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science for a changing world

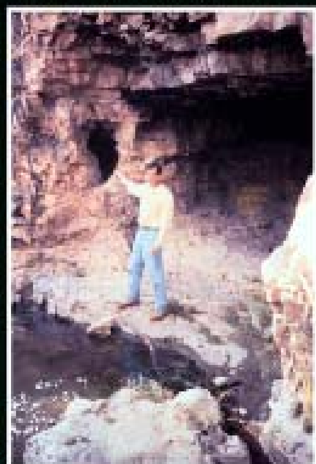
Characterizing Ground-Water Flow and Chemical Transport in Fractured Rock

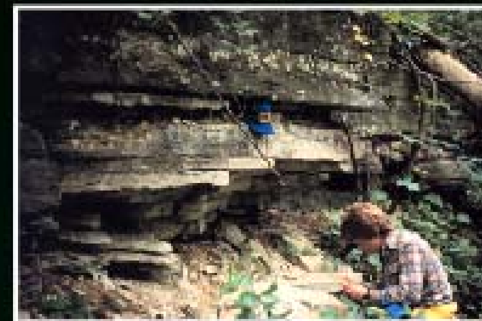
Allen M. Shapiro

U.S. Geological Survey
Reston, VA

Challenges in the Characterizing Fractured Rock

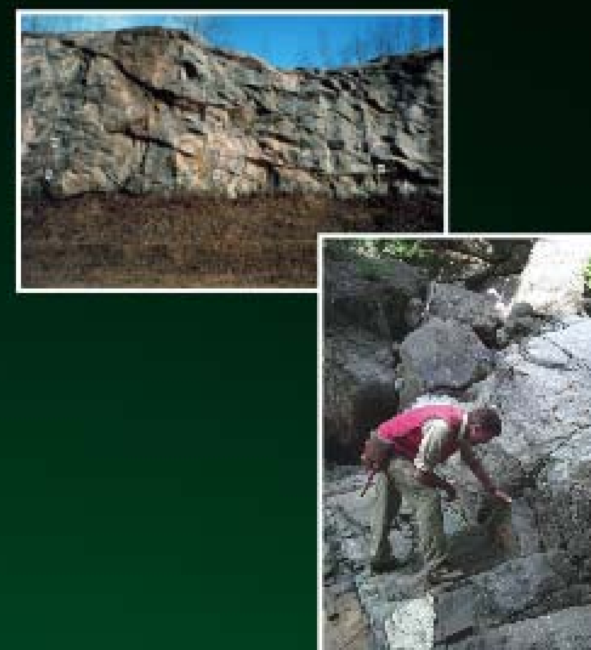
Limestone
Rapid City, SD





Dolomite
Argonne, IL

Granite and schist
Mirror Lake watershed, NH



Mudstone and sandstone
West Trenton, NJ

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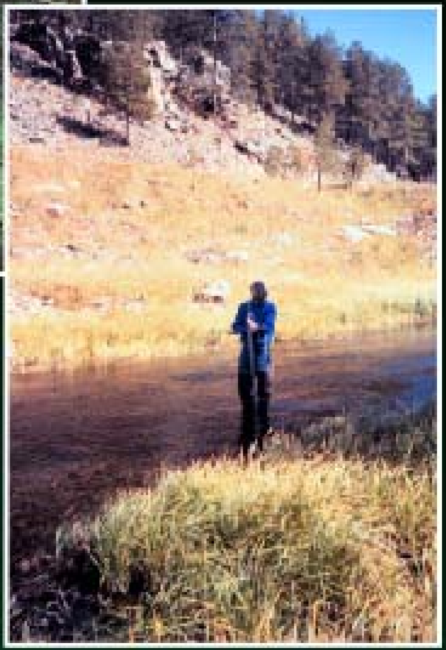
Challenges in the Characterizing Fractured Rock



Complex distribution of recharge

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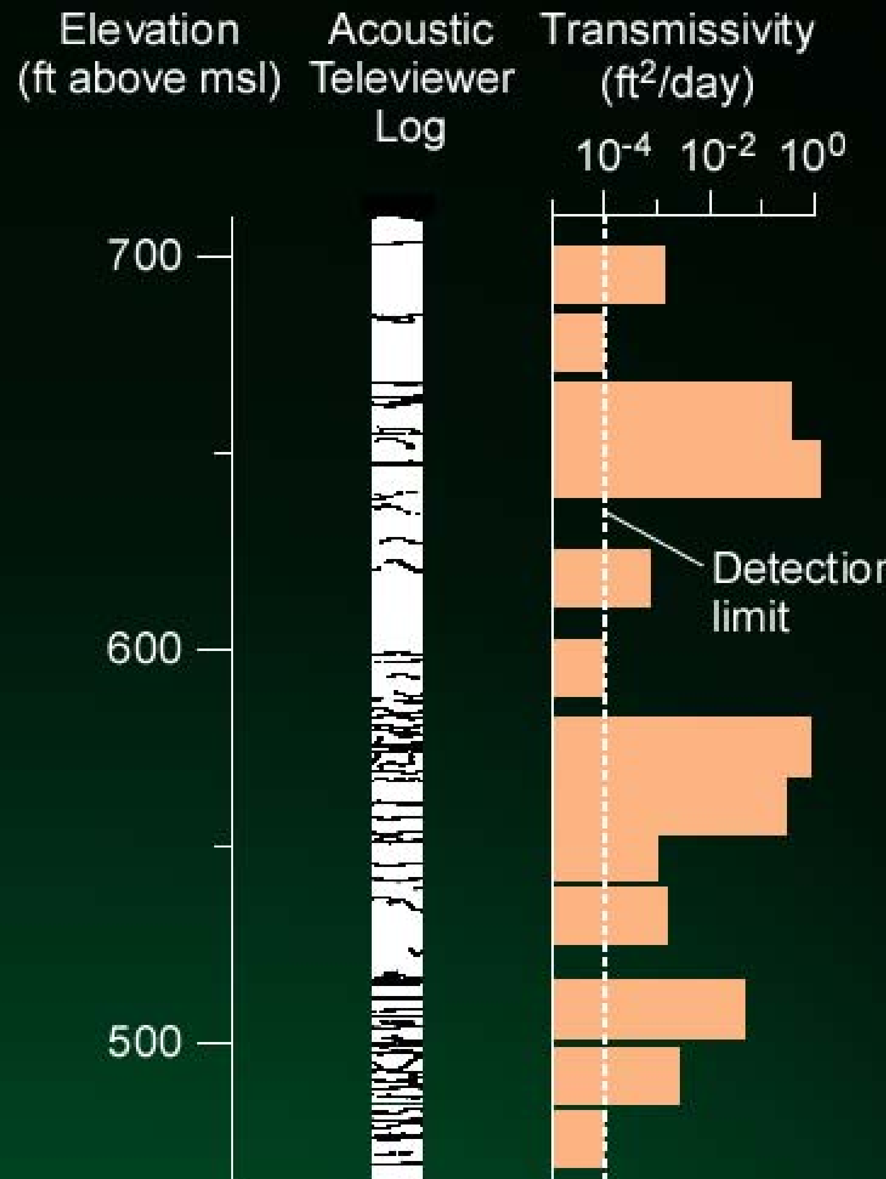
Challenges in Characterizing Fractured Rock

Granite and schist
Mirror Lake, NH



Complex fracture connectivity

Enormous range of hydraulic properties

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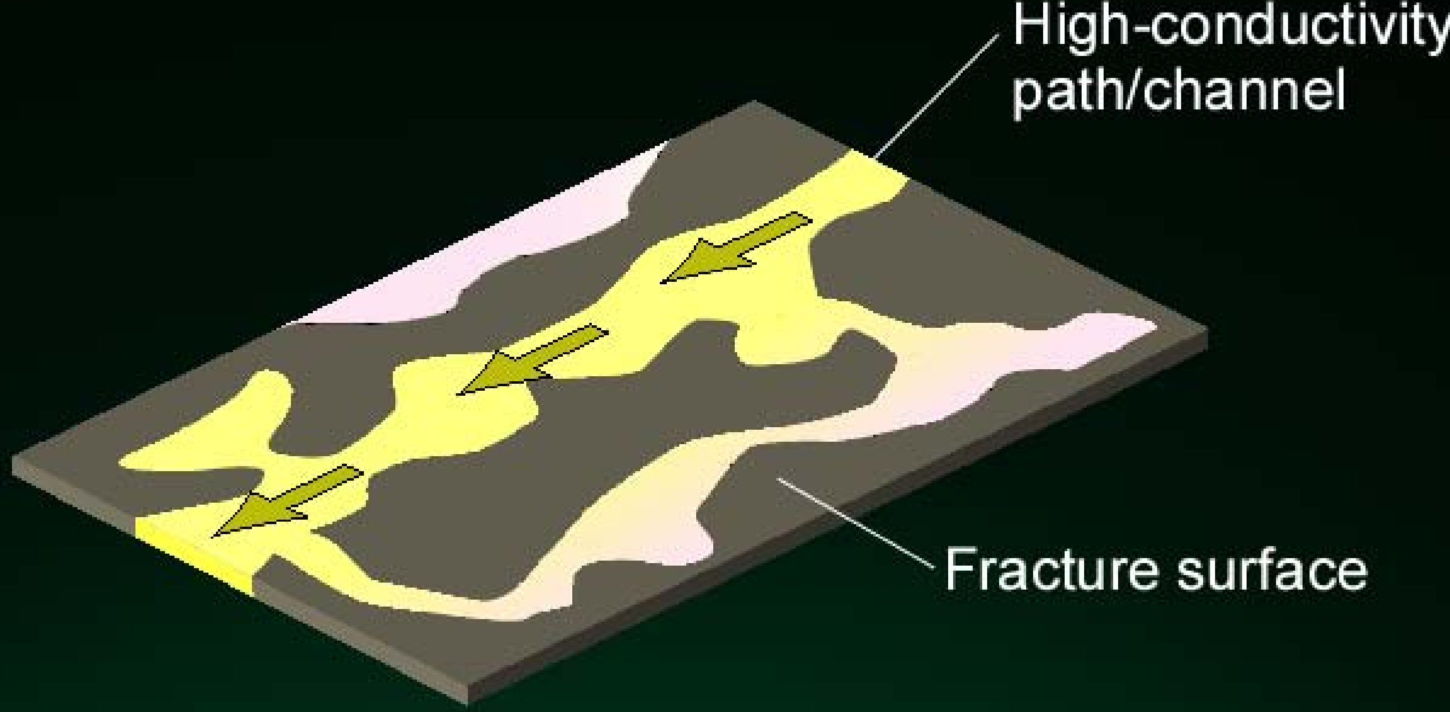
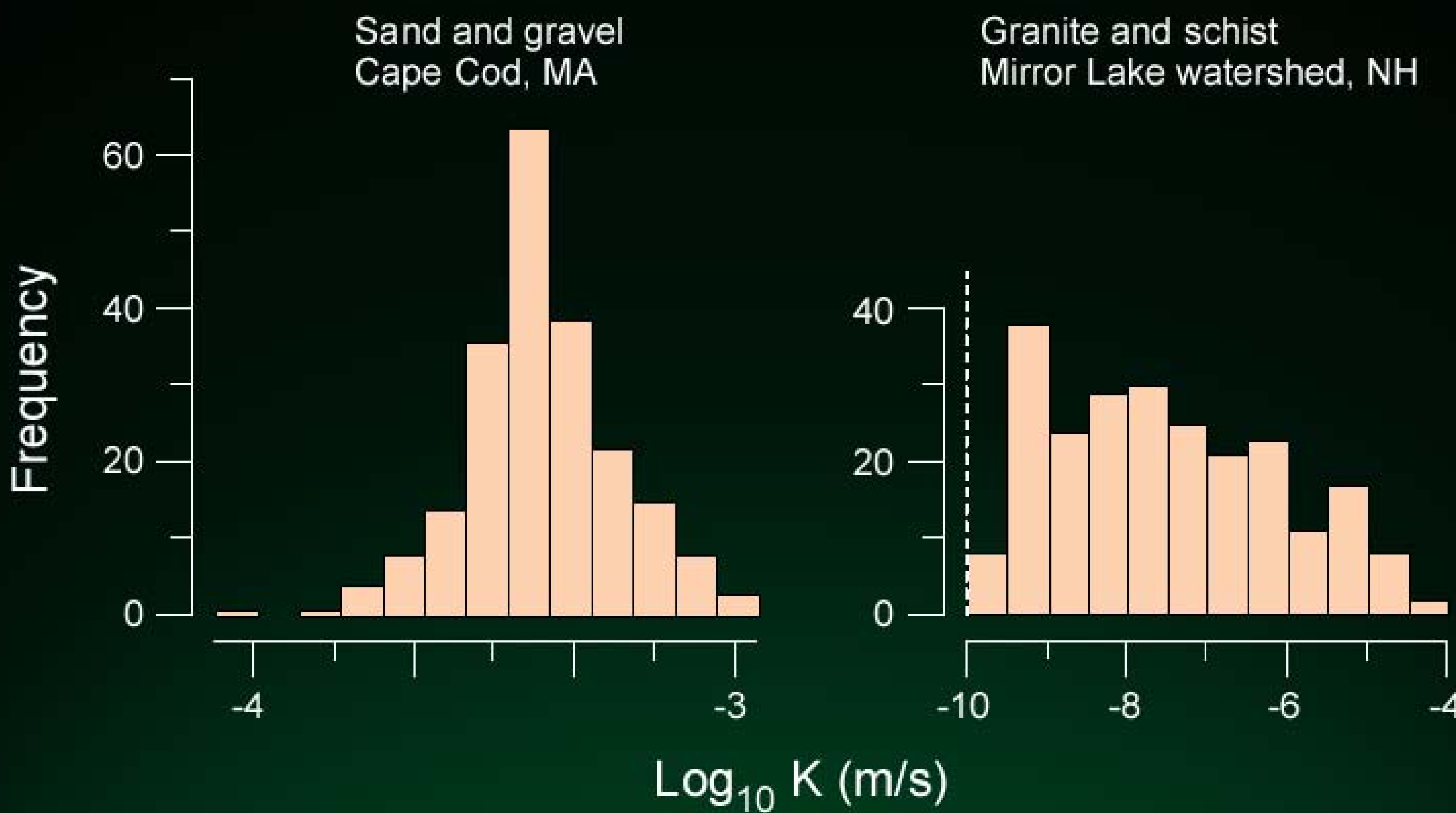
Challenges in the Interpretation of Age-Dating Tracers



USGS

Hydraulic Conductivity



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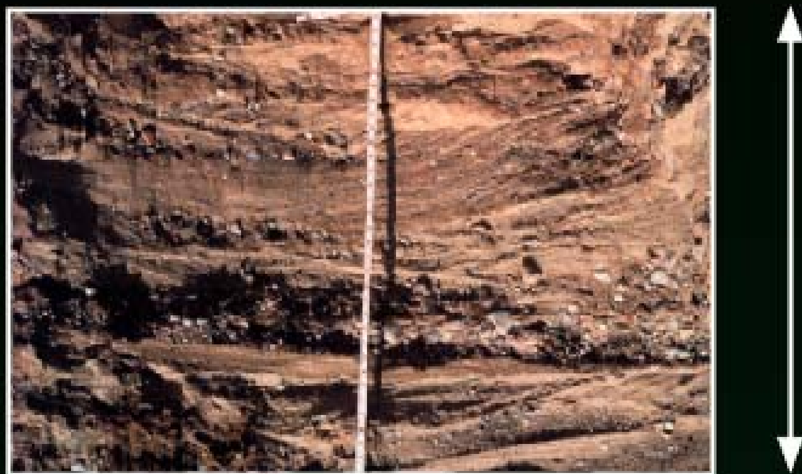
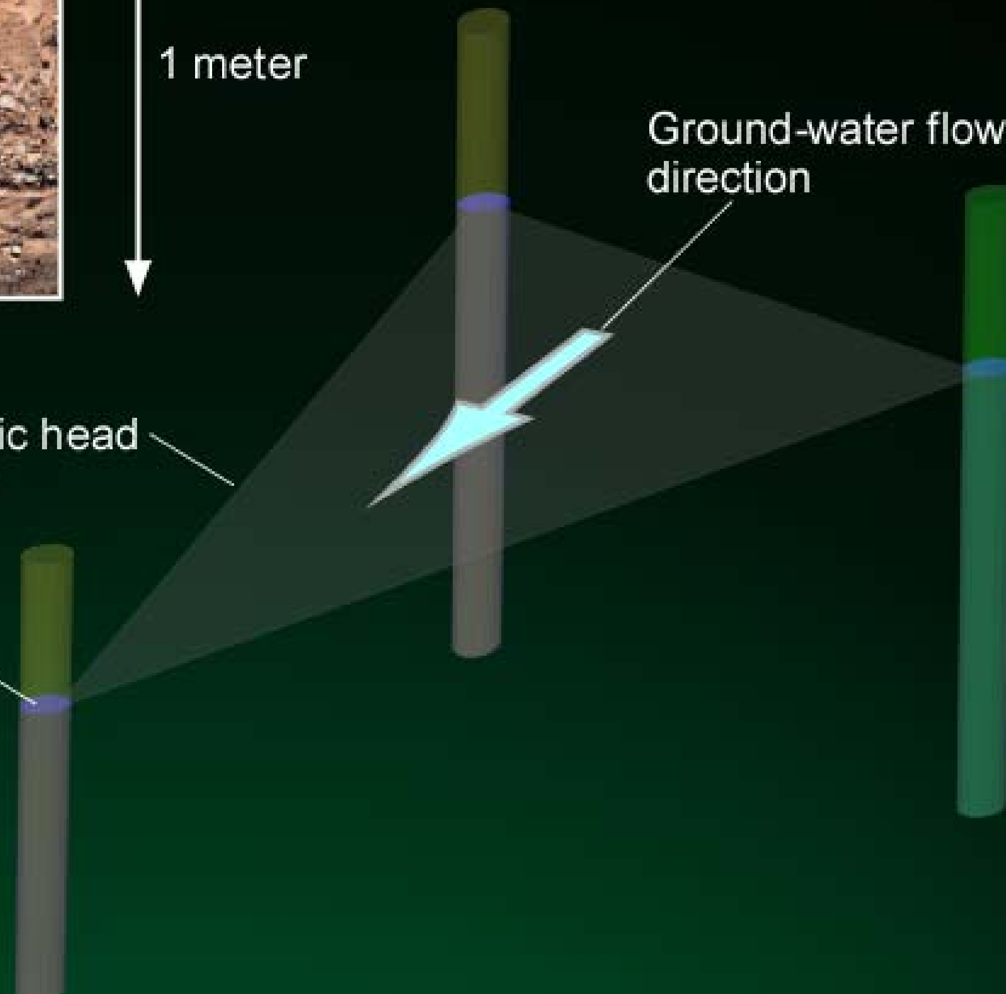
Ground-Water Flow in Unconsolidated Porous Media



