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Sea Water Intrusion in the Coastal Area of Cheju Volcanic Island, Korea

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ABSTRACT: Cheju is the biggest island in Korean peninsula, consisted entirely of volcanic rocks and pyroclastic sediments.The topography is characterized by wide basalt plain in the low altitude,but at the center of island, basalt volcano rises 1,950m above sea-level. Surface drainage is very poor, therefore water supply has been dependent on ground water and natural springs. There are about 1,650 production wells and most of them yield 1,000~2,000m^3/day. According to increase of ground water use, saline water is intruded in the low altitude of coastal area. Specially in the eastern coastal area, the topography is extensively flat and the level of ground water is very close to sea-level, at which overuse of ground water has brought saline intrusion up to maximum 6km far from the coast. Hydrochemical monitoring on this salt water intrusion is now undertaken on long term base.

INTRODUCTION

Cheju island is located at the south of Korean peninsula, 140km far from the main land. This island shows the longest distance of 74km along east-west and the shortest distance of 32km along north-south with its total surface area of 1, 825km^2(Fig.1). The surface geology is entirely composed of basalts and pyroclastic sediments. At the center of the island, the highest peak of basalt volcano(Mt.Halla)rises 1,950m above sea-level. There are many pyroclastic cones at the flanks of the Mt. Halla Extensive basalt plains are developed at the lower altitude than about 200m in the eastern and western parts of island, but less extensive basalt plateaus are also often found at the foothill of the mountain.

Although annual precipitation on island is about 1,630mm, higher than the mean of the Korean main land(1,246mm), surface drainage is very poor because of many opening structures on volcanic rocks. People had been very much suffered from paucity of water supply until the mid of 1960s before ground water develpment was initiated. During the last two decades, a few hundreds of wells were drilled, and thereafter, ground water have been major source of water supply for domestic and agricultural uses. According to this success of ground water development program, landuse became much extended even up to the high flanks of the mountain.

Ground water quality of Cheju island shows fairly good for domestic use. The contents of total dissolved solids are in general lower than 150 ppm, characterized by minor contents of major cations and anions. Any serious features of waste contamination are not detected yet, which are certainly thanks to policy of nature reservation on this island. On the contrany, over-use of ground water resources in the coastal area has triggered salt water intrusion into fresh water. Saline water intruded up to 6km into the land in the eastern coastal area and many pumping wells became recently abandoned. The specific eletrical conductivity of ground water clearly identifies the degree of sea water intrusion, varying from less than 100μs/cm to 4000μs/cm, with a general tendency of increase towards the coast. It is thus, very necessary to regulate the ground water use over water demand, specially in the coastal region of the Cheju island.

VOLCANIC TOPOGRAPHY AND GEOLOGY

Cheju island consists of volcanic and pyroclastic rocks. The basalts are mostly alkali type with phenocrysts of olivine, augite or plagioclase. The eastern and western parts of the island are characterized by very wide basalt plain. This low slope of topography is closely re-

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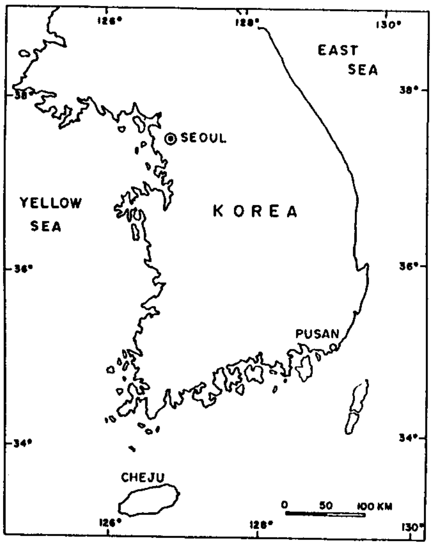
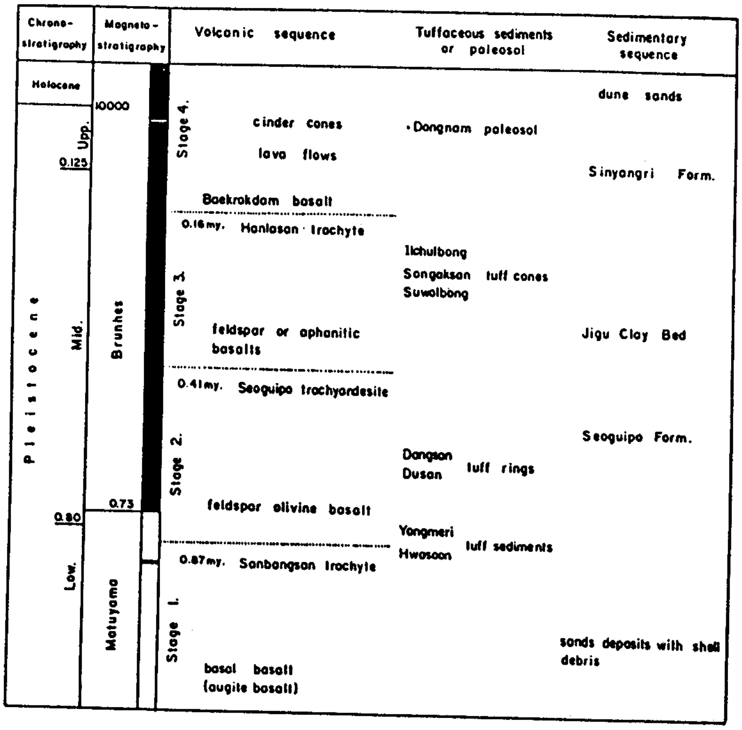


