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REINJECTION EXPERIENCES IN THE OTAKE AND HATCHOBARU GEOTHERMAL FIELDS

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ABSTRACT

This paper presents the recent exploiting state, the developing measures against experienced reinjection problems and geothermal model involved in the underground structure and hot water flow in the Otake-Hatchobaru fields.

The following two problems on reinjection are not disregarded to operate geothermal power plants.
(1) Interference of reinjection with production well
(2) Reduction in reinjection capacity of well
In this paper, the problems are presented and discussed on the basis of the field data in the Otake-Hatchobaru fields. Reinjection methods have been devised for preventing reservoir from cooling. study on silica scale and hydraulic fracturing test have been conducted for the purpose of recovering reinjection capacity or prolonging life time of reinjection well.

According to such investigations on reinjection, the reinjection problems have been able to be solved to some extent, compared with those at the initial stage of reinjection experience.

1. PRESENT STATUS AND EXPERIENCES OF REINJECTION IN THE OTAKE AND HATCHOBARU FIELDS

The Otake and Hatchobaru fields discharging wet steam, around the Kujyu volcanic area in the center part of Kyushu island were developed by Kyushu Electric Power Co., Inc. (KEPCO). KEPCO has constructed two geothermal power plants in these fields. Otake (12.5MW) and Hatchobaru No.1 unit(55MW) with famous double flash type unit had completed in 1976 and 1977, respectively. Table 1 shows present status of the power plants.

First surveys for the developnent of Hatchobaru No.2 was carried out at the west area of the Hatchobaru field in 1983. However, it was unable to gain a large quantity of steam. Therefore, reinvestigations were carried out by using MT survey, geochemical survey, drilling data and geothermal fluid characteristics data, which revealed a new prospective reservoir at the vicinity of Hatchobaru No.1 production zone. A first exploration well produced approximately 6000 kW , which proved the existence of the predominant reservoir in the area. After this, a few exploration wells are to be drilled in the same area for confirming the extent of reservoir and estimating optimum generating capacity, the life time of reservoir, the layout of wells, turbine desiqn condition and so on.

When the Otake power plant started operation, wastewater from the power plant was discharged into the Jizobaru pond about 4 kilometer away through transportation pipe. Scale deposited in the pipe of inside diameter, 350 mm with 30 - 40 mm thick of scale in 1968. Therefore, in the Otake field, we had to throttled the main valve of production wells and decreased the average output, approximately 8.5 MW in 1968 F.Y., because of clogging of hot water transportation pipes. This problem had been solved temporarily by adopting retaining (aging) tank method.

The reinjection has been started since 1972 in the Otake field due to restricting arsenic concentration in drain water by environmental regulation. KEPCO completed the Hatchobaru No. 1 unit in 1977.

when the unit started operation, the output was 23 MW due to the insufficiency of steam production and of reinjection capacity caused by delayed drilling. The output, however, increased steadily with more sucessful drilling, reaching the rated output of 55 MW in 1980.

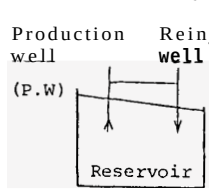
In those days, main reinjection zone (HR-7, 8, 9 etc.) was so close to production zone that its steam production decreased due to cooling effect by reinjection. The reservoir cooling was proved by historical change of reservoir temperature distribution by using silica thermometer, chlorideion concentration distribution and practical data of steam production as described below. Reinjection zone was gradually transfered to the lower altitude part apart from the production zone.

The acidic water zone of below pH5 suppress the scale deposition and reduction rate of reinjection capacity of well are decreased.

On the basis of various experiencesonreinjection, the conditions to decide reinjection drilling site are considered as follows.
(1) High permeability zone in the reservoir.
(2) Low water level zone.
(3) Area able to transport hot water without using pump
(4) Zone free from interfering with production zone
(5) High temperature zone
(6) Acidic water zone less than pH5

In order to prevent the cooling of production wells by reinjection, it is desirable to completely stop reinjection in the neighboring area. However, this is not possible. Accordingly, a part of the total hot water is diverted to the Otake area for reinjection to ease the effect. Moreover a new transportation pipe route for hot water from Hatchobaru to Otake is being planned at present. With the completion of this route, the problem of the falling capacity of production wells is expected to be solved.

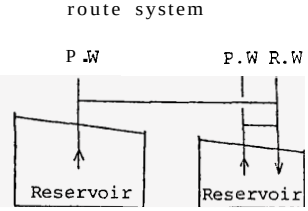
(a) Conventional reinjection route system



Hatchobaru field

(1) Thermal interference with production well
(2) Getting slow the reduction rate of steam production by so-called "Quantitative dam up effect"

(b) Additional reinjection route system



Hatchobaru field Otake field

(1) Non-thermal interference with production well
(2) Decreasing steam production without dam up effect

Table 1. PRESENT STATUS OF THE OTAKE AND HATCHOBARU P.S. (As of Jun. 1985)

	Otake	Hatchobaru
Rated Output	12,500 KW	55,000 KW
Start of operation	Aug. 1967	Jun. 1577
Plant Type	Single Flash	Double Flash
Present Output	9,000 KW	53,000 KW
Total Electricity Generation in 1384 F.Y	77×10^3 MWH	440×10^3 MWH
Capacity Factor in 1984 f.Y	70.2 %	31.4 %
Number of Production Wells (Drilling Depth)	5(370m ~ 550m)	13(760m ~ 1970m)
Number of Reinjection Wells (Drilling Depth)	13(330m ~ 700m)	16(550m ~ 1500m)

2. OTAKE AND HATCHOBARU GEOTIIERYAL MODEL

A geothermal model is important not only for reservoir evaluation, determination of drilling sites and design of casing programs etc. but also for deciding reinjection zone, which had been revised so as to agree with new informations, that is, new exploration and drilling data. The model consists of the broad area data around a geothermal field and the detailed data within the fields. The two kind of data are overlapped and checked well so as to be consistent. The broad area data used for the Hatchobaru model were gravity, MT (magneto telluric), geology, geochemistry (isotope) and drilling data. While, the detailed data within the fields were MT, CSAMT, geochemistry, practical result of production and reinjection and lost circulation, tracer test, well logging, topography and drilling.

The well configuration in the Hatchobaru field is shown in Fig. 1. Fig. 2 shows the plain figure of geothermal model concerning with permeability distribution at Hatchobaru. This model satisfies above survey data. For example, when this model is overlaid on a figure of the predominant wells layout in Hatchobaru (Fig. 1), it will be found that each figure agree with and compatible (Fig. 2).

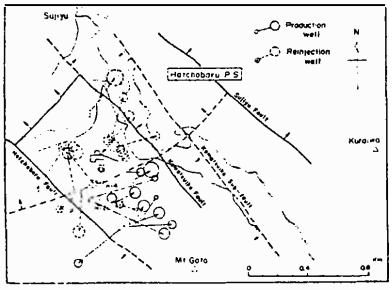


Fig.1 Well layout in the Hatchobaru geothermal field.

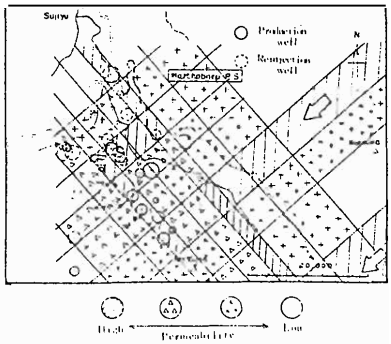


Fig.2 Geothermal reservoir model at Hatchobaru (Block model of permeabilty)

Furthermore, a qualitative geothermal model of Otake and Hatchobaru is shown in Fig. 3. The Otake and Hatchobaru fields are situated at the southern margin of the east-west trending Aso-Beppu depression zone which runs across north-central Kyushu island, and surrounded by Mt. Kujyu Mt. Goto, Mt. Kuroiwa and Mt. Waitaetc. Each field is located within less than 2 km distance.

Fig. 4 shows the general tendency of the basement rock depth by the gravity survey including the fields. As it is clear from the figure, this fields is uplifted and lying in belt towards northeast. Both side of the uprift part sink gradually as shown in Fig. 4. Fig. 5 shows the distribution of deuterium ratio of surface water samples, indicating a southeast reign of the Hatchobaru field and Mt. Goto distributing lower values as same as the values of water in the Otake and Hatchobaru reservoir. The chemical and isotopic survey results for geothermal fliud do not indicate magma gas flowing into reservoir but heating by heat conductivity of deeper rocks and indicate high temperature fluid discharging from deeper level under Mt. Goto. Therefore, the geothermal fluid is supposed to be recharged and heated at the southeast region and discharging through the good permeability path to the vent area, that is, Otake and Hatchobaru fields. A exploration well near Mt. Goto discharged dry steam of equivalent generating output about 6000 kW at the first stage. It was considered that the drilled well was close to the heat and water source. Reservoir mechanism must make more study in future.

The main geologic succession is composed by four group in descending order.

(1) Kujyu volcanic rocks
Hornblend andesite
(2) Hohi volcanic rocks
Pyroxene andesite lavas and tuff breccia
(3) Usa group
Tuffaceous shale and volcanic conglomerate
(4) Basement rocks
Granitic and Matamophic rocks

as shown in Fig. 3 and the tectonics of these areas are prominent with northwest southeast trending faults. Most of geothermal reservoir is associated with vertical type fracture zones and exist in the Hohi volcanicrocks While, there is no remarkable reservoir in the basement rocks at 600 m to 700 m below sea level. The lost circulations at Hatchobaru are most predominant in the region of 0 m to 500 m above sea level as is clear from Fig. 6. MT is becoming most useful method to find reservoir positions and using to understand the extent of reservoir for drilling target and casing program (Figs. 7 and 8). An exploration well drilled on the basis of the MT survey data has Seen discharged sucessfully.

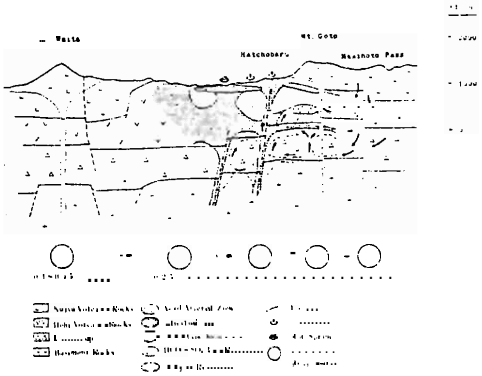


Fig.3 Geothermal model of the Hatchobaru field

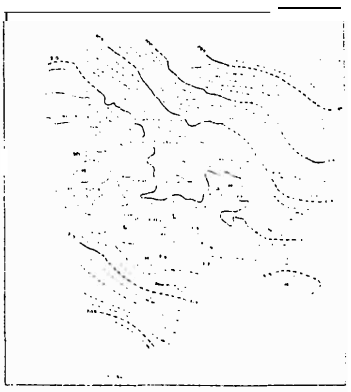
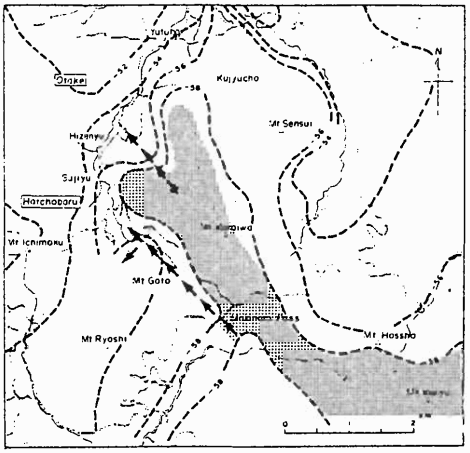


Fig.4 Bouger gravity map of the Otake-Hatchobaru fields (mgal).



Isotopic line of deuterium of surface water

Estimated recharge area of the Otake and Hatchobaru geothermal systems

Flow pattern of geothermal fluid provided to the Otake and Hatchobaru reservoirs

Fig.5 Deuterium ratio distribution of surface water in the Hohi area (‰)

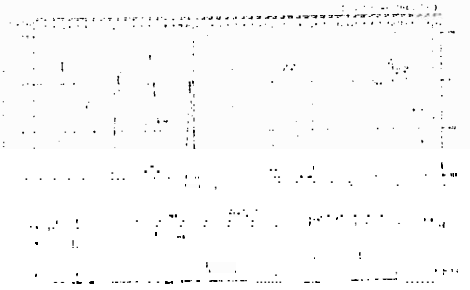


Fig.6 Maximum lost circulation depth and quantity of well at Hatchobaru

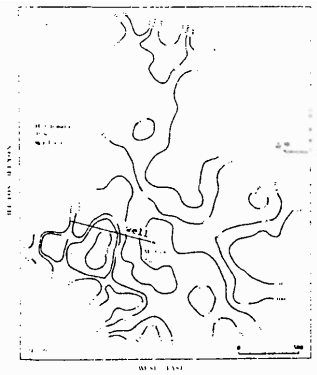


Fig.7 Resistivity at sea level in the Hatchobaru field (MT survey).

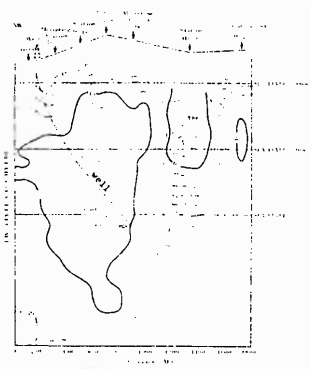


Fig.8 Cross section of apparent resistivity in the Hatchobaru field (MT survey)

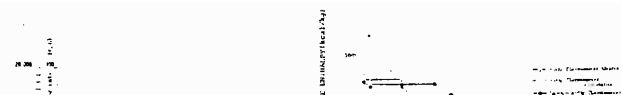
3. PFFECTS OF HOT WATER REINJECTION

(1) Interference of reinjection with production well

The major impact of geothermal reinjection experience in the Otake and Hatchobaru geothermal-fields is the interference of reinjection with the production wells. That is, the reduction of steam productivity (decreasing output) and the change of chemical properties of discharge.

Fig. 9-1 and 9-2 show the changes. in steam flow rate and output and the changes of reservoir temperature (Na-K-Ca-Mg temperature and SiO_2 temperature) of H-4, respectively. Since the tendency of output change is very similar to that of reservoir temperature, the reduction of output must be caused by cooling of reservoir with injected wastewater. The tracer test in the Hatchobaru yeothermal field indicates that injected wastewater travels to the production zone within a very short time and sometime reduces reservoir temperature. For example, the tracer injected into HR-12 reinjection well appeared in the discharged water from H-12 production well within a hour and the distance between the two wells is about one kilometer as shown in Fig. 9-1.

The Hatchobaru reservoir temperature distribution before wastewater reinjection is shown in Fig.10 . The temperatures were calculated by using silica (quartz) thermometer. The high temperature zone corresponds to the discharge zone of main reservoir along the Komatsuike sub-fault in the south-east direction of the power plant. The recent temperature distribution of the Hatchobaru reservoir is shown in Fig. 11. Low temperature zone spreads out toward the part of reinjection zone. The wells at the zone such as HR-5, 12, 13 and so on have been used to inject wastewater. The H-4 well described above must be directly affected by the reinjection water through the wells, because the reinjection wells and H-4 well are tapped the same reservoir along NW-SE fault crossing the Komatsuike subfault. The Otake geothermal reservoir has been cooled as same as the Hatchobaru reservoir. However, the problem is not so serious as compared with that of the Hatchobaru geothermal field. The low temperature zone at Otake is not broadened considerably as shown in Fig. 12.



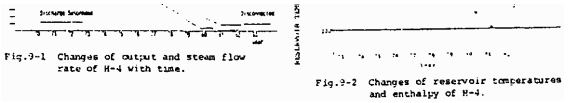


Fig.9-1 Changes of output and steam flow rate of H-4 with time.

Fig.9-2 Changes of reservoir temperatures and enthalpy of H-4.

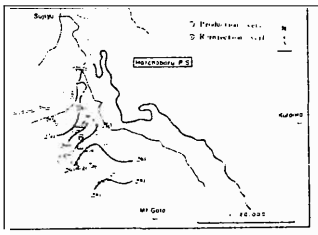


Fig.10 Temperature distribution of main hot-water reservoir in the Hatchobaru field without reinjection effect (°C).

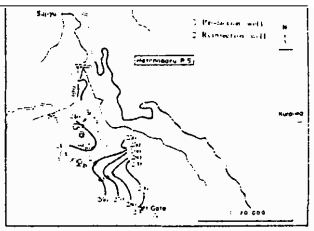


Fig.11 Temperature distribution of main hot-water reservoir in the Hatchobaru field in 1983 (°C).

