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DISTRIBUTION AND CHARACTERISTICS OF ULTRAMAFIC ROCKS AS POTENTIAL NICKEL LATERITE AND THEIR RELATION TO CARBON STORAGE IN SOROWAKO REGION

SEBARAN DAN KARAKTERISTIK BATUAN ULTRAMAFIK SEBAGAI POTENSI NIKEL LATERIT SERTA KAITANNYA DENGAN PENYIMPANAN KARBON PADA DAERAH SOROWAKO

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ABSTRACT

Ultramafic rocks, as the main raw material for the formation of nickel laterite in nature, are important object to study and explore for their availability since nickel is very important mineral in producing batteries for electric cars which is expected to reduce carbon emissions in the future. Along with that, the storage of carbon dioxide in ultramafic rocks is considered as one of the safest storage method because carbon dioxide reacts naturally with magnesium-rich minerals contained in these rocks. The reaction between carbon dioxide and magnesium-rich minerals such as olivine, pyroxene, and serpentine will produce magnesite ($MgCO_3$), which is more stable in nature. Ultramafic rocks have wide distribution in southeastern arm of Sulawesi Island, especially in Sorowako and the surrounding areas. The method used in this research is an observation method on outcrops and supported by laboratory analysis. Ultramafic rocks in Sorowako area have wide distribution and have varying degrees of serpentinization. The magnesium (Mg) element contained in the research area is widely spread as well as the development of geological structure allows the potential development of ultramafic rocks as carbon storage.

Keywords: ultramafic rocks, nickel laterite, carbon capture, Sorowako, Sulawesi.

ABSTRAK

Batuan ultramafik sebagai bahan baku utama pembentukan nikel laterit di alam menjadi objek yang penting untuk dikaji dan dieksplorasi keterdapatannya karena nikel merupakan mineral yang sangat penting dalam pembuatan baterai mobil listrik yang mana diharapkan dapat mengurangi emisi karbon dimasa depan. Sejalan dengan itu, penyimpanan karbon dioksida pada batuan ultramafik dianggap sebagai salah satu metode penyimpanan yang aman karena karbon dioksida direaksikan secara alami dengan mineral yang kaya unsur magnesium (Mg) yang terkandung dalam batuan tersebut. Reaksi antara karbon dioksida dengan mineral kaya magnesium seperti olivin, piroksen, dan serpentin menghasilkan mineral magnesit ($MgCO_3$) yang bersifat lebih stabil di alam. Batuan ultramafik memiliki sebaran yang luas di lengan tenggara pulau Sulawesi khususnya daerah Sorowako dan sekitarnya. Metoda yang digunakan dalam penelitian ini adalah metoda pengamatan pada singkapan batuan di daerah Sorowako dan sekitarnya, didukung dengan analisis laboratorium. Batuan ultramafik daerah Sorowako dan sekitarnya memiliki sebaran yang luas serta memiliki derajat serpentinisasi yang bervariasi. Unsur magnesium (Mg) yang terkandung di daerah penelitian yang tersebar luas serta struktur geologi yang berkembang memungkinkan pengembangan potensi batuan ultramafik sebagai penyimpan karbon.

Kata kunci: batuan ultramafik, nikel laterit, perangkap karbon, Sorowako, Sulawesi.

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INTRODUCTION

Global warming is one of the crucial problems faced by humanity as a consequence of the start of industrial revolution at the beginning of the 18th century. Various efforts have been made globally to find a solution to this problem, including the Net Zero Emission program, which has become popular since the establishment of the Paris Agreement. This program is a condition where the amount of carbon emissions released into the atmosphere does not exceed the amount of emissions that the earth can absorb (Ritchie and Roser, 2020). One effort to control carbon emissions is through the development of electric vehicles, with nickel playing an important role as the main raw material for making electric car batteries (IRENA, 2023). Currently, carbon capture and storage (CCS) technology, a technology for capturing carbon dioxide (CO_2) using direct air capture method, is being massively developed worldwide (Hansson et al., 2022). The principle of carbon capture storage is to move and store CO_2 into storage location within the rock formation at a certain depth so that the negative impacts in the atmosphere can be avoided (Prasetyo and Windarta, 2022). Through this technology, the release of greenhouse gas emissions as a result of fossil fuel utilization activities in industry and large-scale power plants can be mitigated.

