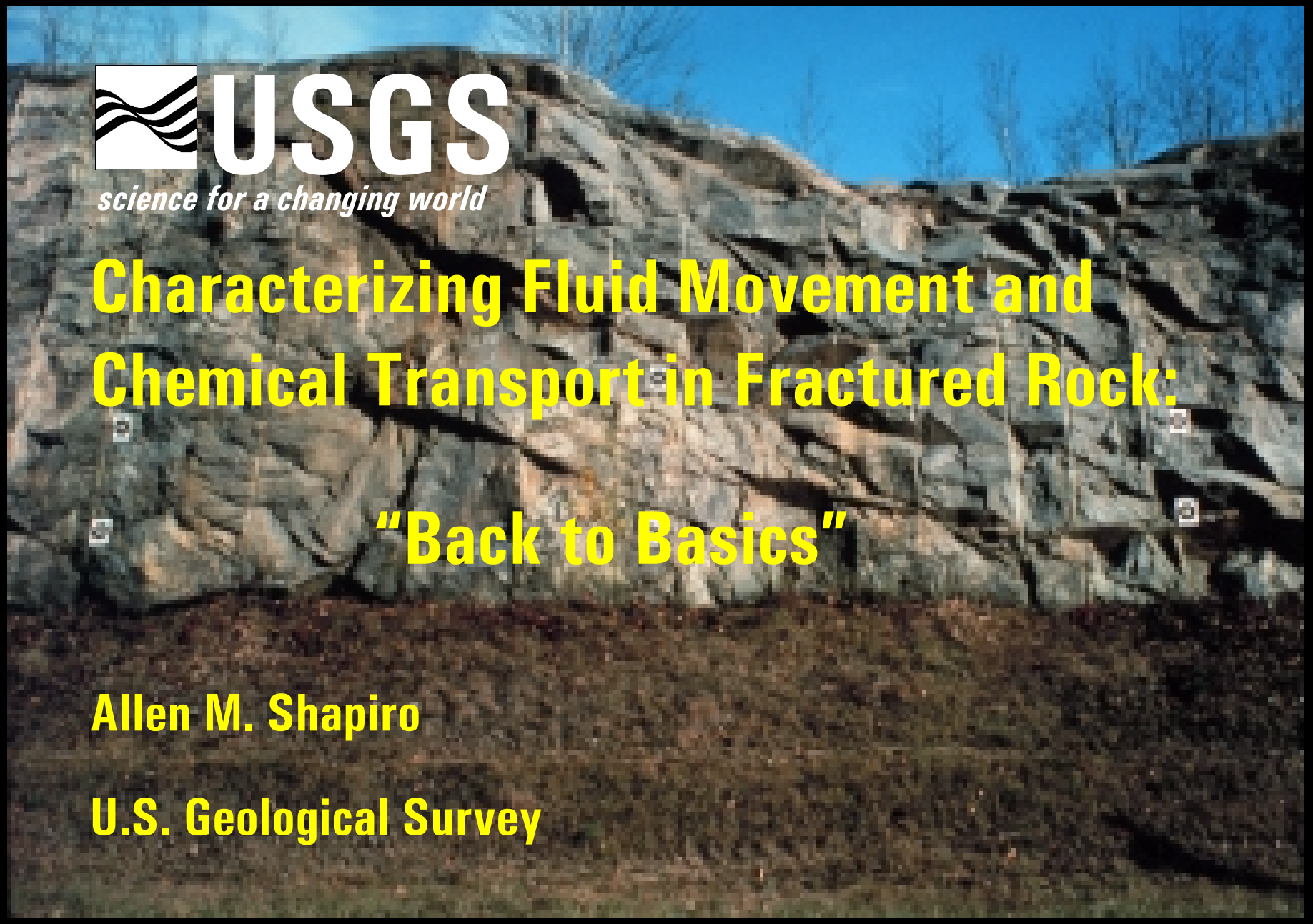
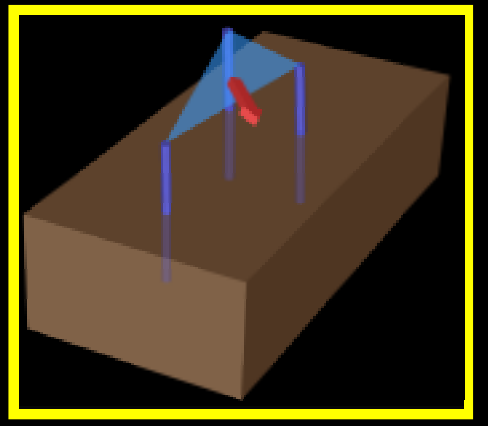

USGS
science for a changing world
Characterizing Fluid Movement and Chemical Transport in Fractured Rock:
"Back to Basics"
Allen M. Shapiro
U.S. Geological Survey

"The Basics"

- How is hydraulic head measured?

- How are water samples collected for chemical and isotopic analyses?

- How is fluid velocity measured?



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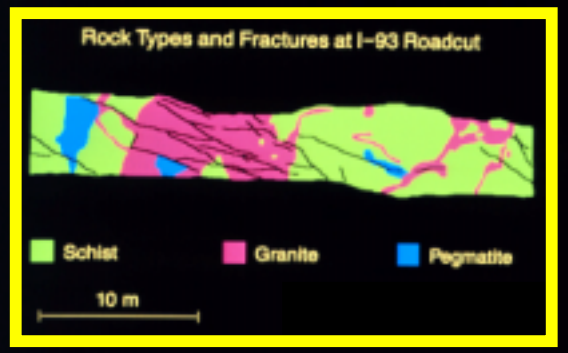
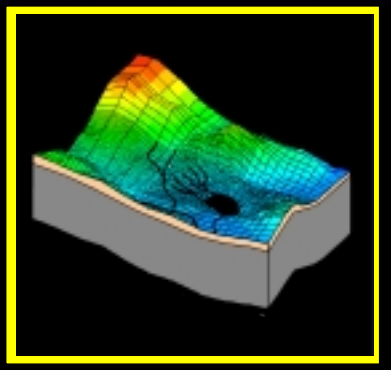
"Other Issues"

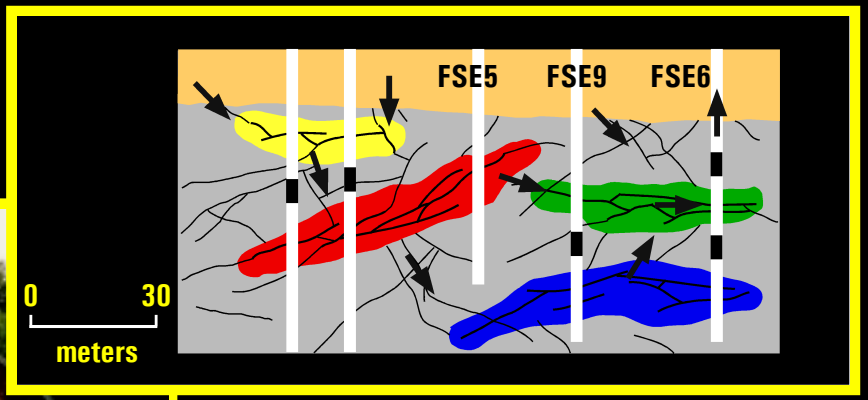
- The level of detail . . .



- Placing the site into a regional perspective . . .



- Synthesizing information . . .



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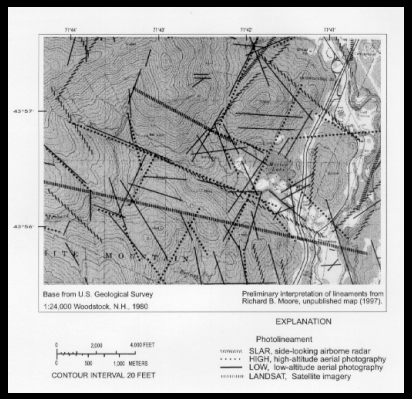
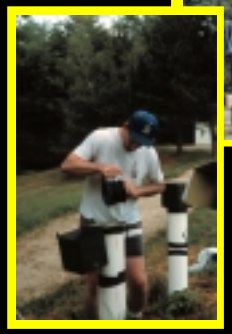
Remote Sensing



