HYDROGEN AND OXYGEN ISOTOPIC RATIOS OF THERMAL WATER IN OYASU-UENOTAI AREA, AKITA, JAPAN

MATSUBAYA, O. and UCHIDA, H., Mining College, Akita Univ., Tegata Gakuencho 1-1, Akita 010, Japan
IWATA, S., Akita Geothermal Energy Co. Ltd., Minowa 9, Kawamuko, Minasemura 012-02, Japan

1. Introduction

Oyasu-Uenotai area is one of geothermal fields where is now in exploration. The area is located at southern inland of Akita Prefecture about 20 km north of the Onikobe Geothermal Plant and also about 90 km south of the Kakkonda Geothermal Plant. According to Naka et al.(1987) and unpublished data in the Akita Geothermal Energy Co. Ltd., an area of about 5 km^2 has been investigated geologically, geophysically, geochemically and also through exploratory drilling. The invęstigation found a fracture zone at a depth of 1200 ~ 1850 m where the temperature is in a range of 280 ~ 335°C. Steam only issued from most of the exploratory wells, while mixture of steam and hot water is obtained some wells in the north-eastern area, where the content of hot water is 20 ~ 30 % after flashing under near atmospheric pressure.

In this study, the hydrogen and oxygen isotopic ratios of thermal water from the exploratory wells were measured and the results were discussed in comparison with the isotopic feature of meteoric water and natural thermal water in the vicinity, to estimate the origins of thermal water in this area. The measurements of isotopic ratios were carried out with conventional methods, and the results were presented as δ values relative to the SMOW standard.

2. δD and $\delta^{18}O$ of meteoric water and natural thermal water in the vicinity of the Oyasu-Uenoti area

(1) Meteoric water

The Oyasu-Uenotai area is located in a catchment area of northern slope surrounding with mounts of Yamabushi-dake, Takamatsu-dake and Oyasu-dake(Fig. 1). As shown in Fig. 2, meteoric water in this catchment area has isotopic ratios in a narrow range from -65 ‰ in δD and -11.0 ‰ in $\delta^{18}O$ at higher altitude(Nos. 5, 8 and 9) to -61 ‰ in δD and -10.5 ‰ in $\delta^{18}O$ at lower altitude(No. 1). Stream waters of Wasabi-zawa(No. 2) on the north-western slope of Yamabushi-dake, Takamatsu-zawa(No. 12, not show in Fig. 1) on the southern slope of Yamabushi-dake and Oyasu-zawa(No. 10) on the eastern slope of Oyasu-dake have similar as or little higher isotopic ratios than those in this catchment area. Minaşe River(No. 11) and Yakunai River(No. 13),

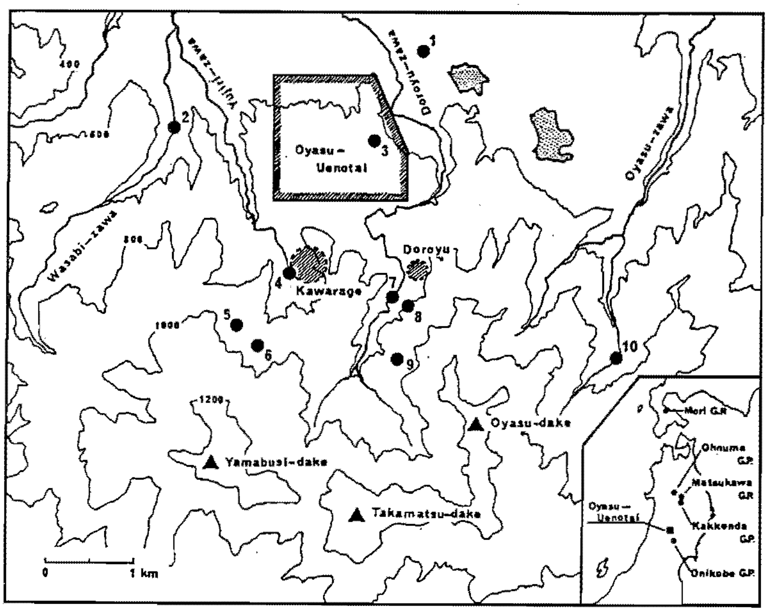

Fig. 1 Map of the Oyasu-Uenotai area and the vicinity
Solid circles show the localities of meteoric water studied and numbers correspond to those in Fig. 2. In the figure at right bottom, the localities of geothermal plants in northern Japan are shown.

which have rather large drainages at the east and the south of this area, respectively, have higher isotopic ratios. These meteoric waters show a relationship of $\delta D = 8\ \delta^{18}O + 23$, which is typically found on meteoric water in Japan Sea side area.

