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RESEARCH ARTICLE

Analysis of Ultramafic Rocks Weathering Level in Konawe Regency, Southeast Sulawesi, Indonesia Using the Magnetic Susceptibility Parameter

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Abstract

The Konawe region is part of the Sulawesi Southeast Arm ophiolite belt where ultramafic rocks are exposed in the form of dunite and peridotite. The formation of nickel deposits is closely related to the weathering process of ultramafic rocks as a source rock. Ultramafic rocks exposed to the surface will experience weathering which is influenced by many factors, including in the form of climate change, topography, and existing geological structures.

The weathering process in the source rock can influence variations in chemical elements and magnetic properties in laterite soil profiles. For example, the chemical weathering might affect magnetic mineralogy and the physical weathering could affect granulometry as well as the quantity of magnetic minerals in the soil. Condition of weathering of ultramafic rocks (initial, moderate and advanced) can affect nickel content in laterite sediments. The weathering profile study of serpentine mineral is an indication of the lateralization process that occurs in ultramafic rocks and is carried out through petrographic analysis of thin cuts and polish cuts. Determination of weathering level like this is based on the level of weathering of the mineral serpentine.

In this study, the determination of the weathering level of ultramafic rocks (initial, moderate, and continued) uses magnetic susceptibility parameter. A total of 232 ultramafic rock core samples obtained from 34 hand samples were taken from different places and weathered levels were analyzed. The results of the research have shown that the magnetic susceptibility of ultramafic rocks in the study area varies, from 580 x 10-6 SI to 4.724 x 10-6 SI. Based on the value of magnetic susceptibility, magnetic minerals contained in ultramafic rock samples are hematite and geotite minerals. This means that the weathering level of ultramafic rock samples is the continued weathering level. The level of continued weathering that occurs in ultramafic rocks in the study area produces nickel laterite deposits with a nickel content of 1.65 - 2.40% in the saprolite zone, 0.42% in the saprock zone, and 0.20 - 0.51% in the basic rock zone (bedrock).

Keywords: Ultramafic rock, weathering level, magnetic susceptibility, Konawe Regency.

1. Introduction

1.1 Background of Research

The Konawe area is part of the Sulawesi Southeast Arm ophiolite belt. In this section, ultramafic rocks are formed in the form of dunite and peridotite (Surono, 2010).

The formation of nickel deposits is closely related to the weathering process of ultramafic rocks as a source rock. Ultramafic rocks exposed to the surface will experience weathering which is influenced by many factors, including in the form of climate change, topography, and existing geological structures. The weathering process in the source rock can influence variations in chemical elements (Maher and Thompsons, 1999) and magnetic properties in laterite soil profiles (Evans and Heller, 2003; Yulianto et al., 2003). For example, the chemical weathering might affect magnetic mineralogy and the physical weathering couldaffect granulometry as well as the quantity of magnetic minerals in the soil. The process of soil formation is divided into several zones with varying thickness and mineral element content (Petrovsky and Ellwood, 1999), for example in laterite soil deposits (Sundari, 2012).

Laterite soils or commonly called laterite or red soil isa type of infertile soil that is fertile and rich in nutrient-rich soil, but it is lost because it is dissolved by high rainfall. This type of soil has a low cation exchange capacity (which causes the metabolic process of plants to be disrupted (Sudarningsih, 2008). According to Sembiring (2008) the land of ex-laterite nickel mining actually shows the condition of the soil that has damaged structure and compaction so that it has a negative effect on the water system and aeration which can directly affect the function and development of roots. This causes the plants to grow normally, dwarf, wither, and die. The deterioration of the soil structure also affects the soil that is unable to store and absorb water during the rainy season resulting in soil erosion. Conversely, in the dry season the soil becomes hard and dense, so the soil becomes difficult to cultivate. Therefore, efforts are needed to increase soil fertility.

Exploration of laterite nickel deposits is thought to be related to weathering of ultramafic rocks in the formation of laterite nickel deposits and the presence of erosion material spread over the surface. In humid tropical climatic conditions, ultramafic rocks decay very quickly and produce ore residues containing nickel, chromium, or iron (Sudarningsih, 2008). The weathering profile study of serpentine mineral is an indication of the lateralization process that occurs in ultramafic rocks and is carried out through petrographic analysis and polish cuts (Boldt, 1967). Determination of weathering levels like this is based on the level of weathering of the mineral serpentine.

