CHANGES OF WELL CHARACTERISTICS IN THE HATCHOBARU GEOTHERMAL FIELD (JAPAN) BY EXPLOITATION OF UNIT NO. 2

T. MIMURA[1], K.OISHI[1], Y. OGATA[1], H. TOKITA[2], Y. TSURU[2] AND K. MATSUDA[2]

[1] Thermal Power Department, Kyushu Electric Power Co. Inc., Fukuoka, Japan
[2] Geothermal Department, West Japan Engineering Consultants Inc., Fukuoka, Japan

SUMMARY - The reservoir exploitation for Unit N0.2 of the Hatchobaru Power Station accelerated the decline of power output of Unit No.1. For the purpose of understanding the mechanism of this output decline, review of existing data, additional well characteristics tests, well loggings and tracer tests were carried out. The results showed that several production wells for Unit No. 1 significantly reduced their productivity due to the inflow of reinjected waste water and due to pressure interference with production wells for Unit No. 2.

1. INTRODUCTION

The Hatchobaru power station, located in central Kyushu, Japan, started its commercial operation with Unit No. 1 (55 MW) in 1977. The second unit (Unit No. 2, 55 MW) was commissioned in 1990. The reservoir is of a water dominated type controlled by faults. Main production zones for Unit No. 1 and No. 2 are found at depths from 800 to 1700 m along the faults, although these production zones are separated horizontally. Acidic alteratian zones play a role of a cap rock at the shallow depth from 200 to 600 m. Both the units use a double-flash system, and totally reinject the waste water at about 90°C under atmospheric pressure from the beginning of operations. As shown in Fig. 1-1, the reinjection strategy adopted is to separate the production and reinjection zones horizontally, such that the northern part of the field is used for reinjection and the southern part for production. It was found, however, that the reinjected water partially circulated to the production zone and that caused a drop of the reservoir temperature. Consequently, some wells have gradually reduced their productivity. Fig. 1-2 shows the power output history of the plant. A power output decline rate of Unit No. 1 was about 6% before operation of Unit No. 2, but it increased to 14% within 3 years after the commencement of Unit No. 2. The results of well characteristics tests and well loggings revealed that after the exploitation for Unit No. 2 had started, fluid production and reinjection increased and the reservoir temperature and pressure began to change significantly.

In this paper, these results of well tests and well loggings conducted at the wells H-14, H-21, H-22 and 2H-12 are introduced, and then the tendencies of the reservoir changes in the field are described.