Fig. 1. Location of Cheju volcanic island at the south of Korean peninsulsa.

lated with the altitude of basalt flow, as which they flowed down very far from the vent. This is the reason why thickness of each flow is very thin and basalt is vesicular. The volcanic vents are often obscured by subsequent flows. Toward the center of island,the slope increases stepwise, showing the margin of each flow unit. The caldera is located at the highest peak of Mt. Halla Around the Mungy there are numerous cinder cones and tuff rings extruding out the ground surface. They show very steep slope of cone shape or ring-type, consisted of pyroclastic debris or lavas.

There are numerous studies concerning the stratigraphic succession of volcanic activities (Haraguch, 1931; Kim,1972 ; Lee, 1982; Lee et. al., 1987). However, there are some different opinions among these previous studies. Recently the core logs down to the depth about 700m revealed that the basement of island consists of crystalline tuff at the lower depth about 250m than sea level and thereabove, about 100m thick marine sediments overlie the tuff, and finally basalts overlie these marine sediments. These

Table 1. Main volcanic sequence and sedimentary stratigraphy in Cheju island.



basalts consist of numerous flows from about 100m below sea level to top of the Halla mountain. Volcanic episodes of Cheju island are subdivided into 4 stages, each stage representing magmatic differentiation from alkali basalt up to trachyte. The first stage represents the period from the beginning of volcanic activities, older than 1.2Ma up to Sanbangsan trachyte dated at 0.87Ma. The basalts of the second stage outcrop at flat area near the present coast. These basalts dated at around 0.60Ma, actually formed an island above the present sea-level. The second stage was culminated by Seogwipo trachyandesite underlain by shallow marine sediments. These sediments previously known as the Pliocene marine sediments are newly defined as the Middle Pleistocene deposits, belonging to this second stage. For the third stage, the volcanic activities were concerntrated toward the center of island, resulted in a shield type volcanic island. At the summit of the Mt. Halla volcanic crater is located. The fourth stage represents the period of volcanic activities after the Hallasan trachyte dated at 0.16Ma. Fissure eruptions along the flanks of Mt. Halla created many isolated cinder cones or coless topographic types with lava flows, some of which can be traced up to the present coastal area. Their ages range from about 100,000yr BP up to the historical period(Table 1).

GROUND WATER RESOURCES AND DEVELOPMENT

As surface water is poor in Cheju island, water supply has been dependent on natural springs or ground water exploration. There are many springs specially around the coastal area, pouring out large amount of fresh water. The recent survey by Choi(1990) showed that total yield of springs reached up to 670,0000㎥/day. Some of these springs have been used for water supply, although the area under water supply from springs was very limited. Therefore, systematic program of ground water development has been continued since the beginning of 1970s There are about 360 wells drilled by governmental organizations and a thousand wells owned by private as well(Fig.2). Most of these wells are functioning with average pumping

