GEOCHEMICAL STUDY ON HOT SPRING WATER IN KOTAMOBAGU GEOTHERMAL FIELD, NORTH SULAWESI, INDONESIA

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PROCEEDINGS, Thirty-Sixth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, January 31 - February 2, 2011
SGP-TR-191

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ABSTRACT

Sixteen water samples were collected from thermal spring, river, and shallow well in Kotamobagu geothermal field. Temperature of waters, Electronic Conductivity (EC) and pH were measured on site and chemical analysis in laboratory. The analyzed results were plotted on Cl-SO_4-HCO_3 ternary diagram, and characterized into form groups of SO_4, Cl-SO_4, and HCO_3 From Na-K-Mg plot, one hot spring water is determined as a partially equilibrium water, and all other samples are immature waters. The geochemical temperature was calculated by quartz no steam loss is about 160°C. The maximum temperature with Na-K-Ca-Mg geothermometer is estimated in a range 180-220°C with the maximum of 260°C. A conceptual model of hydrothermal system of Kotamobagu was developed.

INTRODUCTION

Kotamobagu geothermal field locates in North Sulawesi Province, Indonesia, 200 km to the southwest of Manado city, capital of the province (Fig.1). The field has been proved to be one of the geothermal prospects in Indonesia (Hochstein and Sudarman, 2008). PT. Pertamina Geothermal Energy (PT.PGE) conducted reconnaissance and feasibility studies in Kotamobagu and concluded that the field has high potential for power generation. The results, however, have not been reported in detail in public nor has a conceptual model of the field not been developed yet. Thus, we have carried out geochemical survey in this area and tried to develop a conceptual model of hydrothermal system in Kotamobagu.

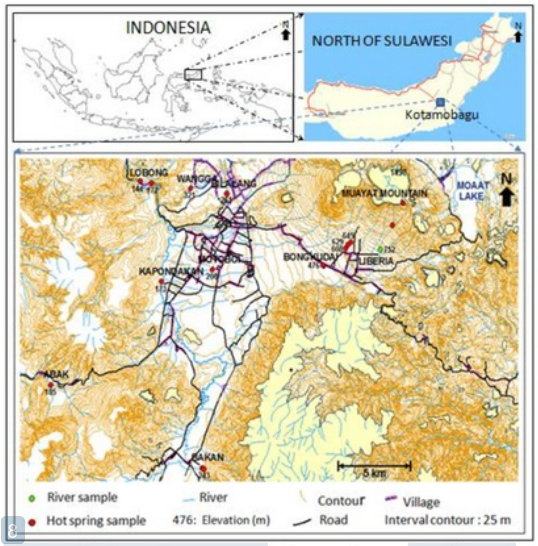

Figure 1: Location map of Kotamobagu geothermal field.

GEOLOGY

Geological Setting

Geological map of Kotamobagu is shown in Fig.2. The area is covered by the Tertiary and the Quaternary rocks. The Tertiary sedimentary rocks consist of shale and sandstone with intercalation of limestone and chert, and are overlain by the Tertiary and Quaternary volcanic rocks. The Tertiary rocks are limestone and chert, and are overlain by the Tertiary and Quaternary volcanic rocks. The Tertiary volcanic rocks are the products of Old volcano and consist of breccia, tuff, andesitic lava, dacite and rhyolite to form Mt. Simut and Mt. Lemibut located to the north of Mt. Muayat. The Quaternary volcanic rocks consist of the Old and Young Ambang volcanic. Tuff-pumice and andesitic-breccia are the products of the Old Ambang Volcano. The Young Ambang volcanic rocks consist of andesitic lava and magma breccia are overlain Mt. Muayat, Mt. Banga, and Mt. Ambang asymmetrically.

