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Remarks on Hydrothermal System in Atami Hotspring Area, Central Japan

By

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Introduction

Atami hotspring area including Atami and Izusan spas, situated at the root of the Izu peninsula, 100km west of Tokyo, is one of the most famous and the biggest resort areas in Japan.

According to the data reported in 1912 (Kozu, 1912), there were natural flowing springs having more than ten issuing points of thermal waters with above 90°C, sitting around small geyser named Oyu in the central part of Atami hotspring area. Though the natural flow of thermal waters in this area was seen till 1948, the water level has decreased down below the ground surface, because the number of bore holes and the amount of discharge of thermal waters have increased since 1948. Accordingly, withdrawal of thermal waters in the Atami hotspring area is carried out by the air-lift method which is used for pumping up of water at present.

This is a report on hydrothermal system in the Atami hotspring area, the data which were obtained from the surveys by Prefectural Health Center Office of Atami in 1964 and 1965 and from the investigation by writers in 1965.

1. Data on number of bore holes, water temperature and amount of discharge of thermal waters

According to Fig. 1 showing the number of bore holes in Atami and Izu-

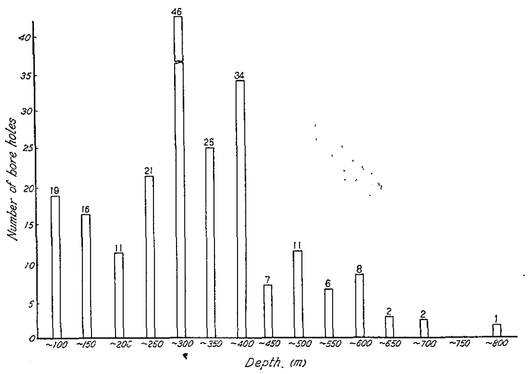

Fig. 1a Number of bore holes divided by different depths in Atami Spa (February, 1964)

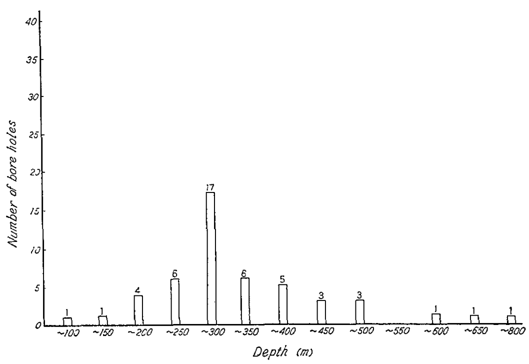

Fig. 1b Number of bore holes divided by different depths in Izusan Spa (February, 1964)

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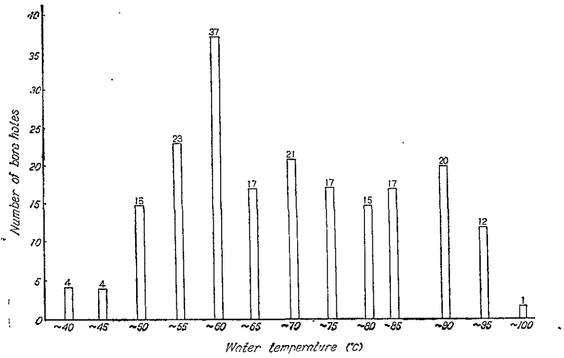

Fig. 2 a Number of bore holes divided by water temperature in Atami Spa (February, 1964)

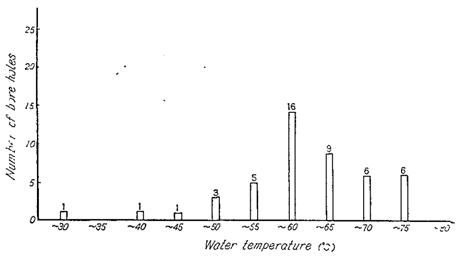

Fig. 2 b Number of bore holes divided by water temperature in Izusan Spa (February, 1964)

san spas arranged by different depths, the distribution of bore holes in this area has a maximum frequency at the depth of about 300m. Among them, about 20 holes shallower than 100m are distributed in Atami spa. This is due to the reason that they were drilled around Oyu hot area in the central part of this field. On the contrary, the holes deeper than 500m are mostly situated on the foot and slope of mountains surrounding the hotspring area.

The statistical data on water temperature and amount of discharge in this area are shown in Fig. 2 and Fig. 3. As to the water temperature, a maximum frequency is found at 60°C, and it can be said in general that the bore holes having temperature from 60°C to 95°C occupy the widest distribution in this area.

As mentioned above, thermal waters in this area are all lifted up by pumping. Then, though the amount of discharge is different from that of natural flow, a maximum frequency is found at 60*l*/min in Atami and 50–60 *l*/min in Izusan.

Table 1 shows the total amount of discharge of thermal waters in Atami and Izusan spas measured by Health Center Office in 1959, 1964 and 1965.

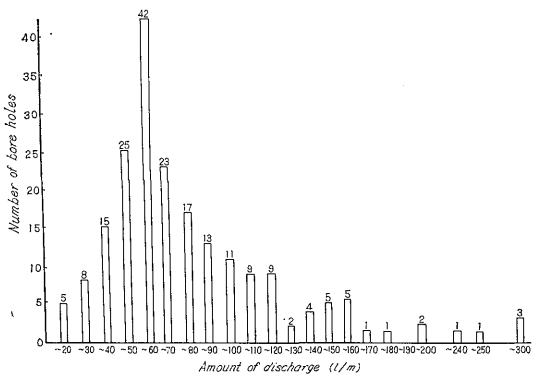

Fig. 3 a Number of bore holes divided by amount of discharge in Atami Spa (February, 1964)

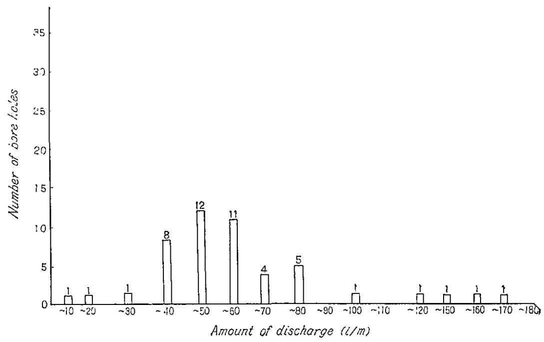

Fig. 3 b Number of bore holes divided by amount of discharge in Izusan Spa (February, 1964)

Table 1

		1959	1964	1965
Atami	Total	13,250l/m	16,314.2l/m	13,695.2l/m
	Number of wells	121	201	197
	Average per a well	109.5l/m	81.1l/m	69.5l/m
Izusan	Total	3,721l/m		2,522.52l/m
	Number of wells	39		48
	Average per a well	93.0l/m		63.0l/m
Atami and Izusan	Total	16,971l/m		16,217.72l/m

2. Data on chemical compositions of thermal waters

At the time of 1964, there were 256 holes used for bathing in the Atami hotspring area, in which 208 holes were included in Atami spa and 48 holes in Izusan spa. In 1964, chemical analyses of thermal waters collected from 87 holes in Atami and in 1965, 48 holes in Izusan were made for the purpose of getting the information about hydrothermal system in the Atami hotspring area.

2.1 Distribution of water temperature

Based on the measurements of water temperature made in 1964 and 1965, the distribution map of water temperature in the Atami hotspring area is given as shown in Fig. 4. According to this map, a high temperature zone passing through the Oyu hot area runs toward north-west direction in Atami spa and along the seacoast in Izusan spa. The result suggests that there may be structural weak zones along each high temperature zone.

To compare the present hydrothermal system with the previous condition, distribution maps made by Prof. T. FUKUTOMI in 1936 (FUKUTOMI, 1937) and Dr. K. YUHARA in 1953–55 (YUHARA, 1961) are shown in Fig. 5 and Fig. 6. From the Fukutomi's map, it is clear that the high temperature area centering around Oyu was remarkably larger than present one about thirty years ago. Even in the case of Yuhara's map, it can be recognized that distribution of high water temperature areas was extended larger all over the area compared with the present state.

In addition to these data, Fig. 7 shows the change of water temperature having occurred in the same hole since 1952, suggesting that water temperature in this area has been decreasing year by year.

2.2 Distribution of Cl^- and SO_4^{2-} content

From the analytical results obtained in 1964 and 1965 (Table 2), a distribution map of Cl^- content can be made as shown in Fig. 8. Comparing Fig. 8 with Figs. 9 and 10 which were made by Prof. FUKUTOMI and Dr. YUHARA, it can be understood that there has happened remarkable change of Cl^- content between the past and present stages. Especially, the most remarkable

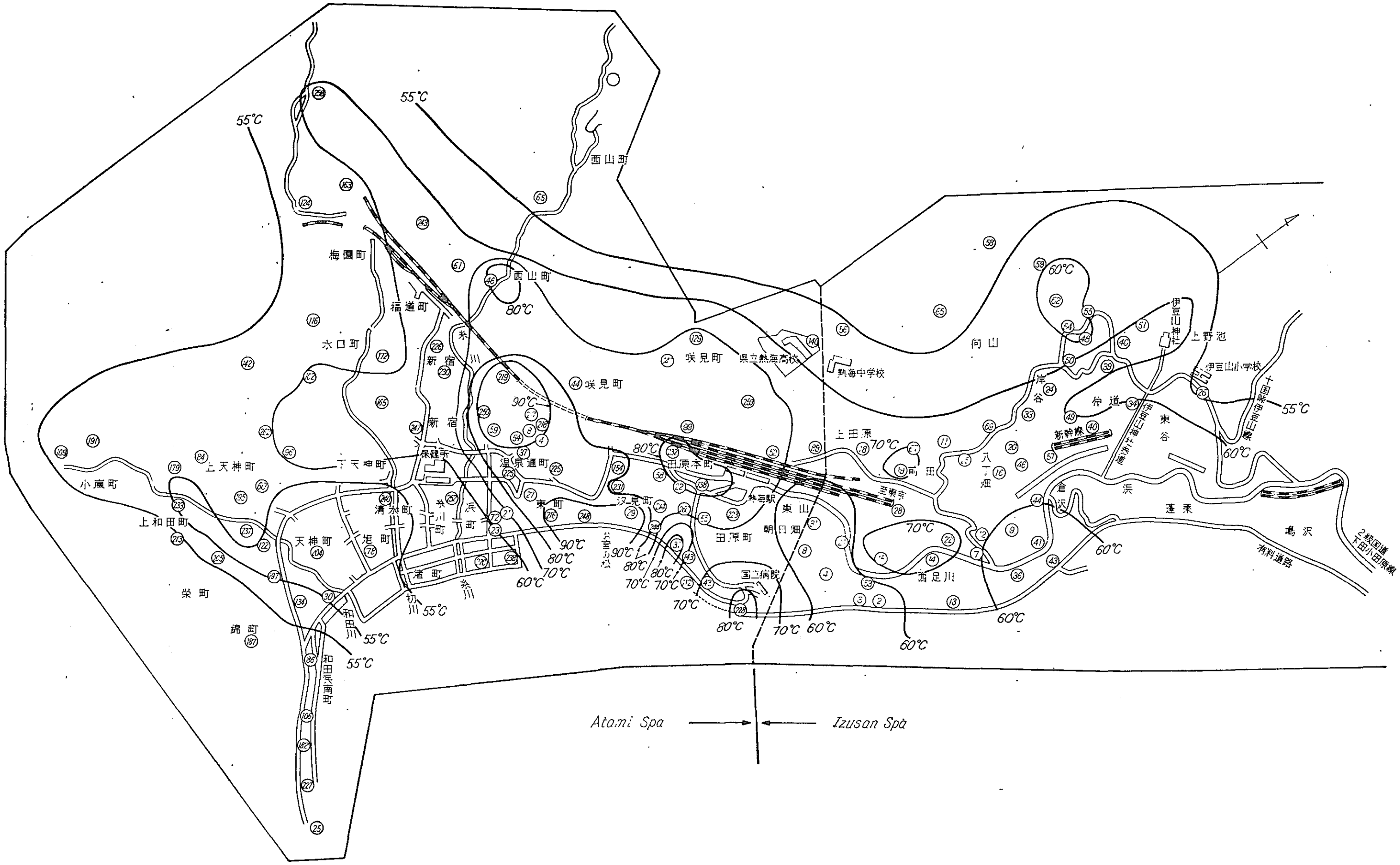

Fig. 4 Distribution map of water temperature in Atami hotspring area in 1964～1965

