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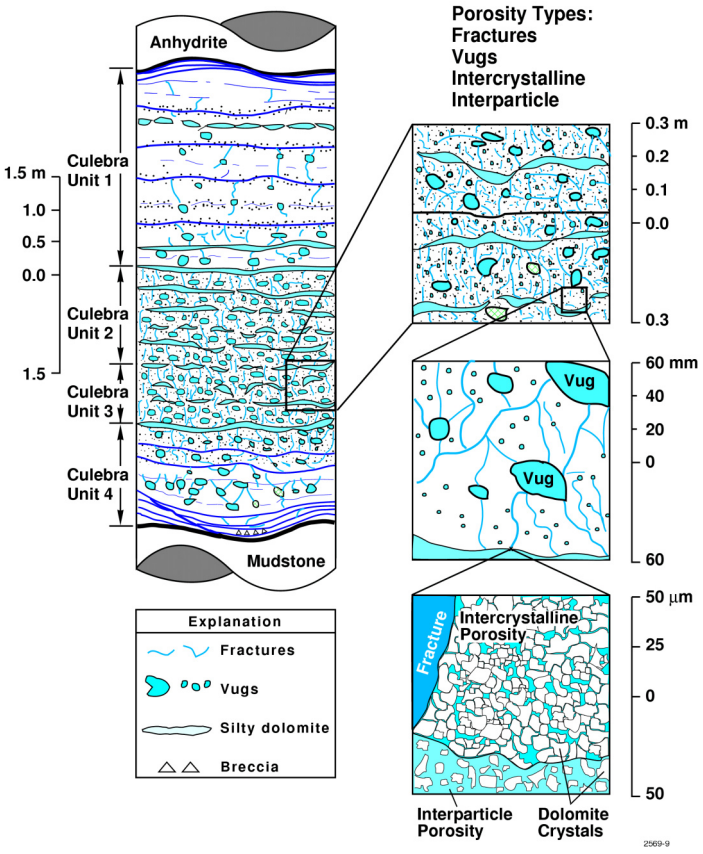
Contaminant Transport in Subsurface Environments: Analysis of Multi-Rate Diffusive Transport

Need

Understanding the controlling contaminant transport processes is a key element in the design and assessment of subsurface disposal or remediation of radioactive and hazardous wastes. In fractured rock and other environments with strong permeability contrasts, diffusion processes exert strong control on contaminant migration. In fractured rock environments, radionuclide migration is strongly retarded by diffusion into the adjacent rock matrix and by chemical interactions within the matrix. In many hazardous waste remediation situations, the effectiveness of a contaminant extraction system is limited by diffusive transport of contaminants from low permeability zones into higher permeability zones that are hydrologically connected to extraction wells. Current field test designs and model analysis techniques commonly assume a single rate of diffusion (i.e., simplified matrix block geometry and homogeneous matrix). Recent solute tracer experiments conducted by Sandia National Laboratories at both field and laboratory scales demonstrate the importance of multiple rates of diffusion resulting from geometric variability and matrix heterogeneity. Building on this experimental basis, Sandia has been conducting research into the recognition and modeling of multi-rate diffusion processes, as well as developing simplified modeling approaches for appropriate incorporation of multi-rate diffusion in site-scale performance assessment models.



Detailed hydrogeologic conceptual model of porosity types that control multi-rate, diffusive transport in fractured dolomite.

Recent Sandia Work on Multi-Rate Diffusion Problems

Field-Scale Testing

Field-scale tracer tests conducted recently by Sandia at the Waste Isolation Pilot Plant [WIPP] site demonstrate the importance of multi-rate diffusion. Sandia developed specialized equipment and techniques for conducting several carefully controlled

