International Journal of Multidisciplinary Research and Publications
ISSN (Online): 2581-6187

Characteristics of Hydrochemical to Determine Reservoir Temperature Banda Baru Area, Amahai District, Central Maluku Regency, Maluku Province

Claudia Natalia Noya[1], Agus Didit Haryanto[1], Johanes Hutabarat[1], Dewi Gentana[1]
[1]Faculty of Geological Engineering, Padjadjaran University, Indonesia
Email address: claudia17003 @ mail.unpad.ac.id

Abstract— *The research area is located in Banda Baru Village, Amahai District, Central Maluku Regency, Maluku Province. This area has surface geothermal manifestations in the form of hot springs, steaming ground, sintered carbonate deposits (travertine), mud pools, and steam-heated water. The research objective was to determine the type, physical characteristics, and chemical characteristics as well as the estimated geothermal subsurface temperature in the research area. The research method used two methods, namely field observations and data processing including data analysis based on the chemical laboratory results of hot and cold spring samples. Plotting results of the Cl-SO_4-HCO_3 ratio from hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, MAP BB-5) and cold springs (MAD BB-1, MAD BB-2) shows the type of bicarbonate of water in the peripheral water condition. Plotting the Cl-Li-B ratio of hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, MAP BB-5) and cold springs (MAD BB-1, MAD BB-2) is in the condition of absorption of high B/Cl steam. Plotting the Na-K-Mg ratio shows MAP BB-1, MAP BB-2, MAD BB-1, and MAD BB-2 as immature waters, while MAP BB-3, MAP BB-4, and MAP BB-5 in partial equilibrium conditions. The results of calculations using the thermal water geothermometer equation, it is estimated that the subsurface temperature of the research area ranges: 96°C–124°C (Silica maximum steam loss equation), 95°C–127°C (Silica no steam loss equation), 135°C–191°C (Na-K equation).*

Keywords— *Banda Baru, Geothermal Manifestation, Geothermal Water Characteristics, Water Geothermometer, Subsurface Temperature.*

I. Introduction

Indonesia has enormous geothermal potential because Indonesia is one of the countries that is passed by the ring of fire. Based on Vulcanology Center and Geological Disaster Mitigation, Indonesia has 127 active volcanoes.

Around 40% or 29.000 MW of the world's total geothermal energy is in Indonesia because Indonesia is a country that has high volcanic potential (Wahyuni, 2012). Based on PT Pertamina Geothermal Energy (PGE) in the 2019 Integrated Annual Report, the potential for energy resources from Indonesia's geothermal energy reaches around 25 GW spread across 349 points throughout Indonesia. Of the total potential, the total installed capacity has reached 2.132 MW and as many as 15.128 MW, of which have been identified as potential reserves that are ready to be developed.

Maluku Province is one of the archipelagic provinces where most of its geothermal potential is associated with non-volcanic geological environments, one of which is the Banda Baru Village Area, Amahai District, Central Maluku Regency, Maluku Province. Geographically, the research area is located at coordinates 129°4'30"–129°6'30" East Longitude and 3°11'30"–3°13'30" South Latitude with an area of about 15 km X 20 km (Fig. 1). This area was chosen to be the research area because it has geothermal manifestations which indicate that it has the potential to be developed later.

The purpose of the research to determine the type, physical properties, and chemical characteristics of geothermal fluids (type, origin, equilibrium or reservoir condition), and also reservoir temperature estimation.

The research method used two, namely field observations and data processing including data analysis based on the chemical laboratory results of hot and cold spring samples.

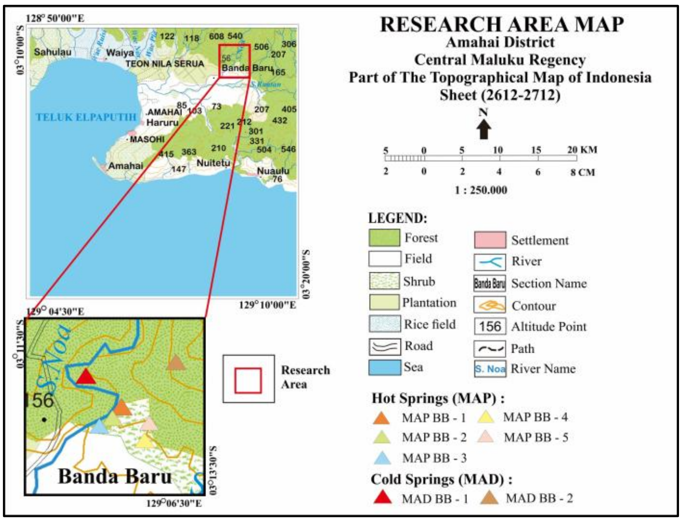

Fig. 1. Location of the research area
(Part map of Indonesia Earth Sheet Ambon 2612 and Sheet Masohi 2712)

