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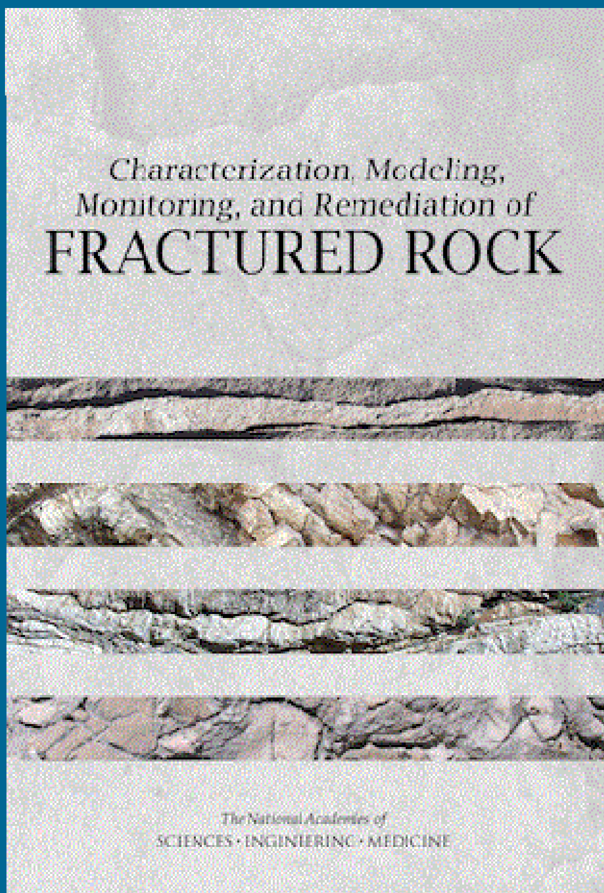