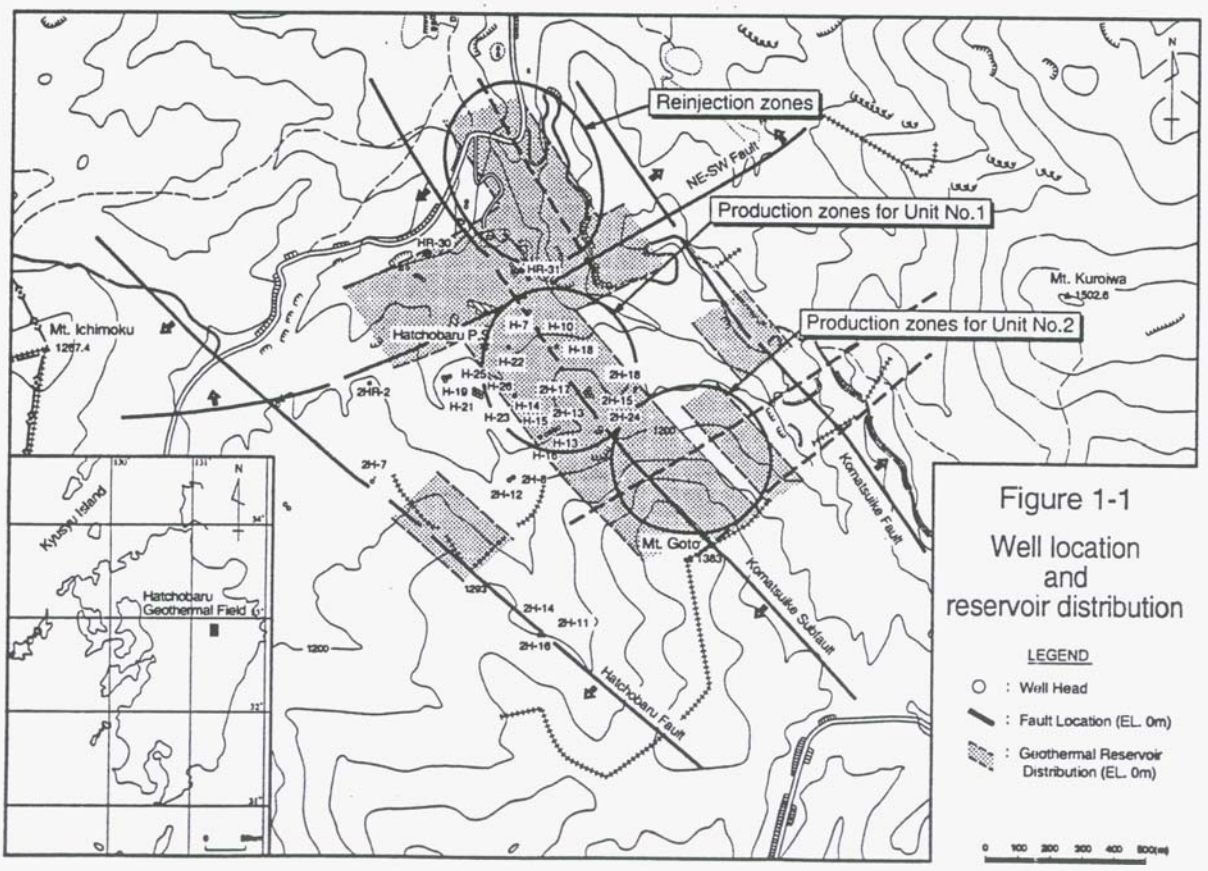

Figure 1-1
Well location and reservoir distribution

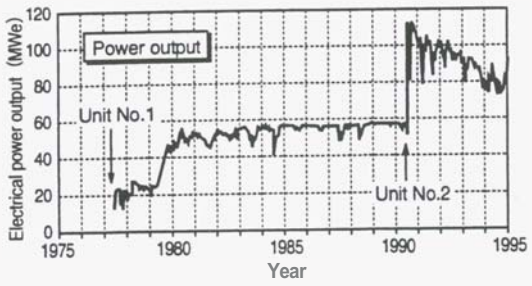

Fig. 1-2 History of power output of the Hatchobaru power plant

2. CHANGE OF WELL CHARACTERISTICS

2-1 Well H-14

The directional production well H-14, located at almost the center of the production area for Unit No. 1, was drilled to a depth of 1,192 m in 1979. The target was the Komatsuike Subfault, believed to play the most important role for fonnation of the reservoir. Fig. 2-1 shows the history of production rate and power output of the well H-14. The early productivity of this well was the largest among the existing wells. Its steam and water production rates at wellhead pressure of 0.8MPa, were 17 kg/sec. and 39 kg/sec., respectively which were equivalent to 10 MW in power output.

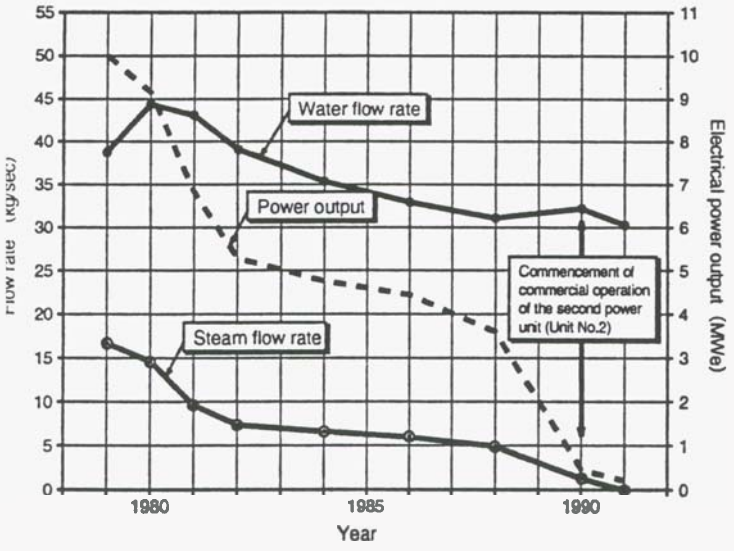

Fig. 2-1 History of production rate and power output of well H-14

Fig. 2-2 shows the temperature profile change of this well from 1979 until 1990. Before the development, the initial formation temperature at the bottom was about 270°C. According to the results of well loggings carried out under discharging condition in 1984, 1988 and 1990, the temperature of the feed point (liquid phase at the depth 1,169 m) dropped by 20°C, from 250°C to 230°C. The temperature drop for the first 11 years after the initial discharge was 40°C, or an average temperature drop of 3.6°C per year for this period.

