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環境同位元素를 利用한 濟州東部地域 帶水層의 海水汚染에 關한 研究

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Environmental Isotope-Aided studies on Sea Water contamination of Eastern Coastal Aquifer in Cheju Island

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Abstract

Cheju Island formed by Quarternary volcanism provides highly permeable hydrogeological environment. To meet the increasing demand of water in the island, many groundwater wells have been developed. The environmental isotopes(oxygen-18, deuterium, tritium) and chemical analysis of water samples from the eastern part of the island were carried out to ascertain whether groundwater in the eastern part of the island was contaminated by sea water. The result of tritium analysis indicated fast infiltration of meteoric water into underground and rapid mixing process between rain water and groundwater. The results of oxygen-18 and deuterium analysis demonstrated that most of the wells in the eastern part of the island were influenced by sea water intrusion. Chemical analysis of water samples revealed that most groundwater in study area were classified into Na-Cl type and showed high chloride/bicarbonate ratios. Sea water intrusion in the northeastern part of the island has proceeded at least 3 km within the coastaline, and in the south eastern part about 700 m.

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1. INTRODUCTION

Cheju Island formed by several episodes of Quarternary volcanisms is located 180km south of the Korean Peninsular and has an area of 1,825km.^{2} with a populaion of 519,000 in 1990. In the center of the island, a volcanic pile, Mt. Halla rises 1,950m above sea level.

This island has the highest precipitation in Korea. However, the rapid infiltration of a large quantity of surface water into underground due to the highly permeable hydrogeological environment of the island, resulted in insufficient surface water resource.

Due to the rapid development of Cheju Island in the fields of tourism, industries, and agriculture etc., water demand continues to increase. To meet the increasing water demand groundwater wells have been intensively developed along the coast. However, it has been concerned that excessive development of wells and heavy pumpage of groundwater might cause sea water intrusion into fresh groundwater in the south eastern part of the island.

In this paper, the environmental isotopes (oxygen-18, deuterium and tritium) and chemical analysis of water samples were carried out to ascertain whether groundwater in the eastern part of the island(Songsan, Kujwa, Pyoson) are contaminated by sea water.

2. HYDROLOGY AND GEOLOGY

Annual evergage precipitation of the island is about 1,600mm. Rainfall at higher altitudes in the interior of the island(Mt.Halla) exceeds the average. The rainfall which amounts to seventy percent of the annual total precipitation concentrates during the monsoon season, from may to September. Despite the heavy rainfall, there is little sustained stream flow on the island, because of high permeability of volcanic rocks. Streams are usually short, steep, and small, because surface water infiltrates into underground very rapidly, Sometimes groundwater flows out through springs at various altitudes and form small streams. Many of these streams run only a few hundred meters and disappear.

The total precipitation volume of Cheju Island is estimated at 2.9 billion m^3 a year. 1.8billion m^3 of the total is estimated to be discharged directly along the river or evaporated, and the remaining 1.1 billion m^3 infiltrates into the underground. 0.2billion m^3 of groundwater flows out through 185 natural springs near the coast. Groundwater retained in volcanic rocks is estimated at 0.9 billoion m^3

Volcanic rocks of the island are mainly composed of various basaltic rocks such as picritic basalt, olivine basalt and aphanitic basalt. Associated rocks are trachyte, trachy-andesite, aphanitic andesite, scoria and ash tuffs. Basaltic rocks in the island are characterized by vesicular matrice and development of numerous joints.

Pyroclastic rocks composed of clinker and scoria are found ubiquitously in the island. Sedimentary deposits composed of sand, gravel and volcanic ash are locally distributed along the coast.

The layers of pyroclasts and lava flows were alternatively developed, which indicates several eruption cycles of volcanism. Basaltic lava flows dip toward the sea, whereas the layers of pyroclastic rocks dip in various directions in conformance with parasitic volcanic cones.

Layers of vesicular basaltic lavas and porous tuffs provide highly permeable hydrological environment in the island, and geological structures such as lava tunnels and scoriaceous contact zones between each lava flows provide conduits for groundwater movement.

3. EXPERIMENT

Water samples were collected seasonally from 23 different sites ; 19 of groundwater, 2 of spring waters and 2 of sea waters(Fig. 1 and Table 1).