II. Literature Review

A. Regional Geology

Regional Geomorphology

Based on the classification of the Deusaunnetes system, 1977 (Todd, 1980) based on the large percentage of slope and different relief height of a place, the Seram Island area is divided into four geomorphologies, namely:

1. Plain Morphological Unit, has a slope percentage of 0-2%.
2. Weak Corrugated Morphological Unit, has a slope percentage of between 2-8%.

Claudia Natalia Noya, Agus Didit Haryanto, Johanes Hutabarat, and Dewi Gentana, "Characteristics of Hydrochemical to Determine Reservoir Temperature Banda Baru Area, Amahai District, Central Maluku Regency, Maluku Province," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 4, Issue 1, pp. 36-40, 2021.

3. Strong Corrugated Morphological Unit, has a slope percentage of 8-16%.
4. The Karst Corrugated Morphological Unit, has a slope percentage of 16-74%.

The shape of the landscape in the research area, namely the Banda Baru Village area, Amahai District, Central Maluku Regency, forms a steep morphological distribution with high peaks (strong wavy hills). The morphology is found in the northern and southern parts of the research area, which are dominated by schist rocks. Meanwhile, in the middle part of the research area, it forms weak wavy hills to plains (Fadhlan, M., 2011).

Regional Stratigraphy

Based on the Regional Geological Map of Sheet Masohi, Maluku (Tjokrosapoetro, S., et al., 1993), the research area is composed of two (2) groups of rock units (Fig. 2):

1. Tehoru Complex (PTRt)
   Consists of metamorphic rock with green schist facies, namely; phyllite, slate, schist, psammite, and marbled limestone. The rocks of the Tehoru Complex (PTRt) of the Permian-Triassic age are found in the north and south of the research area.
2. Alluvium (Qa)
   Consists of silt, sand, and gravel, Quaternary age, located in the western part of the research area

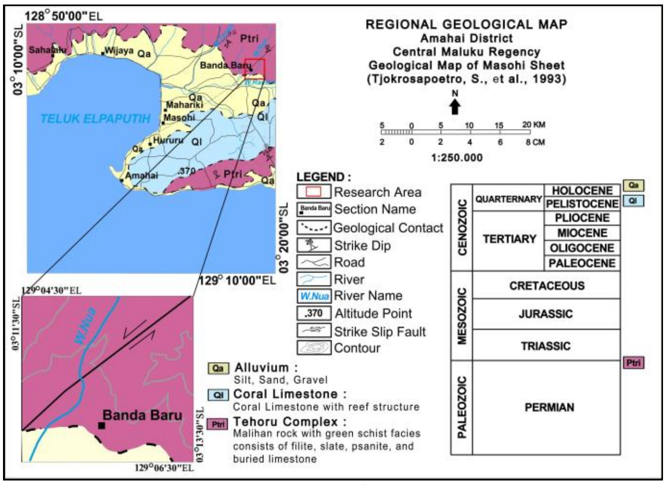

Fig. 2. Regional Sheet of Masohi, Maluku (Tjokrosapoetro, S., et al., 1993)

Regional Geological Structure

Based on the geological map (Maluku, Masohi Sheet - P3G 1993), Central Maluku Regency, the geological structures that developed in this area are:

1. Folds in the form of anticline and syncline involving the Manusela formation, trending East-West.
2. The Thrust Fault which controls the core of Central Maluku Regency involves the Tehoru Complex, Sahu Complex, Kanikeh Formation, Taunusa Complex, and Wahai Formation, also in an east-west direction and curved convex to the North.
3. The Southeast–Northwest and Northeast–Southwest Faults, involving the Taunusa Complex, Tehoru Complex, Sahu Complex, and all other formations of Permian – Late Tertiary Age.