Sulawesi Island is located in the central part of the Indonesian archipelago. Tectonically, Sulawesi Island can be divided into several provinces (Kadarusman *et al.*, 2004): West Sulawesi Plutono-Volcanic Arc (WSPVA), Central Sulawesi Metamorphic Belt, East Sulawesi Ophiolite Belt, and Banggai-Sula and Buton-Tukang Besi Blocks (Figure 1). Sorowako and the surrounding areas are part of eastern Sulawesi Mandala, which is characterized by Ophiolite and Metamorphic rocks, which in some places are overlain by Mesozoic sediments (Maulana *et al.*, 2019). Sorowako and the surrounding areas have a distribution of ultramafic rocks containing olivine and pyroxene minerals abundantly, so it is expected to have good potential as a carbon dioxide storage media. Storing carbon dioxide in ultramafic rocks is considered as a safe storage method since carbon dioxide reacts naturally with magnesium-rich minerals in these rocks (McCafferty *et al.*, 2009). The reaction between carbon dioxide and magnesium-rich minerals such as olivine, pyroxene, and serpentine will produce a new mineral, namely magnesite ($MgCO_3$), which is more stable in nature so it can remain for a very long time (Abu-Jaber and Kimberley, 1992). This is because the potential for carbon dioxide leakage back to the surface is minimal with the method known as “mineral carbonation”. Ultramafic rocks have a very wide distribution in the southeastern arm of Sulawesi Island. The availability of these ultramafic rocks is a distinct advantage for Indonesia in relation to the potential for laterite nickel content as an economical commodity material. It is also related to the availability of carbon dioxide storage location in these rocks.

This research is expected to provide data on the distribution and characteristics of ultramafic rocks in Sorowako and the surrounding areas. The aim of this research is to determine the characteristics of ultramafic rocks containing (Mg) that play a role as carbon storage. Furthermore, this research can also determine the potential of carbon storage in the future. The research location is in Sorowako and the surrounding areas include East Luwu Regency administrative area, South Sulawesi province. Geographically, the research location is at 121º15’ east longitude - 121º26’ east longitude and 2º 41’ south latitude - 2º30’ south latitude.

METHODOLOGY

The step involved in this research is a literature study (previous research in Sorowako and the surrounding areas), namely regional study through Malili Sheet regional geological map (Simandjuntak *et al.*, 1991). Next step is collecting data through field observations, including rock sampling and geological structure field measurement. Geological structure elements (namely joint/fracture measurement) are measured to determine the general pattern (trend) and stress regime of geological structures that developed in the research area (Hamad and Fadli, 2021). Several rock samples were taken for laboratory analysis. X-Ray Fluorescence (XRF) analysis was conducted to determine the chemical compositions of the rocks (Husain *et al.*, 2021). Then, a geological map of ultramafic rocks distribution was produced following the workflow shown in Figure 2.