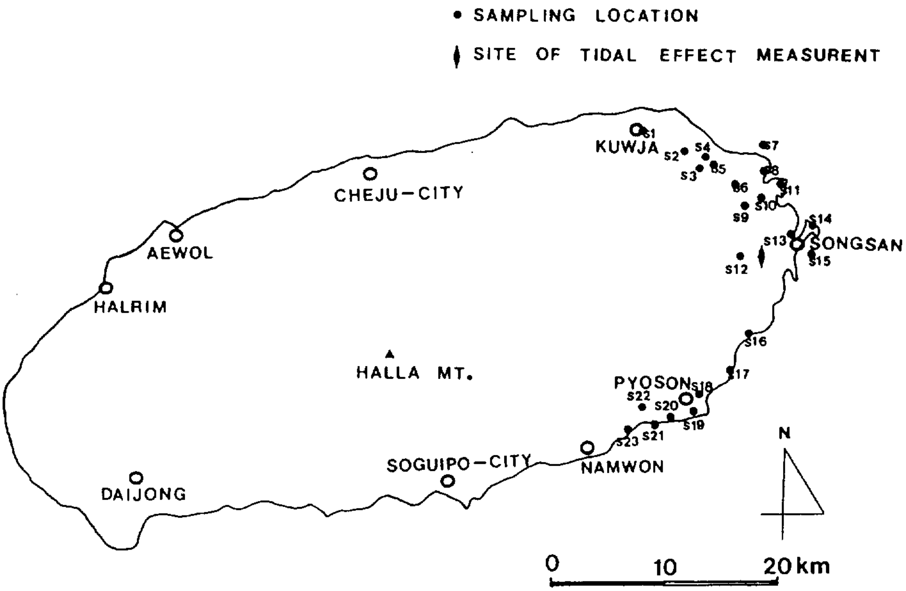

Fig. 1. Map of Sample Locality

Table 1. Specification of sampling sites

Sample No.	Location	Description	Distance from the sea (km)	Depth (m)
S 1	Kujwa	groundwater	2.05	80
S 2	Kujwa	groundwater	2.25	70
S 3	Kujwa	groundwater	3.50	90
S 4	Kujwa	groundwater	2.25	80
S 5	Kujwa	groundwater	2.00	46
S 6	Kujwa	groundwater	3.00	60
S 7	Kujwa	sea water	0.00	0
S 8	Kujwa	spring water	0.00	0
S 9	Kujwa	groundwater	2.75	75
S10	Kujwa	groundwater	1.45	35
S11	Kujwa	groundwater	1.60	25
S12	Songsan	groundwater	4.90	51

S13	Songsan	groundwater	1.00	20
S14	Songsan	groundwater	1.50	50
S15	Songsan	sea water	0.00	0
S16	Songsan	groundwater	0.25	30
S17	Songsan	groundwater	0.75	40
S18	Pyoson	groundwater	1.25	43
S19	Pyoson	groundwater	0.85	36
S20	Pyoson	groundwater	0.30	35
S21	Pyoson	spring water	0.00	0
S22	Pyoson	groundwater	1.10	101
S23	Pyoson	groundwater	0.30	50

Temperature and pH were measured in situ. Main anion and cation contents and electrical conductivity of the samples were measured in the laboratory. The type of water was determined in accordance with Piper's trilinear diagram.[1)]

Tritium content was measured at KAERI, and deuterium and oxygen-18 analysis were done by the Centre for the Application of Isotope and Radiation, Indonesia.

An abandoned well was used to measure the electrical conductivity of groundwater with the change of water table(Fig. 1 and Fig. 5).

4. RESULTS AND DISCUSSION

1) Isotope Analysis

Tritium : the tritium contents of groundwaters are in the range of 4.6-12.2TU except Sample 14(S14), with 13.4-16.7TU. The tritium contents of spring waters range from 6.0 to 12.1 TU, which are within the range of groundwater(Table 2). Tritium contents of groundwaters and spring waters are generally higher in May and July than in March.

Table 2. Environmental isotope compositions of water samples

Smaple	MARCH			MAY		
	0-18 (permil)	Deut. (permil)	Tri. (TU)	0-18 (permil)	Deut. (permil)	Tri. (TU)
S-1	-6.24	-37.3	7.44	-5.44	-49.3	10.67
S-2	-4.53	-29.1	7.5	-4.54	-47.2	8.7
S-3	-5.52	-30.9	5.4	-6.79	-51.1	7.47
S-4	-5.85	-33.3	5.31	-6.38	-49.5	7.88
S-5	-6.53	-49.4	6.43	-5.93	-46.8	9.73
S-6	-6.49	-48.9	5.7	-5.44	-36.7	7.98
S-8	-5.64	-43.3	-	-5.83	-46.6	-
S-9	-6.17	-48.2	8.22	-6.40	-50.2	11.88
S-10	-5.09	-28.3	7.9	-6.20	-48.0	10.99
S-11	-5.09	-28.4	9.77	-4.57	-39.1	9.9
S-12	-6.17	-49.9	12.16	-5.15	-26.9	11.97
S-13	-5.85	-46.9	10.57	-5.03	-28.3	9.51

S-14	-5.20	-43.6	15.49	-4.37	-25.3	16.71
S-16	-5.75	-47.4	10.82	-5.21	-31.1	10.5
S-17	-5.13	-47.3	10.71	-	-	-
S-18	-5.71	-49.4	11.72	-5.67	-29.6	11.04
S-19	-5.71	-47.0	9.12	-5.77	-31.5	8.52
S-20	-5.40	-46.7	9.88	-5.50	-45.6	8.88
S-21	-6.09	-41.7	11.5	-5.99	-33.3	-
S-22	-5.53	-41.7	10.49	-5.97	-36.2	9.62
S-23	-5.92	-48.8	9.86	-	-	-

(Continued)

