SOME HYDRAULIC AND GEOCHEMICAL CHARACTERISTICS OF WASTE DUMPS AT THE ABANDONED IMGI PYROPHYLLITE MINE, KOREA

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Abstract

The abandoned Imgi pyrophyllite mine may directly influence water quality of the Sooyoung River, upstream of the Hoidong reservoir in Busan. The mine has been abandoned for 14 years without any proper measure for pollution prevention. Meteoric waters freely interact with waste rock dumps, which contain acid-generating materials. The objective of this study was to determine some hydrological and geochemical parameters related to generation of acid drainage. The Imgi dump is highly eroded and weathered, and has little vegetation cover, except for scattered shrubs, even after 14 years of existence. The surface soil appears furrowed by deep rills and gullies, poorly agglomerated, with granular structure and little organic matter. Indeed, organic matter content is only 1% compared to an average 4 % in nearby, presumably not contaminated, soils. The soil pH in background samples is 4.9 to 5.7, whereas in the dump it is 2.9 to 3.4. Drainage and seepage mostly occur during peak rainy season. On the basis of borehole data, the local hydraulic gradient is computed as 0.116 m/m. Flow rate is calculated as 4,360 m^3/day (approx.). Therefore, permeability K can be estimated as 0.0005 gm/s^2 (approx.). The Imgi dump soil has little water even at peak rainy season (6 ~ 11%), whereas the background soil samples have water contents of 16 ~ 25%.

Introduction

Since its closure in 1993, the Imgi pyrophyllite mine, located in Imgi-ri, Cheolma-myeon, Kijang-gun, Busan Metropolitan City, has been known as a severe source of water quality degradation at the receiving water bodies because of substantial acid mine drainage. The discharge and drainage from the waste rock dump (marked as 'Dump A' and 'Dump B' in Fig. 1) flows into the Sooyoung River, and thence eventually into the lake that serves as a drinking water reservoir for the Busan area.

The waste rock dumpsites have steep slopes with sparse vegetation, widening rills and gullies, resulting in accelerated soil erosion as well as water quality problem in downstream areas. Therefore, hydrological and geochemical studies were undertaken to address this problem.

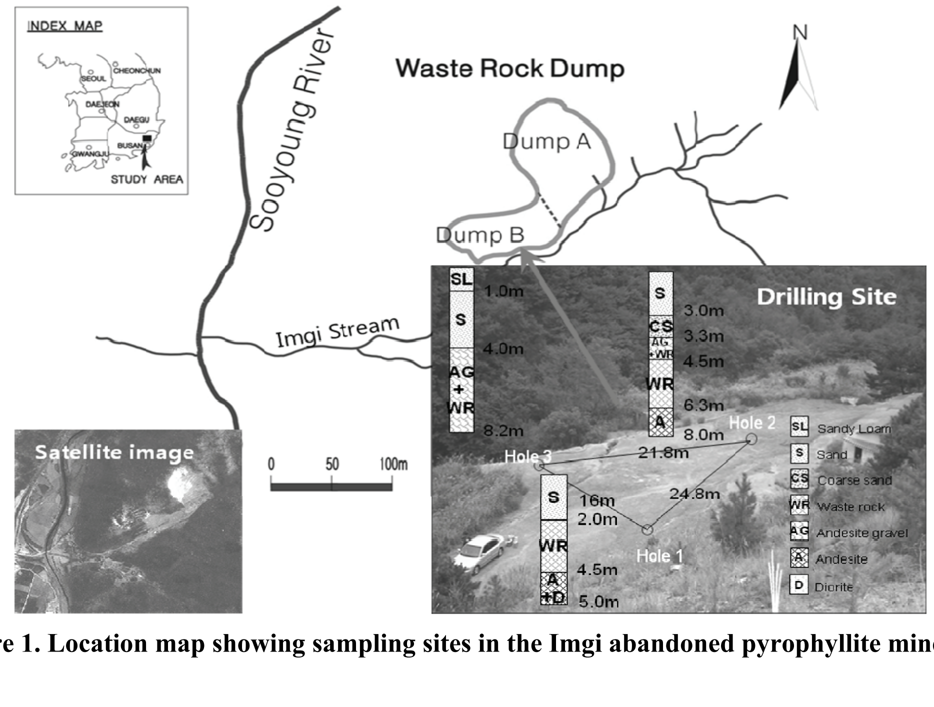

Figure 1. Location map showing sampling sites in the Imgi abandoned pyrophyllite mine area.

