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Thermal Water Level Change and Geochemistry in the Suanbo Area, Korea

수안보지역의 온천수위 변동과 수리지구화학에 관한 연구

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Abstract : Both the groundwater changes due to different pumping rates and the geochemistry of thermal waters in the Suanbo area are considered in this study. The observation of groundwater level change since 1991 shows that the change is directly correlated with pumping rates of thermal waters and reveals the retardation of ca. 5 weeks after pumping. The hydrogeological aquifer in the area is under reducing condition. The thermal waters are of Na-HCO_3 type, and are alkaline (pH = 8.5~8.7) with low TDS values (274~284 mg/l) and high concentrations of Na (68~72 mg/l), F (6.4~8.9 mg/l), and HCO_3 (136~146 mg/l). Oxygen and hydrogen isotope ratios of thermal waters indicate a meteoric water origin. The activities of Rn-222 and Ra-226 in both thermal water and local groundwater were determined to delineate possible geochemical controls on the Rn-222 and Ra-226. The Rn-222 concentrations are several orders of magnitude greater than the Ra-226 concentrations. The concentrations of Rn-222 range from 190 to 7,490 pCi/l with an average of 2,522 pCi/l, and those of Ra-226 average 0.32 pCi/l with the range from 0.25 to 0.42 pCi/l. The concentrations of Rn-222 and Ra-226 are inversely correlated with EC and alkalinity. The pH is positively correlated with Ra-226. The correlation between Rn-222 and Ra-226 is poor. Thermal waters in the study area are produced from highly fractured phyllite. The thermal water quality, CSAMT (controled-source audiofrequency magnetotelluric) prospecting, and petrological evidences, however, indicate that the heat is possibly transmitted through deep normal faults reaching a deep granite batholith, and the phyllite acts only as a groundwater pathway.

요 약 : 이 논문에서는 1991년부터 관측한 수안보지역 온천수 대수층 수위변화와 양수량변화 및 온천수의 지구화학적 특성을 다루었다. 온천수의 수위변화와 양수량변화는 서로 밀접한 관련을 가지며, 양수량에 따른 수위의 피크는 약 5주의 지연효과를 보이며 영향을 받고 있다. 본 연구지역 온천 대수층은 환원환경이 지배하며, 온천수는 알칼리성 (pH = 8.5 ~ 8.7)이며, 총고용물량은 낮고(274 ~ 284 mg/l), 나트륨성분은 높으며(68-72 mg/l), 불소성분(6.4 ~ 8.9 mg/l)과 중탄산성분(136 ~ 146 mg/l)이 비교적 높으며, 나트륨-중탄산 타잎으로 분류된다. 아울러 온천수의 산소와 수소 동위원소 분석결과에 의하면 천수기원이다. 라돈-222와 라듐-226의 거동에 영향을 줄 수 있는 지구화학적 작용을 밝히기 위해 두 동위원소의 활동도를 측정하였다. 라돈 농도는 라듐의 농도보다 천내지 만배에 달한다. 라돈-222의 농도는 평균 2,522 pCi/L이고 190에서 7,490 pCi/L의 범위를 가진다. 또한 라듐-226은 평균농도가 0.32 pCi/L이고 0.25에서 0.42 pCi/L의 범위이다. 두 동위원소의 농도는 EC 및 알칼리도와 역비례하는 관계를 가지는 반면, 라듐-226은 pH와 양의 상관관계를 가진다. 라돈-222와 라듐-226은 거의 상관관계를 가지지 않는다. 조사지역의 온천수는 심하게 파쇄된 천매암층으로부터 양수되나, CSAMT 탐사와 지질조사결과, 그리고 온천수의 지구화학적 분석 결과에 의하면 천매암층은 다만 통로의 역할을 할 뿐, 주요 온천수 대수층은 화강암 저반내에 심부까지 발달한 정단층임을 추정할 수 있다.