Surface Geophysics

Geologic Mapping

Fracture Mapping



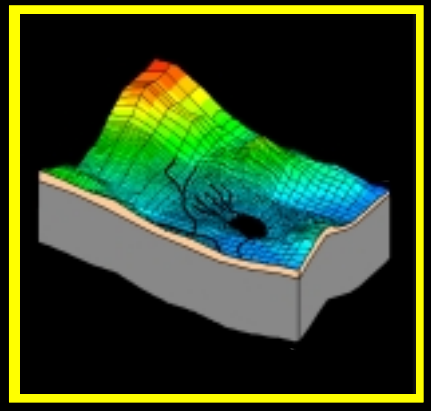
Regional Hydrology

Hydrogeologic Characterization In Fractured Rock

Borehole Geophysics

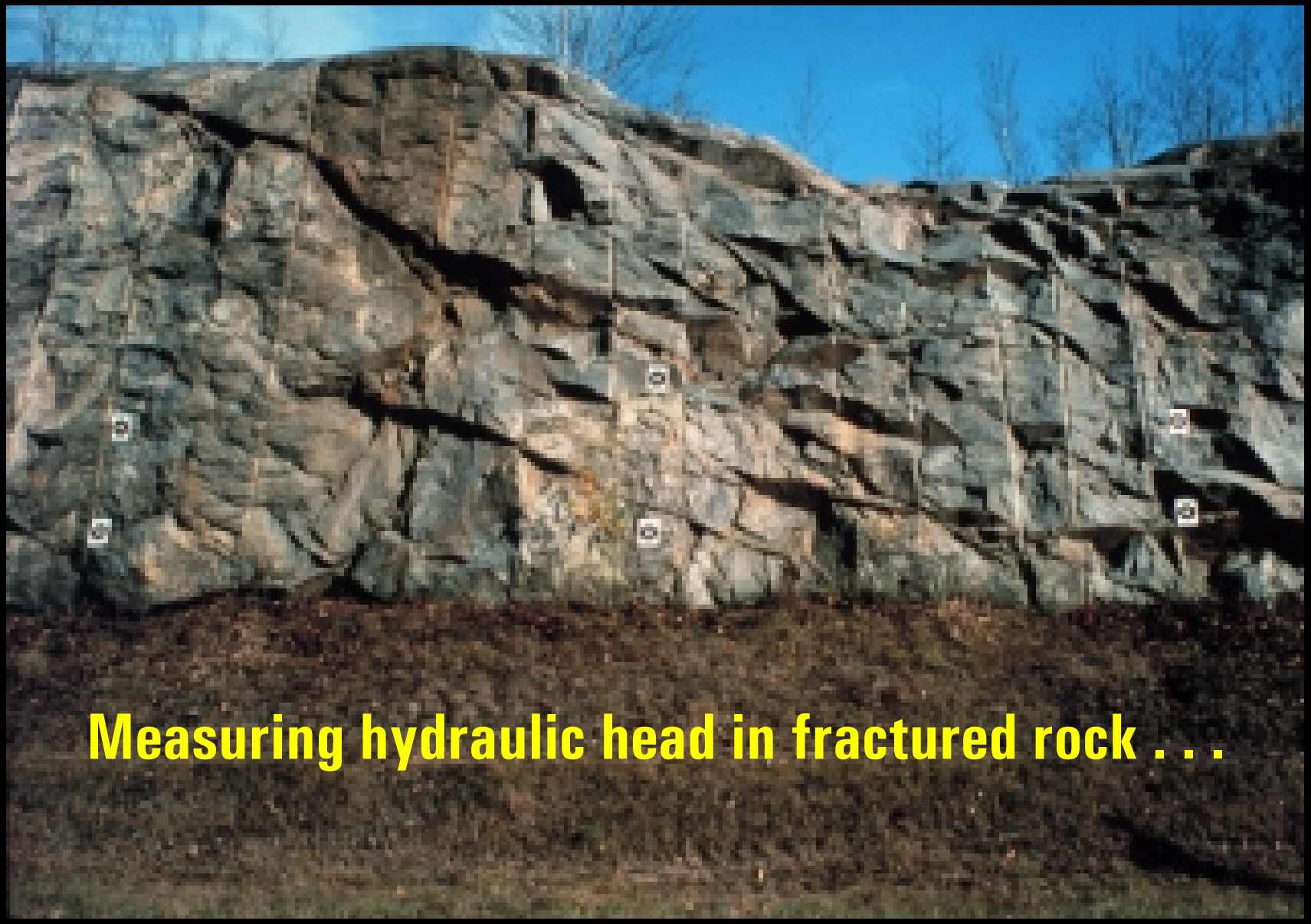
Geochemistry

Ground-Water Modeling

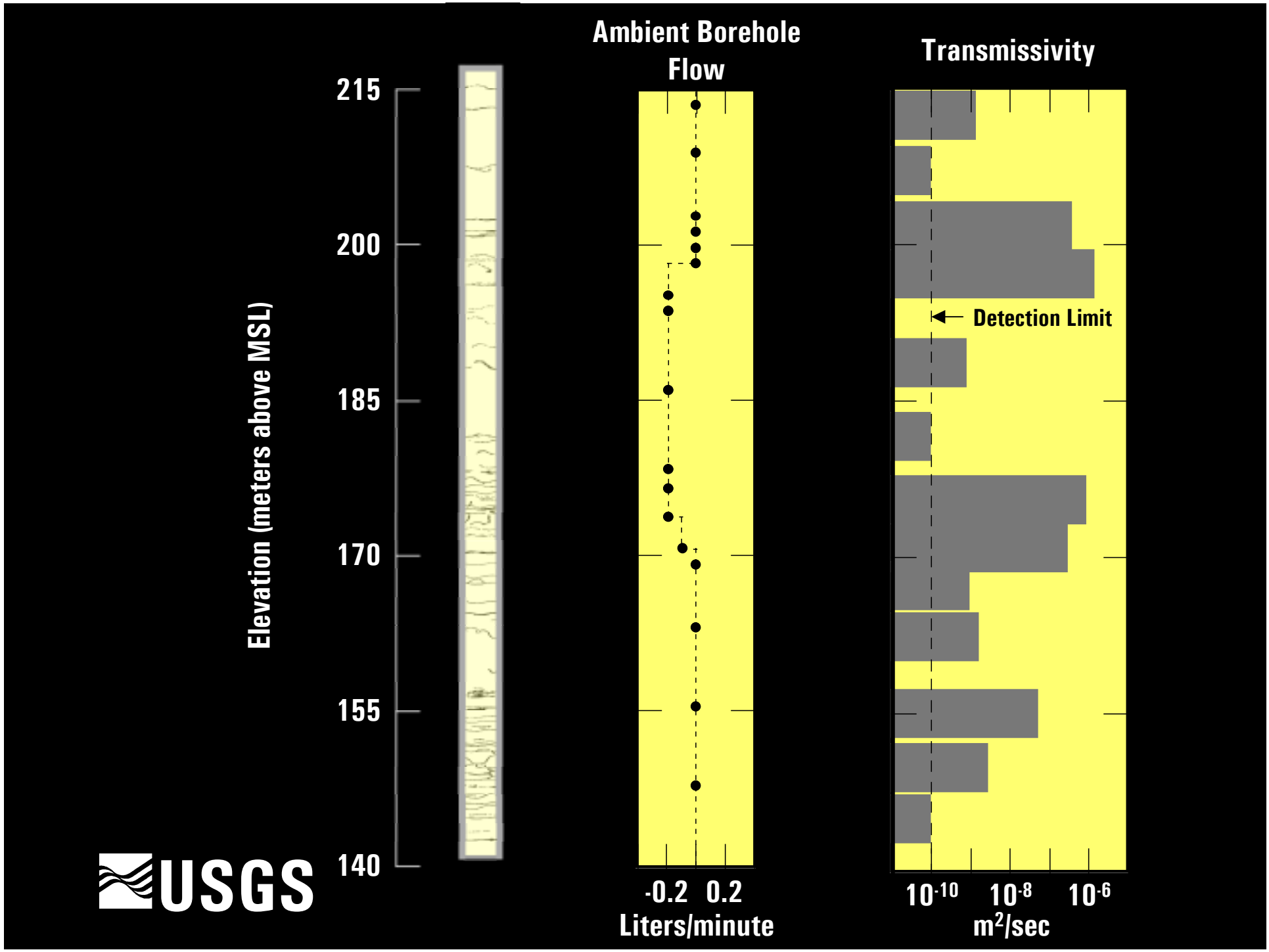


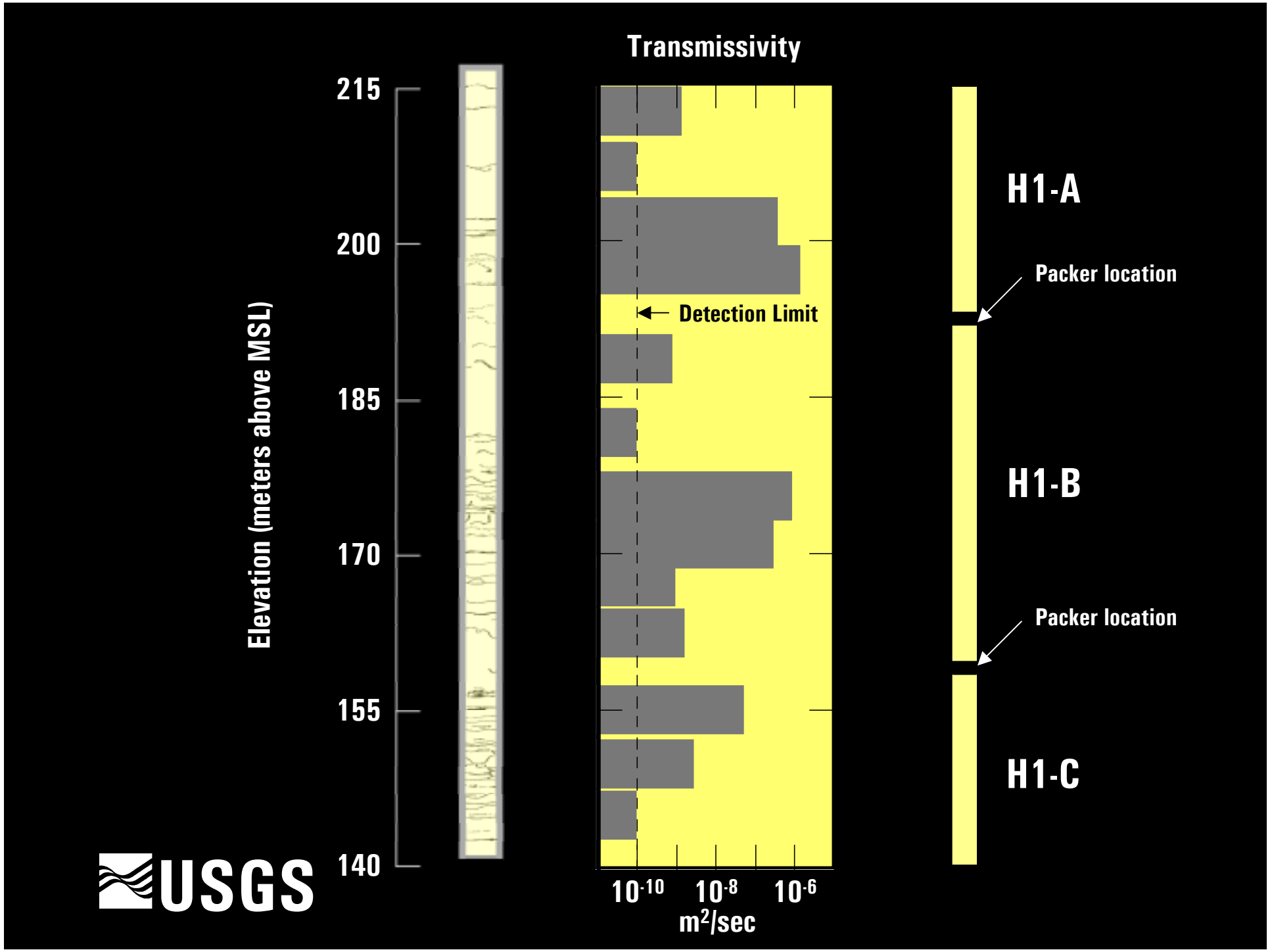
Hydrologic Testing

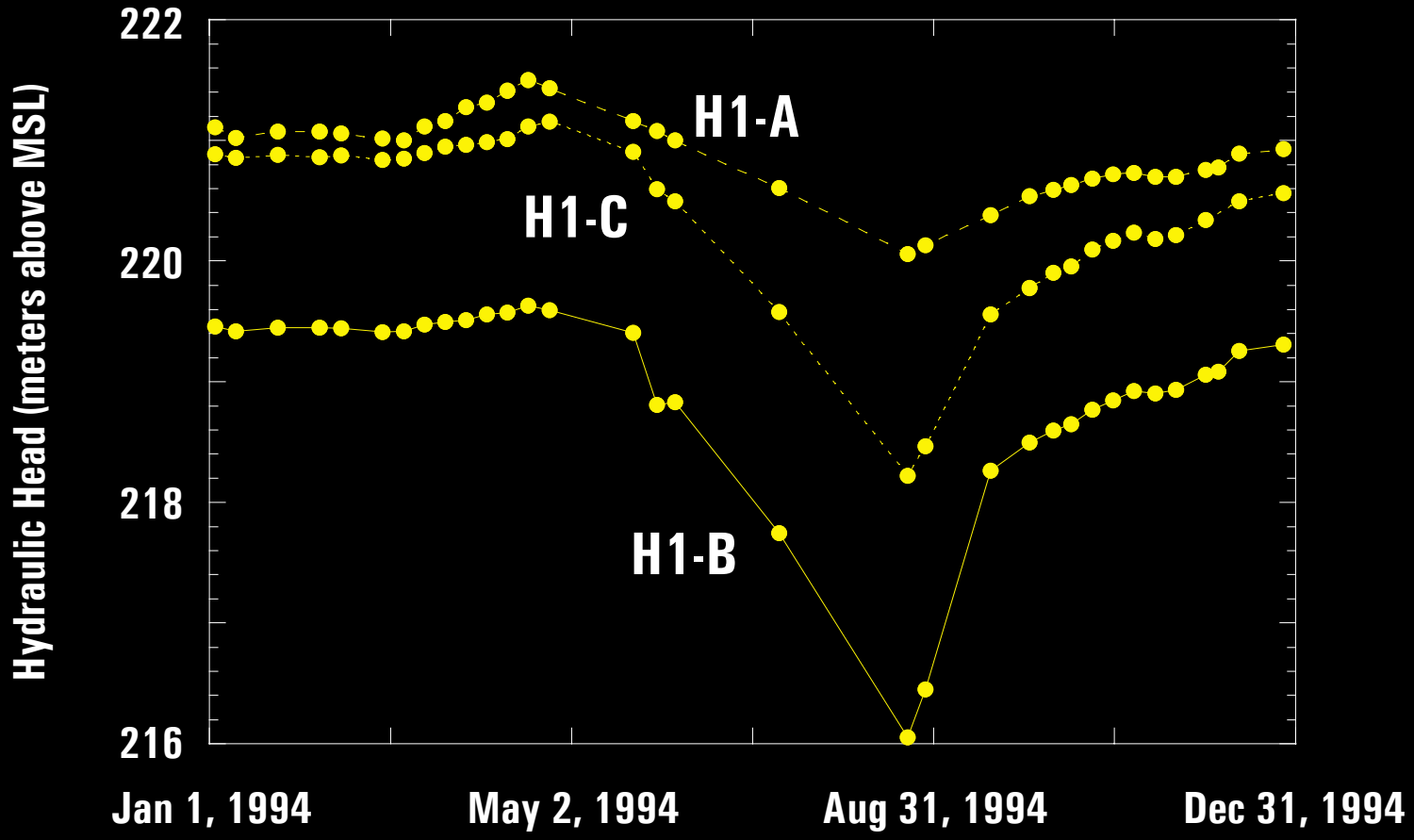
USGS



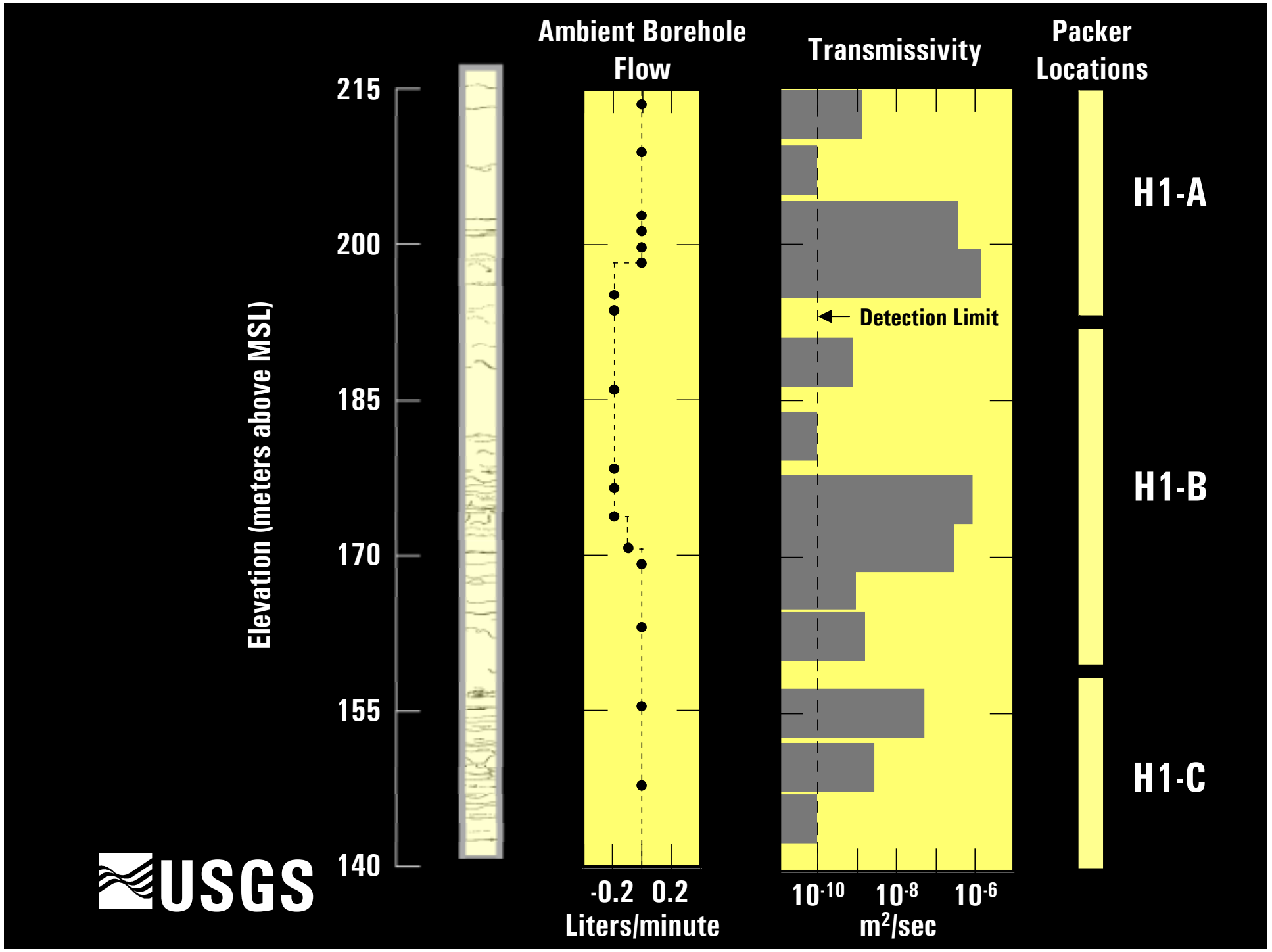
USGS


Ambient Borehole Flow
Transmissivity