Sand and gravel
Cape Cod, MA



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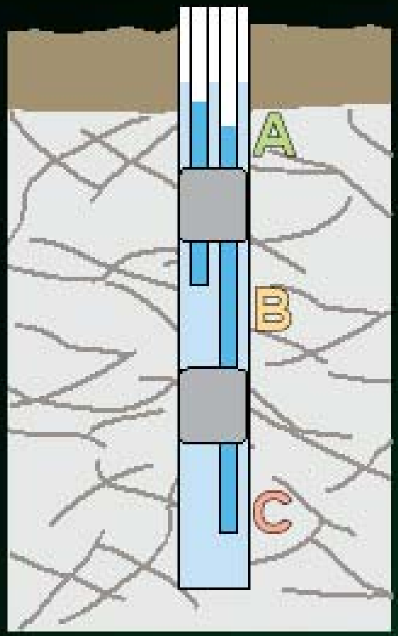
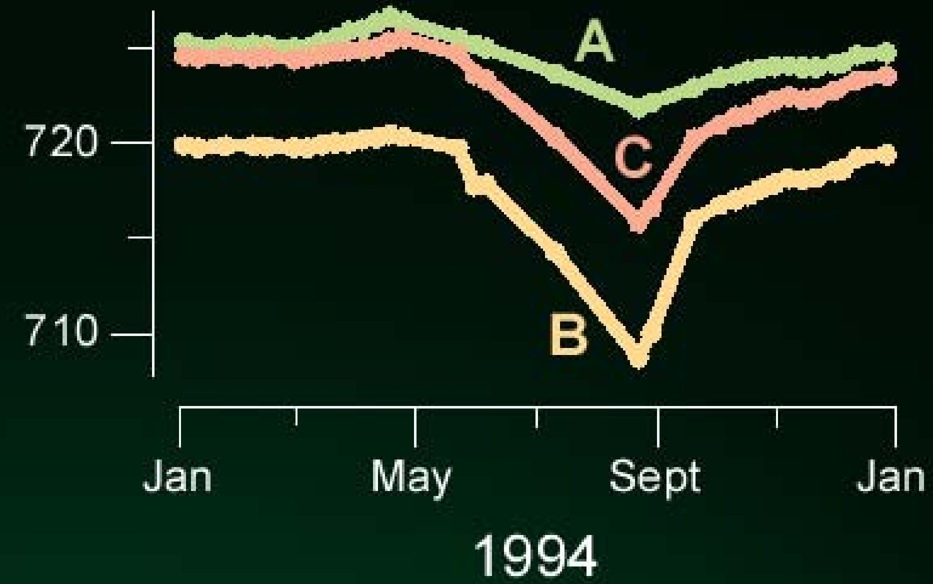
Ground-Water Flow in Fractured Rock

Hydraulic head measured in hydraulically isolated intervals in a borehole



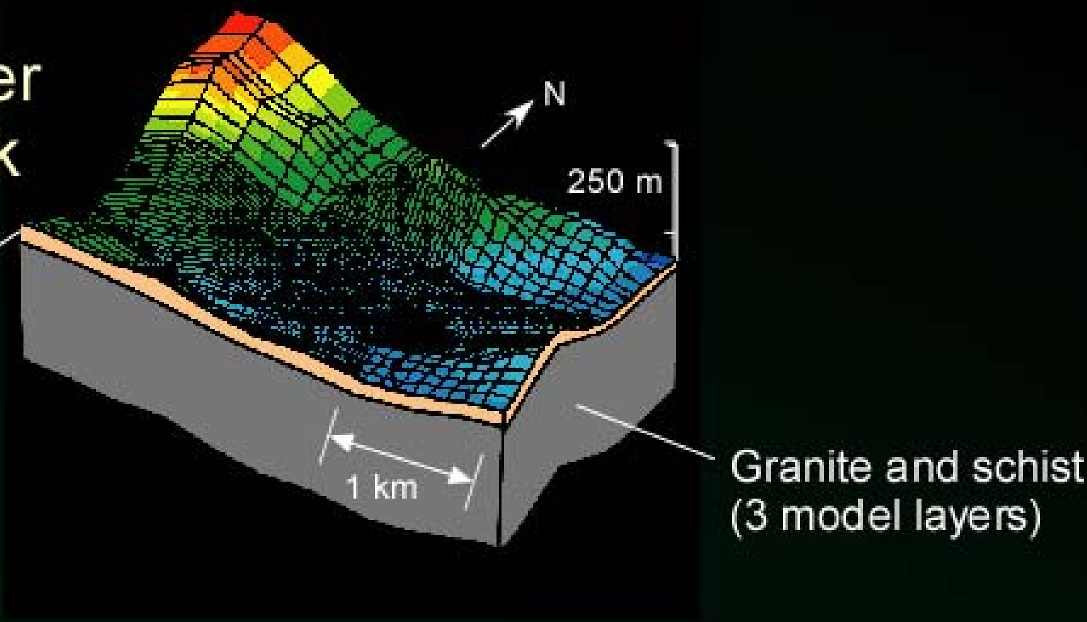
Hydraulic head (ft above msl)



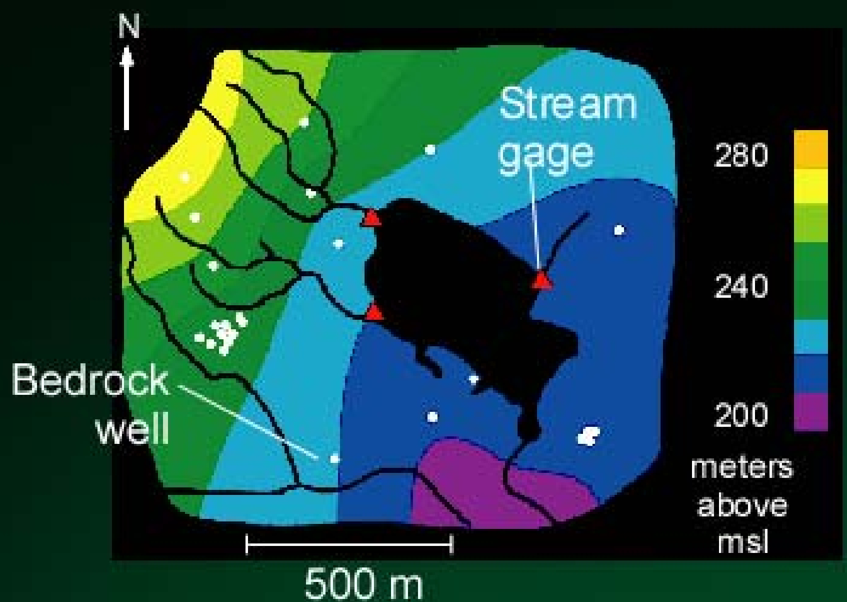
Borehole H1
Mirror Lake watershed, NH

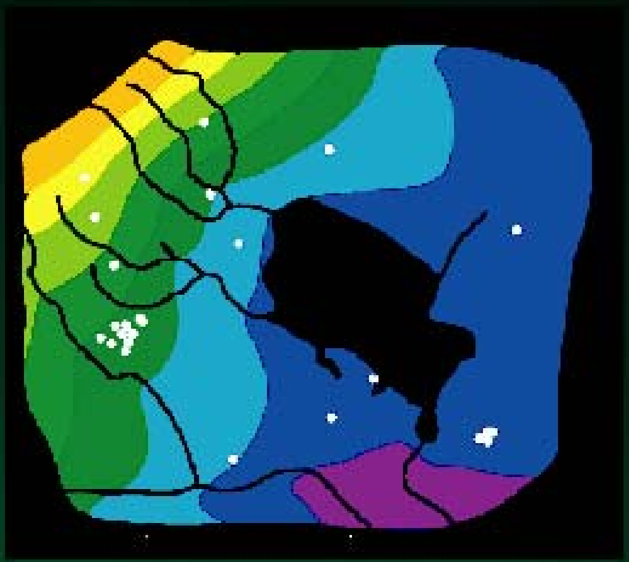
USGS

Regional Ground-Water Flow in Fractured Rock



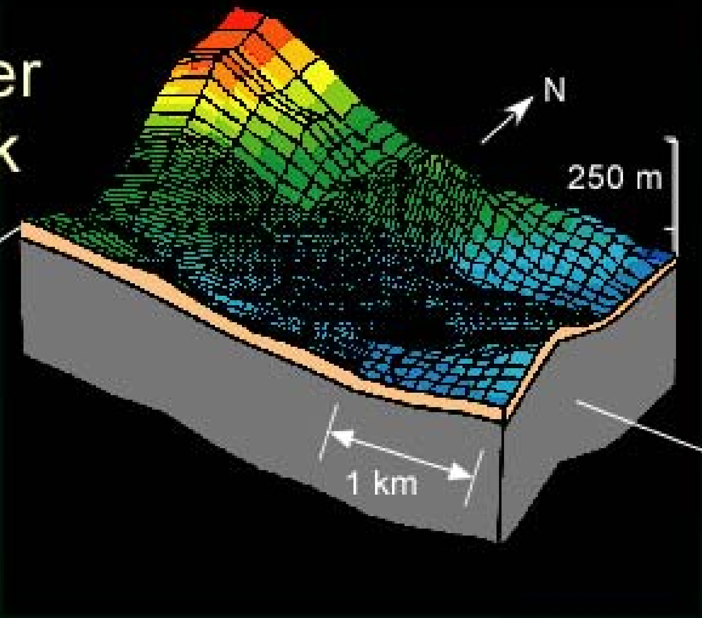
Hydraulic head, upper bedrock





Tiedeman et al., 1997

Regional Ground-Water Flow in Fractured Rock



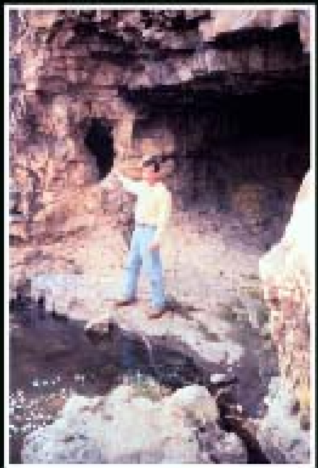
Models of ground-water flow are _water balances_ over a volume of the formation

Reproduce fluxes (e.g., discharges to streams) and the gradients in hydraulic head for a distribution of hydraulic properties

Residence time and flow directions may not be accurately represented by the ground-water flow (water balance) model

Characterizing Flow Paths in Fractured-Rock Aquifers

Limestone
Rapid City, SD



Dolomite
Argonne, IL

Mudstone and sandstone
West Trenton, NJ

Granite and schist
Mirror Lake watershed, NH

Geologic characterization and a hydrogeologic conceptual model

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Characterizing Flow Paths in Fractured-Rock Aquifers

Interrogating the subsurface. . .

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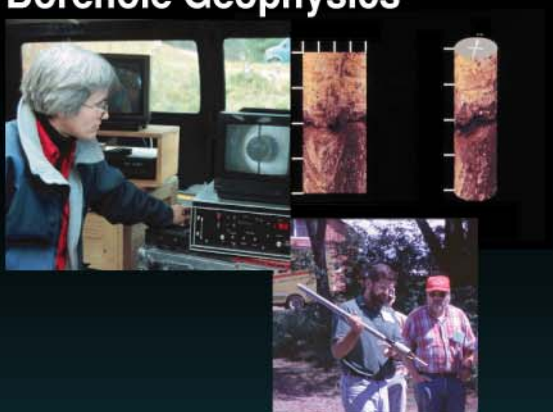
Characterizing fluid movement and chemical transport in fractured rock