Introduction

Thermal waters in Korea can be divided into two major categories according to their occurrence: one is the out-flowing thermal water called as a "fracture type thermal water"; and the other is the thermal water pumped from depths, called as a "deep groundwater type thermal water". The latter may be considered as the deep groundwater whose temperature is determined by depth and thermal gradient. Originally these two types of waters are derived from a non-volcanic source, and their temperatures are dependant on the circulating depths. Yum (1994) classified these two types of thermal waters as "Old Geothermal Water" and "New Geothermal Water", respectively, based on their developing dates and thermal anomalies.

Thermal waters of the Suanbo area belong to the former type because of the outflowing temperature of 45 °C at 200 m depth and its history of a few hundred years. Recently outflowing phenomena have not continued any more in every thermal springs in Korea due to increasing abstraction of groundwaters from the aquifers.

The Suanbo area is located in the central part of the

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Korean Peninsula. The public supply system of thermal waters to hotels, public baths, and condominiums, which is a unique system among Korean thermal areas, is well-controlled. Therefore, the pumping rates from the aquifers and water supplies have been progressively decreased because of the water table declining. The pumping rates of the thermal waters in the study area have been recorded daily since the 1960s, and the thermal water level in the representative borehole (well No. 8) also has been measured monthly since 1985 and weekly since 1991.

The primary purposes of this study are to determine both the thermal water level changes with its pumping rates and the quality of thermal waters and local groundwaters in the Suanbo area. In addition, the concentrations of radon (Rn-222) and radium (Ra-226) in both waters were determined to delineate possible geochemical controls on the Rn-222 and Ra-226.

Geologic and Hydrogeologic Settings

The study area is composed predominantly of the lower Paleozoic (?) Ogcheon Supergroup, represented by pebble-bearing phyllites, black slates, limestones and calc-silicate rocks, and the Cretaceous Wolaksan granite (Figure 1).

In accordance with a recent study of the Ogcheon Supergroup in the Suanbo area (Noh, 1995), the intrusion of granite has superimposed on the regional metamorphic sequences belonging to the greenschist facies and resulted in a contact aureole of hornfels facies, which can be identified by spotted cordierites. Noh (1995) also assumed the emplacement depth of the granite within the Suanbo area to be ranging from 1 to 2 km. The granite batholith in the Suanbo area crops out 4 to 5 km eastward from the study area (Figure 1). However, CSAMT (controled-source audiofrequency magnetotelluric) prospecting reveals that the granite also extends ca. 200-500 m beneath the thermal area as a hidden body (Lim *et al.*, 1996).

The Suanbo thermal area lies between two high-angle faults striking E-W and NW-SE, along which a deep valley develops and extends eastward. The rocks in the study area are highly fractured, which play an important role of the pathway of thermal water.

