GEOTHERMAL FEATURES OF THE YONEZAWA DISTRICT, NORTHEAST JAPAN

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ABSTRACT

Yonezawa district located in the northeast of Japan, has many spring areas. Yonezawa district is geologically composed of the pre-Tertiary basement rocks, Tertiary formations, Pliocene to Pleistocene deposits, and Quaternary volcanoes. Geothermal features in this area are clustered into two groups whether related to quaternary volcanoes. Geothermal resources related to quaternary volcanoes such as Azuma is accompanied by high temperature hot springs and hydrothermal alteration zones on the surface at present. Volcanic activity of Azuma volcano is geologically divided into three stages during the period from 1.3 to 0.08Ma by K-Ar dating. The center of volcanic activity moved from west to east and recent products erupted from fresh craters in the eastern part of the volcano. Azuma volcano is distributed within the up rift zone and volcanic rocks erupted from it are mainly andesitic. The Ubayu depression is also located within the up lift zone and filled with acidic welded tuff. The Ubayu hot spring, situated near the Ubayu depression, is associated with an acidic alteration zone characterized by kaolinite, alunite and pyrophyllite. In Azuma area, maximum temperatures of the exploration wells are above 200 ^{o}C. The cold geyser of Hirogawara hot spring, situated in the west of Azuma volcano, is activated by the evolution of carbon dioxide. The other side many non-volcanic hot springs are scattered mainly along the Yonezawa Basin. The high temperature hot springs Akayu is situated on margin of the Yonezawa Basin and in volcano-tectonic depressions, which is filled with submarine acidic pyroclastic flow of 1,500m thick. The Akayu depression, corresponding to low gravity anomaly, characterizes the geomorphology of this area and has a suitable structure favorable for thermal waters.

Keywords: Yamagata prefecture, Yonezawa district, geothermal resource, hot spring, Ubayu, Akayu, Hirogawara

1. INTRODUCTION

Japan has more than 3,000 hot spring areas and it is the most advanced country for the utilization of hot springs in the world. Yamagata prefecture has about 180 hot spring areas, more than 400 hot spring sources, and total flow rate from these hot springs is about 52,000 L/min (Yamagata Pref., 2013). Figure 1 shows geothermal resources map of Yamagata prefecture. Hot spring water is believed to be good for the treatment of chronic disease and the promotion of health, and Japanese people enjoy the hot springs. Several hot springs, such as the Zao and the Akayu hot spring, have been found and used for bathing for about a thousand years. Especially, the Akayu hot spring used to be visited by the Uesugi house, which is famous feudal lord (daimyo) of the Edo period. The Uesugi house, also, built a palace at the Akayu hot spring in 17th century (Nanyo city, 1994).

Yonezawa district located in the south of Yamagata prefecture, has about 30 hot spring areas. Yonezawa district is geologically composed of the pre-Tertiary basement rocks, Tertiary formations, Pliocene to Pleistocene deposits, and Quaternary volcanoes. Geothermal features in this area are clustered into two groups whether related to quaternary volcanoes. In Yamagata prefecture, the geothermal investigations of these were carried out from late 1960's by Yamagata prefectural office (Tamiya, et al., 1973), after that the nationwide survey was carried out by the Japanese government from 1980's. The geothermal development promotion survey was carried out by the New Energy and Technology Development Organization (NEDO) at Azuma area in Yonezawa district. The exploratory wells were drilled by NEDO and temperature profiles of these were made clear.

2. GEOLOGICAL STRUCTURE

The geography of Yamagata prefecture is characterized by mountain ranges and inland basins. The Ou and the Uetsu

