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An Analysis of the Chemical Compositions of Groundwaters Utilizing a Leaching Technique. An Application to the Rokko Mountains and Their Surroundings

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The chemical composition of groundwaters from granitic alluvial plains is different from that from the clayey "Kobe-group" strata surrounding the Rokko mountains. The former groundwaters are dominantly rich in Ca and HCO_3, while the latter are rich in Na and HCO_3. In order to investigate the difference in the groundwater compositions, a chemical leaching technique was applied to samples of soils, well-sediments, and rocks collected from the Rokko mountains and their surroundings. Three leaching solutions used were as follows. CO_2-saturated water to investigate the effect of chemical weathering; a 0.1 M[†] HNO_3 solution to remove hydroxide, sulfide, and colloidal matters; and a 1 M CH_3COONH_4 solution to leach exchangeable ions from the samples. In the leaching, leachable amounts of Na, K, Ca, and Mg as the major species and Fe and Mn as the minor species in groundwaters were determined. From the results of leaching and adsorption experiments for cations, and from a comparison of the analytical values of the cations in groundwaters with the data of the leaching experiments on the key diagram, the association of the chemical species dissolved in groundwaters with the geological characters was analysed.

The Rokko mountains are located north of Osaka Bay, behind the port of Kobe. The mountains essentially consist of granitic rocks characterized by biotite, and they are covered with granitic detritus called "Masatsuchi." The detritus forms alluvial plains and terrace deposits in the southern part of the Rokko mountains, and the detrital layers form a well aquifer because of the poorly coagulating layers. In the northern or northwestern side of the mountains, the Neogene strata (*ca.* 15 million years old), called argillaceous "Kobe group" strata, which are composed of such detritus as silt mudstone, sandstone, and conglomerates and of volcaniclastic materials containing large amounts of tuff, are widely distributed.[1)]

It has been generally recognized that the chemical species dissolved in groundwaters are mainly Na^+, Ca^{2+}, Mg^{2+}, K^+, HCO_3^-, Cl^-, SO_4^{2-}, and soluble SiO_2, and that these species make up more than 95% of the total dissolved solids.[2)] The chemical compositions of groundwaters in the Rokko mountains and their surroundings have been studied, and the concentrations of major and trace species have been reported by some of the present authors.[3,4)] Table 1 shows some of the analytical results in their reports. This table shows that the groundwaters from the alluvial plains are dominantly rich in Ca and HCO_3, whereas the groundwaters from the Kobe-group area are rich in Na and HCO_3. The difference in the chemical compositions of groundwaters in these two areas is explained by the following reactions of major chemical species: the chemical actions controling the dissolution of the major species are weathering by CO_2 for granitiform soils in the alluvial plains, while the cation-exchange reactions by clay minerals are dominant in the Kobe-group area. In order to analyse the difference in the chemical compositions of groundwaters between the alluvial plains and the Kobe-group area, and in order to elucidate the association of geological strata with the chemical compositions, a chemical leaching technique was applied in this work.

Chemical leaching techniques are generally utilized

Table 1. Mean chemical compositions of groundwaters

Chemical species	Alluvial plains 34 Shallow groundwaters		Kobe-group strata 38 Shallow groundwaters		15 Deep groundwaters	
	ppm Av.±S.D.	epm (% of epm)	ppm Av.±S.D.	epm (% of epm)	ppm Av.±S.D.	epm (% of epm)
Ca	42±15	2.1 (57)	12±9.2	0.60 (26)	1.6±1.3	0.08 (2)
Mg	5.7±2.3	0.47 (13)	2.3±1.7	0.19 (8)	0.2±0.2	0.02 (0.4)
Na	21±8.2	0.91 (25)	32±20	1.4 (62)	99±21	4.3 (97)
K	6.9±3.5	0.18 (5)	3.1±3.1	0.08 (4)	0.9± 1	0.02 (0.6)
Cations		3.66 (100)		2.27 (100)		4.42 (100)
HCO_3	92±26	1.5 (51)	63±51	1.0 (47)	260±67	4.3 (89)
Cl	26±15	0.73 (25)	23±16	0.65 (30)	9.2±7.1	0.26 (5)
SO_4	33±14	0.69 (24)	23± 9	0.48 (23)	14±12	0.29 (6)
SiO_2	21±6.1		29±10		33±10	
Anions		2.92 (100)		2.13 (100)		4.85 (100)

[†] 1 M=1 mol dm^{-3}, 1 ml=1 cm^3.

