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AGE OF THE BEPPU HYDROTHERMAL SYSTEM, JAPAN

Yuki Yusa and Shinji Ohsawa
Beppu Geothermal Research Laboratory, Kyoto University, Beppu 874-0903, Japan

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ABSTRACT

Thermal and chemical data, obtained from a 300 m well drilled in the southern part of the Beppu hydrothermal field, have revealed that a sodium-chloride type water of 150 °C flows laterally through the layer of volcanic breccia at around 250 m depth, and that potassium is highly concentrated in breccia below 250 m deep as K-feldsper replacing the primary plagioclase phenocrysts. These suggest that the potassium metasomatism of the breccia has occurred by a long period of water-rock interaction in the flow path. A potassium budget in the flow system indicates the duration time (age) of the flow system to be 50,000 years, based on the quantities; potassium concentrations of thermal waters flowing in and out the system, residence time of water in the system, initial and present potassium concentrations of rock, and porosity of rock.

1. INTRODUCTION

The Beppu Hydrothermal System is located at the eastern edge of the Beppu-Shimabara graben, crossing Kyushu Island from northeast to southwest. Hydrothermal activity, spreading up from the Tsurumi-Garan volcanic center down to the eastern coast of Beppu City (Figure 1), is feeded by parent geothermal fluid (sodium-chroride type) beneath the volcanic center (Allis and Yusa, 1989). The central part of the city is an alluvial fan made up of debris-avalanches of andesite or dacite from the volcanoes behind, with the northern and southern edges of the fan being bounded by two faults striking along an almost E-W direction, respectively. There are two outflows of geothermal fluid from the volcanic center to alluvial fan along the fault systems; the southern outflow is known as the Beppu thermal zone, and the northern as the Kamegawa thermal zone (Allis and Yusa, 1989). More information of the system is referred to a paper in this proceeding (Yusa et al., 2000a).

During November 1987 and February 1988, a shallow 300 m well was drilled at the site of BGRL in the Beppu thermal zone (Figure 1) to get the temperature profile, and also to collect thermal water and core samples from different depths. Data obtained show that potassium concentrations in core samples below 250 m deep are abnormally high compared with concentrations in shallower samples; suggesting K-metasomatism of the breccia has occurred by a long period of water-rock interaction in the lateral flow path (Gianelli et al., 1992).
Although a preliminary evaluation of the potassium budget in this water-rock system has suggested that the age of the system is about 100,000 years (Gianelli et al., 1992), a re-estimation of the duration time (age) is presented in this paper.

2. WELL STRATIGRAPHY, WATER CHEMISTRY AND TEMPERATURE PROFILE

The well stratigraphy is shown in Figure 2. All sediments are volcanic breccias of hornblende andesite or dacite, and classified into 3 units based on the intensity of alteration. The unit 1 (surface to 61.5 m) consisting of sand and gravel is not altered, through which low temperature groundwater under a water table condition is flowing. The unit 2 (61.5 to 150 m) consists of unaltered tuff breccia. The unit 3 (150 m to bottom) consists of altered tuff breccia; the intensity of alteration is extremely strong.

Water samples were collected from five levels of 50, 100, 150, 200, 250 and 300 m in depth during the drilling work, and chemical compositions are shown in Table 1. Vertical distributions of chloride and bicarbonate and also water quality depicted by hexa-plotts are shown in Figure 3, with temperature profile measured three weeks after the well completion. It is clear that a sodium-chloride type water of 150 °C flows laterally at about 250 m deep.

3. CHEMICAL AND MINERALOGICAL DATA OF BRECCIAS

Summarizing the results of thin section studies, SEM-EDAX observations, X-ray diffractometer analyses and chemical analyses for core samples collected from the well, Gianelli et al. (1992) have reported that the breccia is unaltered from the ground surface to 150 m depth and is highly altered below 150 m. Especially it is noted that the K2O contents at 250 and 300 m depths are 4.5 to 6 times higher than the others (Figure 4). Gianelli et al. (1992) have interpreted that the concentrated K2O is due to K-metasomatism of breccia occurred by water-rock interaction, because K-feldspar (adularia) appears at about 225 m depth (data from cuttings gathered during the drilling) and is very abundant below 250m where it replaces the primary plagioclase phenocrysts.

4. FLOW SYSTEM IN THE BEPPU THERMAL ZONE

There are three principal types of thermal water in the Beppu Hydrothermal System: high-temperature sodium-chloride type, bicarbonate type, and sulfate type. These diverse compositions can be formed from a single parent hydrothermal fluid beneath the volcanic center, which is inferred to be a sodium-chloride type water of 250-300°C and 1400-1600 mg/kg chlorine (Allis and Yusa, 1989).

