Fluid-Rock Hydrothermal Interaction in the Jailolo Geothermal Field Area, West Halmahera, North Maluku Province, Indonesia

by Dwi Fitri Yudiantoro

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Abstract

The Jailolo geothermal system is controlled by a structure with northwest-southeast, north-south, and northeast-southwest directions and is related to the movement of the Halmahera subduction zone. The heat source is related to the structure of the crater under the Idamdehe crater and the cone of Jailolo. Morphologically it is located in volcanic cones, hills of caldera walls, lava flow ridges, and pyroclastic flow ridges. The Jailolo geothermal system consists of the Idamdehe dune, the arugasi dune, and the Jailolo dune which consists of lava, flow pyroclastics, and falling pyroclastics. The magmatism activity of the Jailolo geothermal field is basalt-andesitic. It is estimated that the Jailolo geothermal system produces 29 MW. Hydrothermal fluids interact with the surrounding rock during the formation of the geothermal system. Based on the results of geological mapping, petrographic analysis, main element analysis, and analysis of rare earth elements in general, the results of rock-fluid interactions show a decrease in REE concentrations, both from light REE elements to heavy REE elements, from andesite basalt lava samples to the arugasi hot spring. An unexpected significant decrease from 0.1 times chondrite to 0.03 times chondrite from the Todowongi hot spring sample to the Arugasi hot spring. This research is expected to provide the latest information about the formation of the geothermal system at the Jailolo volcano and contribute to the hydrothermal alteration process in the research area that has never been done by previous researchers.

***Keywords*:** Fluid, Rock, Hydrothermal, Volcano

INTRODUCTION

Fluid-rock interaction is one of the subjects of study that is quite widespread in recent times. (Steefel and Mäher, 2009; Yudiantoro, 2021). The existence of an interaction process between rocks and hydrothermal fluids in a geothermal system has resulted in an alteration process in a rock (Yudiantoro, 2021). Thus, this research was conducted to identify and study the processes that occur in the interaction between rocks and fluids caused by hydrothermal processes. The tectonics of the Maluku region is quite complicated because it is influenced by three main plates, namely the Philippine Plate in the north, the Australian Plate in the south, and the Eurasian Plate in the west (Katili, 1978; Hamilton, 1979; McCaffrey et al., 1980; Hall, 1987; Hall et al. al., 1988; Hakim & Hall, 1991; Baker & Malaihollo, 1996; Gemmell, 2007; Setyanta & Setiadi, 2011; Di Leo et al., 2012; Ipranta & Izron, 2019). The complexity is caused by differences in the direction of movement and composition of the three plates. The collision of the Australian Plate edge with the Pacific ophiolite line, as well as plate movement along the Sorong Fault is thought to be carriers of continental crust-characterized rocks in the region (Hall et al., 1991), as detected in dacite rocks in Bacan (Morris et al., 1983).). On the other hand, the oceanic crust in the Moluccas Sea has narrowed and is nearly lost due to subduction (McCaffrey et al., 1980; Hall, 1987; Bader et al., 1999). However, most of the inactive volcanoes on several small islands south of Halmahera and the ophiolites of the Talaud Islands are thought to be fragments of oceanic crust (Evans et al., 1983; Morris et al., 1983).

Jailolo Volcano is a product of quaternary volcanism on the western island of Halmahera. Regionally, West Halmahera is a volcanic rock path, with hilly morphology with an altitude of between 100 and 1000 m asl consisting of lava flows, tuff, ignimbrites, andesite, dacite, and rhyolite forming the western region of the island (Hase et al., 2015). The material for the formation of Jailolo volcanic rocks may come from mixing oceanic crust with continental crust (Ipranta and Izron, 2019). So it is necessary to conduct research in the area of Mount Jailolo to determine and study volcanic geology and the process of interaction between rocks and fluids caused by a hydrothermal process. The research area has geothermal potential. The location of this research is in Jailolo District, West Halmahera Regency, North Maluku Province.

