Research Objective

The DOE National Laboratories have extensive environmental remediation and operations centers as well as research teams specializing in environmental problems. These organizations are concerned largely with pollution prevention, safe disposal of hazardous materials, polluted site identification and characterization, and cleanup of polluted sites. These organizations, and the private-industry subcontractors they hire, require state of the art tools and techniques for characterization and monitoring. Our research will contribute to this effort by providing descriptions of heterogeneities and scaling properties in the vadose and saturated zones with particular emphasis on flow and transport. This work will also provide an important link between some geophysical measurements and fluid transport characteristics.

At contaminated sites there are a variety of issues ranging from chemical interaction of solutes with the mineral surfaces within pores, to transport of radionuclides affixed to colloids, to bulk flow and transport. Both saturated and unsaturated flow regimes exist and there may be multiple immiscible phases to consider. Multiple phase systems, such as NAPL-water, water-air, or NAPL-water-air, are all similar in that capillary forces, which act at the pore scale, dictate the distribution of each phase at the pore scale and larger. The pore-scale distribution of phases then controls the larger scale (perhaps ultimately continuum) properties such as relative permeability and relative saturation.

Our objective is to develop new tools for flow and transport modeling in these complex systems through a comprehensive study of heterogeneity and scaling of geologic media from sub-millimeter (pore) scale to the meter scale. We focus on measurement of this structure through geophysical methods, synthesis and description through mathematical models, and the implications for flow and transport in the vadose and saturated zones.

To accomplish these goals, we are (1) performing multi-scale measurements of heterogeneity and scaling of physical properties in the laboratory and at the backyard field scale, (2) describing and synthesizing these data and develop mathematical models, and (3) performing parameter studies to explore these models in the context of transport in the vadose and saturated zones.

Research Progress and Implications:

This report summarizes work after 9 months of a 3-year project. As part of our initiative addressing characterization of core scale heterogeneity, we have developed a multi-probe physical properties scanner which allows for the mapping of geophysical properties on a slabbed sample or core. This device allows for detailed study of heterogeneity at those length scales most difficult to quantify using standard field and laboratory practices. The measurement head consists of a variety of probes designed to make local measurements of various properties, including:

- Gas permeability
- Acoustic velocities (compressional and shear pulse propagation)
- Complex electrical impedance (4 electrode, wide frequency coverage)
- Ultrasonic reflection (ultrasonic impedance and permeability)
Figure 1: **Left:** Photographs of the Berea sandstone block used for detailed study of heterogeneity. The block has dimensions of $X=41\text{cm}$ by $Y=34.5\text{cm}$ by $Z=14.5\text{cm}$, with the $X$-$Y$ plane oriented parallel to bedding. The most obvious visual features in the block result from thin, dark brown beds, typically a fraction of a millimeter thick and spaced by a few millimeters. On the top surface, one or two of these beds outcrop due to subtle $Z$ axis irregularity of the bedding. **Center:** Permeability scan on the top surface of the Berea block. Data was taken on a regular grid, with point spacing of 1 cm, using a permeability probe with a approximately 3mm spot size. Gray scale is logarithmic in permeability, with black indicating low values. Permeability ranges from 61 mD to 670 mD. **Right:** Compressional velocity in X-direction.

The scanner allows for the routine generation of detailed geophysical maps on a particular sample. With the exception of the acoustic velocity, we are testing and modifying these probes as necessary for use on soil samples.

As a baseline study we are characterizing the heterogeneity of each of the four properties above for a Berea sandstone block (Figure 1). Berea Sandstone has long been regarded as a laboratory standard in rock properties studies, owing to its uniformity and “typical” physical properties.

To date, we have completed some preliminary scans on the top surface of the Berea block using the gas permeameter probe and the ultrasonic velocity probe (Figure 1). Both permeability and velocity exhibit complex heterogeneity at the centimeter scale. While some correlation with the outcropping of the bedding is apparent, much of the heterogeneity is not clearly associated with visual features.

For the study of soil heterogeneity at a wide range of scales, we are focusing on a local glacial deposit (Figure 2). This deposit is a glacial kame terrace of fluvial origin with multi-scale sedimentary structures comprised of unconsolidated sands, clays, and gravels.(Figure 3). There are also many joints and faults in the unconsolidated sediments (Figure 4), allowing study of these as potential fluid flow conduits or barriers.

We are currently developing new techniques for obtaining undisturbed soil samples for laboratory measurement as well new methods for analogous in-situ measurements at the field site. Samples are brought to the laboratory for detailed study using similar methods to those described for the sandstone block. We will be revisiting the field site frequently for more detailed study.
Figure 2: Soil sampling at glacial kame terrace in Sharon, Vermont.

Figure 3: Variety of sedimentary structures in the glacial deposit.
**Planned Activities**

During the remainder of FY03 and throughout FY04 we will focus on study of samples and data acquired from the Vermont glacial kame deposit. We plan to compare these data with a limited number of samples obtained from Hanford, if possible. The tasks for the next project period are:

- Continue development directional permeability, acoustic pulse, and resistivity probes for unconsolidated soil samples.
- Collect datasets on Berea sandstone and first soil samples from glacial kame deposit.
- Analyze measurements for scaling and other statistical properties as data is acquired and begin statistical model development.
- Begin prediction and physical modeling studies of flow and transport using the measurement-based statistical models.
- Prepare a publication of first results.

**Information Access**

None at this time.