Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Geothermal Fluids Beneath The Songa – Wayaua Area, Bacan Island, North Maluku Province - Indonesia

Herry Sundhoro, B Sulaeman, and Yuanno Rezky

The Center For Geological Resource - The Geological Agency, Jon. Soekarno-Hatta 444, Bandung - Indonesia

phone 022 - 5205572, 022 – 5202698 ext 1318, Fax. 022 – 5226263.

e-mail: herry sundhoro_012070@yahoo.com

Keywords: Geothermal fluids, beneath Songa-Wayaua area

ABSTRACT

The Songa - Wayua geothermal area is located in the middle of Bacan Island, North Maluku Province. Indication of geothermal potential in the area is characterized by surface thermal features, such as hot springs, fumaroles, mud pools, hot grounds, steaming grounds, silica sinter and altered rock. The surface features are Pelepele Besar/ utara, Pelepele Kecil/ selatan, Babale Langsa/ Lansa, Pado pado/ Tawa and Wayaua. Their temperatures vary between 45.1 - 101.6^0 C, and they have a normal pH of hot water acids, of about 6,54 - 6,99. The geothermal manifestations here are covered by volcanic and metamorphic rocks, which are associated with the N 330º E lineament of recent volcanics.

All hot waters represent a high concentration of chloride. Two samples derived from immature waters, while three others are in partial equilibrium. The geothermometer calculation for the thermal reservoir beneath the area varies between 221 and 254° C. The relation between hydrogen and oxygen isotopic ratios of thermal spring waters in Songa-Wayaua shows enriched ^{18}O content, it lies reality distance from the MWL (meteoric water line). This means all hot spring waters are presumably derived from a reservoir beneath the geothermal manifestations.

I. INTRODUCTION

The Indonesian archipelago is settled on the ring-fire belt as a volcanic arc. It extends about 4,300 km from Weh Island and Sumatera Island at the west to Bacan Island, Halmahera Island and Kai Island at the east and also to Buru Island to the north. Along that entire island some active and inactive volcanoes exhibit geothermal manifestations; globally the heat source of geothermal energy in Indonesia is associated with a magma store beneath the volcanic area.

In the Songa-Wayaua area, many geothermal surface manifestations are found, such as: fumaroles, hot grounds, steaming grounds, mud pools, hot springs, silica sinter and altered rocks. The area is characterized by Quatenary volcanic rocks, and is associated with a N 330º E trend of the Recently dike of a volcanic lineament, and it's underlain by metamorphic rocks.

The study area is located in the southern part of Bacan island, South Halmahera Distric, North Maluku Province. It lies between 127.60.00-127.70.00 mE and 0.66.00-0.77.00 mS in UTM coordinates (Figure 1).

The purpose of this paper is to give a geological background, to identify whether geothermal manifestations are from the hot water fluids beneath the area, and to determine the relation between hydrogen and oxygen isotopes from thermal spring waters. Analyzed ^{18}O and Deuterium will identify a depleted or enriched source of ^{18}O, respective to magma degassing for assessment of the condition of the geothermal reservoir underneath Songa-Wayaua area.

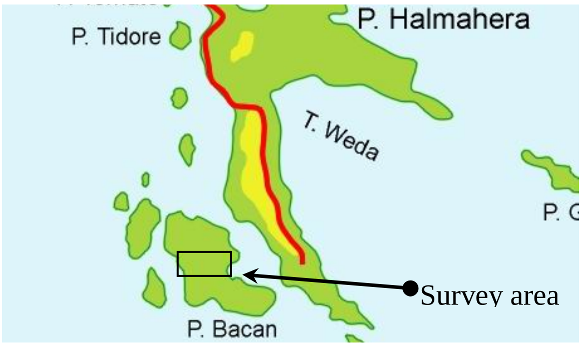

Figure 1. Location of study area.

