The Progress and Process of Salt-Water Encroachment in Itō Hot Spring. I[1] Deterioration of the Spring Resources, Changes in Chemical Composition of Thermal Water and their Relation to Salt-Water Encroachment.

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Summary

Characteristics of salt-water encroachment in Itō hot spring are clarified from the analyses of the changes in chemical components of thermal water and status of the spring resources.

(1) From the chemical contents, the thermal water discharged from Itō hot spring is divided into two groups: one is the $Cl^- > SO_4^{2-}$ type of higher salinity located from the coast to the inland for a considerable distance. The other is a simple thermal of $SO_4^{2-} > Cl^-$ type located in the inland area.

(2) It is found from the analyses of vertical and horizontal distribution of chlorine ion that salt-water encroachment is characterized by the concurrence of the following two phenomena: one is the horizontal extension of the thermal water zone of $Cl^- > SO_4^{2-}$ type, which is revealed by the increase of its content observed in several springs belonging to the unchanged depth group. The ohter is an increase of its content due to the increase in depth of some springs. Chlorine content increase is brought about by withdrawal of deeper thermal water containing a higher content of chlorine ion.

(3) The intrusion of underground water, which is clarified from the decrease of temperature and major components, has been in progress in the inland area.

(4) The intrusion of sea water or underground water has progressed by the drawdown o. the thermal water level which has been caused by the increase of total discharge rate caused by lifting since 1937.

1. Introduction

Itō hot spring is situated on the eastern coast of the neck of Izu peninsula which is projected into the Pacific Ocean in Central Japan. There exist today about 764 hot springs in the town and in the neighboring area, and the spa is both the most famous and the biggest resort in Japan. Though the natural issuing of thermal water in this spa was seen until about 1955, the water level has decreased down below the ground surface as a result of increasing demands for thermal water due to the development of the spa. Since then, exhaustion of the spring resources and its relation to salt-water encroachment have become of a great concern.

The state of the spring resources and the mechanism of formation of thermal water were first investigated from geophysical and geochemical viewpoints by Fukutomi[2] and his coworkers. They reported that the thermal water consisted of three primary sources of entirely different character: the first characterized by high temperature and small amounts of chemical constituents; the second, differing from the preceding in its relatively low temperature, moderate quantity of chloride, sulphate and calcium ions; and the third, the cold underground water. The influence of the ebb and flow of the tide on the chemical composition of the spring water was examined by Kuroda[3] and Nakanishi[4], and it was clarified that the contents of major components decreased

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at full tide (with the increase in flow of thermal water) due to the mixing of underground water.

Kikkawa[5] examined the relationship between chloride-rich thermal water and sea water encroachment and pointed out the effects of the ion exchange function of minerals in the strata on the chemical composition of thermal water. Mashiko and the author[6] have examined the changes of temperature and chemical characteristics of thermal water cuased by the intrusion of sea water and underground water. Recently, surveys on the geology, the nature of the thermal water, and the extent of the water utilization were carried out by the author and coworkers[8] during the period from September to December, 1972.

The present investigation was undertaken to elucidate the mechanism and the extent of the salt-water encroachment by analysing the gradual changes of the spring resources and the nature of the thermal water.

2. The present status of thermal springs

A small stream of Itō-Ōkawa river and its branch called Teradagawa run through the spa town toward the northeast, and at present about 764 thermal springs (all of them are bored wells and 374 are in use) are situated along the two rivers with an area of about 3 square kilometers. Total discharge rate of thermal water with temperature ranging from 25° to 56° is 45200 m^3/day.

From the chemical content, the thermal water discharged from Itō hot springs, which has already been reported by the present author[7], is divided into two groups as shown in Fig. 1: one is the $Cl^- > SO_4^{2-}$ type of higher salinity with the evaporation residue ranging from 0.46 to 22 g/l. Springs of this type are found from the coast to the inland for a considerable distance. Chemical characteristics of these thermal waters show that they are common salt springs, simple thermals, and calcium chloride springs. The other is a simple thermal of the $SO_4^{2-} > Cl^-$ type containing sodium ion as major cation constituents. Thermal springs of this type are located in the inland area, and their temperature is higher than those of the $Cl^- > SO_4^{2-}$ type.

