ISOTOPE BEHAVIOR OF SEVERAL HOT SPRING AND GEOTHERMAL FIELD FOR BINARY SYSTEM IN JAPAN

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ABSTRACT

There are various origins of high temperature hot springs in Japan, for example, separation from magma, heating meteoric water heated near volcanic area and hot sedimentary aquifer. Recently in several hot spring, small binary power generation projects are progressing. And several geothermal power plant project is progressing near hot spring field, we have to survey relationship between hot spring reservoir and geothermal reservoir to understanding for hot spring owners. To understand geothermal system including hot spring resorts, we survey the isotope behavior at several hot spring fields in Japan.

For example, in Matsunoyama hot spring field, the binary power generation test is carried out using Takanoyu #3 hot spring fluid with about 100 degree C and 10,000 mg/l Cl. The hydrogen isotope ratio is about -20 ‰ and oxygen isotope ratio is about 1.8 ‰ and higher than meteoric water. The origin of Takanoyu#3 is fossil salt water with methane gas and geo-pressure structure.

In other case, in Hachijo Island, there is a geothermal power plant (3.3MW) and several hot spring wells. The hot spring fluid in Hachijo Island has two kind properties. One is the origin of meteoric water and another is the origin of seawater due to similar isotope ratio as seawater. The isotope ratio and Cl concentration of fluid in geothermal plant suggests that the fluid origin of geothermal plant is mainly magmatic fluid and slightly mixing with meteoric water and isolated from hot spring fluid..

1. INTRODUCTION

The geothermal potential in Japan was estimated about 23,000MW of conventional hydrothermal excluding EGS and 3rd ranking high next to Indonesia and United States of America. And the potential of hot spring binary power generation using developed high temperature hot springs is about 700MW.

But in Japan, 17 geothermal power plant sites established and started generation before 1999. And after 2002, our government, Ministry of Economy, Trade and Industry (METI), broke off the support for research and development of geothermal energy.

And the reasons of interruption of geothermal development are as follows; 1) high initial cost and long lead time are needed for new geothermal power plant, 2) 80% of geothermal potential exists inside special region of national park and we cannot develop at these region, 3) several hot spring owners resist to development due to afraid decreasing hot spring resource.

Then, two project started by Ministry of Environment (MOE) from 2010 to solve the hot spring owner issues. These are the project “Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources” and the project "Development and Demonstration of Small-Grid Power Generation System using Hot Spring Heat Source".

In these projects, the major issue is how to estimate the origin and change of hot spring reservoir and the relationship with reservoir for geothermal power plant. The geochemical survey is useful method to understand relationship between hot spring and geothermal reservoir. Especially, the isotope survey show important data for reservoir estimation.

This paper shows the results of stable isotope survey at several hot spring fields including for binary plant and discuss the relationship between hot spring reservoir and geothermal reservoir or meteoric water.

2. HOT SPRINGS IN JAPAN

To develop geothermal plant, one of problems is the understanding of hot spring resort owners. Usually the reservoir of geothermal power plants exist about 2 or 3 km depth and that of the hot springs for bathing exist shallower than 1 km depth. But due to the hopeful geothermal reservoir exist close to hot springs reservoir, several hot spring owners resist to develop geothermal power plants due to afraid to decrease the hot spring resource.

As one of geothermal direct use, bathing in hot spring is used for many people and countries. In Japan, about 28,000 hot springs (Onsen) and 15,000 hotels related hot springs exist at 2010. And total guests staying hotels of hot springs per year is about 130 million as same as population in Japan. And the range of temperature of hot springs is from 25 to over 100 degree C.

In volcanic area, for example Hokkaido, Tohoku-area, Kyushu Island etc., the temperature of many hot spring is higher than 42 degree C. Kimbara (2005) collected temperature data of 4,536 hot springs in Japan. According to this data, the temperature of about 650 hot springs is higher than 60 degree C and the temperature of about 180 hot springs is higher than 90 degree C. And based on this data, Muraoka et al. (2008) estimated about 700MW of the electrical potential of hot spring binary generation in Japan.

And the origin of high temperature (about 100 degree C) to suitable hot spring binary system is classified in 4 types as shown in figure 1.