Fracture Mapping

Geologic Mapping

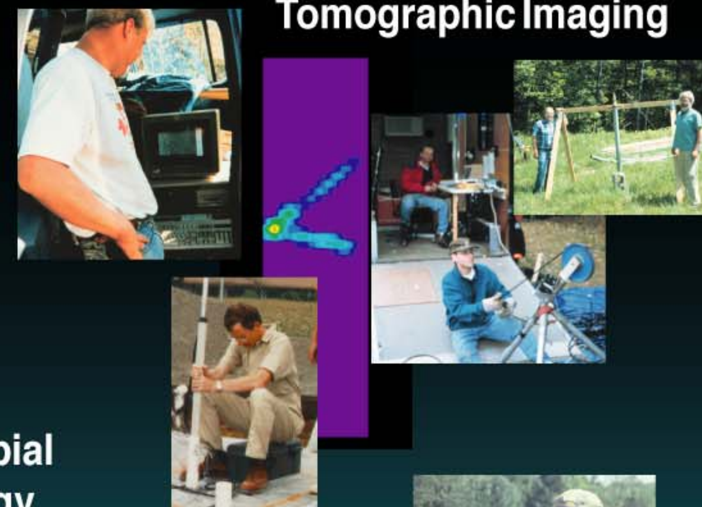
Surface Geophysics

Borehole Geophysics



Hydrologic Testing

Tomographic Imaging

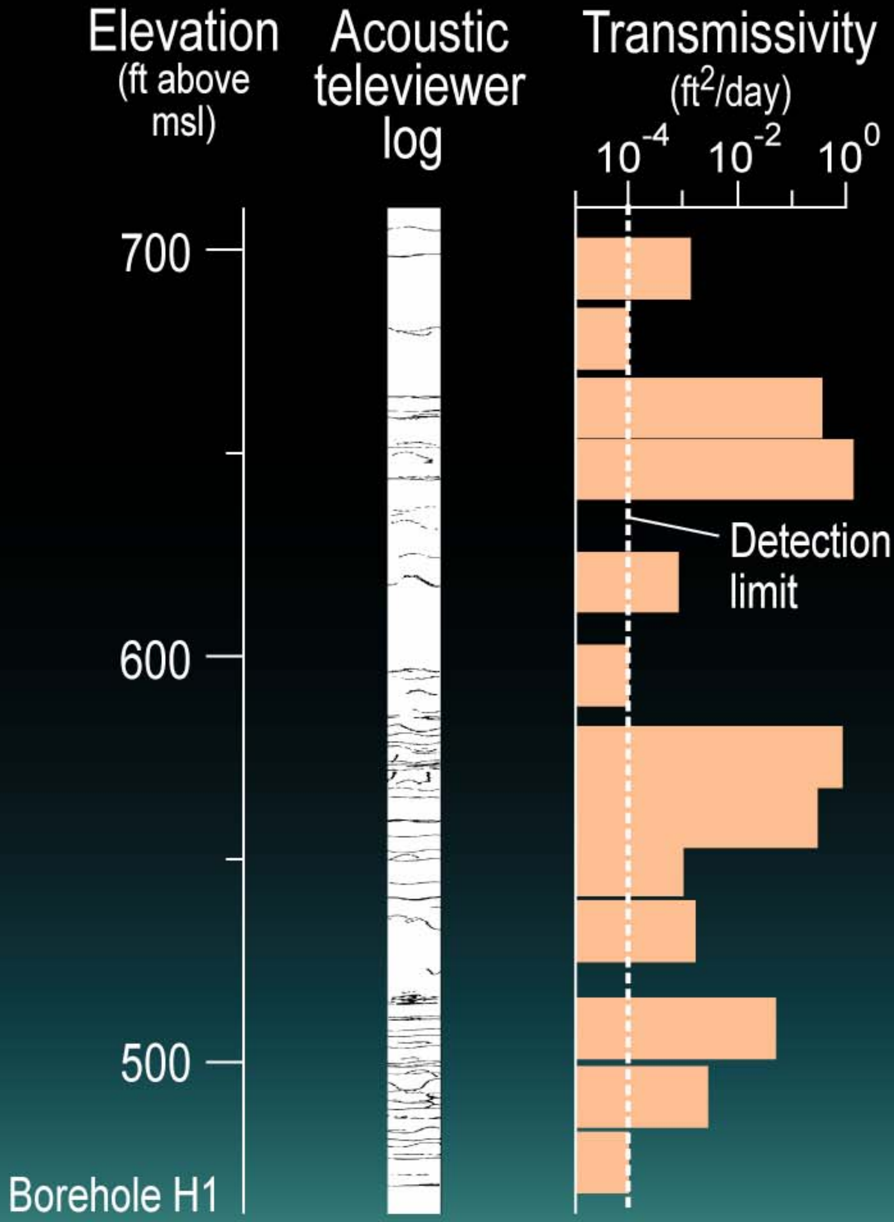


Geochemistry

Microbial Ecology and Microbial Transport

Ground-Water Flow and Transport Modeling

Road cut near
Mirror Lake watershed,
New Hampshire



Shapiro and Hsieh, 1998

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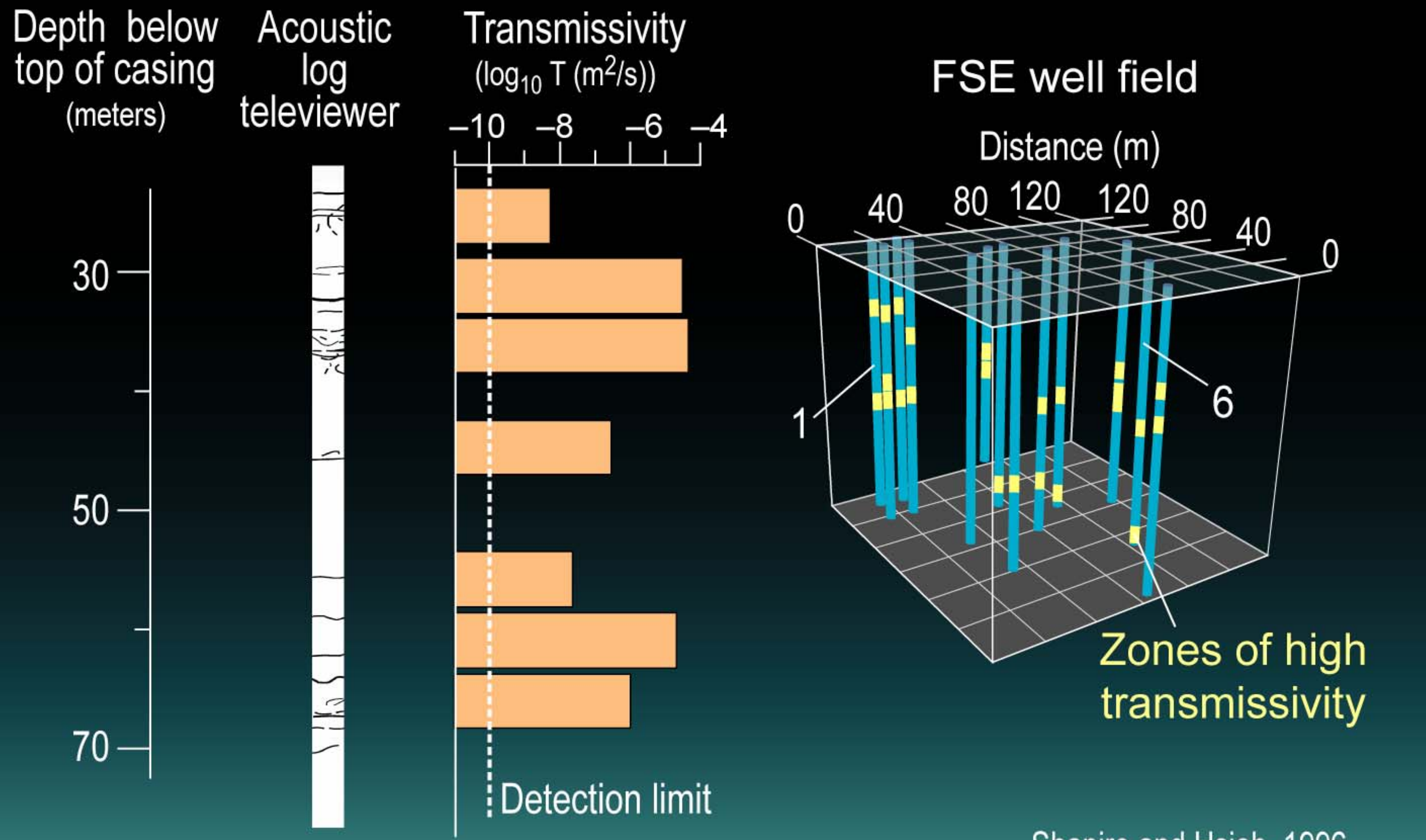
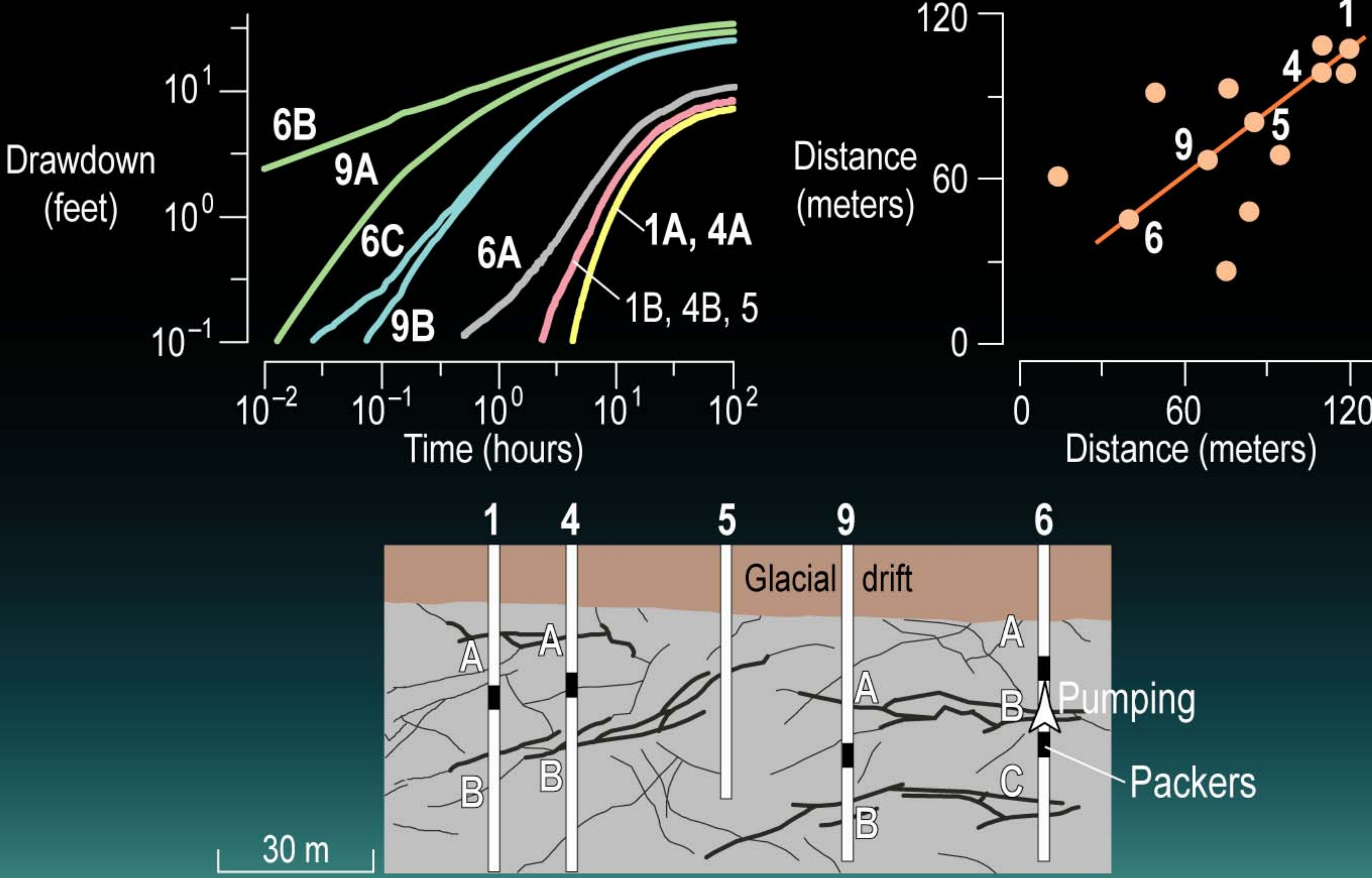
Estimating hydraulic properties over 10s of meters



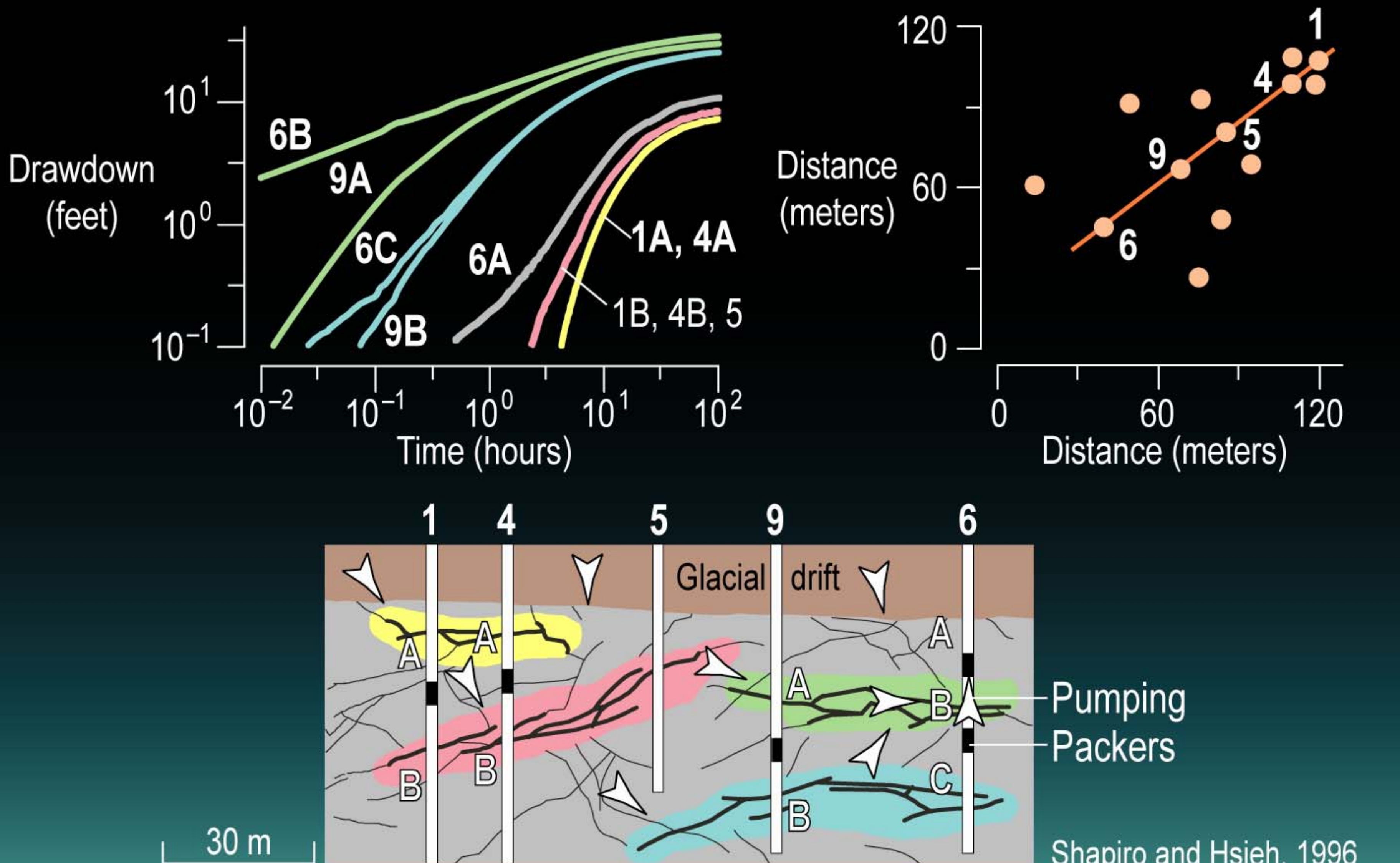
Shapiro and Hsieh, 1996
Hsieh et al, 1999

USGS

Hydraulic testing over tens of meters



Hydraulic testing over tens of meters

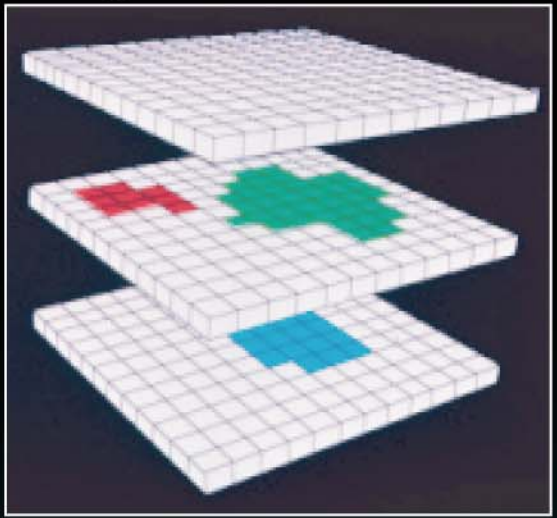


Shapiro and Hsieh, 1996
Hsieh et al, 1999

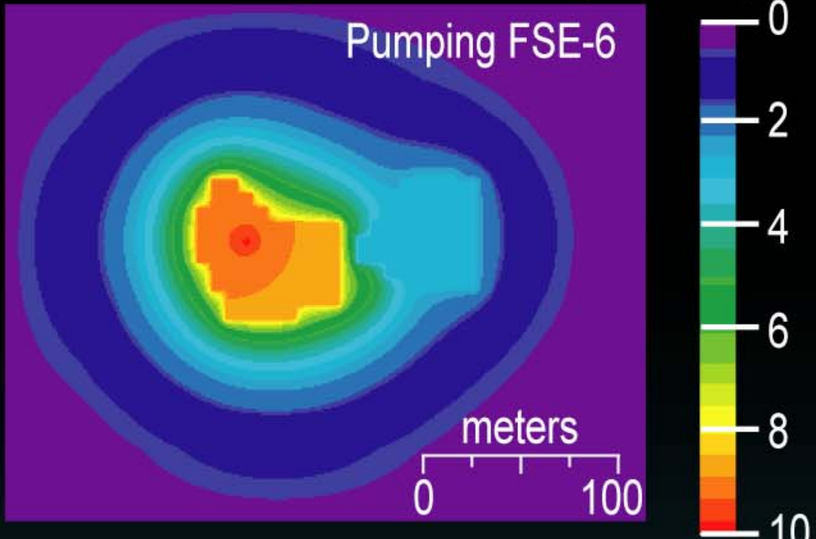
USGS

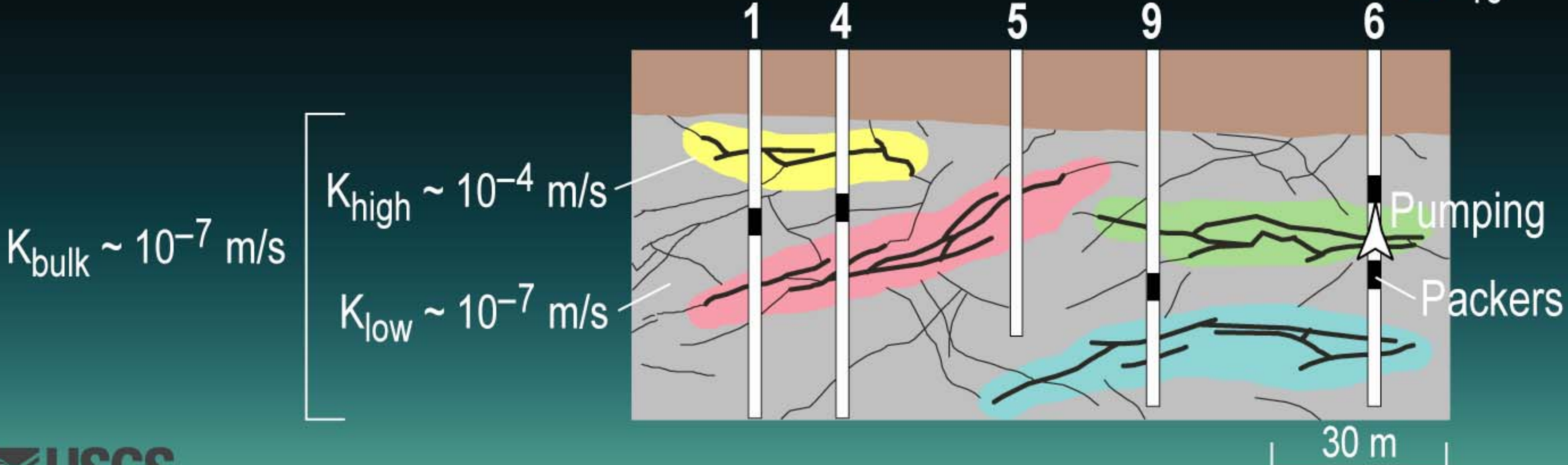
Hydraulic testing over tens of meters

Finite-difference model for ground-water flow



Simulated drawdown (meters)





