Hydrothermal Fluids-Rock Interactions in the Geothermal Area of the Ngebel Volcano Complex Ponorogo, East Java, Indonesia

by Dwi Fitri Yudiantoro

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Hydrothermal Fluids-Rock Interactions in the Geothermal Area of the Ngebel Volcano Complex Ponorogo, East Java, Indonesia

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Abstract
The Ngebel geothermal area is morphologically in several volcanic cones arranged as lava domes, volcanic hills, and lake craters. Volcanic cones are composed of lava, pyroclastic falls, pyroclastic flows, volcanic cones such as Jeding Volcano, Kemlandingan Volcano, Manyutan Volcano, and Ngebel Volcano. The magmatism activity that occurs in this area is andesitic-dacitic and also forms a geothermal system. This geothermal system is estimated to produce 50 MWe. During the formation of a geothermal system, hydrothermal fluids interact with the surrounding rock. Based on the results of geological mapping, petrographic analysis, and analysis of rare earth elements. In general, the results of rock-fluid interactions show a decrease in the concentration of rare earth elements, both light and heavy REE elements, from andesite basaltic samples to cold water samples. However, an unexpected reduction from 10 times chondrite to 0.3 times chondrite from hot water to cold water. This research will contribute to the hydrothermal alteration process in the research area that previous researchers have never done and expect to provide new information about forming the geothermal system in the Ngebel Volcanic Complex area.

Keywords: volcano, geothermal, rock, fluid, alteration

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INTRODUCTION

Fluid-rock interaction is a subject that has long developed quite widely (Steefel and Mäher, 2009). The research area is a complex volcanic area that forms alteration rocks. These alteration rocks occur due to the interaction process between rocks and hydrothermal fluids from a geothermal system. Therefore, the research is conducting in addition to studying volcanic geology and studying the process of rock-fluid interaction caused by the hydrothermal process.

Ngebel Wilis Volcano is a Quaternary stratovolcano type with composition andesitic (Hartono, 1994). Geologically, the area was located in the Liman, Limas, and Ngebel Quaternary volcanic complex, which has an almost east-west direction with the youngest eruption point located at Ngebel Lake (Hartono, 1994, Putra et al., 2014 and Yudiantoro et al., 2020). Therefore, research was conducted in the Ngebel area to study volcanic geology and the process of rock-fluid interaction caused by hydrothermal processes. In addition to the research, the site is part of the volcanic activity on the island of Java. The research area has geothermal potential. The location of research activities is administratively located in Ngebel District, Ponorogo Regency, East Java Province. In the research area, there is a tourist site of Lake Ngebel, about 40 minutes from Ponorogo City (Figure 1).

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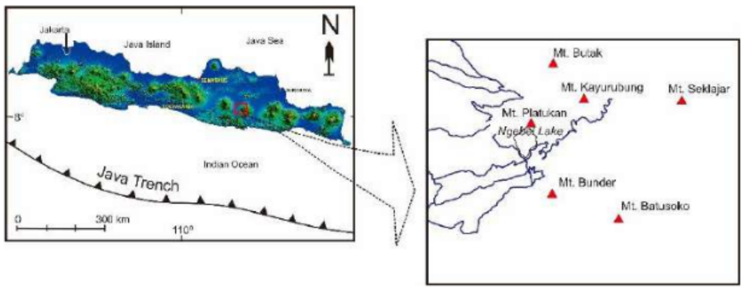


Figure 1. Location map of the Ngebel Lake research area.

II. LITERATURE REVIEW

2.1 Geological setting

Physiographically, the research area is included in the central depression or the Solo zone in the Ngawi sub-zone (Bemmelen, 1949). This zone is overgrown with active Quaternary volcanoes (modern volcanic arc), including the Wilis Volcano Complex. In general, on the surface, this plain is covered by young volcanic deposits (Late Pleistocene and Holocene).

Wilis Volcano Complex (WVC) is one of the volcanoes that forms a volcanic chain of basaltic and andesitic magma types along the Sunda Arc. The Sunda-Banda magmatic arc results from the initiation of the subduction of the Indo-Australian plate to the north and subducts under the Eurasian Plate. The Sunda-Banda magmatic arc consists of Miocene–Pliocene volcanoes, and Quaternary volcanoes, indicating that volcanic arc migration events occur not only with the EW trend but also to the north (Soeria-Atmaja et al., 1994).