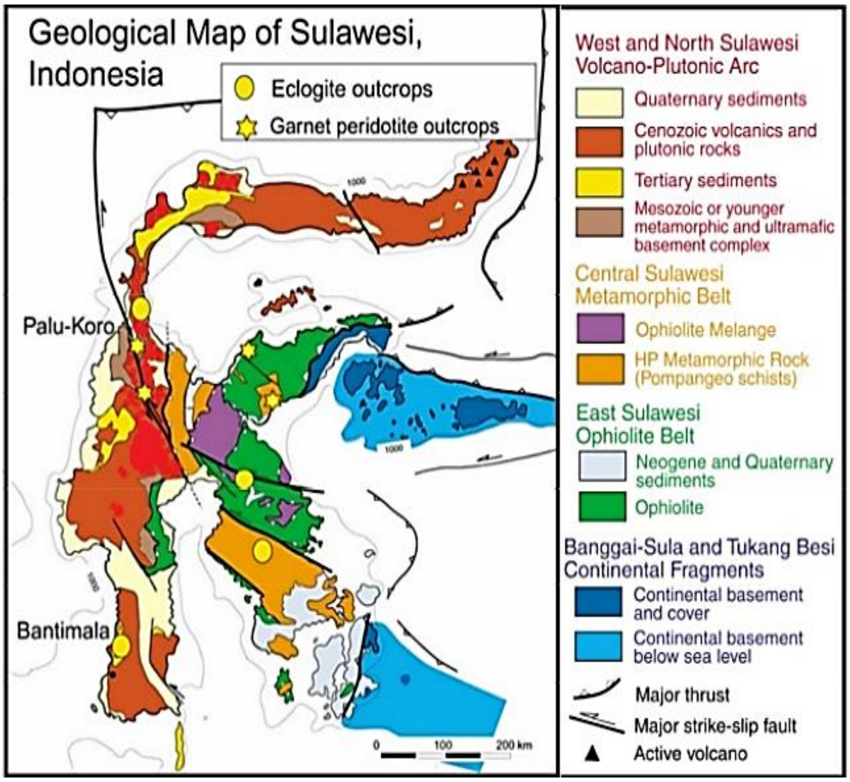

Figure 1. Regional geology of Sulawesi showing distribution of ultramafic rocks as nickel laterite potential (Kadarusman *et al.*, 2004).

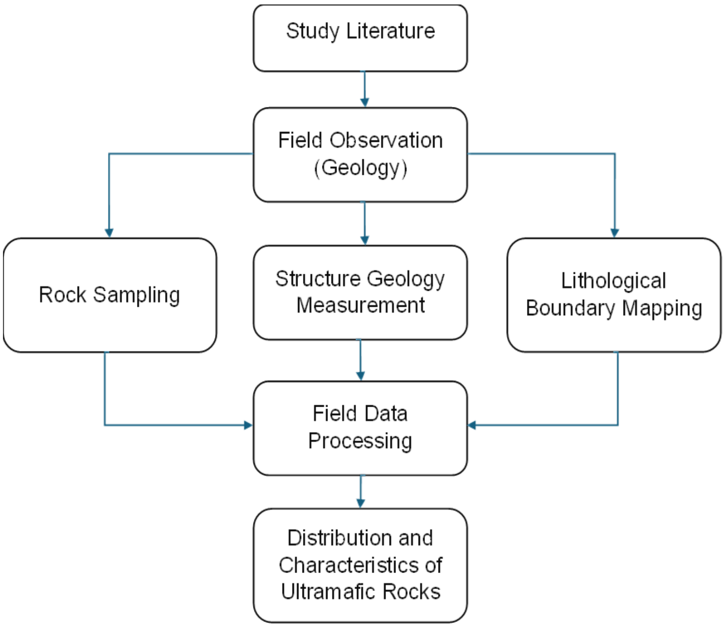

Figure 2. Research flow chart of distribution and characteristics of ultramafic rocks.

Once the result of laboratory analysis of ultramafic rocks is known, it can be predicted which areas have potential for carbon storage due to the magnesium (Mg) element contained in ultramafic rocks found that spread in Sorowako and the surrounding areas.

RESULTS AND DISCUSSION

Sorowako and the surrounding areas are composed of Mesozoic to Paleogene rocks (Osborne and Waraspati, 1987). This research produced a detailed geological map with 12 unofficial geological rock units. Especially for ultramafic rocks, the level of detail is higher since this activity was focused on ultramafic rocks mapping. At several observation points, the measurement of joint structure was carried out to determine the trend of stress developed in Sorowako and the surrounding areas.

Lithological Units

Based on the field observation result, through observations of rock outcrops and laboratory analysis result, can be inferred that Sorowako and the surrounding areas divided into 12 lithological units according to an unofficial stratigraphic code: Alluvial Deposits, Lacustrine Deposits, Colluvial Deposits, Larona Sandstone, Breccia Peridotite, Wasuponda Melange, Wasuponda Limestone, Wasuponda Serpentinite, Malano Limestone, Low Serpentinized Peridotite, High Serpentinized Lherzolite, and Dunite. The appearance of ultramafic rock outcrops is often found on the ground and in former mining site (Figure 3).

The result of XRF analysis of the 18 samples describes content of magnesium (Mg) element as the main factor in ultramafic rocks that play an important role in carbon storage (McCafferty *et al.*, 2009) that widely spread in the Sorowako Region. The values of (Fe) and (Ni) can also explain oxidation level and nickel potential in the research area. The values for magnesium (Mg), iron (Fe), and nickel (Ni) are shown in Table 1.