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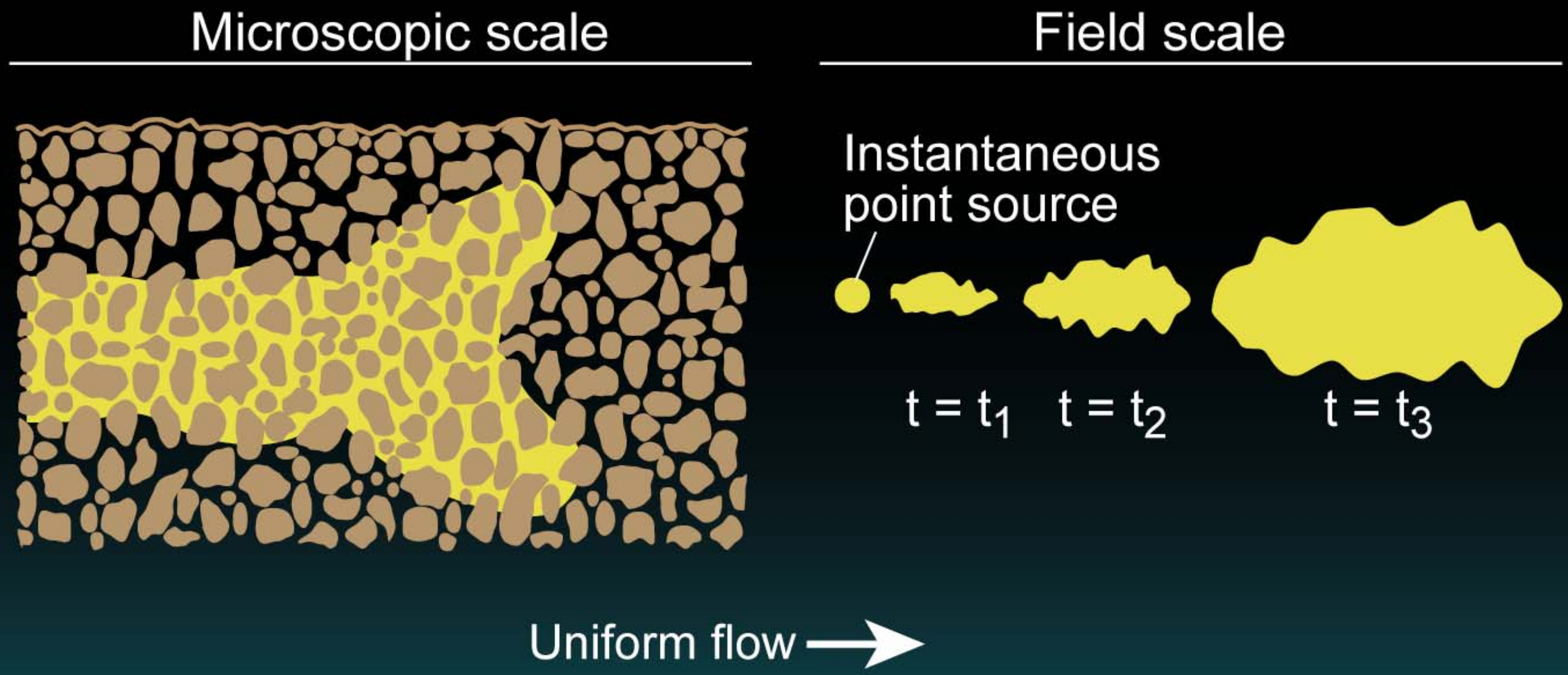
Chemical transport in a porous medium is controlled by fluid velocity (advection)

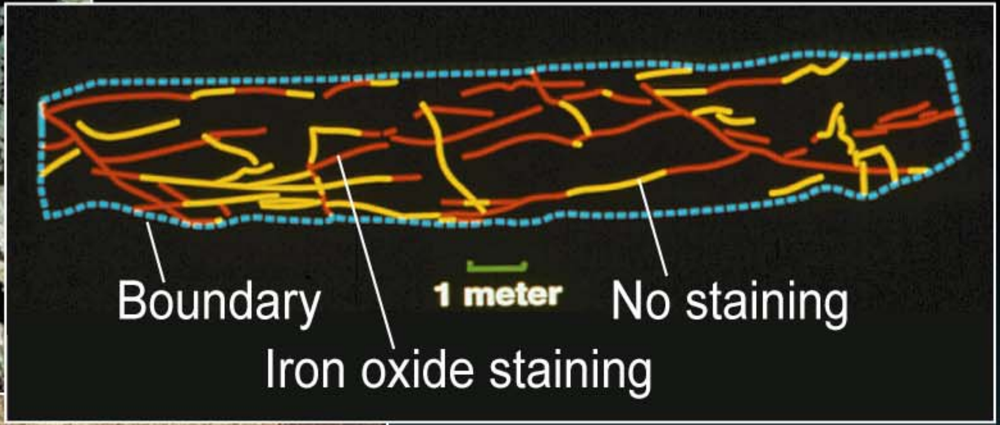


USGS

Fracture connectvity is complex and yields a complex distribution of chemical constituents in ground water

Roadcut from Mirror Lake

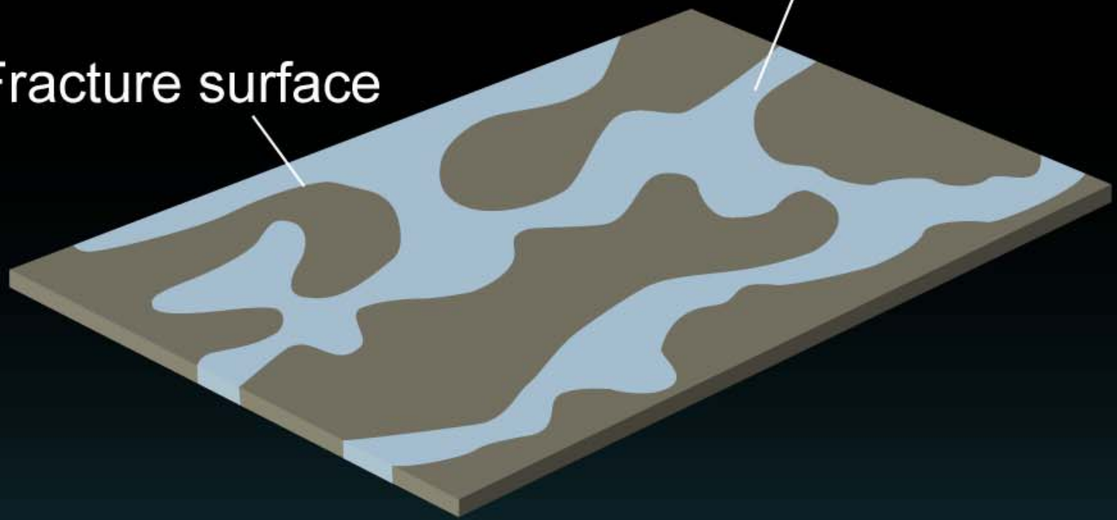
Section of roadcut mapped for iron hydroxide staining along fractures



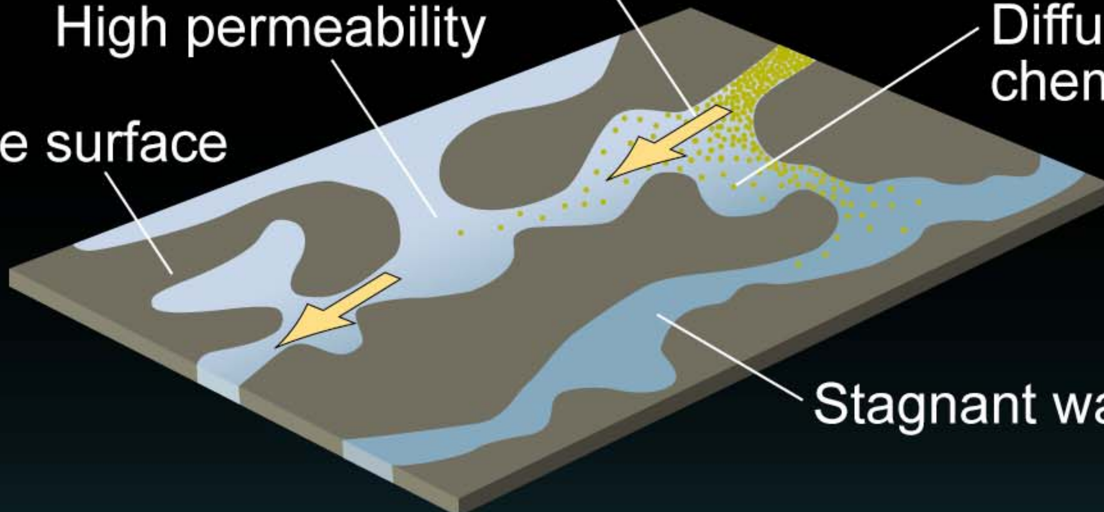
Iron-hydroxide stained fracture

USGS

A single fracture has complex paths of fluid movement



A single fracture has complex paths of chemical migration



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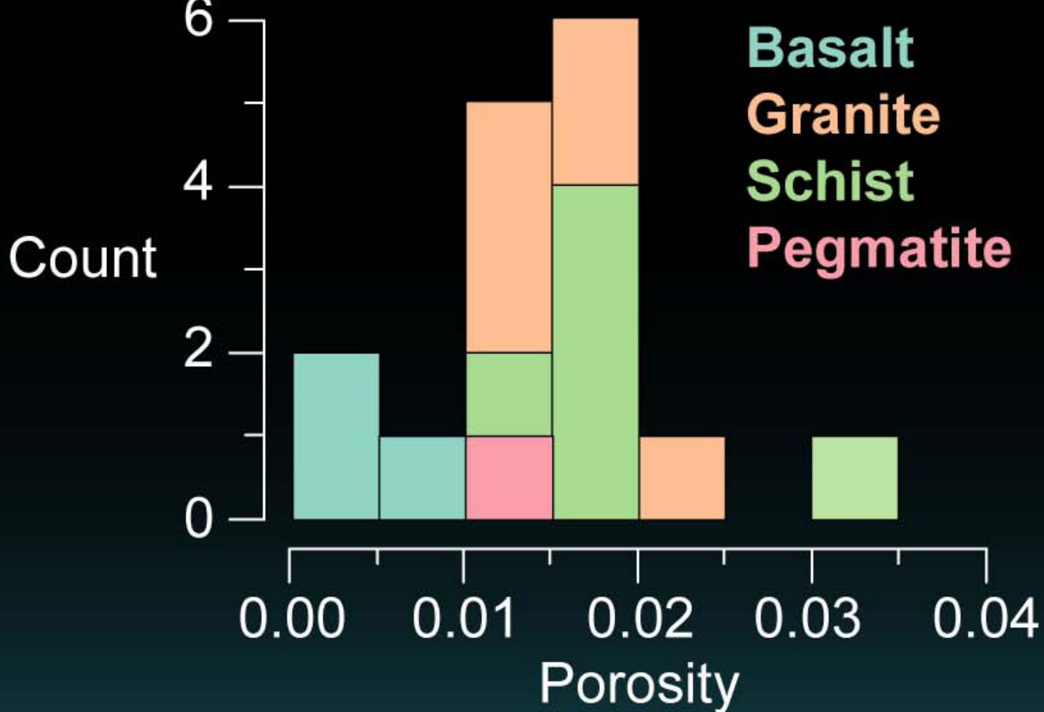
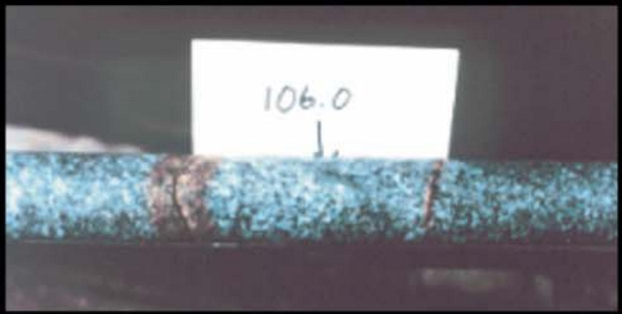
The porosity of rock offers a volume of water into which chemicals can diffuse



Rock samples from the
Mirror L. watershed,
New Hampshire

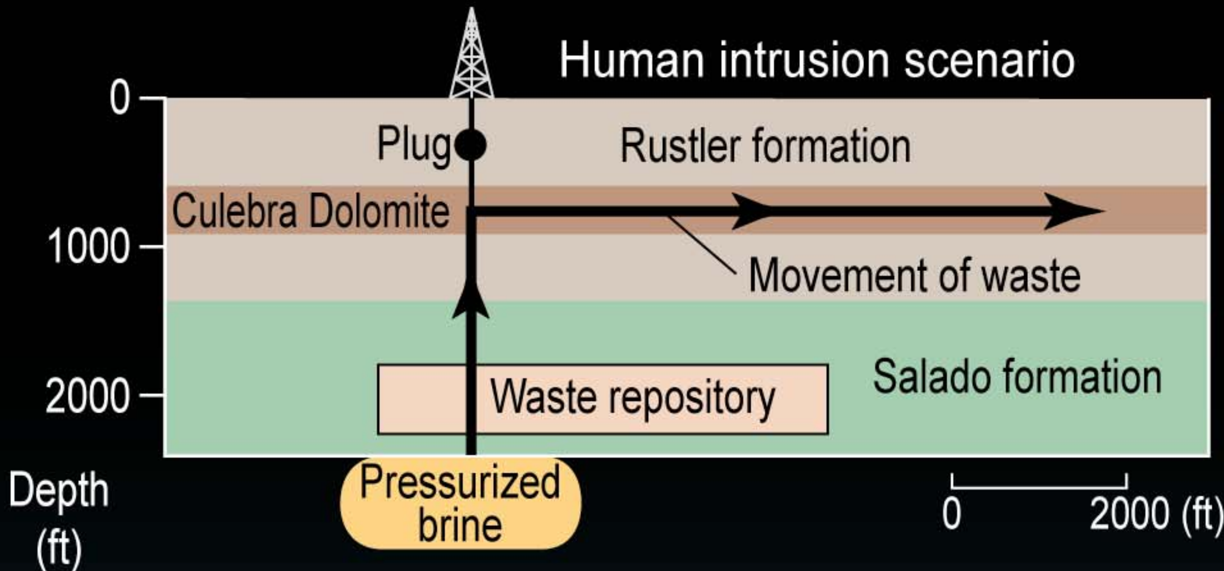


Iron hydroxide staining from diffusion of oxygen into rock adjacent to a fracture

Wood et al, 1996

USGS

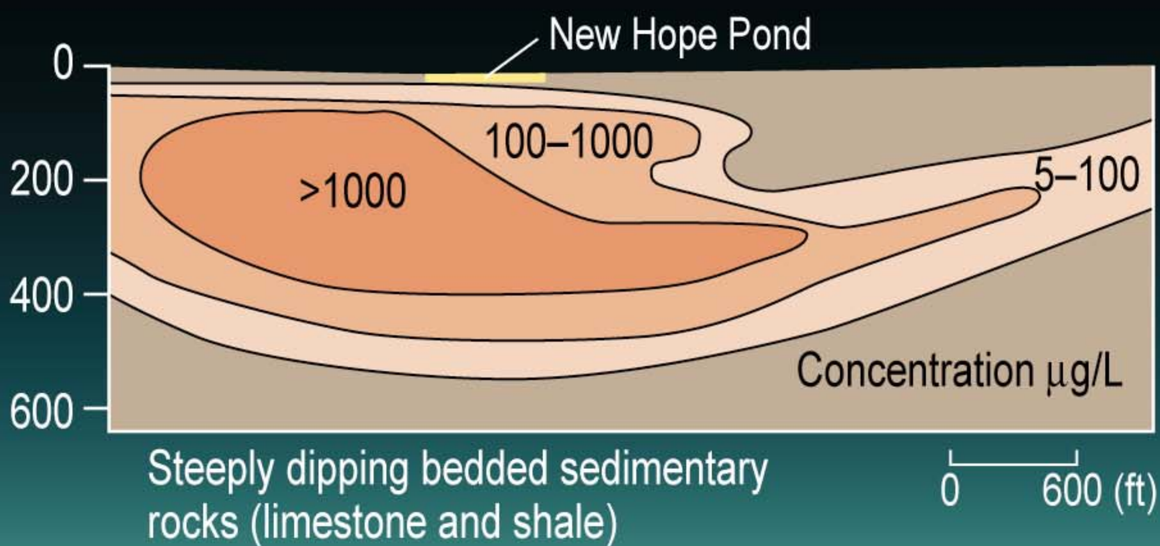
Matrix diffusion has mixed blessings



A BLESSING

Isolating waste

(Waste Isolation Pilot Plant–WIPP, New Mexico)



