GEOCHEMISTRY OF HOT SPRING WATERS AT BAJAWA AREA, CENTRAL FLORES, NUSA TENGGARA TIMUR, INDONESIA

Masaaki Takahashi[1], Minoru Urai[1], Kasumi Yasukawa[1], Hirofumi Muraoka[1], Koji Matsuda[2], Hideo Akasako[2], Takehiro Koseki[3], Koichi Hisatani[4], Dedi Kusnadi[5], Bangbang Sulaeman[5] and Asnawir Nasution[5]
[1]Geological Survey of Japan, 1-3, Higashi 1-chome, Tsukuba, Ibaraki, 305-8567, Japan
[2]West Japan Engineering Consultants, Inc., 1-82, Watanabe-dori 2-chome, Chuo, Fukuoka, 810-0004, Japan
[3]Mitsubishi Materials Natural resources Development Corp., 6-23, Takanawa 4-chome, Minato, Tokyo, 108-0074, Japan
[4]New Energy and Industrial Technology Development Organization, Sunshine 60, 30F, 1-1, Higashi-Ikebukuro 3-chome, Toshima, Tokyo, 170-6030, Japan
[5]Volcanological Survey of Indonesia, Jl Diponegoro 57, Bandung, 40122, Indonesia

Key Words: Indonesia, Flores, geochemistry, hot spring, acid sulfate type

ABSTRACT

Thermal and cold spring water, and stream water were analyzed to understand geochemical characteristics of geothermal resources in Bajawa area, central Flores, eastern part of Nusa Tenggara Timur, Indonesia. In this area, three active volcanoes, Inerie, Inerika and Ebulobo, form an isosceles triangle with sides 26-27 kilometers (Eburobo-Inerie and Eburobo-Inerika) and 18 kilometers (Inerie-Inerika). More than 30 monogenetic volcanoes are distributed in the triangle. Only one fumarolic area exists at western outside of a crater rim of Wolo Bobo monogenetic volcanoes.

Seven prospective manifestation areas are situated near the volcanoes. Mataloko, Nage, Keli and Soka areas are in south to southeast of Bajawa city, and Mengeruda, Gou and Boba-Soa areas are in northeast of the city. Temperatures of thermal springs are > 90°C at Mataloko, >75°C at Nage, >70°C at Keli and 40-45°C at other areas. Geochemical characteristics of most thermal waters are acid sulfate type, except for Nage thermal waters, acid sulfate-chloride type.

Acid thermal springs are formed by mixing relatively low temperature volcanic gases containing hydrogen sulfide gases, interstitial waters in acid alternation zone and meteoric/subsurface/stream waters, whereas Nage thermal springs may originate from high temperature volcanic gases, which contain hydrogen chloride and sulfur dioxide.

Chemical and isotopic characteristics of dissolved sulfate show that Mataloko, Nage and Keli thermal waters are similar to those in Rank A volcanic geothermal resources areas in Japan, whereas Mengeruda, Gou and Soka thermal waters are related to those in Rank B volcanic geothermal resources areas in Japan. Thus it is deduced that geothermal resources of Mataloko, Nage and Keli areas are more prospective compared with those of Mengeruda, Gou and Soka areas.

1. INTRODUCTION

In the modern Indonesian state, the next groups of islands east of Bali are called Nusa Tenggara, the "Southeastern Islands", or the Lesser Sunda Islands. The islands of Nusa Tenggara are spanning a distance of 1,300 kilometers and lying 8 to 10 degrees south of the equator. They connect the Greater Sunda Islands in the west to the scattered islands of Maluku (the Banda Islands), and the large island of New Guinea (Irian Jaya) to the east, forming a central link in the 5,600 kilometer Indonesian archipelago (Fig.1). They form two distinct arcs. The long northern arc (Lombok, Sumbawa, Komodo, Flores, Lembata, Alor, etc.) is volcanic in origin. The islands of the shorter, southern arc (Sumba, Savu, Rote, Timor, etc.) are formed of raised coral reef limestone and sedimentary rocks. Most of these volcanic islands have the potential to provide geothermal energy. The Indonesian government is supporting the construction of small-scale geothermal power stations in those islands, Sembalun (Lombok, 5,000kW) and Ulumbu (Flores, 3,000kW), through the Rural Electrification Program (Fig.1). Two Japanese national research organizations, the Geological Survey of Japan (GSJ) and the New Energy and Industrial Technology Development Organization (NEDO) started an international cooperation program between Indonesia and Japan, named the "Research Cooperation Project on Exploration of Small-scale Geothermal Resources in the eastern part of Indonesia (ESSEI)". Participating organizations are the Directorate General of Geology and Mineral Resources of the Mines and Energy of the Republic of Indonesia (DGGMR), NEDO and GSJ. The Volcanological Survey of Indonesia (VSI) and the Indonesian State Electricity Company (PLN) also participate in this project under coordination by DGGMR. In this paper, we report geochemical characteristics of hot springs at Bajawa area, central Flores, where is selected for the ESSEI project.

