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Geothermal Surface Alteration and Water Chemistry: An Updated Geochemical Data in Gunung Endut Geothermal Area, Banten, Indonesia

Dyah N. Sahdarani[1*], F. Primayudha[1] C. Risman[1], Felix M.H. Sihombing[1], Supriyanto[1,2], Grandprix T.M. Kadja[3,4]

[1]Geology Study Program, Faculty of Mathematics and Natural Sciences, Universitas Indonesia

[2]Geophysics Study Program, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Kampus UI Depok, Depok 16424, Indonesia

[3]Division of Inorganic and Physical Chemistry, Institut Teknologi Bandung

[4]Research Center for Nanosciences and Naotechnology, Institut Teknologi Bandung, Jalan Ganesha no. 10, Bandung, 40132, Indonesia.

E-mail address: dyahnindita@ui.ac.id

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ABSTRACT

Gunung Endut in Java Island is one of the prospected geothermal area to expand geothermal capacity in Indonesia. With limited scientific data in Gunung Endut, the aim of study is to complete scientific data to build an updated conceptual model. This study focuses on the association of surface alteration and water chemistry at Gunung Endut Geothermal Working Area, Banten, Indonesia. Water chemistry were analysed from surface manifestations had pH values of 6.8 – 7.6 indicating Cl-HCO_3 water type. Surface alteration were also collected from the surrounding area of Gunung Endut. Alteration mineral assemblage groups were laid out based on its surface intensity. Montmorillonite, dickite and chlorite predominated at distal-proximal facies of Gunung Endut. Alteration factors can be driven by the mobility of ions, the protolith physical properties, fluid type circulating in the near surface, and water chemistry and topography. The type of altered clay mineral assemblage, the richness of Na, K, and Mg indicates an intense fluid-rock interaction, promoting rock leaching and altering both parent rock composition and mineralogy.

1. INTRODUCTION

Geological Agency Indonesia completed preliminary survey of Gunung Endut Geothermal Prospect in 2009 (Kusnadi et al., 2009). A follow up and more detail survey was then conducted by researchers from Universitas Indonesia, including geological, geochemical and geophysical surveys which lasted from 2014 to 2018 (Supriyanto et al., 2017, Supriyanto et al., 2019). Gunung Endut is located in Banten Province, 70 km southwest of Jakarta. Ministry of Energy and Mineral Resources (2017) reported that Gunung Endut has 61 MWe speculative of geothermal energy.

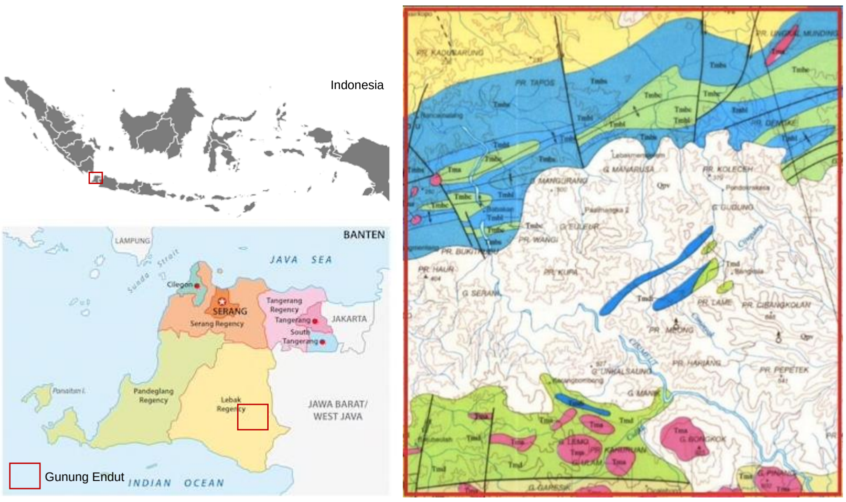

Figure 1: (a) Location map of Gunung Endut, Indonesia, (b) Geological map of Gunung Endut based on Sujatmiko and Santosa, 1992).

Previous research in resistivity methods has been performed over the years to gain deeper and more thorough image of a geothermal system (Supriyanto et.al., 2017, Supriyanto et.al., 2019). The aim of resistivity study is to obtain the information on fluid circulation in the subsurface in the form of subsurface alteration (Bromley and Espanola, 1982, Ussher et al., 2000). Altered rocks appears to have lower resistivity values compared to unaltered rocks (Anderson et al., 2000). The resistivity interpretation can then lead to the determination of the lithologies and permeability properties of the geothermal area (Anderson et al., 2000).