Characterization, Modeling, Monitoring, and Remediation of Fractured Rock

A New Academies Report

December 2, 2015
Sammantha Magsino

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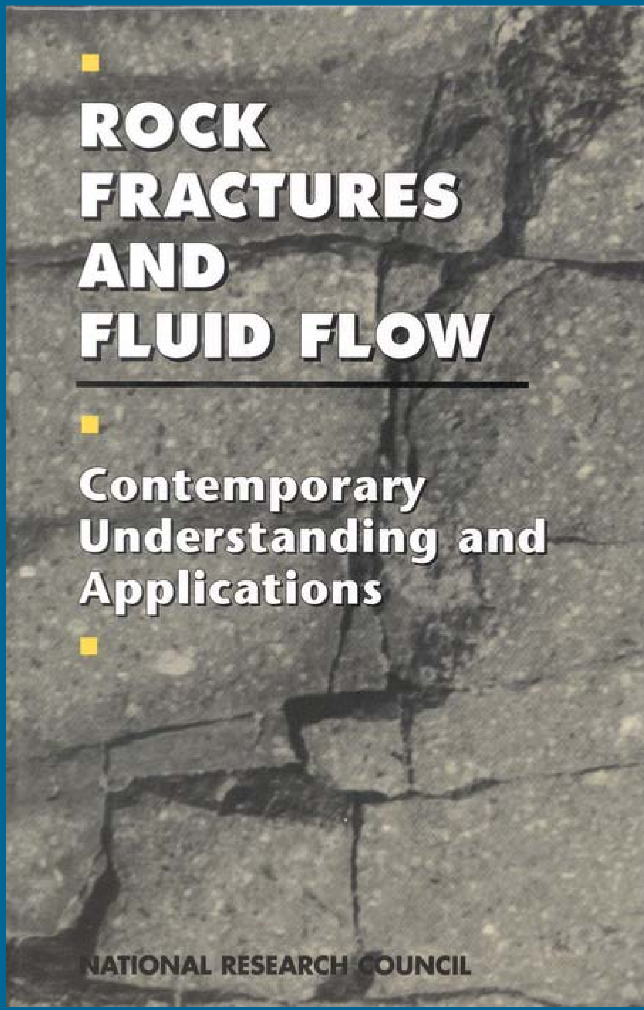
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AND
FLUID FLOW
Contemporary
Understanding and
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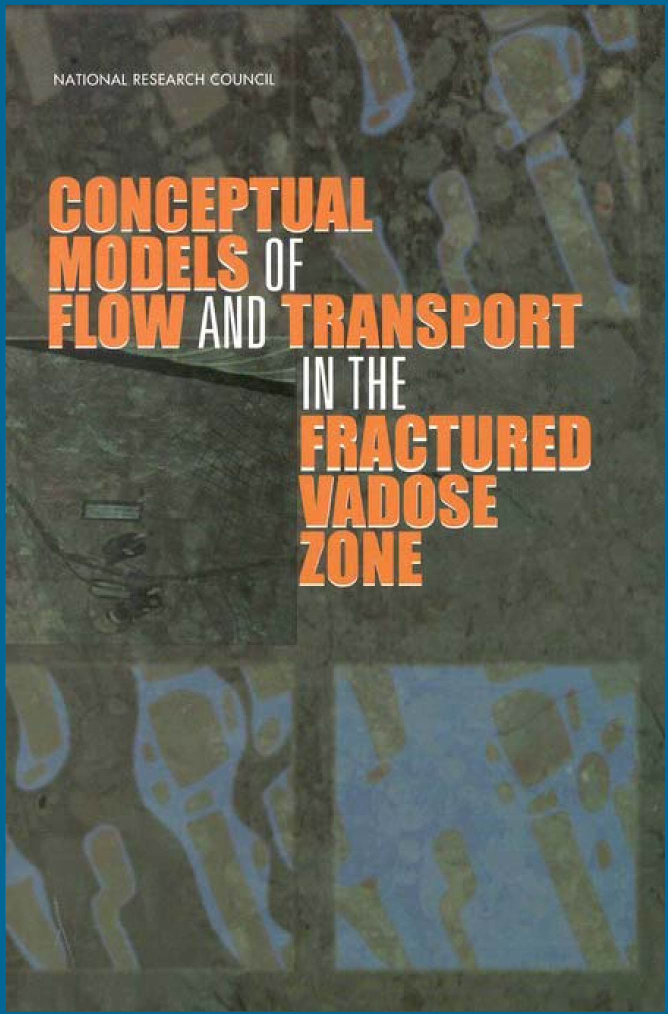
NATIONAL RESEARCH COUNCIL
CONCEPTUAL
MODELS OF
FLOW AND TRANSPORT
IN THE
FRACTURED
VADOSE
ZONE

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Statement of Task

Address issues related to flow and transport in fractured rock for lifecycle of infrastructure

Photo: USGS

- Fracture/matrix characterization, conceptual modeling
- Detection of pathways/travel times
- Thermal, hydrological, chemical, mechanical, and coupled processes
- Remediation and monitoring
- Decision making

RECOMMENDATIONS

(two types)

