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NITROGEN GAS IN HOT-SPRING WATERS

BY

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ABSTRACT

Nitrogen and oxygen gases are measured of about three hundred hot-spring waters. The nitrogen is rich in the springs of low and moderate tempreatures and poor in those of high temperatures. The relation between the flow temperatures and the nitrogen contents differs from Winkler's solubility curve, that is, supersaturation predominates at low and moderate temperatures, and unsaturation at high temperatures. The magmatic water which may be contained in hot-spring water does not play an important role to make such temperature-nitrogen relation. Oxygen contents are little in every spring and the oxygen consumption under the ground may contribute to make oxygen-poor waters. Some examples of geographical distribution of the nitrogen and the oxygen consumption are shown for some spas, suggesting the flow direction of hot-spring water and the relation with the usual ground-water. Annual and daily variations of the nitrogen and oxygen contents in hot-spring water are discussed together with the variations of other physical and chemical factors of the springs.

1. Introduction

It is a general conception that hot-spring water consists of meteoric and magmatic waters. On this theme, a number of scientists have studied for the estimation of the mixing ratio of these waters[1,2,3,4]: but since we cannot take the magmatic water as a concrete material, there is no prospect of deciding the mixing ratio and trailing the origin of water for each hot spring. Methods of distinguishing the magmatic water from the meteoric have been proposed by many chemists whose arguments have been based on chemical and isotopic compositions of the hot-spring waters. While, the meteoric water had to contact with the atmosphere, so it dissolves atmospheric gases. Oxygen and nitrogen are chief compoments of the atmosphere, the former is easy to be consumed but the latter inactive, therefore, to compare the nitrogen contents with the oxygen in the hot-spring water seems to lead some indices for the mixing of meteoric water and the hysteresis of the hot-spring waters. But, as later written in details, magmatic nitrogen may not be negligible and we can not separate atmospheric and magmatic nitrogen, therefore, it is a matter of course that to research the nitrogen should not lead directly the mixing ratio of meteoric and magmatic components in hot-spring water. Though argon is more suitable than nitrogen for the study of hysteresis of meteoric water, we use the sum of nitrogen and argon, because total volume of argon is little, and in order to discuss of the data as many as possible. Henceforth in this paper, "nitrogen" means sum of nitrogen and argon.

Nitrogen gas is inactive inorganically but reacts biochemically at ordinary temperature, and organic reaction sometimes exhaust nitrogen gas: therefore, nitrogen content in ground water changes under above reaction, and it is reported to be usually supersaturation of nitrogen in ground water as a result of such reactions[5]. The nitrogen-rich ground water permeates deeply, mixes with magmatic vapour or liquid, and sometimes is heated by only thermal conduction, then returns to flow out as hot spring. Nitrogen content in the hot-spring water may change by its boiling or exhausting of other gases and the addition of magmatic fluid.

Some springs may be fed by connate water from sediments being compacted, or by metamorphic water from rocks being progressively metamorphosed[6]. Here, these waters are included in meteoric water in its wide sense, because connate and metamorphic waters were at one time in atmospheric circulation. After all, the purpose of this study is to find out the nitrogen contents in hot-spring water comparing with that in ground water, and to offers some informations in connection with the problem: what *is the origin of the hot-spring water?*

We measured the nitrogen in about three hundred hot springs, which are in Beppu, Kamegawa, Kannawa, Myoban, Yunohira, Amagase, Yufuin and Otake, Oita Prefecture; Uchinomaki, Kumamoto Prefecture; Yuda, Yamaguchi Prefecture: Nakafusa, Nagano Prefecture. The methods of meaurement of nitrogen followed Winkler's one improved by S. Oana[7], the results being listed in Table 1.

2. Relation between Nitrogen and Spring Temperature

Nitrogen contents are plotted in Fig. 1 with respect to spring temperature, the relation between nitrogens and temperatures differs from Winkler's solubility curve, that is, nitrogen is supersaturation in low and moderate temperature and unsaturation in high temperature. Such general tendency suggests that the nitrogen contained in hot spring of low and moderate tempreature is non-volcanic, and its origin is like that of usual ground water. One of the reasons of the supersaturation is biochemical reaction. Fermentation of organic matter exhausts nitrogen and enriches its contents in water. It was reported that usual ground waters contain nitrogen of 13.37–22.99 cc/l at 12.4–17.8 °C, saturation percentage ranging 98.5–170.8 % and the main about 120 %[5]. When the nitrogen-rich ground water is heated, the degree of supersaturation becomes large because the temperature rise brings reduction of the solubility. Therefore, at the atmospheric pressure, nitrogen is apt to release from the water to the atmosphere or forms gas bulles, thus, in order to keep equilibrium in apparent supersaturation, the water must be confined.

Table 1. Flow temperature, nitrogen, and oxygen of hot-spring waters except fumarole or steam well.

Spa	No.	Temp. °C	N_2+A cc/l at OC°	O_2 cc/l at OC°	Spa	No.	Temp. °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C
Beppu	3	50.4	8.8	0.8	Beppu	452	50.0	11.0	0.7
"	4	44.2	8.4	1.4	"	468	46.7	9.5	0.6
"	13	53.7	9.7	1.3	"	472	55.1	10.1	1.0
"	17	51.0	11.3	1.0	"	478	56.5	9.7	1.0
"	19	50.5	10.6	0.9	"	483	55.5	8.1	1.1
"	23	42.5	10.7	1.1	"	516	49.6	8.1	1.7
"	30	43.5	9.1	1.5	"	531	63.0	6.9	1.1
"	35	36.6	7.4	0.4	"	534	56.2	7.9	2.6
"	46	45.4	8.5	1.2	"	535	56.0	9.7	1.3
"	47-1	50.8	8.4	1.3	"	545	55.5	9.6	0.6
"	55	43.2	11.0	0.6	"	555	48.0	6.9	0.9
"	58	49.7	11.7	0.3	"	564	48.1	12.3	0.8
"	66	26.0	13.4	1.8	"	580	48.9	9.5	1.1
"	77	44.3	13.4	0.6	"	594	45.0	8.1	1.6
"	81	56.6	8.1	0.6	"	634	46.0	6.7	1.1
"	92	60.0	6.8	0.9	"	645	45.0	6.1	0.6
"	97	47.5	7.7	0.8	"	664	47.0	8.1	1.2
"	118	45.0	8.3	0.5	"	674	42.5	9.4	1.7
"	140	58.9	6.7	1.0	"	695	43.5	6.8	0.8
"	162	50.2	10.8	1.7	"	696	42.2	10.6	1.2
"	180	57.8	6.1	0.8	"	708	54.4	9.1	1.2
"	203	45.2	10.1	1.9	"	737	52.8	6.6	0.8
"	207	55.0	6.6	0.5	"	751	52.5	6.0	1.7
"	210	52.3	11.2	1.0	"	770	52.8	7.8	0.8
"	211	47.5	9.9	1.1	"	785	47.3	10.6	0.5
"	214	55.1	9.1	1.3	"	819	40.0	7.8	1.8
"	244	51.8	11.1	2.9	"	833	48.9	7.5	0.9
"	283	56.5	8.2	1.5	"	852	48.3	7.5	0.9
"	291	58.0	10.4	2.1	"	869	44.0	9.3	1.3
"	295	61.4	8.5	1.5	"	874	45.1	13.7	1.2
"	301	55.0	10.1	0.9	"	879	50.5	12.6	2.1
"	311	56.8	12.0	3.1	"	892	36.8	10.5	0.6
"	322	61.8	6.6	0.4	"	896	45.8	8.4	1.3
"	338	54.5	6.5	0.3	"	920	40.5	12.0	1.8
"	343	63.0	10.7	1.1	"	971	44.7	11.7	5.6
"	350	62.8	7.7	0.8	"	979	63.5	9.9	2.9
"	381	50.5	11.8	3.5	"	990-1	37.6	7.4	0.2
"	384	51.0	10.6	3.0	"	1013	54.6	8.9	0.7
"	389	55.2	10.0	1.5	"	1022	40.6	10.1	1.2
"	393	58.0	9.2	0.6	"	1045	44.3	9.6	1.4
"	398	57.3	10.4	0.4	"	1138	46.5	9.7	1.6
"	405	54.1	9.4	0.8	"	1149	49.7	11.8	1.2
"	411-1	48.1	12.5	3.7	"	1165	41.6	12.5	2.0
"	414	39.3	9.8	2.9	"	1175	36.8	13.7	1.7
"	415	63.5	11.2	1.8	"	1179	50.2	10.3	1.2
"	429	61.6	10.8	1.1	"	1184	43.2	9.9	0.9
"	429-1	57.2	9.7	1.1	"	1186	59.0	9.0	1.0
"	431	62.6	10.3	2.0	"	1218	45.7	6.5	0.7
"	433	45.5	10.0	1.5	"	1224	47.1	6.3	2.6
"	434-5	53.9	11.0	1.9	"	1256	37.0	15.1	0.9
"	434-6	51.7	12.1	3.1	"	1284	49.5	10.1	1.8
"	434-16	41.6	12.3	0.3	"	1285	56.3	9.0	0.9
"	435	53.5	8.4	1.6	"	1289	37.0	8.7	0.9
"	437	57.9	8.7	1.3	"	1295	51.0	6.5	1.8
"	442	56.6	10.5	1.2	"	1297	45.4	11.3	1.8
"	443	61.0	9.6	2.7	"	1298	51.8	12.9	0.9
"	444	69.0	11.9	1.9	"	1300	47.7	11.0	0.7
"	448	62.8	11.1	3.5	"	1308	48.3	7.8	2.8
"	448-1	51.3	11.2	2.2	"	1311	41.2	12.0	1.0
"	449	56.5	8.5	0.8	"	Hosenso	50.0	7.4	3.1

