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RESEARCH ARTICLE

Serpentinization Study On Ultramafic Rock at Morombo Area, Lasolo Islands District, North Konawe Regency, Southeast Sulawesi, Indonesia

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Abstract

The research is in Morombo area, North Konawe Regency, Southeast Sulawesi. The purpose of this study was to determine the characteristics of serpentinized ultramafic rock and serpentine paragenesis. Research was conducted using field observations and laboratory analysis consisting of petrographic and geochemical analysis in the form of X-Ray Fluorosence (XRF). Petrographic analysis was carried out to identify the mineral content and textures in the rock and to determine the percentage of serpentine mineral presence. Both of these rocks are petrographically dominated by primary minerals olivine and clinopyroxine and secondary minerals namely lizardite, chrysotile, antiorite and opaque minerals. The XRF analysis was to determine the elements of Ni, Fe, Co, MgO, SiO2, CaO, Al_2O_3 and P in ultramafic rocks. The results of petrographic analysis show that serpentinized ultramafic rocks in the study area consist of serpentinized dunite and serpentinized peridotite. The formation of clay minerals in rocks does not occur because of the low serpentinization process in the rock. The results of XRF analysis showed that all samples in the bedrock showed Ni content above 0.2%. This is caused by the enrichment of Ni which is interpreted as a result of the serpentinization process along with the formation of lizardite in the rock. The serpentinization sub-processes in the study area comprised by hydration, serpentine recrystallization, and deserpentinization. Serpentine paragenesis is formed from the mid-oceanic ridge ocean floor, the orogenic phase to weathering. Substitution of Mg by Ni in ultramafic rocks will produce Ni-Serpentin. It is estimated that in the research area lizardite and chrysotile lizardite and chrysotile are the causes of Ni enrichment in bedrocks. The serpentinization characteristics of ultramafic rocks in the study area show a low to moderate level of serpentinization.

Keywords: Serpentine, Serpentinization, Ultramafic, Morombo.

1. Introduction

Serpentinization is an exothermic, hydration reaction in which water reacts with mafic minerals such as olivine and pyroxine to produce lizardite, antigorite, and/or chrysotile (Palandri and Reed, 2004, in Kurniadi et al., 2017). Or in other words, the conversion process of olivine and pyroxine minerals in ultramafic rocks (peridotite and dunite) is replaced by serpentine minerals. According to (Moody, 1976) ultramafic rocks that experience hydration will make part or all of the rock body undergo a serpentinization process.

Knowledge of serpentinization will be very important in determining the composition of the host rock, determining the temperature and pressure conditions during hydration and being able to determine the fluid composition and fluid source (Moody, 1976). As is known no less important, knowledge of serpentinization will also be useful for exploration activities, especially exploration of laterite nickel deposits, because the majority of laterite nickel ore production comes from chemical weathering of serpentinized ultramafic rocks (Freyssinet and Butt, 2005; Hasria et al., 2019a,b; 2020; 2021). An understanding of sepentinization will also be needed in assessing the tectonic processes associated with the displacement mechanism of ultramafic rocks during the rock deformation process (Oud, 2010). In this study, the characteristics of the serpentinized rocks include the level of serpentinization in the rock and its chemical content based on X-Ray Fluorescence (XRF) data. So that information support the determination of serpentine mineral paragenesis is obtained.

The area selected as a research location for conducting research on ultramafic rock serpentinization is Morombo area, Lasolo Kepulauan district, North Konawe Regencyt, South East Sulawesi (Figure 1). In this area, there is an ophiolite strip that runs along the east coast of the Southeast Sulawesi Arm, from Tolo Bay to Tinobu and Tanjung Laonti (Rusmana et al, 1993) to characterize the Hialu lane. In this area, an ultramafic rock complex spreads out wide and becomes the IUP area of PT. Bumhi Karya

Utama, which has been operating since 2017. Some of these factors underlie the authors to conduct research related to serpentinization studies in ultramafic rocks in the Morombo area, Lasolo Kepulauan District, North Konawe Regency, South East Sulawesi (Figure 1).