In this study, the determination of the weathering level of ultramafic rocks (early, moderate, and continued) uses magnetic susceptibility parameter. This is new and is expected to be an inexpensive and environmentally friendly alternative method for assessing weathering of ultramafic rocks and their relationship to nickel content. An illustration of the relationship of weathering levels of ultramafic rocks with nickel content can be used to support the exploration of the presence of laterite nickel.

1.2 Basic Theory

According to regional geology, Sulawesi is located at the confluence of 3 large plates, which causes very complex tectonic conditions, where a collection of rocks from the archipelago, ophiolite, and chunks of microcontinent are carried along with subduction, collision and other tectonic processes (Surono,2010). For the Southeast Sulawesi region which is in the East Sulawesi Ophiolite Lane group, the rocks consist of mafic and ultramafic rocks accompanied by pelagic and melange sedimentary rocks in several places. Ultramafic rocks are dominant in the Southeastern Arm, but the mafic rocks are dominant further north, especially along the North coast of the Southeast Arm of Sulawesi (Fig. 1).

The weathering rock is a process of physical disintegration and chemical decomposition of rock material that is on the surface or near the surface of the earth (Parker, 1997 in Waheed, 2002). Ultramafic rocks that undergo chemical weathering will change the composition of the mineral, as illustrated in Table 1.

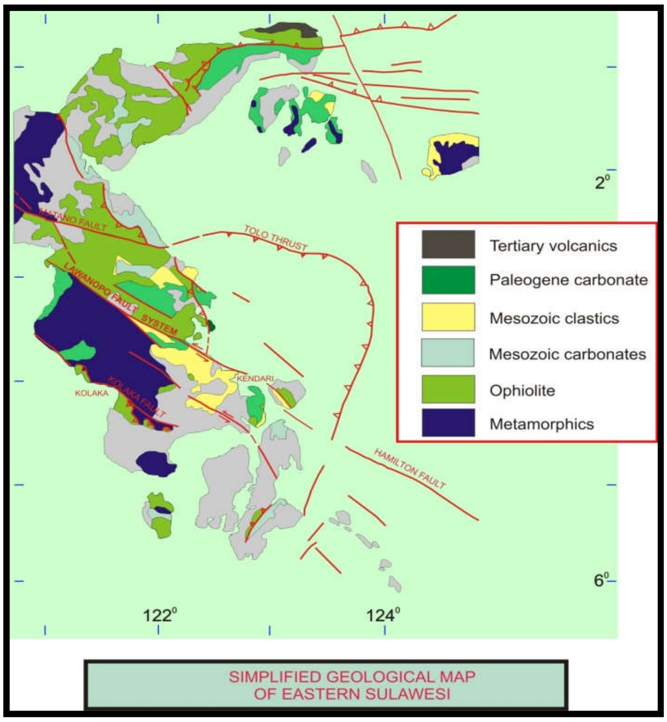

Fig. 1. Map of the Geology of the Southeast Arm of Sulawesi (Surono, 2010).

Table 1. Mineral content at weathering level (Mitchell & Soga, 2005)

Weathering Level	Mineral Content
Early weathering level	Gypsum (also halite, sodium nitrat) Calcite (also dolomite apatite) Olivine-hornblende (also pyroxenes) Biotite (also glauconite, nontronite) Albite (also anorthite, microcline, orthoclase)
Moderate weathering level	Quartz Muscovite (also illite) Layer silicate (including vermiculite, expanded hydrous mica) Montmorillonite
Continued weathering level	Kaolinite Gibbsite Hematite (also goethite, limonite) Anatase (also rutile, zircon)

2. Research Method

Samples in the form of ultramafic rocks and soil analyzed in this study were taken at Pondidaha District and Puriala District Konawe Regency. The samples were taken at the nickel mining site, rock mining, and post nickel mining. For rock samples, they are taken in the form of hand samples and made in the core for magnetic susceptibility measurement purposes and made in powder form for the measurement of mineral / elemental content.

Measurement of the magnetic susceptibility of ultramafic and soil rock was carried out on 232 ultramafic rock core samples obtained from 34 hand samples and 20 soil samples taken around ultramafic rocks. Magnetic susceptibility values for each rock and soil sample site were measured using the MS2B susceptibilitymeter. Measurement of mineral content/sample elements was performed using X-Ray Difraction and X-Ray Fluorescence.