Maluku regional tectonic activity has a role in the development of geological structures in the research area, in the form of a northwest-southeast trending fault structure, the dominant type of which is a right-hand horizontal fault (dextral horizontal fault) which is the oldest fault resulting in a shift in the previously formed lithology. In addition, the northwest-southeast trending fault has a left movement (sinistral horizontal fault) which affects the emergence of Banda Baru hot springs and has a different period from other northwest-southeast trending faults. Then a southwest-northeast trending fault was formed, which is a horizontal fault that generally has a left shift (sinistral horizontal fault) and an oblique fault which is formed as a normal horizontal fault that has a left movement (Munandar, R., et al., 2013).

B. Geothermal System

The geothermal system formed in the earth's crust has 5 (five) main components, namely:

1. Heat Source
   The formation of geothermal sources requires heat which will form a hydrothermal fluid cycle in the form of a comparison of steam and hot water, where the hot mass can be in the form of solid hot mass, liquid hot mass, radioactive mineral hot mass, chemical reactions (exothermic).
2. Geothermal Fluid
   Geothermal fluid is a phase consisting of a mixture of steam and water, which becomes hot due to the convection process from the reservoir zone to the fluid and surrounding rock through which the fluid passes.
3. Reservoir Rock
   Reservoir rock, namely rock located as a place for accumulation of geothermal fluid (steam, thermal water).
4. Caprock
   Caprock is a zone that has not passed or waterproof (impermeable) or low permeability compiled by various types of rocks and is above the reservoir rock, serves to prevent convection heat to the fluid reservoir beyond the surface.
5. Permeability
   Permeability is the ability of rocks to be able to pass one type of fluid if two types of fluids do not mix with each other (Peng, Suping, and Zhang, Jincai, 2007).

C. Geochemistry of Thermal Water

Types of Thermal Water

Nicholson (1993) divided the types of thermal water based on the dominant anion content, namely Cl, SO_4, and HCO_3 anions.

1. Chloride water is a type of deep geothermal fluid, generally found in high-temperature geothermal systems. Hot springs with chloride water type have high-temperature, large discharge, high CI/SO_4 ratio, pH 5-9, and high chloride content that comes directly from the reservoir.

2. Sulphate water is a type of geothermal fluid that is formed due to the condensation of geothermal gases in surface water. Hydrogen sulphide (H_2S) contained in the hot steam undergoes oxidation to become sulphate.
3. Bicarbonate of water is a type of geothermal fluid that is formed due to the condensation of steam and gases into oxygen-poor surface water. This type of thermal water consists of two types, namely the first type which has a low chloride (Cl) and high bicarbonate (HCO_3) content, due to the condensed steam rich in carbon dioxide (CO_2) relatively close to the surface and causes the HCO_3 content to increase. The second type contains relatively more Cl than the first type and high HCO_3 content, due to chloride moving relatively horizontally (as an outflow) during its journey to experience changes in HCO_3 due to reactions with side rocks or the dissolution of CO_2 with shallow groundwater.
4. Chloride sulphate water is a type of geothermal fluid formed by mixing chloride water and sulphate water where the Hydrogen Sulphide (H_2S) in alkaline chloride water is oxidized to sulphate ions (SO_4^{2-}).
5. Bicarbonate of chloride dilute water is formed due to the interaction of chloride water with groundwater (bicarbonate of water) during lateral travel. This thermal water is probably located at the boundary of the upflow zone and outflow structure in high-temperature geothermal systems.

The Cl–SO_4–HCO_3 ternary diagram, Giggenbach (1988) can be used to determine the type of thermal water. Anions in the form of Cl, SO_4, and HCO_3 are solutes that are often found in geothermal fluids.

Origin of Geothermal Fluids

Geothermal fluid can come from meteoric water that enters through it's permeable zone, connate water that has long been in rock formations, metamorphic water, and magma (juvenile water) (Nicholson, 1993).

To determine the origin of geothermal fluids, a Cl-Li-B plotting diagram is used. The content of Cl, Li, and B can provide information about the subsurface conditions because it is conservative (Giggenbach, 1985).

Equilibrium of Geothermal Fluids

Geothermal fluid equilibrium in rock and reservoir temperature estimates can be determined using the Na-K-Mg ternary diagram (Giggenbach, 1988).

Geoindicators

Geoindicator is a method to determine upflow and outflow zones in geothermal systems. Dissolved substances are divided into two categories, namely geoindicator and tracer (Giggenbach, 1991). Tracer geochemically is difficult to react with other compounds and when in the geothermal fluid would be permanent and can track their origin. Geoindicators are solutes that are reactive and reflect the equilibrium or equilibrium environment (Nicholson, 1933).