On the other hand, as shown in Fig. 2-3, the chloride ion concentration in the reservoir fluid gradually increased fiom 2,000 ppm to 3,000 ppm due to the reinjected water inflow. Consequently, the power output declined by 6 MW, from 10 MW to 4 MW during these 11 years, or an annual averaged power decline rate at 5%. After the commencement of operation of Unit No. 2 in 1990, however, the reservoir pressure decreased and thus the power decline rate significantly increased from 5% to 27%.

Fig. 2-4 and Fig. 2-5 show tendencies of a well productivity decline and a pressure decrease calculated using a wellbore simulator. The reservoir pressure around well H-14 was estimated to decrease by 0.6 MPa due to the increase of total production rate from 41 1 kg/sec to 600 kg/sec. in 1990. This pressure decrease brought the immediate power output decline from 4 MW to 1.5 MW once the exploitation for Unit No. 2. had started.

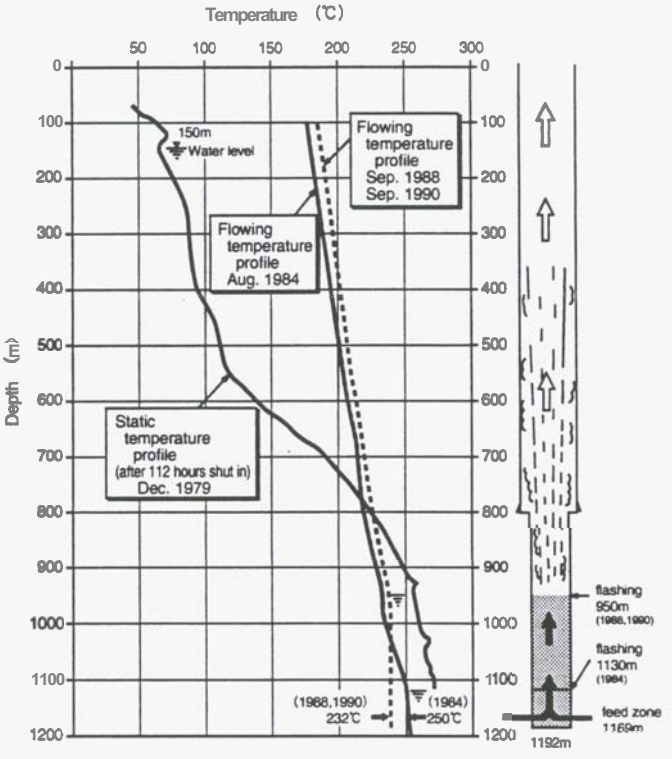

Fig. 2-2 Temperature profile of well H-14



Fig. 2-3 Chloride ion concentration in the reservoir fluids of well H-14

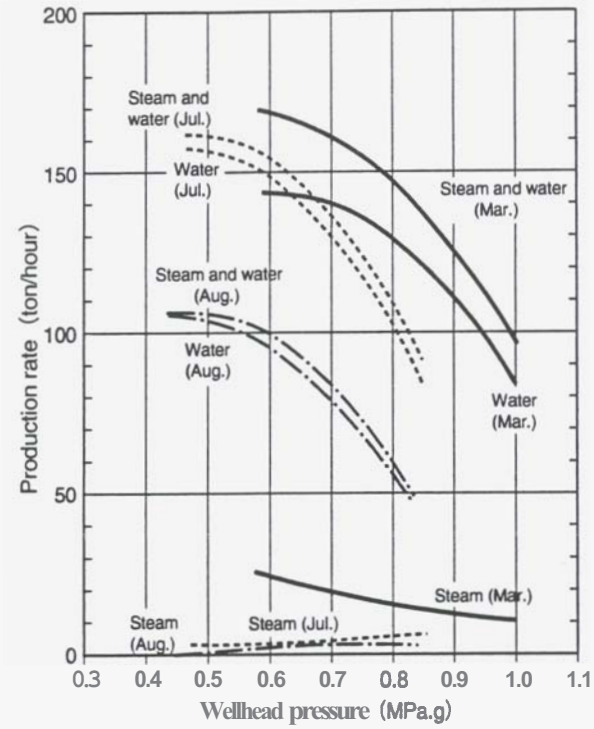

Fig. 2-4 Decline of productivity of well H-14 after the exploitation for Unit No. 2 in 1980