TABLE 2. SAMPLING DESCRIPTIONS

Sample	Location	Geology
Soil No. 1	Konan University #9	Alluvial plains
Well-sediment No. 1	Konan University #18	Alluvial plains
Well-sediment No. 2	Ohgo-cho, Kita-ku, Kobe	Kobe-group strata
Well-sediment No. 3	Yokawa-cho, Kita-ku Kobe	Kobe-group strata
Well-sediment No. 4	Yokawa-cho, Kita-ku Kobe	Kobe-group strata
Well-sediment No. 5	Ohzo-cho, Kita-ku, Kobe	Kobe-group strata
Montmollironite	Mississippi, U.S.A.	
Bentonite	Gunma prefecture	
Kaolinite	Georgia, U.S.A.	
Mt. Rokko Granite	Okamoto, Kobe	
JB-1	Japanese basalt, G.S.J.[a)]	

a) Detailed locations are described by Ando.[11)]

to separate different minerals, such as ferro-manganese and carbonate, or trace elements adsorbed on minerals to solutions by means of chemical reactions.[5-7)] This technique is also used for the state analysis of Se in sediments.[8)] In this work, a chemical leaching method was applied to powdered samples of rocks, soils, and well-sediments collected from Mt. Rokko and its surroundings, using leaching solutions of 0.1 M HNO_3, 1 M CH_3COONH_4, and CO_2-saturated water. From the results of 1) the X-ray diffraction patterns of the samples, 2) leaching experiments in which amounts of Na, K, Ca, Mg, Fe, and Mn removed from the samples by the leaching solutions were determined, 3) adsorption experiments using commercially available clay minerals and the samples, and 4) the analysis of key diagrams on which the leaching and analytical results of groundwaters had been plotted, it has been concluded that the chemical composition of each groundwater from the alluvial plains and the Kobe-group area depends on their geological strata, and that the leaching method is significant in analysing the influence of the geological strata on the chemical species dissolved in groundwaters.

Experimental

Samples, Reagents, and Apparatus. The sampling descriptions of the well-sediments, rocks, soils, and clay minerals used for these experiments are given in Table 2. The sediment samples were collected from the bottom to a depth of about 5 cm in relatively shallow wells, using a mud-sampler (Rigo Co., Ltd., model No. 2007).

The solutions of 0.1 M HCl, 0.1 M HNO_3, and 0.1 M CH_3COOH were prepared by diluting each reagent of an analytical-reagent grade with distilled water. The pH 7 solution of 1 M CH_3COONH_4 was also prepared by dissolving 77.09 g of CH_3COONH_4 with water to a 1000 ml volume and by adjusting the pH to 7.0 with a small quantities of CH_3COOH and NH_4OH solutions.

The following pieces of apparatus were employed; a flame photometer (Hiranuma-sangyo Co., Ltd., model FPF-2A), a spectrophotometer (Hitachi, Ltd., model 100-10), an atomic absorption spectrophotometer (Hitachi, Ltd., model 207), an X-ray diffractometer (Rigaku-denki Co., Ltd., model MJ-200-DH), and a washer-bath with irradiation by ultrasonic waves (Shimada Physical and Chemical Industrial Instruments Co., Ltd., model CF-16-2B, 200 W 28 kHz, and Branson Instruments Co., Ltd., model Bransonic 12,80 W 60 Hz).

Preparation of Samples. Wet sediment samples collected from wells were centrifuged, and the solid parts of the samples were dried for 5 h at 110 °C. After cooling, the samples were crushed in an agate mill and then powdered so as to pass through a 100-mesh-size sieve. Finely powdered dry samples were prepared by quartering them four times after the samples had been mixed in an agate mill for 10 min. Samples of rocks and clay minerals were also prepared in the same manner. In this sample preparation, about 95% of the homogeneities for trace elements in sediment samples and more than *ca.* 90% of the homogeneities for major constituents in artificial samples were estimated.[9,10)]

Leaching Solutions. The solutions used for the chemical leaching experiments were as follows. 1) CO_2-saturated water to investigate the effect of chemical species being dissolved in groundwaters by chemical weathering by CO_2; 2) a 1 M CH_3COONH_4 solution to remove the exchangeable ions sorbed by clay minerals; 3) a 0.1 M HCl solution to leach the metal sulfides and hydroxides and loosely adsorbed metal ions that were originally present in overlying water as fine-grained suspended phases;[6)] and 4) 0.1 M HNO_3 and 0.1 M CH_3COOH solutions to compare the effects of the leaching.