2. TECTONIC FRAME WORK

The Indonesian archipelago is one of the most tectonically complex regions in the world; it is located at the three junctions of major plates: the Eurasian, the Indian, the Australian and the Phillipine plates (Figure 2). The Indian plate is moving to the north at about five cm/ year, and the Australian plate is moving to the north at about eight cm/ year. The Eurasian plate is stationary with respect to a static hotspot reference frame (Katili, 1973, Minster and Jordan, 1978; Nishimura and Suparka, 1990). Its geomorphologic features are characterized by an arc-trench system, island arc (Sunda arc and Banda arc), and trenches (Java trench and Timor trough). The island arc extends about 4,300 km from the western part to the eastern part of the Indonesian islands, and is made up of several main islands, beginning with Sumatera, Java, Bali, Lombok, Sumbawa, Sumba, Flores, Alor, Timor, and bending to the northern part at Sulawesi, the Maluku islands and Phillipine island.

The Sunda-Banda arc extends about 4,300 km from Sumatera Island at the west through the Kai islands at the east, and to Buru Island to the north. This arc is broadly divided into two contrasting sectors: the Greater Sunda sector in the west and the Lesser Sunda-Banda sector in the east. The Greater Sunda sector is an active continental margin, which is situated at the southern front of the broad continent Sundaland, that contains Indochina Peninsula, Malaya Peninsula, Sumatera Island, Sunda shelf, Java Island, Java Sea and Borneo Island and is mainly concealed under a shallow sea. A subducting plate that basically consists of oceanic crust allows a stable subduction regime into the Greater Sunda sector. The Lesser Sunda-Banda sector is an immature island arc, and the arc has marginal seas with oceanic crust behind it, such as the Flores Sea and Banda Sea.

The subducting plate that consists of the Australian continent and the Lesser Sunda-Banda arc has buoyant lithosphere that is underplating less buoyant lithosphere and resulting in unstable subduction or collision tectonics.

Eastern Indonesia is a place of interactions between the Pacific, Eurasian and Indian-Australian plate. It is not a simple triple junction and many micro plates are involved in this interaction, making it one of the most complicated tectonic regions on the globe. Numerous tectonic studies have been done in this region but many topics remain controversial (Hall and Wilson, 2000).

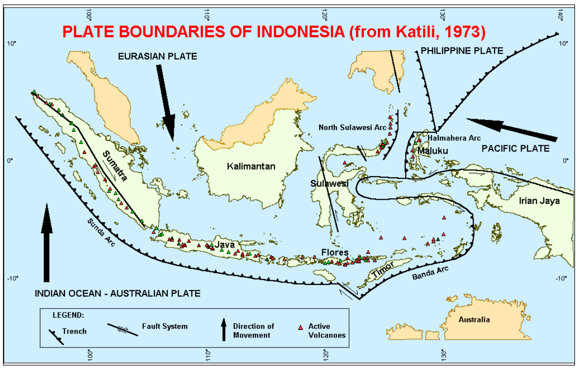

Figure 2. Tectonic map of the Indonesian archipelago (Katili, 1973).

3. GEOLOGICAL SETTING

The study area is comprised of Upper Cenozoic rocks, which are dominantly of mafic to intermediate calc-alkaline compositions and are unconformably underlain by the oldest of Mesozoic metamorphic rocks.

The youngest Quaternary lava is derived from Mt. Lansa, Songa and Bibinoi. The stratigraphic succession of rocks from the youngest to the oldest consists of Alluvium (Al), Colovium (Qcv), Coral reef (Qcr), Mt. Lansa Pyroclastic fall (Qfll), Mt. Songa Pyroclastic fall (Qfls), Mt. Songa Pyrolastic flow (Qfs), Mt. Songa Lava (Ols), Mt. Bibinoi Lava (Olb), Mt. Lansa Lava (Oll), limestone that contains molusca and foraminifera fossils (Qpl), Pele Pyroclastic flow (Qfp), Tawa Granit (Tmgt), Mt. Jere Lava (To-mlj), and a Metamorphic formation (Crm) that is exposed in the western part and northern part of the study area over Pele-Pele fault (Figure 3).

