

Geochemical Study of Ground Waters in the Matsushiro Area

Part 1: Chemical Composition of Ground Waters

By Yasushi KITANO*, Ryuma YOSHIOKA*,
Setsuo OKUDA** and Kazuo OKUNISHI**

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Abstract

The authors determined the chemical composition of ground waters in the Matsushiro area from September 1966. In this paper, we show the time change in the chemical composition of ground waters taken from September 1966 to February 1967, and discuss the origin of the ground waters.

From the investigation it was found that the change in the chemical composition has a relation to the occurrence of the Matsushiro swarm earthquakes.

Introduction

The Matsushiro swarm earthquakes occurred in and around the Matsushiro town area of Nagano Prefecture in August 1965.¹⁻⁵⁾ The total number of earthquakes was counted as 630,935 and the number of felt earthquakes was counted as 59,484 between August 1965 and January 1967.

Three very active periods with frequent earthquakes were observed: the first active period was November 1965, and on the 22nd of November 1965 the total number of earthquakes was counted as 2,000 and the number of felt earthquakes was counted as 229; the second active period was from March to May 1965, and on the 17th of April 1966 the total number of earthquakes was counted as 6,780 and the number of felt earthquakes was counted as 661; and the third active period was from August to September 1966, and the total number of earthquakes was counted as 5,100 and the number of felt earthquakes was counted as 540.

Originally, the seismic area lay near Mt. Minakami which is situated east of Matsushiro town. The seismic area extended to the northern part of Nagano city, the Kōsyoku city area and further to the Obasute area. The area of the Matsushiro swarm earthquakes is estimated at 40 km×20 km. The felt earthquakes occurred most frequently in a circular area with a radius of 6 km, the center lying in the vicinity of Mt. Minakami.

The hypocenter of the swarm earthquakes is within 10 to 20 km under the ground. Because of the shallow hypocenter, the damage from earthquakes was limited to particular localities. The damage from landslides was caused after the third active period (of August 1966). In January 1966 five cracks were first

* Water Research Laboratory, Faculty of Science, Nagoya University, Nagoya.

** Disaster Prevention Research Institute, Kyoto University, Kyoto.

observed in the Sezeki and Takehara areas. The amount of hot spring waters increased in the Kagai and Tennozsan areas which are northwest of Mt. Minakami, and ground waters in large amounts gushed out at many locations near the foot of Mt. Minakami. After the middle of August 1966, there were ground upheavals of about 30 cm per month, and the five above mentioned cracks soon became large. From the end of August 1966, many cracks and large amounts of ground waters were observed at many places in the seismic areas, such as the Sezeki, Makinouchi, Takimoto and Sugama areas. Then three landslides occurred, at first in the Makiuchi area on the 17th of September, secondly in the Kirikubo area on the 25th of September, and thirdly in the Nishidairayama area on the 9th of October 1966. Tremendous amounts of ground waters gushed out in these areas.

A positive relationship between the activity of the swarm earthquakes, the amount and the concentration of chemical constituents of ground waters in the area has been observed.⁶¹ It seems possible that a change in the conditions under the ground can be expected through a change in the chemical composition of the ground waters. Knowledge of conditions under the ground is both useful and important for understanding the mechanism of the occurrence of the swarm earthquakes.

The authors measured the change with time in the chemical compositions of ground waters. That is, since September 1966 ground water samples were taken monthly and the chemical compositions were determined. We were very sorry that we did not take ground water samples before September 1966.

In this paper, we will discuss the origin of ground waters with reference to the chemical compositions of ground water samples taken from September 1966 to February 1967.

1. Hydrology of the areas surveyed

The hydrological research of springs in this area was carried out from the 19th to 22nd of September 1966 just after the landslide in the Makiuchi area. The spring waters on the line between the Kagai and Sezeki areas were relatively hot and contained bubbles of CO₂ gas, while those of the Makiuchi and Kaminoyama areas were of normal temperature and contained no bubbles of CO₂. The discharge of spring waters in the Makiuchi area was 117 l/sec and that in the Kaminoyama area was 300 l/sec.

The landslides in the Makiuchi and Nishidairayama areas were characterized by a sudden gushing-out of spring waters. Because the rainfall preceding these landslides was not unusually heavy, it could not have been the main cause of these landslides. The amount of rainfall is shown in Fig. 1. Thereafter the discharge of waters from springs and the test borings were measured continuously in the Sezeki and Sugama areas by the office of Nagano Prefecture, and in the Makiuchi and Nishidairayama areas by the authors and they show a general trend towards decreasing (See Fig. 2). Assuming the decrease to be exponential, the total discharge of spring waters in the Makiuchi and Kaminoyama areas is calculated to be $1.12 \times 10^6 \text{ m}^3$, which is equivalent to the rainfall in these areas in 2.3 years. The values calculated are given in Table 1.

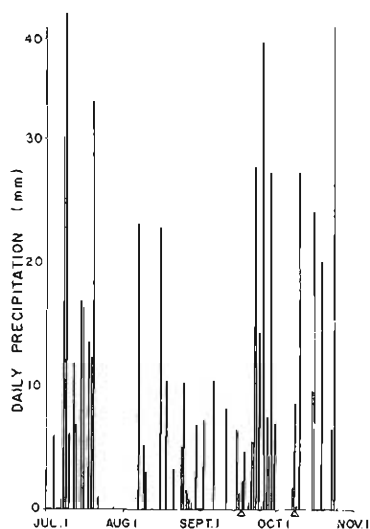


Fig. 1. Daily precipitation on Mt. Chausuyama near Matsushiro town in 1966. Δ : Occurrence of landslides.

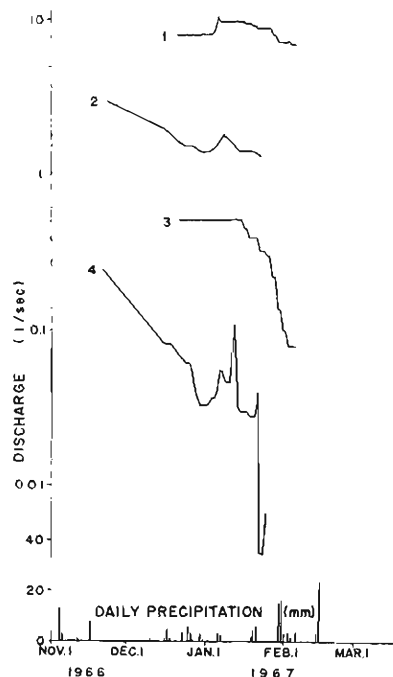


Fig. 2. Discharge rate of water from the springs and the test borings. 1: the spring in the Makiuchi area (sampling station No. 1), 2: the spring in the Sezeki area, 3: the spring in the Nishidairayama area (sampling station No. 8), 4: the test boring in the Sugama area.

TABLE 1.

Comparison of the amount of rainfall at Chausuyama near the Matsushiro town with the discharge of spring waters in the Makiuchi and Kaminoyama areas.

Discharge of spring waters on September 21st, 1966	417 l/sec	1455 mm/month or 17450 mm/year
Time constant of the decrease of discharge	Ca 50 days	Ca 50 days
Total amount of discharge as the product of the about two	$1.12 \times 10^6 \text{ m}^3$	2420 mm
Annual rainfall as the average of 1965 and 1966	$4.83 \times 10^5 \text{ m}^3$	1028 mm
Rainfall from January 1st to September 17th, 1966	$2.91 \times 10^5 \text{ m}^3$	695 mm

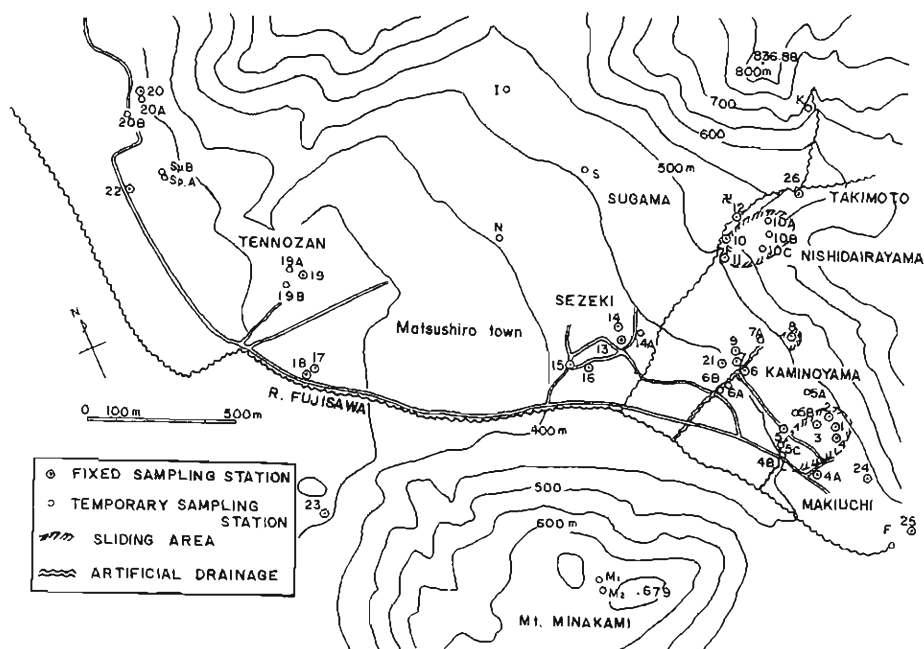


Fig. 3. Location of the water sampling stations.

2. Experimental

Sampling of ground waters: The locations for sampling ground waters are given in Fig. 3. Ground waters were collected monthly.

Analytical method: Temperature and pH values were measured in the field and chemical constituents such as Na^+ , Ca^{2+} , Mg^{2+} , Cl^- , SO_4^{2-} , HCO_3^- , borate-B and soluble SiO_2 were determined in the laboratory of the Disaster Prevention Research Institute, Kyoto University.

pH : Glass electrode-pH meter or colorimetric method.

Na^+ : Flame photometric method.

Ca^{2+} : Titration method with EDTA standard solution and Dotite NN (2-hydroxy-1-(2-hydroxy-4-sulfo-1-naphthylazo)-3-naphthonic acid) indicator.

Mg^{2+} : Titration method with EDTA standard solution and Dotite NN and EBT indicators.

Cl^- : Titration method with silver nitrate standard solution and potassium chromate indicator or colorimetric method with mercury thiocyanate.⁷⁾

SO_4^{2-} : Gravimetric method as barium sulfate or colorimetric method with barium chromate and diphenylcarbazide.⁸⁾

HCO_3^- : Titration method with hydrochloric standard solution and bromocresol purple indicator.

Soluble SiO_2 : Colorimetric method with ammonium molybdate.⁹⁾

Borate-B : Colorimetric method with curcumin¹⁰⁾ or titration method.