3. Results and Discussion

3.1 Magnetic Susceptibility of Samples

Magnetic susceptibility is a function of the concentration, grain size and type of magnetic minerals. Variable magnetic susceptibility values indicate the concentration of magnetic minerals, grain size, and types of magnetic minerals that vary (Jahidin et al., 2019). The greater the value of magnetic susceptibility means the more concentration of magnetic minerals. High magnetic susceptibility also shows that magnetic mineral typesare dominated by ferrimagnetic and ferromagnetic magnetic minerals, magnetic susceptibility in the medium category is dominated by paramagnetic and antiferromagnetic magnetic minerals, whereas magnetic susceptibility is very low (negative) including non-magnetic (diamagnetic) minerals.

The magnetic susceptibility values for each rock and soil sample site measured using the MS2B susceptibility instrument can be seen in Table 2.

Table 2. The magnetic susceptibility value of the samples

Sample Type	Site Name	Number of Hand Samples	Number of Core Samples	Location	Magnetic Susceptibility Value (x 10^{-6} SI)
Ultramafic rock	P1	2	23	Rock mining (Puriala District)	960 - 2.128
	P2	2	16	Rock mining (Puriala District)	690 - 1364
	P3	2	26	Rock mining (Puriala District)	1.610 - 2.860
	ST2	2	9	Rock mining (Puriala District)	1.218 - 4.724
	ST3	1	2	Rock mining (Puriala District)	3.700 - 4.364
	D1	3	16	Post nickel mining(Pondidaha district)	679 - 1.439
	D2	4	32	Nickel mining(Pondidaha district)	640 - 1543
	D3	9	70	Post nickel mining(Pondidaha district)	580 - 1460
	ST1	2	6	Nickel mining(Pondidaha district)	666 - 814
	ST2	2	9	Post nickel mining(Pondidaha district)	586 - 901
	ST3	3	10	Rock mining(Pondidaha district)	992 - 1.434
	ST5	2	8	Nickel mining(Pondidaha district)	894 - 1.603
Soil	ST1	1	3	Nickel mining(Pondidaha district)	37,9 - 40,3
	ST2	1	2	Post nickel mining(Pondidaha district)	334,6 -381,6
	ST3	1	2	Rock mining(Pondidaha district)	71,8 - 119,8
	ST5	3	7	Nickel mining(Pondidaha district)	91,4 - 156,6
	ST2	1	2	Rock mining (Puriala District)	959,5 - 991,3
	ST3	1	2	Rock mining (Puriala District)	269,2 - 285,9

Based on the Table 2, it can be seen that the magnetic susceptibility value in ultramafic rock samples and soil samples in the study area varies. Ultramafic rock samples have magnetic susceptibility values ranging from580 x 10^{-6} SI to 4,724 x 10^{-6} SI and soilsamples have magnetic susceptibility values of 37.9 x 10^{-8} m3/kg to 991.3 x 10^{-8} m3/kg. Ultrabasic rock samples such as P3, ST2, and ST3 sites in Puriala District show a greater magnetic susceptibility than other sites. The magnitude of the magnetic susceptibility value indicates that the concentration of magnetic minerals in the sample is higher and is suspected to have a different type of magnetic mineral than the others. In soil samples taken from around the area of the presence of ultramafic rocks, the magnetic susceptibility value per unit of mass indicates that the soil samples originated from weathering of host rock(ultramafic rocks). Based on the value of magnetic susceptibility and field observations, it is suspected that soil samples contain the same magnetic minerals as ultramafic rocks.

From the results of the measurement of magnetic susceptibility in some ultramafic rock samples that produce two or more core samples from hand sample drilling, it is found that the magnetic susceptibility values for the cores above tend to be greater than the cores below. The above cores are samples taken from rock drilling in the uppermost structure, while the next cores are in the lower structure. The existence of the upper core has a high magnetic susceptibility compared to the bottom core due to weathering ultramafic rock always starts at the top of the structure towards the bottom structure. This allows a greater concentration of magnetic minerals in the upper core than the bottom core. The presence of magnetic susceptibility values of the lower core is higher than the upper core may be caused by the structure in the form of fractures at the bottom so that it will facilitate the entry of water and means the weathering process will be more intensive. As a result, the concentration of magnetic minerals at the bottom becomes greater and the value of magnetic susceptibility becomes higher. Next, the magnetic susceptibility values for the cores at each site are shown in Fig.2, Fig. 3, Fig. 4, Fig. 5, Fig. 6, Fig.7, and Fig. 8.

