Scaling and Hierarchy of Models for Flow Processes in Unsaturated Fractured Rock

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RESEARCH OBJECTIVE

The goal of this research is to investigate whether a hierarchy of scales is needed to conduct measurements and develop models for an accurate description of the spatial-temporal behavior of flow and transport processes in unsaturated fractured rock.

APPROACH

The alternative approach to volume-averaging and scaling in unsaturated fractured rock is to use a hierarchy of scales. This approach is based on a system structure, i.e., the classification of a graded (ranked) series of system parts (subsystems). Each subsystem is dominant over those below it and dependent on those above it.

The concept of a hierarchy of scales in unsaturated fractured rock involves the following scales: *elemental*—for laboratory cores or a single fracture at a field site; *small scale* (approximately 0.1–1 m^2)—for a single fracture, including fracture-matrix interaction, film flow, and dripping water phenomena; *intermediate scale* (approximately 10–100 m^2)—for flow in the fracture network on a field scale, and *large scale*—for the fracture and fault network flow. Each of these scales should be investigated on a minimum of three hierarchical levels. For the level of interest, called Level 0, a hierarchy should include at least one hierarchical level above it, called Level +1, and at least one hierarchical level below it, called Level -1. The low-frequency behavior at Level +1 constrains the higher-frequency dynamics of Level 0 and thus determines the system boundary condition, constraining the system behavior over time. Because small-scale intrafracture flow processes are neither physically nor geometrically analogous to large-scale fracture-network processes, different conceptual approaches are required for modeling at different scales.

ACCOMPLISHMENTS

Figure 1 presents an example of a hierarchy of scales for flow processes in fractured tuff at the Yucca Mountain site. If Level 0 investigations are conducted to develop an intermediate-scale model (e.g., flow and transport processes in a fracture network around a tunnel, lateral flow at the interface between the Tiva Canyon and Paintbrush (PTn) hydrogeologic units, dispersion in the PTn unit, and a perched-water zone at the Topopah Spring and Calico Hill interface), Level -1 investigations include the study of small-scale processes taking place in small fractures and lithophysal zones (e.g., seepage, evaporation caused by tunnel ventilation, and intrafracture fingering). Level +1 investigations should be used to assign boundary conditions for the whole TSw unit. We have found that a trace length of 2 m represents a critical fracture length separating small and intermediate scales. A length of 10 m represents a critical fracture length separating intermediate and large scales.

SIGNIFICANCE OF FINDINGS

The concept of a hierarchy of scales and models will improve predictions of both water seepage and chemical transport through unsaturated fractured rocks at different scales, and reduce uncertainty in predictions of such processes.

RELATED PUBLICATION

Faybishenko, B., G.S. Bodvarsson, P.A. Witherspoon, and J. Hinds, Scaling and hierarchy of models for flow processes in unsaturated fractured rock. In: Scaling Methods in Soil Physics (Y.A. Pachepsky, D.E. Radcliffe and H. M. Selim, eds.), pp. 373–417, CRC Press, LLC, 2003.

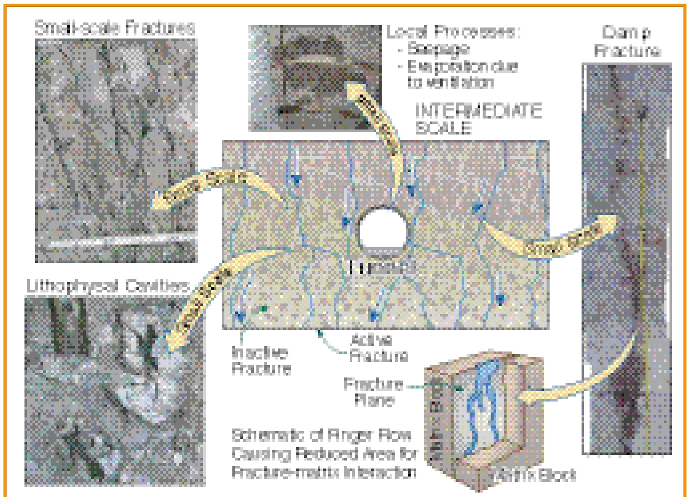

Figure 1. A hierarchy of scales for flow processes in fractured tuff at Yucca Mountain

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