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Overview of the petrophysical and geochemical properties of the Ungaran Quarternary Volcano in relation to geothermal potential

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Abstract. Ungaran geothermal field is estimated to have a potential of 15 MWe. The volcano is located in the middle of Java Island which is a range of Quaternary volcanoes. As in other islands in Indonesia that indicate that this volcano has a potential energy of geothermal. This volcano is a strato volcano with andesitic composition. The Ungaran volcano geothermal system is located within a young cone depression, overgrown by Mount Gugon and Mount Megi that form the depressive ring. Geothermal manifestations contained in Gedongsongo include: fumarola, hot springs, travertine, steaming ground and alteration rocks. The temperature of the hot springs is about 50ºC, the pH of hot water is acidic (ranging from pH 1.5 to 5.5), bubble gas and around fumarola are found sublimation of sulfur and pyrite.This research uses analytical methods of geochemistry (water and rock), petrography and petrophysics. Based on geothermometer analysis shows that the reservoir temperature is 300ºC. The composition of fumaroles is strongly influenced by magmatic elements with temperatures greater than 300ºC. While petrography analysis yields that the material of Ungaran volcano rock is andesite-basaltic. Knowing the geothermal potential of this area is expected to increase the Java-Bali power supply.

1. Introduction

Ungaran volcano is a part of volcano chain which is located in the center of Java Island and is north-south oriented. The order from north to south is Ungaran-Telomoyo-Merbabu-Merapi. This volcanic chain consists of Quaternary volcano and has basaltic-andesite composition. From this volcanic chain, only theUngaranvolcano has a potential of geothermal. Several researches have been conducted, such as geological, geochemical, and geophysical research, so the results of this research can be used as parameter that determined the characterization of the geothermal system of Ungaranvolcano.

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Geothermal manifestations suchas hot springs in Ungaran volcano can be found in Gedongsongo, Bumen, Banaran, Kendalisodo, Diwak, Derakan, and Kaliulo. Not only hot springs and fumarole, but steaming ground and alteration rocks can also be found. The existence of geothermal manifestations coupled with the presence of Gedongsongo temple adds to the attraction of the area as an object of tourism.

2. Method

2.1. StudyArea
The research area is located in Ungaran volcano by showing the appearance of several manifestations of hot springs and alteration rocks. This area is the hot water location which is best known by the people is Gedongsongo area. This area is a complex of Hindu cultural heritage buildings precisely in Darung Hamlet, Candi Village, Ambarawa District, Semarang Regency. Travel to the area when taken from the Ambarawa city as far as 9 km, and 12 km when taken from the Ungaran city (Figure 1).

Figure 1. Location of research area.

2.2. Analysis Tools
This study aims to study the potential of geothermal in the research area based on the study of magmatism, the type of reservoir rock, petrophysic and geothermal fluid. To know the magmatism and type of reservoir rock by using the method of petrography and igneous rock geochemistry. To know the characteristic of reservoir rock by using petrophysic analysis of 5 rock samples. The measurements include: intensity of alteration, porosity, density and permeability. While to know temperature reservoir by using geothermometer method. Besides using the data analysis, this study also uses literature study related to Ungaran volcano. By conducting primary and secondary data, it is hoped that this research can give more information about geothermal field in Ungaran volcano.

To find out the magmatism of the research area, samples of basaltic andesite lava were analyzed, and to find out the characteristic of reservoir rocks by using andesite fragments, andesite lava, volcanic breccia (grain supported), brecciated tuff (matrix supported), and travertine. While the geothermometer analysis is used on hot springs that were found around the research area.

