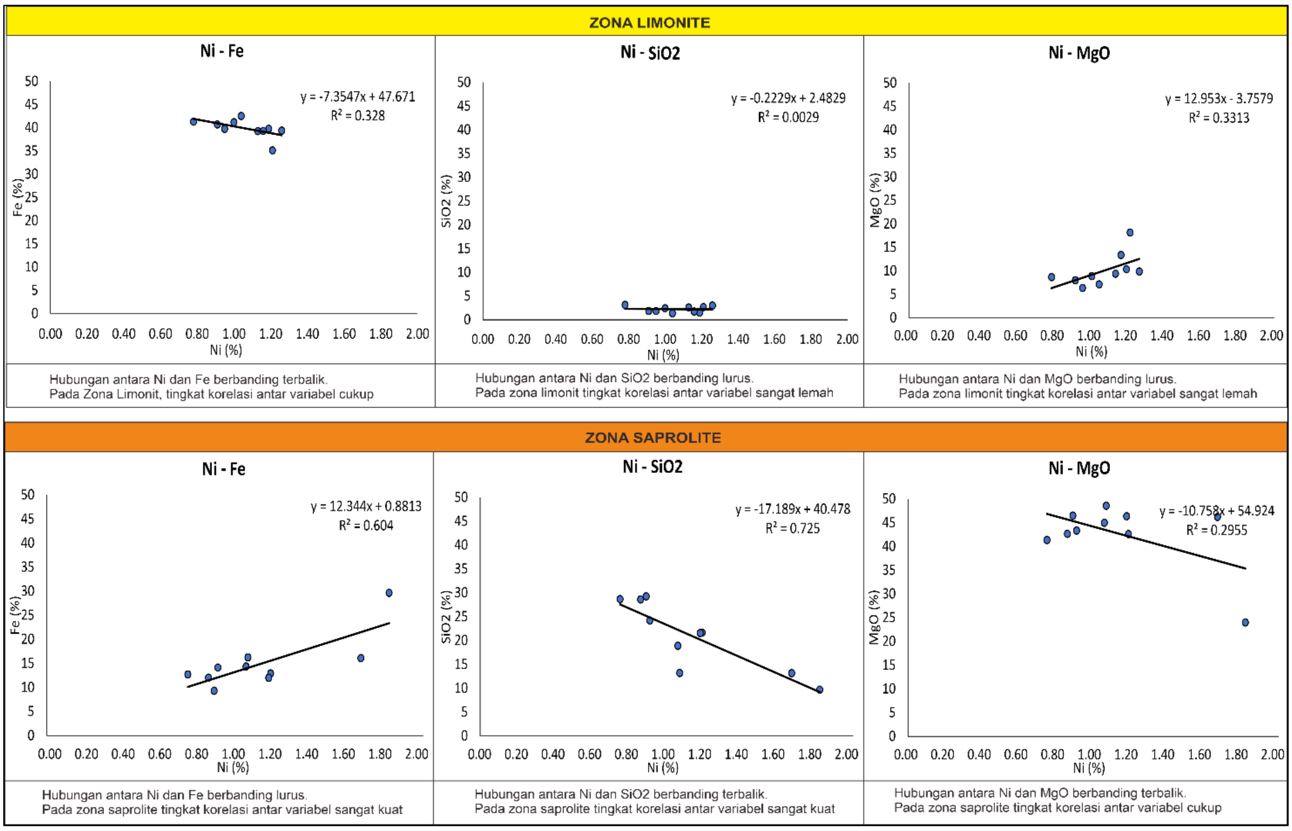


Figure 8. Correl of Ni to Fe, SiO2, MgO in limonite zone and bedrock zone

3.1.5 Correlation of Serpentinization to Ni Composed

The bedrock zone shows Ni levels that are not influenced by the enrichment zone, the element enrichment zone. It can be seen that the highest Ni element is found at the medium serpentinization level station with lherzolite lithology having an average Ni level of (0.50%) then the highest Ni at the weak serpentinization level with an average Ni level of (0.32) then at stations not affected by the serpentinization process with an average Ni level of (0.30%), and the lowest Ni is found at the strong serpentinization level to serpentinite alteration with an average Ni level of (0.22).