Table 1. continued

Spa	No.	Temp. °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C	Spa	No.	Temp. °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C
Beppu	Furukawa	43.2	8.4	3.4	Kamegawa	Sakurai	49.0	10.6	2.4
"	Sudo	49.0	7.8	1.6	"	155	57.2	8.0	1.0
"	Fujimi	48.1	5.2	1.3	"	166	65.2	4.9	1.0
"	Yumigahama	49.5	8.2	0.8	"	177	51.0	6.3	0.6
"	Nikkoso	51.5	11.1	0.9	"	188	52.4	9.1	0.6
"	Tenrikyo	47.6	9.8	0.7	"	191	36.8	14.9	0.6
"	station	56.7	6.9	0.9	"	197	49.2	8.5	1.6
"	Shinneko	42.5	9.8	1.9	"	210	31.8	13.7	1.3
"	Matogahama	51.8	12.1	0.9	"	217	41.8	11.9	1.2
"	Hori	46.9	11.1	0.9	Kannawa	5	41.0	8.0	1.5
"	Matogahama	46.0	11.9	0.6	"	10	60.8	6.7	0.7
"	Seitenkaku	49.5	10.7	3.5	"	25	91.4	2.7	1.1
"	Abe	55.5	9.5	0.7	"	33	48.0	7.6	3.1
"	Nijyokan	60.6	11.8	1.0	"	59	78.0	5.4	1.7
Kamegawa	1	47.0	13.3	1.2	"	73	58.0	7.1	2.8
"	8	49.4	13.3	1.1	"	76	50.0	8.7	3.2
"	12	42.0	12.3	2.4	"	79	40.6	10.8	3.6
"	34	52.0	11.8	1.5	"	120	61.4	6.4	2.7
"	38	70.8	9.7	1.2	"	Yamajigoku	88.0	2.5	0.4
"	51	54.8	8.5	3.1	"	A spring near Juman	97.0	1.5	0.4
"	56	47.8	8.8	2.6	Myoban	101	70.0	5.5	1.1
"	75	58.2	9.0	1.5	"	104	57.0	6.5	0.6
"	87	49.4	8.2	3.0	"	111	80.0	1.4	0.3
"	119	55.5	9.2	3.5	"	113	52.0	8.2	3.2
"	123	60.4	8.4	2.2	"	120	58.0	2.9	0.5
"	132	51.0	12.1	1.8	"	134	72.0	5.7	2.3
"	134	59.8	13.7	1.1	"	367	58.0	5.6	0.2
"	135	58.4	14.1	3.6	"	377	53.0	4.9	0.3
"	141	42.0	9.5	3.8	Yunohira	5	61.5	5.0	2.0
"	145	53.0	8.7	2.7	"	6	68.0	5.1	2.4
"	155	58.0	8.3	2.1	"	7	64.8	6.2	2.3
"	191	47.2	7.8	2.9	"	8	89.0	2.6	0.9
"	212	58.0	11.2	1.1	"	9	58.8	6.9	2.3
"	215	59.4	13.1	0.7	"	13	66.2	3.2	1.0
"	220	60.4	13.0	0.6	"	14-1	60.4	5.1	1.5
"	221	63.5	9.1	1.7	"	14-2	67.6	2.7	0.5
"	223	52.4	9.6	1.8	Amagase	1	69.0	4.1	0.2
"	227	49.8	8.6	3.1	"	2	56.0	7.6	0.4
"	229	48.6	8.9	2.5	"	3	48.8	8.3	3.0
"	233	47.8	10.7	0.9	"	4	65.2	3.8	0.2
"	244	71.5	3.3	1.1	"	5	82.0	2.8	0.2
"	248-4	50.2	11.7	0.8	"	6	99.5	2.2	0.2
"	255	56.0	10.1	2.0	Yufuin	14	84.1	5.2	1.1
"	281	65.9	6.5	0.8	"	19	64.0	8.4	1.5
"	287	44.6	10.5	1.2	"	30	67.0	9.0	2.1
"	312	44.8	11.6	1.3	"	32	72.8	9.5	1.1
"	318	42.0	13.1	1.2	"	63	61.6	7.7	1.7
"	320	49.0	10.9	2.0	"	98	65.4	10.5	0.8
"	334	46.4	10.7	1.5	"	191	92.2	1.8	0.5
"	339	39.4	13.4	3.3	"	200	84.2	4.7	1.3
"	347	99.0	1.5	0.6	"	201	64.2	7.7	1.9
"	362	50.0	11.1	0.6	"	203	83.8	6.1	1.0
"	373	52.2	11.2	1.6	"	204	82.2	3.5	1.3
"	390	74.6	8.2	3.0	"	207	90.0	3.0	1.3
"	396	52.4	7.8	2.9	"	209	85.0	4.2	1.9
"	402	77.8	8.8	0.6	"	229	84.8	5.4	0.9
"	406	79.8	5.7	1.2	"	253	61.6	11.5	0.3
"	410	58.5	7.3	3.6	"	260	71.0	11.3	0.6
"	414	85.0	4.3	1.6	"	262	76.6	5.0	1.4
"	420	64.5	8.0	1.4	"	263	78.5	5.8	1.0
"	424	64.8	8.5	1.0	"	266	72.0	6.8	0.9
"	Kamegawaunso	64.2	13.8	0.8	"	267	75.2	8.4	1.6
"	Takemori	47.4	9.7	3.5					

Table 1. continued

Spa	No.	Temp. °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C	Spa	No.	Temp. °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C
Otake	11	83.1	3.1	1.3	Yuda	10	54.5	17.4	1.5
"	12	92.6	2.0	0.4	"	18	47.5	14.6	2.4
"	13	79.5	2.3	0.4	"	20	50.4	16.7	1.5
"	14	56.0	4.4	1.7	"	21	39.5	18.6	0.8
"	15	97.5	1.0	0.4	"	22	50.0	16.6	3.0
"	16	66.4	2.1	0.4	"	25	48.5	13.8	1.0
Uchinomaki	6-4	47.4	15.0	0.7	"	26	45.0	14.4	1.6
"	8	39.0	13.3	2.1	"	28	35.6	16.4	1.5
"	8-1	43.0	12.7	1.4	"	29	39.5	12.3	1.4
"	10	44.3	16.5	0.3	"	31	39.5	14.9	1.4
"	22-1	36.5	17.7	0.8	"	34	46.3	15.5	1.1
"	25-1	39.9	12.9	1.7	"	37	38.2	16.1	1.2
"	38	36.9	14.0	1.6	"	38	43.4	14.7	0.4
"	42-1	35.0	17.8	0.1	"	41	20.0	18.1	0.1
"	46-1	42.9	15.8	0.6	"	43	23.2	18.1	1.4
"	58	38.2	13.8	1.5	"	45	26.4	17.2	0.9
"	59	38.9	12.7	1.5	"	50	21.5	13.1	3.5
"	61	47.5	16.0	0.7	"	52	53.7	15.7	0.7
"	63-1	46.0	16.0	0.3	"	53	27.0	19.7	1.5
"	64	38.2	12.9	0.5	"	55	24.8	18.3	1.7
"	68-1	38.8	14.4	0.9	"	57	37.2	14.9	0.8
"	69	40.0	14.0	1.4	"	58	51.5	14.0	1.6
"	70	47.1	17.0	0.2	"	59	50.0	16.0	1.9
"	71-1	46.0	15.1	0.0	"	62	30.0	18.7	0.7
"	75	46.1	16.1	1.1	"	64	32.5	14.6	2.9
"	84	47.1	9.3	0.7	"	65	24.5	14.3	1.2
"	86	41.1	12.9	0.9	"	68	58.8	15.1	1.1
Yuda	2	61.2	15.7	3.0	Nakabusa	Konabetate	94.5	2.2	0.2
"	7	41.5	11.8	2.2	"	Ojigoku	86.0	2.0	0.2

