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GEOTHERMAL AND HOT SPRING WATER ORIGIN DETERMINATION USING OXYGEN AND HYDROGEN STABLE ISOTOPE IN THE TOYOHIRAKAWA CATCHMENT, HOKKAIDO, JAPAN

* Hiroyuki Ii[1], Hiroshi Kanbara[2], and Yohei Kawabata[2]

[1] Faculty of Systems Engineering, Wakayama University, Japan;
[2] JX Nippon Mining & Metals Corporation, Japan

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ABSTRACT: Jyozankei hot spring located near Sapporo City in Hokkaido is famous for many visitors and hot spring quality in Japan. Ground temperatures of 220 °C were reached in the Toyoha Mine10 km west of Jyozankei hot spring where several boreholes less than 2000 m in depth for investigating geothermal water were drilled. Subsequently, a hydrological investigation to clarify the influence of geothermal development on Jyozankei hot Spring was performed. Snow, river, well, spring, hot spring and the geothermal borehole waters in the Toyohirakawa catchment including Jyozankei hot spring were sampled and oxygen and hydrogen stable isotopes of water were analyzed to determine water origin for hot spring and geothermal water. As a result, Jyozankei hot spring and the borehole waters were thought to arise from mixed waters of magmatic and surface waters. Borehole water, from less than 2000 m in depth, was 10 to 30 % of the magmatic water and Jyozankei hot spring water was less than 10 % of the magmatic water. Surface water was recharged at the upstream of the Toyohirakawa catchment, with snow from the upper stream of the northwest catchment being an important resource of surface water for both Jyozankei hot spring water and geothermal water from the boreholes.

Keywords: Geothermal, Recharge, Oxygen isotope, Hydrogen isotope, Hot spring

1. INTRODUCTION

Jyozankei hot spring, located near Sapporo City in Hokkaido, is visited by as many as 2.4 million people annually. There are 56 hot spring sources in the Jyozankei district, from which 8,600 liters of hot water with temperatures ranging from 60 to 80 °C surface each minute [1]. The active area of ground temperature around the Toyoha Mine was 220°C 10 km to the west of Jyozankei, and geothermal water sampled from bore holes at the -300 m level tunnel in the Toyoha Mine was 30 to 100 liters per minute [2], [3]. Although metal ore production in the Toyoha Mine ceased, waste water treatment from the Mine area was still active. The mining company responsible planned to obtain revenue from geothermal power to compensate for the treatment of waste water

Geothermal power stations require large amounts of geothermal water. It is necessary to evaluate the influence of pumping up geothermal water on hot spring temperature and quantity around geothermal boreholes [4]. In particular, hydrogen and oxygen isotopic ratios were very useful in determining recharge or water sources of hot spring and geothermal water [4], [5], [6]. As a result, a hydrological investigation was performed to clarify the influence of geothermal development