Recommended Leaching Procedure. Figure 1 shows the recommended procedure for the leaching method as established from the experimental results of investigating the effect of the reaction temperatures of leaching solutions, the effect of the intensity of ultrasonic waves irradiated during the leaching, and the effect of the irradiation time of ultrasonic waves on the leachable amounts of Na, K, Ca, Mg, Fe, and Mn.

One gram of a powdered sample was placed in a stoppered centrifugal tube (Vol. 50 ml), and a 25-ml portion of a leaching solution was added to the tube. The tube was set in a water-bath filled with hot water (40 °C) and irradiated by ultrasonic waves with an electric current of 3 A and for an irradiation time of 20 min. The tube was centrifuged for 10 min at 2500 rpm; then the supernatant solution was filtered (filter pore-size: 0.45 μ) and transferred to a 50-ml measuring flask (Fraction No. 1). A 25-ml portion of the same fresh leaching solution was added to the residue in the tube; the mixture was irradiated for 20 min and then centriguged. The solutions from Fractions No. 2 to No. 5 were prepared in the same way.

In the leaching with CO_2-saturated water, CO_2 gas was introduced into a mixture of 1 g of the sample and 25 ml of H_2O in a centrifugal tube under the same reaction conditions as are shown in Fig. 1.

Procedure of Adsorption Experiments. A solid-residue sample, after treatment by the leaching procedure with the 1 M CH_3COONH_4 solution, was used for the experiments. The sample was washed with water and then centrifuged.

Table 3. Chemical compositions of samples

Sample	Na(%)	K(%)	Ca(%)	Mg(%)	Fe(%)	Mn(ppm)
Soil No. 1	1.78	3.45	1.09	0.397	2.78	1790
Well-sediment No. 1	1.32	2.12	0.735	0.358	3.12	931
Well-desiment No. 2	1.17	1.93	0.435	0.427	3.35	577
Well-sediment No. 3	1.03	1.27	0.418	0.336	6.74	2460
Well-sediment No. 4	1.44	2.11	0.541	0.273	1.81	349
Montmollironite	0.258	0.623	0.431	1.48	3.25	147
Bentonite	2.69	1.56	0.258	0.325	0.129	87
Kaolinite	0.045	0.279	ND	0.062	0.502	ND
Mt. Rokko Granite	2.60	3.29	0.303	0.041	1.10	384
JB-1[a)]	2.08	1.19	6.63	4.66	6.30	1200

a) Certified values.[11)]

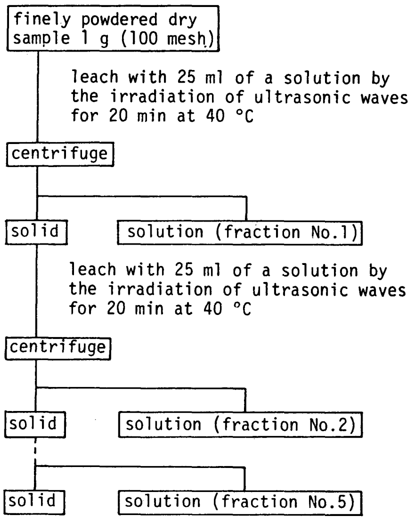


Fig. 1. The flow diagram of the leaching procedure.

After washing with water twice, a 25-ml portion of the solution adjusted to pH 7 and containing definite amounts of the chloride of each Na, K, Ca, and Mg was added to the sample. The mixture was irradiated by ultrasonic waves for 100 min (20 min × 5) at 40 °C. Then, after the centrifugation, the amounts of Na, K, Ca, and Mg in the supernatant liquid were determined.

Determination of Elements. To each solution from Fractions No. 1 to No. 5, 1 ml of a 10% La solution and 1 ml of a 5 M HNO_3 solution were added, and the mixture was diluted with water to 50 ml. In the solution, the Na and K were determined by flame photometry, and the Ca, Mg, Fe, and Mn, by atomic-absorption spectrophotometry.