Smaple	JULY			AUGUST		
	0-18 (permil)	Deut. (permil)	Tri. (TU)	0-18 (permil)	Deut. (permil)	Tri. (TU)
S- 1	-5.87	-36.5	10.72			11.49
S- 2	-6.57	-38.8	10.31			9.40
S- 3						7.12
S- 4	-6.28	-40.0	9.77			8.28
S- 5	-6.30	-37.4	10.40			9.80
S- 6	-5.89	-39.7	9.27			8.31
S- 8	-5.36	-34.7	9.41			
S- 9						9.65
S-10	-6.0	-45.1	11.29			10.56
S-11			8.85			9.58
S-12	-5.66	-46.0	10.98			10.74
S-13	-5.10	-34.1	8.98			10.01
S-14	-5.87	-48.1	15.60			13.44
S-16	-6.10	-48.2	10.20			10.02
S-17						
S-18	-4.94	-41.0	11.60			10.64
S-19	-4.14	-29.2	6.30			7.60
S-20						16.0
S-21	-5.76	-38.8	11.22			
S-22	-6.07	-28.2	11.26			9.46
S-23	-5.74	-30.9	10.33			8.88

Tritium content of rain water is higher in May(9.0TU) than in March(5.7TU) and April(6.0TU). Tritium contents of rain water in Cheju Island including previous studies[2,3] are compiled with those measured in Daejeon City(unpublished data, Korea Atomic Energy Research Institute, 140km south of Seoul) (Table 3).

Table 3. Tritium content of rain water in Korea

		Cheju Island	KAERI*
1983	Mar.	5.9	
	Apr.	13.9	
	May.	12.1	
	Jun.	17.4	
1989	Jan.		8.6
	Feb.		12.6
	Mar.		12.3
	Apr.		19.1
	May.		22.3
	Jun.		12.0
	Jul.		5.4
	Aug.		11.4
	Sep.	2.4	8.5
	Oct.	8.3	
	Nov.	3.6	10.7
	Dec.		10.2
1990	Jan.		5.8
	Feb.		
	Mar.	5.7	10.2
	Apr.	6.0	15.7
	May.	9.0	

*Korea Atomic Energy Research Institute

Even though there are differences in absolute values between the tritium contents of Cheju Island and those of Daejeon City, their seasonal variations show a very similar ; tritium content in rain water is generally low in March and increases in May and June, then decreases. It is believed that the similar trend observed in groundwater is due to fast infiltration of rain water into aquifers.

Oxygen-18 and Deuterium : Ranges of the oxygen-18 and deuterium contents are -6.6 to -4.1 permil and -50 to -28.3 permil in groundwater, and -6.4 to -5.4 permil and -43.3. to -34.7, in spring water respectively (Fig. 2).

When the data from the previous studies of western part of the Island(Aewol and Halrim.[4]) are plotted with the present data (Fig. 2), data cluster around the world-wide meteoric water line.[5] However, the data from the eastern part are higher by more than 1 permil in oxygen-18, and higher up to 15 permil in deuterium than those from the

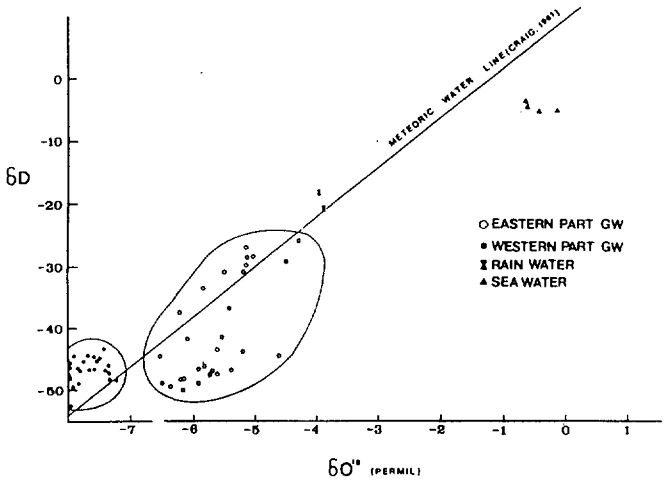

Fig. 2. Oxygen-18 and Deuterium Compositions of Water Samples : Meteoric water line is from Craig (1961). Data of Western part, sea water and rain water are from Ahn and others(1987).

western part of the island. Even though data from the eastern part seem rather scattered, they are plotted between the values of sea water and those of fresh groundwater of western part. Since the previous study[4] showed that the groundwaters in western part of the island retained the characteristics of fresh groundwater, this comparison provides a clear evidence of sea water intrusion into the groundwater of the eastern part of the island.

2) Chemical Analysis

Temperature and pH : The temperature of sea water shows the range of 14-26°C. The temperature of groundwater and spring water is 16-17°C. The pH range of sea water is 7.9-8.8, and that of groundwater and spring water is 7.3-8.8, which are similar to those of other area such as Cheju City[2]. Soguipo City,[6] Daijung[3] and Aewl-Halrim[4] by 3 to 10 times in groundwater, and by 20-60 times in spring water. These values show the highest values in March, decrease in summer and increase again later.