Elevation (meters above MSL)
215
200
185
170
155
140
Detection Limit
-0.2
0.2
Liters/minute
10-10
10-8
10-6
m2/sec
USGS

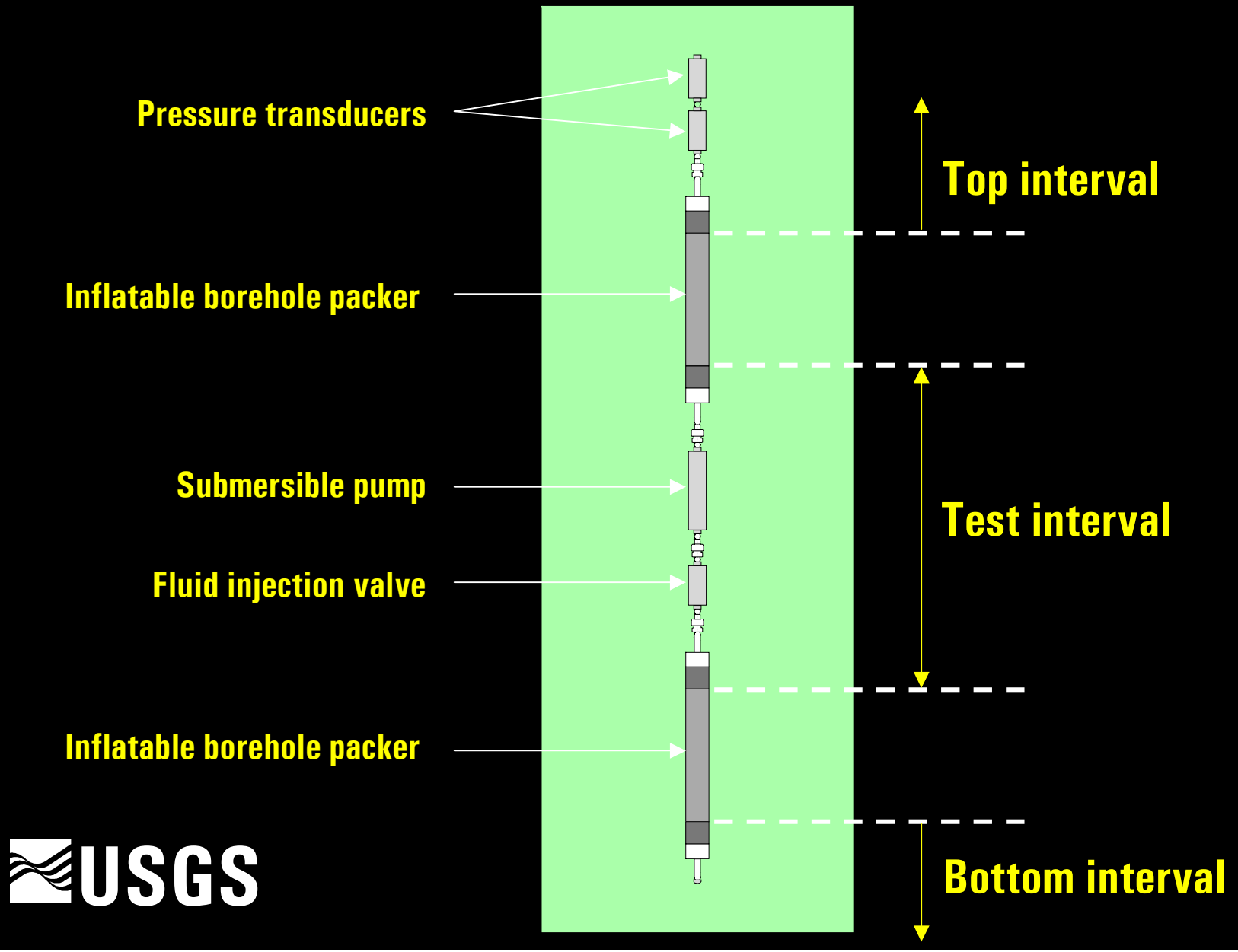

Transmissivity
Elevation (meters above MSL)
215
200
185
170
155
140
Detection Limit
H1-A
Packer location
H1-B
Packer location
H1-C
10-10
10-8
10-6
m2/sec
USGS


222
220
218
216
Hydraulic Head (meters above MSL)
H1-A
H1-C
H1-B
Jan 1, 1994
May 2, 1994
Aug 31, 1994
Dec 31, 1994

USGS


Ambient Borehole Flow
Transmissivity
Packer Locations
Elevation (meters above MSL)