For the determination of the Na, K, Ca, Mg, Fe, and Mn content of the samples given in Table 2, the samples were wet-ashed by general $HF–HClO_4–HNO_3$ treatments; these elements were then determined by the analytical procedure described above.

Results and Discussion

Analytical Data of Samples. Table 3 lists the Na, K, Ca, Mg, Fe, and Mn content of the samples. As shown in this table, the content of each element in the Mt. Rokko granite sample is fairly close to that of one reported by Kasama.[1)] However, it is difficult to find the geological differences between samples from the chemical compositions shown in this table.

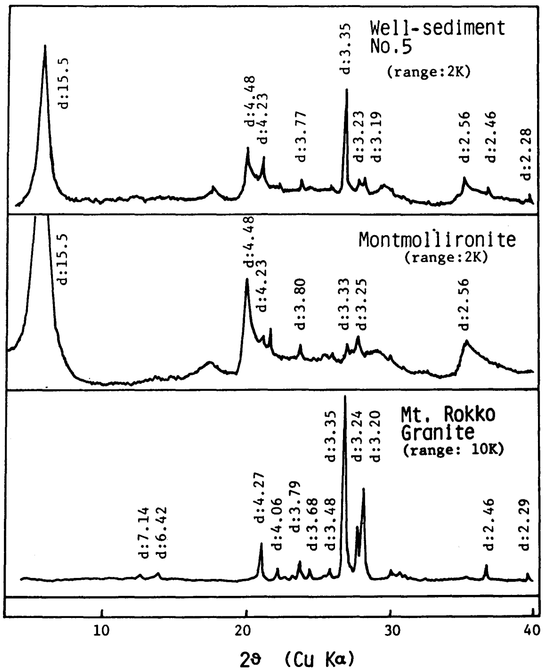


Fig. 2. X-Ray diffraction spectra of samples.

Figure 2 shows some typical X-ray diffraction patterns of the samples. The diffraction patterns of the soil No. 1 and the well-sediment No. 1 from the alluvial plains were identical with that of the Mt. Rokko granite, in which peaks corresponding to quartz (d: 4.26, 3.35, 2.46, 2.24, and 2.13) were found. In the well-sediments No. 2—No. 5 from the Kobe-group area, the peaks of montmollironite and quartz were detected.

Reprogucibility of the Leaching Method. Table 4 shows the reproducibility of the leaching method, repeated four times by the recommended procedure given in Fig. 1. In this experiment, the soil No. 1 and a 0.1 M HNO_3 solution were used as the sample and the leaching solution respectively. For each element, in the sum of five fractions, a coefficient of variation of 0.99—4.5%, which was approximately within the limits of analytical error, was obtained.

Effect of Leaching Solutions. Table 5 gives the experimental results of the leaching with different solutions from the samples. It may be found from the table that the amounts of each of six elements leached

TABLE 4. REPRODUCIBILITY OF THE LEACHING METHOD

Run No.	Sample	Fraction	Na	K	Ca	Mg	Fe	Mn
1	Soil No. 1	1	185	195	8270	398	536	257
		2	20	60	617	82	352	69
		3	10	35	190	55	278	55
		4	15	35	79	34	214	32
		5	8	18	45	23	158	18
		Sum	238	343	9201	592	1538	431
2	Soil No. 1	1	195	190	8300	378	513	250
		2	20	60	657	89	335	66
		3	10	35	193	54	262	45
		4	15	28	85	34	212	29
		5	9	18	52	23	152	19
		Sum	249	331	9287	587	1474	409
3	Soil No. 1	1	185	180	8300	393	543	257
		2	23	58	661	84	328	61
		3	19	40	151	47	257	40
		4	9	28	88	34	199	30
		5	9	28	70	30	194	29
		Sum	245	334	9270	588	1521	417
4	Soil No. 1	1	185	185	8450	376	525	244
		2	13	30	446	55	180	39
		3	13	48	367	75	308	58
		4	9	28	91	34	188	30
		5	8	28	67	30	168	28
		Sum	288	319	9421	570	1389	399
Average±S.D.		Sum	240±9.20	332±9.91	9295±92.0	584±9.74	1481±66.7	414±13.5
C.V. (%)			3.83	2.98	0.99	1.67	4.50	3.26

Values: μg/g (microgram amounts of an element leached from a 1-g sample).