The hydrothermal waters in the Beppu Thermal Zone, where the well was drilled, are formed predominantly by dilution of the parent fluid by cold groundwater in the mountainous area. The diluted hydrothermal water flows out towards the lowland along the Asamigawa fault until it reaches the junction with an unnamed fault (Figure 1), and then rises and boils. This process has caused a steam-dominated two-phase zone to form at shallow depths (Figure 1), and subsequently the shallow groundwater has been heated by rising steam and converted into bicarbonate type thermal water. The detailed flow paths including the lateral flow of sodium-chloride type water are shown in Figure 5 (Ohsawa et al., 1994).

5. DURATION TIME OF THE SYSTEM

Gianelli et al. (1992) proposed a model for evaluating the duration time (age) of the water-rock interaction occurring in the outflow zone of the Beppu Hydrothermal Field based on the K-metazsomatism of the volcanic breccia. The idea is shown in Figure 6, and the duration time **t** is given as follows:

where Q is flow rate of thermal water, Vw volume of pores

$$t = \frac{V_W \cdot (d \cdot C_K - d_0 \cdot C_{K0})}{\phi \cdot Q \cdot (Fkin - Fkout)}$$

filled by solution, ϕ porosity, d density of rock, C_K content of K (weight ratio) in rock (suffix 0 means initial value at t=0), and Fkin and Fxout are concentrations of K in thermal waters flowing in and out the system respectively.

Vw/Q means the residence time of thermal water in the system, which is evaluated hydrologically. Other quantities except Fkin are given by field data. Since around 1970s, however, the Cl-concentration of the chloride-type thermal water in the Beppu thermal zone has decreased remarkably and other chemical concentrations including K have also changed associated with exploitation of high temperature chloride water at highland (Yusa et al., 2000a and 2000b). Accordingly it is considered that the chemical composition in Table 1 has been modified from the original one. Therefore, in the present analysis, we will use the old chemical data which was obtained from the Tenma well located at nearly end of the lateral flow zone (Figure 1). For the unknown Fkin, we calculate the K-concentration in the parent geothermal fluid (300°C and 1600 mg/l chlorine) assuming a chemical equilibrium with surrounding minerals, and then estimate the value by interpolation using the chlorine concentration of the Tenma water (849 mg/l).

Using the quantities Vw/Q = 7.8 years (Yusa, 1984), d0 = 2300 and d = 1960 kg/m3 (compiled in this study), _ = 0.2696 (NEDO, 1990), Ck0 = 1.33 and Ck = 5.06 % (Gianelli et al, 1992), Fkout = 0.0645 kg/m3 (Oita Prefecture, 1966) and Fkin = 0.105 kg/m3 (estimated in this study), we obtain the duration time to be around 50,000 years.

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Table 1. Chemical concentration (mg/l) and temperature (°C) for the waters in BGRL well.

Depth (m)	Temp.	pH	SiO2	Na	K	Ca	Mg	Cl	HCO3	SO4
50	20.9	7.30	99	32.3	3.6	20.5	10.5	17.5	127	34
100	42.0	6.86	197	73.8	13.1	57.9	46.7	36.9	569	60
150	54.4	7.04	168	97.5	13.3	41.5	44.2	42.1	536	78
200	125.6	7.23	191	154	16.8	65.4	48.2	65.7	714	84
250	147.9	8.82	353	380	23.0	1.4	7.1	282	390	166
300	101.8	8.42	246	229	17.9	5.8	6.1	64.6	487	85