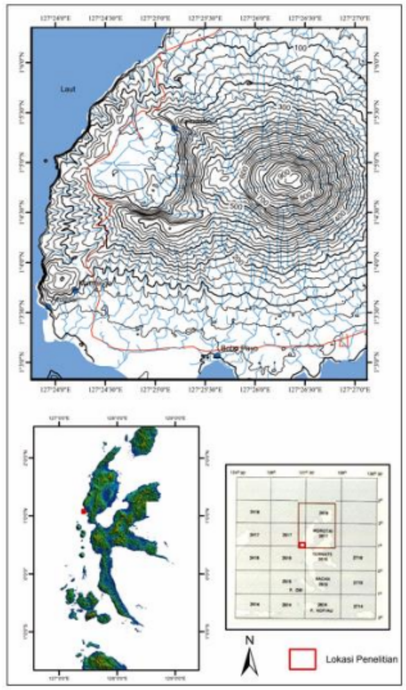


Figure 1. Map of the location of the research area

II. LITERATURE REVIEW

2.1 Geology

The physiographical geology of the study area is included in the arc of the Quaternary volcanic islands that form a volcanic chain in the western part of Halmahera. The active volcanic arc of Halmahera is associated with a beneficiary zone that dips to the east from the northwest side of northern Maluku. Geologically, according to the Geological Map Sheet Morotai Sheet (Supriatna, 1980), consists of igneous rock, volcanic rock, and sediment units. Ultramafic Rock Complex, Gabbro, Diorite and Andesite are igneous rock units. The two oldest igneous rock units formed before the Cretaceous, while diorite and andesite froze during the Miocene and Holocene, respectively. Sedimentary rock units from old to young sequentially are Dodaga Formation (Cretaceous), Dorosagu Formation (Paleocene), Tutuli Formation (Miocene), Tingteng Formation (Miocene - Pliocene), Weda Formation (Pliocene), Togawa Formation (Plistocene), Limestone Reefs (Pleistocene - Holocene), and Alluvium (Holocene).

The volcanic unit consists of the Bacan Formation, Kayasa Formation, Tuff, and Holocene Volcanic Rocks. The western part of Halmahera is composed of lava flows, tuff, ignimbrite, andesite, dacite, and rhyolite to form the western region of the island (Hase et al., 2015). The research area is a Holocene volcanic rock. Jailolo volcano area is one of the quarter volcanoes with basal-andesite type. (Figure 2)

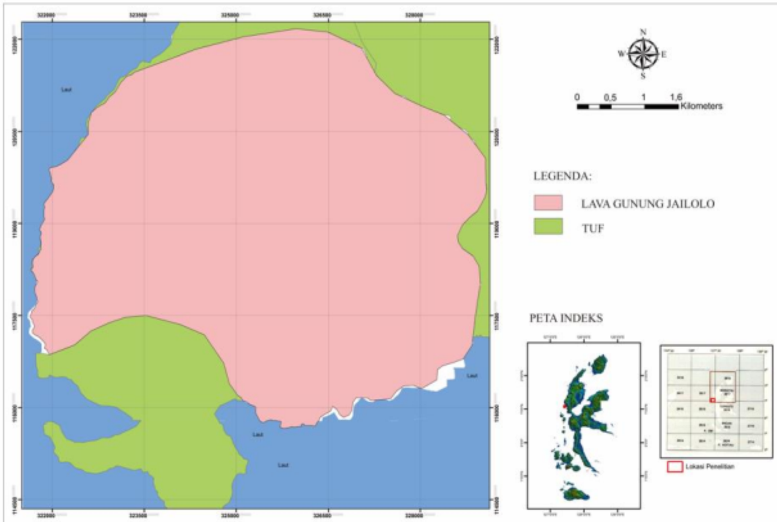


Figure 2. Regional Geological Map of Mount Jailolo (modified from Supriatna, 1980)

III. Research Methodology

The stages of this research were carried out by doing several stages; studying secondary data, geological mapping, and laboratory analysis. Geological mapping is carried out for the purpose of collecting data in the field, such as observing rock outcrops, geological structures, collecting geological data, stratigraphy, and taking rock samples and hot springs for laboratory analysis. Then rock and water samples were taken for laboratory analysis, such as petrographic analysis, rock geochemistry, and water geochemistry. Rock and water samples obtained from the field were subjected to petrographic analysis, *X-Ray Fluorences* (XRF), Induced Coupled Mass Spectrometry (ICP-MS) analysis, and Induced Coupled Mass Spectrometry (ICP-OES) analysis. Mapping and laboratory analysis was carried out to determine the hydrothermal fluid-rock interaction.