Geological Structure

Faults in Kotamobagu have directions northwest to southeast, northeast to southwest and west to east as shown in Fig. 2. In this figure, the fault is indicated with solid line and the inferred fault with dashed line. A fault system with a direction of west to east which is crossing the sedimentary rocks controls the appearance of hot springs at Pusian and Bakan, located to the southwest and south of Kotamobagu. Another fault system with a direction of northwest to southeast controls the presence of hot springs at Lobong in the east of Kotamobagu (PT.PGE, 2005). Fumaroles on top of Mt. Muayat located in the east of Kotamobagu have a high temperature 102.7°C and are associated with faults running northeast to southwest (PT.PGE, 2005). This fault system also controls an appearance of hot spring at Liberia village as well as Bongkudai village.

SAMPLING LOCATION

Water samples at sixteen locations were collected from hot spring and shallow wells in the area 20 km NS and 30 km EW of Kotamobagu. As shown in Fig 2, elevation of sampling site ranges from 144m up to 1438 m. Sample MUAH-16 was collected at a natural discharge at an elevation 1438 m near fumaroles on top of Mt. Muayat. The number of the sample ID corresponds to that in Fig.2. Two samples were collected from shallow wells; LOBH-9 from the well of 20 m depth and MOTH-12 from that of 80m. The river water was collected on the slope of Mt. Muayat; LIBR-4. Hot springs at Bakan (BAKH-6 and BAKH-7) and Abak (ABAH-8) are located the south eastern end of Kotamobagu, about 20 km south east of Mt. Muayat. Samples at Liberia village (LIBH-1, LIBH-2, LIBH-3) were collected in the paddy field. Natural discharges on river bank or river floor were collected at Abak (ABAH-8), Kapondakan (KAPH-11), Lobong (LOBH-10) and Bongkudai (BONH-6).

SAMPLING METHOD AND ANALYSIS METHODS

All samples were collected in 250 ml polythene bottle after filtrating by 0.45μm membrane filter Water temperature, Electric Conductivity (EC) and pH were measured on site by portable instruments. The anion (F, Cl, NO_3, SO_4,) and cation (Na, NH_4, K, Mg, Ca) were analyzed using ion chromatography system (Dionex ICS-90). Bicarbonate (HCO_3^-) was measured using a titration method. Concentration SiO_2 and Fe total were measured by spectrophotometer (Hitachi U 1800) using the molybdate yellow method.

RESULT AND DISCUSSION

Water Chemistry

Analyzed results are summarized in Table 1. Samples of LIBR-4, MUAH-15, MUAH-16 show very acidic as low as pH about 2, and high conductivities in the range from 2860 to 5670μS/cm. Other samples have pH of relatively neutral about 6-7. Samples are divided into two groups with respect to EC; 240-698 μS/cm for (LIBH-1, LIBH-2, LIBH-3, BONH-5, BILH-13, WANH-14, LOBH-9). and 1376-3210 μS/cm (BAKH-6, BAKH -7, ABAH-8, LOBH-10, KAPH-11, MOTH-12). Temperature of hot spring waters shows relatively high, 70-93°C, for BAKH-6, BAKH-7, ABAH-8, LOBH-10, KAPH-11. These hot springs discharge at the margin of Kotamobagu (Fig.2) whereas other hot springs in closer locations to Mt. Muayat where active fumaroles present and their temperature are relatively low temperature; 37-52°C.

Ternary diagram is plotted for Cl-SO_4-HCO_3 in Fig. 3. From this figure, we can say there are three type of water;