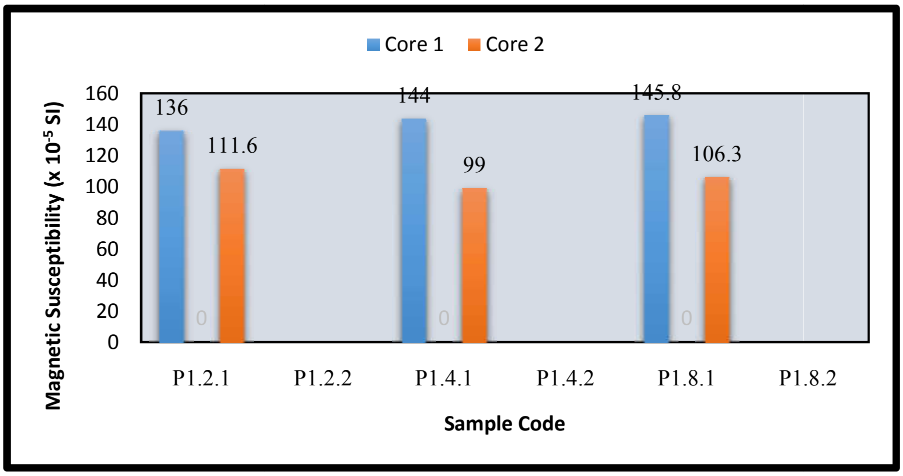

Fig. 2. Magnetic susceptibility values of upper core (core 1) and bottom core (core 2) ultramafic rock samples at Site P1 Puriala District

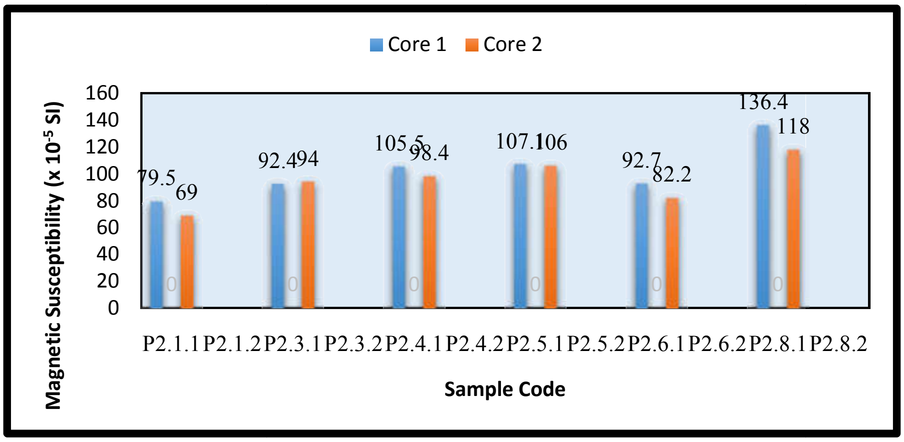

Fig. 3 Magnetic susceptibility values of the upper core (core 1) and bottom core (core 2) ultramafic rock samples at Site P2 Puriala District

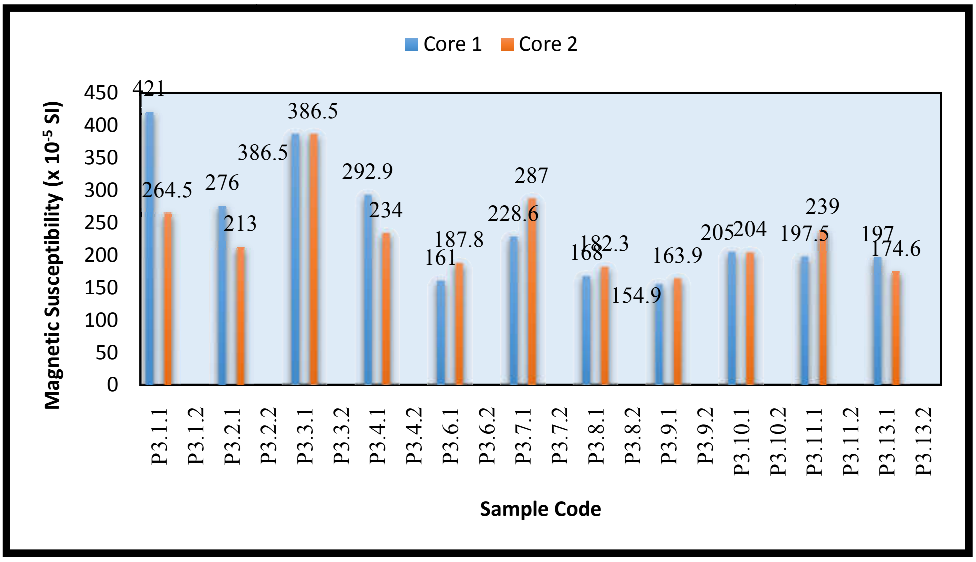

Fig. 4 Magnetic susceptibility values of upper core (core 1) and bottom core (core 2) ultramafic rock samplesat Site P3 Puriala District