Table 2. Serpentinization level and Ni composed

Station	Lithology	Serpentinisasi Level	unsur Ni		
			Limonite	Saprolite	Bedrock
DPA0101	Lherzolite	Strong	1,19	1,19	0,22
DPA0102	Serpentinit	Strong	1,04	1,18	0,20
DPA0105	Serpentinit	Strong	0,78	0,75	0,24
DPA0104	Lherzolite	Moderate	1,26	1,82	0,50
DPA0103	Lherzolite	Weak	0,91	0,10	0,36
DPA0107	Lherzolite	Weak	1,13	0,89	0,36
DPA0108	Lherzolite	Weak	1,11	0,91	0,26
DPA0109	Lherzolite	-	1,16	0,67	0,23
DPA0110	Lherzolite	-	0,95	1,06	0,36
DPA0106	Olivine Websterite	-	1,00	0,86	0,33

3.1.6 Correlation of Serpentinization Level to Ni Distribution

Weak Serpentinization This level of serpentinization is characterized by thin section petrographic observations at station 3, station 7, station 8 with a percentage of serpentine minerals of 10%. Mineral percentage ⩽ 15% can be classified into weak serpentinization level Moderate Serpentinization This level of serpentinization is characterized by thin section petrographic observations at station 4 with a percentage of 35% serpentine minerals. Mineral percentage of 35% - 50% can be classified into moderate serpentinization level.

Strong Serpentinisation This level of serpentinisation is characterized by petrographic observations of tipig incisions at station 1, station 2, and station 5 with a percentage of serpentine minerals of 75% - 92%. The percentage of serpentine minerals 55% - 75% can be classified into the strong serpentinization level. Non Serpentinization At this station with the results of thin incision petrographic observations, no serpentine minerals were found, namely the olivine and pyroxine minerals showed no changes marked by intact crystal shapes. So that at station 6, station 9, station 10 did not experience the serpentinization process.