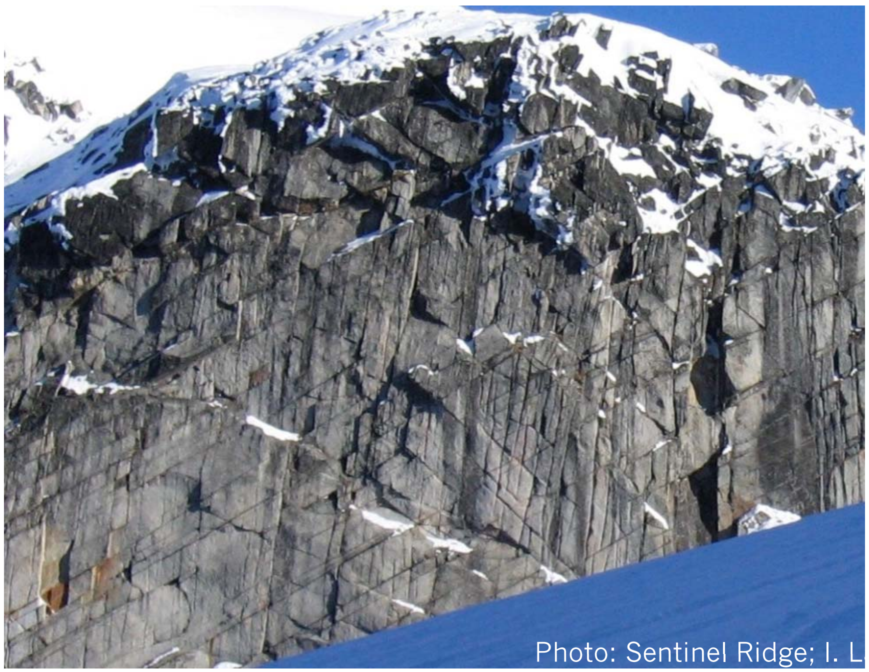
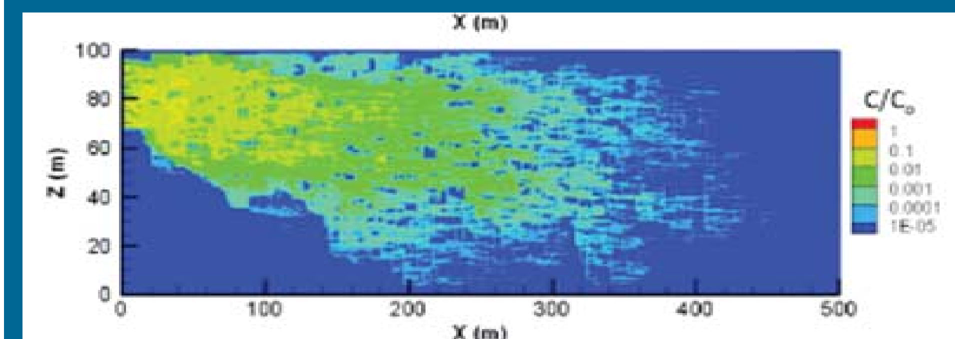


Photo: Sentinel Ridge; I. L

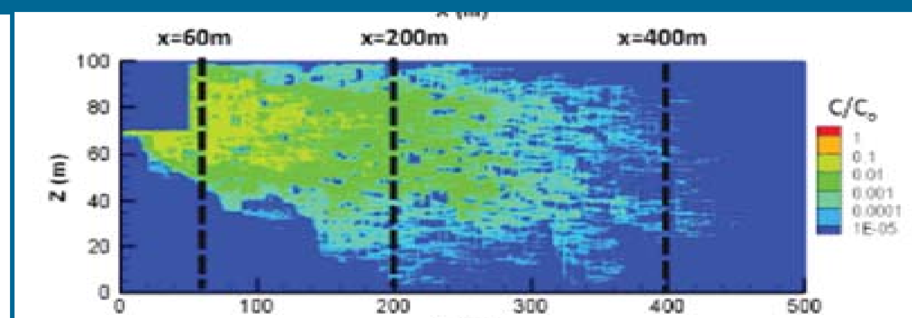
- Ways to improve engineering practice given today's tools and knowledge
- Suggestions for R&D to improve future practice

Develop and communicate realistic expectations related to remediation effectiveness

Effective characterization and parameterization, and explicit understanding of matrix diffusion → realistic and achievable remediation goals



No Source Remediation



Modified from Parker et al., 2010

With Source Remediation

Honesty is the *only* policy…

– The technical community needs to document failures as well as successes

– Existing resources (e.g., Clu-in) provide access to vast amounts of data and studies, however there are significant gaps in communication of remediation

– Monitoring programs need to be comprehensive from spatial, analyte, process, and temporal standpoints to help us <u>believe</u>

Take an *interdisciplinary* approach to engineering in fractured rock

- use site geologic, geophysical, geomechanical, hydrologic, and biogeochemical information
- conceptualize
  - transport pathways
  - storage porosities
  - Fate/transport mechanisms
  - coupled processes that control rock fracture-matrix interactions.

