CHANGES IN THE BEPPU HYDROTHERMAL SYSTEM (JAPAN) DUE TO EXPLOITAION

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ABSTRACT

The exploitation in the Beppu hydrothermal system started in the 1880s, and by the 1920s the number of wells increased to about 1,000. This caused the seawater to intrude into the thermal aquifer at the coast, and to draw the piezometric pressure of the thermal aquifer down. The second flurry of exploitation was during 1960s to 1970s, by which the number of wells incresed to over 2,300 and the discharge increased from about 450 kg/s to about 650 kg/s. The increase of discharge was mainly due to the increase of the chloride water discharge at highland. By this, the subsurface flow rate of the chloride water towards the lowland has decreased and also the steam-heated shallow water intrudes into the chloride water layer.

INTRODUCTION

Beppu on Kyushu Island is one of the largest spa resorts in Japan, and has a long history tracing back to the 8th Century at least. Its surface thermal activity varies from hot springs (boiling and subboiling) to superheated fumaroles and steaming grounds on the volcanoes behind Beppu City. Since the Meiji Restoration in the 19th Century, the hydrothermal exploitation at Beppu has been promoted to enhance the flow of hot water and steam. Today there are about 2,300 wells in an area of 5 km (E-W) × 8 km (N-S), and the total flow of hot water and steam amounts to around 50,000 tons per day.

In this paper the history of the hydrothermal exploitation of the Beppu system is described briefly, and the changes associated with the exploitation is reviewed.

Beppu hydrothermal system

The Beppu hydrothermal system is located at the eastern end of the Beppu-Shimabara graben crossing Kyushu Island from east to west, along which there are many Quaternary volcanoes (Fig.1). The hydrothermal activity is developed on the eastern flanks of the Yufu-Tsurumi-Garandake volcanic center. Both Mt. Tsurumi and Mt. Garandake have fumaroles near their summits. There are three principal types of thermal water in the Beppu hydrothermal system; a high-temperature sodium-chloride type, a bicarbonate type, and a sulfate type. These diverse compositions can be formed from a single parent thermal fluid.

The parent hydrothermal fluid beneath the volcanoes is inferred to be 250-300 ℃ and 1400-1600 mg/kg chlorine, and it flows out towards the coast along the two major flow paths. The southern flow path (the Beppu thermal zone) is along the Asamigawa Fault. The hydrothermal waters in this zone are formed by predominantly dilution of the parent fluid by cold groundwater at the mountainous area. The diluted hydrothermal water reached another fault crossing with the Asamigawa Fault uprises to boil. By this process, a steam-dominated two-phase zone is formed, and subsequently shallow groundwater is heated by steam.

On the other hand, the northern flow path (the Kamegawa thermal zone) coincides with the Kamegawa Fault and/or the ridge of lava. Here steam loss by boiling and subsequent mixing with steam-heated groundwater are significant. Recently, the third (westward) flow path towards the Yufuin area has been suggested (Fig. 2; Allis and Yusa, 1989 and Sturchio et. al, 1996).

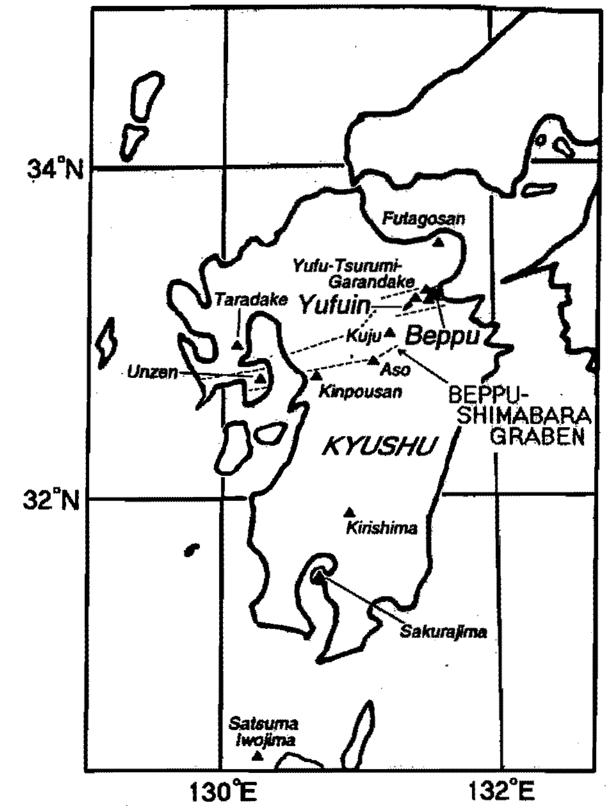


Fig.1 Location map showing Beppu and Yufuin on northeastern Kyushu Island, Japan. Solid triangles are locations of Quaternary volcanic centers. Dashed line encloses Beppu-Shimabara graben. (After Sturchio et.al, 1996)