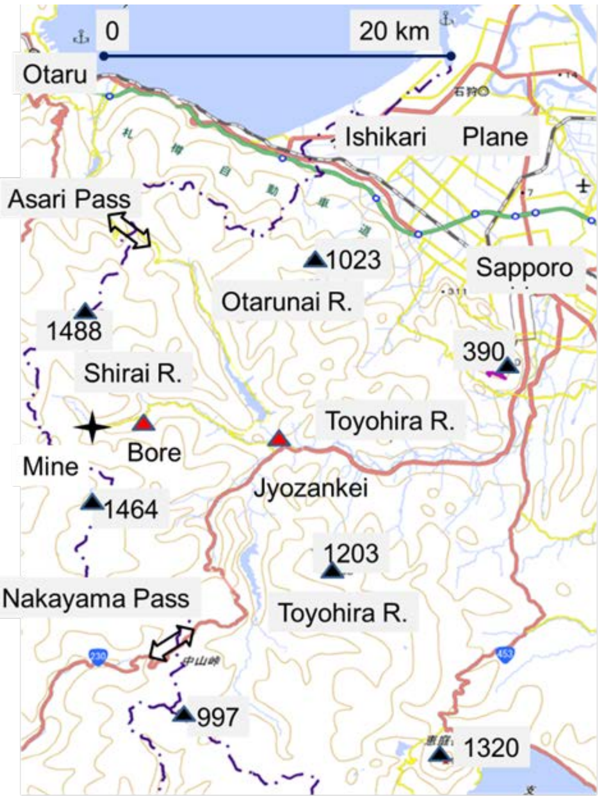

Fig. 1 Study area at the west of Sapporo

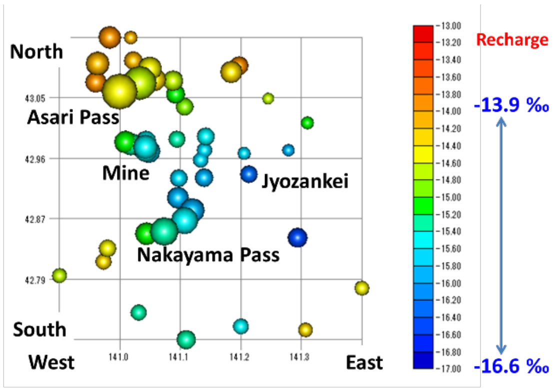

Fig. 2 δ¹⁸O distribution of snow in March 2014 color and circle size show δ¹⁸O value and altitude

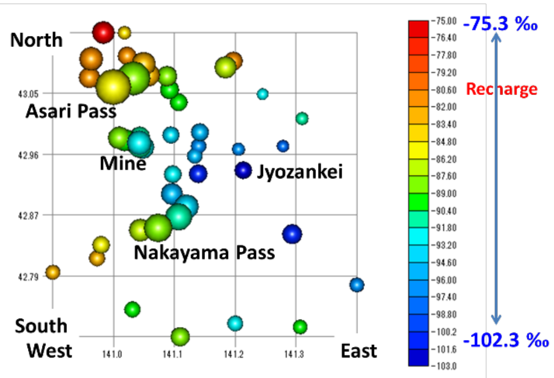

Fig. 3 δD distribution of snow in March 2014 color and circle size show δD value and altitude

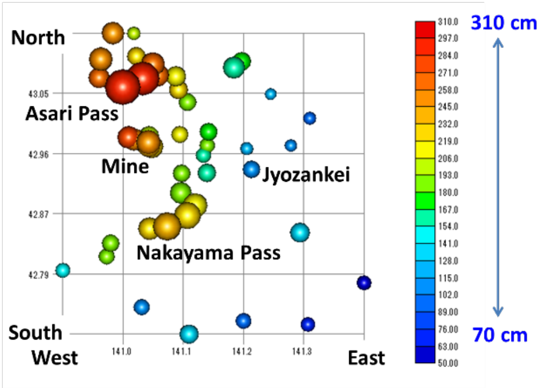

Fig.4 Snow depth in March 2014. Circle size and color show altitude and snow depth (cm)

on Jyozankei hot spring. Snow, river, well, spring, hot spring and the borehole waters in the Toyohirakawa catchment including Jyozankei hot spring were sampled and their respective oxygen and hydrogen stable isotopes were analyzed to determine water origin for both the hot spring and the geothermal waters.

2. STUDY AREA AND METHOD

Volcanic and sedimentary rocks from the Miocene to the Quaternary are found in the Toyohirakawa catchment. Basalt, andesite and rhyolite make up the volcanic rocks. Sapporodake

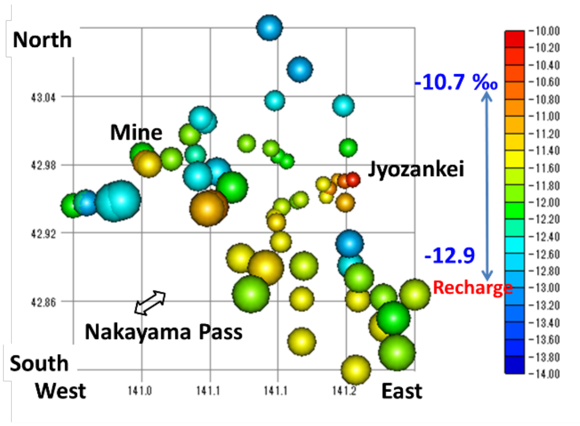

Fig. 5 δ¹⁸O distribution of river water in October 2012 Color and circle size show δ¹⁸O value and altitude