Table 4. Chemical data of water samples(March)

Sample No.	Temp. (°C)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S 1	16.0	7.52	104	6.20	10.3	11.9	139	0.70	18.0	37.3	608
S 2	16.0	7.40	49.8	4.45	5.32	6.93	74.8	1.51	12.6	28.6	359
S 3	16.5	7.31	46.6	4.80	11.2	8.82	85.3	1.73	14.1	27.6	410
S 4	17.0	7.53	158	10.1	17.5	22.0	248	1.67	23.4	27.5	1,002
S 5	16.5	7.48	85.6	7.00	10.0	14.2	147	2.54	16.4	29.9	640
S 6	17.0	7.62	115	9.83	10.6	15.0	207	0.50	23.5	34.9	613
S 7	17.0	8.17	9,110	1,132	620	1,250	19,466	0.71	1,832	112	49,500
S 8	16.0	7.77	980	65.7	38.2	114	2,146	1.24	105	40.6	6,884
S 9	16.0	7.53	59.3	5.86	6.72	9.08	113	0.96	23.0	30.7	505
S10	16.0	7.48	112	9.23	8.50	14.5	208	1.04	16.9	31.2	862
S11	17.0	7.91	1,730	109.3	73.6	225	3,589	3.28	191	70.1	11,770
S12	16.0	7.32	26.8	3.03	4.34	6.20	40.8	2.61	8.61	28.0	237
S13	17.0	7.94	146	21.7	21.2	17.3	193	6.02	11.4	255	1,160
S14	17.0	8.03	40.7	6.90	15.6	10.1	52.5	1.68	6.59	101	402
S15	14.0	8.11	4,230	452	336	900	12,159	1.41	1,071	75.8	25,220
S16	17.0	7.59	129	8.93	7.65	15.6	232	1.26	14.5	34.2	883
S17	17.0	7.55	710	30.3	23.6	70.6	1,481	1.80	66.5	35.7	3,360
S18	17.0	7.32	11.0	2.30	4.57	5.12	22.8	1.23	6.15	26.2	141
S19	17.0	7.56	540	30.3	23.3	62.6	1,890	3.59	64.4	25.6	3,270
S20	17.0	7.53	284	17.4	15.8	36.5	491	3.02	39.0	32.3	1,850
S21	16.5	7.61	310	20.1	16.5	41.3	464	1.72	47.6	32.4	2,210
S22	16.0	7.29	7.32	1.69	4.65	3.82	14.2	1.11	5.10	27.2	103
S23	17.0	7.38	37.1	4.03	4.66	6.51	68.7	1.18	7.20	28.9	313

Table 5. Chemical data of water samples(April)

Sample No.	Temp. (℃)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S 1	17.0	7.53	56.6	4.85	10.1	9.03	102	0.68	19.2	39.7	486
S 2	16.0	7.50	44.6	4.44	6.40	7.01	78.0	1.51	13.0	25.3	380
S 3	16.0	5.59	36.5	4.56	10.9	8.70	79.7	2.29	12.7	25.5	387
S 4	16.5	7.50	97.6	8.59	15.4	18.2	208	1.84	24.0	27.9	874
S 5	16.5	8.40	85.1	7.11	10.1	15.0	164	2.78	16.6	31.2	715
S 6	16.0	7.64	119	9.83	9.32	14.9	186	0.52	18.3	34.6	904
S 7	15.0	8.21	9,330	1,506	402	1,036	17,713	0.43	1,878	111	51,000
S 8	16.0	7.79	968	54.5	40.6	118	2,016	0.76	92.0	40.0	4,070
S 9	16.0	7.42	57.6	5.51	6.09	8.42	109	0.79	13.7	31.6	489
S10	16.5	7.53	117	8.99	8.07	13.9	205	0.96	22.1	32.0	865
S11	17.0	7.99	1,187	100	69.4	213	3,310	4.68	194	85.4	11,050
S12	16.0	7.54	19.8	2.97	4.39	6.24	40.6	2.54	7.73	27.3	236
S13	16.0	7.65	86.2	18.8	25.0	14.5	184	8.08	14.1	221	1,040
S14	17.0	7.97	32.9	7.09	16.7	10.7	60.7	1.68	11.8	99.1	425
S15	15.0	8.13	4,820	339	300	979	13,639	1.11	1,519	81.4	37,560
S16	16.0	7.53	119	10.4	11.4	23.2	247	1.18	26.8	33.5	974
S17	16.0	7.50	291	24.0	20.5	65.0	562	1.54	52.8	35.7	2,820
S18	16.5	7.50	7.17	2.34	4.95	5.30	19.6	1.66	5.01	24.1	128
S19	16.0	7.46	237	1,902	14.8	42.0	617	3.49	57.6	23.5	2,260
S20	16.0	7.43	128	11.1	14.7	23.5	339	4.28	22.5	26.5	1,290
S21	16.5	7.42	53.6	5.60	6.01	10.8	144	2.33	12.5	28.4	588
S22	16.0	7.27	5.96	1.30	5.33	4.67	16.8	3.55	5.19	22.6	127
S23	17.0	7.34	26.5	3.54	4.83	6.57	70.5	2.00	8.87	28.1	315

Table 6. Chemicaldataofwatersamples(July)

Sample No.	Temp. (℃)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S 1	17.0	7.89	49.6	4.39	8.30	8.44	101	0.16	14.5	39.1	411
S 2	16.0	7.68	38.0	4.74	4.38	5.69	69.6	0.77	10.4	28.7	300
S 3	-	-	-	-	-	-	-	-	-	-	-
S 4	17.0	8.07	89.0	7.62	12.6	14.5	195	0.83	24.3	30.6	665
S 5	17.0	7.89	94.4	8.14	9.26	14.1	191	1.13	29.1	33.8	645
S 6	17.0	8.02	210	15.8	13.3	24.9	413	0.78	47.2	36.4	1,329
S 7	28.0	8.40	8,210	382	270	1,004	17,296	0.51	1,948	114	44,100
S 8	16.0	8.18	887	53.2	32.7	94.2	1,935	0.25	70.0	42.3	6,290
S 9	17.0	7.76	38.9	3.77	3.82	5.07	74.2	0.39	10.5	31.6	320
S10	16.5	7.91	95.7	7.65	6.25	10.6	186	0.48	21.3	34.1	643
S11	17.0	8.52	1,100	78.7	72.2	162	2,490	2.40	176	109	6,710
S12	17.0	7.80	24.8	2.58	6.07	7.88	54.7	1.85	9.49	29.0	273