Futhermore, hot water reinjection effected on chemical properties of discharge and reservoir fluid. Until a few years ago, discharging hot water from production well affected by reinjected water had been weakly acidic pH. As shown in tables 2 and 3, pHs of discharged waters from H-3 and 4 wells had decreased with their reservoir temperatures since start of reinjection of water into wells around them. Simultaneously, trogen gas concentration in noncondensable of discharge increased with pH reduction of water. It is reasonable to consider that the remarkable rise in nitrogen concentration is caused by reinjection. That is, the high nitrogen concentration indicates the contamination of air with westewater injected into open wellheads of reinjection wells and transportation of oxygen gas from the surface to the reservoir. From these results, it is considered that hydrogen sulfide (H_2S) in the reservoir was oxidized by oxygen (O_2) transported through reinjection wells and sulfuric acid (H_2SO_4) was generated in the reservoir water as following chemical reaction.

$$H_2S + 2O_2 \longrightarrow H_2SO_4$$

This mechanism is supported by the results of sulfur isotope survey. $S^{34}S$ of sulfate ion (about + 18 ‰) in discharged water affected reinjection is slightly smaller than that (about + 22 ‰) in the water free from reinjection effect. Sulfate ion in the former water must be mixture of dissolved sulfate ion from rocks and sulfate ion from hydrogen sulfide. The air-contamination exerted not only pH-reduction but also silica scale formation described below. Therefore, air-free system for transpoting and reinjecting water pipe line were adopted to avoid the air-exposure or'

geothermal water and not to contaminate air into reservoir water a several years ago.

The cocentrations of nonvolatile chemical components in discharged water and reservoir water have increased by reinjection, because chemical components dissolved in water have concentrated by steam separation in production wells and reinjected water dissolving high concentration chemical-components have mixed with originally reserved water. Intermixture of reinjected water is able to be detected by chemical analysis of discharged water. Especially, chloride ion in the water is a good indicater due to unreactive element with rocks. As an example, change in chloride concentration in the H-4 reservoir water with time is shown in Fig. 13. The Cl concentration has gradually increased with the lapse of time since start of reinjection. Cl concentration having been monitored, mixing ratio of reinjected water in reservoir water is able to be calculated by comparison of Cl concentrations in reservoir water and reinjected water, such as 54 % of reinjection water in 1975 and 63 % in 1979 in H-4 reservoir water. Chemical components were altered by reinjection in large areas of reservoir along the Komatsuike sub-fault and NE-SW fault crossing it in analogy with reservoir temperature. Figs. 14 and 15 show Cl concentration distributions in reservoir water before and after reinjection start, respectively. From these figures, it is found that the reservoir of H-12, 13, 15, 16 and 20 at the mountainside of Mt. Goto is hardly effected by reinjection. This interpretation is supported by the temperature distribution of reservoir (Fig. 10 and 11).

Furthermore, stable (hydrogen and oxygen) of hot water is effected by reinjection, because hydrogen and oxygen isotopes of wastewater is heavier than those of originally reserved water due to separation of steam below 224°C (in practice, the Separation temperatures are 161°C for primary steam and 109°C for secondary steam in the Hatchobaru power plant). So, it is able to detect reinjection effect by isotope shifts of hydrogen and oxygen. The changes in chemical component concentration and hydrogen and oxygen isotope ratios in the Hatchobaru field are considered to be more remarkable than that in the Otake field due to difference of the type of power unit i.e., double flash type in the former and single flash type in the later.

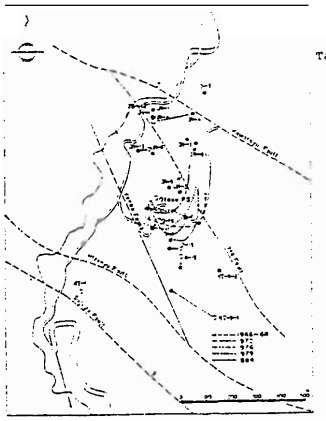


Fig.12 Change of isothermal contor of reservoir temperature (220°C) in the Otake field.

Table 2 Change of chemical characteristics of discharge from H-3 in the Hatchobaru field.

Year		1973	1978	1979
pH		5.1	4.1	4.6
Na	(ppm)	1,270	2,660	2,192
K	(ppm)	245	398	289
Ca	(ppm)	5.5	190	120
Mg	(ppm)	0.6	12.6	7.8
Li	(ppm)	6.7	–	14
Cl	(ppm)	2,106	5,034	4,300
SO_4	(ppm)	49	290	267
HCO_3	(ppm)	9	0	0
HBO_2	(ppm)	138	347	267
SiO_2	(ppm)	980	602	630
As	(ppm)	2.25	–	3.19

Year		1973	1974	1975	1978	1980	1981	1982
Analysis of Noncondensable Gas in Steam	CO_2	86.1	95.3	72.9	75.5	75.3	84.3	75.0
	H_2S	10.0	1.5	2.1	14.8	5.6	3.5	2.9
	O_2	0.9	1.0	0.5	0.2	0.3	0.4	0.3
	N_2	3.0	2.2	24.5	9.5	18.8	11.8	21.8
Analysis of Hot Water	pH	7.9	7.3	5.8	6.5	7.3	7.6	7.2
	Na (ppm)	1550	1780	1880	2200	2241	2200	2140
	K (ppm)	284	328	348	–	268	236	231
	Ca (ppm)	9.2	10.0	10.0	34.0	91.2	74.2	83.5
	Mg (ppm)	0.03	0.4	0.46	1.20	1.40	1.78	2.60
	Cl (ppm)	2550	2990	3210	3850	3740	3660	3690
	SiO_2(ppm)	1040	1016	850	922	565	592	538

(2) Decrease in reinjection capacity of well.

An other impact of geothermal reinjection experience in the Otake and Hatchobaru geothermal-fields is the decrease of reinjection capacity of well, as shown in Fig.16. Since the reinjection capacity decreases by a few decade % every year, it is necessarytoprovide *two* or three additional reinjection wells annally and to cause great expense. This trouble must be caused by blockage of reinjection well with deposited scale and ascending underground water level around reinjection well. After suspending reinjection into well for a long time, the reinjection capacity of the well hardly recovered in spite of descending underground water level. Therefore, it is considered that scale deposition is very important factor to decrease the reinjection capacity. As same as the trouble for reinjection well, blockage of wastewater transportation pipes to reinjection wells by scale was a serious problem. Chemical components of these scales, which contain silica (SiO_2) as main component are shown in Table 4. According to silica chemistry study, it is revealed that silica scale is mainly formed by the following chemical reaction.

$$= Si\text{-}O\text{-} + Si(OH)_4 \longrightarrow = Si\text{-}O\text{-}Si(OH)_3 + OH^-$$

Surface of silica scale (solid) — Monosilisic acid or low molecular weight silicic acid in water (unionized species) — Silica scale

So, it seems that the methods to prevent monosilicic acid deposition are effective for avoiding silica scale formation from wastewater. However, in some case, polysilicic acid formed in reinjected water was confirmed to act as mechanical blockage in rock fissure by recent study.



Fig. 13 Change of Cl^- ion concentration in H-4 reservoir water with time.

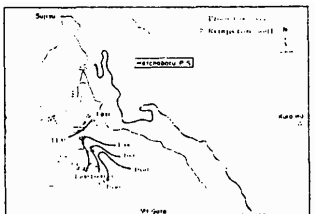


Fig. 14 Chloride ion concentration distribution of main hot water reservoir in the Hatchobaru field without reinjection effect (ppm)

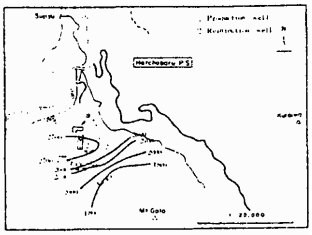


Fig. 15 Chloride ion concentration distribution of main hot water reservoir in the Hatchobaru field in 1993 (ppm)

Table 4 Chemical compositions of scales deposited in the Otake and Hatchobaru fields (%).

Site name	SiO_2	FeO_3	FeO	MnO	MgO	Al_2O_3	Cl	SO_4	CaO	
Otake No. 0-9. retaining tank	94.8	<0.01	0.05	<0.01	<0.01	0.57	0.01	<0.01	0.16	amorphous silica
Otake Transportation pipe	84.6	0.66	0.81	0.02	0.02	3.14	<0.01	<0.01	0.51	amorphous silica
Hatchobaru retaining tank	92.0	0.23	0.13	0.02	0.05	1.01	0.01	<0.01	0.07	amorphous silica

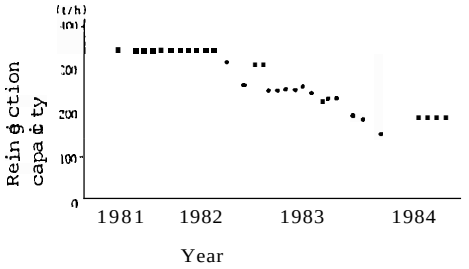


Fig. 16 Change of maximum reinjection capacity of **HR-18** in the Hatchobaru field.

(3) Tracer test and reinjected water flow pattern

Tracer tests in the Otake and Hatchobaru geothermal-fields have been carried out by a fluoresent chemical reagent as a tracer not to effect on surrounding environments. So, quantative calculations of reinjected water behavior could not be carried out. The tracer test results have been used to decide production reservoir area. and depth affected by reinjection water, as shown in Figs. 17 and 18.

According to the tracer test result and chemical interpretation of discharge, flow pattern of high temperature water and low temperature (reinjected) water in the main reservoir at Hatchobaru is proposed **as** shown in Fig. 19. Taking into account geological structure in the Hatchobaru field, flow pattern model in the reservoir is shown in Fig. 20.

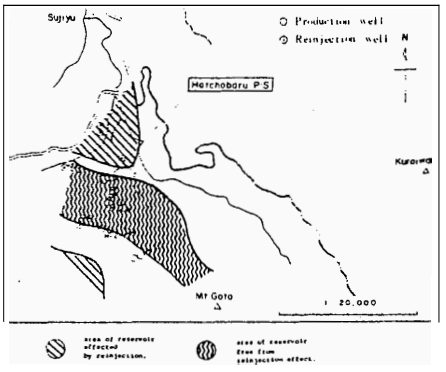


Fig. 17 Results of tracer test in the Hatchobaru field.

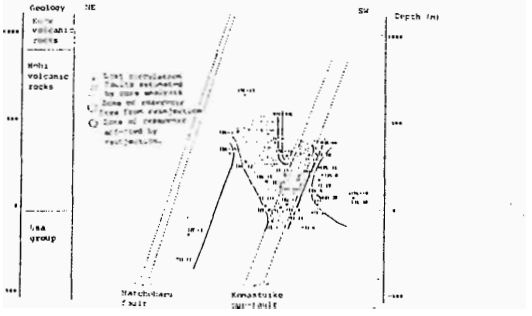


Fig. 18 Results of tracer test in the Hatchobaru field.

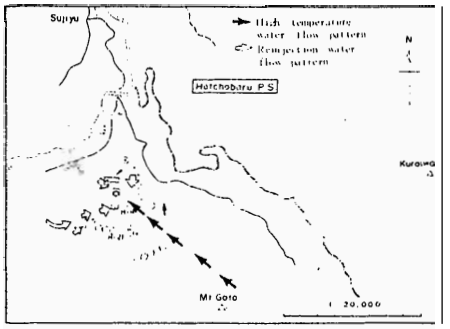


Fig. 19 Flow patterns of geothermal fluids in the Hatchobaru main reservoir.

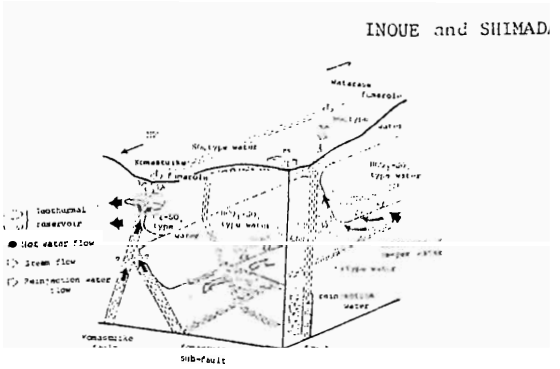


Fig. 20 Flow patterns of geothermal fluids in the Hatchobaru main reservoir.

4. COUNTERMEASURES AGAINST REINJECTION TROUBLES

(1) Cooling of reservoir

According to the experiences of reinjection in the Otake and Hatchobaru fields, a few countermeasures against cooling of reservoir have been devised and adopted. The reinjection wells most affecting production zone were removed to such a distance that cooler reinjected water is reheated before arriving at the production zone. The reinjection and production wells were arranged roughly in side-by-side configurationwith reinjection in the NW area and production in the SE area in the Otake and Hatchobaru fields, respectively by considering distance not to interfere with production zone, so-called "safe distance". However, the safe distances have varied, because the mobility of reinjected water depends on permeability along fracture, geological structure and reinjection waterflow rate. The safe distance in the fields has not kept for all reinjection wlls and reservoir temperature and steam productivity have been gradually decreased with time.

Consequentry, a third amount of discharged water from the Hatchobaru field is deverted to the Otake field for reinjection to prevent the Hatchobaru reservoir from cooling. Moreover, the remainder of wastewater in the Hatchobaru field is injected in the areas and depths **of** reservoir free from mixing of reinjection water with high temperature water in production zone, as **shown** in Figs. 17 and 18. The areas are in the fracture zone different from the main production reservoir or the downstream of a geothermal water flow in the main reservoir. The areas in the later is preferable to reinject, because pumps to draw up and inject wastwater into the areas in the former such as the fractures along the Hatchobaru fault is necessary due to topography. And then, reinjection in the later must be desirable for protecting geothermal resources unless cooling effect. However, deciding the reinjection well site is very difficult not to effect production zone as described above. Therefore, more detailed study on underground reservoir structure should be carried out to select optimum sites for reinjection wells. Anyway, cooling of the Hatchobaru reservoir by reinjection is prevented considerably by separation of reinjection zone from main production zone at present.

(2) Scale deposition

In the Otake and Hatchobaru fields, various meth**ods** to prevent and remove silica deposit such as floatation, adding chemical reagents including silica colloid and so on have been examined but almost methods are ineffective or uneconomic to adopt and have technical uncertainties, except for retaining tank method and air-free method.

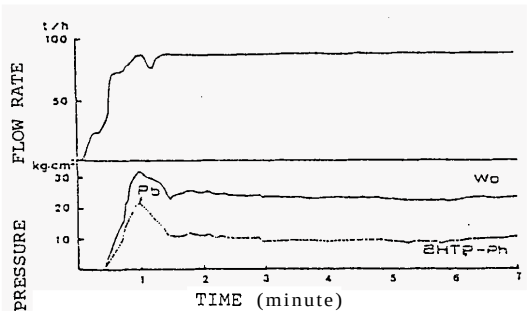
In view of theoritical aspect, preventing silica reaction described above is applied to almost methods devised for avoiding silica scale deposition in the transportation pipes and reinjection wells. In the Otake and Hatchobaru geothermal fields, the following methods are adopted. (i) retaining tank, (ii) air-free pipe system, (iii) selecting acidic altered zone or acidic water reservoir (Cl-SO type water reservoir) as reinjection zone. Method (i)'devised by Yanagase et al. is to retain (age) separated water **for** a certain time and flow **it** into pipe and well. This metod was appreciably effective for prolonging reinjection well life time. The retaining conditions such as water flow rate and retaining tank capacity depend on pH and temperature of hot water and concentrations of monosilic acid and polysilicic acid. Actually, retain-

ing time can be decided by using an induction period, because after the period, the reaction between monosilicic acid and polysilicic acid tends to occur and monosilicic acid concentration decrease rapidly due to increase in Si-0-, active site formed on polysilicic acid surface in water. Consequently, the chemical reaction of silica scale formation described above hardly occur. It was found that exposure of geothermal water to air accelated silica scale formation. Therefore, it is advisable to avoid the air-exposure of a geothermal water at surface equipments (Method (ii)). Cor preventing the chemical reaction of silica scale formation, pH reduction of hot water must be effective due to decrease of ionized (reactive) silanol group on silica scale. In practice, the reinjection capacity of well drilled into acidic altered zone or acidic water reservoir hardly decreased for a long time (Method (iii)). Furthermore, according to the basic test on reinjection in the Otake and Hatchobaru geothermal fields, we are convincing that high temperature water reinjection and pH control of reinjection water by mineral acid are very effective methods to prolong the reinjection well life time. But, these methods is not possible to adopt under the Otake-Hatchobaru conditions. The former method bring about decreasing steam flow rate and the later method has engineering uncertainty for transportation and well casig pipes and possibility of environmental pollution. At present, pH-control method free from engineering uncertainty and environmental pollution is being developed in KEDCO laboratory.

(3) Recovery of reinjection wells by hydraulic fracturing

Simple hydraulic fracturing no using additions are applied to wells for increasing reinjection capacity in Otake and Hatchobaru. As a result of fracturing, it is possible to develop lost circulation of water artificially by reparting appropriate pressurization. Such fracturing in this field has shown the sufficient effect in the recovery of reinjection capacity. However, the capacity recovered by the fracturing decreased gradually. If we use propper additions keeping fracture in open, it will be expected a constant capacity.

Fig. 21 shows a fracturing test at reinjection well No. 14 (HR-14). When the well was pressurized at 20 kg/cm^2 to 30 kg/cm^2. The capacity increased from about 4 tons/hour before the test to over 65 t/h after the test and reduced to 16 t/h after 3 moths. In another HR-13, the capacity changed from 5.6 t/h to over 100 t/h by fracturing and continued at 40 t/h for 4 months.



Wp :Wellhead pressure BHTP : Bore hole pressure
Ph :Static head pressure Pb:Breakdown pressure (about 90 kg/cm^2)

Fig. 21 Result of fracturing at HR-14 in the Hatchobaru field

KEPCO has set up micro-earthquake observation system and always observes micro-earthquake in the fields, as a result of which, it was found that the correlation has not been observed between reinjection and micro-earthquake.