215
200
185
170
155
140
Detection Limit
H1-A
H1-B
H1-C
-0.2
0.2
Liters/minute
10-10
10-8
10-6
m2/sec
USGS

Transportable Multifunction Borehole Testing Apparatus



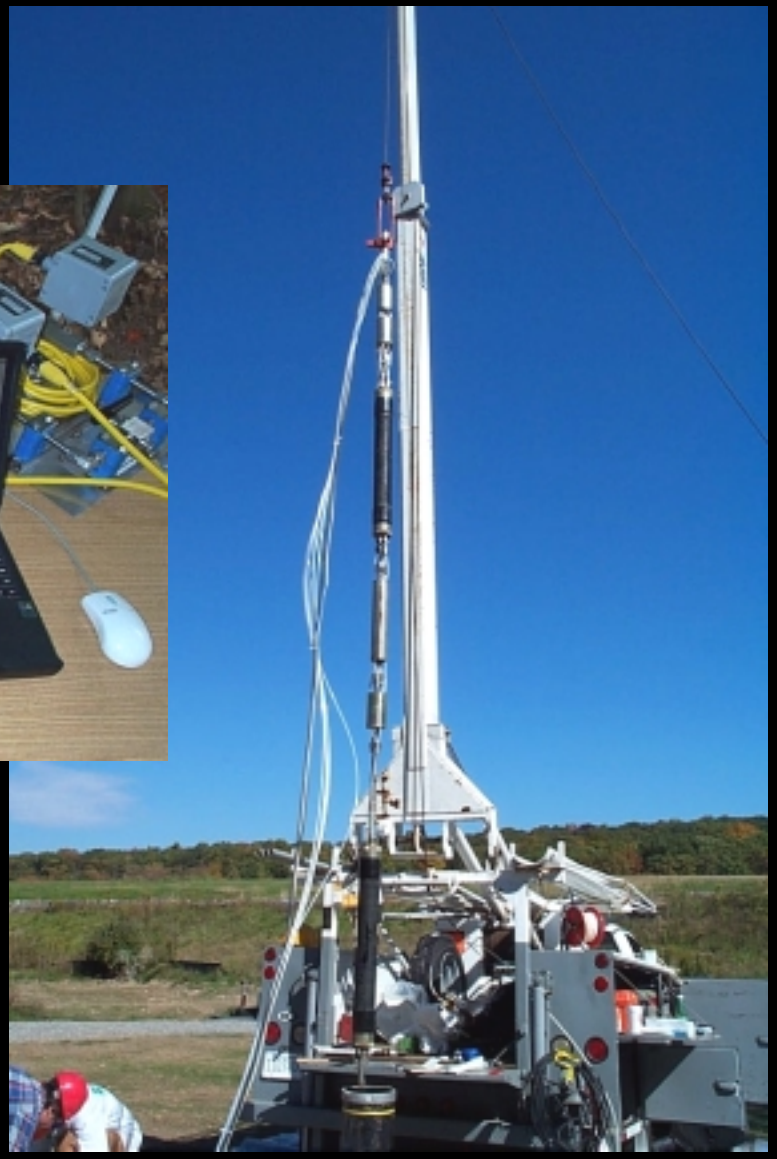
USGS

Transportable Multifunction Borehole Testing Apparatus

- Rapid assembly
- Isolate discrete intervals
- Geochemical sampling
- Hydraulic head
- Estimate hydraulic properties:
  - Fluid injection tests
  - Slug tests
  - Pumping
- Single-hole tracer tests
- Real-time data display & interpretation