Geothermometers

Geothermometer is a method for estimating the temperature of geothermal reservoirs. The types of geothermometers used as parameters for determining the temperature or reservoir temperature are as follows:

1. Silica Geothermometer
   Silica geothermometers are made based on the solubility of various types of silica in water as a function of temperature determined by simulation/experiment. The reaction which is the basis for dissolving silica in water is SiO_2 (s) - $2H_2O$ $\rightarrow$ H_4SiO_4. This geothermometer is not suitable for high temperature (>225°C) geothermal systems, where quartz can precipitate due to slow cooling if cooling is very rapid.
2. Na-K Geothermometer
   The calculation of the Na-K geothermometer can be applied to chloride water reservoirs with T > 180°C. This geothermometer has the advantage that it is not much affected by dilution or steam loss. This geothermometer is not good for T < 100°C, as well as water-rich in Ca and associated with travertine deposits.
3. Na-K-Ca Geothermometer
   Used in water that has a high concentration of Ca. This geothermometer is empirical with a theoretical basis that is not completely understood. A good temperature range for geothermometer Na-K-Ca is 120°–200°C, the rest is not too good.

III. METHOD

The method used in geochemical research of thermal water is divided into two, namely:

1. Geoindicator
   Geoindicators were used in this study to determine the fluid type and fluid origin.
2. Geothermometer
   Geothermometers are used to determine the approximate temperature of the reservoir.

IV. RESULTS AND DISCUSSION

A. *Types and Physical Characteristic of Geothermal Manifestations*

The type of geothermal manifestation in the research area is Banda Baru hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, and MAP BB-5), mud pool, steam-heated water, steaming ground, and travertine.

The physical properties of the five hot springs as a whole have an acidic pH close to neutral (5.8-7), have a sulfuric odor, colored (slightly cloudy), sour taste, thermal water temperature ranges from 43°–80°C.

B. *Geochemical Characteristic of Geothermal (Hydrochemical) Fluid*

Characteristic of Thermal Water Type

In determining the characteristics of thermal water in the form of a fluid type in the reservoir using the relative content of chloride (Cl), sulphate (SO_4), and bicarbonate (HCO_3) which is treated first by calculating the percentage of each of the elements Cl, SO_4, and HCO_3 (Table 1). The results of the calculation of the percentage of the relative content of Cl, SO_4, HCO_3 show that the type of hot spring in the research area is bicarbonate water. This is because, from the results of the

Claudia Natalia Noya, Agus Didit Haryanto, Johanes Hutabarat, and Dewi Gentana, "Characteristics of Hydrochemical to Determine Reservoir Temperature Banda Baru Area, Amahai District, Central Maluku Regency, Maluku Province," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 4, Issue 1, pp. 36-41, 2021.

chemical analysis, it is known that the element HCO_3 (bicarbonate) is the most dominant element.

Bicarbonate of water generally forms close to the surface, where CO_2 gas contained in water vapor will condense when it interacts with groundwater. Steam condensation can heat ground water (steam heated), thus produce bicarbonate water (HCO_3).

The high bicarbonate in thermal water in the research area, apart from being thought to be due to condensation of steam containing CO_2 gas, it is also estimated that thermal water has experienced a lot of mixing with surface water or the type of bicarbonate water in the research area is interpreted to have been contaminated by metamorphic rocks originating from sedimentary rocks.

TABLE 1. Concentration value and percentage of element/compound Cl-SO_4-HCO_3

Hot Springs	Concentration (mg/L)			Percentage (%)		
	Cl	SO_4	HCO_3	Cl	SO_4	HCO_3
MAP BB-1	133.22	75.58	145.58	37.59	21.32	41.08
MAP BB-2	22.14	15.70	418.12	4.85	3.44	91.70
MAP BB-3	720.68	30.00	1494.45	32.09	1.33	66.56
MAP BB-4	568.00	3.87	1391.38	28.93	0.19	70.87
MAP BB-5	497.00	6.03	1353.44	26.77	0.32	72.90
MAD BB-1	2.50	3.05	9.37	16.5	20.44	6.80
MAD BB-2	2.50	3.31	24.59	8.22	10.88	80.88

The results of plotting chemical ions on the Cl-SO_4-HCO_3 ternary diagram of all hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, and MAP BB-5) in the research area showed that overall hot springs have a fairly dominant bicarbonate fluid composition compared to other anions and overall hot springs enter the peripheral water type (Fig. 3). Peripheral water type fluid has a pH close to neutral and a normal temperature as a result of the reaction of water with the side rocks in its path. Most of these fluids will tend to move horizontally and can usually be found in areas quite far from the heat source.