The geological structure of the area is indicated by horst and graben features, volcanic lineaments, craters, triangular facets, fault scarps, off-set rocks, slicken-sides, brecciated colovium sediment deposits, some geothermal surface manifestations and a spread of altered rocks.

Geothermal surface manifestations are exposed along the NE-SW trending Pele-Pele fault, which is associated to the N 330º E of the Recently dike of a volcanic lineament, and thermal surface features are exposed also along the NW-SE trending Wayaua fault (Figure 3). The geothermal surface manifestations include hot springs, fumaroles, mud pools, hot grounds, steaming grounds,, silica sinter and altered rock. Hot spring temperatures vary between 45.1-101.6^0 C, and have a pH of about 6,54-6,99 (neutral pH hot water conditions).

4. GEOCHEMISTRY OF HOT SPRINGS

The analyses of chemistry data from all hot water samples in Songa-Wayaua is shown in Table 1. A ternary diagram of Cl-SO_4-HCO_3 for a neutral-pH shows that all of the hot water was classified as Chloride type (Figure 4 A). A ternary diagram of Na/1000-K/100-√Mg (Figure 4 B) shows that hot water samples of Pelepele selatan and Padopado had reached partial equilibrium, and Pelepele utara lies on the border of partial equilibrium, where like Padopado and Wayaua, hot waters are included into immature type.

Basically, the relationship between hydrogen and oxygen isotopes based on the ratio diagram of ^{18}O and Deuteriumin was used to determine how to understand whether fluids are depleted or enriched of ^{18}O content respectively to magma degassing (Craig, 1961; Zainal Abidin, 1989). Five water samples have been analyzed (Table 2). All of them are hot springs, except Talaga Songa, which is taken from a crater lake.

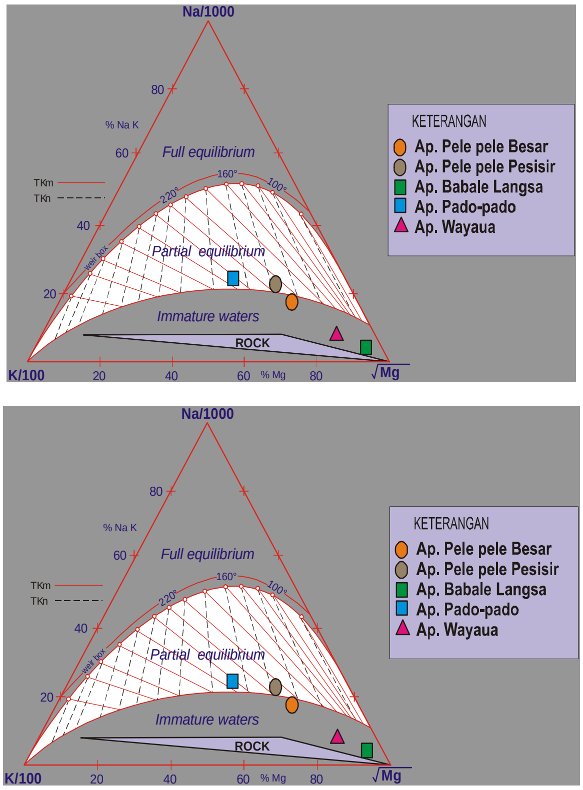

Figure 4A and 4B: Ternary diagram of Cl, SO_4 HCO_3 for hot spring waters type (up), and ternary diagram of Na,K,VMg for hot spring maturity (bottom). The ternary diagram are Adopted from Giggenbach, 1988.

The relationship between the hydrogen and oxygen isotopic ratios of thermal spring waters in Songa-Wayaua, shows that the Pele-pele Pesisir and Pele-pele Besar are enriched in ^{18}O, which means both of the hot fluids are presumably derived from a geothermal reservoir beneath area. In contrast, Pado-pado and Wayaua hot springs are close to the MWL (Figure 5). Both of these springs are depleted in ^{18}O content, meaning that both the hot fluids are possibly contaminated by a Meteoric water.