3. Result

3.1. Geological Setting

Ungaran volcano is physiographically located in the Solo zone [1]. This zone is a landscape of depression in the form of an inter-mountain plain in the middle of a chain of volcanoes. In general, Ungaran volcano is a strato-type volcano consisting of lava, pyroclastic and tuff with of andesitic-basaltic composition. The rocks are deposited well around the peaks and the foot of the volcano and covering the Tertiary sedimentary rocks. [2] explains that Ungaran volcano is a Quaternary andesitic volcano complex. The stratigraphy of this volcano is composed of andesitic, perlitic lava, and pyroclastic breccia of the Post Caldera formation. This formation is deposited on old volcanic rocks formed before the Ungaran caldera formation. The geological structure that develops in this volcano complex is controlled by the Ungaran collapse structure which has west to southeast orientation from Ungaran. While the fault structure that cuts off old volcanic rocks from Pre-Caldera formation is a structure that has northwest-southwest and southeast-southwest orientation. Gedongsongo area as a geothermal resource center is located on the southern slopes of Ungaran volcano. This volcano is about 1200 to 2000 m above sea level. In this area, the geothermal manifestations of fumarole, steaming ground and alteration rocks are found.

3.2. Volcanic rocks

Interpertation of the magmatism of Ungaran volcano can be obtained from the observation of volcanic rock petrography found in the research area (Figure 3.). The rock that represents the type of igneous rock in Ungaran volcano is basaltic andesite lava. The results of petrographic analysis of the basaltic andesite lava can be explained as follows:

3.2.1. Basaltic andesite

Basaltic andesite is a lava that located on top of Ungaran volcano as a lava dome. Microscopically, thebasaltic andesite lava shows the structure of scoria and generally was hypocrystalline, porphyritic, pilotaxitic and intersertal textureand scoria structure. The phenocrysts (65%) have a size 0.2-1.2 mm consists of plagioclase, pyroxene (augite), hornblende and opaque minerals. Phenocrysts were embedded in the groundmass of volcanic glass and plagioclase microlites. Some opaque minerals were present as inclusion in plagioclase and pyroxene.

Plagioclase present about 45% appears colorless, in the form of subhedral-anhedral, long prismatic, 0.2-1.2 mm in size present as phenocryst and as groundmass show plagioclase microlite type Labradorite (An_{63}-An_{69}). The phenocrysts of plagioclase generally exhibit albite twining and some individuals show zoning composition. Some phenocrysts show corrosion by groundmass and inclusion by opaque mineral. Pyroxene (augite) is present about 15%, as phenocryst and groundmass, thin prismatic or subhedral-anhderal with size 0.2-0.4 mm. Some phenocrysts show inclusion by opaque mineral. Hornblende present 5%, as phenocryst and groundmass, subhedral shaped with size 0.2-0.4 mm. Some phenocrysts show oxidized by iron oxide minerals. Opaque minerals are present at about 5%, sometimes clustered within the groundmass and partially as mineral inclusion at pyroxene, plagioclase and olivine. Volcanic glass was present 30%, as groundmass was fine-sized with plagioclase microlite and opaque minerals show intersertal and pilotaxitic textures.

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Figure 2. Outcrop of basaltic andesite lava that has composition of plagioclase, pyroxene, hornblende, and volvanic glass, located at Candi village.

3.2.2. Geochemistry of Volcanic Rocks

The volcanic rocks of the study area are represented by basaltic-andesite rocks. Since Ungaran volcano is a part of the alignment of Ungaran volcano, Telomoyo, Merbabu and Merapi, the discussion of geochemistry of volcanic rock of the study area is also compared with some volcanic rocks in Merapi. Selected Merapi rocks are from lava that were erupted from 1888-1992 [3].

