GEOTHERMAL RESOURCES IN YAMAGATA PREFECTURE, NORTHEAST JAPAN

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ABSTRACT

Yamagata prefecture, located in the northeast of Japan, has more than 100 hot spring areas and hot spring is used for mainly bathing. The geothermal investigations of these were carried out from late 1960's by Yamagata prefectural office, then after that the nationwide geothermal survey was carried out from 1980's. In Yamagata prefecture, the geothermal development promotion surveys were conducted by NEDO in Hijiori, Azuma, Ginzan and Akakura areas. Geothermal resources related to quaternary volcanoes such as Azuma, Zao, and Hijiori areas, are accompanied by high temperature hot springs and hydrothermal alteration zones on the surface at present. A large quantity of thermal waters (above 60 ^{o}C) gushes out in the Zao hot spring. Azuma and Hijiori areas are related with volcanic depression and maximum temperatures of the exploration wells are above 200 ^{o}C. Akakura area related with caldera is accompanied by high temperature thermal waters (70 ^{o}C). Many non-volcanic hot springs are scattered mainly along the Yonezawa Basin and the Yamagata Basin. Some of the high temperature hot springs such as Akayu, Kaminoyama, Tendo and Higashine are situated on margin of these basins or in volcano-tectonic depressions, which are suitable structures for thermal waters reservoirs. In Yamagata prefecture, there are several promising areas for the small-scale geothermal power development. It is considered to be necessary to continue investigation for geothermal development.

Keywords: Yamagata prefecture, geothermal resources, hot spring, Azuma, Zao, Akayu, Hijiori, Ginzan

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, also, has more than 100 hot spring areas and hot spring is used for mainly bathing (Fig. 1). 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).

Yamagata prefecture has many Quaternary volcanoes with high temperature hot springs and hydrothermal alteration zone, and 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. In Yamagata prefecture, the geothermal development promotion survey was carried out by the New Energy and Technology Development Organization (NEDO) in Hijiori, Azuma, Ginzan and Akakura areas. The exploratory wells were drilled by NEDO and temperature profiles of these were made clear (Fig. 2).

The current technology of the binary cycle geothermal power generation system enables us to develop the small-scale geothermal power plants and the binary Kalina cycle expanded the power generation sources to most of the temperatures of hot spring (Muraoka et al. 2004). The areas of geothermal resource were generally categorized into following three types: 1. geothermal resources area related to Quaternary volcanoes; 2. geothermal resources area not related to Quaternary volcanoes; 3. deep-seated hot water resource area (Sakaguchi and Takahashi, 2002). This paper deals with the areas of the former two types. The purpose of this paper is to review the geothermal resources in Yamagata prefecture and to promote the small-scale geothermal power development.

2. Geological structure

The geography of Yamagata prefecture is characterized by mountain ranges and inland basins. The Ou and the Uetsu mountains, forming north-south trending uplift zones in the area, are distributed eastern region and central region of

