EMSP
Environmental Management Science Program
Project Summary Fact Sheet • October 1999

# VADOSE AND SATURATED ZONE CHARACTERIZATION, MONITORING, AND ANALYSIS – FRACTURED SYSTEMS

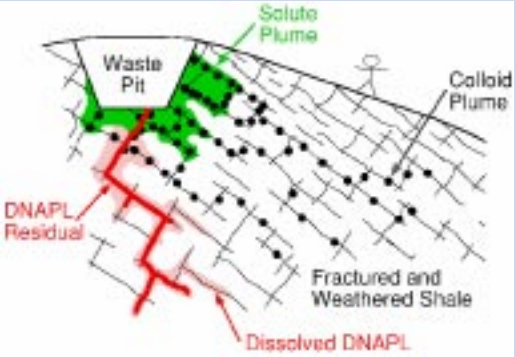
## SCIENTIFIC STUDIES OF THE FLOW OF FLUIDS AND CONTAMINANTS IN FRACTURED ROCK AQUIFERS WILL BE USED TO DESIGN IMPROVED SITE INVESTIGATIONS AND MONITORING NETWORKS THAT ULTIMATELY SUPPORT MORE EFFECTIVE REMEDIATION SYSTEMS AT FRACTURED-ROCK SITES

Fractured-rock sites are extremely complex both geologically and hydrologically. Characterization of and/or prediction of the migration of contaminants at such sites is difficult. Tools and methods that improve our understanding of fractured-rock aquifers and fluid flow through them can be extremely useful when designing characterization, modeling, and remediation activities at contaminated sites. Because of the complexity and heterogeneity of fractured-rock sites, basic science can provide an enhanced foundation on which to conduct efficient drilling and sampling programs.

At contaminated sites, investigations are performed to determine the location, total mass, mobility, and travel time to receptors for contaminants moving in the vadose and saturated zones. At fractured-rock sites, the contaminants travel downward through narrow pathways that can be difficult to find or predict. Methods to better understand these preferential flow paths, which are well known to exist at such complex sites and which greatly impact contaminant migration, are being investigated.

EMSP projects targeting characterization, monitoring, modeling, and analysis of contaminant transport in fractured-rock aquifers involve:

- use of naturally occurring strontium, uranium, and thorium isotope ratios as tracers to define regional-scale flow behavior and rates of contaminant transport;
- use of hydrologic inverse methods to define regional-scale flow behavior;
- use of dynamical chaos theory to investigate fluid infiltration and contaminant transport in fractured rocks using numerical modeling and field/laboratory tests;
- studies of basalt surface chemistry related to sorption and degradation of chlorinated organics;
- transport and retention of colloids in fractured media; and
- behavior of dense nonaqueous phase liquids (DNAPLs) in fractured clay-rich soils.




**Contaminant Migration in Fractured Shales at Oak Ridge National Laboratory**
The University of Tennessee team is studying DNAPL sources in fractured clays or shales. As shown here, DNAPL can rapidly infiltrate downward through fractures and then slowly dissolve, forming plumes in the fractures and matrix pores.

### PROBLEMS/SOLUTIONS

- Fluid and contaminant transport at fractured rock sites is extremely complex. The design of improved site investigation and remediation systems can be enhanced with a better understanding of geohydrologic systems.
- Enhanced transport of radionuclides and other contaminants via colloids in aquifers is known to occur at several U.S. Department of Energy (DOE) sites. Improved understanding of the physical and chemical controls on this transport will allow for better design of remediation systems that address this problem.
- Current models require enhancements to address the complexities of subsurface flow in heterogeneous fractured systems. Improved understanding of fracture flow and transport on a regional- and micro-scale can be used to develop better modeling approaches.

### ANTICIPATED IMPACT

- An improved understanding of flow and transport at fractured-rock sites will address two Remedial Action EM Science Needs: (1) Characterization and Monitoring and (2) Stabilization and Treatment. For example, Basic Science Need BS-11 calls for destruction or removal of DNAPL sources from fractured geological formations and soils.
- An improved understanding of flow and transport at fractured-rock sites will promote more cost-effective characterization and cleanup at sites such as Idaho National Engineering and Environmental Laboratory (INEEL), Oak Ridge National Laboratory (ORNL), and Lawrence Berkeley National Laboratory (LBNL). INEEL Science Need ID-S.1.08 calls for technologies, instruments, and approaches for characterizing and monitoring beneath several INEEL sites. An understanding of the significance of preferential flow is needed to predict potential human health risks for these sites.
- The Snake River Plain Aquifer at INEEL is one of the largest sole-source aquifers in the world. Better methods to address its remediation can have a significant impact on millions of gallons of a precious resource.