TABLE 2.
Chemical Composition of ground waters in the Matsushiro area (September 1966)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l	Remarks
1	21	14.6	7.2	25	73	21	63	128	112	29	
2	"	15.4	7.4	20	51	22	51	89	87	31	
4A	"	13.4	7.7	11	23	1	14	65	28	20	1 m ³ /min
4B	"	16.0	8.0	21	57	17	48	100	111	27	
5	"	"	6.9	14	53	7	18	40	59	34	
5A	"	13.0	7.0	8	16	4	4	46	21	44	
5B	"	"	6.4	16	31	8	16	77	51	28	
5C	"	17.8	7.6	15	47	7	22	52	68	40	6 m ³ /min
6	"	15.0	"	36	69	8	94	87	59	49	
6A	"	17.6	6.1	17	60	6	54	34	103	37	
6B	"	15.1	7.5	36	133	26	211	132	123	60	18 m ³ /min
7	"	15.2	6.9	36	188	20	277	134	113	40	
7A	"	15.7	6.5	91	300	103	586	406	176	43	
8	"	13.5	5.8	28	5	3	6	30	45	45	
12	"	13.1	7.9	9	31	2	7	37	40	34	
13	"	14.6	6.0	105	269	31	486	276	122	50	
14	"	19.0	6.0	420	809	164	1851	1126	225	61	300 l/min bubbling CO ₂
19	"	27.4	7.3	61	69	15	90	193	102	65	bubbling CO ₂
19A	"	15.2	6.2	38	12	16	20	73	79	53	
19B	"	14.7	6.1	33	15	16	21	96	53	42	
20	"	20.4	6.7	46	237	50	342	464	86	60	80 l/min
20A	"	19.8	7.3	25	110	10	102	238	29	50	80 l/min
20B	"	24.7	6.4	1380	349	15	1974	1662	146	86	bubbling CO ₂
F	"	13.5	7.7	28	108	4	33	30	245	18	
I	"	14.9	7.6	5	8	2	4	33	6	39	
K	"	17.5	8.2	5	8	6	3	24	10	34	
M ₁	22	16.6	5.9	10	44	8	9	10	121	33	
M ₂	"	16.8	6.8	6	15	1	7	29	18	21	
N	21	16.6	6.2	29	100	23	124	90	64	65	
S	"	15.2	6.1	46	294	69	527	438	40	60	

TABLE 3.
Chemical Composition of ground waters in the Matsushiro area (October 1966)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l	Borate -B mg/l	Remarks
1	28th	15.0	7.1	86	378	83	585	512	213	31	13	
2	"	13.5	6.9	73	387	131	735	521	232	35		
3	"	14.2	6.6	88	417	145	770	540	210	39	17	
5	"	13.4	6.4	18	77	16	87	76	75	43		
6	"	15.5	7.2	130	499	222	1242	585	207	54	28	
7	"	16.0	6.6	195	736	208	1593	790	223	68	42	
8	"	13.5	6.4	48	98	25	215	90	101	45	1.4	
10A	"	12.2	7.5	65	129	106	395	117	226	31	3.6	
10B	"	12.8	7.1	80	166	156	475	116	419	33		
10C	"	12.6	6.4	77	214	138	623	200	196	39		
11	"	12.2	7.3	53	171	79	351	203	175	31		
12	"	12.2	7.3	53	211	36	314	116	139	30		
13	29th	14.5	6.2	103	302	56	575	321	130	47		
14	"	18.4	6.1	750	1187	273	3076	1496	288	79	105	bubbling CO ₂
14A	28th	20.5	6.0	740	1389	219	3187	1513	367	77		bubbling CO ₂
19	"	27.8	7.3	78	88	17	139	249	82	48		bubbling CO ₂
20	"	20.5	6.7	118	341	66	539	696	71	59	13	
N	"	13.8	6.2	145	478	132	1134	488	63	49	48	

TABLE 4.
Chemical Composition of ground waters in the Matsushiro area (November 1966)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l	Borate -B mg/l
1	19	15.7	6.8	190	688	154	1213	860	291	41	30
2	"	14.8	6.8	101	543	183	1124	695	263	40	
3	"	14.7	6.6	127	585	186	1137	733	248	32	27
4	"	15.0	6.6	89	384	78	594	497	209	31	13
5	"	13.5	6.2	27	111	25	188	105	75	38	
6	"	14.8	7.4	171	592	286	1539	708	207	51	34
7	"	15.5	6.6	256	857	275	1933	941	276	65	50
8	"	13.5	6.6	57	113	66	316	135	94	47	3.1
9	"	15.0	6.4	186	572	194	1291	700	238	67	
10	"	10.5	8.2	111	272	193	768	274	347	42	10
11	"	11.5	7.6	71	222	110	480	292	221	35	7.0
12	"	12.0	7.2	70	221	59	375	306	192	33	
13	23	13.3	6.9	100	305	113	667	418	121	46	11
14	"	19.6	6.1	665	1332	296	3104	1593	316	70	96
15	"	15.5	6.8	26	46	12	51	101	46	52	0.4
16	"	16.2	7.1	25	66	15	87	128	45	56	
17	"	21.4	7.3	49	50	12	63	190	43	48	0.9
18	"	20.5	7.4	46	51	13	69	197	33	44	
19	"	28.0	7.3	86	79	32	145	256	121	50	2.3
20	"	21.3	6.8	197	403	85	717	844	84	46	18

TABLE 5.
Chemical Composition of ground waters in the Matsushiro area (December 1966)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l	Borate -B mg/l
1	25	16.2	6.3	285	966	203	1841	1101	365	46	48
2	"	14.0	6.7	173	766	254	1622	932	268	46	
3	"	14.5	6.5	179	796	235	1605	962	303	45	38
4	"	14.0	6.5	150	579	114	978	690	234	37	
8	"	12.0	6.5	72	168	111	495	205	162	49	6.1
9	"	15.8	6.5	212	683	237	1581	826	285	70	36
10	"	6.9	8.2	143	336	246	1024	406	379	46	16
11	"	10.0	7.6	102	275	128	603	369	256	38	
12	"	11.6	7.3	85	237	85	428	344	188	40	7.5
13	"	11.5	7.2	105	410	107	795	510	134	48	15
14	"	19.0	6.2	600	1660	357	3548	1794	328	72	101
16	"	16.0	7.2	42	103	16	136	164	58	62	
17	"	20.3	7.6	47	46	14	67	199	41	74	0.9
18	"	19.5	7.5	48	52	15	72	204	34	50	
19	"	28.0	7.2	87	86	18	145	246	82	58	
20	"	22.5	6.7	230	437	83	826	871	92	73	
21	"	15.0	6.7	240	772	300	1890	915	283	65	44
22	"	35.0	6.2	735	607	153	1957	1140	186	86	62

TABLE 6.
Chemical Composition of ground waters in the Matsushiro area (January 1967)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l	Borate -B mg/l
1	12	16.3	6.2	290	1077	222	2128	1186	370	48	54
2	"	13.2	6.7	193	826	264	1802	964	291	46	
3	"	14.9	6.3	187	884	246	1815	1045	293	42	
4	"	15.8	6.1	162	683	111	1173	741	267	37	
8	13	13.1	6.4	70	193	127	581	241	169	46	
9	"	16.0	6.4	165	732	252	1722	879	299	68	
10	"	6.0	8.2	139	340	204	1085	423	373	42	
11	"	9.9	7.5	105	297	126	644	396	288	38	
12	"	11.0	7.3	77	249	56	428	346	196	40	
13	"	11.0	7.3	103	455	116	912	555	147	48	
14	"	18.5	6.2	520	1616	388	3650	1815	323	73	
16	15	15.8	7.2	37	97	34	180	194	67	58	1.6
17	"	21.0	7.6	46	45	12	60	190	36	72	
18	"	19.9	7.5	41	52	15	78	202	36	46	
19	"	27.3	7.5	72	78	22	148	251	97	54	
20	"	21.7	6.7	228	441	85	876	880	100	66	21
21	13	15.4	6.7	270	815	323	2049	965	270	60	48
22	15	35.7	6.5	733	608	148	2070	1142	197	80	
23	"	15.9	7.6	23	20	9	39	106	24	62	
24	12	12.0	7.1	80	131	46	191	186	278	18	
25	"	13.0	6.7	142	600	228	1270	804	341	25	20

TABLE 7.
Chemical Composition of ground waters in the Matsushiro area (February 1967)

Station No.	Day of Sampling	Water temp. °C	pH	Na ⁺ mg/l	Ca ²⁺ mg/l	Mg ²⁺ mg/l	Cl ⁻ mg/l	HCO ₃ ⁻ mg/l	SO ₄ ²⁻ mg/l	Soluble SiO ₂ mg/l
1	25	16.8	6.5	350	1290	271	2619	1318	389	50
2F	"	16.0	6.6	320	1180	306	2414	1258	374	50
8	"	13.3	6.6	80	230	153	686	280	171	50
9	"	15.8	6.6	281	843	290	1992	964	321	73
10	"	5.5	8.0	133	272	197	867	342	310	37
11	"	8.2		55	127	62	315	153	112	32
12	"	9.0	7.1	37	98	33	168	142	84	38
13	"	11.2	6.9	86	384	96	781	440	94	49
14	"	18.3	6.4	550	1727	416	3849	2291	343	82
16	"	16.1	7.0	46	146	43	272	253	67	62
17	"	20.5	7.5	51	52	9	74	191	35	56
18	"	19.7	7.5	45	55	15	83	209	34	49
19	"	28.0	7.4	87	81	24	169	272	69	56
20	"	22.0	6.6	235	405	87	843	784	96	71
21	"	16.9	6.1	334	1058	342	2493	1161	336	72
22	"	35.0	6.4	820	616	158	2054	1132	166	76
23	"	16.0	7.5	34	20	10	43	108	32	49
24	"	12.0	7.3	85	139	54	259	191	214	20