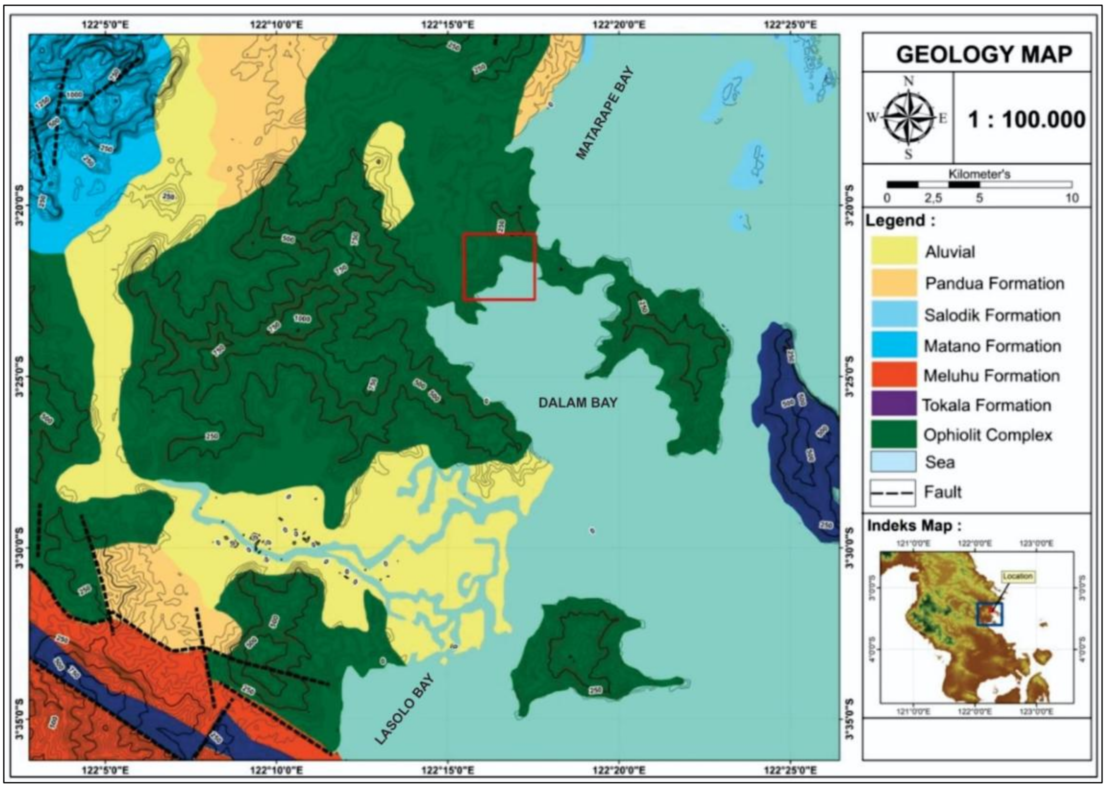

Fig 1. Geology Map Lasusua Kendari, (modified from Rusmana et al., 1993).

1. Research Methods

The method used in this study is divided into four stage namely: (1) Desk Study, (2) Fieldwork (3) Laboratory analysis and (4) data interprestasion.

2.1 Desk Study

At this stage secondary data collection and literature review of the results of previous studies were carried out relating to the geological conditions of the study area.

2.2 Fieldword

This research is located in the Morombo area, IUP PT. Bhumi Karya Utama, Lasolo Islands District, North Konawe Regency, Southeast Sulawesi (Figure 1). Field work includes observation and mapping of surface geology and representative sampling, geomorphological, lithological and structural geological observations. The secondary data collected in the form of bedrock test data obtained in the laboratory of PT. Bhumi Karya Utama and other data that support the research..

2.3 Laboratory Analysis

This analysis includes petrology, petrography, and geochemistry. Petrology analysis begins with megascopic description of the sample. Petrographic analysis aims to identify mineral content and specific textures in rocks and to determine the percentage of serpentine minerals. The geochemical analysis aims to determinate the major elements in bedrock is Ni, Ni, Fe, Co, MgO, SiO_2, CaO, Al_2O_3 and P. Petrographic analysis was carried out at the Geological Engineering Laboratory of the Teknik Faculty of Hasanudin University and geochemical analysis in the form of XRF (X-Ray Fluoresence) analysis was carried out at PT. Bhumi Karya Utama.