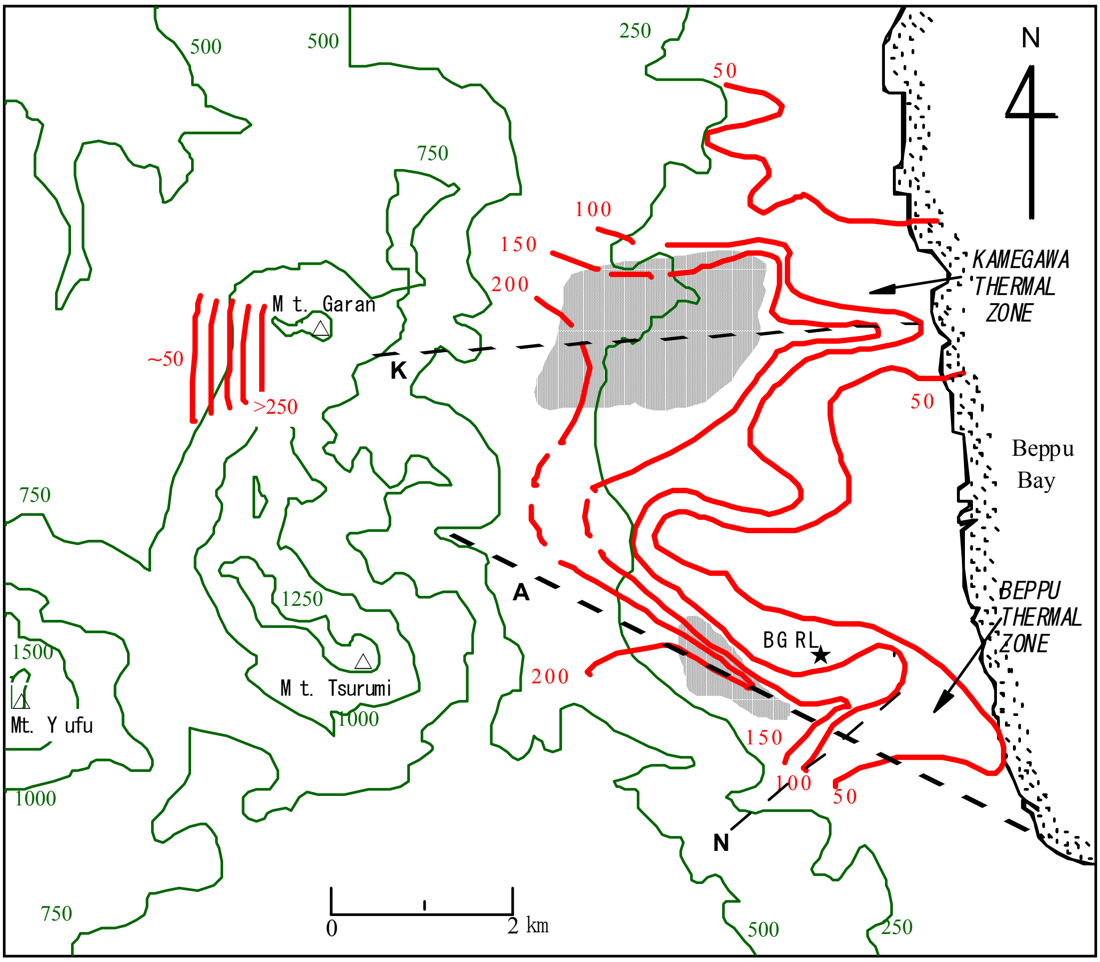


Figure 1. Map of Beppu Hydrothermal Field and sites of BGRL and Tenma. Thick curves show isotherms °C at 100 m below sea-level. Shaded areas are two-phase zones. Dashed lines A and K are the Asamigawa and the Kamegawa faults respectively, and dashed line N is an unnamed fault. Elevation contours (m) above mean sea level.