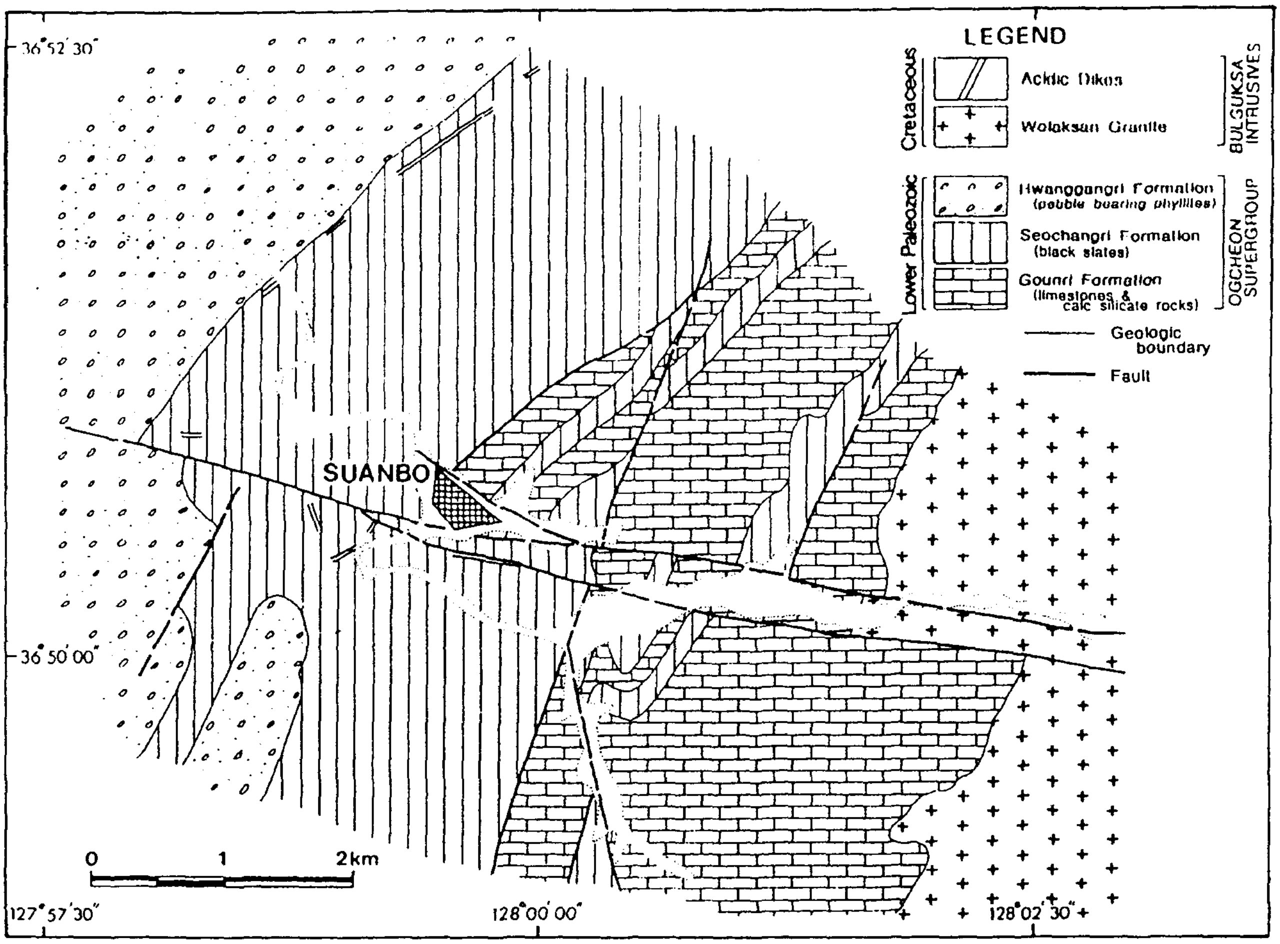

Figure 1. Geologic map of the study area. The hatched area indicates the Suanbo Resort area, where thermal wells including borehole No. 8 and various facilities are intensely provided.

Regionally, groundwaters in the Suanbo area generally flow from eastern mountainous area to west through the deep valley. The water tables measured in the boreholes with depths of 200~250 m are now located 130 to 132 meters beneath the land surface. On the other hand, the groundwater tables in areas outside the thermal area range from 3 to 6 m. Groundwater tables vary significantly around the faults and are considered to have the "no-flow" boundary condition. The vertical temperature distribution is also sharply changed along these faults (Lim *et al.*, 1996).

Results and Discussion

Thermal Water Level Change

The District Office of Chungjoo City is in charge of management of thermal water distribution since the 1960s. Figure 2 shows the level changes of borehole No. 8 thermal water in this area since January 1985, when the water levels were abruptly declined on account of the rapid increase in tourists and thus pumping rates. In particular the water levels decreased as the increase of tourists during winter seasons, and the water level declining continued until the following May. These fluctuations were repeated annually, and the total amounts of annual pumping rates reflect the total amounts of water level declining. The water level, the general water level in the thermal aquifer of the area, was recorded weekly in borehole No. 8 in every Friday afternoon. The thermal waters had been simultaneously pumped out from 3 to 5 boreholes in the area, and the pumping was started at 6 a.m. and continued until 2 or 5 p.m. Daily records of the duration time and rates of pumping are well described.

Figure 2 also illustrates that the annual fluctuation before 1990 was much larger than those since 1991. In the year of 1990 the City of Chungjoo made plans that daily supply (or pumping rate) of thermal waters did not exceed 3,000 m^3 and reduced the total amounts of thermal water supply on purpose, which made declining water level be stabilized.

