Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Geothermal Resources of the Yonezawa District in Yamagata Prefecture, Northeast Japan.

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Keywords: Yamagata, Yonezawa, Azuma, Akayu, geothermal, geology, volcano, hot spring

ABSTRACT

The Yonezawa district, located in the northeast Japan, has many spring areas. The area is underlay by pre-Tertiary basement rocks, Tertiary formations, Pliocene to Pleistocene deposits, and Quaternary volcanoes. Geothermal resources in this area are clustered into two groups whether related to quaternary volcanoes or not. Geothermal resources related to quaternary volcanoes such as Azuma are accompanied by high temperature hot springs and hydrothermal alteration zones on the surface at present. 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 is filled with acidic welded tuff. The Ubayu hot spring, situated near the Ubayu depression, located north of Azuma volcano, is associated with an acidic alteration zone characterized by kaolinite, alunite and pyrophyllite. In the Azuma area, maximum temperatures recorded in the exploration wells are above 260 ^{o}C. The second group is made of many non-volcanic hot springs, which are scattered mainly along the Yonezawa Basin. The high temperature hot springs of Akayu is situated on the margin of the Yonezawa Basin and in a volcano-tectonic depression, which is filled with thick submarine acidic pyroclastic flows. The Akayu depression, corresponding to a low gravity anomaly, characterizes the geomorphology of this area and has a suitable structure favorable for thermal waters.

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 with a total flow rate of about 52,000 l/min (Yamagata, 2013). Figure 1 shows a map with geothermal resources 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 one thousand years. Especially, the Akayu hot spring used to be visited by the Uesugi house, which is a 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 is located in the south of the Yamagata prefecture, has about 30 hot spring areas (Figure 1). Yonezawa district is geologically composed of pre-Tertiary basement rocks, Tertiary formations, Pliocene to Pleistocene deposits and Quaternary volcanoes. Geothermal resources in this area are clustered into two groups whether they are related to quaternary volcanoes. In Yamagata prefecture, geothermal investigations of these springs were carried out from late 1960's by Yamagata prefectural office (Tamiya et al., 1973). After that, a nation-wide 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 the Azuma area in the Yonezawa district. The exploratory wells were drilled by NEDO and temperature profiles of these wells were made clear.

2. GEOLOGICAL FEATURES

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

Yamagata prefecture is geologically composed of 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 and Yonezawa basin. K-Ar ages of the granitic rocks show Middle to the Late Cretaceous ages (Sugai, 1985). The Tertiary formations, unconformable overlying 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 the western region and mainly of submarine volcanic rocks in the 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.

The 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 an uplift zone 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.