IV. RESULTS AND DISCUSSION

Geology of Jailolo Volcano

The research area's geomorphology is dominated by mountains, hills, and calderas that drain water from higher ground controlled by volcanism, lithology, structure and surface erosion processes. According to Supriatna (1980), the research area is generally composed of on volcanic rocks. The volcanic rocks are Basalt Lava, Andesite Breccia, and Tuff quarter old. But in this study the rocks commonly found are lava, pyroclastic flows, and fall. The following is the stratigraphy of the research area from the oldest to the youngest;

Idamdehe Volcano

Idamdehe volcano unit consists of flow pyroclastic breccia, pyroclastic lapilli flows, and basalt lava. The pyroclastic breccia of this flow shows very poor sorting with various fragments name basalt and scoria. The flow pyroclastic lapilli has a massive structure with the composition of fragment deposits in the form of lapilli-sized basalt. Then the lava is basalt showing the structure of autobreccia, (Figure 3) the composition consists of plagioclase, orthopyroxene, hornblende, clinopyroxene, quartz, and base mass of volcanic glass.

Figure 3. Idamdehe basalt lava outcrop shows the autobreccia structure of Arugasi

Arugasi Volcano.

This volcano is composed of pyroclastic breccia flows and andesite lava. The flow pyroclastic breccia has a graded layered structure with andesite fragments. Andesite lava has a sheeting joint structure (Figure 4). The composition of andesite lava is plagioclase, orthopyroxene, clinopyroxene, opaque minerals, and the base mass of volcanic glass.

Figure 4. Andesite lava outcrop shows the sheeting joint structure

Jailolo Vulcano

Volcano. This volcano is composed of flow pyroclastic breccias, basalt lava, basaltic-andesite 1 lava, basaltic-andesite 2, and basaltic-andesite lava 3. pyroclastic flow breccias are composed of pumice, basalt block andesite, basalt scoria, fragments of gravel to block size. Basalt lava has an autobreccia structure with a composition of plagioclase, orthopyroxene, clinopyroxene, opaque minerals, and the bottom mass of volcanic glass. The basaltic-andesite 1 lava unit found an autobreccia structure with a composition of plagioclase, pyroxene, opaque minerals, and the bottom mass of volcanic glass. Basaltic-andesite lava 2 found autobreccia structure with the same composition as basaltic-andesite lava 1. Andesite basaltic lava 3 found autobreccia structure with the same composition as basaltic-andesite lava 1.

Figure 5. Outcrop of pyroclastic breccia flows showing poor sorting

Figure 6. Outcrop basaltic-andesite lava shows an autobreccia structure.

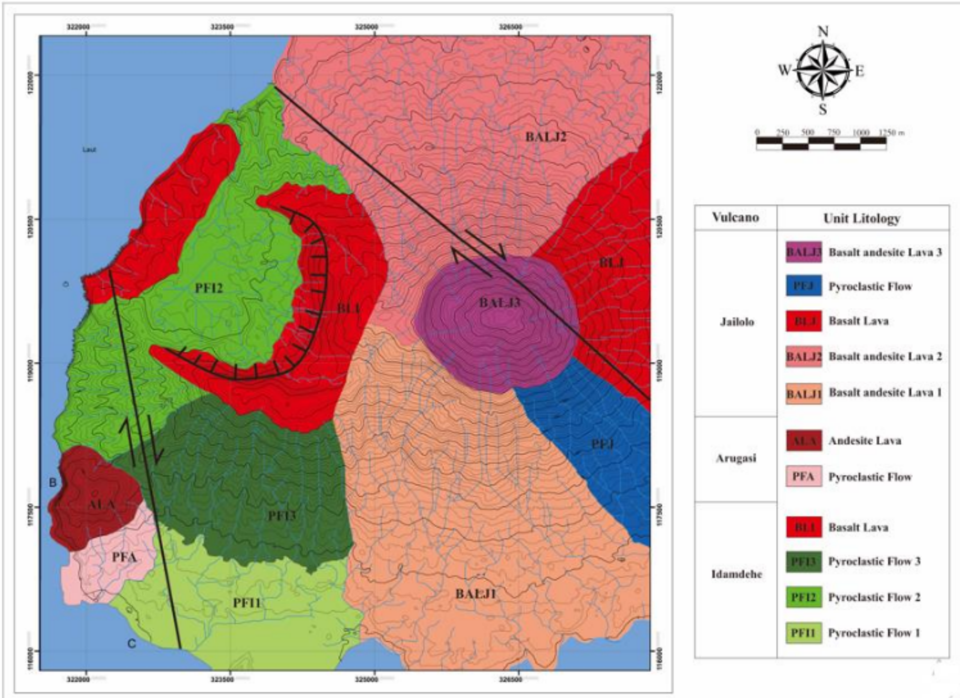


Figure 7. Geological map of the research area.