2. STUDY AREA

2.1 Volcanoes

Bajawa area is one of the most prospective geothermal fields in Flores. Three large-scale active volcanoes, Inerie, Inelika and Ebulobo, form an isosceles triangle in this area (Fig.1). The distances between Eburobo and other two volcanoes are 26-27 kilometers, whereas the length between Inerie and Inelika is 18 kilometers. Inerika and Ebulobo volcanoes have records for historical eruption, and have fumaroles at their summits (Simkin and Siebert, 1994). More than 30 monogenetic volcanoes also distribute within the triangle. Muraoka et al. (1999) classified those monogenetic volcanoes into 4 groups, Bajawa, Mataloko, Wolo Bobo and Inelika. Only one fumarolic area exists at western outside of a crater rim of Wolo Bobo monogenetic volcanoes (1400m above sea level). The steaming field is 100m in diameter. Temperature of fumarolic gas is boiling point. The alternation zone is 300m in diameter and forms a landslide open to the western foot (Fig.1).

2.2 Thermal springs

Thermal springs of Bajawa area cluster into five groups, Mataloko, Nage-Keli Tiworiwu-Wolo Bobo, Soka, Mengeruda and Gou-Boba Soa (Fig.1).

Mataloko area

Mataloko area is 10km southeast of Bajawa city and 1000m above sea level near the southern foot of a small cone volcano, Wolo Balu, one of Mataloko monogenetic volcanoes. Thermal waters more than 90°C are discharged from the steaming ground of 150m in diameter. The flow rate of those thermal springs is, however, very small. The acid alternation zone is extent to the area of 300m by 1000m elongated along the Wae Belli and the Wae Luja rivers.

Nage-Keli Tiworiwu-Wolo Bobo area

Nage area is 8km southwest of Bajawa city and 520m above sea level, where is the bottom of a small basin. The steaming field is extent to the area of 200m by 500m elongated along the Wae Bana river, and thermal waters more than 75°C gush out from three or more springs. Total flow rate of those hot springs is very large, more than 30tons/min. The acid alternation zone is extent to the area of 500m by 1500m up to the surrounding wall of the basin.

Keli Tiworiwu area is 2km northwest of Nage area and 850m above sea level, where is southern end of Wolo Bobo monogenetic volcanoes. Thermal waters more than 70°C flow out from two or more springs. The flow rate of thermal springs is middle, 2-3 tons/min.

In Bobo (Wae Putih=White River) area, 1km north of Keli Tiworiwu area and 2km southeast of fumarolic area of Wolo Bobo momogenetic volcanoes as mentioned above, low temperature fumarolic gases (about 25°C) ooze out from the bottom of a ravine.

Soka area

Soka area is 10km south of Mataloko area and 90m above sea level near the southern coast. Thermal water more than 45°C is discharged from a pond. The flow rate of the spring is middle, about 3-4 tons/min. Muraoka et al. (1999) categorized the closest volcanoes to the Soka thermal spring into Bajawa monogenetic volcanoes, which is the oldest monogenetic volcanoes in Bajawa area.

Mengeruda area

Mengeruda area is 18km northeast of Bajawa city and 310m above sea level. Thermal waters about 40°C gash out from three or more springs (Mengeruda, Wae Bana and Piga). Total flow rate of those hot springs is very large, more than 30 tons/min. Muraoka et al. (1999) noted Mengeruda thermal springs are located at the easten end of Lahar deposits of Inerika monogenetic volcanoes. Thermal waters may flow laterally about 12km from Inerika monogenetic volcanoes to Mengeruda area.

Gou-Boba Soa (Tukapela) area

Gou-Boba Soa area is 6km north-northeast of Bajawa city and 800m above sea level. Thermal waters more than 45°C flow out from three or more springs. Total flow rate of those hot springs is large. This area is so close to Inerika monogenetic volcanoes.

2.3 Sampling and Analytical Methods

Locality map of sampling points of thermal and cold springs, and stream waters is shown in Fig.1. Samples were filtrated with 0.20-micrometer cellulose acetate membrane filters immediately to avoid sample oxidation by microbial activities. Temperature, pH, Electro-Conductivity and Redox Potential of them were also measured in place. Flow rates of springs and streams were measured by the modified velocity-area method.

