Petrography and geochemistry preliminary study of Pucangan Serpentinite Geosite Karangsambung – Karangbolong Geopark Central Java, Indonesia

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Abstract. Geosite is a Geological Heritage object in the Geopark area with specific characteristics and is an integral part of the evolutionary history of forming an area. Serpentinite Pucangan is one of the Geosite located in Karangsambung – Karangbolong geopark. This study aims to find out the characteristics of petrography and geochemistry of Serpentinite Pucangan Geosite. The methods used in this study include literature studies, fieldwork research, petrography analysis, ore microscopy analysis, whole rock analysis consist of major element analysis using fusion inductively coupled plasma (Fus ICP) methods, trace element analysis, and rare earth element analysis using inductively coupled plasma mass spectrometry (ICP-MS) methods. Serpentine minerals with antigorite type dominate the petrography composition of Pucangan serpentinite with a little magnetite mineral. SiO$_2$, MgO, and Fe$_2$O$_3(t)$ are the major elements with the largest percentage of 37.93%, 5.78%, and 9.73% that have an agreement with the mineralogical composition of the rock that dominated by ferromagnesian minerals. This Geosite is interpreted to be formed due to the metasomatic process when the subduction process is happening in this area in the Pre-tertiary period.

1. Introduction

Geopark is a geographical area with valuable Geosite and landscapes related to Geoheritage, Geodiversity, Biodiversity, and Cultural Diversity [1]. Karangsambung - Karangbolong Geopark is located in Kebumen Regency, Central Java, has 41 Geosites spread across northern Kebumen, central Kebumen, to Southern Kebumen. The entire Geosites reflect the geological history on the Java Island from the Pre-Tertiary until the Quaternary period that begins with java island formation due to plate subduction. These tectonic events produce a diversity of igneous, sediments, and metamorphic rocks that we can find in the northern Kebumen. One of the subduction process evidence is serpentinite rock that was well outcropped in the Pucangan area.

Serpentinite is a greenish-black metamorphic rock dominated by serpentinite minerals: antigorite, chrysotile, or lizardite (allomorphs of Mg$_3$Si$_2$O$_5$(OH)$_4$), which are formed from the hydrous alteration of olivine minerals, orthopyroxene, and sometimes, clinopyroxene [2]. Serpentinite generally formed beneath the earth's surface and are rarely exposed to the surface. Therefore, the serpentinite outcrop in the Pucangan area, North Kebumen, is significant to be conserved to maintain the rocks' educational value. One way to conserve a geological heritage is to make it a Geosite within the Geopark area. Geosite
is a Geological Heritage object (Geoheritage) in the Geopark area with specific characteristics and is an integral part of forming a region's evolutionary history. This study aims to determine the attributes of petrography and geochemistry of serpentinite rocks in the Pucangan area, one of the Geosite in Karangsambung – Karangbolong Geopark so that the history of Geosite formation can be known.

2. Geological setting

This research is located at coordinates E 0355735 N 9168547, Pucangan Village, Sadang Sub-District, North Kebumen (Figure 1). This area is included in the Luk Ulo Melange Complex (KMLU), which consists of a varied block (igneous, sediment, and metamorphic) that mixed tectonically within the black shale matrix [3]. The components of KMLU, in general, include:

- Metamorphic rocks are the oldest rocks found and consist of Gneiss, Green Schist, Mica Schist, Blue Schist, phyllite, amphibolite, eclogite, and marble. Rb – Sr dates of the Garnet-Phengite Schists indicate the age of 118 and 114 Ma [4].
- Igneous rocks: a series of ophiolite rocks exposed in this area consisting of peridotite, serpentinite, gabbro, diabase, and basal rocks that commonly form pillow structures. Pillow-structured basalt is generally associated with deep-sea sediment.
- Deep-sea sediment: consists of a Chert interlayered with red clay or red limestone clay. Sedimentary rocks generally consist of layered pelitic rocks with sandstone, greywacke, and metagreywacke, which generally form boudinage structures.