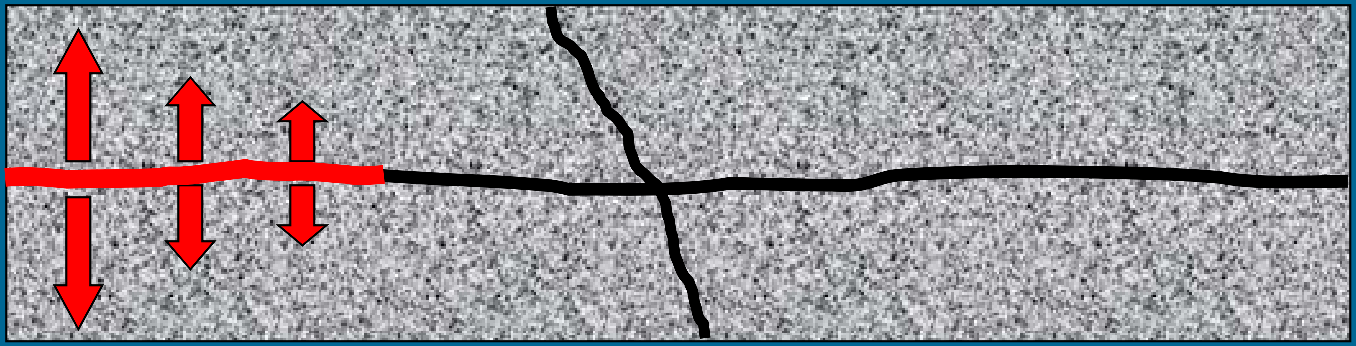
Use observational methods and adaptive approaches to inform engineering decisions

Conceptualization is Key

- What types of transport pathways may exist?
- What boundary conditions may exist?
- What storage porosities need to be considered?
- What fate/transport mechanisms need to be considered?
- Which coupled processes need to be estimated or considered explicitly?

Estimate the potential for contaminant transport into and back out of rock matrix over time.

- Interactions between fracture and matrix are rapid and powerful!



- Fick's First Law:

$$J_m = -\phi D_e \frac{\partial C}{\partial x}$$

Porosity: ϕ; Diffusive Flux: J_m; Diffusion Coefficient: D_e; Concentration Gradient: $\frac{\partial C}{\partial x}$

Quantify contaminant in mobile and immobile zones

– Monitoring wells provide limited information about where contaminant is, but can tell you where it is going
– Core section analysis needs to be a fundamental component of any site investigation

Photo: USGS

Develop *appropriate* hydrostructural conceptual models for fracture and rock matrix geometries and properties

– Perform preliminary calculations (e.g., analytic or simple numerical) to better inform and allocate resources for site characterization, modeling, and remediation