In Type 1, the meteoric water heated shallow heat source for example, geothermal feature. This type exists mainly inside volcanic body. In Type 2, the meteoric water heated deeper reservoir than Type 1 and the hot spring fluid from several hundred meter depth. In some case, the hot spring fluid flow up along fault and fractures.

Type 3 is geo-pressured type found near oil and gas field. Matunoyama hot spring field is one of typical geo-pressured field. This type exists at Gulf coast in USA (Esposito et al., 2012), Cooper-basin Australia etc. Type 4 is hot sedimentary aquifer. According to geothermal gradient, even if non-volcanic Plain area, high temperature spring fluid exist at deep reservoir.

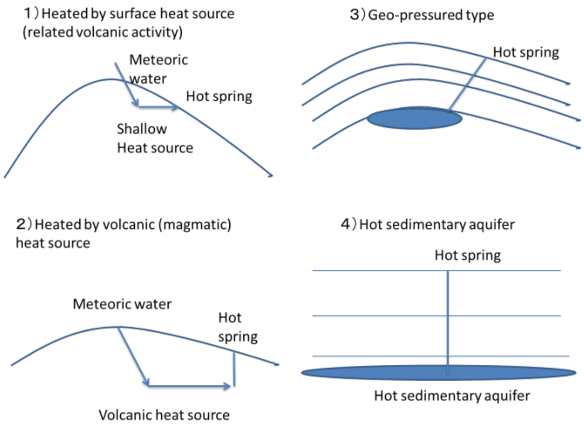

Figure 1: Several types of high temperature (about 100 degree C) hot spring origin.

3. CASE1：MATSUNOYAMA BINARY PLANT TEST FIELD

3.1 Geology

Matsunoyama hot spring field is located in Tokamachi city in the middle part of Niigata prefecture (about 200km NNW from Tokyo). The geological map of central Japan which include the Matsunoyama region (Takeuchi et al., 2000) is shown in Figure 2. The central Japan near Matsunoyama hot spring field in Niigata Prefecture is pressured by Izu Peninsula, which is defined by the presence of syntaxis. In Matsunoyama geo-pressured region, a big Matsunoyama dome structure exists, where the natural gas field is characterized by Tertiary sediments.

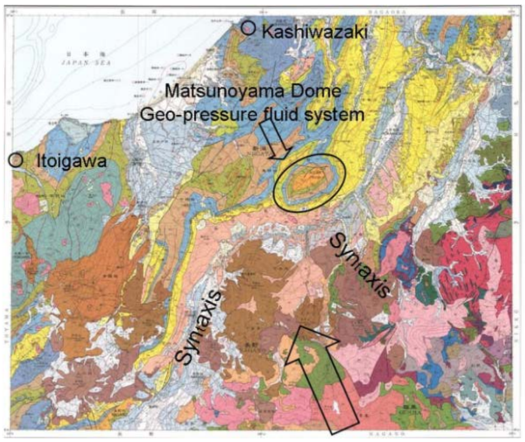

Figure 2: Geological map of central Japan including Matsunoyama region (modified Takeuchi et al., 2000).

The geo-pressured reservoir is characterized by the following; 1) the source of hot fluid is sea water, captured in the sedimentary basin formation at deep sea; 2) the hot fluid is present at depth of 2 to 7 km; 3) the pressure of the formation is much higher than the hydrostatic pressure; 4) the hot fluid has methane gas (CH_4); and 5) the heat source is through conduction from deep crustal, with fluid temperature of over 100°C depending on the heat source and reservoir depth.

3.2 Hot spring wells

There are several hot spring wells in Matsunoyama hot spring field as shown in Figure 3. The oldest well, Takanoyu#1, was drilled in 1938 at depth of 170 meters, fluid temperature of this is about 90 °C. The second well, Takanoyu#2 was drilled in 1964 at depth of 284 meters, with 90 °C fluid.