Shown in Figure 3(A), (B), and (C) are the biennial thermal water level changes and the pumping rates during the periods of 1991~1992, 1993~1994, and 1995~1996, respectively. The quantities of pumping presented in Figure 3 represent the calculated average values for the neighboring 5 weeks data. The solid curves in Figure 3 represent the best fitting using the polynomial method. The lowest water level was recorded during February to April, 1994. The weekly pumping rates were generally higher before that time than

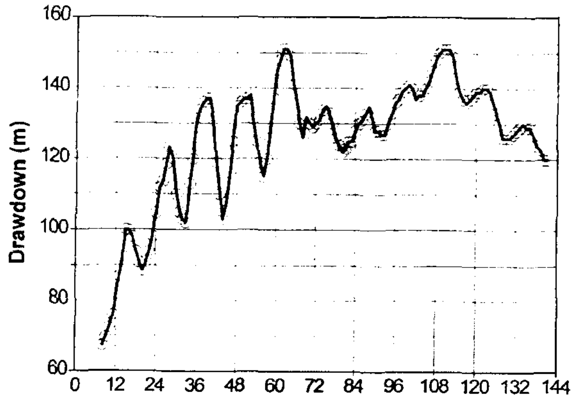

Figure 2. Water level changes of borelole No. 8 in the Suanbo area since Sept. 1985.

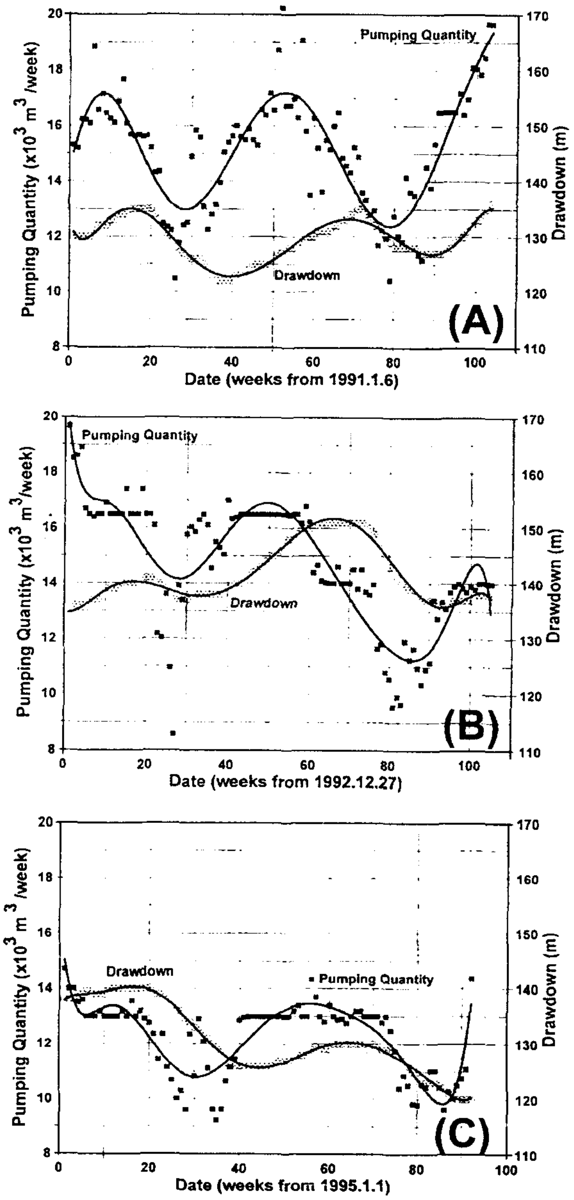

Figure 3. Diagrams showing the relationships between water level changes and pumping rates for the borehole No. 8 during the periods of 1991-1992 (A), 1993-1994 (B), and 1995-1996 (C).

those after the time (Figures 2 and 3). Reducing the weekly pumping rates resulted in the restoration upclimbing of the water level. Therefore, the weekly pumping rate of 13,000 m^3/week was recommended as a reasonable condition to stabilize the water level for the sustainable development of the thermal water. Figure 3 also shows the annual fluctuations of the pumping rates and drawdown. The changes of the pumping rates do not reflect the instant water level, and have approximately 5 weeks of retardation.

