BEPPU HOT SPRINGS

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INTRODUCTION

Beppu is one of the largest hot springs resorts in Japan. There are numerous fumaroles and hot springs scattered on a fan-shaped area, extending 5 km (3.1 miles) from east to west and 8 km (5.0 miles) from north to south. Some of the thermal manifestations are called "Jigoku (Hells)", and are of interest to visitors. The total amount of discharged hot springs water is estimated to be 50,000 ton/day (9,200 gpm) indicating a huge geothermal system. The biggest hotel in Beppu (Suginoi Hotel) installed a 3-MW geothermal power plant in 1981 to generate electricity for its own private use.

BEPPU JIGOKUS

There is a worldwide interest in a special kind of jigokus or "hell" found in Beppu--the city's famed natural steaming hot springs. Beppu's most unusual sightseeing attractions are eight jigokus. The word "jigokus" originates from the "burning hell" of the Buddhist sutras, and the Beppu jigokus truly remind one of "burning hells." The Bozu jigoku, contains boiling gray viscous mud which bubbles incessantly with a menacing sound. More attractive jigokus to be seen in around Beppu are the Umi jigoku, or Sea Hell, contains white particles that reflect the color of the sky. Another, the Chinoike, or Bloody Pond, has a vermillion color. Tatsumaki jigoku (water-spout hell) is a geyser which forcefully shoots up water to a height of 20 meters (82 ft) every 25 minutes.