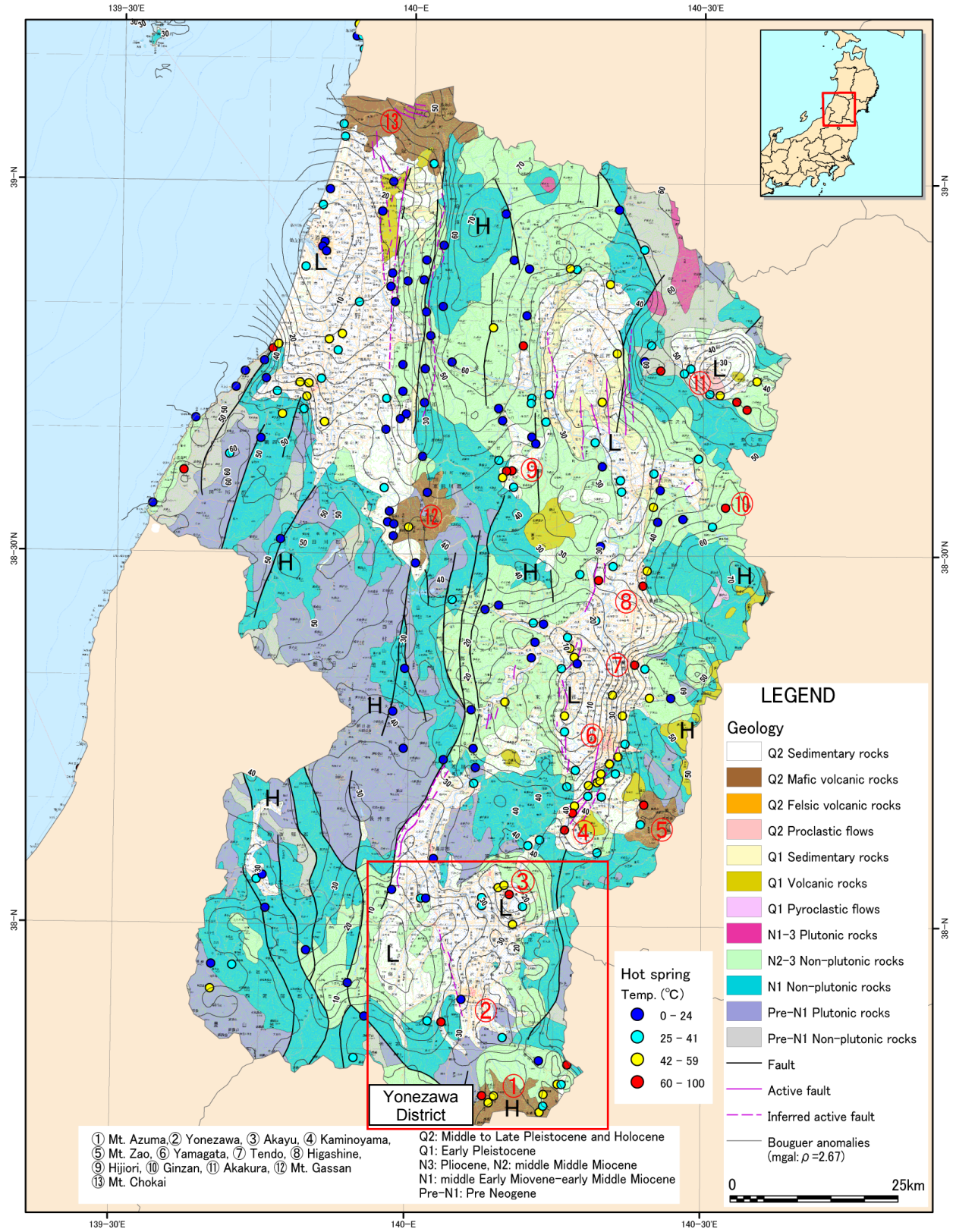


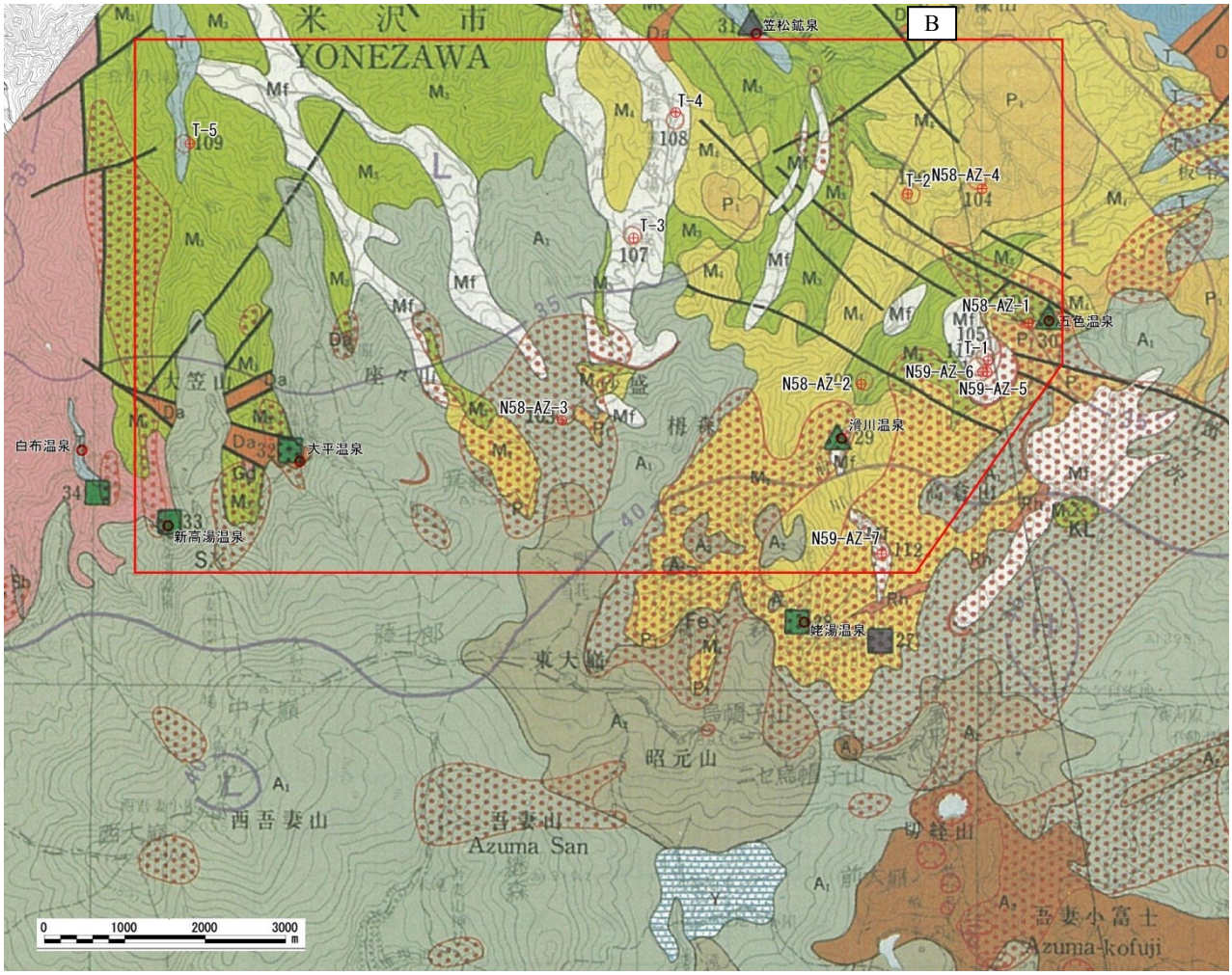
Figure 1: Map with geothermal resources of the Yamagata prefecture (Modified after Sakaguchi and Takahashi, 2002).

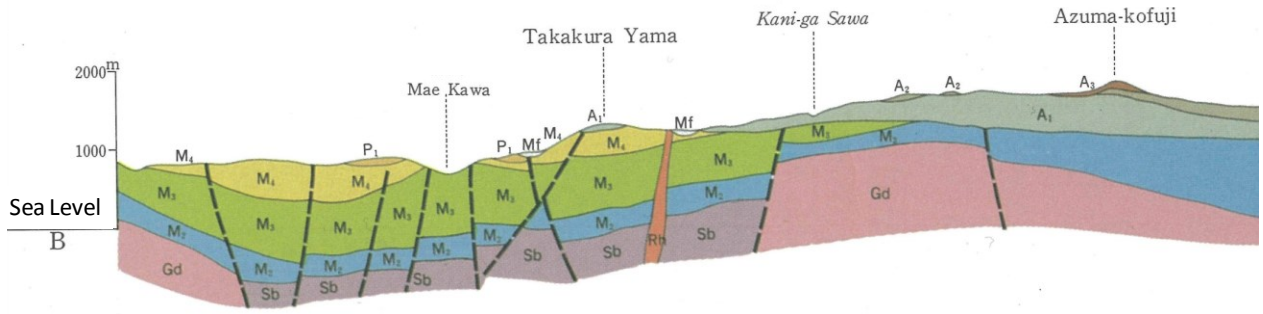
3. GEOTHERMAL RESOURCES

3.1 The Azuma Area

The Azuma area, related to the Azuma volcano, is located south of Yamagata Prefecture and has many hot springs. The Azuma volcanic rocks unconformably overlie Tertiary formations and granitic basement rocks (Figure 2). Volcanic activity is 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 main volcano. The geothermal structure of the Azuma area is characterized by an E-W trending rift zone and two depression zones, the Ohdarira and the Itaya

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 tuffs. The Ohdaira and the Itaya depression zones are 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 (Figures 2 and 3). The Ubayu alteration zone is extended over about 10km^2 (Kimbara and Sakaguchi, 1989).