REFERENCES

1) Yoshida, K. (1980) Chinetsu (Jour. of the Japan Geothermal Energy Association) No. 15.
2) Yoshida K., Tanaka K. and Kushunoki K. (1983), Electric Power Research Institute, 1983.
3) Yoshida. K., Ejima Y. and Shimoike T. (1984) Third ASEAN Geothermal Energy Seminer, 1984, Bandung Indonesia.
4) Shimada K. (1984) Textbook of the 15th international group training course in geothermal energy held at Kyushu University, 1984.
5) Fujino T. and Yamasaki T. (1985) Geothermal energy council bulletin, April
6) Hirowatari K., Shimada K. and Nishiyama E. (1985) Report of Kyushu Electric Power Co. Laboratory No. 8005.

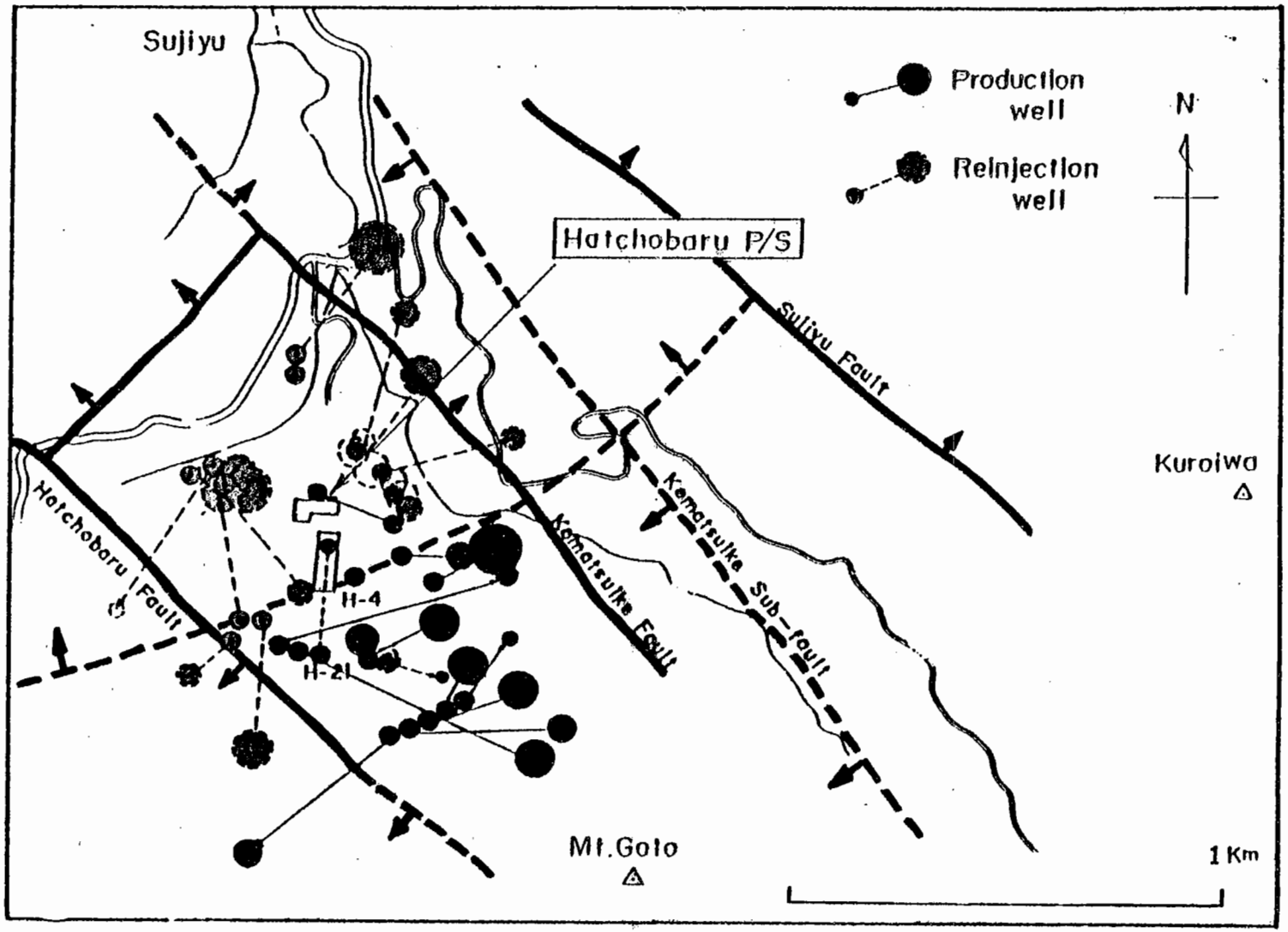


Fig.1 Well layout in the Hatchobaru geothermal field.

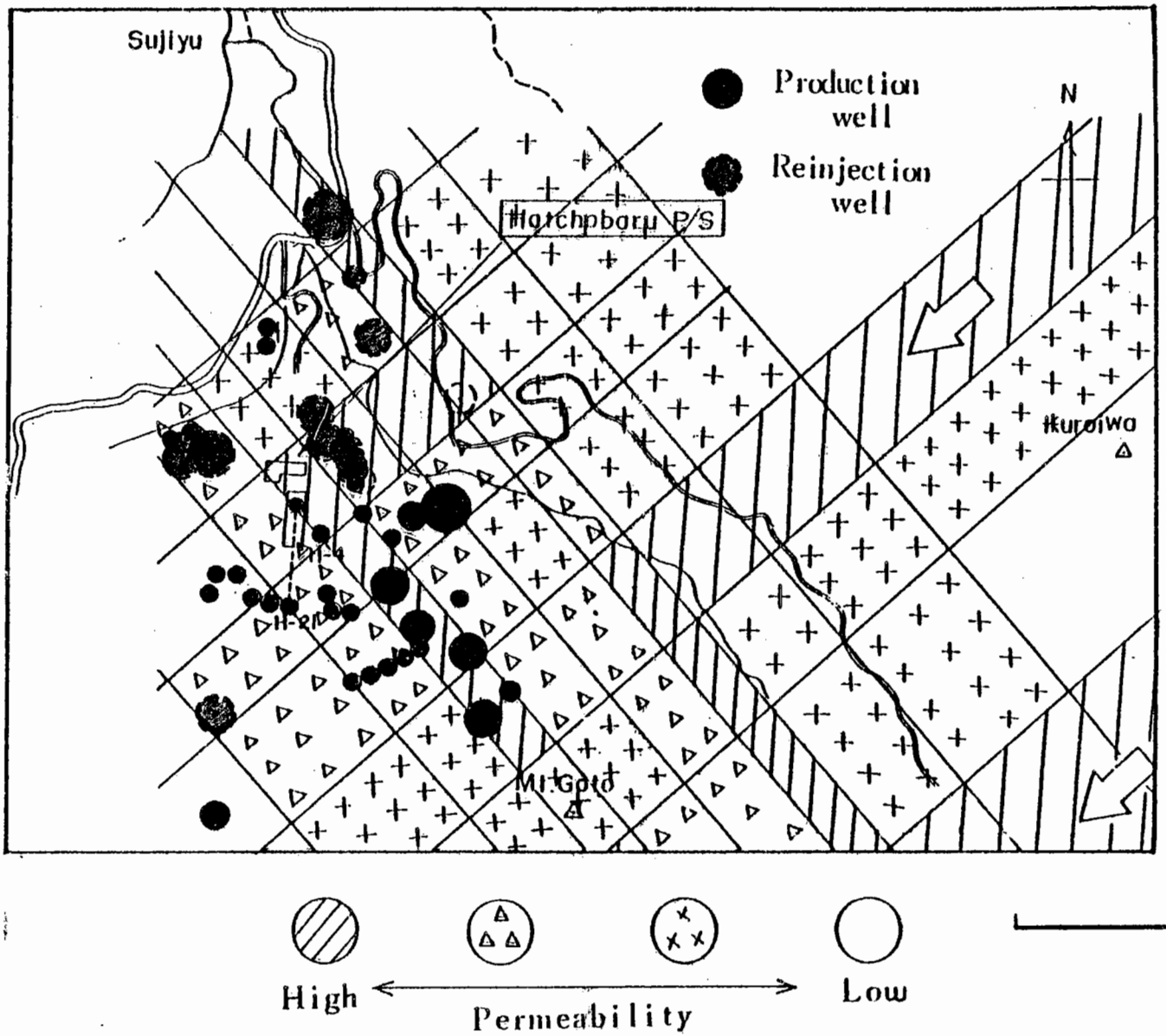


Fig.2 Geothermal reservoir model at Hatchobaru
(Block model of permeabilty)

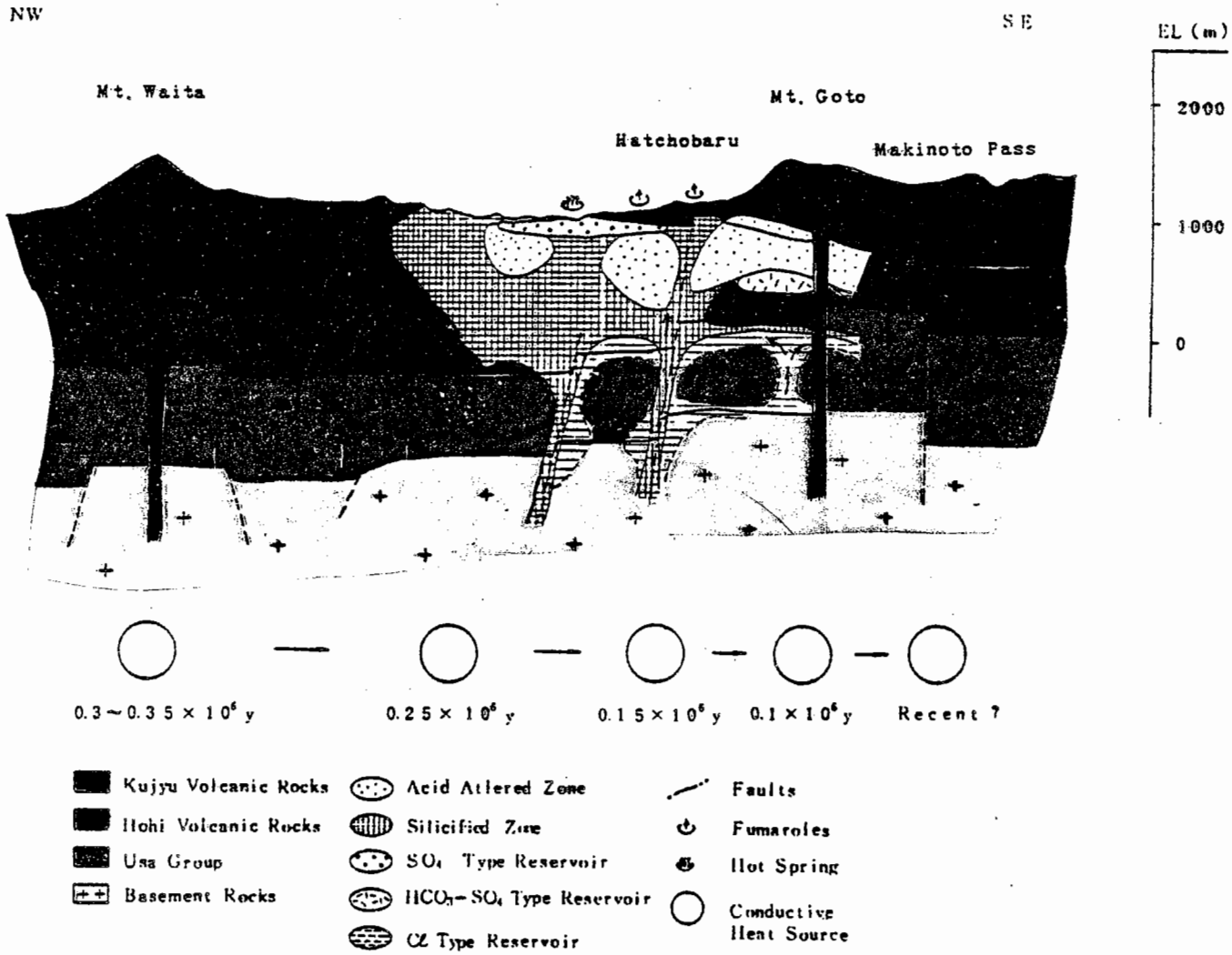


Fig.3 Geothermal model of the Hatchobaru field

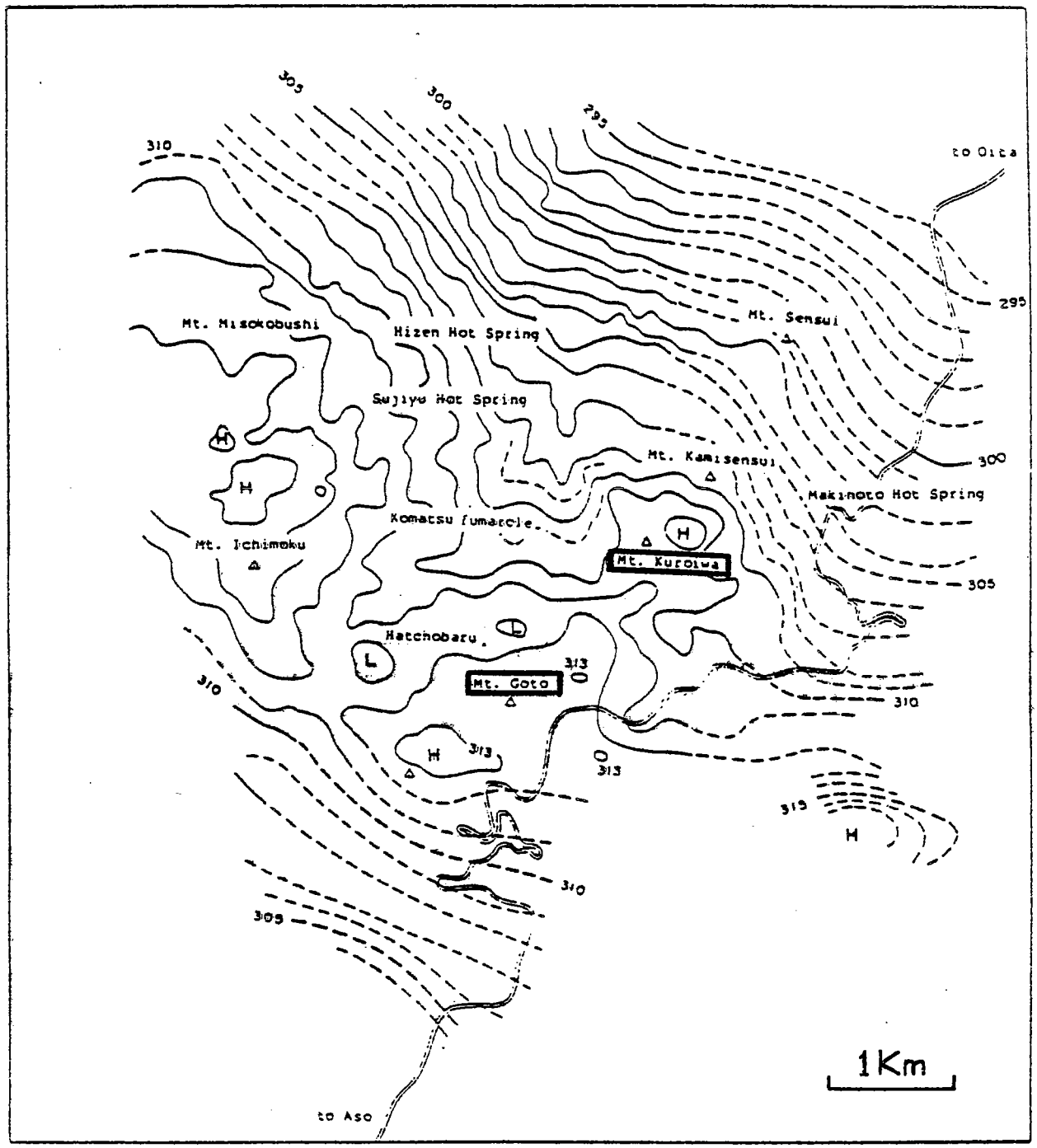
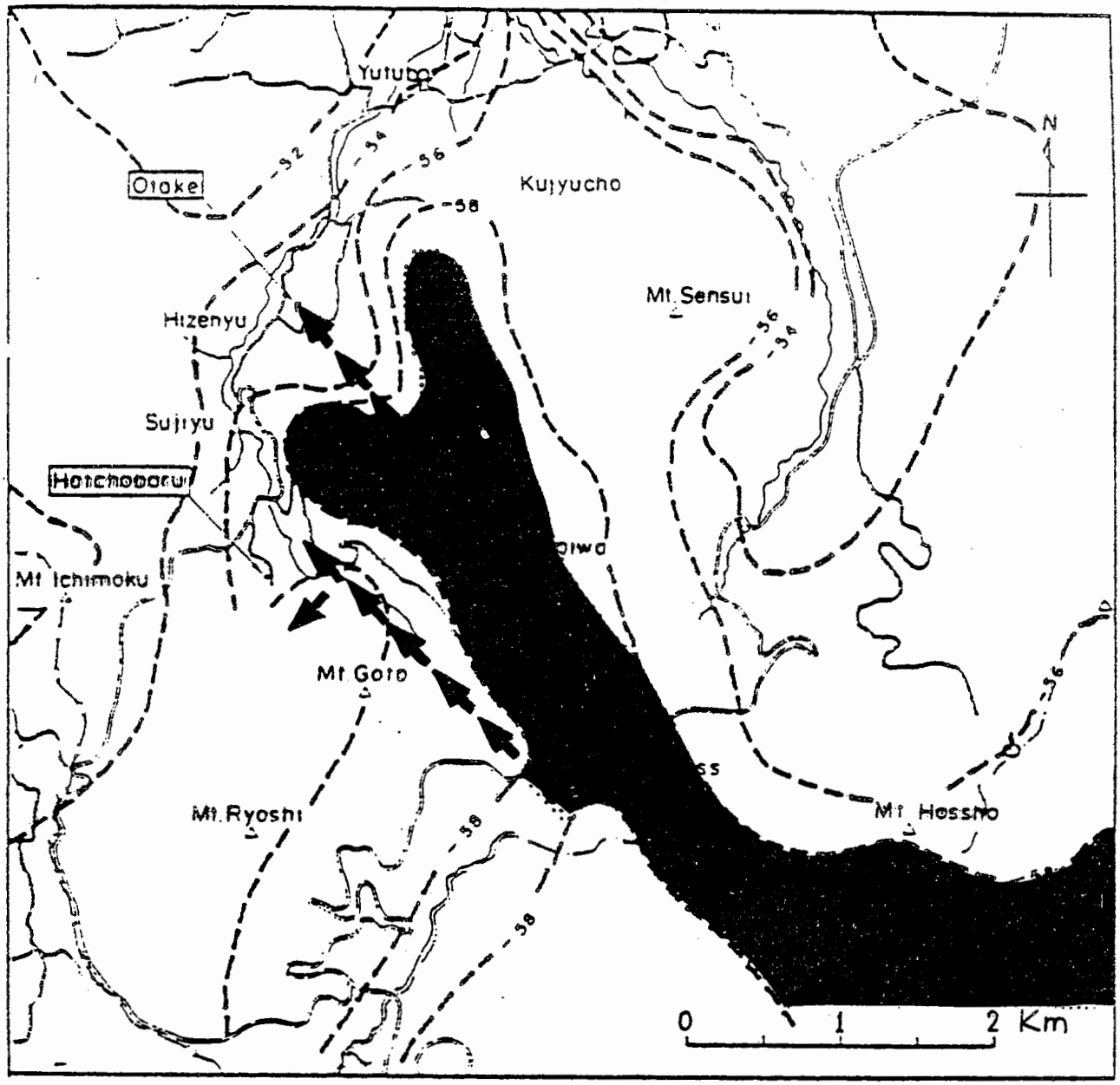