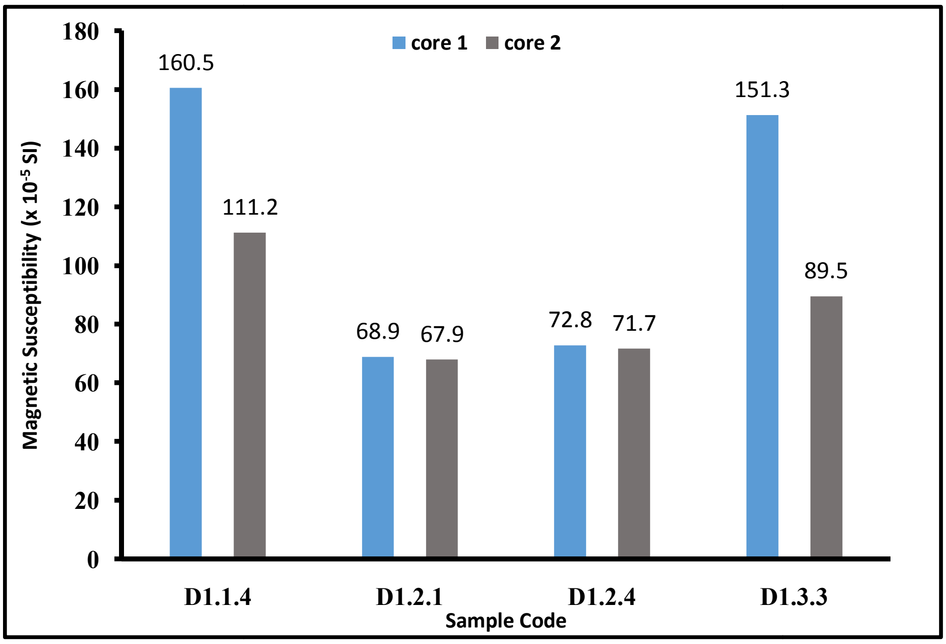

Fig. 5 Magnetic susceptibility values of upper core (core 1) and bottom core (core 2) ultramafic rock samples at Site D1 Pondidaha District

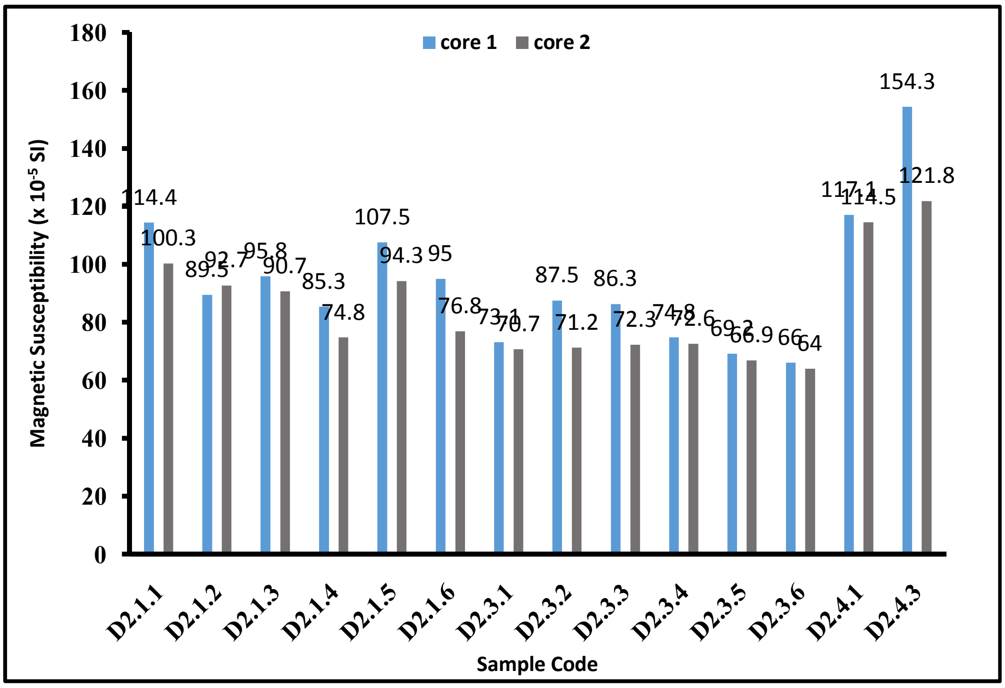

Fig 6. Magnetic susceptibility values of the upper core (core 1) and bottom core (core 2) ultramafic rock samples at Site D2Pondidaha District

