Preliminary study on the characterization of geothermal fluids at Mount Jobolarangan (old Mount Lawu) western side and its implications for geothermal exploration

Oky Sugarbo[1], *Hilltrudis Gendoet* Hartono[1], *Jaden* Gil Lodar[1] and *Ignatius* Adi Prabowo[2]

[1] Geological Engineering, Faculty of Engineering and Planning, Institut Teknologi Nasional Yogyakarta, Indonesia
[2] Universiti Teknologi Malaysia, Johor Bahru, Malaysia

Abstract. Mount Jobolarangan, also known as Old Lawu, is located on the southern side of Mount Lawu in Karanganyar, Central Java. This Research is crucial to understand the geothermal resource potential within it. The purpose of this study is to conduct a lithology and geochemical analysis of geothermal fluids to determine the characteristics of the fluids and their potential implications for geothermal exploration. The research method used is in the form of surface geological research, which is divided into field data analysis, petrography and geochemistry. The geochemistry method used in this research involves fluid (water and gases) geochemical sampling with AAS and XRF analysis. The study area contains andesite lava formed from volcanic activity that products by subduction with the temperature of magma forming in the range 1090°C - 1098°C. The geothermal manifestations in the study area are hot springs, which exhibit a bicarbonate fluid type. These geothermal fluids belong to the boundary zone between immature water and partial equilibrium, with a subsurface temperature ranging from 80°C to 120°C. The high magnesium content indicates that the geothermal fluid has been influenced by surface water and contact with surrounding rocks. The reservoir temperature is between 82°C and 86°C included in low-temperature geothermal system category.

1 Introduction

Indonesia is a country that has a lot of volcanoes that are still active and that are no longer active as a result of the subduction of three large plates, this makes the existence of volcanoes in Indonesia have a very abundant geothermal potential. Indonesia's potential is 40% of all geothermal potential in the world and the amount of energy is only used at 4.2% [1], so that the development of geothermal energy exploration for use in daily life in Indonesia is urgently needed. One of the geothermal potential locations in Indonesia that has not been optimally developed by the government as a reserve of geothermal energy sources is the area of Old Mount Lawu or known as the Jobolarangan

Volcano which is the area of this research. Mount Jobolarangan has many interesting things that need to be researched further, especially research related to the existence of geothermal systems.

The purpose of this study is to analyze lava characteristics related to the geochemical character of geothermal fluids in the research area. Afther that, this study can explain about the character of magma affinity, magma differentiation stage and magma temperature form rocks so that their relationship with the geochemical character of geothermal fluids and their potential for geothermal energy exploration can be seen and studied. Mount Lawu has andesite and basalt type parent rocks with very high crystallization between 986°C – 1320°C [2], this indicates that the research area is a product of volcanism activity, subduction products that are interesting to be researched in relation to geothermal exploration.

2 Location and Method

2.1. Location

The location of this research is located on the west side of Mount Jobolarangan which is often known as Old Lawu Mountain. Based on the administrative area, the research area is included in the Jatiyoso area, Karanganyar Regency, Central Java Province. Fluid sample billing and gas tests were carried out in Jatiyoso Village and its surroundings.

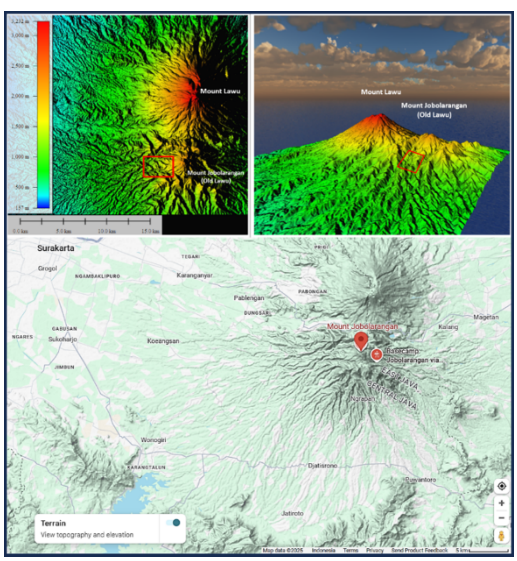

Fig. 1. The location of the research area is seen from the satellite map (Google Map, 2025) and digital elevation model (DEM).