Geochemistry of Thermal Water and Local Groundwater

The thermal waters in Korea in general come from confined aquifers in crystalline rocks, and are spatially closely related with the Mesozoic granites (Yum, 1994). Thermal waters in granitic rocks show the chemical characteristics as follows: low TDS (150~350 mg/l), high pH (8.0~9.5), relatively high concentrations of Na, SiO_2 and F, low concentrations of Ca and K, and prevailing anion of HCO_3 (Yum, 1993). This water type can be classified as Na-HCO_3 type.

The thermal waters in the Suanbo area come from phyllite aquifers. Chemically, the water is the Na-HCO_3 type with low TDS content (275~285 mg/l), high concentrations of Na (68.4~71.1 mg/l), F (6.41~6.89 mg/l), SiO_2 (63.1~63.8 mg/l) and HCO_3 (136~146 mg/l), and low concentrations of Ca (9.53~11.4 mg/l) and K (2.06~2.22 mg/l) (Table 1). By combining with the CSAMT prospecting and the petrologic evidence, such water quality indicates the presence of a granite body at depth beneath the thermal water area. It is assumed that the phyllite aquifer plays a major role as a pathway of thermal waters that were evolved mainly through the interaction with the granite (Lim *et al.*, 1996). A trilinear diagram shown in Figure 4 presents the chemical differences between local groundwaters (Ca-HCO_3 type) and thermal waters (Na-HCO_3 type). High amounts of Na in thermal waters of Korea are interpreted as the results of cation exchange between Ca and Na (Yum, 1995) and of the breakdown of albite plagioclase (Yum, 1993). This mechanism is also applicable to the thermal water of the Suanbo area.

The concentration of hydrogen sulfide (H_2S) analyzed ranged from trace to 1.0 mg/l. However, at present it is not detected any more. Oxidation-reduction potential measured in situ is -0.2 mV, indicating reducing environment.

Results of the oxygen and hydrogen isotope analysis for

Table 1. Physical and chemical water analyses in Suanbo area (sampling on July 1996).

Sampling No.	Local groundwater								Thermal water	
	1	2	3	4	5	6	7	8	No. 8	No. 12
Temp. (°C)	14.0	10.0	14.6	13.3	13.7	7.80	14.3	16.7	50.3	45.2
pH	6.97	7.00	7.60	7.45	7.60	6.97	7.00	8.45	8.53	8.64
EC (μS/cm)	86.0	41.0	90.0	199	288	350	550	125	387	383
T-Solid	89.0	42.0	77.0	155	237	240	358	91.0	284	274
K	0.85	0.34	0.38	1.03	2.44	6.87	2.38	0.31	2.22	2.06
Na	8.20	2.93	6.11	4.23	3.34	8.30	4.54	11.0	71.1	68.4
Ca	5.65	3.23	10.9	27.4	39.1	42.4	60.1	13.7	9.53	11.4
Mg	0.73	0.73	0.73	4.41	9.06	7.59	31.1	0.73	0.44	0.68
Fe	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Mn	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Li	0.01	0.00	0.02	0.02	0.02	0.03	0.04	0.06	0.24	0.22
Sr	0.04	0.04	0.04	0.04	0.04	0.09	0.09	0.04	0.04	0.04
Al	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.04	0.04
Br	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cu	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zn	0.03	0.03	0.00	0.17	0.10	0.01	0.09	0.00	0.01	0.01
Cl	2.40	2.32	2.03	8.51	9.98	20.9	20.8	1.94	15.2	13.7
SO_4	0.41	3.03	2.75	10.1	11.3	19.7	24.0	5.06	27.0	35.0
PO_4	0.00	0.00	0.00	0.00	0.00	0.54	0.00	0.00	0.00	0.00
F	0.16	0.40	1.75	0.36	0.13	0.31	0.13	3.10	6.89	6.41
t-HCO_3	33.0	9.00	42.0	79.0	117	99.6	236	56.0	146	136
H_2S	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SiO_2	35.7	12.8	24.6	23.9	36.4	17.5	19.4	18.2	63.1	63.8
$\delta^{18}O$ (‰)	-9.40		-9.90		-9.00	-8.70		-9.90	-9.64	-9.62
$\delta^{2}H$ (‰)	-65.7		-75.1		-70.4	-68.3		-72.8	-69.0	-69.0
geology	granite	granite	granite	calcic	calcic	alluvium	?	granite	granite	granite
well depth (m)	120	40	30	30	120	7	70	300	250	240