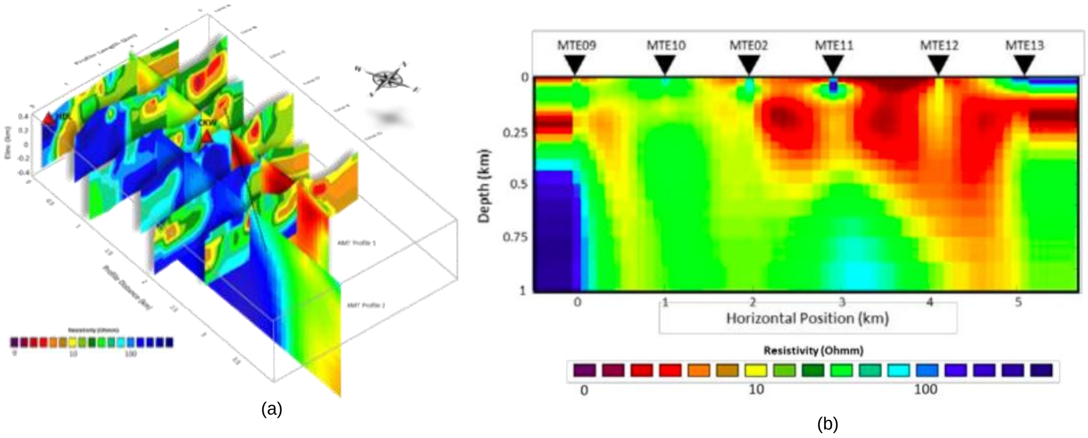

Figure 2: Geophysical investigation in Gunung Endut (Supriyanto et al., 2019) (a) complete AMT profiles (b) AMT profile line 2, used as the base for geothermal conceptual model.

Mapping surface hydrothermal alteration can identify the total area of geothermal prospect (Wohletz and Heiken, 1992). Hydrothermal alteration is a common feature and also the response of mineralogical, textural and chemicals of rocks to a changing thermal and chemical environment in the presence of hot water, steam and or gas (Henley and Ellis, 1983, Stefansson and Kline, 2018). The presence of certain altered mineral can determine the fluid pH and the extent of circulating thermal fluid within the hydrothermal system (Nicholson, 1993). The type of host rocks affects the product of hydrothermal alteration and can infer the changes in permeability property of the rocks (Stefansson and Kline, 2018). Minerals from kaolinite group (e.g. kaolinite, dickite, halloysite) are common to indicate weak acidic to neutral alteration (Browne, 1978, Corbett and Leach, 1998, Nicholson, 1993).

The collective data for this study is based on the compilation field work of geological mapping course for 3rd year Geological Science students of Universitas Indonesia. This study will highlight the updated geochemical data of thermal water and surface hydrothermal alteration from around Gunung Endut. three thermal manifestation of Handeleum, Cikawah and Gajrug. Both Handeleum and Cikawah are located to the proximity of Gunung Endut, Gajrug however is located 6 km farther north of Gunung Endut. The aim of this study is to create an alteration zonation based on its mineralogy and fluid composition and to create a 2-dimensional conceptual model of Gunung Endut geothermal prospect by integrating all the available data.

2. GEOLOGICAL OVERVIEW

Sujatmiko and Santosa (1992) completed a Geological Map of Leuwidamar. The lithologies of Gunung Endut were formed since the Middle Miocene until the Pleistocene period. The oldest lithology is Baduy Formation consists of conglomerate, sandstone and tuff. Followed by Genteng Formation (tuff, pumice, tuffaceous sandstone, tuffaceous claystone, breccia, conglomerate, marl and silicified plant remains), andesitic intrusion, Bojongmanik Formation (limestone, sandy limestone, claystone, sandy claystone and lignite seams) and Endut volcanic deposits. Gunung Endut is situated following the trend of Meratus (Pulunggono and Martodjojo, 1994) trending NE-SW.