Chemically, Ungaran volcanic rocks have several elements, such as SiO_2 (53.30%), TiO_2 (0.964%), Al_2O_3 (22.00%), Fe_2O_3 (3.30%), FeO (18.49%), MnO (0.221%), MgO (0.913%), CaO (7.57%), Na_2O (1.86%), K_2O (3.27%) dan P_2O_5 (0.39%). The geochemical data of volcanic rocks representing Merapi Volcano has the following characteristics SiO_2 (50.74-53.78%), TiO_2 (0.65-1.10%), Al_2O_3 (18.36-20.11%), Fe_2O_3 (1.15-1.76%), FeO (6.45-9.89%), MnO (0.18-0.36%), MgO (2.18-4.40%), CaO (8.64-10.94%), Na_2O (1.66-3.59%), K_2O (1.66-3.59%) dan P_2O_5 (0.16-0.95%). Compared to Merapi volcano, Ungaran has higher Fe_2O_3 content, which was used to form hornblende. While other elements relatively lesser than Merapis's. Chemical elements of Ungaran and Merapi volcanic rocks are presented in Table 1. and can be explained as follows:

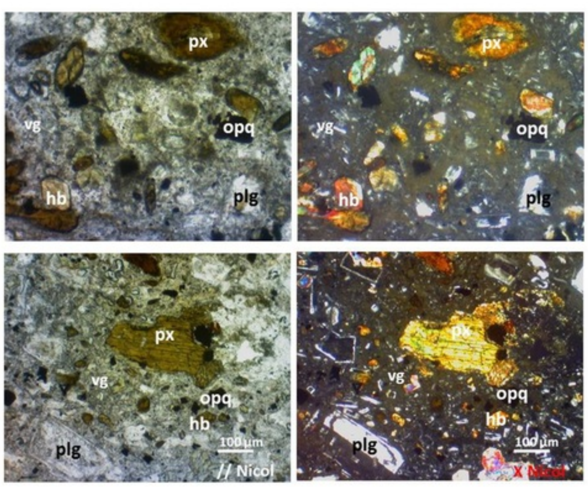

Figure 3. Shows basaltic andesite lava with intersertal texture composed by plagioclase (plg), pyroxene (px, hornblende (hb) in groundmass of plagioclase microlite and volcanic glass (vg).

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Table 1. Chemical Elements of Ungaran and Merapi volcanic Rocks

Samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5
ML1006	50.74	0.96	18.36	1.26	7.08	0.21	4.16	10.05	3.28	1.60	0.35
ML1992B	51.33	0.84	20.11	1.15	6.45	0.17	4.35	10.64	1.66	1.96	0.17
ML1992L	51.45	0.77	19.97	1.76	9.89	0.16	4.40	10.94	1.68	2.07	0.16
UNG	53.30	0.96	22.00	3.30	7.67	0.22	0.91	7.57	1.86	3.27	0.39
ML1986	53.53	1.10	15.76	1.38	7.75	0.36	2.45	9.39	3.73	2.63	0.38
ML1888	53.78	0.82	18.54	1.37	7.67	0.18	2.77	8.64	3.59	2.48	0.95

Annotation : UNG: Ungaran ML: Merapi Lava [3]

The result of plotting of $SiO_2$with the total of Na_2O+K_2O from Tas Le Maitre USGS diagram (1989) shows that there are several types of volcanic rocks, which the Merapi volcanic rocks consist of basalt, basaltic-andesite, basaltic trachy-andesite, and for Ungaran sample is basaltic andesite (Figure 3.).

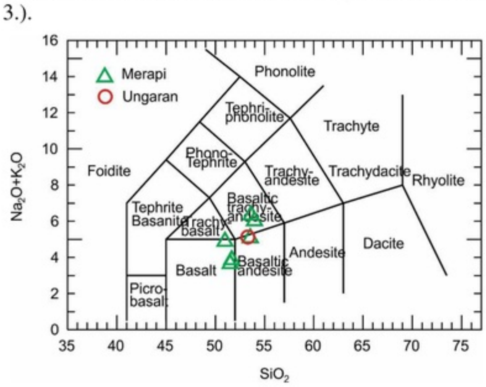

Figure 4. Shows the results of Ungaran and Merapi volcanic rock plots on the diagram of Tas Le Maitre USGS (1989).

While the result of plotting SiO2 element against K_2O on the diagram [4] showed that the sample Ungaran is shoshonitic affinity and the samples of Merapi show High K calk-alkaline series (Figure 5a). Fe element of Ungaran volcanic rock has a higher composition than the volcanic rocks group of Merapi. However, the content of Mg and alkali elements of Ungaran volcanic rock is lower than that of Merapi volcanic rocks (Figure 5b).