Chemical and isotopic analyses are conducted by the following methods.
Bicarbonate: Methyl-Red alkalinity method
Free carbon dioxide: Phenol-Phthalein acidity method
Total iron: Ferro Ver method
Hydrogen Sulfide: Methylene blue method
Aluminum: Aluminon method
Other cations and anions: The Yokogawa IC-7000RP Ion Chromatography are utilized for measuring concentrations of cations (lithium, sodium, ammonium, potassium, magnesium and calcium) and anions (fluoride, chloride, bromide, nitrite, nitrate, phosphate and sulfate). An eluent for cation analyses is an 18mM methanesulfonic acid solution. For anion analyses, an eluent is a 3.0mM sodium carbonate solution and a scavenger is a 15mM sulfuric acid solution.
Sulfur isotopic ratios of dissolved sulfate: A Finnigan-MAT DELTA-E Mass Spectrometer is utilized for analyzing sulfur isotopic ratios of dissolved sulfate. Dissolved sulfate is precipitated as barium sulfate. Barium sulfate is directly converted to sulfur dioxide with use of vanadium pentoxide (Ueda et al., 1991).

3. RESULTS and DISCUSSIONS

Results of chemical and isotopic analyses are shown in Table 1. The relation between dissolved chloride and sulfate of thermal and cold springs, and stream waters in Bajawa area is shown in Fig.2. Geochemical characteristics of most thermal waters from Mataloko, Keli, Soka, Mengeruda and Gou-Boba Soa areas are acid sulfate type, except for Nage thermal waters which is classified into acid sulfate-chloride type.

Acid sulfate type thermal waters in Bajawa area are plotted in the diagram among type "F/G" and type "H" source waters, and meteoric waters. Noda and Takahashi (1992) described that the type "F/G" source water originates from oxidation of hydrogen sulfide in relatively low temperature volcanic gases and the type "H" source water is in acid alternation zone. Thus, most acid thermal waters in Bajawa area is formed by mixing relatively low temperature volcanic gases containing hydrogen sulfide gases, interstitial waters in acid alternation zone and meteoric/subsurface/stream waters.

Only Nage thermal waters, which show acid sulfate-chloride type, are plotted among type "H", type "A" and "V"-letter noted thermal waters. Takahashi et al. (1998) found that chemical compositions of interstitial waters, which centrifuged from altered clay in acid alternation zone and from volcanic ash of the 1998 phreatic eruption of Akita-Yakeyama volcano, northeast Japan, are plotted in the diagram between the type "H" source water and the "V"-letter-noted water. Geochemical characteristics of interstitial waters are sulfate to sulfate-chloride type, and fluctuation patterns of dissolved sulfate and chloride ion concentrations are so similar to those of acid sulfate type thermal waters (Fig.2). Thus, only Nage thermal water may originate from high temperature volcanic gases, which contain hydrogen chloride and sulfur dioxide.

The relation between dissolved chloride and sulfate of acid thermal springs in Sengan area, Akita Prefecture, northeast Japan is also shown in Fig.2. Both thermal springs of acid sulfate type and chloride type are in Sengan area. Acid chloride type thermal waters in Sengan area are distributed in the diagram near the type "A" thermal water, which originates from high temperature volcanic gases containing hydrogen chloride and sulfur dioxide (Noda and Takahashi, 1992). As shown in Fig.2, there are no hot springs of acid chloride type in Bajawa area.

The relation between dissolved sulfate and its sulfur isotopic ratio of thermal and cold springs, and stream waters in Bajawa area is shown in Fig.3. They are plotted in the V-letter shape in the diagram. The relation of volcanic thermal waters, seawater, thermal waters from greentuff regions and granitic provinces in Japan is also shown in Fig.3. They are distributed in the V-letter shape in the diagram, too.

In Bajawa area, Mataloko thermal waters are plotted in left side of the V-letter. Nage and Keli thermal waters are distributed in both sides of the V-letter. Several sulfur isotopic studies (Hoefs, 1987) show volcanic thermal waters originated from oxidation of hydrogen sulfide in volcanic gases lay left side of the V-letter in the diagram. NEDO (1991) noted thermal springs around Akita Komagatake volcano, southern part of Sengan area, are plotted in both sides of V-letter in the diagram (Nyuto and Kakkonda areas). These areas are classified into Rank A volcanic geothermal resources where is hot spring >90°C. Thus, these thermal waters are affected from volcanic activities and are originated from oxidation of hydrogen sulfide and/or sulfur dioxide in volcanic gases.