1. SO_4 type (MUAH-16),
2. Cl-SO_4 (LIBR-4 and MUAH-15),
3. HCO_3 (LIBH-1, LIBH-2, LIBH-3, BONH-5, BILH-13, WANH-14).

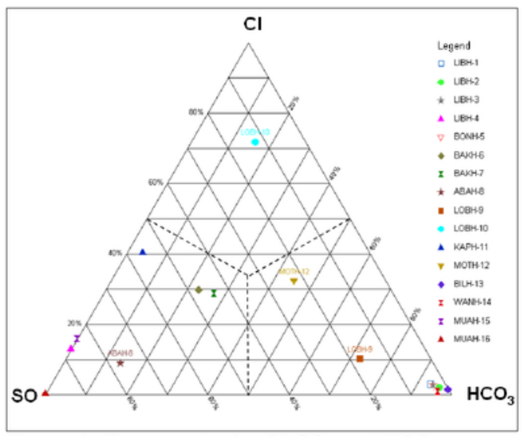

Figure 3: Ternary plot for Cl, SO_4 and HCO_3

MUAH-16 is plotted on the corner of SO_4 indicating of steam heated water. As this sample was collected near fumaroles at the top of Mt. Muayat, H_2S gas released from deep CL-SO_4 water by boiling at depth react with oxygen rich near surface water and form SO_4 rich acidic water. At lower elevation of Mt. Muayat, there are natural discharges from the surface of cliff where MUAH-15 was collected. This sample is of Cl-SO_4 type, and this discharge may be directly delivered from a lateral flow of deep Cl-SO_4 water. Furthermore, this sample is plotted between MUAH-16 and MUAH-15 on the SO_4-Cl axis. This implies the river water is a mixture of waters of MUAH-16 and MUAH-15. Samples collected at lower elevations on the southern slope of Mt. Muayat are plotted on the corner of HCO_3 and are identified as of HCO_3 type.

Bicarbonate water may occur near the surface in geothermal areas where steam containing carbon dioxide condenses into an aquifer. Under stagnant conditions, reaction with rocks produces neutral pH and discharges as hot springs such as in Liberia, Bongkudai, Bilalang and Wangga (LIBH-1, LIBH-2, LIBH-3, BONH-5, BILH-13 and WANH-14).

High concentration of Cl in Lobong, LOBH-10, may be caused by geothermal waters from the depth flow through a fault where interaction with sedimentary rocks occurred before discharging as hot spring.

Geothermometer

Quartz and Na-K-Ca-Mg geothermometers were used for temperature calculations; Quartz no steam loss and α-Cristobalite (Fournier, 1977), and Na-K-Ca-Mg with Magnesium corrected (Fournier and Potter II, 1979).

Results of geothermometer computation show the minimum temperature by quartz no steam loss is about 160°C (Fig.4). The temperatures with the Na-K-Ca-Mg geothermometer are calculated in a range from 180 to 220°C for LIBH-1, LIBH-2, LIBH-3, BONH-5 and about 260°C for MOTH-12.

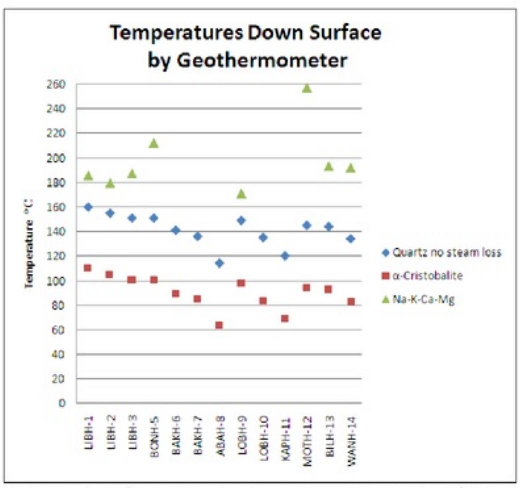

Figure 4: Calculated temperatures with Quartz geothermometers and Na-K-Ca geothermometer with magnesium correction.

Data except acidic waters are plotted on a Na-K-Mg diagram in Fig.5. The figure shows only one sample of KAPH-11 indicates temperatures by the Na-K and Mg-K geothermometer as 132 and 160°C, respectively. Samples plotted in immature waters but not at the corner of Mg are used to estimate temperatures using the Na-K geothermometer by linearly extrapolating for full equilibrium.