### Natural Isotope Ratios as Tracers

An INEEL team (211) and the University of Illinois team are studying the use of natural strontium isotope ratios, in conjunction with hydraulic head distributions, to define regional-scale groundwater flow. These studies are being conducted at the INEEL site, where groundwater emanates from different sources and mixes in patterns related to specific geohydrological features. The objectives of these studies are to (1) identify preferential pathways, (2) determine the role of mixing of different recharge waters, and (3) define the effects of rock/sediment geochemistry on groundwater composition within the Snake River Plain Aquifer. Numerical modeling, using inverse methods and fractal geometry concepts, has been conducted to simulate the geochemical evolution of groundwater across the site. Researchers have identified zones of faster and slower groundwater flow in different areas of the 900 square-mile site.

The Los Alamos National Laboratory/University of Southern California team is studying the use of natural uranium and thorium isotopes (and their daughter products) as tracers to provide information on transport of contaminants and fluids through fractured rock settings. Isotope ratios in both water and rock facies are being analyzed to improve the understanding of retardation and sorption. Flow paths at INEEL from areas of recharge down gradient can be mapped using the $^{234}U/^{238}U$ ratios. Radioactive disequilibrium measurements are also being used to map the degree of retardation of different radionuclides. Results have shown that radionuclide migration potential can be grouped into three classes: (1) high mobility (e.g., uranium), (2) low mobility (barium, strontium, and cesium), and (3) very low mobility (thorium and lanthanum).

### Rock-Water Interactions

Another INEEL project (205) is studying the surface chemistry of subsurface basalt at INEEL to improve understanding of sorption/desorption of chlorinated organic contaminants on fractured rock surfaces and their ultimate fate and transport in this setting. Surface analytical techniques have provided insight on chemical reactivity of rock surfaces.

### Chaotic-Dynamical Conceptual Model

The LBNL and coworkers team is using dynamic chaos theory to investigate flow and contaminant transport processes in fractured rocks and heterogeneous soils. This approach is based on the assumption that spatial heterogeneity and temporal variability of flow phenomena are affected by nonlinear dynamical processes. Experiments are being conducted on different scales to develop improved conceptual models that could ultimately support design of improved remediation systems with a particular focus on the vadose zone.

### Colloid Transport and Retention in Fractured Media

The ORNL and coworkers team is investigating the transport and retention of colloids in fractured media. The project goal is to identify the chemical and physical factors that control the transport of colloids in fractured formations and to develop a capability to make predictions based on hydraulic factors, physical structure, and chemical properties. This project supports findings of enhanced colloidal transport of radionuclides and other contaminants at many DOE sites. Ultimately, this work may yield novel techniques to immobilize or mobilize colloids to enhance site remediation effectiveness. Work has concentrated on (1) fundamental description of particle transport in fractures; (2) colloid transport in geological columns; (3) field-scale colloid tracer migration; and (4) modeling of colloid transport in complex fracture networks. Results have shown that both physical and chemical factors contribute to the overall potential for colloidal transport.

### Behavior of Dense Immiscible Solvents (DNAPLs) in Fractured Clay-Rich Soils

The University of Tennessee and coworkers team is studying the nature and distribution of DNAPL sources in fractured clays or shales and the potential for natural attenuation of plumes derived from these sources. Preliminary investigations indicate that DNAPL source removal will be much more difficult at fractured-rock sites; research is needed to build the scientific framework for assessing remediation options at these sites. Two fractured clay-rich materials (weathered shales in Tennessee and weathered glacial till in Ontario, Canada) have been investigated. The field studies in Tennessee demonstrated a fast-flowing fracture regime and a fine-grained matrix regime with very slow flow. The Canadian studies indicated that most of the DNAPL mass has diffused into the matrix, forming a halo around the fractures. DNAPL remediation under these conditions will be extremely difficult, as diffusion processes will control DNAPL migration back into the fractures.

## PROJECT TEAMS

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