On the other hand, Mengeruda, Gou and Soka thermal waters, however, are plotted only in right side of V-letter. Several sulfur isotopic studies also describe geothermal fluids from power plants, volcanic thermal waters originated from self reduction-oxidation reaction of sulfur dioxide in high temperature volcanic gases, those from Rank B volcanic geothermal resources where is no hot springs >90°C, seawater, thermal waters from greentuff regions and granitic provinces, lay right side of the V-letter in the diagram. Meteoric waters and stream/river waters lay bottom of the V-letter, and have 0 to +10‰ sulfur isotopic ratios. Plotted region of Mengeruda, Gou and Soka thermal waters is close to those of Naeba, Yunosawa and Matsushiro, where are classified into Rank B volcanic geothermal resources. Thus, Mengeruda, Gou and Soka geothermal resources may not be so prospective compared with Mataloko, Nage and Keli geothermal resources.

4. CONCLUSIONS

Thermal and cold spring waters and stream water were analyzed to understand geochemical characteristics of geothermal resources in Bajawa area, central Flores, eastern part of Nusa Tenggara Timur, Indonesia. Seven prospective manifestation areas are situated near the volcanoes. Mataloko, Nage, Keli and Soka areas are in south to southeast of Bajawa city, and Mengeruda, Gou and Boba-Soa areas are in northeast of the city. Temperatures of thermal springs are > 90°C at Mataloko, >75°C at Nage, >70°C at Keli and 40-45°C at other areas. Geochemical characteristics of most thermal waters are acid sulfate type, except for Nage thermal waters, acid sulfate-chloride type.

Acid thermal springs are formed by mixing relatively low temperature volcanic gases containing hydrogen sulfide gases, interstitial waters in acid alternation zone and meteoric/subsurface/stream waters, whereas Nage thermal springs may originate from high temperature volcanic gases, which contain hydrogen chloride and sulfur dioxide.

Chemical and isotopic characteristics of dissolved sulfate show that Mataloko, Nage and Keli thermal waters are similar to those in Rank A volcanic geothermal resources areas in Japan, whereas Mengeruda, Gou and Soka thermal waters are related to those in Rank B volcanic geothermal resources areas in Japan. Thus it is deduced that geothermal resources of Mataloko, Nage and Keli areas are more prospective compared with those of Mengeruda, Gou and Soka areas.

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Table 1. The result of chemical anbalyses for thermal and cold spring waters, and stream waters

sample		date & sample number	flow rate	altitude	Temp.	pH	EC	ORP	Na	K	Ca
			(t/min)	(m)	(C)		(mS/cm)	(mV)	(ppm)	(ppm)	(ppm)
1	Nage-1	9.8E+07	10.	537	79.4	2.09	53000	63	150.	37.9	130.
2	Nage-2	9.8E+07	10.	525	73.2	2.16	48000	22	154.	36.7	140.
3	Nage-3	9.8E+07	10.	512	72.0	2.17	47000	11	136.	31.9	114.
4	Bena(Wae Wewu)	9.8E+07	M	812	36.2	6.49	1540	52	63.2	20.6	182.
5	Mataloko-upper	9.8E+07	0.	1000	88.3	2.45	2500	176	27.0	5.86	61.0
	Mataloko-upper	9.7E+07		1000	94.6	3.00	1550		43.7	3.10	107.
6	Stream of Mataloko	9.8E+07	L	1000	26.2	7.06	240	25	11.2	3.08	24.1
7	Mataloko-lower	9.8E+07	0.	1000	84.9	2.76	1190	-12	18.3	8.61	29.3
	Mataloko-lower	9.7E+07		1000	92.0	3.74	490		17.1	5.10	17.7
8	Wae Ya (spring)	9.8E+07	LL	1100	24.2	6.50	230	207	10.0	2.72	24.3
9	Liba	9.8E+07	S	1100	34.8	6.66	430	127	16.4	5.32	42.2
10	Keli Tiworiwu-1	9.8E+07	0.9	840	52.8	3.59	1480	-118	69.9	29.0	147.
11	Keli Tiworiwu-2	9.8E+07	0.9	850	72.1	5.97	2100	-256	115.6	61.5	238.
12	Stream of Keli Tiwo	9.8E+07	S	850	25.4	6.81	410	137	15.5	2.91	41.5
13	Mengeruda	9.8E+07	24.	312	41.6	2.89	1780	422	53.5	15.9	116.
	Mengeruda	9.7E+07		312	41.1	2.97	1740		50.4	16.1	115.
14	Wae Bana	9.8E+07	5.	362	37.2	2.85	1790	476	47.8	14.1	123.
15	Gou (Wae Mega)	9.8E+07	L	800	35.2	3.59	1100	-106	29.6	6.43	130.
16	Gou (Wae Bana Wat	9.8E+07	S	800	40.5	2.47	2900	-28	52.1	12.4	160.
17	Tukapela (Boba-Soa	9.8E+07	S	775	47.7	1.93	7300	70	83.5	31.4	208.
18	Paidae (Wae Wutu)	9.8E+07	0.12	350	43.4	6.87	460	2	28.1	7.11	43.4
19	Soka (Wae Pana)	9.8E+07	3.6	90	45.7	5.35	850	-182	38.8	8.08	134.
20	Wae Veni	9.8E+07	0.01	110	27.8	7.06	196	120	12.8	2.24	20.0
22	Wae Roa	9.8E+07	13.	1025	22.8	7.35	230	113	10.4	3.29	25.5
23	Bobo (Wae Putih)	9.8E+07	0.	1050	21.6	2.73	1420	-60	21.5	4.42	51.1
	Bobo (Wae Putih)	9.7E+07		1050	21.0	2.73	1700		26.4	3.90	80.3
24	Wae Guru	9.8E+07	0.07	900	25.3	6.01	600	192	20.3	4.94	73.1
25	Dhokimatawae	9.8E+07	0.86	550	35.4	6.81	340	152	19.3	4.03	32.9
26	Mukufoka	9.8E+07	0.27	1275	19.4	6.70	180	149	8.98	2.48	19.8
27	Wae Woki	9.8E+07	0.006	1162	22.1	6.66	260	152	10.7	1.69	29.8
28	Wae Lapo	9.8E+07	0.9	100	28.1	7.16	270	189	14.8	1.50	28.7
29	Bereweke	9.8E+07	5.	430	27.0	6.95	240	184	12.2	2.59	25.4
30	Radabata (Wae Ba)	9.8E+07	0.003	1160	20.8	7.30	290	182	13.1	16.3	29.4
31	Nage (spring)	9.8E+07	0.001	462	23.5	6.81	250	173	12.4	2.98	24.8
32	Wae Aru	9.8E+07	0.06	610	23.3	6.93	270	148	16.2	2.46	23.8