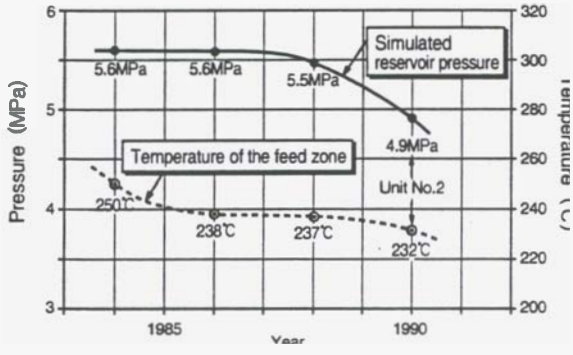

Fig. 2-5 Measured feed temperature and simulated reservoir pressure of well H-14

2-2 Well H-21

The drilling of the directional production well H-21 to a depth of 1,839 m was completed in 1984. The bottom hole is located 1,800 m nearly below the power plant, and reached the geological basement (granitic and metamorphic rocks) at the depth of 1,750 m. The result of well loggings carried out in 1984 under production conditions indicated that there were two feed points; one at a depth of 1,300 m and the other at 1,800 m. Judging from the irregular change of pH and enthalpy in the discharged fluid, it was considered that the acid brine water (pH 4) mixed with returned reinjected water occasionally affected this well at the shallower feed zone.

Fig. 2-6 shows the change of silica temperature and chloride ion concentration in discharged fluids of well H-21. Although the initial silica temperature and chloride ion concentration were 270°C and 1,650 ppm, respectively, the silica temperature dropped to 260°C and the chloride ion concentration increased to 2,400 ppm within 6 years after the initial discharging. These reservoir changes were relatively slower than those before the commissioning of Unit No. 2. Once the operation of the Unit No. 2 *started* in 1990, however, the reservoir began to change more rapidly, such that the silica temperature decreased by 30°C to 230°C and the chloride ion concentration increased by 600 ppm up to 3,000 ppm within the first year. Subsequently, the power output of the well declined from 6 MW to 1.6 MW, that made it difficult to connect the well with the *steam* gathering line.

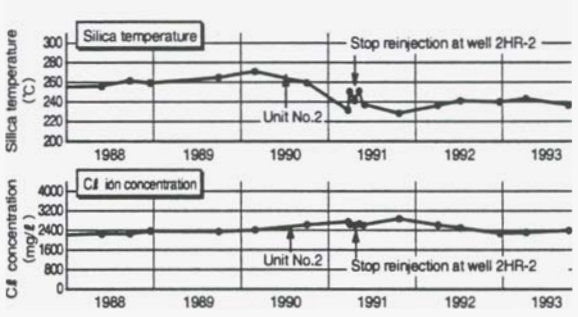

Fig. 2-6 Silica temperature and Cl ion concentration of well H-21

To clarify the cause of such significant power decline of well H-21, tracer tests using sodium fluorescein as a tracer were conducted.

The results revealed *that* about 10% of the water reinjected at the well 2HR-2, 200 m away from the well H-21, returned and *mixed* with the production fluid of the well H-21 (Tokita et al., 1995).

Inflow of the reinjected water from 2HR-2 greatly caused the temperature drop of well H-21 and it was estimated at as high as 16°C, while the actual temperature drop was 30°C including the cooling effects caused by other reinjection wells. Immediately, therefore, the reinjection at well 2HR-2 was stopped in April 1991 to mitigate the cooling effect. As soon as the reinjection with the well had been stopped, it was observed that the silica temperature recovered to 240°C and the chloride ion

concentration decreased to 2,400 ppm, which was the same value before the start of the Unit No. 2 operation. Naturally, the productivity of well H-21 recovered to 4 MW, and that allowed to connect the well with the power station again in April 1991.