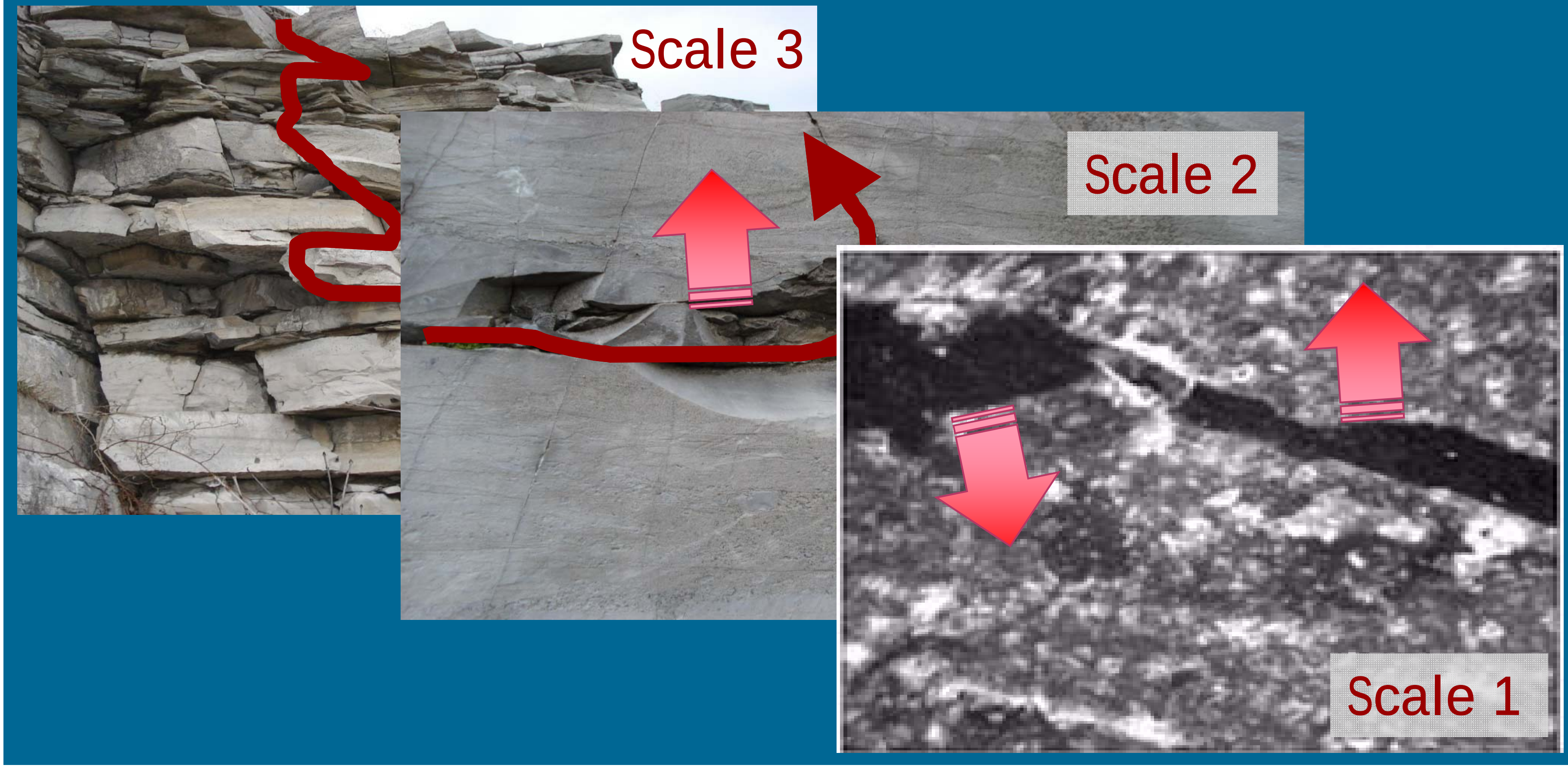

Photo: L. Lau


Photo: USGS


Photo: T. Engelder

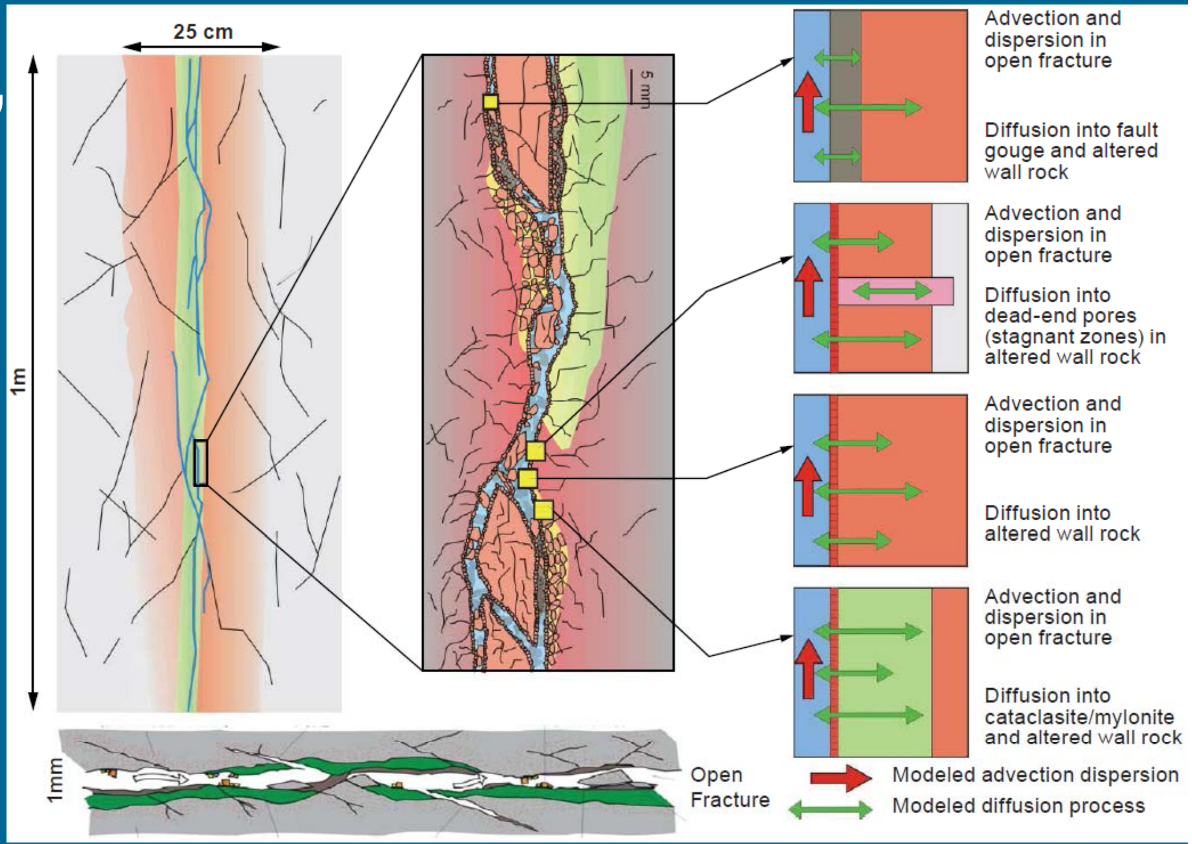

Photo: R. Keller

Recognize processes and their scales



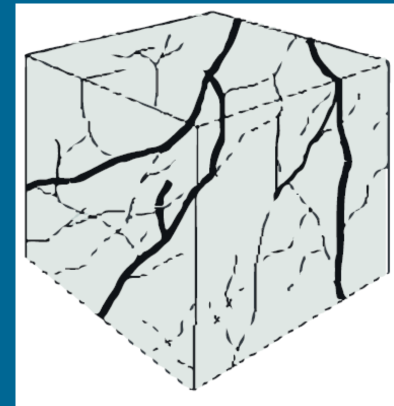
Characterize processes at the appropriate scales

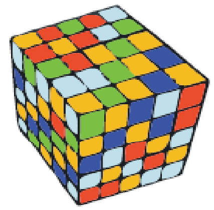
- Chem, bio, thermal, mechanical, hydraulic
- Coupling of processes and conditions that can lead to coupling



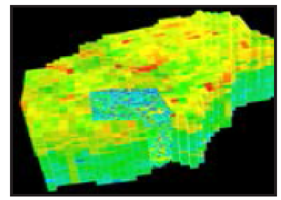
Adapted from Winberg, et al., 2003

Base numerical models on an appropriate hydrostructural model

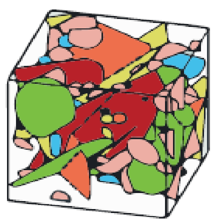




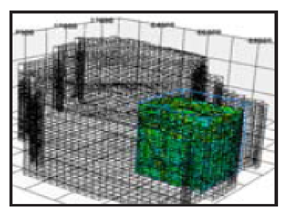
Single or Dual Porosity Equivalent Porous Medium (EPM, MINC)



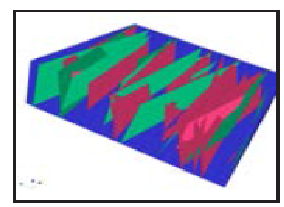
Channel Network (CN) and Lattice-Boltzman Model