The research area belongs to the South Serayu Mountains physiography zone [5] that dominates the structural hills morphology. The geological structure found in the research area is strike-slip faults with directions almost north-south and northwest-southeast [3].

![Figure 1. Geological map of the research area (modified after [3]).](image-url)
3. Methods
The method used to achieve this research's objectives includes three stages, the literature study stage, the fieldwork stage, and the laboratory analysis stage. The first stage is to study the research area's regional geological conditions and a review of previous research. The fieldwork activities carried out are the plotting of outcrop location, lithology description in the research area, rock sampling, and documentation. The last stage is laboratory analysis, including petrography analysis, ore microscopy analysis, XRD (X-Ray Diffraction) analysis, and bulk rock chemical analysis.

A sample from the research area with code SR – 41 was carried out for the petrography analysis, ore microscopy analysis, XRD (X-Ray Diffraction) analysis, and bulk rock chemical analysis. The thin section and polished surfaces were made in the optical laboratory of Gadjah Mada University. Subsequently, petrography observations were carried out in the optic laboratory of the Research & Development Division for Earth conservation and Information – LIPI. Preparation and Analysis of XRD were done in the laboratory of the Geological Survey Center, Bandung, while the bulk rock chemical analysis was carried out at Activation Laboratories LTD., Canada. Bulk rock chemical analysis consists of the analysis of the major elements using fusion inductively coupled plasma (Fus ICP) method with units of measurement in the form of a percentage (%), analysis of trace elements, and analysis of rare earth elements use the method of inductively coupled plasma mass spectrometry (ICP-MS) with units of ppm (part per million).

4. Result
Based on field research, it is known that Pucanga serpentinite outcropped in Karangsambung - Sadang highway precisely at coordinates E 0355735 N 9168547. The outcrop has dark green - blackish colors with quite large dimensions covering a hill (Figure. 2). The condition of the outcrop is not damaged, but it is intensively fractured. Some sides of the outcrop were weathered until a layer of soil forms. When observed in more detail, fresh rocks are green, and some parts still show the original rock's texture.

Figure 2. Condition of the Pucangan serpentinite outcrop (a) the dimension is covering a hill; (b) located on the side of Karangsambung – Sadang highway; (c) the color of fresh rock; (d) intensively fractured.
The thin sections from the research area showed the rocks’ composition was dominated by serpentine, with minerals size 0.05-0.5mm, subhedral - anhedral shape as presented in figure 3. Another mineral found in the thin section is the opaque mineral. Mineral serpentine (96%), colorless - brownish-green, has low relief, flaky shape, and weak pleochroism. Opaque mineral (4%), color black, has high relief, and having size 0.02 – 0.15mm. The opaque mineral is magnetite with brownish-grey color based on ore microscopy analysis, does not show pleochroism, euhedral shape, size <10-75 μm, and dark interference color (figure 4). XRD analysis shows that the type of serpentine mineral in rock sampling is an antigorite type.

Figure 3. Thin section of serpentinite Pucangan geosite showing serpentine (srp) and opaque (opq) minerals.

Figure 4. Ore microscopy of serpentinite Pucangan geosite showing magnetite (mag) mineral.
Figure 5. Spektrum XRD of Serpentine Pucangan.

Table 1. Serpentine Pucangan minerals composition based on XRD analysis.

| Ref. Code | Score | Compound Name | Displacement [°2θ.] | Scale Factor | Chemical Formula |
|-----------|-------|---------------|---------------------|--------------|-----------------|
| *00-052-1572 | 30 | Antigorite | 0.000 | 0.406 | Mg₃Si₂O₅(OH)₄ |
| *00-029-0853 | 29 | Clinochlore | 0.000 | 0.192 | Mg₅Al(Si₃Al)O₁₀(OH)₈ |
| *00-001-1111 | 31 | Magnetite | 0.000 | 0.057 | Fe₃O₄ |

The major elements of serpentine Pucangan are presented in table 2, whereas all of trace elements and rare earth elements are below to detection limit except Ba = 8 ppm.