2.2. Method

The research method used by the researcher is in the form of surface geological research which is divided into field data analysis, petrography and geochemistry. Surface research includes field geological surveys, water sampling and fluid testing in the field. The parameters used in fluid analysis in the field use the parameters of temperature, pH, air humidity, air temperature, Total Dissolved Solids (TDS), Electrical Conductivity (EC), aroma, and color. The collected samples were subsequently subjected to laboratory analyses, including petrographic thin-section and geochemical tests.

The geochemical analysis was divided into two categories. The first was a major element geochemical analysis of lava using the X-Ray Fluorescence (XRF) method to determine the lava's geochemical characteristics. The second was a geothermal fluid analysis employing the Atomic Absorption Spectrophotometry (AAS) technique, aimed at identifying the chemical elements and compounds contained in the hot spring water. The analytical results were then compared with field-based measurements of the hot springs. The chemical parameters analyzed included sodium (Na), calcium (Ca), potassium (K), magnesium (Mg), chloride (Cl), fluoride (F), bicarbonate (HCO_3), sulfate (SO_4), and silica (SiO_2). Sample collection followed the standard procedure [3], in which geothermal fluid samples were taken from one location at three different times in morning, noon, and night to capture temporal variations in chemical composition.

3 Result and Discussion

3.1 Result

The results of the study showed that the igneous rocks taken in the study area were in the form of andesite lava, supported by petrographic and geochemical data (Figure 2). Petrographic data show the abundance of glass that is combined to form the base mass, in addition to the incision results show the direction of mineral orientation as a result of the influence of lava flow or called pilotaxtitic texture. This texture indicates that a volcanism process has occurred with implications for geothermal systems that are associated and controlled by volcanist activities and not only magmatism (intrusion). Geochemical results of major oxide (Table 1) showed that both rock samples were andesite. The classification using the magma affinity diagram [4] was carried out based on the weight percentages of SiO_2 and K_2O. The analysis revealed that the lava samples from the study area belong to the Calc-alkaline Series (Figure 3), which is typically associated with subduction-related magmatic processes.

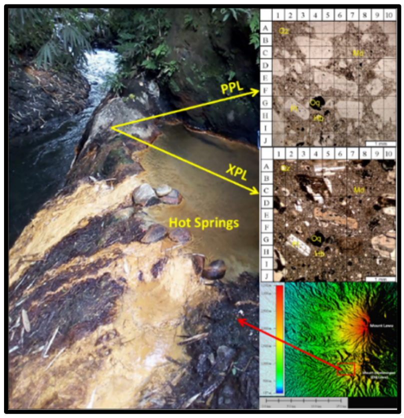

Fig. 2. The manifestations of hot springs and andesite lava found in the study area show the appearance of incisions that characterize an andesite lava.

Table 1. Major oxide results from geochemical tests after normalization

Major Oxide	Lava 1 JBL (Weigt Percent)	Lava 2 JBL (Weigt Percent)
SiO_2	56.42 %	57.20 %
TiO_2	0.68 %	0.53 %
Al_2O_3	5.09 %	6.60 %
Fe_2O_3	8.32 %	8.25 %
FeO	5.52 %	4.74 %
MnO	8.32 %	6.66 %
MgO	3.47 %	3.31 %
CaO	6.18 %	7.22 %
Na_2O	7.36 %	4.14 %
K_2O	0.73 %	0.92 %
P_2O_5	0.54 %	0.43 %
Total	100 %	100 %

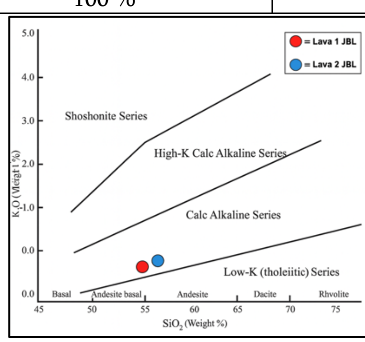

Fig. 3. The affinity of andesite lava-forming magma in the study area showed calc alkaline series.