2-3 Well H-22

The target of the directional production well H-22 drilled to the depth of 1,650m was the Komatsuike Fault, believed to control the fluid behavior at the east area of the field. Fig. 2-7 shows temperature profiles after completion of the well drilling in 1985. These temperature profiles indicate that inflow of reinjected water had already cooled a zone at depth from 900 m to 1,200m.

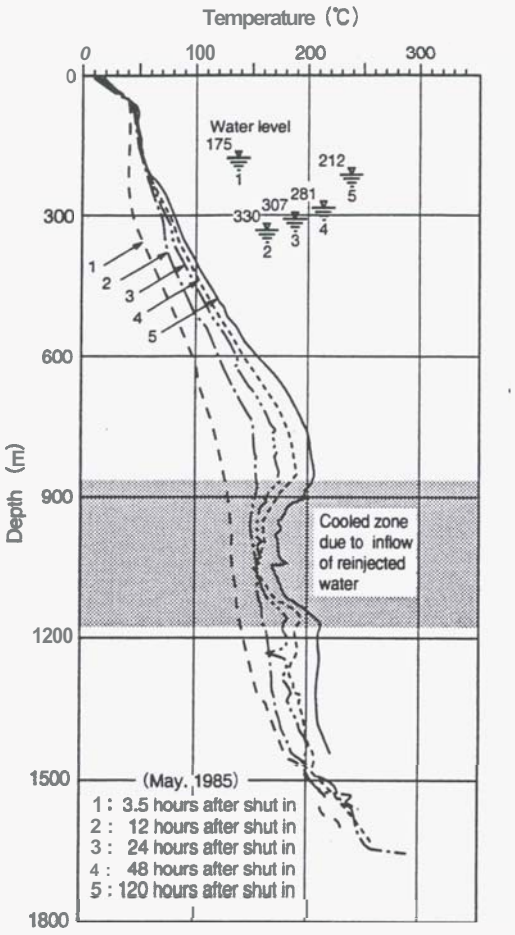

Fig. 2-7 Temperature profiles of well H-22

The results of tracer tests made clear that some reinjected water circulated into the production area along the Komatsuike Fault, and some others flew along the Komatsuike Subfault. According to the results of well loggings carried out under production conditions, the temperature of fed liquid at 258°C in 1988 dropped to 252°C in 1990.

2-4 Well 2H-12

The directional production well 2H-12 was drilled to a depth of 1,500 m, targeting the southeastern area of Komatsuike Subfault and an NE-SW trending fault close to Mt. Goto. The high temperature fluid is believed to ascend from deep levels in the southeastern area of the field. Fig. 2-8 and Fig. 2-9 show the history of power output and the change of well characteristics of the well 2H-12. At the beginning of its production in 1985, the discharged fluid was almost steam with a steam production rate of 14 kg/sec. as against a water production rate of only 0.6 kg/sec. Both the steam and water production rates gradually increased in a year after the start of production. Namely, the steam reduction rate increased to 22 kg/sec. and water production rate to 20 kg/sec. Therefore, the power output increased by 5 MW from 7 MW to 12 MW in 1986.

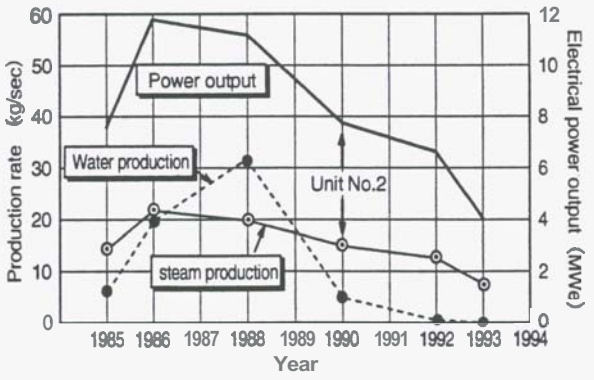

Fig. 2-8 History of production rate and power output of the well 2H-12

The continuous discharge of the well is considered to improve permeability of the formation around the well, which increased productivity greatly. After 1988, however, the productivity began to decline, and the power output derated to 8 MW because of the reinjected water inflow. Within a half year after the start of the Unit No. 2 operation, the steam production rate increased to 21 kg/sec., while the water production rate remarkably decreased to 0.33 kg/sec. Consequently, the power output recovered to 11 MW in this period. These phenomena were thought to derive from vaporization in the reservoir induced by a rapid pressure drawdown.

