Hydrothermal alteration studies of Gunung Endut, Banten with petrographic method

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Abstract. Hydrothermal alteration is a great indicator of thermal fluid dynamics, especially in a geothermal system. Hydrothermally altered minerals are formed based on temperature and the properties of the protolith. Hydrothermal alteration samples from Gunung Endut Geothermal Working Area were analysed using petrography methods. Importance in determining the hydrothermal alteration for geothermal alteration are use as geothermometers, predict scaling and corrosion, estimate fluid pH and many more. Temperature, permeability and fluid type involved in the alteration process were identified based on the thin section observation. Majority of the samples shows the presence of clay minerals, chlorite and pyrite, indicating a moderate intensity of alteration formed under an argillic alteration environment at \( \sim 180 \, ^\circ C \). Based on the altered minerals observed under the petrographic microscopy, we then deduce that acidic fluids are the main type of fluid found in Gunung Endut Geothermal Working Area because that argillic alteration minerals showed acid environment.

Keywords: Geothermal, Gunung Endut, hydrothermal alteration, petrography

1. Introduction
More than 200 volcanoes are located within the Ring of Fire around Sumatra, Java, Bali and East Archipelago of Indonesia [1]. The Indonesian archipelago sits on top of three active subducting plates entrusting high enthalpy geothermal system [2]. MEMR database (2017) reported that there are 33 Geothermal Working Area (GWA) and 28 Prospetced Geothermal (PGA) to be further developed. Gunung Endut is located geographically at 6°34'12” – 6°40'48” S and 106°15'36” – 06°22'12” E, Lebak Region, Banten – 40 km south of Rangkasbitung has speculated geothermal energy up to 80 MWe [3].

The hydrothermal system can be related to a volcanic system and the formation of volcanoes in a subduction zone with high heat flow [4]. An active subducting plate drives heat transfer at depth to the surface through faults and fractures [5]. Hydrothermal alteration is one indication of a hydrothermal system [6]. Hydrothermal alteration is the interaction between heated fluid with host rock resulting in secondary minerals [7]. The importance of hydrothermal alteration studies in a geothermal potential area is as temperature, permeability and fluid type indicators [8]. Reported that the lithology distribution of Gunung Endut consists if pyroclastic (tuff and andesitic breccia), limestones, and clays [9].

Hydrothermal alteration minerals are formed due to the interaction between rock and fluids [10]. Typical alteration product can be identified based on the temperature-, permeability- and fluid type-indicating minerals [8]. Different minerals also show different susceptibility of alteration [6].
The intensity of alteration (Ia) is a measure of how completely a rock has reacted to produce hydrothermal mineral or secondary mineral [11]. The intensity of alteration is the ratio of unaltered minerals to the altered minerals (table 1). The permeability property of the rock has an inversely proportional relationship to the intensity of alteration. The altered or secondary mineral can alter the porosity and permeability properties of the lithology thus sealing the fluid pathways to transport more hydrothermal fluids.

Argillic alteration is a condition with a wide variety of clay minerals, including kaolinite, smectite and illite. In general, occurs where low-temperature groundwater becomes acidic usually < 200 °C and some may occur in atmospheric conditions causing primary minerals to be converted to clay minerals [12]. Each mineral has a geological significance each divided into a geothermometer, permeability indicator, indicating fluid chemistry, fluid-inclusion studies, suggests high steam to water ratio. It shows only certain minerals that can be used as geothermometer (figure 1) [8].

The aim of this research is to determine hydrothermal alteration in Gunung Endut area using petrographic methods to understand the genesis, distribution and intensity of hydrothermal alteration in the Gunung Endut area.

2. Methodology

Samples were retrieved during geological mapping. Ten samples were classified as representative and prepared as thin sections and analysed using petrographic microscope. Lithology of the research area consists of Pumice tuff, tuffaceous sandstones, conglomerate breccias, and marl which are

| The intensity of alteration (Ia, %) | Host rock condition |
|-----------------------------------|---------------------|
| 0 ≤ Ia < 25; weak                | Groundmass/matrix or phenocrysts/grains is slightly altered. |
| 25 ≤ Ia < 50; moderate           | Groundmass/matrix or phenocrysts/grains are moderately altered. |
| 50 ≤ Ia < 75; strong             | Groundmass/matrix or phenocrysts/grains are almost altered completely. Original texture and phenocrysts are still visible. |
| 75 ≤ Ia < 100; very strong       | Groundmass/matrix or phenocrysts/grains are altered where original textures are difficult to be identified. |

Gf = used in fluid-inclusion studies; suggests high steam to water ratio.

Figure 1. Temperature-dependent selected alteration mineral (adapted from Reyes [8]).
included in the Pliocene Genteng Formation (Tpg) located in the north of research area [9]. Bojongmanik Formation (Tmb) consists of sandstones, limestones, and claystone aged Late Miocene located in the Southwest and Northeast of the research area. Bedouin Formation (Tmd) consists of a conglomerate, Sareweh Formation (Tms) consists of claystone, and Andesite rock (Tma), each of which is Middle-Late Miocene, Middle Miocene, Late Miocene and Pleistocene Endut Volcanic Rocks (Qpv) located in the middle of the research area and consists of volcanic breccia, lava, and tuff (figure 2).