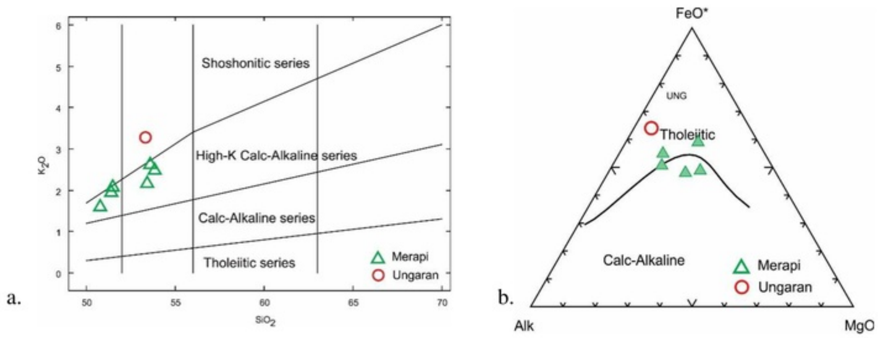

Figure 5. a. Shows the result of plotting K_2O and SiO_2 on [4] diagram. b. Plotting total FeO, MgO and total $Na_2O + K_2O$ (AFM diagram) volcanic rocks of Ungaran and Merapi.

3.3 Magmatism

The geology of Java Island was strongly associated with a magmatic arc from the Sunda subdution zone [5]. Magmatic arcs in Java are spread from west-east and consists of Quaternary magmatic arc in the middle of Java Island. [6] explains that subduction pathways in Java form a magmatic arc that is west-east oriented. The magmatic arc consists of tholeiitic-calc-alkaline volcanic rocks from the Old Andesite Formation of the Late Eocene-Early Miocene. Magmatic arc with tholeiitic composition (Late Miocene- Pliocene) and magmatic arc with calc-alkaline composition is from Quaternary.

In Central Java, a series of quaternary volcanoes forms a straight-line with north-south direction, which consists of Ungaran, Telomoyo, Merbabu and Merapi volcano. Seeing the appearance of this volcanic phenomenon shows that Merapi volcano is the youngest and most active volcano compared to Ungaran volcano, Telomoyo and Merbabu located on the north.

Based on the petrographic observation of the Ungaran volcano sample shows that it generally has a strong porphyritic texture (Figure 3.). According to [7] and [8] states that these characteristics are owned by volcanic rocks which tectonically formed in island arc. The volcanic rocks in the research area have an abundant phenocryst about 65%, consisting of plagioclase (45%), pyroxene (15%), hornblende (5%), and opaque minerals about 5%. The presence of pyroxene minerals, hornblendes and opaque minerals gives clues that the study area's volcanic rocks are enriched in iron, then decreased, consistent with the magma differentiation process. Based on these characteristics, the petrographical volcanic rocks of the research area is calc-alkaline [8]. In conclusion, volcanic rocks of Ungaran and Merapi are formed in island arc environments with calc-alkaline composition at Quaternary period.

3.4 Petrophysic

Petrophysic analysis was conducted on 5 rock samples, then analyzed the level of hydrothermal alteration, porosity, density and permeability. The hydrothermal alteration level shows medium level (25-75%), porosity about 8.43-12.04, density about 1.90-12.04 gr/cc, permeability about 15.78-1145.05 mD or 0.016-1.145 D.

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Table 2. Result of petrophysic measurement of samples from research area.