In total, 90 rock outcrops were found in the field for observation stations in Sorowako and the surrounding areas. In most of the observation points, many joint structures were found, as seen in Figure 4. The locations of observation stations in the research area are widely spread out and cover the entire research area, as seen in the rock observation map (Figure 5). The rock samples collected from the research area generally consist of bedrock layers that that are visible as rock outcrops, confirmed by the presence of nickel (Ni) element value. Consequently, the levels of iron (Fe), magnesium (Mg), and nickel (Ni) found in this samples are generally lower than those typically found in saprolite or limonite layers (Osborne and Waraspati, 1987). The content of these elements is also influenced by geological structures.

Figure 3. Fields outcrops of lherzolite (A), harzburgite (B), serpentinite (C), and larona sandstone (D).

Table 1. Content of Fe, Mg, and Ni elements obtained from laboratory analysis (X-RF) from several outcrops in the research area

Observation Station	Fe (%)	Mg (%)	Ni (%)
St. 01	5.93	23.57	0.199
St. 03	8.29	29.07	0.60
St. 04	8.24	30.94	0.35
St. 08	7.11	24.69	0.24
St. 10	8.02	27.10	0.64
St. 11	7.90	27.99	0.33
St. 15	6.95	21.35	0.26
St. 56	7.10	22.53	0.25
St. 57	8.03	27.40	0.29
St. 58	7.46	25.36	0.26
St. 59	9.38	23.78	0.75
St. 61	8.20	26.34	0.31
St. 62	7.54	28.16	0.40
St. 63	7.62	31.20	0.31
St. 65	7.64	26.88	0.30
St. 66	7.63	29.03	0.29
St. 67	7.82	28.86	0.28
St. 68	7.59	28.94	0.27

Geological structures that play an important role are the fractures and faults, since their presence will influence and facilitate the seepage of water into the soil and speed up the weathering process of the parent rock (Fatimah *et al.*, 2023). Moreover, the fractures and faults can also function as a place for the deposition of fluids containing metals. Based on the results of XRF analysis, as seen in Table 1, Sorowako and the surrounding areas contain magnesium (Mg) elements and are widely distributed as evidence that the ultramafic rocks in Sorowako and the surrounding areas have potential as carbon storage. In this research, fracture measurement was carried out to determine the stress regime and trend (dominant direction) of geological structure in Sorowako and the surrounding areas.

As we can see on the geological map as the result of field observations in Sorowako areas (Figure 6), then it can be expected that in the eastern, northeastern, and southern regions of the research area, the characteristics of ultramafic rocks were found to tend to be more ideal, as well as from the content of mineral magnesium (Mg) from laboratory analysis than other areas, even though that other areas also contain ultramafic rocks with different characteristics. This can be seen from the distribution of peridotite, dunite, and harzburgite that scattered in those regions. This provides an assumption and belief that the potential for laterite nickel and potential for carbon storage media in Sorowako and the surrounding areas is promising. It is also known from the laboratory results that the research area has been affected by an intense oxidation process, with elements of (Fe) that found in the rock samples.

Figure 4. Joint structures that appear in the research area.