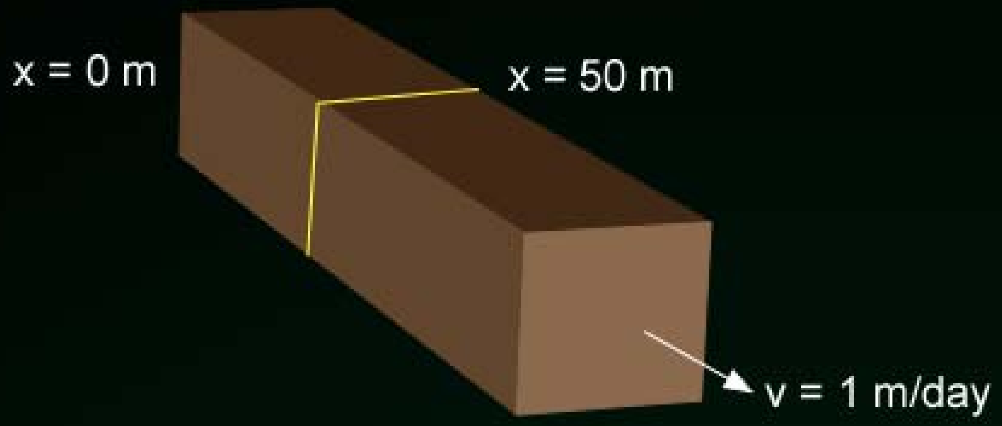
A CURSE

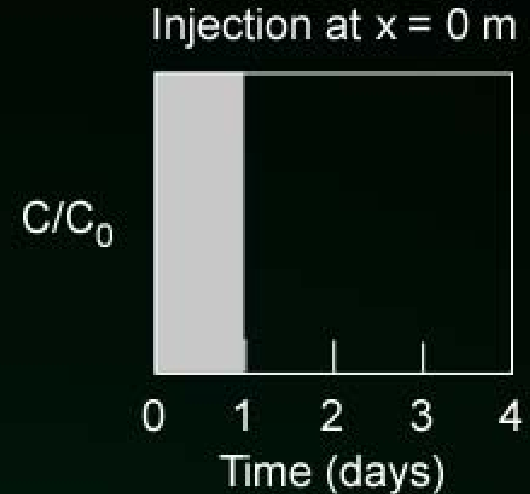
Remediating contaminated groundwater

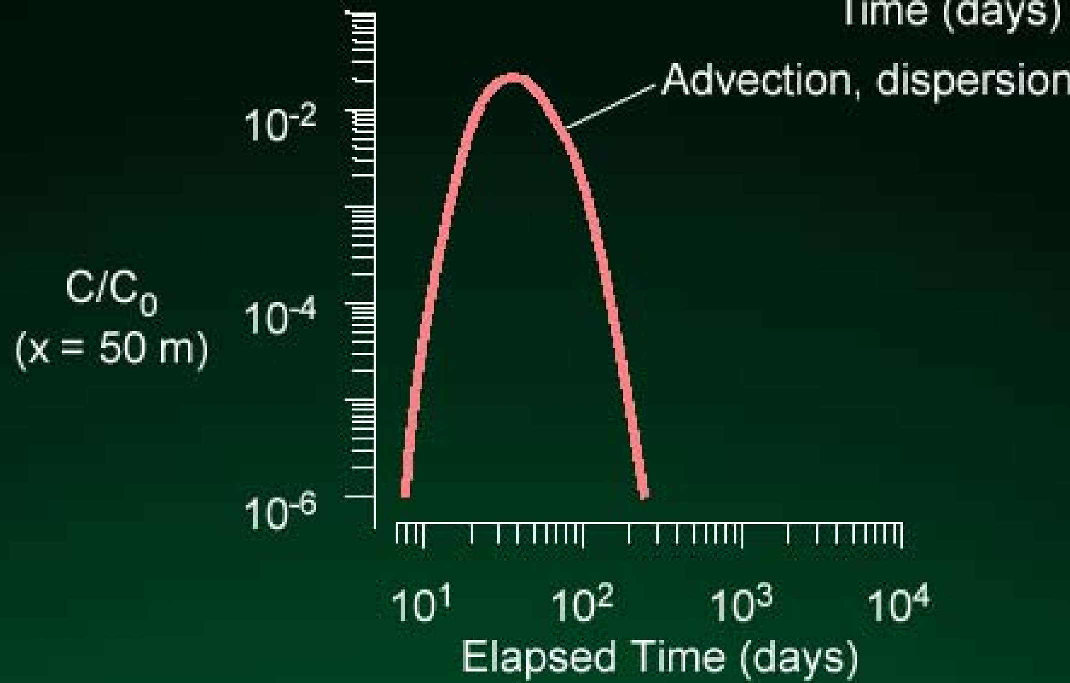
(Dissolved-phase carbon tetrachloride plume, Oak Ridge National Lab)