TABLE 5. EFFECTS OF LEACHING SOLUTIONS

Sample	Leaching soln	Na(μg/g)	K(μg/g)	Ca(g/g)	Mg(μg/g)	Fe(μg/g)	Mn(μg/g)
Soil No. 1	CO_2-saturated water	327	288	5815	251	ND	57
	0.1 M HCl	234	288	8720	558	2000	467
	0.1 M HNO_3	240	332	9300	584	1480	414
	0.1 M CH_3COOH	230	245	8460	335	24	255
	1 M CH_3COONH_4	148	186	7400	146	ND	293
Well-sediment No. 2	CO_2-saturated water	544	666	549	177	ND	15.0
	0.1 M HCl	533	1482	4080	1640	6406	83.6
	0.1 M HNO_3	547	1652	3550	1670	6488	84.1
	0.1 M CH_3COOH	513	969	1410	564	4904	29.4
	1 M CH_3COONH_4	580	1565	2750	455	ND	42.7

Values: μg amounts of an element leached in the sum of 5 fractions from 1 g of a sample.

with the 0.1 M HCl solution was nearly equal to that leached with the 0.1 M HNO_3 solution, but was larger than that leached with the 0.1 M CH_3COOH and 1 M CH_3COONH_4 solutions. In the leaching with the CO_2-saturated water, the dissolved amounts of the elements tended to agree with that of the 0.1 M HCl or 0.1 M HNO_3 solution from the soil No. 1 and not with that from the well-sediment No. 2. This difference between the two samples probably depends on the characteristics of their samples, *i.e.*, the fact that montmollironite was contained in the well-sediment No.2, while quartz was found in the soil No. 1.

Leaching of Elements from Samples. Table 6 lists the amounts of elements leached from different samples. From the table, the following characteristics of the leaching could be recognized.

In the alluvial soil No. 1, the considerably large amount of Ca was more easily dissolved with the CO_2-saturated water than in the Kobe-group samples. In the well-sediments from the Kobe-group strata, the percentages of Na and K leached with the CH_3COONH_4 solution were remarkably higher than that from the alluvial samples, and the amounts of Na, K, Ca, and Mg leached by the HNO_3 solution were almost equal to that by the CH_3COONH_4 solution. Similar results of the leaching were found in the clay minerals, montmollironite and kaolinite. This similarity is considered to be due to the presence of montmollironite in all the Kobe-group samples.

Adsorption of Cations on Samples. Adsorption experiments were carried out in order to investigate the chemical state of the elements in these samples;