Based on the results of geochemical data calculation, it is known that the results of the Mafic Index (MI) and Felsic Index (FI) calculations of the JBL Lava 1 sample are 79.16 (MI) and 45.96 (FI) while the JBL Lava 2 sample is 79.98 (MI) and 41.62 (FI). The crossplot diagram of the mafic index and felsic index [5] shows that the lava in the study area has undergone a magma differentiation process in the last stage (Figure 4).

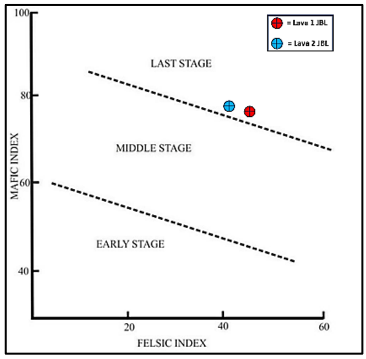

Fig. 4. The results of plotting magama differentiation show in the last stage.

The determination of magma temperature based on geochemical data was carried out by referring to the value of the dark mineral index (Mafic Index), the plot is manually using the formula to find the value of the dark mineral index/mafic index: MI = 100 (FeO + Fe_2O_3) / FeO + Fe_2O_3+ MgO. Based on the results of plotting the MI value in the diagram [6], it shows that the Lava 1 JBL and Lava 2 JBL were formed from magma with temperatures in the range 1090°C - 1098°C. Geothermal fluid analysis in the field aims to find out the initial data from the condition of the fluid directly in the field (Table 2) and as a comparison with the data from fluid analysis in the laboratory (Table 3).

Table 2. Analysis of fluid conditions in the field (in percent).

PARAMETERS	Geothermal Fluid Samples		
	JBL F1	JBL F2	JBL F3
Color	Clear	Clear	Clear
Aroma	Sulfur aroma is not too strong	Sulfur aroma is not too strong	Sulfur aroma is not too strong
pH	5,9	5,8	6
Temperature	38^0 C	37 ^{0}C	38 ^{0}C
Air Temperature	28,6 C	27,8 ^{0}C	27,4 ^{0}C
Humidity	69%	67%	67%
TDS	5367	5721	5629
EC	2726	2655	2412

Table 3. Results of fluid tests in the laboratory

Indicator	Na (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	SiO_2 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	HCO_3 (mg/L)
JBL F1	674.00	13.40	71.00	29.88	35.02	0.03	28.02	967.88
JBL F2	685.00	13.00	72.50	30.62	35.26	0.03	29.50	969.90
JBL F3	681.00	13.60	72.00	31.04	35.29	0.03	29.00	952.91

Before further analysis of fluid geochemistry in geothermal manifestations, an evaluation of the feasibility of the fluid must first be carried out by checking the ion balance. Ion equilibrium analysis was performed on all hot fluids with the following results (Table 4).

Table 4. Result of ion equilibrium analysis.

Indicator	JBL F1	JBL F2	JBL F3
Number of Cations (M)	34,45	35,41	34,71
Number of Anions (M)	16,46	16,50	16,22
Ion Balance (%)	0,71	0,72	0,72

Determination of hot spring type based on geochemical analysis of hot springs in the study area using diagram classification [7], Fluid type analysis using elemental and compound parameters HCO_3, SO_4 and Cl. The data is plotted into a Ternary diagram to find out the type of hot water fluidae (Figure 5).

