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 the formation 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 serpentinite.

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 the formation 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 could affect 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 is a 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 (Sudarningisih, 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 (Sudarningisih, 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.
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 susceptibility meter. Measurement of mineral content/sample elements was performed using X-Ray Diffraction 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 types are 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.

| 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 - 1,218                            |
|               | P2        | 2                      | 16                     | Rock mining (Puriala District) | 690 - 1,364                            |
|               | 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 - 1,543                            |
|               | D3        | 9                      | 70                     | Post nickel mining (Pondidaha district) | 580 - 1,460                            |
|               | ST1       | 2                      | 6                      | Nickel mining (Pondidaha district) | 666 - 814                             |
|               | ST2       | 2                      | 9                      | 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                            |
|               | ST1       | 1                      | 3                      | Nickel mining (Pondidaha district) | 37,9 - 40,3                            |
|               | ST2       | 1                      | 2                      | Nickel mining (Pondidaha district) | 334,6 - 381,6                          |
| Soil          | 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 from $580 \times 10^{-5}$ SI to $4,724 \times 10^{-5}$ SI and soil samples have magnetic susceptibility values of $3.79 \times 10^{-4}$ m$^3$/kg to $991.3 \times 10^{-4}$ m$^3$/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. 4 Magnetic susceptibility values of upper core (core 1) and bottom core (core 2) ultramafic rock samples at 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 D2 Pondidaha 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
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| ST1       | Puriala District | 960 - 2.128                              | Hematite (αFe₂O₃)                  |
|                | ST2       | Puriala District | 690 - 1364                               | Geotite (FeOOH)                    |
|                | ST3       | Puriala District | 1.610 - 2.860                             | Hematite (αFe₂O₃)                  |
|                | ST4       | Puriala District | 1.218 - 4.724                             | Geotite (FeOOH)                    |
|                | ST5       | Puriala District | 3.700 - 4.364                             | Hematite (αFe₂O₃)                  |
|                | ST6       | Puriala District | 679 - 1.439                               | Geotite (FeOOH)                    |
|                | D1        | Pondidaha District | 640 - 1.543                              | Hematite (αFe₂O₃)                  |
|                | D2        | Pondidaha District | 580 - 1.460                              | Geotite (FeOOH)                    |
|                | D3        | Pondidaha District | 666 - 814                                | Geotite (FeOOH)                    |
|                | ST2       | Pondidaha District | 715 - 71                                  | Hematite (αFe₂O₃)                  |
|                | ST3       | Pondidaha District | 71.8 - 119.8                              | Hematite (αFe₂O₃)                  |
|                | ST5       | Pondidaha District | 91.4 - 156.6                              | Hematite (αFe₂O₃)                  |
|                | ST2       | Puriala District | 959.5 - 991.3                             | Hematite (FeTiO₃)                  |
|                | ST3       | Puriala District | 269.2 - 285.9                             | Hematite (FeTiO₃)                  |
| Soil           | ST1       | Pondidaha District | 37.9 - 40.3                              | Hematite (FeTiO₃)                  |
|                | ST2       | Pondidaha District | 334.6 - 381.6                            | Hematite (FeTiO₃)                  |
|                | ST3       | Pondidaha District | 71.8 - 119.8                              | Hematite (FeTiO₃)                  |
|                | ST5       | Pondidaha District | 91.4 - 156.6                              | Hematite (FeTiO₃)                  |
|                | ST2       | Puriala District | 959.5 - 991.3                             | Hematite (FeTiO₃)                  |
|                | ST3       | Puriala District | 269.2 - 285.9                             | Hematite (FeTiO₃)                  |
The presence of hematite and geotite magnetic minerals in the ultramafic rock samples was also confirmed by XRD (X-Ray Diffraction) 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 results of the XRF analysis, obtained elemental content XRF (X-Ray Diffrac- tion) analysis. In 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 (αFe₂O₃)       | Continued       |
| P2        | Puriala District | Olivine websterite       | 690 - 1.364                               | Hematite (αFe₂O₃)       | Continued       |
| P3        | Puriala District | Lherzolite               | 1.610 - 2.860                             | Geotite (FeOOH)         | Continued       |
| ST2       | Puriala District | Lherzolite               | 1.218 - 4.724                             | Geotite (FeOOH)         | Continued       |
| ST3       | Puriala District | Lherzolite               | 3.700 - 4.364                             | Hematite (αFe₂O₃)       | Continued       |
| D1        | Pondidaha District | Lherzolite               | 679 - 1.439                               | Hematite (αFe₂O₃)       | Continued       |
| D2        | Pondidaha District | Lherzolite               | 640 - 1.543                               | Geotite (FeOOH)         | Continued       |
| D3        | Pondidaha District | Lherzolite               | 580 - 1.640                               | Hematite (αFe₂O₃)       | Continued       |
| ST1       | Pondidaha District | Lherzolite               | 666 - 814                                 | Geotite (FeOOH)         | Continued       |
| ST2       | Pondidaha District | Lherzolite               | 586 - 901                                 | Hematite (αFe₂O₃)       | Continued       |
| ST3       | Pondidaha District | Lherzolite               | 992 - 1.434                               | Geotite (FeOOH)         | Continued       |
| ST5       | Pondidaha District | Lherzolite               | 894 - 1.603                               | Hematite (αFe₂O₃)       | Continued       |

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.

### 3.3 Weathering Level of Ultramafic Rock Samples

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.

| 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               | Pondidaha District | 2.08               | Saprolite                            |
|                  |                                     | ST5.3               | Pondidaha District | 1.96               | Saprolite                            |
| Continued        | D2 on the core:                     |                     | Pondidaha District | 0.51               | Bedrock                              |
|                  | D2.1.5.1                            |                     |             | 0.30               | Bedrock                              |
|                  | D2.1.5.3                            |                     |             | 0.29               | Bedrock                              |
| Continued        | D3 on the core:                     |                     | Pondidaha District | 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, cristobalite, 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 of ultramafic rock samples which shows the magnetic susceptibility parameter can explain the weathering conditions of ultramafic rocks.

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).

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