On the Salinities and Overdraft Conditions in Itō Thermal Springs

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§1. Introduction.

Itō Thermal Springs, Shizuoka Prefecture, are now in critical situation owing to their reckless overdrafts to meet great demands of thermal water. It is most important in such coastal spring areas to clarify the relation between the salinity of thermal spring and the sea water. Some measurements were made in Aug. 1952 and compared with the results obtained by Dr. K. Fukutomi in Aug. 1936[1)2)] which involved detailed measurements and discussions on the water systems forming Itō Thermal Springs with their mixtures.

§2. Measurements.

Among all of Itō Thermal Springs, we picked up 120 wells distributed in the whole area for the observation, of which only 91 springs coincided with those observed by Dr. Fukutomi. The measurements of water temperature and samplings of water were performed after several minutes since pumpings began, when temperatures were found to reach their maximum. Waters were analysed to determine their Cl' and HCO_3' contents. The results of measurements are all tabulated in Table 3 at the end of this paper.

The tidal effects on temperatures or chemical compositions can be neglected because their amplitudes were smaller than 0.5°C of temperature or 1/30 of chlorine content as observed by Dr. K. Kuroda.[3)]

§3. General Aspects.

Data preserved in the Thermal Springs Association show the progressive increase of the total number of springs from 487 in 1926 to 776 in 1952. Wells which actually discharge the thermal water are 277 in 1926 and 404 in 1952. Almost of them now rely on pump-lift, while natural flow can be seen in only several springs, The strongest pumpage have 10 H.P..

These extreme developments may follow the declining conditions of thermal springs which can be also conceived by the next example.

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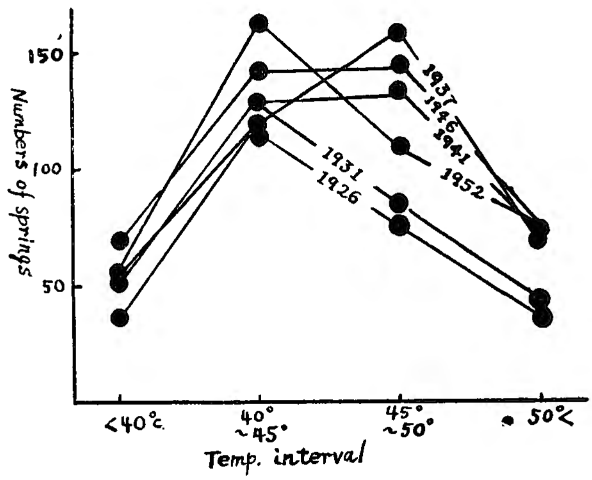
The total range of spring temperature is divided into four intervals such as lower than 40°, from 40° to 45°, from 45° to 50° and higher than 50°C, and the number of springs belonging to each interval is shown in Fig. 1 for the last 27 years. Water temperatures increased to the highest state in 1937 owing to the new bore-holes or heavy drafts but, since then, some of the springs belonging between 45° and 50° tended to be removed to the lower interval despite of the continued developments of spring areas and this tendency was accelerated after the war to the present state which is similar as in 1926.

Fig. 1. The variations of the numbers of springs in each temperature interval for the last 27 years.



Geographical distributions of water temperature, Cl′ and HCO_3' contents measured in 1952 are given by Figs. 2,3 and 4. It appears that temperature is gradually lowered from the upper inland parts toward the coast and the concentrations of chemical elements are on the contrary. These states are similar as in 1936.

Fukutomi and Fujii showed by the graphical analysises of mutual relations among water temperature and the concentrations of chemical elements that Itō Thermal Springs were formed by the mixtures of two kinds of thermal waters and two kinds of cold ground waters. The present author found the same result by the similar treatments with respect to the new data of temperature, Cl′ and HCO_3' contents. Therefore, it may be proper to say that apparent changes have not been taken place in the water systems.

In order to compare the water temperature, Fig. 5 shows the distributions of the difference between observed values in 1952 and in 1936. Consi-

Fig. 2. Geographical distribution of spring temperature observed in 1952. Dots show the places of observed springs.