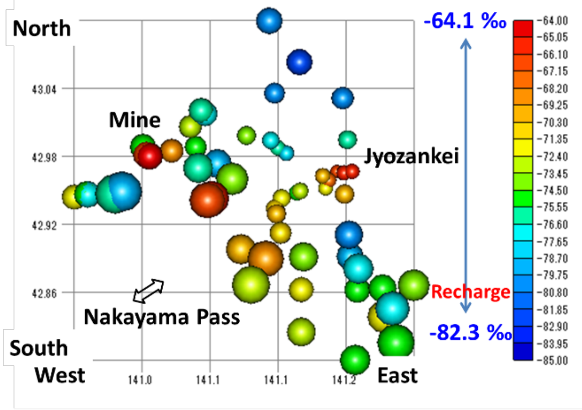

Fig. 6 δD distribution of river water in October 2012 color and circle size show δD value and altitude

and Eniwadake, located 10 and 20 km south of Jyozankei hot spring, erupted one million and several tens of thousands of years ago respectively. The Toyoha Mine was located 10 km to the west of Jyozankei hot spring and its high ground temperature was found south-east of the Toyoha Mine[2], [3]. Deep boreholes less than 2000 m in depth were drilled south-east of the Toyoha Mine for researching geothermal water. The catchment at the upstream of Jyozankei is composed of three rivers, the Otarunai, Shirai and Toyohira river as shown in Fig.1. The catchment was covered with heavy snow in winter.

Water sampling was performed using snow, river, hot spring and the geothermal water obtained from bore holes. Geothermal waters over 250 °C were sampled from deep boreholes in June 2012 and March 2013. Hot spring waters around Jyozankei were sampled in 2013. To determine the recharge area, a small branch river was selected for sampling. Branch river waters in the catchment were sampled in October 2012, June 2013 and August 2013. In particular, Takami and Migioe creeks at the upstream of the Toyoha Mine, were sampled every day from April 2013 to April 2014 and again from June 2013 to April 2014. Snow

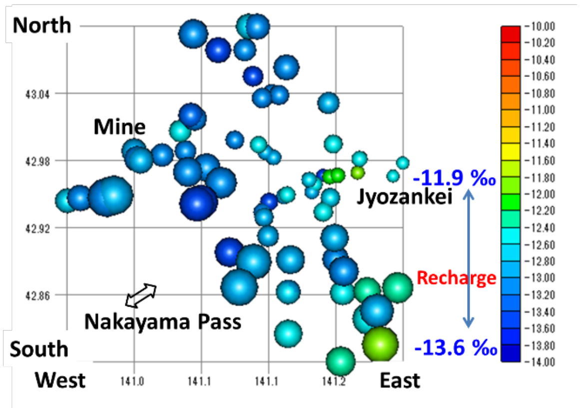

Fig. 7 δ^{18}O distribution of river water in June 2013 color and circle size show δ^{18}O value and altitude

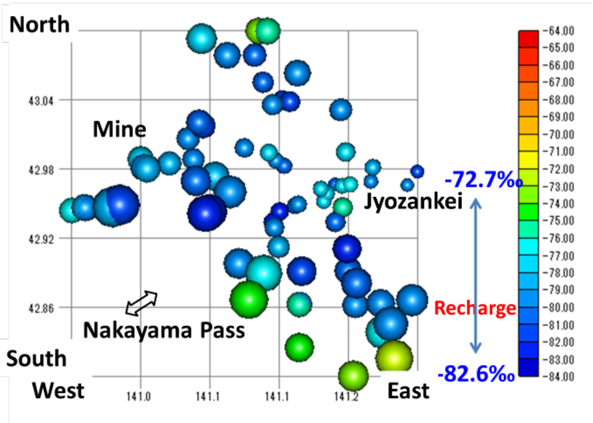

Fig. 8 δD distribution of river water in June 2013 color and circle size show δD value and altitude

was sampled in March 2014 beside roads and ski slopes. Measurement of δD and δ^{18}O for sampled water was carried out using an isotopic ratio measurement system (Sercon Geo Wet System). δD and δ^{18}O are presented in per mil (‰) of the standard average seawater (SMOW: Standard Mean Ocean Water). The formulas are shown in equation (1) and (2). δD and δ^{18}O of SMOW are denoted as (D/H) SMOW, (^{18}O/^{16}O) SMOW and δD and δ^{18}O of sample are denoted as (D/H) Sample, (^{18}O/^{16}O) Sample. Measurement error of δD is ±1.0 ‰ and measurement error of δ^{18}O is ±0.1 ‰.