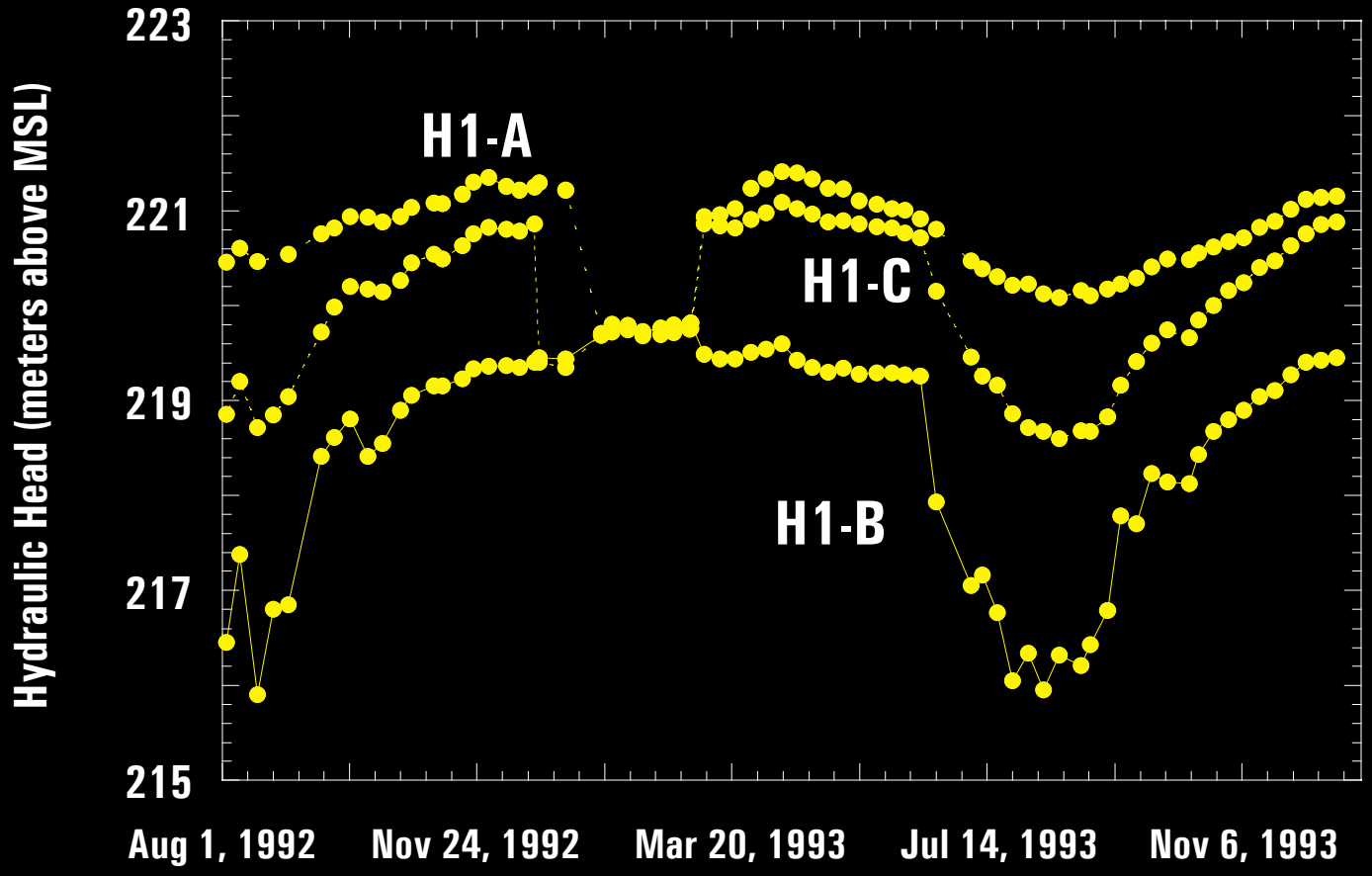
USGS

Transportable Multifunction Borehole Testing Apparatus

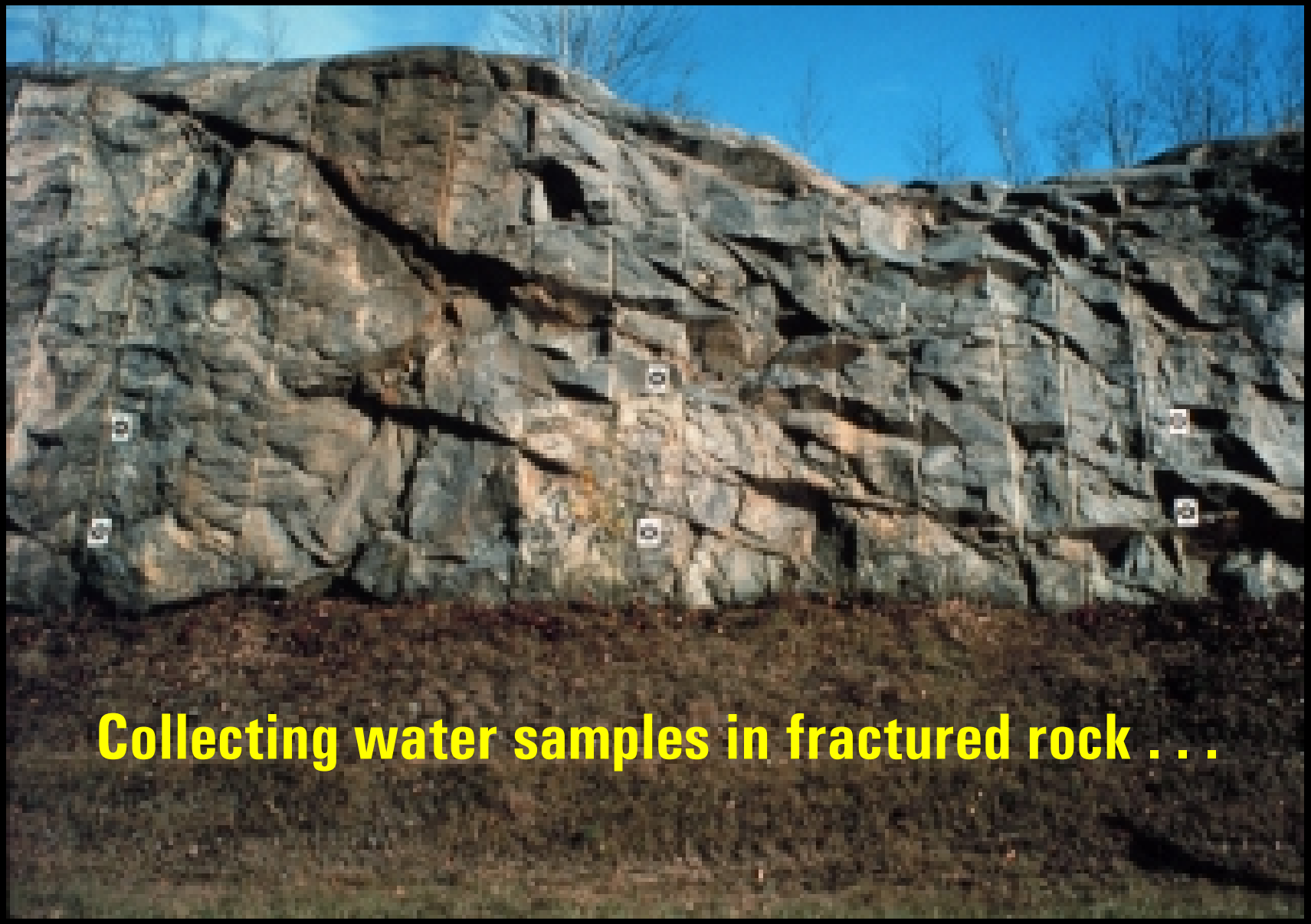


USGS

What is the meaning of an "open-hole" hydraulic head?