Methods

A total of 25 soil samples were collected every 50 m along five existing benches on the waste dump (dumpsites A and B in Fig. 1), over a grid of 20 m vertical and 50 m lateral. Five background soil samples were also collected from nearby locations supposed free of contamination. The groundwater hydraulic gradient was measured based on groundwater table data obtained from three test boreholes. Samples were air-dried and sieved; the fraction smaller than 2 mm was used for analysis. To estimate soil moisture contents of the waste dump, samples were weighted before and after oven-drying at 105 °C for 24 hours. Soil pH was measured with a glass electrode (pH-meter, ORION) in a 1:1 soil/water suspension using the method of Peech (1965), referred to water and 1M KCl. Total organic matter was determined by weight loss in furnace at 400℃ for 8 hours. Analysis for dissolved cations was performed using an inductively coupled plasma atomic emission spectrophotometer (ICP-AES; Jobin Yvon 38) at the Korean Inistitute of Geoscience and Mineral Resources (KIGAM).

Results and Discussion

Over the last 14 years, dumps at the Imgi site, particularly dump A (dump B was not investigated in this study), have been quite compacted. Based on field observation of surface water drainage and groundwater seepages at numerous rills and gullies, we can infer that there is a semi-confined aquifer underlying dump A. In addition, confined ground water seepage contributes to the Imgi stream mostly without the influence at the base rocks. Drainage and seepages can be clearly seen during the peak rainy season. Generation of acid mine drainage can be schematized as shown in Figure 2. In the dry season, most of acid mine drainage is contributed to the stream in the form of groundwater, or base flow. During peak rainy season, both surface runoff and groundwater contribute significant amounts of acid mine drainage to the stream.

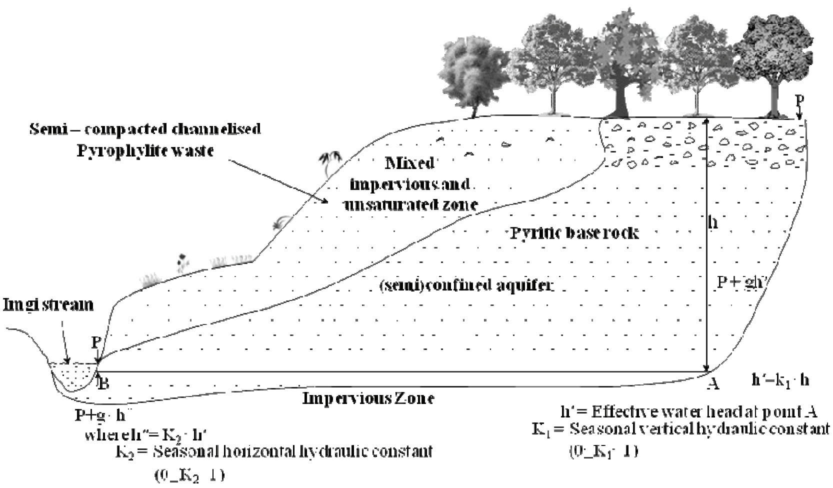

Figure 2. Cartoon of the development of acid mine drainage at the Imgi site.

Based on water table data from three test boreholes, relative hydraulic heads were computed as shown in Figure 3. The local hydraulic gradient ($\Delta h / \Delta l$) can be computed as below:

$$\Delta h / \Delta l = \text{Difference in water head /distance} = (35.9 - 34.15) / 15.1 = 0.116 \text{ m/m}$$

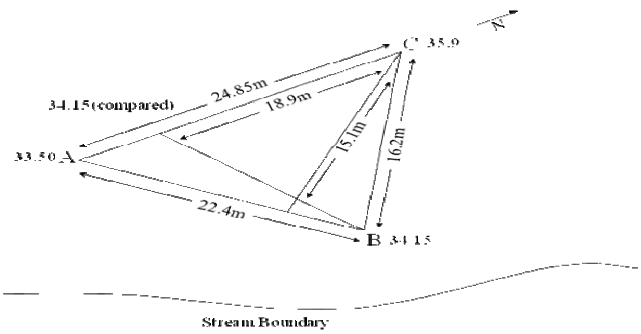

Figure 3. Hydraulic gradient computation on the basis of measurements at test bore-hole sites