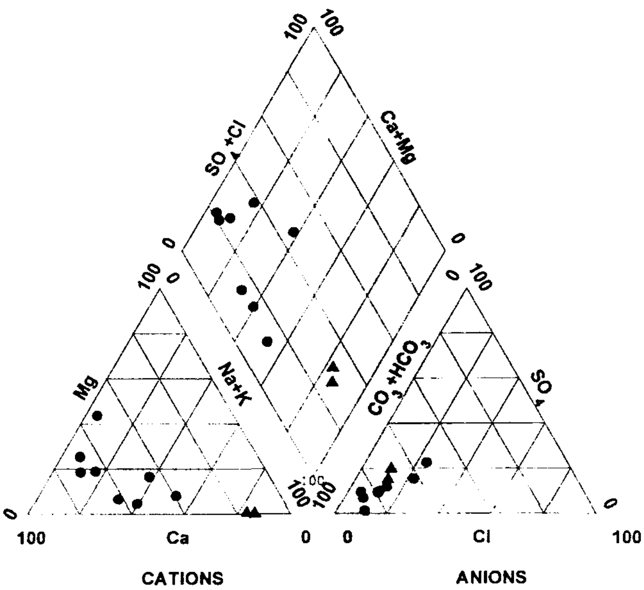

Figure 4. Trilinear diagram showing the chemistry of local groundwater (●) and thermal water (▲).

thermal waters and local groundwaters are illustrated in Figure 5. The isotopic values of thermal waters in the Suanbo area are relatively lower compared to those of other thermal waters reported by Kim and Nakai (1981). This phenomenon can be explained by the topographic effect: the Suanbo area is located at higher altitude than the other areas in Korea. The thermal waters in the study area are originated from meteoric water, and do not show any isotopic shift from the worldwide meteoric water line (Craig, 1961).

Radioactivities of natural radionuclides, especially Rn-222 and Ra-226, in both thermal waters and local groundwaters were determined using an alpha liquid scintillation counter by the staff at Korea Institute of Geology, Mining and Materials.

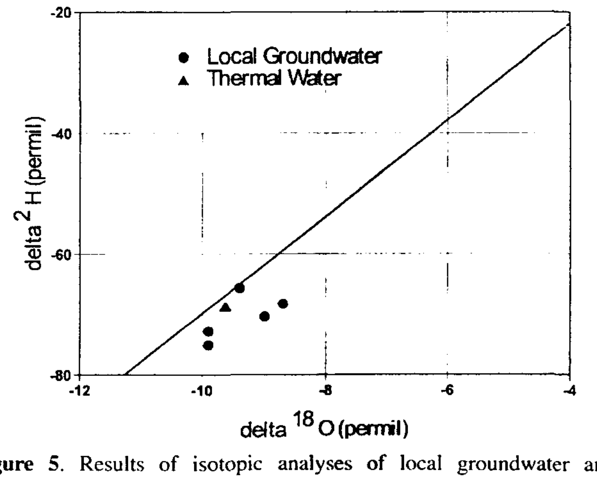

Figure 5. Results of isotopic analyses of local groundwater and thermal water int he Suanbo area. The solid line represents a worldwide meteoric water line proposed by Craig (1961).

A summary of the physical properties and radionuclides contents in thermal waters and groundwaters is presented in Table 2. The Rn-222 concentrations seem to be several orders of magnitude greater than the Ra-226 concentrations. The concentrations of Rn-222 in two thermal water and three groundwater samples range from 190 to 340 pCi/l and from 210 to 7,930 pCi/l, respectively. The Ra-226 concentrations range from 0.29 to 0.32 pCi/l and from 0.25 to 0.42 pCi/l, respectively. Higher Rn-222 and Ra-226 activities are found in groundwaters than in thermal waters.