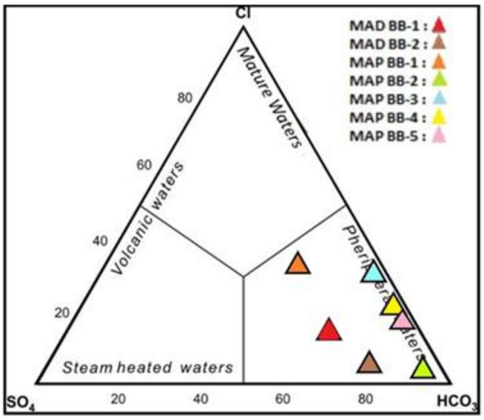

Fig. 3. Result of plotting element content relative Cl-SO_4-HCO_3 hot springs in the research area (Giggenbach, 1988)

Reservoir Characteristic and Origin of Thermal Water

The results of plotting the relative contents of Cl, B, and Li obtained from laboratory analysis data, were first processed into Cl/100, B/4, Li, then the percentage value (%) of each of these elements was calculated (Table 2).

Table 2 shows MAP BB-4, and MAP BB-5 has a more dominant percentage (%) chloride (Cl) content than lithium (Li) which is relatively smaller, and has a more dominant Cl percentage content than boron (B) with the percentages are not much different. The high Cl at MAP BB-4 and MAP BB-5 indicate that this hot spring is relatively closer to the heat source compared to other hot springs.

TABLE 2. Concentration value and percentage of element/compound Cl-Li-B

Hot Springs	Concentration (mg/L)			Percentage (%)		
	Cl	Li	B	Cl	Li	B
MAP BB-1	133.22	0.54	5.59	40.74	16.51	42.74
MAP BB-2	22.14	0.15	0.93	36.66	24.83	38.49
MAP BB-3	720.68	4.03	38.21	34.66	19.38	45.94
MAP BB-4	568.00	2.26	19.11	44.66	17.77	37.56
MAP BB-5	497.00	2.12	18.64	42.29	18.04	39.65
MAD BB-1	2.50	0.00	0.14	41.66	0.00	58.33
MAD BB-2	2.50	0.00	0.14	41.66	0.00	58.33

MAP BB-1, MAP BB-2, and MAP BB-3 contain a more dominant percentage (%) of boron (B) when compared to Cl and Li. The high concentration of boron (B) indicates that the hot spring discharge process in the research area is not related to volcanic processes or hydrothermal processes, indicating that the hot springs are located far from the main flow of the geothermal system. The high concentration of boron (B) indicates that there has been a dilution process when the fluid moves to the surface and interacts with metamorphic rocks in the research area which originate from sedimentary rocks that are rich in organic matter. This is confirmed in the field, the emergence of hot springs is in metamorphic rocks, namely muscovite schist, and graphite schist, which are derived from sedimentary rocks, namely sandstone, claystone, and shale.

MAD BB-1, MAD BB-2 have relatively the same boron (B) content as MAP BB-1, MAP BB-2, and MAP BB-3. This shows that there is a melting process with the surrounding rock when the fluid rises to the surface.

The results of plotting elements Cl, Li, and B on the ternary diagram Cl/100-B/4-Li (Fig. 4) show the entire hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, MAP BB-5) and cold spring samples (MAD BB-1, MAD BB-2) were in the “absorption of high B/Cl steam” condition.

