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# Geochemical transport and water-sediment partitioning of heavy metals in acid mine drainage, Kwangyang Au-Ag mine area, Korea

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**Abstract**

Total extraction of stream sediments in the Kwangyang mine area shows their significant pollution with most trace metals such as Cr, Co, Fe, Pb, Cu, Ni, Zn and Cd, due to sulfide oxidation in waste dumps. Calculations of enrichment factor shows that Chonam-ri creek sediments are more severely contaminated than Sagok-ri sediments. Using the weak acid (0.1N HCl) extraction and sequential extraction techniques, the transport and sediment-water partitioning of heavy metals in mine drainage were examined for contaminated sediments in the Chonam-ri and Sagok-ri creeks of the Kwangyang Au-Ag mine area. Calculated distribution coefficient (Kd) generally decreases in the order of Pb $\geq$ Al > Cu > Mn > Zn > Co > Ni $\geq$ Cd. Sequential extraction of Chonam-ri creek sediments shows that among non-residual fractions the Fe-Mn oxide fraction is most abundant for most of the metals. This indicates that precipitation of Fe hydroxides plays an important role in regulating heavy metal concentrations in water, as shown by field observations.

**Key words:** Mine drainage sediment, Kwangyang gold-silver mine, Enrichment factor, Distribution coefficient, Sequential extraction

## Introduction

Accompanying the pH decrease toward downstream sites within a mine drainage, heavy metals in dissolved phase are finally deposited as diverse solid phases. Stream sediments are the most favorable sink for potentially toxic heavy metals in such acid mine drainage because of their high sorption capacity. Therefore, sediments play a critical role in water quality by the storage and release of metals.

In this study, sequential and weak acid extraction procedures were used to partition the metals into various operationally defined fractions and to determine the amount of anthropogenic input of heavy metals in acid mine drainage of the Kwangyang mine area. The objectives of this study are (1) to understand both the distribution of heavy metals between water and sediment and the mechanism(s) which controls the mobility of heavy metals and (2) to define operationally the speciation of heavy metals in stream sediments in order to assess bioavailability and the problem of heavy metal remobilization.

## Materials and methods

Stream water and sediment samples for this study were collected in July and October 1997 and May 1998 from the Chonam-ri and Sagok-ri creeks of the Kwangyang mine area. The water samples were filtered through a 0.45 ㎛ membrane filter. The samples for cation analysis were acidified to pH<2 with concentrated $HNO_3$. The collected samples were stored at 4°C and immediately transported to laboratory for chemical analyses. Dissolved cations were determined by ICP-AES (Perkin-Elmer model Optima 3000XL). Composite sediment samples were collected from the top 2~3 cm of stream bed along a cross section at each site, and were homogenized and transferred with acid washed plastic scoop into polythene bags. They were kept cool with ice during transportation to the laboratory. In laboratory, weak acid extraction, strong acid extraction, and sequential extraction were used to analyze the heavy metals in sediment samples.

## Results and discussion

### 1. Water and sediment geochemistry

The difference in water chemistry between Chonam-ri creek and Sagok-ri creek is best illustrated on a Ficklin plot which shows the water pH versus the sum of dissolved metals (Zn, Cu, Cd, Co, Ni and Pb; Fig. 1). Although the pH values were similar each other, the metal concentrations were significantly higher in Chonam-ri creek water. This difference may be attributed to the difference in the content of base-metal sulfides in waste dumps and ores.

Using the weak acid extraction data, the enrichment factor (E.F.) of sediments was calculated to determine the extent of contamination (Fig. 2). The results of calculation indicated that the degree of sediment pollution is also higher in Chonam-ri creek. The average E.F. values are approximately 2 for Cr, Co and Fe, 4 for Pb, Cu and Ni, 10 for Zn and Cd in Chonam-ri creek, while the values for Sagok-ri creek sediments are mostly less than 1 with the exception of Cd and Zn (Fig. 2). Therefore, anthropogenic input of heavy metals by sulfide oxidation in waste dumps is more serious in Chonam-ri creek.