S13	17.0	8.93	113	19.7	12.5	13.8	170	3.03	24.0	226	890
S14	17.0	8.38	45.4	6.67	17.5	11.0	68.9	0.64	15.9	106	444
S15	28.0	8.55	4,990	192	206	674	10,508	0.59	1,571	83.8	29,846
S16	18.0	8.40	109	7.52	5.94	11.2	205	1.08	25.1	37.5	719
S17	18.0	7.97	241	11.7	9.50	53.1	443	0.92	52.8	35.6	1,509
S18	17.0	7.67	9.32	2.22	4.97	4.91	22.4	0.95	4.49	28.6	132
S19	18.0	7.68	271	9.00	8.10	27.0	331	2.70	35.3	20.9	1,108
S20	17.0	8.15	229	14.9	10.2	20.5	412	2.53	51.8	37.0	1,384
S21	17.0	7.69	131	8.06	5.06	9.04	217	1.24	28.3	37.1	755
S22	17.0	7.69	7.50	1.69	5.57	4.81	16.7	1.13	4.22	28.7	117
S23	16.5	7.74	15.9	1.05	1.95	3.65	29.1	1.51	5.89	30.8	169

Table 7. Chemicaldataofwatersamples (August)

Sample No.	Temp. (°C)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S 1	16.0	7.22	54.1	5.88	9.40	9.24	114	0.24	16.7	38.14	462
S 2	16.0	7.48	35.1	4.65	4.74	6.23	68.2	1.35	10.0	29.1	293
S 3	16.0	7.67	37.0	5.13	9.21	7.90	94.1	1.41	12.3	39.7	343
S 4	16.0	7.75	101	10.2	13.8	20.6	223	1.74	28.3	31.0	864
S 5	16.0	7.57	101	9.51	10.2	17.7	212	1.99	27.9	34.8	821
S 6	16.0	7.67	241	17.4	14.8	27.6	424	0.55	49.4	38.2	1,530
S 7	26.0	7.47	8,820	626	355	1,081	17,215	0.32	2,503	119	47,377
S 8	15.0	7.90	1,011	62.6	43.0	124	201	0.07	120	43.2	5,794
S 9	15.5	7.70	51.1	5.83	7.31	9.66	108	0.22	16.4	32.8	461
S10	16.0	7.73	132	11.7	8.29	14.9	253	0.36	33.5	36.1	977
S11	17.0	7.84	1,297	94.0	77.2	188	2,712	4.29	209	88.9	8,291
S12	16.0	7.65	31.7	4.28	7.14	9.24	64.3	2.66	10.7	33.0	292
S13	17.0	7.91	142	12.3	24.0	19.7	211	6.96	21.5	318	1,218
S14	17.0	8.14	50.1	7.95	19.1	12.0	77.4	1.31	17.0	120	454
S15	26.0	8.23	5,310	361	223	701	11,022	1.26	1,447	92.4	31,724
S16	16.0	7.72	120	10.4	8.49	16.2	255	1.56	34.9	36.0	853
S17	17.5	7.59	693	24.5	17.4	49.5	692	2.31	75.6	35.4	2,344
S18	16.0	7.48	10.0	3.07	4.81	4.63	19.2	0.85	3.64	30.7	123
S19	17.5	7.66	323	25.7	20.5	57.9	710	5.43	27.8	25.3	2,437
S20	16.5	7.50	206	14.2	14.3	23.4	652	5.19	48.6	32.9	1,511
S21	15.0	7.66	86.4	8.22	4.63	9.03	150	2.38	16.6	37.6	607
S22	16.0	7.36	8.60	2.50	7.04	5.27	14.9	4.85	2.81	28.6	132
S23	16.0	7.49	22.6	2.97	3.02	3.07	28.8	1.99	4.38	31.1	177

Table 8. Chemicaldataofwatersamples(September)