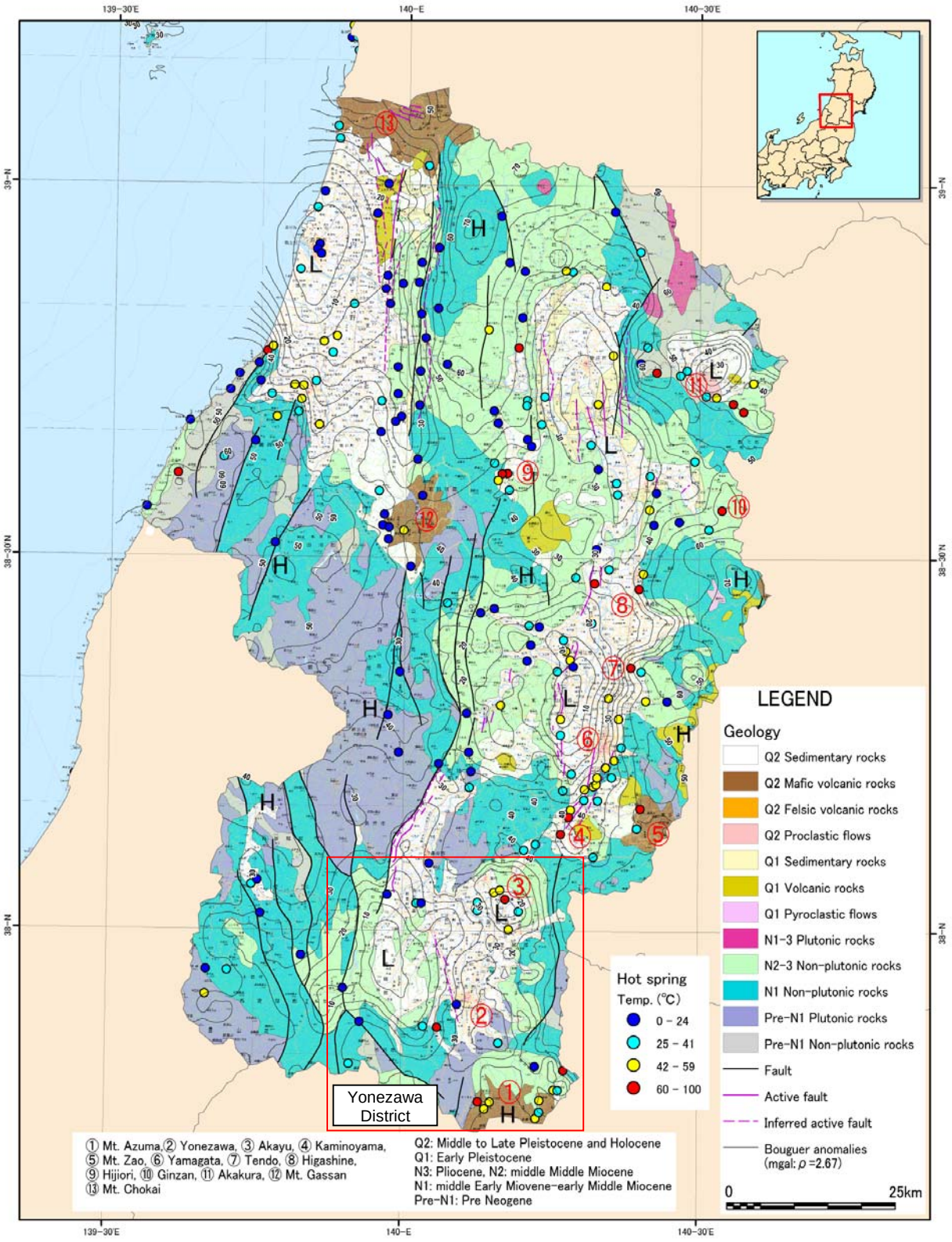

Fig.1 Geothermal resources map of Yamagata prefecture. (modified after Sakaguchi and Takahashi, 2002)

mountains, forming north-south trending uplift zones in the area, are distributed eastern region and central region of Yamagata prefecture, respectively. Inland basins are situated between the Ou and the Uetsu mountains and are divided by the E- W trending uplift zones (Tamiya, 1983).

Yamagata prefecture is geologically composed of the pre-Tertiary basement rocks, Tertiary formations, Pliocene to Pleistocene deposits, and Quaternary volcanoes (Fig. 1). The basement rocks of this area are composed mainly of hornfels, gneiss and granitic rocks, and they are distributed in the southwestern region and in the eastern environs of the Yamagata Basin and Yonezawa basin. K-Ar ages of the granitic rocks show the Middle to the Late Cretaceous (Sugai, 1985). The Tertiary formations, unconformably overlying on or in fault contacting with the basement rocks, are extensively distributed in this area. The Tertiary formations of the area, so-called Green Tuff, are mainly products of submarine volcanic activity. These formations are composed mainly of sedimentary rocks in western region, but mainly of submarine volcanic rocks in eastern region. Pliocene to Pleistocene deposits consists mostly of sands and silts. Quaternary volcanoes are Funagata, Zao and Azuma in the Ou mountains, and Chokai, Gassan, Hayama, and Hijiori in the Uetsu mountains.