2.4 Data Interpretation

The interpretation of the data in this study includes all relevant data from the results of field and laboratory work which are evaluated and compiled to produce research objectives.

3. Result and Discusision

3.1. Characteristics of Serpentinized Ultramafic Rock

3.1.1 Serpentinization on Ultramafik Rock by Petrography Analysis

The number of station in this study was 44 stations, but there were 9 representative samples analyzed by petrography. Petrographic analysis result showed that the characterisics of ultramafic rocks in the study area divided into 2 rock types, namely serpentinized dunite and serpentinized peridotite (Streckeisen, 1974).

A. Dunite Serpentinized

Dunite serpentinized covers 36% of the total area of the study area and is found mostly in hilly landscape. Based on petrographic analysis, serpentinized dunit rock found at ST 12 H1, ST. 5 H1, ST 3 H3, ST 5 H5, BKN 17 and BKN 20. Petrographic analysis result on ST 5 H1 showed the mineral composition in rock sample consisted of 83% olivine, 10% chrysotile, 5% lizardite and 2% opaque minerals (Figure 2,B). Microscopis appearance showed olivine minerals have been broken down and to be replaced by serpentine minerals which form a mesh texture. Chrysotile is present as a secondary mineral in the form of veins that fill the fractures. At Figure 2D, the percentage of antigorite is 11% with a non pseudomorphic texture because it does not show its original mineral form. Almost all the samples that were observed microscopically showed incomplete mineral olivine crystals. This mineral crystal has been broken apart showing a fractured texture. And the fractions of the olivine crystals have been filled with lizardite by showing the mesh structur (Figure 2F).

Based on microscopic analysis, presence of serpentine minerals in dunite serpentinized rocks is different, at ST 5 H1 for serpentinized rocks by 15%. ST 12 H1 for serpentinized rocks by 40%, ST 3 H3 for serpentinized rocks by 65%, ST 5 H5 for serpentinized rocks by 40%, BKN 17 for serpentinized rocks by 27%, and BKN for 20 for serpentinized rocks by 42%. Of the six samples, the average rock undergoes a low serpentinization rate, which was bellow 45%. Except for ST 3 H3, the rock serpentinization rate occurred with a high intensity, namely 65% (Jacques, 2002).

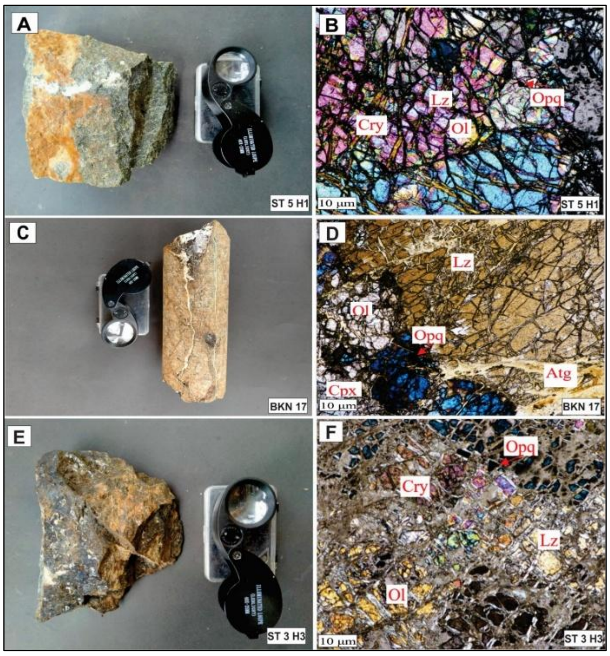

Fig 2. Sample and microscopis appearance ST 5 H1 (A,B). Sample and microscopis appearance showed antigorite minerals with a non pseudomorphic structure at BKN 17 (C,D). Sample and microscopis appearance of sample point ST 3 H3 showed lizardit mineral-rich with a mesh structure (E,F). Chrysotile mineral (cry), lizardite mineral (lz), antigorite mineral (atg), olivine mineral (ol), clinopiroksin mineral (cpx), and opak mineral (opq).