According to Hartono (1994), Satyana (2005) and Putra, et al. (2014), the oldest rock, which is the basement of WVC, is a member of the Mandalika Formation, which was formed in the Oligocene-Early Miocene. In general, the volcanic rocks of WVC began to form in the Early Pleistocene to Late Pleistocene in the Quaternary Period (± 1800 - 11 kyr ago). In the Early Pleistocene, sediments formed from volcanic eruptions from the Ngebel, Jeding, and Klotok volcanoes were formed: volcanic breccias, andesite lava, tuff, and pumice. Meanwhile, in the Middle Pleistocene, sediments formed from volcanic eruptions from Gajahmungkur Volcano. The volcano consists of volcanic breccias and pyroxene andesitic lava. This volcanic breccia has andesitic fragments. The lithology of Ngargokalangan Volcano is composed of andesitic volcanic breccias and andesitic lava, and the volcanic product is in the Late Pleistocene (Figure 2).

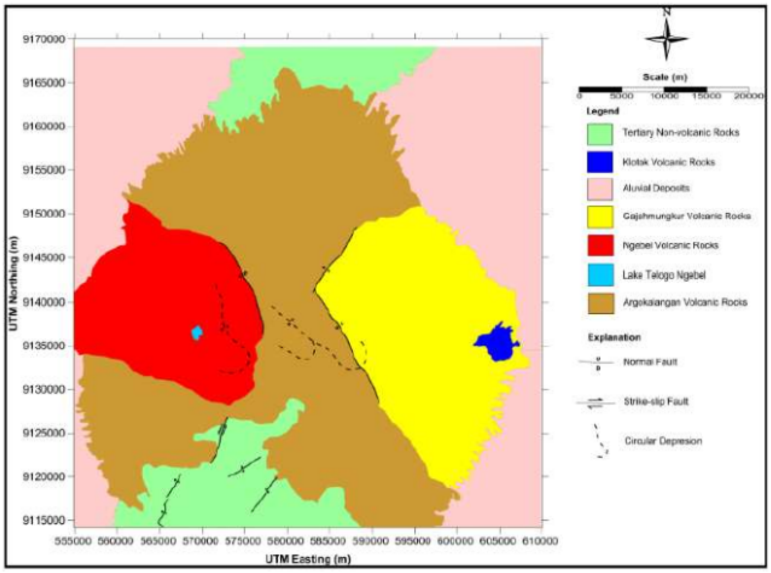


Figure 2. Morphostratigraphic map of the Ngebel area, Mount Wilis (Hartono, 1994; Putra et al., 2014).

Geologically, Java Island is a historical complex of basin subsidence, fault, folding, and volcanism under the influence of different stress regimes from time to time. There are three general structural patterns: the northeast-southwest (NE-SW) direction, the Meratus pattern, the structure with the north-south direction (NS), or the Sunda pattern. In contrast, the structural pattern with an east-west direction (EW) is called the Javanese pattern (Pulunggono and Martodjojo, 1994). According to Sribudiyani et al. (2003), the subduction path trending northeast-southwest (NE-SW) to relatively east-west (EW), which has taken place since the Oligocene until now, has produced a Tertiary geological order on Java Island (Figure 3).

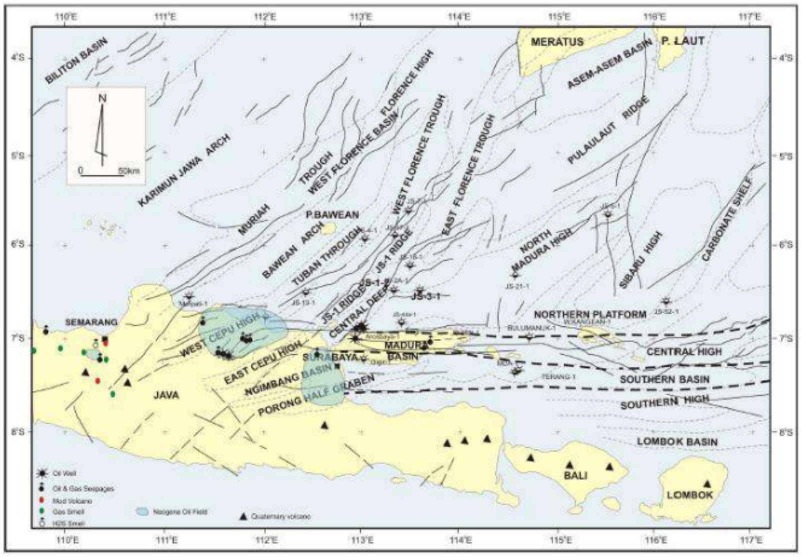


Figure 3. Distribution of tectonic structural elements in the eastern part of Java Island (Sribudiyani et al., 2003).