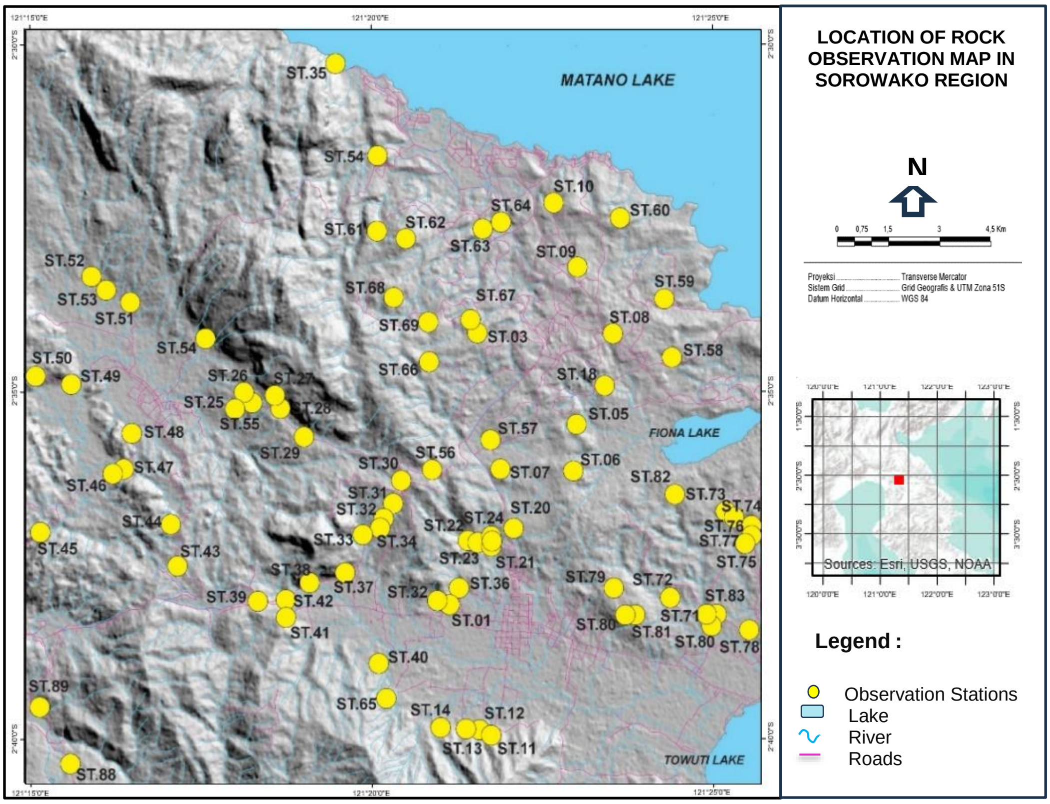

Figure 5. Map of rock observation locations in Sorowako and the surrounding areas.

Geological Structure

Intensive geological structure in the research area is characterized by the presence of joints and faults in the rock formation. At several locations, joint measurement was carried out to determine the stress regime that formed the geological structure. From analysis result using stereonet diagrams using measurement data of joint structure in the field, the stress regime that is distributed in the research area can be known (Hamad and Fadli, 2021). It is thought that the rocks formation found in Sorowako and the surrounding areas are strongly influenced by compressive stress, extensive stress and strike-slip as seen in the measurement results of joint structure carried out in the field (Table 2). The joints and faults in the research area are dominated by structures that have northwest-southeast and southwest-northeast in directions.

In several observation stations, joint structures were found to have west-east trend directions. The results of joint structures measurement were analyzed to determine the tectonic pattern that developed in Sorowako and the surrounding areas. In general, Sorowako and the surrounding areas can be divided into several stress regime group (Bellier *et al.*, 2006): In Larona Formation, stress regime that influenced the formation of geological structure is extensional strike-slip, pure extensive, oblique extensive, and strike-extensive slip. Stress regime that works on Matano Formation based on field measurements and joint structure analysis was dominated by compression stress. Furthermore, stress regime working on Wasuponda Melange was dominated by strike slip and compressive stresses, while extensive force was not dominant.

As an example, the joint measurements and stereonet analysis were carried out at station 45 and obtained pure compressive stress regime (Figure 7). At station 78, joint measurements and stereonet analysis were also carried out and obtained extensional strike-slip stress regime (Figure 8). This plays as a critical role for the quality of nickel laterite in Sorowako and the surrounding areas, because the presence of geological structrure will provide opportunities for supergene enrichment process to occur in the rock formations (Patria and Putra, 2020).

Lineament patterns in the research area can be seen to find out the geological patterns and relative tectonic activity from the surface that developed in the research area (Hutami, Anas and Fattah, 2024). The faults structures trend that developed in the research area can be observed and recognized through the observation of digital elevation model (DEM) image. The fault structures are dominated by trending northwest-southeast and southwest-northeast in directions (Figure 9). This fault generally becomes contact between rock units, such as contact between ultramafic rocks, limestone, and Wasuponda Melange.

Table 2. Stress regime from joint structures measurement analysis in the research area.