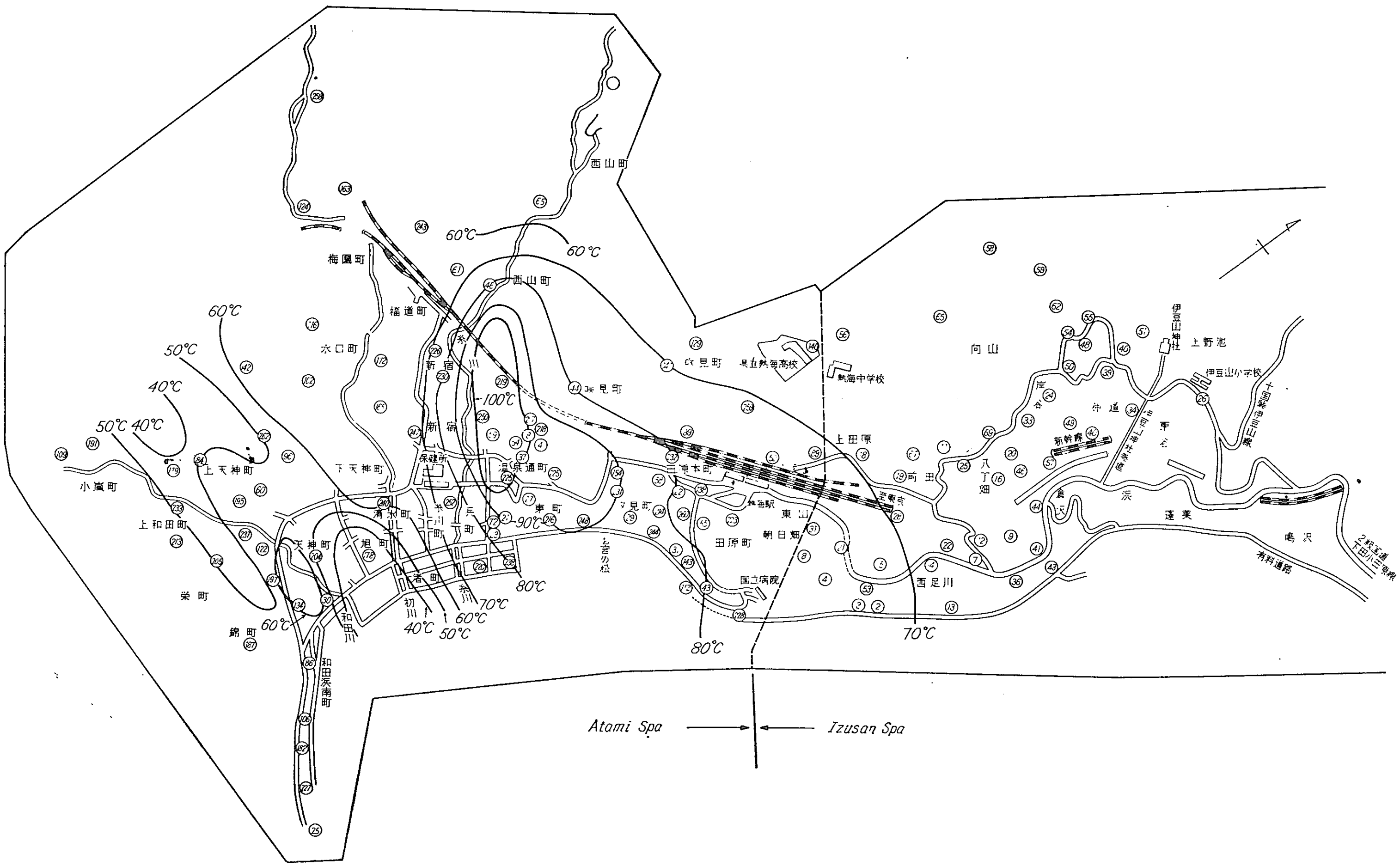

Fig. 5 Distribution map of water temperature in 1938 (After T. Fukutomi)

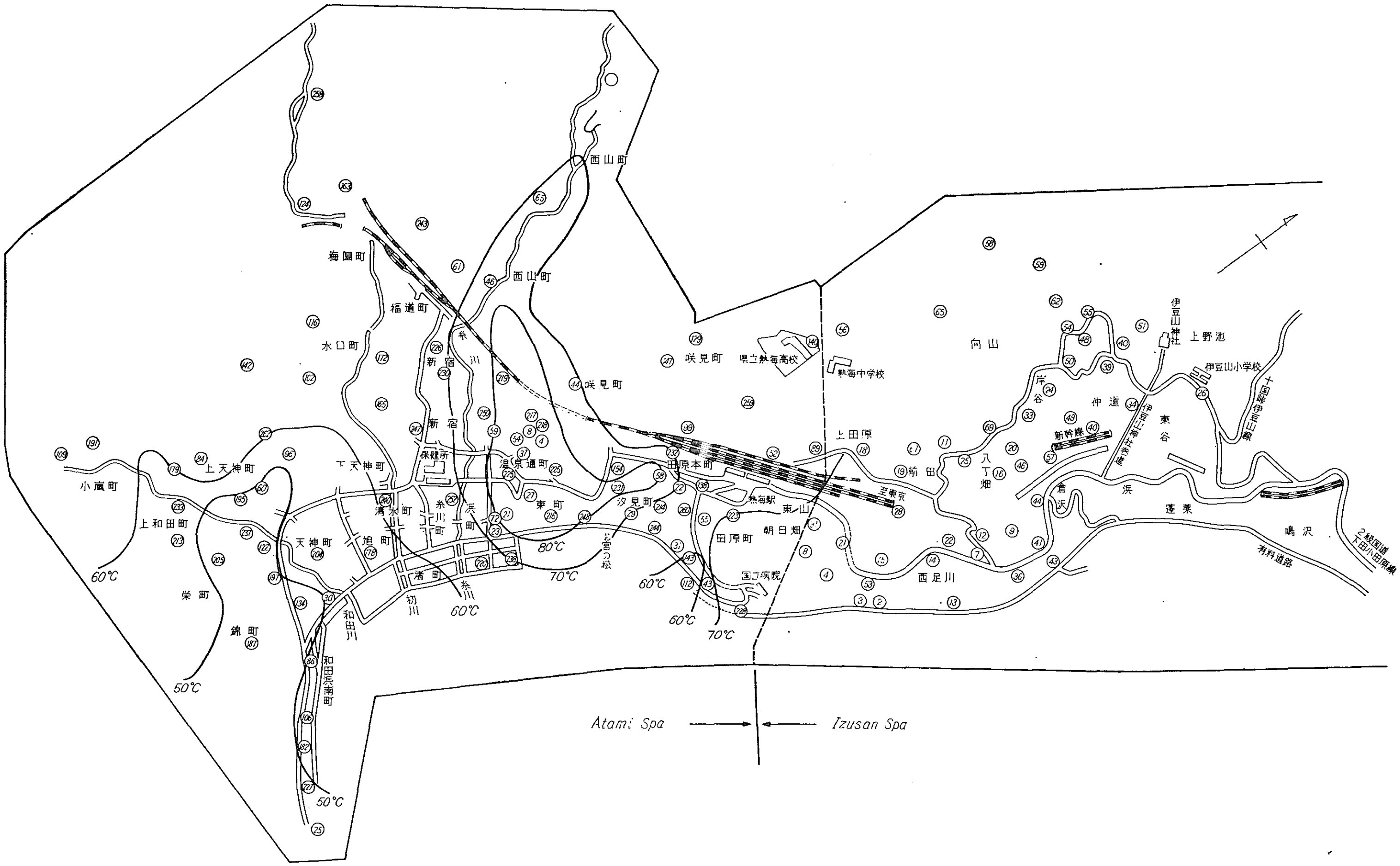

Fig. 6 Distribution map of water temperature in 1953～1955 (After K. Yuhara)

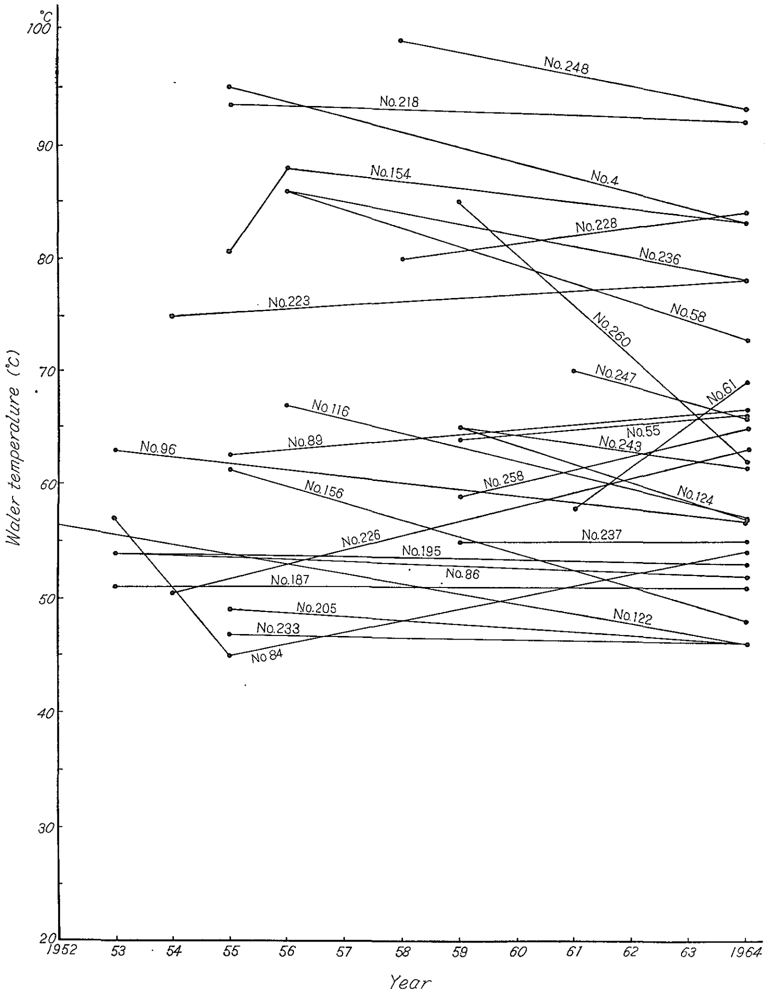

Fig. 7 Change of water temperature of the same thermal water year by year in Atami hotspring area

change of Cl^- content has happened in the areas along the Wada river of Atami spa and the seacoast of Izusan spa during past ten years. However, it is interesting that Cl^- content of thermal waters in the Oyu hot area has been unchanged from the past to the present. The change of Cl^- content in the same thermal water is shown in Fig. 11.