(2) Natural thermal water

In the immediate vicinity south-west of the Oyasu-Uenotai area, there is Kawarage geothermal system, which is an acid type one associated with a felsic intrusive rock. From lower parts of the intrusive rock, hot water of acid Cl-SO_4 type flows out, while steam containing no HCl issues from higher parts. The differences of δD and $\delta^{18}O$ between the hot water and the steam are 10 ‰ and 3.1 ‰, respectively, and correspond to the fractionation in boiling at 175°C(Fig. 2). The same feature was observed in Mt. Atosanupuri-Kawayu Hot Spring syatem (Matsubaya et al., 1983a) and also in Mt. Yake-Tamagawa Hot Spring system(Matsubaya et al., 1983b), and the thermal water before the boiling is considered as a mixture of volcanic steam and shallow ground water. This kind of volcanic steam is estimated to have a characteristic isotopic feature(δD = -20 ∿ -35 ‰ and $\delta^{18}O$ = +5 ∿ +8 ‰) and to be released directly from magma(Kiyosu, 1985; Kusakabe and Matsubaya, 1986). In the Kawarage system, the extension of line joining the points of hot water and steam in Fig. 2 reaches the range of typical volcanic steam, suggesting the magmatic origin of thermal water in the Kawarage system.

Doroyu Hot Spring is located about 1 km east of the Kawarage area, where two kinds of thermal water, that are neutral or slightly acid steam and hot water of Cl-SO_4 type(pH = 5.6) are found. The former has isotopic ratios similar as the meteoric water and may not be connected with the Kawarage geothermal system of volcanic origin. Isotopic ratios of the latter are rather similar as the hot water in the Kawarage system, but Cl content is much lower(370 ppm) than the Kawarage hot water(1800 ∿ 2100 ppm). At present, therefore, it cannot be concluded whether the latter is meteoric origin one slightly enriched in ^{18}O or some derivation from the Kawarage volcanic system.

In Oyasu Hot Spring area about 5 km east of the Oyasu-Uenotai area, boiling hot water at the surface has δD similar as and $\delta^{18}O$ higher by 0.5 ∿ 1 ‰ than the meteoric water, and also steam from shallow part shows similar feature(Abe et al., 1979). In Akinomiya area about 8 km south-weat of the Oyasu-Uenotai area, hot water of neutral NaCl type(60 ∿ 80°C) issues, of which isotopic feature is also meteoric one slightly modified in oxygen isotopic ratio. Both of these thermal waters may be of meteoric origin, and their oxygen isotopic ratios are heightened through isotopic exchange with rocks.

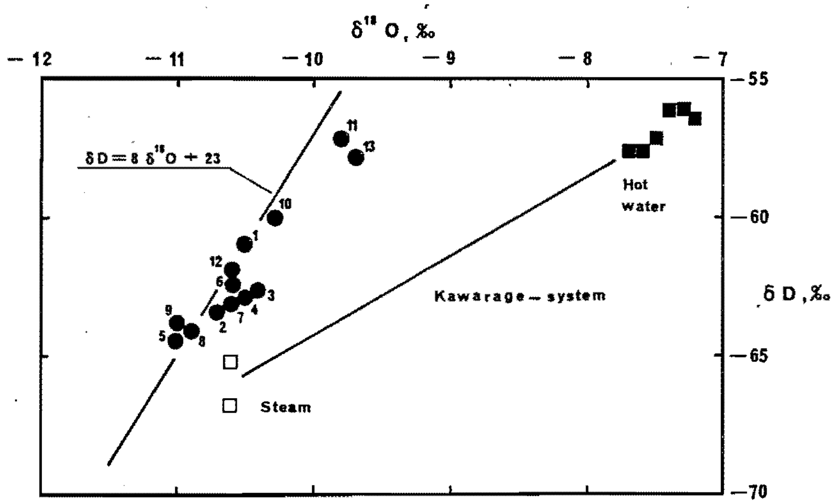

Fig. 2 δD and $\delta^{18}O$ of meteoric water in the Oyasu-Uenotai area and the vicinity as well as of thermal water from the Kawarage geothermal system
Solid circles are for the meteoric water and numbers correspond to those in Fig. 1.

3. δD and $\delta^{18}O$ of thermal water from wells in the Oyasu-Uenotai area

(1) Comparison of two methods of sample collection; collection of two phases in a lump and respective collections of steam and hot water separated

In a collectin of thermal water from a well, if the well is equipped with a separater, it is easy to collect separately steam and hot water after the flashing in the separater. In that case, the ratio of steam to hot water is necessary to know the isotopic ratio of the total thermal water issuing from the well. On the other hand, if the sream and hot water are collected in a lump from the flow of mixture of two phases, there is some uncertainty whether the two phases are collected in proportion to the real abundance. This problem was examined on a well (T-51) in the following way.

This well issues mixture of steam and hot water, of which ratio is comparble after flashing under near atmospheric pressure, and the well is equipped with a separater of large capacity enough for the flow rate of thermal water. Both of the mixture of two phases and the set of steam and hot water were collected, and their hydrogen and oxygen isotopic ratios, Cl content, and CO_2 (or total dissolved CO_2) content were measured. The results are shown in Table 1. The following relationship can be considered about each of these components among the mixture of two phases, the steam and the hot water,

$$C_m = C_s \cdot X_s + C_w(1 - X_s)$$

where, C_m, C_s and C_w are the content of some of these four components in the mixture of two phases, the steam and the hot water, respectively, and X_s is the fraction of the steam.