USGS

Interpreting controlled tracer tests

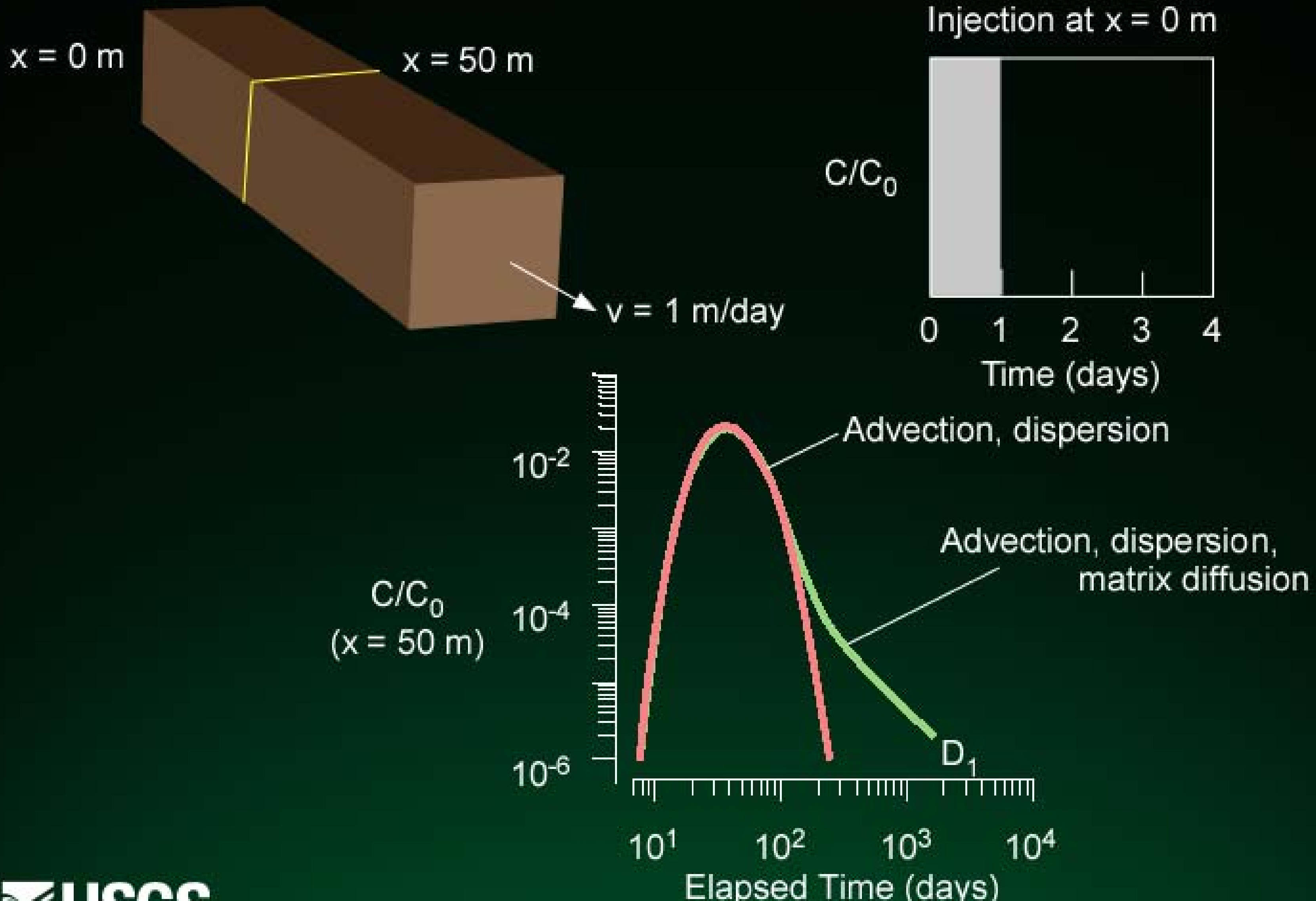






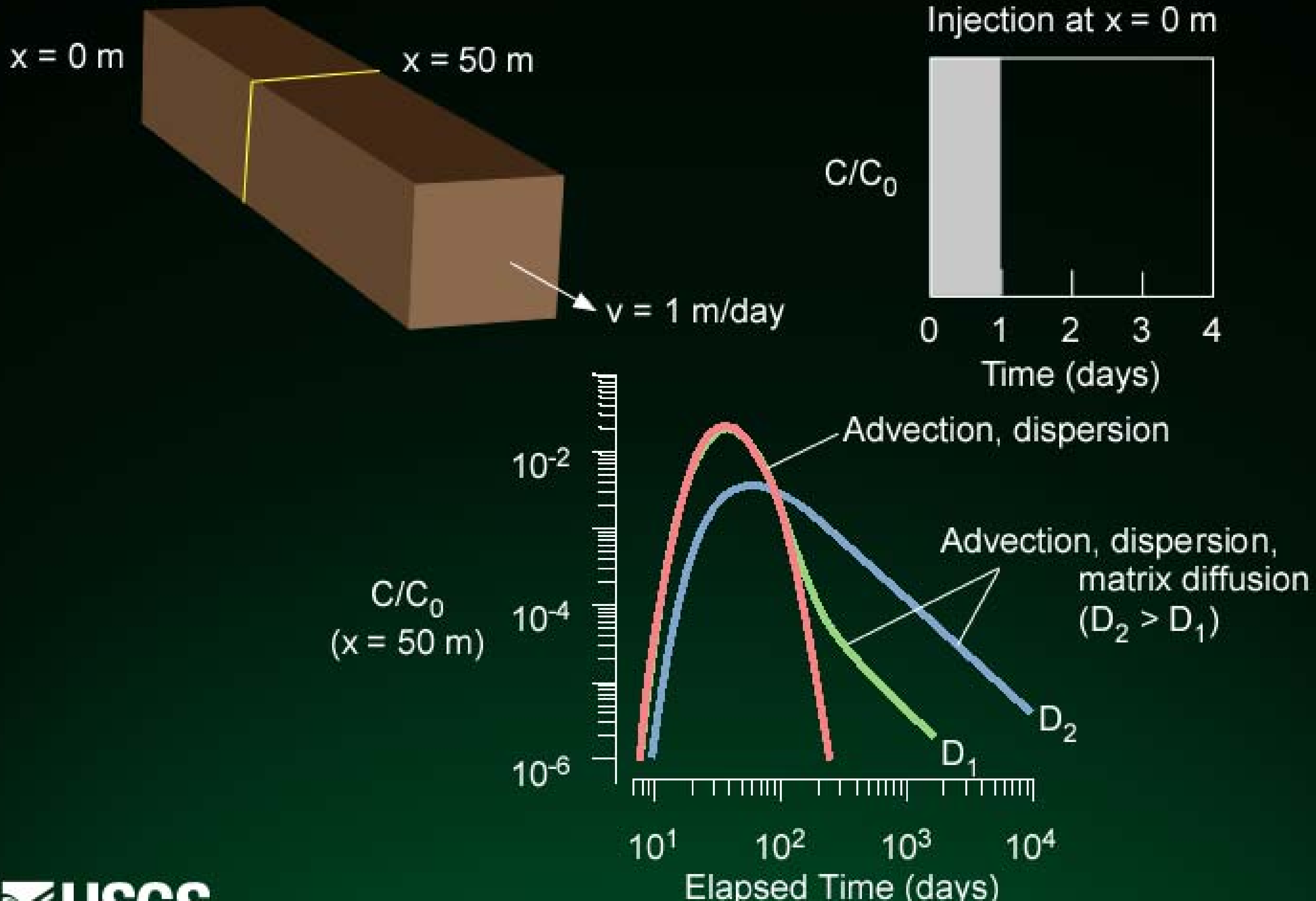
USGS

Interpreting controlled tracer tests



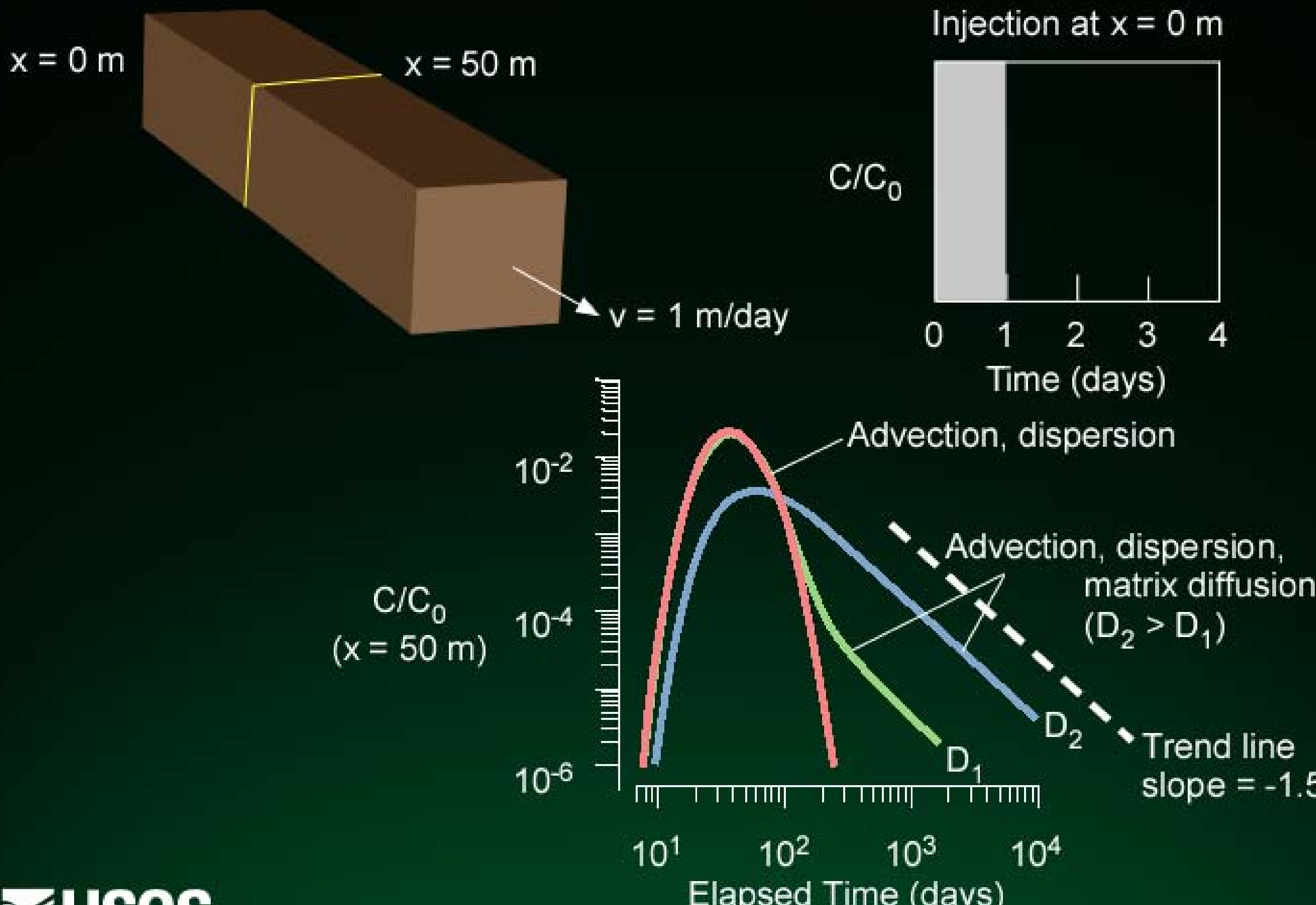
USGS

Interpreting controlled tracer tests



USGS

Interpreting controlled tracer tests



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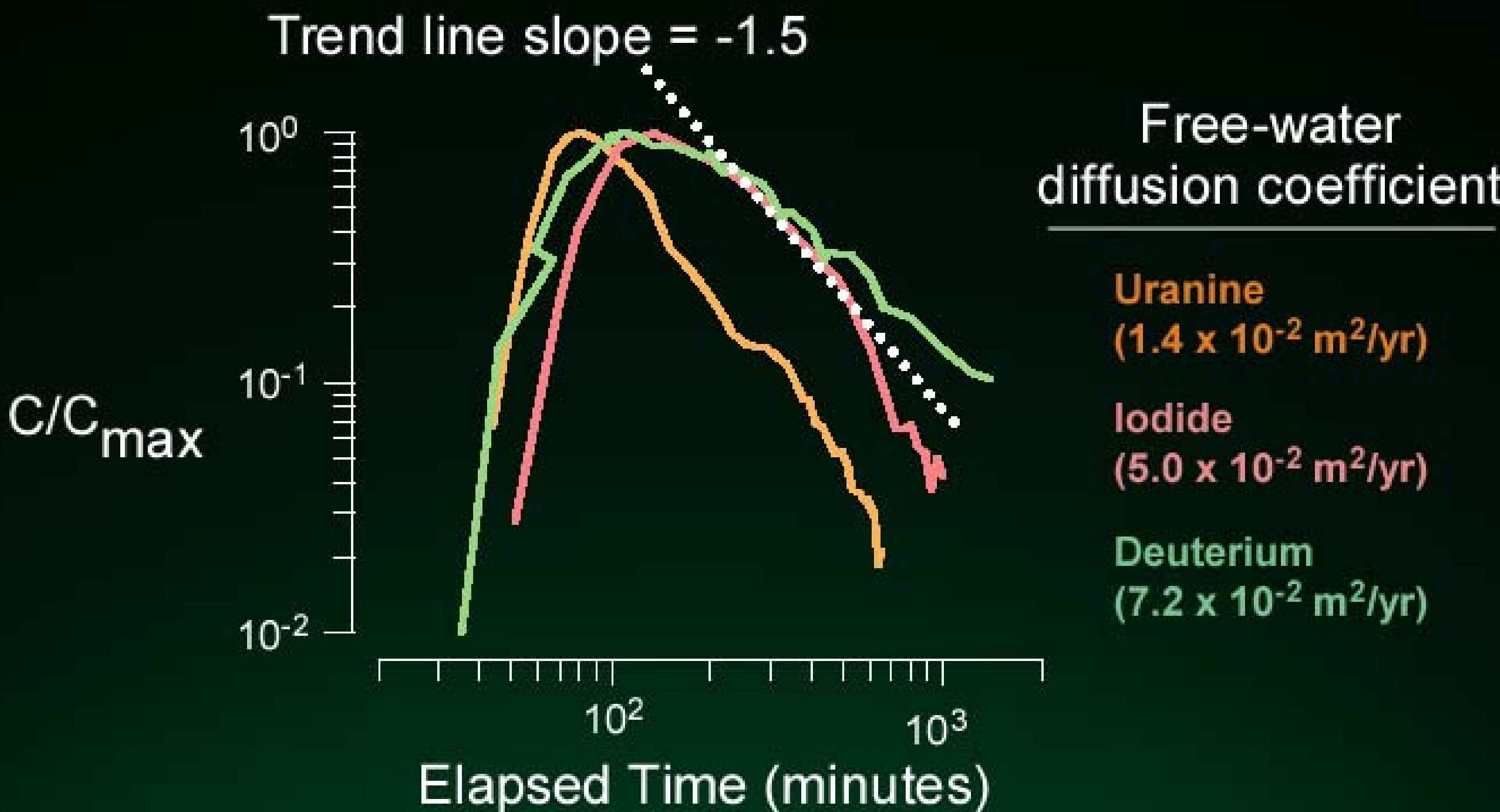
Tracer Tests in Fractured Rock



Converging tracer test in a chalk aquifer, Béthune, France

Garnier et al., 1985

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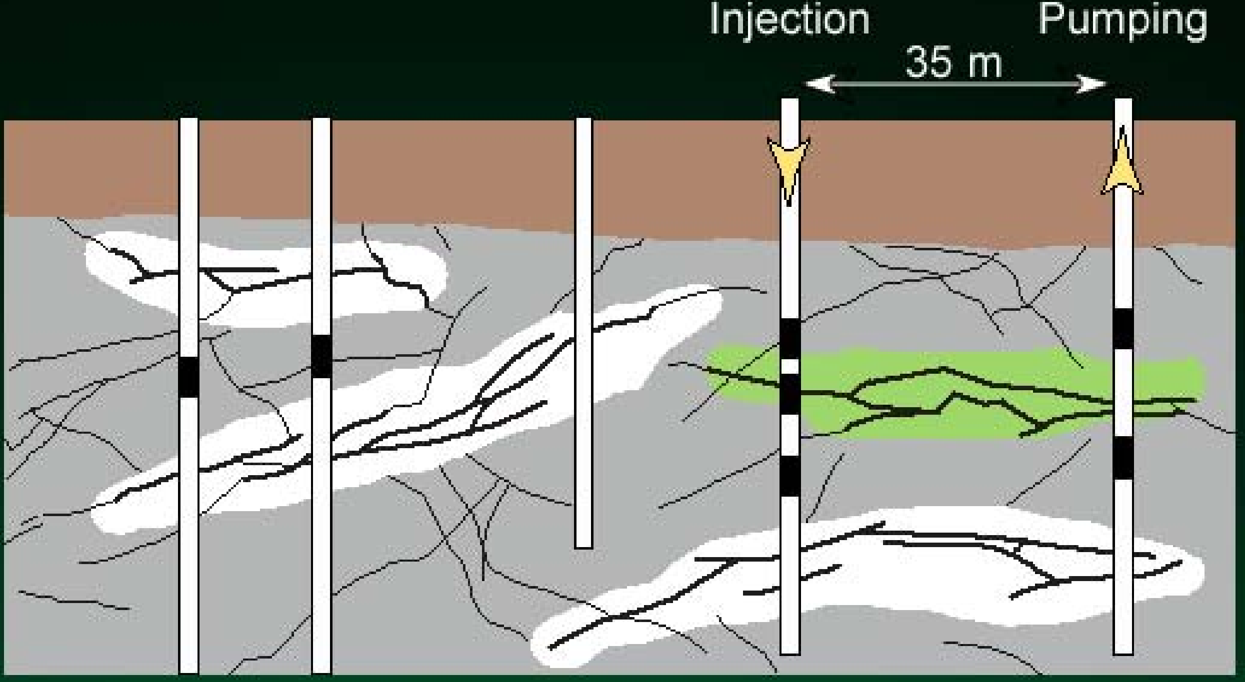
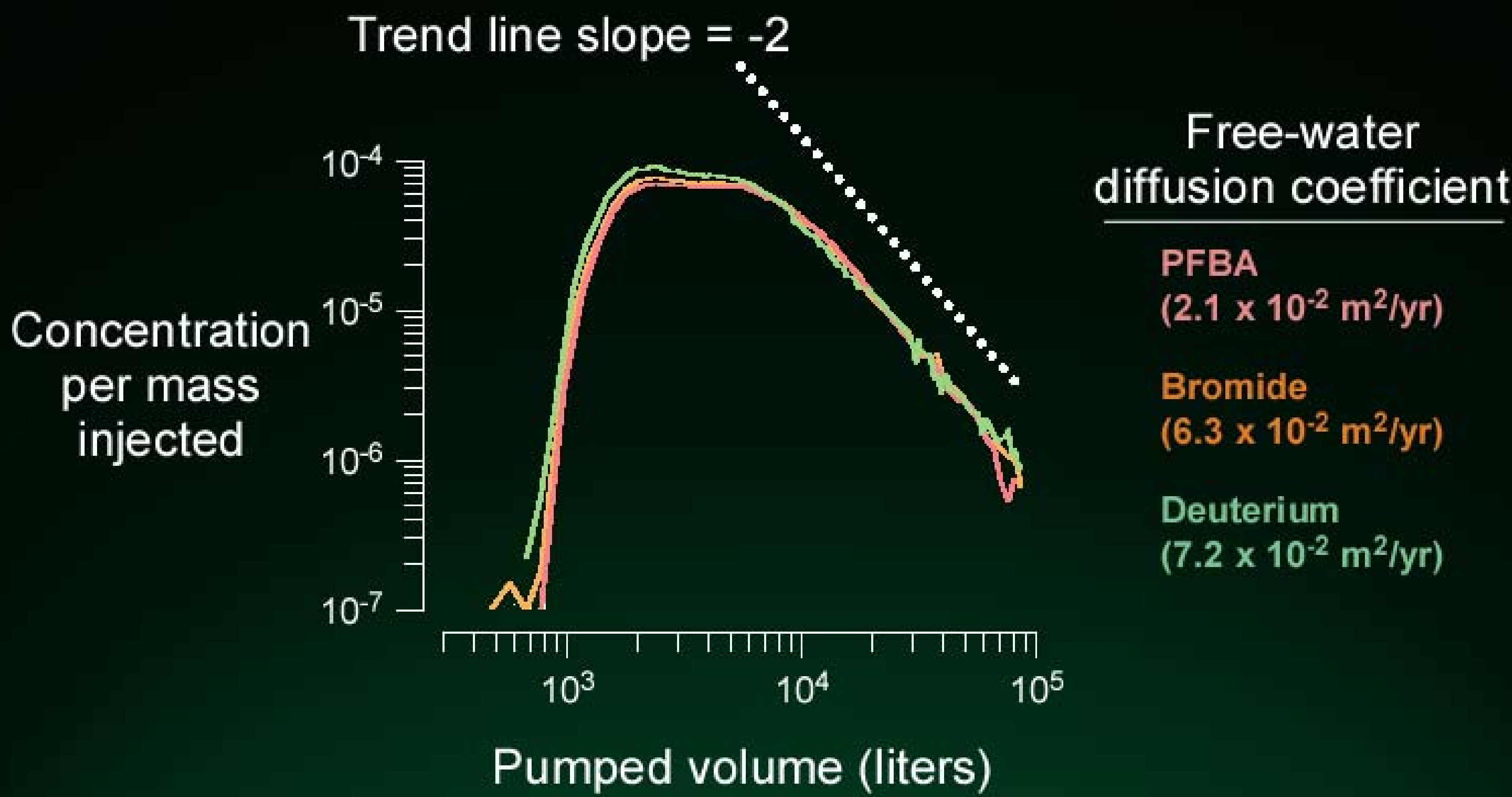
Granite and schist - Mirror Lake, New Hampshire

FSE well field
Mirror Lake,
New Hampshire



USGS

Granite and schist - Mirror Lake, New Hampshire



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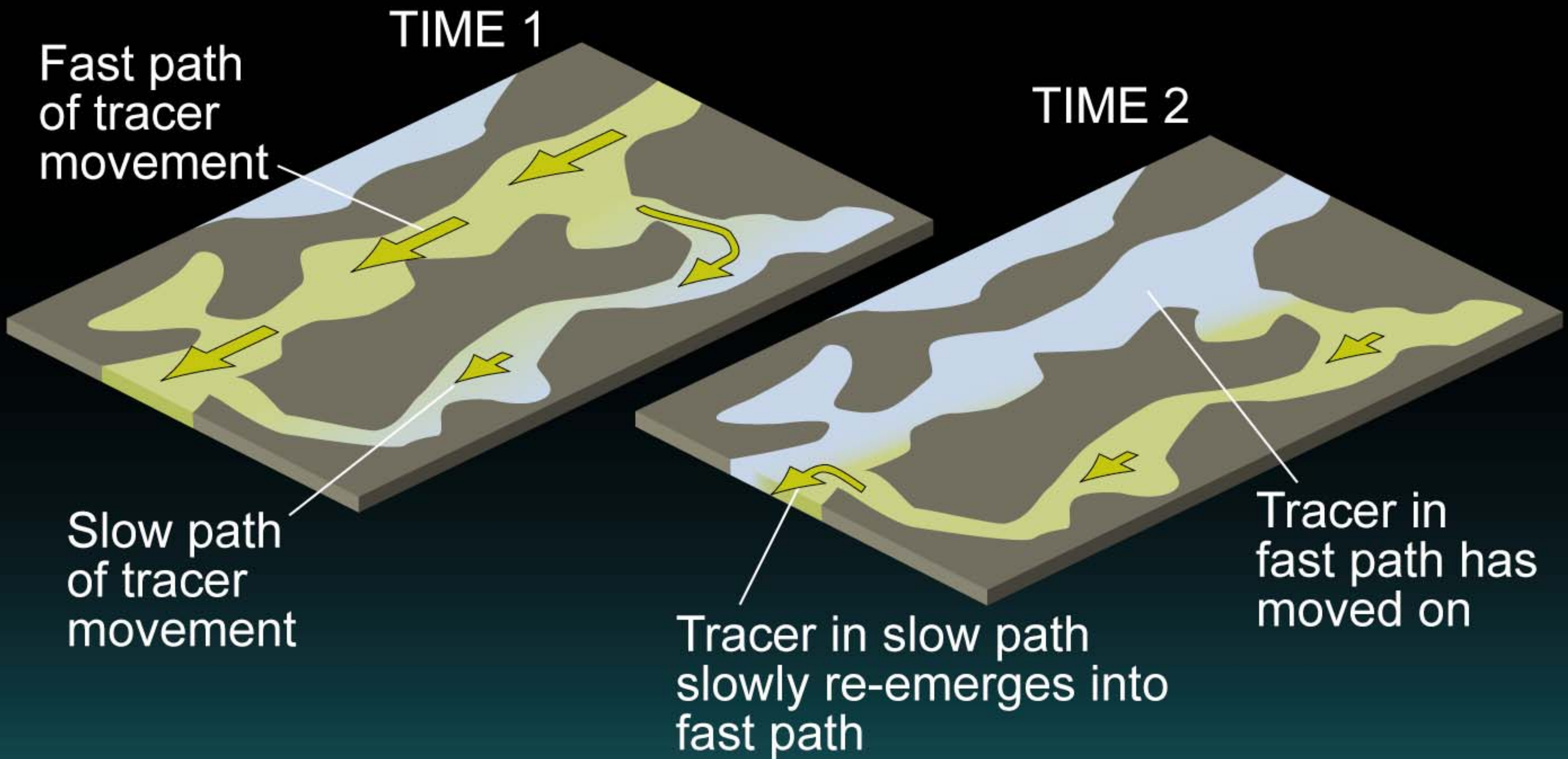
The large "effective" matrix diffusion is an artifact of fluid advection



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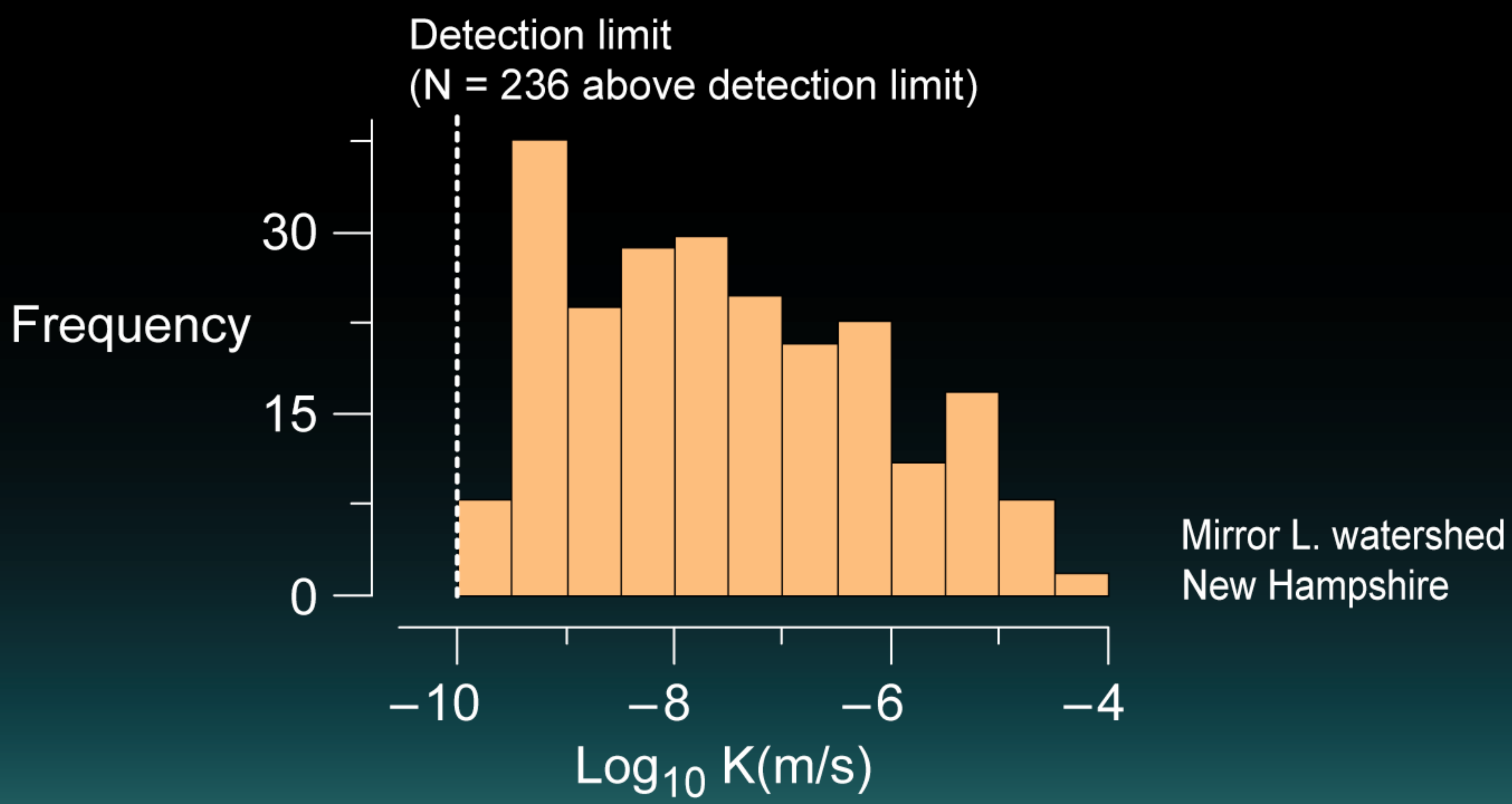
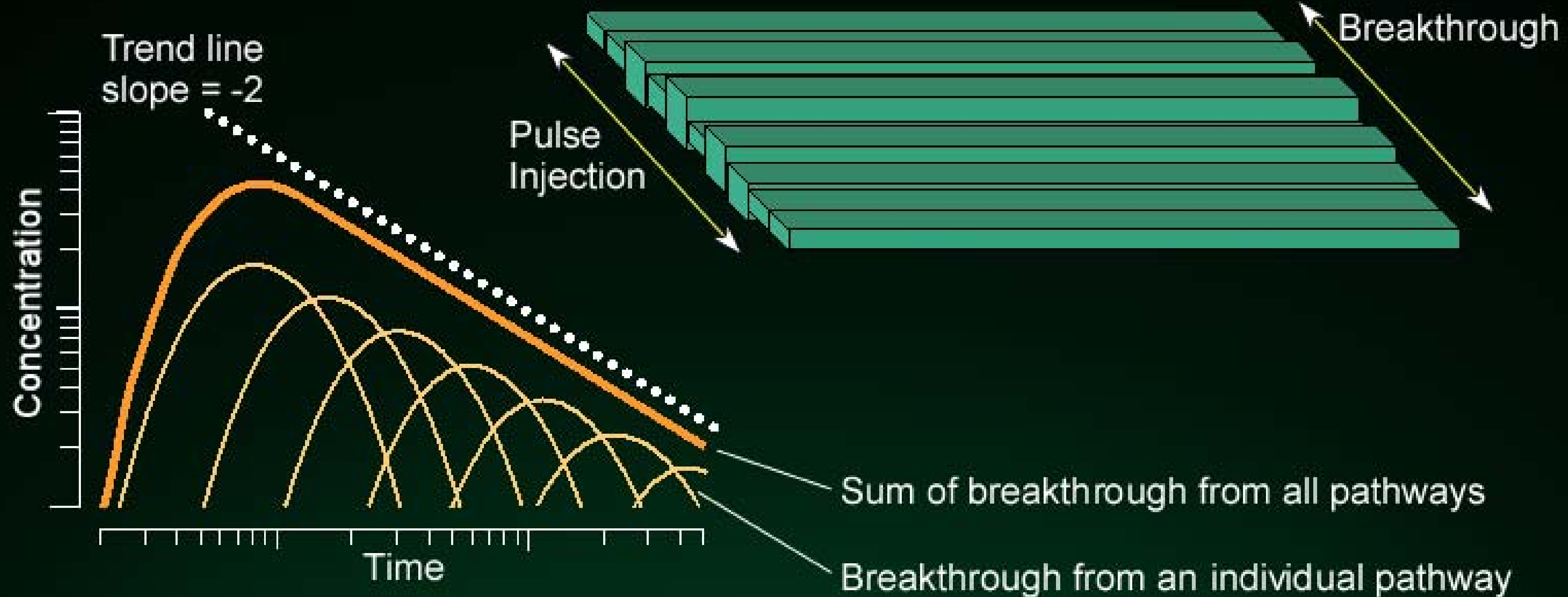
Hydraulic conductivity in fractures in granite and schist