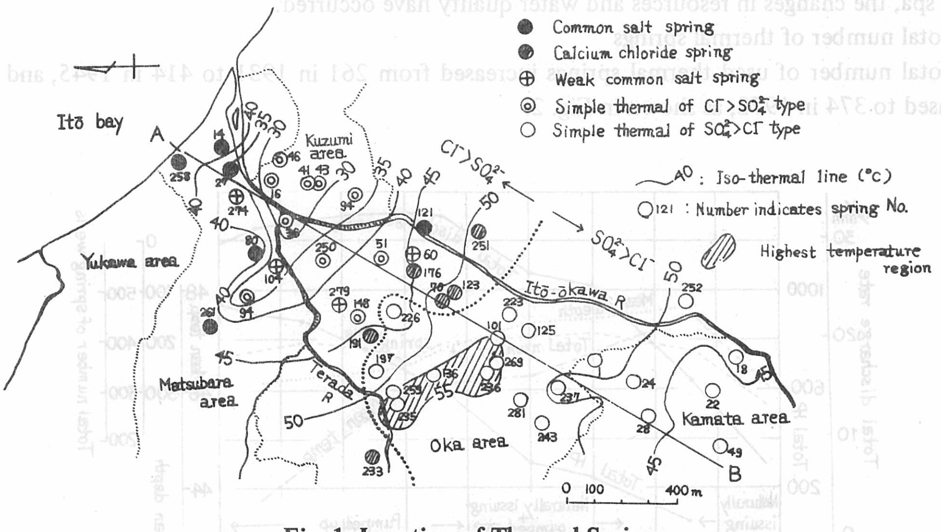

Fig. 1 Location of Thermal Springs

Calcium chloride springs are found in the contact zone of the two types of thermal water.

The orifice temperature measured in 1972 are also shown in Table 1. The maximum temperature is 56° at No. O-236 spring, and simple thermals above 55° are located in the inland area "Oka Area".

Geology[8] of the surroundings of Itō spa consists of alluvial deposits, quaternary volcanic products (Ōmuro and Usami volcanic products etc.), tertiary volcanic rocks (Shiofukizaki basalts, Jōyama decites etc.), and Yugashima formation. The basement in this area is Yugashima formation which consists of basaltic and andestic lavas and their tuffbreccia. The formation crops out only on the western area of Itō-Ōkawa river and subsides in its eastern part.

It is pointed out from the results of a survey in 1972 that some tectonic lines such as faults, weak zones and dykes have a close relation with the location and issuing of thermal water: 1) faults in the NS direction along Ito-Ōkawa river; 2) a weak zone which can be suggested by the linear distribution of small creater hollows in the NWW-SEE direction; 3) andestic dyke situated in the upper stream of Terada river.

The thermal water in Itō hot spring is originally of the $SO_4^{2-} > Cl^-$ type characterized by low salinity and high temperature, which may be flowing and reserved in the horizontal aquifer after ascending from the deep through the faults and the weak zone in the southern part of the Oka Area. It is probable that the thermal water has its source in Yugashima formation.

The majority of thermal springs are distributed on the alluvial plain of Itō-Ōkawa and Terada rivers. The thickness of the alluvial deposit, which may have close relation with the intrusion of underground water in the later chapter, is deep in the coastal area and shallow in the upper stream of Itō-Ōkawa river.

It was reported by Kikkawa[5], Mashiko and writer[6] that the thermal water of the $Cl^- > SO_4^{2-}$ type is formed by intrusion of sea water into the thermal water of the $SO_4^{2-} > Cl^-$ type.

3. The changes in spring resources

More than 50 years ago, in the whole town of Itō there were more than 260 naturallly issuing springs. Since then, however, with increasing demands for thermal water due to the development of the spa, the changes in resources and water quality have occurred.

3.1 Total number of thermal springs

Total number of used thermal springs increased from 261 in 1931 to 414 in 1945, and then decreased to 374 in 1972, as shown in Fig. 2.