B. Peridotites Serpentinized

Peridotite serpentinized covers 39% of the total area of the study area and is found mostly in hilly and plain landscapes (Figure 3). Based on petrographic analysis, serpentinized peridotite rocks found at ST 4 H1, BKN 8 and BKN 11. Petrographic analysis result on ST 4 H1 showed the mineral composition in rock sample consisted of 65% olivine, 18% clinopiroksin, 5% chrysotile, 10% lizardite and 2% opaque minerals (Figure 3F). Petrography analysis result of the serpentinized peridotite rocks are almost the same as the serpentinized dunit rocks, which distinguish only the abundance of the mineral olivine which is less. Lizardite comes with a mesh texture to fill the fractures. Chrysotile veins are also seen to cut other minerals.

Based on microscopic analysis, presence of serpentine minerals in dunite serpentinized rocks is different, at ST 4 H1 for serpentinized rocks by 15%. BKN 8 for serpentinized rocks by 20%, (Figure 3D) and BKN for 11 for serpentinized rocks by 10% (3B). Of the three samples, the average rock undergoes a low serpentinization rate, which was bellow 45% (Jacques, 2002).

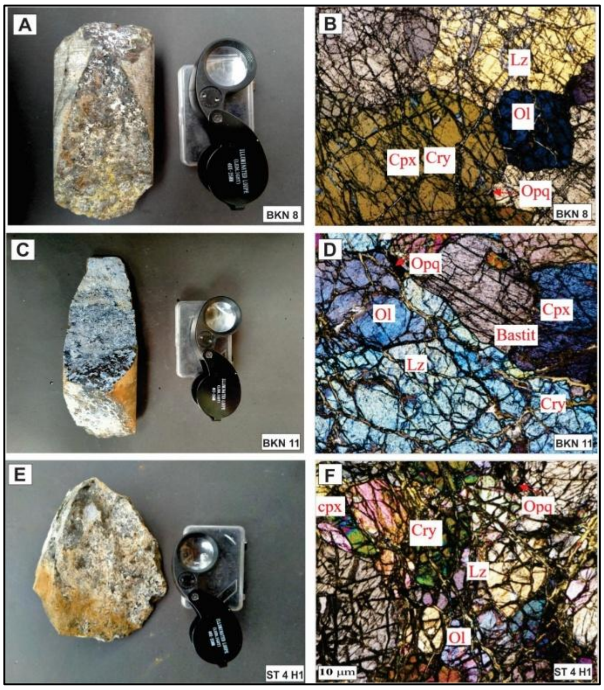

Fig 3. Sample and microscopic appearance of sample point BKN 8 (A,B). Sample and microscopic appearance of sample point BKN 11 (C,D). Sample and microscopic appearance of sample point ST 4 H1. Chrysotile mineral (cry), Lizardite mineral (lz), olivine mineral (ol), clinopyroxine minerals (cpx), and opaque minerals (opq).

3.1.2 Serpentinization on Ultramafik Rock by XRF Data.

The geochemical analysis of bedrock was carried out using X-Ray Fluorescence (XRF), to get the major element namely Ni, Fe, Co, MgO, SiO2, CaO, Al2O3, and P. The determination of main element of ultramafic rocks in the study area was carried out on 6 samples representing rock units contained in the study areas, namely the peridotite serpentinized and dunite serpentinized that had been previously performed petrographic analysis to determine the mineral content contained in the rock.

The sedimented rocks tend to be rich in oxides. serpentinization will tend to substitute magnesium in brucite into iron compounds. This can be seen from the BKN 17 for serpentinized by 27% and the BKN 20 for serpentinized by 42% (Table 1) both of these samples have more serpentine mineral presentations than the other. The same thing is also shown in the geochemical sample in the southern part which is represented by BSO 25 for serpentinized by 15%. The enrichment of the MgO element is shown by serpentinized rocks and will gradually decline due to the substitution of magnesium by iron compounds as in BKN 17. In this case there is a negative trend between MgO and FeO.