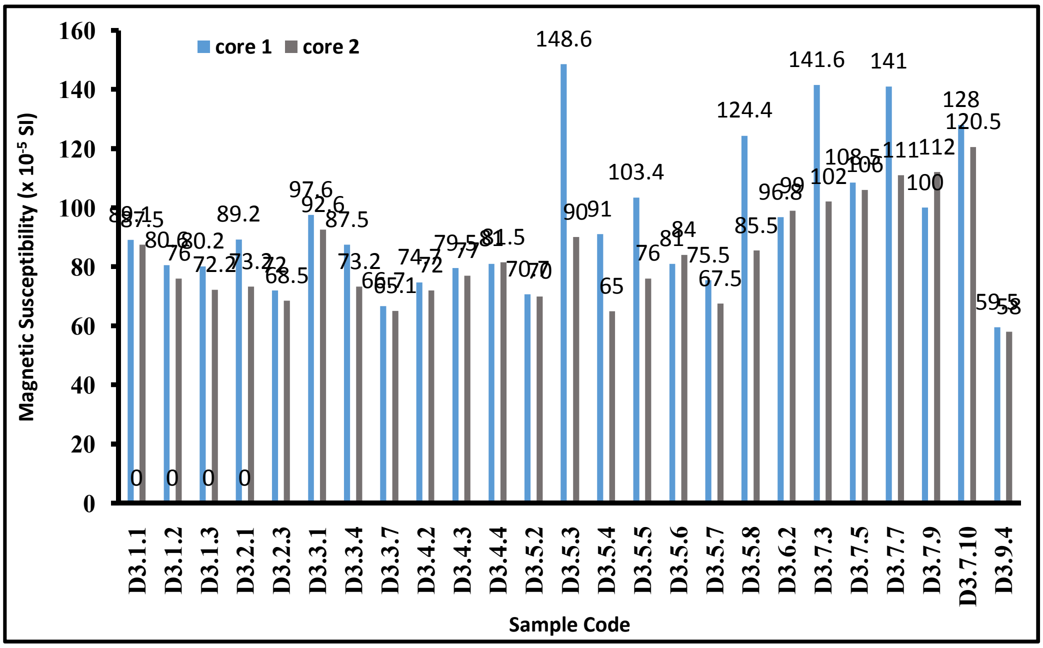

Fig. 7 Magnetic susceptibility values of the upper core (core 1) and bottom core (core 2) ultramafic rock sample at Site D3 Pondidaha District