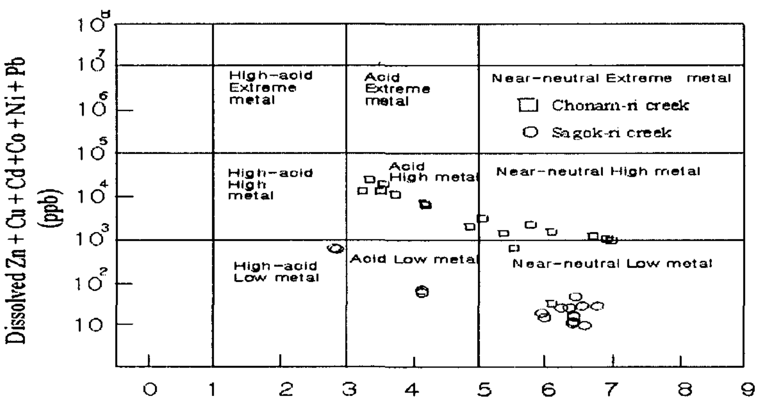


**Fig. 1** Ficklin plot showing the water pH versus the sum of dissolved base metals relationship for mine drainage of the Kwangyang mine area

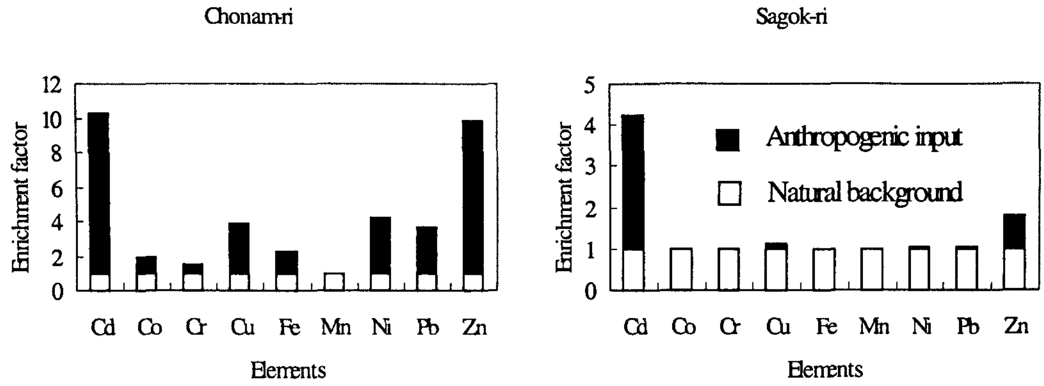


Fig. 2. Heavy metal distribution in terms of enrichment factors in Chonam-ri and Sagok-ri creek sediments

## 2. Sediment-water partitioning of heavy metals

To investigate the transport and fate of heavy metals, it is important to understand the partitioning of metals between dissolved and solid phases. Because the calculation of saturation indices (S.I.) revealed that the Chonam-ri creek water is undersaturated with respect to most minerals, we consider that other types of interaction, such as sorption, probably control the mobility of heavy metals.

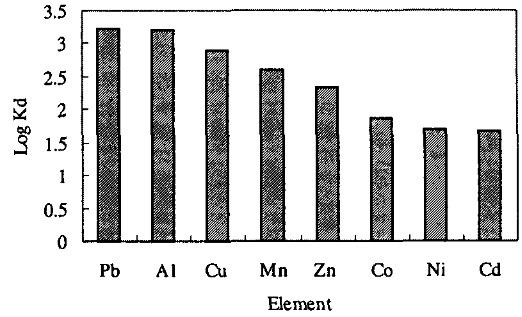


Fig. 3. Sequence of average Kd values for trace metals in Chonam-ri creek

Fig. 3 shows that the sequence of calculated Kd values for the Chonam-ri and Sagok-ri creek sediments. The sequence is Pb $\geq$ Al > Cu > Mn > Zn > Co > Ni $\geq$ Cd, in a good agreement with that generally reported for adsorption on synthetic iron oxyhydroxides in well defined media. Fig. 4 also shows the relationships between pH and Kd values for heavy metals in Chonam-ri and Sagok-ri creeks. The regressed equations for the relationships indicate that the distributions of Al, Cu and Zn are more sensitive to fluctuation in pH (Fig. 4)