Fluid Geochemistry

Hydrothermal fluids is known from two manifestation surface in the form of springs hot ie eye hot water arugasi and eyes hot water Tododongi. Manifestations of hot springs Arugasi has a temperature of 74°C, pH 7, while the Todowongi hot spring has the highest temperature of 70.6°C with a pH of 6.56. Sourced Geothermometer results Na-K (Giggenbach, 1988. well as Fournier 1981) obtained value temperatures of 214°C and 197°C for arugasi hot springs, and temperature values of 195°C and 177°C for Todowongi hot springs. Both hot springs have a fluid type hot water with type of chloride (Figure 8), evidenced by the high content of chloride ions.

Table 1. Geochemical analysis table of Todowongi hot springs

Code Sample	Elevation	Li	Na	K	Ca	Mg
APTo	80	0,11	307,74	18,47	92,89	8,07
		SiO2	**B**	**Cl**	**F**	**SO4**
		159,62	0,4	572,54		159,03
		HCO3	**CO3**	**NH4**	**As**	**Rb**
		67,36		0,91	0,1	
		Cs	**Sr**	**Ba**	**Fe**	**Mn**
					0,74	

Table 2. Geochemical analysis table of Arugasi hot springs

Code Sample	**Elevation**	**Li**	**Na**	**K**	**Ca**	**Mg**
APAr	60	1,46	3139,6	246,88	572,4	153,62
		SiO2	**B**	**Cl**	**F**	**SO4**
		266,63	5,94	6488,83		264,5
		HCO3	**CO3**	**NH4**	**As**	**Rb**
		203,44		1,44	0,4	
		Cs	**Sr**	**Ba**	**Fe**	**Mn**
					0,74	

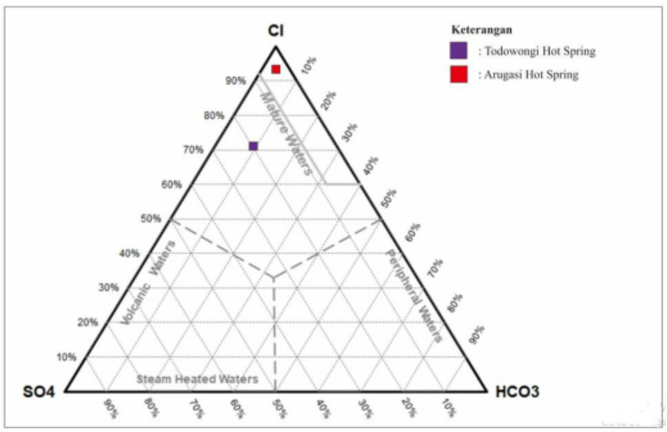


Figure 8 Diagram of Cl-SO_4-HCO_3 hot springs arugasi and todowongi.

Hydrothermal rock-fluid interactions

Hydrothermal fluids will interact with the surrounding rock and form altered rock, during the formation of the geothermal system, (Yudiantoro, 2021). In the research area, the petrography results of andesite rocks are evidence of changes in these rocks which indicate a process of rock interaction with hydrothermal fluids. The hot spring with a temperature of 74°C with a pH of 7 has a composition of chloride water interacting with the surrounding andesite rocks so that it undergoes hydrothermal alteration. These changes are shown in the main mineral in the form of pyroxene being replaced by hydrothermal fluid. The main minerals that undergo changes to swelling chlorite (montmorillonite), iron oxide quartz, and groundmass are converted to chlorite. The presence of these primary and secondary minerals is shown in Figure 9. Generally, hydrothermal minerals are used as geothermometers (Gianelli et al., 1998; Reyes, 2000). The temperature distribution of minerals in the study area is presented in Table 3.