RESEARCH METHODOLOGY

The implementation of this research uses several stages, namely: the stages of studying secondary data or selected literature, interpretation of topographic maps, geological mapping, laboratory analysis, and reporting of research results. Geological mapping performs data collection in the field, such as observation of rock outcrops, geological data collection, stratigraphy, geological structures, and taking rock samples for laboratory analysis. In addition to using the field data collection method, the next stage is laboratory analysis. The rocks obtained in the field will be subjected to petrographic and geochemical analysis of rocks. Petrographic analysis was carried out to determine the mineral content, structure, and texture of rocks, as well as rock genesis. While the geochemical analysis to determine the hydrothermal rock-fluid interaction used Induced Coupled Mass Spectrometry (ICP-MS) analysis to obtain the concentration of rare elements (REE).

FINDING AND DISCUSSION

Geology of Ngebel Volcano

The geomorphology of the study area is dominated by mountain and valley formations. This area drains water from higher areas to lower areas. The morphology of this area is more influenced by volcanism from the WCV, so that its morphology is in the form of craters, volcanic slopes, volcanic domes, and volcanic hills.

Hartono (1992) divided the research area into three morphosets: Jeding morphonite, Patukbanteng morphonite, and Ngebel morphonite. Jeding and Patukbenteng morphonites are composed of volcanic breccias, pyroxene andesite lava, and inserts of pumice tuff. The Ngebel morphonites were composed of volcanic breccias, pyroxene andesite, hornblende andesite, diorite, tuff, and volcanic conglomerates.

According to this volcanic rock is of Hartono (1992), early Pleistocene age. However, in this study, the rocks found by the researchers were generally pyroclastic falls, flows, and lava. By doing geological mapping, it is possible to arrange the stratigraphic sequence of the research area from old to young. The stratigraphic and lithological sequence of the study area (Figure 9) can be explained as follows:

Jeding Volcano

The Jeding Volcano unit consists of pyroclastic flows breccia and basaltic-andesite lava. The pyroclastic flow breccia exhibited very poor sorting with blocky basalt-andesite fragments (Figure 4.). In contrast, the lava is basaltic-andesite by showing the structure of *autobreccia.* The composition is composed of plagioclase, pyroxene, and volcanic glass as the groundmass.

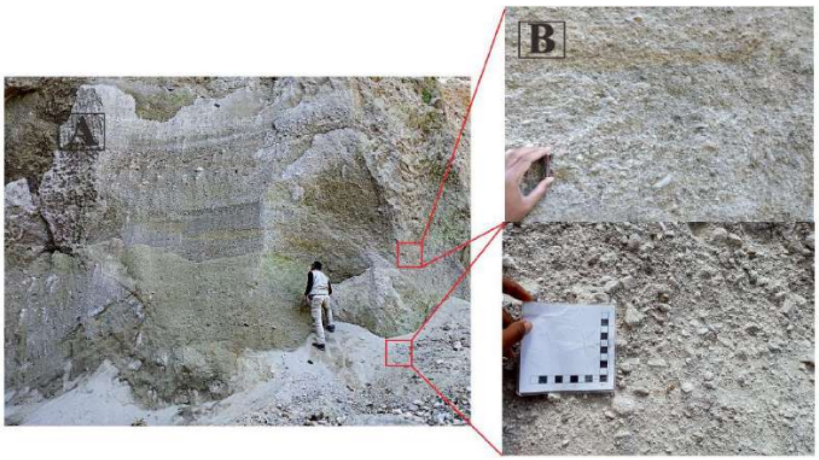


Figure 4. Outcrop of breccia pyroclastic flow breccia Jeding showing poor sorting.