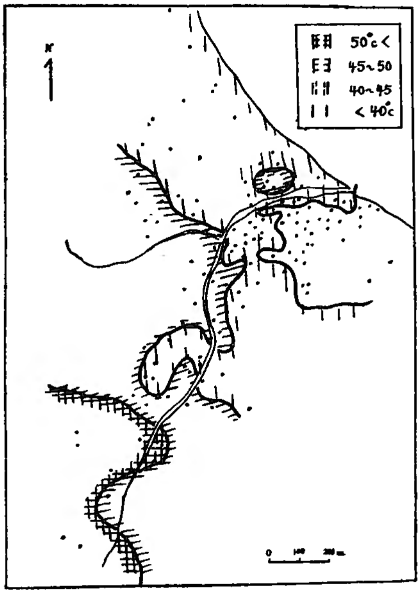


Fig. 3. Geographical distribution of Cl' contents observed in 1952.

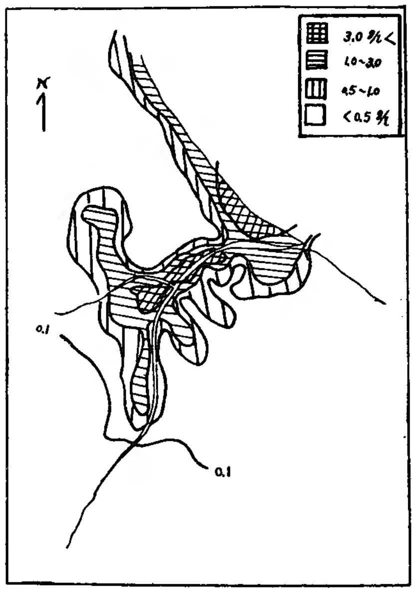
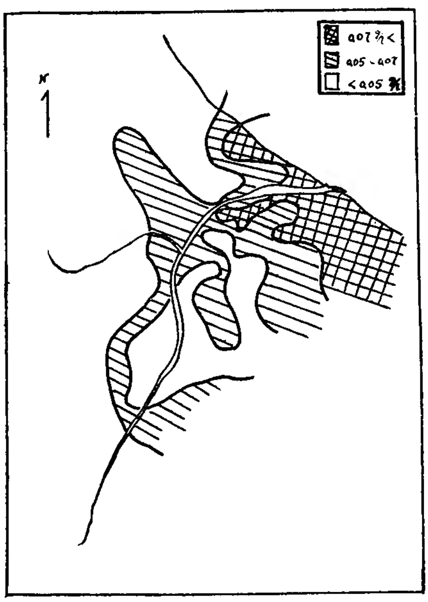


Fig. 4. Geographical distribution of HCO'_3 contents observed in 1952.



derable lowerings of temperature are found in almost whole area. The distribution of the ratio of the Ci′ content in 1952 to in 1936 for each spring is also given by Fig. 6. The areas having been rich in chlorine show the still more increase in general, but some decreases appear in both sides of this central part, where the greatest mixing ratios of ground water were shown in the past and lowerings of temperature now amount to more than 5°C. Probable explanation on these decreases is the dilution by the ground water which is intensified with the lowering of thermal water pressure.

The areas of large salinities are found from Fig. 6 to be spread toward upper parts along the river.

Fig. 5. Geographical distribution of the deviations of temperature observed in 1952 from those in 1936.

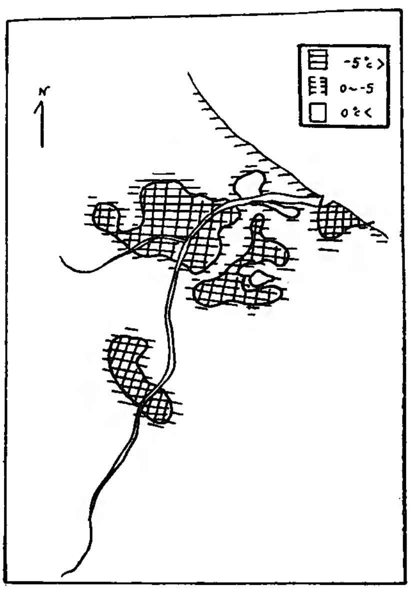
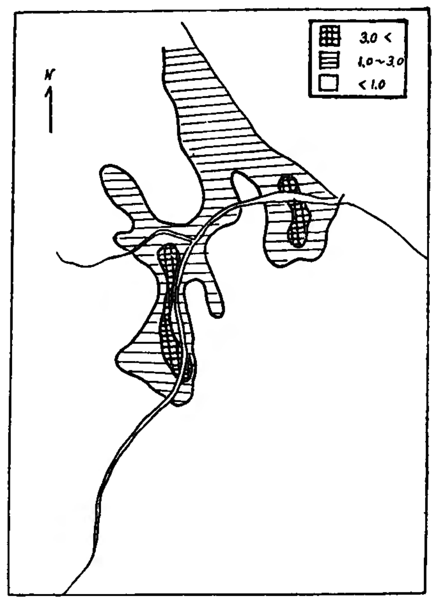