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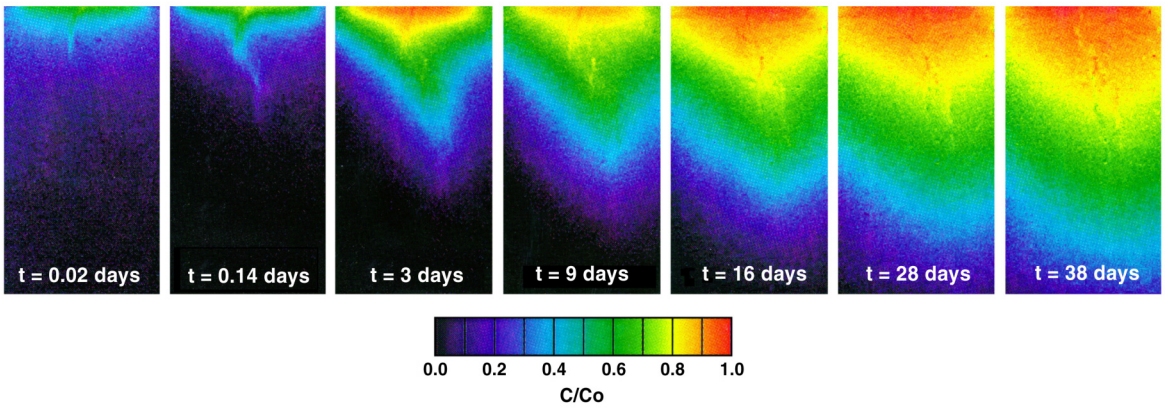
single- and multi-well tracer tests. The single-well injection-withdrawal tests produce solute recovery curves which provide clear demonstration of the importance of matrix diffusion, and indicate that the commonly used single-rate diffusion models cannot adequately explain the data. Properly designed single-well injection-withdrawal tests provide data to demonstrate matrix diffusion and differentiate between single- versus multiple diffusion rate models. Combining single-well test results with multi-well tests conducted at different pumping rates provides the data necessary for robust parameter definition.

Tracer injection at the H-19 Multi-Well Test Site at the Waste Isolation Pilot Plant [WIPP] in southeastern New Mexico

Laboratory-Scale Testing

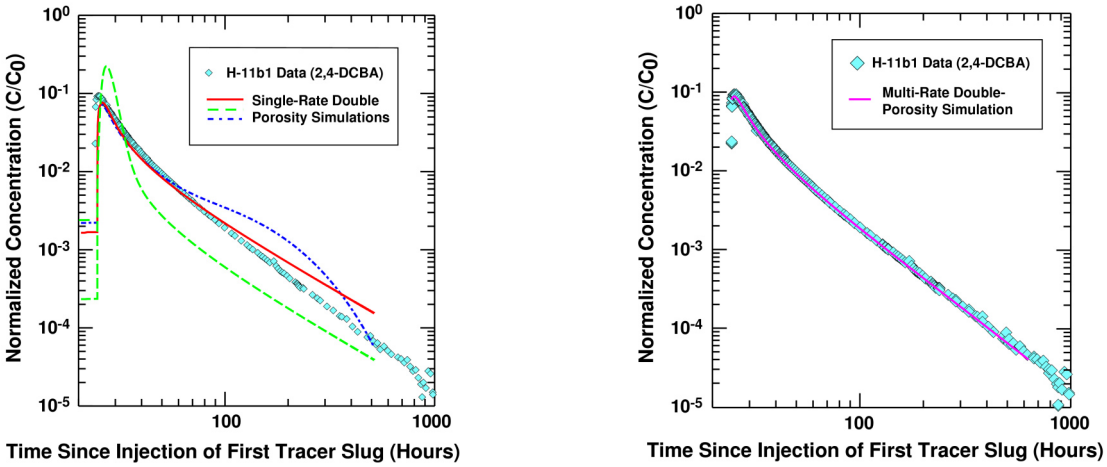
X-ray absorption imaging of matrix diffusion in dolomitic rocks with varying porosity structures and textural characteristics in the Sandia Flow and Transport Processes Laboratory provides real-time, high resolution digital imaging of extremely fine-scale diffusion processes. Analysis of digital images provides the basis for precise determination of diffusion rates and the magnitude of variations between different porosity types. These laboratory experiments provide rigorous, pore-scale, quantitative information that is a strong complement to field-scale tracer tests.



Digital images showing time sequence of relative concentration (C/Co) fields in 7 x 4 cm sample of dolomite. Note local enhancement of diffusion associated with small fracture at upper end of sample

Numerical Modeling and Analysis

Sandia National Laboratories is currently furthering the development and application of solute transport models to field- and laboratory-scale problems exhibiting multiple, simultaneous rates of diffusion. These numerical models are being used to explore various conceptualizations of multi-rate diffusion, to quantify the distributions of multiple diffusion rates responsible for observed transport behavior, and to predict the effect of multiple rates of diffusion over time and length scales that cannot be directly examined (e.g., for long-term performance assessment of nuclear waste repositories).



Numerical simulations of single-well recovery curves. Single-rate double-porosity simulations (left) do not adequately fit data. A multi-rate simulation (right) provides an excellent fit to the observed data.

Advantages

Sandia's approach to understanding diffusion processes in groundwater systems involves a strong coupling of field, laboratory, and numerical capabilities. This integrated approach provides a rigorous basis for the creation of defensible conceptual and numerical models that are tested at several time and length scales. Researchers at Sandia work closely with collaborators in academia, industry, and at other laboratories to provide state-of-the-art solutions to problems for which multiple rates of diffusion are a key component.

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