The typical weathering results of ultramafic rocks, especially in serpentinized dunite and dunite, the low Al content will limit the formation of clays such as in BKN 17 and BKN 20 which are dunite rocks.

In other rocks which are peridotite such as BKN 11, the aluminum content is also quite low, which is interpreted because of the abundant presentation of olivine minerals compared to BKN 8.

Table 1. Assay bedrock in research area

NO	HOLE ID	From	To	Mat	XRF Analisis				
					Ni (%)	Fe (%)	MgO (%)	SiO2(%)	Al2O3 (%)
1	BKN-17	29	30	BRK	0.38	7.74	24.61	36.86	1.16
2	BKN-20	13	14	BRK	0.29	7.02	32.02	32.95	0.79
3	BKN-08	7	8	BRK	0.26	6.66	27.56	37.46	2.19
4	BKN-11	9	10	BRK	0.23	6.42	27.53	32.16	1.09
5	BS025	32	33	BRK	0.89	7.616	-	-	-
6	BS044	19	20	BRK	0.69	5.256	-	-	-

3.2 Serpentinization Stage in Morombo Area

Based on its morphology, serpentine minerals are divided into 3 namely chrysotile, lizardite, and antigorite (Wicks and O,Hanley, 1988). The serpentinization process in olivine is followed by an opaque mineral, namely magnetite. The nonpseudomorph texture is shown in the antigorite which develops as a sheet. The vein texture in the rock is dominated by chrysotile and lizardite with a mesh texture.

O'Hanley (1991) divides 3 subproces of serpentinization, namely hydration, serpentine recrystallization, and deserpentinization (Table 2). In the research area, the hydration sub-process is the role of H2O or exostermic reactions that cause the presence of a mesh texture by lizardite and chrysotile minerals. The formation of serpentinite by hydration of peridotite results in a decrease in rock density (O'Hanley, 1992).

Recrystallization sub-process that converts the mineral lizardite into chrysotile. And the deserpentinization sub-process is to produce H2O and antigorite which comes with an interprenetrating texture and is endothermic.

According to (Mevel, 2003) it seem that serpentinization does not occur at a constant volume and apart from hydration and oxidation, the main elements of the rock are less affected. The average density of fresh peridotite is about 3.3 g/cm3 and serpentinite has a density of about 2.5 g/cm3. Therefore, serpentinization is responsible for the decrease in density. From this it means that there is an inverse correlation between density and degree of serpentinization. In the extensional environment of the mid-ocean ridge (MOR), this increase in volume is likely accommodated by tectonic activity, as evidenced by the vein system.

Table 2. Subprocess of the Serpentinization Process (O'Hanley, 1991)

Sub Process	Characteristics of reactions (resulting minerals & textures)	Reacsions	Entalphy Change (kj/mol H2O)
Hydrasion	H_2O-consumming heat-evolving (lizardit ± chrysotile or antigorite mesh-rim texture)	2F + 3W = C3 + B	-71,69 -21,5
Serpentine Recrystallization	H_2O-conservative, heat- consumming (lizardit hourglass&lizardit ± chrysotile ± antigorite interlocking texture)	L = C C + 0,11SiO2 = A+0,07W C=A+0,16B	3507,0 17,32
Deserpentinization	H_2O-evolving, heat- consuming (antigorite± brucite interprenasting texture)	20B+A-34F+51W A=18F+4T+27W	70,98 78,0

A = antigorite ; B=Brucite ; C=Chrysotile ; F=Forsterite ; L=Lizardit ; T=Talc ; W=Steam

In the expansion phase of the ocean floor, the first generation serpentine minerals will be formed (Figure 4). Serpentinization begins at high temperatures, in the range of 300–500° C. Formed in this phase which slowly penetrates the body of the primary mineral olivine to produce antigorite with an interpreted structure as a sheet followed by the formation of magnetite. An overview of mineral assemblages in serpentinite from the mid-ocean ridges also shows the dominance of lizardite and chrysotile minerals with magnetite (Mevel, 2003). This means that after the formation of antigorite, there is a decrease in temperature to form small amounts of lizardite and chrysotile. The presence of lizardite affects the microstructure of the rock. The reaction between peridotite and seawater at 300° C produces lizardite in this main phase. The presence of fractures by intersecting each other will result in loss of alignment of the pseudomorphic texture of the primary mineral.