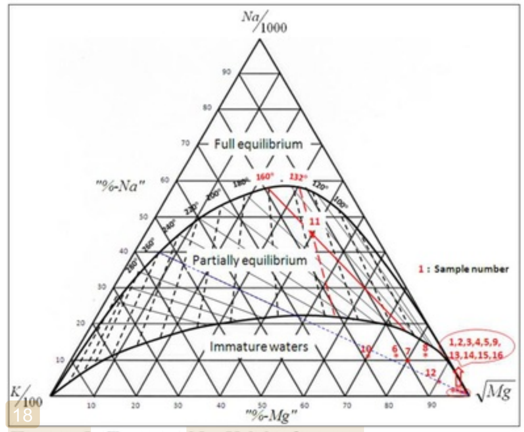

Figure 5: Ternary Na-K-Mg diagram.

Conceptual Model

On the basis of the results above, a conceptual model of a hydrothermal system in Kotamobagu was developed as shown in Fig.6. High temperature geothermal fluid of Cl-SO_4 type flows upward below Mt. Muayat and eventually starts boiling at depth, releasing H_2S gas which forms steam heated waters near the fumaroles by mixing with oxygen rich surface water. The deep water also flows laterally to the south and discharges Cl-SO_4 type water. This deep water further flows south through fault systems to lower elevation and discharged to the surface.

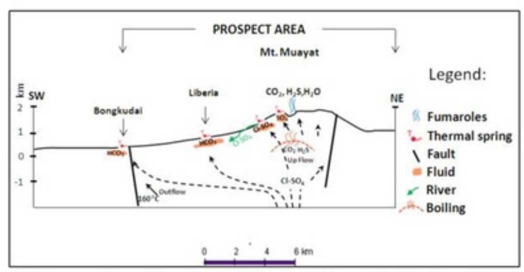

Figure 6: Conceptual model of Kotamobagu geothermal field.

CONCLUSIONS

Geochemical studies in the Kotamobagu geothermal field are summarized as follows:

1. The water samples are divided into three groups: SO4, Cl-SO4, HCO3 types.
2. Hot spring waters in high elevations of Mt. Muayat are acidic and of SO_4 and of Cl-SO_4 type.
3. Hot spring waters of lower elevation of Mt. Muayat are of HCO_3 type.

4. Geochemical geothermometer presents temperature of 132-160°C by quartz geothermometer and of 180-260°C with Na-K-Ca-Mg geothermometer.
5. Conceptual model of a hydrothermal system in Kotamobagu was developed.

ACKNOWLEDGMENTS

The author's great acknowledge to the Global-Center of Excellence in Novel Carbon Resource Sciences, Kyushu University for financial support for this work, and Directorate General Higher of Education National Ministry of Education Indonesia for Scholarship Abroad.

REFERENCES

Fournier, R. O. (1977)."Chemical Geothermometers and Mixing Models for Geothermal Systems", Geothermics, **5**, 41-50.

Fournier, R. O. and Potter II, R. W. (1979)."Magnesium correction to the Na-K-Ca Chemical Geothermometer", Geochimica et Cosmochimica Acta **43**, 2749-2765.

Giggenbach, W. F. (1988)."Geothermal Solute Equilibria, Derivation of Na-K-Mg-Ca Geoindicators", Geochimica et Cosmochimica Acta **52,** 2749-2765.

Hochstein, M. P. and Sudarman, S. (2008). "History of Geothermal Exploration in Indonesia from 1970 to 2000", Geothermics, **37**, 220-266.

Mohammadi, Z., Bagheri, R., Jahanshasi, R. (2010). "Hydrochemistry and Geothermometry of Changal Thermal Springs, Zagros Region, Iran", Geothermics, **39**, 242-249.

Ozgur, N. (2010). "Hydrogeological, Hydrogeochemical and Isotope Geohemical Modeling of the Thermal Waters in the Continental Rift Zones of the Menderes Massif, Western Anatolia, Turkey", Proceeding World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010.

PT. Pertamina Geothermal Energy. (2005), "Feasibility Studies Kotamobagu-North Sulawesi", June 2005, Unpublished Report, 2005.

Saibi, H., Ehara, S. (2010). "Temperature and Chemical Changes in the Fluids of the Obama Geothermal Field (SW Japan) in Response to Field Utilization", Geothermics, **39**, 228-241.