As shown in the bottom line in Table 1, values of the fraction of steam calculted about these four sets agree well to each other. This means that the mixture of two phases can be collected in proportion to the real abundance.

Table 1 Comparison of hydrogen and oxygen isotopic ratios, Cl content and CO_2/H_2O ratio between thermal water collected as mixture of two phases and steam and hot water separately collected, and the fraction of steam calculated from these results

	δD(‰)	$\delta^{18}O$(‰)	Cl^- (ppm)	CO_2/H_2O
Mixture of two phases	-70.9	-10.6	98	1.33×10^{-3}
Steam separated	-79.5	-12.3	2	2.38
Hot water separated	-56.1	- 7.4	310	0.02
Fraction of steam	0.63	0.65	0.69	0.56

(2) δD and $\delta^{18}O$ of the thermal waters from 5 wells

Thermal waters were collected at intervals of a few days after the starts of ejection in 5 wells, T-41, T-44, T-49, T-50 and T-51. The δD and $\delta^{18}O$ of these thermal waters are shown in Fig. 3.

In all of 5 wells, δD and $\delta^{18}O$ show a typical relationship of thermal water of meteoric origin, and these thermal waters are considered to be of meteoric origin, but not be directly connected with the geothermal system of volcanic origin as seen in the Kawarage area.

The δD of these thermal waters are distinctly lower by 5 ∿ 10 ‰ than those of meteoric water in this area. Giggenbach(1978) found a similar feature in the El Tatio geothermal field and concluded that the source meteoric water comes from more inland and higher altitude area. In the case of Oyasu-Uenotai area, however, meteoric water having such low δD as the thermal water is not found within several killometers around. δD of -70 ‰ corresponds with meteoric water in more northern area, for instance, the meteoric waters in the areas around the Ohnuma, Matsukawa and Kakkonda Geothermal Plants have δD of -68 ∿ -75 ‰ (Matsubaya et al., 1983b, 1985). If the thermal water in the Oyasu-Uenotai area originates from some of northern area, the meteoric water should move for a distance more than 100 km without influence of surface topography and perhaps of structure of basement rock. At present, however, there is no evidence for such a large scale circulation of meteoric water.

It is one of important features observed that the differences in the isotopic ratios of thermal water among 5 wells are clearly larger than the fluctuation within each single well. This suggests that there is no horizontal connection among these wells, and the thermal water may comes up through isolated vertical fissures reaching deeper part. Judging from the fact that steam or steam partly containing liquid phase are coming up through the wells, it is expected that boiling of some original thermal water takes place underground. If it is the case, the isotopic ratios of thermal water coming up can be changed by the isotopic fractionation in the boiling, and the extent of change may be different in each well reflecting the differnces in the temperatures of boiling and also in the ratio of steam separated to the residual liquid. If the thermal water in the Oyasu-Uenotai area is derived from an original thermal water having the same δD as the meteoric water in this area, the lowering of δD by 5 ∿ 10 ‰ happened in the boiling. However, such a large fractionation of hydrogen isotopes cannot be expected in the boiling under equilibrium condition at temperatures higher tham those at the bottom of wells (280 ∿ 335°C). If some kinetic effect can be considered in the boiling process as seen in the case of evaporation from an open surface of hot water pool, the extent of isotopic fractionation may become large enough to explain the difference between the thermal water and the meteoric water. To examine the possibility of this kinetic effect, information from other wells may be useful, and also a long term observation of the variation in the isotopic ratios of thermal water may bring some evidence for the kinetic evaporation.

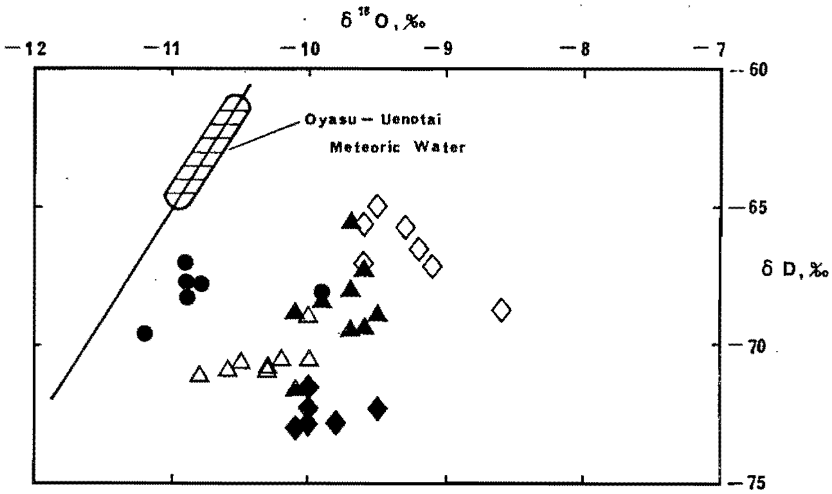

Fig. 3 δD and $\delta^{18}O$ of thermal water from exploratory wells in the Oyasu-Uenotai area
▲, T-41; ◆, T-44; ●, T-49; ◇, T-50; △, T-51

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