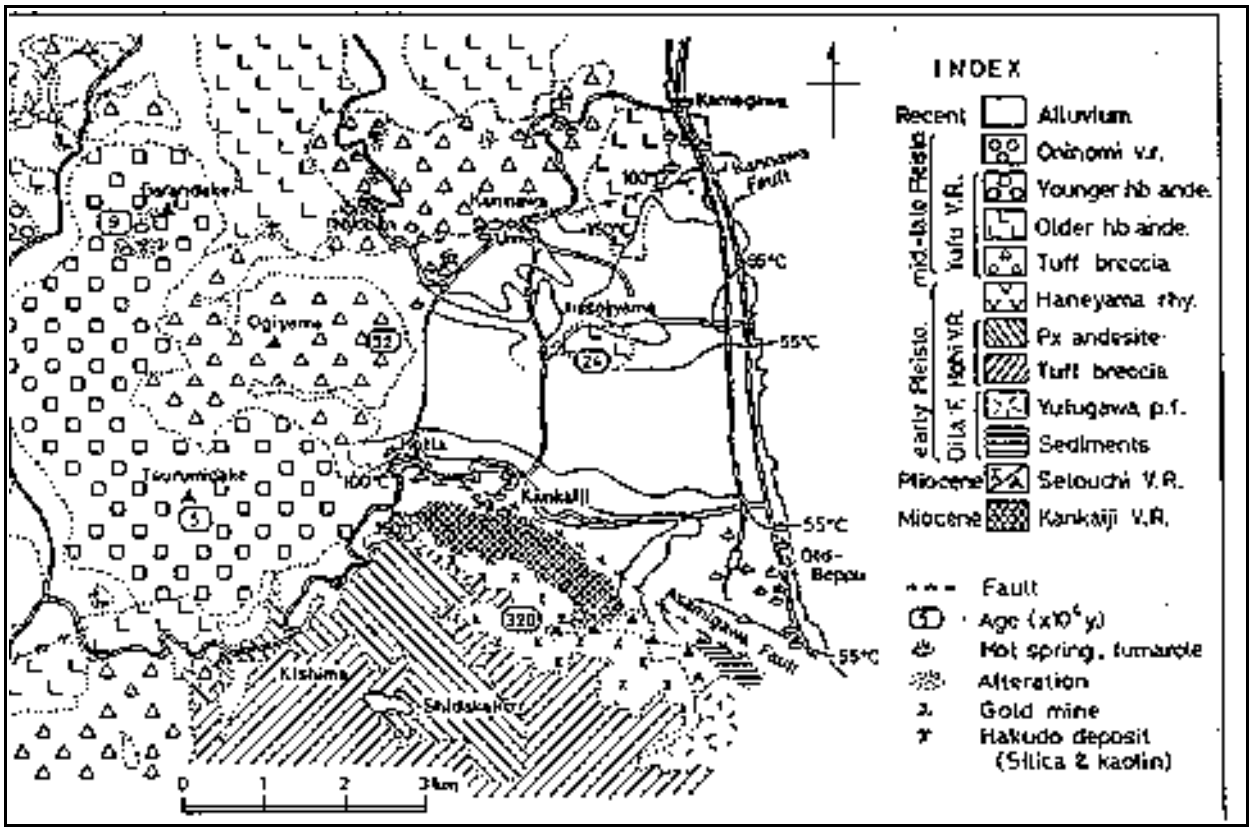

Figure 1. Geological map of the Beppu geothermal area, partly modified after Hayashi and Taguchi (1987). Temperature contours at 200 m below surface are from Kikkawa (1972). Sg = Suginoi geothermal power station, Ch = Chino-ike Jigoku, Um = Umi Jigoku, Bz = Bouzu Jigoku.

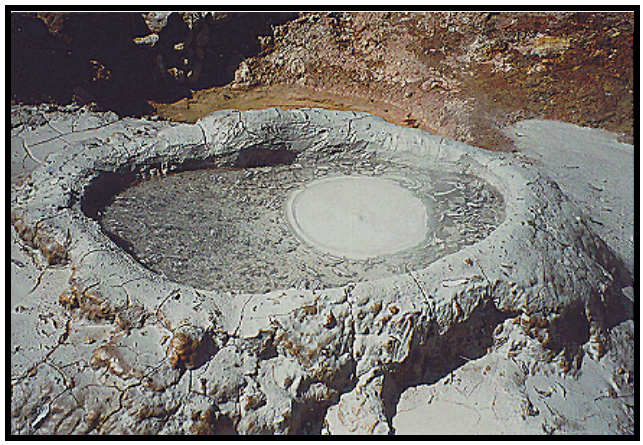

Figure 2. Bozu jigoku.

Figure 3. Chinoike jigoku.

One of Japan's most popular hot springs resort cities, Beppu is tucked between a bay of the Inland Sea and two dormant volcanoes on the edge of the Island of Kyushu. Hot water is the keystone of Beppu's tourism; but, it also plays an important part in the daily lives of the city's residents. Steam from wells is used to heat water which is delivered by pipes to homes and businesses. Some of it goes into homes and restaurants for cooking vegetables. The water is also used for agricultural research, physical therapy and of course, recreational bathing.

Figure 4. Beppu residence.

Bathing has long been a national passion in Japan. Even if there is a bath at home, the family often goes out to soak with friends and strangers at a public bathhouse. There are baths for every pocket book in Beppu, and the municipality itself runs several especially for poorer residents.

The majority of Beppu's *onsens*--hot springs baths--cater to a clientele ranging from vacationers at posh hotels to workers stopping by to clean up before going home. Since there is little central heating in Beppu and elsewhere in Japan, the baths serve some people as a warm and cozy refuge during the long gray winters. The number of amenities provided at a Japanese hot springs bath do not alter its basic properties. First and foremost, it is *very hot*--usually kept between 41°C (105°F) and 48°C (118°F). Cooling or diluting the water at Beppu is often necessary because the springs range from 50 - 100°C (120 - 212°F). The Japanese bath is more a place for soaking than for scrubbing. No bather would think of entering the pool without first washing his entire body and rising it. In fact, relaxation is the bather's primary goal.

Figure 5. Production well site for steam injection into distribution system.

Figure 6. Japanese bath.

At Umi jigoku, which is much hotter than the bathing springs, piped steam heats a large banana greenhouse alongside the pond. At another steam vent, more than 900

tons/day (238,000 gal/day) of water bubble out in a garden of a Buddhist statuary. A small zoo has been constructed around the Yama jigoku, and the animals that drink and wallow in the warm water include hippopotamuses, monkeys, snakes and pelicans. Nearby, as at other jigokus, attendants constantly hard-boil eggs in the water, and vendors sell cans of powdered mineral sediments for use in tubs at home.