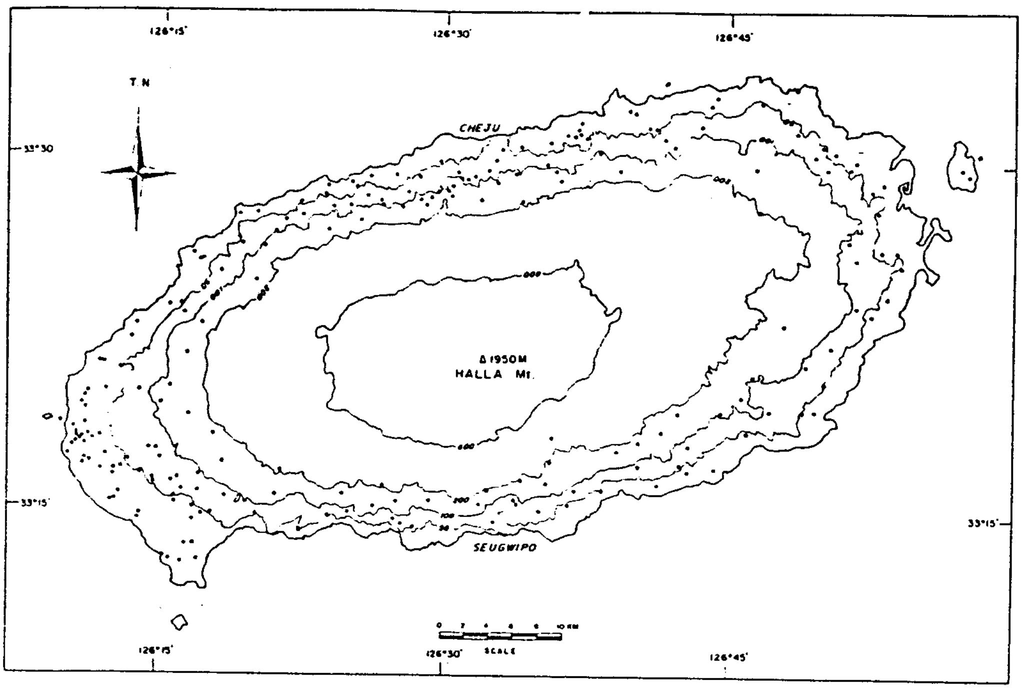


Fig. 2. Location of ground water production wells (dots) drilled by government organizations during the last two decades.

yield of 1,000 ~2,000 m^3/day. The land use became much extended even to high altitude, but there are still further demands for more water supply. Moreover all these wells are located lower than the level of 200msl. Therefore, large basalt plateaus above 200msl still remain uncultivated, which must be future subject of ground water development in this island.

According to the results on previous well developments, ground water is taken mostly from volcanic rocks which are located down to the depth about 100m below sea level. The unconsolidated marine sediments below these basalts may behave as aquifer, but it is unnecessarily too deep for ground water development and also they contain fossil salinity as evidenced by high specific electrical conductivity as much as 3,000 μs/cm in ground water from these sediments. Therefore, available ground water resources in this island is considered as fresh water body con-

Table 2. Hydraulic characteristics of the representative wells in Cheju volcanic island.

Ref. NO.	Well No.	Area Name	El.(m)	well Depth (m)	S.W. L (m)	Drawown (m)	Pumping rate(/d)	Specific Capacit (m/d)	translmiss Ivity(/d (m/D/a)	perasblity (m/min)	Strorege Coefficiant	Development organization
SPA 5	D-38	Hoasoo	180	122	77.4	0.3	1.088	3.626.6	1.811	3.93 10^{-2}	1.95 10^{-1}	KIER
SEA 17	D-54	Siheung	30	42	22.7	3.5	2.000	571.4	1.927.5	1.09 10^{-1}	1.245 10^{-1}	〃
NWA 27	D-52	Josoo	70	125	53.2	6.8	900	132.3	249.7	6.936 10^{-3}		〃
NEK 1	K-1	Sehwa	180	680	165.7	30.01	300	9.7	2.966	8.582 10^{-3}		〃
NEA 2	K-2	Jongda	21	701	14.2	70.53	350	4.96	1.126	1.958 10^{-3}		〃
NEU 1	U-34	Shinchon	20.38	42	18.5	0.033	2.130	64.545	20.000	5.763 10^{-1}	3 10^{-1}	UNDP/FAO