Kemlandingan Volcano

The volcano is composed of pyroclastic flow breccia, pyroxene andesite lava 1, and pyroxene andesite lava 2. The pyroclastic flow breccia has a massive structure and is very poorly separated, and the fragments are in the form of blocky andesite. The pyroxene andesite lava 1 has an autobreccia structure. The composition of the lava is plagioclase, pyroxene, and volcanic glass. While pyroxene andesite lava 2 shows sheeting joint with the mineral composition same as with pyroxene andesite lava 1 (Figure 5).

Figure 5. Outcrop of pyroxene andesite lava 2 Kemlandingan.

Manyutan Volcano

The volcano is composed of pyroclastic flow breccia, hornblende andesite lava 1, and hornblende andesite lava 2. The pyroclastic flow breccia is composed of pumice, blocky andesite, andesite scoria. The fragments are gravel to gravel in size. In contrast, the pyroclastic fall breccia has a reverse graded bedding structure and good sorting. The hornblende andesite lava 1 has a joint sheeting structure. The composition of the lava is plagioclase, hornblende, and pyroxene. Hornblende andesite lava 2 unit found a spheroidal watering structure with a mineral composition same as with hornblende andesite lava 1.

Ngebel Volcano

The volcano is composed of agglomerate 1, pyroclastic fall breccia, pyroclastic flow breccia 1, pyroclastic flow breccia 2, dacite lava 1, agglomerate 2 and dacite lava 2. Agglomerate 1 with fragments in the form of andesite bombs and andesite scoria. Some fragments show the radial joint structure as a characteristic of agglomerate fragments. Pyroclastic fall breccia has reverse graded bedding and graded bedding structures and is very well sorted. The fragments consist of blocky andesite, accretionary lapilli, andesite scoria in a volcanic ash matrix (Figure 6).

The pyroclastic breccia flow 1 is very poorly separated and composed of fragments in the form of blocky andesite, andesite scoria, pumice. The pyroclastic flow breccia 2 has a fragment composition of blocky andesite, pumice, and andesite scoria. While the dacitic lava 1 has a fresh gray autobreccia structure. The mineral compositions are plagioclase, hornblende, quartz, pyroxene in the bottom mass of volcanic glass. Agglomerate 2 shows very poor sorting deposited on top of dacitic lava 1 (Figure 7). The end of the volcanic activity of Ngebel Volcano is the presence of dacite 2 lava. This lava is fresh gray in color and has an autobreccia structure. The minerals plagioclase, hornblende, quartz, and pyroxene in the groundmass of volcanic glass make up this dacite lava (Figure 8).

Figure 6. The pyroclastic fall breccia Ngebel showing accretionary lapilli.

Figure 7. The agglomerate 2 Ngebel shows a very poor sorting texture composed of bomb fragments showing radial joint.

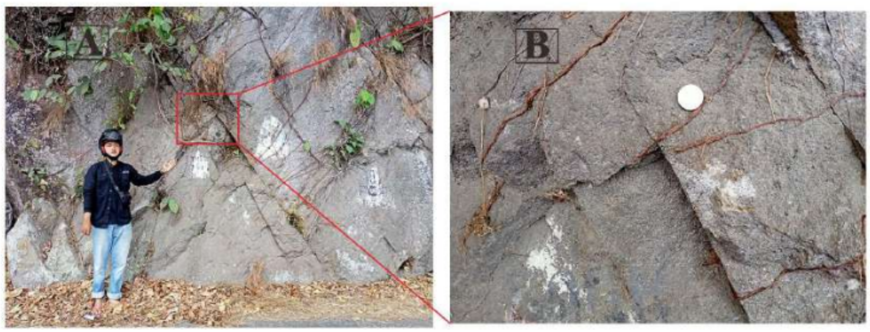


Figure 8. The dacitic lava 2 Ngebel, this lava is fresh gray in color and has a joint structure.