Fig. 12 is the distribution map of SO_4^{2-}content made by the writers and Fig. 13 is that made by Prof. FUKUTOMI. As to SO_4^{2-} content, no remarkable change has happened except in the areas along the Wada river of Atami spa and the seacoast of Izusan spa. In these areas, SO_4^{2-} content of thermal waters has increased during past thirty years as well as Cl^- content. On the other hand, it is worth to notice that thermal waters in the Oyu hot area containing high content of Cl^- are characterized by relatively low content of SO_4^{2-}. And then, from the Fukutomi's map, it can be known that thermal waters of this

Atami Spa

Table 2 Chemical compositions of thermal waters

No.	Depth (m)	Temp (C°)	pH	CO_2 (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)
226	300	63.0	8.0	—	—	21.4	2,155.8	629.2
219	250	94.5	8.0	—	—	18.3	5,159.0	146.1
218	145	92.0	8.2	—	6.0	10.7	3,864.8	324.3
229	200	88.0	8.2	—	6.6	11.3	3,403.9	414.8
230	350	61.0	8.0	—	—	36.6	1,219.7	378.6
250	250	92.0	8.5	—	13.5	11.4	3,304.6	216.4
54	73	91.2	8.3	—	7.5	11.5	3,843.5	290.1
8		93.0	8.2	—	6.0	12.2	4,155.6	267.1
4	90	83.0	8.2	—	6.0	16.2	3,063.5	310.3
71	775	81.0	8.1	—	3.0	33.6	2,666.4	279.4
23	123	63.0	8.2	—	3.0	48.2	670.1	187.6
72	123	62.0	8.3	—	6.0	48.8	492.9	63.0
216	200	93.2	8.3	—	9.0	7.6	5,616.4	342.4
27	160	82.0	8.2	—	6.0	15.3	2,957.1	427.1
248	200	93.0	8.3	—	6.0	9.2	7,977.8	363.4
29	350	91.2	8.2	—	6.0	18.3	8,936.0	656.8
244	350	64.0	8.2	—	6.0	22.9	8,434.6	657.6
214	450	73.0	8.2	—	7.5	11.4	4,753.4	312.3
232	350	83.0	8.2	—	4.5	21.4	1,286.6	665.8
221	350	84.0	8.1	—	3.0	24.4	2,330.3	891.9
154	260	83.0	8.2	—	4.5	25.9	11,186.6	1,081.0
236	250	78.0	8.1	—	3.0	27.5	11,186.6	999.9
31	350	80.5	8.0	—	—	33.6	6,111.5	937.8
143	236	54.0	8.0	—	—	73.2	10,471.8	1,386.8
112	181	65.5	7.8	—	—	45.8	6,808.5	996.2
228	350	84.0	7.9	—	—	24.4	3,770.6	751.0
260	300	62.0	7.9	—	—	25.0	3,484.7	862.1
43	234	72.0	8.2	—	3.0	43.5	6,947.9	1,341.9
55	297	66.0	7.8	—	—	33.6	1,815.6	642.4
223	350	78.0	8.2	—	3.0	42.0	10,757.7	1,649.3
156	250	48.0	8.2	—	9.0	105.3	18,048.7	2,568.2
138	302	80.5	7.9	—	—	30.5	3,270.2	932.0
52	336	73.0	8.2	—	3.0	31.3	1,930.0	801.6
99	293	78.5	8.2	—	3.0	19.1	1,518.4	776.1
89	363	67.0	8.0	—	—	35.1	5,503.9	950.6
140	303	58.0	7.7	—	—	29.0	459.6	625.5
259	450	78.2	8.2	—	3.0	33.6	1,088.3	826.7
129	310	71.0	8.0	—	—	33.6	430.7	740.7
147	250	72.0	8.2	—	3.0	25.2	370.6	632.7
44	245	78.0	8.0	—	—	24.4	3,545.7	650.2
46	303	81.2	8.2	—	3.0	29.0	2,978.3	240.7
65	327	50.5	8.0	—	—	56.0	79.7	35.4
243	450	61.2	7.4	—	—	25.9	3,627.6	761.7
61	327	69.2	8.0	—	—	32.0	3,216.6	654.3

Br^- (mg/l)	I^- (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Fe (mg/l)	Al^{3+} (mg/l)	HBO_2 (mg/l)	H_2SiO_3 (mg/l)	T.S.M. (mg/l)
—	—	1.7	980.6	555.0	15.1	0.7	0.6	8.2	254.8	9,300.0
—	—	7.2	1,109.7	1,980.0	206.3	—	—	—	—	—
12.8	<0.05	3.7	1,054.4	1,438.0	125.8	1.1	0.7	17.8	172.9	7,014.5
—	—	4.4	1,014.9	1,156.0	86.0	—	—	11.7	—	—
—	—	1.7	573.6	312.5	7.5	—	—	—	—	—
—	—	2.2	822.4	1,156.0	111.0	0.6	0.4	—	157.3	6,354.0
—	—	1.6	1,012.2	1,368.0	125.2	—	—	—	—	—
14.1	<0.05	1.7	1,057.0	1,492.0	140.8	0.6	0.5	18.6	180.7	7,829.0
—	—	3.3	877.8	996.0	85.0	—	—	—	—	—
—	—	0.9	722.3	1,024.0	89.0	—	—	—	—	—
—	—	2.8	164.5	316.5	18.7	—	—	—	—	—
—	—	0.9	43.2	297.0	23.5	0.8	0.7	6.5	63.7	1,041.0
—	—	1.7	1,644.8	1,800.0	171.6	—	—	—	—	—
—	—	3.7	891.0	1,040.0	75.2	0.5	0.5	—	133.9	6,144.7
—	—	9.6	2,646.5	2,135.0	166.0	0.8	0.5	8.2	135.2	14,058.5
—	—	108.8	2,630.0	2,530.0	107.5	1.2	0.6	8.2	98.8	16,422.0
—	—	96.0	3,677.2	1,344.0	66.8	—	—	—	—	—
—	—	6.4	1,457.7	1,404.0	125.6	—	—	—	—	—
—	—	0.6	416.5	626.0	51.6	—	—	—	—	—
—	—	11.2	888.3	854.0	37.3	—	—	—	—	—
—	—	220.7	3,194.8	3,555.0	106.0	1.1	0.5	11.5	62.4	21,968.0
—	—	215.9	3,184.3	3,595.0	97.5	—	—	—	—	—
21.0	<0.05	74.8	2,095.8	1,882.0	64.8	—	—	—	—	—
36.2	<0.05	366.2	2,111.2	4,270.0	109.0	1.2	0.7	8.2	58.5	21,416.0
—	—	78.5	2,216.5	2,342.5	74.0	—	—	—	—	—
—	—	7.2	1,643.8	937.0	44.0	1.3	0.4	10.4	92.3	7,501.0
—	—	3.1	1,443.4	1,012.0	48.2	—	—	—	—	—
—	—	9.4	1,037.6	3,555.0	121.3	—	—	—	—	—
—	—	9.4	755.1	652.0	39.2	—	—	—	—	—
—	—	386.5	2,029.0	4,790.0	133.8	1.2	0.7	13.7	84.5	22,274.5
—	—	1,241.2	500.8	10,000.0	343.0	1.7	0.6	16.4	29.9	35,908.5
—	—	28.1	1,124.9	1,300.0	42.4	—	—	—	—	—
—	—	26.5	708.9	839.0	32.9	0.2	0.9	12.3	94.9	5,622.5
—	—	2.0	698.6	642.0	28.7	—	—	—	—	—
—	—	18.7	1,849.2	1,916.0	53.8	0.6	0.6	—	63.1	10,339.0
—	—	2.5	267.1	313.0	12.0	1.2	0.5	8.7	68.9	1,921.0
—	—	12.5	416.1	645.0	23.6	—	—	—	—	—
1.50	—	3.1	256.8	351.0	27.8	—	—	—	—	—
—	—	1.1	226.0	300.5	21.5	—	—	—	—	—
—	—	<0.1	1,384.4	984.0	36.8	0.5	0.6	10.1	76.1	7,425.1
—	—	1.7	1,014.5	906.0	53.2	0.4	0.3	12.6	120.9	5,989.0
—	—	5.3	45.7	20.1	1.0	—	—	—	—	—
—	—	7.8	1,592.4	792.0	27.8	0.2	0.5	—	68.3	7,416.0
9.90	<0.05	9.4	1,386.9	684.0	24.0	—	—	—	—	—

No.	Depth (m)	Temp (C°)	pH	CO_2 (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)
124	363	57.0	7.7	—	—	30.5	196.9	760.5
163	300	56.0	7.9	—	—	40.6	167.2	673.6
258	400	65.0	7.7	—	—	30.5	225.8	901.6
165	250	68.0	7.8	—	—	24.4	593.3	897.9
172	300	58.0	8.1	—	3.0	48.8	389.6	583.5
102	363	63.0	7.9	—	—	27.5	285.9	897.1
116	303	57.0	7.8	—	—	40.6	157.3	612.3
178	353	48.0	7.6	—	—	30.5	181.6	415.4
240	400	43.0	7.9	—	—	64.1	114.4	163.8
252	400	53.0	8.3	—	3.0	58.7	216.2	102.9
254	401	66.0	7.8	—	—	27.5	857.8	479.4
247	575	66.0	7.7	—	—	27.5	605.8	781.2
217	168	94.0	8.3	—	6.0	22.9	4,404.9	223.9
59	112	95.0	8.2	—	4.5	16.0	4,521.1	225.5
37	100	87.0	8.4	—	6.0	24.4	3,529.3	360.9
225	50	89.0	8.3	—	3.9	15.6	3,699.1	343.2
58	272	73.0	8.3	—	4.5	23.3	1,314.5	515.2
220	300	53.0	7.4	—	—	27.5	2,162.3	499.6
238	250	65.0	8.0	—	—	48.8	3,323.8	429.6
182	300	49.0	7.3	—	—	21.7	6,915.7	1,006.5
25	300	54.6	7.8	—	—	29.6	9,113.7	1,313.1
227	400	54.0	7.5	—	—	27.5	7,655.5	1,173.6
96	363	65.5	7.8	—	—	30.5	7,541.1	1,137.8
262	350	59.0	7.9	—	—	27.5	373.5	865.8
60	364	48.0	7.8	—	—	54.9	2,712.5	384.8
195	350	53.0	7.6	—	—	33.0	872.1	628.4
84	318	54.0	8.0	—	—	27.5	586.5	860.0
179	352	53.0	7.7	—	—	24.4	1,402.8	815.6
191	650	60.5	8.2	—	3.0	20.6	253.8	1,043.6
109	539	57.0	7.8	—	—	32.0	210.9	801.7
142	333	57.0	7.6	—	—	25.9	403.9	890.3
122	236	46.0	8.0	—	—	36.6	2,123.0	436.6
237	300	55.0	7.6	1.9	—	28.9	6,433.2	1,043.6
106	400	52.0	7.4	4.0	—	26.9	6,361.7	948.1
86	261	52.0	7.7	2.7	—	30.5	3,225.5	758.4
137	190	51.0	7.7	1.3	—	42.7	1,858.5	409.0
30	383	42.0	7.7	1.3	—	45.8	250.2	220.6
204	445	53.0	7.4	3.0	—	27.5	7,898.5	1,175.7
197	350	46.0	7.6	3.5	—	18.3	7,498.3	1,116.4
187	300	51.0	7.6	3.0	—	16.8	2,055.1	955.9
233	380	46.0	7.7	3.2	—	33.6	343.1	475.7
213	420	53.0	7.9	2.1	—	54.9	1,558.3	774.8
205	400	46.0	7.8	2.4	—	21.4	4,717.7	914.4