NEU 2	U-35	〃	39.95	47.2	37.1	1.096	1.819	1.700	4.000	2.777 10^{-2}	1.5 10^{-1}	〃
NEU 3	U-52	〃	33.43	45.5	30.1	1.10	2.327	2.150	8.787	3.958 10^{-1}	2 10^{-1}	〃
NEU 4	U-53	〃	27.93	54.4	26.45	0.85	2.889	3.450	8.850	2.194 10^{-1}		〃
	Average						2.291	2.433	7.212	3.084 10^{-1}	2.16 10^{-1}	〃
NWU 2	U-40	Kosan	26.95	115	21.31	7.75	1.950	253	1.420	3.944 10^{-2}	〃	NWU
3	U-41	〃	16.36	118	15.39	3.40	2.712	796	2.050	1.875 10^{-2}		〃
NWU 4	U-42	〃	15.83	101	13.93	7.10	2.270	317	745	5.972 10^{-3}	〃	
NWU 5	U-43	〃	14.67	62.3	13.6	4.74	2.650	559	1.280	1.805 10^{-2}	〃	
NWU 6	U-44	〃	20.68	89.65	17.32	3.4	2.900	853	3.560	3.402 10^{-2}		〃
	Average						2.946	556	1.811	2.324 10^{-2}		
SWU 1	U-36	Sagae	26.36	47.5	24.2	2.3	2.500	1.085	1.110	3.680 10^{-2}		〃
SWU 2	U-48	〃	27.71	102.5	24.5	8.3	2.910	342	2	2.576 10^{-2}		〃
SWU 3	U-50	〃	14.72	50	12.65	3.4	751	221	340	1.381 10^{-2}		〃
	U-51	〃	15.03	110	10.8	10.3	915	89	156	1.597 10^{-2}		〃
	Average						1.769	434	402	2.433 10^{-2}		
	78-5	Wolsan	110		87.1	14.4	2.415	167.7	803.5	1.86 10^{-2}		ADC
	W-4	Seuhong	70.35	42.5	16.56	0.44	2.163	4.916	1.131.8	3.14X10^{-2}		〃
SPA 2	W-24	Shinhyo	38.1	43.5	38.1	5.78	1.662	287.5	132.2	1.66X10^{-2}		〃
		Sanghyo	314	100	38.4	17.11	1.237	72.3	45.2	8.22X10^{-4}		〃
		Kwangreung	190	201	115	25	1.200	48	23.8	8.28X10^{-4}		〃
NWA 17	D-32	Dongwl	30	34	14.25	0.24	1.503	6.262.5	1.443	5.89x10^{-2}		〃
		Wollin	120	140	89.5	28.5	1.200	42.1	21.5	8.76x10^{-4}		〃
	D-191	Sanyang	98	123	60.07	0.78	2.160	2.769	1.270	5.88x10^{-2}		〃
		Pando	45	153	32.8	18.35	1.052	57.3	31.3	4.44x10^{-4}		〃
SWA 32	D-144	sindo	52	130	34.0	17.81	1.237	69.5	37.6	1.74x10^{-3}		〃
SWA 13	D-31	Yeongrak	20	130	11.15	33.08	1.054	31.9	19.2	8.34x10^{-4}		〃
NWA 22	D-44	Gwlue	30	130	11	19	1.000	52.6	37.7	1.74x10^{-3}		〃
Average							1.454	1.127	1.587	3.548x10^{-2}	1.939x10^{-1}	