No	Rock Type	Intensity Alteration	Porosity (%)	Density (gr/cc)	Pemeability mD	Darcy
UN-01	Andesite fragmen	medium	9.89	1.89	152.46	0.152
UN-03	Andesite lava	medium	11.12	1.90	15.78	0.016
DRK-02	Volcanic breccia	medium	12.04	1.92	289.43	0.289
DWK-02	Breccia tuff	medium	8.43	2.26	21.05	0.021
DRK	Travertin	medium	27.24	1.66	1145.05	1.145

3.5 Fluids Geochemistry

Geothermometer analysis in this study used secondary data collected from several authors, such as [2, 10, 11, 12 and 13]. Geothermal geochemical fluid analysis using stable isotopes, water and gas geochemistry is used to determine the origin of fluids, water types and geothermal reservoir temperatures.

3.5.1 Isotope Stable

This analysis is used to find out the origin of geothermal fluid. It uses the δD data and δO^{18}, with the data (Table 3.) then plotted on the δD isotope variation image with δO^{18}. From the results indicate that the origin of the Ungaran geothermal heat fluids is meteoric water (Figure 6.). Water samples analyzed by isotope δD and δO^{18} are in the meteoric water line. This line has the equation $\delta D = 8\delta^{18}O + 10$ [14 and 15]. According to [10], based on geochemistry isotope proves that the water in Gedongsongo geothermal field is slightly fluid compared to geothermal fluid in general. The origin of hydrothermal fluid systems in the area is largely derived from meteoric water. Furthermore, isotope and chemical composition indicate that the origin of fluid from local meteoric water. Sea water contributes to varying proportions and becomes hot water that is actively out of the area.

Tabel 3. Analysis of $\delta\ ^{18}O$ and δ D in the research area [10].

Location	Sampel Label	**$\delta\ ^{18}O$**	**δ D**
Gedongsongo	UGW2	-7.86	-49.33
Gedongsongo	UGW3	-7.95	-50.21
Bumen	UGW6	-7.60	-47.46
Bumen	UGW7	-7.60	-47.71
Banaran	UGW8A	-7.48	-46.62
Banaran	UGW8B	-7.51	-47.08
Kendalisodo	UGW15A	-5.30	-39.36
Kendalisodo	UGW15B	-5.26	-39.78

3.6 Water Chemistry

The water chemical analysis is used to determine the fluid type and the geothermal fluid composition. Water samples were taken on fumarole and hot springs (Table 4.). Several hot water samples were taken from Gedongsongo, Bumen and Kendalisodo. The result of ploting the water chemistry data on Cl-HCO_3-SO_4diagram (Figure 7.) shows that the water type or geothermal fluid in Ungaran includes: chloride water, bicarbonate and sulphate. The chloride water is owned by the UK-1 sample, bicarbonate water is represented by UGW 3, 6,7, 8 (A, B), 15 (A, B) and UN-1 samples, whereas sulphate water is owned by UGW-2 sample. The sulphate water type contains 136 ppm of SO_4, bicarbonate water has a HCO_3 concentration of 58.6-1824 ppm, while chloride water has Cl content

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(5900 ppm). High content of sodium element (5300 ppm), chloride (5900 ppm) and boron (250 ppm) in hot water show that hot water is affected by connate water trapped in marine volcanic sediment Tertiary rocks.

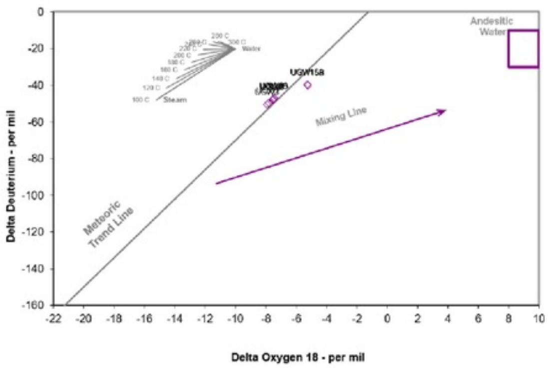

Figure 6. Results of δD isotope and δO^{18} plotted indicating that the origin of Ungaran geothermal fluid is meteoric water.