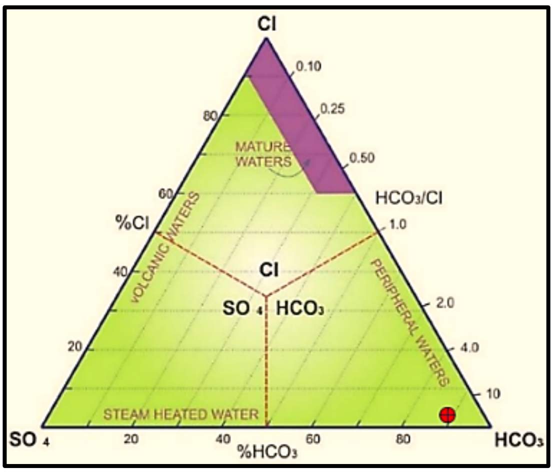

Fig. 5. Ternary diagram plotting results Cl-SO4-HCO3

The calculation of the subsurface temperature of the research area can be done using the Na-K-Mg geothermometer method [7]. Analysis of subsurface temperature using the parameters of sodium (Na), potassium (K), magnesium (Mg) and ion content calculation for the spring water of the research area. Data were plotted into a Ternary Na-K-Mg diagram [7] to determine the type of hot water phlyids at the research site (Figure 6). Geothermal systems associated with volcanic magmatism are generally geothermal systems with high-temperature reservoirs ≥ 200° C [8]. Based on the results of the plotting of the Ternary Na-K-Mg diagram on geothermal manifestations at the research site, it was found that the reservoir temperature only ranged from 80 °C-120 °C.

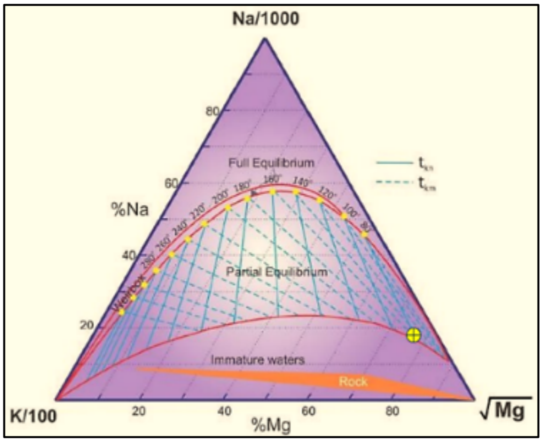

Fig. 6. Plotting Results Chart Na-K-Mg

3.2 Discussion

The results of petrographic observations showed that the igneous rock in the study area is andesite with a dominant mineral composition of intermediate minerals. Lava indicates that the geothermal environment in the study area was formed as a result of volcanic activity. The Calc Alkaline Series of magma indicates that the magmatism and volcanism of geothermal formation in the study area are associated with a subduction system with a medium distance (not too far from the subduction zone) with the original magma at a temperature in the range 1090°C - 1098°C, so that it tends to form fluids whose character is similar to the range of volcanoes on the island of Java in the middle row. The differentiation of magma in the research area has entered the Last Stage so that the volcano tends to form a geothermal system left over from volcanism.

Equilibrium analysis are performed to compare the concentration of positively charged ions with the concentration of negatively charged ions. The content of positively charged ions (cations) such as $Ca^{2+,}$ $Mg^{2+,}$ Na^{+}, K^{+} and negatively charged ion content (anions) Cl^{-}, $SO4^{2-}$, HCO^{3-} and F^{-}. The result of the ion balance calculation has a value of less than 1. An ion equilibrium that has a value of less than or equal to 5% is said to be feasible. The high ion balance is also affected by the type and process that the hot water is subjected to. This type of peripheral hot water generally forms near the surface. This type of water is formed due to a mixture of reservoir hot water that moves horizontally with surface water (meteoric water).