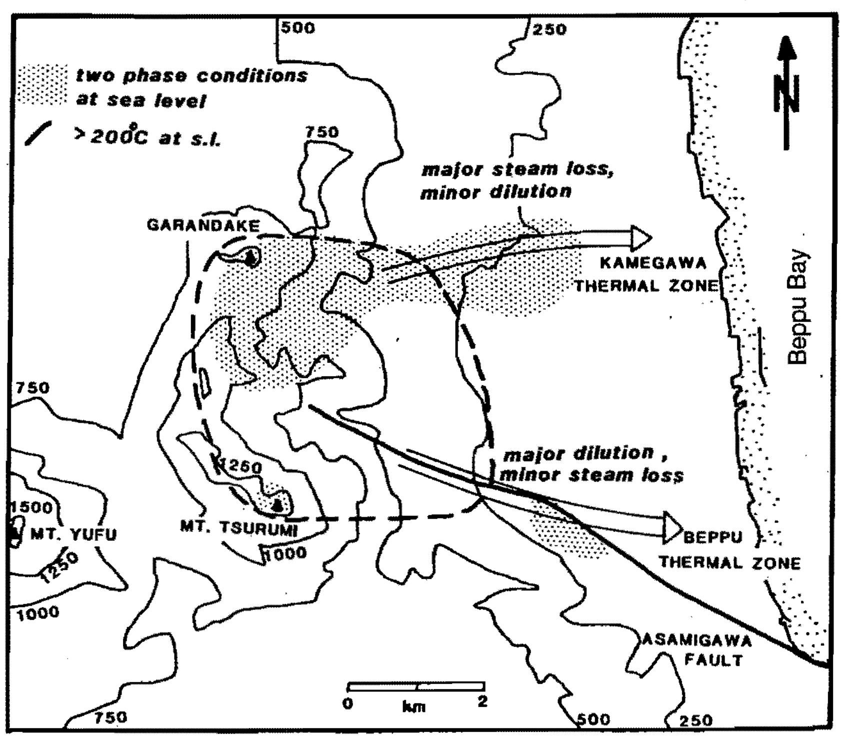
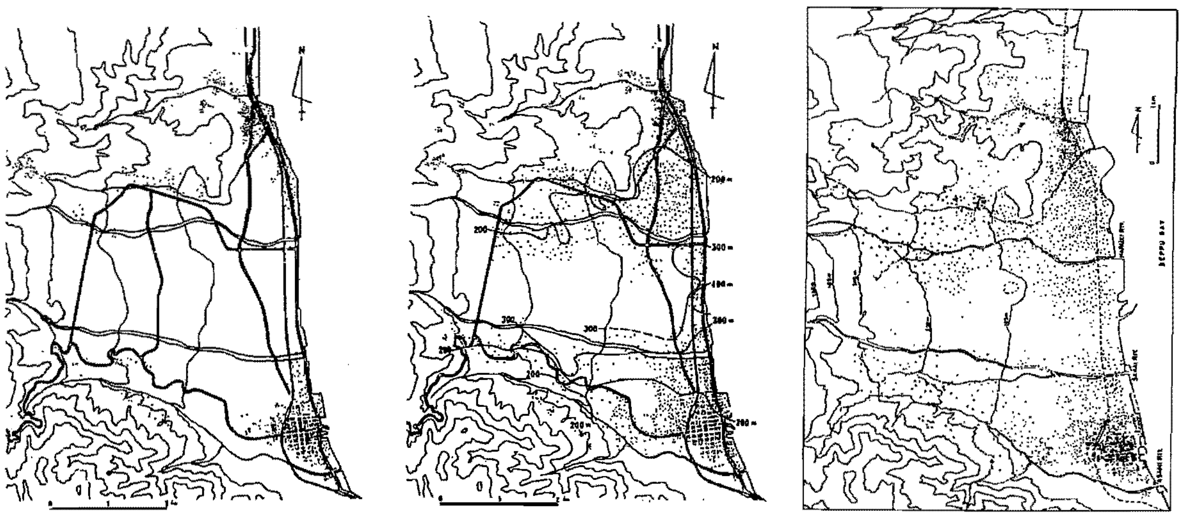


Fig.2 Major fluid flow patterns of the Beppu hydrothermal system. (after Allis and Yusa, 1989)

BRIEF HISTORY OF EXPLOITATION

The first record of the Beppu hydrothermal system appeared in a book published in the beginning of the 8th Century. Ancient people had used natural hot springs and steams for bathing and cooking etc. over long periods.