Fig. 6. Geographical distribution of the ratios of Cl' content observed in 1952 to those in 1926.



§4, Salinity of Thermal Water.

Itō Thermal Springs contain large amounts of chlorine especially along the lower parts of the river, the greatest of which among our measurements is 6.52 g/l.

It is interesting to research the origine of these large salinities, on which Fukutomi surmised some effects of the sea water. In order to trace this problem, we try to investigate as follows using the data analysed chemically by the Central Institute of Thermal Springs in 1952.

Proportional amounts of chief chemical constituents to chlorine contained in some saline thermal springs are compared in Table 1 with those in the sea water which are taken as almost constant in general.

Table 1. The ratios between the concenentrations of chief constituents and chloirne.

	Cl' content g/l	Na/Cl ×100	SO_4/Cl ×100	Mg/Cl ×100	Ca/Cl ×100	K/Cl ×100
Thermal Springs.	8.964	51.2	16.5	4.9	9.8	1.3
	7.0338	54.	16.6	5.24	7.72	0.92
	5.341	56.2	17.6	2.1	10.0	1.7
Sea-Water	....	55.3	14.	7.	2.16	2.0

Well agreements are found with sea water, except some discrepancies in cations which have often been noticed in other spring areas[4] undoubtedly contaminated by the sea water. Then, it is properly concluded that the large salinities in Itō Springs are originated principally in the sea-salts.

With respect to the small discrepancies in the cations, some explanation is tried in the next section.

§5. Cation Exchange in the Aquifer.

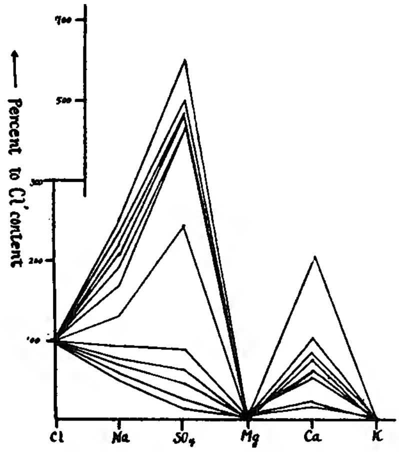
Among three water systems of A, B and C which compose Itō Thermal Springs, A is taken to have the same chemical composition as the sea water. In order to analyse the mixtures of three waters, it is very difficult and involves probable errors to use the absolute concentrations of elements.

Then, our treatments are founded on the proportional amounts of chief elements to Cl′ content in each spring,[5] so that we can discuss the mixtures of only two waters, A and B, by excluding the effects of ground water. These treatments are possible only under the assumption of negligiblly small chemical concentration of mixed ground water named C, which was also supported by Fukutomi's results.

The chemical character of each spring given by the abovementioned method is shown in Fig. 7, from which we take the character of B as follows.

Cl′ content	Na/Cl	SO_4/Cl	Mg/Cl	Ca/Cl	K/Cl
0.0571 g/l	0.146	0.351	0.0022	0.064	0.0016

Fig. 7. Proporional concentrations of chief constituents to Cl' contents. (From the chemical analysises by the Central Institute of Thermal Springs.)