Relations between Rn-222 or Ra-226 activities and water quality parameters, including temperature, pH, EC, and alkalinity, are shown in Figures 6 and 7. Both Rn-222 and Ra-226 concentrations are inversely correlated with EC and alkalinity, whereas pH shows a weak positive correlation with the Ra-226 concentrations. Figure 8 shows the relation between the Rn-222 concentration and the concentration of the imme-

Table 2. Physical properties and radionuclides (Rn-222 and Ra-226) contents in the study area (sampling on Sept. 1996).

Sampling No.	Local ground water			Thermal water	
	2	7	8	No. 8	No. 12
Temp. (°C)	12.4	15.1	16.6	50.6	42.3
pH	7.69	7.69	8.54	8.27	8.14
EC (μS/cm)	52.0	535	122	370	415
t-HCO_3	60.0	206	75.0	117	116
Rn-222 (pCi/l)	7930	210	3940	340	190
Ra-226 (pCi/l)	0.34	0.25	0.42	0.29	0.32

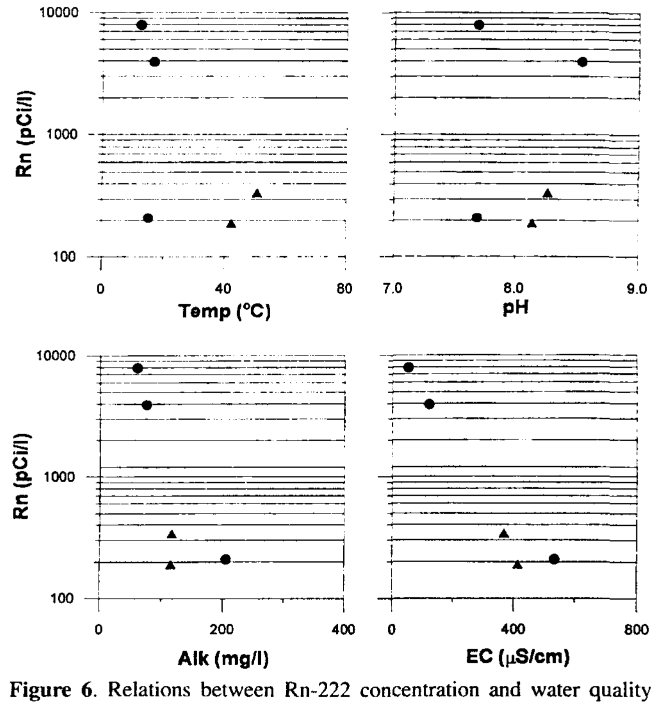

Figure 6. Relations between Rn-222 concentration and water quality parameters for local groundwater (●) and thermal water (▲).

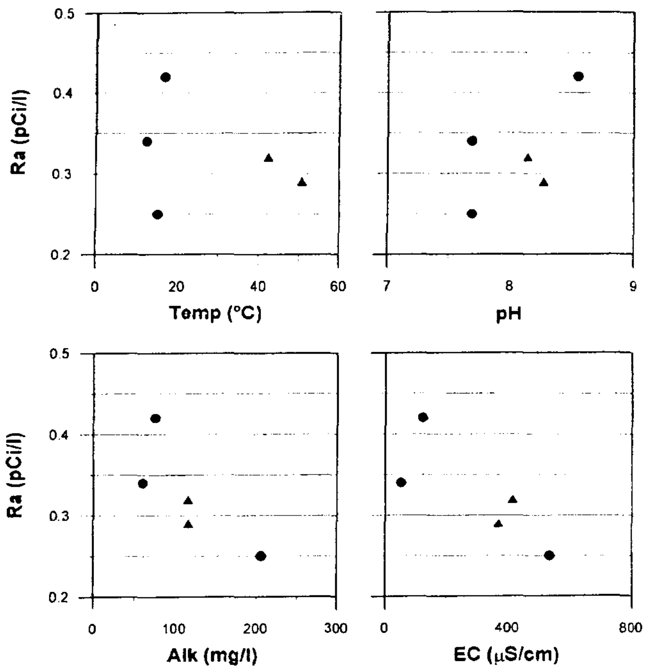

Figure 7. Relations between Ra-226 concentration and water quality parameters for local groundwater (●) and thermal water (▲).