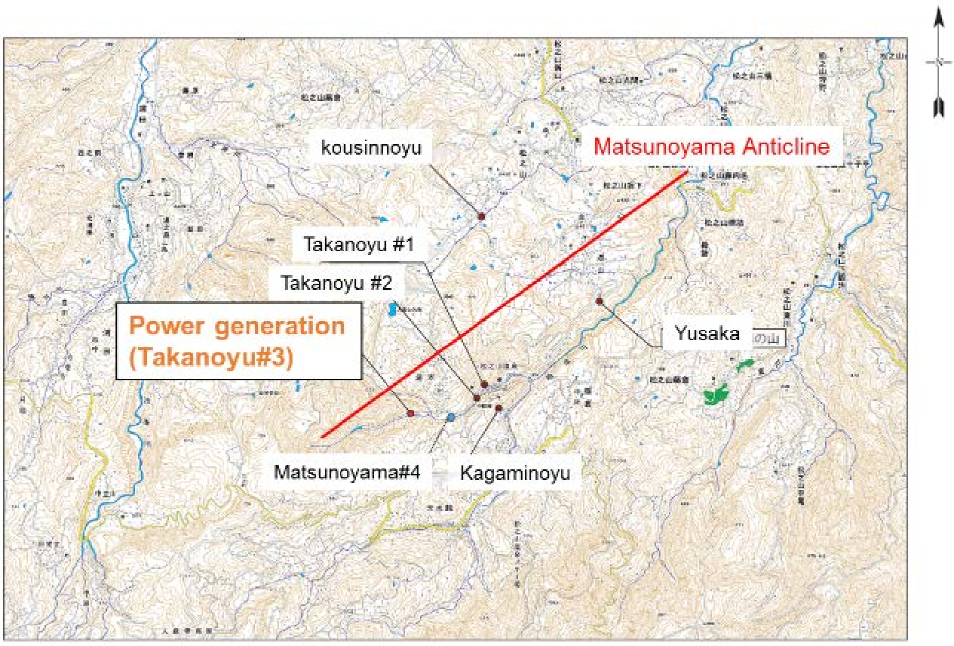

Figure 3: Location of Takanoyu#3 and the surrounding hot spring monitoring wells.

In 2007, a new hot spring well Takanoyu#3 was drilled up to 1,300 meters depth. During the initial production test, the well has a flow rate of 623 L/min (98°C fluid) which is the largest in Matsunoyama hot spring field. Then, a 50kW Kalina cycle power plant was installed with fluids supplied from Takanoyu#3 using about 300L/min of fluid or 200L/min of fluid with 1.5 ton/hour steam. And these fluid has high Cl concentration, about 9,500 mg/L

In Matsunoyama field, other two hot spring, Kagaminoyu and Yusaka produce the hot fluid about 90 degree C with about 9,000 mg/L Cl. But the temperature of two well, Matsunoyama#4 and Kousinnoyu, are about 30 degree C. The chemical composition is different between two wells, the Cl concentration of Kousinnoyu is about 8,500mg/L similar as Takanoyu#3 but that of Matsunoyama#4 is about 1,000mg/L about 1/10 of Takanoyu#3.

3.3 Result of isotope analysis

To analyze the hydrogen and oxygen isotope ratio, the fluid of Takanoyu#3, Kousinnnoyu, Matsunoyama#4 and river water near Takanoyu#3 well sample were collected. The isotope analysis was carried out at laboratory of Mitsubishi Material Techno Co. Ltd. And the Cl concentration was analyzed by ion chromatograph.

The hydrogen and oxygen isotope diagram of Matsunoyama hot spring is shown in Figure 4. Firstly the isotope ratio of hydrogen and oxygen of river water are -56.8 ‰ and -10.0 ‰ respectively. This value is on line of average meteoric water of central Japan as $\delta D=8\delta^{18}O+24$. And the isotope ratio of hydrogen and oxygen of Takanoyu#3 fluid are -21.9 ‰ and 1.8 ‰ respectively. These value are far from meteoric line and closer from that of sea water. The isotope ratio of hydrogen and oxygen of fluids from Takanoyu#2, Kagaminoyu and Yusaka at about 90 degree C are similar as those of Takanoyu#3.

In the case of 30 degree C fluid, the isotope ratio of hydrogen and oxygen of Kousinnoyu are -14.8 ‰ and 1.3 ‰ respectively. These value are not on line of meteoric line and closer to sea water than those of Takanoyu#3. On the other hand, the isotope ratio of hydrogen and oxygen of Kousinnoyu are -51 ‰ and -8.2 ‰ respectively. These value are not on meteoric line but close to river water than Takanoyu#3. And these value plot on line between river water and Takanoyu#3.