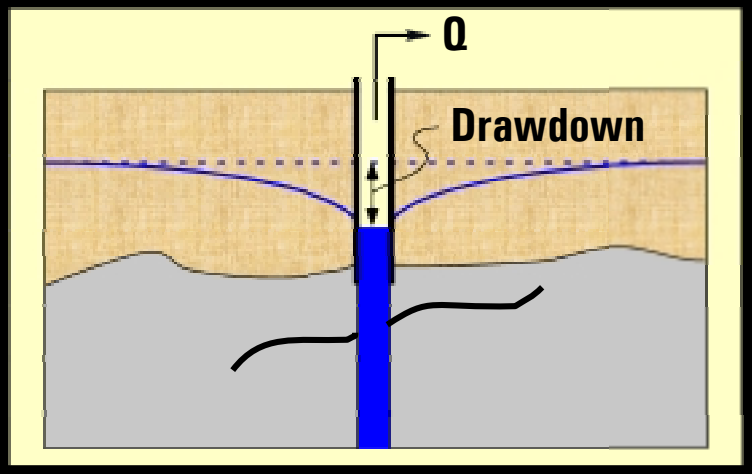


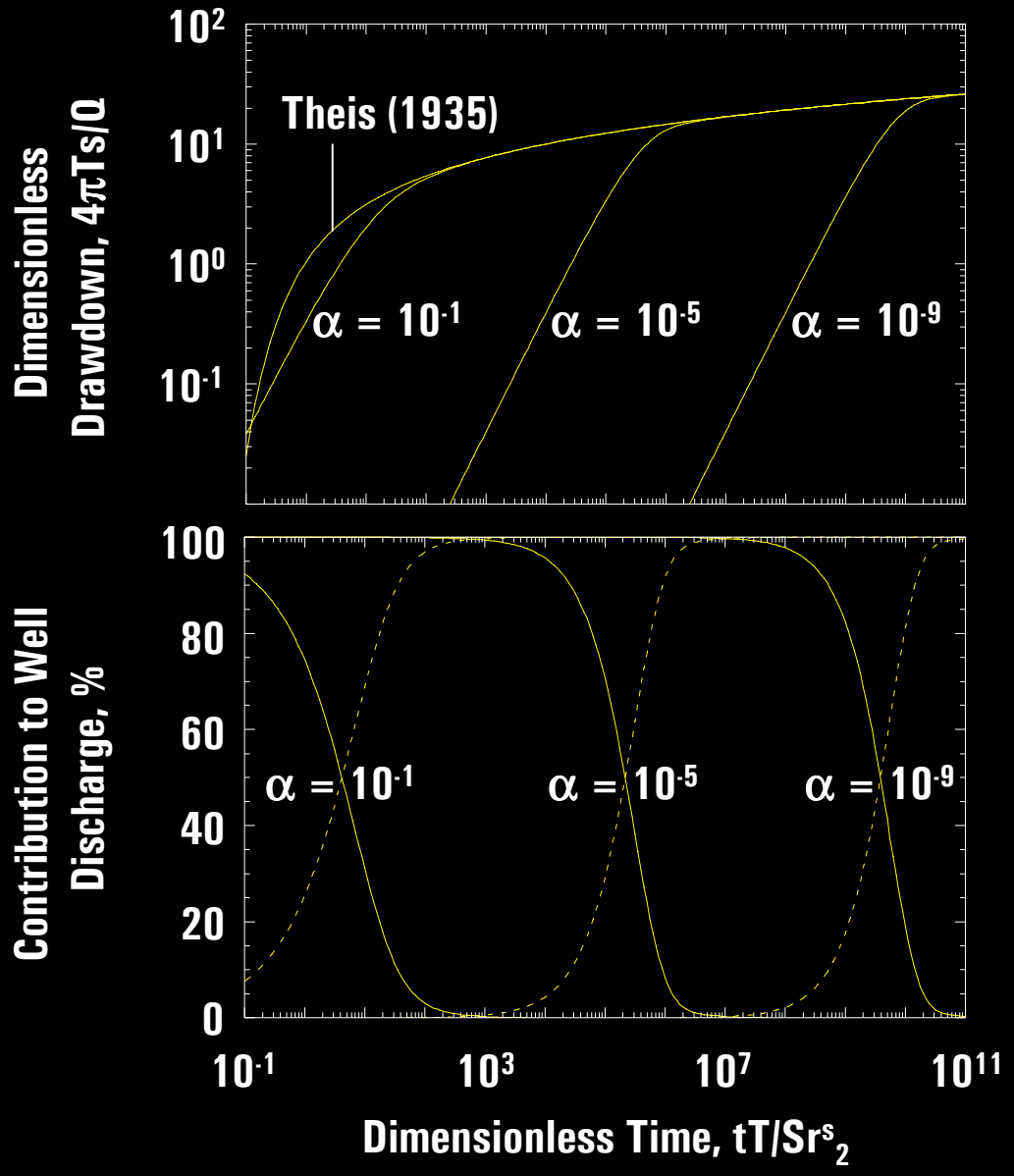
USGS



USGS

Sampling in an "open-hole" - a single fracture



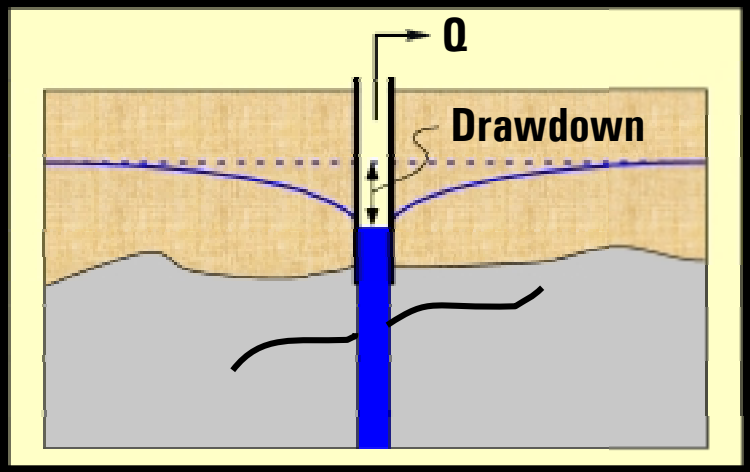


USGS

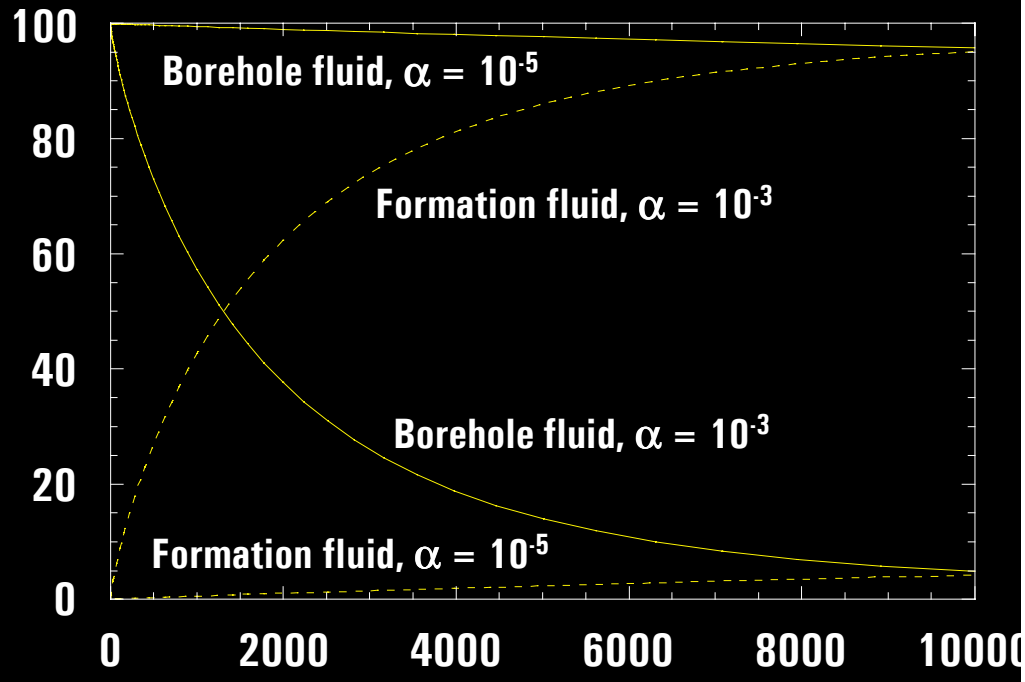
$\alpha = Sr_s^2/r_c^2$