Strelbitskaya, S. and Radmehr, B. (2010). "Geochemical Characteristics of reservoir Fluid from NW- Sabalan Geothermal Field, Iran", Proceeding World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010.

Taran, Y. A. and Peiffer. L. (2009). "Hydrology, Hydrochemistry and Geothermal Potential of El Chicon Volcano-Hydrothermal System", Mexico, Geothermics, **38,** 370-378.

Yildrim, N., Onc, S., Akman A. U. (2010). "Geochemical Investigation in Areas without Geothermal Surface Geothermal Manifestations Kucuk Menderes Graben Western Turkey", Proceeding World Geothermal Congress 2010 Bali, Indonesia, 25-29 April 2010.

Table 1: Results of chemical analysis of waters in Kotamobagu.

Sample Number	Elev. (m)	Sample ID	Sample Date	Temp. (°C)	pH (-)	EC (field) µS/cm	$HCO3^-$	F^-	Cl^-	NO_3^-	SO_4^{2-}	Li^+	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	Fe total	SiO2
							mg/L												
1	608	LIBH-1	6/03/2010	48	6.02	516	307.5	0	9.3	0.13	12.02	0.04	36.8	0.10	11.42	13.17	52.4	1.70	148
2	645	LIBH 2	6/03/2010	43.4	5.89	490	290.4	0	5.80	0.11	6.21	0.03	31.0	1.0	10.78	11.68	51.2	0	136
3	629	LIBH -3	7/03/2010	52.2	6.06	535	314.8	0	9.0	0	10.71	0.04	36.5	0.23	12.55	13.76	55.8	0.22	128
4	752	LIBR-4	8/03/2010	24.7	2.24	4490	0.0	0.5	285	0	1940	0.10	79.6	0.48	10.93	39.3	223.9	28.90	126
5	476	BONH-5	6/03/2010	46.4	6.04	698	338.0	0	8.6	0	11.23	0.06	44.1	0.20	11.64	21.9	65.1	0.07	128
6	243	BAKH-6	8/03/2010	87.0	6.78	1687	176.9	1.0	228	0	365	1.50	224	0	22.55	2.44	114.2	0.07	107
7	240	BAKH-7	8/03/2010	87.0	7.40	1604	191.6	0.5	201	0.09	311	1.34	208	0	20.45	2.77	112.5	1.84	97
8	185	ABAH-8	8/03/2010	75.4	7.37	1376	97.6	0.5	61.6	0	534	0.16	201	0	7.56	2.22	97.5	0.22	65
9	172	LOBH-9	8/03/2010	43.5	6.71	240	91.5	0	12.7	10.26	22.24	0.01	19.3	0	4.67	5.43	22.13	0	122
10	144	LOBH-10	8/03/2010	70.0	6.26	3210	155.0	0.6	700	0	121.9	2.26	445	14.3	75.2	8.03	178.6	0.22	96
11	185	KAPH-11	18/03/2010	93.1	7,56	2350	39.1	0.5	402	0	556	0.33	384	0	12.16	0.12	106.5	0.41	72
12	222	MOTH-12	18/03/2010	47.7	6.65	2220	458.8	0	327	0	230.8	0.34	324	3.33	53.8	71.4	109.1	0	144
13	296	BILH-13	19/03/2010	48.8	6.34	433	268.5	0	3.38	0	0.75	0.01	42.6	0.12	7.37	12.95	39.5	0.07	112
14	344	WANH-14	19/03/2010	37.1	6.96	399	185.5	0	1.64	0	5.67	0.01	21.8	0	5.09	14.82	49.9	0	94
15	969	MUAH-15	8/03/2010	49.5	2.72	2860	0.0	0.6	320	0	1713	0.12	88.8	0.60	11.83	40.0	221.0	17.60	152
16	1438	MUAH-16	19/03/2010	49.1	2,25	5670	0.0	0	3.63	0.39	2420	0.04	31.6	0.59	2.36	35.4	116.6	10.95	232