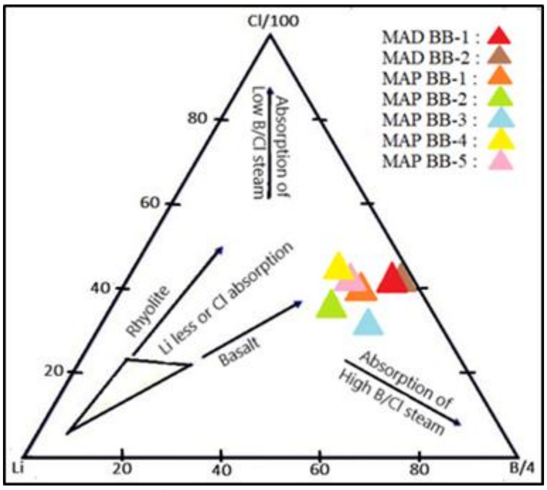

Fig. 4. Result of plotting element content relative Cl-Li-B hot springs in the research area (Giggenbach, 1988)

Geothermal Fluid Equilibrium

The interpretation of the origin of the fluid from the hot springs in the research area can be done by looking at the relative content of the Na-K-Mg elements, based on data from laboratory chemical analysis. Na-K-Mg is used to determine the fluid equilibrium of the geothermal reservoir.

From the data from the analysis of the water chemistry laboratory, the values of Na/100, K/100, and $\sqrt{Mg}$ were calculated, then they were processed to obtain the percentage value (%) of the three elements (Table 3).

TABLE 3. Concentration value and percentage of element/compound Na-K-Mg

Hot Springs	Concentration (mg/L)			Percentage (%)		
	Na	K	Mg	Na	K	Mg
MAP BB-1	256.81	10.61	13.95	6.26	2.58	91.14
MAP BB-2	61.60	4.07	16.69	1.47	0.97	97.55
MAP BB-3	1045.26	36.48	11.46	21.79	7.60	70.59
MAP BB-4	862.87	25.27	5.06	25.64	7.50	66.84
MAP BB-5	835.38	24.08	4.53	26.06	7.51	66.41
MAD BB-1	3.00	0.77	0.02	1.97	5.06	92.96
MAD BB-2	4.97	1.57	0.97	0.49	1.56	97.94

Based on the ternary diagram of Na-K-Mg (Fig. 5), the samples of MAP BB-1, MAP BB-2, MAD BB-1, and MAD-BB-2 have Mg levels higher than Na and K levels, including immature waters, indicating that the thermal water has experienced a reaction with other elements of shallow groundwater when it moves to the surface. The condition of immature waters indicates that thermal water has not matured properly, it can be interpreted that thermal water from samples of MAP BB-1, MAP BB-2, MAD BB-1, and MAD-BB-2 is not representative of geothermal fluid.

According to Nicholson (1993), high Mg levels indicate that geothermal water has experienced mixing with meteoric water or shallow groundwater which has higher Mg concentrations.

The concentration of Mg in geothermal fluids with high temperatures or directly from geothermal reservoirs without going through a dilution process is 0.001 ppm-0.1 ppm.

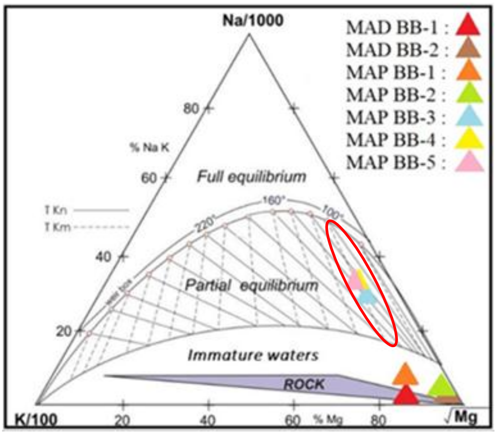

Fig. 5. Result of plotting element content relative Na-K-Mg hot springs in the research area (Giggenbach, 1988)

MAP BB-3, MAP BB-4, and MAP BB-5 in the Na-K-Mg ternary diagram are in the partial equilibrium zone. This shows that the fluid contained in the hot springs has interacted with the side rocks it passes for a while sufficient to create equilibrium (Nicholson, 1993).

C. *Estimation of Reservoir Temperature*

Geothermometer equation was chosen, to calculate the estimated subsurface temperature (reservoir), by using the geothermometer equation; (1) Silica (SiO_2) at maximum steam loss conditions (Fournier, 1977) and (2) no steam loss (Fournier, 1977), and (3) Na-K (Fournier, 1979).