TABLE 6. ANALYTICAL RESULTS OF ELEMENTS IN THE LEACHING EXPERIMENT

Sample	Leaching soln	Na(μg/g)	K(μg/g)	Ca(μg/g)	Mg(μg/g)	Fe(μg/g)	Mn(μg/g)
Soil No. 1	0.1 M HNO_3	240(1.35)	332(0.962)	9295(85.3)	584(14.7)	1481(5.33)	414(23.1)
	1 M CH_3COONH_4	184(1.03)	186(0.539)	7397(67.9)	146(3.68)	ND	294(16.4)
	CO_2-saturated water	226(1.27)	241(0.699)	5508(50.5)	157(2.95)	ND	57(3.2)
Well-sediment No. 1	0.1 M HNO_3	151(1.14)	411(1.94)	2978(40.5)	552(15.4)	4611(14.8)	414(44.5)
	1 M CH_3COONH_4	92(0.70)	242(1.14)	1406(19.1)	158(4.41)	ND	161(17.3)
	CO_2-saturated water	342(2.59)	635(3.00)	1349(18.4)	270(7.54)	ND	ND
Well-sediment No. 2	0.1 M HNO_3	547(4.68)	1562(8.09)	3543(81.5)	1668(39.1)	6488(19.4)	84(15)
	1 M CH_3COONH_4	580(4.96)	1565(8.11)	2760(63.5)	455(10.7)	ND	43(7.4)
	CO_2-saturated water	544(4.65)	666(3.45)	549(12.6)	177(4.15)	ND	15(2.6)
Well-sediment No. 3	0.1 M HNO_3	2758(26.8)	1633(12.9)	3051(73.0)	243(7.23)	29660(44.0)	1312(53.3)
	1 M CH_3COONH_4	2683(26.1)	2038(16.1)	3368(80.6)	212(6.31)	114(0.17)	764(31.1)
Well-sediment No. 4	0.1 M HNO_3	703(4.88)	639(3.03)	1912(35.3)	389(14.2)	1858(10.3)	133(38.1)
	1 M CH_3COONH_4	718(4.99)	711(3.37)	2098(38.8)	303(11.1)	20(0.11)	113(32.4)
	CO_2-saturated water	1059(7.35)	387(1.83)	849(15.7)	173(6.34)	ND	ND
Montmollironite	0.1 M HNO_3	65(2.5)	399(6.31)	3805(88.3)	2991(20.2)	200(0.62)	56(38)
	1 M CH_3COONH_4	63(2.4)	348(5.51)	4532(105)	3313(22.4)	ND	51(35)
	CO_2-saturated water	83(3.2)	403(6.38)	200(4.64)	119(0.80)	ND	ND
Bentonite	0.1 M HNO_3	6862(25.5)	484(3.10)	676(26.3)	379(11.7)	116(9.00)	13(15)
	1 M CH_3COONH_4	10262(38.2)	1006(6.47)	2422(94.0)	572(17.6)	ND	ND
Kaolinite	0.1 M HNO_3	10(2.2)	13(0.47)	ND	284(45.8)	4(0.08)	ND
	1 M CH_3COONH_4	18(4.0)	30(1.1)	ND	281(45.3)	ND	ND
Mt. Rokko Granite	0.1 M HNO_3	146(0.56)	470(1.43)	303(10.0)	66(16)	1523(13.8)	110(28.6)
	1 M CH_3COONH_4	84(0.32)	116(0.35)	218(7.19)	15(3.7)	ND	30(7.8)
	CO_2-saturated water	362(1.39)	388(1.18)	323(10.7)	30(7.3)	ND	ND
JB-1	0.1 M HNO_3	388(1.87)	276(2.34)	4377(6.65)	7918(17.1)	4889(7.74)	177(14.3)
	1 M CH_3COONH_4	96(0.46)	169(1.43)	1439(2.19)	786(1.70)	ND	50(4.0)
	CO_2-saturated water	73(0.31)	99(1.7)	1243(1.89)	998(2.16)	ND	62(5.0)

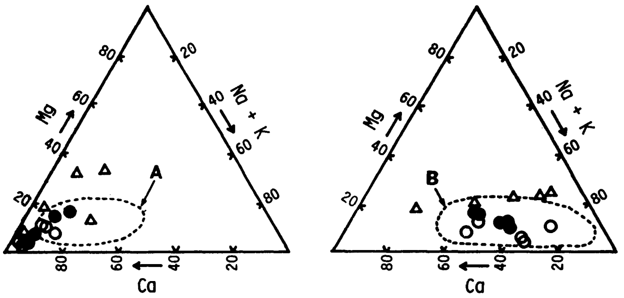
Values: microgram amounts of an element leached in the sum of 5 fractions from a 1-g sample,

$$\text{Values in parentheses: } \frac{\text{microgram amounts of an element leached in the sum of 5 fractions from a 1-g sample}}{\text{total microgram amounts of an element in a 1-g sample}} \times 100\ (\%).$$