$$\delta D = [(D/H)\ Sample/(D/H)\ SMOW-1] \times 1000: (1)$$

$$\delta\ ^{18}O = [(^{18}O/^{16}O)\ Sample/\ (^{18}O/^{16}O)\ SMOW-1] \times 1000: (2)$$

3. RESULTS

Fig.2 and Fig.3 show oxygen and hydrogen isotopic ratios for snow sampled in March 2014. Oxygen and hydrogen isotopic ratios for snow varied from -16.6 to -13.9 ‰ and -102.3 to -

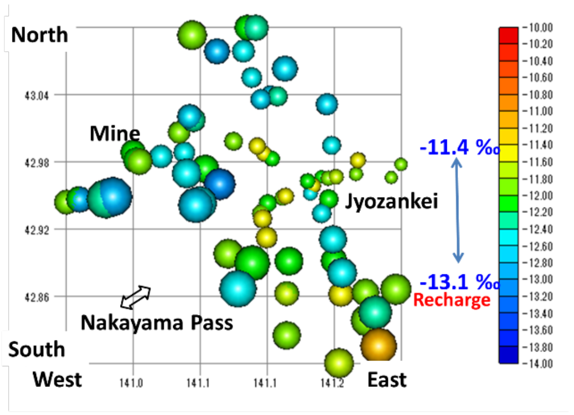

Fig. 9 δ^{18}O distribution of river water in August 2013 color and circle size show δ^{18}O value and altitude

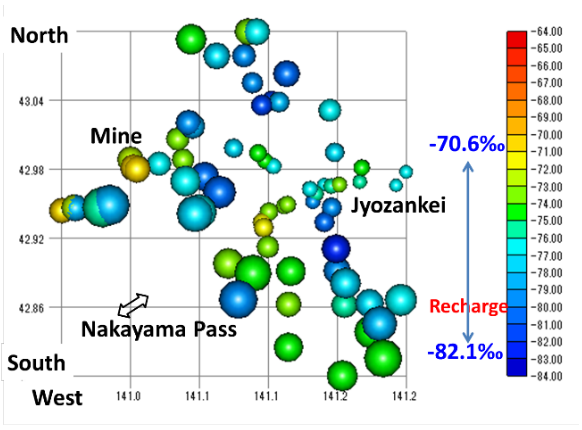

Fig. 10 δD distribution of river water in August 2013 color and circle size show δD value and altitude

75.3 ‰ respectively. Both values were lowest around the Jyozankei hot spring area and highest around Asari Pass in the north-west of Toyohirakawa catchment. Both values were medium around Nakayama Pass and low in the south area. Fig.4 shows snow depth in March 2014. Snow depth was found to increase with both oxygen and hydrogen isotopic ratios. Snow depth was found to increase with altitude and decrease from north-west to south-east. Therefore, oxygen and hydrogen isotopic ratios for snow increased with precipitation owing to precipitation effect for isotope [6]. In winter, precipitation depended on cloud from the Japan Sea so isotopic ratios were thought to increase from north-west to south-east.

Fig.5 and Fig.6 show oxygen and hydrogen isotopic ratios for river water sampled in October 2012. These ratios varied from -12.9 to -10.7 ‰ and -82.3 to -64.1 ‰ respectively. Both values were higher than those for snow and their variations were smaller than those for snow. Both values were highest around Jyozankei hot spring area and lowest north of the Toyohirakawa catchment. Both values increased from south to north and decreased with altitude. The pattern of both isotope values in October 2012 was reverse to

