Study of altered lithologies in Gunung Lawu, Central Java, Indonesia using petrographic analysis

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Abstract. Gunung Lawu is one of the areas that have geothermal potential in Indonesia. One way to find out if an area has a geothermal potential is to know the alteration that occurs in the rocks in that area. Alteration is a very complicated process that involves changes in mineralogy, chemistry, and texture caused by the interaction of hot fluids with the rock in its path. This research aims to identify mineral and intensity of alteration in the research area with petrographic analysis and hand specimen description. The petrographic analysis method is used to identify unaltered or altered minerals present in the sample rocks of the study area. In addition to using petrographic analysis, it is also seen through hand specimen descriptions and also outcrops to see the lithology of rocks in the research area. From the sample of this research, it can be classified by three categories. There are unaltered rocks, weak intensity alteration and strong intensity alteration. Unaltered rocks were found in SLM and BNA, weak intensity alteration was found in NGY 1 and strong intensity alteration was found in LWU. In NGY 1 sample, chlorite alteration mineral was found, while in LWU, goethite alteration mineral was found. The occurrence of alteration in the area may be due to the area being passed by faults which interact with hydrothermal fluid. These faults also become the fluid pathway for the geothermal reservoir. The heat from the reservoir is able to change the mineral composition of the rock. In LWU, a fault is passed which produces fumarole manifestations, and NGY 1 is passed by a fault that forms hot spring manifestations.

Keywords: Gunung Lawu, alteration, petrographic, geothermal, mineral

1. Introduction

Gunung Lawu is one of the regions in Indonesia that hold large geothermal potential [1]. Geothermal area of Gunung Lawu is located in Karanganyar district, Central Java province (figure 1). Geothermal occurrences are usually related to hydrothermal alteration in subsurface. A good indicator of thermal fluid dynamics in geothermal systems is hydrothermal alteration [2]. Hydrothermal alteration has many benefits in identifying geothermal systems such as permeability indicators, fluid chemistry, geothermometers, thermal history, setting the production casing, and predicting scaling and corrosion tendencies of a well [3]. In previous research conducted by [4] and [5] in the same research area in Gunung Lawu, only focus on geochemistry and base metals in Gunung Lawu and there has not been any alteration study in this area. Therefore, this study aims to identify mineral and intensity of alteration in the research area and also to determine the causes of alteration in the rocks in the Gunung Lawu area. This research also aims to help prove previous research, that Gunung Lawu has a geothermal system...
due to the discovery of alterations in the geothermal area of Gunung Lawu. Mineral alteration in the study area is analysed by describing the hand specimen and also observing the thin section under a microscopic petrography. In the area of Gunung Lawu itself, the intensity of alteration is divided into 3 categories based on [6] the percentage of alteration ranges from weak (0–25 %), moderate (25–50 %), strong (50–75 %), very strong (75–100 %). The categories in Gunung Lawu are strong intensity alteration, weak intensity alteration and unaltered rocks. Alteration in the Gunung Lawu area is caused by a fault which is the fluid pathway for the geothermal reservoir. Geothermal fluids that have high temperatures can change the mineral composition of rocks. In the alteration classification summarized by [7], the classification of important alteration is based on the identification of the alteration mineral, mineral assemblage, or chemical change that has occurred during the alteration [7]. The collection and classification of alteration minerals should be combined with field observations as well as petrographic analysis, and in some cases supported by other techniques [8].

2. Geology overview
Gunung Lawu has an elevation ranging from 350 to 3100 masl. Geological map of the research area referring to Sampurno et al. [9] and further geological mapping was completed by [4]. The research area consists of Gunung Lawu volcanism products from the Quaternary period (figure 2). This lithology consists of Lawu volcanic rocks (Qvl), Lava Jabolarangan (Qvjl) and Lava Candradimuko (Qvcl) [9]. Following are the rock formations found in the research area referring to Geological Map of Ponorogo Sheet from old to young, sequentially [9] :

1. Jobolarangan Lava (Qvjl); consists of andesitic lava,
2. Lawu Volcanic Rocks (Qvl); consists of volcanic breccia and andesitic lava,
3. Lava Candradimuko (Qvcl); consists of altered rocks around the Candradimuko manifestation area.