2.1. Petrography analyses
A polarized microscope was used to observe thin sections of rock samples. The details of the sample’s lithologies and mineralogy were able to be detailed including the mineral compositions, textures, and the type and intensity of hydrothermal alteration from the research area. The analyses were completed macroscopically and microscopically. Altered minerals were determined based on their characteristic with visual observation. Rock nomenclature according to Schmid’s classification (1981) was used to classify pyroclastic based on the composition of volcanic glass, rock- and crystal-fragments [13]. Travis classification (1955) was used as a reference for igneous rock observations based on the rock texture, mineral composition (such as quartz, plagioclase, and alkali-feldspar) [14]. Analyses also could be compared with X-Ray Diffraction (XRD) analyses for more detail minerals content. The result of petrography analyses can help determine both geological and hydrothermal process occurred around Gunung Endut area based on the mineral association formed in the alteration zone and its intensities.

3. Results and discussion
Altered rock samples indicate the presence of secondary quartz, silica sheet minerals, and sulphide minerals. Table 2 summarizes the petrography analyses from the samples taken around the area of Gunung Endut.

Ten sample exhibits hydrothermal mineral such as secondary quartz, chlorite, pyrite and clay minerals by using classification (table 1) with results (table 2). Type of alteration divided into three results, there are weak (figure 3), moderate (figure 4) and strong (figure 5 and figure 6). Secondary quartz is abundant in the research area indicating alteration by acid fluids. Quartz can be found as a replacement and vein filling mineral.

Figure 2. (a) Research area, (b) geological map of research area [8].
| Sample code | The intensity of alteration (Ia, %) | Unaltered minerals | Altered minerals |
|-------------|-----------------------------------|--------------------|-----------------|
| F.6.2       | Weak (5)                          | Quartz             | Clay mineral    |
| J. 9        | Moderate (45)                     | Plagioclase, quartz, k-feldspar | Clay mineral |
| V.56        | Strong (51)                       | Quartz, k-feldspar, plagioclase | Clay mineral, pyrite |
| N. 14       | Weak (24)                         | K-feldspar, quartz | Clay mineral, chlorite, pyrite |
| N. 15       | Weak (18)                         | Quartz             | Quartz polycrystalline |
| R.51        | Strong (53)                       | Quartz, opaque     | Clay mineral, quartz polycrystalline, fe-oxide |
| St.01       | Moderate (49)                     | Quartz, plagioclase, opaque | Clay mineral, pyrite |
| Z.3.1       | Moderate (42)                     | K-feldspar         | Clay mineral, pyrite |
| Z.8.3       | Moderate (45)                     | Quartz, k-feldspar, pyroxene | Clay mineral, chlorite, pyrite |
| Z.9.8       | Moderate (33)                     | K-feldspar, Quartz | Clay mineral, pyrite |

**Figure 3.** Petrography specimens of Sample F.6.2 tuff (weak).

**Figure 4.** Petrography specimens of Sample Z.9.8 andesite (moderate).
Silica sheet minerals such as chlorite, clay minerals and pyrite were also found in sample N.14 and Z.8.3. Similar to secondary quartz, chlorite is a void filling mineral. Sample Z.8.3 (andesite) exhibits pyrite where most pyrite is distributed in the groundmass (figure 4). Pyrite is one of acid hydrothermal mineral, abundant in most area, alteration product that associated with thermal manifestations, also scales and corrosion product.

All the altered minerals observed from thin section petrography analyses indicated argillic alteration with temperature ranging approximately from 180–200 °C. Argillic alteration is triggered by the change of primary minerals to clay minerals such as chlorite, quartz and pyrite. It is possible to determine the type of clay minerals only by using a polarized microscope based on their characteristic with few precautions because not all clay minerals could be determined only by visual description.

3.1. Calc-silicate

The hydrothermal fluid conducting alteration process may infer the presence of geothermal system underlyng in Gunung Endut Area. Argillic alteration is commonly a sign for geothermal upflow zone in a volcanic terrain system [15]. The intensity of alteration indicates the hydrothermal fluid dynamic in the region. The higher the intensity of alteration may point to the direction of the hydrothermal fluid source.

3.2. Alteration intensity

Based on petrography analyses on ten samples, alteration distribution on Gunung Endut, Banten can be seen in figure 7. Interpolation for zoning alteration distribution by using kriging methods. In addition,
Figure 7. Intensity alteration zone map

the distribution of alteration is also supported by the location data of geothermal manifestations. The closer to the geothermal manifestation, the higher the alteration intensity, because it affects the duration of interaction between rocks and fluids. Otherwise, the distance from the geothermal manifestation location is lower then the alteration intensity is low. Gunung Endut is divided into three alteration intensities, consists of weak (below 25 %), moderate (25-50 %), and strong (above 25 %).

4. Conclusion
Petrographic studies of rock samples from Gunung Endut area revealed the distribution of argillic alteration indicated by the presence of clay minerals and calc-silicate minerals. The alteration temperature ranges from 180-200 ºC with most sample presenting moderate to high intensity of alteration. Argillic alteration and the intensities of alteration can point out to the possible upflow zone of the geothermal system in Gunung Endut area.

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