

Assessing the scale-dependence of mineral weathering rates at the Aitik waste rock deposit in northern Sweden

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This study uses data from earlier investigations of the waste rock deposits at the Aitik site in northern Sweden, currently Europe's largest operating copper mine (Strömberg *et al.*, 1994; Strömberg and Banwart, 1994, 1995; Eriksson, 1996; Strömberg, 1997; Eriksson and Destouni, 1997; Eriksson *et al.*, 1997; Strömberg and Banwart 1998a,b). The previous investigations aimed to identify dominant contaminant generation and attenuation processes and to quantify their rates across a range of physical scales, including small-scale batch experiments, large-scale column experiments, and field investigations at the site (Table 1). This study is focused on resolving an observed scale-dependence in mineral weathering rates, which control both contaminant loads and contaminant natural attenuation at the site.

Scale-dependence of weathering rates at the Aitik site

Table 1 lists the characteristics of the three different experimental scales. A comparison between the rates at different scales reveals a significant scale-dependence, with one to three orders-of-magnitude lower rates in the field than in the batch experiments

(see Fig. 1) and with the rates for the large column experiments in between.

To resolve the cause of the scale-dependence at the Aitik site, we identified five main differences between the prevailing experimental conditions at the different scales. The identified differences are related to: (a) environmental temperature (Table 1); (b) pore water pH (Table 1); (c) particle size distribution, differing between all experimental scales and with different particle sizes exhibiting significantly different weathering rates for some minerals (Strömberg and Banwart, 1998a); (d) mineral content, e.g. sulphide content that is highly variable in the field, and on the average considerably lower than on the other experimental scales (Strömberg and Banwart, 1998b); and (e) water flow patterns, ranging from total mixing and no flow in the batch experiments, via homogeneous flow in the column experiments, to existence of preferential flow paths in the field (Eriksson and Destouni, 1997).

Based on these differences, we quantified associated scaling factors, α_i , with the index i referring to the specific experimental difference, labeled as above, for upscaling the batch dissolution rates to apply to the two larger scales, such that

TABLE 1. Characteristics of the three experimental scales

Experimental scale	M , mass of solid material (kg)	Q , water flow ($\text{m}^3 \text{s}^{-1}$)	T , temperature ($^{\circ}\text{C}$)	pH
¹ Batch	0.15	—	20–23	3.3
² Column	⁴ $1.8 \cdot 10^3$	$9.2 \cdot 10^{-9}$	4–10	≈ 3.5
³ Field	⁴ 9.5×10^{10}	⁵ 1.7×10^{-1}	1–4	3.8–4.2

¹From Strömberg and Banwart (1998a); ²From Strömberg and Banwart (1998b); ³From Strömberg and Banwart (1994); ⁴Calculated as: $M = H A (1-n) \rho_s$ where H is height, A is total area, n is porosity, and ρ_s is density of the solid material; in the field, the average $H = 20$ m, $A = 2.6 \times 10^{-6} \text{ m}^2$, $n = 0.35$, and $\rho_s = 2.8 \times 10^3 \text{ kg m}^{-3}$; in the column experiments, $H = 2$ m, $A = 0.5 \text{ m}^2$, $n = 0.35$, and $\rho_s = 2.8 \times 10^3 \text{ kg m}^{-3}$; ⁵Average flow in the main drainage ditch at the Aitik site (Strömberg and Banwart, 1994).

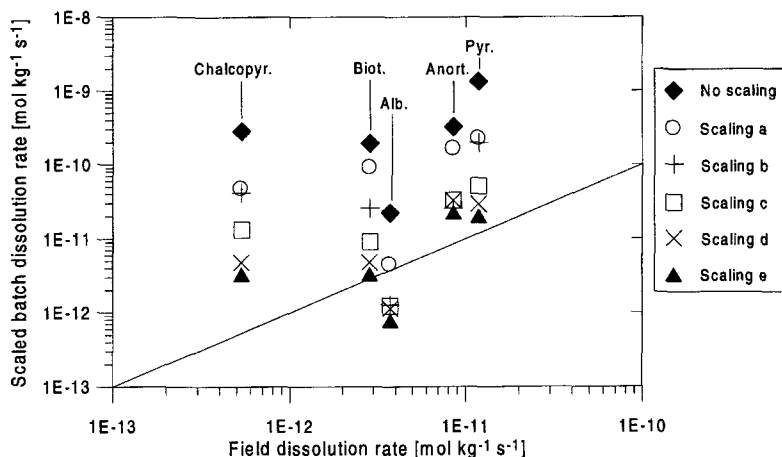


FIG. 1. Cumulative effect of upscaling dissolution rates from batch experiments to the field according to equation (1) as a function of observed dissolution rates in the field. The solid line denotes the ideal case, 'perfect prediction', where the scaled batch rate equals the observed field rate. Individual minerals are denoted Alb. (Albite), Anort. (Anorthite), Biot. (Biotite), Chalcopyr. (Chalcopyrite), and Pyr. (Pyrite), respectively.

$$R_s^{C/F} = \Pi \alpha_i R^B \quad (1)$$

where $R_s^{C/F}$ is the dissolution rate that is being upscaled from the corresponding batch dissolution rate R^B to column or field conditions, indicated by index C or F. The detailed description of the actual quantification of the different α_i is presented in Destouni, Banwart and Malmström (manuscript in preparation).

Results and conclusions

For the upscaling from batch to field, Fig. 1 summarizes upscaled rates, R_s^F according to equation (1). Figure 1 also shows the individual contributions of the different scaling factors α_i in equation (1). The results shown in Fig. 1, and similar results for the upscaling from the batch to the large column experiments, imply that the identified experimental differences and associated scaling factors can to a large degree explain the observed scale-dependence in mineral dissolution rates in the waste rock material from the Aitik site.

This analysis has provided an assessment of important factors that contribute to scale-dependent weathering rates at a particular mine waste deposit. The relative magnitude of the discrepancy between laboratory rates and rates at the field scale, however, is similar to previous observations of mineral weathering in laboratory and watershed studies (White and Peterson, 1990). This consistency

suggests that at least some of the effects identified in our analysis may be generally applicable and important when extrapolating weathering rates from laboratory to field scale.

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