* S.W.L : Static Water Level

tained only in the volcanic rocks. These volcanic rocks do not behave as continuous aquifer, but there are many opening structures along the contacts of each basalt flow, which plays a role in fact as discontinuous aquifer. The transmissivity of whole rock ranges about between 1,000 and 2,000 m²/day. The storage coefficient averages about 1.9×10^{-1}(Table 2). These hydrogeological characteristics of the island indicate possibilities of ground water potentials in the volcanic rocks.

There are two types of ground water occurrence in Cheju island. One type is perched ground water and the other is basal ground water. As soon as precipitation falls on the surface, most parts of this precipitation immediately infiltrate through the ground surface, and on any dis-

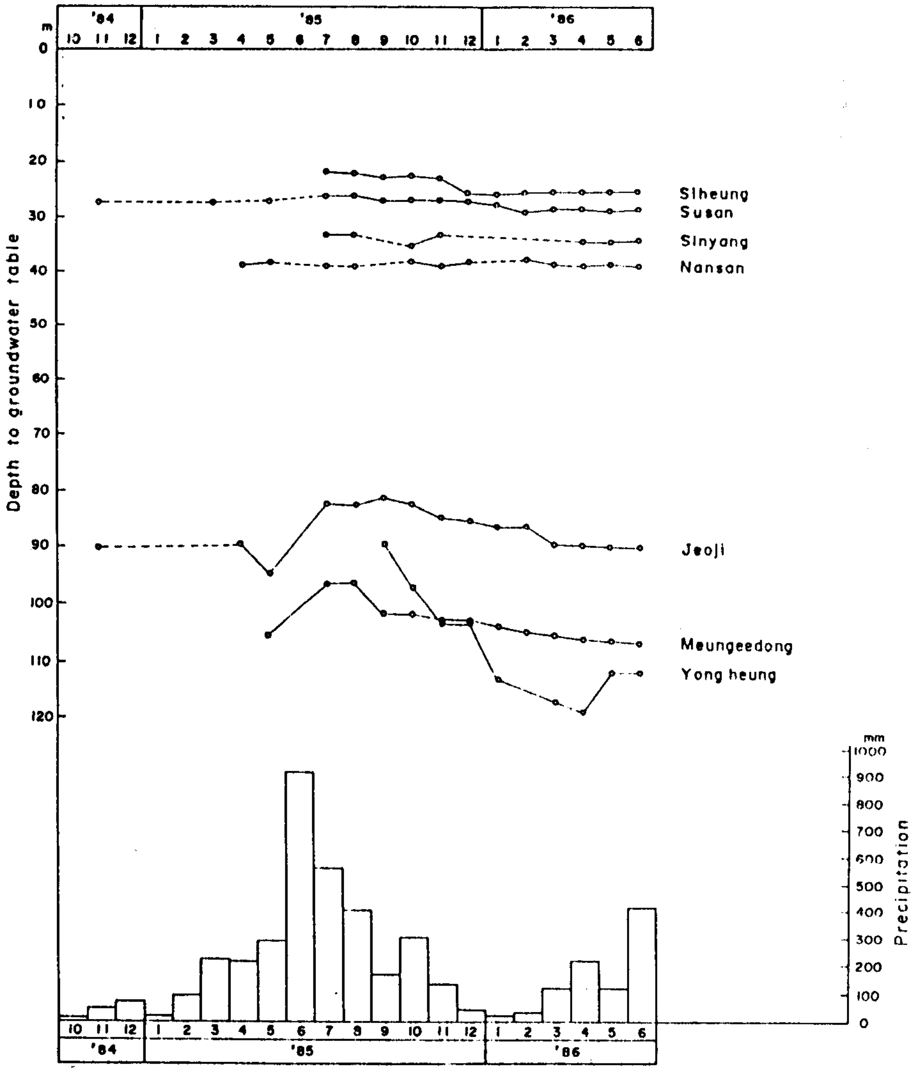


Fig. 3. Fluctuation of ground water table according to precipitation. Upper group: belong to wells drilled for basal aquifer, ground water table remains stable. Lower group: belong to wells drilled for perched aquifer, ground water table changes seriously according to precipitation.

Table 3. Composition of main cations and anions in springs and ground water of Cheju island.