3. METHODS

An updated geological data was put together to create an updated geological map. Rock samples were also collected to ensure different lithologies in the research area. 10 rock samples with alteration indicators were further analysed using petrographic and diffraction to confirm the altered minerals. Geochemical water sampling was taken untreated and treated with acid (Nicholson, 1993) for each thermal manifestation Thermal water analysis results are then integrated using Powell calculation to determine the characteristics of the water and geothermometer. For diffraction analysis, Bruker D8 Advance was utilized with step size $2\theta = 0.0205$deg. Based on all the obtained data, the distribution of alteration intensity and altered mineral was inferred, integrating the alteration data with thermal water analysis.

4. RESULTS & DISCUSSION

4.1 Geology and geochemistry of Gunung Endut

Recent geological mapping divided sub-units of lithologies to the Bojongmanik Formation (Risman, et al., 2018). Additional structures were found with normal fault (N45E/46º) and horizontal fault (N160E/32º). Based on mapping observations, the lithologies of Gunung Area consists of andesitic lava, volcanic breccia, limestone, fine and coarse tuff.

The thermal springs around Gunung Endut has surface temperature ranging from 73 – 76 ºC with pH 6.8 – 7.6. Risman et. al. (2018) stated that the manifestation in Gunung Endut has chloride-bicarbonate type water. Some thermal manifestations are partially equilibrated with high concentrations of Mg, possibly an indication of groundwater dilution. Based on Na-K geothermometer, the reservoir temperature ranges from 111 – 127 ºC. The increasing concentration HCO_3 in Gunung Endut area may originate from the product of reaction between $CaCO_3$ from the limestone in Baduy Formation and thermal fluid. With most thermal fluid samples lies in the partially equilibrated region (Figure 4b), indicating that the fluid-rock has interaction has almost reach its equilibration. An anomaly is found for one of the thermal samples (Cikawah). It is thought that the fluid may have been mixed with the nearby stream water.

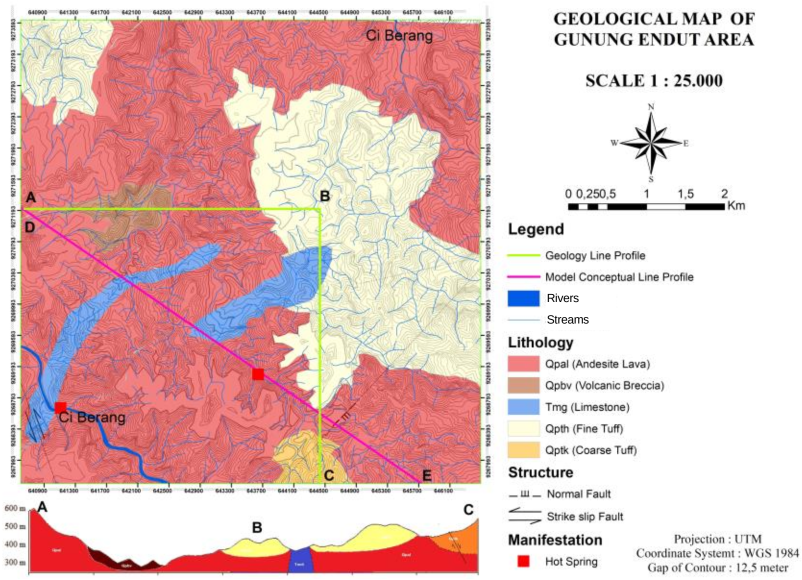

Figure 3: Updated geological map of Gunung Endut. Two manifestations of Handeuleum and Cikawah are found on the eastern side of Gunung Endut.