The exploitation at the Beppu hydrothermal system by drilling started as early as 1880. During the early part of the 20th Century, the number of drilled wells increased rapidly to reach around 1,000. Between 1925 and 1945 there was an economic depression, and drillings were scarce. During the 1960s and 1970s after the Second World War, many drillings by modern techniques were carried out extensively, and the number of wells reached over 2,300. The transition of distribution of drilled wells is shown in Fig.3. Associated with the exploitation, both the mass output and the heat output from wells increased specially after the 1960s as shown in Table 1. This increase is mainly due to the exploitation of high-temperature fluids at the highland area (Yusa, 1985).



1949 1969 1985

Fig.3 Transition of distribution of drilled wells.

Table 1 Statistics on the amounts of hydrothermal fluid extracted from wells in the Beppu hydrothermal system

		1924	1949	1959-61	1973-75	1985
Number of Wells	Beppu	826	674	785	1132	975
	Kamegawa	?	305	535	1250	1269
	Total	?	979	1320	2382	2244
Mass Output (kg/s)	Beppu	189	218	213	266	226
	Kamegawa	?	213	252	390	353
	Total	?	431	465	656	579
Heat Output (MW)	Beppu	43	48	67	119	126
	Kamagawa	?	52	86	231	226
	Total	?	100	153	350	352

(Data in 1924 and 1949 are for only subboiling wells.)

Seawater intrusion into the coastal confined aquifer (Fig.4)

A phenomena of seawater intrusion into the coastal aquifer of thermal groundwater at the Beppu thermal zone was detected by the first geochemical survey in 1926. The intruded region was limited to be narrow within a southeast corner of the zone. In 1950 - about 25 years later, the intruded region extended wider northwards. Comparing the results obtained in 1963 and 1976, it seems that the intruded region extended slightly with time along the coast (northwards). This indicates the development of drawdown of piezometric level due to withdrawal of thermal groundwater. The retreat of the intruded region at the north side of the River Asami may be apparent because of lack of data (Kikkawa and Kitaoka, 1977).

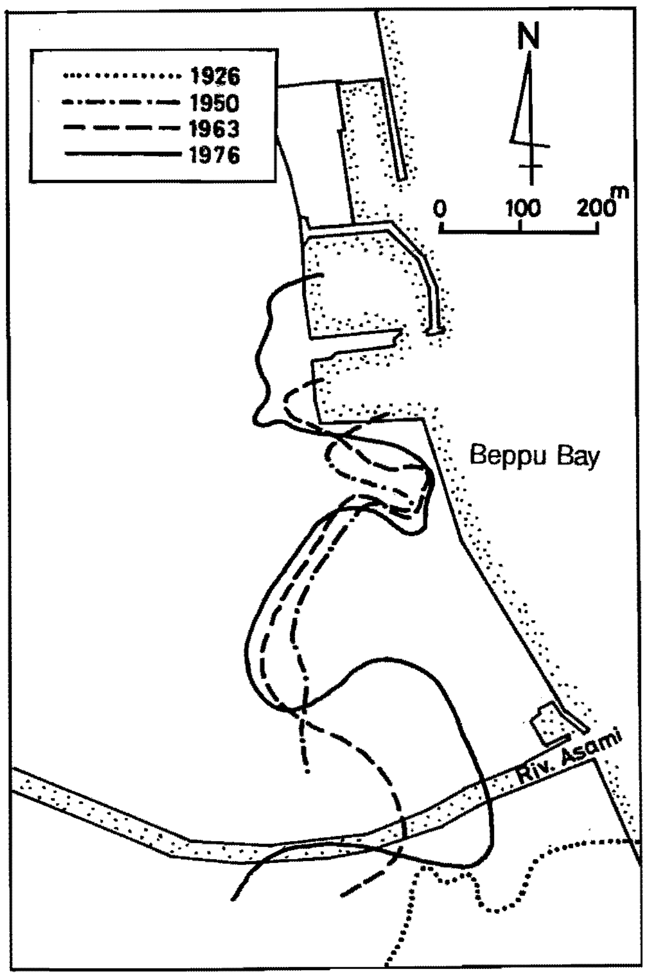


Fig.4 Transition of the front of seawater intrusion. (after Kikkawa and Kitaoka, 1977)

Lowering of water level and water temperature in the unconfined aquifer (Fig.5)

There was a shallow well digged by hand, about 8.5 m in deep and about 1 m in diameter, at about 1.5 km from the coast in the Beppu thermal zone. The temperature by the first measurement in January 1925 was high up to 43.2℃. It is thought that such high temperature was brought from uprising of deep confined thermal water with high pressure.

