GEOTHERMAL GEOCHEMISTRY IN BOLIOHUTO AREA, GORONTALO REGION, GORONTALO PROVINCE, NORTH SULAWESI, INDONESIA

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Keywords: *Geothermal Manifestation, Boliohuto, Water Characteristic, Sub-surface Temperature, Geothermal System*

ABSTRACT

The research area is in the Kecamatan Boliohuto, Kabupaten Gorontalo, Gorontalo Province, North Sulawesi, Indonesia. Geographically, it is located between 62962 mU – 87815 mU and 442701 mT - 467717 mT on Zone 51 UTM Coordinate System. This research is a further survey, after the preliminary survey in 2013 by Pusat Sumber Daya Geologi (Indonesian Center of Geological Resource). The purpose of this research is to understand the geothermal manifestation characteristics in the surrounding area.

The analysis results from 5 hot water manifestation samples obtained at the surface. The Cl-SO_4-HCO_3 and Na-K-Mg ternary diagrams, cation geothermometer and the relationship between Cl and B were used to characterize the water and estimate the subsurface temperature. The highest surface temperature of hot water is around 64.3^{0}C. Mostly, the hot waters in this area can be classified as chloride type. However, at some locations there is bicarbonate water type due to contamination by polluted water at the surface. Based on the Cl/B ratio, the reservoir here is believed to be associated with volcanic rocks. Most the hot water is located at the *partial equilibrium zone* while a small part of it is located at *Immature Waters Zone*. The estimated reservoir temperature ranges from 131 to 152°C which is classified as a *medium enthalpy geothermal system.*

1. BACKGROUND RESEARCH

Administratively, the study area is in the Boliohuto District, Gorontalo, Gorontalo Province, North Sulawesi, Indonesia. Geographically, located in mU 62 962 - 87 815 and 442 701 mU mT - 467 717 mT on Zone 51 UTM Coordinate System (Figure 1). The need for electrical energy is quite large, with a growth in electricity consumption of 15%. Current energy sources such as coal, oil and gas, will not be able to fulfill consumer demand for electricity. However, this problem can be solved by utilizing the geothermal energy potential, from a number of active volcanoes in this area.

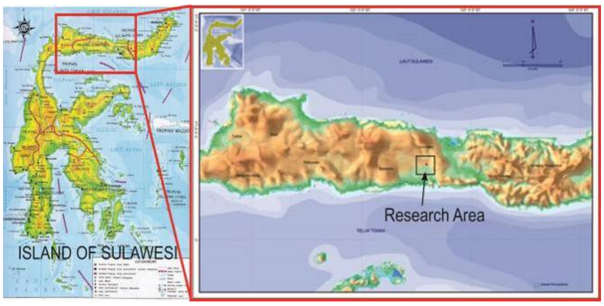

Figure 1: Location of Research Area, in the center of northern part of the Island of Sulawesi

Tectonically, Sulawesi Island is influenced by three converging plates, the Indo-Australian, Pacific and Eurasia plates, which produces a lot of volcanic activity (Villeneuve et al, 2001). Geothermal systems on the island of Sulawesi are generally associated with andesitic-basaltic volcanoes. Furthermore, the geothermal systems on the island of Sulawesi are more controlled by local fault systems and caldera depressions formed by the removal of rock mass below the surface during volcanic eruptions.

The results of a preliminary survey conducted by PSDG in 2012, in the Boliyohuto District found three hotspring to determine: geothermal systems, reservoir temperature, manifestations that are located in the Diloniyohu Village. Therefore, this paper will discuss the geochemical characteristics of hot water from these geothermal surface manifestations. The geochemistry of the hot water will help type of hot water and type of reservoir rock. In addition, there are supporting data, including lithologic information and geological structure.

2. REGIONAL GEOLOGY

Some previous researchers have observed the Gorontalo area and surrounding areas, for example, Villeneuve, et al. (2011), van Leeuwen (1994), Simanjuntak (1997) (in Geological map sheet Tilamuta, North Sulawesi), Ratman (1993) and the Center for Geological Resources (in Preliminary Survey of Geothermal in Gorontalo District, North Sulawesi Province). Sulawesi Island is located in the active regional margin of the Eurasian Plate which experienced four main periods of tectonic activity in the middle Cretaceous, late Oligocene, mid-Miocene, and the mid-Pliocene. They were associated with the development of three blocks (blocks Banda, Bolok Iron Works, and Banggai Sula) in the active region of the eastern margin of the Eurasian plate (Villeneuve et al, 2001). The main tectonic activity in the investigation area is related to tectonic activity that occurred in the Oligocene, as a result of collision between the block of the Eurasian Plate and Banda Block which is in the southern part (Fig 2). Regionally, the research areas are located in the West Mandala Northern Sulawesi magmatic arc which is in the north. The main geological structures in the area of research are horizontal faults and normal faults.