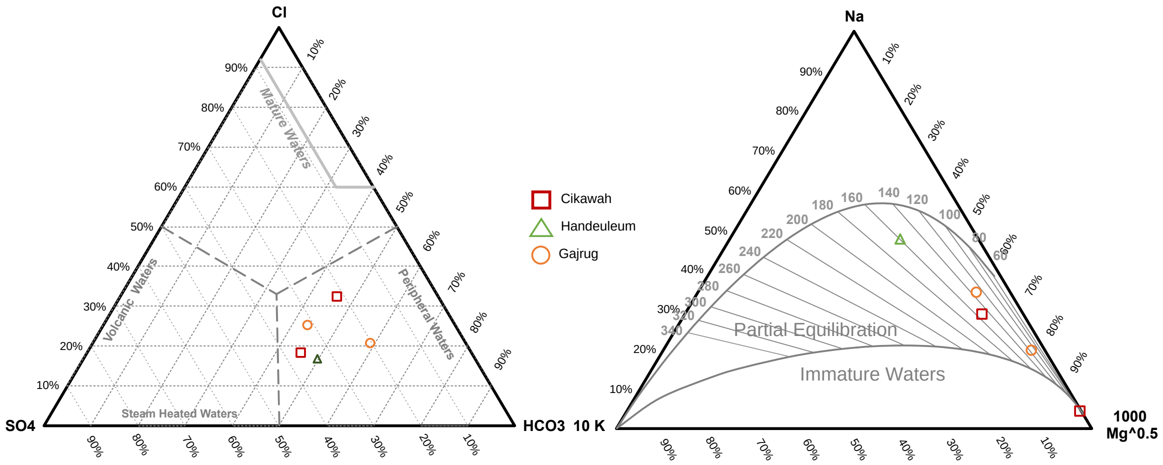

Figure 4: (a) Cl-SO_4-HCO_3 and (b) Na-K-Mg ternary diagram for thermal fluid in Gunung Endut (adapted from Risman, et al., 2018)

4.2 Surface alteration from around Gunung Endut

Altered rock samples were selected among other rock samples during geological mapping. The altered samples found have a trend towards the NW direction (Primayudha, 2019). From the sample collection, several samples undergo petrographic analysis. Petrographic analysis confirms the presence of plagioclase, feldspar, opaque, quartz and clay minerals for most altered rocks. Unaltered minerals such as olivine and feldspar are still visible in the intermediate alteration intensity sample (Figure 5d). Thin section analysis revealed that intermediate and high intensity alteration ranges from 33-49% and 53-55 % respectively (Primayudha, 2019)

Clay mineral was confirmed from the diffraction analysis. High intensity alteration revealed peaks for dickite, kaolinite and chlorite. While intermediate alteration revealed more diverse clay mineral such as dickite, kaolinite, pyprophyllite, illite, chlorite, diaspore, and montmorillonoids. Unaltered minerals such as feldspar, muscovite and quartz were also traced from the diffraction analysis.

Parent lithology of the area also plays an important part when observing the altered clay minerals. At the proximal facies of Gunung Endut, Endut volcanics consist of tuff and lava flow are presumed to have good permeability properties (Brace, 1980). Both primary permeability from the lithology (i.e. tuff and lava flow) and secondary permeability (normal fault and strike-slip) within the proximal facies helps the flow of thermal fluid and ion mobilities resulting in high intensity surface alteration. The thermal fluid flow is in line with regional structure trending NW-SE.

Montmorillonoids and chlorite predominated around distal-proximal area of Gunung Endut towards the NW direction and both minerals indicate an argillic alteration (Corbett and Leach, 1998). The composition of Na from montmorillonoids and Mg from chlorite may originate from an intense fluid-rock interaction which eventually is deposited into the altered clay minerals. The presence of olivine in sample Z83 (Figure 5e), can contribute to the formation of chlorite since olivine is a mineral rich in Fe and Mg.