The pressure drawdown after starting exploitation for Unit No. 2 has been monitored with a capillary tubing system at the observation well 2H-11, 700 m away from the well 2H-12 in the southeastern area. According to the pressure monitoring data of well 2H-11 as Fig. 2-10 shows, the reservoir pressure decreased by 0.4 MPa from 3.7 MPa to 3.3 MPa within the first 2 years after the start of Unit No. 2 operation.

Pressure drawdown in the reservoir was also suggested by an increase of non-condensable gas concentration in discharged fluid of the well 2H-12. It doubled to as much as 4.102 weight % within the first 2 years. Based on the results of wellbore simulations, it was estimated that the reservoir pressure decreased by 2 MPa and the temperature by 26°C in these 2 years.

The silica temperature drop 50°C from 280°C to 230°C from 1991 also suggests that the reinjected water had returned to the southeastern production area within a year after the start of Unit No. 2 operation. The decline rate of the power output was 16% per year after initial exploitation for Unit No. 2.

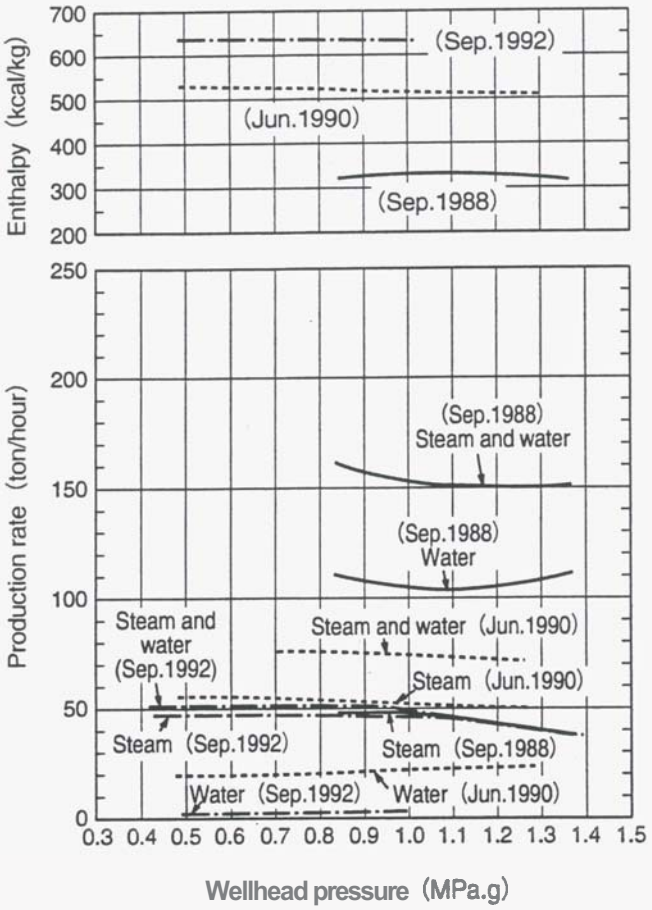

Fig. 2-9 Productivity change of the well 2H-12

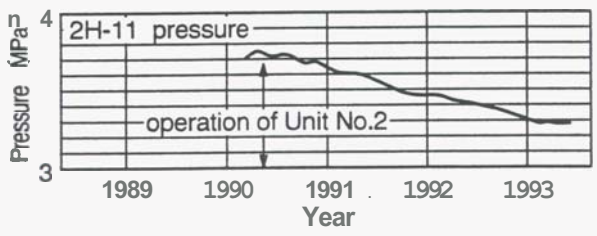

Fig. 2-10 Pressure decrease of the observation well 2H-11

3. TENDENCY OF RESERVOIR CHANGES

The exploitation at the southeastern production area for Unit No. 2 widely influenced the pressure and temperature distribution in the reservoir, including the production area for Unit No. 1. As shown in Fig. 3-1, the reservoir has been divided into three regions from the viewpoint of the kind of influence, such as 1) cooled region due to inflow of reinjected water, 2) cooled region with pressure drawdown, and 3) pressure decreased region.