Based on a stratigraphical survey, the study area is composed of:

(i). The Tinombo Formation, consisting of Eocene-Oligocene volcanic rocks and clastic sedimentary rocks, intrusive diorite rocks,
(ii). Bone and Boliyohuto at the age of Miocene Formation
(iii). Dolokalapa composed of clastic sedimentary rocks
(iv). Middle Miocene overrides, not aligned to the Formation Tinombo,
(v). Overlay of Pinogu volcano rocks in the Pliocene,

(vi). Followed by Lake Sediment from the quarternary (Ratman, 1993).

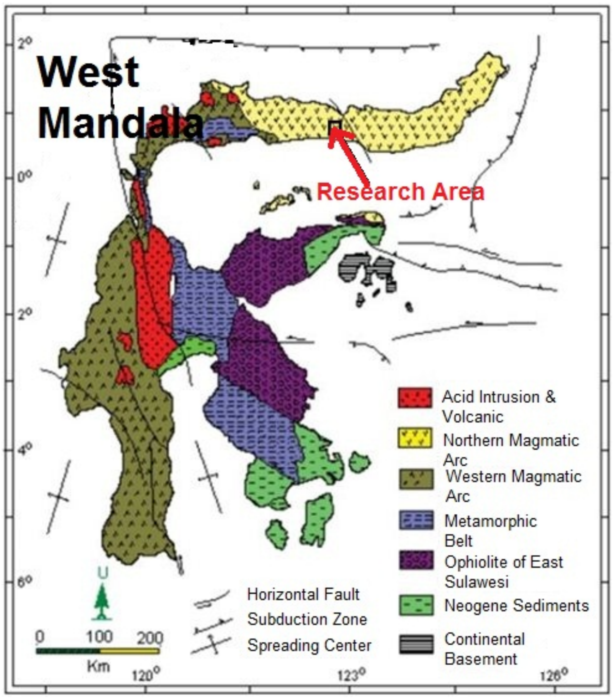

Figure 2: Lithotectonic Units in the research area that is included in West Mandala Sulawesi (Van Leeuwen, 1994)

Normal faults at Mt. Boliyohuto show a radiating pattern. Generally, the fault movement are strike slip dextral, but others are sinistral (Bachri, et al, 1994).

3. METHODS

Geological mapping was carried out to identify lithological unit and geological structure and record geothermal manifestations. Measurement of physical properties was conducted at each of the manifestation points, such as: temperature of hot water, air temperature, pH of hot water, water discharge, and electrical conductivity. Then, samples of surrounding rock at the manifestation point were taken, as well as samples of hot water and cold water.

In the laboratory, petrographic analysis was conducted to determine the texture, structure and mineral content of rock samples. The element contents and ion concentration of hot water and cold water were analyzed by fluid geochemistry. Geochemical analyzes were conducted on 5 samples of hot water and 2 samples of cold water. They were used for: a) determining the type of hot water based on the content of Cl, SO_4, and HCO_3; b) Interpreting reservoir rock types based on the content of relative ion Cl / 100, B / 4, and Li; c) Determining the origin of the hot water based on the relative position of Na / 100 K / 100, and $\sqrt{Mg}$. Furthermore, the estimation of reservoir temperature were made by solute Geothermometers, namely: the Na-K Geothermobarometer method of Fournier (1979) and Giggenbach Equations (1988); and Na-K-Ca Geothermobarometer of Fournier and Truesdell Equations (1973).

Results of the geochemical data processing were used for estimating the geothermal potential that may be developed in this study area. This geochemical analysis was supported by an understanding of stratigraphic aspects and geological structures so it can be used as a guide for advanced exploration activities.

4. RESULTS

The results of this research include: a study of regional geology, characteristics of geothermal manifestation and the relationship between geological conditions and hot water geochemistry.