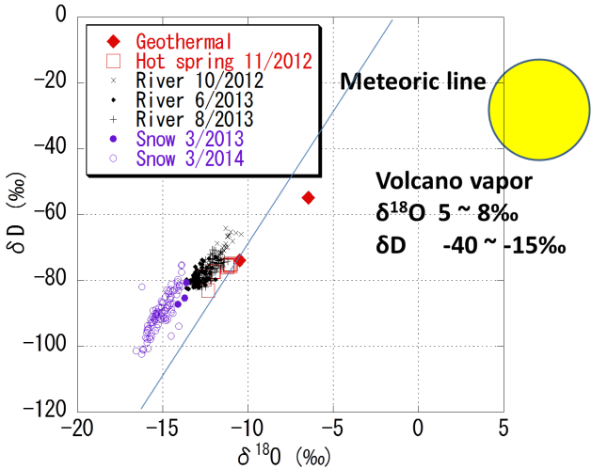

Fig. 11 δD and δ^{18}O values for water in Toyohira catchment and volcanic vapor

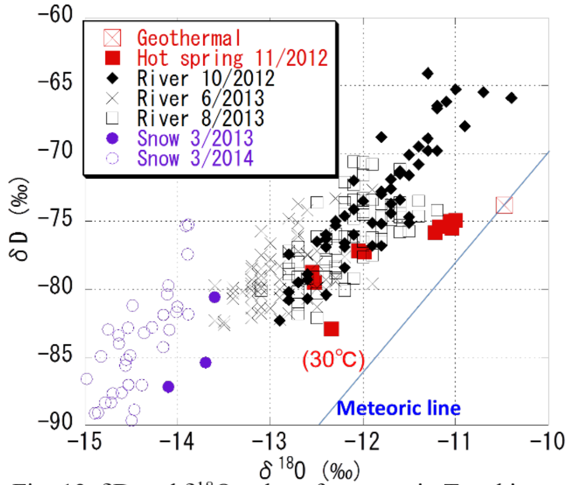

Fig. 12 δD and δ^{18}O values for water in Toyohira catchment

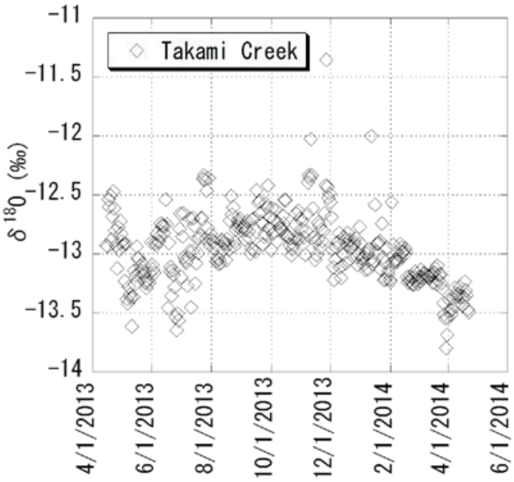

Fig. 13 Time series of δ^{18}O of Takami creek

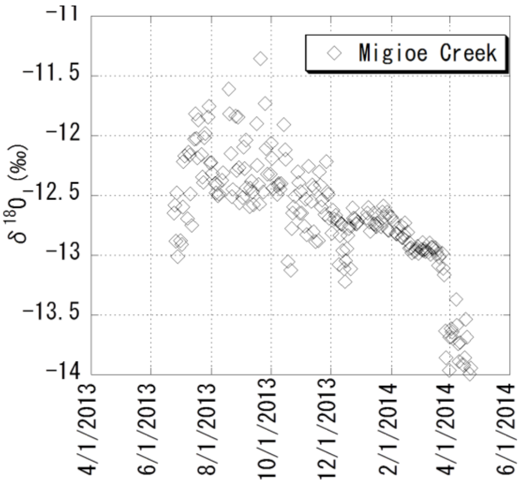

Fig. 14 Time series of δ^{18}O of Migioe creek

those for snow in March 2014. Excluding winter, cloud passes through the south of Jyozankei from the Pacific side. Thus the pattern was thought to be due to an inner effect from the Pacific side and an altitude effect for isotope [7]

Fig.7 and Fig.8 show oxygen and hydrogen isotopic ratios for river water sampled in June 2013. These ratios for river water varied from -13.6 to -11.9 ‰ and -82.6 to -72.7 ‰ respectively. Both values were higher than those for snow and marginally smaller than those of October 2012 and their variations were smaller than those for snow. Both values were high around Jyozankei hot spring area and in the south of catchment and lowest in the west of the Toyohirakawa catchment. The pattern for both isotope values was not clear.