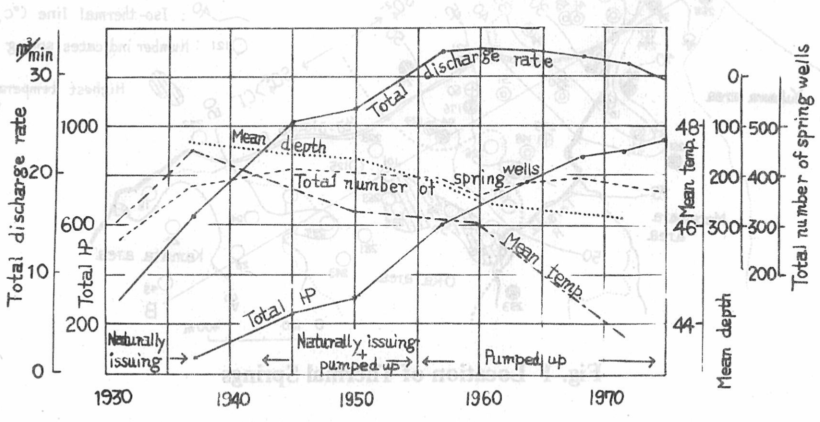

Fig. 2 Changes in Thermal Water Resources

The majority of the used springs were distributed in the coastal region of Matsubara, Yukawa, and Kuzumi Areas from 1930 to 1945. However, with the development of the spa, springs (bored wells) have spread to the inland area "Oka and Kamata Areas", where the springs of higher temperature are found. At present, about 55% of the total number of used springs are distributed in the Oka and Kamata Areas.

3.2 Depth of spring wells

The depth tends to become deeper with the lapse of years. The maximum depth in 1931 was 270m in No. Y-15 spring (in the Yukawa Area), and in 1972, it is 800m in No. O-132 spring (in the Oka Area). The change in mean depth is shown in Fig. 2. At present, it is seen from Fig. 6 that the farther the distance from the coast the greater the depth of the well. As it seems that the depth of hot springs indicates approximately the depth of the source of the hot water, it may be interesting to know their changes. Increase of depth suggests the increase of the withdrawal of thermal water from deeper reservoirs rich in chlorine ion as discussed later.

3.3 Withdrawal of thermal water

Since the withdrawal of thermal water from the wells by pumping began in 1937, the total number of naturally issuing springs has decreased. Pumps of turbine and airlift types have been generally used. The total horse power of pumping has increased since 1937 as shown in Fig. 2. In 1972, the maximum horse power is 15 HP at No. O-246 spring, but as a general rule in Itō spa, the power is controlled under 5 HP. About 60% of total amount of thermal water is withdrawn by pumping from the springs in the Oka and Kuzumi Areas.

3-4 Thermal water level

The gradual drawdown of thermal water level due to the increase of total discharge rate by lifting has been proved from the decrease in the number of naturally issuing springs. According to Fukutomi[2)], thermal water level in 1936 was above the ground surface, and then the gradual drawdown of the level has been caused by the development of the spa. The average annual draw-down of depth was 0.14m from 1936 to 1955, and 0.57m from 1955 to 1972. At present, the mean level of thermal water is about 25m under the ground surface.

3.5 Orifice temperature of thermal water

The changes in orifice temperature of thermal water examined for 31 samples are shown in Table 1. These results are summarized as follows;

1) Decrease: 18 springs (M-14, M-27, M-94, M-104, M-145, M-258, S-16, S-41, S-46, S-94, O-36, O-121, O-123, O-197, O-250, O-251, O-279, O-60)
2) Decrease following increase: 2 springs (M-274, O-148)
3) Increase: 5 springs (M-9, O-124, O-223, O-236, O-259)
4) Increase following decrease: 1 spring (O-70)
5) Nearly constant: 5 springs (M-261, O-101, O-125, O-237, O-269)

From the above changes, thermal springs are divided into two groups. The first is the group of temperature decrease (1) and 2)) which is distributed in the area (Kuzumi, Matsubara, and northern part of Oka Area) from the coast to the inland for a considerable distance as shown in Fig. 3. Thermal waters of this group belong to the $Cl^- > SO_4^{2-}$ type. The other is the group located in the Oka Area, which shows increase or nearly constant temperature.