Measurements of temperature and water level were conducted once every day until 1967, when the well lost its water completely. The annual mean values of water level below the ground surface, temperature and precipitation are drawn in Fig.5. The water level fluctuated around a level of about 7 m below the ground surface in clearly response to the precipitation until the middle of 1950s. After that, the water level dropped rapidly to disappear at last in 1967 though it rised a little temporarily in 1961-63. The temperature fluctuated irregularly, but maintained a level of 30 - 40℃ until around 1950. However, it showed a slightly lowering trend, and dropped down below 30℃ after 1950 though rised up higher than 30℃ temporarily. These phenomena indicate lowering of pressure of the deep thermal water associated with the exploitation (Yusa, 1989).

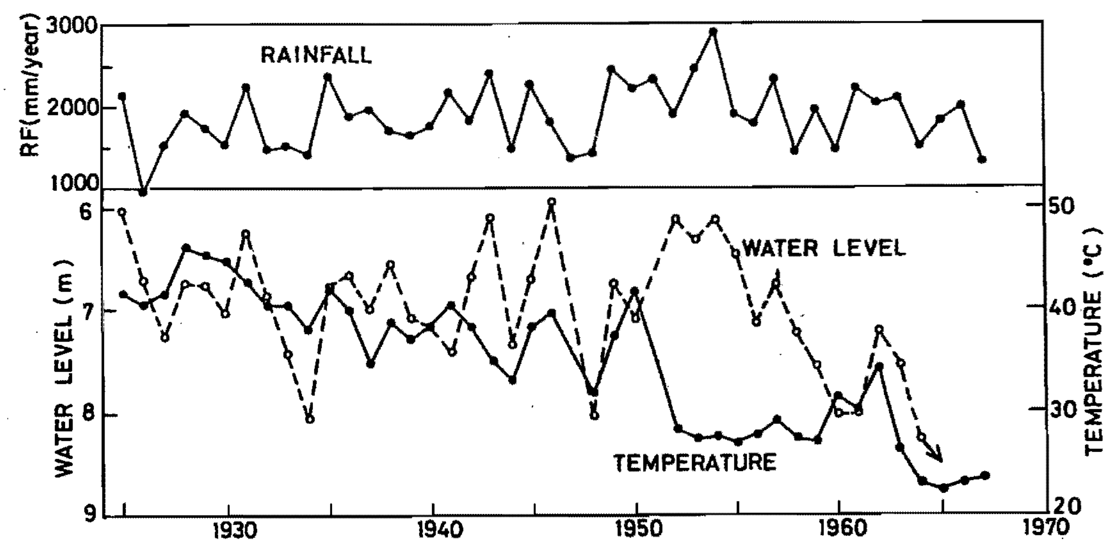


Fig.5 Long-term changes in water level and temperature in a shallow well with precipitaion in the Beppu thermal zone. (after Yusa, 1989)

Decline of chloride concentration (Figs.6 and 7)

During the flurry of exploitation in the 1960s and 1970s, as mentioned before, many boiling wells were drilled at the highland, by which a quite large amounts of Na-Cl type water has discharged. After this, a decline trend of chloride concentration has become evident both in boiling waters at highland and subboiling waters at lowland. Change in average concentration of Cl in the Beppu thermal zone is shown in Fig.6 with change in HCO_3 concentration, which has increased on the contrary. This trend has been clearly observed at a boiling well located near the coast (Fig.7). A similar decline of chloride concentration has been also observed at the Kamegawa thermal zone. Since the Cl is the main anion of the deep chloride type water, the decline of Cl indicates a progress of dilution of the deep water by shallow water (Yusa, 1984).