Borehole fluid

Formation fluid



Sampling in an "open-hole" - a single fracture



USGS

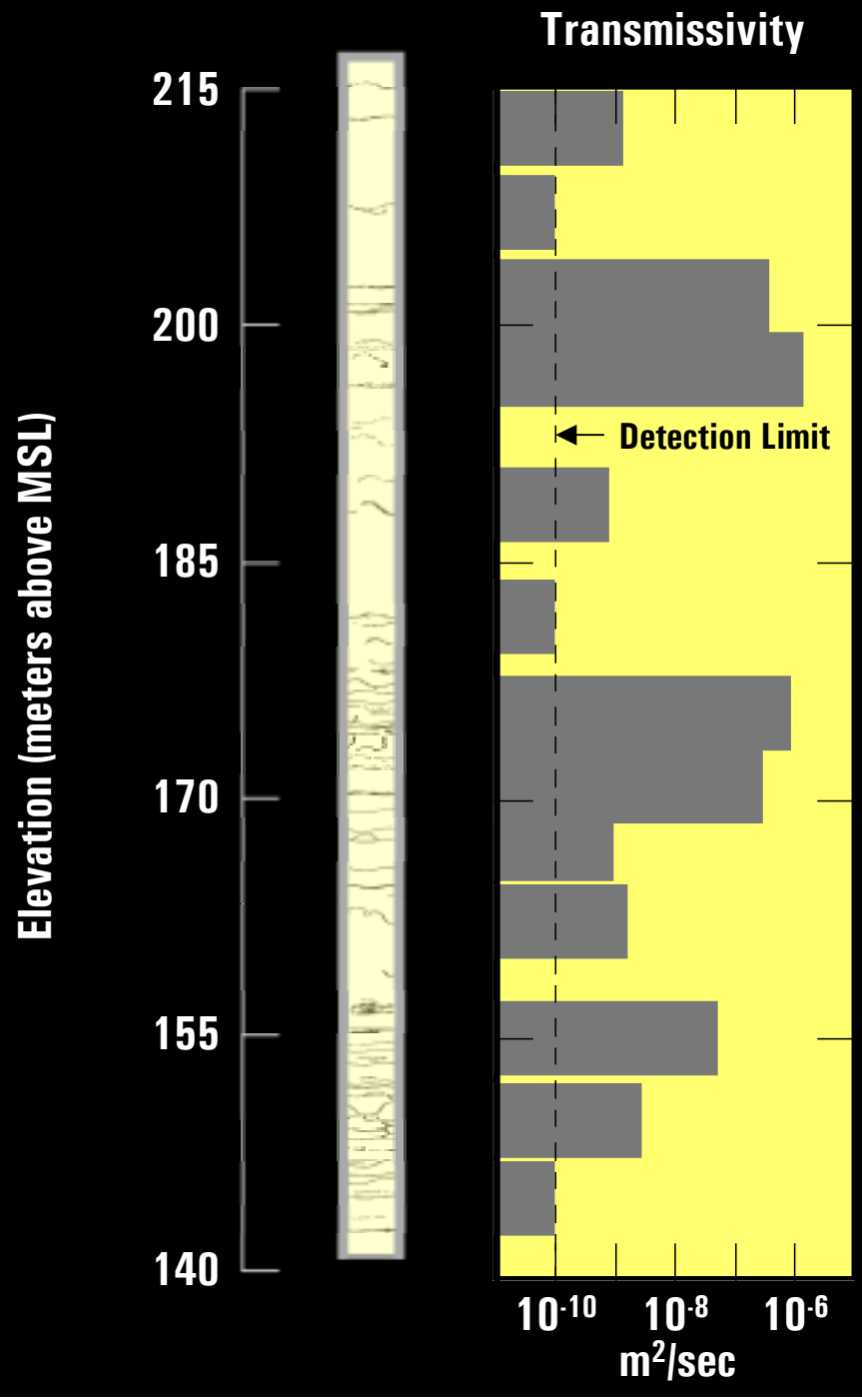
Sampling in an "open-hole" - multiple fractures

$$K_{borehole} = r_s^2 g/8\nu$$

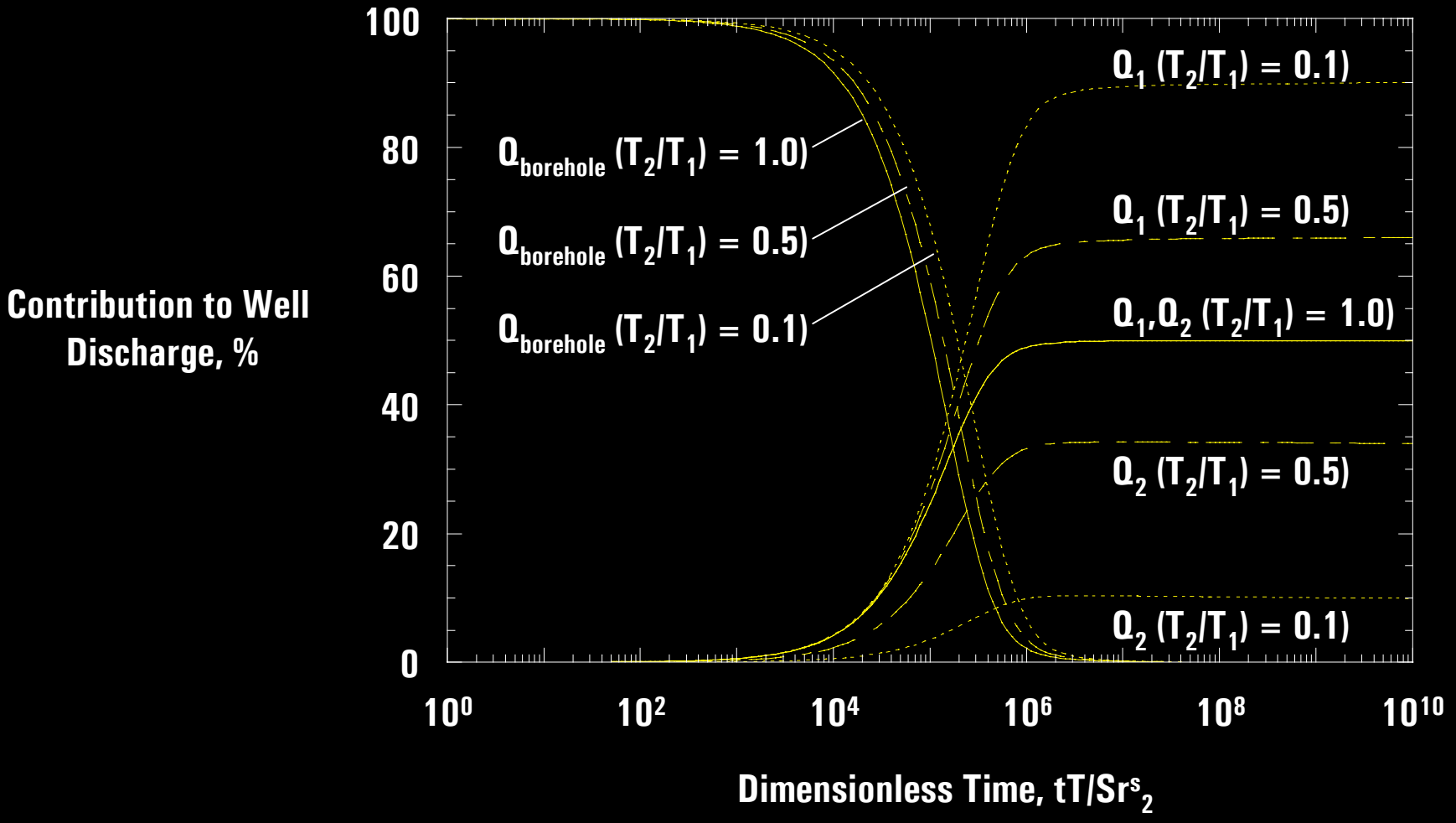
for $r_s = 0.075$ m :