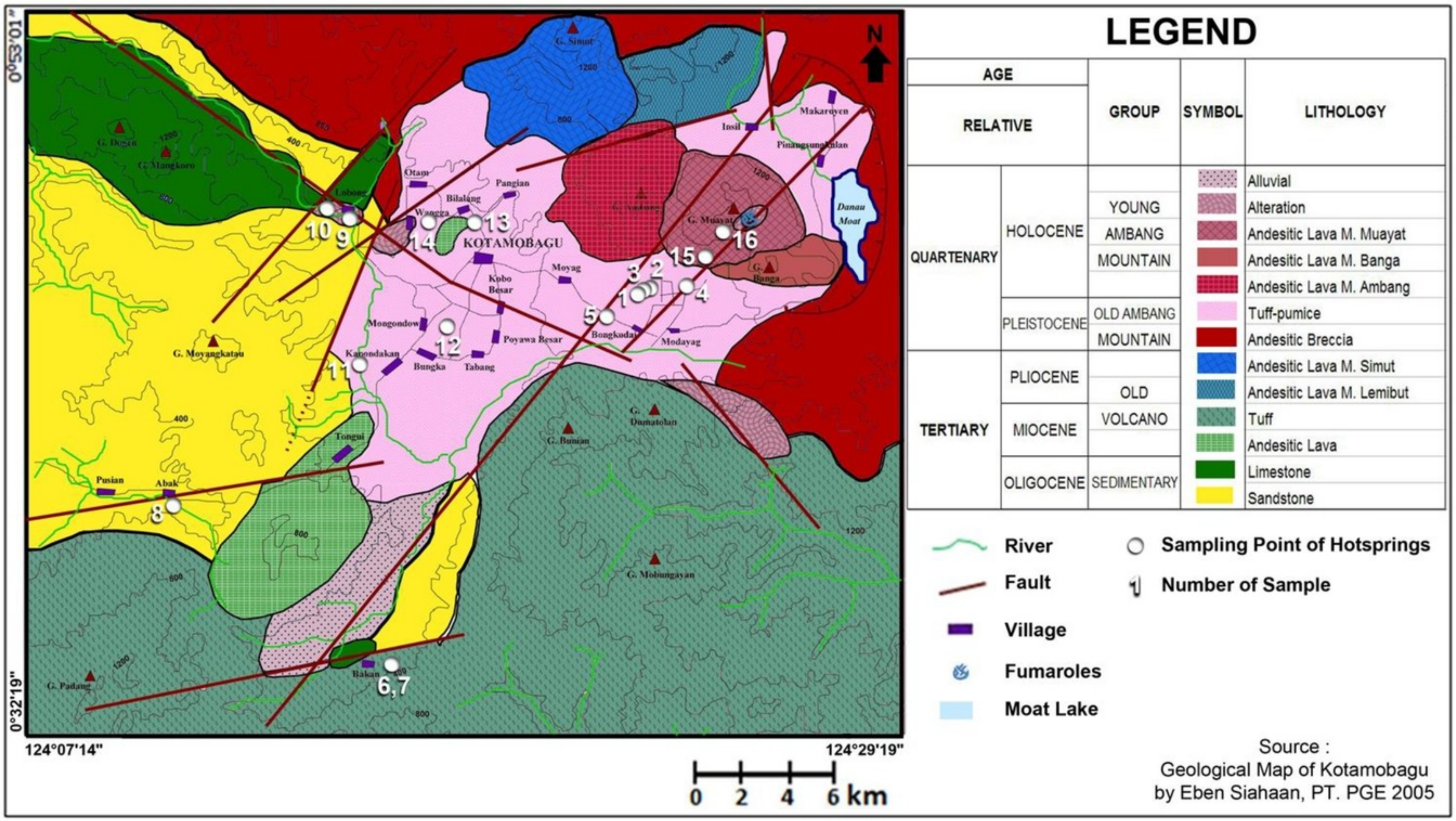

Figure 2: Geological Map of Kotamobagu (Modified from PT.PGE (2005)).

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