BEHAVIOR OF DENSE IMMISCIBLE SOLVENTS (DNAPLS) IN FRACTURED CLAY-RICH SOILS

EMSP Project 55083 Sept/96 - Aug/99

Introduction

Fractured clay-rich soils are widespread in the eastern U.S and include soils developed on saprolite or highly weathered rock, glacial tills, and lake or marine deposits. Many DOE facilities, including those at Oak Ridge, TN, Fernald, OH, and West Valley, NY, are located on fractured clay-rich soils.

Dense, non-aqueous phase liquids (DNAPLs) can enter small aperture fractures or biopores in clay-rich soils, causing significant contamination of the soil, nearby streams or underlying aquifers. Contamination tends to be highly erratic, with much of the DNAPL mass residing in the fine-grained matrix, which can act as a long term source. Conventional monitoring and remediation methods are often ineffective in these materials.

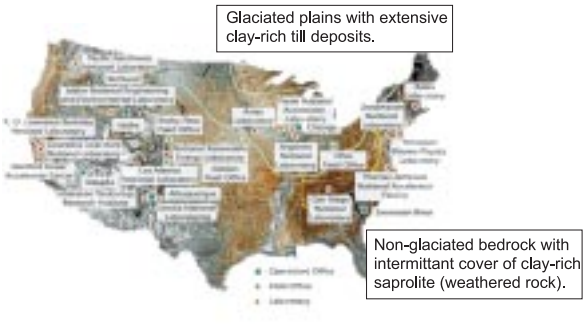

Figure 1. Distribution of fractured clay-rich saprolites and glacial tills.

Figure 2. Waste disposal in unlined trenches at ORNL.

Figure 3. Fractured and weathered shale.

Goals and Objectives

Investigate factors controlling migration and distribution of immiscible phase.

Investigate dissolution of DNAPL and diffusion into matrix.

Assess potential for natural attenuation.

Address the relevance for DOE and other federal agencies.

- implications for monitoring & site characterization
- limitations for conventional remediation methods
- potential for natural attenuation

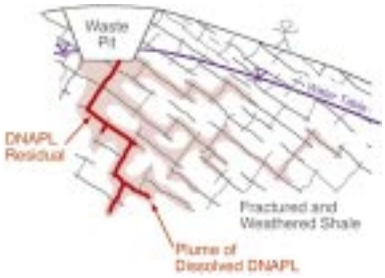

Figure 4. Conceptual model of DNAPL distribution in fractured clay-rich soils.

Investigative Methods

Monitoring of chlorinated solvent contamination in fractured & weathered shales near existing waste trenches at ORNL.

Laboratory investigations of DNAPL behavior in undisturbed columns of

- fractured shale saprolite from ORNL
- fractured till from Sarnia, Ontario

Analysis of microbial populations using DNA probes to assess potential for biodegradation.

Figure 5. Field excavation of undisturbed saprolite sample.

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Natural Attenuation Field Site

An instrumented site was developed adjacent to existing waste trenches at ORNL. Preliminary monitoring showed presence of chlorinated solvents.

Objectives

Determine if natural attenuation is occurring in fractured saprolite & shale at the WAG 5 site.

Figure 6. View of experiment/monitoring facility at WAG 5. Waste trenches are located 15 meters behind tent.

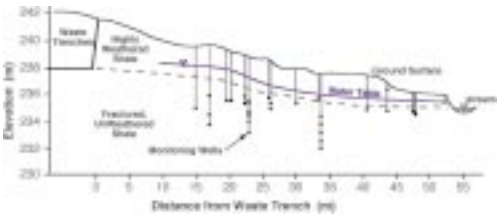

Figure 7. Monitoring of contaminant plume from trenches.

Summary of Monitoring at WAG 5

Evidence of natural attenuation

- declining concentrations of TCE away from trench
- appearance of daughter products (DCE, VC, & ethylene)
- presence of anaerobic TCE-degrading organisms (methanotropes, heterotrophs, & sulphate reducing bacteria)

Capillary Pressure - Saturation (Pc-S) Behavior in Fractured Shale Saprolite

Objectives

Determine whether DNAPL (Fluorinert^{TM}) can enter fractures and fine-grained matrix under realistic spill conditions.