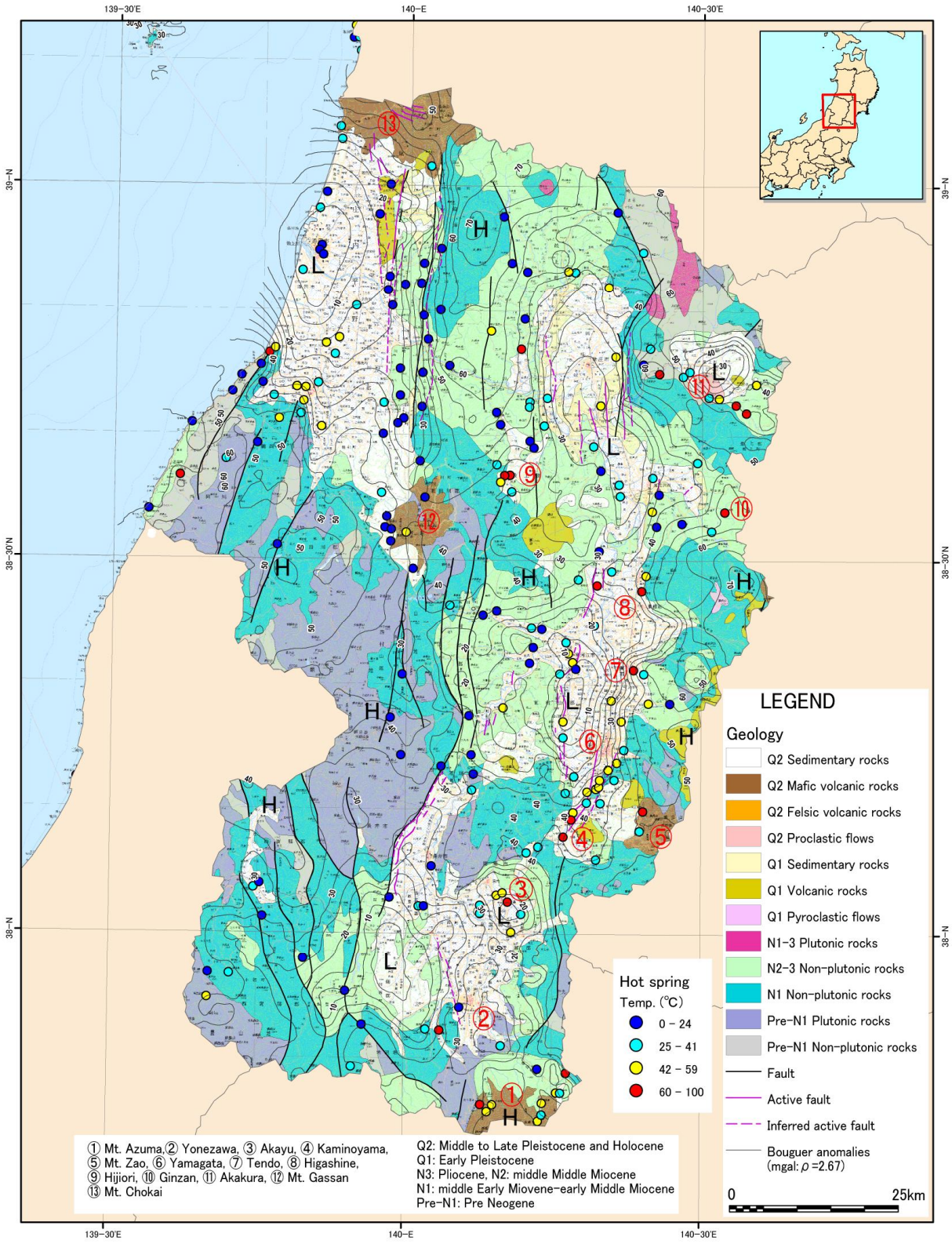
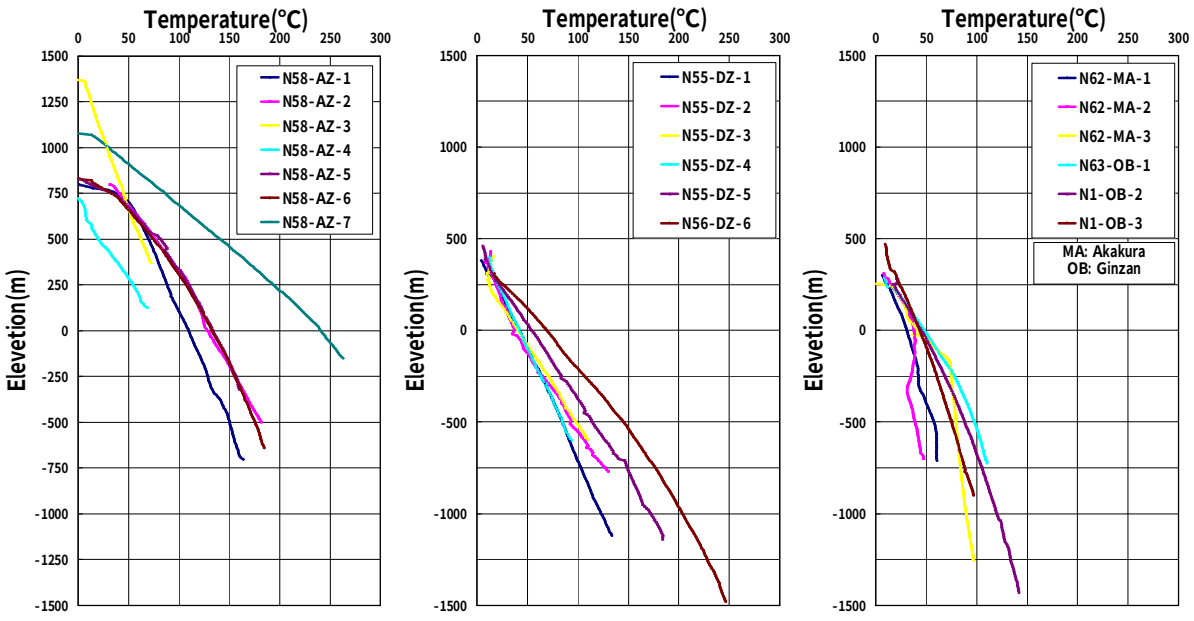