The pressure distribution at the early stage of the development was believed to be simpler. The initial pressure in production zone was higher than that in reinjection zone, reflecting the topography of the field. However, the pressure began to decrease in the production zone, while increase in the reinjection zone after the start of plant operation. Consequently, the changed pressure distribution tended to induce the inflow of the reinjected water to the production zone from the reinjection zone. In particular, the start of Unit No. 2 operation accelerated the inflow of reinjected water to the production zone for Unit No. 1. That is why the total power output declined by 20 MW from 110 MW to 90 MW within the first 2 years after the commencement of No. 2 Unit operation.

4. CONCLUSIONS

The results of well characteristics tests and well loggings conducted at the wells H-14, H-21, H-22 and 2H-12 helped us understand the reservoir changes before and after the start of Unit No. 2 operation. Before exploitation for Unit No. 2, the temperature of the production zone for Unit No. 1 had already dropped by 40°C from 270°C to 230°C within the first 11 years after the reinjection started in 1977. In this period, the power output of Unit No. 1 declined by 3 to 4 MW (about 6 %) every year because the reservoir had been cooled down by inflow of the returned reinjected water.

Furthermore, it began to decline by 7 or 8 MW (about 14%) every year, reflecting the accelerated temperature drop and the significant pressure decrease after the start of production and reinjection for Unit No. 2. It was estimated that the reservoir pressure in the production zone for Unit No. 2 decreased by 2.0 MPa because of the start of the production, and it induced the pressure decrease of 0.6 MPa in the production zone for Unit No. 1.

It is important to carry out periodical well tests such as well characteristics tests, well logging and tracer tests for the reservoir monitoring and management. Based on the results of these well tests, a strategy is presently under trial to stop the reinjection close to the production zone, and move the main reinjection zone to the north, to avoid cooling of the production zone.