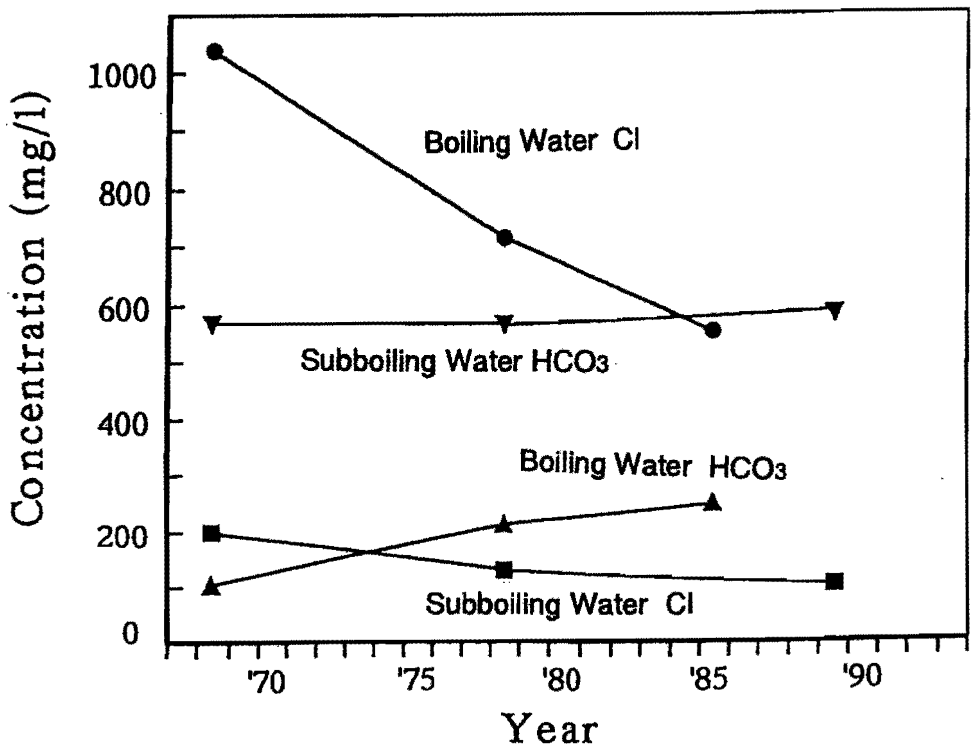


Fig.6 Change in average concentrations of chloride (Cl) and bicarbonate (HCO_3) in the Beppu thermal zone.

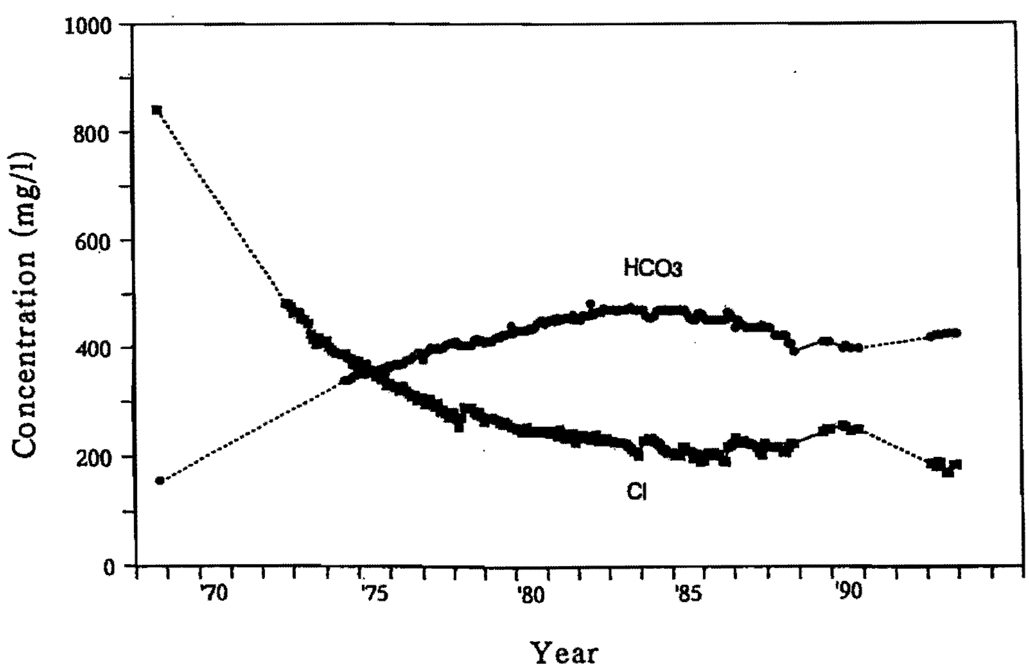


Fig.7 Change in concentrations of chloride (Cl) and bicarbonate (HCO_3) of a boiling water in the Beppu thermal zone.