Figure 7. Umi jigoku (Sea Hell) greenhouse.

Geothermal water also is used in several agricultural research facilities like the Oita Research Station for Agricultural Utilization of Hot Springs. There, the mineral water irrigates and heats vegetable, fruit and flower greenhouses all year. Experimental crops of tomatoes, cucumbers and eggplant are harvested regularly along with bananas, mangos, papayas and other tropical fruits. There's also extensive research on the breeding of plants and shrubs such as azaleas, camellias, rhododendrons and carnations.

GEOLOGY

Beppu is located at the eastern end of the Beppu-Shimabara Graben. The basement rocks are probably the same as those of the Hatchobaru geothermal field: Paleozoic crystalline schists and Cretaceous granite intrusions. This is based on the fact that such rocks are found as xenoliths in rocks such as the Yufugawa pumice flow, the Hohi volcanic rocks and the Yufu volcanic rocks and formations (the Kankaiji and the Setouchi volcanic rocks, Oita formations, and Hohi volcanic rocks in ascending order) are mainly situated in the southern part of the field (Figure 1). The middle-to-late Pleistocene Yufu volcanic rocks (<0.32 Ma) form lava domes of hornblende andesite such as the Tsurumi-dake and the Yufu-dake, located to the west of the field. Fission track ages of the domes are younger than 100,000 years, and the heat source of the area is probably related to the post volcanic activity of the domes.

GEOTHERMAL SYSTEM

There are various type of active geothermal manifestations: hot springs, hot pools, mud pools,geysers and fumaroles. Those are mainly distributed along and/or around the Asamigawa fault to the south and the Kannawa fault to the north (Figure 1). Steaming ground and advanced argilic alteration zones (Hakudo deposit) are dominant at Myoban, west of the Kannawa fault.

Table 1. Typical Chemical Compositions of Hot Springs in Beppu

Area Name	Kannawa Ishimatsu	Kannawa Chinoike	Myoban Yamadaya	Kamegawa Shinoyu	Old-City Kimura	Hotta Hotta	Kankaiji Jizouyu
Temp.	100	60	67.5	56.6	55.6	75.5	50
pH	7.7	2.4	1.7	8.2	7.4	6.2	6.9
Na^+	882	700	24.1	182	170	26.78	30
K^+	97.8	103	16.7	28.6	14.1	3.438	5
Mg^{2+}	1.0	17.6	10.2	6.6	33.2	12.22	12
Ca^{2+}	24.5	42.0	26.0	20.4	47.5	17.91	57
Al^{3+}	0.1	2.28	203	0.1	0.1	0.12	
Mn^{2+}	0.4	4.3	0.4			0.005	
Cl^-	1104	1003	5.7	225	107	17.88	3
SO_4^{2-}	455	570	1649	152	53.4	66.05	45
HSO_4^-			1108				
HCO_3^-	49			108	504	76.25	188
$HAsO_2$	1.63	1.3		0.7	0.21		
H_2SiO_3	506	299	411	198	252	112	126
HBO_2	39	72	49.9	15.8	4.7	22.7	
Ref.	1	2	1	3	1	4	5

Ref. 1: Oita-ken (1982), Ref. 2: Koga (1972), Ref. 3: Oita-ken (1984), Ref. 4: Oita-ken (1970), Ref. 5: Koga (personal communication).

The chemistry of hot spring waters is rich in variety (Figure 8 and Table 1): sulfate-rich steam heated water (at Myoban), chloride-rich deep water (at Kannawa), bicarbonate-dominant water (Old Beppu), and their intermediate types (at Kamegawa, Hotta and Kankaiji).

Chemically estimated subsurface temperatures in Beppu are shown in Figure 9. High temperature zones above 200ºC are distributed at Myoban, Ogura, and Kannawa along the Kannawa fault to the north, and also at Hotta-Kankaiji along the Asamigawa fault to the south. The Suginoi geothermal power station is located on the latter fault. However, cooling also seems to have occurred from the southeast along the same fault (Figure 1).