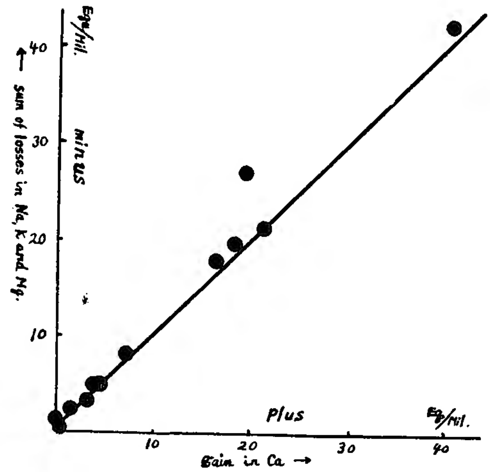
Then, we obtain the chemical compositions of hypothetical mixtures of water A and B in such proportions that their values of SO_4/Cl are equivalent to those of observed waters. The differences in equivalent per million between the hypothetical and the actual contents of the cations are computed for twelve springs which have larger Cl′ contents than 1 g/l. Deviations in calcium concentrations are positive, while deviations in magnesium and sodium concentrations are negative for almost all springs given in Table 2, and the gain in Ca is approximately equal to the sum of the losses in Mg, Na and K as shown in Fig. 8, in which plotted points are found to de distributed along the line being at 45°.

Table 2. Deviations of cation concentrations from computed values. (Equivalents per million)

Na+K,	Mg,	Sum of Na, K, Mg	Ca,	Cl', content g/l
-24.61	-17.7	-42.3	40.3	8.964
- 8.93	-10.84	-19.77	18.3	7.0338
- 4.67	-12.94	-17.63	16.2	6.785
- 5.37	-21.4	-26.7	19.2	5.341
-16.8	- 4.5	-21.3	21.3	4.249
- 0.41	- 7.66	- 8.07	7.06	4.034
1.4	- 3.62	- 2.22	1.4	3.998
- 4.11	- 0.54	- 4.65	3.82	2.249
- 3.61	- 1.22	- 4.83	4.66	2.908
2.18	- 3.16	- 1.08	0.	2.096
0.	3.1	- 3.1	3.1	1.635
2.76	- 2.5	- 0.26	0.26	1.3197

It is probable to say that, in Itō Springs, sea-water contamination follows cation-exchange which takes place between Mg, Na and K ions in the water-mixtures and Ca ions adsorbed in the aquifer, as already found by S. K. Love in the Miami Area, U. S. A.[6].

Fig. 8, The relations between the gain of Ca and the sum of losses of Na, K and Mg.



§6. Summary.

In Itō Thermal Springs, heavy drafts follow the progressive lowerings of thermal water pressure and spring temperature. The geographical distributions of spring temperature, Cl' and HCO_3' contents observed in 1952 show no great changes in their tendencies compared with those in 1936. Area having large Cl' content is spread toward the upper parts and the amounts of mixed ground water are increased in both sides along the river.

Large salinities in Itō Thermal Springs are considered to be originated in the sea water, which composes the thermal water with the primary hot water from upper inland parts and the cold ground water.

Cation-exchanges are taken place in the salt-contaminated aquifer.

§7. Acknowledgment.

Greatfull acknowledgments are made to Dr. K. Seno for his guidance and to the Itō Municipal Office and Thermal Springs Association for their helpful cooperations.

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伊東溫泉の含塩量と過剰揚水について （抄録）

吉　川　恭　三

1952年８月に伊東溫泉全域にわたる120口の湧出口で泉溫、Cl' 及び HCO_3' 含有量の測定が行われ、其等の地理的分布の状況が1936年福富氏の調査当時と余り変化していないことが知られた。ただし泉溫は全体としてかなり低下して居り、この低下の状況が溫泉組合から提供された過去27年間の資料からも明かにされた。Cl'含有量の極大部が川に沿い上流部えやや拡大して居り、同時に地下水混入の増加によるCl'減少地域がその両側にあらわれている。之等の現象はすべて過剰揚水に伴つて起つたものと推定された。伊東溫泉の大きい塩分含有量は川の下流地域からの海水と相似の化学組成をもつた水系との混合から説明され、之は海水の侵入と同時に其等の混合水と層との間に陽イオン交換が起つているものとして解釈される。

Table 3. Spring temperature, Cl' and HCO_3' contents in Itō Thermal Springs. (Aug. 1952.)