Table 2. The concentration of major elements in Serpentine Pucangan.

| Major Elements (wt%) | SR-41 |
|----------------------|-------|
| SiO₂                 | 37.93 |
| Al₂O₃                | 0.22  |
| Fe₂O₃(t)             | 9.73  |
| MnO                  | 0.108 |
| MgO                  | 35.78 |
| CaO                  | 0.02  |
| Na₂O                 | 0.01  |
| K₂O                  | 0.009 |
| TiO₂                 | 0.009 |
| P₂O₅                 | 0.009 |
| LOI                  | 13.88 |
| Total                | 97.68 |
5. Discussion

Petrography and XRD analysis of rock samples from the research area showed antigorite-type serpentine minerals' dominance. Serpentine minerals are formed due to the hydration process of Mg-rich minerals such as olivine, orthopyroxene, and clinopyroxene at various temperatures, including at hydrothermal temperatures and sub-surface conditions [6]. According to [7], antigorite is a type of serpentine mineral stable at high temperatures and high pressures. The process of serpentinization of antigorite minerals generally occurs at a temperature of 400 – 600 °C [8], usually occurs in partially recrystallized and metamorphosed serpentinite [6]. [9] reported that antigorite serpentinite was found in three paleo-subduction zones: The Himalayas, the Alps, and the Cub and associated with High Pressure to Ultra-High Pressure (HP-UHP) metamorphic rocks. This theory agrees with the geological conditions of the research area: a Pre-Tertiary subduction zone that can form serpentinite antigorite due to the metamorphosis process. Moreover, near the research area precisely in Muncar and Loning rivers were found high-pressure metamorphic rocks such as eclogite-, blueschist-, and amphibolite-facies [10]. Serpentinite is believed to have an important role in the outcropping of high pressure to ultra-high pressure (HP-UHP) metamorphic rocks due to their lighter physical properties (buoyant) than other rocks [9].

Another mineral found in the rock sample is magnetite mineral (Fe₃O₄). In the serpentinization process, the content of #Mg in origin minerals such as olivine, orthopyroxene, and clinopyroxene will be distributed in serpentine minerals. In contrast, the content of #Fe will precipitate into magnetite minerals [6]. Furthermore, [8] explained that the higher the serpentine mineral formation’s temperature, the less magnetite mineral formation would be. That's why lizardite serpentinite, in general, have more abundant magnetite content than antigorite serpentinite. Petrographic analysis on serpentinite Pucangan from the research area shows results in agreement with the theory that magnetite content is not abundant, only about 4%.

The chemical composition of Serpentinite Pucangan is presented in Tables 2. The composition of the major elements of Serpentinite Pucangan is dominated by SiO₂ 37.93%, MgO 35.78%, and Fe₂O₃(t) 9.73%. The value agrees with the results of the petrography analysis that shows the dominance of ferromagnesian minerals. Other major elements are Al₂O₃ 0.22%, MnO 0.108%, CaO 0.02%, Na₂O 0.01%, K₂O 0.009%, TiO₂ 0.009%, and P₂O₅ 0.009%. The LOI (lost of ignition) value of 13.88% indicates the high number of hydrous minerals.

The result of most trace elements and rare earth elements analysis of Pucangan serpentinite are below detection limits. Therefore, advanced research is needed with another geochemical analysis method so that the trace element value in this rock can be detected and the origin can be known.

6. Conclusion

Serpentinite Pucangan Geosite is composed by the dominance of antigorite type serpentine minerals (956%) and a little magnetite mineral (4%). The rocks are interpreted to be formed due to the metamorphism process at the time of pre-tertiary Subduction. The major element content of Serpentinite Pucangan is dominated by SiO₂ 37.93%, MgO 5.78%, and Fe₂O₃ 9.73% that agrees with the mineralogical composition that is dominated by ferromagnesian minerals.

Limited data, especially about trace elements in Pucangan serpentinite, interpret the rock genesis has not suffered yet. Therefore, further research is needed so that the rock formation can be known. The increase in the number of rock samples is recommended for where further research is. Besides, it considers choosing other geochemical methods with smaller detection limits so that traces and rare earth elements in Pucangan serpentinite can be detected.
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