Br^- (mg/l)	I^- (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)	Fe (mg/l)	Al^{3+} (mg/l)	HBO_2 (mg/l)	H_2SiO^3 (mg/l)	T.S.M. (mg/l)
—	—	0.9	251.7	187.0	6.7	—	—	—	—	—
—	—	1.1	228.6	156.0	5.1	0.4	0.3	5.5	59.8	1,387.5
—	—	0.9	297.9	216.0	8.5	0.2	0.4	7.1	52.7	1,852.0
—	—	0.7	444.3	308.5	9.0	0.6	0.3	7.1	65.7	2,746.5
—	—	6.2	303.1	176.0	6.2	—	—	—	—	—
0.90	—	0.4	318.5	219.5	7.0	—	—	—	—	—
—	—	3.1	205.5	145.0	4.9	—	—	—	—	—
—	—	0.6	209.6	64.1	3.1	—	—	—	—	—
—	—	3.1	91.4	55.5	2.7	—	—	—	—	—
—	—	1.1	57.5	120.5	12.8	1.2	1.0	5.5	66.3	657.5
—	—	<0.1	403.2	272.0	16.7	0.1	0.5	5.5	59.3	2,750.0
1.80	—	2.2	408.4	252.5	9.2	—	—	—	—	—
15.20	<0.05	6.2	1,089.0	1,624.0	159.6	—	—	—	—	—
—	—	1.6	1,081.4	1,666.0	164.0	—	—	—	—	—
12.00	<0.05	6.2	1,004.3	1,054.0	98.0	—	—	—	—	—
12.50	<0.05	3.1	973.5	1,404.0	100.0	—	—	—	—	—
—	—	6.2	416.1	601.0	36.0	—	—	—	—	—
—	—	14.0	1,143.0	377.5	16.9	—	—	—	—	—
—	—	12.5	896.5	1,334.0	69.6	1.4	0.3	4.6	67.6	6,970.0
—	—	56.1	2,699.6	1,832.0	36.8	—	—	—	—	—
—	—	93.3	3,070.1	2,850.0	24.5	0.6	2.1	10.4	48.1	18,550.0
—	—	55.8	2,707.2	2,044.0	35.0	—	—	—	—	—
—	—	42.0	2,883.0	2,240.0	33.7	—	—	—	—	—
—	—	0.4	343.4	272.0	8.4	—	—	—	—	—
—	—	43.4	1,036.9	655.0	13.5	0.1	0.4	3.3	37.1	6,177.5
—	—	6.2	461.3	333.5	7.9	—	—	—	—	—
—	—	0.7	425.4	308.5	8.1	0.4	0.5	6.8	45.5	2,581.5
—	—	3.1	740.6	461.0	10.3	—	—	—	—	—
—	—	3.1	328.0	289.0	5.2	—	—	—	—	—
—	—	<0.1	256.3	232.5	5.8	0.2	0.3	7.1	46.2	1,639.9
—	—	3.1	353.6	281.5	7.4	0.2	0.3	7.6	55.9	2,150.5
—	—	18.7	840.5	620.0	13.0	—	—	—	—	—
—	—	26.4	575.5	1,716.0	28.8	—	—	—	—	—
—	—	49.8	2,324.3	1,812.0	27.0	—	—	—	—	—
—	—	20.2	1,335.1	937.0	12.6	0.2	0.7	6.6	31.2	7,380.5
—	—	9.3	779.0	505.5	8.1	0.2	0.5	3.3	28.6	4,569.5
—	—	0.1	137.4	122.0	2.7	—	—	—	—	—
—	—	51.3	3,118.7	2,014.0	28.5	—	—	—	—	—
6.40	<0.05	46.6	2,931.7	2,000.0	31.4	—	—	—	—	—
—	—	3.1	1,025.1	614.0	15.8	0.1	0.3	6.8	37.1	5,762.9
—	—	<0.1	220.4	186.0	3.5	0.6	0.4	4.4	41.0	1,494.5
—	—	1.5	609.9	447.0	7.0	—	—	—	—	—
—	—	20.2	1,916.9	1,310.0	17.0	0.2	0.4	6.8	33.2	10,418.6

Izusan Spa

No.	Depth (m)	Temp (C°)	pH	CO_2 (mg/l)	CO_3^{2-} (mg/l)	HCO_3^- (mg/l)
56	600	55.0	8.0	1.2	—	37.5
67	350	61.5	8.0	3.6	—	29.0
18	450	65.0	8.0	3.9	—	44.2
19	327	76.0	8.0	2.4	—	26.3
28	275	65.0	7.9	1.7	—	24.4
11	449	63.0	8.0	1.2	—	40.6
69	345	68.5	8.2	—	11.1	9.5
20	300	59.7	8.2	—	2.1	26.2
33	300	61.5	7.1	2.9	—	22.0
50	290	55.0	4.2	9.7	—	—
26	620	45.5	7.8	1.2	—	32.0
34	240	59.0	4.6	38.8	—	2.1
39	299	63.5	4.2	8.9	—	—
48	450	61.0	4.2	8.7	—	—
54	570	69.0	8.0	0.7	—	22.9
24	272	60.0	4.6	10.9	—	3.1
49	293	54.0	7.1	2.7	—	17.4
40	455	65.0	8.2	—	1.5	21.4
43	393	58.0	7.8	2.7	—	59.5
57	400	61.0	8.1	—	3.0	30.5
16	295	71.0	8.3	—	4.5	23.2
46	300	51.0	8.1	—	2.1	17.7
51	379	66.2	4.2	9.7	—	—
55	350	59.0	4.5	6.1	—	—
59	500	58.0	7.1	2.4	—	12.2
58	500	52.0	8.2	—	3.0	32.0
62	530	70.5	8.4	—	4.5	27.5
60	300	66.0	4.4	8.5	—	—
9	280	55.0	7.8	1.7	—	25.0
44	393	68.2	8.0	1.7	—	27.5
25	300	35.0	8.2	—	3.0	39.7
8	330	56.0	8.0	1.2	—	70.2
31	272	59.0	8.2	—	5.4	72.9
15	242	73.0	8.2	—	3.0	19.8
21	290	53.0	8.2	—	6.0	103.1
4	180	52.2	8.2	—	7.5	91.8
53	250	61.0	8.2	—	3.6	80.0
13	197	69.5	8.0	2.2	—	22.3
2	145	48.2	8.0	2.4	—	90.5
14	242	72.0	8.2	—	3.0	19.8
3	200	59.5	8.0	1.7	—	73.2
22	329	75.0	8.2	—	2.1	21.4
7	171	59.0	7.8	1.5	—	29.0
30	200	61.0	7.8	2.7	—	31.4
12	363	63.0	8.1	—	1.5	25.3
36	230		7.8	2.4	—	36.6
41	397	36.2	7.9	2.2	—	68.7
35	695	28.0	7.3	1.7	—	19.2

Cl^- (mg/l)	SO_4^{2-} (mg/l)	Br^- (mg/l)	I^- (mg/l)	Mg^{2+} (mg/l)	Ca^{2+} (mg/l)	Na^+ (mg/l)	K^+ (mg/l)
773.0	720.1	—	—	8.7	368.9	382.0	15.1
5,796.5	1,054.7	—	—	100.3	2,118.4	1,615.0	45.0
4,985.3	1,097.5	—	—	161.6	1,335.9	1,932.5	55.3
2,836.6	877.1	—	—	28.6	946.3	1,100.0	39.6
2,036.6	659.0	—	—	30.9	847.7	620.0	20.8
393.6	573.6	—	—	2.4	225.6	275.0	9.5
851.0	776.1	—	—	1.2	419.2	425.0	17.4
875.7	785.4	—	—	1.2	433.1	4,415.0	17.2
436.1	595.2	2.00	<0.05	7.2	219.5	241.0	10.2
141.8	436.0	—	—	12.1	135.7	114.0	5.6
95.7	288.1	—	—	4.8	101.8	91.6	4.1
285.4	753.9	—	—	9.7	223.6	247.5	12.9
276.6	749.6	—	—	12.1	233.5	232.5	11.6
202.1	716.8	—	—	9.7	215.6	195.0	9.5
320.9	773.2	1.10	—	8.5	239.5	284.0	11.1
149.6	441.1	—	—	13.3	127.7	123.0	6.1
159.6	489.9	—	—	20.6	153.7	126.0	5.6
1,338.0	797.9	—	—	40.0	624.7	442.5	11.8
9,403.3	1,249.9	—	—	268.1	3,053.9	2,525.0	49.5
1,614.4	447.3	—	—	55.8	624.7	432.0	9.7
890.1	739.7	—	—	33.9	367.3	442.0	16.2
244.6	365.0	—	—	2.4	107.8	205.0	2.9
338.6	856.3	—	—	23.1	243.5	290.0	14.6
283.7	746.9	—	—	23.1	207.6	247.0	11.6
273.0	703.3	—	—	6.1	225.5	235.0	8.8
343.9	750.6	—	—	1.2	245.5	290.0	11.8
333.3	793.4	1.10	<0.05	1.2	245.5	303.0	9.5
351.0	837.2	—	—	2.4	259.5	300.0	15.3
5,536.6	703.7	20.20	<0.05	140.7	2,239.5	1,060.0	26.0
4,506.6	863.3	—	—	46.1	1,840.3	1,108.0	26.0
510.6	519.7	—	—	1.2	243.5	297.0	12.3
16,083.5	1,999.9	—	—	780.1	2,219.6	7,005.0	249.0
16,821.0	2,241.0	—	—	973.0	1,269.4	8,040.0	296.0
9,396.2	1,501.6	—	—	280.5	2,009.9	374.0	100.0
18,622.3	2,592.5	—	—	1,223.4	552.1	10,000.0	371.0
15,757.3	2,230.7	52.9	<0.05	1,020.4	585.7	8,220.0	306.0
16,650.8	2,310.6	—	—	950.7	1,845.8	7,700.0	180.0
8,314.0	968.9	—	—	181.1	3,355.2	1,715.0	54.0
15,920.2	2,231.8	—	—	884.3	1,855.7	7,200.0	162.0
1,201.9	741.5	—	—	7.2	530.4	500.0	17.1
15,512.4	2,075.6	—	—	748.5	2,306.1	6,900.0	139.0
1,170.1	749.8	—	—	10.8	514.7	495.0	18.0
5,503.0	681.6	—	—	54.3	1,890.4	966.0	25.2
10,650.7	1,172.2	—	—	175.0	4,077.7	2,455.0	52.0
1,060.2	368.6	3.90	<0.05	18.0	395.8	360.5	11.1
9,183.4	1,097.5	—	—	295.8	3,078.1	2,342.5	41.5
9,076.9	1,177.7	—	—	325.4	2,596.4	2,750.0	21.3
2,066.1	1,079.8	—	—	85.2	866.4	696.0	13.4