TABLE 8.
Chemical Composition of ground waters in the Matsushiro area (September 1966)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	1.1	3.6	1.7	17	56	27	1.8	2.1	2.3	29	34	37
2	0.9	2.5	1.8	17	49	35	1.4	1.5	1.8	30	31	39
4A	0.5	1.1	0.1	28	67	5	0.4	1.1	0.6	20	52	28
4B	0.9	2.8	1.4	18	55	27	1.4	1.6	2.3	25	31	44
5	0.6	2.6	0.6	16	69	15	0.5	0.7	1.2	21	28	51
5A	0.3	0.8	0.3	22	55	23	0.1	0.8	0.4	9	58	33
5B	0.7	1.5	0.7	24	53	23	0.5	1.3	1.0	16	46	38
5C	0.7	2.3	0.6	18	66	16	0.6	0.9	1.4	21	30	49
6	1.6	3.4	0.7	28	60	12	2.6	1.4	1.2	50	27	23
6A	0.7	3.0	0.5	17	71	12	1.5	0.6	2.1	37	13	50
6B	1.6	6.6	2.1	15	64	21	5.9	2.0	2.6	57	19	24
7	0.7	9.4	1.6	12	74	13	7.8	2.0	2.4	64	17	19
7A	4.0	15.0	8.5	15	55	31	16.5	6.7	3.7	61	25	14
8	1.2	0.3	0.2	70	16	14	0.2	0.5	0.9	10	31	59
12	0.4	1.5	0.2	18	74	8	0.2	0.6	0.8	13	37	50
13	4.5	13.4	2.5	22	65	13	13.7	4.5	2.5	66	22	12
14	18.3	40.4	13.5	25	56	19	52.2	18.4	4.7	70	24	6
19	2.7	3.4	1.2	36	47	17	2.5	3.2	2.1	33	40	27
19A	1.7	0.6	1.3	46	17	37	0.6	1.2	1.6	17	35	48
19B	1.4	0.7	1.3	41	21	38	0.6	1.6	1.1	18	48	34
20	2.0	11.8	4.1	11	66	23	9.7	7.6	1.8	51	40	9
20A	1.1	5.5	0.8	15	74	11	2.9	3.9	0.6	39	53	8
20B	60.0	17.4	1.2	76	22	2	55.7	27.6	3.0	64	32	4
F	1.2	5.4	0.3	18	78	4	0.9	0.5	5.1	14	8	78
I	0.2	0.4	0.1	26	52	21	0.1	0.5	0.1	14	69	16
K	0.2	0.4	0.5	19	36	45	0.1	0.4	0.2	11	59	30
M ₁	0.4	2.2	0.7	13	67	20	0.3	0.2	2.5	9	6	85
M ₂	0.3	0.7	0.1	25	67	8	0.2	0.5	0.4	19	45	36
N	1.3	5.0	1.9	15	62	23	3.5	1.5	1.3	55	23	22
S	2.0	14.7	5.7	9	66	25	14.9	7.3	0.8	64	32	4

TABLE 9.
Chemical Composition of ground waters in the Matsushiro area (October 1966)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	3.7	18.9	6.8	13	64	23	16.5	8.4	4.4	56	29	15
2	3.2	19.3	10.9	10	58	32	20.7	8.5	4.8	61	25	14
3	3.8	20.1	11.9	11	56	33	21.7	8.9	4.4	62	25	13
5	0.8	3.8	1.3	13	65	22	2.4	1.3	1.6	81	8	11
6	7.8	24.9	18.3	15	49	36	35.0	9.6	4.3	71	20	9
7	8.5	36.7	17.1	14	59	27	44.9	13.0	4.6	72	21	7
8	2.1	4.9	2.1	23	54	23	6.1	1.5	2.1	63	15	22
10A	2.8	6.4	8.7	16	36	48	11.1	1.9	4.7	63	11	26
10B	3.5	8.3	12.8	14	34	52	13.4	1.9	8.7	56	8	36
10C	3.4	10.7	11.3	13	42	45	17.6	3.3	4.1	71	13	16
11	2.3	8.6	6.5	13	49	38	9.9	3.3	3.7	58	19	23
12	3.2	10.5	3.0	19	63	18	8.9	1.9	2.9	65	14	21
13	4.5	15.1	4.6	19	62	19	16.2	5.3	2.7	67	22	11
14	32.6	59.2	22.5	29	52	19	86.8	24.5	6.0	74	21	5
14A	32.2	69.3	18.0	27	59	15	89.9	24.8	7.7	74	20	6
19	3.4	4.4	1.4	37	48	15	3.9	4.1	1.7	77	16	7
20	5.1	17.0	5.4	19	62	19	15.2	11.4	1.5	54	41	5
N	6.3	23.9	10.9	15	58	27	32.0	8.0	1.3	78	19	3

TABLE 10.
Chemical Composition of ground waters in the Matsushiro area (November 1966)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	8.3	34.4	12.6	15	62	23	34.2	14.1	6.1	63	26	11
2	4.4	27.2	15.0	10	59	31	31.7	11.4	5.5	65	24	11
3	5.5	29.3	15.2	11	59	30	32.0	12.0	5.2	65	24	11
4	3.9	19.2	6.4	13	65	22	16.7	8.2	4.4	57	28	15
5	1.2	5.6	2.1	13	63	24	5.3	1.7	1.6	62	20	18
6	7.4	29.6	23.4	12	49	39	43.4	11.6	4.3	73	20	7
7	11.1	42.9	22.5	15	56	29	54.5	15.4	5.8	72	20	8
8	2.5	5.7	5.4	18	42	40	8.9	2.2	2.0	68	17	15
9	8.1	28.6	15.9	16	54	30	36.4	11.5	5.0	69	22	9
10	4.8	13.6	15.8	14	40	46	21.6	4.5	7.2	65	13	22
11	3.1	11.1	9.0	13	48	39	13.5	4.8	4.6	59	21	20
12	3.0	11.1	4.8	16	59	25	10.6	5.0	4.0	54	26	20
13	4.4	15.3	9.3	15	53	32	18.8	6.9	2.5	67	24	9
14	28.9	66.6	24.3	24	56	20	87.4	26.0	6.6	73	22	5
15	1.1	2.3	1.0	26	52	22	1.4	1.7	1.0	35	41	24
16	1.1	3.3	1.2	19	59	22	2.5	2.1	0.9	45	38	17
17	2.0	2.5	1.0	36	46	18	1.8	3.1	0.9	31	54	15
18	2.0	2.6	1.1	35	46	19	2.0	3.2	0.7	33	55	12
19	3.7	4.0	2.6	36	38	26	4.1	4.2	2.5	38	39	23
20	8.6	20.2	7.0	24	57	19	20.2	13.8	1.8	56	39	5

TABLE 11.
Chemical Composition of ground waters in the Matsushiro area (December 1966)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	12.4	48.3	16.6	16	63	21	51.9	18.0	7.6	67	23	10
2	7.5	38.3	20.8	11	58	31	45.7	15.3	5.6	69	23	8
3	7.8	39.8	19.3	12	59	29	45.2	15.8	6.3	67	24	9
4	6.5	29.0	9.3	14	65	21	27.5	11.3	4.9	63	26	11
8	3.1	8.4	9.1	15	41	44	13.9	3.4	3.4	68	16	16
9	9.2	34.2	19.4	15	54	31	44.5	13.5	5.9	70	21	9
10	6.2	16.8	20.2	14	39	47	28.8	6.7	7.9	67	15	18
11	4.4	13.8	10.5	15	48	37	17.0	6.1	5.3	59	23	18
12	3.7	11.9	6.9	16	53	31	12.1	5.6	3.9	56	26	18
13	4.6	20.5	8.8	13	61	26	22.4	8.4	2.8	67	25	
14	26.1	83.0	29.3	19	60	21	99.9	29.4	6.8	73	22	5
16	1.8	5.2	1.3	22	62	16	3.8	2.7	1.2	49	35	16
17	2.1	2.3	1.2	38	41	21	1.9	3.3	0.9	32	54	14
18	2.1	2.6	1.2	36	44	20	2.0	3.3	0.7	33	55	12
19	3.8	4.3	1.5	40	45	15	4.1	4.0	1.7	42	41	17
20	10.0	21.9	6.8	26	57	17	23.3	14.3	1.9	60	36	4
21	10.4	38.6	24.7	14	53	33	53.2	15.0	5.9	72	20	8
22	32.0	30.4	12.5	43	40	17	55.1	18.7	3.9	71	24	5

TABLE 12.
Chemical Composition of ground waters in the Matsushiro area (January 1967)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	12.6	53.9	18.2	15	64	21	59.9	19.4	7.7	69	22	9
2	8.4	41.3	21.6	12	58	30	50.8	15.8	6.1	70	22	8
3	8.1	44.2	20.2	11	61	28	51.1	17.1	6.1	69	23	8
4	7.0	34.2	9.1	14	68	18	33.0	12.1	5.6	65	24	11
8	3.0	9.7	10.4	13	42	45	16.4	3.9	3.5	69	16	16
9	7.2	36.6	20.7	11	57	32	48.5	14.4	6.2	70	21	9
10	6.0	17.0	16.7	15	43	42	30.6	6.9	7.8	68	15	17
11	4.6	14.9	10.3	15	50	35	18.1	6.5	6.0	59	21	20
12	3.4	12.5	4.6	17	61	22	12.1	5.7	4.1	55	26	19
13	4.5	22.8	9.5	12	62	26	25.7	9.1	3.1	68	24	8
14	22.6	80.8	31.8	17	60	23	103.0	29.8	6.7	74	21	5
16	1.6	4.9	2.8	17	53	30	5.1	3.2	1.4	53	33	14
17	2.0	2.3	1.0	38	43	19	1.7	3.1	0.8	31	55	14
18	1.8	2.6	1.2	32	46	22	2.2	3.3	0.8	35	52	13
19	3.1	3.9	1.8	35	44	21	4.2	4.1	2.0	41	40	19
20	9.9	22.1	7.0	25	57	18	24.7	14.4	2.1	60	35	5
21	11.7	40.8	26.5	15	52	33	57.7	15.8	5.6	73	20	7
22	31.9	30.4	12.1	43	41	16	58.3	18.7	4.1	72	23	5
23	1.0	1.0	0.7	37	37	26	1.1	1.7	0.5	33	52	15
24	3.5	6.6	3.8	25	48	27	5.4	3.1	5.8	38	22	40
25	6.2	30.0	18.7	11	55	34	35.8	13.2	7.1	64	23	13

TABLE 13.
Chemical Composition of ground waters in the Matsushiro area (February 1967)

Station No.	Concentration			Percent of Concentration			Concentration			Percent of Concentration		
	Na ⁺ m.eq./l	Ca ²⁺ m.eq./l	Mg ²⁺ m.eq./l	Na ⁺ %	Ca ²⁺ %	Mg ²⁺ %	Cl ⁻ m.eq./l	HCO ₃ ⁻ m.eq./l	SO ₄ ²⁻ m.eq./l	Cl ⁻ %	HCO ₃ ⁻ %	SO ₄ ²⁻ %
1	15.2	64.4	22.3	15	63	22	73.9	21.6	8.1	71	21	8
2 F	13.9	55.8	25.2	15	59	26	68.1	20.6	7.8	71	21	8
8	3.5	11.5	12.6	13	42	45	19.3	4.6	3.6	70	17	13
9	12.2	42.1	23.8	16	54	30	56.2	15.8	3.7	71	20	9
10	5.8	13.6	16.2	16	38	46	24.4	5.6	6.5	67	15	18
11	2.4	6.3	5.1	17	46	37	8.9	2.5	2.3	65	18	17
12	1.6	4.9	2.7	17	53	30	4.7	2.3	1.8	54	26	20
13	3.7	19.2	7.9	12	62	26	22.0	7.2	2.0	71	23	6
14	23.9	86.2	34.2	16	60	24	108.5	37.6	7.1	71	25	4
16	2.0	7.3	3.5	16	57	27	7.7	4.2	1.4	58	31	11
17	2.2	2.6	0.7	40	47	13	2.1	3.1	0.7	35	53	12
18	2.0	2.7	1.2	36	46	18	2.3	3.4	0.7	36	53	11
19	3.8	4.0	2.0	39	41	20	4.8	4.5	1.4	45	42	13
20	10.2	20.2	7.2	27	54	19	23.8	12.9	2.0	61	33	6
21	14.5	52.8	28.1	15	55	30	70.3	19.0	7.0	73	20	7
22	35.7	30.7	13.0	45	39	16	57.9	18.6	3.5	72	23	5
23	1.5	1.0	0.8	45	30	25	1.2	1.8	0.7	33	48	19
24	3.7	6.9	4.4	25	46	29	7.3	3.1	4.5	49	21	30