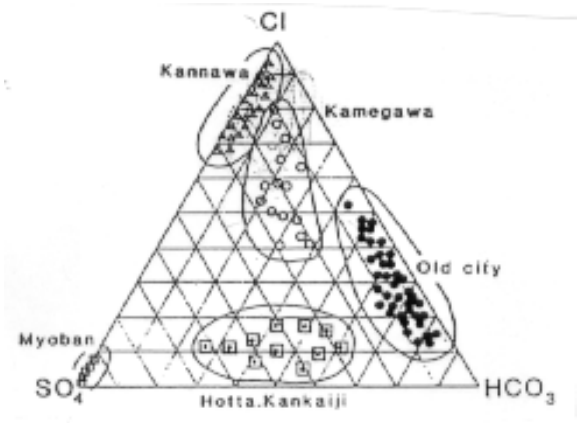

Figure 8. Chemical compositions of Beppu hot springs waters (Koga, 1985).

Among the many Jigoku, the Chino-ike Jigoku (Blood-pond hells) is perhaps the most spectacular, since its color resembles that of blood, due to the red precipitates. This Jigoku is a hydrothermal eruption crater (Figure 10), and eruptions were recorded nine times during the period from 1875 to 1927 (Yoshida, et al., 1978). Total output of hot water from the crater is 100 l/min (23 gpm), and the maximum temperature is 136.8ºC (278ºF) at the bottom (-26 m, -85 ft). The chemistry of the water suggests a blend of sulfate-rich water (SO_4 = 604 mg/l) and deep chloride-rich water (Cl = 1,002 mg/l). The red precipitates are rich in heavy metals (Au = 23, Ag = 383, As = 4,440, Sb = 180, Pb = 442, Zn = 104 and Cu = 57 ppm respectively), and consist of low cristobalite, tridymite, kaolin, hematite, and montmorillonite (Koga, 1972; Yamashita, 1977; Yoshida, et al., 1978).

Gold and silver were also reported from other Jigoku and hot springs in the Kannawa area: Yunohara, Umi, Kyuman, Raisen, Shibaseki, and Honbouzu (Koga, 1961). Epithermal gold veins, embedded in the Kankaiji volcanic rocks, were once mined in small scale south of Kankaiji. There was, however, some trouble with steam discharge.

According to the recent work on the Beppu geothermal system (Allis and Yusa, 1988), the characteristics of the thermal manifestations are interpreted using a simple model as shown in Figure 10: the main steam loss with minor dilution occurs along the Kannawa fault and the major dilution with minor steam loss along the Asamigawa fault. Koga (1987) also proposed similar fluid paths according to the hot water chemistry.