Fig.4 Bouger gravity map of the Otake-Hatchobaru fields (mgal).



Iso-ratio line of deuterium of surface water

Estimated recharge area of the Otake and Hatchobaru geo thermal-systems

Flow pattern of geo thermal fluid provided to the Otake and Hatchobaru reserwirs

Fig.5 Deuterium ratio distribution of surface water in the Hohi area (‰)

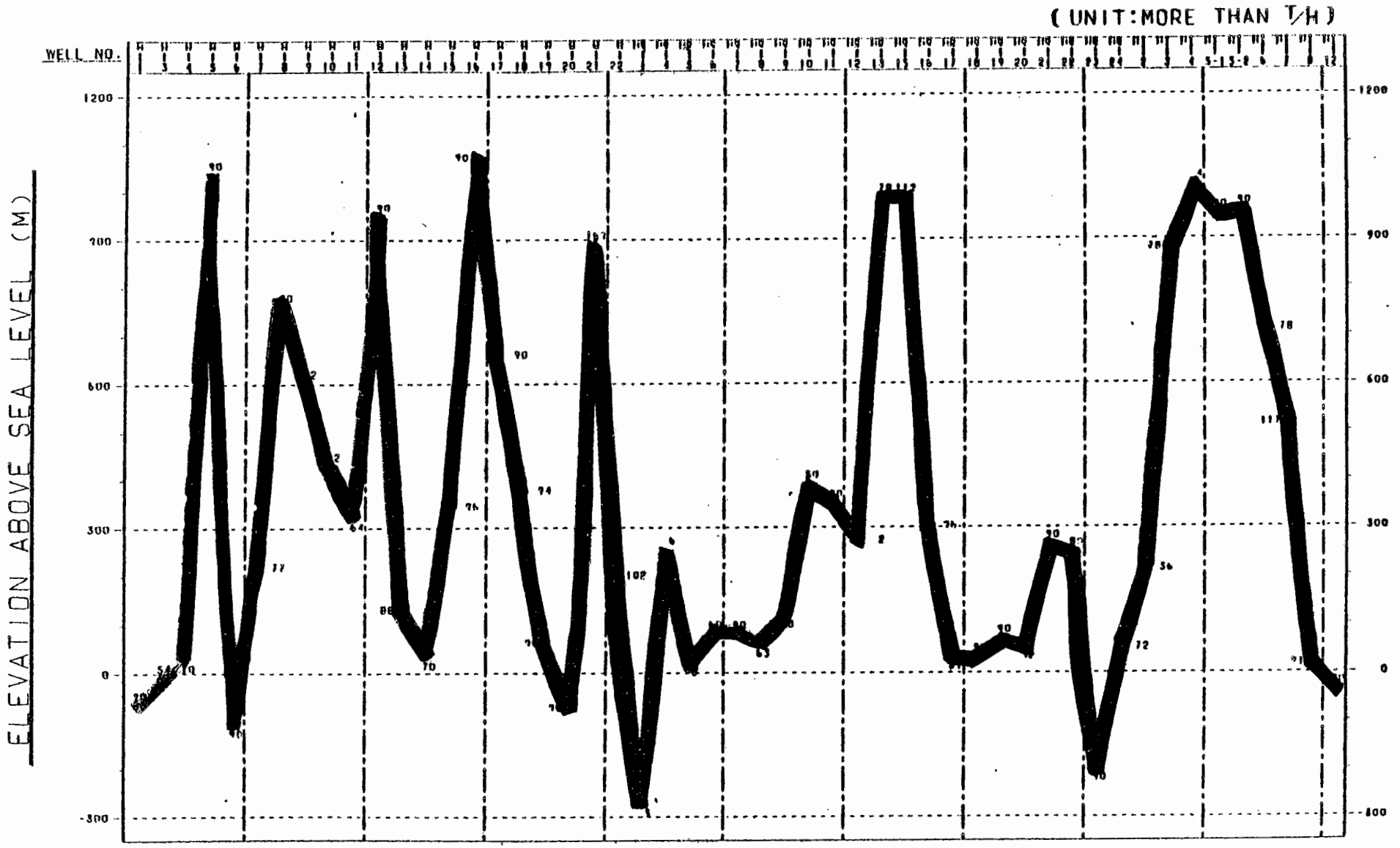


Fig.6 Maximum lost circulation depth and quantity of well at Hatchobaru

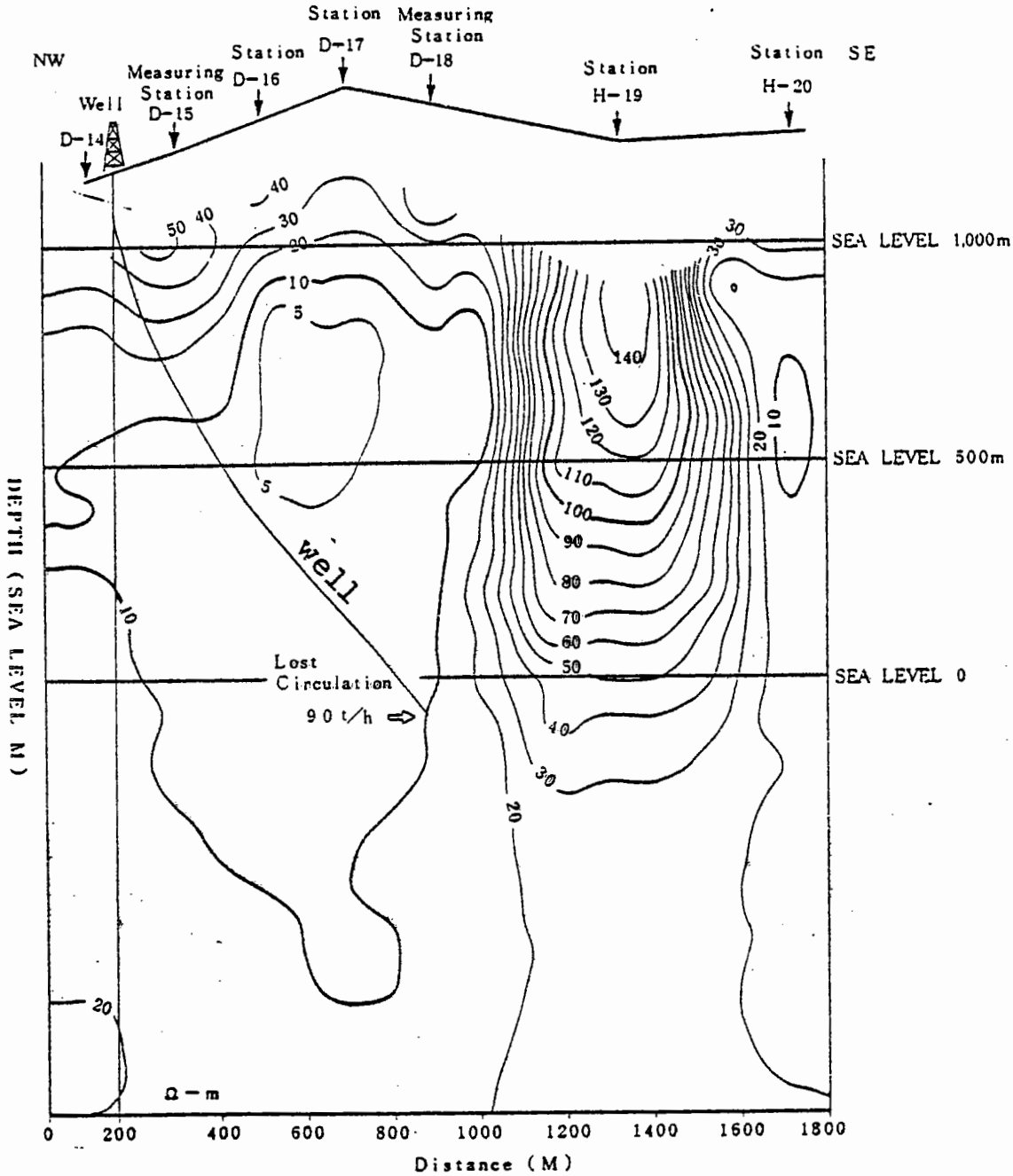


Fig.8 Cross section of apparent resistivity in the Hatchobaru field (MT survey)

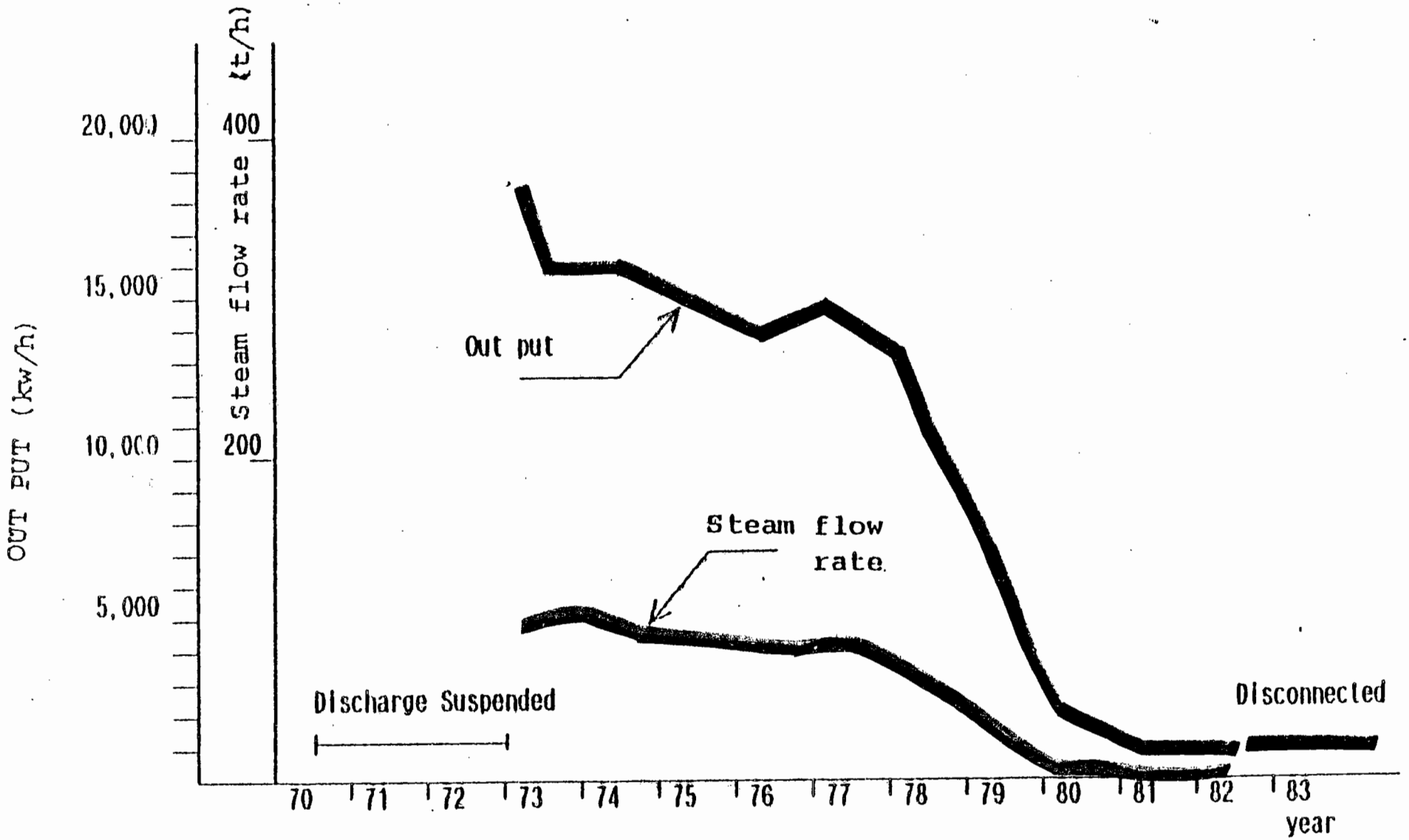


Fig.9-1 Changes of output and steam flow rate of H-4 with time.

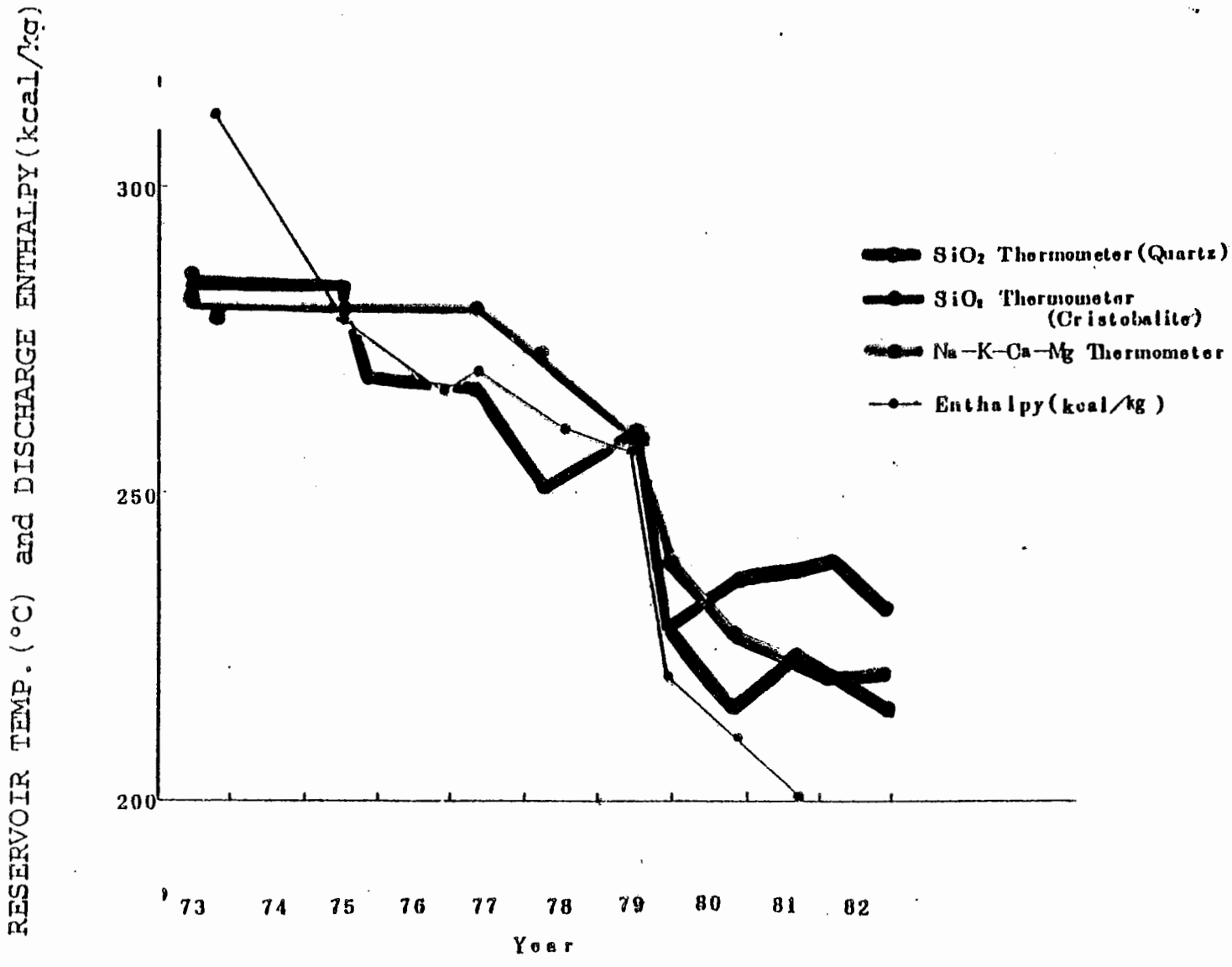


Fig.9-2 Changes of reservoir temperatures and enthalpy of H-4.