Spring Number	Temp. °C.	Cl' g/l.	HCO_3' g/l.
Kusumi			
3	43.5	6.39	0.130
4	41.5	0.261	0.051
5	41.0	1.60	0.061
6	41.0	0.596	0.055
16	40.0	0.382	0.046
8	41.0	0.61	0.055
10	45.0	2.688	0.055
15	43.0	0.452	0.036
18	40.0	0.362	0.048
22	44.0	0.557	0.055
23	39.0	0.670	0.055
24	42.0	0.563	0.041
9	43.0	0.567	0.034
41	45.2	0.462	0.024
42	36.0	0.429	0.061
46	42.7	0.716	0.055
49	37.5	0.328	0.051
59	45.0	1.176	0.041
61	42.0	0.458	0.046
69	40.0	0.168	0.048
71	47.0	0.117	0.034
78	42.0	0.386	0.045
81	48.0	1.195	0.051
87	41.0	0.949	0.034
93	42.5	0.899	0.048
99	32.0	0.342	0.060
100	49.5	0.382	0.034
102	49.0	0.134	0.034
111	39.0	4.03	0.102
121	33.0	0.584	0.079
123	33.0	0.443	0.070
124	33.0	0.433	0.065
150	37.2	0.271	0.046
156	38.0	1.870	0.067
34	43.5	0.469	0.034

Spring Number	Temp. °C.	Cl' g/l.	HCO_3' g/l.
Matsubara			
3	46.8	3.57	0.060
6	43.0	4.03	0.064
14	43.0	6.52	0.108
22	46.5	0.307	0.034
17	47.2	0.107	0.034
27	40.2	1.10	0.036
29	41.5	0.338	0.036
41	—	3.516	0.072
46	41.4	3.930	0.072
69	52.0	0.278	0.044
79	47.5	2.89	0.041
77	46.0	1.38	0.041
82	47.5	1.78	0.041
83	45.5	0.52	0.034
88	42.0	0.145	0.034
99	41.0	0.302	0.058
103	—	0.403	0.061
109	42.3	0.369	0.048
119	41.0	0.412	0.051
132	40.0	1.01	0.051
136	38.0	0.200	0.051
150	47.0	3.38	0.048
160	40.5	0.201	0.036
165	40.5	1.62	0.048
167	37.5	6.06	0.099
170	44.2	2.39	0.069
171	35.0	0.134	0.075
173	34.5	0.164	0.048
174	43.5	1.038	0.065
176	37.5	0.744	0.058
178	42.6	0.362	0.069
179	39.2	0.382	0.051
181	40.5	0.389	0.041
186	42.3	0.636	0.055
191	37.2	0.447	0.06

Spring Number	Temp. °C.	Cl' g/l.	HCO_3' g/l.
Matsubara			
194	38.0	0.324	0.058
187	43.5	0.493	0.051
173	34.5	0.164	0.048
174	43.5	1.034	0.065
176	37.5	0.744	0.058
203	39.5	2.062	0.072
205	39.0	0.772	0.063
215	28.5	0.147	0.055
218	41.7	2.14	0.051
219	39.0	1.34	0.068
220	38.2	1.85	0.072
221	41.5	2.165	0.068
222	42.0	2.745	0.085
224	40.0	2.90	0.068
225	38.8	1.52	0.065
228	40.5	2.770	0.084
232	34.0	0.550	0.072
Yukawa			
1	40.0	0.207	0.048
27	42.2	0.30	0.026
29	42.3	4.07	0.093
33	43.5	0.469	0.034
44	42.5	0.244	0.027
Oka			
19	47.0	2.99	0.065

Spring Numder	Temp. °C.	Cl' g/l.	HCO_3' g/l.
26	47.3	1.39	0.041
35	46.5	1.18	0.058
42	46.1	0.529	0.041
46	47.9	1.35	0.051
52	43.	0.168	0.041
55	45.	0.118	0.044
62	44.5	0.084	0.051
63	24.5	0.030	0.058
68	49.0	0.069	0.034
78	45.1	0.168	0.041
59	47.2	1.114	0.036
75	44.0	1.476	0.034
87	46.5	0.086	0.043
88	—	0.086	0.055
102	40.0	0.202	0.055
107	32.0	0.034	0.051
112	45.0	0.084	0.177
124	55.8	0.096	0.026
129	49.3	0.074	0.034
205	52.0	0.064	0.027
236	56.7	0.071	0.029
269	50.5	0.074	0.026
275	50.0	0.067	0.034
Kamata			
6	53.5	0.077	0.034
45	53.0	0.071	0.019