Figure 1. Research location map
3. Methodology
Geological mapping was carried out in an area of 20 x 15 km² with altitude up to 3100 masl [4]. 20 outcrop samples were observed and rock samples were taken at various altitudes to see whether the rocks taken in the region have alterations which indicate that there has been a chemical or physical change in the rocks in the area. The method used in this research is a hand specimen description and also a petrographic analysis to see clearly whether there are clay minerals present in thin sections of the existing rock samples. Thin sections were prepared at Obsidian Geo-Laboratory Services, Bandung. Petrographic analysis was carried out at the Petrographic Laboratory, Geosciences Study Program, Faculty of Mathematics and Natural Sciences, Universitas Indonesia using the Leica DM750P petrographic microscope.

4. Results and discussions
Various samples retrieved are dominated by volcanic rocks in the form of volcanic breccia, tuff and andesitic intrusions (figure 2) where the rock samples correspond to the proximal facies [10] of a stratovolcano such as Gunung Papandayan [11]. Judging from the geothermal system, the dominant lithology of volcanic activity is accompanied by geomorphological data, so the research area is a volcanic area with the characteristics of geothermal play convection dominated type CV-1 [12]. This type of geothermal play has a heat source that comes from magmatic activity below the surface with rocks in the form of andesite and has a pyroclastic rock host rock with good porosity and permeability [12]. This study uses Four outcrops location and five hand specimens samples which were retrieved from the research area. The outcrop can be seen in figure 3. NGY 1 outcrop is found at an altitude of about 900 masl with volcanic breccia lithology. NGY 1 has two types of fragments in the form of scoria and andesite with tuff matrix. BNA 1 outcrop is at an altitude of 464.7 masl with andesite lithology, SLM 3 outcrop is at an altitude of 1100 masl with andesite lithology, while the LWU outcrop is at an altitude of 2514 masl with lithology sulfur deposit.

![Figure 2. Geological map of the Ponorogo modified sheet of Sampurno and Samodra.](image-url)
4.1. Unaltered rocks

Unaltered rocks were found in two outcrops and hand specimen samples in SLM and BNA. SLM and BNA’s lithology type are in the form of andesite rocks. On a megascopic scale, the hand specimens is gray in colour, where the weathered part is gray-brown accompanied with 20 % of plagioclase phenocrysts and 75 % mafic mineral base. The rock has porphyritic granularity texture, the degree of crystallization is holocrystalline, has an inequigranular sorting, and a subhedral crystal shape. There is no apparent alteration found in the SLM rock sample, this could indicate that SLM 3 rock is a protolith rock, the original composition of rock that has not undergone alteration. The absence of alteration in the SLM rocks was confirmed by petrographic analysis as shown at figure 4. In the thin section of rock, it is seen that the predominance of minerals in the form of plagioclase and also pyroxene are visible.

![Figure 3](image1.png)

**Figure 3.** Outcrop rock in the research area (a) NGY1, (b) SLM3, (c) BNA1, and (d) LWU.

![Figure 4](image2.png)

**Figure 4.** (a) Hand specimen and (b) thin section of SLM 3.
In addition to SLM, unaltered samples were also obtained in the outcrop and hand specimens of BNA with andesite lithology. BNA sample has a fresh gray color, where the weathered part is brownish gray color accompanied with 10% of plagioclase phenocryst and mafic mineral base of 75%. For rock texture, BNA has a porphyritic crystal size, has a crystallization degree of holocrystalline, has an inequigranular sorting, and subhedral crystal shape. In BNA rock samples, BNA manifested hot water at an altitude of 1100 m above sea level, while rock samples were taken at an altitude of 464.7 masl. In the BNA sample, no alteration was found due to the absence of structure. When viewed from the geological and lithology distribution map (figure 2), this outcrop point or sampling location is not crossed by the alignment of the structure which is the fluid pathway for the rock alteration process. This was confirmed by the thin section analysis as shown in figure 5. In the thin section of BNA 1, no clay minerals were found, only plagioclase and pyroxene were found which indicates that this rock is a protolithic rock with andesite lithology.