Fig.1 Geothermal resources map of Yamagata prefecture. (modified after Sakaguchi and Takahashi, 2002)



(1) Azuma (2) Hijiori (3) Akakura, Ginzan

Fig.2 Temperature profiles of geothermal wells.

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. 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 consist 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.

3. Geothermal features

3.1 The areas related to Quaternary volcanoes

Geothermal resources related to quaternary volcanoes are accompanied by high temperature hot springs, and are believed to be caused by volcanic activity in the area. These areas have many indications for existence of geothermal resources such as SO_4 type acid hot springs and hydrothermal alteration zones on the surface at present.

The Azuma area, related with Azuma volcano, is situated in the south of Yamagata Prefecture and is accompanied by many hot springs. The Ubayu hot spring is discharged from acidic alteration zone characterized by kaolinite, alunite and pyrophyllite (Fig. 3). The discharge temperature of the Ubayu hot spring is 49 °C and type of hot spring is acid SO_4 type (Takahashi et al., 1993). The Shirabu hot spring is discharged from granitic basement rocks in the southern margin of Azuma area and the discharge temperatures are 58-62°C (Yamagata HSA, 1973). The hot spring water discharged from the well higher than 100 °C was recorded in this area (Abiko, 1990). The New Energy and Technology Development Organization (NEDO) drilled at a depth of between 600 and 1,500 meters and the temperatures of 67 to 267°C were encountered (NEDO, 1987). Geothermal structure of Azuma area is characterized by Azuma volcano and a depression called "Ubayu depression" (NEDO, 1987). The Ubayu depression was confirmed by drilling well named N58-AZ-7 which encountered temperature of 267 °C.

Fig.3 Hydrothermal alteration zones at the Ubayu hot spring.

Fig.4 The Zao crater lake (Okama).

The Zao area, related with Zao volcano, is situated in the east of Yamagata prefecture and is accompanied by the Zao hot spring and fumaroles. Zao volcano is famous for large crater lakes (Fig. 4). The Zao hot spring is discharged from volcanic rock in the explosion crater extending about 3 km wide. The discharge temperature of the Zao hot spring is 65^{o}C (Takahashi et al., 1993) and discharge rate 5,000 l/min (Yamagata pref., 2008). The Zao hot spring is also acid type hot spring but the major difference from the Ubayu hot spring is the presence of relatively high chloride concentration and strongly acidity. The high chloride concentration is 665mg/l and pH is 1.3, suggesting that the origin of dissolved sulfate and chloride may be from high temperature volcanic gases.

The Hijiori area, related with Hijiori caldera, is situated at the center of Yamagata prefecture and is accompanied by the Hijiori hot spring. The Hijiori hot spring is discharged from Hijiori caldera of about 2km across and the discharge temperature is 84 ^{o}C (Takahashi et al., 1996). Hijiori volcano erupted about 10,000 years ago with collapse of caldera. The Hijiori hot spring is neutral Cl-HCO_3 type hot spring with relatively high chloride concentration of 1,390mg/l. NEDO drilled to depth of between 1,000 and 1,800 meters and encountered temperature of 94 to 248 ^{o}C (NEDO, 1983). NEDO, also, conducted research on HDR (Hot Dry Rock) development techniques from FY1985 to FY2002. In this project, three wells were drilled at a depth of around 2,300 meters, and a heat extraction experiment called "Long-term Circulation Test" was conducted at Hijiori test site to study the life of the HDR reservoir (Oikawa and Tosha, 2001).