Breakthrough as the summation of transport along multiple pathways



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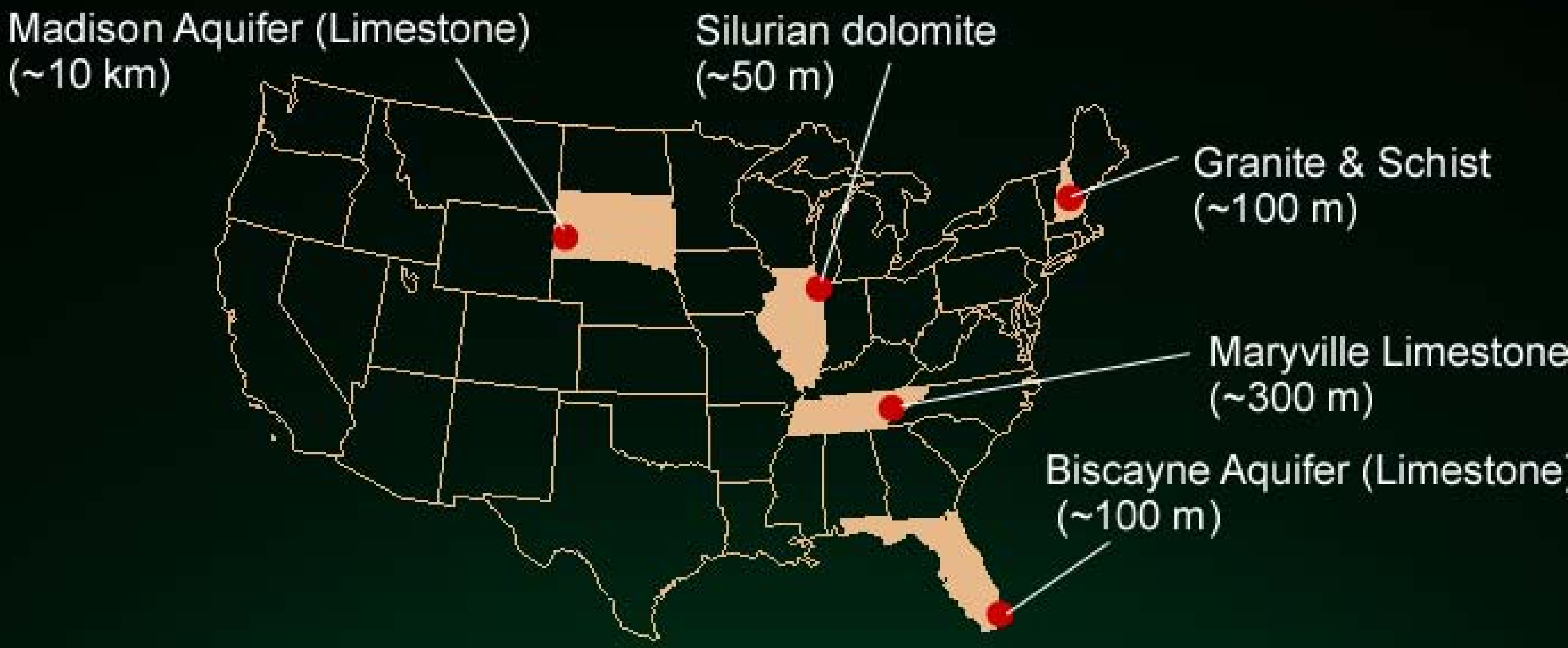
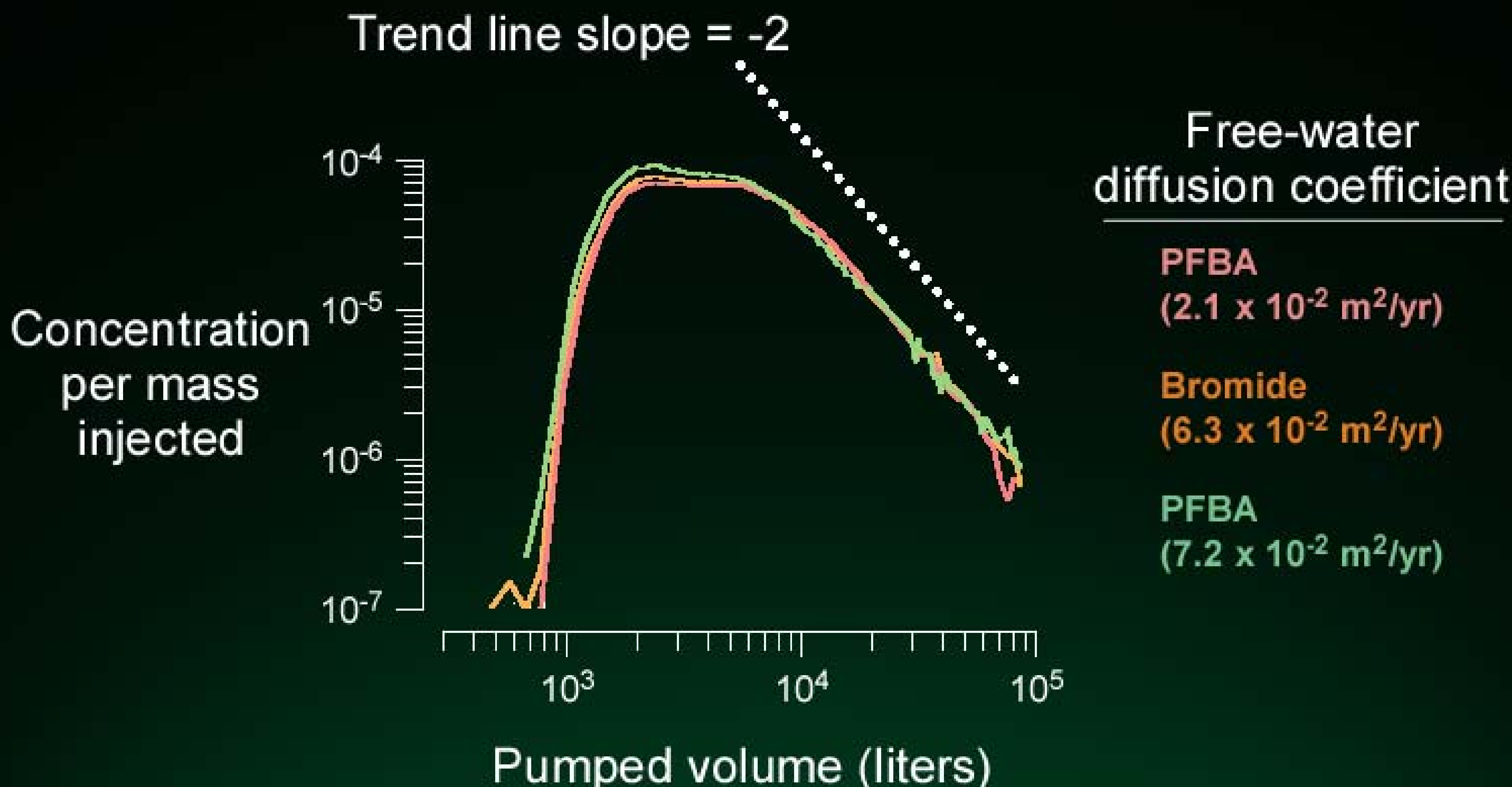
Chemical Transport in Fractured-Rock Aquifers



Controlled tracer tests in different geologic settings and over distances from meters to kilometers. . .

Granite and schist - Mirror Lake, New Hampshire



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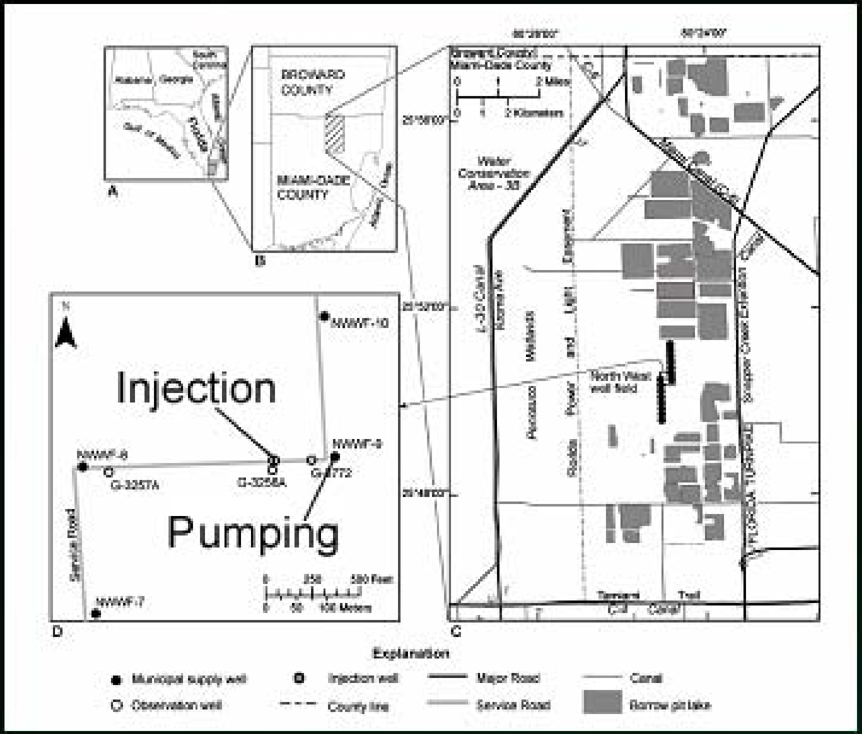
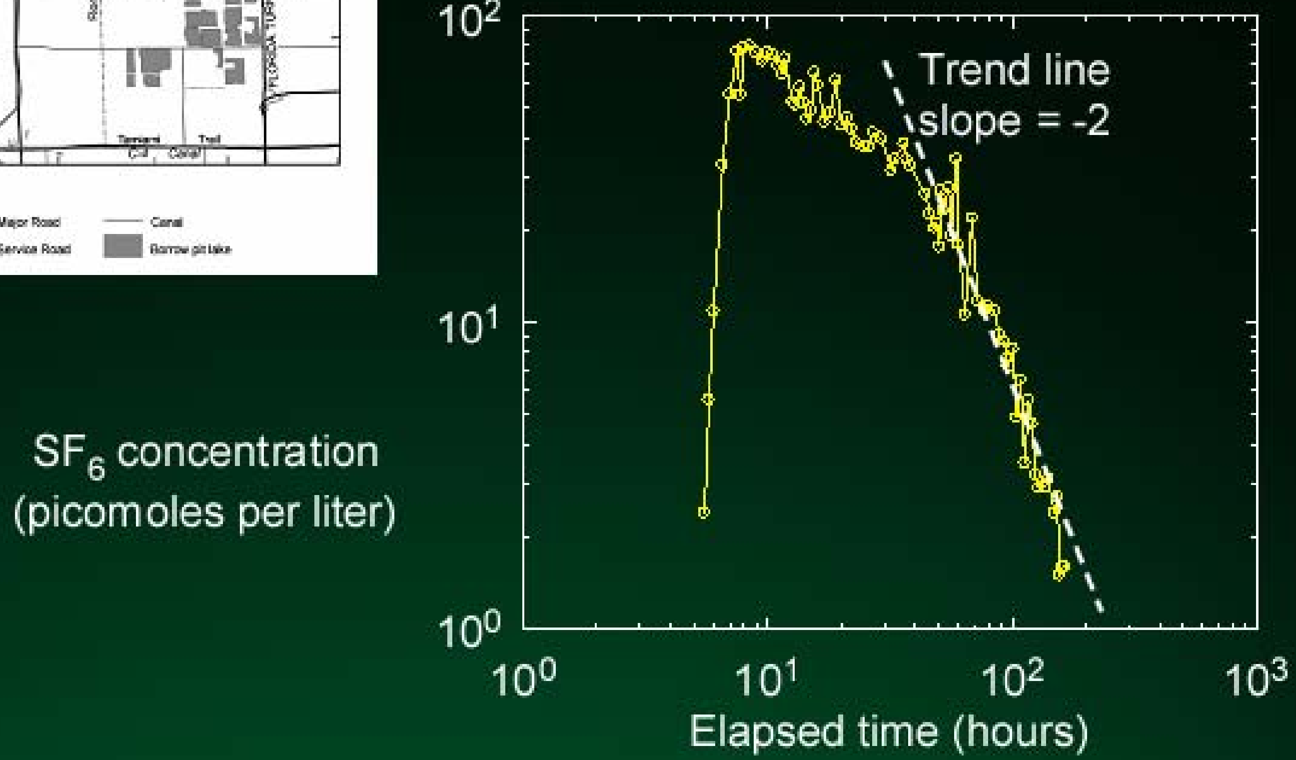
Biscayne Aquifer, Miami - Limestone - ~100 m