Ref. NO.	Name	K^+	Na^+	Ca^{++}	Mg^{++}	Cl^-	$SO4^{--}$	NCO_3^-	NO_3^-	SiO_2	TDS	EC	pH
CIA 3	Whangsaeat	2.6	13.5	9.3	5.5	18.0	0	48	0.5	21	182	190	7.7
CIA 4	Ar	2.7	19.5	15.5	10.0	32	0	46	1.4	17	144	232	7.4
CIA 9	DODU	3.5	13	7.1	6.3	17.5	0	57	0.5	16.5	139	195	7.1
NWA 5	WOLREUNG	4.3	20	8.3	8.2	31	1.3	44	0.5	19	203	221	7.2
NWA 13	JEUJI	5.1	18	6.5	4.9	17.5	1.8	58	0.5	16	143	206	7.6
NWA 18	DONGAYUNG	3.0	11	5.5	5.4	16.5	TR	41	<0.5	14.5	120	156	6.6
NWA 34	KOSAN	4.5	26	12	13.0	43	1.7	53	0.9	17	260	276	7.1
NWA 36	MYUNGEEDON	2.8	12	3.6	<0.5	14	1.4	(23)	(<0.5)	17	94	119	7.4
NWA 49	yongsoo	5.2	22	14.5	4.5	26	1.1	73	0.5	14	157	268	7.7
NWA 52	Haga	3.1	8.5	4.7	4.0	12	0	44	0.5	19	100	155	7.8
SPA 1	Wolpyung	2.6	11	19	1.2	18	N.D	(86)	(<0.5)	29	130	138	7.4
SPA 2	Sinhyo	6.3	18.5	17.5	11	33	0	29	1.8	16	133	215	7.0
SPA 5	Hoesu	3.4	8.9	4.9	5.3	8	N.D	52	(<0.5	)32	73	185	7.2
SPA 6	Sakdai	1.6	11	8.1	4.7	1.5	N.D	(53)	(<0.5)S	13	112	172	7.3
SPA 13	Yongheung	2.0	5.3	2.8	2.1	7.2	Tr	(23)	(<0.5)	18	48	98	7.8
SPP 10	Midojang	2.7	9	6.9	3.7	14	1.4	41	0	10	126	144	7.2
SPP 11	Yongsunjang	6.0	34	16	11	40	7.6	126	0	10	263	405	7.6
SEA 3	Pyosun	3.3	14.5	5.7	11.5	28	5.4	62	0.5	14.5	138	234	7.6
SEA 5	Whajeon	3.8	30	4.9	8.9	50	2.1	42	0	17	201	511	7.2
SEA 5	Whajeon	3.8	20	4.9	8.9	50	2.1	42	0	17	201	511	7.2
SEA 6	Taeheung	4.2	30	12.5	11.5	59	1.3	28	0.7	15.5	167	269	6.7
SEA 7	Gasl	2.4	8	4.9	4.4	11	0	42	0.5	7.3	85	131	7.7
SEA 9	Tosan	2.4	7.4	4.7	7.8	9	1.4	39	0.5	13.5	82	132	7.7
SEA 10	Sungup	3.3	9.4	5.8	3.8	9.2	0	53	0.5	14.5	97	181	7.5
SEA 1	7Siheung	9.8	154	20	33	297	49	52	(<0.5)	30	688	1040	7.1
SEA 22	Sunang	3.2	9.8	6.1	4.9	16	0	37	0.5	18	124	160	7.4
SEA 26	Susan1	13.5	255	17	38	431	11.5	42	0	16.5	1103	1329	7.2
NEA 2	Keumang	9.5	137	14	24	253	43	51	0.5	9.5	577	873	7.5
NEA 4	Sewha	7	82	13	18	159	24	53	0.5	16	417	577	7.7
NEA 5	Hamdeug	5.7	15.5	15	8.6	299	5.9	83	0.5	12.5	179	284	7.3
NEA 13	Dugchun	2.7	8.4	2.8	3.1	9.6	Tr	41	0.5	14.5	95	133	7.6
NEA 14	Songdang	3.2	10	4.3	3.7	166	0.6	29	0.5	15	100	132	7.7
NEU 1	Sinchon	2.9	11	5.2	5.3	14	0.7	(51)	(<0.5)	20	96	178	7.3
SWA 8	Gamsan	3.9	16	9.2	5.1	20	Tr	(67	(<0.5)	32	133	248	7.5
SWU 2	Sage	2.2	16	9.6	2.9	17	Tr	(64	(<0.5)	14.5	99	209	7.7
CIS 1	Samyang	3.0	7.5	2.4	4.1	12	T	r33	<0.5	15.5	98	126	6.8
CIS 2	Eorimok	0.9	3.7	1.5	1.5	6.1	1.1	16	<0.5	10.5	49	58	7.5
NES 1	Jangsumul	2.6	13	9.3	5.1	281	2.2	(47)	0	(10)	179	191	7.3
NWS 3	Dongmyung	3.6	19	2.5	17	43	0.7	41	1.5	15	166	268	6.5
NWS 2	Hanlinchun	4.4	13.5	4.9	6.3	17	Tr	53	<0.5	19	132	192	7.3
NWS 3	Dongmung	3.6	19	2.5	17	43	0.7	41	1.5	15	156	268	6.5
SWS 3	Sulia	3.4	11.5	4.6	4.3	18	Tr	34	1.2	16	129	150	7.3
SWS 4	Andug	19.5	27	24	11.5	55	1.0	31	2.1	14.5	186	299	6.8
SPS 1	Sugwl hanil hotel	2.2	6.4	3.9	2.7	12	Tr	26	<0.5	15	102	111	6.7
SPS 2	Chunjeyoen	2.2	10.5	7.4	4.9	16	Tr	37	<0.5	13	139	148	6.8
SPS 3	Yongsil	0.9	3.5	1.5	1.1	6.6	Tr	17	<0.5	6	40	60	7.5
NES 1	Sunllungmul	41	796	43	109	1400	249	(49)	<0.5	9.5	2881	4350	6.9
NEX 1	Sehwa	1.78	612	52	16.5	560	176	651		40	1790	2940	7.39
NEX 2	JOngdal	10.1	4480	1621	175.4	9270	1574	35.5		18.4	18980	30400	7.75
	Singyang Seawater483	10430	367.6	1350	18575	2331	119.45		ND	1.69			8.0

unit : ppm and ( ) : estimated.

continuous impermeable layer temporarily forms ground water reservoir. This high level ground water can remain at any location for certain time, but at the end, flows much downward into the basal ground water reservoir. Thereby, the basal ground water stays at much lower altitude than the perched ground water. It is difficult to seperate these two types of ground water in many places. But based on previous results of ground water exploration, the perched aquifer is found at the ground elevation generally higher than 100m. The ground water level in this altitude stands 30m higher than sea-level. While continuous pumping in the perched aquifer, the drawdown of water level is anticipated greater than 20m and finally lowering down to the level of basal ground water. On the other hand, the basal ground water is developed at low altitude, generally lower than 100msl. The water level lies lower than 30m, but gradually much lower toward the coast. The drawdown in pumping well is not greater than about 20m. This difference of ground water occurrence is also demonstrated by fluctuation of ground water level according to precipitation. A monthly mean precipitation is the highest in August and the lowest in January. About 60% of the total annual precipitation falls between June and September. The ground water level fluctuates following to the amount of precipitation. The ground water level in the perched aquifer is directly influenced according to presipitation, while the basal ground water remains rather stable throughout the year around(Fig.3).