Legend

T: Gravel	A3: L-Stage Azuma Vol.	P1: Pliocene Volcanic Rocks	Gd: Granitic Rocks
Mf: Mudflow, Debris	A2: M-Stage Azuma Vol.	M4: L-Miocene Volcanic Rocks	A: Acidic Alteration
Y: Yachidaira F.	A1: E-Stage Azuma Vol.	M3: M-Miocene Volcanic Rocks	
	Da: Dacite dyke	M2: E-Miocene Sedimentary Rocks	

Figure 2: Geological Map of Northern Azuma area and geological cross-section (NEDO, 1991).

Figure 3: Hydrothermal alteration zones at the Ubayu hot spring with snow in May 2014.

Discharge temperature of the Ubayu acid, SO_4 type (Figure 4) hot spring is 49 ^oC (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^oC (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 ^oC and its chemical composition of hot spring is neutral-pH, HCO_3 type (NEDO, 1991a). The hot spring water discharged from the well is about 100 ^oC and was recorded on the east margin of the depression (Abiko, 1990). As shown in Figure 5, hydrogen and oxygen isotope compositions of sampled thermal waters plot close to the meteoric water line, suggesting that water is 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 process.

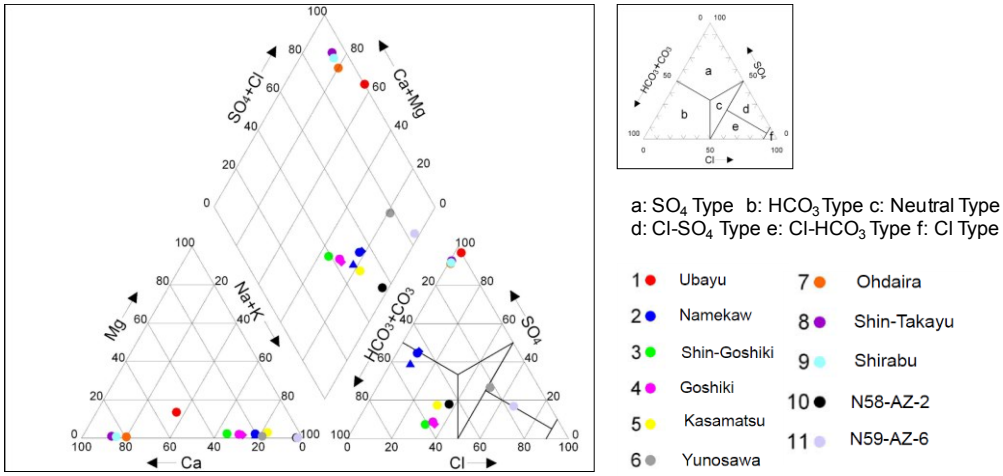


Figure 4: Chemical compositions of the major high temperature hot springs in Azuma geothermal field.

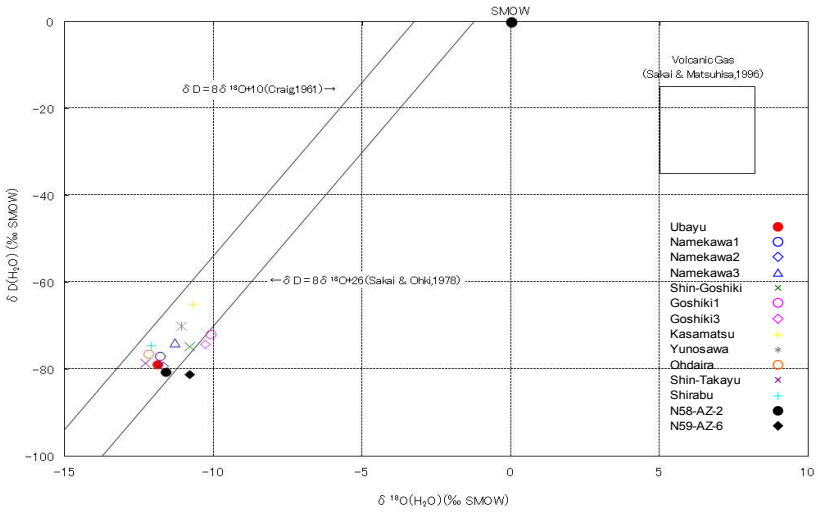


Figure 5: Relation between $\delta^{18}O$ and δD for thermal waters from Azuma geothermal field.