Determine whether air-water Pc-S data can be "scaled" to predict DNAPL-water behavior.

Figure 8. Lab setup for measurement of Pc-S behavior.

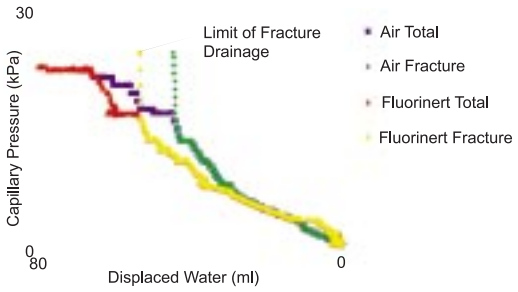

Figure 9. DNAPL-water and Air-water drainage curves.

Summary of Air-DNAPL-Water Experiments

Fluorinert entry to fractures and matrix occurs at small pressures (10 to 140 cm head). This indicates that even a small DNAPL spill will readily penetrate the soil.

Air-water Pc-S data provides a useful first approximation of DNAPL-water behavior. Air-water data already exists for many soils and can readily be measured.

TCE Migration in Fractured Clay Till

Objectives

Measure TCE entry pressure & distribution in fractures in a very low permeability till (7 E-10 m/s).

Determine rates of dissolution & diffusion of TCE residual.

Figure 11. Dismantled sample. Round holes represent "micro-cores" used to measure TCE concentration.

Figure 10. Excavation of undisturbed column of fractured clay-rich till.

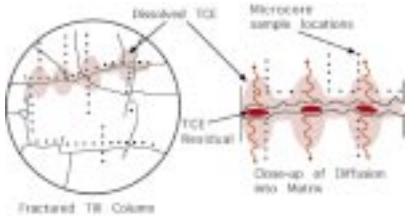

Figure 12. Schematic diagram showing fractures containing immiscible TCE and diffusion into matrix.

Summary of TCE - Till Experiment

TCE entered till at pressures corresponding to 29 cm head, indicating that small fractures (17 microns) can be penetrated by DNAPLs.

TCE distribution in fractures was highly erratic, with only 5-15% of the fracture surface area showing evidence of contamination.

Within 3 weeks of the start of the injection, most of the TCE had already dissolved and diffused into the matrix.

Summary and Implications

DNAPL contaminants can readily penetrate the small fractures found in many clay soils or aquitards.

★ Many clays are not barriers to DNAPL migration.

DNAPLs can penetrate the fine-grained matrix of some clays at low capillary pressures.

★ This will tend to spread contamination through the matrix where it is more difficult to remove, but will also "soak up" the spill more quickly.

DNAPLs in fractures can rapidly (a few weeks to months) dissolve and diffuse into matrix.

★ Remedial methods aimed at removing immiscible DNAPLs are likely to be ineffective.

★ Removal of dissolved contamination from matrix is diffusion-controlled and is very slow.

Preliminary studies suggest that natural biodegradation of chlorinated solvents can occur in some fractured clays.

★ In these cases, containment and/or monitoring may be an acceptable, cost-effective option.

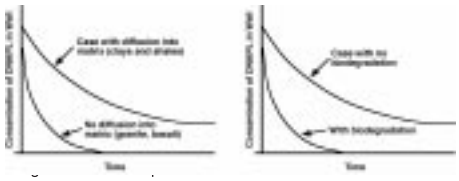

Figure 13. Graphs of contaminant concentration versus time for "pump and treat" remediation well.

Ongoing and Planned Activities

Preparation of additional manuscripts including an overview paper "Contaminant behavior in fractured clays and shales" aimed at the working professional.

Further characterization of microbial populations.

Additional lab experiments to examine longer term interactions between DNAPLs and clay soils.

Additional field investigations to examine geochemical and microbiological controls on biodegradation.

Publications and Presentations

Two MS theses complete, one MS and one PhD in progress.

Journal manuscripts in review or preparation.

Approximately 6 presentations annually at local, national, international conferences and workshops.