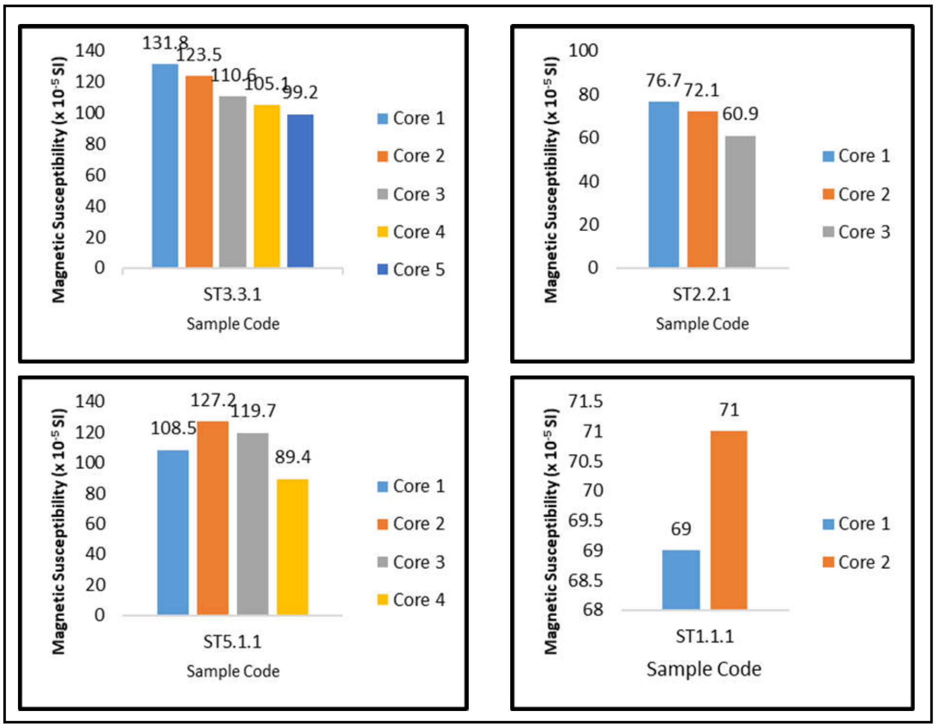

Fig 8. Magnetic susceptibility values of core 1, core 2, core 3, core 4, core 5 ultramafic rock samples at Site ST3, ST2, ST5, and ST1 Pondidaha District

3.2 Mineral Content of Samples

The magnetic mineral content in the sample can be determined based on the magnetic susceptibility value. By referring to the classification of magnetic mineral types based on magnetic susceptibility prices according to Hunt et al. (1995), the magnetic mineral content of ultramafic and soil rock samples can be seen in Table 3.

Table 3. Magnetic mineral content of ultramafic and soil rock samples

Sample Type	Site Name	Area	Magnetic Susceptibility Value (x 10^{-6} SI)	Type of Magnetic Mineral
Ultramafic rock	P1	Puriala District	960 - 2.128	Hematite (αFe_2O_3) Geotite (FeOOH)
	P2	Puriala District	690 - 1364	Hematite (αFe_2O_3) Geotite (FeOOH)
	P3	Puriala District	1.610 - 2.860	Hematite (αFe_2O_3) Geotite (FeOOH)
	ST2	Puriala District	1.218 - 4.724	Hematite (αFe_2O_3) Geotite (FeOOH)
	ST3	Puriala District	3.700 - 4.364	Hematite (αFe_2O_3) Geotite (FeOOH)
	D1	Pondidaha District	679 - 1.439	Hematite (αFe_2O_3)
	D2	Pondidaha District	640 - 1543	Geotite (FeOOH)
	D3	Pondidaha District	580 - 1460	Hematite (αFe_2O_3)
	ST1	Pondidaha District	666 - 814	Geotite (FeOOH)
	ST2	Pondidaha District	586 - 901	Hematite (αFe_2O_3)
	ST3	Pondidaha District	992 - 1.434	Geotite (FeOOH)
	ST5	Pondidaha District	894 - 1.603	Hematite (αFe_2O_3)
Soil	ST1	Pondidaha District	37,9 - 40,3	Hematite (αFe_2O_3)
	ST2	Pondidaha District	334,6 -381,6	Hematite (αFe_2O_3) Ilmenite ($FeTiO_3$)
	ST3	Pondidaha District	71,8 - 119,8	Hematite (αFe_2O_3) Ilmenite ($FeTiO_3$)
	ST5	Pondidaha District	91,4 - 156,6	Hematite (αFe_2O_3) Ilmenite ($FeTiO_3$)
	ST2	Puriala District	959,5 - 991,3	Ilmenite ($FeTiO_3$)
	ST3	Puriala District	269,2 - 285,9	Hematite (αFe_2O_3) Ilmenite ($FeTiO_3$)

The presence of hematite and geotite magnetic minerals in the ultramafic rock samples was also confirmed by XRD (X-Ray Difraction) analysis. In addition to the magnetic minerals in the form of hematite and geotite, in the ultramafic rock samples there are other minerals in the form of olivine minerals, cristabolite, wuestite, calcite, and nickel. The presence of hematite and ilmenite magnetic minerals in soil samples is also confirmed by the results of the XRF (X-Ray Fluorescence) analysis. Based on the results of the XRF analysis, obtained elemental content in soil samples in the form of Fe and Ti as the forming elements of hematite and ilmenite minerals.

3.3 Weathering Level of Ultramafic Rock Samples

To find out the level of weathering of ultramafic rocks in the study area, an analysis was made of the presence of magnetic minerals in rock samples based on the magnetic susceptibility of the sample. With reference to the mineral content in the rock weathering level as contained in Table 1, the presence of magnetic minerals in the form of hematite and geotite in the sample shows that the weathering level of ultramafic rocks in the study area is the continued weathering level. Overall, a description of the weathering level of rock samples by site and sub-district in the study area can be seen in the following Table 4.