It is well known that the shift of iso-thermal line indicates the regional change of temperature. In Ito spa, the 45° iso-thermal line A situated in the coastal area shifted to the inland area from 1936 to 1972 as shown by an arrow in Fig. 4. Line B in the inland area shifted in a northern direction. Namely, the high temperature area was larger than the present one about 30 years ago. This phenomenon suggests narrowing of the high temperature region and enlargement of the low

Table 1 Changes in Depth, Orifice Temperature, and Three Anions

Spring No.	Years	Depth (m)	Temp. (℃)	Three Anions Cl^-	SO_4^{2-}	(mg/l) HCO_3^-
M−9	1952	157.4	42.7	4034	737.8	87.5
	1961	167.5	43.2	5810	711.8	69.9
M−14	1952	213.5	43.0	6672	1169	129
	1961			7056	1226	113
	1972	226	42.0	6425	1132	107
M−27	1936	78	44.0	2950	711	61
	1961	87.8		1387		
	1972	88	35.0	5877	755.1	62.5
M−72	1952	87.8		2905	771	
	1961	197	43.0	5652	1237	
M−94	1952	215	43.0	306.5	286.4	58.1
	1961	227.8	37.5	247.6	201.6	73.2
	1972	228	33.0	289.1	133.3	76.5
M−104	1952	290	49.0	2244	567.8	63.8
	1972	300	34.0	1146	401	89.5
M−145	1952	290	46.0	7034	1171	
	1961	300	38.0	2964	638	
M−258	1952	148	43.0	6785	1160	88.7
	1961	158.8	41.5	7843	1276	107
	1972	186	42.0	10586	1383	76.8
M−261	1952	368	42.0	4249	810.8	65
	1972	380	42.0	8863	1117	52.2
M−274	1936	91	38.2	1470	418	61.0
	1961	122	43.5	275.7		
	1972	122	37.5	1738	399.2	82.3
S−16	1936	63	44.8	1815	495	57.3
	1952	52.7	40.5	423	234.3	67.6
	1961	63.6	32.0	105.8	83.1	90.0
	1972	67	28.0	262.8	120.2	61.4
S−41	1936	64	48.4	865	413	37.8
	1961	244	30.5	189.3		76.6
	1972			220.5	90.5	63.3
S−46	1936	82	44.8	2668	632	67.1
	1952	72.6	42.7	753.8	317.6	67.7
	1961		34.0	228.6	125.1	
	1972	83	25.0	116.8	70.0	67.8
S−94	1952	190	47.8	3998	830.4	81
	1961	200	36.0	287.2	132.5	66.6
	1972	200	33.0	226.3	121	73.9

Spring No.	Years	Depth (m)	Temp. (℃)	Three Anions		(mg/l)
				Cl^-	SO_4^{2-}	HCO_3^-
O−6	1952	144	44.0	5341		
	1961	165		677.3		
O−36	1952	77.5	47.3	1319	436.2	62.8
	1961	94.5	42.0	79	298.3	41.3
	1972	95	28.0	270	125.1	73.9
O−60	1961	550	50	2080	259.2	49.9
	1972	550	46	1662	425.1	60.8
O−70	1936	91	53.0	88	316	28.0
	1952	75.9	49.5		332.9	70.7
	1972	600	54.0	2858	574.5	25.6
O−101	1961	450	55.0	72.6	353.1	40.0
	1972	450	55.0	65.7	232.9	40.1
O−121	1961	600	52.2	8467	1179	36.6
	1972	600	49.0	10133	1189	53.9
O−123	1961	473	52.8	361.7		36.6
	1972	473	50.0	1825		28.9
O−124	1952	398	25.0	78.5	369.6	55.1
	1961	394	53.5	70.5	351.4	40.0
O−125	1952	160	55.0	75.6	351.4	57.
	1961	446	55.0	72.0	347.4	33.3
	1972	466	55.0	94.9	381	28.3
O−148	1952	107.3	51.8	133.8	351.7	56.1
	1961	127.3	53.0	502	344.8	36.6
	1972	154	44.0	251	192.6	48.9
O−191	1936	190	49.0	88		
	1961			377.3		
	1972			386.9		
O−197	1952	91.8	51.0	957.1	351.2	51.6
	1961	672	49.0	422.6	242.8	46.6
	1972	672	48.0	113.2	350.3	38.4
O−223	1961		54.0	73.8		
	1972	500	54.5	80.3		
O−236	1952	218	55.0	72.6	372	47.9
	1961	233	55.5	73.2		
	1972	233	56.0	80.3	386.8	40.2
O−237	1952	237	49.8	73.7	331.6	48.
	1961	337		56.0	163.8	
	1972	377	49.5	29.2	108.6	55.8
O−250	1952	84.2	51.0	102.2	340.7	54.2
	1961	97.2	48.5	214.9	228.8	46.6