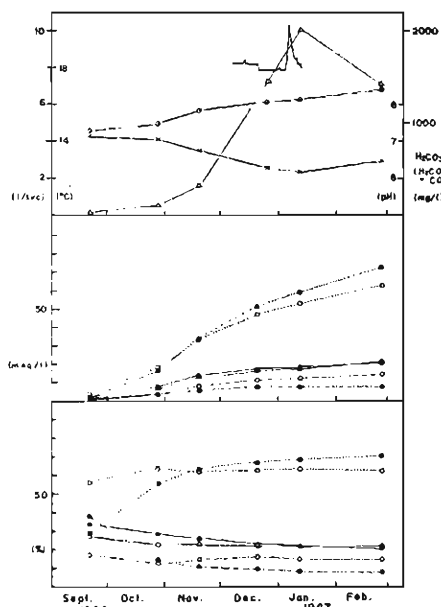


Fig. 4. Time change in concentrations and percentages of major ions in ground waters (Station 1).

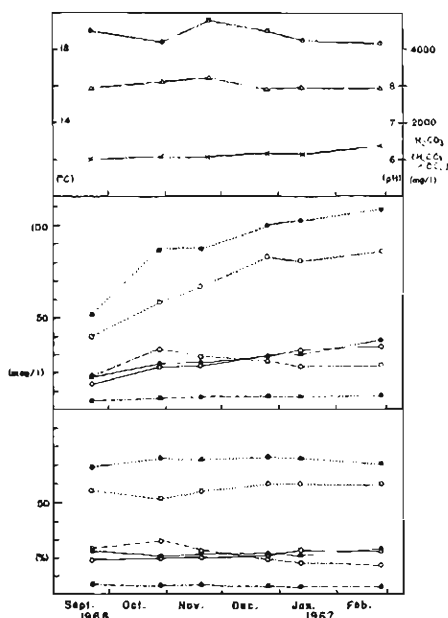


Fig. 5. Time change in concentrations and percentages of major ions in ground waters (Station 14).

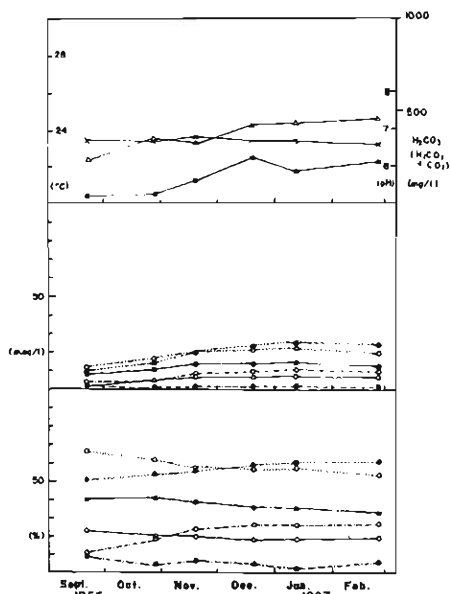


Fig. 6. Time change in concentrations and percentages of major ions in ground waters (Station 20).

Fig. 4.

○·····○: Ca^{2+} , ○——○: Mg^{2+}
 ○- - -○: Na^+ , ●·····●: Cl^-
 ●——●: HCO_3^- , ●- - -●: SO_4^{2-}
 ×——×: pH
 △——△: H_2CO_3 ($\text{H}_2\text{CO}_3 + \text{CO}_2$)
 ⊙——⊙: Water temp.
 ●·····●: Discharge of spring waters.

Fig. 5.

○·····○: Ca^{2+} , ○——○: Mg^{2+}
 ○- - -○: Na^+ , ●·····●: Cl^-
 ●——●: HCO_3^- , ●- - -●: SO_4^{2-}
 ×——×: pH
 △——△: H_2CO_3 ($\text{H}_2\text{CO}_3 + \text{CO}_2$)
 ⊙——⊙: Water temp.

Fig. 6.

○·····○: Ca^{2+} , ○——○: Mg^{2+}
 ○- - -○: Na^+ , ●·····●: Cl^-
 ●——●: HCO_3^- , ●- - -●: SO_4^{2-}
 ×——×: pH
 △——△: H_2CO_3 ($\text{H}_2\text{CO}_3 + \text{CO}_2$)
 ⊙——⊙: Water temp.

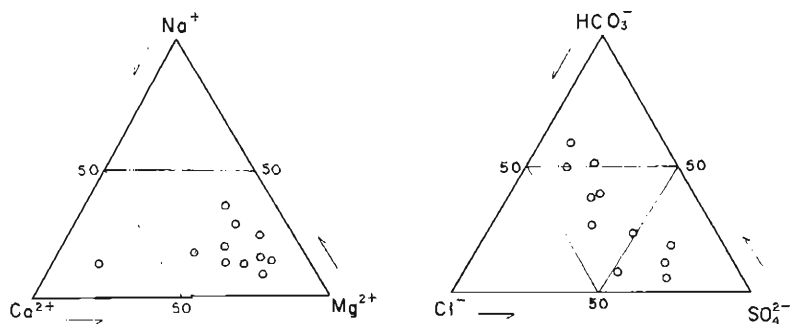


Fig. 7. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in September 1966, respectively.

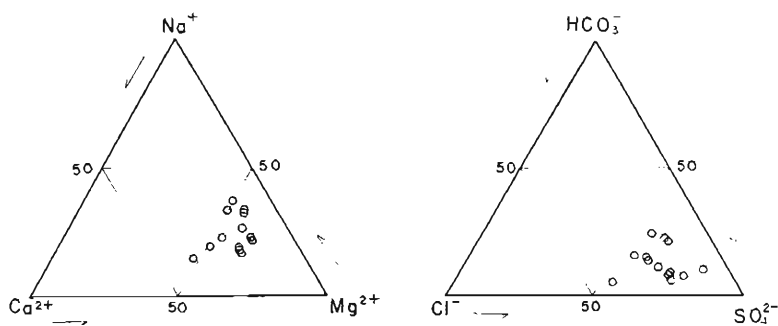


Fig. 8. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in October 1966, respectively.

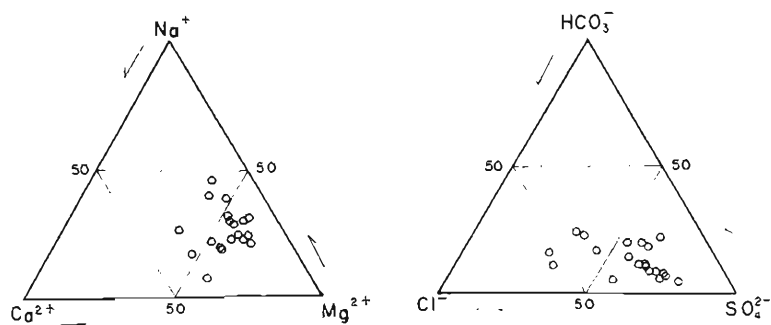


Fig. 9. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in November 1966, respectively.

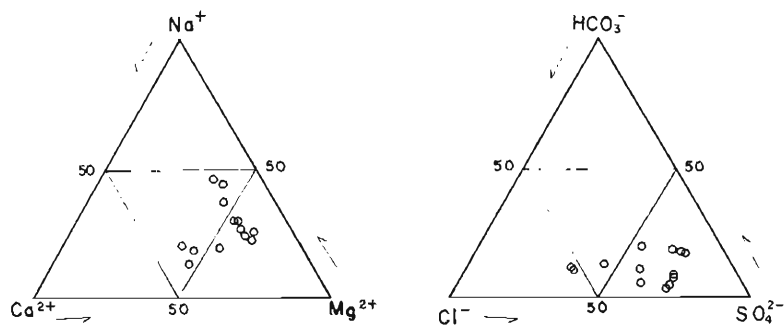


Fig. 10. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in December 1966, respectively.

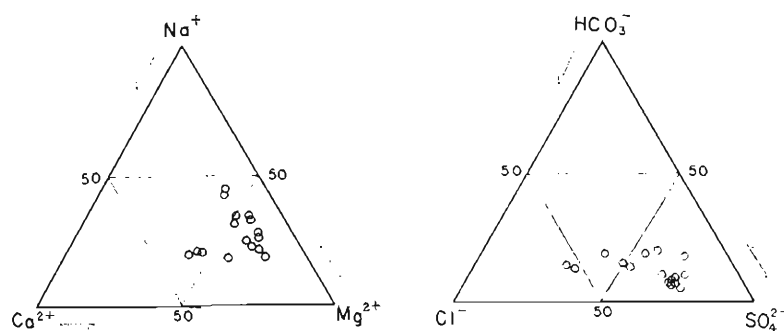


Fig. 11. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in January 1967, respectively.

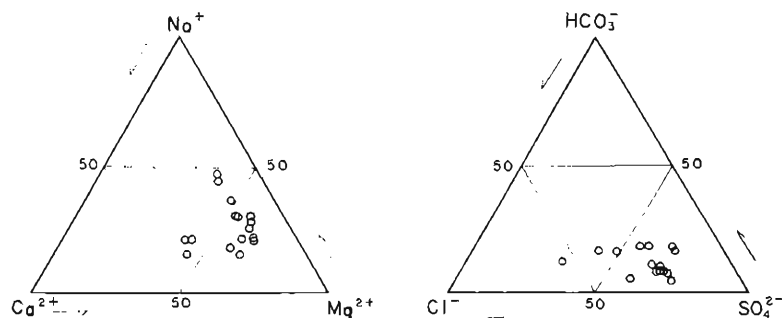


Fig. 12. Na^+ - Ca^{2+} - Mg^{2+} and HCO_3^- - Cl^- - SO_4^{2-} diagrams of ground waters in February 1967, respectively.