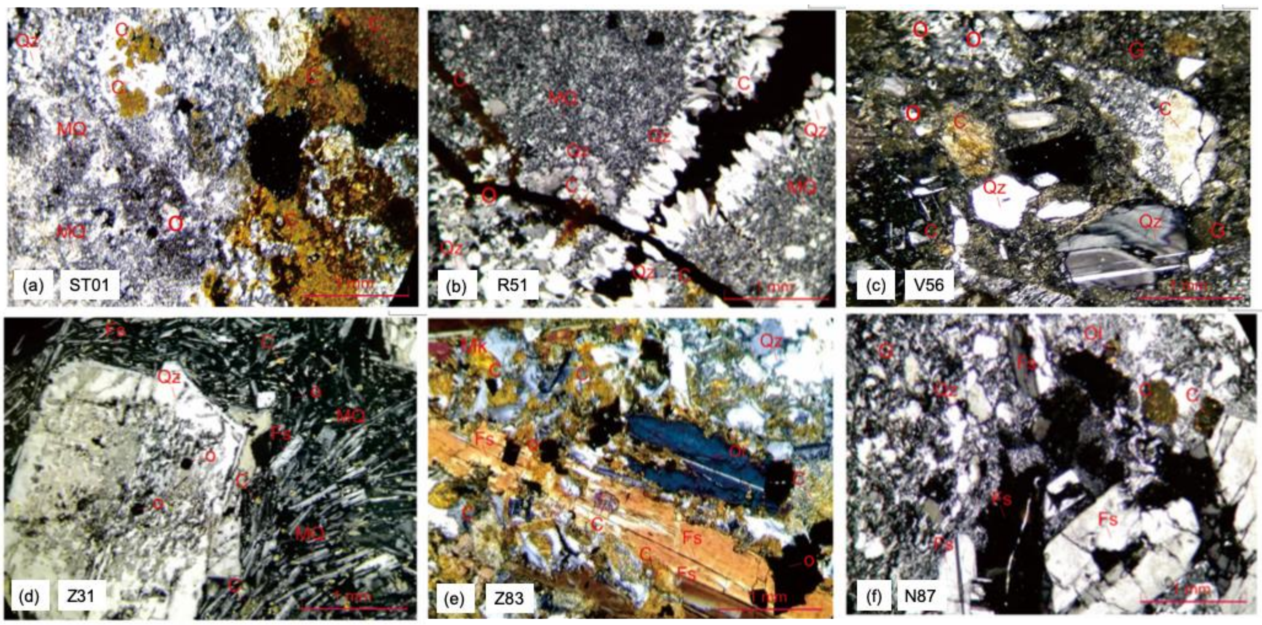

Figure 5: Petrographic analysis for thin sections in cross polarized light; (a-c) high intensity alteration (d-f) intermediate intensity alteration. Qz: quartz, C: clay minerals, Fs: feldspars O: opaque, G: glass, MQ: microcrystalline quartz, Ol: olivine

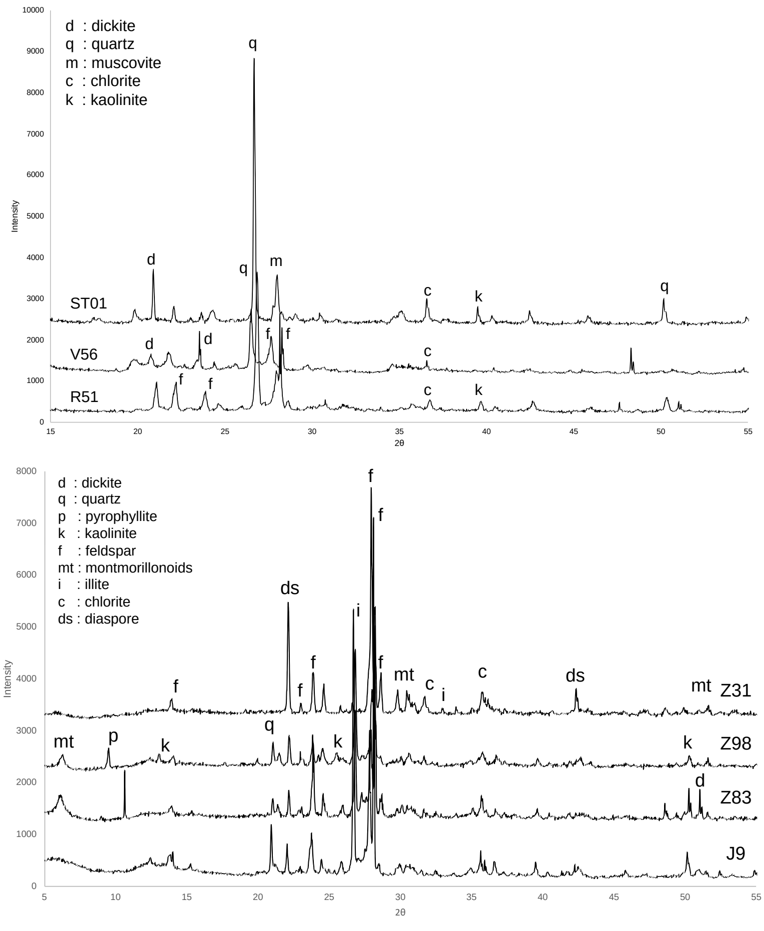

Figure 6: Diffraction analysis (above) high intensity alteration, (below) intermediate – low intensity alteration from selected samples around Gunung Endut

With kaolinite-dickite presence at the proximal distance, it is inferred that the thermal fluid circulating undergoes argillic alteration (Corbett and Leach, 1998). Though fluid type of Gunung Endut has diluted chloride-bicarbonate water, it may seem that near surface oxidation with shallow groundwater may have affect the pH altering the rocks from neutral to slightly acidic water. An anomaly seems to appear with the zonation of kaolinite-dickite. The absence of kaolinite and dickite at the medial facies infer that a change of fluid pH may have occurred in the medial facies.