Observation Station	Rocks Formation	Trend	Plunge	Stress Regime
St. 78	Larona Fm	N127°E	19°	Extensional strike-slip
St. 88	Larona Fm	N26°E	41°	Pure extensive
St. 85	Larona Fm	N245°E	46°	Oblique extensive
St. 83	Larona Fm	N36°E	75°	Strike slip extensive
St. 71	Larona Fm	N232°E	83°	Pure extensive
St. 70	Larona Fm	N228°E	87°	Pure extensive
St. 45	Matano Fm	N246°E	7°	Pure compressive
St. 35	Matano Fm	N93°E	12°	Extensional strike-slip
St. 27	Matano Fm	N182°E	27°	Pure compressive
St. 28	Matano Fm	N112°E	31°	Oblique compressive
St. 57	Wasuponda Melange	N170°E	1°	Pure strike-slip
St. 56	Wasuponda Melange	N195°E	4°	Extensional strike-slip
St. 01	Wasuponda Melange	N338°E	12°	Pure compressive
St. 39	Wasuponda Melange	N316°E	29°	Oblique compressive
St. 26	Wasuponda Melange	N121°E	32°	Radial compressive

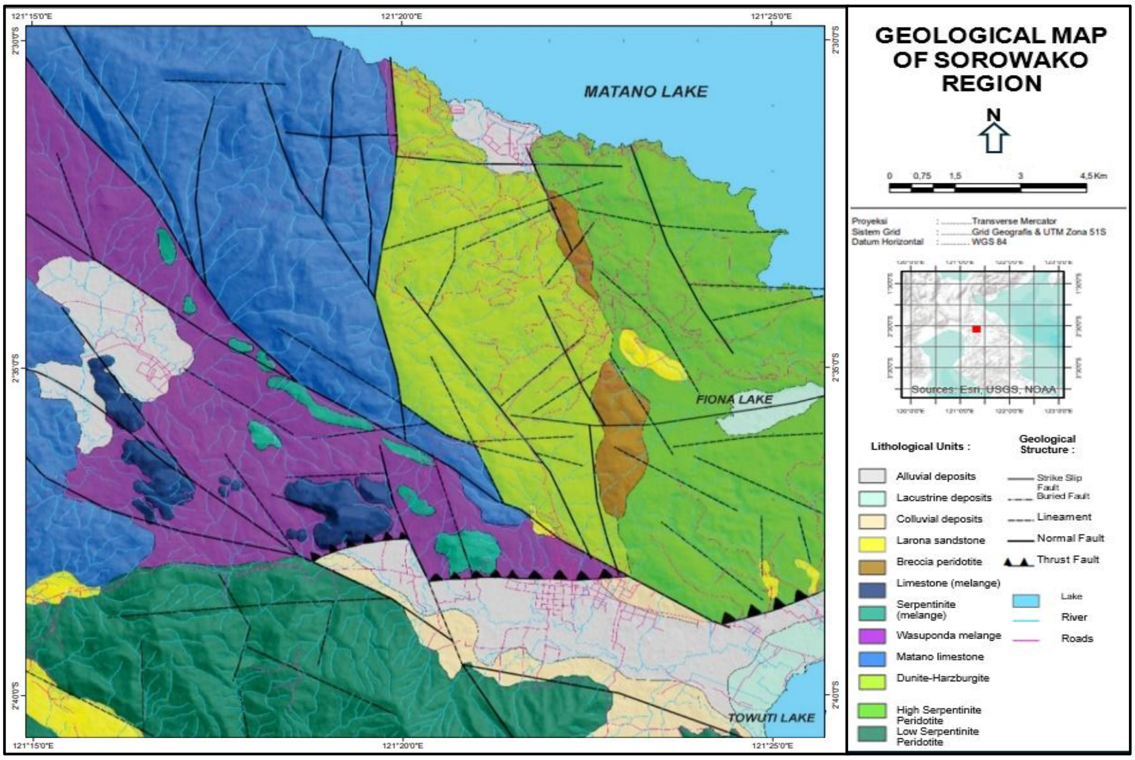

Figure 6. Geological map of Sorowako and the surrounding areas showing the distribution of ultramafic rocks.