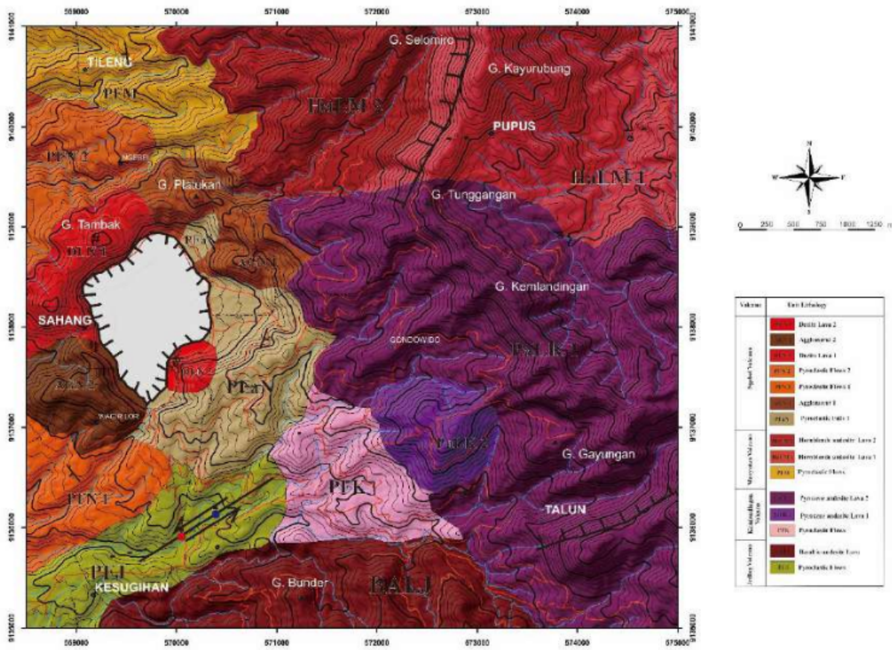


Figure 9. Geological map of the research area.

Fluid geochemistry

The hydrothermal fluid in the study area is known from two surface manifestations, namely hot springs and mud pools. Manifestations of hot springs have the highest temperature of 70°C, pH 5.8 with a surface temperature of 32°C, while the temperature of the mud pool is 80°C, pH 2 with a surface temperature of 32°C. According to Paramita (2014), the lower temperature surface based on the Na-K geothermometer (Fournier 1981 and Giggenbach, 1988) obtained temperature values of 189°C and 206°C. In contrast, the type of hot water fluid is included in the type of chloride (Figure 10), which is indicated by a relatively high chloride ion content. The results of the chemical analysis of hot water are presented in Table 1.

Table 1. Geochemical analysis table of Ngebel hot springs (Paramita, 2014).

Elements	ml / L	Elements	ml / L
SiO_2	262.44	NH_4^+	1:39
B	14:06	Cl	529.25
Fe_3^+	1:37	SO_4^{2-}	18:00
Ca_2^+	16.83	HCO_3^-	385.01
Mg_2^+	15:56	K^+	32.8
Na_2^+	461.6	Li^+	1:14
As_3^+	1		

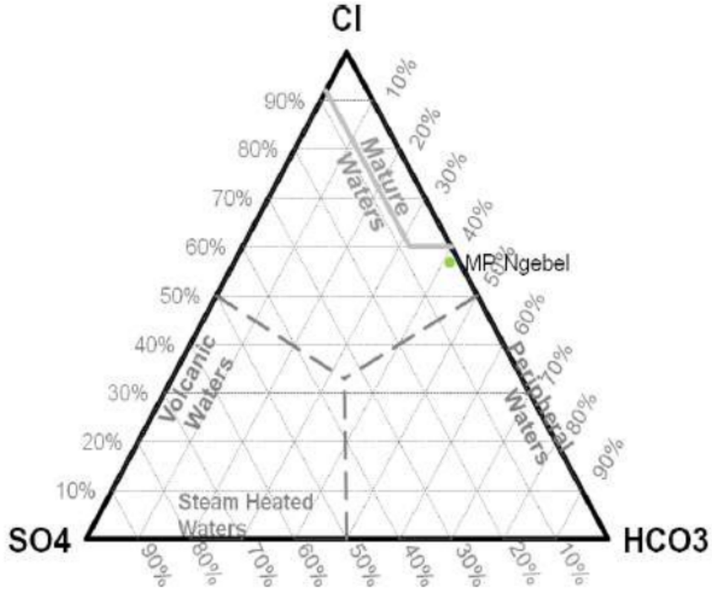


Figure 10. Diagram of Cl - SO_4 - HCO_3 Ngebel hot spring (Paramita, 2014).