The results of the calculation of the estimated subsurface temperature (reservoir) of each sample of hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, MAP BB-5) shows that the research area has a subsurface temperature (reservoir) that varies (Table 4), as follows:

(1) SiO_2 geothermometer equation (silica – maximum steam loss) obtained temperature; 122°C (MAP BB-1), 96.58°C (MAP BB-2), 119.16°C (MAP BB-3), 124.71°C (MAP BB-4), and 123.66°C (MAP BB-5); (2) The equation for SiO2 (silica – no steam loss) is obtained by temperature; 124.58°C (MAP BB-1), 95.84°C (MAP BB-2), 121.18°C (MAP BB-3), 127.71°C (MAP BB-4), and 126.48°C (MAP BB-5); (3) The Na-K equation is obtained by temperature; 158.12°C (MAP BB-1), 191.71°C (MAP BB-2), 147.20°C (MAP BB-3), 136.42°C (MAP BB-4), and 135.48°C (MAP BB-5).

There are differences in the calculation results in subsurface temperature using a fluid (water) geothermometer is very possible because when the geothermal fluid (water) from below the surface (reservoir) is on its way to the surface there is contamination with other chemical elements, either chemical elements from rocks and mixing or diltuting with meteoric water forms a new equilibrium (Gentana, D., et al., 2020).

The results of geothermal calculations for water (fluid) from hot springs (MAP BB-3, MAP BB-4, and MAP BB-5) which are in partial equilibrium, show that the geothermal system in the research area is classified as a low-temperature geothermal system. medium (Hochstein and Browne, 2000), with an estimated subsurface temperature (reservoir) ranging from 119.60°C–147.20°C (Table 4), there is an agreement with the results of plotting the relative elements of Na-K-Mg on the ternary diagram Na/1000-K/100-√Mg (Giggenbach, 1983) showing the reservoir equilibrium temperature ranges from 120°–140°C.

TABLE 4. The calculation result geothermometer Silica (SiO_2) and Na-K

Hot Springs	SiO_2 (°C)		Na-K (°C)	Remarks
	Maximum Steam Loss (Fournier, 1977)	No Steam Loss (Fournier, 1977)	(Fournier, 1979)	
MAP BB-1	122.00	124.58	158.12	Immature waters
MAP BB-2	96.58	95.84	191.71	Immature waters
MAP BB-3	119.60	121.18	147.20	Partial equilibrium
MAP BB-4	124.71	127.71	136.42	Partial equilibrium
MAP BB-5	123.66	126.48	135.48	Partial equilibrium

Claudia Natalia Noya, Agus Didit Haryanto, Johanes Hutabarat, and Dewi Gentana, "Characteristics of Hydrochemical to Determine Reservoir Temperature Banda Baru Area, Amahai District, Central Maluku Regency, Maluku Province," *International Journal of Multidisciplinary Research and Publications (IJMRAP)*, Volume 4, Issue 1, pp. 36-41, 2021.

V. CONCLUSIONS AND SUGGESTIONS

A. Conclusions

From the results of this research it can be concluded as follows:

1. The types of geothermal manifestations in the research area are hot springs (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, MAP BB-5), hot mud pools, steam-heated water, steaming ground, and travertine.

   The physical characteristics of the five hot springs relatively have an acidic pH close to neutral (5.8 to 6.7), sulfur-smelling, colorless (slightly turbid), sour taste, thermal water temperatures ranging from 43°–80°C.
2. Geochemical characteristics of geothermal fluids in the research area are:
   a. The types of hot springs in Banda Baru (MAP BB-1, MAP BB-2, MAP BB-3, MAP BB-4, and MAP BB-5) relatively are bicarbonate water, formed in peripheral water conditions, this indicates the thermal water tends to move horizontally and away from the heat source.
   b. The high boron (B) concentration indicates that the thermal water in the research area comes from a reservoir contaminated by shallow groundwater (meteoric water), away from the heat source flow, and undergoes fusion with the surrounding rock when the fluid moves to the surface or is associated with metamorphic rocks originating from the reservoir of sedimentary rock.
   c. Fluid equilibrium of MAP BB-1, MAP BB-2 under immature waters condition, while MAP BB-3, MAP BB-4, MAP BB-5 under "partial equilibrium" condition. High Mg concentration indicates the thermal water has been mixed and diluted by shallow groundwater (meteoric water) rich in Mg or other elements when the hot fluid moves to the surface.
3. Estimated reservoir temperature using a SiO_2 and Na-K geothermometer in thermal water in partial equilibrium conditions as follows:
   a. MAP BB-3; 119.16°C, MAP BB-4; 124.1°C, MAP BB-5; 123.66°C (Silica-maximum steam loss equation). MAP BB-3; 121.18°C, MAP BB-4; 127.71°C, MAP BB-5; 126.48°C (Silica no steam loss equation).
   b. MAP BB-3; 147.20°C, MAP BB-4; 136.42°C, MAP BB-5; 135.48°C (Na-K equation)

B. Suggestions

To delineate geothermal prospects by obtaining additional detailed research results, further exploration is necessary, such as conducting subsurface petrographic analysis and geophysical methods. The geothermal system in the research area has low to moderate temperatures, so if it is developed it is necessary to pay attention to the economic value, generating system, and geotourism value.