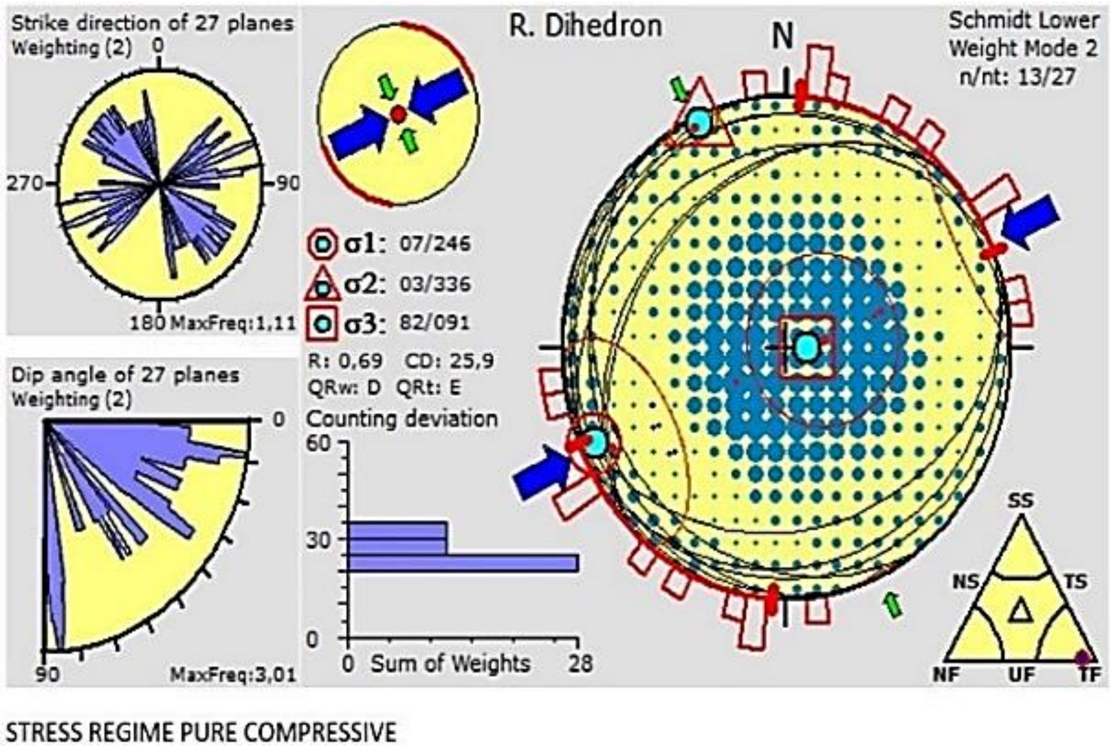

Figure 7. Stereonet and rosette diagram from joint structures measurement analysis results at station 45 in the research area.