Change in chemical composition (Fig. 8)

The decline of Cl concentration is remarkable for the chloride-type water in the Beppu thermal zone. In place of that, HCO_3 concentration increases as shown in Figs. 6 and 7. To investigate this change in detail, transitions of chemical compositions of some boiling and subboiling waters are shown in Fig.8 using hexaplots. It is conspicuous that chloride type waters in original lose Cl and get HCO_3 and/or SO_4. Since the latter two components, HCO_3 and SO_4, are the main anions of the shallow thermal water heated by steam, these changes indicate increases of mixing ratios of shallow waters (Yusa et. al, 1989).

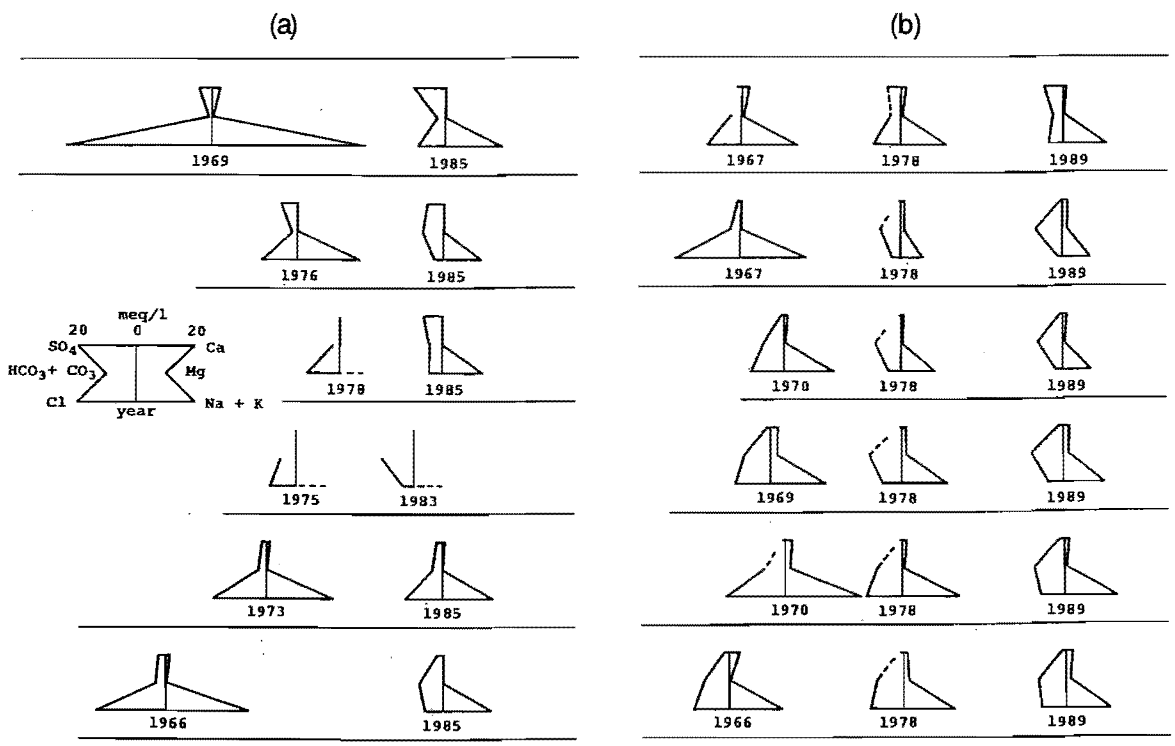


Fig.8 Examples on transition of chemical composition of thermal water in the Beppu thermal zone; (a) boiling water, (b) subboiling water. (after Yusa et. al, 1989)

DISCUSSION AND CONCLUSION

The phenomena reviewed in this paper suggest that the exploitation developed during the long period since 1880s, specially the increased discharge from boiling wells at highland in 1960s to 1970s, has caused the pressure of deep chloride water to drop; by which the flow rate of the chloride water towards the lowland has decreased and also the steam-heated shallow water intrudes into the chloride water layer to lower the chloride concentration and to raise the bicarbonate and/or sulfate concentrations. Thus some chloride type thermal waters in the Beppu hydrothermal system have changed their water quality into the bicarbonate (and/or sulfate) type under the influence of exploitation.

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