ACKNOWLEDGMENT

The author would like thank to the Faculty of Geological Engineering, Padjadjaran University for permitting this research activity and the preparation of the scientific article. We hope this article is academically useful for all people in the field of science expertise.

REFERENCES

[1] Fadhlan, M., and Intan, S., 2011. Eksplorasi Geoarkeologi Gua-Gua Karst Amahai, Kabupaten Maluku Tengah, Provinsi Maluku. Jurnal Penelitian dan Pengembangan Arkeologi Nasional, Vol. 19 (1), 27-42.

[2] Fournier, R. O., 1985. Application of Water Geochemistry to Geothermal and Reservoir Engineering, Vol. 5, United States Geological Survey, Reston.

[3] Fournier, R. O., and Rowe, J. J., 1977. Estimation of Underground Temperatures from the Silica Content of Water From Hot Springs and Wet-Steam Wells, American Journal of Science, Vol. 264.

[4] Gentana, D., Haryanto, D. A., Hutabarat, J., 2020. Geochemical and Isotope Analyses in Geothermal System of Mt. Rendingan and Its Surrounding, Lampung Province, Southern Part of Sumatra. Proceeding 5th International Conferences of Geological Engineering Faculty (ICGEF 2020).

[5] Giggenbach, W, F., 1988. Chemical Techniques in Geothermal Exploration Chemistry Division, DSIR, Private Bag.

[6] Giggenbach, W, F., 1988. Geothermal Solute Equilibria.: Derivation of Na-K-Mg-Ca Geoindicators, Geochemica Acta, Vol. 52, 2749-2765.

[7] Giggenbach, W., 1991. Geochemical Techniques in Geothermal Exploration, UNITAR UNDP, Guidebook: Application of geochemistry in resources development, 119-144.

[8] Hochstein, M. P., and Browne, P. R. L., 2000. Surface Manifestation of Geothermal System with Volcanic Heat Sources, In Encyclopedia of Volcanoes Academic Press, 835-855.

[9] Muda, P. B., 2013. Panas Bumi Non Vulkanik di Indonesia. GEOMAGZ majalah geologi popular. Available online at: http://geomagz.geologi.esdm.go.id/panasbumi-non-vulkanik-di-indonesia/ (Accesed Februari 4, 2021).

[10] Munandar, A., Simarmata, R. 2013. Survei Aliran Panas Daerah Panas Bumi Banda Baru, Kabupaten Maluku Tengah, Provinsi Maluku. (5). Bandung: PSDMBP.

[11] Nicholson, K., 1993. Geothermal Fluid Chemistry and Exploration Techniques. Springer-Verlac Inc : Berlin.

[12] Peng, Suping and Zhang, Jincai., 2007. Engineering Geology for Underground Rocks. Berlin: Springer.

[13] PT Pertamina Geothermal Energy., 2019. Geothermal Beyond Energy. Laporan Tahunan Terintegrasi 2019. Jakarta: PT PGE.

[14] Summardi Eddy, Bakrun, Syuhada, and Rihardiana Liliek., 2011. Survei Terpadu Geologi dan Geokimia Panas Bumi Daerah Banda Baru Kabupaten Maluku Tengah, Provinsi Maluku. Bandung: PSDG.

[15] Tjokrosapoetro, S., Achdan, A., Rusma, E., Suwitodirdjo, K., and Bidin, H. Z., 1993. Peta Regional Lembar Masohi, Maluku skala 1:250.000. Pusat Penelitian dan Pengembangan Geologi Lembar 2612, 2613, 2712, 2713.

[16] Todd, D. K., 1980. Groundwater Hydrology. New York: Wiley.

[17] Vulcanology Center and Geological Disaster Mitigation., 2019. Tipe Gunung Api di Indonesia (A, B, dan C). ESDM. Available online at: https://magma.esdm.go.id/v1/edukasi/tipe-gunung-api-di-indonesia-a-b-dan-c (Accesed October 18, 2020).