sample		Mg	NH_4	Fe	Al	Cl	SO_4	F	NO_3	H_2S	$d^{34}S$
		(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(ppm)	(permil)
1	Nage-1	53.1	2.39	13.4	24.70	485.	770.	8.93		1.55	13.2
2	Nage-2	49.6	2.98	15.8	22.45	424.	730.	4.92		1.25	10.6
3	Nage-3	49.1	2.73	14.0	25.45	414.	707.	7.01		2.00	10.8
4	Bena(Wae Wewu)	68.2	0.18	0.00	-	42.1	520.	0.27	3.61	-	14.0
5	Mataloko-upper	28.6	4.36	46.0	34.65	8.21	807.	0.43		0.02	-1.3
	Mataloko-upper	31.1	8.72			2.60	741.	0.29	0.15		
6	Stream of Mataloko	9.02		0.02	-	3.35	6.14	0.24		-	0.8
7	Mataloko-lower	17.0	1.04	5.6	1.99	4.31	303.	0.16	0.17	1.45	-0.9
	Mataloko-lower	8.7	2.10			3.70	135.	0.07	0.42		
8	Wae Ya (spring)	9.08	0.65	0.01	-	3.03	4.35	0.38	3.76	-	-0.2
9	Liba	22.6	0.43	0.08	-	3.12	13.8	0.25		-	-1.3
10	Keli Tiworiwu-1	50.4	0.41	0.04	2.67	48.6	637.	0.71		19.0	5.0
11	Keli Tiworiwu-2	77.7	0.25	0.00	0.36	103.4	929.	0.83		28.5	10.9
12	Stream of Keli Tiwo	14.6	0.03	0.03	-	3.67	131.	0.18	6.05	-	4.3
13	Mengeruda	33.1	0.21	17.8		98.1	631.	3.88	0.25	-	13.8
	Mengeruda	34.4				84.9	592.	3.62	0.27		
14	Wae Bana	33.7	0.23	15.2		90.8	625.	3.71		-	13.7
15	Gou (Wae Mega)	26.2	0.19	0.92		28.6	461.	1.56		6.10	10.1
16	Gou (Wae Bana Wat	39.7	0.42	6.8		128.4	891.	3.97		12.3	13.9
17	Tukapela (Boba-Soa	53.9	0.93	24.5		383.	####	10.8		3.35	16.8
18	Paidae (Wae Wutu)	16.8	0.53	0.00		4.61	24.9	2.02	1.02	-	8.1
19	Soka (Wae Pana)	14.0		0.02		10.0	407.	0.92		4.70	9.7
20	Wae Veni	5.28	0.41	0.01		9.00	19.0	0.12	1.40	-	5.6
22	Wae Roa	8.64		0.02		3.39	23.0	0.46	3.58	-	7.0
23	Bobo (Wae Putih)	19.7	0.39	3.15		4.95	512.	0.47		11.5	-3.4
	Bobo (Wae Putih)	30.3				4.90	692.	1.17			
24	Wae Guru	20.7	0.89	0.00		4.04	191.	0.39	0.81	-	6.6
25	Dhokimatawae	13.6	0.49	0.02		3.69	8.84	0.22	0.78	-	3.0
26	Mukufoka	7.16	0.12	0.03		3.08	10.3	0.38	2.55	-	4.7
27	Wae Woki	10.4	0.24	0.01		4.10	1.61	0.22	2.81	-	8.4
28	Wae Lapo	9.60		0.00		7.15	5.94	0.25	2.58	-	5.9
29	Bereweke	9.00		0.00		4.17	6.60	0.15	2.08	-	5.8
30	Radabata (Wae Ba)	9.48	0.04	0.00		3.15	3.50	0.21		-	7.4
31	Nage (spring)	8.81		0.03		3.27	76.3	0.40	0.76	-	-3.8
32	Wae Aru	7.73		0.10		4.37	91.1	0.15	0.23	-	-4.2

