

Bimodal, Hydrogeochemical and Isotopic Evolution of Bedrock Groundwaters in Relation to Underground Tunneling

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1. Introduction

Although the pattern of groundwater flow is in practice estimated from the permeability of rock and the hydraulic gradient, we cannot confirm whether the estimated pattern is reasonable or not. An integrated hydrogeologic and hydrogeochemical survey would be helpful to predict or measure the origin, residence time, and flow path of bedrock groundwater at depths, because using the hydrogeochemical data we may estimate how long it takes groundwater to reach a specific location at depths and what the mechanisms and processes happen to produce the groundwater chemistry. In a slowly moving groundwater, isotope composition and ionic concentrations generally change along the length of the groundwater flow path due to water-rock interaction.

The present study was undertaken to examine the spatial variation of hydrogeochemistry of tunnel seepage waters, in order to characterize the dynamic changes of groundwater flow during the tunnelling at depths in crystalline rocks.

2. Study Area

The YangYang Power Plant Construction (PPC) site is located in the Taebaek Mt. A set of vertical and horizontal tunnels are being constructed (Fig. 1). The geology consists mainly of Precambrian basement rocks, which are composed of porphyroblastic gneiss, granitic gneiss, migmatitic gneiss, and mylonite. In the tunnel, a system of near-vertical faults and fractures typically acts as a major conduit of groundwater seepage.

3. Sampling and Analysis of Groundwaters

Tunnel seepage waters (TSW; N=30) and local surface waters (N=3) were collected between May and December of 2000 (Fig. 1). During the sampling, the trends of major faults and fractures with groundwater seepage were also measured in each locality. The seepage water sampling were undertaken carefully to minimize the degassing and potential contamination.

In the laboratory, the ionic concentrations were measured with ICP-AES and IC. The hydrogen and oxygen isotopic compositions (relative to V-SMOW standard) of waters also were determined. For the evaluation of relative age of groundwater recharge, tritium content of waters was also measured.

Keywords: hydrogeochemistry, seepage water, underground tunneling

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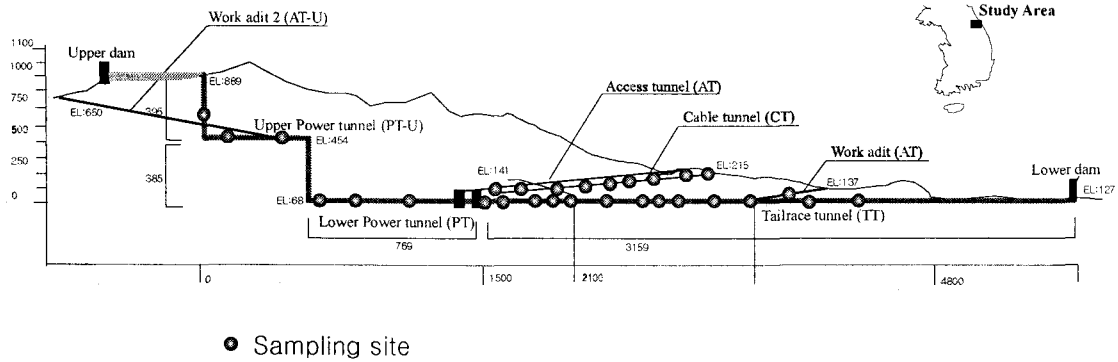


Fig. 1. (A) Location of the YangYang Power Plant Construction site, and the seepage water sampling site in the tunnels. The main tunnel has a total length of 4,250 m and is deep down to 885 m from the local land surface.

4. Results and Discussion

4.1. Hydrogeochemical facies: grouping of TSW

The hydrogeochemical data of tunnel seepage waters (TSW) generally show very wide ranges. The ranges of pH and TDS content are 8.0-9.7 and 70.3-870.9 mg/l, respectively. These two parameters generally reflect the kinds and degrees of water-rock interaction in crystalline rock aquifers. As the lithology in tunnel area is simple, however, the wide ranges may indicate varying degrees of water-rock interaction occurring during the groundwater flow. The TDS value showed good positive correlations with the concentrations of Na, K, Cl, and F.

Together with the plots of hydrochemical data on a Piper diagram, the ANOVA test (using SPSS) of solute concentrations of TSW indicates the coexistence of two facies of water: facies 1, and facies 2 (Table 1). The two facies TSW characteristically show a locality control. The facies 1 waters (sample PT0, PT1, PT2, TT7, AT1, AT2, WA4-1) occur restrictedly in the areas with vertical depths of >640 m (see Fig. 1) and belong to the Na-HCO₃ type. They were formed at depths by the dissolution of carbonate, plagioclase (mostly albite) and K-feldspar (mostly microcline). The facies 2 waters (Ca-HCO₃ type) occur in the areas at depths less than 600 m from the land surface, whose chemistry were controlled by the dissolution of mainly calcite and plagioclase.

Table 1. Comparison of two facies TSW.