Figure 2 shows the chemical compositions of the major high temperature hot springs in study area. The chemical compositions of hot springs can be grouped into three water types, (a) Neutral pH, Cl-HCO_3/SO_4 type thermal water (Akayu, Ginzan, Higashine, Hijiori hot spring), (b) Neutral pH SO_4 type thermal water (Tendo, Akakura, Shirabu hot spring), (c) Acidic pH, SO_4 type thermal water (Zao, Ubayu hot spring). Fig. 3 shows a relation between $\delta^{18}O$ and δD for thermal waters from Azuma, Ginzan and Akakura areas. Most of the thermal waters of the hot springs plots within the meteoric water line.

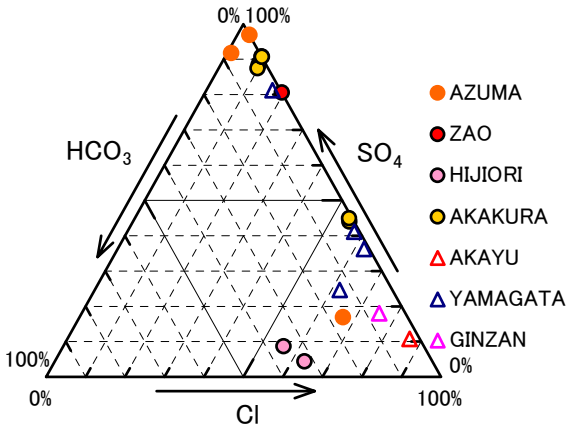

Fig.2 Chemical compositions of the major high temperature hot springs in Yamagata Pref.

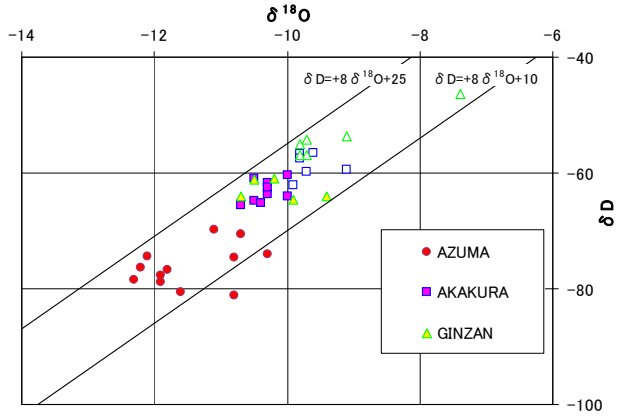

Fig.3 Relation between $\delta^{18}O$ and δD for thermal waters from Azuma, Ginzan and Akakura geothermal fields.

Yonezawa district is located in the southern part of Yamagata prefecture. The southern part of the Yonezawa district is situated in the margin of the Ou mountains, which is uplift zone and geologically composed of basement rocks and Azuma volcanic rocks. On the other side, the northern part of this district is an inland basin called the Yonezawa basin.

3. GEOTHERNAL FEATURES

3.1 The Azuma Area

The Azuma area, related to Azuma volcano, is located south of Yamagata Prefecture and has many hot springs. The Azuma volcanic rocks overlie unconformably the Tertiary formations and granitic basement rocks. Volcanic activities are geologically divided into three stages during the period from 1.3 to 0.08Ma by K-Ar dating (NEDO, 1991b). The center of volcanic activity moved from west to east and recent products erupted from fresh craters in the eastern part of the volcano. The geothermal structure of Azuma area is characterized by E-W trending up rift zone and two depression zones of the Ubayu depression and the Namekawa east depression. Azuma volcano is distributed within the up rift zone and volcanic rocks erupted from it are mainly andesitic. The Ubayu depression is also located within the up lift zone and filled with acidic welded tuff. The Namekawa east depression zone is situated north of the up rift zone. The Ubayu hot spring, situated near the Ubayu depression, is associated with an acidic alteration zone characterized by kaolinite, alunite and pyrophyllite (Fig. 4). The Ubayu alteration zone is extended over about 10km^2 (Kimbara and Sakaguchi, 1989),

Fig.4 Hydrothermal alteration zones at the Ubayu hot spring.