[10], sulphate hot water type is located in Gedongsongo and bicarbonate water fluid is located in Bumen, Banaran, Kendalisodo, Diwak, Derakan and Kaliulo areas. This type of water is caused by the mixing of hot water with shallow surface water. The result of the plot in the diagram of the water sample shows the type of water is in the "peripheral water" area. This water sample according to Giggenbach (1988) can not be used as a geothermometry for reservoir temperature estimation in this geothermal system. However, silica geothermometer can provide a minimum reservoir temperature range of 140°C. According to [12],the type of fluid from a water sample manifestation of western part of Gedongsongo is *a sulfate water* type, as well as water samples from well west Ung-1. While the samples from shallow well, whis is east Ung-2 well, shows the type of fluid is chlorite water. So this water sample can be used to determine reservoir temperature.

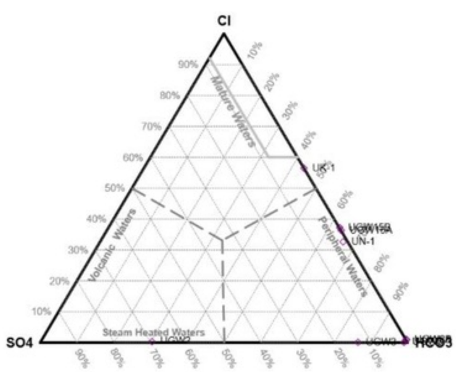

Figure 7. Results of plotting Ungaran water chemistry data on the Cl-HCO_3-SO_4 diagram.

3.7 Water Geothermometer

The result of this analysis is used to determine reservoir temperature. Chemical samples of hot water obtained from the field, then plotted on the Na/1000-K/100-VMg (Figure 8.). The result of ploting the water samples in the diagram shows that only the UK-1 sample is located on the partial equilibrium area with temperature 170°C. The composition of hot water in this sample is very high in Na (5300 ppm), K (213.3 ppm), and Mg (42 ppm). While the other water sample lies in the area of immature waters. The hot water sample is dissolved with shallow groundwater, so it contains high Mg (10.34-126 ppm). Thus, this hot water sample is the outflow from the process of dissolving reservoir water of Ungaran geothermal system.

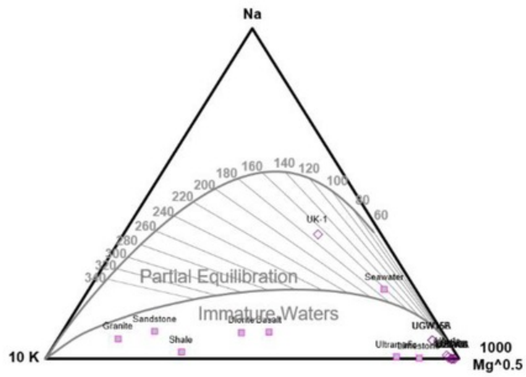

Figure 8. The result of ploting water sample on Na/1000-K/100-√Mg diagram.

3.8 Gas Geothermometer

The result of this analysis is used to determine reservoir temperature. The gas sample from hot water was obtained from the sample location (Table 4.), then plotted on the log diagram (rH_2S) against the log FT (rCO_2) + 4 log (rH_2) - log (rCH_4) (Figure 9). The result of ploting gas samples on the diagram shows only the sample of GDS located in the area with temperature 300°C, so this temperature is used as reservoir temperature in Ungaran geothermal system. The non-condensable gas content such as CO_2 is quite high (963.9 ppm) indicating the high concentration of the bicarbonate element. According to [11], the geothermal prospect area is located in the southern slopes of Ungaran Mountain which is Gedongsongo area with an estimated reservoir temperature of 231°C and an area power forecast of 15 Mwth / Km^2. This indicates a source of heat in the Gedongsongo area.

Table 4. Analysis of gas geothermometer of Gedongsongo [2].