Fig.9 and Fig.10 show oxygen and hydrogen isotopic ratios for river water sampled in August 2013. These ratios for river water varied from -13.1 to -11.4 ‰ and -82.1 to -70.6 ‰ respectively. Both values were higher than those for snow and marginally smaller than those of October 2012 and their variations were smaller than those for snow. The pattern for both isotope values was not clear. The pattern for both isotope values in August 2013 was thought to be somewhere between those in October 2012 and those in June 2013.

4. DISCUSSION

The pattern of oxygen and hydrogen isotopic ratios for snow and river water seemed to change seasonally. Both values for all waters were plotted as shown in Fig.11 and 12. Geothermal water and hot spring water was not on the Meteoric line. Oxygen and hydrogen isotopic ratios for volcanic vapor were 5 to 8 ‰ and -40 to -15 ‰ [8] and oxygen and hydrogen isotopic ratios for volcanic vapor, the geothermal water and hot spring water could all be on one line which then crossed the river water isotopic value at the point where the oxygen isotopic ratio was -13 ‰ and the hydrogen isotopic ratio was -80 ‰.

Subsequently, estimated oxygen and hydrogen isotopic ratios for recharge water from the surface

Fig. 15 Snow sampling at Asari Pass

were thought to be -13 and -80 ‰. Therefore, geothermal and hot spring waters were thought to be a mix of volcanic vapor with recharge water. The difference between hot spring and geothermal water was the mixing ratios for volcanic vapor and recharge water. Volcanic vapor ratios for geothermal water were high, 1/10 to 1/3, however volcanic vapor ratios for hot spring water was very low, less than 1/10. This lead to the conclusion that the main water origin for hot spring water was recharge water.

Oxygen and hydrogen isotopic ratios for the estimated recharge water were -13 and -80 ‰. Although most oxygen and hydrogen isotopic ratios for snow were lower than that for recharge water, these isotopic ratios around Asari Pass and north areas were close to that for the recharge area. In contrast, although most oxygen and hydrogen isotopic ratios for river water sampled in October 2012 were higher than that for the estimated recharge water, these isotopic ratios around the north area were close to those for the estimated recharge water as shown in Fig.5 and 6. Oxygen and hydrogen isotopic ratios for western and mountainous river water sampled in June 2013 were the same as those for estimated recharge water as shown in Fig.7 and 8. Similarly, some oxygen and hydrogen isotopic ratios for river water sampled in August 2013 were the same as those for recharge water as shown in Fig.9 and 10. Then, from Fig.12, isotopic ratios for snow in 2013 and 2014 and river water in October 2012 were the lowest and the highest respectively among snow and three-season river waters. Isotopic ratios for river water in June and August 2013 were midway between ratios for snow and river water from October 2012. As isotope values for river water decreased from October to June and then increased from June to August, and the isotope value for snow was lowest, melting snow was thought to cause the decrease isotope values in June.

Fig.13 and 14 show the time series of $\delta^{18}O$ for Takami and Migioe creeks at the upstream of the Toyoha Mine. Isotope values for both creeks reached their minimum value in snow melting seasons and then gradually increased till autumn. They decreased from winter to spring. Average values for both creeks were about -13.0 to -12.5 ‰. As oxygen isotopic ratios for snow in the catchment were markedly lower than those for river water, snow melt water was thought to decrease river water isotopic ratios. And low isotope values in winter were also thought to be brought out by snow or rain in winter. Therefore, two types of precipitation based on isotope values and cloud origin were determined. One precipitation is derived from the Japan Sea in winter and the other is derived from the Pacific Ocean excluding winter. Consequently, isotope values for river water were influenced by two types of precipitation and were lowest in snow melting season and the highest before winter. Then the average isotopic ratio for the catchment was thought to be values for river water in August. As the estimated oxygen and hydrogen isotopic ratios for the recharge area were -13 and -80 ‰, the recharge area was, from isotope values for river water sampled in August, estimated to be the northern and western mountain areas as shown in Fig. 9 and 10. The western and northern mountainous areas in the catchment were also heavy snow areas with snow reaching depths of over 200 cm as shown in Fig.15. Therefore, snow was important for recharge water.