On the other hand, even if nitrogen does not come from biochemical reaction, the supersaturation of nitrogen may be caused by the following: when the water containing reasonable nitrogen at the ground surface permeates into the deep ground, it becomes confined and high temperature, than the high pressure is able to keep the much nitrogen as solute in spite of the high temperature. Fig. 2 shows the solubility at various total pressures calculated with Henry's law from the Winkler's data[7),8)]. In order to keep the just saturation at every temperature, pressure is necessarily decided according to nitrogen contents. These relation are shown in Fig. 3: for instance, the water dissolving 18.99 cc/l of nitrogen at 1 atmospheric total pressure and 0°C does not exhale nitrogen unless its temperature and pressure vary in a domain of left and up side to a line of 18.99 cc/l. Even this extreme case, the maximum pressure increment reuqired for no nitrogen exhaustion is at most ten odd meters of water column, and it may be easily satisfied as the hot-spring aquifers are generally deeper than this depth.

Thus, the maximum nitrogen contents in the hot-spring water should be 18.99 cc/l without biochemical reaction, and observed values are less than this value except one or two as shown in Fig. 1. After all, the apparent supersaturation of nitrogen in hot-spring water refers to that the nitrogen dissolved at low temperature and ordinary pressure is kept up to comparatively high temperature by pressure increment,

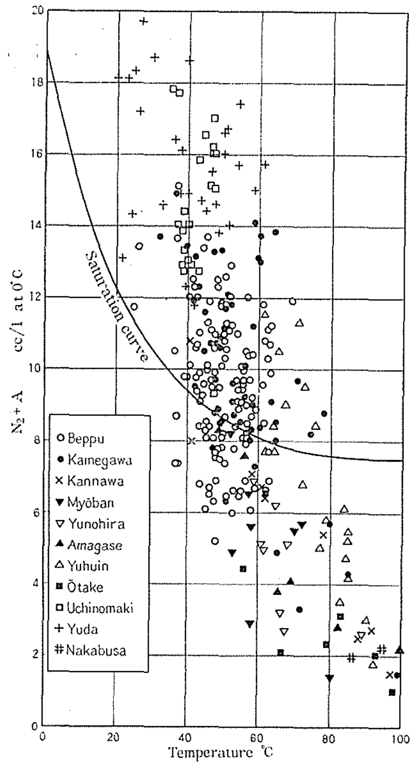

Fig. 1. Nitrogen contents to flow temperature of hot springs : the curve shows the winkler's solubility of atmospheric nitrogen.

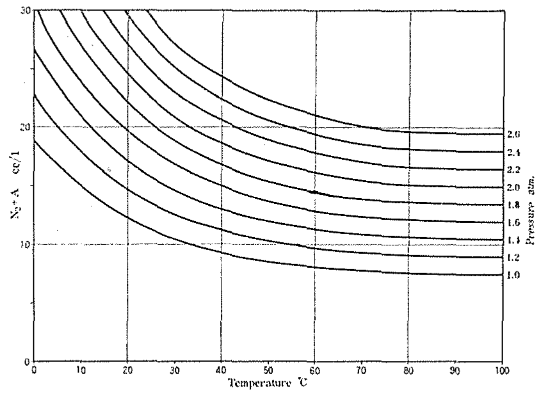

Fig. 2. Nitrogen solubility at various pressures, calculated from Winkler's experimental data.

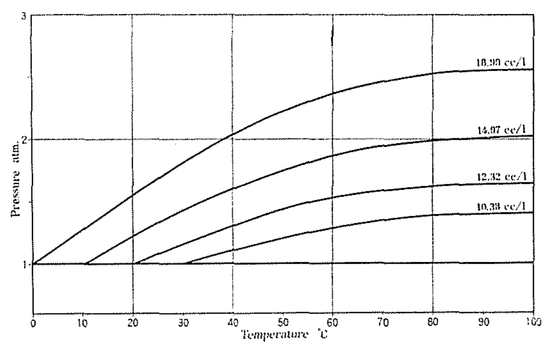

Fig. 3. Temperature-pressure relation to keep a constant volume of nitrogen in the saturation at every temperature.

and the most part of nitrogen can be explained as from the atmosphere.

Very little content of nitrogen in high-temperature hot spring may be essentially based on either following ground; the magmatic water having originally no nitrogen occupies the most part of hot-spring water, or the nitrogen being dissolved originally is expelled by the boiling or exhausting of other gases. If we are going to discuss on the former ground, it is necessary to know nitrogen contents in the magmatic water, but now, there are two kinds of opinions which oppose each other. Jaggar[9),10)] maintained that nitrogen in volcanic exhalations is mostly magmatic. Barth[11)] concluded that nitrogen is of atmospheric origin from his study of hot-spring gases in Iceland, but he regarded that springs rich in volcanic gases always contain a small amount of nitrogen, some of which may be magmatic. Although the weight or volume ratio of nitrogen gas to vapour are very small in general volcanic gases, if the volcanic vapour condenses to water, the volume ratios of nitrogen to the water are larger than that of hot-spring waters, as illustrated in Table 2[12),13)]. Therefore, the condensation of volcanic vapour can not be the origin of the nitrogen-poor hot springs, while magmatic liquid which is the remain in the magmatic differentiation may be the origin. But the nitrogen in the inclusion water which is perhaps magmatic is 6.32~13.54 cc/l[5)], and not less than in the hot-spring water. Eventually, from above discussion, it seems inadequate to take the magmatic water as general main factor for the very small amount of nitrogen in the hot-spring waters.

Table 2. Volume ratio of nitrogen to water in volcanic gases

Volcano	Temp.	Volume ratio between vapour and nitrogen in volcanic gas	N_2 cc per liter of liquid water at 0°C
Kilauea	1200°C	H_2O 97.07 % N_2 0.68	8300
Syowashinzan	655°C	H_2O 99.48 N_2 0.014	170

It is natural that nitrogen in the hot spring escapes from the water with boiling or exhaust of carbon dioxide. This escape may be expected not only from the water boiling itself but near a boiling spring or a humarole. Under the geothermal area, ground temperature exceeds sometimes the boiling temperature corresponding to the hydrostatic pressure in that place[14)]. In this case, steam zone forms above the water. Nitrogen and other gases gather in the steam zone which spout out as fumarole, and not in the water which flows out as hot spring. Table 3 lists the practical data which show that the condensed water from fumarole vapour have not so little nitrogen as the hot-spring water in geothermal areas. Table 4 shows the results of experiments in

Table 3. Comparison between steam well and hot spring of nitrogen contents

Name of spa	Number of steam well or hot spring	Distance between steam well and hot spring	Temperature °C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C
Kannawa	No. 126 steam well	100m	99.5	2.8	0.3
	A hot spring near Juman		97.0	1.5	0.4
Yubuin	No. 205 steam well	60	95.0	5.3	1.9
	No. 207		90.0	3.0	1.3
Myboan	No. 442 steam well	8	94.0	6.6	1.8
	No. 111 hot spring		80.0	1.4	0.3
Amagase	Komatsuya steam well	100	98.0	3.8	0.2
	No. 6 hot spring		99.5	2.2	0.2
Otake	No. 1 steam well	30	96.8	4.2	0.2
	No. 12 hot spring		92.6	2.0	0.4

Table 4. Experimental comparison between condensed water and residual water of nitrogen contents

	I		II		III	
	N_2+A cc/l at 0°C	O_2 cc/l at 0°C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C	N_2+A cc/l at 0°C	O_2 cc/l at 0°C
City water	16.1 (140%)	7.4 (126%)	18.4 (160%)	9.1 (154%)	18.1 (147%)	8.4 (148%)
Condensed steam	9.4	4.7	6.3	3.5	5.8	2.7
Residual water	0.7	0.1	1.6	0.8	1.4	0.6

which, for the covering the flank of above phenomenon, the city water was boiled and nitrogen content in condensed steam was compared with that in the residual water. Field data and experimental results agree with each other. Therefore, the very small amount of nitrogen in the most hot-spring water of high temperature seems to be explainable with the escape of nitrogen by the boiling.