5. DISCUSSION

The hot springs of Tawa/ Padopado, Babale Lansa and Wayaua are located nearby the coast, and all of them are clearly contaminated by sea water, but Pele-pele hot springs are distal from the coast. The chloride characterization of hot waters, except for hot springs that are contaminated by sea water (Figure 4A), suggest that the thermal fluids beneath the area are presumably sourced from a geothermal reservoir beneath the surface geothermal manifestations.

Figure 4B shows that the Wayaua and Babale Lansa hot springs are immature waters, and the Mg content are small compared to Na and K (Tabel 2). This means that both of the hot springs are relatively contaminated by surface meteoric waters.

The Pelepele Besar/ utara and Pelepele Kecil/ selatan hot springs are manifested on land. They are characterized by a high Cloride type of hot water (Figure 4A), and they lie in partial equilibrium (Figure 4B). The isotopic ratio of thermal spring waters based on a diagram of ^{18}O vs Deuterium is enriched ^{18}O (Figure 5). This means that both Pele-pele hot springs are up-flow systems, and that both of them are basically derived from a deep water (Fournier, 1981; Mahon dan Ellis, 1977). The geothermal fluids are presumably derived from a reservoir beneath the hot springs area.

Pelepele hot spring water samples are ideal for estimating a geothermometer for the reservoir beneath Songa-Wayaua. Using Na/K of the Fournier equation (1981) and Giggenbach equation (1988), the geothermal reservoir temperature here varies between 221-254° C (high enthalpy, Table 2).

A heated water-dominated geothermal system normally contains a silica sinter (SiO_2) deposit as the surface feature, due to boiling water within a reservoir up-flow system, which manifests as small geysers and fumaroles. The presence of SiO_2 in the surface manifestation is probably also evidence of a geothermal reservoir in high P and T conditions. Presence of NaCl deposits in the Pelepele hot spring possibly has a hydrothermal fluid source of a brine-water reservoir..

Enrichment of ^{18}O on the isotopic ratio diagram of ^{18}O and Deuterium means that these hot fluids are presumably reflecting a magma degassing, and can be used for assessment of the condition of the geothermal reservoir underneath the area. The depleted content of ^{18}O are representative of hot fluids that have been contaminated by surface meteoric water.

6. CONCLUSION

The characterization of Pelepele hot spring is that it has normal pH (6,54-6,99), temperatures between 97,8-98,8° C, chloride-type waters, is in partial equilibrium, and is enriched in ^{18}O content. This means that the Pelepele hot springs is an up-flow geothermal system, and geothermal reservoir fluids are probably dominated by a water heated system. It is assumed that geothermal reservoir temperatures beneath the Pelepele hot springs vary between 221-254 °C (high enthalpy geothermal reservoir).

ACKNOWLEDGEMENT

We thank to our institution for permission to publsh this paper. We also express gratitude to the committee who gave the opportunity for editing and publishing the paper on this 5th Proceedings World Geothermal Congress (WGC) in Bali island, Indonesia 25-29 April 2010.

REFERENCES

API NEWS: Information And Comunication Of Indonesian Geothermal Asosiasi, No 3, volume 2 (2004).

Fournier, R.O.: Application Of Water Geochemistry Geothermal Exploration and Reservoir Engineering, Geothermal System: Principles and Case Histories. John Willey & Sons. New York (1981).

Giggenbach, W.F.: Geothermal Solute Equilibrium Deviation of Na-K-Mg-Ca Geo- Indicators, Geochemical Acta 52, (1988), 2749-2765.

Hall, R and Wilson, M.E.J.: Neogene sutures in eastern Indonesia. Journal of Asian Earth Sciences, 18 (2000), 781-808.

Hochstein, MP. Introduction To Geothermal Prospecting, Geothermal Institute, University of Auckland, New Zealand (1982).

Katili, J.A.: Geochronology of West Indonesia and Its Implications on Plate Tectonic, Tectonophysics, 19, (1973), 195-212.

Mahon, K and Ellis, A.J.: Chemistry and Geothermal System. Academic Press Inc. Orlando, (1977).