The Akakura area, related with the Mukaimachi caldera (Ui and Shibahashi, 1985), is situated in the northeast of Yamagata prefecture and is accompanied by the Akakura hot spring. The Akakura hot spring is discharged from the central part of Mukaimachi caldera and the discharge temperature is 74 ^{o}C (Takahashi et al., 1996). The Akakura hot spring is neutral SO_4 type hot water. NEDO drilled at a depth of between 1,000 and 1,500 meters and encountered temperature of 47 to 97 ^{o}C (NEDO, 1990).

3.2 The areas not related to Quaternary volcanoes

Many non volcanic related hot springs are scattered mainly along the Yonezawa basin (Fig.5) and Yamagata basin. Some of the hot springs are situated at margin of these basins or in volcano-tectonic depression.

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.6). 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 ^{o}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).

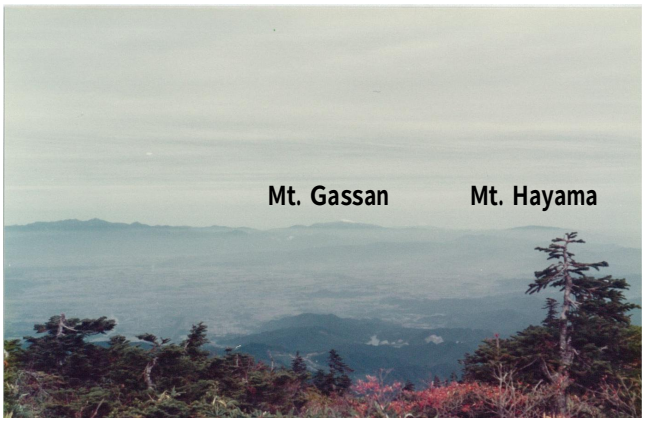


Fig.5 The Yonezawa basin

Fig.6 A footbath and thermal waters tanks at the Akayu hot spring.

Many hot springs, such as the Kaminoyama, Tendo and Higashine, are distributed along the margin of Yamagata Basin, which is formed by tectonic movement controlled by the NNE-SSW fault system. The Kaminoyama hot spring is situated in southern part of Yamagata basin. The thermal waters are discharged from shallow wells that encountered granitic rocks with temperatures of about 70 ^{o}C (Takahashi et al., 1993). The Tendo and Higashine hot springs are situated in northeastern corner of Yamagata basin. Thermal waters of the Higashine hot spring with temperatures of 49 to 70 ^{o}C are pumped from six production wells drilled to depths of 120 to 130m (Urakami, 1994). Three production wells are drilled to depths of 180 to 220m at the Tendo hot spring and the discharge temperatures are 61 to 69 ^{o}C (Urakami, 1995). The aquifers of these consist of mainly Quaternary sediments, and thermal waters arise from deep permeable aquifers spread out in the area.

The Ginzan area is located northeastern up-lift zone and is accompanied by the Ginzan hot spring. Thermal waters with temperatures of 45 to 64 ^{o}C gush out along the Ginzan River. NEDO drilled to depths of between 1,000 and 1,700 meters and temperatures of 97 to 142 ^{o}C were encountered (NEDO, 1991).

4. SUMMARY

Geothermal resources in Yamagata prefecture are clustered into two groups whether related to quaternary volcanoes. Geothermal resources related to quaternary volcanoes are accompanied by high temperature hot springs and hydrothermal alteration zones at the surface at present. Azuma and Zao areas are accompanied by high temperature hot springs and hydrothermal alteration zone. High temperature thermal waters (above 60 ^{o}C) gush out in the Zao hot spring. Azuma and Hijiori areas are related with volcanic depression and the maximum temperatures of the exploration wells are above 200 ^{o}C. Akakura area related with caldera is accompanied by high temperature thermal waters (70 ^{o}C). Many non volcanic related hot springs are situated mainly along the Yonezawa basin and the Yamagata basin. Some of the high temperature hot springs such as Akayu, Kaminoyama, Tendo and Higashine are situated at margin of these basins or in volcano-tectonic depression, which have a suitable structure for thermal waters reservoirs. It is considered that the high temperature hot springs facilitated by central control system of the thermal waters are suitable for the thermal waters utilization. In Yamagata prefecture, there are several promising areas for the small-scale geothermal power development. It is considered that further continue investigation for geothermal development is necessary.

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