Thus, we conclude that whether it is magmetic or mateoric the hot-spring water having little nitrogen might have come through a chance of boiling or separating the gas phase from the liquid, and consists of the residuary liquid phase.

3. Relation between Nitrogen and Oxygen Contents

The origin of nitrogen in hot-spring water of high temperature is not clear whether it comes from the atmosphere or from the magma, but it is true, as formerly described, that the hot springs of low and moderate temperature contains much atmospheric nitrogen. Thus, oxygen which is another main component of the air is important to discuss the nitrogen in the hot spring. Oxygen is always less than the saturation given by Winkler at every temperature, in detail, little at low temperature as well as at high temperature. This is illustrated in Fig. 4 in which a full line shows the Winkler's saturation relation, the side figures the water temperature. The nitrogen-and oxygen-poor water consists of the gas-free magmatic water or the boiled water. When the meteoric water is boiled, the nitrogen and oxygen in the residual water may be roughly given by the exterpolation of the full line of Fig. 4, therefore, it may be said that the nitrogen and oxygen in the hot springs near this exterpolated line are atmospheric and that the water is the residual of boiling, while the nitrogen-rich and oxygen-poor water is not magmatic. Though the biochemical action can not be denied as the origin of the nitrogen, we here consider only the atmospheric mitrogen, because the nost of the nitrogen contents are less than the maximum which is explainable as atmospheric. Then the oxygen accompanied with nitrogen has been consumed in the ground by oxidizing reaction. In Fig. 4, a length parallel with O_2-axis from a point denoting a hot spring to the saturation curve expresses the consumed oxygen in the spring. This consumption can be directly calculated from the observation with following relation;

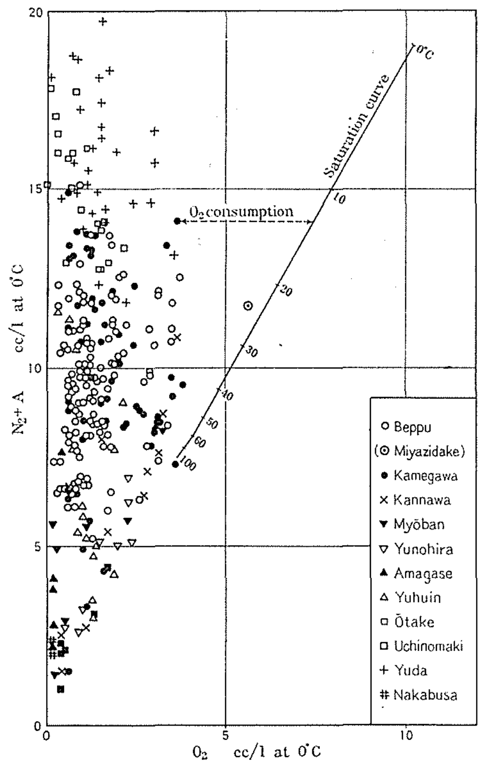

Fig. 4. Nitrogen and oxygen in hot springs : a full line shows the Winkler's saturation relation and the side figures are the solvent temperatures ; length of a broken line parallel with O_2-axis from a point denoting a hot spring to the saturation curve shows the oxygen consumption of the spring, and the mark, ⊙, indicates a shallow well in Beppu, which will be discussed in latter section.

$$(O_2 \text{ consumption}) = (N_2 \text{ content}) \times 0.56 - 0.5 - (O_2 \text{ content}) \quad \text{cc/l},$$

where the constants are given by regarding the saturation curve in Fig. 4 as straight. Large amount of the oxygen consumption suggest the long period of oxidation or flowing in the ground. In the other case, apparent oxygen consumption may increase as the ground water having much nitrogen and little oxygen add to the hot-spring water having little nitrogen and oxygen. So the geographical distribution of the amount of oxygen consumption may be said to be a suggestive factor to show the direction of the underground flow of hot water, this examples being shown in next section.

Another interesting point in Fig. 4 is that oxygen is comparatively much in the water of 7∼14 cc/l nitrogen or of moderate temperature. The mark, ⊙, represents a shallow well in Beppu, both nitrogen and oxygen being nearly saturation. It has been cleared from Seno's study[15] about this well that the hot-spring water and usual ground water is mixed each other in it. This phenomenon will be discussed in connection with the time-variation of nitrogen content in latter section.

4. Geographical Distribution of Nitrogen in Some Spas

The nitrogen is generally little in high-temperature springs and much in low and moderate temperature ones as shown in Fig. 1, but, in one thermal or hot-spring area, it is not always so, and sometimes may be rather the inverse. In order to clear this point, geographical distribution of nitrogen in each area is available.

(1) Beppu Hot Springs

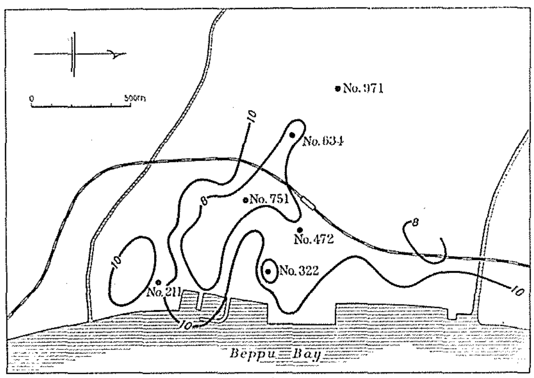

Fig. 5. Distribution of nitrogen in Beppu Hot Spring ; iso-content lines are drawn with respect to 8 and 10 cc/l nitrogen, and six points with number are hot springs which were observed to find daily and annual variations of nitrogen.

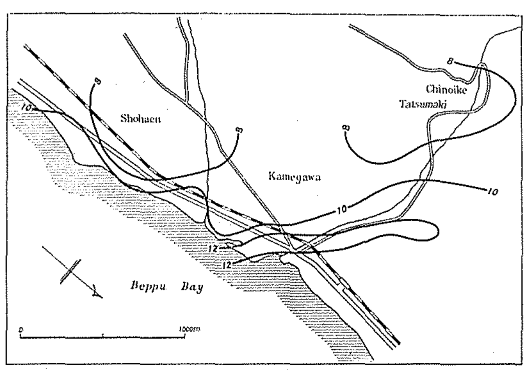

Fig. 6. Distribution of nitrogen in Kamegawa Hot Springs ; isocontent lines are drawn with respect to 8, 10 and 12 cc/l.

Fig. 5 shows the distribution of the nitrogen in Beppu, where we can not find the definite relation between nitrogens and the flow temperatures, but the zones less in nitrogen coincide with the most active parts of hot springs[16]. Therefore, we see that, the essential hot-water has little nitrogen, mixing with ground water or sometimes sea-water rich in nitrogen to form the various types of hot-spring water.

(2) Kamegawa Hot Springs

In Kamegawa Hot Springs which are in the north of Beppu, the nitrogen-temperature relation is the same as the general shown in Fig. 1. Distribution of nitrogen given in Fig. 6 suggests that the high-temperature and nitrogen-poor water gushing out from the deep, flows to the north-east through the ground, mixing with ground water to become low-temperature and nitrogen-rich water[17]. The "oxygen consumption" defined previously is calculated for these springs, their distribution being shown in Fig. 7 which clarifies that the oxygen in the water is consumed more and more from up- to down-stream.