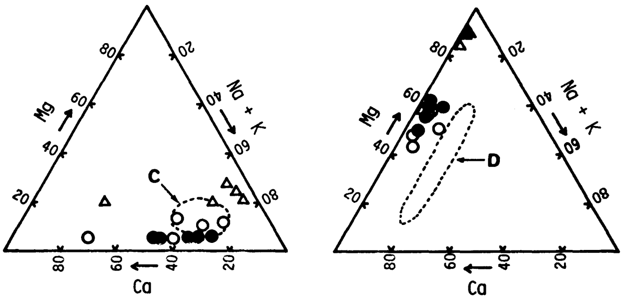
TABLE 7. ANALYTICAL RESULTS OF CATIONS IN THE ADSORPTION EXPERIMENT

Sample[a]	Cation	Added (μg)	Adsorbed (μg)	Leached[b] (μg)	Ratio of adsorbed to leached
Montmollironite (1 g)	Na	4980	1730	63	27
	K	5130	1880	348	5
	Ca	4980	2480	4532	0.5
	Mg	4880	2430	3313	1
Bentonite (1 g)	Na	4980	720	10262	0.07
	K	5130	1130	1006	1
	Ca	4980	4730	2422	2
	Mg	4880	1380	572	2
Kaolinite (1 g)	Na	4980	1130	18	63
	K	5130	325	30	11
	Ca	4980	350	ND	ND
	Mg	4880	225	281	0.8
Soil No. 1 (1 g)	Na	1130	100	184	0.5
	K	1800	110	186	0.6
	Ca	9690	560	7397	0.08
	Mg	2000	110	146	0.8
Well-sediment No. 2 (1 g)	Na	900	100	580	0.2
	K	1440	440	1565	0.3
	Ca	7750	1480	2760	0.5
	Mg	1600	219	455	0.5

a) Samples treated by leaching with the 1 M CH_3COONH_4 solution. b) Amounts of cations leached with the 1 M CH_3COONH_4 solution (see Table 6).



(1) Soil No.1 (2) Well-sediment No.4



(3) Mt. Rokko Granite (4) JB-1 (Japanese Basalt)

Fig. 3. Key diagram of relative percentages of milligram equivalents.

●: Leaching by CO_2-saturated water, ○: 1 M CH_3COONH_4 leaching, △: 0.1 M HNO_3 leaching, A: 34 Groundwaters from the alluvial plains, B: 38 Groundwaters from the Kobe-group strata, C: 7 Stream waters from topmost Mt. Rokko, D: 8 groundwaters from the worldwide 8 basaltic regions.

the soil No. 1 from the alluvial plains, the well-sediment No. 2 from the Kobe-group strata, and the clay minerals. Table 7 shows the results of the experiments. In this table, the amounts of elements leached from the original sample (see Table 6) are also listed.

In the montmollironite and bentonite, the amounts of divalent Ca adsorbed was higher than that of monovalent Na and K. The adsorptive behavior of the cations was observed also in the soil No. 1 and the well-sediment No. 2. However, from the fact that the ratio of the amounts adsorbed to those leached is 0.08 for Ca in the soil, it can be seen that scarcely no exchangeable Ca existed in the soil from the alluvial plains. In contrast, from the relatively high ratio of 0.5 for Ca in the well-sediment No. 2, it seems that much Ca was present as exchangeable ions in the sediment from the Kobe-group strata.

Association of the Chemical Species Dissolved in Groundwaters with Their Surrounding Geology. Figure 3 gives the key diagram of the relative percentages of milligram equivalents for Na+K, Ca, and Mg leached from the four samples. In Fig. 3-(1) for the soil No. 1, it is indicated that the plots of cations leached from the soil agree almost entirely with the A area, the plots of the 34 shallow groundwaters from the alluvial plains (see Table 1). A similar agreement is also found in the well-sediment No. 1 from the same alluvium.

In Fig. 3-(2) for the well-sediment No. 4 from the Kobe-group strata, the plots of leached cations, especially with the CH_3COONH_4 solution or the CO_2-saturated water, overlap well with the analytical results of the 38 shallow groundwaters (B) from the Kobe-group strata.[3,4] This agreement is also found in the well-sediment No. 3 from the same strata.

The leaching data of the Mt. Rokko granite, plotted in Fig. 3-(3), are somewhat scattered, but those with the CO_2-saturated water tend to overlap with the results of the 7 stream waters located at the top of Mt. Rokko (C).[12] From this tendency, it can be pointed out that the chemical composition of stream waters is determined by the leaching of constituents in the granitic rocks by chemical weathering with CO_2.

In Fig. 3-(4) for JB-1, it is shown that the plots of cations leached with the CO_2-saturated water or the CH_3COONH_4 solution fall close to the analytical data of the 8 groundwaters in the 8 basaltic regions worldwide (D).[13]

In conclusion, it can be analysed that the chemical compositions of groundwaters are considerably influenced by the geological strata through which the groundwaters pass, and that they can be estimated by utilizing the proposed leaching experiments for the solid samples around the groundwater area. In the leaching, the CO_2-saturated water is effective for investigating the influence of rocks on groundwaters, whereas the 1 M CH_3COONH_4 solution is useful for the samples containing clay minerals.

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