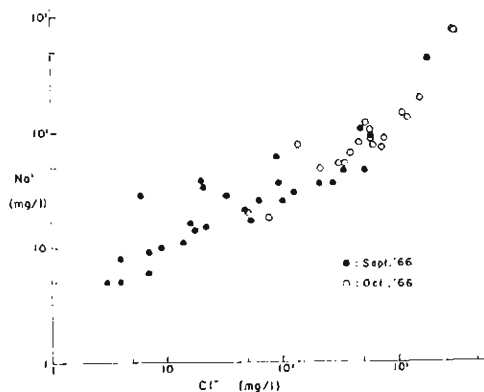


Fig. 13. Relation between contents of chloride and sodium ions in ground waters in September and October 1966.

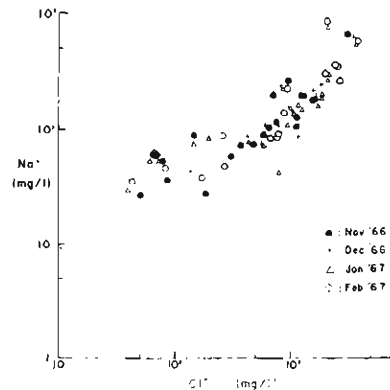


Fig. 14. Relation between contents of chloride and sodium ions in ground waters in November and December 1966 and January and February 1967.

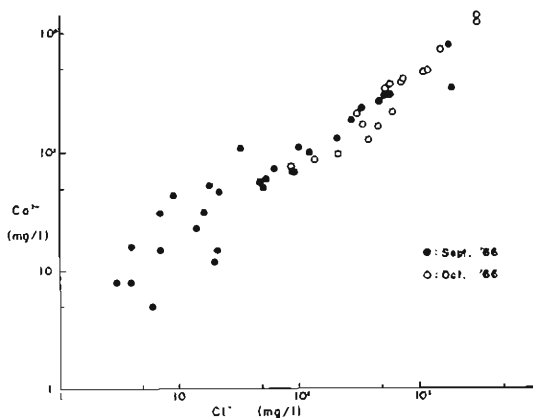


Fig. 15. Relation between contents of chloride and calcium ions in ground waters in September and October 1966.

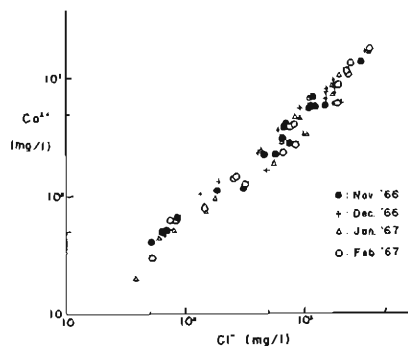


Fig. 16. Relation between contents of chloride and calcium ions in ground waters in November and December 1966 and January and February 1967.

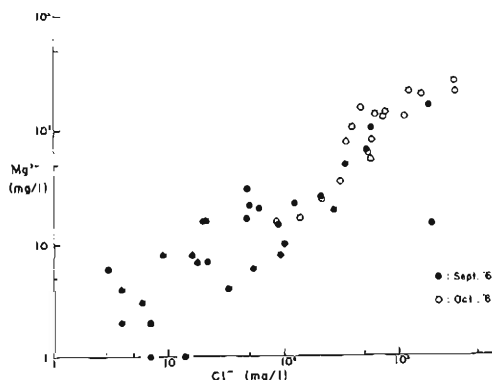


Fig. 17. Relation between contents of chloride and magnesium ions in ground waters in September and October 1966.

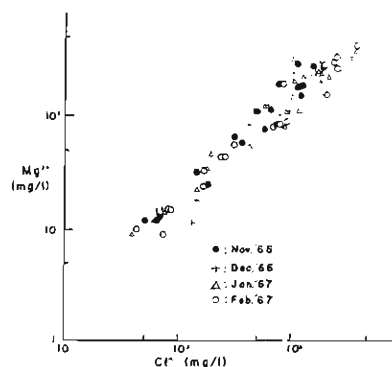


Fig. 18. Relation between contents of chloride and magnesium ions in ground waters in November and December 1966 and January and February 1967.

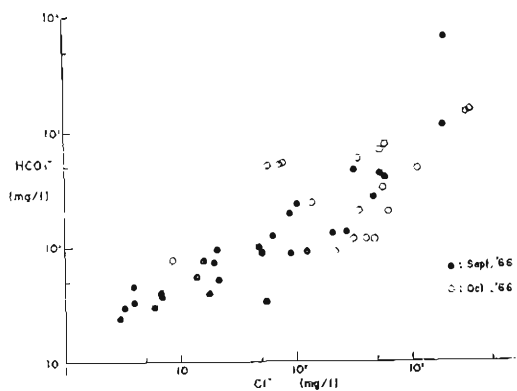


Fig. 19. Relation between contents of chloride and bicarbonate ions in ground waters in September and October 1966.

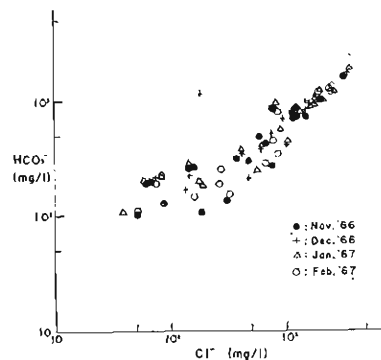


Fig. 20. Relation between contents of chloride and bicarbonate ions in ground waters in November and December 1966 and January and February 1967.

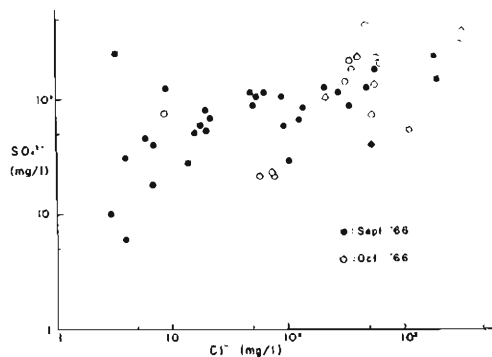


Fig. 21. Relation between contents of chloride and sulfate ions in ground waters in September and October 1966.

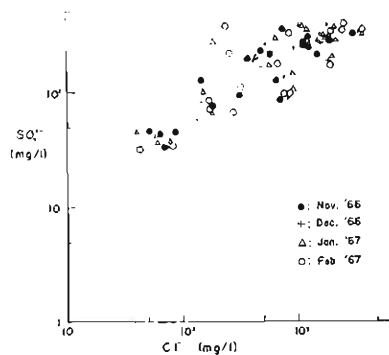


Fig. 22. Relation between contents of chloride and sulfate ions in ground waters in November and December 1966 and January and February 1967.

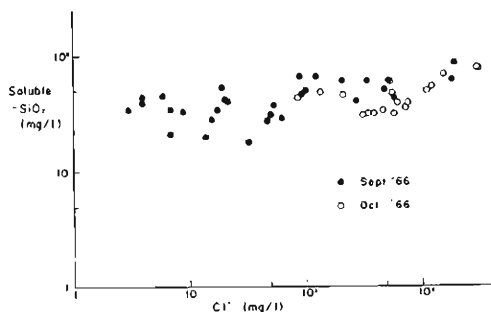


Fig. 23. Relation between contents of chloride ions and soluble silica in ground waters in September and October 1966.

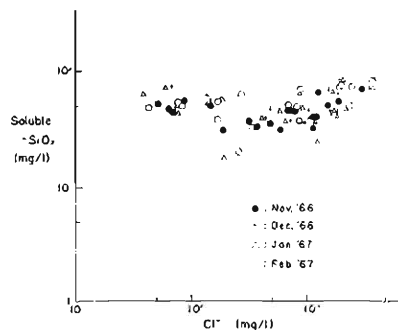


Fig. 24. Relation between contents of chloride ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

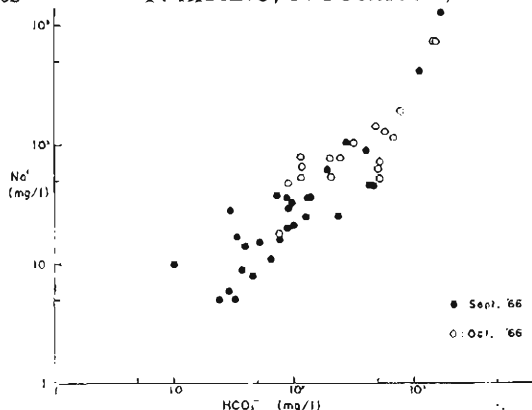


Fig. 25. Relation between contents of bicarbonate and sodium ions in ground waters in September and October 1966.

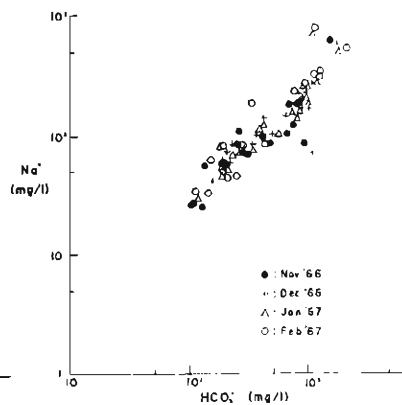


Fig. 26. Relation between contents of bicarbonate and sodium ions in ground waters in November and December 1966 and January and February 1967.

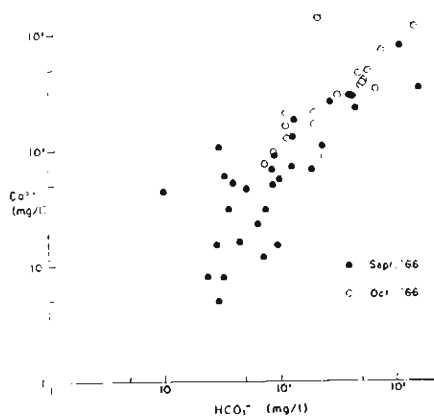


Fig. 27. Relation between contents of bicarbonate and calcium ions in ground waters in September and October 1966.

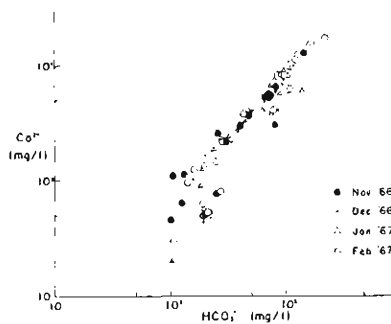


Fig. 28. Relation between contents of bicarbonate and calcium ions in ground waters in November and December 1966 and January and February 1967.

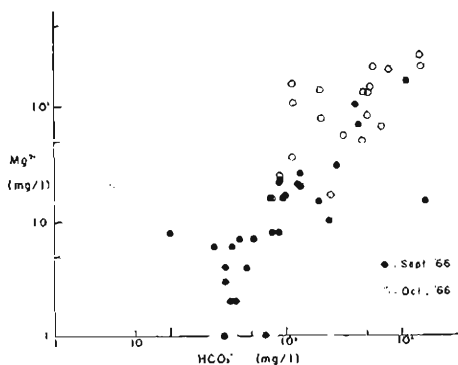


Fig. 29. Relation between contents of bicarbonate and magnesium ions in ground waters in September and October 1966.