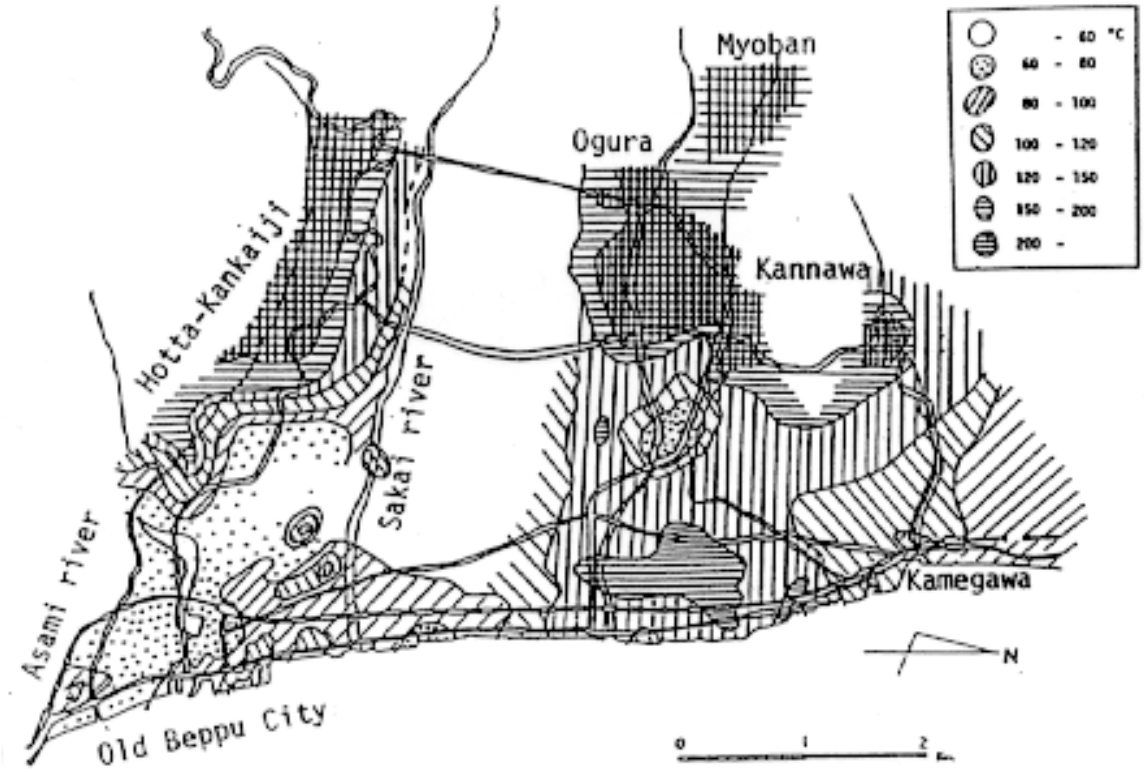

Figure 9. Chemically estimated subsurface temperature distributions in Beppu (Koga, 1987).

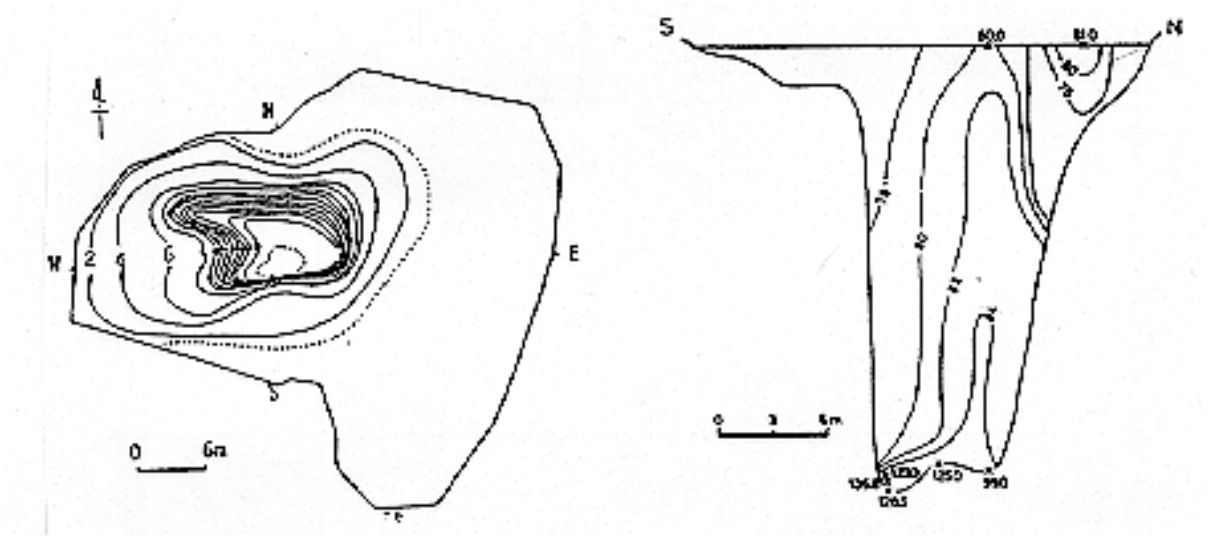

Figure 10. Isobath of the Chino-ike Jigoku in meters (left), and cross section of the Jigoku (right) showing temperature profiles in °C (right) (Yuhara, et al., 1978).