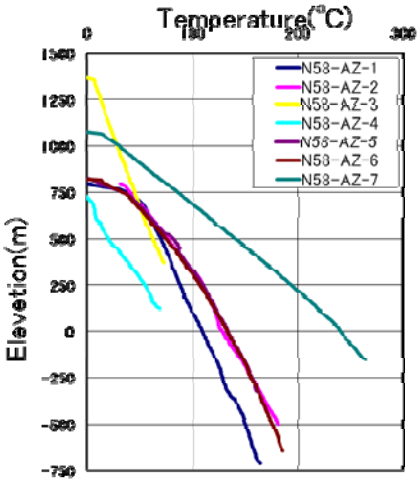

Fig.5 Temperature profiles of the Azuma geothermal field.

The discharge temperature of the Ubayu acid SO_4 type of hot spring is 49 °C (Takahashi et al., 1993). The Shirabu hot spring is discharged from granitic basement rocks in the southern margin of Azuma area and has discharge temperatures of 58-62°C (Yamagata HSA, 1973). The Goshiki spring is situated on the western margin of the Namekawa east depression. The discharge temperature of the Goshiki hot spring is 47 °C and chemical composition of hot spring is neutral-pH HCO_3 type (NEDO, 1991a). The hot spring water discharged from the well about 100 °C was recorded on the east margin of the depression (Abiko, 1990). As shown in Fig. 3, hydrogen and oxygen isotope compositions of thermal waters are plotted close to the meteoric water line, suggesting the water originated from meteoric water. Thermal waters from the well show a little oxygen isotopic positive shift, which can be explained by a water- rock interaction.