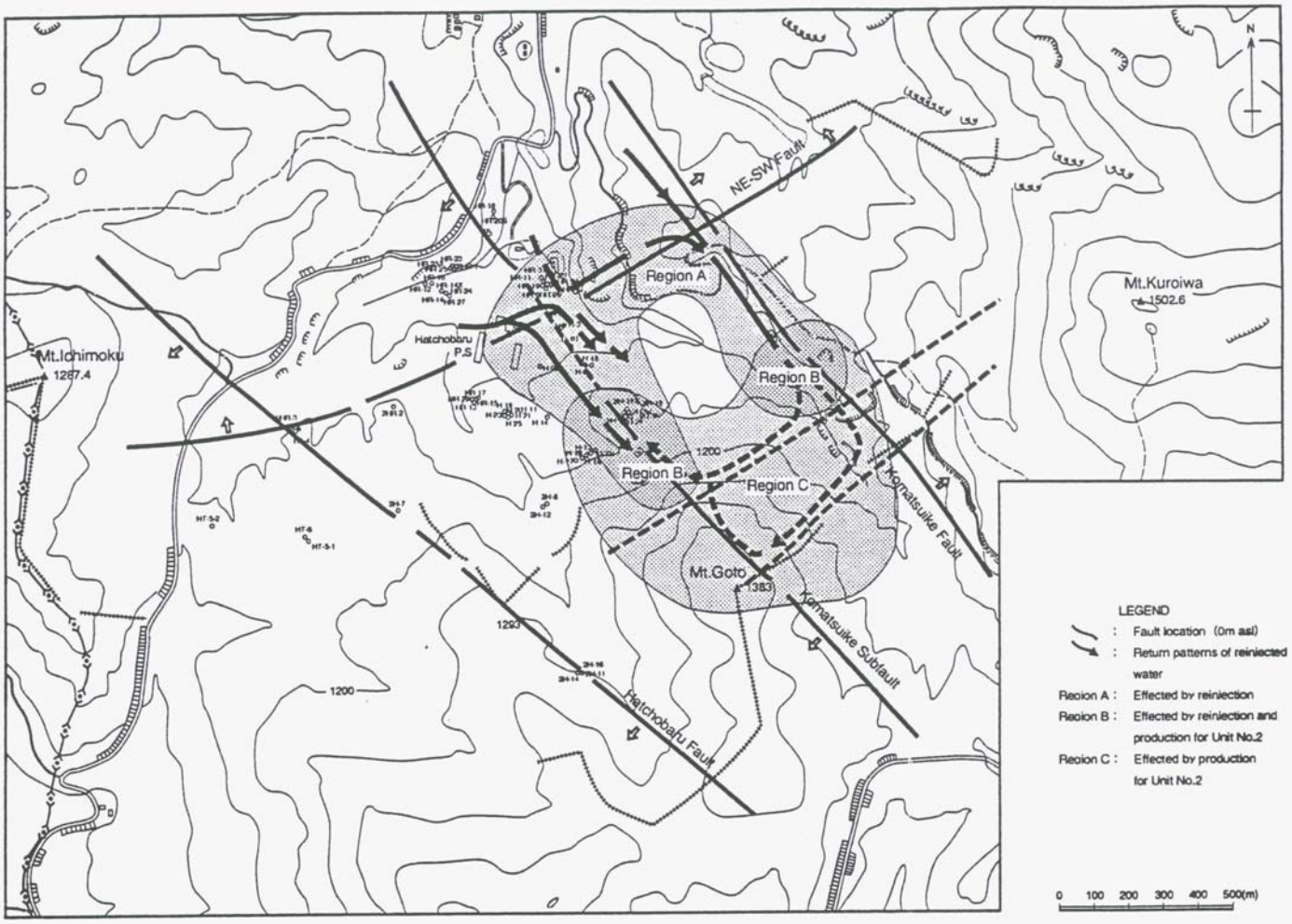

Fig. 3-1 Reservoir classification from the viewpoint of effects of reinjection and production for Unit No. 2

5. REFERENCES

R Itoi and M. Fukuda (1982). Well Inlet Pressure and Steam Quality of Hatchobaru Production Wells. *Geothermal Resources Council* Trans., Vol.6, 277-280

K. Shimada, T. Fujino, A. Koga and K. Hirowatari (1985). Acid Hot Water Discharging from Geothermal Wells in the Hatchobaru Geothermal Field *Chinetsu* (Jour. of the Japanese Geothennal Energy Association), Vol.22, No. 4,276-292 (in Japanese with English abstract)

S. Taguchi, M. Nakamura, H. Takagi and M. Hayashi (1986). Fracture Control of Fluid Flow Revealed by Fluid Inclusions at the Hatchobaru Geothermal Field. *Geothermal Resources Council* Trans., Vol. 10, 199-202

T. Manabe and Y. Ejima (1986). Reservoir Structure of the Hatchobam Geothermal Field and Evaluation. *Chinetsu* (Jour. of the Japan Geothermal Energy Association), Vol.23 No. 3 (Ser.93) 1-9 (in Japanese with English abstract)

T. Manabe, I. Kumagai, S. Harada, T. Fujino, T. Yahara and H. Takagi (1989). Operation Record and Management of the Otake Hatchobaru Geothermal Field and Evaluation. *Chinetsu* (Jour. of the Japan Geothermal Energy Association), Vol.26 No. 4 (Ser. 109) 1-23 (in Japanese with English abstract)

S. Kawazoe and H. Tokita (1993). Reservoir Management of the Hatchobaru Geothermal Field. *Pmceedings of the 15th New Zealand Geothermal Workshop* 1993, 291-2%

K. Shimada, K. Tagomori, T. Fujino and I. Kitakoga (1994). Deep Geothermal Structure and Targets of Future Development in the Hatchobaru Geothermal Field. *Chinetsu* (Jour. of the Japan Geothermal Energy Association), Vol. 31, No. 4, 301-319 (in Japanese with English abstract)

Y. Tsuru and H. Tokita (1994). Monitoring of the Reservoir Pressure and Temperature in the Hatchobaru Geothexmal Field, Japan. *Pmceedings of the 15th PNOC-EDC Geothermal conference,* 95-102

K. Matsuda and K. Shimada (1994). Change of Geothexmal Field in the Hatchobaru Geothexmal Field Derived from Chemical and Isotopic Data. *Proceedings of the 15th PNOC-EDC Geothermal Conference,* 15-21

H. Tokita, T. Yahara and I. Kitakoga (1995). Cooling Effect and Fluid Behavior Due to Reinjected Hot Water in the Hatchobam Geothermal Field, Japan. *Proceedings of the World Geothermal Congress 1995,* Vol.3, 1869-1874