GROUND WATER QUALITY AND SALINE INTRUSION

To generalize ground water quality in Cheju island, representative water samples of each area were analyzed for main cations and anions (Table 3). Most of these samples show very low contents of each anion and cation. The total dissolved solids (TDS) are less than 150ppm varying from <60ppm in the mountain springs to <140ppm in the basal ground water. The content of NO_3 is almost nil or less than 2ppm,

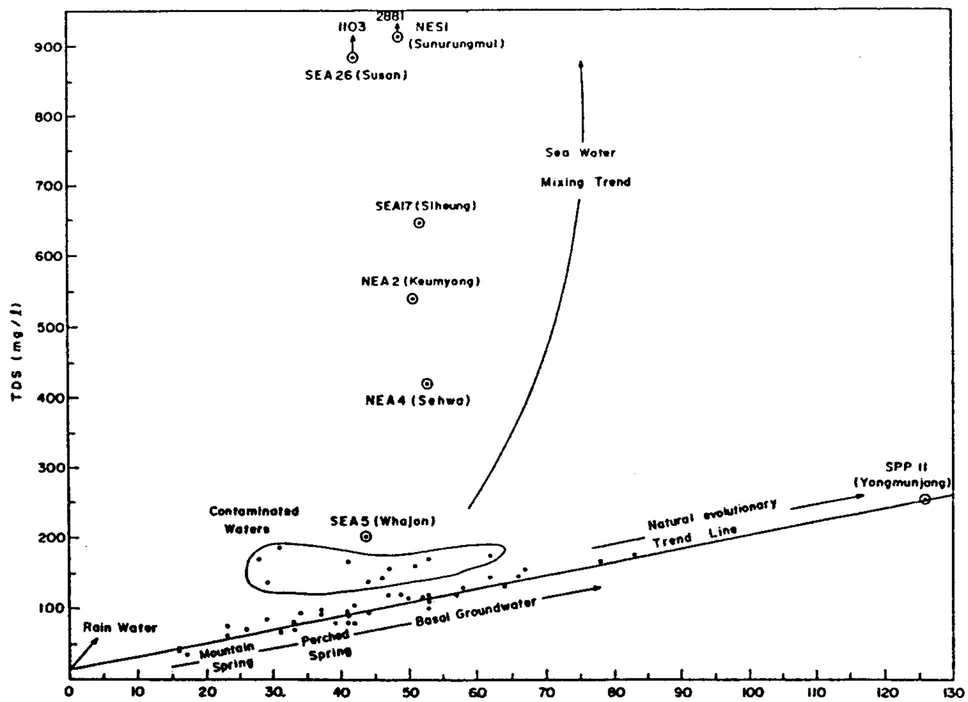


Fig. 4. Comparision of contents of total dissolved solids (TDS) with contents of bicarbonates in springs and ground water of Cheju island. This relationship shows evolutionary trend of Cheju ground water from mountain spring to sea water.