4.1. Regional Geology

4.1.1. Lithological Unit

Based on field data acquisition in the study area, this area is dominated by sedimentary rock which occupies the north, northeast and southern portion. The volcanic rocks, such as andesite lava, partially occupy the eastern, northern and southeast parts. Then, intrusive rocks, such as granodiorite and diorite, occupy the center and northwest. The center is also covered by lacustrine deposits. The lithology can be divided into six units, as shown on the geological map (Fig. 3), with the following explanation:

1. Sandstone Unit

In general, the unit is composed of sandstone with a light gray to brown color, medium-coarse grained, well sorted**,** closed fabric and with a strong hardness. The sandstone unit is generally already oxidized.

2. Granodiorite Unit

The lithological characteristics of the granodiorite unit are: a gray color with black spots, faneritic granularity**,** holocrystalline, equigranular. The minerals contained in this rock are quartz, alkali feldspar and biotite.

3. Diorite Unit

In general, this unit is characterised by blackish gray massive diorite, faneritic granularity, holocrystalline, inequigranular. The minerals contained in the rocks are plagioclase, amphibole and pyroxene. The age of the granodiorite and diorite ranges from Miocene middle-late Miocene (Ratman, 1994).

4. Andesite Lava Unit

The andesite lava is a product of a paleovolcano that has a characteristic gray color, afanitic granularity, hyphocrystalline, equigranular. Mostly, andesit lava in this unit is oxidized.

5. Lacustrine Deposits

These deposits occupy the plain area with relatively gentle contours. These deposits are characterized by layer of light gray colored mudstone.

6. Alluvial

This sediment material is found in rivers that pass through the study area, and is characterized by the presence of loose materials, with a grain size from fine sand to boulder.

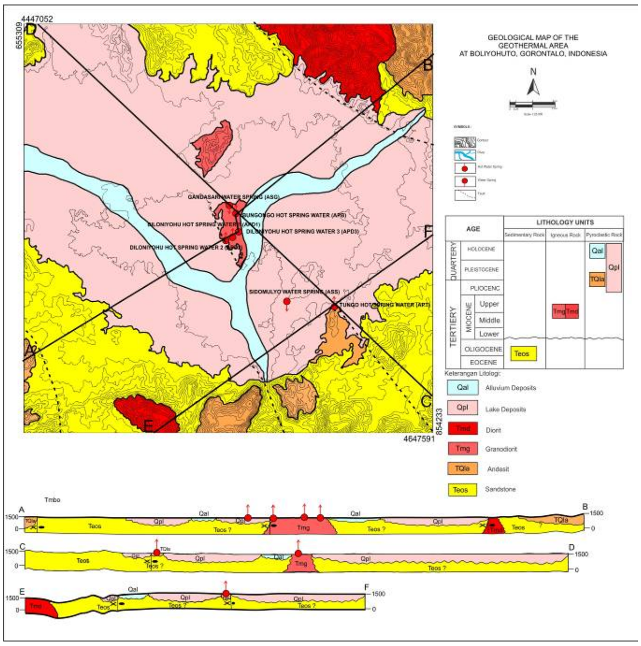

Figure 3: Geological Map of Boliyohuto Geothermal Area

4.1.2. Structural Geology

Based on aster image and topography analysis (Fig. 4) there are number of lineaments of valleys and ridges which have a dominant northwest-southeast direction, and the other lineaments has east-west and northeast-southwest direction. These directions are interpreted as geological structures such as faults. East-west direction are formed by normal faults, northeast-southwest direction are also formed by normal faults, and the northwest – southeast until north - south faults are formed by horizontal and normal faults (PSDG, 2012).

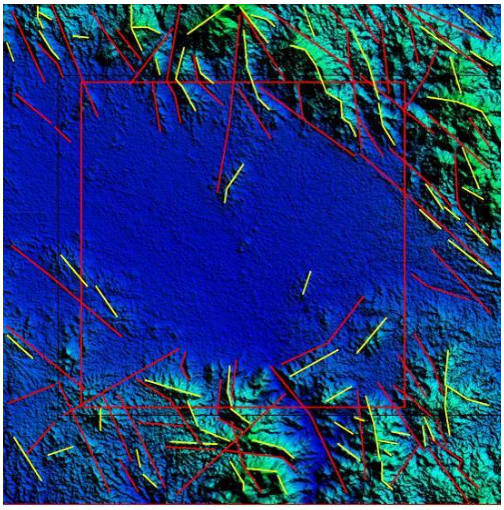

Figure 4: Topographic map and lineament lines in the Boliyohuto Area

4.2 Geothermal manifestations

Field observations show the existence of geothermal manifestations in the study area in the form of hot springs. There are five locations of hot springs, including: Diloniyohu1, Diloniyohu2, Diloniyohu3, Bungogo and Tungo that are located in Boliyohuto District, as well as two cold springs that are used for comparison such as Gandasari, that is located in Tolangohulo District, and Sidomulyo wells that is located in the Boliyohuto District (Fig 5).