Sample No.	Temp. (℃)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S1	16.0	7.24	45.9	5.34	8.45	8.21	86.6	0.14	13.0	42.1	381
S2	15.0	7.54	34.9	4.76	4.73	6.11	65.7	1.98	10.2	26.8	282
S3	16.0	7.45	14.2	3.49	5.85	5.30	30.0	1.53	5.75	25.9	165
S4	16.0	7.72	77.4	8.17	11.4	15.0	168	2.31	22.1	30.8	635
S5	16.0	7.70	80.2	7.64	8.32	13.3	156	3.75	21.2	31.4	617
S6	16.0	7.78	193	16.3	15.0	23.8	375	2.23	48.8	37.8	1,037
S7	21.0	8.34	8,230	632	390	1,212	18,480	0.33	2,613	115	48,528
S8	15.0	8.06	852	57.0	35.4	96.1	179	0.20	105	41.8	5,245
S9	15.5	7.72	47.6	5.66	6.67	8.53	92.7	0.84	14.0	32.9	385
S10	15.0	7.84	102	9.76	7.48	12.2	196	1.31	22.6	33.2	737
S11	16.0	8.34	1,190	92.2	73.8	171	3,110	6.45	214	101	7,468
S12	16.0	7.77	23.6	4.31	7.32	21.5	45.1	7.34	8.23	29.1	253
S13	16.0	7.75	154	24.0	24.9	8.51	217	6.29	21.2	26.5	1,153
S14	15.0	8.30	48.0	7.75	17.7	11.1	63.5	1.31	13.7	109	398
S15	22.0	8.32	8,690	591	346	1,129	17,415	0.60	2,329	53.3	46,120
S16	16.0	7.29	130	9.76	7.42	14.3	233	1.71	29.5	40.8	855
S17	16.0	7.95	839	30.1	16.8	51.1	839	2.13	86.4	36.9	2,697
S18	16.0	7.55	9.50	3.18	5.31	5.19	16.7	2.85	3.27	27.1	125
S19	16.0	7.61	119	13.3	5.53	15.9	118	7.14	86.8	18.5	857
S20	16.0	7.77	167	17.8	12.1	26.2	661	2.04	38.8	28.0	1,190
S21	16.5	7.81	97.4	8.89	6.57	12.5	186	2.71	21.9	38.7	718
S22	16.0	8.58	4.70	3.29	3.46	3.38	27.3	2.68	2.72	29.9	173
S23	16.0	7.56	9.10	2.38	12.1	8.54	19.5	2.08	2.81	28.0	189

Table 9. Chemicaldataofwatersamples(October)

Sample No.	Temp. (℃)	pH	Na ppm	K ppm	Ca ppm	Mg ppm	Cl ppm	NO_3 ppm	SO_4 ppm	HCO_3 ppm	Conductivity (μmho/cm)
S1	16.0	7.63	50.4	5.58	8.69	8.64	101	0.14	15.9	33.2	412
S2	16.0	7.52	35.1	4.72	4.80	6.26	65.3	1.83	11.1	26.2	281
S3	16.0	8.01	34.7	4.91	9.01	7.58	71.7	1.90	13.9	24.7	312
S4	16.0	7.72	81.3	8.60	12.8	16.4	178	2.09	27.3	28.6	715
S5	17.0	7.78	116	10.7	10.1	18.1	237	2.10	27.8	32.9	939
S6	17.0	7.89	234	17.2	14.0	25.1	401	1.21	48.6	36.9	1,488
S7	19.0	8.23	9,050	610	379	1,167	18,655	0.36	2,567	114	50,518
S8	15.0	8.09	974	60.6	38.4	106	205	0.23	126	42.7	5,850
S9	16.5	7.66	47.3	5.52	6.02	8.23	110	0.58	13.8	30.2	395
S10	16.5	7.81	154	13.5	8.74	16.4	307	0.65	38.9	34.4	1,144
S11	17.0	8.15	1,540	105	64.9	192	2,521	3.90	286	58.2	9,072
S12	16.0	7.69	27.7	4.29	6.90	8.62	55.7	3.39	10.6	29.6	279

S13	17.0	8.45	112	24	17.5	25.8	158	11.2	29.7	159	915
S14	17.0	8.26	42.2	7.75	17.7	10.9	60.7	1.25	15.7	106	422
S15	20.0	8.21	8,330	508	364	1,163	17,840	0.65	2,329	109	47,796
S16	16.0	7.85	120	10.4	8.20	14.5	257	1.35	29.3	32.3	953
S17	17.0	7.70	696	22.9	15.2	43.1	606	2.29	78.0	32.9	2,144
S18	16.5	7.27	10.5	3.05	5.06	5.03	22.0	1.78	3.55	20.4	133
S19	17.0	7.73	377	27.5	22.2	66.0	413	5.88	96.3	26.2	2,785
S20	17.0	7.84	243	20.5	15.2	36.0	987	4.50	51.7	34.7	1,814
S21	16.0	7.70	159	15.2	8.69	19.1	314	2.82	55.9	34.7	1,176
S22	17.0	7.45	7.0	2.38	5.23	3.89	11.7	1.28	2.54	21.0	104
S23	17.0	7.52	21.8	3.12	2.86	3.05	28.4	1.66	3.37	25.0	166

Based on trilinear diagrams.[1], groundwaters having high salt content(S1, S2, S3, S5, S6, S9, S10, S12, S13, S16, S17, S19, S23) are classified into Na-Cl type. Although there are slight seasonal variations, groundwater samples with low salt content(S18, S22) are classified into Ca-Cl or Ca-HCO_3 type, which are considered to be volcanic origin.

In Fig. 3 the electrical conductivity of groundwater and the distance of sample site from the sea are plotted. Most wells near the coast exhibit high electrical conductivities. Two wells(S18, S22) in the southeastern part of the island show low electrical conductivities.