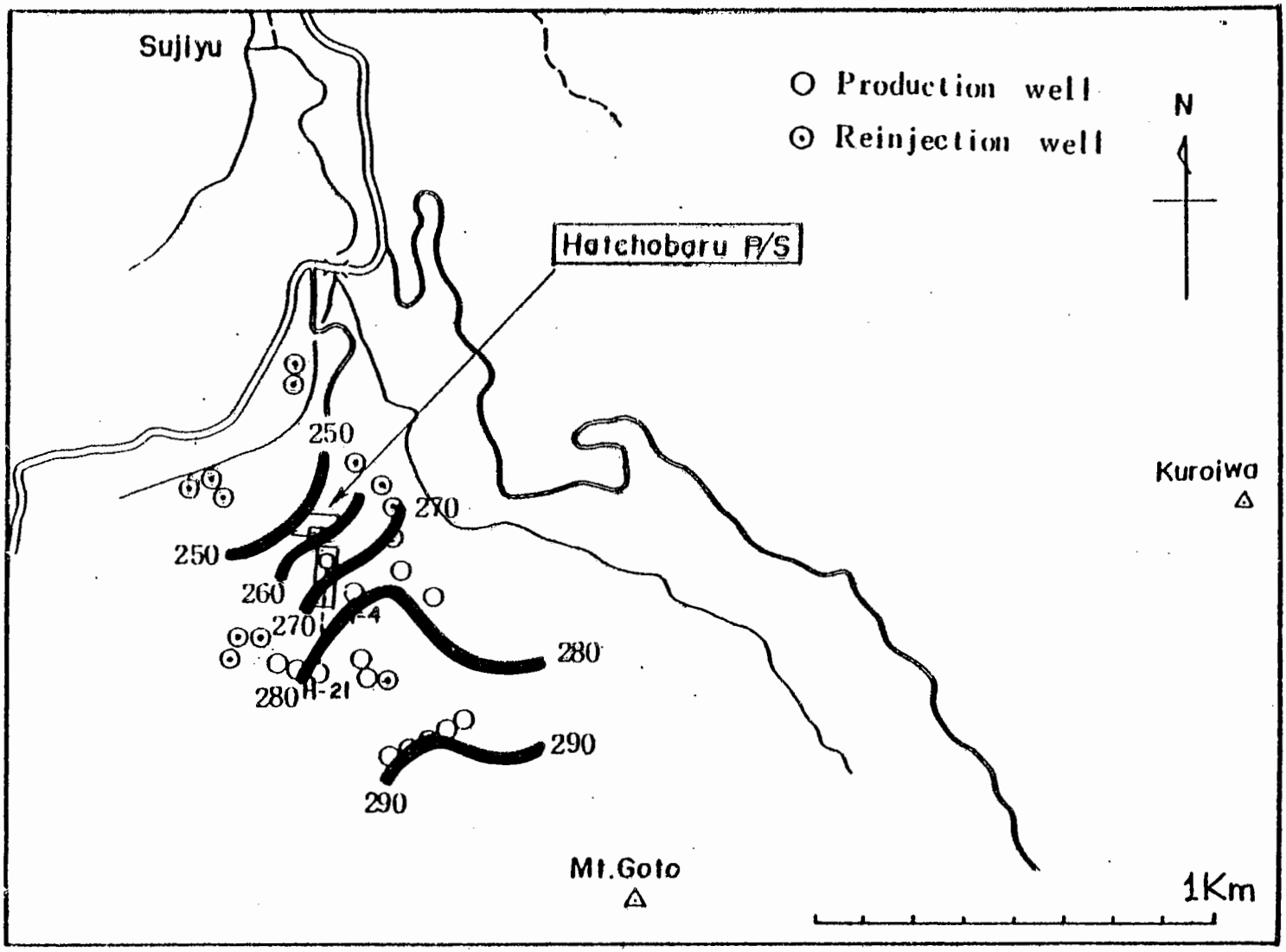


Fig.10 Temperature distribution of main hot-water reservoir in the Hatchobaru field without reinjection effect (°C).

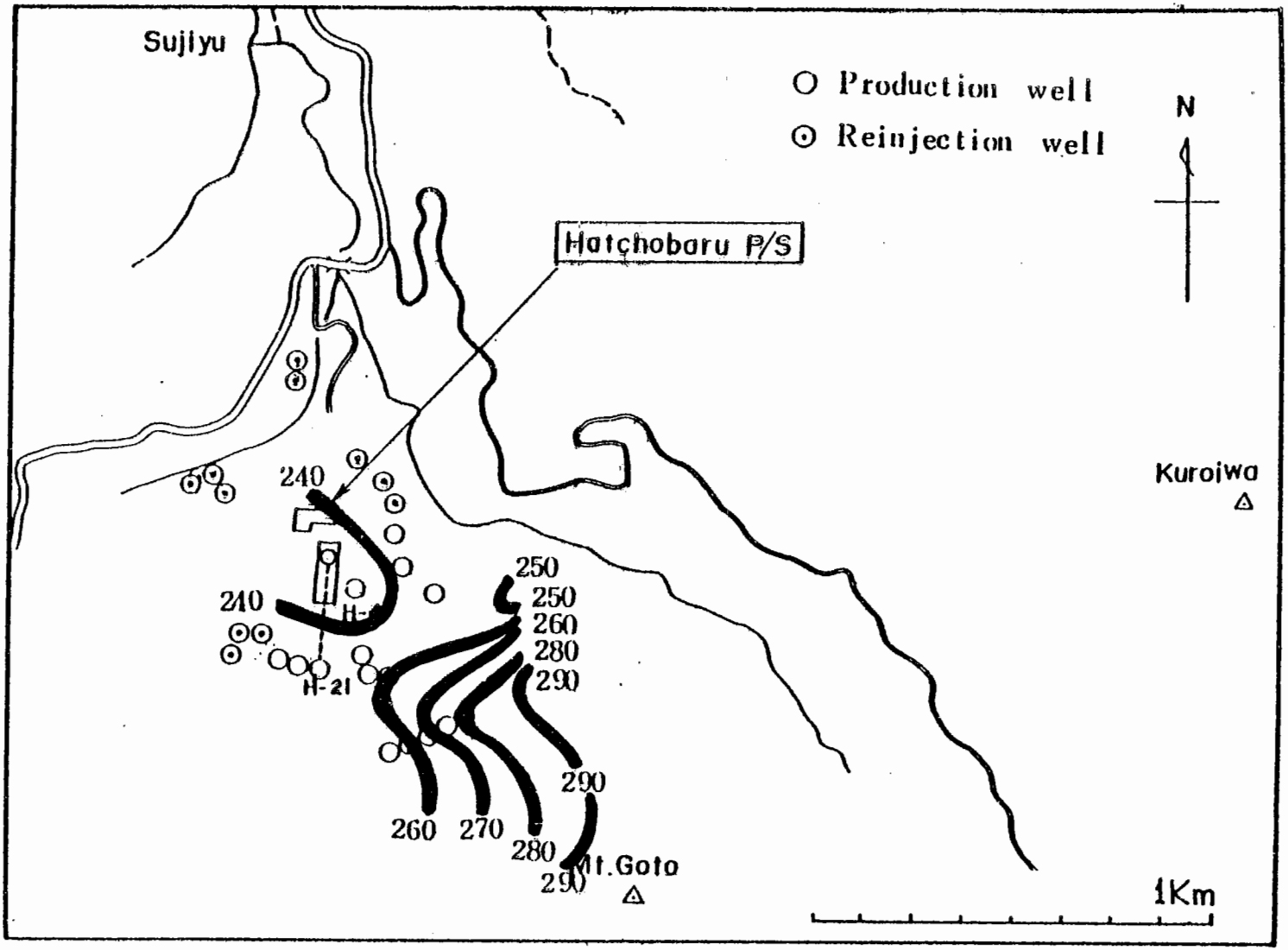


Fig.11 Temperature distribution of main hot-water reservoir in the Hatchobaru field in 1983 (°C).

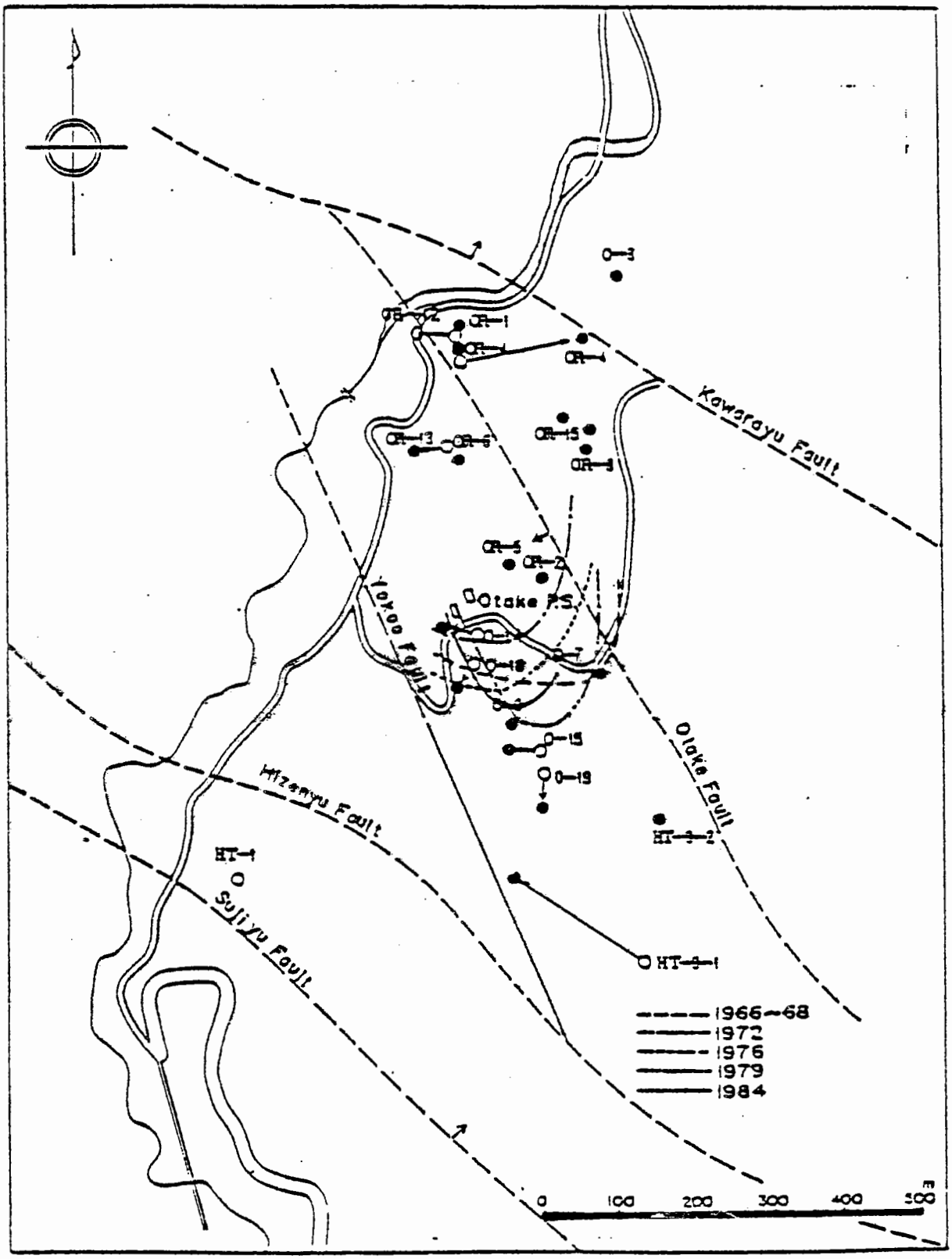


Fig.12 Change of isothermal contor of reservoir temperature (220°C) in the Otake field.

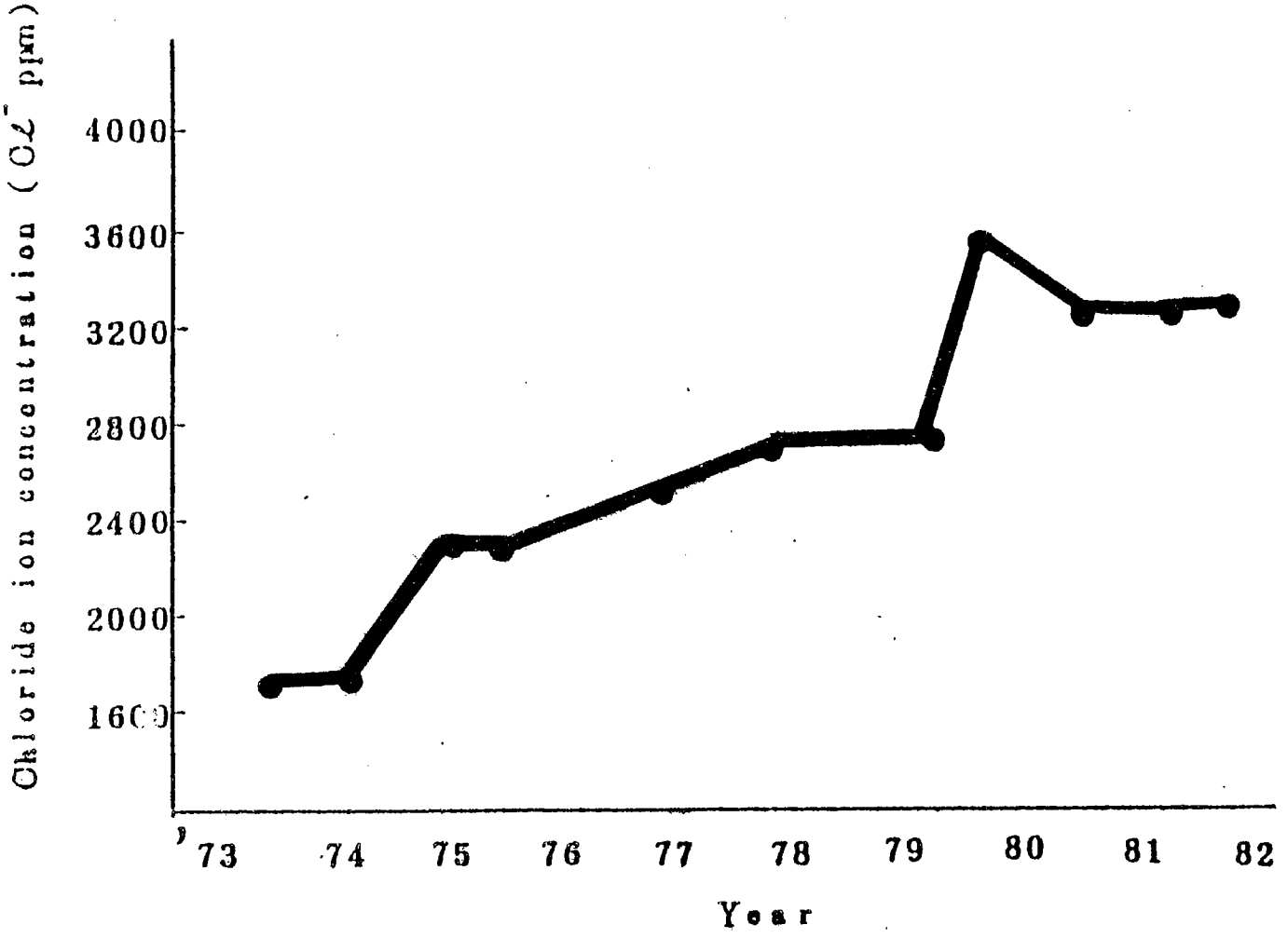


Fig. 13 Change of Cl^- ion concentration in H-4 reservoir water with time.