A geothermometer that is suitable for calculating reservoir fluid temperature is the Na-K-Ca Geothermometer which is quite good for use at temperature range 120° C - 200° C. This geothermometer is applied to water that has a high concentration of Ca, corresponding to geothermal fluids in the study area. This geothermometer is empirical with a theoretical foundation that has not yet been fully understood [9]. The theoretical limitation for this geothermometer is the equilibrium between Na and K Felspar as well as the conversion of calcium minerals alumino silicate (e.g. plagioclase) to calcite. The assumption used to make the Na-K-Ca geothermometer equation is that there is an excess of silica (usually true) and aluminum remains in the solid phase (usually true because the fluid is usually poor Al).

The geothermal manifestations in the study area are hot springs, which exhibit a bicarbonate fluid type. These geothermal fluids belong to the boundary zone between immature water and partial equilibrium, with a subsurface temperature ranging from 80°C to 120°C. The high magnesium content, reaching 86.8%, also indicates that the geothermal fluid has been influenced by surface water and contact with surrounding rocks. The Na-K-Ca geothermometer calculation shows that the reservoir temperature is between 82°C and 86°C, placing it in the low-temperature geothermal system category.

4 Conclusion

The study area contains andesite lava formed from volcanist activity products of subduction with the temperature of magma forming in the range 1090°C - 1098°C. The research area has the potential for natural resources in the form of geothermal energy. which is influenced by the magmatism and volcanism activities of Mount Jobolarangan and Mount Lawu which is a type of volcanic geothermal associated with tectonics. Based on the results of geochemical analysis of geothermal fluids, the hot water at the research site has the characteristics of a bicarbonate geothermal fluid type, and has a fluid maturity level immature until partially equilibrium. The high Mg content indicates that geothermal fluids are already affected by surface water and side rocks. The chemical content of the hot water and the geochemical characteristics of the three samples showed almost identical or identical results, This is shows that the geochemical characteristics of geothermal fluids taken at one location at different times do not affect the ions contained in the fluid. Research areas in general have potential for geothermal development, especially as power plants, but need further and comprehensive analysis.

References

1. M. N. Siahaan, A. Soebandrio, and K. Wikantika, Geothermal Potential Exploration Using Remote Sensing Technique (Case Study: Patuha Area, West Java). Jakarta: Asia Geospatial Forum (2011)
2. U. Hartono, The Petrology and Geochemistry of The Wilis and Lawu Volcanoes, East Java, Indonesia. Tasmania: Dissertation of Geology Department, University of Tasmania (1994)
3. K. Nicholson, Geothermal fluids: Chemistry and Exploration Techniques. (Springer-Verleg, Berlin Heldederberg, 1993)
4. R. Peccerillo, and S. R. Taylor, Geochemistry of Eocene calc-alkaline volcanic rocks from the Kastamonu area, northen Turkey. Contrib Mineral. **58**, 63-81 (1976)
5. C.P. Thornton, and O.F. Tuttle, Chemistry of Igneous Rocks, Part 1, Differentiation Index. American Journal of Science. **258**, 664–684 (1960).
6. C. E. Tilley, Pyroxene Fractination in Mafic Magma at High Pressure and it Bearing on Basalt Genesis, Gephys. **8**, 114-121 (1964).
7. S.F. Simmons, Geochemistry Lecture Notes. Geothermal Institute. University of Auckland (1998)

8. M.P Hochstein, dan P.R.L. Browne, Surface Manifestation of Geothermal with Volcanic Heat Source, In Encyclopedy of Volcanoes, (H. Siguardson, B.F. Houghton, S.R. Mc Nutt, H. Rymerdan J. Academic Press. 835–855, (2000)
9. A. Yoga, Prediksi Temperatur Reservoar Panasbumi Dengan Menggunakan Metoda Geotermometer Kimia Fluida. Teknik. **32**, (2011)