Confirmation of the Scale Dependence of the Effective Matrix Diffusion Coefficient

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RESEARCH OBJECTIVES

Matrix diffusion in fractured rock refers to the exchange (through molecular diffusion) of solute mass between fractures and surrounding rock matrix. Owing to the much slower water velocity in the rock matrix compared to fractures, matrix diffusion can significantly retard contaminant transport and increase the spreading of a contaminant plume. The effective matrix diffusion coefficient is an important parameter controlling this process. Matrix-diffusion-coefficient values measured from small-scale rock samples in the laboratory have often been used for modeling large-scale contaminant transport processes at many different sites, including the proposed Yucca Mountain nuclear waste repository site. In a recent study, Liu et al. (2003) indicated that the effective matrix diffusion coefficient may be scale dependent and generally increases with test scale. The major objective of this work is to confirm this scale-dependent behavior, based on a data set from a comprehensive literature survey.

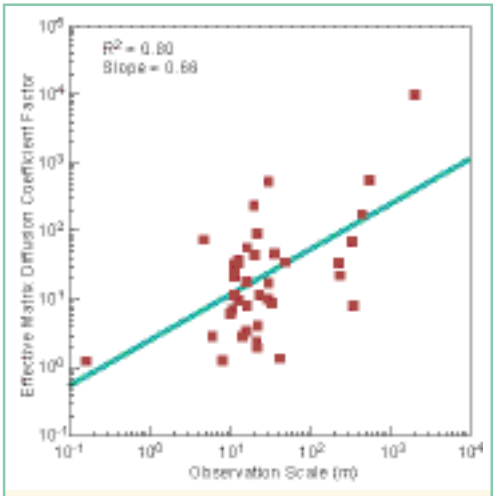

Figure 1. Effective matrix diffusion coefficient factor as a function of test scale

APPROACH

We conducted a comprehensive literature survey of field tracer tests, with scales ranging from 5 to 2,000 m and corresponding effective diffusion coefficient values (Zhou et al., 2005). Forty field tracer tests at 15 fractured geologic sites were selected for this study, based on data availability and quality. For the field tracer tests without reported matrix-diffusion-coefficient values, reanalysis of the tracer breakthrough curves was performed to calibrate transport parameters that included the effective matrix diffusion coefficient. This reanalysis was conducted using an analytic solution for linear flow and a semi-analytic solution for radial flow. To compare data from tests associated with different tracers, we compiled the ratio of an estimated effective matrix diffusion coefficient to its local value (corresponding to a small core sample), called the "effective matrix-diffusion-coefficient factor," as a function of test scale (Figure 1).

ACCOMPLISHMENTS

Based on results from the comprehensive literature survey (Figure 1), our work confirms that the effective matrix diffusion coefficient is scale dependent and generally increases with test scale. In addition, the surveyed data indicate that field-scale longitudinal dispersivity also increases with observation scale, which is consistent with previous studies. A preliminary explanation for the scale dependence of the effective matrix diffusion coefficient was reported in Liu et al. (2003), based on the argument that solute travel paths in a fracture network are fractal, and therefore the fracture-matrix interface area (contributing to the effective matrix diffusion coefficient) is scale dependent. Further investigation into the scale-dependence mechanisms is ongoing.

SIGNIFICANCE OF FINDINGS

While the scale dependence of permeability and dispersivity has been an active research topic for many years, this study confirms that the effective matrix diffusion coefficient, an important parameter controlling matrix diffusion processes, is also scale dependent. This finding has many important implications for problems involving matrix diffusion. For example, the performance of the Yucca Mountain site may be significantly underestimated when this scale dependence is not considered. This is because a large degree of matrix diffusion significantly retards radionuclide transport and decreases the concentration of (by increasing the spreading of) the radionuclide plume.

RELATED PUBLICATIONS

Liu, H.H., G. Zhang, and G.S. Bodvarsson, The active fracture model: Its relation to fractal flow behavior and a further evaluation using field observations. Vadose Zone Journal, 2, 259–269, 2003. Berkeley Lab Report LBNL-52824.

Zhou, Q., H.H. Liu, F.J. Molz, Y. Zhang, and G.S. Bodvarsson, Field-scale effective matrix diffusion coefficient for fractured rock: Results from literature survey. Water Resour. Res. (in review), 2005. Berkeley Lab Report LBNL-57368.

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