The direction of alteration can help determine the flow of higher to lower fluid temperature. Moreover, the fluid flow direction is also determined by the topography of the area. Higher temperature fluid tends to alter rocks within the proximal facies (Figure 7). As the fluid temperature decrease, it does so by altering the medial and distal facies respectively. Some clay minerals are also temperature dependent meaning that each clay mineral formation serves as its own surface temperature gradient. With this said, we can infer that the heat source of Gunung Endut lies underneath the mountain underneath the central facies.

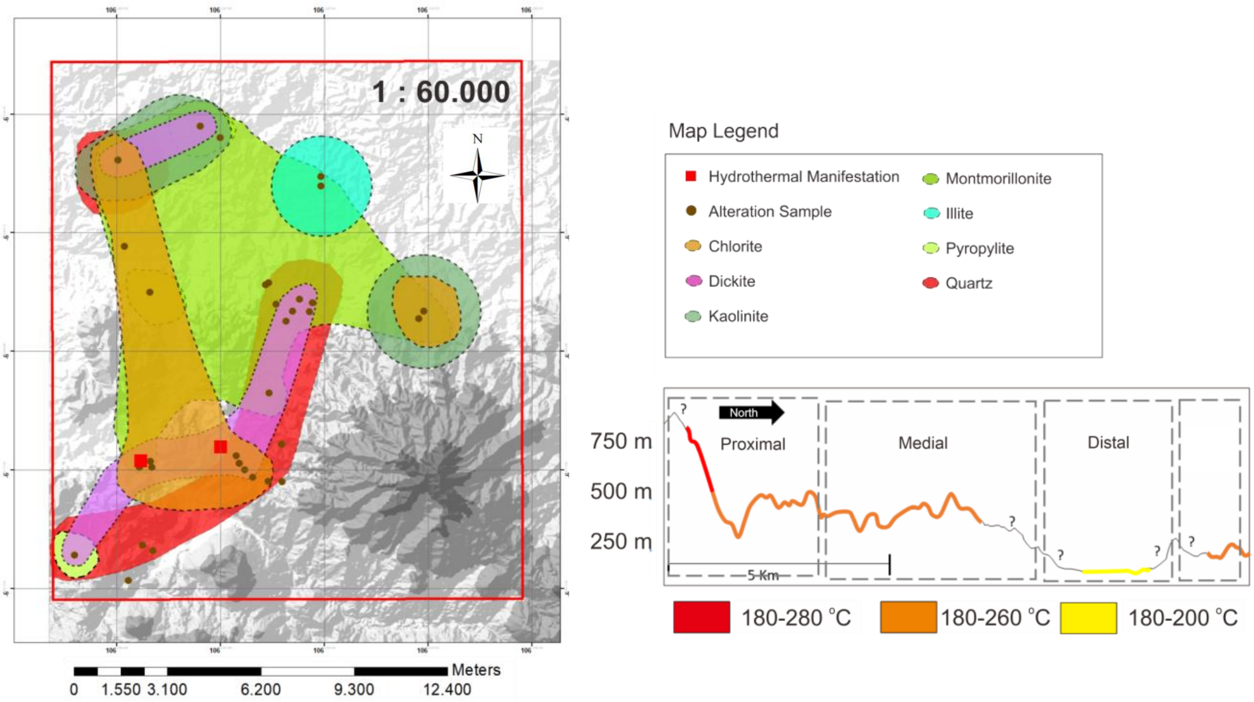

Figure 7: Clay minerals distribution as alteration product in Gunung Endut. Clay minerals temperature range were also laid out according to the volcanic facies.