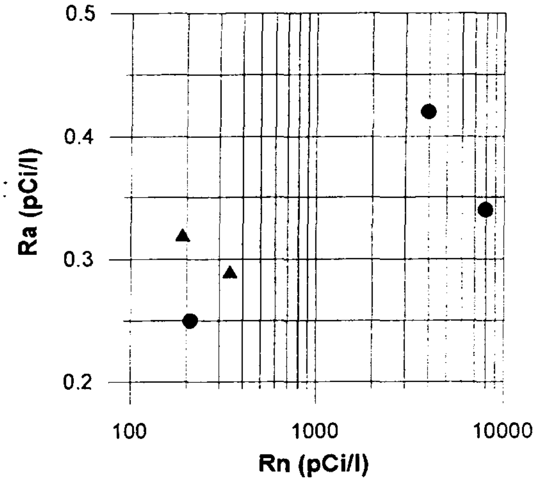

Figure 8. Relations between Rn-222 and Ra-226 concentrations for local groundwater (●) and thermal water (▲).

diate parent Ra-226 isotope, indicating a week correlation. Lack of correlation between Rn-222 and Ra-226 suggests that the Rn concentrations in groundwater are not certainly produced by dissolved Ra-226 in solution. Rather, Rn-222 is transferred to the solution via alpha-decay and recoil from Ra-226 in the aquifer matrix (Gilkeson and Cowart, 1987; Cecil *et al.*, 1993; Stanton *et al.*, 1996).

The deficiency of Ra-226 contents in waters in the study area can be resulted from the adsorption onto particle surfaces which are very abundant in the groundwater regimes. Anderson (1983) reported that Ra-226 is most efficiently adsorbed when solutions reach pH values of approximately 8 or above. Tanner (1964) indicated that many groundwater systems are not in secular equilibrium with respect to the ratio of Rn-222 to its parents, Ra-226 and U-238. As Rn-222 has a limited range of migration due to its short half-life (3.825 days), significant portion of the dissolved Rn-222 has to be sourced from Ra-226 and U-238 in the host rock, either from within the crystal lattice via a microfracture system or from Ra-226 and U-238 adsorbed on secondary mineral surfaces, close to the water-rock interface (Wanty *et al.*, 1992).

A possible factor which contributes to higher Rn-222 and Ra-226 activities in local groundwaters than in thermal waters may be in situ decay of the parent radioisotope in groundwaters. The geochemical behavior of U-238 in the subsurface environment is primarily dependent on the Eh-pH conditions, the concentration and availability of complexing ions, and the temperature. In oxidizing water, U^{6+} has the greatest solubility, whereas, in reducing water, uranium is precipitated in the insoluble 4+ valence state (Langmuir, 1978). The thermal waters with reducing condition observed in the study area, therefore, probably contain less dissolved U-238 compared to the groundwaters, reflecting less Rn-222 and Ra-226 concentrations.

Conclusions

The thermal waters in the Suanbo area come from the Cretaceous fractured granite via phyllite. Meteoric waters recharged in surrounding mountainous region circulate deeply in granites, and heat and dissolved solids are provided during its residence. In this case, the structural feature of deep normal faults is very important when it is found near the surface.

The data of pumping rates and water table recorded in a borehole in the Suanbo area since 1991 show a very interesting feature, the harmonious fluctuations with 5 weeks-retardation. Further studies on this phenomenon will be helpful to elucidate the aquifer characteristics under debate.

Analyses of Rn-222 and Ra-226 activities show an average of 2,522 pCi/l (190 to 7,490 pCi/l) and 0.32 pCi/l (0.25 to 0.42 pCi/l), respectively. The concentrations of Rn-222 and Ra-226 are inversely related to EC and alkalinity, whereas pH shows a positive correlation with Ra-226. The relation between Rn-222 and Ra-226 is poor. A possible factor which contributes to higher Rn-222 and Ra-226 activities in local groundwaters than those in thermal waters can be in situ decay of the parent radioisotope in the groundwaters.

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