Drilling was conducted at depths between 600 and 1,500 meters and temperatures of 67 ^oC to 267^oC were encountered (NEDO, 1987). The Ubayu depression was confirmed, by drilling a well named N58-AZ-7 which encountered a temperature of 267 ^oC

(Figure 6). 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 lavas with minor intercalations of andesitic tuffs. The Ubayu welded tuff is composed of welded tuffs, tuff breccias and a basal conglomerate. Alteration minerals of the well AZ-7, from shallow to deeper zone, are characterized by smectite, smectite/chlorite mixed-layer, chlorite and wairakite. These alteration minerals indicate high-temperature (>200 °C), neutral- pH geothermal fluids.

The chemical composition of thermal water from well AZ-6 is neutral, Cl-SO_4 type. Thermal fluid from AZ-6 and AZ-2 indicates that there are fluids that reached a partial equilibrium state (Figure 7). It is estimated that fluid in a certain state of equilibrium with rocks of the underground is ascending, and the underground temperature would be comparatively high.

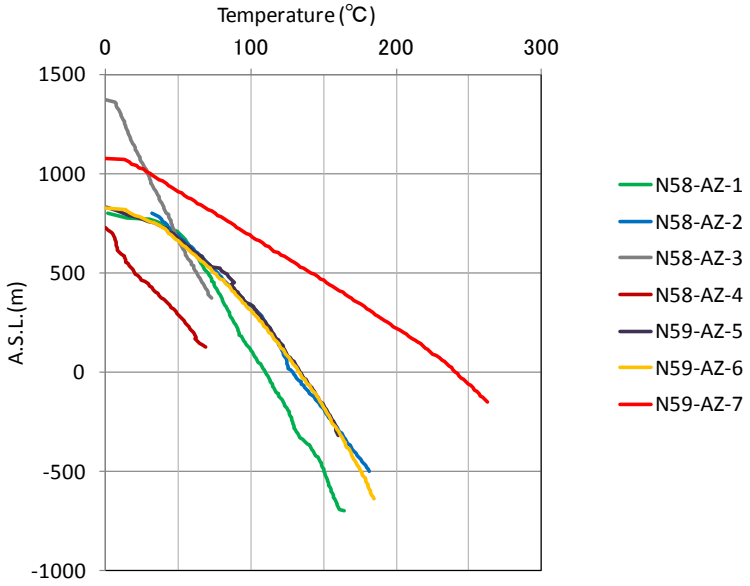


Figure 6: Temperature profiles of the Azuma geothermal field.