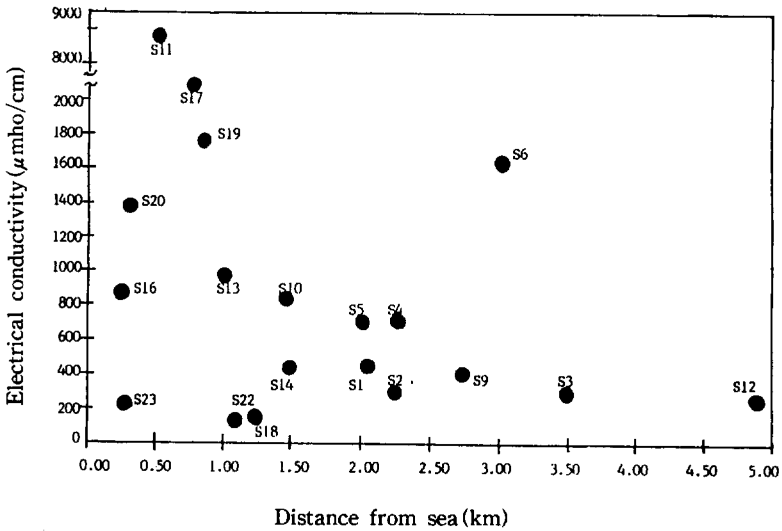

Fig. 3. Electrical conductivity of ground water with the distance from sea.

Chloride/Bicarbonate Ratio : Chloride is abundant in sea water whereas it exists in trace amount in fresh groundwater. But bicarbonate is in reversed situation Both ions are not affected by the various chemical reactions such as ion exchange and sulfate reduction when sea water is mixed with groundwater.[6] Ravelle.[7] used Cl/HCO_3 ratio to evaluate the extent of mixing of sea water with groundwater ; When Cl/HCO_3 ratio is less than 0.5, there is no sea water contamination, the range of 0.5-1.3 indicates slight contamination, the range of 1.3-2.8 indicates inter mediate and 2.8-6.6 indicates serious contamination. Based on the criteria, all wells in Kujwa and Songsan areas(northeastern part of the island) are considered to be seriously contaminated(4-88). Wells(S3, S5, S6) 3km away from the coast also show values higher than 4(Table 10).

Table 10. Chloride-bicarbonate ratios as a criterion of sea water intrusion.

Sample No.	sampling date Mar. 28	Apr. 28	May 28	Jun. 28	Jul. 28	Aug. 28	Sept. 28	Oct. 28
	$Cl/CHCO_3$	Cl/HCO_3	Cl/HCO_3	Cl/HCO_3	Cl/HCO_3	Cl/HCO_3	Cl/HCO_3	Cl/HCO_3
S 1	6.41	5.93	4.80	3.66	4.44	5.13	3.54	5.20
S 2	4.50	5.97	4.05	4.66	4.17	4.03	4.21	4.29
S 3	5.32	3.43	5.32	3.18	-	4.08	1.99	5.00
S 4	16.0	12.0	11.3	9.93	11.0	12.3	9.37	10.7
S 5	8.46	6.86	8.88	7.50	9.72	10.5	8.56	12.4
S 6	10.2	9.82	-	-	20.0	19.1	17.1	18.7
S 7	299	277	316	274	261	250	277	282
S 8	91.0	369	102	82.8	79.0	8.00	7.37	8.26
S 9	6.33	6.49	4.78	5.25	4.04	5.66	4.84	6.27
S10	12.0	11.4	9.22	10.0	9.39	12.08	10.1	15.4
S11	88.1	37.0	64.0	67.7	39.3	52.5	52.9	74.5
S12	2.51	1.93	2.56	0.49	3.25	3.35	2.67	3.24
S13	1.30	1.48	1.40	3.21	1.29	1.14	1.41	0.99
S14	0.89	1.08	1.07	4.55	1.12	1.21	1.00	0.99
S15	276	222	126	87.1	216	205	262	282
S16	12.0	13.7	6.16	12.2	9.41	12.2	9.80	13.7
S17	23.2	38.5	23.7	21.8	21.4	33.7	39.1	31.7
S18	1.50	1.51	0.78	1.51	1.35	1.08	1.06	1.85
S19	26.2	34.3	39.0	19.8	27.3	48.3	11.0	27.1
S20	26.2	22.4	26.2	16.9	19.2	34.2	40.6	48.9
S21	24.6	10.1	6.32	4.71	10.1	6.89	8.27	15.5
S22	0.90	1.24	0.96	1.02	1.00	0.90	1.57	0.96
S23	4.09	3.10	2.96	1.97	1.63	1.59	1.20	1.96

The situation in south eastern part(Pyoson) is somewhat different. Wells(S18, S22) of about 1km from the coast show the ratios of less than 2. Only wells located within 700m from the coast show the ratios of higher than 5 up to 50. However, one groundwater(S23) of which the location is just 300m from the coast is less than 4. Therefore the contamination of groundwater by sea water is especially serious in the north eastern part of the island (Kujwa and Songsan). Previous studies.[2-4,6] on other parts of the island indicated that sea water contamination was mostly limited in area near the coast(less than 1km from the sea).

One exceptional case is the groundwater from S13; it shows high electrical conductivity and salt content, but shows Cl/HCO_3 ratio of about 1.5, which indicates minimal influence of sea water. Also, interestingly, NO_3 content of about 10 ppm is the highest value in the studied area. Since sample site of S13 is very close to the highly populated town (Songsan), it is believed that high NO_3, content is caused by the mixing of groundwater with the city sewage water.

In Fig. 4, the chloride/bicarbonate ratios are also plotted aginst the distance from the coast. It shows a very similar result to that of Fig. 3. Conclusively, it is estimated that the boundary of fresh groundwater in north eastern part(Kujwa and Songsan) lies 3-5km within the coast. However, in south eastern part(Pyoson) that boundary might lie abuout 700m from the coast.