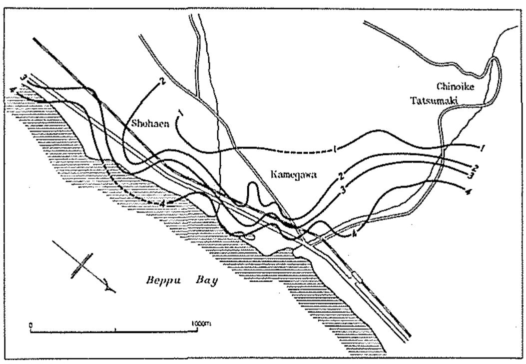

Fig. 7. Oxygen consumptions defined in former section in Kamegawa ; numbers beside isocontent lines denote the consumption quantity cc/*l*.

3) Uchinomaki Hot Springs

Uchinomaki is the largest spa in Aso Caldera, but the flow temperatures of hot spring are about 50 °C at the highest, the nitrogens being more than the saturation. The nitrogen distribution is shown in Fig. 8, where nitrogen-rich area has been known as the center of Uchinomaki Hot Springs[18][19]. Here, original hot water differs from the above two examples, having much nitrogen than ground water. In the marginal regions, the hot water mix with cold ground water having about 14 cc/l nitrogen, then the nitrogen contents in hot springs rather decrease from the center to the circumference. The distribution of this type is also shown in Yuda Hot Springs[20], Yamaguchi

Prefecture, and generally, the hot springs comparatively low temperature and rich in nitrogen seem to belong to this type.

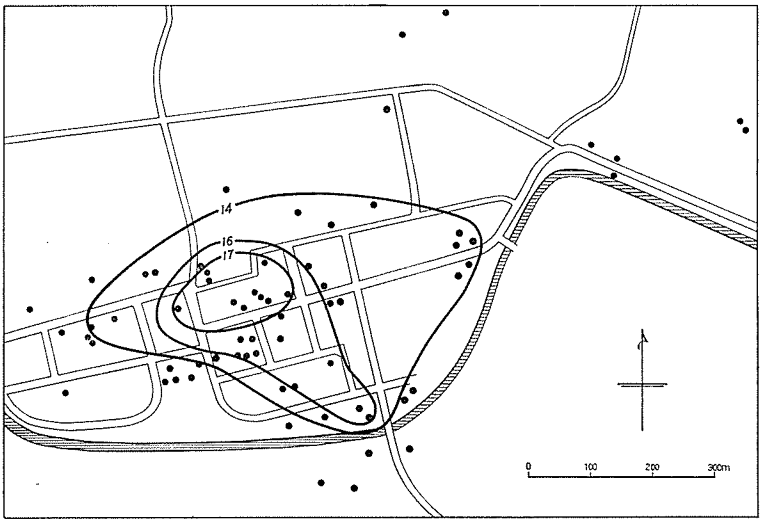

Fig. 8. Distribution of nitrogen in Uchinoamki Hot Springs ; isocontent lines are drawn with respect to 14, 16 and 17 cc/*l*.

We conclude from above examples that the essential hot-spring waters gushing out from the deep ground are different for each area, some of them being high temperature and poor in nitrogen, and others are comparatively low and rich. In the former case, as the hot waters mix with the usual ground water, they become tepid and nitrogen-rich, while in the latter, tepid but nitrogen-poor.

5. Daily and Annual Variation of Nitrogen Gas in Hot-spring Waters

It is known that ion contents in hot spring vary with time, so the gas components such as nitrogen and oxygen may vary. Their daily variation of two hot springs and their annual variation of the four ones are observed in Beppu, the locations of the observed hot springs being seen in Fig. 5.

(1) Daily Variation

Flow rate, temperature, chemical contents of hot springs near the sea-shore vary with the tide, so we observed nitrogen and oxygen together with them at intervals of two hours. The results are shown in Table 5 and Fig. 10, where the longitudinal lines drawn in the rows of nitrogen and oxygen show the scattering of the observation. In both springs, No. 322 and No. 211, high tide causes increase of the flow rate and high flow temperature, while Cl is diluted at high tide in No. 211. Tidal variations of flow

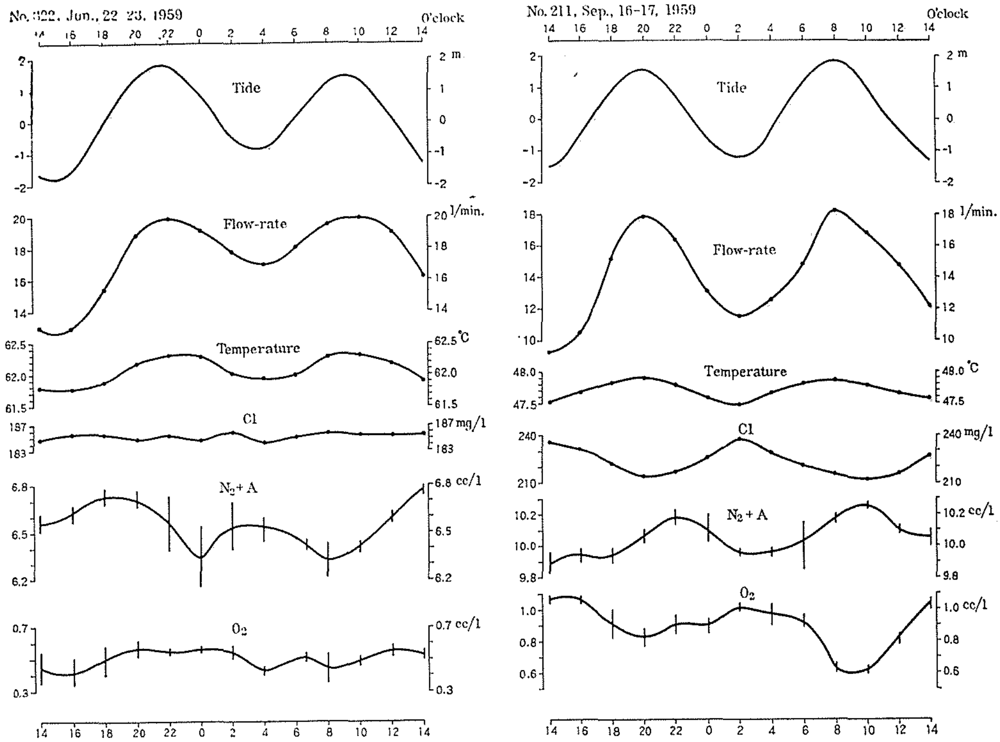

Fig. 9. Tidal variations of flow rate, temperature, chlorine, nitrogen and oxygen in No. 322 and No. 211 hot springs.

Table 5. Tidal variations of physical and chemical factors of two hot springs in Beppu

Hour	Flow rate L/min.	Temp. °C	Cl mg/l	N_2+A cc/l at 0°C		O_2 cc/l at 0°C	
	Beppu No. 322			June 22 & 23, 1959			
14	13.0	61.8	185	6.51	6.60	0.53	0.35
16	13.0	61.8	186	6.55	6.64	0.36	0.49
18	15.4	61.9	186	6.69	6.77	0.57	0.42
20	18.8	62.2	185	6.76	6.67	0.53	0.60
22	19.9	62.3	186	6.39	6.75	0.54	0.54
0	19.2	62.3	185	6.54	6.06	0.57	0.56
2	17.9	62.0	186	6.40	6.69	0.50	0.57
4	17.0	61.9	185	6.59	6.46	0.43	0.43
6	18.8	62.0	186	6.45	6.46	0.53	0.50
8	19.5	62.3	186	6.23	6.43	0.53	0.36
10	19.9	62.3	186	6.43	6.41	0.50	0.50
12	19.2	62.2	186	6.60	6.60	0.53	0.57
14	16.1	61.9	186	6.77	6.71	0.53	0.54

Table 5. cotinued

Hour	Flow rate L/min	Temp. °C	Cl mg/1	N_2+A cc/1 at 0°C		O_2 cc/1 at 5°C	
	Beppu. No. 211			September 16 & 17, 1959			
14	9.6	47.5	236	9.83	9.94	1.06	1.07
16	10.2	47.7	230	9.90	9.96	1.06	1.07
18	15.1	47.8	224	9.96	0.90	0.99	0.82
20	18.0	47.9	214	10.08	10.04	0.86	0.78
22	16.3	47.8	217	10.14	10.21	0.96	0.85
0	13.2	47.6	224	10.19	10.03	0.85	0.93
2	11.6	47.5	238	9.94	9.97	1.00	1.03
4	12.6	47.7	229	9.97	9.94	1.03	0.89
6	14.7	47.8	221	9.86	10.14	0.89	0.96
8	18.3	47.9	215	10.18	—	0.61	—
10	16.7	47.8	212	10.26	10.26	0.61	0.64
12	15.1	47.7	215	10.10	10.11	0.79	0.81
14	12.2	47.6	228	10.10	9.90	1.03	1.03