The orogenic phase is the formation of the second generation of serpentine minerals which are formed as a result of the uplifting process. At a temperature of ± 250º C and the presence of pressure and the addition of water, the mineral crystals of olivine or pyroxine are slowly changing and producing lizardite with a fractured structure in more than one direction. The presence of a mesh texture in rocks also indicates that there is a hydration process (O'Hanley, 1992). The hydration process in rocks occurs because of the subduction zone formed by tectonic activity between continental plates and oceanic plates. The serpentinization layer that is formed comes from the hydration process, which occurs when the movement is above the surface (Guillot et al., 2015). Furthermore, the appointment process occurs, In this phase, chrysotile minerals are present with the appearance of mineral morphology that are fibrous and present with a vein texture formed at a temperature of ± 200ºC. Veins that form in rocks also prove that there is a process of adding volume to rocks. The presence of chrysotile minerals as a replacement for the mineral olivine is evidenced by the clear trace of olivine crystals around the chrysotile mineral body. Meanwhile, the presence of chrysotile as a replacement mineral clinopyroxine is still low. The BKN 8 sample showed the presence of 72% clinopyroxine. According to (Guillot et al., 2015) clinopyroxine-rich rocks are formed near the surface during orogenic processes. The presence of chrysotile minerals is dominated by olivine. Chrysotile mineral with a vein texture is interpreted as a type of chrysotile mineral that is formed at low temperature and pressure, which is close to the surface. This type of crysothyl mineral formation process is thought to have lasted until now. The development of the vein texture in rock outcrops filled with stringy chrysotile minerals is influenced by the weathering process. This type of chrysotile is also interpreted as a replacement for lizardite due to the recrystallization process.

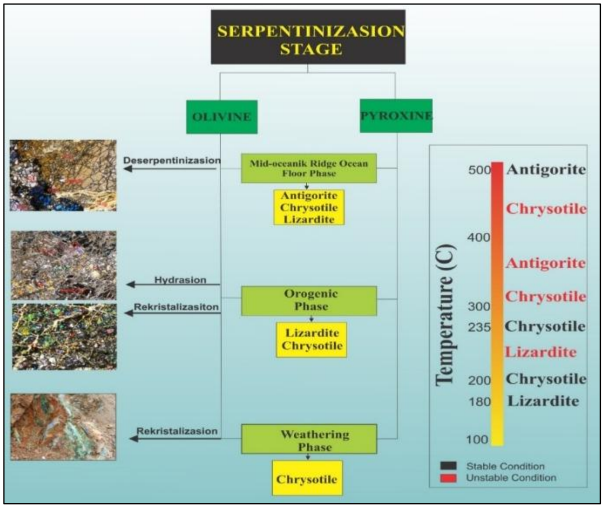

Fig 4. Ultramafik rocks serpentinization scheme in research area

3.3 Implication Serpentinization on Ni in Bedrock

According to (Sufriadin, 2009) ultramafic rock that undergoes serpentinization and does not undergo serpentinization will have different characteristics in its laterite nickel deposits. The differences that occur can be seen from the mineral composition, chemical compounds, the thickness of the limonite and saprolite zones, the character of the boulder in the saprolite zone and even the color of the laterites produced.

The serpentine which replaces olivine is usually devoid of aluminum and chromium but contains some nickel, which is equivalent in composition to olivine. In contrast, serpentine from bastite contains aluminum and chromium. The amount of iron in serpentine varies with associated magnetite abundance, thereby reflecting oxidizing conditions. When recrystallization occurs, secondary serpentine often takes the form of chrysotile, replacing primary lizardite. The serpentine in veins also tends to have less substitution, which is consistent with the fact that Al, Cr, Ni are relatively immobile during the change, therefore remaining in their original microstructural site, and with chrysotile predominance.