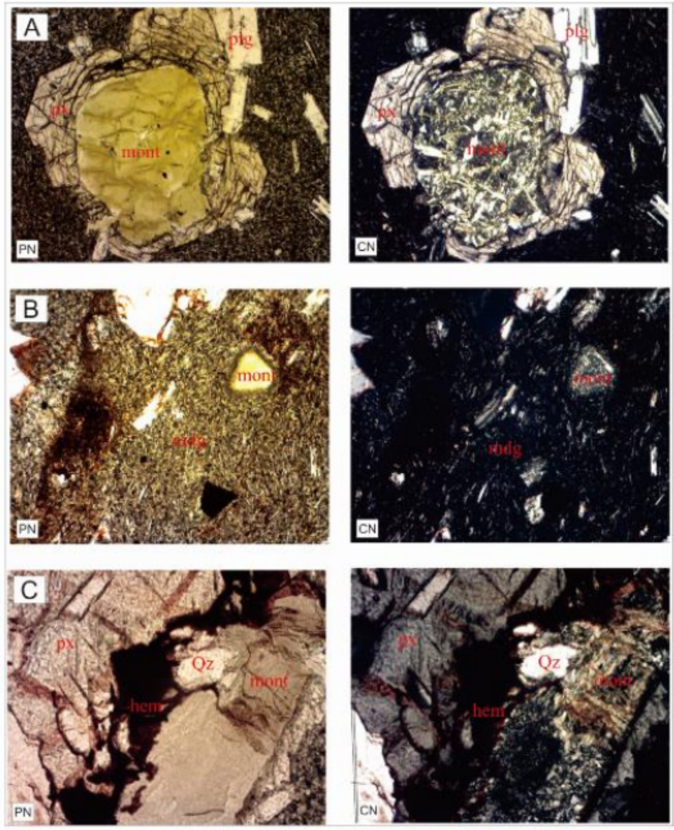
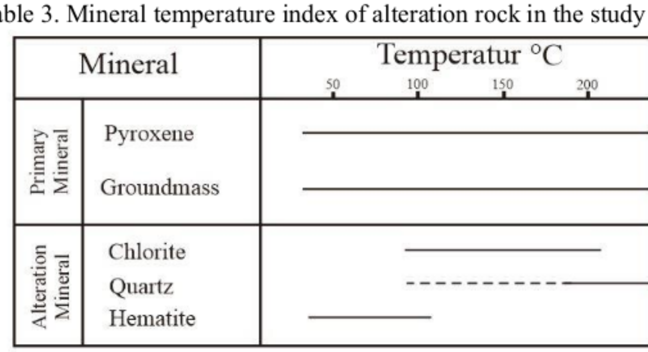


Figure 9. Alteration rocks formed from hydrothermal rock-fluid interactions which show pyroxene minerals and the base mass are transformed into swelling chlorite (montmorillonite), quartz, and iron oxide. Information; px: pyroxene, mont: montmorillonite, plg: plagioclase, Qz: quartz, hem: hematite, mdg: glass base mass, A and B 100x magnification, C 200x magnification; PN: Nicol's Parallel; CN: Cross Nicol

Table 3. Mineral temperature index of alteration rock in the study area



Rare Earth Element (REE)

In previous studies, REE content did not move during the hydrothermal alteration process (Hanson, 1980). However, there is strong evidence that REE moves from the rock during hydrothermal alteration processes (Arribas et al., 1995; Fulignati et al., 1999; Yudiantoro et al., 2021), particularly the interaction between seawater and basalt (Hellman and Henderson, 1977; Ludden, 1979). Also, the resulting REE concentrations in hydrothermal fluids have been shown to be below the chondrite values (Wood, 2002). The concentrations of REE content in hydrothermal fluids and alteration minerals found can be used as parameters and

tracers for geothermal fluids (Wood, 2002; Humphris and Bach, 2004). Williams-Jones et al (2012) concluded that the hydrothermal concentration of REE occurs mainly when fluids containing chloride complexes interact with colder neutral pH rocks or mix with colder rocks, and fluids with neutral pH can mobilize sufficient amounts of REE. big.

In the study area, REE analysis was carried out on 2 hot spring samples and several igneous rock samples. The results of the analysis of the REE concentration content are shown in Table 3, and the chondrite normalization profit diagram from the REE element plot shows that in general the characteristics of LREE and HREE show a decrease in concentration. The same pattern was seen in the REE concentrations of andesite and basaltic andesite, but in the Nd element, there was a significant decrease from 100 times chondrite to 3 times chondrite.