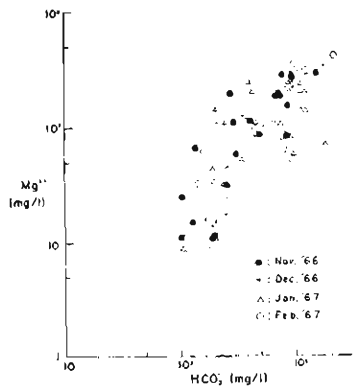


Fig. 30. Relation between contents of bicarbonate and magnesium ions in ground waters in November and December 1966 and January and February 1967.

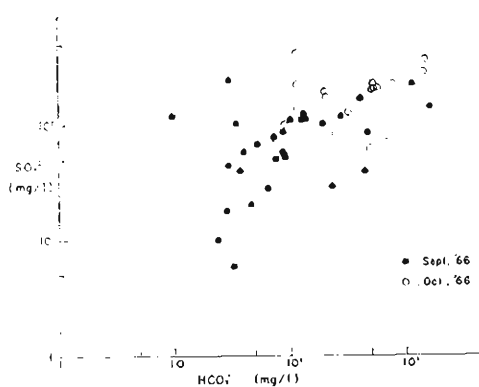


Fig. 31. Relation between contents of bicarbonate and sulfate ions in ground waters in September and October 1966.

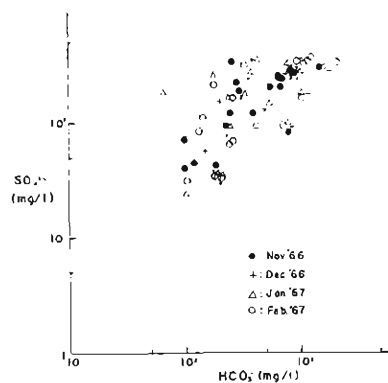


Fig. 32. Relation between contents of bicarbonate and sulfate ions in ground waters in November and December 1966 and January and February 1967.

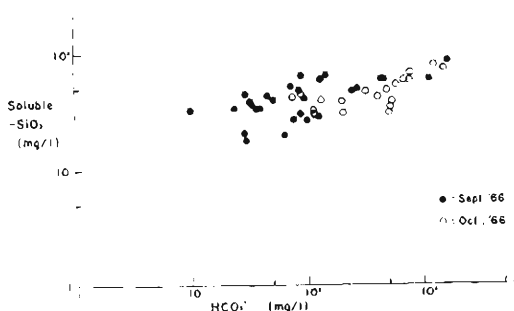


Fig. 33. Relation between contents of bicarbonate ions and soluble silica in ground waters in September and October 1966.

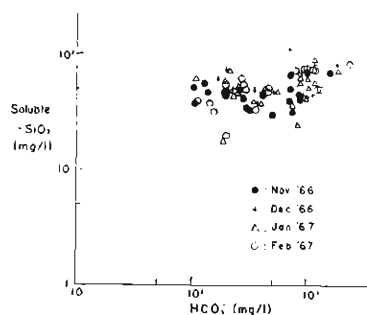


Fig. 34. Relation between contents of bicarbonate ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

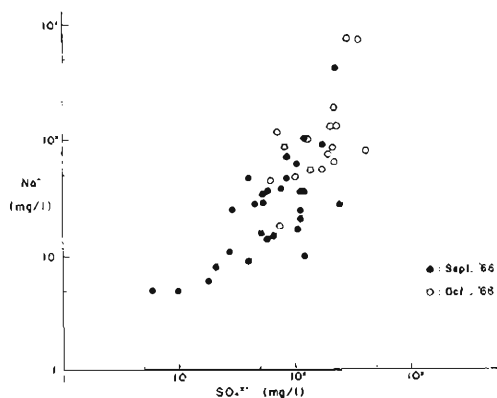


Fig. 35. Relation between contents of sulfate and sodium ions in ground waters in September and October 1966.

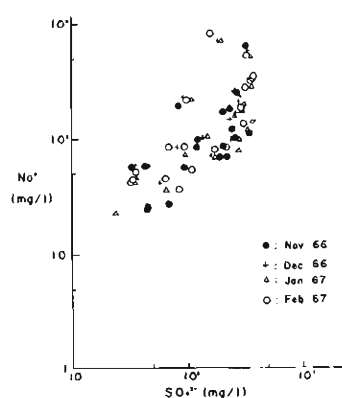


Fig. 36. Relation between contents of sulfate and sodium ions in ground waters in November and December 1966 and January and February 1967.

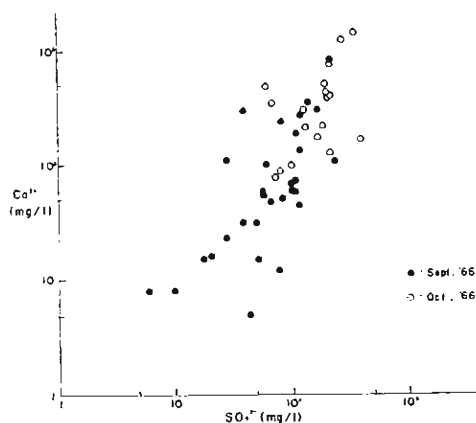


Fig. 37. Relation between contents of sulfate and calcium ions in ground waters in September and October 1966.

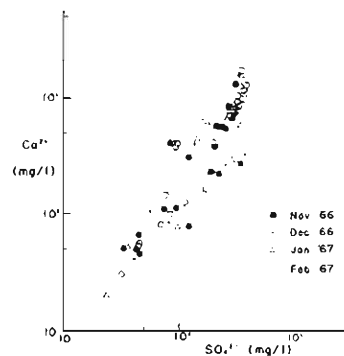


Fig. 38. Relation between contents of sulfate and calcium ions in ground waters in November and December 1966 and January and February 1967.

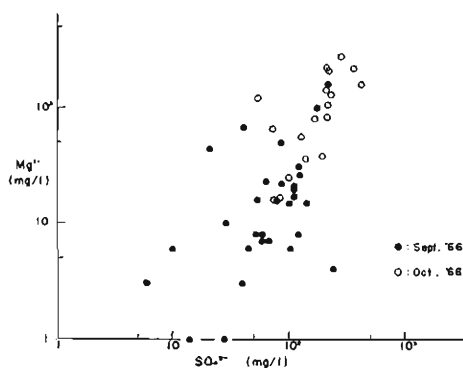


Fig. 39. Relation between contents of sulfate and magnesium ions in ground waters in September and October 1966.

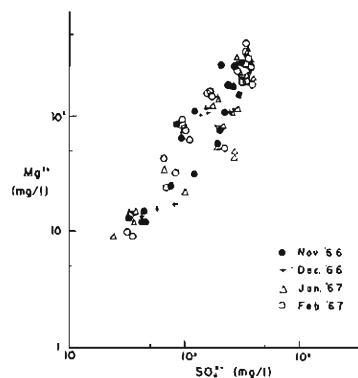


Fig. 40. Relation between contents of sulfate and magnesium ions in ground waters in November and December 1966 and January and February 1967.

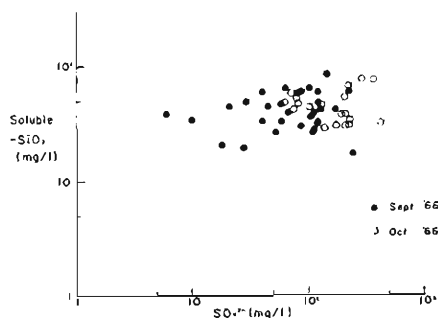


Fig. 41. Relation between contents of sulfate ions and soluble silica in ground waters in September and October 1966.

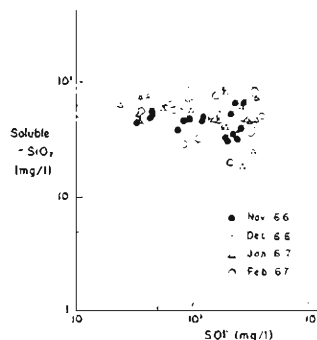


Fig. 42. Relation between contents of sulfate ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

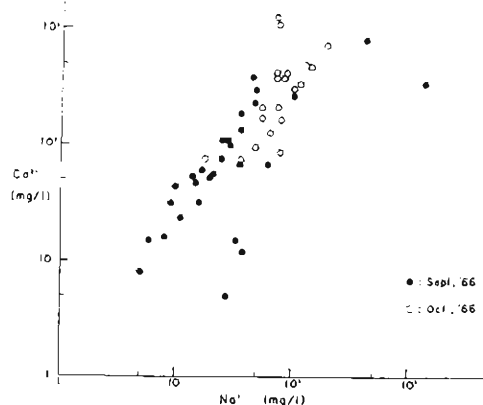


Fig. 43. Relation between contents of sodium and calcium ions in ground waters in September and October 1966.

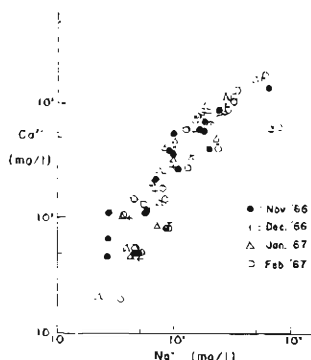


Fig. 44. Relation between contents of sodium and calcium ions in ground waters in November and December 1966 and January and February 1967.

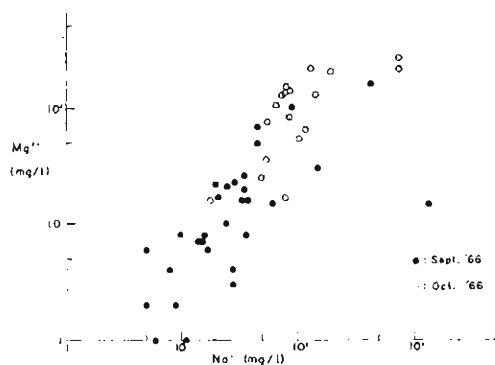


Fig. 45. Relation between contents of sodium and magnesium ions in ground waters in September and October 1966.

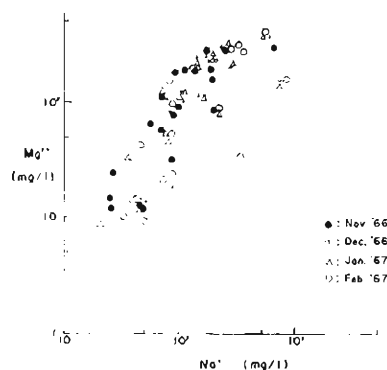


Fig. 46. Relation between contents of sodium and magnesium ions in ground waters in November and December 1966 and January and February 1967.

