Project Title: **Fast Flow in Unsaturated Coarse Sediments**

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Research Objectives

Unsaturated flow in very coarse sediments is a critical area for improving our basic understanding of vadose zone flow and transport because it contains important aspects that are beyond the realm predictable by classical Miller-Miller scaling analyses. In particular, very coarse-textured (>1 mm grain-size) media can sustain high flow rates at relatively low saturations, doing so via film flow rather than by flow through an interconnected network of saturated pores. Thus, the physics of fast flow processes in unsaturated very coarse media is fundamentally different from that traditionally recognized in finer textured sediments. Our general objectives are (i) to quantify the macroscopic hydraulic properties of very coarse textured sediments in the near-zero (-10 to 0 kPa) matric potential region, and (ii) determine the microscale basis for fast unsaturated flow. Through these macroscopic and microscale studies, we intend to develop appropriate scaling relations for unsaturated flow in coarse-granular sediments.

Gaining improved understanding of unsaturated flow in coarse granular sediments is important for practical concerns. Effective remediation and management of contaminated coarse-grained sediments such as those found at the Hanford Site requires knowledge of unsaturated fast flow. A better understanding of the failure mode for natural and engineered capillary barriers is also needed. This research proposal was developed to improve our understanding of the physics of unsaturated flow in coarse- to very coarse-textured sediments, and through this meet practical needs related to contaminant transport in such vadose environments.

Research Progress and Implications

This report summarizes progress during the first year of our newly funded project. In pursuit of our research objectives, studies are being conducted to quantify macroscopic (column scale) and microscopic (grain-film scale) hydraulic properties and processes in coarse sands and gravels. In order to obtain results that are directly relevant to the DOE, we are focussing most of our efforts on sediments from the Hanford Site (Hanford formation, grain-sizes ranging from 0.1 to 50 mm). Tests of similar nature are being conducted on quartz sands and gravels for the purpose of obtaining more general results.

Our analyses of film flow in coarse sediments are showing that fast flow is possible only at near-zero matric potentials. This is a difficult energy region to study because of extreme changes in saturation and conductance that take place, especially in coarser textured media.

Some of the established macroscopic methods for measuring unsaturated hydraulic properties of porous media are unsuitable for coarse-grain sediments because they require that variations in saturation over short vertical distances be negligible. As part of this project, we have utilized three types of column methods that permit acquisition of saturation-potential-conductance relations. The first method is designed to provide saturation-potential-conductance information based on monitoring matric potential and saturation during a series of constant rate infiltration tests. The recent initial testing of this method on Hanford formation gravel was successful. The apparatus is being modified to permit more rapid measurements. The second type of column device will permit hydraulic characterization based on transient imbibition and drainage experiments. The third method permits determination of conductance-potential relations during steady-state evaporation.

Microscale tests of film flow have also been started. These experiments build on our previous experience with film flow on roughened quartz glass surfaces that served as model rock fracture surfaces (Tokunaga et al., 2000). The method relies on determining average water film thicknesses using x-ray fluorescence of a solute tracer. A Hanford gravel sample is placed in a small suction plate device, and scanned with a defocused synchrotron x-ray microbeam while equilibrating to selected boundary matric potentials. Important differences and complications introduced in the studies on Hanford gravel include a high matrix fluorescence background and greater surface roughness. The latter feature is important in permitting stable film flow, but also requires more measurements for proper characterization. These x-ray experiments are conducted at beamline X26A of the National Synchrotron Light Source (Brookhaven National Laboratory). Experiments were conducted in the 0 to –10 kPa matric potential range, with most tests in the 0 to –2 kPa region. This latter region is important because it permits fast film flow in larger, unsaturated pores.

The studies on Hanford sediments described above have only recently been started, but it is anticipated that measurements of film flow at near-zero matric potentials will reveal a previously unrecognized mechanism for fast, unsaturated flow in coarse sediments.

Planned Activities.

The macroscopic and microscale studies described above will be continued on a range of grain sizes, in both well-sorted and mixed size distributions. The combined data set will permit testing of scaling laws relevant for unsaturated flow in coarse granular sediments. The microscale x-ray fluorescence experiments will continue in conjunction with grain surface microtopography measurements. The combined results of macroscopic and microscopic experiments will be used to develop a tested, consistent physical model of unsaturated flow in coarse sediments. Column experiments of well-sorted sediments, and further microscale measurements will be in progress for the remainder of FY2000. Inverse modeling (Stefan Finsterle, LBNL) of column experiments will be done to better quantify hydraulic relations. Studies on mixtures of grain sizes will be done during FY2001. Implications of these results on capillary barrier performance will be tested during FY 2002.

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Related Publications

Tokunaga, T.K., and J. Wan. 1997. Water film flow along fracture surfaces of porous rock.

Water Resour. Res., 33, 1287-1295.
Tokunaga, T. K., J. Wan, and S. R. Sutton. 2000. Transient film flow on rough fracture surfaces. Water Resour. Res., 36, 1737-1746.