The decrease from about 0.1 to 0.03 times chondrite for the samples of Tododongi Hot Springs and Arugasi Hot Springs which have a similar pattern. (Figure 10). According to Humphris and Bach (2004) and Fowler and Zierenbergg (2015) changes in pH and temperature result in a decrease in REE concentrations that occur during the process of rock interaction with hydrothermal fluids from a
geothermal system in the study area and differences in grade values between rock and fluid indicate a new interaction. (Williams-Jones et al., 2012).

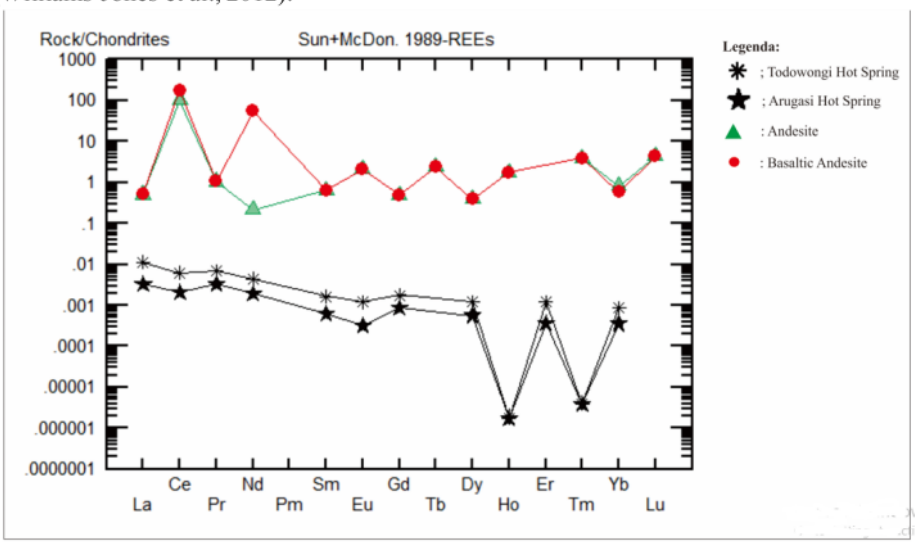


Figure 10. Showing rock-fluid interactions shown by REE elements from igneous rocks, Todowongi hot springs, and Arugasi hot springs

Table 3. REE analysis and pH measurements in hot springs

Element	Arugasi Hot spring	Todowongi Hot spring	Andesite	Basaltic Andesite
pH	7	6,56		
La	0,000765	0,00267	0,12	0,12
Ce	0,001271	0,003761	61,58	107,02
Pr	0,000312	0,000641	0,10	0,10
Nd	0,000911	0,002058	0,10	25,65
Sm	0,000096	0,000252	0,10	0,10
Eu	0,000018	0,00007	0,12	0,12
Gd	0,000181	0,000361	0,10	0,10
Dy	0,000143	0,000303	0,10	0,10
Ho	0,0000001	0,0000001	0,10	0,10
Tm	0,0000001	0,0000001	0,10	0,10
Yb	0,00006	0,000149	0,10	0,14
Er	0,000061	0,000198		
Lu			0,11	0,11
Tb			0,09	0,09

CONCLUSION AND FURTHER RESEARCH

The Jailolo volcanic area is part of the Quaternary volcanic series in the western part of Halmahera, so that the geothermal manifestations formed are the result of a subduction zone in the western part of Halmahera Island. The heat source is related to the structure of the crater under the Idamdehe crater and the cone of Jailolo. The composition of the hydrothermal fluid obtained from the analysis of the manifestation of hot water is a chloride type with a neutral pH which then interacts with andesite and andesite basalt rocks in the vicinity. The results of this interaction can be seen from the presence of alteration rocks. Chemically, there was a decrease in the REE concentration value from the andesite basalt sample to the REE concentration value of the Arugasi hot spring which has LREE and HREE characteristics from the andesite basalt sample to the Arugasi hot spring sample showing a decrease in concentration.

However, there was a significant decrease in Nd from 100 times chondrite to 3 times chondrite from andesite basalt samples to andesite samples. The same pattern of decline was also shown by samples of the Todowongi hot springs and the Arugasi hot springs, which were about 0.1 to 0.003 times. Changes in pH, and hydrothermal fluid temperature resulted in differences in the concentration of REE values. This occurs during the process of rock with hydrothermal fluid interactions.

This research is expected to make further research for the next researcher, so that knowledge about REE in geothermal fluids can develop well in the field of geothermal exploration.

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