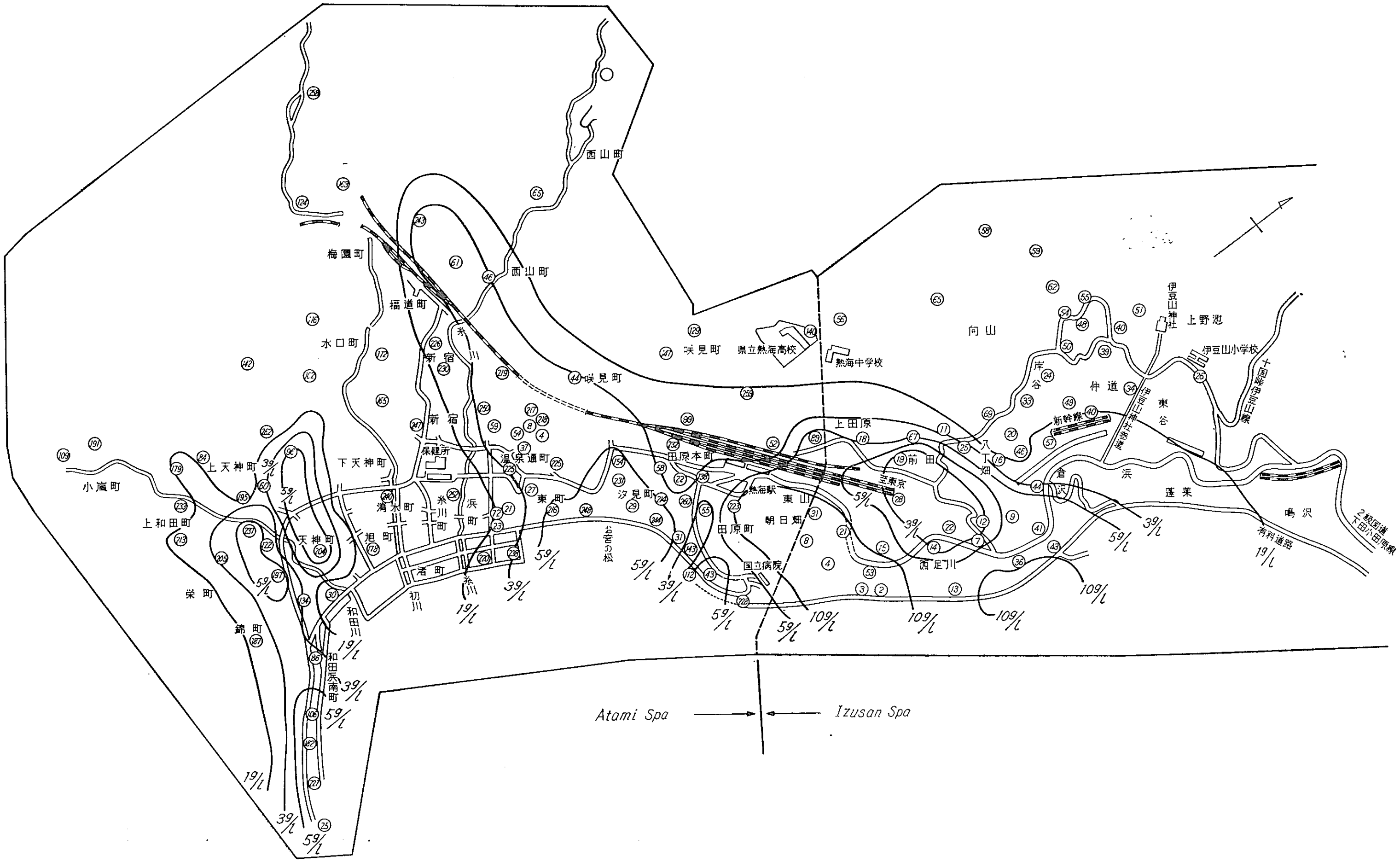

Fig. 8 Distribution map of Cl^- content in Atami hotspring area in 1964～1965

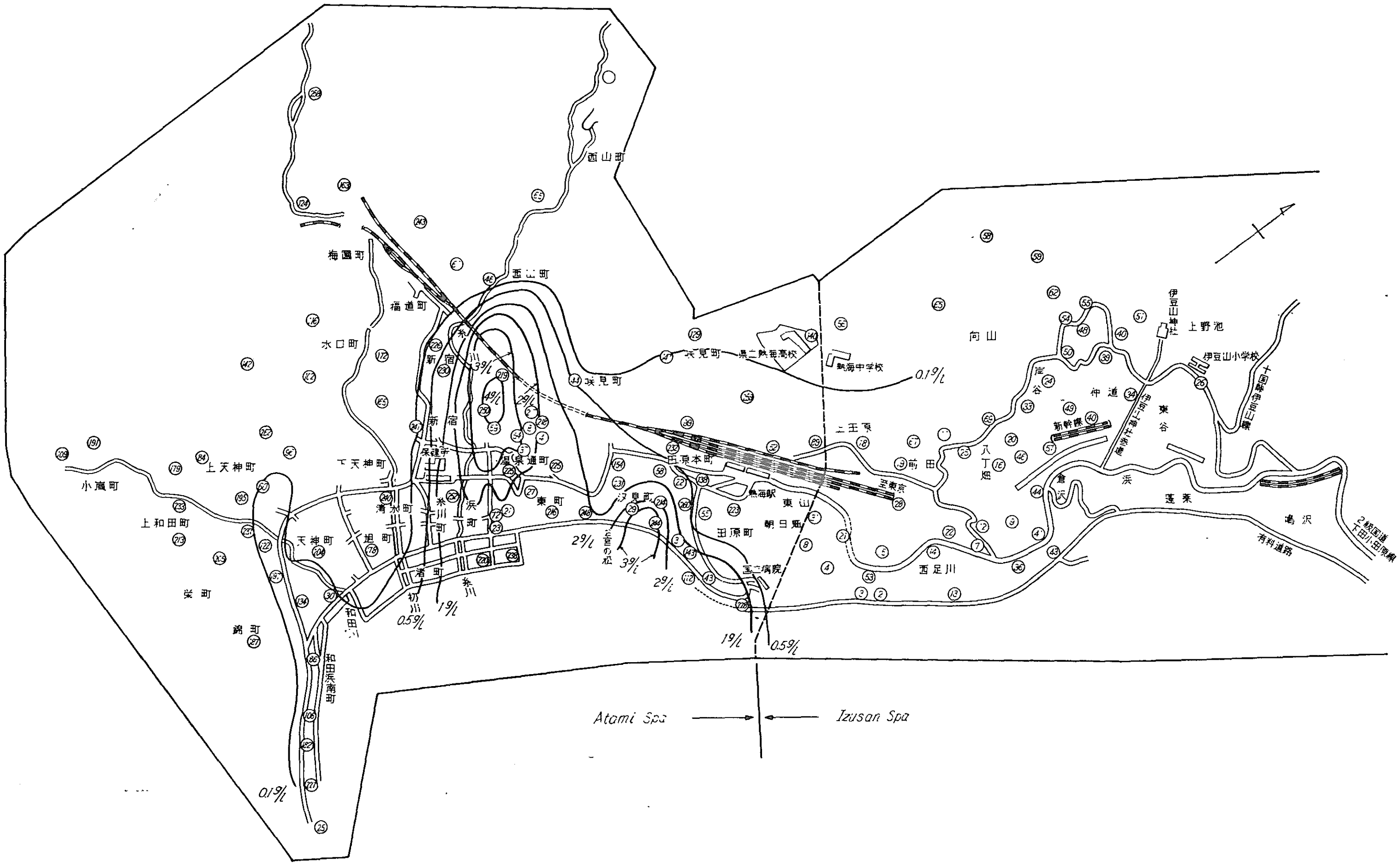

Fig. 9 Distribution map of Cl^- content in Atami hotspring area in 1938 (After T. Fukutomi)

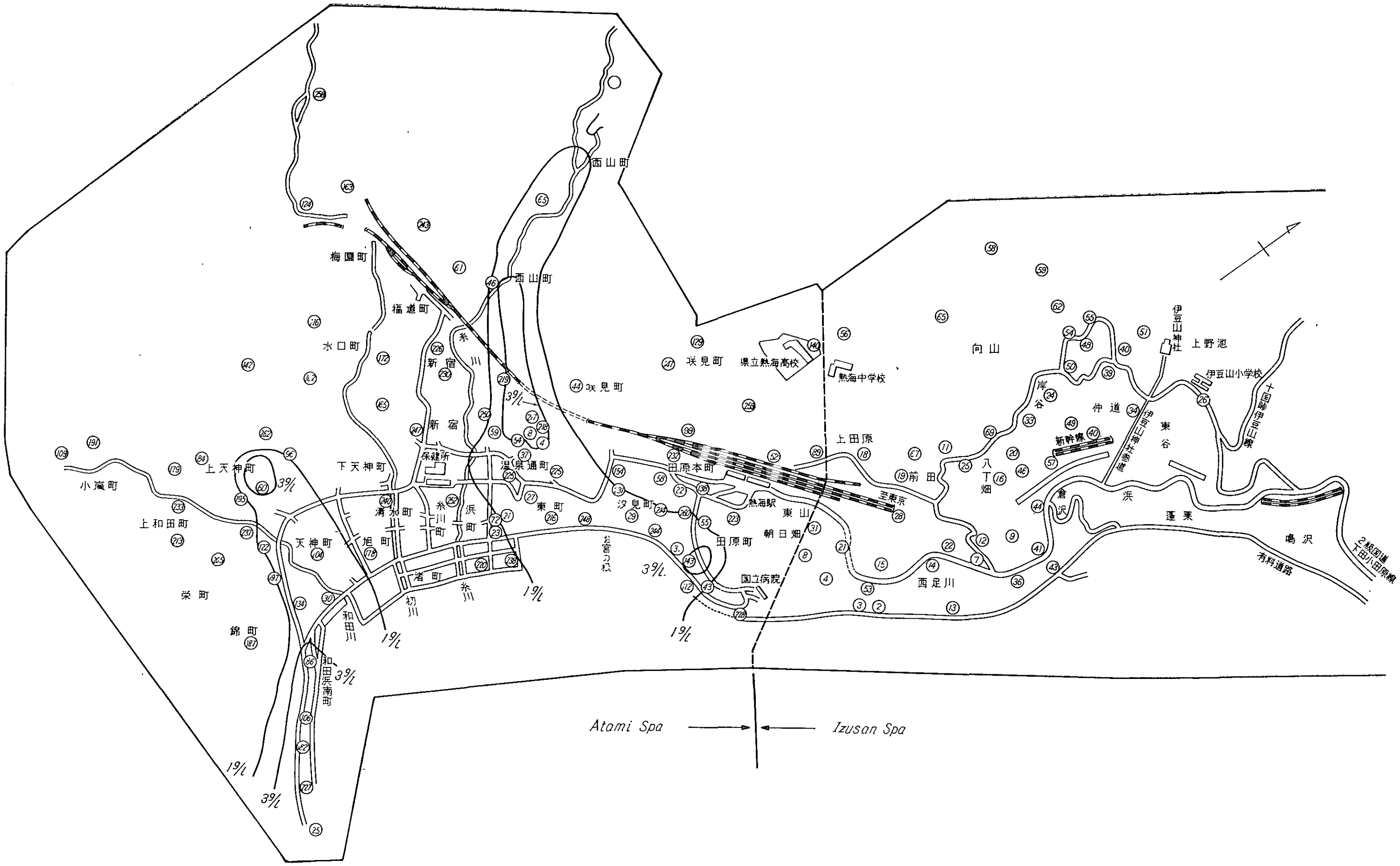

Fig. 10 Distribution map of Cl⁻ content in Atami hotspring area in 1953～1955 (After K. Yuhara)

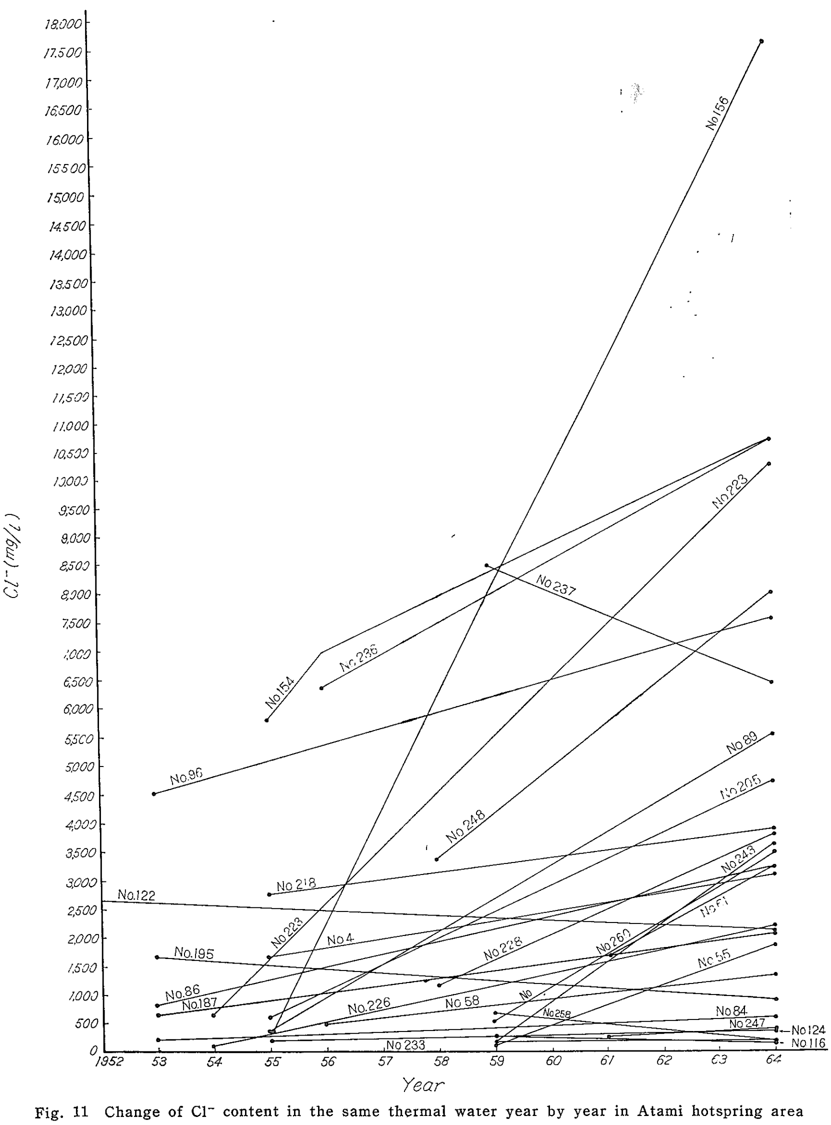

Fig. 11 Change of Cl^- content in the same thermal water year by year in Atami hotspring area

area, in general, have a tendency to increase SO_4^{2-}content with a distance from the central area cut by the Itogawa river in this field to north and south sides.