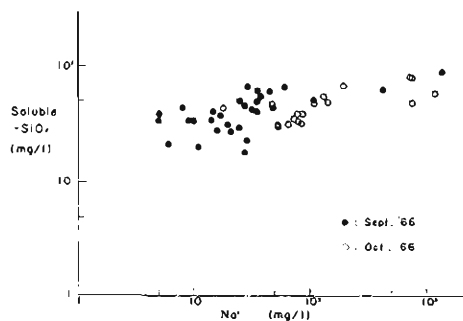


Fig. 47. Relation between contents of sodium ions and soluble silica in ground waters in September and October 1966.

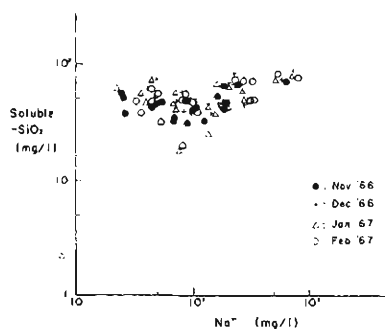


Fig. 48. Relation between contents of sodium ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

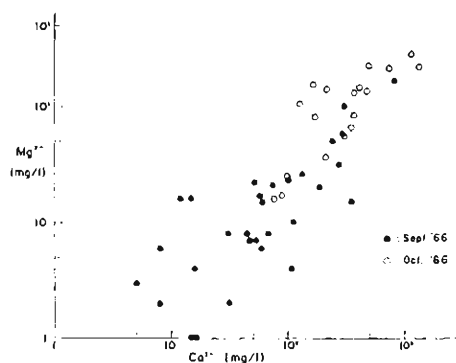


Fig. 49. Relation between contents of calcium and magnesium ions in ground waters in September and October 1966.

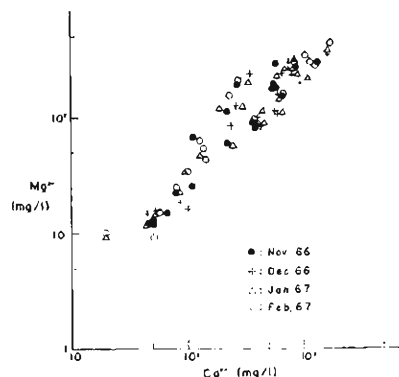


Fig. 50. Relation between contents of calcium and magnesium ions in ground waters in November and December 1966 and January and February 1967.

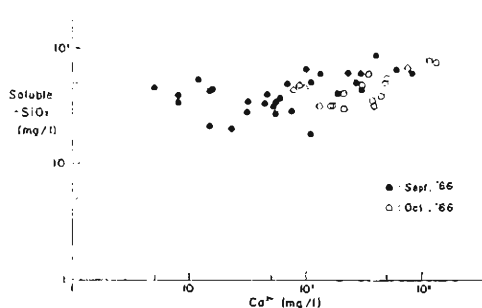


Fig. 51. Relation between contents of calcium ions and soluble silica in ground waters in September and October 1966.

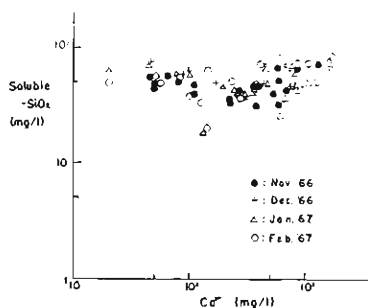


Fig. 52. Relation between contents of calcium ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

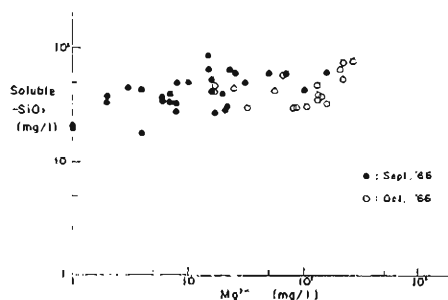


Fig. 53. Relation between contents of magnesium ions and soluble silica in ground waters in September and October 1966.

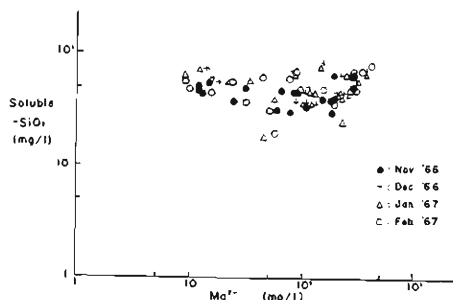


Fig. 54. Relation between contents of magnesium ions and soluble silica in ground waters in November and December 1966 and January and February 1967.

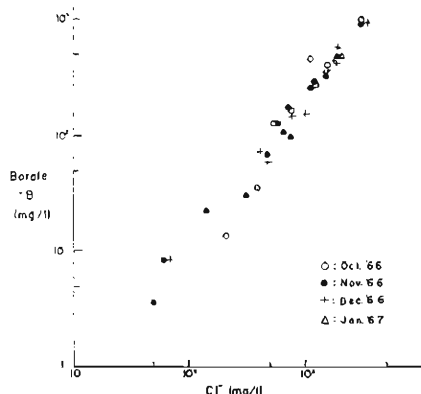


Fig. 55. Relation between contents of chloride ions and borate boron in ground waters in October, November and December 1966 and January 1967.

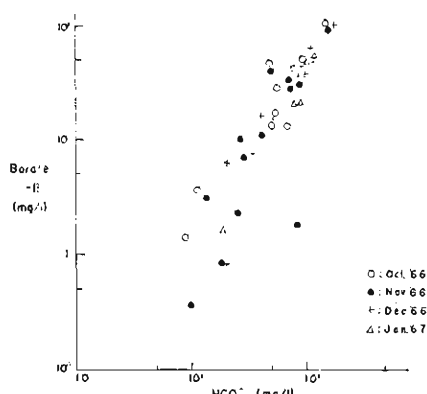


Fig. 56. Relation between contents of bicarbonate ions and borate boron in ground waters in October, November and December 1966 and January 1967.

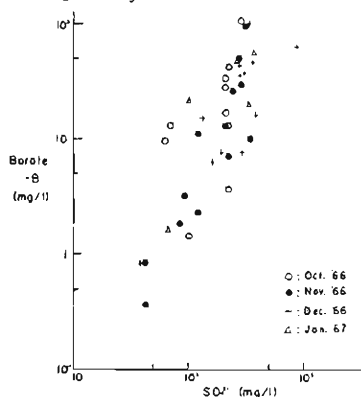


Fig. 57. Relation between contents of sulfate ions and borate boron in ground waters in October, November and December 1966 and January 1967.

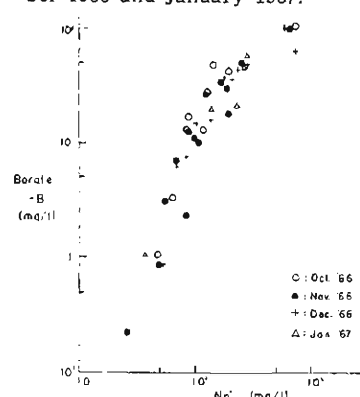


Fig. 58. Relation between contents of sodium ions and borate boron in ground waters in October, November and December 1966 and January 1967.

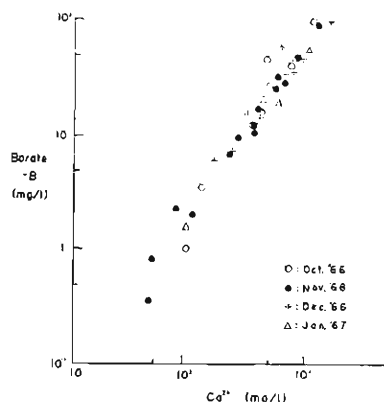


Fig. 59. Relation between contents of calcium ions and borate boron in ground waters in October, November and December 1966 and January 1967.

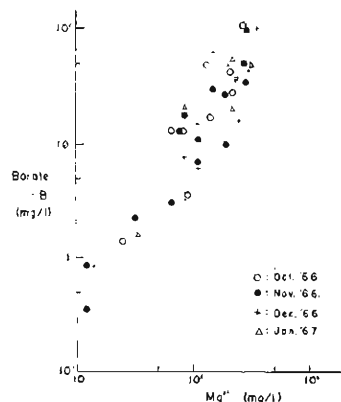


Fig. 60. Relation between contents of magnesium ions and borate boron in ground waters in October, November and December 1966 and January 1967.

3. Results and Discussion

(3-1) The chemical compositions of ground waters collected monthly from September 1966 to February 1967 are shown in Tables 2 to 13. Percentages of the contents of major cations (Na^+ , Ca^{2+} , Mg^{2+}) and of major anions (HCO_3^- , Cl^- , SO_4^{2-}) were calculated. The values calculated are included in Tables 8 to 13.

(3-2) The changes with time in the concentrations and in the percentages of the major cations and anions are shown in Figs. 4 to 6 for three samples of ground water. These figures include the change in pH value, water temperature and the amount of ground water.

(3-3) Figs. 7 to 12 show the percentages of the contents of the major cations and anions of ground waters collected monthly as Na^+ - Ca^{2+} - Mg^{2+} diagram and HCO_3^- - Cl^- - SO_4^{2-} diagram, respectively.

(3-4) The relations between concentrations of dissolved elements are given in Figs. 13 to 61.

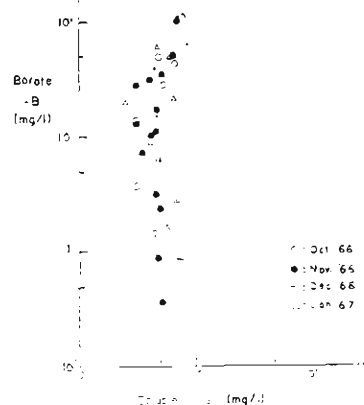


Fig. 61. Relation between contents of soluble silica and borate boron in ground waters in October, November and December 1966 and January 1967.