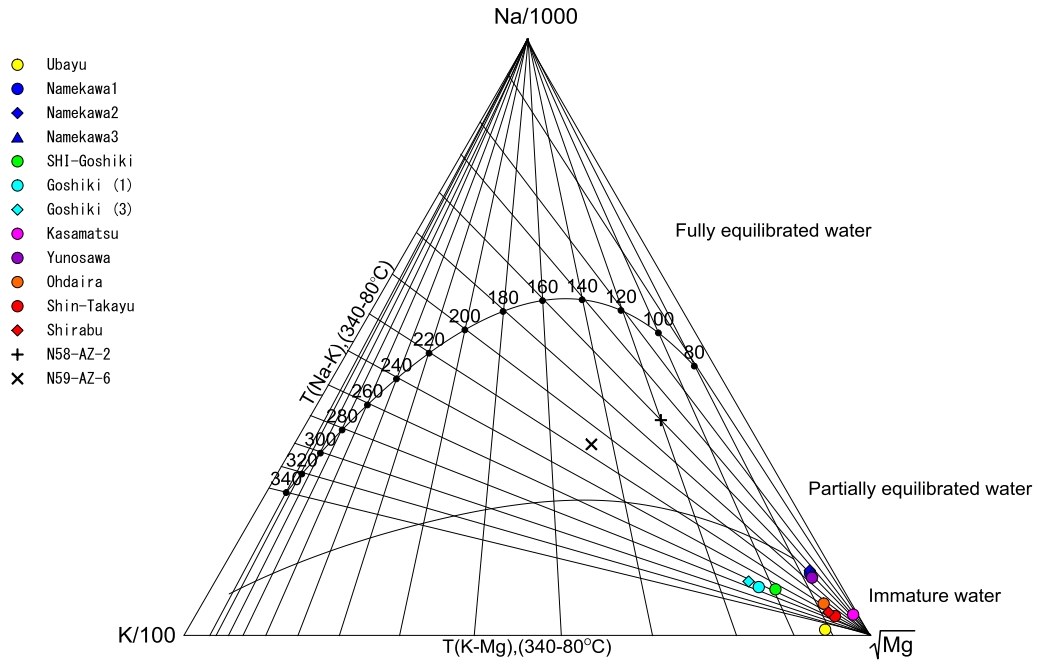


Figure 7: Ternary diagram for Na-K-Mg from Azuma geothermal field.

The Azuma geothermal field is located south of the Yonezawa district. The geothermal structure of Azuma area is characterized by an E-W trending up rift zone surrounded by two depression zones of the Ohdaira and Itaya low gravity zones (Figure 8). Volcanic activity of Azuma volcanoes are divided into three stages during the period from 1.3 to 0.08 Ma. The Ubayu depression is also located within an uplift zone. An acidic alteration zone is distributed southeast of this area and Ubayu hot spring, acid SO_4 type, is gushing out from the acidic alteration zone. Center of geothermal activity in this area is around Ubayu hot spring and an underground temperature of above 260 °C is encountered.