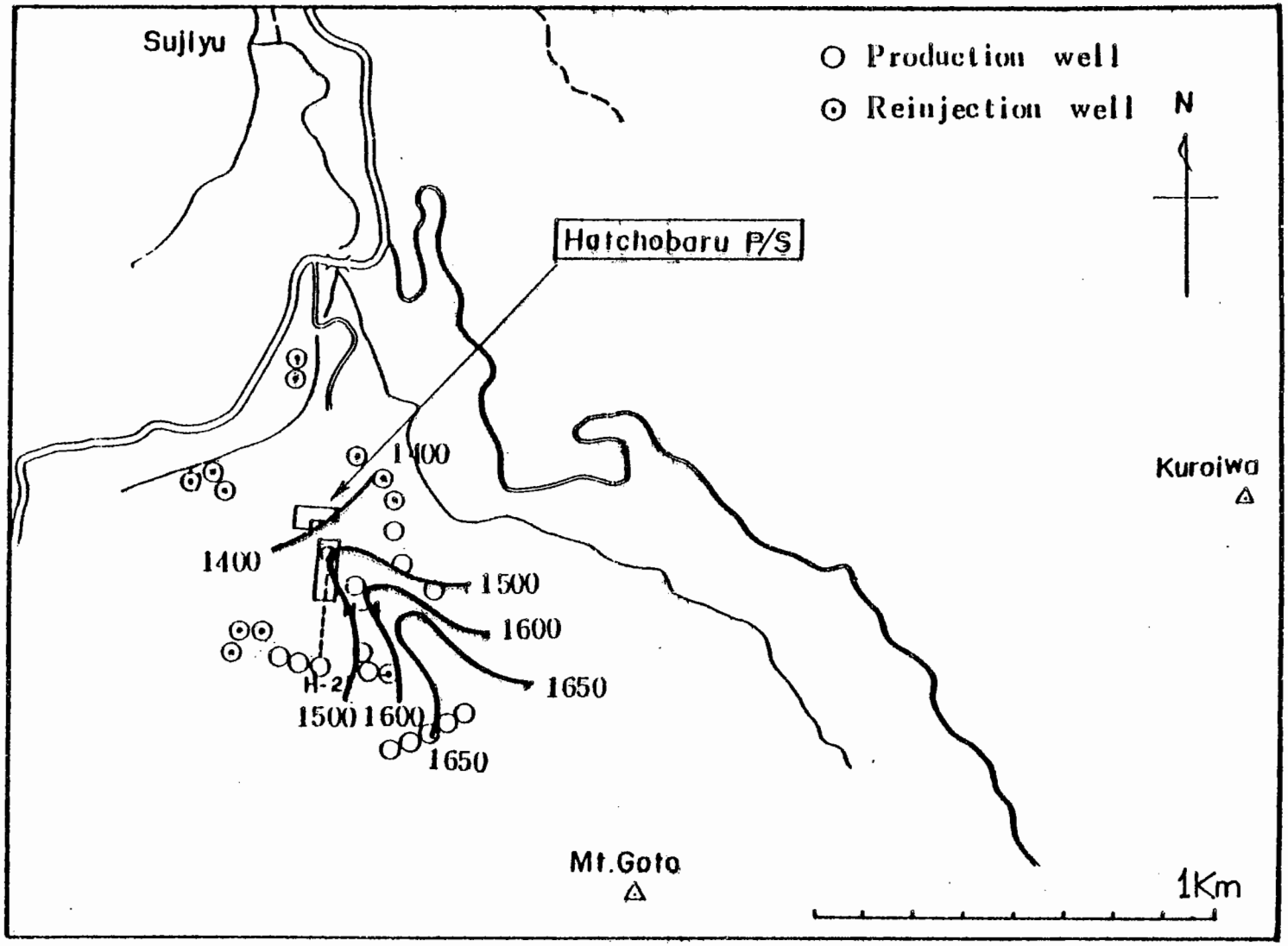


Fig. 14 Chloride ion concentration distribution of main hot water reservoir in the Hatchobaru field without reinjection effect (ppm)

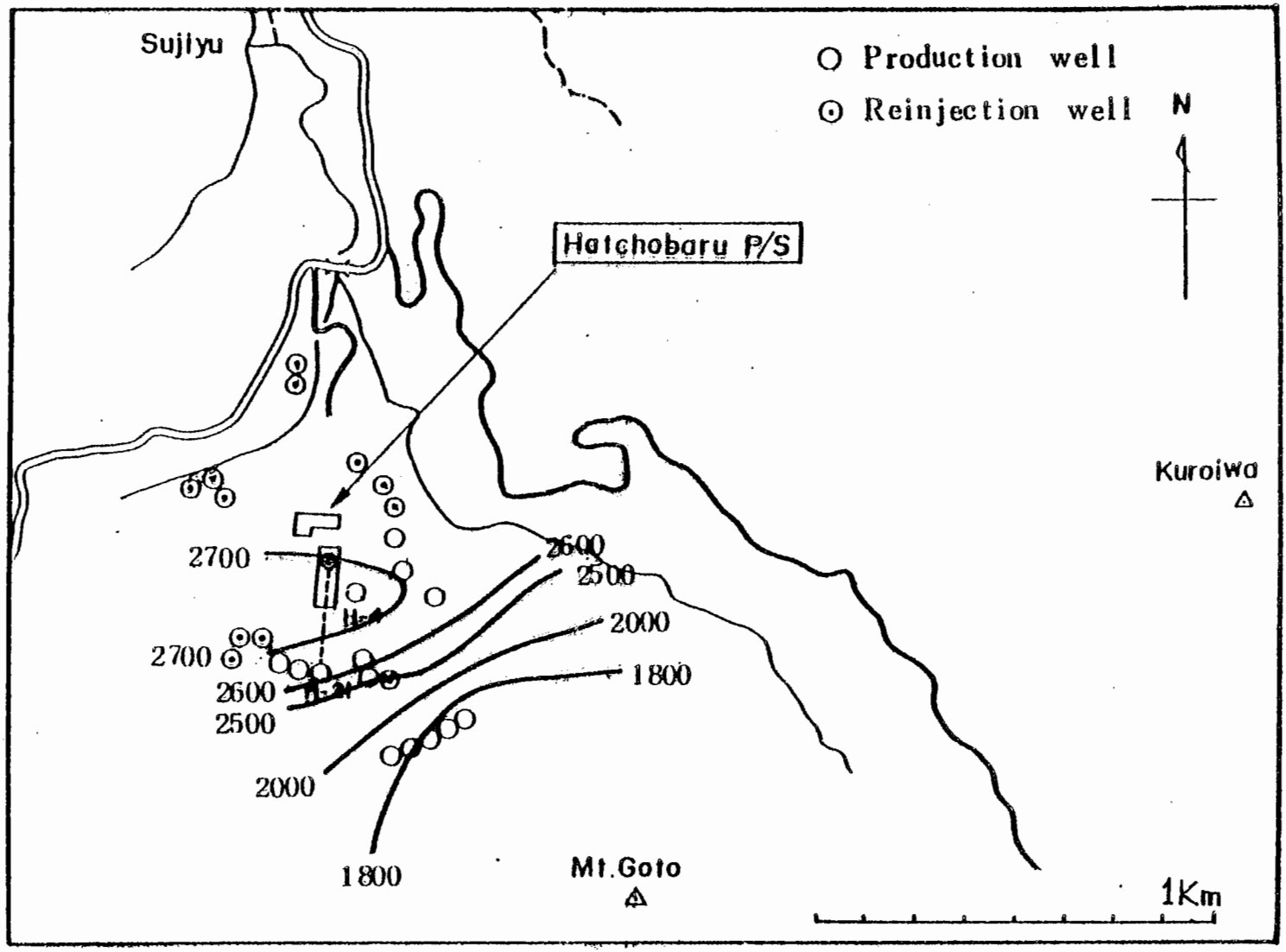


Fig. 15 Chloride ion concentration distribution of main hot water reservoirin the Hatchobaru field in 1983 (ppm)

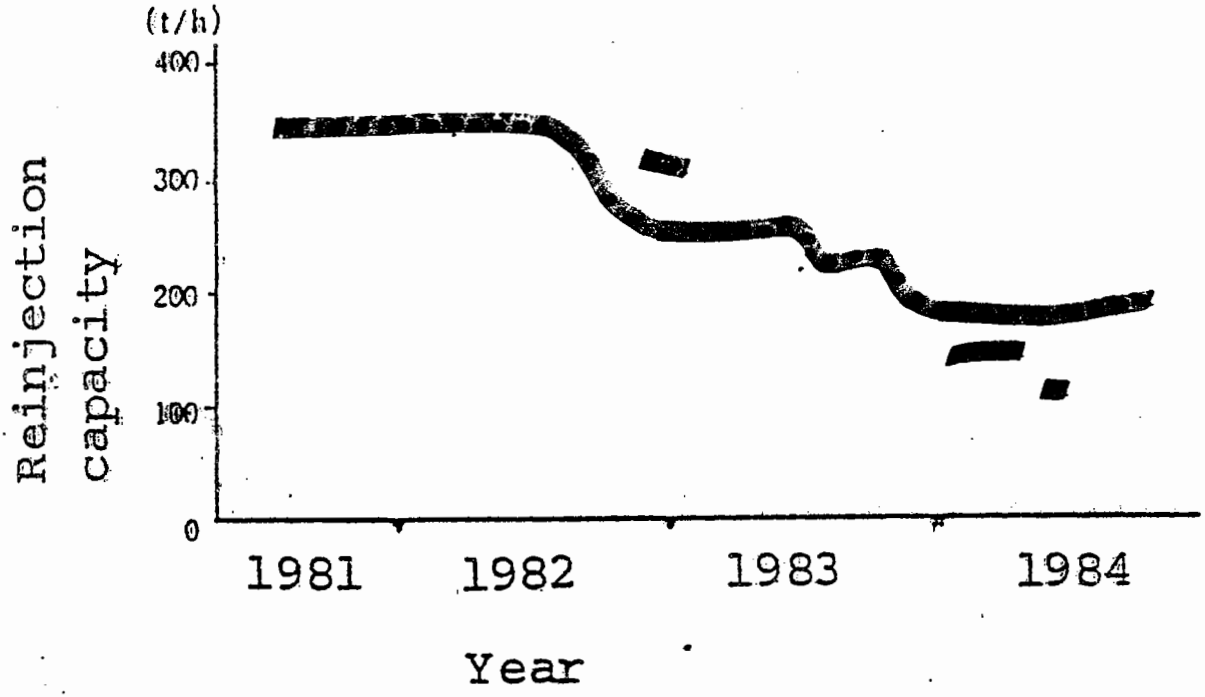


Fig. 16 Change of maximum reinjection capacity of HR-18 in the Hatchobaru field.

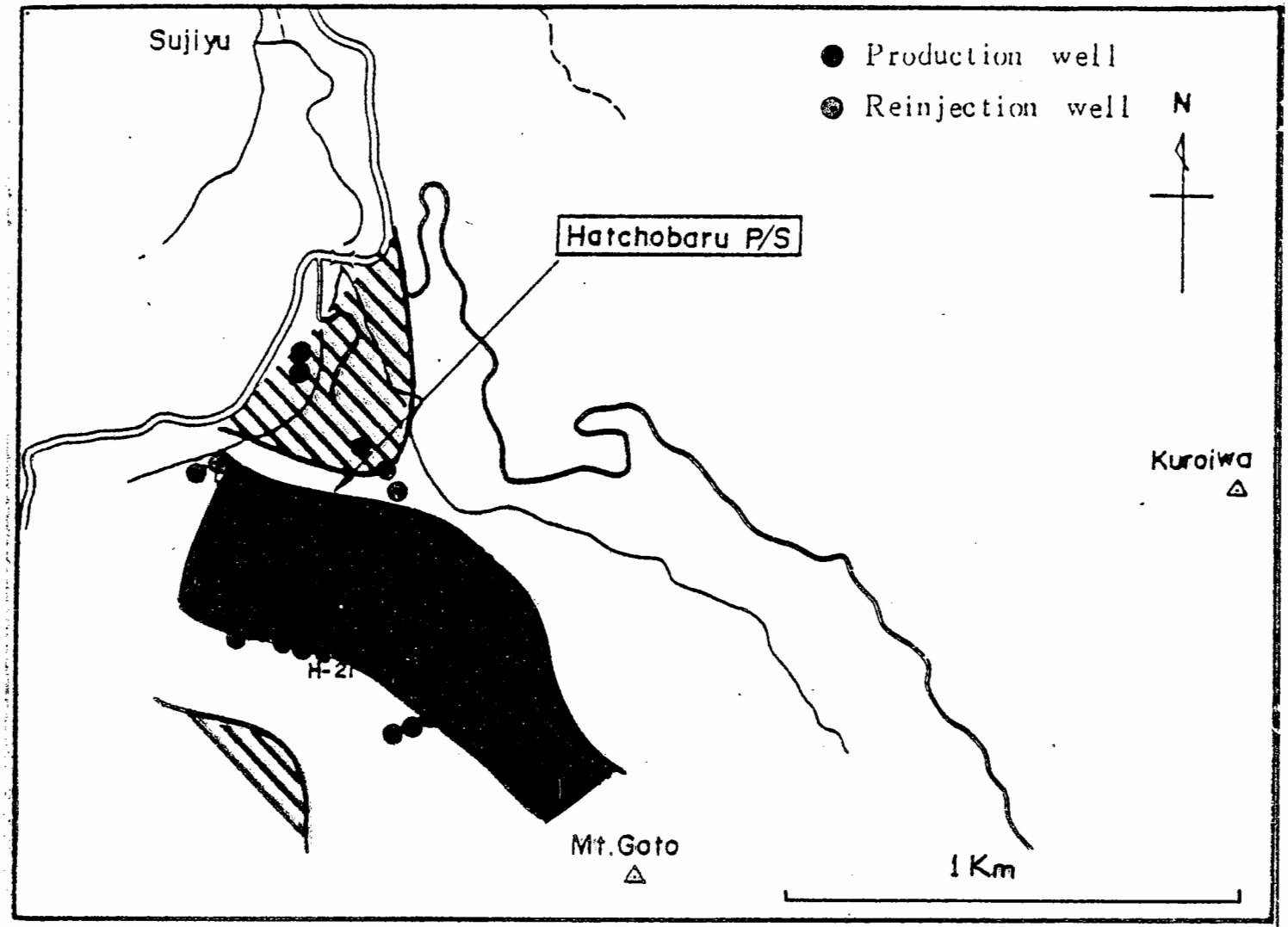


Fig. 17 Results of tracer test in the Hatchobaru field.

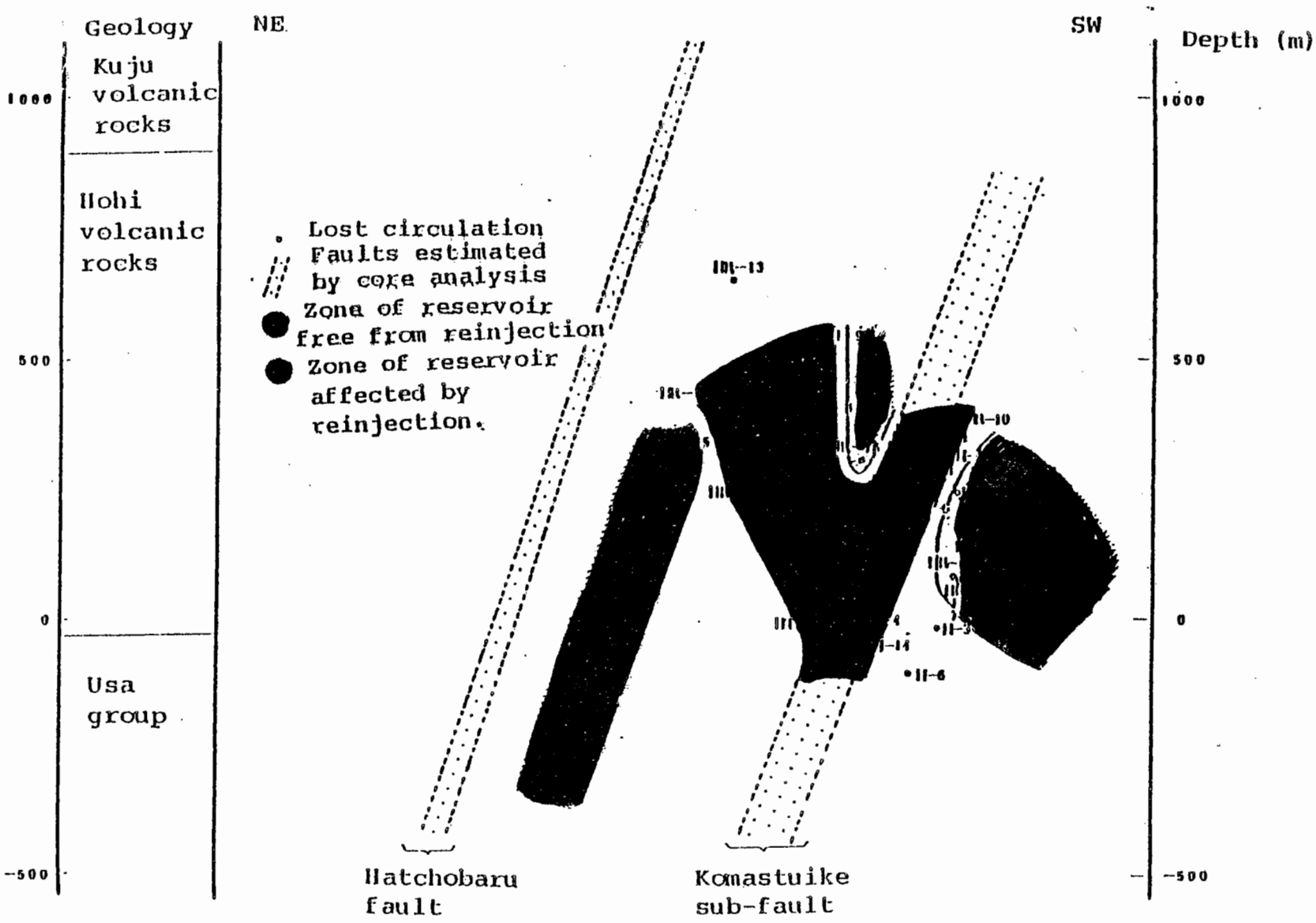


Fig. 18 Results of tracer test in the Hatchobaru field.