Sampel Name	Type	Sampel Label	CO_2	H_2S	NH_3	Ar	N_2	CH_4	H_2	He	CO
Gedongsongo	fumarola	GDS	963.9	10.7		0.0290	9.90	9.94	4.64	0.0078	963.90

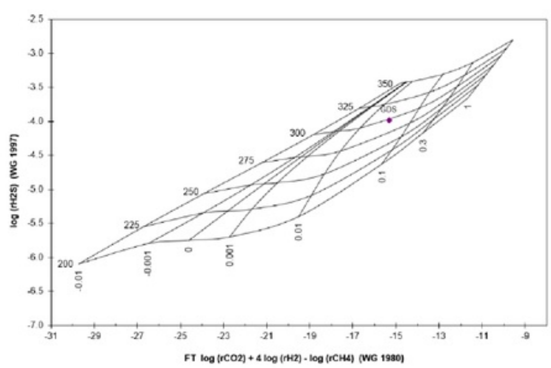

Figure 9. Plotting of gas sample on log (rH_2S) diagram vs FT log (rCO_2) + 4 log (rH_2) – log (rCH_4), the result indicates that the reservoir temperature is 300°C.

Ungaran geothermal system geologically is located in island arc with calc-alkaline magma type. This composition forms Quaternary Ungaran Volcano with strato type. The type of rocks erupted by the volcano is lava, pyroclastic breccia, and tuff with basaltic andesite composition.

Based on water geochemical analysis, the hot water of Gedongsongo is formed by steam heated meteoric water and consists of chloride, bicarbonate, and sulphate water.High concentrations of HCO_3, sodium and boron in hot water show that hot water is affected by connate water trapped in Tertiary volcanic marine sediment rocks. However, from the analysis of water and gas geothermometer shows the temperature of reservoir around 170-300^oC.

Characteristics of reservoir rock of Ungaran's geothermal system consist of lava and volcanic basaltic-andesite breccia with moderate level of alteration, porosity about 9.69-12.04%, density varies between 1.89-2.26 gr/cc and permeability about 21.04-289.43 mD or 0.021-0.289 D. The best rock as the best reservoir is volcanic breccia (grain supported) with permeability value about 21.04-289.43 mD or 0.021-0.289 D. This rock is filled by meteoric water with temperature of 300^oC and also produces steam that can generate electricity about 15 Mwth/Km^2.

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Table 5. Results of geothermometer analysis of hot water around Ungaran volcano[10(1),2(2)].

Location	Sampel Label	Temp. °C	pH	Na	K	Ca	Mg	SiO_2	B	Cl	F	SO_4	HCO_3	NH_4
Gedongsongo(1)	UGW2	40	5.36	25.31	8.63	32.55	10.34			1.16	0.21	136.00	58.60	0.64
Gedongsongo(1)	UGW3	56	6.10	14.89	7.90	37.13	15.14			0.77	0.12	31.80	200.00	0.50
Bumen(1)	UGW6	20	6.23	11.89	4.56	44.19	13.52			0.94	0.01	2.59	240.00	0.28
Bumen(1)	UGW7	19	6.25	12.28	4.67	45.71	14.02			0.98	0.01	2.60	248.00	0.29
Banaran(1)	UGW8A	20	6.04	10.42	5.58	37.06	11.29			2.46	0.09	0.11	207.00	0.13
Banaran(1)	UGW8B	18	6.02	10.30	5.57	37.06	11.18			2.44	0.01	0.08	221.00	0.14
Kendalisodo(1)	UGW15A	35.2	6.84	710.20	44.14	217.30	117.70			997.80	0.06	0.10	1732.00	16.08
Kendalisodo(1)	UGW15B	38.1	6.78	746.10	47.11	278.40	126.00			1088.00	0.06		1824.00	17.01
UK-1(2)	UK-1	48	7.66	5300.00	213.30	60.00	42.00	40.00	250.00	5900.00	1.00	9.00	4500.00	0.05
UN-1(2)	UN-1	17	6.62	146.70	27.30	78.00	105.00	124.00	5.90	50.00	0.23	2.00	100.00	1.80

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