Hydrothermal rock-fluid interactions

In geothermal systems, primary minerals usually turn into secondary minerals that are metastable or stable in this environment (Lagat, 2007) due to hydrothermal alteration processes (Yudiantoro et al., 2012). During the formation of the geothermal system, the hydrothermal fluid will interact with the surrounding rock and form altered rock. In the research area, the interaction process of surrounding rocks with hydrothermal fluids can be studied from petrographic incisions of andesite-basaltic rocks, which have been converted into altered rocks. Andesite-basaltic rocks found in hot springs interact with hot water with a temperature of 70°C with a pH of 5.8 and chloride water composition undergoing hydrothermal alteration. The alteration shows that the primary mineral plagioclase, pyroxene, is replaced by the fluid. The mineral alterations are swelling chlorite (montmorillonite), chalcedony, quartz, and iron oxide. In contrast, the groundmass was changed to swelling chlorite (montmorillonite) and quartz. The presence of these primary and secondary minerals is presented in Figure 11. The distribution of major hydrothermal minerals is a function of temperature (Gianelli *et al.*, 1998), (Reyes, 2000). The distribution of mineral temperatures in the study area is presented in Table 2.

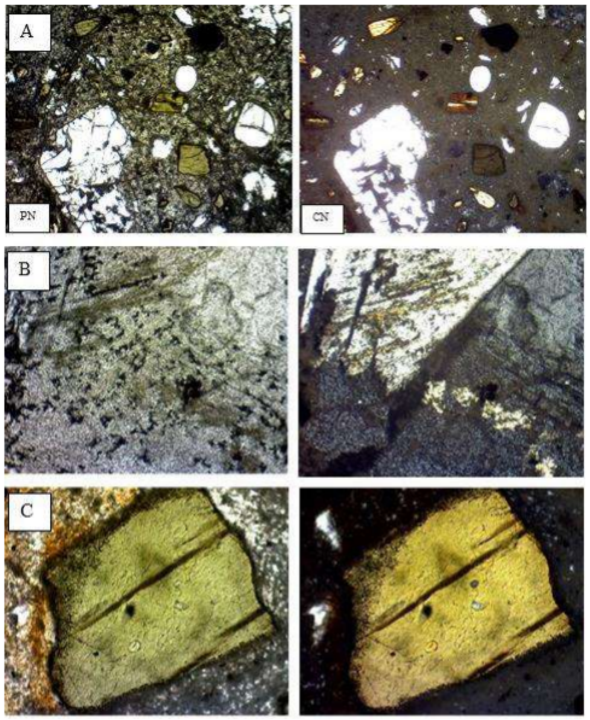
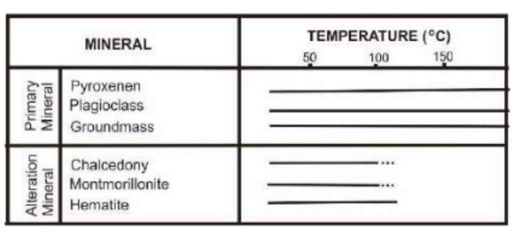


Figure 11. Shows alteration rock formed by hydrothermal rock-fluid interactions. Plagioclase, pyroxene, and groundmass minerals were converted into swelling chlorite (montmorillonite), chalcedony, and iron oxide. Description: A. 40x magnification; B. Magnification 100x; C. Magnification 200x; PN: Parallel Nicol; CN: Cross Nicol

Table 2. Mineral temperature index of alteration rock in the study area.



REE

Several studies have shown that REE does not change during hydrothermal alteration (Hanson, 1980). Also, very low REE concentrations in hydrothermal fluids show that REE concentrations from host rock are not affected by hydrothermal alteration (Michard, 1989). However, contrary to this, there is strong evidence to suggest that REEs move from the rock during hydrothermal alteration (Arribas et al., 1995;

Fulignati et al., 1999). Also, REE concentrations in hydrothermal fluids have been shown to range from detection below the chondrite values (Wood, 2002). The REE content of geothermal fluids and deposited alteration minerals also could be used as tracers for geothermal fluids and processes (Humphris and Bach, 2004).

In the research area, samples of REE elements were carried out on igneous rock samples and several hot water samples, mud pools, and cold water. The results of the analysis are shown in Table 3. The results of the REE element plot on the spider diagram show that, in general, there is a decrease in the concentration of rare earth elements, both light and heavy REE elements. The case for both basaltic andesite samples and cold water samples. The basaltic-andesite and mud pool REE elements have the same pattern, although there is a slight decrease in the REE elements from basaltic-andesite to the mud pool water to about 40-10 times chondrite.