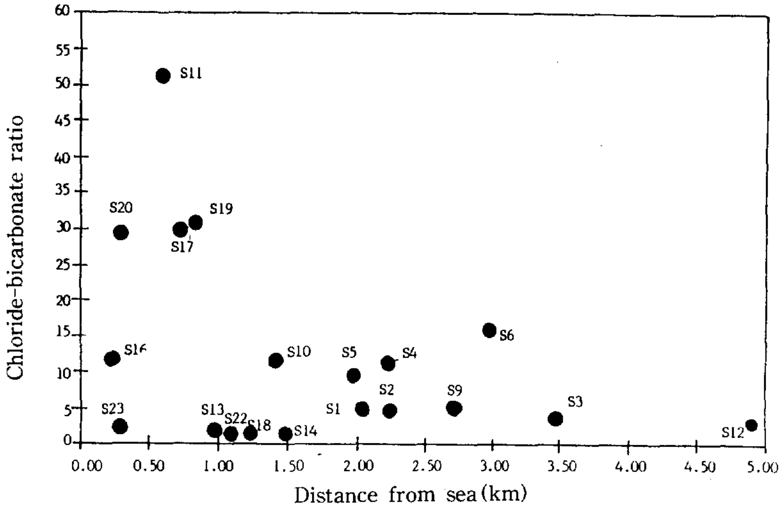

Fig. 4. Chloride-bicarbonate ratio of ground water with the distance from sea.

Tidal Effect on Electrical Conductivity of Groundwater : Electrical conductivity meter with recorder was installed in an abandoned well(Fig. 1) and the electrical conductivity was measured with the water level(Fig. 5). It shows an apparent positive relationship between sea water level and electrical conductivity. That is, when sea water level rises, the water level of the well rises and the conductivity of the groundwater increases simultaneously. And when sea water level goes down, the conductivity of the groundwater decreases at the at the same time.

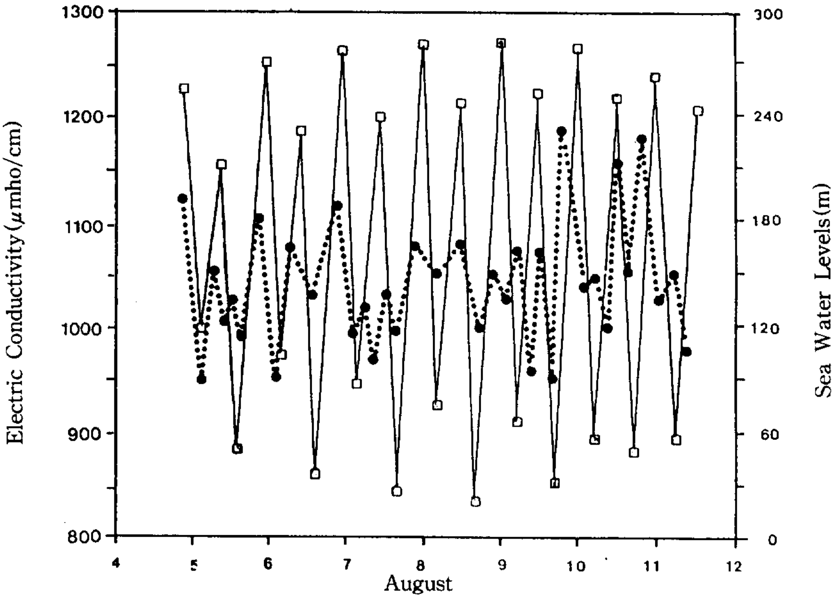

Fig. 5. Tidal effect on electrical conductivity of ground water(electrical conductivity ; □——□, sea water levels ; ●······●).

5. CONCLUSIONS

1. The tritium contents of rain water, groundwater and spring water in Cheju Island show a similar seasonal variation, which indicates the fast infiltration of rain water within underground and rapid mixing between rain water and groundwater.

2. The oxygen-18 and deuterium analysis demonstrate that groundwater and spring water in the eastern part of the island is contaminated by sea water.

3. Based on the results of chemical analysis, most groundwater in the eastern part of the island are classified into Na-Cl type and show high chloride/bicarbonate ratio.

4. Sea water intrusion in the northeastern part of the island has proceeded at least 3km within the coastline, and that in the southeastern part has proceeded about 700m or less within the coastline.

요 약

제주도 동부지역 대수층의 지하수에 대해 환경동위원소(산소-18, 중수소 및 삼중수소)의 조성 및 화학적특성을 구명하였다. 이 지역의 지하수에 대한 동위원소의 조성을 제주서부지역의 순수한 지하수와 연안의 해수와 비교한 결과 지하수에의 해수침투현상이 밝혀졌으며 음·양이온함량, 염소·중탄산염비 및 전기전도도 등도 이 결과를 뒷받침했다. 제주도 북동부지역의 지하수는 염분함량이 식수의 한계농도인 150 ppm 이상으로 오염되었고 이러한 해수에 오염된 지하수의 경계는, 해안으로부터 3 km 이상의 내륙에 위치한 대수층까지 침투되었다. 또한 남동부에서의 이 경계는 대략 700 m 정도까지 침투된 것으로 사료된다.

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