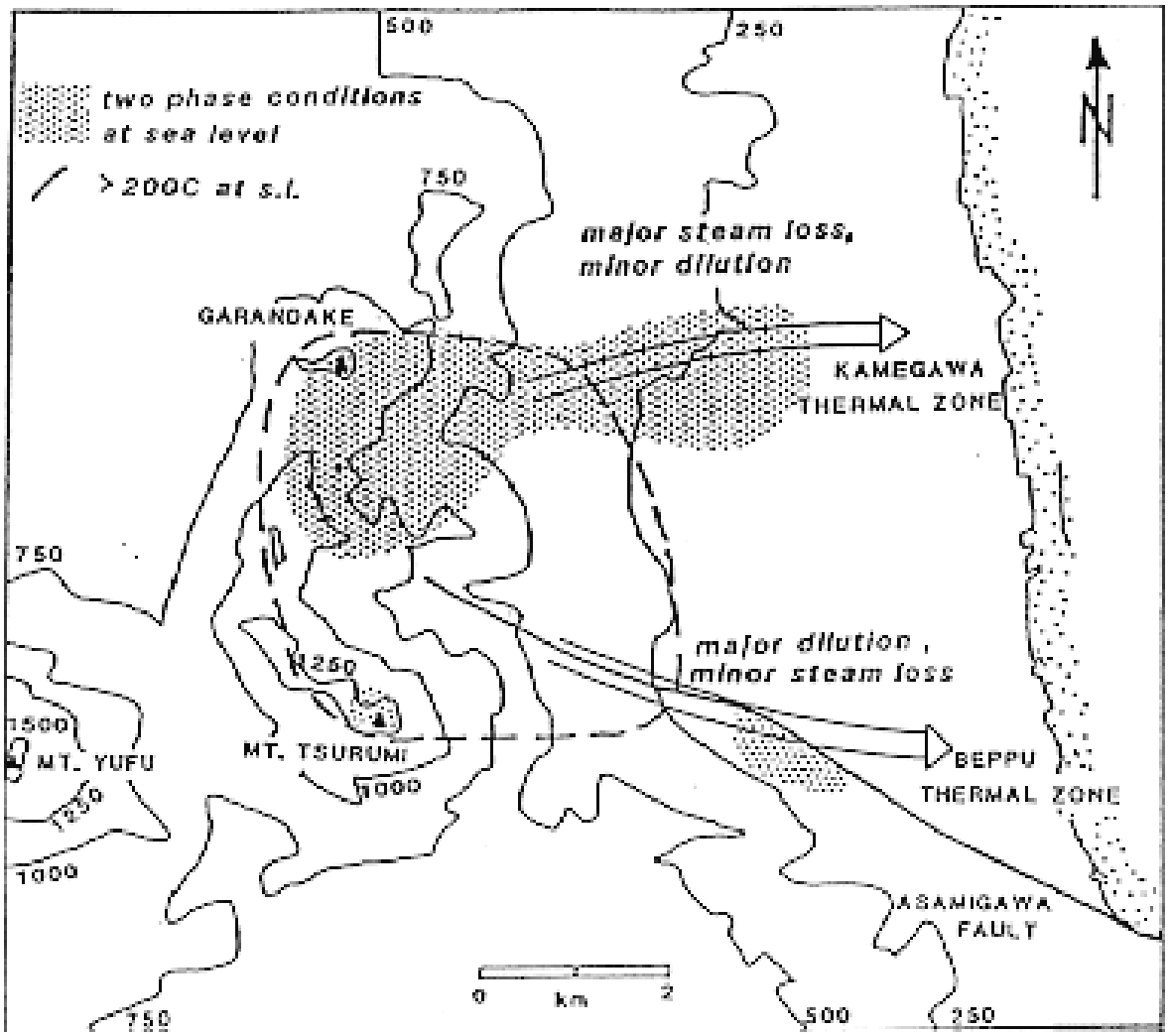

Figure 11. Identification of the main fluid flow processes in the Beppu geothermal system (Allis and Yusa, 1988).

EDITOR'S NOTE:

Paul Lienau and John Lund of the Geo-Heat Center had the opportunity to visit Beppu's most unusual sightseeing attractions, four of eight jigokus in this paper. Beppu is one city being considered for the World Geothermal Congress 2000.

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