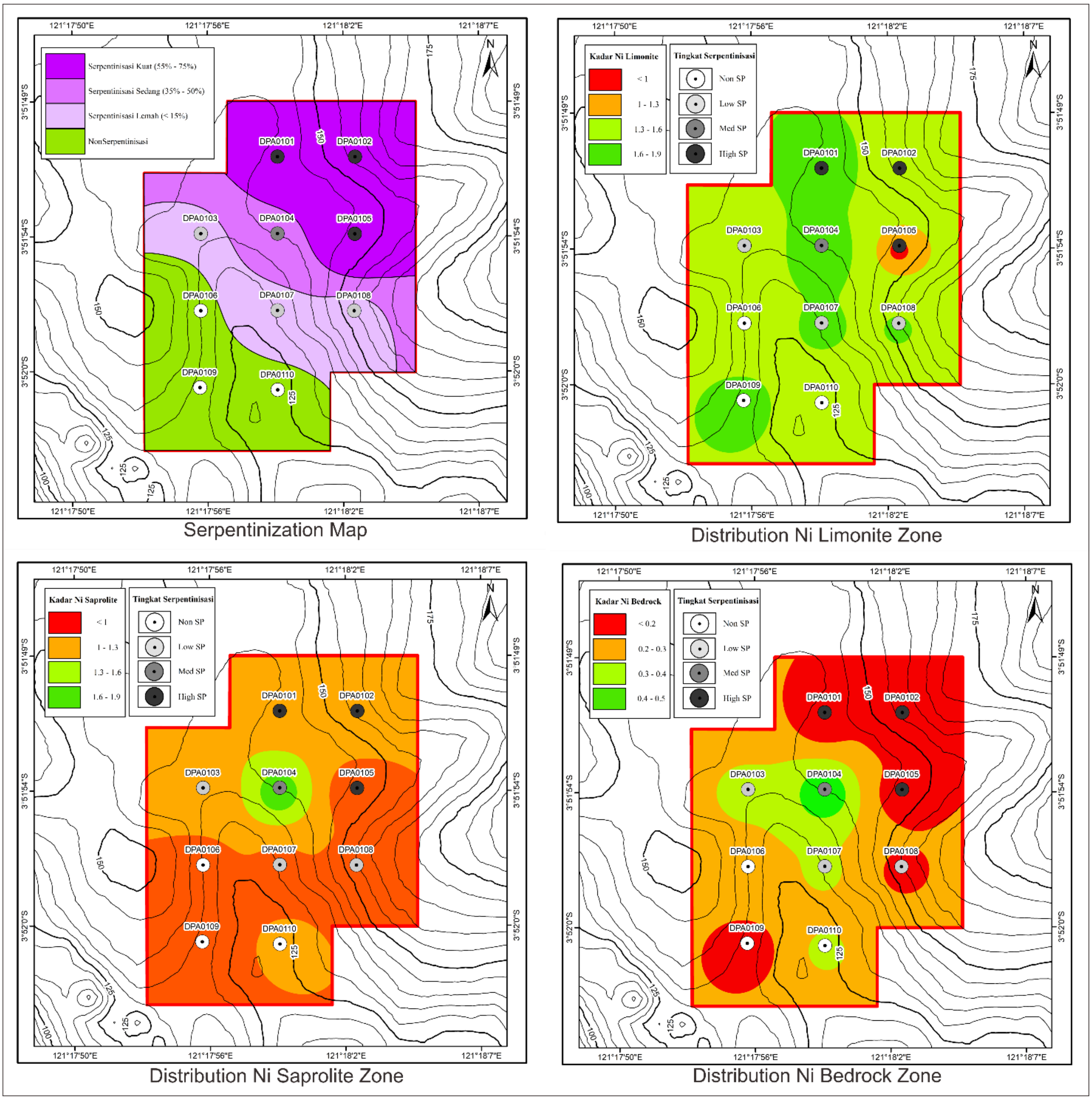


Figure 9. Serpentinization Level and Distribution Map of Nickel Laterite in limonite, saprolite and bedrock zoos

3.2 Discussion

Ultrabasic rocks (peridotite) in the study area, which has an average elevation of 50 to 200 m above sea level, have a hilly topography. The lithology in the area is mostly composed of lherzolite, olivine websterite, and serpentinite. The rocks contain primary minerals such as olivine, pyroxene, and serpentine. According to field data and petrographic observations, the blackish brown color is expressed as weathering on clear peridotite and, based on microscopic studies, these rocks are represented as granulose and non-foliated textures with dominant acicular mineral forms. The morphology of these rocks is, in part, due to the degree of serpentinization, in which olivine and pyroxene minerals are transformed into serpentine, a process that significantly affects the distribution of nickel. The study area is categorized based on the degree of serpentinization into weak, moderate, and strong levels in relation to its characteristics. Strong serpentinization type (55% to 75% serpentine) can be seen in rocks such as serpentinite, while lherzolite shows moderate serpentinization (35% to 50% serpentine). Example: Minor alteration, with less than 15% serpentine, has occurred in some areas due to weak serpentinization. Nickel content was found to be inversely proportional to the degree of serpentinization (geochemical analysis based on basement zone). In moderately serpentinized rocks (lherzolite), nickel content increases to 1.82% in the saprolite zone and 0.50% in the basement zone. In contrast, serpentinite, which has undergone intense serpentinization, shows lower nickel concentrations, especially at the basement level. Nickel distribution is also related to the mineralogical variations produced during serpentinization. In the limonite zone with intense weathering processes, nickel concentration is higher in well-serpentinized rocks but maximum in moderately serpentinized rocks. In the saprolite zone, which has undergone further weathering, nickel concentrations decrease, especially in serpentinites where nickel is leached out in the longer weathering process. In the basement zone, which has undergone the least weathering, nickel concentrations are generally lower. Serpentinization, in general, is positively correlated with nickel content and is more abundant in moderately serpentinized lithologies, especially in lherzolites and olivine websterites, where nickel is more concentrated than in highly serpentinized serpentinites. It can be concluded that moderate serpentinization is favorable for nickel enrichment, especially in limonite and saprolite zones. On the other hand, extensive serpentinization can result in lower nickel content, which can aid exploration efforts for lateritic nickel deposits. Information about the effect of serpentinization on nickel distribution can guide more effective exploration and extraction strategies, since areas that have undergone moderate levels of serpentinization are expected to favor higher nickel concentrations.