TABLE 14.
Increase with time in contents of dissolved elements as expressed in the ratio:
(Content at one month)/(Content at the next month)

Station No.	Na^+					Ca^{2+}					Mg^{2+}				
	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.
1	3.4	2.1	1.5	1.0	1.2	5.2	1.8	1.4	1.4	1.2	4.0	1.8	1.3	1.1	1.2
2	3.7	1.4	1.7	1.1	1.7	4.3	2.5	1.4	1.1	1.4	10.7	0.8	1.4	1.0	1.2
3		1.4	1.4	1.0			1.5	1.4	1.1			1.3	1.3	1.1	
4			1.7	1.1				1.5	1.2			1.5	1.0		
5	1.3	1.5				1.5	1.5				2.3	1.6			
6	5.0	1.0				7.2	1.2				2.8	1.3			
7	5.4	1.3				3.9	1.2				10.4	1.3			
8	1.7	1.2	1.3	1.0	1.2	8.1	1.2	1.5	1.2	1.7	8.3	2.6	1.7	1.1	1.2
9			1.1	0.8	1.7			1.2	1.1	1.2			1.2	1.1	1.2
10			1.3	1.0	1.0			1.2	1.0				1.3	0.8	1.0
11		1.3	1.4	1.0	0.5		1.3	1.2	1.1	0.8		1.4	1.2	1.0	0.5
12	8.4	1.0	1.2	0.9	0.5	6.8	1.1	1.1	1.1	0.4	18.0	1.6	1.4	0.7	0.6
13	1.0	1.0	1.1	1.0	0.8	1.1	1.0	1.3	1.1	0.8	1.8	2.0	1.0	1.1	0.8
14	1.8	0.9	0.9	0.9	1.1	1.5	1.1	1.3	1.0	1.1	1.7	1.1	1.2	1.1	1.1
16			1.7	1.1	1.3			1.6	0.9	1.5			1.1	2.1	1.3
17			1.0	0.9	1.1			0.9	1.0	1.1			1.2	0.9	0.7
18			1.0	0.9	1.1			1.0	1.0	1.1			1.2	1.0	1.0
19	1.3	1.1	1.0	0.8	1.2	1.3	0.9	1.1	0.9	1.0	1.1	1.9	0.6	1.2	1.1
20	2.6	1.7	1.2	1.0	1.0	1.4	1.2	1.1	0.1	0.9	1.3	1.3	1.0	1.0	1.0
N	5.0					4.8					5.8				
21				1.0	1.2					1.3					1.1
22					1.1				1.0					1.0	1.0
23					1.5					1.0					1.2
24					1.1					1.1					1.2

TABLE 15.

Increase with time in contents of dissolved elements as expressed in the ratio:
(Content at one month)/(Content at the next month)

Station No.	HCO ₃ ⁻					Cl ⁻					SO ₄ ²⁻				
	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.	Oct./Sept.	Nov./Oct.	Dec./Nov.	Jan./Dec.	Feb./Jan.
1	4.0	1.7	1.3	1.1	1.2	9.3	2.1	1.5	1.2	1.2	1.9	1.4	1.3	1.2	1.1
2	5.9	1.3	1.3	1.0	1.3	14.5	1.5	1.4	1.1	1.3	2.7	1.1	1.0	1.5	1.3
3		1.4	1.3	1.1			1.5	1.4	1.1			1.3	1.2	1.3	1.0
4			1.4	1.1				1.7	1.2				1.1	2.2	1.1
5	1.9	1.4				4.7	2.2				1.3	1.0			
6	6.7	1.2				13.3	1.2				3.5	1.0			
7	6.4	1.2				5.8	1.2				2.0	1.2			
8	3.0	1.5	1.5	1.2	1.2	38.4	1.5	1.6	1.2	1.2	2.2	0.9	1.7	4.3	1.0
9			1.2	1.2	1.1			1.2	1.1	1.2			1.2	1.5	1.1
10			1.5	1.0	0.8			1.3	1.1	0.8			1.1	2.2	0.8
11		1.4	1.3	1.1	0.4		1.4	1.3	1.1	0.5		1.3	1.2	3.2	0.4
12	3.1	2.6	1.1	1.0	0.4	42.4	1.2	1.1	1.0	0.4	3.5	1.4	1.0	4.8	0.4
13	1.2	1.3	1.2	1.1	0.8	1.2	1.2	1.2	1.2	0.9	1.1	0.9	1.1	2.9	0.6
14	1.3	1.1	1.1	1.0	1.3	1.7	1.0	1.1	1.0	1.1	1.3	1.1	1.0	0.7	1.1
16			1.3	1.2	1.3			1.6	1.3	1.5			1.3	2.0	1.0
17			1.1	1.0	1.0			1.1	0.9	1.2			1.0	5.9	1.0
18			1.0	1.0	1.0			1.1	1.1	1.1			1.0	8.1	0.9
19	1.3	1.0	1.0	1.0	1.1	1.5	1.1	1.0	1.0	1.1	0.8	1.5	0.7	1.4	0.7
20	1.5	1.2	1.0	1.0	0.9	1.6	1.3	2.6	1.1	1.0	0.8	1.2	1.1	2.7	1.0
N	5.4					9.1					1.0				
21					1.2					1.2				1.3	1.2
22				1.0	1.0				1.1	1.0					0.8
23					1.0					1.1					1.3
24					1.0					1.4					0.8

TABLE 16.

Change in chemical composition of Kagai hot spring waters

Orifice	Spring-A					Spring-B				
Date Temp (°C) pH	July 5, 1967 41 6.7	Feb. 22, 1967	(Content at Feb. 22, 1967)/(Con- tent at July 5, 1965)			Oct. 1930 39	Feb. 22, 1967 33.8 6.5	(Content at Feb. 22, 1967)/(Con- tent at Oct. 1930)		
Na ⁺	mg/l 1717 m.eq./l 75	mg/l 2730 m.eq./l 119	1.6			mg/l 1790 m.eq./l 78	mg/l 2160 m.eq./l 94	1.2		
Ca ²⁺	429	21	1030	51	2.4	383	18	1039	52	2.7
Mg ²⁺	60	5.0	168	14	2.8	23	1.9	159	13	6.9
Cl ⁻	3064	86	5409	153	1.8	2360	67	4671	184	1.9
HCO ₃ ⁻	1164	19	1810	30	1.6	2312	38	1225	20	0.5
SO ₄ ²⁻	175	3.6	165	3.4	0.9	259	5.4	148	3.1	0.6
Soluble-SiO ₂			125			82		119		

(3-5) The authors calculated the ratios of the concentrations of elements in water samples of September to those of October; ratios of those of October to those of November; ratios of those of November to those of December; ratios of those of December to those of January; and ratios of those of January to those of February. These ratios calculated are given in Tables 14 to

15. Table 16 gives the chemical compositions and the ratios between concentrations of dissolved elements in Kagai hot spring waters collected at different times.

These results make it possible to say the following: with the increasing activity of the Matsushiro swarm earthquakes, the content of most dissolved chemical constituents as well as the amount of ground waters greatly increased from September 1966 to February 1967. The greatest increase during our observations occurred from September to October 1966.

- (a) The content of carbonate material including the carbon dioxide gas of ground waters increased greatly with time, in other words with the activity of the earthquakes.
- (b) The concentrations of calcium and chloride ions increased most remarkably with time, among dissolved ions. Although the concentrations of sodium and bicarbonate ions increased with increasing concentration of chloride ions, the remarkable increase in the concentrations of calcium and chloride ions is to be emphasized as the chemical characteristic of the ground waters. It was also noted that the concentrations of magnesium and borate ions increased proportionally with the increasing concentrations of calcium and chloride ions.
- (c) The concentration of sulfate ions increased only a little in spite of the increase in chloride concentration.
- (d) The concentration of soluble silica was not changed, independent of time and of the increase in the concentration of chloride ions.

The concentrations of most dissolved elements increased with the increasing activity of the earthquakes, and the temperature of the ground waters increased in spite of the decrease in the atmospheric temperature. The amount of ground waters was independent of the amount of precipitation. These facts indicate that the ground waters are not influenced either directly or greatly by surface waters, but seem to be derived from a deep origin under the ground.

The remarkable increase in the concentrations of carbonate material, calcium and chloride ions with magnesium and borate ions may indicate the source of the ground waters in this area. One of the simplest chemical reactions leading to its increase is as follows: hydrochloric acid, one of the volatile substances, reacts with limestone under the ground in the presence of water. But, we do not yet know the exact reaction and explanation. Thermal and mineral waters were observed, the major constituents of which are calcium and chloride ions with carbon dioxide gas in large amounts.^(11,12) If we could know the conditions under which such spring waters exist, we could imagine the conditions under the ground in the Matsushiro town area, with the aid of geological observations and this would help to know about the mechanism of the Matsushiro swarm earthquakes.

The authors are continuing observations on the amount and chemical composition of the ground waters. When they have completed hydrological and geochemical observations of the ground waters for a whole year, they will discuss the source of the ground waters and the conditions under the ground in this area.

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Shimura of Matsushiro High School and Mr. S. Ogahara of Sarashina Agricultural High School, Nagano Prefecture.

References

- 1) The Party for Seismographic Observation of Matsushiro Earthquakes and the Seismometrical Section (Earthquake Research Institution, Univ. of Tokyo) and others; Research on the Matsushiro earthquakes (1) (No. 18-No. 24), Bull. Earthq. Res. Inst., 44 (1936), 307-445.
- 2) Hamada, K., Hagiwara, T. and others; Research on the Matsushiro earthquakes (2) (No. 59-No. 65), *ibid.*, 44 (1936), 1213-1395.
- 3) Nagumo, S. and others; Research on the Matsushiro earthquakes (3) (No. 77-No. 83), *ibid.*, 44 (1936), 1623-1792.
- 4) Hamada, K., Hagiwara, T. and others; Research on the Matsushiro earthquakes (4) (No. 10-No. 14), *ibid.*, 45 (1937), 159-288.
- 5) Network of JMA during Aug. 1935 to Dec. 1936 (National Res. Center for Disa. Prev.); Seismological data of Matsushiro earthquake swarm, Rev. Res. Disa. Prev. No. 1 (1937), 1-140.
- 6) Noguchi, K.; Matsushiro earthquake and hot spring, Chemistry and Chemical Industry (Kagaku to Kōgyō), 20 (1937), 69-72 (in Japanese).
- 7) Utsumi, S.; A new spectrophotometric determination of small amounts of chloride ions with mercury thiocyanate and iron ammonium sulfate, J. Chem. Soc. Japan (Nippon Kagaku Zasshi), 73 (1952) 836-841 (in Japanese).
- 8) Iwasaki, I., Usumi, S., Hagino, T., Tarutani T. and Ozawa, T.; A new spectrophotometric determination of small amounts of sulfate ions with barium chromate and diphenylcarbazide, J. Chem. Soc. Japan (Nippon Kagaku Zasshi), 79 (1958), 32-50 (in Japanese).
- 9) Kato, K. and Kitano Y.; Salt error in colorimetric determination of the molybdate-reactive silica in sea water, J. Earth Sciences, Nagoya Univ., 14 (1936), 151-158.
- 10) Greenhalgh, R. and Riley, J. T.; The development of a producible spectrophotometric curcumin method for determining boron, and its application to sea water, Analyst, 87 (1932), 970-976.
- 11) National Parks Division, Ministry of Health & Welfare in Japan; Mineral springs of Japan (1954) Aoyama Shoin Ltd. Co., 1-785.
- 12) Graf, D. L., Meets, W. F., Friedman, I. and Shimp, N. E.; The origin of saline formation waters, III: Calcium chloride waters (1936) Ill. State. Geol. Survey (U.S.A.) Circular 397.