The Diloniyohu1, Diloniyohu2, Diloniyohu3, Bungogo hot springs appear on granodiorite lithology unit, while the Tungo hot spring appears on an andesite lava unit.

The hot springs temperature reach 60.9°C at an air temperature which is about 30.6°C, pH is 6.94 and electrical conductivity of 4640 µS/cm and water flow discharge is 2.5 liters/sec. The hot springs are formed by the flow of hot water from beneath the surface through the rock fractures.

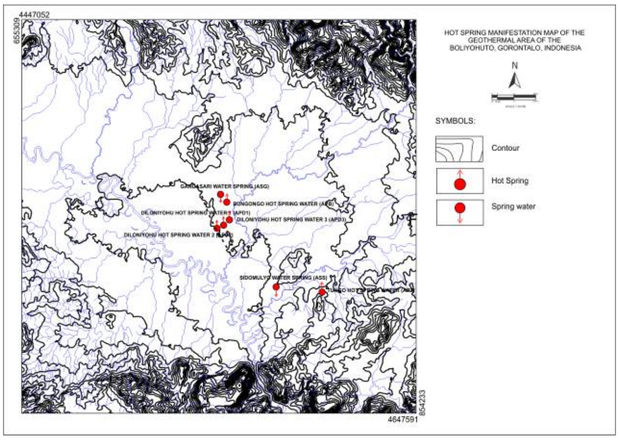

Figure 5: Location of hot water manifestations

Figure 6: Condition of Diloniyohu 3 hot water (MAP3)

Table 1: Laboratory results of hot water geochemistry

KODE	AP. DILONIYOHU 1	AP. DILONIYOHU 2	AP. DILONIYOHU 3	AP. BUNGO	AP. TUNGO	AS. GANDASARI	AS. SIDOMULYO
	APD 1	APD 2	APD 3	APB	APT	ADG	ADS
T.air(°C)	62.17	64.3	54.43	40.94	48.15	29.98	29.40
T ud (°C)	32.14	32.92	27.87	32.58	31.9	31.89	32.49
pH	6.60	6.78	7.20	7.50	7.21	6.40	6.49
EC (µS/cm)	2600	2095	3000	3600	1487	550	465
SiO_2 (mg/l)	58.73	57.96	58.05	46.60	54.84	53.32	44.49
B	8.11	5.63	6.80	21.11	1.03	0.50	0.45
Al^{3+}	0.01	0.02	0.02	0.02	0.01	0.02	0.01
Fe^{3+}	0.04	0.04	<0.03	<0.03	0.03	<0.03	<0.03
Ca^{2+}	125.09	123.34	127.28	191.21	27.71	31.74	53.44
Mg^{2+}	3.98	3.88	3.83	0.79	19.50	19.03	6.32
Na^{+}	417.27	414.50	436.81	605.67	299.63	70.05	36.90
K^{+}	12.37	12.02	11.86	12.27	8.44	4.37	10.61
Li^{+}	0.17	0.18	0.20	0.34	0.16	0.02	0.02
As^{3+}	0.50	4.00	4.00	<0.01	<0.01	<0.01	<0.01
NH_4^{+}	0.06	0.02	0.19	0.43	0.03	<0.01	<0.01
F^{-}	1.35	1.43	1.56	1.66	<0.01	0.28	0.15
Cl^{-}	589.28	595.80	641.47	983.95	61.77	5.27	7.30
SO_4^{2-}	335.51	330.07	322.67	323.53	294.17	8.38	21.03
HCO_3	79.89	82.88	77.15	31.11	438.83	375.31	274.27
$CO_3^{=}$	0.00	0.00	0.00	0.00	0.00	0.00	0.00
ion balance	0	1	0	3	4	1	1

4.3 Characteristics of Hot Water Geochemistry

Validation results of the geochemical laboratory was done by calculating the percentage of ion equilibrium between cations and anions that exist in the sample. The results of chemical analysis can be determined to be good if the error of the ion equilibrium of cations and anions is less than 5% (Nicholson, 1993).

