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 second year of our 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, and crushed tuff gravel for the purpose of obtaining more general results.

Our analyses of film flow in coarse sediments have shown 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. The energy gap separating fast unsaturated flow and from much slower diffusion-like flow can be less than 100 Pa (1 cm). Many of the established macroscopic methods for measuring unsaturated hydraulic properties of porous media are unsuitable for very coarse-grain sediments because they require that variations in saturation over short vertical distances be negligible. Many established methods are also unsuitable for investigating the near-zero matric potential region in coarse sediments because they do not permit regulation of boundary potentials with the necessary accuracy (on the order of 10 Pa, or 1 mm). We have developed several experimental methods to circumvent these limitations, and are applying them to gravelly sediments. Deviations from Miller-Miller scaling have been identified for media with characteristic grain sizes greater than 3 mm. Especially above this size, grain-surface hydraulic properties play an important role in unsaturated flow characteristics.

In order obtain a more comprehensive understanding of the influences of Hanford formation gravels in general flow and transport, we have also examined these sediments over a much wider potential range (down to -370 MPa, or -3,600 atm). These measurements reveal that the gravels have significant intragranular porosity (about 5%), fairly high internal surface area, and low intragranular mass transport rates. This shows that intragranular matrix of Hanford gravels is involved in solute transport processes, although on a diffusion-limited time scale.

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. Studies on monodisperse gravels and mixtures of grain sizes are continuing through FY2001. Implications of these results on capillary barrier performance will be tested during FY 2002.

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Related Publications

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

Tokunaga, T. K., and J. Wan. 2001. Surface zone flow along unsaturated rock fractures. Water Resour. Res., 37, 287-296.

Tokunaga, T. K., and J. Wan. 2001. Approximate boundaries between different flow regimes in fractured rocks. Water Resour. Res., in press (accepted March 2001).