The water flow rate from the aquifer to the stream can be approximated as the difference between flow rate before the stream enters dump boundary, and flow rate before it exits the influence of the dump .
On the basis of the observation carried out on August 8 2006, the flow rate can be calculated as:

$$\text{Aquifer flow rate} = 4.46 - 1.43 = 3.03\ m^3 / min = 4{,}360\ m^3 / day\ (approx.)$$

The flow area can be considered as the cross-section area obtained by multiplying the width of the aquifer in contact with the stream (average 2 m), by the length of the stream under consideration (400 m). The resulting cross-section area is hence 2 x 400 = 800 m^2. Now, permeability can be calculated, by applying Darcy's law:

$$Q = \frac{-kA}{\mu}\frac{(P_b - P_a)}{L}$$

where Q is the flow rate (m^3 / min), k the permeability of the medium, A the flow cross-section area, P_b-P_a the hydraulic gradient over a length L, and μ the viscosity. In this case, Q = 4360 m^3 / day, P_b - P_a / L = 0.116, A = 800 m^2, $\mu = 8.90 \times 10^{-4}$ kg/m/s = 0.9 gm/m/s (using the standard value for water at 25° C). So permeability K can be expressed as:

$$K = \mu \times Q / A \times L / (P_b - P_a) = 0.9\ gm/m/s \times ((3.03\ m/min) / 800\ m^2) \times 1 / 0.116 = 0.0005\ gm/s^2$$

The physical characteristics of dump A are given in Table 1. The Imgi dump is highly eroded and weathered, and has little vegetation cover, except for shrubs, even after 14 years of existence. Due to well-developed rills and gullies, the surface soil at the dumpsite looks poorly agglomerated, of granular structure, and with little organic matter. An area of about 100 x 300 m^2 area has surface colour brown to yellow brown. This can be compared to the physical features of background samples: brown-black colour, high agglomeration, prismatic/platy structure, high content of organic matter, and little drainage at moderate precipitation.

Table 1. Physical soil characteristics at the Imgi Dump.

Sample	Sampling Depth (cm)	Color	Agglomeration	Structure	Visible OM	Surface Drainage
Dump						
I - 1	25	br - yb	medium	granular/single grained/massive	poor	rills/gullies
I - 2	24	yb	poor	granular/single grained/massive	nil	rills/gullies
I - 3	40	pb - y	medium	granular/single grained/massive	poor	rills/gullies
I - 4	20	br - yb	medium	granular/single grained/massive	little	rills/gullies
I - 5	20	pb - y	very poor	granular/single grained/massive	little	rills/gullies
II - 1	40	pb - y	medium	granular/single grained/massive	little	rills/gullies
II - 2	35	br - yb	medium	granular/single grained/massive	nil	rills/gullies
II - 3	35	br - yb	medium	granular/single grained/massive	nil	rills/gullies
II - 4	40	br - gr	medium	granular/single grained/massive	little	rills/gullies
II - 5	50	br - yb	medium	granular/single grained/massive	little	rills/gullies
III - 1	20	br	medium	granular/single grained/massive	roots	rills/gullies
III - 2	40	br - gr	medium	granular/single grained/massive	little	rills/gullies
III - 3	35	br - yb	medium	granular/single grained/massive	little	rills/gullies
III - 4	22	pb - y	medium	granular/single grained/massive	little	rills/gullies
III - 5	45	yb - y	medium	granular/single grained/massive	little	rills/gullies
IV - 1	30	by	poor	granular/single grained/massive	little	rills/gullies
IV - 2	20	br	poor	granular/single grained/massive	roots/shoots/leaves	rills/gullies
IV - 3	43	by - br	poor	granular/single grained/massive	roots/shoots/leaves	rills/gullies
IV - 4	27	yb - br	poor - medium	granular/single grained/massive	little	rills/gullies
IV - 5	20	y	poor - medium	granular/single grained/massive	little	rills/gullies
V - 1	20	pb - by	poor	granular/single grained/massive	nil	rills/gullies
V - 2	25	pb - y	medium	granular/single grained/massive	nil	rills/gullies
V - 3	25	br - yb	poor	granular/single grained/massive	poor	rills/gullies
V - 4	35	yb	poor	granular/single grained/massive	poor	rills/gullies
V - 5	25	by	poor	granular/single grained/massive	poor	rills/gullies
Background samples						
BGS - 1	50	br - black	high	prismatic/platy	high,plant roots,microrg	little*
BGS - 2	30	br - black	high	prismatic/platy	high,plant roots,microrg	little*
BGS - 3	18	dark grey	high	prismatic/platy	high,plant roots,microrg	little*
BGS - 4	40	br - black	high	prismatic/platy	high,plant roots,microrg	little*
BGS - 5	50	dark grey	high	prismatic/platy	high,plant roots,microrg	little*

b = brown, yb = yellow-brown, pb = pale-brown, y = yellow, gr = grey; * under moderate precipitation