4.3 Conceptual model of Gunung Endut Geothermal Prospect Area

AMT Profile 2 (Figure 2b) was set as the baseline for our conceptual model. Although the profile line seems to have not reached the most potent and the depth of the heat source, the resistivity trend seems to direct the heat source towards the central facies of Gunung Endut. Following the heat source is the presence of clay cap which is deducted from a significant change of the resistivity value from 0 to 0.75 km. An apparent fault was observed at the proximity of the AMT Profile 2 line leading to the abundance of alteration in the subsurface. Meanwhile, no structure was found around Cikawah. However, considering the location of Cikawah (positioned at a much lower topography), this field observation can infer that Cikawah may be located at a fault zone most likely at the hanging wall and indicating a weak and permeable zone allowing high intensity of alteration to occur at the subsurface.

From our geological mapping, limestone outcrop was observed adjacent to the breccia lithology unit. It is predicted that the limestone outcrop is part of Baduy Formation which was subsequently overlaid by volcanic deposits from Gunung Endut during the Pleistocene period. Over the time, the volcanic deposits were thought to be eroded and eventually revealing parts of the limestone outcrop. This finding is also supported with thermal fluid analysis, reporting a quite high concentration of HCO_3.

According to Hochstein and Browne (2000), Gunung Endut has a similar type of eroded volcanic complex settings. Thermal manifestations of diluted-chloride carbonate springs ruled out as the outflow zone for Gunung Endut geothermal system. The presence of horizontal and normal fault in the proximity of Cikawah and Handeuleum also support the zonation of outflow zone. The upflow zone is yet to be determined from further geological findings of high intensity argillic alteration at a higher topography and geophysical interpretations from Magneto-telluric investigations. Isotopic analysis can also aid the completion of the conceptual model to help determine the origin of geothermal fluid circulating in Gunung Endut.

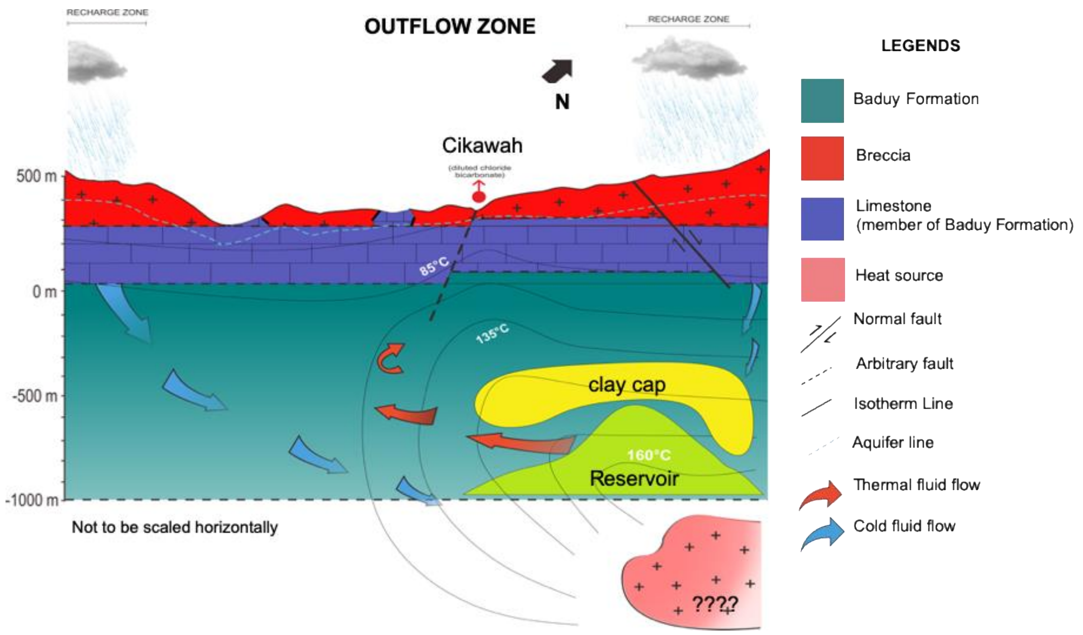

Figure 8: Conceptual model of Gunung Endut geothermal prospect area

5. CONCLUSIONS

The catalogue geochemical data of Gunung Endut was successfully updated. Thermal fluid shows the characteristic of diluted chloride-carbonate with pH of 6.8 – 7.3. Surface hydrothermal alteration reveals the fluctuation of pH and temperature as the facies moves further to the north. The intensity of alteration decreases as it moves northwards in alignment with regional structure trending NS.

6. ACKNOWLEDGEMENT

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