Discrete Fracture Network (DFN) or Dual Porosity DFN



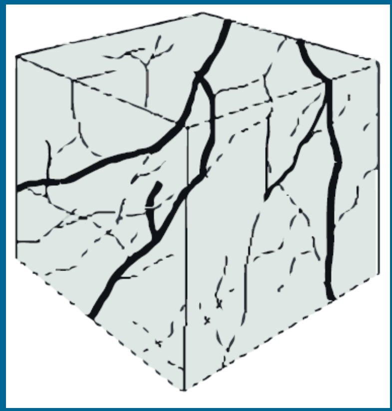
Hybrid DFN/Equivalent Porous Media (DFN/EPM)



Dual Permeability DFN/EPM

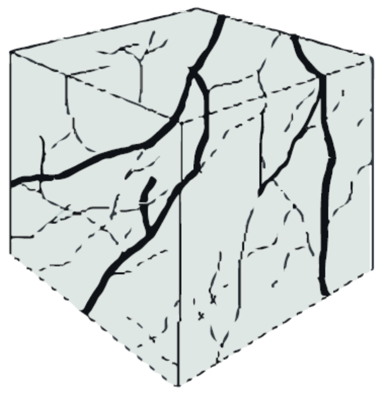
Courtesy of B. Dershowitz

- Number/connectivity of mobile (advective) and immobile (diffusion, sorption) porosities
- Geometry/reactive surface area of transport pathways (e.g., streamline vs branching)
- Matrix/fracture interaction (Sigma factor, flow wetted surface)
- Infilling, coatings, matrix
- Geochemical and geobiologic processes (solution/precipitation, filtering, colloid transport)



Courtesy of B. Dershowitz

Error, bias, and uncertainty introduced by simplification and upscaling



- Equivalent continuum models
  – *are they equivalent?*
- Upscaling for flow

  vs upscaling for transport

  vs upscaling for geomechanics
- Discrete models
  – *are they over or underconnected?*

Courtesy of B. Dershowitz

Incorporate long-term behavior into monitoring system design.

- Planning for change means less changes in plan
- Understand most of the action starts in the fractures
  - but not all fractures are active
  - and the action shifts from where it started

Base design on understood discrete pathways, matrix contaminant storage, and issues of geologic heterogeneity and anisotropy when using point source concentration measurements

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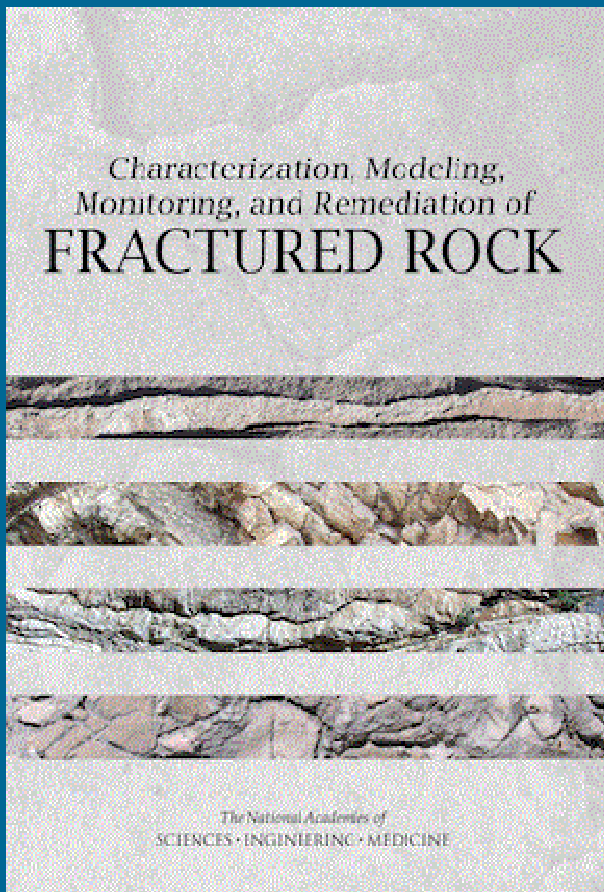

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Contact: Sammantha Magsino
smagsino@nas.edu

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