Some chemical characteristics of dump soils are given in Table 2. The Imgi dump soil has little water content (6 ~ 11 %) even at peak rainy season, while the background soil samples have 16 ~ 25 %. Water retention capacity of the Imgi dump did not improve even after 14 years. Organic matter content was also reduced to 1 %, from 4 % in the background samples. The texture has changed from loamy sand-sandy loam to mainly sand. The soil pH in the background samples ranged from 4.9 to 5.7, whereas in the dump it ranged from 2.9 to 3.4. This indicates the possible contribution of leachates from soil overlying the dumpsites to the acid drainage to the stream.

Table 2. Imgi dump soil chemical characteristics.

sample No.	pH	Water (%) (w)	Organic Matter (%)	Texture
Ⅰ - 1	3.13	9%	1.21	sand
Ⅰ - 2	3.27	8%	1.01	sand
Ⅰ - 3	2.94	10%	1.51	loamy sand
Ⅰ - 4	2.96	6%	0.63	loamy sand
Ⅰ - 5	3.43	9%	0.85	loamy sand
Ⅱ - 1	3.49	10%	1.00	loamy sand
Ⅱ - 2	3.47	11%	1.45	sand
Ⅱ - 3	3.46	9%	1.58	sand
Ⅱ - 4	3.38	11%	2.04	loamy sand
Ⅱ - 5	3.42	9%	1.01	loamy sand
Ⅲ - 1	3.30	13%	1.71	sand
Ⅲ - 2	3.29	11%	1.32	sand
Ⅲ - 3	3.44	11%	1.53	sand
Ⅲ - 4	3.45	10%	1.71	sand
Ⅲ - 5	3.37	9%	1.25	sand
Ⅳ - 1	3.56	7%	1.05	sand
Ⅳ - 2	3.23	11%	1.52	sand
Ⅳ - 3	3.66	8%	1.07	loamy sand
Ⅳ - 4	3.42	8%	1.22	sand
Ⅳ - 5	3.23	11%	1.88	sand
Ⅴ - 1	3.00	7%	1.23	sand
Ⅴ - 2	2.84	10%	2.28	sand
Ⅴ - 3	3.47	8%	1.18	sand
Ⅴ - 4	3.55	9%	0.93	sand
Ⅴ - 5	3.36	10%	1.39	sand
BGS - 1	4.82	25%	4.68	sandy loam
BGS - 2	4.91	17%	3.31	loamy sand
BGS-3	4.98	16%	3.46	loamy sand
BGS-4	5.68	20%	3.78	loamy sand
BGS-5	4.79	22%	4.09	sandy loam

Conclusions

The Imgi dump is highly eroded and weathered, and has little vegetation except shrubs even after 14 years of existence. Furrowed by deep rills and gullies, the surface soil looks poorly agglomerated, of granular structure, and with little organic matter. An area of about 100 x 300 m^2 area has surface colour brown to yellow brown. The drainage and seepage are mostly seen during peak rainy season. On the basis of the borehole data, local hydraulic gradient can be computed as 0.116 m/m. Flow rate can be calculated as 4360 m^3/day (approx.). Therefore permeability K can be expressed as 0.0005 gm / s^2 (approx.).

Compared with pre-mining soil quality as deduced from background samples of fertile land (pH 4.9 - 5.7; OM 4%; water 16 ~ 25%; texture: loamy sand), the dump soil is much degraded even after 14 years of mine closure (pH 2.9 - 3.4; OM 1%; water 6 ~ 11 %, texture: sand). It can be inferred that soil leachates can be a contributor of acidity to the receiving stream.

Although the waste rock dump at Imgi has a very low infiltration rate, a great hydraulic conductivity, and hence a significant amount of infiltration into the ground, results from many "V" type erosion gullies and coarse clastic particle layers over steep slopes of the waste rock dumps. These layers could have played an important role as an aeration path and generation of acid drainage over the years.

Acknowledgements

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