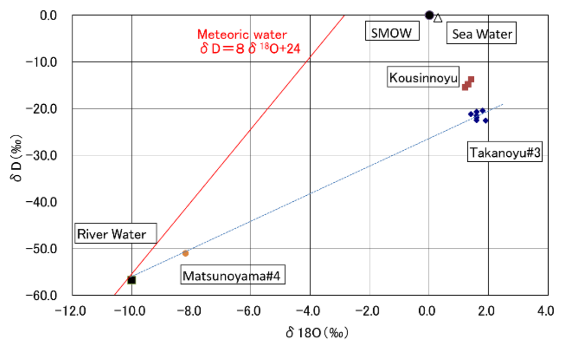

Figure 4: Isotope diagram of hot spring fluid in Matsunoyama field.

From the isotope ratio, the origin of Takanoyu#3 and Kousinnnoyu are not meteoric water and seems to be geo-pressured sea water because the isotope ratio are close to sea water. And the evidence of geo-pressure at Matsunoyama are dome structure and high methane gas ratio (Yanagisawa et al., 2013). And the origin of Matsunoyama#4 is mixing meteoric water and Takanoyu#3 due to on line between river water and Takanoyu#3.

Figure 5 shows the relationship between Cl concentration and oxygen isotope. The higher Cl concentration fluid shows higher oxygen isotope ratio. These four data exist on one line. This suggest that Matsunoyama#4 is mixed fluid of Takanoyu#3 and meteoric water.

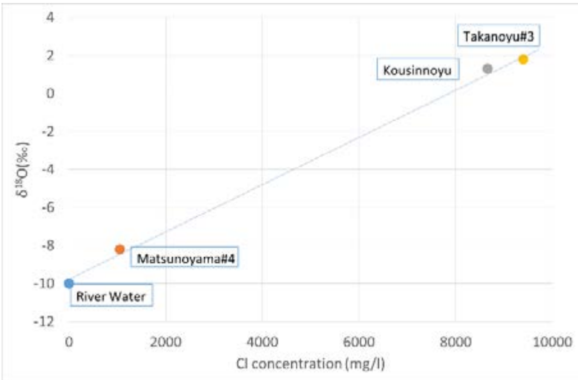

Figure 5: Relationship between Cl concentration and oxygen isotope of hot spring fluid in Matsunoyama field.

Then, we try to estimate the geological relationship between Takanoyu#2, Takanoyu#3 and Matsunoyama#4. There is the reverse fault near the top of Matsunoyama dome including Takanoyu#3 well. The reverse fault is found by Muraoka et al., (2011). In Matsunoyama region, the reverse fault exists at the center of anticline which runs from north to south and leans to west at depth.

Figure 6 shows the location of the reverse fault and hot spring wells in Matsunoyama. Wells Takanoyu #1, #2, #3 and Matsunoyama#4 are located on the western side of the reverse fault. Takanoyu#1 is 170 meters depth, Takanoyu#2 is 280 meters depth, Takanoyu#3 is 1300 meters depth and Matsunoyama#4 is 400meter depth, with the wells depths proportional to the distance from the fault. The reservoir is spread in high permeability layer and the layer thickness around Takanoyu#3 is estimated to be more than 300 meter from the geological column.

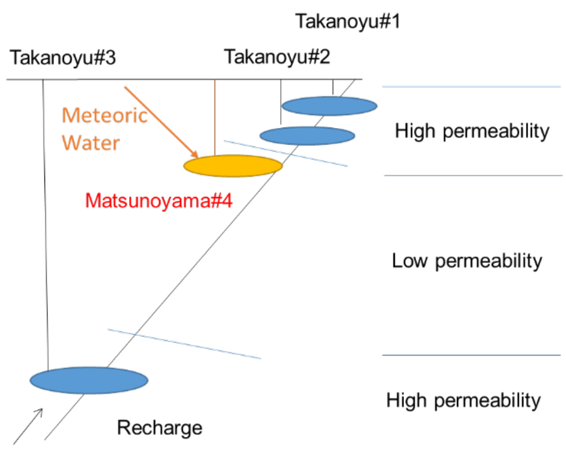

Figure 6: Reservoirs connection around Takanoyu #1, #2 and #3 and the reverse fault