The results of the calculation in Table 1 above indicate that chemical number is valid and the data are feasible to be used in further investigation due to the good quality of all of hot water samples with an error in ion equilibrium percentage less than 5%.

4.3.1 Type of Hot Water

Analysis was conducted to determine the type of hot water from each manifestations by calculating the ratio value of Cl, SO_4, and HCO_3 in the Cl-SO_4-HCO_3 triangular diagram (Fig 6). Based on the diagram, there are 2 types of hot water in the study area, chloride water which is composed of Cl as the main anion, and bicarbonate water which is composed of HCO_3 as main anion.

4.3.2 Reservoir

The classification of Cl / 100-B / 4-Li triangular diagram shows that all samples from the hot springs give Cl / 100 values which shows that hot springs are in equilibrium and not changed much from the original conditions. It also means that during the hot water flow to the surface, it tends to be associated with volcanic rocks. In addition, the mixing (dilution) with ground water is relatively low.

The results of the calculation of the Cl / B ratios was used to determine the similarity of the reservoirs (Nicholson, 1993). The Cl / B ratios indicate that the hot water from Diloniyohu 1 (APD 1), Diloniyohu 2 (APD 2), and Diloniyohu 3 (APD 3) have relatively close values that range from 72.7 to 105.8. It shows that the heat sources of these three hot springs come from the same reservoir. While Bungo (APB) and Tungo shows ratios of 46.6 and 60.0 which suggests they could come from different reservoirs.

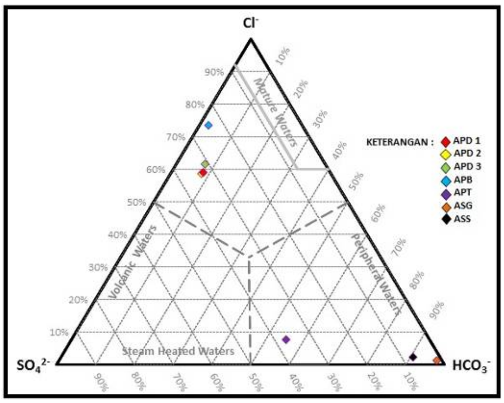

Figure 7: Data Plotted on a Cl-SO_4-HCO_3 Diagram

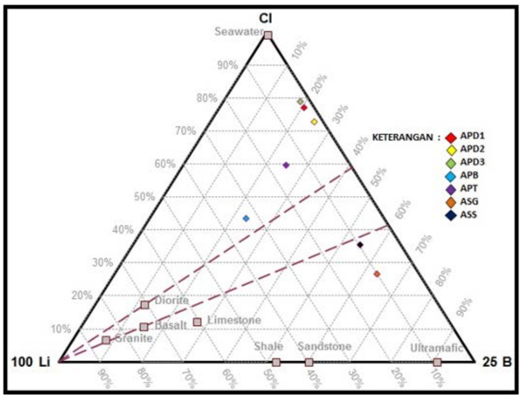

Figure 8: Data Plotted on a Cl-100Li-25B Diagram

In terms of Li show all of the hot springs have concentrations below 1 mg / L. This result indicates that the lithology below the surface is dominated by basaltic rock (Ellis, 1979 op.cit. Nicholson, 1993).

4.3.3 Origin of Hot Springs

The concentrations of Na / 1000, K / 100, and √Mg in the triangular diagram (Fig. 8) show generally hot water is in the partial equilibrium zone. This zone describes the condition of the hot water that is likely to have come directly from its source at a high temperature and it is only slightly mixed with meteoric water. Meanwhile the hot water from Tungo (APT) that is in the *immature waters zone* indicate that the hot water was mixed with meteoric water. Thus the Tungo (APT) samples cannot be used to determine the subsurface temperature due to a lack of accuracy.

Most of the hot water samples have a relatively high Mg content. This shows either the reaction of the fluid with the surrounding rocks that causes a carryover of Mg content from the surrounding rocks into the fluid, or the fluid interaction with subsurface water. The concentration of Mg in hot water in the *immature waters zone* is higher than in the *partial equilibrium zone.* It indicates that there has been leaching of Mg from the surrounding rocks or dilution with groundwater which contains a high concentration of Mg (Nicholson, 1993).