Meanwhile, it decreased to about 0.3-0.1 times chondrite towards the hot and cold water samples. However, a significant decrease in the element Eu from 10 times chondrite to 0.3 times chondrite from hot water to cold water (Figure 12). The decrease in REE elements is caused by the interaction of rocks with hydrothermal fluids from the geothermal system in the study area. The pH and fluid temperature are believed to be the result of changes in the concentration of the REE element as stated by Humphris and Bach (2004) and Fowler and Zierenbergg (2015).

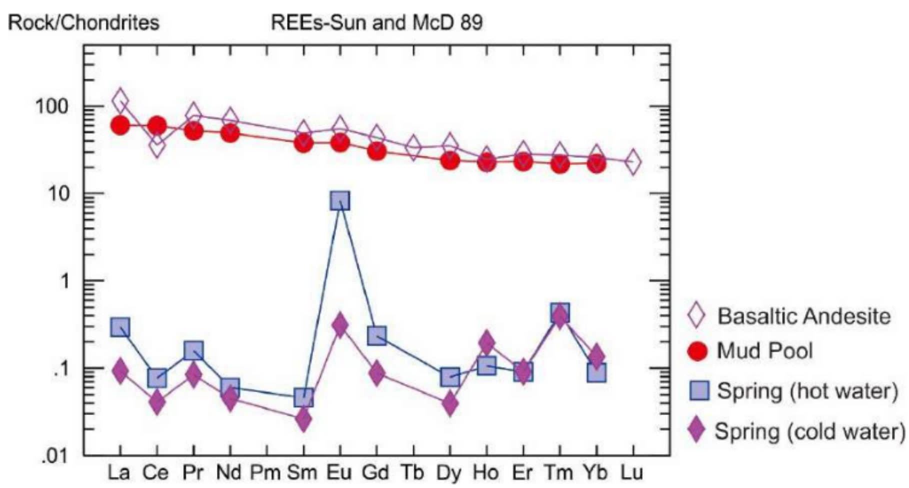


Figure 12. Shows rock-fluid interactions shown by REE elements of igneous rocks with hot water, cold water, and mud pools.

Table 3. REE analysis and measurement of pH temperature in hot springs, mud pools, and cold springs.

Element	Hot Spring	Mud Pool	Cold Spring	Basaltic-Andesite
pH	5.8	2	7	
La	0.07	14.347	0.082	27.2
Dy	0.02	6.087	0.015	8.9
Ce	0.047	36.606	0.086	21.9
Ho	0.006	1.289	0.007	1.4
Pr	0.015	4.972	0.015	7.41
Er	0.015	3.844	0.008	4.7
Nd	0.028	23.029	0.077	32.1
Tm	0.011	0.555	0.008	0.7
Sm	0.007	5.806	0.004	7.5
Yb	0.015	3.747	0.018	4.4
Eu	0.48	2.225	0.019	3.2

CONCLUSION AND FURTHER RESEARCH

The Ngebel Volcano Complex is part of the Wilis Volcano complex. This volcanic complex is also part of the Quaternary volcanic range on the island of Java, so the geothermal manifestations formed in the Ngebel volcanic complex result from the Wilis magmatism activity. The hydrothermal fluid composition obtained from the analysis of the hot water manifestation is a chloride type with a pH close to neutral. This fluid will interact with the surrounding andesitic rock, which results in hydrothermal alteration. The results of this interaction can be seen from the decrease in the concentration of rare earth elements from andesitic rocks to the REE element properties of cold water. The characteristics of light and heavy REE elements from andesitic samples to cold water samples showed decreased concentrations. However, a significant decrease in the element Eu from 10 times chondrite to 0.3 times chondrite from the hot water sample to the cold water sample.

Meanwhile, it decreased to about 0.3-0.1 times chondrite towards the hot and cold water samples. The REE element decreased significantly in Eu from 10 times chondrite to 0.3 times chondrite from hot water to cold water. The decrease in REE elements is caused by the interaction of rocks with hydrothermal fluids, especially due to changes in pH and hydrothermal fluid temperature.

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