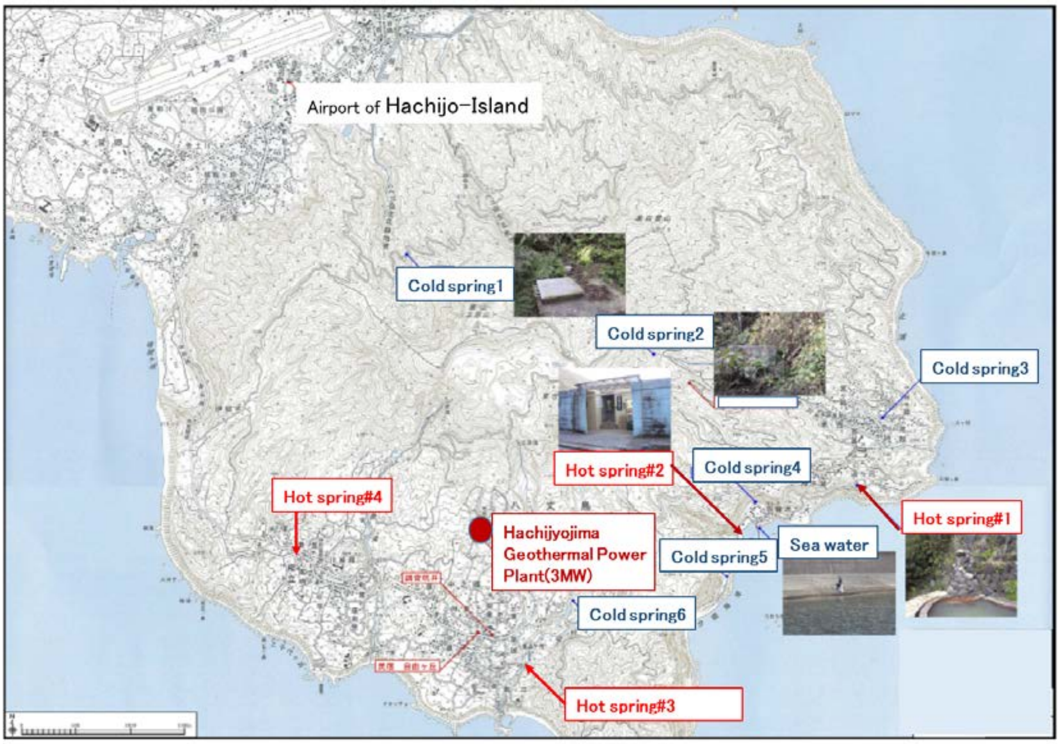

Figure 7: Location of sampling points at geothermal power plant, hot spring well and meteoric underground water (cold spring) in the south part of Hachijo Island.

The layers between the reservoir of Takanoyu#2 and Takanoyu#3 are low permeability sediment, with Takanoyu#2 believed to be connected to Takanoyu#3 through the reverse fault. The source of the hot spring fluid tapped by Takanoyu#1, #2 and #3 come from the deeper reservoir through the reverse fault, and spreads out horizontally along a high permeability sediment layer. And Matsunoyama#4 exist on reverse fault but mixing with meteoric water occurred in reservoir. This is reason for lower temperature, lower Cl concentration and lower oxygen isotope ratio.

4. CASE2 : HACHIJO ISLAND GEOTHERMAL FIELD

4.1 Background of survey at Hachijo Island

As mentioned above, the Ministry of Environment support the project to solve the problems about relationship between geothermal power plant developer and hot springs owners. Then, the project of “Development of an advanced geothermal reservoir management system for the harmonious utilization with hot spring resources” had been done from 2010 (Yasukawa et al., 2013).

An integrated geothermal reservoir operation system for adequately controlled utilization was developed to avoid interference to nearby hot springs. Hachijo Island was selected as model fields to apply this system and various field surveys and monitoring were conducted. The final product is an integrated system that enables to evaluate impacts of geothermal development on surrounding hot springs and to design geothermal exploitation without negative impacts on hot springs.

To support this system, we need the estimate the relationship between fluid from geothermal power plant, meteoric water and several hot springs in Hachijo Island.

Hachijo Island lies about 300 km south of Tokyo. Hachijo Island is about 70 square kilometer including two active volcano about 800 meter height. The population is about 8,200. In Hachijo Island, geothermal power plant start from 1999 with 3.3MW flush type system. This is enough for base load electricity and several diesel generator exist to cover peak time electricity.