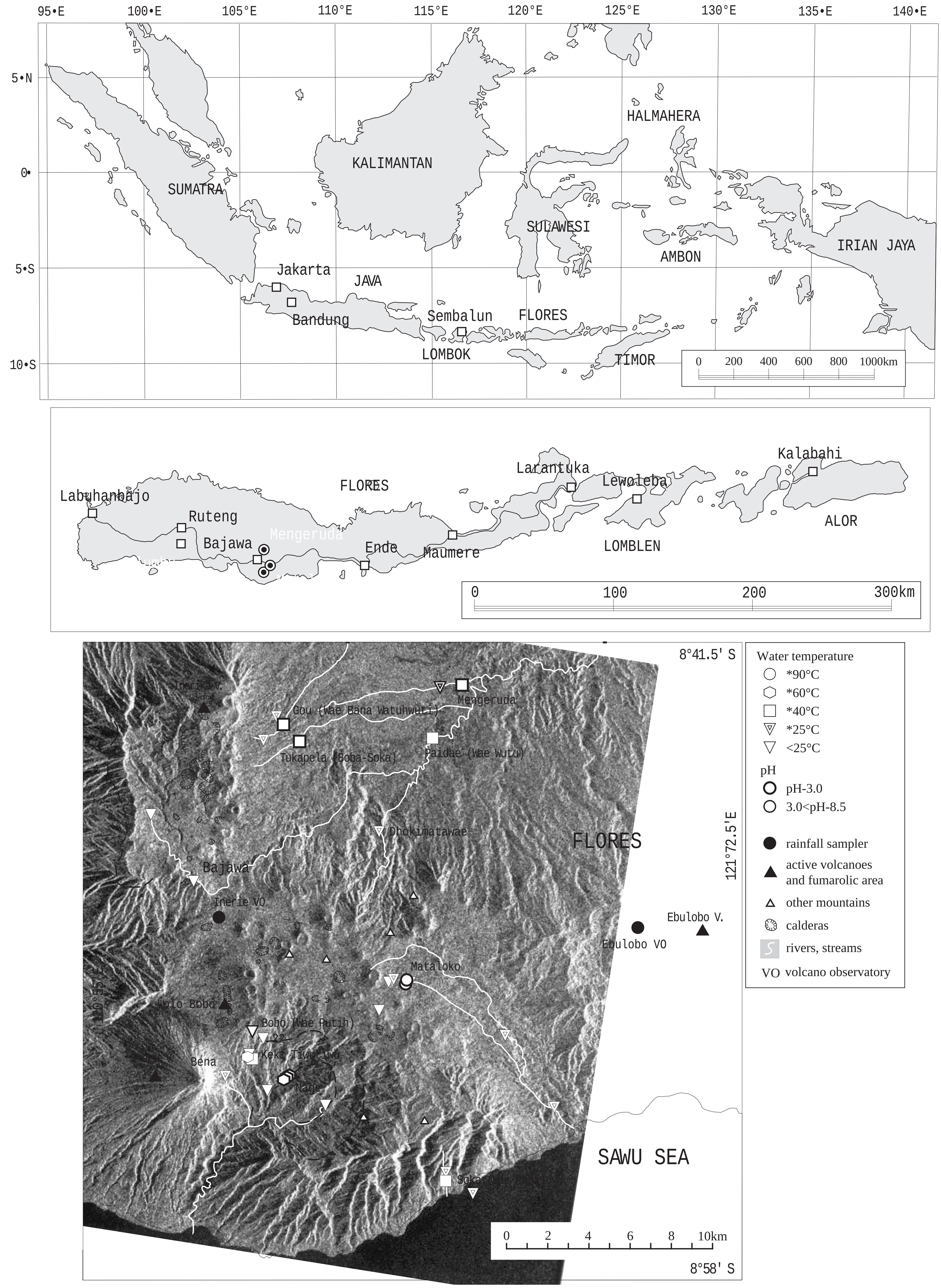

Fig.1 Locality map of sampling points of thermal and cold spring waters, and stream waters in Flores island. Maps of Indonesia (Top) and eastern part of Nusa Tenggara (Middle) are also shown.