In general, the Ni content in fresh ultramafic rock is 0.2% and the highest is 0.3%. The entire sample shows a Ni content above 0.2% and the highest is at BSO 25 and BSO 44 where Ni content reaches 0.89% and 0.69%. In all these samples it is interpreted that Ni enrichment occurs due to the serpentinization process. According to Mavel (2003) substitution of Al and Fe3^{+} for Si can occur at the tetrahedral site, and Fe2^{+}, Fe3^{+}, Cr, Al, Ni, and Mn for Mg at the octahedral site. Lizardite tends to receive more substitutions than chrysotile, and is usually more Al-enriched, although the compositions do overlap. In highly serpentinized rocks, Ni-rich lizardite is the main ore mineral.

Based on this, it is estimated that lizardite and chrysotile in rocks are the carriers of Ni or Ni-Serpentin (Figure 5). Lizardite which contains Ni is nepouite containing 6-33% Ni (Butt and Cluzel, 2013) and chrysotile which contains Ni is pecroaite. As for Ni and Mg ion exchange reactions in serpentine minerals can occur with the reaction equation below.

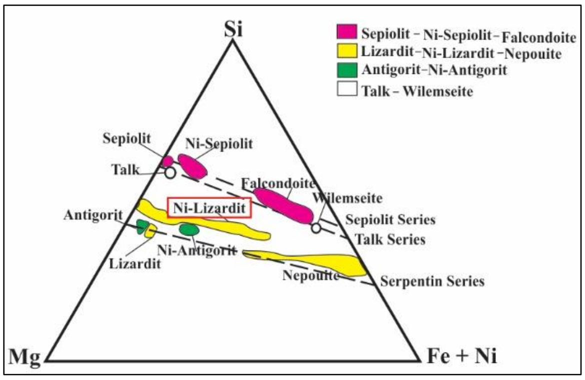

Fig 5. Plotting the relationship between Si, Mg, Fe+Ni with Ni hydrous silicate (modified from Brand et al., 1998)

However, if you look again at the low serpentinization level in the rock, it is only 15%. The high level of Ni at BSO 25 and BSO 44 can be interpreted because the high concentration of Ni content also comes from the primary mineral content, namely olivine because serpentinization only occurs locally in bedrock (Sufriadin, 2013).

4. Conclusion

1. Rock characteristics in the study area when viewed from the level of serpentinization that takes place is divided into 2, namely low serpentinization level and medium serpentinization level. A high degree of serpentinization occurs in dunite rocks but the spread of serpentinization is not evenly distributed in all types of dunite rocks. The high degree of serpentinization covers only a small area and is dominated by low serpentinization. Geochemically, MgO element enrichment is shown by serpentinized rocks. However, the magnesium content in rocks will be substituted by iron compounds so that there will be a reduction in its content and iron (Fe) compounds in the rock will be higher followed by the presence of magnetite. And rocks that are not serpentinized tend to be rich in oxides. Al formation occurs due to the low level of serpentinization and will inhibit the formation of clay minerals.
2. In the research area, serpentine mineral paragenesis is formed through several tectonic phases characterized by the presence of serpentine minerals with a distinctive structure. First, the expansion phase of the ocean floor produces antigorite with a structure

interpreting as a sheet followed by the formation of magnetite. After the formation of antigorite, there is a decrease in temperature to form lizardite. Second, the orogenic phase, which produces lizardite with a fractured and mesh structure which indicates the hydration process. Furthermore, when the removal is formed chrysotile minerals which are present as veins. The weathering process of exposed rock will convert lizardite minerals into chrysotile.

3. All samples in bedrock showed Ni content above 0.2% and the highest at BSO 25 and BSO 44, which contained Ni content reaching 0.89% and 0.69%. In all these samples, Ni enrichment is interpreted due to the serpentinization process along with the formation of lizardite in the rock.

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