Spring No.	Years	Depth (m)	Temp. (℃)	Three Anions (mg/l) Cl⁻	SO₄²⁻	HCO₃⁻
	1972	97	40.5	262.8	129	19.9
O−251	1961	476.5	52.4	405.6		33.3
	1972	600	51.0	1679		42.6
O−259	1952	27.6	52.3	72.4	360.4	49.7
	1962	286	55.0	201.4	372	27.4
O−269	1952	195.4	56.0	77.0	354.8	57.6
	1972	250	56.0	80.3	365.4	28.4
O−279	1952	240	49.7	99.6	340.6	53.4
	1961	250	49.9	1108	208.2	46.6
	1972	250	42.5	730.1	187.6	59.7
K−1	1936			59.1		
	1972	602	52.5	46.7		
K−22	1936	113	45.2	68	258	26.8
	1972			43.8	176.1	37.8

M, Matsubara area; S, Kuzumi area; O, Oka area; K, Kamata area

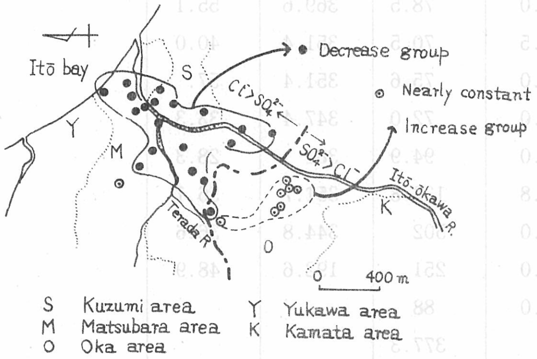

Fig. 3 Change in Orifice Temperature

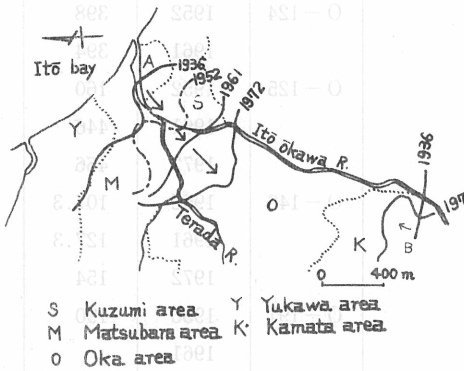

Fig. 4 Change of the 45° Iso-thermal Line

temperature region with the lapse of years.

The change of mean temperature defined by the following equation has been often used in the examination[8)] of exhaustion of the srping resources and its relation to overlifting.

$$T = (T_1 \cdot Q_1 + T_2 \cdot Q_2 + T_3 \cdot Q_3 + \ldots\ldots)/(Q_1 + Q_2 + Q_3 + \ldots\ldots)$$

where T shows the mean temperature of the Itō spring, T_1 T_2, ... show the orifice temperatures of a spring, and Q_1, Q_2, ... , the amounts of flow of a spring.

The mean temperature, as shown in Fig. 2, increased from 1931 to 1937, and then decreased gradually. The decrease of temperature has been caused by intrusion of sea water and underground water as a result of excessive withdrawal.

3.6 Total discharge rate

The total discharge rate, as shown in Fig. 2, had increased from 7.57 m^3/min in 1931 to 32.5 m^3/min in 1957, and then decreased to 31.4 m^3/min in 1972. The increase of the total discharge rate is mainly caused by pumping since 1937. The slight decrease in the total discharge rate during the last decade is due to the legal control on lifting of thermal water.