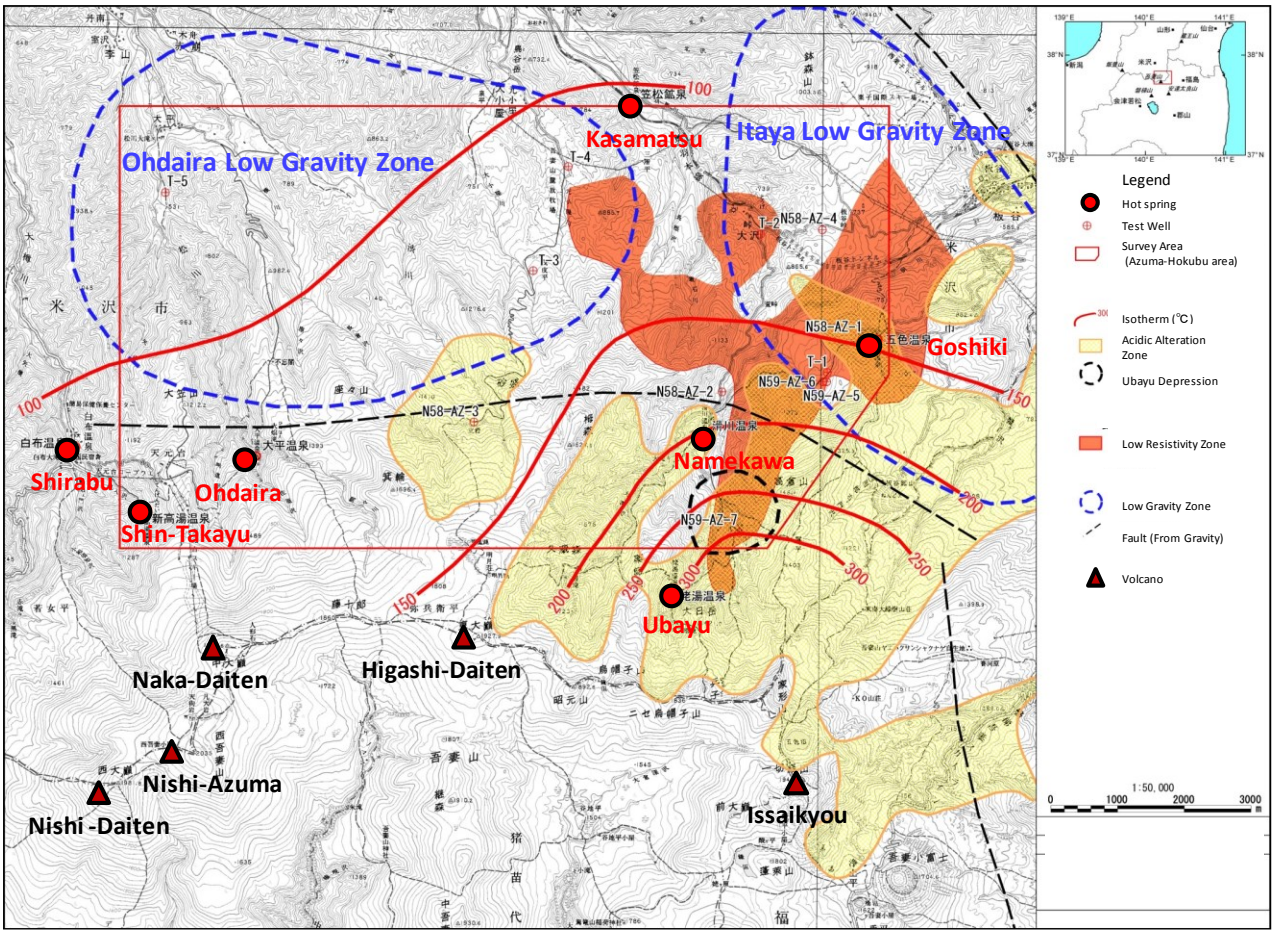


Figure 8: Geothermal interpretation map of the Azuma geothermal field.

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 one well, drilled to the depth of 88m, is 35 ^{o}C (Ishii, 2006). Travertine is distributed in the spread of 50m x 50m around the hot springs (Figure 9).

Figure 9: The geyser and travertine in Hirogawara hot spring.

3.3 The Akayu Area

The Akayu area is located at the northern margin of the Yonezawa basin in the southern Yamagata prefecture. The related volcano-tectonic depression was formed in late Miocene (Figure 10). The Akayu depression is filled with submarine, acidic pyroclastic flows of 1,500m thick (Honda et al., 1985). Akayu depression, which corresponds to a low gravity anomaly (Figure 1), characterizes the geological structure of this area and has a suitable structure for providing favorable conditions for thermal waters. Several hot springs are distributed in the Akayu depression including the Akayu hot spring situated in the central part of Akayu depression (Figure 1). According to the results of the 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 one 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 (Figure 11) and chloride concentration is 1,118mg/l (Takahashi et al., 1993).

Figure10: Akayu hot spring is located at the northern margin of the Yonezawa basin.

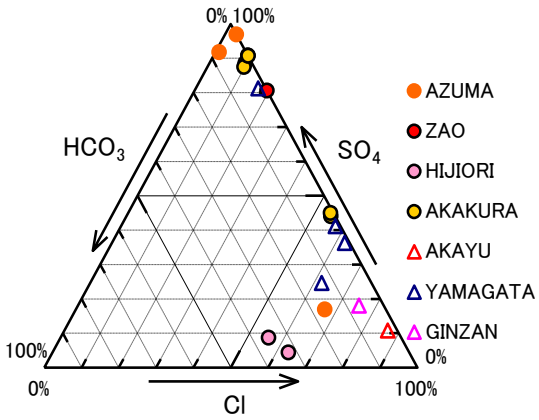


Fig.11 Chemical composition of the major high temperature hot springs in Yamagata Prefecture.

4. CONCLUSIONS

Geothermal resources of Quaternary volcanic areas have many indications of the existence of deep 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 ago. High temperature thermal waters (above 60 ^oC) gush out in the Shirabu hot spring. In the Azuma area, the maximum temperatures of the exploration wells are above 260 ^oC. Many hot springs, not directly related to volcanic activity are situated mainly along the Yonezawa basin. The high temperatures hot springs, such as Akayu is situated on the margins of these basins or in volcano-tectonic depressions, which is a suitable structure for thermal waters reservoirs. There are some promising areas for geothermal energy utilization around the Yonezawa district in Yamagata prefecture. A continuous investigation for geothermal energy utilization is, therefore, necessary in the future.

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