In Hachojo Island, several hot spring resort and hotel exist for tourist. Due to remote-island from Tokyo, tourism including hot spring resort is very important.

4.2 Sampling point at Hachijo Island

The survey of hydrogen and oxygen isotope is carried out the south part of Hachijo Island as shown in Figure 7 (AIST, 2011). The sample collected at six cold springs about 10 degree C as meteoric underground water, at four hot springs about 40 to 60 degree C and the fluid of the geothermal power plant about 200 degree C. And sea water is sampled due to two of four hot spring face to sea (Pacific Ocean).

4.3 Result of isotope analysis

The hydrogen and oxygen isotope diagram of cold springs, hot springs, geothermal fluid and sea water of Hachijo Island is shown in Figure 8.

Firstly the isotope ratio of hydrogen and oxygen of river water are about -32 ‰ and -6 ‰ respectively. These value is near line of $\delta D=8\delta^{18}O+8$. According to the isotope study of rain in Hachijo Island, the hydrogen and oxygen isotope ratio exist between line of $\delta D=8\delta^{18}O+24$ and line of $\delta D=8\delta^{18}O+8$ (Machida et al., 2005). The isotope data of cold spring water is match to that of rain and the origin of cold spring water is meteoric water.

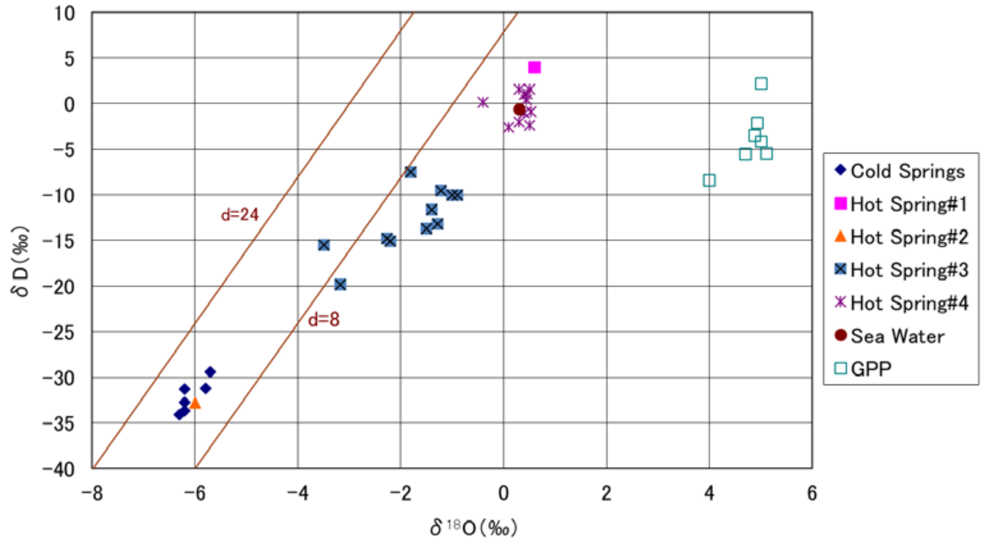

Figure 8: Isotope diagram of cold and hot springs fluid in Hachijo Island field.

The isotope ratio of hydrogen and oxygen of hot spring has wide range. The isotope ratio of hydrogen and oxygen of Hot spring #2 near sampling point of cold water are -32.8 ‰ and -6 ‰ respectively. These value are almost same as those of cold springs and the origin of hot spring #2 is meteoric water as same as cold springs.

On the other hand, the isotope ratio of hydrogen and oxygen of Hot spring #1 are 4 ‰ and 0.6 ‰ respectively. The oxygen ration is higher than meteoric water line and near from sea water.

The range of isotope ratio of hydrogen and oxygen of Hot spring #4 are from 1.6 ‰ to -2.6 ‰ and from 0.5 ‰ to -0.4 ‰ respectively. The average value of those of Hot spring #4 is almost same as those of sea water. And Cl concentration of Hot spring #4 is about 19,000 mg/L and similar as sea water. Then the origin of Hot spring #4 seem to be sea water.