4. Changes in the contents of chlorine, sulphate, and bicarbonate ions

Analytical results of major components of thermal water have been reported by Fukutomi[2], Mashiko and the writer[6),7)]. The changes in the contents of three anions obtained by rearranging their data are shown in Table 1. The changes of three anions are summarized as follows;

(1) Chlorine ion

Increase: 14 springs (M-9, M-72, M-258, M-261, O-70, O-121, O-123, O-191, O-223, O-236, O-250, O-251, O-259, O-269)

Increase following decrease: 7 springs (M-27, M-94, M-274, S-16, S-41, O-36, O-125)

Decrease: 12 springs (M-104, M-145, S-46, S-94, O-6, O-60, O-101, O-124, O-197, O-237, K-1, K-22)

Decrease following increase: 3 springs (M-14, O-148, O-279)

(2) Sulphate ion

Increase: 9 springs (M-27, M-72, M-258, M-261, O-60, O-70, O-236, O-259, O-269)

Increase following decrease: 3 springs (S-16, O-125, O-197)

Decrease: 16 springs (M-9, M-94, M-104, M-145, M-274, S-41, S-46, S-94, O-36, O-101, O-124, O-148, O-237, O-250, O-279, K-22)

Decrease following increase: 1 spring (M-14)

Nearly constant: 1 spring (O-121)

(3) Bicarboate ion

Increase: 9 springs (M-27, M-94, M-104, M-274, O-60, O-121, O-237, O-251, K-22)

Increase following decrease: 4 springs (S-94, O-36, O-148, O-279)

Decrease: 11 springs (M-9, M-14, M-261, O-123, O-124, O-125, O-197, O-236, O-250, O-259, O-269)

Decrease following increase: 4 springs (M-258, S-16, S-41, O-70)

Nearly constant: 2 springs (S-46, O-101)

From the above changes, the following facts are revealed: 1) thermal springs which show an increase in chlorine content belong to the $Cl^- > SO_4^{2-}$ type, and their sulphate contents increase with chlorine contents in many cases; 2) bicarbonate ion decreases in the thermal springs which show an increase in both chlorine and sulphate contents.

It is extremely interesting to point out that the change of the regional distribution of the two types of thermal water – $Cl^- > SO_4^{2-}$ and $SO_4^{2-} > Cl^-$ – was accompanied by an increase of total discharge rate. Fig. 5 shows the marked changes in the regional distribution of the two types of thermal water from 1937 to 1972. In the past the area of the $Cl^- > SO_4^{2-}$ type springs was narrower than the present one. In other words, the distribution area of the $Cl^- > SO_4^{2-}$ type has extended farther to the inland. The contact zone of the two types of thermal water situated at the coastal area in 1937 has moved toward inland, and the zone, in 1972, was situated in the central part of the Oka Area as shown in Fig. 5.

The change in vertical distribution of chlorine contents is a particularly significant problem for elucidating the mechanism of salt-water encroachment. The changes in vertical distribution from 1936 to 1972 are illustrated in Fig. 6, showing the aquifer cross-section in the NE-SW direction along Itō-Ōkawa river. Iso-chlorine lines are drawn with the assumption that the chlorine content of the thermal water sampled at the orifice of the well is the same with that of the thermal water at the bottom of the well, and that the dilution by underground water due to

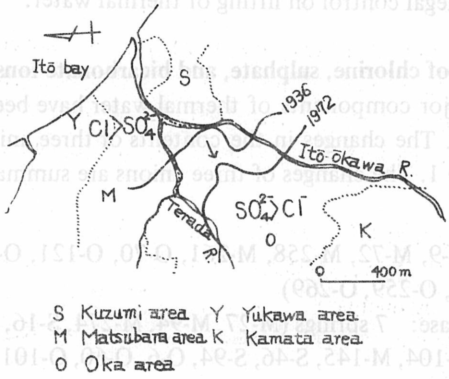

Fig. 5 Change in the Distribution of Thermal Water of Two Types – $Cl^- > SO_4^{2-}$ and $SO_4^{2-} > Cl$