3. Hydrothermal system in Atami hotspring area

3.1 Classification of thermal waters

From the data on water temperatures and chemical compositions of thermal waters in the past and present, thermal waters in the Atami hotspring area can be divided into following three types:

A. Hot water type

This type is characterized by

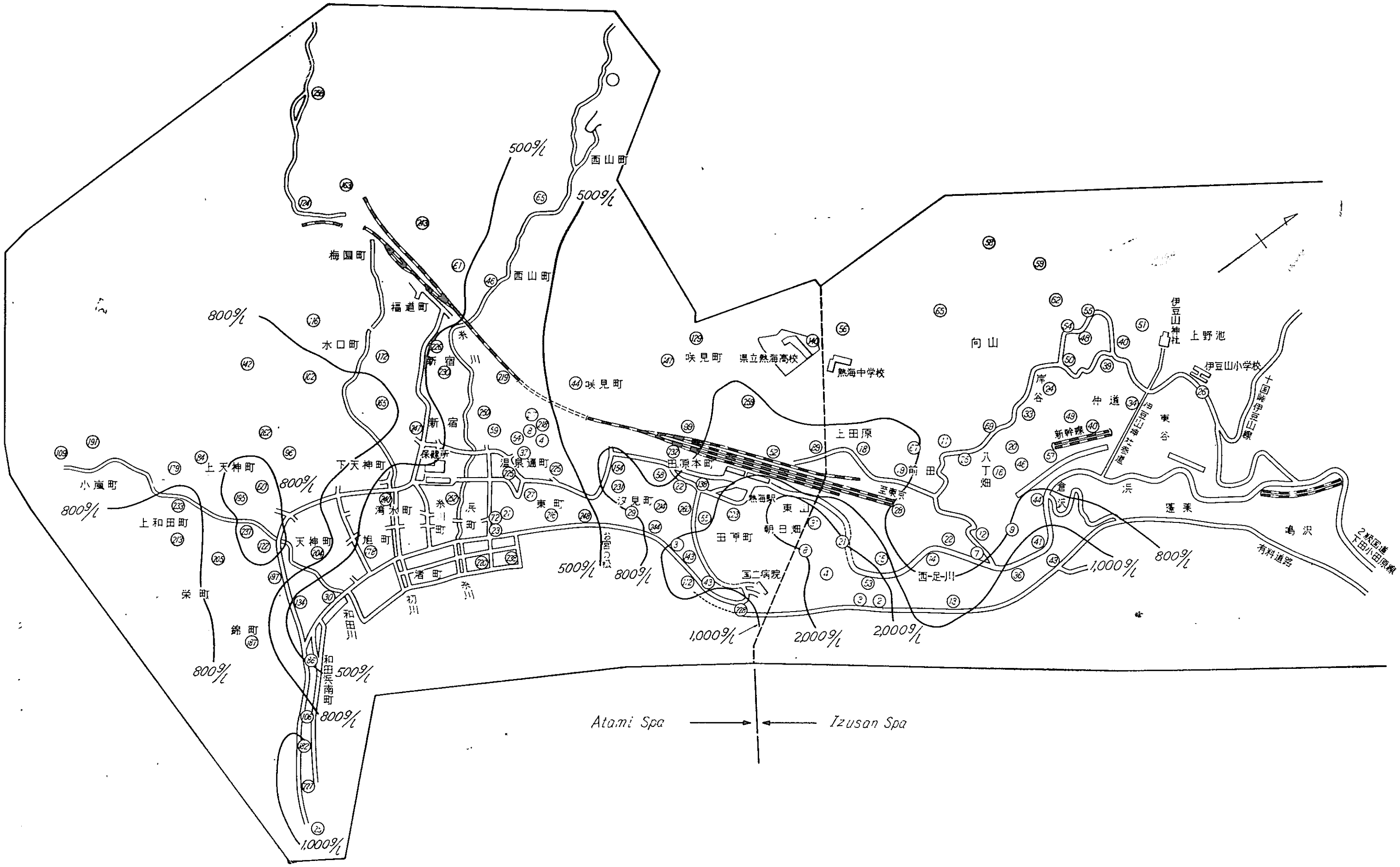

Fig. 12 Distribution map of SO_4^{2-} content in Atami hotspring area in 1964～1965

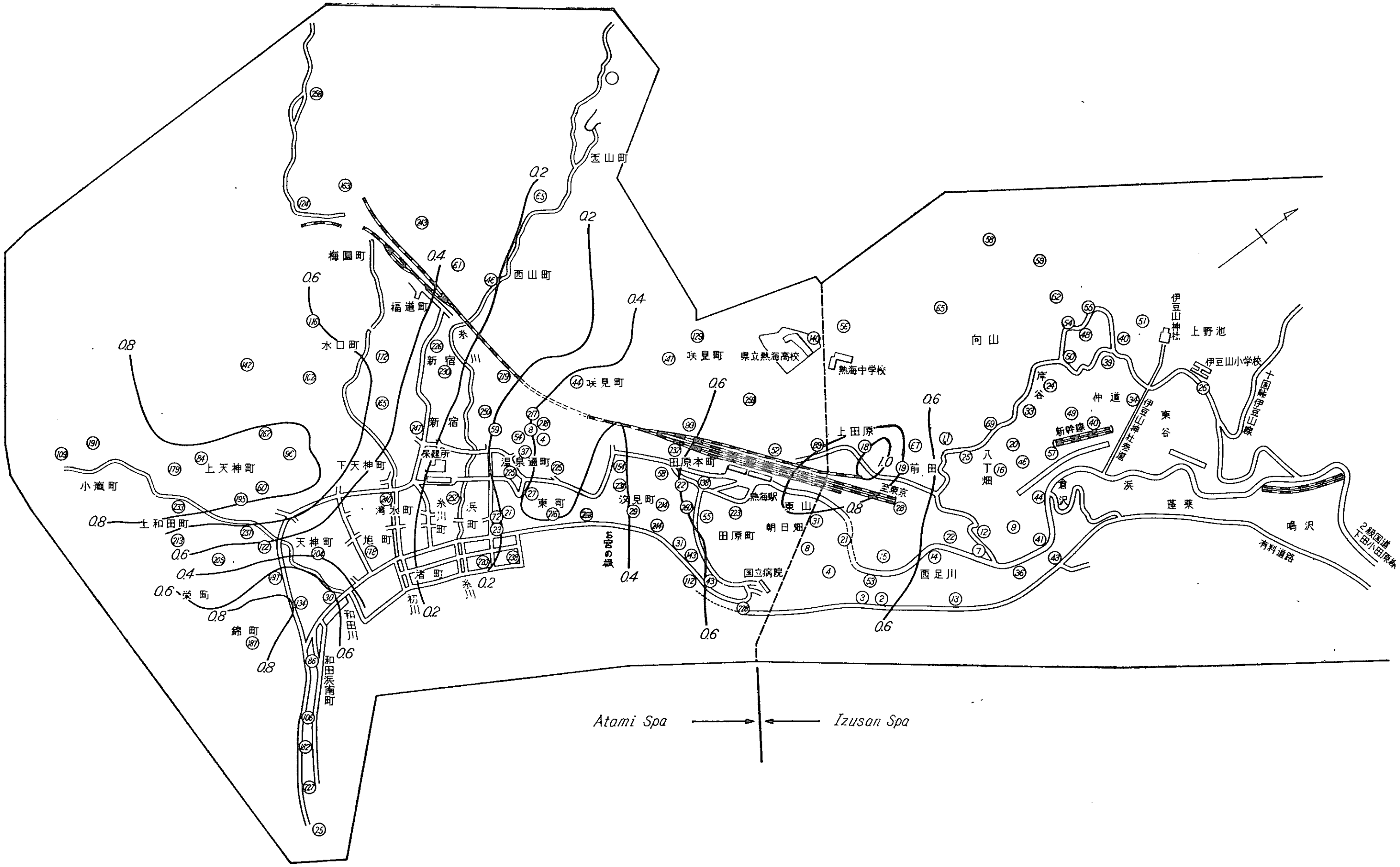

Fig. 13 Distribution map of SO_4^{2-} content in Atami hotspring area in 1938 (After T.Fukutomi)

a) high temperature (above 90°C),

b) relatively high content of Cl^- (about 5,000mg/l),

c) low content of SO_4^{2-}(150-300mg/l),

d) remarkably low content of Mg^{2+} (1-10mg/l),

e) high content of K^+ (100-200mg/l)

and f) $Na^+ > Ca^{2+}$ content.

Thermal water of this type is distributed around Oyu hot area and regarded as original hot water in this area because of having no remarkable changes of water temperature and chemical compositions during past thirty years.

B. Mixed type of hot water and underground water containing SO_4^{2-}

The second type has following characteristics :

a) water temperature ranging from 50∼70°C,

b) relatively low content of Cl^- (less than 1,000mg/l),

c) high proportion of SO_4^{2-} to Cl^- content (400-1,000mg/l)

d) remarkably low content of Mg^{2+} and K^+ (less than 10mg/l)

and e) $Ca^{2+} > Na^+$ content.

Judging from the distribution of thermal water of this type located on the outside of central area with thermal water of hot water type, it can be considered that the main component of this type is characterized by that of underground water containing SO_4^{2-}.

C. Mixed type of hot water and sea water

The last type has the same chemical property as sea water, that is

a) more than 10,000mg/l of Cl^- content,

b) SO_4^{2-} content of seventh of Cl^- content

and c) $Mg^{2+} > Ca^{2+} \fallingdotseq K^+$ content.

However, some of this type have not always the same ratio of chemical compositions as that of sea water. In this case, Mg^{2+} content plays a roll as indicator of this type. In other words, when the thermal water contains not only high content of SO_4^{2-} but also has several ten mg/l of Mg^{2+} having the content which is higher than K^+, it is considered that it would be composed of hot water and sea water which has remained chemical characteristics represented by compositions such as SO_4^{2-} and Mg^{2+}, besides Cl^-.

Fig. 14 shows the distribution of these three types of thermal waters in this area. From this map, it can be recognized that thermal water of hot water type occupies only the hot area around Oyu and that thermal water contaminated by sea water is found along the seacoast of Izusan spa and the Wada river of Atami spa, though there had not been any thermal water of this type in the Atami hotspring area thirty years ago.