The range of isotope ratio of hydrogen and oxygen of Hot spring #3 are from -7 ‰ to -20 ‰ and from -0.9 ‰ to -3.5 ‰ respectively. And these value are on line between cold spring water and sea water. And Cl concentration of Hot spring#3 shows from 6,400 to 12,000 mg/L and about half of Hot spring#4 and sea water. Then the origin of Hot spring#3 seem to be mixing of sea water and meteoric water.

The range of isotope ratio of hydrogen and oxygen of fluid of geothermal power plant from 2 ‰ to -8 ‰ and from -5 ‰ to 4 ‰ respectively. And the oxygen isotope ratio is quite higher than meteoric water and sea water. And Cl concentration of geothermal power plant is about 2,500 mg/L. Then the origin of fluid at geothermal power plant is not meteoric water or sea water. The origin seem to be magmatic fluid or mixture of magmatic water and meteoric water.

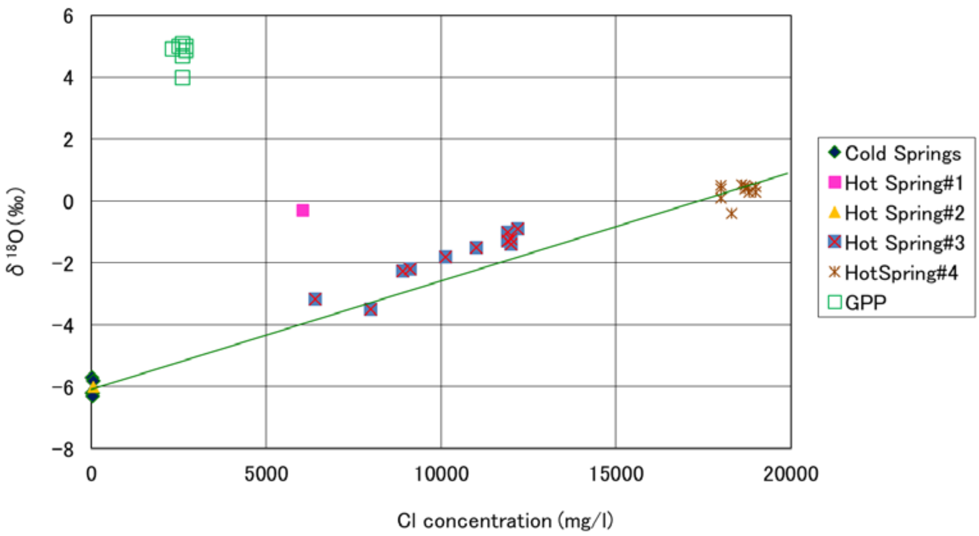

Figure 9: Relationship between Cl concentration and oxygen isotope of hot spring fluid in Hachijo Island field.

Figure 9 shows the relationship between Cl concentration and oxygen isotope. In the relationship between, cold spring water and Hot spring #2, Hot spring #3 and Hot spring #4, the higher Cl concentration fluid shows higher oxygen isotope ratio. These four data exist on one line. This suggest that Hot spring #3 is mixed fluid of sea water and meteoric water. On the other hand, the fluid at geothermal power plant is higher oxygen isotope ration than the line from sea water to meteoric water. This suggest the origin of geothermal fluid is different from other hot springs and the geothermal fluid production do not influence the production of hot springs in Hachijo Island.

5. CONCLUSION

To understand origin of hot spring fluid and the relationship with meteoric water, sea water and geothermal fluid, we surveyed the isotope behavior at several hot spring fields.

In Matsunoyama hot spring field, the hot spring fluid of Takanoyu #3 is about 100 degree C and 10,000 mg/l Cl. The hydrogen and oxygen isotope ratio of Takanoyu#3 is -21.8 ‰ and 1.8 ‰ respectively and theoxygen isotope ratio is about 1.8 ‰ higher than meteoric water. The origin of Takanoyu#3 is fossil salt water with methane gas and geo-pressure structure.

In Hachijo Island, the hot spring fluid has two kind properties. One is the origin of meteoric water and another is the origin of seawater due to similar isotope ratio as seawater. The isotope ratio and Cl concentration of fluid in geothermal plant suggests that the fluid origin of geothermal plant is mainly magmatic water slightly mixing with meteoric water and isolated from hot spring fluid..

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