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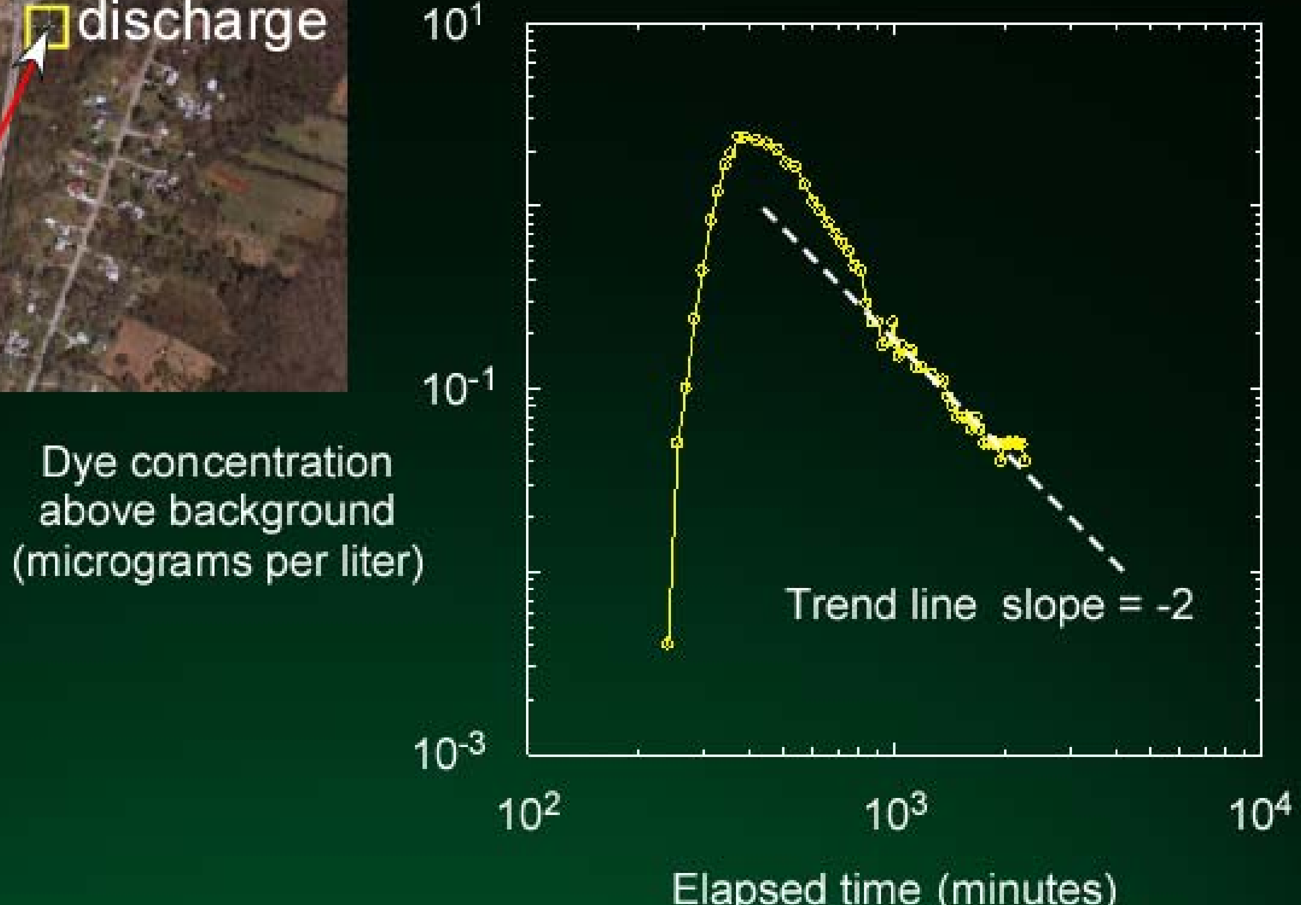
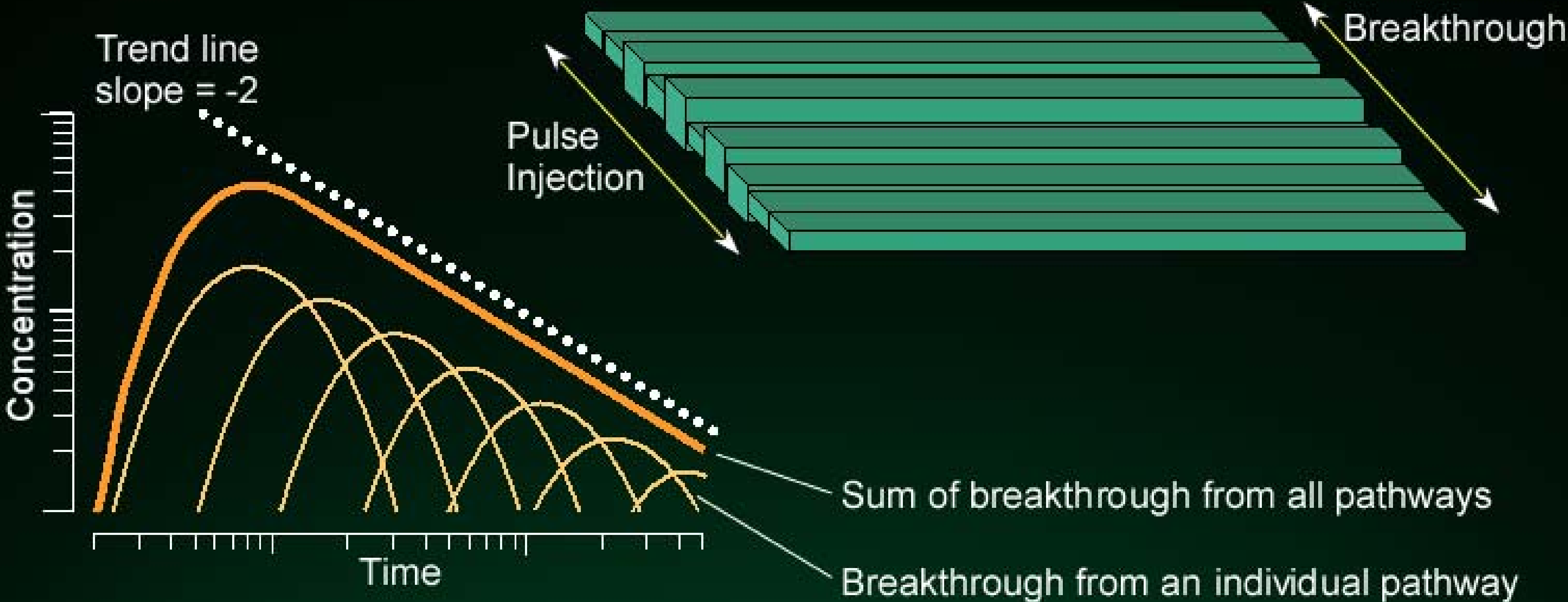
Maryville Limestone, Alcoa, Tennessee - ~300 m

(courtesy of Gareth Davies, Cambrian Ground Water, Oak Ridge, TN)



USGS

Breakthrough as the summation of transport along multiple pathways



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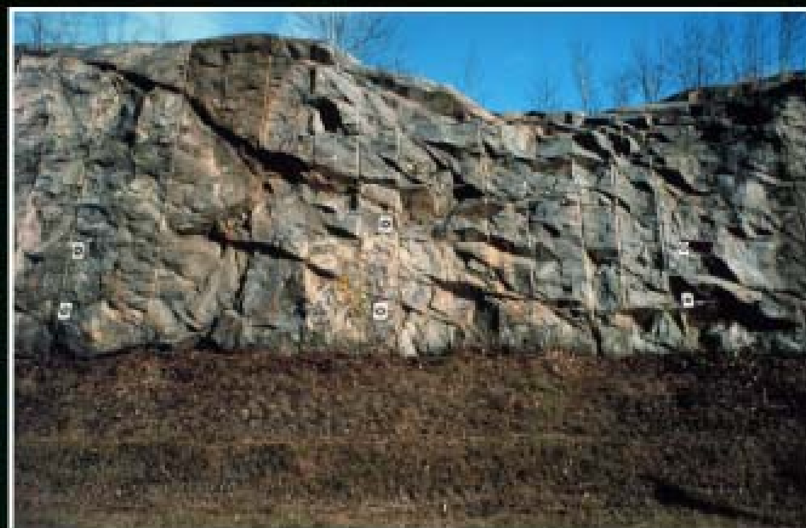
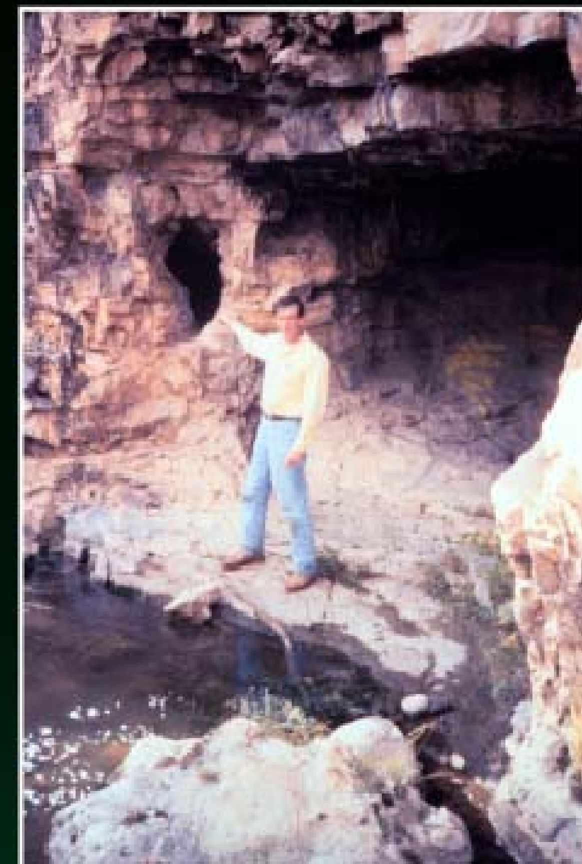
Chemical Transport in Fractured-Rock Aquifers

- Dissolved constituents will move rapidly through the most permeable fractures. . . .
- Chemical retention in fractured-rock aquifers over extremely long time frames. . .
- Advection through fractures of low permeability. . .
- Diffusion into the primary porosity of the rock. . .

USGS

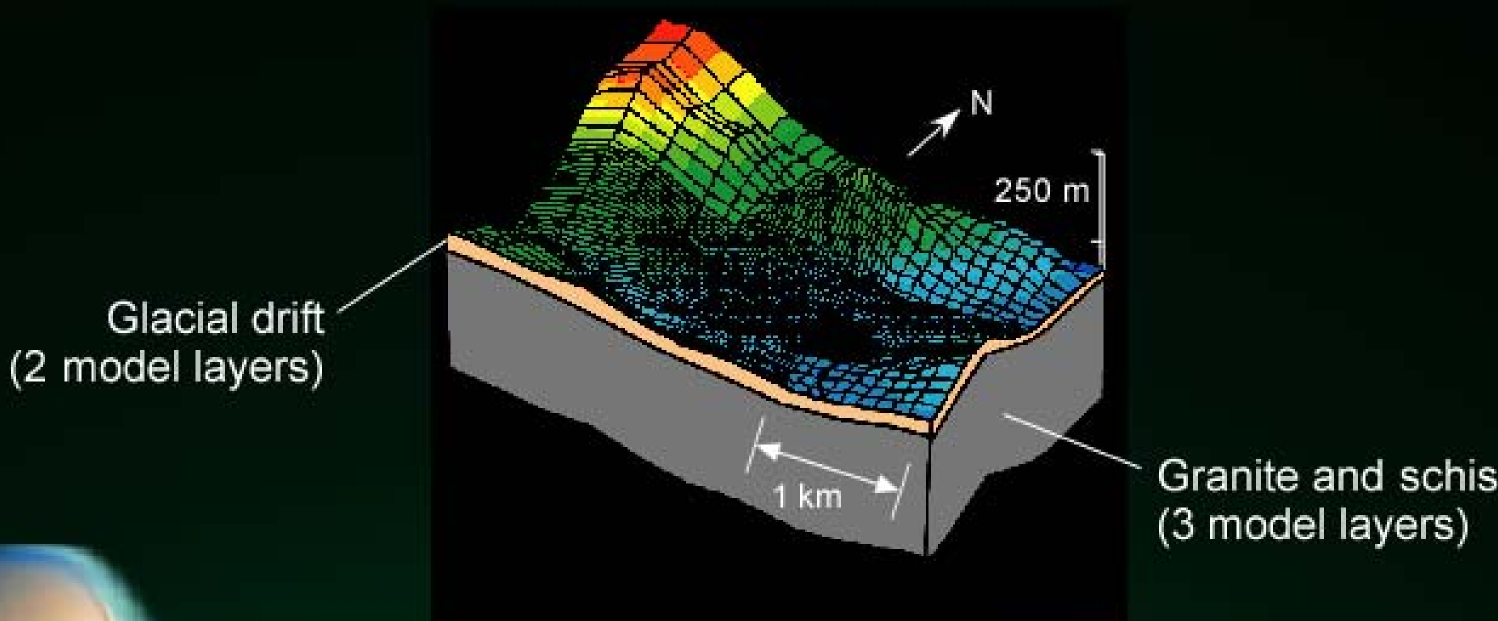
Conclusions





Characterizing ground-water flow and chemical transport in fractured rock is not an insurmountable task . . .

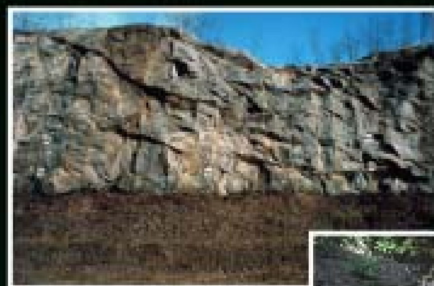
Conclusions

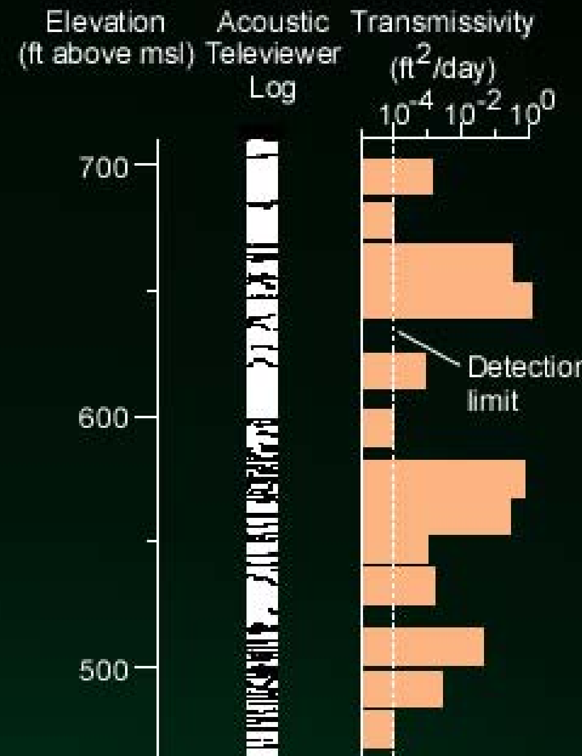


Ground-water flow models of fractured-rock aquifers are water balances . . .

Conclusions

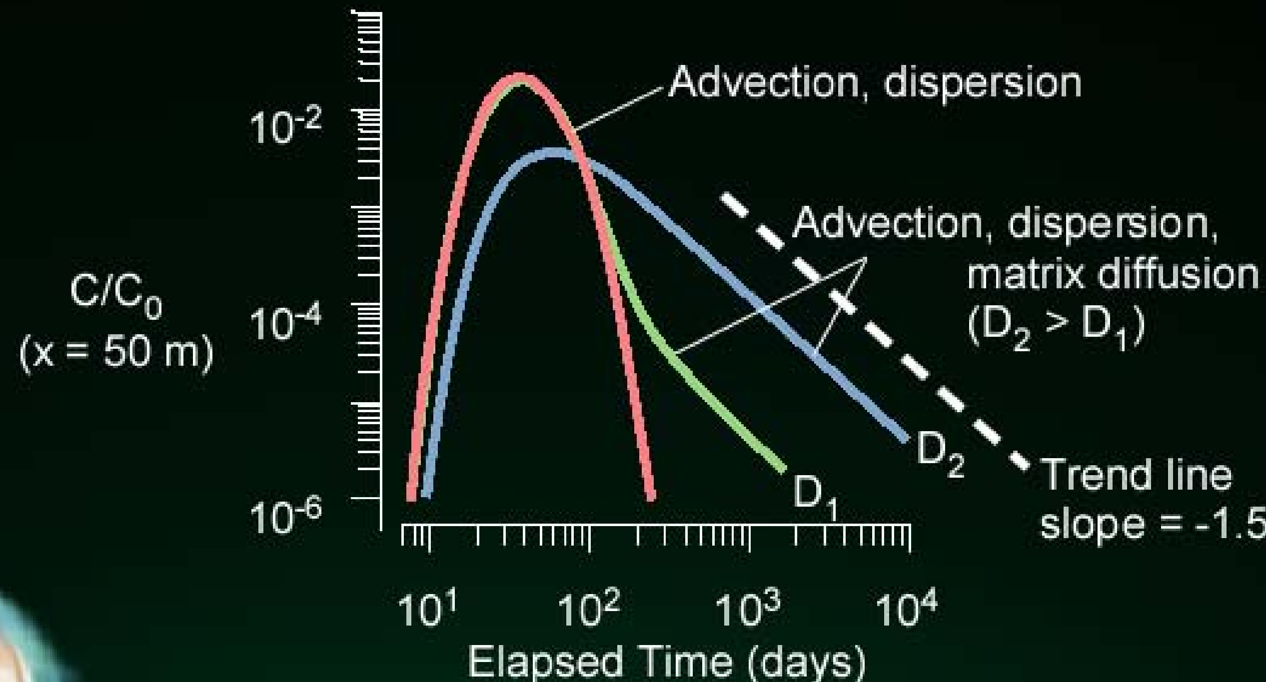
Granite and schist
Mirror Lake watershed, NH





Detailed characterization is needed to identify flow paths for chemical migration in fractured-rock aquifers . . .

Conclusions



Fractured-rock aquifers have the capacity to retain chemical constituents over extremely long time frames . . .