4. Related Work

Nickel is one of the world's most important minerals, with significant implications for industrial processes, particularly in the production of stainless steel and batteries. The world's nickel production is largely derived from nickel sulfide deposits, which account for 58%, while laterite nickel deposits account for the remaining 42%. Laterite nickel deposits, formed from the weathering of ultramafic rocks, are the primary source of nickel and have been the subject of extensive research. The objective of this study is to explore the influence of serpentinized ultramafic rocks on laterite nickel content, using a geocomputational approach to better understand this complex relationship. Geocomputational methods, particularly the Inverse Distance Weighting (IDW) interpolation technique, are widely used to model and predict the spatial distribution of geological resources, including laterite nickel deposits. The IDW method is a geostatistical technique commonly applied in geospatial analysis, where the value of an unsampled location is estimated based on the value of nearby sampled points. This technique is known for its effectiveness in producing accurate geological maps and is often used in mineral resource estimation, particularly for laterite nickel deposits. Previous studies have applied the IDW method in various contexts, demonstrating its ability to produce reliable resource estimates under complex geological conditions [6].

Geocomputing has developed as a foundation for GIS research and geospatial analysis, greatly influenced by advances in programming, computing power, and user interface design. Nickel laterite resource exploration and estimation is a complex process involving various techniques, including predictive mineral modeling, inverse distance weighting, and structural analysis. For mining companies, effectively evaluating new exploration areas and planning future exploration programs for nickel laterite reserves is critical. Thus, geocomputing techniques have become an indispensable tool for resource management and exploration strategies [4][7].

A large number of studies have focused on the role of serpentinization in the formation of nickel laterite. Serpentinization refers to the transformation of ultramafic rocks, especially those containing olivine and pyroxene, into serpentine minerals. This process is often associated with increased nickel concentrations, and several studies have explored this relationship. Dermawan *et al*. (2023) studied the impact of serpentinization on the formation of nickel laterite, showing that the degree of serpentinization affects the nickel content in the laterite profile [11]. Similarly, a study by Abbas and Maulana (2021) in South Kalimantan highlighted that higher degrees of serpentinization in ultramafic rocks correlated with lower nickel concentrations, likely due to nickel leaching during the serpentinization process [12].

The influence of serpentinization on the distribution of nickel laterites was further discussed by several authors using geospatial modeling. Putri *et al*. (2019) applied remote sensing and GIS techniques to map the distribution of nickel laterites in Southeast Sulawesi, which showed the role of serpentinized ultramafic rocks in the formation of nickel-bearing laterites [13]. Similarly, Mongelli *et al.* (2019) conducted a study in Iran, where they examined the mineralogical and geochemical characteristics of nickel laterite deposits, confirming that serpentinized ultramafic rocks significantly affect the nickel concentration in laterite profiles [14]. Beyond geochemical studies, the physical properties and weathering of ultramafic rocks have been investigated as factors influencing the distribution of nickel in laterites. Kandji *et al.* (2017) and Siebecker *et al.* (2018) focused on the geochemical behavior of serpentinized ultramafic rocks, exploring their interactions with environmental factors such as the presence of minerals such as goethite and lizardite, which control nickel retention and mobility [16][15]. In addition to geochemical and environmental studies, biogeochemical studies have also explored the potential use of plant growth as a biological indicator to explore nickel laterite deposits. Rasti *et al.* (2020) investigated the factors affecting nickel uptake by plants growing on Ni-laterite soil, suggesting that biogeochemical methods could play a role in future nickel exploration strategies [17]. Firdaus *et al.* (2022) and Puspita *et al.* (2022) have further refined the application of geospatial tools such as GIS and remote sensing in nickel exploration, improving the accuracy of nickel laterite resource mapping for future exploration and resource estimation [18][19]. These advances reflect the increasing importance of integrating geospatial data with geochemical analysis to predict nickel concentrations in laterite deposits. Siebecker *et al.* (2018) and Mongelli *et al.* (2019) also underline the importance of understanding the mineralogical and chemical changes that occur during serpentinization, as these changes directly affect the viability of nickel laterite deposits for extraction [20]. As global nickel demand continues to increase, understanding the relationship between meandering ultramafic rocks and nickel laterite formation will remain a key focus area for future resource exploration and management.

5. Conclusion

Ultramafic rock types in the study area: lherzolite, olivine websterite and serpentinite Some lherzolite rocks are serpentinized and some are not serpentinized. Lherzolites that are serpentinized are classified as strong, medium, weak. Strongly serpentinized lherzolite has an average Ni composed of (0.22%), moderately serpentinized lherzolite has an average Ni composed of (0.50%). Weakly serpentinized lherzolite has an average Ni composed of (0.32%), while non- serpentinized lherzolite has an average compsed of (0.30%).

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