Table 4. Weathering level of ultramafic rock samples

Site Name	Area	Type of Ultramafic Rock	Magnetic Susceptibility Value (x 10^{-6} SI)	Type of Magnetic Mineral	Weathering Level
P1	Puriala District	Olivine websterite	960 - 2.128	Hematite (αFe_2O_3) Geotite (FeOOH)	Continued
P2	Puriala District	Olivine websterite	690 - 1364	Hematite (αFe_2O_3) Geotite (FeOOH)	Continued
P3	Puriala District	Lherzolite	1.610 - 2.860	Hematite (αFe_2O_3) Geotite (FeOOH)	Continued
ST2	Puriala District	Lherzolite	1.218 - 4.724	Hematite (αFe_2O_3) Geotite (FeOOH)	Continued
ST3	Puriala District	Lherzolite	3.700 - 4.364	Hematite (αFe_2O_3) Geotite (FeOOH)	Continued
D1	Pondidaha District	Lherzolite	679 - 1.439	Hematite (αFe_2O_3)	Continued
D2	Pondidaha District	Lherzolite	640 - 1543	Geotite (FeOOH)	Continued
D3	Pondidaha District	Lherzolite	580 - 1460	Hematite (αFe_2O_3)	Continued
ST1	Pondidaha District	Lherzolite	666 - 814	Geotite (FeOOH)	Continued
ST2	Pondidaha District	Lherzolite	586 - 901	Hematite (αFe_2O_3)	Continued
ST3	Pondidaha District	Lherzolite	992 - 1.434	Geotite (FeOOH)	Continued
ST5	Pondidaha District	Lherzolite	894 - 1.603	Hematite (αFe_2O_3)	Continued

In the study area, determination of weathering levels of ultramafic rock samples and nickel content contained in laterite sediments was carried out on several samples representing different sites and sub-district areas. The analysis results of these samples are presented in Table 5.

Table 5. Weathering level of ultramafic rocks and nickel content

Weathering Level	**Name of Ultramafic Rock Sample Site**	**Name of Soil Samples**	**Area**	**Nickel Content (%)**	**Finding in Laterite Sedimentary Layer**
Continued	ST2	ST2	Puriala District	2,34	Saprolite
Continued	ST3	ST3	Puriala District	2,40	Saprolite
Continued	ST1	ST1.1	Pondidaha District	2,37	Saprolite
Continued	ST2	ST2.1	Pondidaha District	2,40	Saprolite
Continued	ST3	ST3.1	Pondidaha District	0,42	Saprock
Continued	ST5	ST5.1	Pondidaha District	1,65	Saprolite
		ST5.2		2,08	Saprolite
		ST5.3		1,96	Saprolite
Continued	D2 on the core:		Pondidaha District		
	D2.1.5.1			0,51	
	D2.1.5.2			0,30	*Bedrock*
	D2.1.5.3			0,29	
Continued	D3 on the core:		Pondidaha District		
	D3.5.3.2			0,20	*Bedrock*

4. Conclusion

Based on the finding in this study, some conclusions can be summarized, as the following :

1. The magnetic susceptibility value of ultramafic rocks in the study area varies from 580 x 10^{-6} SI to 4,724 x 10^{-6} SI. The magnetic susceptibility of ultramafic rock samples shows different values in the upper and lower cores where the magnetic upper core susceptibility values tend to be greater. This relates to the weathering process which always starts in the upper structure so that it allows greater concentrations of magnetic minerals. The difference in value indicates that the

magnetic susceptibility parameter can explain the weathering conditions of ultramafic rocks.

2. The magnetic minerals present in the ultramafic rock samples are hematite and geotite minerals. In addition to these two magnetic minerals, there are other minerals in the form of olivine minerals, cristabolite, wuestite, calcite, and nickel.
3. Based on the value of magnetic susceptibility of ultramafic rock samples which shows the magnetic susceptibility of hematite and geotite minerals, the weathering level of ultramafic rock samples in the study area includes continued weathering level (magnetic susceptibility value of samplesis 580 x 10^{-6} SI to 4,724 x 10^{-6} SI).
4. The level of weathering of ultramafic rocks can affect nickel content in lateritic nickel sediments. The level of continued weathering that occurs in ultramafic rocks in the study area produces nickel laterite deposits with a nickel content of 1.65 - 2.40 % in the saprolite zone, 0.42 % in the saprock zone, and 0.20 - 0.51 % in the basic rock zone (bedrock).

5. Acknowledgment

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