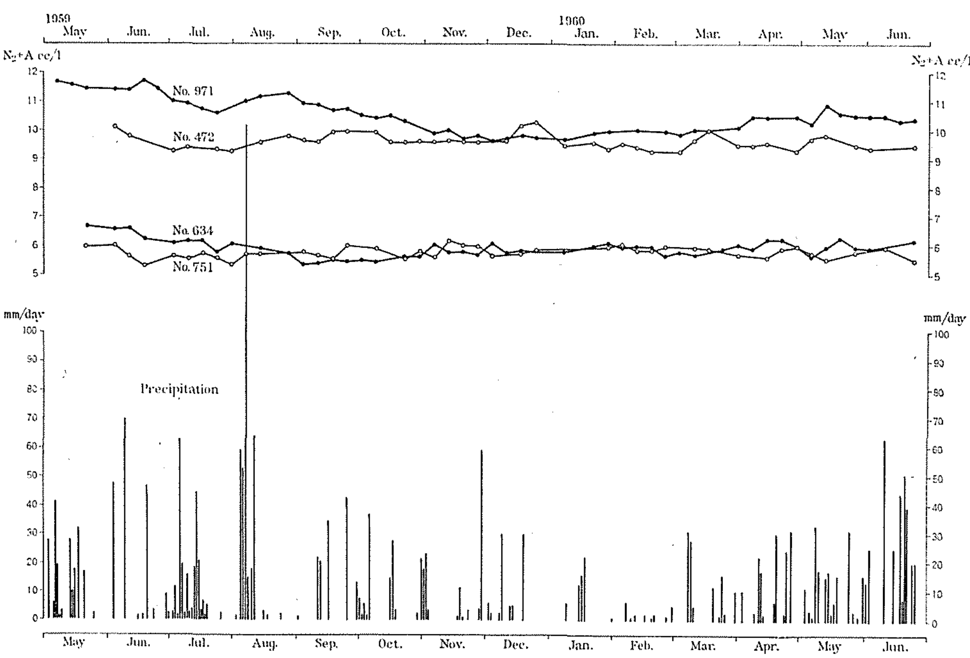

Fig.10 Variation of nitrogen in hot springs is compared with precipitation.

Fig. 10. Variation of nitrogen in hot springs is compared with precipitation.

rate, flow temperature and Cl ion content are the already known phenomena, for which following explanation has been recognized[21]. High tide brings increment of sea-bottom pressure, then suppresses the submarine leak of hot water or compresses its aquifer to increase the flow rate of hot springs near the sea shore. Variations of flow temperature and Cl content are secondary, that is, when the flow rate increases, the cooling of hot water decreases on the way up to the surface, and Cl concentration dilutes because the dissolution rate does not correspond to the increase of the flow rate, however, the variation is not so distinct for the springs of poor chlorine.

Tidal nitrogen variation of No. 322 and No. 211 have opposite sense each other; increase of flow accompanies less nitrogen in No. 322 but more in No. 211. The oxygen variation is clear in No. 211 but not in No. 322. Phase lags of these variations to the tide can not be found practically, and even if they may be seen, they are shorter than two hours. To express the nitrogen variation as a secondary effect by the flow-rate change is somewhat difficult, because, (1) the variations caused by the tide of similar phase are different for two examples, (2) nitrogen does not come from underground rocks, and (3) exhaustion of other gases is not found. Therefore, we suppose at first that the essential hot water is mixed with a different water, the mixing ratio being effected by the tidal change. The different water may be sea water as the springs are near the sea, but opposite correlations between tide and Cl remove this suspicion. In No. 211, high tide may cause the more addition of nitrogen-rich, oxygen-and chlorine-poor water to the essential hot water. This, eventually, suggests that the added water is also a kind of hot water and in an artesian aquifer of which tidal efficiency is larger than that of essential hot water owing to the difference of their elastic characters, furthermore, the impermeable layer between these aquifers is imperfect to permit the waters to interchange each other[22]. The difference between No. 322 and No. 211 of nitrogen variations may be explained as follows: in No. 322, the tidal efficiency of the aquifer of nitrogen-poor water may be larger than the others, while in No. 211, it may be smaller.

(2) Annual Variation

Flow rate, temperature, chlorine, nitrogen and oxygen of four hot springs are measured every Friday from May 1959 to June 1960, the results being listed in Table 6, shown in Fig. 5. The main factor bringing about the annual variation of physical and chemical elements of hot spring may be precipitation, so we compare it with nitrogen as shown in Fig. 10. This figure seems to show that the precipitation gives little effect on nitrogen in hot springs except No. 971 spring for which the detail will be given later. While, the annual flow-rate variations are found obviously in many springs, as an example, the data of No. 634 are shown in Fig. 11. The flow rate is much in summer or autumn, a little in spring, and this trend is caused by precipitation. But the rain does

Table 6. Annual variations of physical and chemical factore of four fot springs in Beppu

	No. 472				
	Flow rate 1/min.	Temp. °C	Cl mg/1	N_2+A cc/1	O_2 cc/1
1959					
May 8	11.9	57.0	–	–	
15	12.6	57.0	–	–	
22	11.7	56.1	–	–	
29	–	–	–	–	–
June 5	12.0	66.5	223	10.10	1.03
12	12.3	55.3	–	9.76	0.85
19	12.0	55.2	–	–	–
26	–	–	–	–	–
July 3	11.9	55.5	207	9.21	0.71
10	12.6	55.2	216	9.41	0.81
17	12.9	55.2	–	–	–
24	12.9	55.3	214	9.36	0.67
31	12.6	55.8	219	9.25	0.82
Aug. 7	13.2	55.0	–	–	–
14	13.6	54.4	218	9.58	0.99
21	13.7	55.2	–	–	–
28	13.1	55.2	226	9.85	0.78
Sept. 4	13.2	55.0	228	9.68	0.74
11	13.6	55.2	233	9.61	0.92
18	13.8	55.0	–	9.94	0.64
25	13.6	55.0	228	9.93	0.61
Oct. 2	13.5	54.9	–	–	–
9	14.1	55.0	226	9.94	0.96
16	13.5	55.0	224	9.60	0.75
23	13.7	55.0	227	9.60	0.93
30	13.2	55.0	234	9.65	0.93
Nov. 6	13.9	54.9	233	9.58	1.03
13	13.3	55.0	233	9.65	1.03
20	13.5	55.0	237	9.61	0.89
27	13.0	55.0	238	9.58	0.99
Dec. 4	–	–	–	–	–
11	13.0	54.9	–	9.69	0.71
18	13.1	54.9	236	10.19	0.89
25	12.8	54.6	224	10.30	0.78
31	13.6	55.0	–	–	–
1960		55.0			
Jan. 8	12.0		240	9.48	0.96
15	12.0	55.0	–	–	–
22	12.6	55.0	227	9.58	0.96
29	12.4	55.0	227	9.33	1.20
Feb. 5	11.6	55.2	235	9.59	1.10
12	11.6	54.9	232	9.45	1.00
19	11.8	54.9	226	9.30	1.13
26	12.2	54.9	–	–	–
Mar. 4	13.0	54.9	224	9.25	0.82
11	13.2	54.8	226	9.69	1.13
18	12.4	54.8	223	10.17	0.81
25	11.5	55.0	–	–	–
Apr. 1	12.0	54.8	216	9.49	0.78
8	11.6	55.2	228	9.50	0.89
15	12.0	54.8	228	9.55	0.64
22	11.7	55.0	228	–	–
29	12.0	54.8	220	9.28	0.86
May 6	12.1	55.0	224	9.73	0.88
13	11.1	55.1	238	9.86	0.77
20	–	–	–	–	–
27	11.6	54.4	243	9.50	0.71
June 3	12.3	55.0	231	9.40	0.88
10	–	–	–	–	–
17	–	–	–	–	–
24	12.0	54.8	246	9.46	0.64