Minster, J.B and Jordan, T.H. Present-Day Plate Motions. Journal Geophysics. Research, 83, (1978), 5331-5354.

Mukhsin, et al: Inventory of Hot Springs in Bacan Island, North Maluku. Un-Publish Report (1976).

Nishimura, S,. And Suparka, S: Tectonics of East Indonesia. Tectonophysics, 181 (1990), 257-266.

CGR. Geological Report Of Songa-Wayaua area, South Halmahera, North Maluku. Un-Publish Report (2006).

------, Integrated of Geological, Geochemical and CGR. Geological Report Of Songa-Wayaua area, South Halmahera, North Maluku. Un-Publish Report (2006).

CGR.: Geological Report Of Songa-Wayaua area, South Halmahera, North Maluku. Un-Publish Report (2006).

Yasin .A, et al.: Geological Map of Bacan Island, North Maluku, and Scale 1: 250.000. CGS. Bandung (1975).

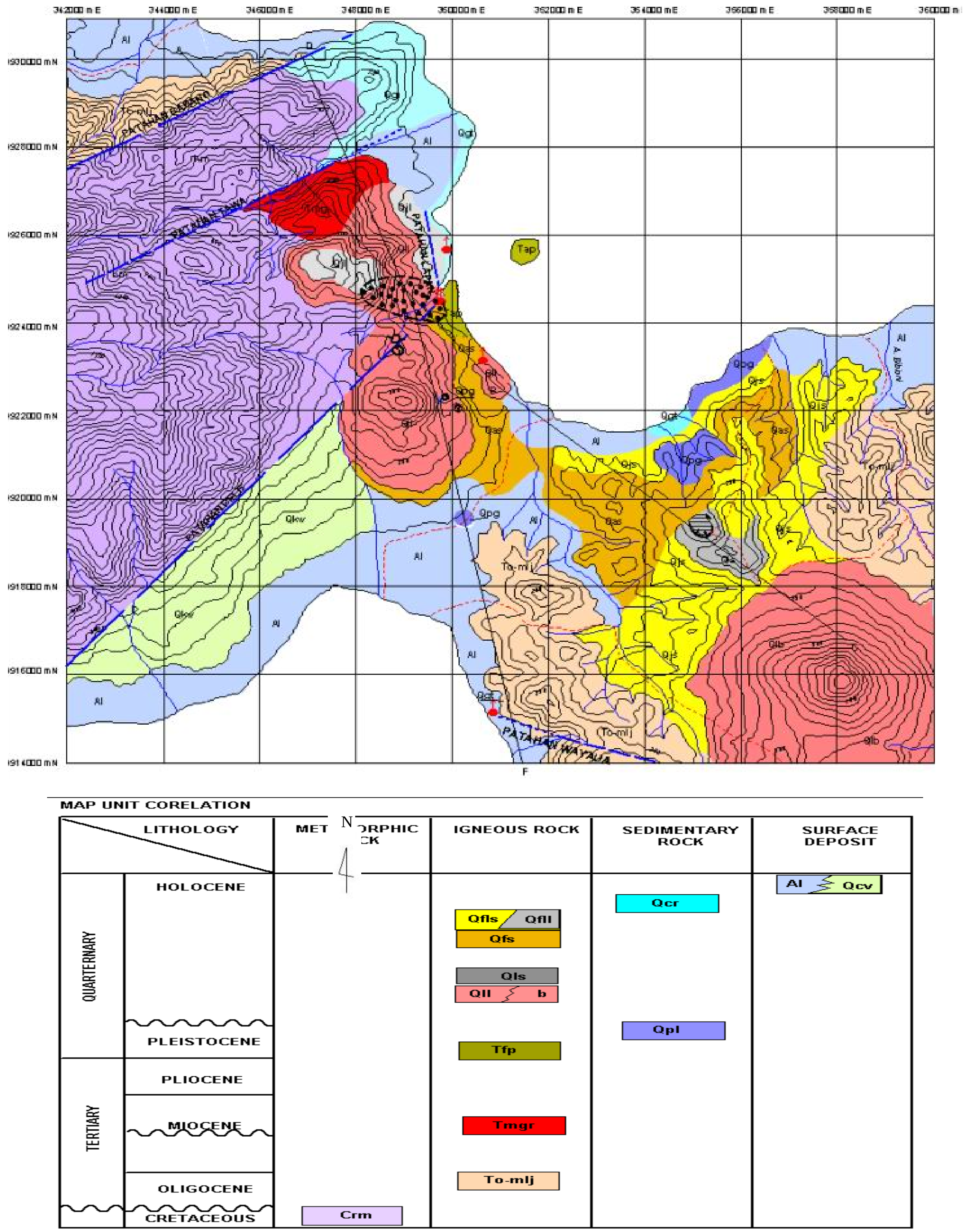

Figure 3: The geoflogical map and stratigraphy successions of the Songa-Wayaua area.

Table 1. Analyses Data of Hot Springs In Songa-Wayaua Area, Bacan Island–North Maluku Province.

Parameter	Units	Pelepele Besar/ utara	Pelepele Kecil/ selatan	Babale Langsa/ Lansa	Padopado/ Tawa	Wayaua
UTM Coordinate	X =	349576	349724	350657	349446	350995
	Y =	9924522	9924436	9923124	9926510	99149916
Elevation	m asl	2.0	5.0	3.0	2.0	3.0
Hot spring temperature	^oC	99.8	97.8	45.0.	91.3	69.2
Air temperature	^oC	29.6	28.4	36.0	28.9	30.1
Flow rate	Liter/second	0.5	1.0	0.5	1.0	0.5