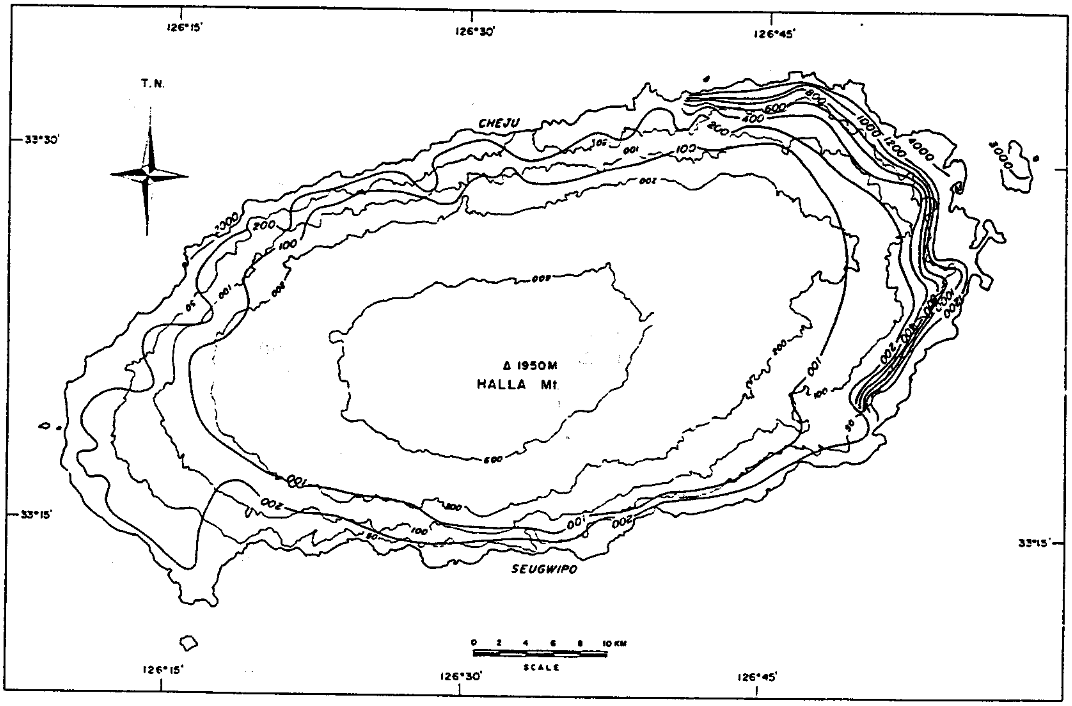


Fig. 5. Ditribution of electrical conductivity ($\mu s/cm$) in ground water of Cheju island. The EC value is lower than 100$\mu s/cm$ in spring or perched aquifer, but increases following the low gradient of topography up to maximum 4,000$\mu s/cm$.

which means that the Cheju ground water is uncontaminated. The content of bicarbonate(HCO_3^- shows a trend of increase according to evolutionary trend of ground water such as from rain water to basal ground water. The bicarbonate contents in the mountain springs range between 20-30ppm, and the ground water from perched aquifer contains 30-40ppm, while ground water from basal aquifer reaches up to about 70ppm (Fig.4). The trace elements show also very minor contents in most ground water.

As water demand in this island has been continuously increased, number of production wells and total yields of ground water have been gradually increased during the last decade. But increase of ground water development has brought the problem of saline water intrusion along the coastal area. This saline intrusion is clearly marked by high contents of Na^+ and Cl^- in the eastern coastal area. This area is exceptionally flat with very low hydraulic gradient(0.0036). Thus, ground water level is very close to the mean sea-level, and remains lower than 5m above sea level up to the distance of 4km from the coast. Therefore, the zone of interface between fresh and salt water must be very shallow and also wide. As the pumping activity is increased, the zone of interface becames much shallower, creating the uprise of sea water. The degree of saline water intrusion was expressed by the measure of specific electrical conductivity of ground water. The EC value ranges lower than 100μs/cm in fresh ground water, but in the eastern coastal area, it gradually increases up to 5, 000μs/cm in the ground water near the coast (Fig.5). As any other contaminations in this area are not forseen except saline intrusion, such a high value of EC can indicate the result of saline water intrusion. Many wells in this area have been already abandoned and now new production wells for domestic supply are under construction much far from the coast.

CONCLUSION

Cheju island consists entirely of volcanic rocks and sediments. The surface drainage is less developed due to many opening structures of the regional geology, although rainfall is high as compared to the main land. During the last two decades, ground water development program has been carried out with great success of ground water yields in this island. A total of about 1,650 production wells are under operation and most of these wells yield ground water about 1,000~2,000 m³/day. According to increase of ground water development, problem of saline water intrusion is already foreseen along the coastal area. The eastern coastal area is hydrogeologically vulnerable against saline water intrusion. The topography in this area is extensively flat and the ground water level is very close to sea-level. Thus, with continuous pumping activity, zone of interface between salt and fresh water became shallow and thick, which finally bring up the increase of salinity in fresh ground water. The electrical conductivity reveals the degree of saline intrusion ranging from less than 100 μS/cm in the fresh water to 4,000μS/cm in ground water of the coastal area. Many wells located up to maximum 6km distance far from the coast already abandoned. The new research program on this saline water intrusion must be undertaken to reserve ground water resources in this island.

KEY WORDS

Korean Peninsula, Cheju island, basalt plain, saline intrusion, basal aquifer, perched aquifer, ground water overuse, electrical conductivity, total dissolved solids, well logs

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濟州島 臨海地域에서의 海水侵入

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要約 : 濟州島는 火山岩과 火山碎屑性堆積層으로 形成된 韓半島에서 가장 큰 섬이다. 地形은 低地帶로 玄武岩이 넓게 分布하며 섬 中央에는 1950m의 火山이 우뚝 솟아 있으며 정상에는 火山噴出에 依해 形成된 火口가 存在한다. 地表水의 流出은 대단히 빈약하여 用水利用은 地下水와 湧出水에 거의 依存한다. 本 島에는 約 1650여개소의 地下水開發孔이 있는데 대부분 1,000~2,000m³/day의 産出이 可能하다. 근래에 와서 地下水利用增大에 따라 海岸 인접지역 特히 東部地域中 一部에서는 海水侵入現象이 일어나고 있다. 이 地域의 地形은 아주 平坦하고 地下水位도 海水面 가까이에 位置하여 지하수의 과잉 揚水는 결국 海岸으로부터 最高 6km 내륙까지 海水侵入을 초래하게 되었다. 이러한 문제를 해결하기 爲하여서는 長期 水理化學的인 감시체계망 설치가 무엇보다도 必要하다.