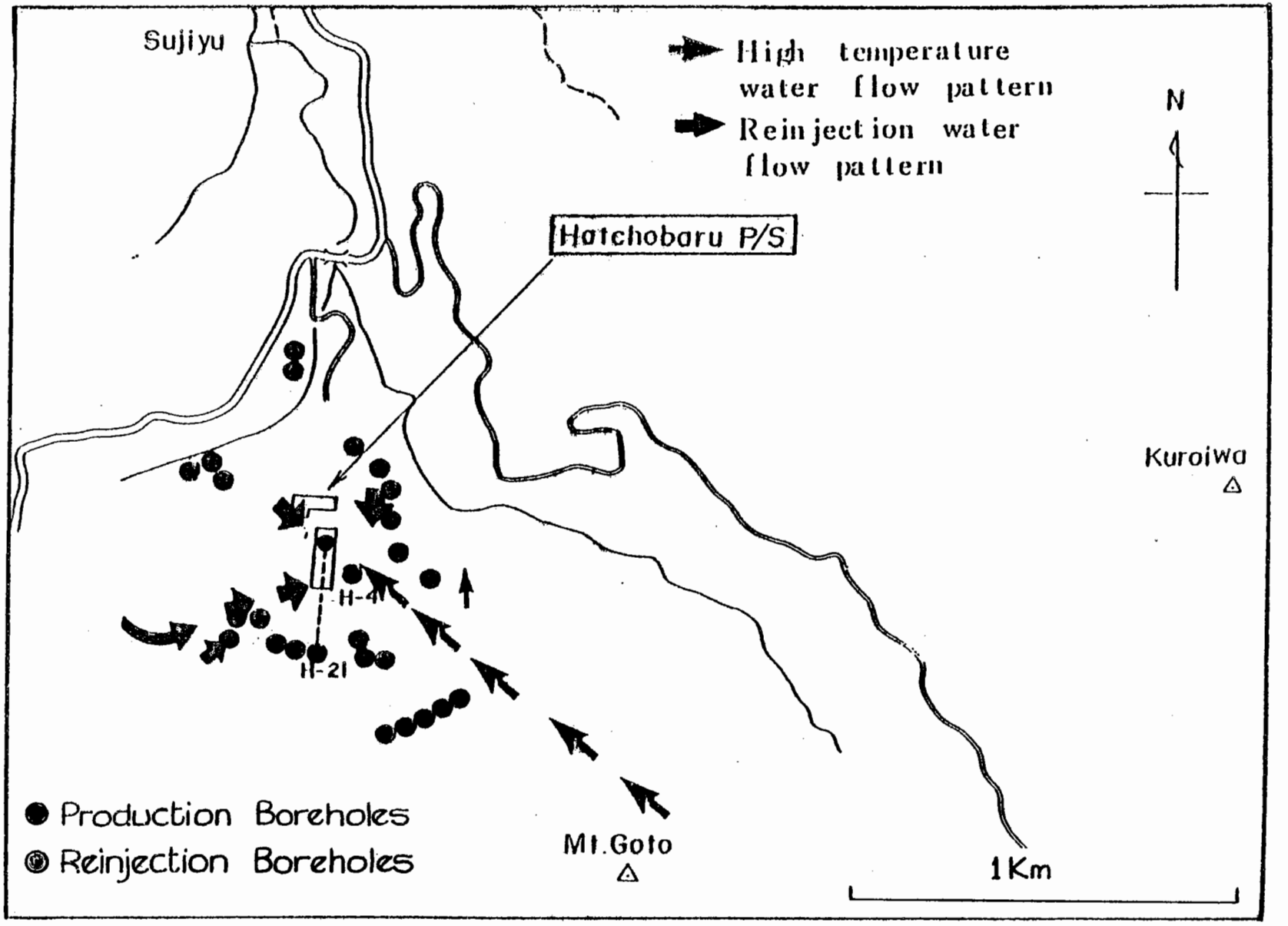


Fig. 19 Flow patterns of geothermal fluids in the Hatchobaru main reservoir.

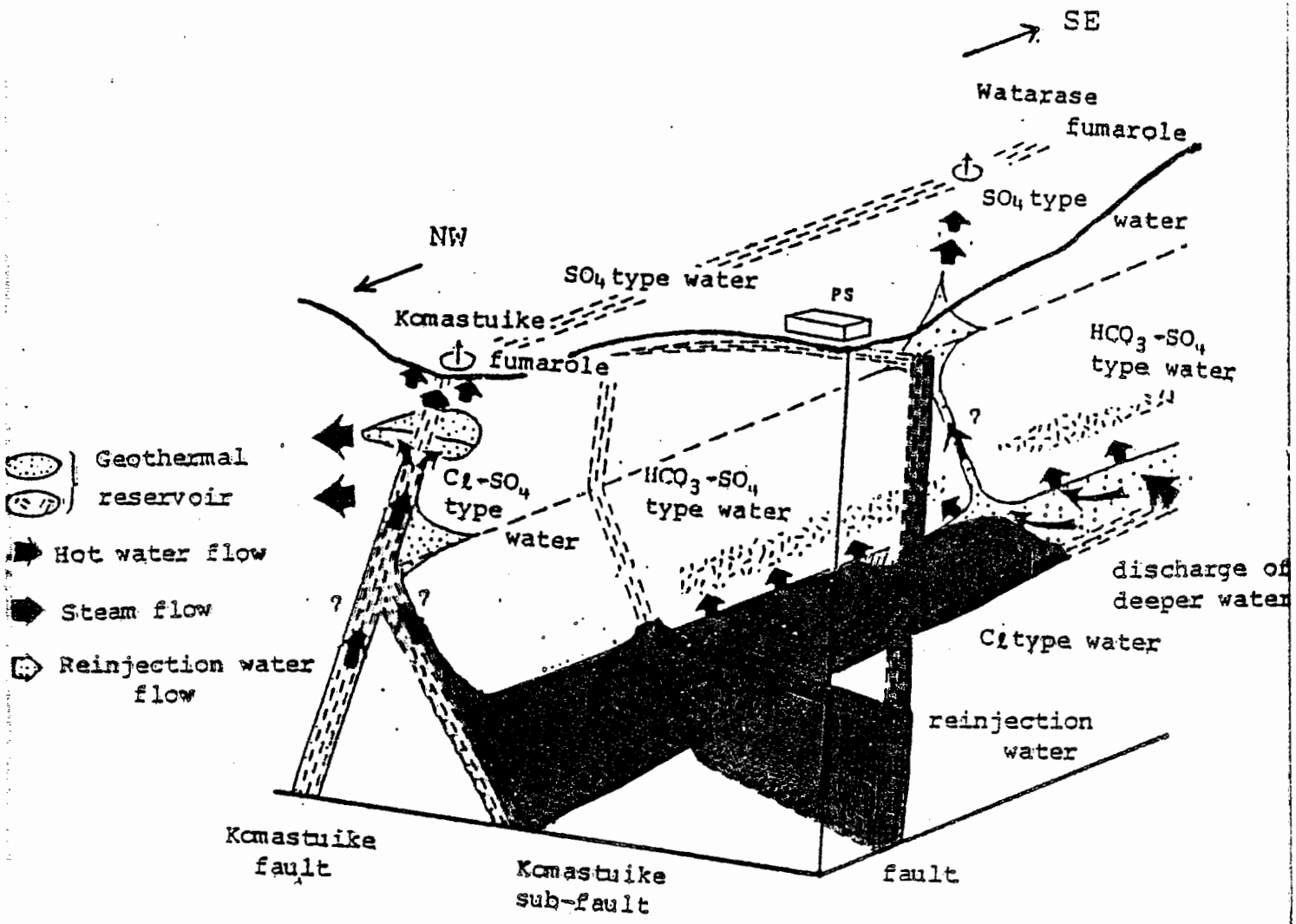
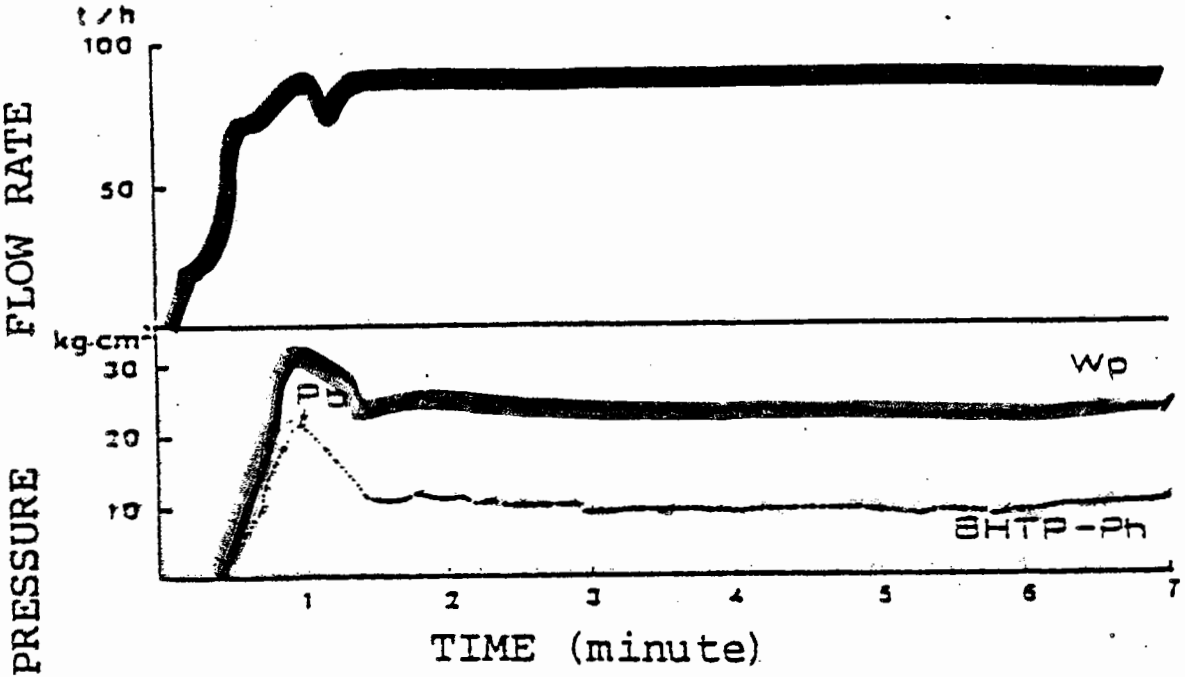


Fig. 20 Flow patterns of geothermal fluids in the Hatchobaru main reservoir.



Wp :Wellhead pressure BHTP : Bore hole pressure
Ph :Static head pressure Pb :Breakdown pressure
(about 90 kg/cm^2)

Fig. 21 Result of fracturing at HR-14 in the Hatchobaru field

Table 1. PRESENT STATUS OF THE OTAKE AND HATCHOBARU P.S.
(As of Jun. 1985)

	Otake	Hatchobaru
Rated Output	12,500 KW	55,000 KW
Start of Operation	Aug. 1967	Jun. 1977
Plant Type	Single Flash	Double Flash
Present Output	9,000 KW	53,000 KW
Total Electricity Generation in 1984 F.Y	77×10^3 MWH	440×10^3 MWH
Capacity Factor in 1984 F.Y	70.2 %	91.4 %
Number of Production Wells (Drilling Depth)	5 (370m ∿ 550m)	13 (760m ∿ 1970m)
Number of Reinjection Wells (Drilling Depth)	13 (330m ∿ 700m)	16 (550m ∿ 1500m)

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Table 2 Change of chemical characteristics of discharge from H-3 in the Hatchobaru field.

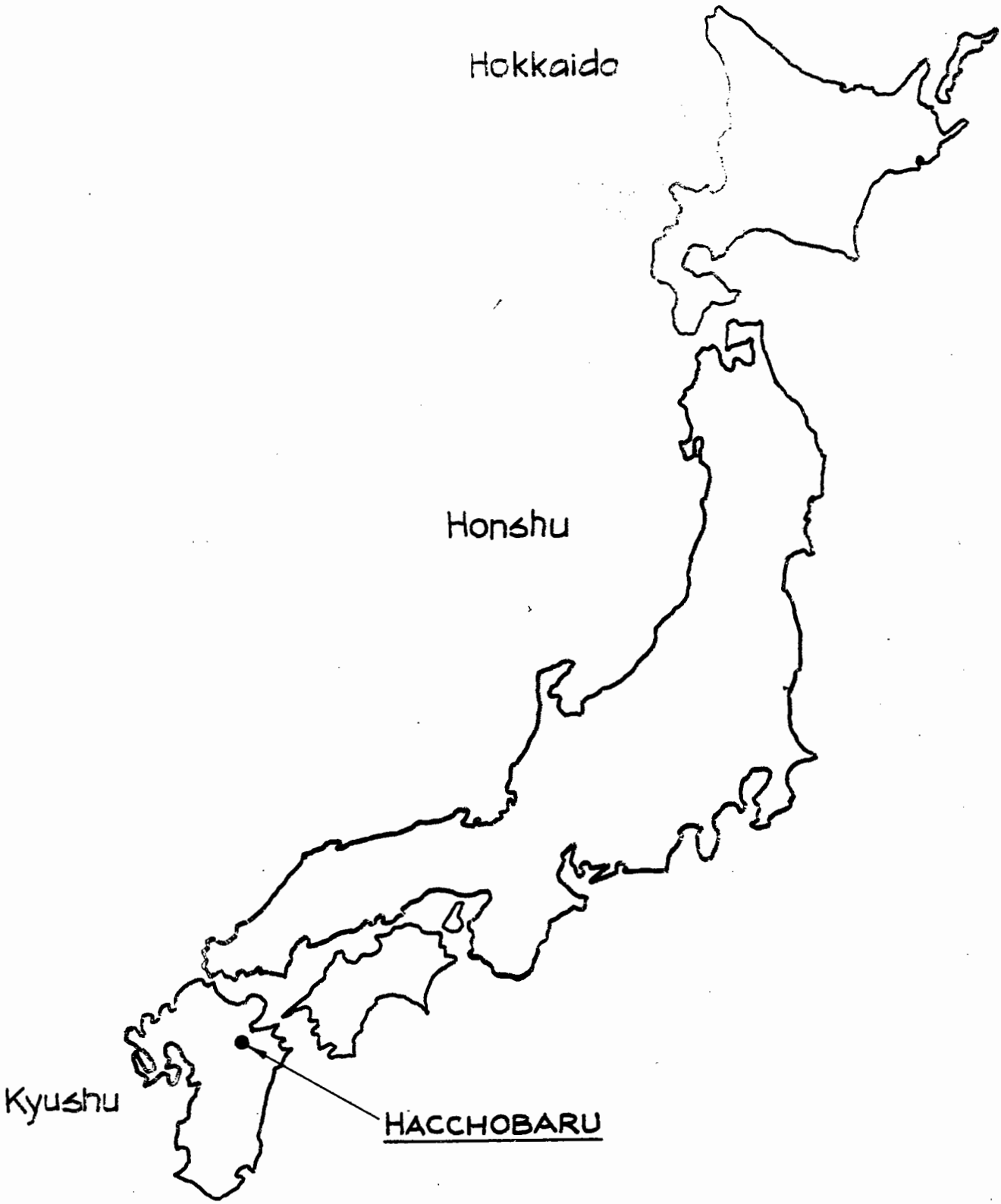
Year		1973	1978	1979
pH		5.1	4.1	4.6
Na	(ppm)	1,270	2,660	2,192
K	(ppm)	245	398	289
Ca	(ppm)	5.5	190	120
Mg	(ppm)	0.6	12.6	7.8
Li	(ppm)	6.7	—	14
Cl	(ppm)	2,106	5,034	4,300
SO_4	(ppm)	49	290	207
HCO_3	(ppm)	9	0	0
HBO_2	(ppm)	138	347	267
SiO_2	(ppm)	980	602	630
As	(ppm)	2.25	—	3.15