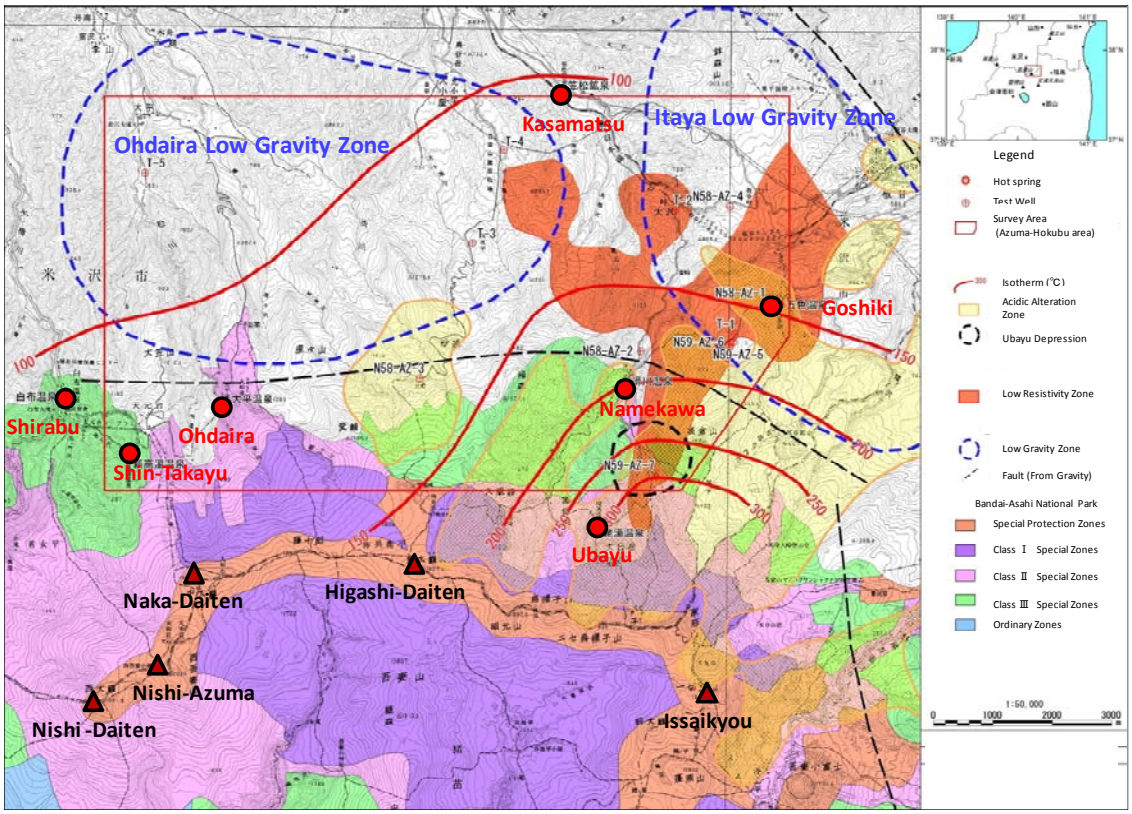

Fig.6 Geothermal interpretation map of the Azuma geothermal field.

Drilling was conducted at depths between 600 and 1,500 meters by NEDO and the temperatures of 67 °C to 267°C were encountered (Fig.5). The Ubayu depression was confirmed by drilling well named N58-AZ-7 which encountered a temperature of 267 °C. The geology of well AZ-7 is mainly composed of the Azuma volcanic rocks and the Ubayu welded tuff. The Azuma volcanic rocks are mainly composed of andesite lava with minor intercalations of andesitic tuff. The Ubayu welded tuff is composed of welded tuff, tuff breccia and basal conglomerate. The alteration minerals of the well AZ-7, from shallow to deeper zone, are characterized by smectite, smectite/chlorite mixed-layer, chlorite and wirakite. These alteration minerals indicate high-temperature (>200℃) neutral- pH geothermal fluids. Fig. 6 shows geothermal structure of the Azuma area. It seems that the high geothermal potential area is distributed in southeast area.

3.2 The Hirogawara Area

The cold geyser of Hirogawara hot spring, situated in the west of Azuma volcano, is activated by the evolution of carbon dioxide. The temperature of the thermal waters discharged from well, drilled to the depth of 88m, is 35 °C (Ishii, 2006). The travertine is distributed in the spread of 50m x 50m around the hot springs (fig.7).

3.3 The Akayu area

The Akayu area is located at the north margin of Yonezawa basin in southern Yamagata prefecture and the related volcano-tectonic depression was formed in late Miocene. Akayu depression is filled with submarine acidic pyroclastic flow of 1,500m thick (Honda et al., 1985). Akayu depression, which corresponds to low gravity anomaly (Fig.1), characterizes geological structure of this area and has a suitable structure for providing favorable conditions for thermal waters. Several hot springs are distributed in Akayu depression including the Akayu hot spring situated in the central part of Akayu depression (Fig.8). According to the result of geological survey, it is considered that the fracture trending NE-SW is developed around the Akayu hot spring. The shallow geothermal system in this area seems to be controlled by the NE-SW fracture system. The temperature of the thermal waters discharged from well, drilled to the depth of 400m, is 63 °C. Geochemical characteristics of thermal waters from the Akayu hot spring are neutral chloride type and chloride concentration is 1,118mg/l (Takahashi et al., 1993).

Fig.7 The geyser and the travertine in Hirogawara hot spring.

Fig.8 Akayu hot spring is located at the north margin of the Yonezawa basin.

4. CONCLUSIONS

Geothermal features of Quaternary volcanic areas have many indications for existence of geothermal resources such as fumaroles, acid SO_4 type hot springs and hydrothermal alteration zones on the surface. The Azuma area is accompanied by high temperature hot springs and hydrothermal alteration zones. Volcanism of the area started at about 1Ma. In the Azuma area, the maximum temperatures of the exploration wells are above 200 °C. Many hot springs, not directly related to volcanic activities, are situated mainly along the Yonezawa basin. Some of the high temperature hot spring such as Akayu is situated on the margins of these basins and in volcano-tectonic depressions, which are suitable structures for thermal waters reservoirs. There are several promising areas for geothermal energy utilization in the Yonezawa district. A continuous investigation for geothermal resource utilization is, therefore, necessary in the future.

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