4.2. Weak intensity alteration
Weak intensity alteration in the study area was found in NGY 1 outcrop and hand specimen sample. NGY 1 is a grey-white consolidated volcanic breccia with one type of fragment in the form of scoria and andesite with tuff matrix. Fair numbers of lithic fragments with poor sortation and massive structure define NGY 1 as pyroclastic deposits. When observed under the microscope, NGY 1 consists of 20% of plagioclase phenocrysts and some clay minerals indicating weak intensity alteration as shown in figure 6. Weak alteration in NGY 1 is indicated by the presence of chlorite and clay minerals in both XPL and PPL aspects. Chlorite is a common hydrothermal alteration in many systems, particularly in peripheral propylitic alteration or retrograde overprinting alteration. Chlorite has the platy habit of mica, and is pleochroic (green). Grain sizes are generally small, but may range up to 200 micrometers in rocks of lower green schist metamorphic grade [8].

Chlorite alteration in NGY 1 can be caused by the presence of a geological structure and the presence of hot fluid (hydrothermal). The hydrothermal fluid is estimated to flow through lineament which is indicated as a structure that can be seen on the geological map as shown at figure 2. This type of hydrothermal fluid is also caused by the presence of thermal manifestations in the form of bicarbonate of water where chlorite minerals are most likely to be formed [13]. This finding also suggested that there is a correlation between the proximity of NGY 1 with a thermal manifestation and also the altitude of NGY 1 at 1100 m above sea level. Based on the intensity of alteration [6] the alteration in NGY 1 is considered as a weak alteration with the presence of 7% and 13% in NGY 1 tuff and andesitic hand specimens respectively with a total of 20% of alteration intensity.

4.3. Strong intensity alteration
Strong intensity alteration in the study area was found in both LWU outcrop and hand specimen sample. However, in previous studies conducted by [4] and [5] there was no discussion of alteration at this
point sample. For comparison, Gunung Papandayan is reported to have strong intensity alteration in Gunung Nangklak crater zone and around the flank areas. Gunung Nangklak is located between two main faults where solfataras and fumaroles are also present around the Nangklak crater. It is reported that majority of the rocks found in the crater area are hydrothermal altered [11]. Similar geothermal feature such as fumaroles are also present at LWU sample point where LWU sample point exhibit strongly altered rocks. Macroscopically, LWU sample has a gray-white color with a level of cohesiveness of consolidated rocks, has brittle hardness, with yellow sulfur minerals in some parts of the rock. Microscopically, LWU has a gray color and has a plagioclase as phenocryst of 15%. Alteration in LWU is characterized by the appearance of clay minerals and goethite minerals which can be seen on thin sections in cross Nichols (XPL) and parallel Nichols (PPL) as shown in figure 7. According to Gunnlaugsson in [13] based on the results of petrographic interpretations combined with geological maps and geological structures in the form of lineament, changes in goethite (Fe-oxide) and clay can be caused by the presence of geological structures and the presence of boiling hydrothermal fluids which lead to deposition of iron oxide minerals such as goethite. The lineament of the area serves as a fluid pathway leading to an alteration process. The presence of sulfate type water in LWU according to [4], where sulfate water leads to the formation of argillic, kaolinite, alunite, goethite-hematite alteration. Moreover, sulfate water can also produce surface sulfur deposits [13]. Typical sulfuric water can form in high topography above the water table with high temperatures and can occur in the surface manifestations of hot springs in the form of fumaroles and hot pools [13]. The overall alteration intensity in LWU shows a strong intensity alteration. However, in order to determine what altered minerals are formed in these altered rocks will require further diffraction and elemental analysis.

Figure 6. (a) and (b) hand specimen and thin section from NGY 1 tuff, (c) and (d) hand specimen and thin section from NGY 1 andesite.
5. Conclusion
In this research it can be concluded from the existing sample that the study area has 3 categories of alteration intensity. Strong intensity alteration can be found in the LWU sample, which is located at an altitude of 2514 masl, this sample has mineral clay above 70% with the appearance of rock that has been severely destroyed due to the alteration process in the area. Then weak intensity alteration was found at NGY 1 with volcanic breccia lithology. NGY 1 has a bicarbonate water type which results in chlorite alteration as shown in the thin section. SLM 3 and BNA 1 with andesitic lithology are considered unaltered because they are protolithic rock. For more detailed zonation of alteration in Gunung Lawu area, further alteration research is needed with other analyzes such as X-Ray Diffraction and X-Ray Fluorescence.

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