Table 6. continued

	No. 634				
	Flow rate 1/min.	Temp. °C	Cl mg/1	N_2+A cc/1	O_2 cc/1
1959					
May 8	39.0	46.0	–	–	–
15	43.0	46.1	–	–	–
22	45.9	46.0	104	6.65	1.14
29	50.3	46.0	104	–	–
June 5	50.3	46.0	104	6.56	1.05
12	50.3	45.8	99	6.62	1.25
19	52.0	45.8	95	6.26	1.18
26	53.8	45.8	90	–	–
July 3	48.8	45.8	88	6.04	1.21
10	52.0	45.7	95	6.20	1.39
17	48.8	45.5	97	6.20	1.21
24	52.0	45.5	94	5.76	1.21
31	55.7	45.7	94	6.05	1.10
Aug. 7	55.7	45.7	97	–	–
14	57.8	45.7	102	5.94	1.12
21	48.8	45.8	–	–	–
28	53.8	45.9	108	5.72	1.23
Sept. 4	57.8	45.8	–	5.34	1.30
11	57.8	46.0	102	5.37	0.98
18	55.7	46.0	107	5.48	1.10
25	55.7	46.0	110	5.44	1.17
Oct. 2	60.0	46.0	–	5.51	1.10
9	57.8	46.0	–	5.48	1.17
16	53.8	46.1	115	–	1.31
23	55.7	46.1	106	5.62	1.13
30	53.8	46.2	–	5.66	1.13
Nov. 6	53.8	46.3	112	6.05	1.32
13	52.0	46.2	104	5.77	1.10
20	50.3	46.4	104	5.79	1.29
27	48.8	46.5	101	5.70	1.31
Dec. 4	52.0	46.5	108	6.19	1.21
11	48.8	46.5	101	5.77	1.42
18	45.9	46.5	102	5.80	1.24
25	48.8	46.7	–	5.83	1.38
31	48.8	46.7	–	–	–
1960					
Jan. 8	48.8	46.5	115	5.84	1.49
15	47.3	46.6	–	–	–
22	47.3	46.7	–	5.98	1.55
29	44.6	44.6	100	6.12	1.60
Feb. 5	47.3	46.8	100	5.96	1.18
12	45.9	46.5	108	6.04	1.38
19	41.1	46.5	102	6.00	1.38
26	40.0	46.5	107	5.71	1.11
Mar. 4	39.0	46.3	108	5.79	1.40
11	42.2	46.3	98	5.69	1.34
18	41.1	46.3	92	–	1.45
25	40.0	46.3	101	5.94	1.25
Apr. 1	38.0	46.1	99	6.04	1.39
8	43.3	46.1	95	5.96	1.31
15	42.2	46.0	96	6.22	1.20
22	41.1	46.0	95	6.22	1.26
29	39.0	46.0	95	5.94	1.27
May 6	41.1	46.0	98	5.65	1.14
13	40.0	46.0	110	5.94	1.24
20	40.0	45.7	111	6.30	1.02
27	45.7	46.0	108	5.98	1.13
June 3	41.1	45.7	108	5.90	1.24
10	39.0	45.7	110	–	1.06
17	39.3	45.5	–	–	–
24	43.3	45.5	103	6.28	1.30

Table 6. continued

	No. 751				
	Flow rate 1/min.	Temp. °C	Cl mg/1	N_2+A cc/1	O_2 cc/1
1959					
May 8	5.9	52.5	–	–	–
15	5.7	52.5	–	–	–
22	5.9	52.5	102	5.95	1.71
29	5.4	52.5	–	–	–
June 5	5.5	52.9	99	6.02	1.64
12	5.5	52.8	97	5.50	1.53
19	5.6	52.9	92	5.30	1.53
26	5.6	53.0	–	–	1.46
July 3	5.2	53.0	92	5.66	1.60
10	5.5	53.0	94	5.55	1.45
17	6.1	53.0	92	5.76	1.52
24	5.8	53.0	95	5.59	1.07
31	5 7	53.0	90	5.34	1.00
Aug. 7	6.3	53.0	97	5.76	1.49
14	6.6	53.0	94	5.74	1.57
21	6.0	53.0	–	–	–
28	6.1	53.0	99	–	–
Sept. 4	6.2	53.0	103	5.80	1.49
11	6.4	53.1	–	5.69	1.45
18	6.3	53.0	101	5.51	1.46
25	6.4	53.0	96	6.00	1.73
Oct. 2	6.3	53.0	–	–	–
9	6.6	53.0	96	5.87	1.77
16	5.5	52.9	94	–	–
23	6.5	53.0	96	5.51	1.54
30	6.6	53.0	91	5.80	1.59
Nov. 6	7.0	53.0	96	5.62	1.70
13	6.3	53.0	94	6.18	1.75
20	6.5	53.2	95	5.99	1.89
27	6.2	52.9	94	5.99	1.92
Dec. 4	6.5	53.0	92	5.64	1.60
11	6.7	53.0	91	–	–
18	6.5	53.0	94	5.75	1.68
25	6.4	52.9	–	5.84	1.85
31	6.5	53.0	–	–	–
1960					
Jan. 8	5.8	51.5	99	–	–
15	5.9	53.0	–	–	–
22	6.2	53.0	92	–	–
29	5.4	52.8	95	6.04	1.89
Feb. 5	5.5	52.7	107	6.05	1.78
12	5.8	53.0	95	5.82	1.68
19	5.9	53.0	93	5.84	1.57
26	5.7	53.0	93	5.98	1.63
Mar. 4	5.7	53.0	91	–	–
11	6.3	53.2	87	5.96	1.74
18	5.7	53.0	95	5.90	1.79
25	5.5	53.0	100	–	1.73
Apr. 1	5.5	52.8	99	5.69	1.51
8	5.2	53.0	97	–	–
15	5.6	53.0	96	5.58	1.23
22	5.6	53.0	99	5.90	1.80
29	6.1	53.1	101	6.00	1.79
May 6	5.8	53.1	93	5.76	1.77
13	5.3	53.1	93	5.55	1.43
20	6.2	53.5	96	–	–
27	5.5	54.2	103	5.84	1.75
June 3	6.5	53.7	97	–	–
10	6.2	53.5	101	6.00	1.75
17	4.2	53.0	–	–	–
24	6.8	53.7	95	5.51	1.45

Table 6. continued

	No. 971				
	Water level cm	Temp. °C	Cl mg/l	N_2+A cc/l	O_2 cc/l
1959					
May 8	831	24.7	57	11.70	5.55
15	821	24.8	53	11.59	5.15
22	807	24.9	58	11.43	5.50
29	805	25.1	–	–	–
June 5	803	25.2	53	11.40	5.34
12	796	25.3	60	11.38	5.05
19	792	25.6	51	11.72	5.40
26	784	26.0	55	11.41	5.27
July 3	785	26.2	62	11.95	4.84
10	775	26.4	64	10.90	4.64
17	761	26.5	62	10.75	4.54
24	741	26.8	60	10.60	4.46
31	735	26.8	62	–	–
Aug. 7	733	27.0	64	11.00	4.13
14	660	27.0	71	11.18	–
21	646	27.5	–	–	–
28	644	28.2	65	11.25	4.46
Sept. 4	644	28.6	67	10.90	4.29
11	647	29.0	67	10.85	4.43
18	641	29.4	72	10.68	–
25	639	29.6	78	10.75	4.61
Oct. 2	642	29.8	79	10.52	4.59
9	641	30.2	82	10.42	4.66
16	656	30.5	76	10.47	4.52
23	662	31.1	84	10.30	4.56
30	668	31.6	97	–	–
Nov. 6	672	32.2	92	9.86	4.36
13	682	32.2	94	10.00	4.38
20	691	32.6	102	9.69	4.49
27	699	32.8	97	9.79	4.57
Dec. 4	708	33.1	94	9.65	4.48
11	715	33.4	95	9.72	4.63
18	727	33.5	97	9.84	4.59
25	735	33.6	93	9.75	4.43
31	738	34.2	–	–	–
1960					
Jan. 8	755	33.6	92	9.65	4.59
15	763	34.0	–	–	–
22	772	33.4	87	9.90	4.80
29	782	32.8	88	9.94	4.66
Feb. 5	795	32.8	81	–	–
12	801	32.8	79	10.02	4.63
19	809	32.6	83	–	–
26	820	33.4	79	9.94	4.17
Mar. 4	825	32.0	77	9.86	4.66
11	835	31.5	77	10.00	4.71
18	843	31.0	72	10.02	4.66
25	841	30.6	68	–	5.02
Apr. 1	849	30.2	73	10.13	5.00
8	861	29.8	80	10.49	5.05
15	856	30.0	73	10.47	4.79
22	859	29.7	76	–	–
29	855	30.3	72	10.52	5.05
May 6	855	30.4	67	10.25	4.63
13	855	29.6	80	10.90	4.82
20	853	30.0	77	10.63	4.95
27	850	30.4	69	10.52	5.05
June 3	845	30.2	67	10.52	4.97
10	847	30.2	64	10.57	4.42
17	835	30.2	67	10.36	4.74
24	809	30.8	61	10.40	4.21