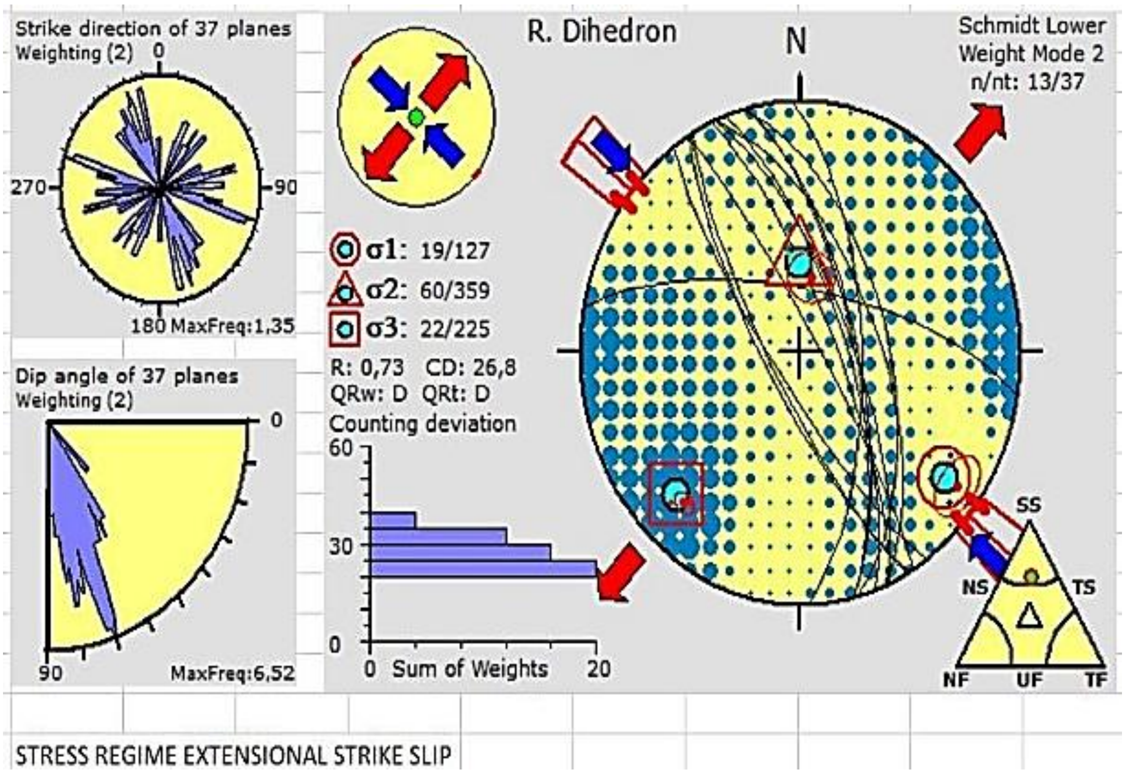

Figure 8. Stereonet and rosette diagram from joint structures measurement analysis result at station 78 in the research area.

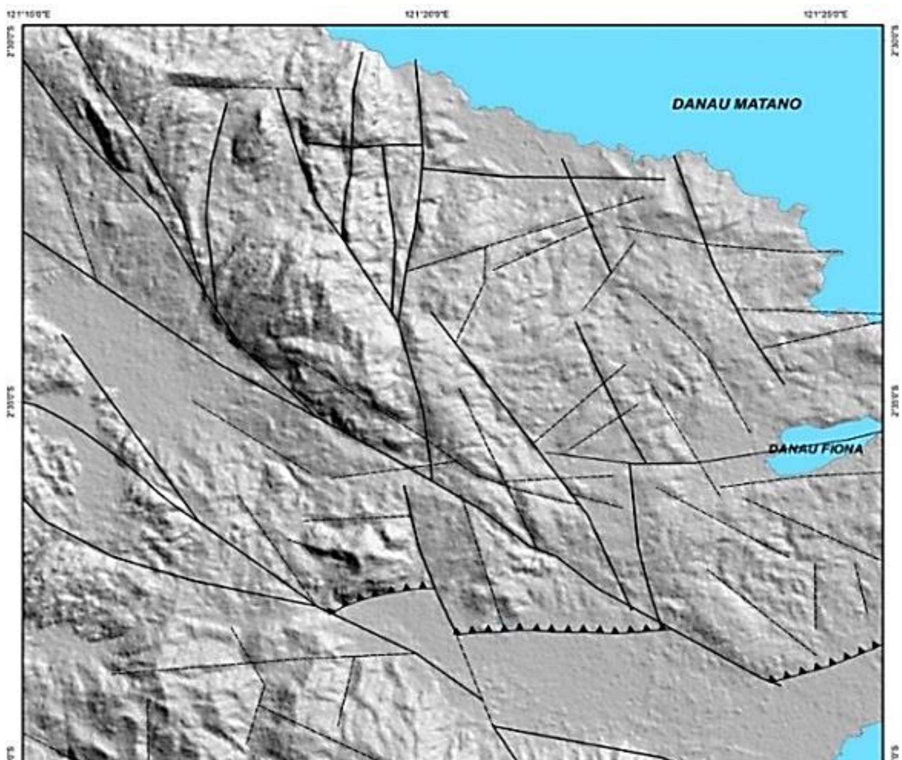

Figure 9. Lineaments appear as evidence of geological structure that developed in the research area.

CONCLUSIONS AND SUGGESTIONS

Ultramafic rocks in Sorowako and the surrounding areas have wide distribution which have varying degrees of serpentinization. Serpentinite also presents as fragments in several observation station (rock outcrops) in the research area. In the research areas, especially in eastern, northeastern, and southern areas, the characteristics of ultramafic rocks tend to be more ideal, as well as the content of magnesium (Mg) element from laboratory analysis than other areas, even though other areas also contain ultramafic rocks with different characteristics. The presence of geological structures that massively developed in Sorowako is believed to be one of the factors that control the quality of nickel laterite contained in Sorowako and the surrounding areas. This is because geological structures are very supportive to the occurrence and processes of supergene enrichment in the ultramafic rocks. Potential development of ultramafic rocks as carbon storage in Sorowako and the surrounding areas is very promising in the future; this is because the magnesium (Mg) element contained in the rock formation is quite widespread in the research area. The geological structure that is highly developed causes rocks to have fractures, which can increase contact area between the rocks and carbon dioxide, so it has sufficient porosity as carbon trap media. Therefore, it can be concluded that Sorowako and the surrounding areas have very promising potential as carbon storage media.

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