3.2 Original property of thermal water of hot water type

As explained already, thermal water of hot water type is different in chemical characteristics from that of other two types. Therefore, it is an in-

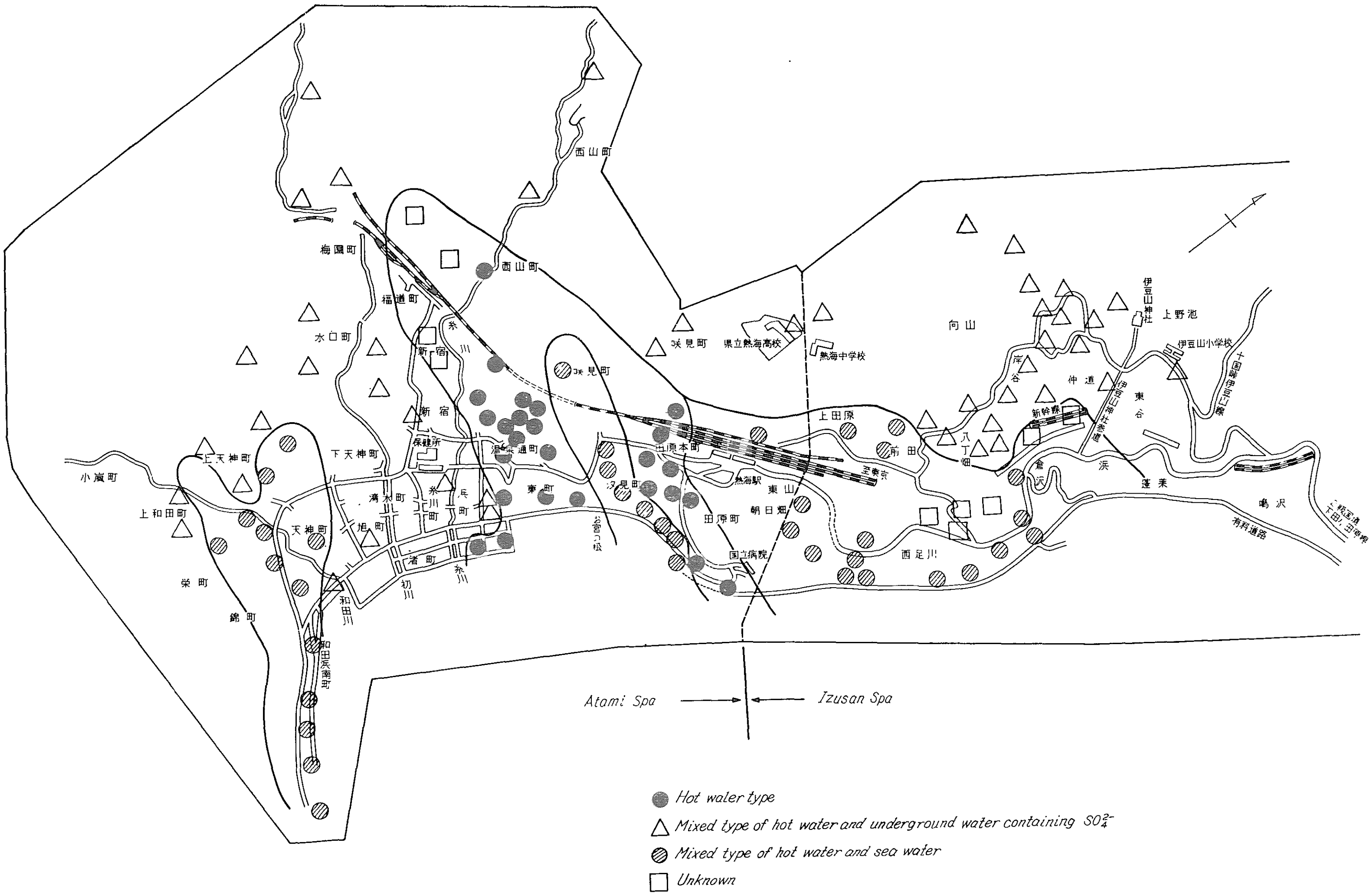

Fig. 14 Distribution map of three types of thermal waters in Atami hotspring area

teresting problem that what kind of original property it has. To get information about this problem, the chemical analyses of Br^- and I^- in representative thermal waters in this area have been made.

As known well, in the case of sea water, the ratio of Br^- to $Cl^- \times 100$ is 0.34 and I^- content is only 0.05mg/l. According to the analytical result, it has become clear that the ratio of Br^- to Cl^- is the same as that of sea water and that I^- content is also very low. This means that thermal water of hot water type keeps characteristics of sea water as original property.

Though there remains unsoluble problems yet, it is possible to consider that thermal water of hot water type comes from sea water originally and on the way coming up from deeper part to the ground surface, exchange and replacement of chemical compositions between hot sea water and wall rocks, in addition to reduction of SO_4^{2-} have occurred, resulting in characteristics of hot water type different from sea water.

As conclusion, it can be summarized that hydrothermal system in the Atami hotspring area is given by combination of three types of thermal waters; one is hot water type which is derived from sea water permeated into deeper part, the next is mixed type of hot water and sea water characterized by chemical compositions such as Cl^-, SO_4^{2-} and Mg^{2+}, existing in the upper part of system, and the last is mixed type of hot water and underground water containing SO_4^{2-}, prevailed also in the upper part of system on land side.

4. Change of water level in the hotspring area by pumping

Because of withdrawing thermal waters by pumping up in many holes, there is no natural flowing springs in this area at present. To know the change of water level from the past to the present, data on water level in

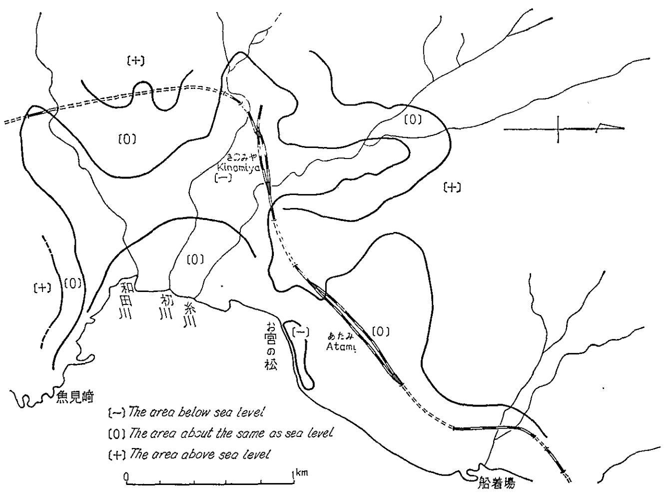

Fig. 15 Distribution map of water level in Atami hotspring area in 1959

bore holes when they were drilled were collected, and the estimation of water level in acting holes was done by using informations about the depth of air pipe in bore holes and the value of back pressure of compressor used to lift water at the starting time (KODAI, 1965).

Fig. 15 shows the distribution of water level in 1959. In this time, most thermal water kept water level as same as or above sea level. However, it is clear that water level has decreased down during the past ten years, as shown in Fig. 16 and Fig. 17 made by the above-mentioned method, and that the rate of decreasing of water level shows 2-3m per year near the seacoast of Atami spa and 8m on the mountain side of Izusan spa (Fig. 18 and Fig. 19). At present, water level of most thermal water in this area has decreased down below sea level. This fact suggests that there is an intimate relation between pressure drop of thermal water and invasion of sea water into the hotspring

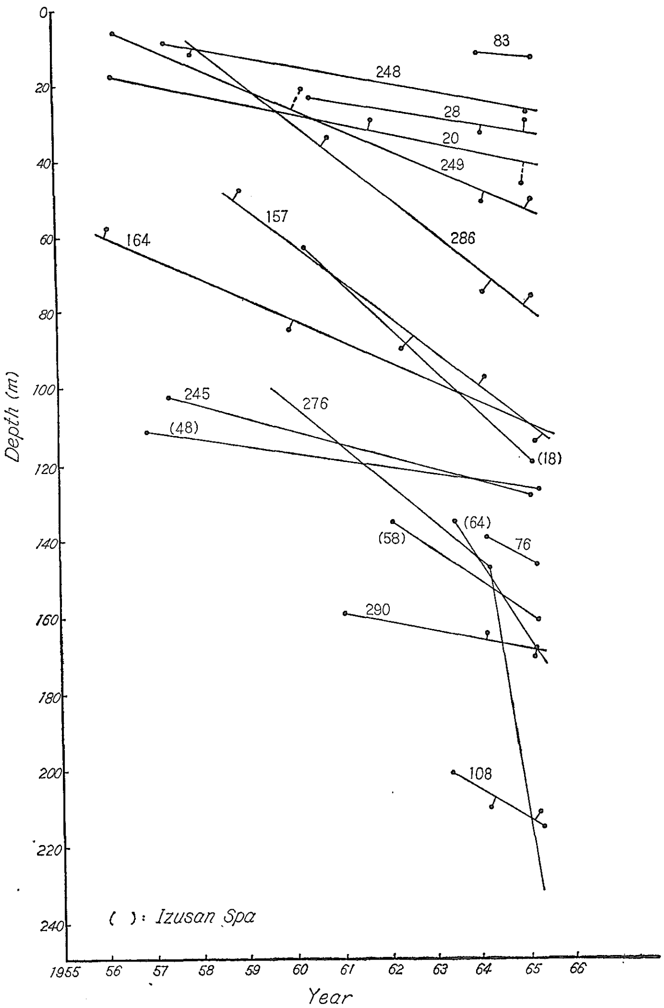

Fig. 16 Change of water level year by year in Atami hotspring area (1)

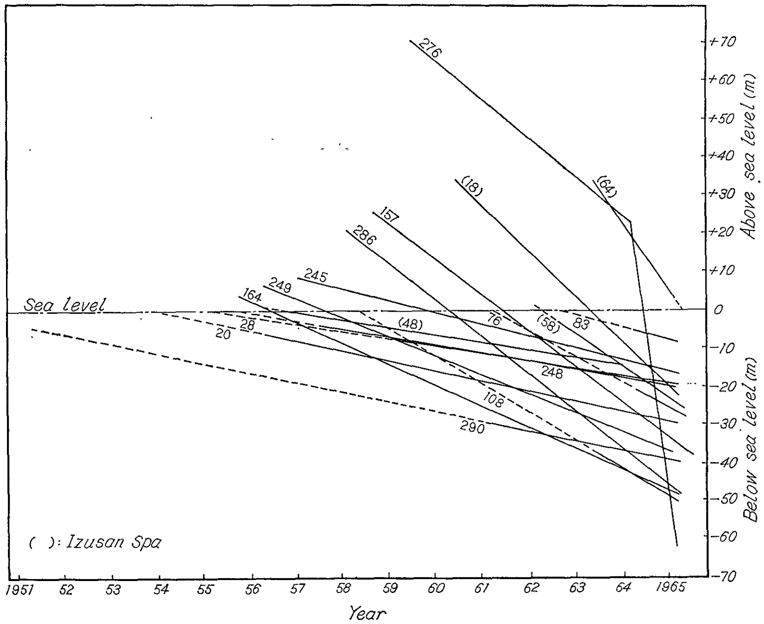

Fig. 17 Change of sea level year by year in Atami hotspring area (2)

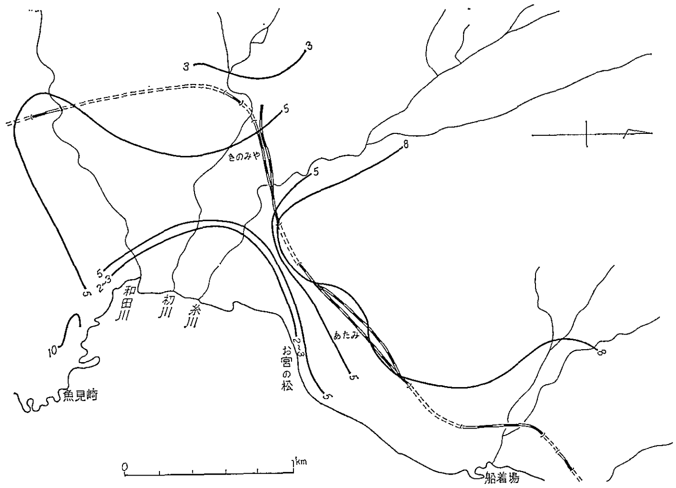

Fig. 18 Rate of decreasing of water level per year in Atami hotspring area (unit : m)

system.