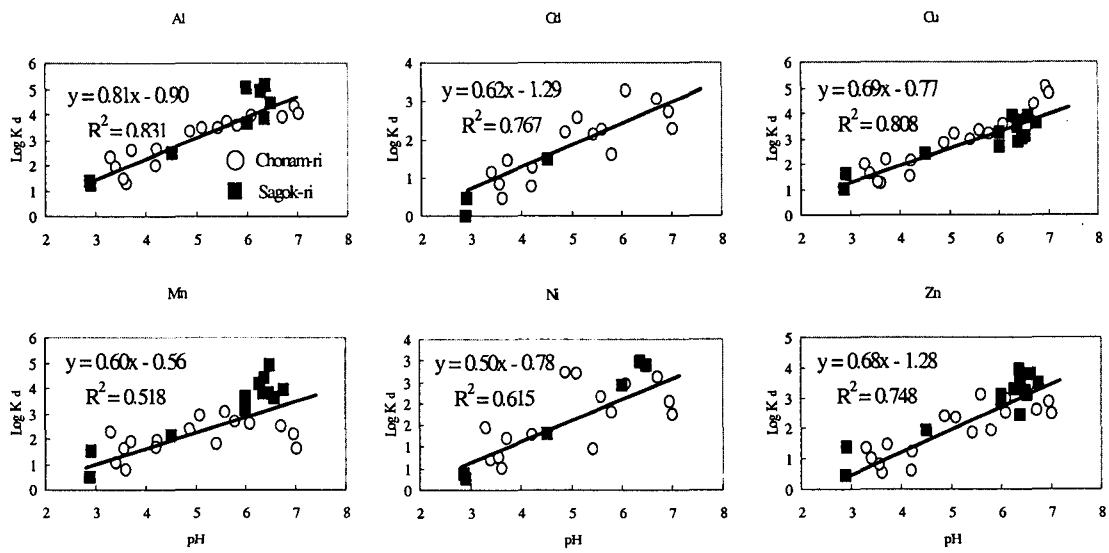


Fig. 4. Log Kd versus pH for trace metals in Chonam-ri and Sagok-ri creek

### 3. Geochemical association of heavy metals in sediment

The sequential extraction of Chonam-ri creek sediments shows that the exchangeable fractions are negligible (<4%) for all the metals examined. Carbonate fraction is also negligible (<4%) for the occurrence of metals (Fig. 5), because metal scavenging by carbonates is not so effective compared to iron and manganese oxides.

Previous studies reported that Fe-Mn oxides play a dominant role in heavy-metal distribution in AMD-affected stream sediments. Our data show that in average, the amounts of metals bound to Fe-Mn oxide phase are Mn (58%), Co (50%), Zn (33%), Cu (30%), Ni (23%), Pb (17%), Fe (15%), and Cd (14%). Therefore, these heavy metals are removed from water by adsorption onto or coprecipitation with Fe-hydroxides.

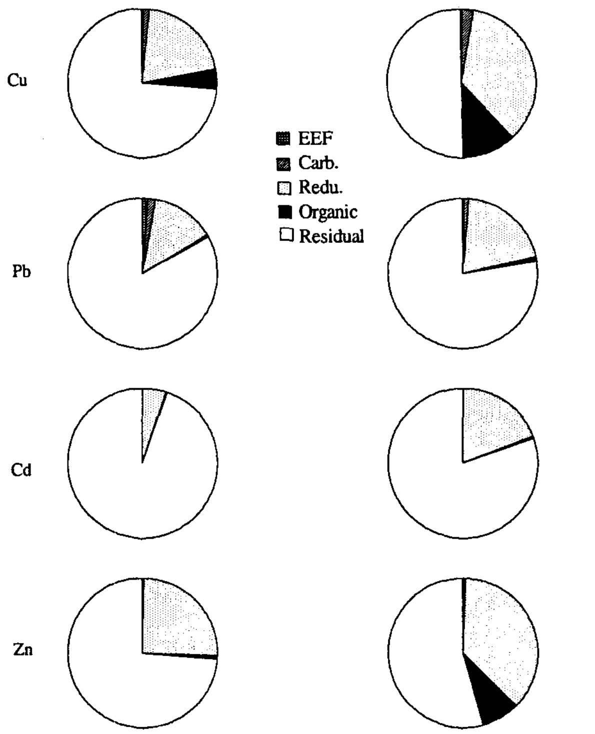


Fig. 5. Relative proportions of heavy metals in different fractions in Chonam-ri creek sediments

## Conclusion

In the Kwangyang area, Chonam-ri creek is more severely polluted by heavy metals than Sagok-ri creek. This phenomenon is possibly related to relatively higher content of base-metal sulfides in waste dumps of Chonam-ri creek. Calculated enrichment factors also showed that the degree of heavy metal pollution of sediments is higher for Chonam-ri creek. Distribution coefficients (Kd) of heavy metals generally increased with increasing pH in both creeks. Sequential extraction of sediments also showed that among the non-residual fractions, the greatest percentage of heavy metals is present in Fe-Mn oxides. Likewise, strong correlations between Fe concentration and Al, Co, Cu, Mn, Ni and Zn concentrations associated with Fe-Mn oxide fraction suggest that these metals are removed in water by adsorption onto or coprecipitation with Fe-hydroxides.

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