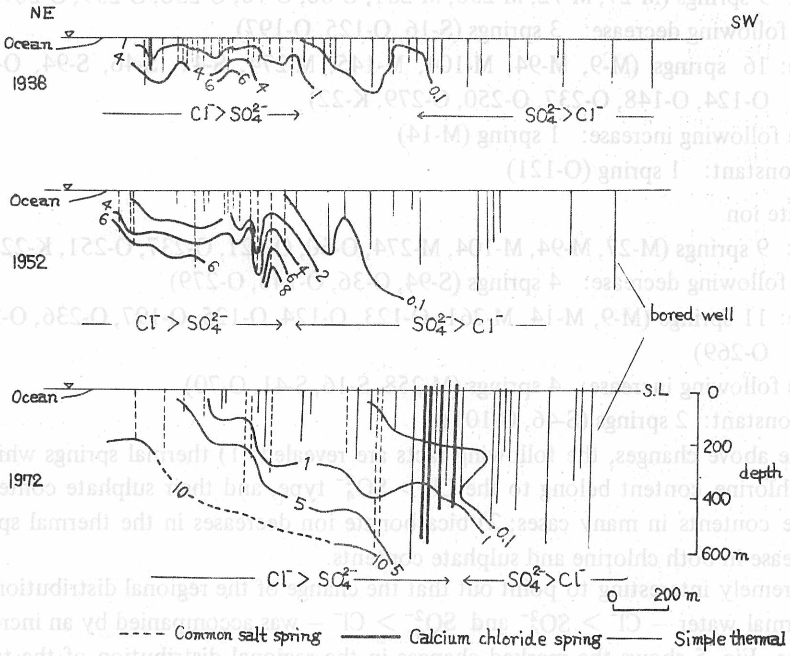

Fig. 6 Vertical Distribution of Chlorine Ion Contents

the breakdown of casing pipes is negligible.

The following facts are revealed from the changes in the vertical distribution: 1) The maximum content of chlorine ion has increased from 1936 to 1972 as the depth of the wells has become deeper; 2) the contact zone of the two types of thermal water tends to move farther to the inland with the lapse of years; 3) iso-chlorine content lines seem to show stratiform with the lapse of years, and in 1972, it was deduced that thermal-salt water interface (contact surface) slopes downward from the coast; 4) the intruded salt-water edge has reached farther inland with years (the intruded salt-water edge, which was about 700m from the coast at the depth of 200m in

1936, was about 1200m from the coast at the depth of 650m in 1972). It is to be concluded from these results that the salt-water encroachment is characterized by the concurrence of the following two phenomena: one is the horizontal extension of the thermal water zone of the $Cl^- > SO_4^{2-}$ type, which is revealed by the increase of chlorine content in such springs belonging to the unchanged-depth group as M-27, M-261, M-274, O-36, O-70, O-121, O-123, O-250. The other is an increase of chlorine content due to the increase in depth of some springs such as M-72, M-258, O-70, O-251. The chlorine content increase is brought about by withdrawal of deeper thermal water containing a higher content of chlorine ion.

It is noteworthy that the salt-water encroachment has progressed with the increase in the total discharge rate of thermal water, especially with the withdrawal by pumping since 1937. Wherever overdraft conditions occur in coastal aquifer connected to the ocean, sea water intrusion can result. Excessive withdrawal of thermal water leads to the progress of sea water encroachment whenever thermal water level falls below the sea water level. In Itō spa, however, this is not the only cause of the salt-water encroachment. Another important factor is excessive withdrawal of chlorine-rich thermal water from the deeper strate.

The other undesirable phenomena similar to salt-water encroachment is the intrusion of underground water which was caused by excessive withdrawal. In the previous report[7], the degree of mixing sea water and underground water with the original thermal water was calculated with an assumption that the thermal waters were mixtures of the original thermal water of the $SO_4^{2-} > Cl^-$ type, underground water, and sea water. It is clear from the distribution of the degree of mixing of underground water that intrusion of underground water has been in progress in the area surrounding the confluence of Itō-Ōkawa and Terada rivers.