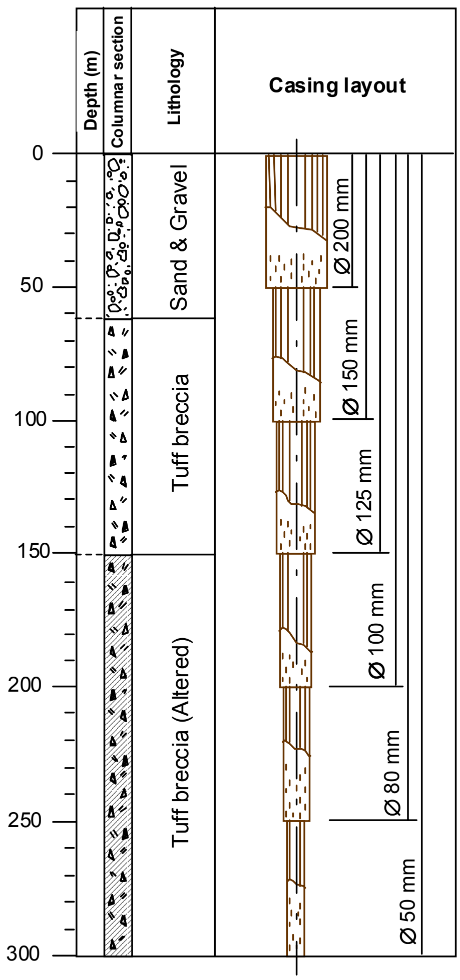


Figure 2. BGRL well stratigraphy

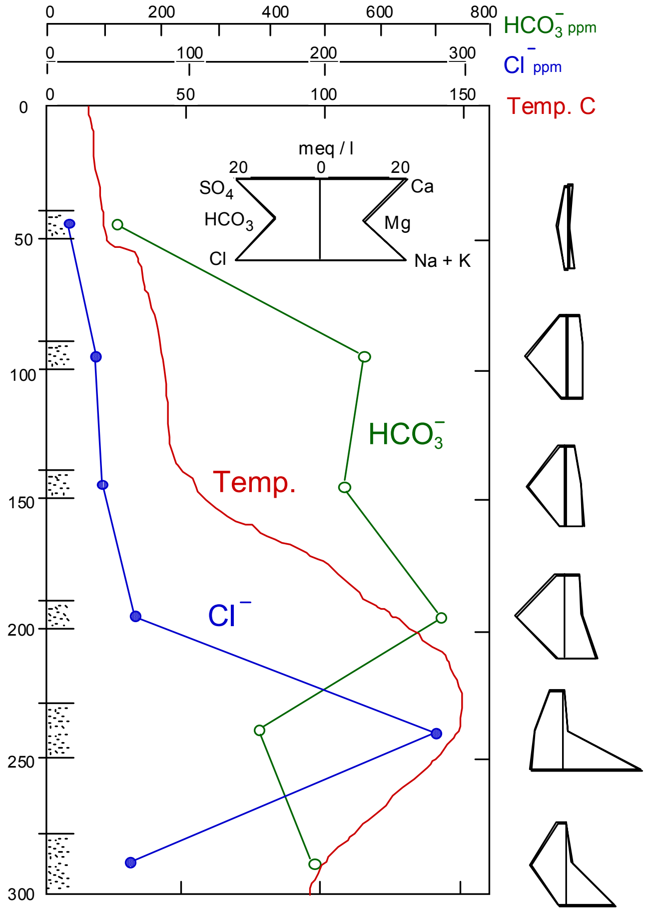
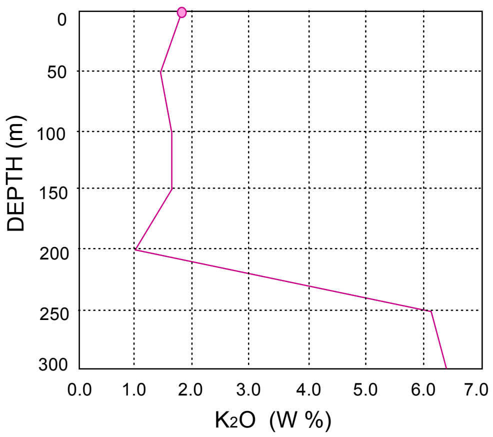


Figure 3. Distribution of water quality with depth and temperature profile at BGRL well.

Figure 4. Vertical distribution of K2O content



(weight %) in the core samples.

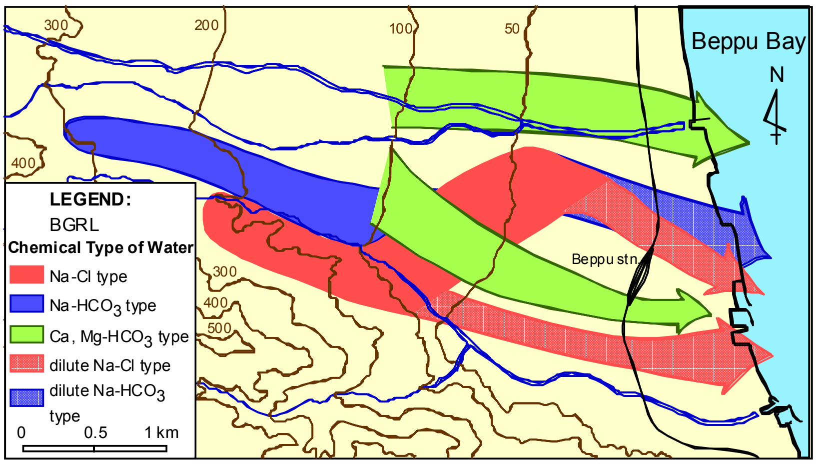


Figure 5. Flow system in the Beppu thermal zone.

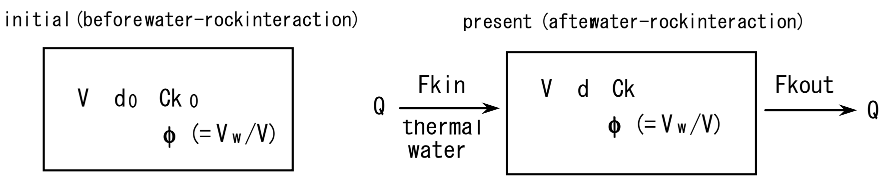


Figure 6. A lumped model for estimation of duration time of water-rock interaction.