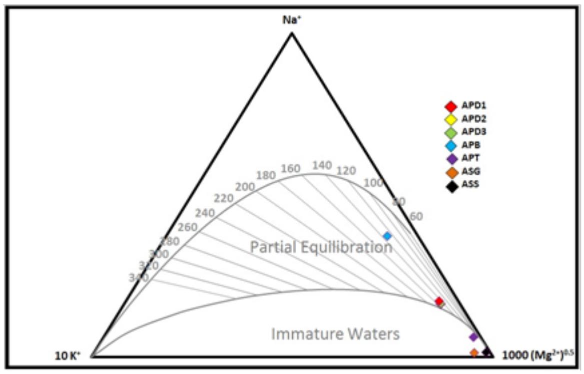

Figure 9: Na-K-Mg Diagram

4.3.4 Geothermometer

Hot water samples that were used in geothermometer calculations were from Diloniyou 1 (APD1), Diloniyohu 2 (APD2), Dinloniyohu 3 (ADP3), and Bungongo (APB). These samples are in the *partial equilibrium zone*, thus allowing a more accurate calculation due to a lesser influence of meteoric water. Table 2 below shows the results of calculations using several geothermometer methods.

Based on the calculation results of several geothermometer methods, the estimated temperature reservoir in the study area is about 131° C - 151° C. The result from the Na - K geothermometer method is the most appropriate to be used, because the content of the element Na in hot water is more abundant than the other cation elements.

Table 2: Estimated Subsurface Temperature by using Geothermometer Calculations

Manifestation	Na-K (°C)		Na-K-Ca (°C)
	Giggenbach (1988)	Fournier (1979)	Fournier & Truesdell (1973)
APD1	151.0	131.2	122.8
APD2	149.8	129.9	121.9
APD3	146.1	126.1	119.7
APB	130.7	110.1	109.8

4.4 Geothermal systems

The chloride water type contains high Cl, Na and K. This type is characteristic of high-temperature geothermal systems (Nicholson, 1993). The bicarbonate water type appears in the Tungo hot water. This water has a neutral mode.

Based on the geothermometer calculation results, the estimated reservoir temperatures ranges from 131°C to 151°C, which means they are included in the category of medium enthalpy geothermal systems (between 90°C-151°C) (Muffler & Cataldy, 1978).

Based on the results of geochemical analysis, the geothermal system of this research area is a single-phase high-temperature water dominated system (Nicholson, 1993). The grouping of all geothermal systems of the manifestations in study area are shown in Table 3 below:

Table 3: Geothermal systems in the research area

No.	1	2	3	4	5
Sample code	APD1	APD2	APD3	APB	APT
Type of manifestation	Hot water	Hot water	Hot water	Hot water	Hot water
Chemistry	Chloride	Chloride	Chloride	Chloride	Chloride
Equilibrium	Partial Equilibrium	Partial Equilibrium	Partial Equilibrium	Immature Waters	Partial Equilibrium
Temperature	High Enthalpy	Medium Enthalpy	Medium Enthalpy	Medium Enthalpy	Medium Enthalpy
System Type	Water Dominated	Water Dominated	Water Dominated	Water Dominated	Water Dominated

5. DISCUSSION

5.1 Flow of Hot Water Manifestations

Flow of hot springs in the study area is divided into two zones: the upflow and outflow. The hot springs Diloniyohu1, Diloniyohu2, Diloniyohu3, Bungogo that appear on granodiorite unit are included in the upflow zone. This is proved by the chloride chemical properties, with no or little mixing with meteoric water (described in Section 4.3.3). Additionally the Mg / Ca ratio in the hot springs shows a low value and the ratio of Na / Mg shows a high value. It can be explained by the fact that the zones in the study area are in an upflow zone. While the Tungohot spring, that appears on andesite lava unit, is in the outflow zone, as evidenced by the abundant HCO_3 content, and the influence of meteoric water contamination (Nicholson, 1993).

6. CONCLUSIONS AND RECOMMENDATIONS

Based on the final results of geothermometer calculations, geothermal energy production in the study area is not feasible, given that the minimum temperature in a good geothermal system is > 180^0 C.

To strengthen the research results, geophysical data is needed that will support the existence of anomalies which can be estimated to be a geothermal reservoir.

ACKNOWLEDGEMENTS

The authors want to convey gratitude profusely to Mr. Dr. Sc. Yoga Andriana S, ST., M.Sc as our supervisor. Thanks are also extended to Mr. Lano, Mr. Smith, and all the staff of PSDG, for guidance and support, both morally and materially, provided during the execution of this research.

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