5. Relation of structural weak zone to high discharging areas

The bore holes in the Atami hot spring area are all drilled in Miocene Yugashima formation which builds up the basement rocks of the Izu peninsula. From the fact that there are predominant faults trending from north-west to south-east in this area (KUNO, 1952) which are accompanied with thermal water of hot water type and those contaminated by sea water, it is considered that

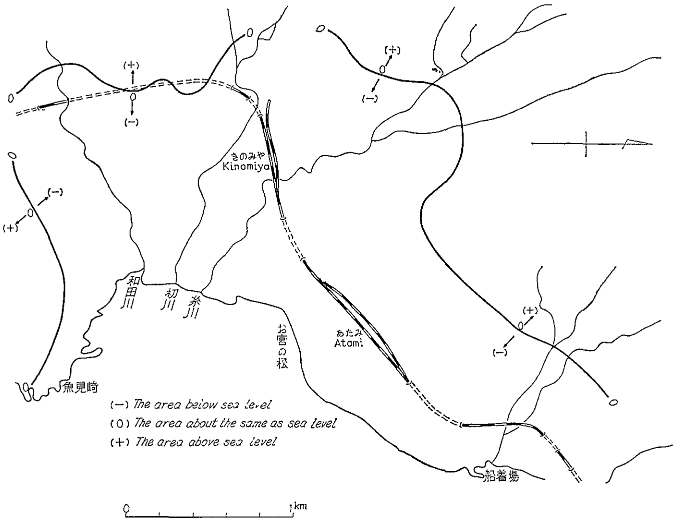

Fig. 19 Distribution map of water level in 1965 in Atami hotspring area

thermal waters come up along the faults and spread into horizontal cracks developed in the Yugashima formation. And then, considering the distribution of mixed type of hot water and sea water along the seacoast of Izusan spa, it can be expected that there may be a structural weak zone, though no positive data on geologic background are found.

On the other hand, the data on discharge of thermal water suggest that the hydrologic condition in this area may relate to fracture permeability in the weaked zone formed by structural movement. According to the data on amount of discharge in this area, mean value shows about 60 l/min. Therefore, it will be deduced that the bore holes with above 100 l/min of discharge may be situated on the areas included in the fractured zone having good condition as reservoirs of thermal waters. As seen in Fig. 20 showing the distribution of high discharging holes, they are all situated on the areas around Oyu, along the Wada river of Atami and the seacoast of Izusan, namely on the areas along fractured zones. This may be another reason that contamination by sea water occurred rapidly in these areas because of high discharge of thermal waters.

6. Distribution of underground temperature in the Atami hotspring area

Fig. 21, Fig. 22 and Fig. 23 show the distribution of underground temperature at the depths of 200, 300 and 400m respectively which were made from the data at the time of drilling. From these maps, it can be pointed up that this area has a large scale of high temperature zones and that Oyu hot area occupies the central part of thermal activity area through which high tem-

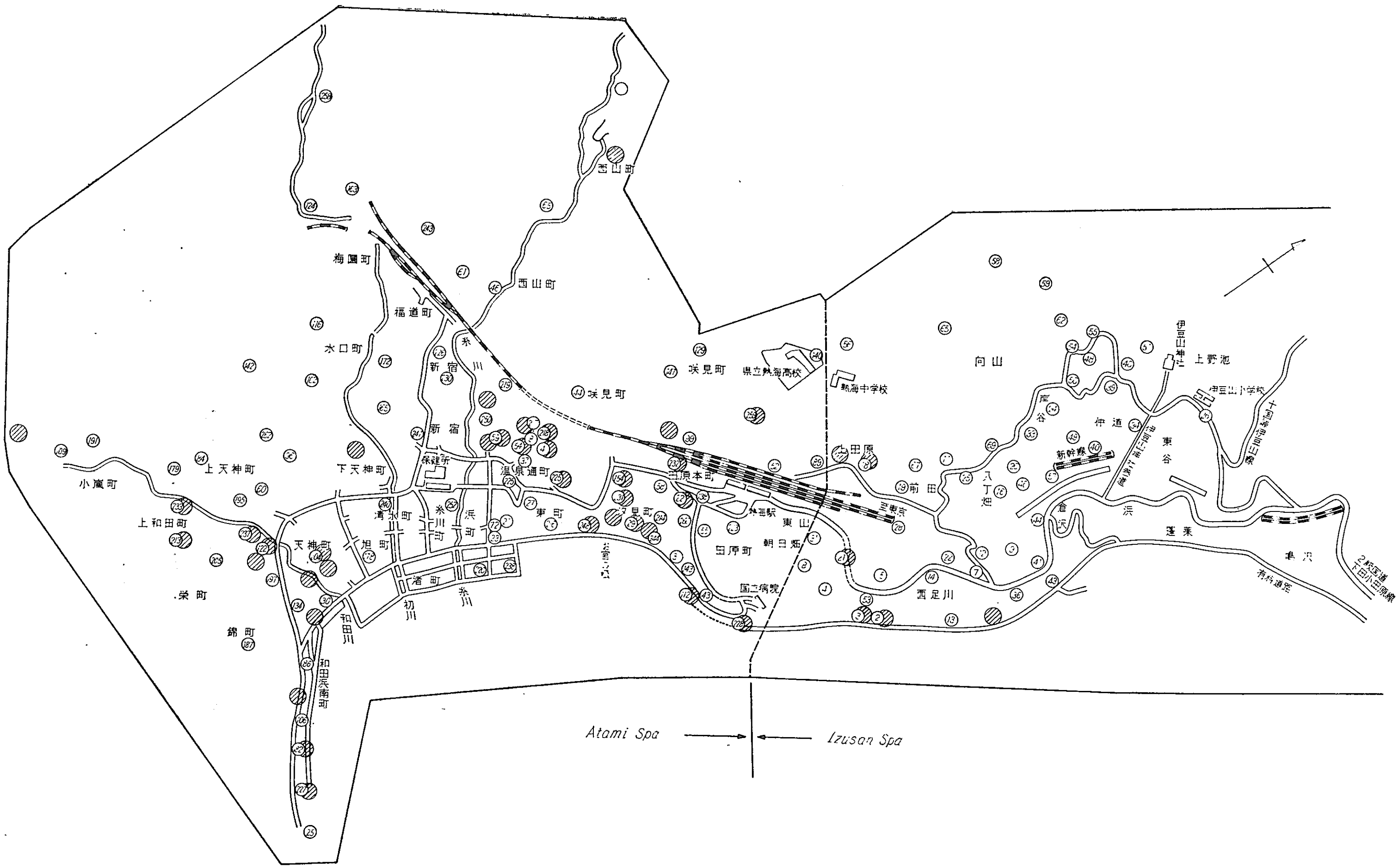

Fig. 20 Distribution map of bore holes with above 100 l/m of discharge

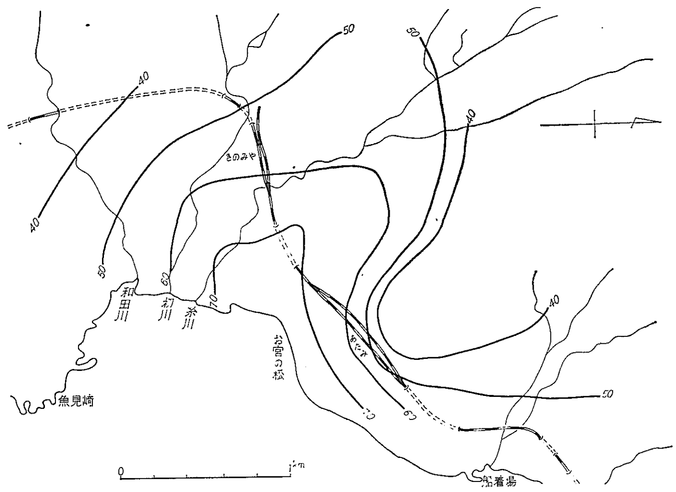

Fig. 21 Distribution map of underground temperature at the depth of 200m (unit : °C)

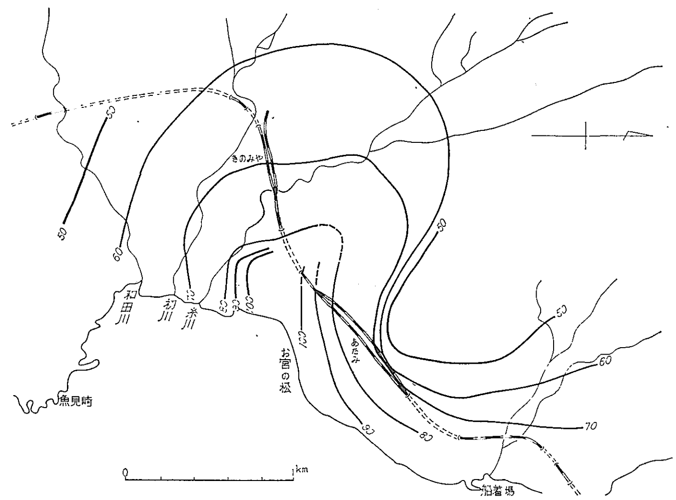

Fig. 22 Distribution map of underground temperature at the depth of 300m (unit : °C)

perature zone trends toward north-east direction along the seacoast of Izusan spa. As conclusion, it can be said that the distribution of high temperature zones coincides with that of structural weak zones in the Atami hotspring area.

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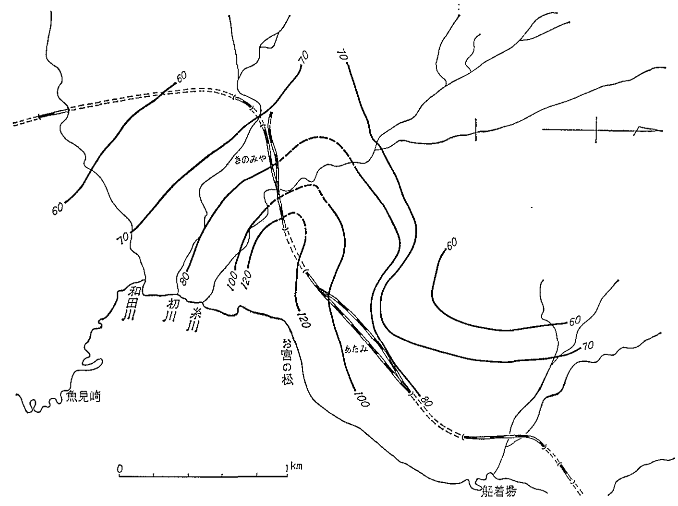

Fig. 23 Distribution map of underground temperature at the depth of 400m (unit : °C)

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熱海温泉の熱水系に関する考察

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要　旨

昭和40年に行なった筆者等の調査の資料と福富孝治教授（昭和11年）および湯原浩三博士（昭和28年～30年）による既存資料を比較すると水温，Cl^- 含量ともに変化が著しく，特に後者は熱海温泉の和田川沿い，伊豆山温泉の海岸に沿って過去30年の間に著しく含量が増大していることが明らかになった。このような水温，Cl^- 含量の変化と SO_4^{2-} の分布から熱海温泉の温泉水は

A　熱水型

B　SO_4^{2-} を含む地下水と熱水との混合型

C　海水と熱水との混合型

とに分けられ，Aの熱水型は大湯を中心とする高温地域，Bのいわば地下水型は高温地域の外側，Cの海水型は上記和田川沿いおよび伊豆山海岸に沿って分布することを指摘した。このうち，熱水型の温泉水も Br^-/Cl^- の比率と I^- 含量の点からみて海水が深部に浸透し，湧出するまでの間に現在の海水の化学成分と異なる形になったものと考えた。

以上の資料と，揚水量 100 l/m 以上の温泉井の分布，さらに地下温度（深度 200～400m）の分布の組合せから，この地域の構造的弱帯の方向について言及した。