		Altitude	TDS	Dissolved constituents (mg/l)				
		(asl,m) **	(mg/l)	Na	K	HCO ₃	Cl	F
Facies1	Mean	682.9	646.9	169.16	1.46	421.26	12.39	11.97
	Std. Dev.	51.2	174.8	50.68	0.69	123.28	4.52	5.68
	Max	760.0	871.3	223.32	2.26	585.76	20.09	17.80
	Min	620.0	451.4	100.15	0.28	291.36	7.76	0.10
	Number*	7	7	7	7	7	7	7
Facies2	Mean	338.6	114.8	14.99	0.68	60.82	3.38	3.18
	Std. Dev.	182.9	36.1	9.83	0.68	26.86	1.46	2.75
	Max	600.0	194.4	48.91	3.55	114.71	7.76	11.36
	Min	20.0	29.5	7.27	0.14	3.30	0.94	0.00
	Number	23	23	23	23	23	23	23
Surface water	Mean	130.0	43.7	4.21	0.73	16.80	5.14	3.79
	Std. Dev.	98.5	10.7	1.23	0.15	7.11	2.49	6.56
	Max	240.0	52.2	5.19	0.83	25.00	7.76	11.36
	Min	50.0	31.7	2.84	0.56	12.40	2.79	0.00
	Number	3	3	3	3	3	3	3

4.2. Environmental isotopes

The δD and $\delta^{18}O$ values of TSW indicate their meteoric origin, which were less or not affected by evaporation or isotopic exchange with rocks. The facies 1 waters occurring at deeper parts have lower $\delta^{18}O$ and δD values and are also lower in tritium contents than the facies 2 waters. Toward the eastern parts of the tunnel, TSW generally shows the increasing δD and $\delta^{18}O$ values, which can be well explained by the altitude isotopic effect. Therefore, we suggest that the recharge of tunnel seepage waters mainly occurs along near-vertical fractures extending to surfaces with different attitudes. Based on tritium contents, the facies 1 waters likely represent very old meteoric waters that were recharged along lengthy fractures at least before pre-bomb ages.

4.3. Hydrogeochemical modeling: evolution of TSW

To understand the evolution of two facies TSW, we performed geochemical modeling using the programs PHREEQC and NETPATH (Fig. 2; Table 2). The most appropriate reaction paths are summarized in Table 2. The model predicts that dissolution of albite is the predominant reaction governing the evolution of facies 2 waters, whereas the chemistry of facies 1 waters are controlled by dissolution of K-feldspar, calcite and albite. In both facies waters, chlorite and illite are precipitated.

We consider that relatively TDS-poor facies 2 waters are chemically controlled by lesser degree of water-rock interaction, whereas TDS-rich and more alkaline, facies 1 waters were evolved sufficiently through prolonged water-rock interaction in the lengthy passage way.

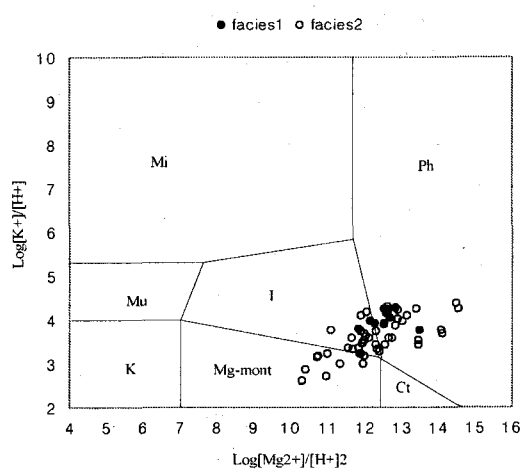


Fig. 2. Stability of selected minerals in the system $K_2O-MgO-Al_2O_3-H_2O-HCl$, such as kaolinite(K), illite(I), montmorillonite(Mg-mont), chlorite(Ct), microcline(Mi), muscovite(Mu) and phlogopite(Ph).

Table 2. Results of NETPATH modeling to the observed chemistry of tunnel seepage waters PT1 (facies 1) and TT1 (facies 2).

	TT1	TT1	TT8	PT1	PT2
	Model3	Model5	Model4	Model1	Model1
Illite	-0.31	-0.08	-0.46	-14.39	-15.07
Albite	0.26	0.04	0.35	9.06	9.6
Calcite			-0.09	-8.06	-9.02
Chlorite	-0.08	-0.08	0.14	-0.9	-1.06
K-feldspar	-0.05	0.001	-0.08	0.09	0.04
Dolomite	0.27	0.27	0.18	8.13	9.12
Anorthite		0.11			
K-mica	0.22	0.04	0.04	8.59	9.05
Exchange	0.12		0.13		

For facies 1: Initial water = SW2 (surface water),
Final water = PT1 (or PT2)

For facies 2: Initial water = SW1 (surface water),
Final water: TT1 (or TT8)

* Note that positive values denote that the indicated mineral is dissolved, while negative figures denote that

it is precipitated in the groundwater.

4.4. Conclusion and discussion

The results of this study indicate that hydrogeochemistry of fracture-controlled groundwaters is controlled primarily by water-rock interaction in the passage way.

However, we consider that the coexistence of two different types of TSW within a tunnel likely reflects the effect of underground tunneling on hydrogeology and hydrogeochemistry.

Tunneling-induced hydrologic disturbance possibly resulted in rapid inflow of near-surface waters to the underground tunnel space, more preferentially in shallow, eastern part of the tunnel. Before the tunnel excavation, regional groundwater flow was probably slow and was generally directed toward topographically low, eastern part of the area. Then, the hydrogeochemistry and environmental isotopic composition of groundwaters were possibly uniform and similar to those of the facies 1 waters. However, the tunneling resulted in rapid pressure change and formed newly a rapid flow of groundwaters along near-vertical fracture zones. The generation of tunneling-induced, near-vertical fracture flow also resulted in rapid inflow of TDS-poor, near-surface waters (facies 2 waters) to replace the pre-existing, deeply circulated groundwaters (facies 1 waters). Under such condition, the stability of the preexisting groundwater system possibly depends on the extent of the fracture network connectivity.

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