pH	-	7.30	6.80	8.20	7.50	7.70
Na^+	ppm	3533.57	8558.40	489.68	2807.49	3388.35
K^+	ppm	458.00	898.00	23.90	388.00	151.60
Li^+	ppm	6.60	8.60	0.44	5.70	0.13
Ca^{++}	ppm	292.00	743.00	100.50	390.00	663.00
Mg^{++}	ppm	195.20	545.00	88.30	35.90	387.00
Fe^{++}	ppm	0.01	2.10	2.00	0.02	0.01
Mn^{++}	ppm	0.00	0.00	0.00	0.00	0.00
$CO_3^=$	ppm	0.00	0.00	0.00	0.00	0.00
As	ppm	1.40	1.60	0.00	0.80	0.20
NH_4^+	ppm	3.32	2.31	2.18	2.16	2.45
HCO_3	ppm	13.98	52.12	533.92	101.70	53.39
Cl^-	ppm	7253.25	16933.50	878.00	5280.63	7472.75
$SO_4^=$	ppm	448.54	1123.40	97.94	132.09	1069.49
B^{+++}	ppm	16.68	27.94	1.67	15.15	2.94
F^-	ppm	0.00	0.50	1.00	1.00	0.00
SiO_2	ppm	261.50	220.70	139.78	96.16	37.99
Conductivit y	uhos/cm	21178.00	48274.00	3021.00	16929.00	25204.00

Calculations of Geothermometer Hot Spring.

No	Hot Spring	Temperature (ºC)	SiO_2 (CC)	SiO_2 (AC)	Na-K Fournier (ºC)	Na-K Giggenbach (ºC)
1.	Pele pele Besar	99,8	228	184	2.40	254
2.	Pele pele Pesisir	97,8	215	174	221	236
3.	Pado pado	91,3	160	131	246	260

Table 2. The Isotope Data of ^{18}O and Deuterium from Hot Spring Samples In Songa-Wayaua, Bacan Island-North Maluku Province.

No.	Hot Spring and Lake	Temperature	Oxygen - 18	Deuterium
			(o/oo)	(o/oo)
1.	Pelepele Besar/ utara	99.8	-0.86	-34.7
2.	Pele-pele Pesisir/ selatan	97.8	+0.71	-15.0
3.	Tawa/ Pado pado	45.0	-3.11	-39.3
4.	Wayaua	69.2	-2.90	-22.8
5.	Tonga Lake	24.0	+0.11	-21.9