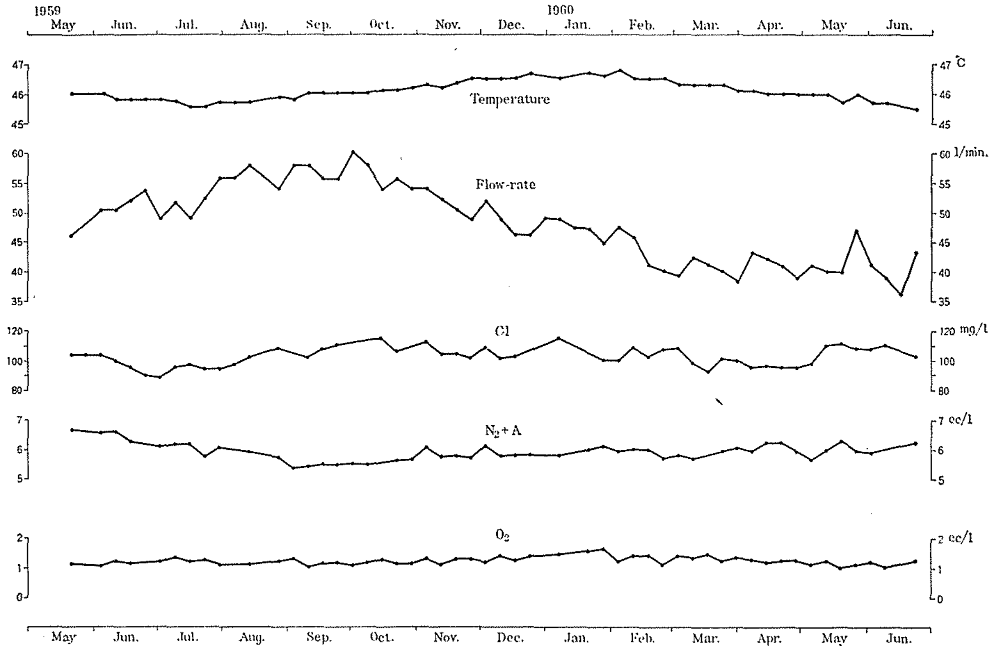

Fig. 11. An example of annual variation of flow rate, temperature, chlorine, nitrogen and oxygen in a hot spring.

not mix with the hot water directly, because the variation of chlorine, nitrogen and oxygen are little in comparison with that of flow rate, so the rain seems to foster a fundamental source of the hot spring. For the springs, No. 472, No. 751 and No. 634, the trends of the annual variation are the same as the above example.

No. 971 indicates a well in the precincts of the Miyajidake Shrine, bottom of which is about 9m under ground surface. The past investigators[15] showed that hot water and cool ground-water mix each other in this well, and the water level and the temperature change remarkably and irregularly. Fig. 12 shows that the relation between level and temperature changes are not simple like the past state, while the temperature rise corresponds to chlorine increasing and nitrogen decreasing. Therefore, it seems to exhibit realistically that the hot water contains much chlorine and little nitrogen and its mixing ratio varies seasonably.

7. Conclusions

(1) The relation between the flow temperature and the nitrogen contents differs wholly from the Winkler's solubility curve, that is, supersaturation predominates at low and moderate temperatures, and excessive unsaturation at high temperature.

(2) One of the causes of the apparent supersaturation may be a biochemical reaction,

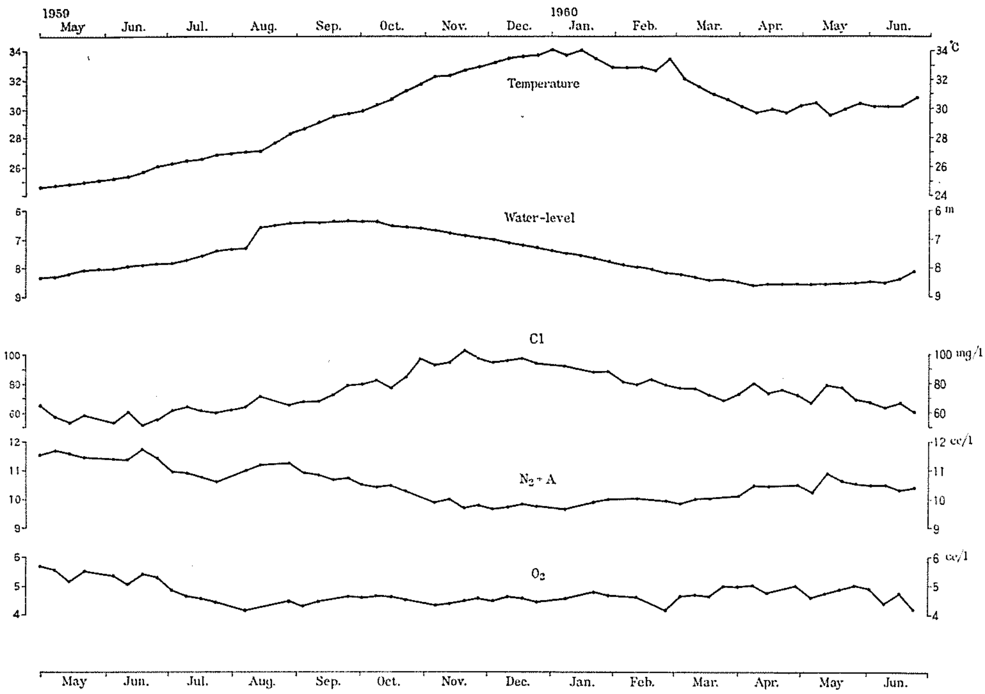

Fig. 12. Annual variations of water level, temperature, chlorine, nitrogen and oxygen in a shallow well, where it has known that hot water and cold ground water mix with each other.

and the hot water is desirable to be artesian to keep this supersaturation. While, we can illustrate the nitrogen as coming from the air, because even the maximum contents is less than the solubility at 0 °C when the water and the air are in equilibrium at one atmospheric pressure, and the pressure required to sustain the nitrogen up to high temperature is about ten odd meters of water column.

(3) Remarkable unsaturation of the nitrogen in the high-temperature hot springs refers to its escape from the water with the boiling or the exhaustion of other gases, and it is not general to assume that the magmatic water which has little nitrogen occupies the main part of the hot-spring water.

(4) Oxygen contents is little in both springs extremely rich and poor in nitrogen, much in springs of moderate nitrogen. Consumption of oxygen in the meteoric hot water contributes to make oxygen-poor water, and geographical distribution of the quantity of oxygen consumption may suggest the route of underground flow of hot water.

(5) Hot water gushing out from the deeper ground contains a little nitrogen in some spas, and much nitrogen in others. In the former case, as the hot waters mix with the usual ground-water, they become tepid and nitrogen-rich as seen in Beppu and

Kamegawa, while in the latter, tepid but nitrogen-poor as in Uchinomaki and Yuda. (6) Nitrogen contents in hot-spring water varies with the time. The appreciable variations by tide are found in some springs near the sea shore but the correlation between nitrogen and tide is positive or negative for individual spring. Effect of precipitation on the nitrogen is little except a particular shallow well, that is, even if the flow rate widely vary seasonably, nitrogen keeps nearly constant, and this fact may show that the rain recharges the essential source of hot spring but does not dilute the hot water.

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