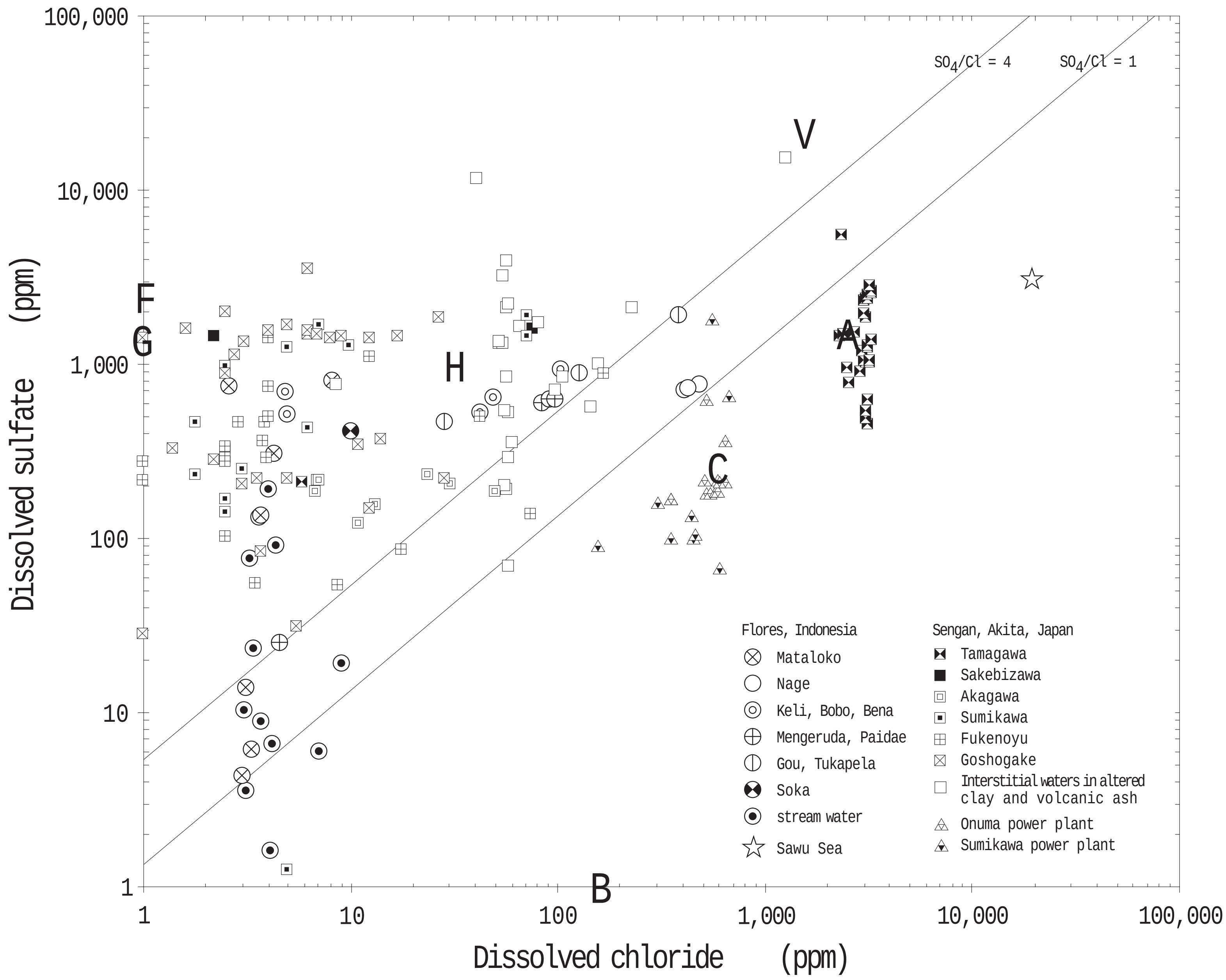

Fig.2 The relation between dissolved chloride and sulfate of thermal springs in Flores, Indonesia and in Sengan, Japan. Large letters are from the classification scheme of Noda and Takahashi (1992).