The following facts in regard to the intrusion of underground water are clarified from analyses of the changes in chlorine, sulphate, and bicarbonate ions.

(1) Thermal springs such as M-104, M-145, S-16, S-41, S-46, O-101, O-124, O-237, K-22 show a decrease in both chlorine and sulphate ion content, and some of them, for example M-104, S-16, S-41, S-46, etc., located in the area surrounding the confluence of two rivers above mentioned show a decrease in temperature and an increase in bicarbonate ion. This phenomenon may be caused by intrusion of underground water of the bicarbonate-rich type.

(2) A few springs of high temperature located in the inland area such as O-101, O-236, O-269 show slight changes in chlorine , sulphate and bicarbonate ions and temperature as shown in Table 1. Some springs in the Kamata Area which is located in the western part of the high temperature region show high mixing ratios of underground water as reported by the author[7]. It is deduced from these facts that intrusion of underground water has progressed in the area except in the high temperature region.

5. Conclusion

Changes in the chemical components of thermal water and status of the spring resources are investigated, and the following results are obtained.

(1) Changes in the status of spring wells

In Itō hot spring, marked changes in the status of spring wells have occurred since 1937 because of the increase in demands for thermal water due to the development of the spa. Main phenomena are as follows:

a) Increase in the total number of spring wells (bored wells);

b) Increase in the depth of the wells

c) Decrease of naturally issuing springs by the drawdown of the thermal water level which has been caused by the increase in total discharge rate by lifting.

d) Lowering of temperature is observed in many springs located in the area from the coast toward inland. Shifting of the 45° iso-thermal line suggests the narrowing of the high temperature region and enlargement of the low temperature region.

Characteristic phenomena which have occurred with the changes of the status of spring wells are salt-water cnroachment and underground water intrusion.

(2) Changes of chemical characteristics

Changes of chemical characteristics of thermal water caused by the intrusion of sea water or underground water are examined by comparing the analytical results of chlorine, sulphate and bicarbonate ions obtained in 1936, 1952, and 1972.

a) The degree of sea water intrusion is obtained from the increase of chlorine ion content. It is clear from the analyses of horizontal and vertical distribution of chlorine ion that the salt-water encroachment is characterized by the concurrence of the following two phenomena: one is that the horizontal extension of the thermal water zone of the $Cl^- > SO_4^{2-}$ type in the coastal region has occurred toward the inland area; the other is an increase of chlorine content due to the increase in depth of springs. The chlorine content increase is brought about by the withdrawal of deeper thermal water containing a higher content of chlorine ion.

b) Intrusion of underground water has progressed in thermal springs of the inland area except for a few springs of high temperature. This phenomenon is characterized by the decrease in temperature and contents of chlorine and sulphate ions, and by the increase of bicarbonate ion.

Changes in chemical characteristics of thermal water by the intrusion of sea water or underground water are closely connected with the drawdown of the water level caused by the excessive withdrawal of thermal water.

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伊東温泉における塩水化の進展と機構
その１　温泉水の湧出状況，化学成分の変化と塩水化現象との関係

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要　旨

伊東温泉における塩水化現象の特徴を，湧出状況と化学成分の変化の解析から明らかにすることができた．

(1) 温泉水の化学的タイプは２種類に大別される．１つは海岸から内陸にかけて分布している$Cl^- > SO_4^{2-}$型，他は内陸に分布している$SO_4^{2-} > Cl^-$型の単純温泉である．

(2) 塩素イオンの水平及び垂直分布から，塩水化現象は次の二つの現象が共存している点に特徴がある．１つは$Cl^- > SO_4^{2-}$型温泉水が内陸方向へ広がってきた点で，これは深度が変わらない源泉におけるCl^-の増加としてとらえられた．他はより深層のCl^-に富んだ温泉水の揚水が増加したことからくるCl^-の変化である．

(3) 温度や主要成分の減少から明らかにされた地下水の浸入は内陸地域で進展する傾向にある．

(4) 海水や地下水の浸入は，1937年以来動力による総採取量の増加による温泉水位の低下によって進展したものである．