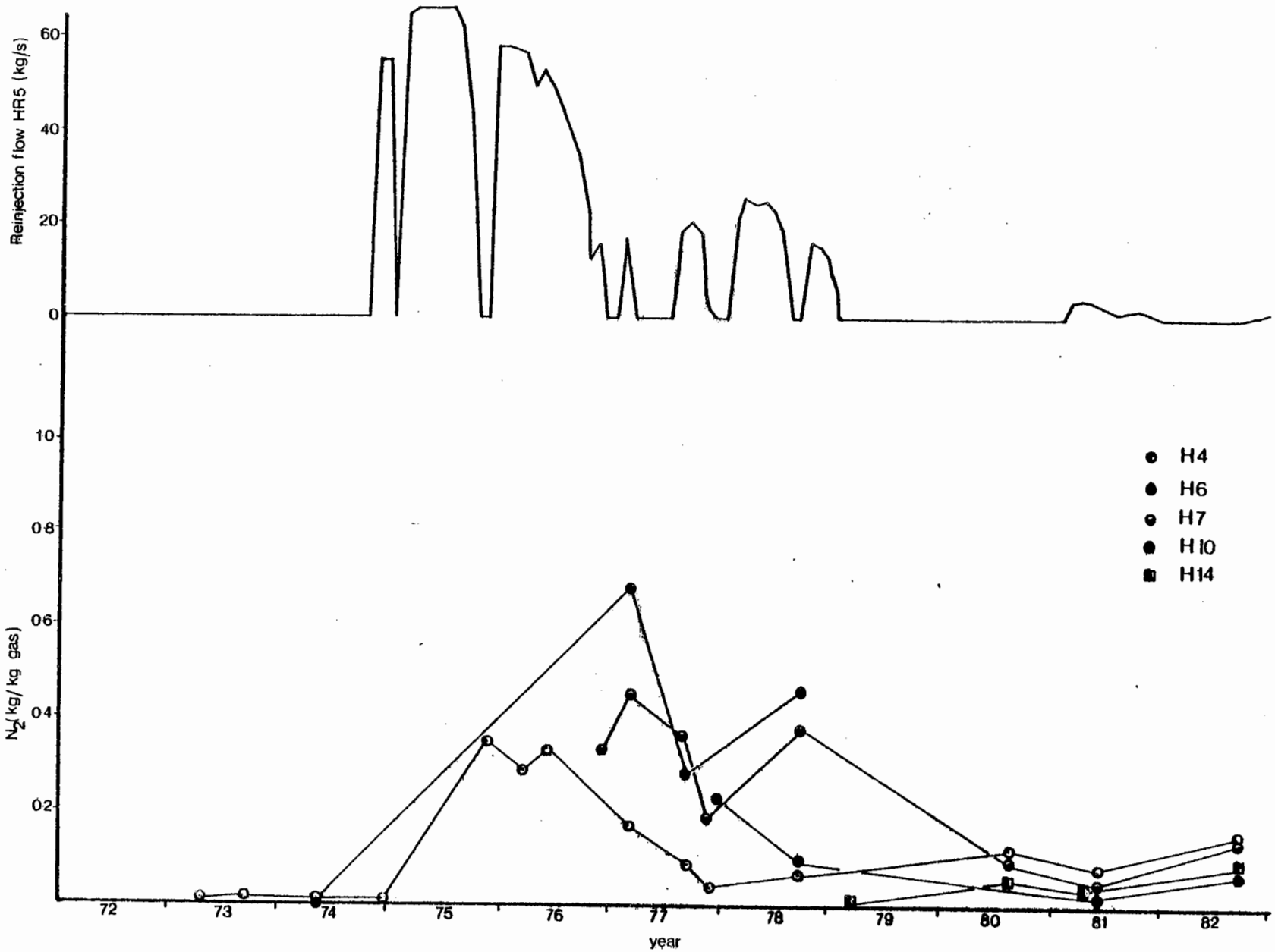
Table 3 Change of chemical characteristics of discharge from H-4 in the Hatchobaru field.

Year		1973	1974	1975	1978	1980	1981	1982
Analysis of Nonconden-sable Gas in Steam	CO_2	86.1	95.3	72.9	75.5	75.3	84.3	75.6
	H_2S	10.0	1.5	2.1	14.8	5.6	3.5	2.9
	O_2	0.9	1.0	0.5	0.2	0.3	0.4	0.3
	N_2	3.0	2.2	24.5	9.5	18.8	11.8	21.8
Analysis of Hot Water	pH	7.9	7.3	5.8	6.5	7.3	7.6	7.2
	Na (ppm)	1550	1780	1880	2200	2241	2200	2140
	K (ppm)	284	328	348	—	268	236	231
	Ca (ppm)	9.2	10.0	10.0	34.0	91.2	74.2	83.5
	Mg (ppm)	0.03	0.4	0.46	1.20	1.40	1.78	2.60
	Cl (ppm)	2550	2990	3210	3850	3740	3660	3690
	SiO_2 (ppm)	1040	1016	850	922	565	592	538

Table 4 Chemical compositions of scales deposited in the Otake and Hatchobaru fields (%).

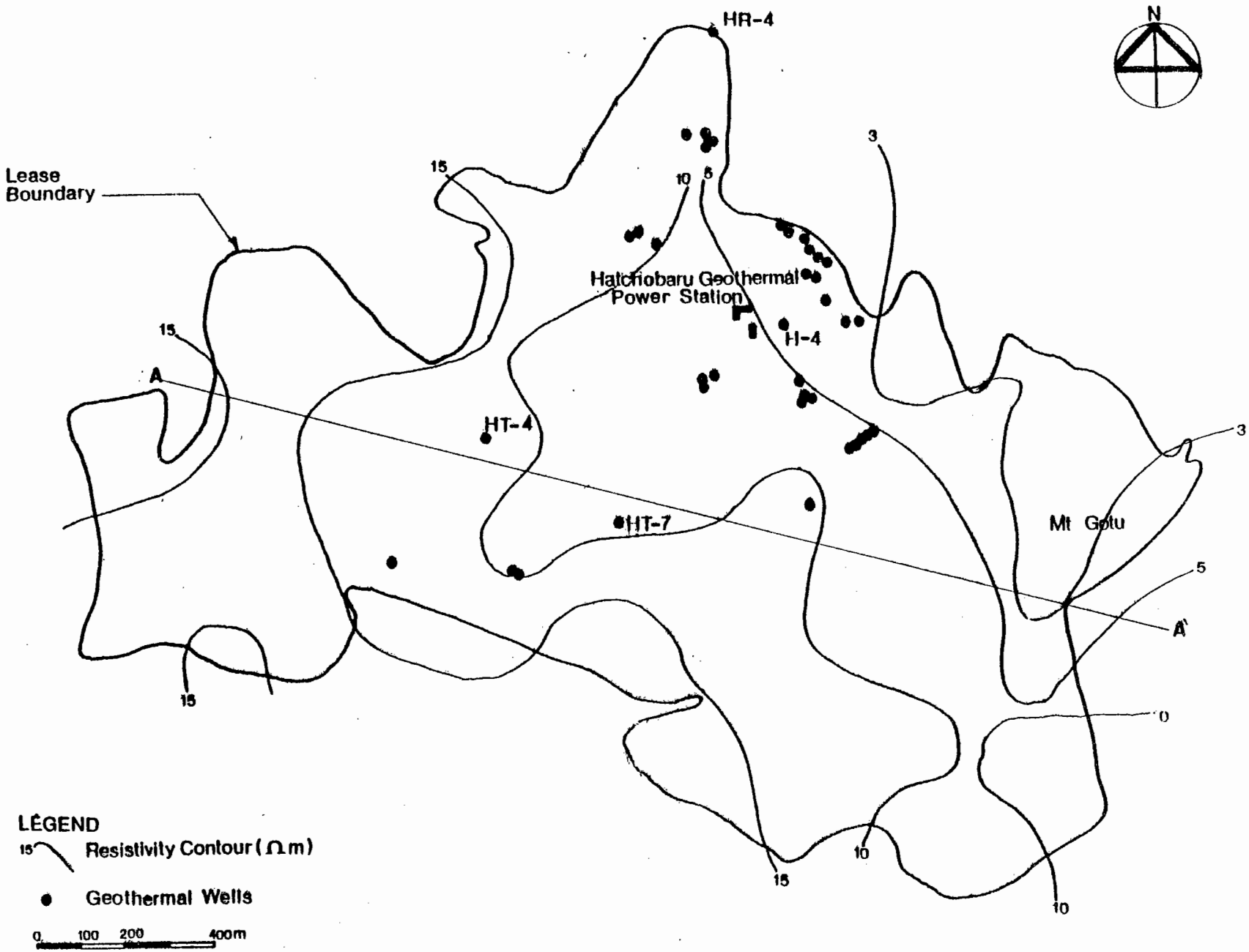
Site name	SiO_2	FeO_3	FeO	MnO	MgO	Al_2O_3	Cl	SO_4	CaO	
Otake No 0-9. retaining tank	94.8	<0.01	0.05	<0.01	<0.01	0.57	0.01	<0.01	0.16	amorphous silica
Otake Transportation pipe	84.6	0.66	0.81	0.02	0.02	3.14	<0.01	<0.01	0.51	amorphous silica
Hatchobaru retaining tank	92.0	0.23	0.13	0.02	0.05	1.07	0.01	<0.01	0.07	amorphous silica


Hokkaido
Honshu
Kyushu
HACCHOBARU

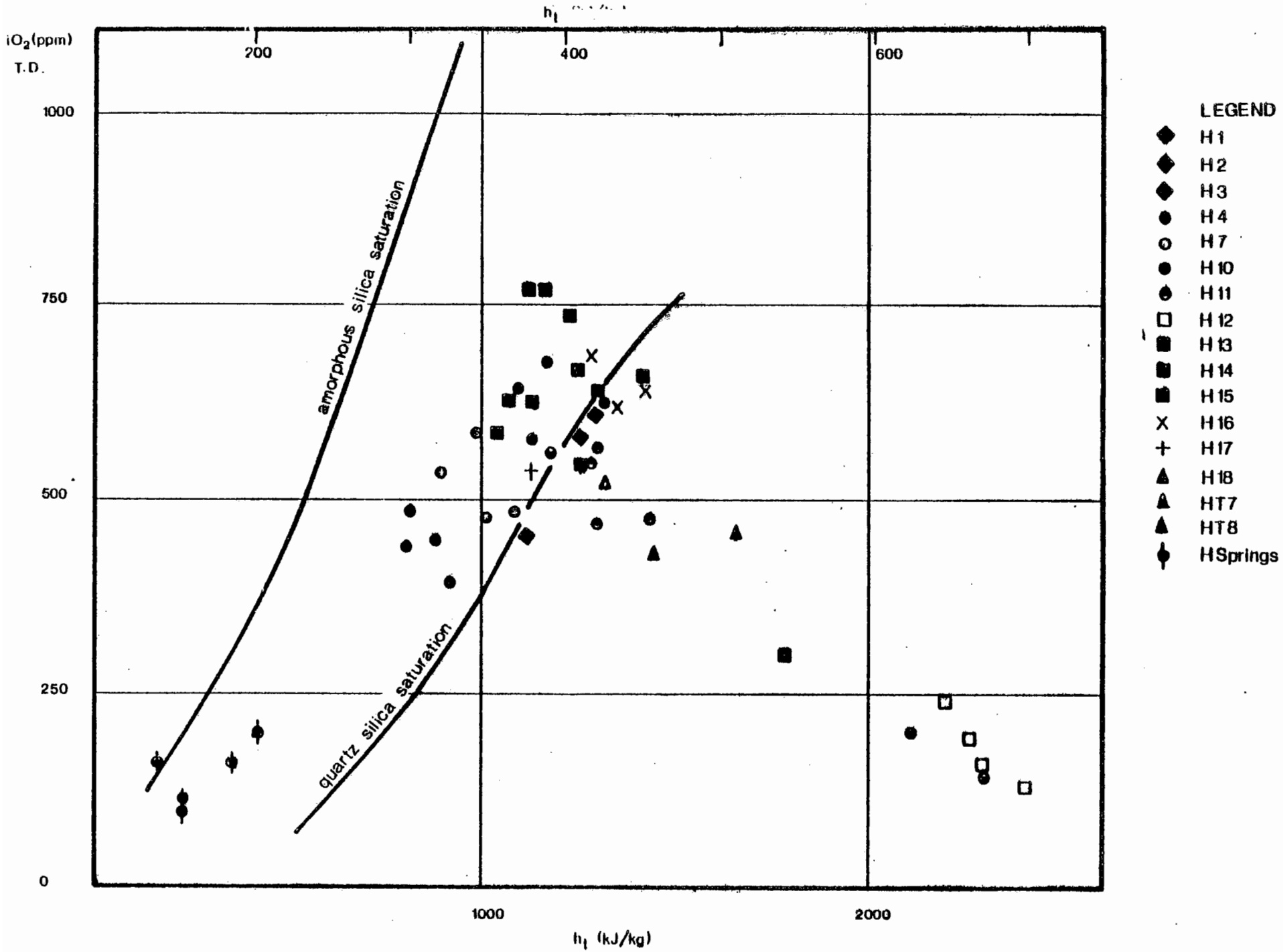


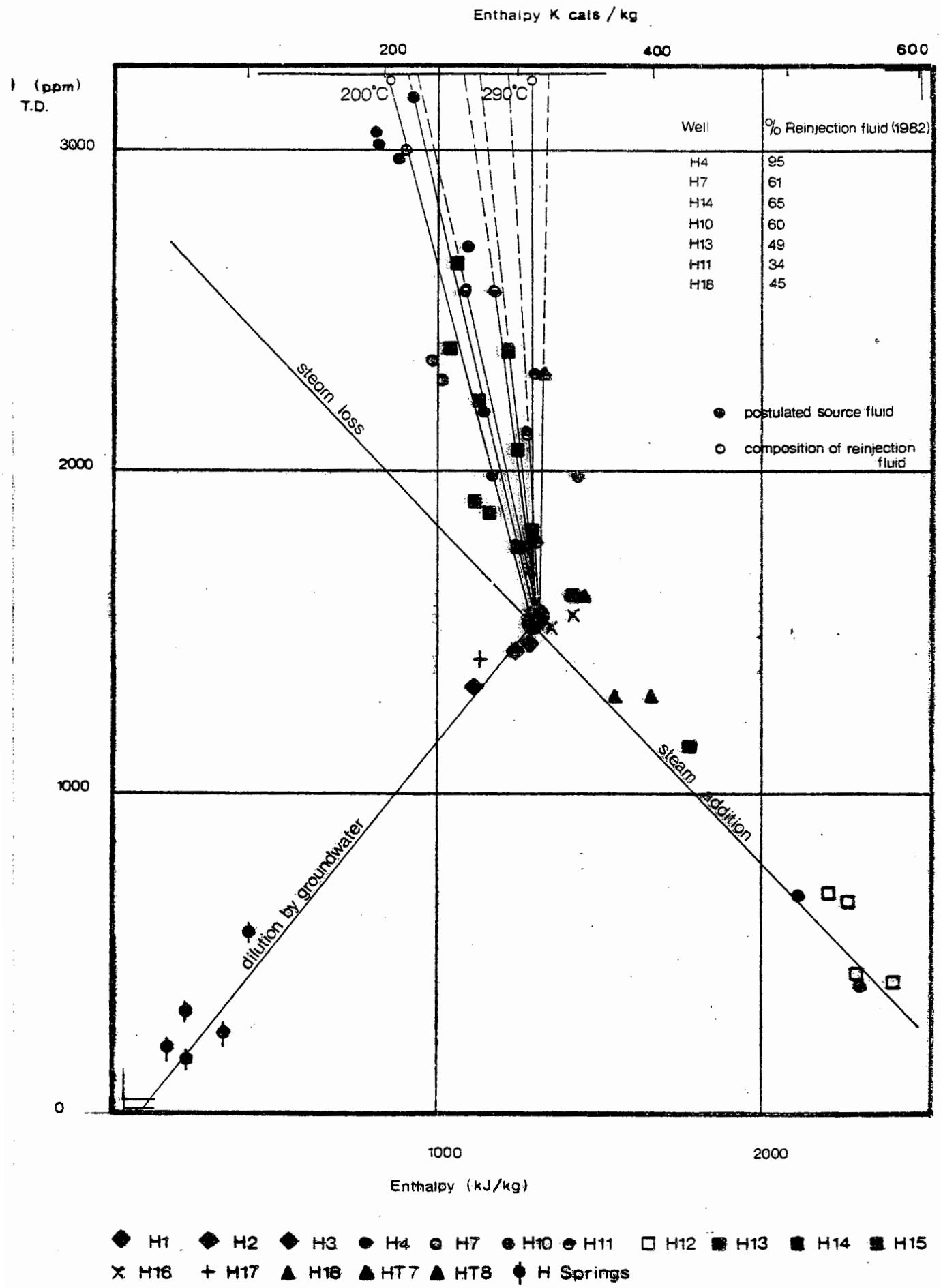
Nitrogen Concentration in Discharge

fig 8



Contours of the Interpreted Resistivities within the Hatchobaru Lease


h_t
iO_2(ppm)
T.D.
200
400
600
1000
750
500
250
0
amorphous silica saturation
quartz silica saturation
1000
2000
h_t (kJ/kg)
LEGEND
H 1
H 2
H 3
H 4
H 7
H 10
H 11
H 12
H 13
H 14
H 15
H 16
H 17
H 18
HT7
HT8
HSprings


Enthalpy K cals / kg
200
400
600
(ppm)
T.D.
3000
2000
1000
0
200°C
290°C
Well
% Reinjection fluid (1982)
H4 95
H7 61
H14 65
H10 60
H13 49
H11 34
H18 45
postulated source fluid
composition of reinjection fluid
steam loss
steam addition
dilution by groundwater
1000
2000
Enthalpy (kJ/kg)
H1 H2 H3 H4 H7 H10 H11 H12 H13 H14 H15
H16 H17 H18 HT7 HT8 H Springs