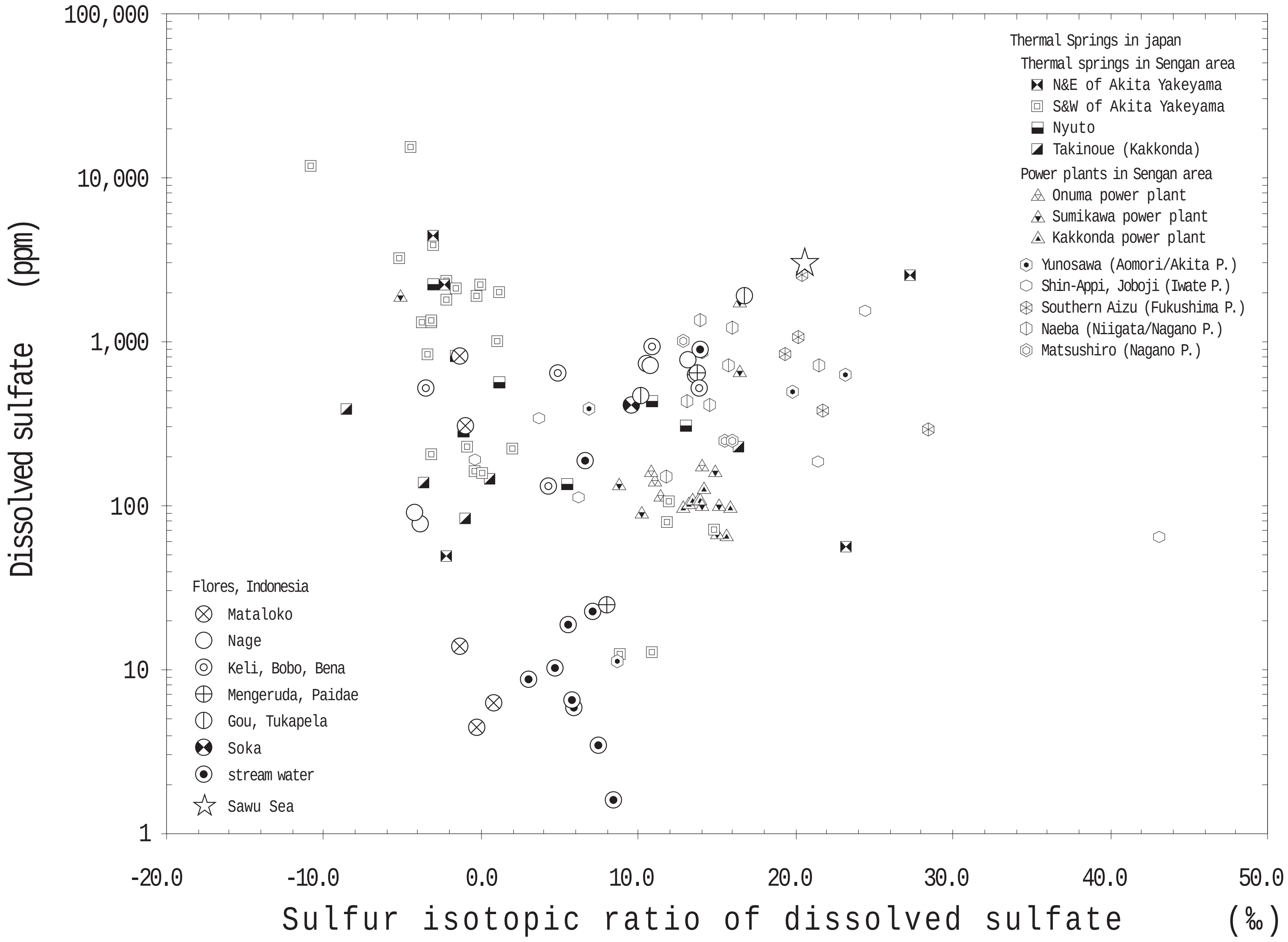

Fig.3 The relation between dissolved sulfate and its sulfur isotopic ratio of thermal waters in Flores, Indonesia and several types of volcanic thermal waters in Japan.