As oxygen and hydrogen isotopic ratios for volcanic vapor, geothermal and Jyozankei hot spring waters were on the one line and that line intersected with river water values at the point where the oxygen isotopic ratio was -13 ‰ and the hydrogen isotopic ratio was -80 ‰, river water with an oxygen isotopic ratio of -13 ‰ and a hydrogen isotopic ratio of -80 ‰ was thought to be recharge water. Therefore, the recharge water for the geothermal and Jyozankei hot spring waters was thought to be the same and to be snow in the

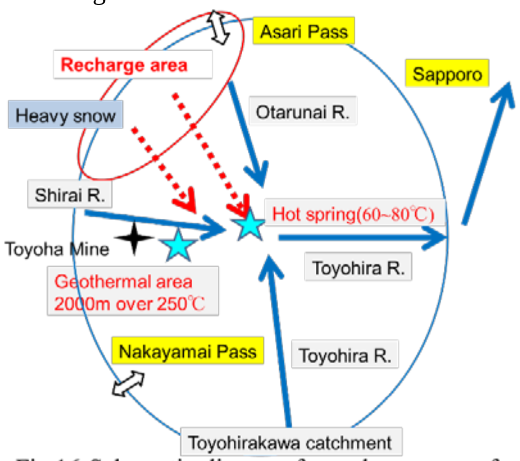

Fig.16 Schematic diagram for recharge area of hot spring and geothermal water

northwest mountains of Toyohirakawa catchment as shown in Figs. 16 and 17.

5. CONCLUSION

Geothermal power stations require large amounts of geothermal water. It is necessary to evaluate the influence of pumping up geothermal water on hot spring temperature and quantity around geothermal boreholes. Jyozankei hot spring is an important hot spring in Hokkaido and many people visit the hot spring annually. 10 km upstream of Jyozankei hot spring, is a geothermal area. Investigative bore holes less than 2000 m in length were drilled and 250 °C geothermal water was sampled. To determine the source of Jyozankei hot spring and geothermal waters, river, snow, hot spring and geothermal waters in the Toyohirakawa catchment which includes Jyozankei hot spring and geothermal area were sampled and isotope values were studied. As a result, Jyozankei hot spring and borehole waters were thought to be a mixture of water between magmatic water and surface water. Borehole water from 2000 m in depth was composed of 10 to 30 % magmatic water and Jyozankei hot spring water was less than 10% magmatic water. The surface water was recharged at the upstream of the Toyohirakawa catchment and in particular snow at the upper stream of the northwest catchment was an important source of surface water for both Jyozankei hot spring water and geothermal water from the boreholes.

As oxygen and hydrogen isotopic ratios for volcanic vapor, geothermal and Jyozankei hot spring waters were on the one line and the line intersected with river water values at the point where the oxygen isotopic ratio was -13 ‰ and the hydrogen isotopic ratio was -80 ‰, river water with the oxygen isotopic ratio -13 ‰ and hydrogen isotopic ratio -80 ‰ was thought to be recharge water. Therefore, the recharge water for the geothermal and Jyozankei hot spring waters was thought to be the same and to be snow from the upstream of the northwest of Toyohirakawa catchment.

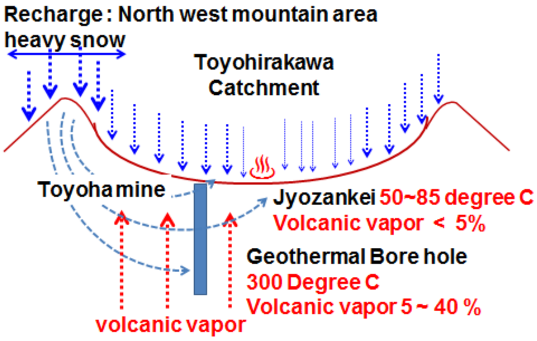

Fig. 17 Schematic diagram for recharge area of hot spring and geothermal water

6. ACKNOWLEDGEMENTS

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