$$K_{borehole} \sim 3 \times 10^4 \text{ m/sec}$$

USGS

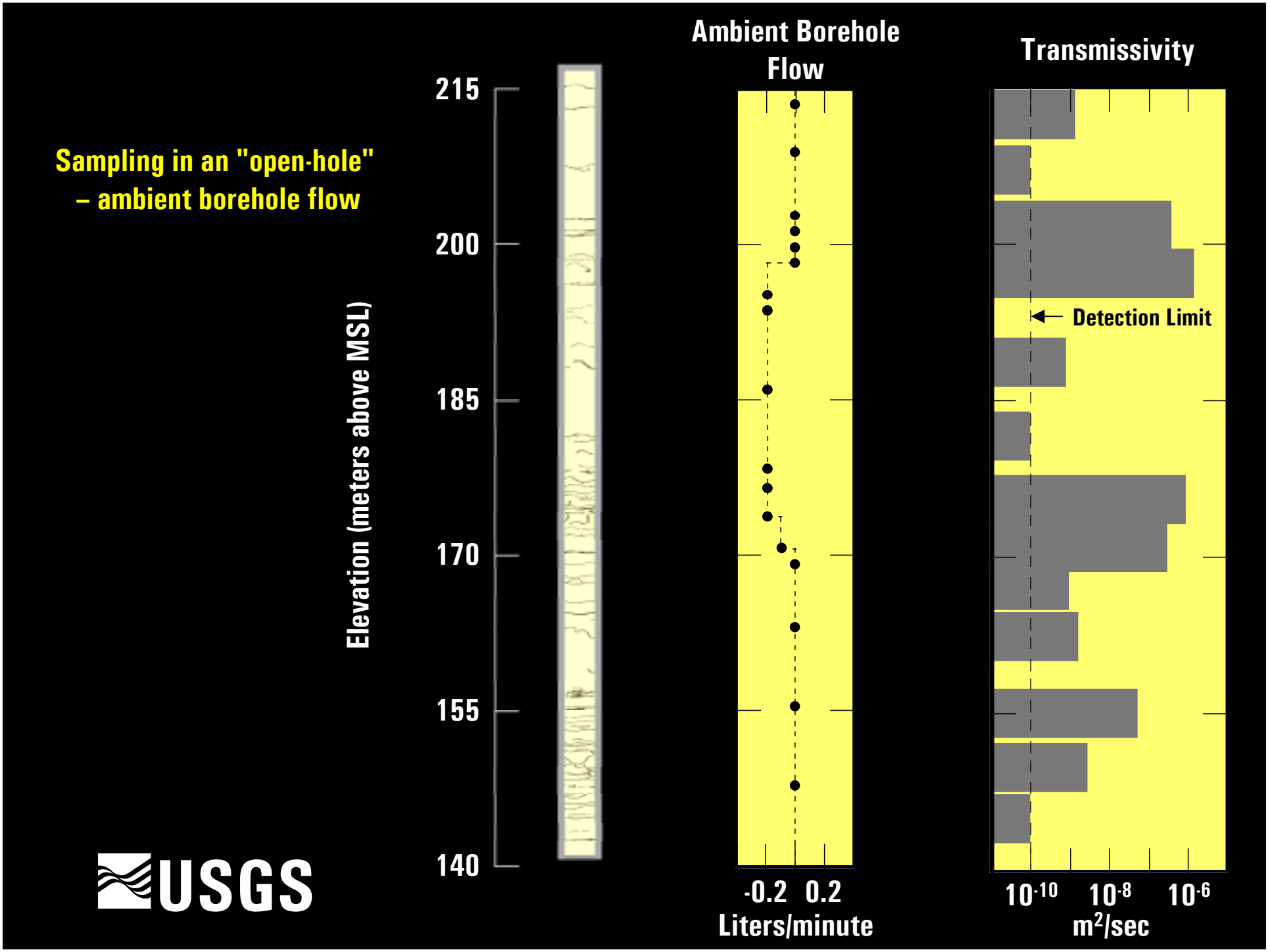


Sampling in an "open-hole" - the case of 2 fractures

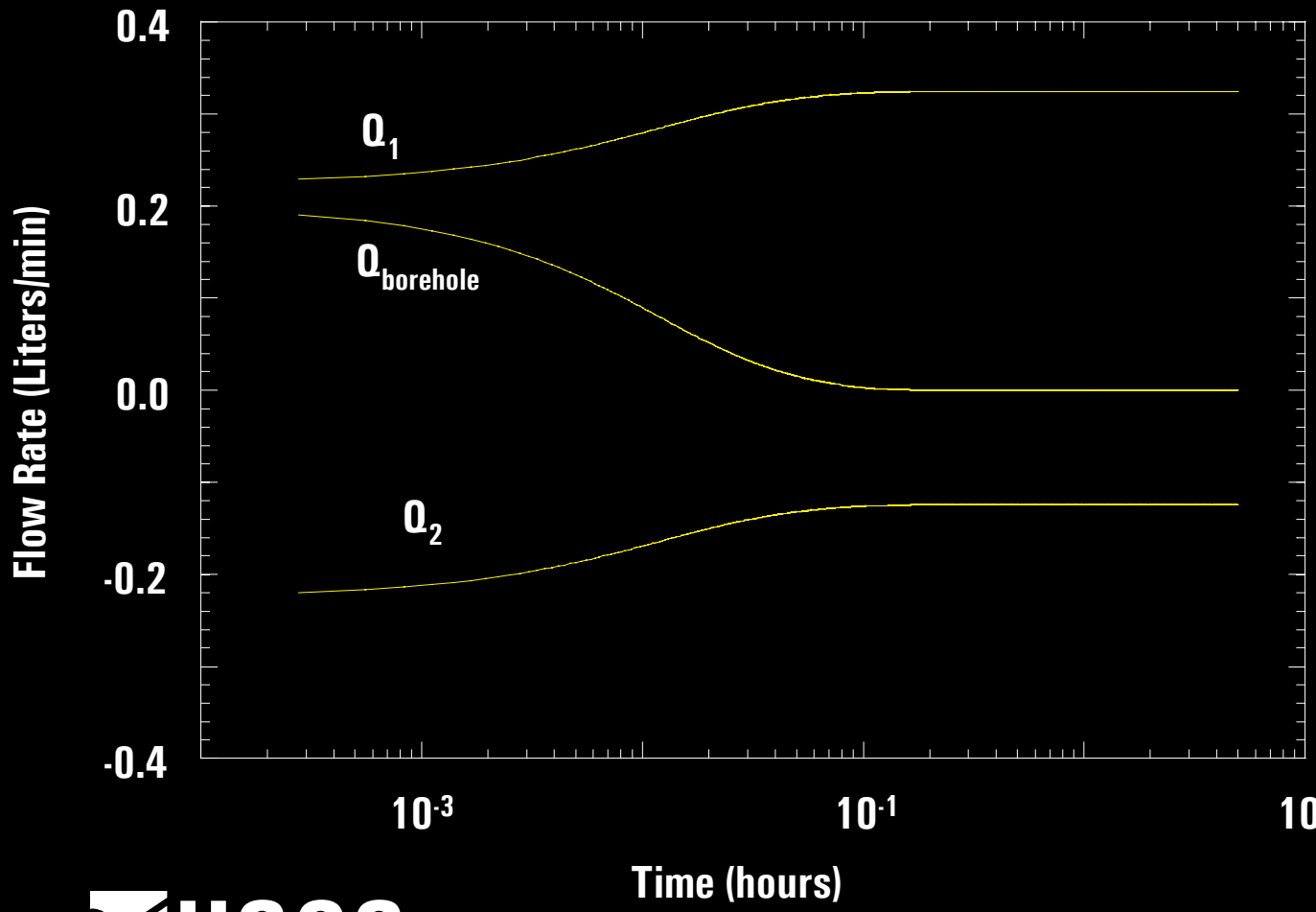


USGS

$\alpha = Sr_s^2/r_c^2 = 10^{-5}$ $S_1 = S_2$


Sampling in an "open-hole"
– ambient borehole flow
Elevation (meters above MSL)
215
200
185
170
155
140
Ambient Borehole Flow
-0.2
0.2
Liters/minute
Transmissivity
Detection Limit
10^{-10}
10^{-8}
10^{-6}
m^2/sec
USGS

Sampling in an "open-hole"
- ambient borehole flow - the case of 2 fractures



$Q = 2.0$ Liters/min

$H_{01} = 0.05$ m

$H_{02} = 0.00$ m

$T_1 = T_2 = 10^{-4}$ m^2/s

$S_1 = S_2 = 10^{-5}$

USGS

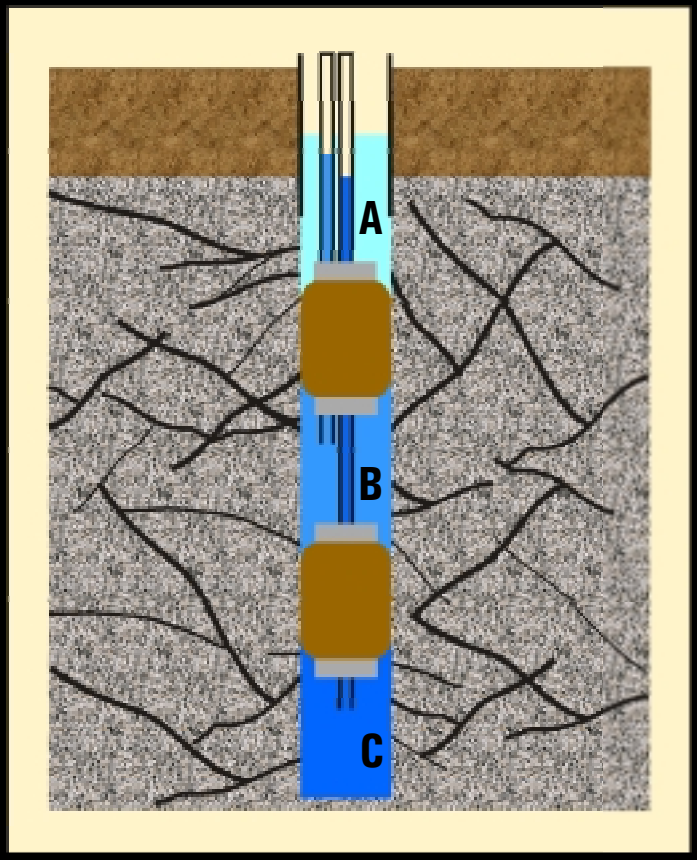
Isolate discrete intervals for collecting water samples

USGS

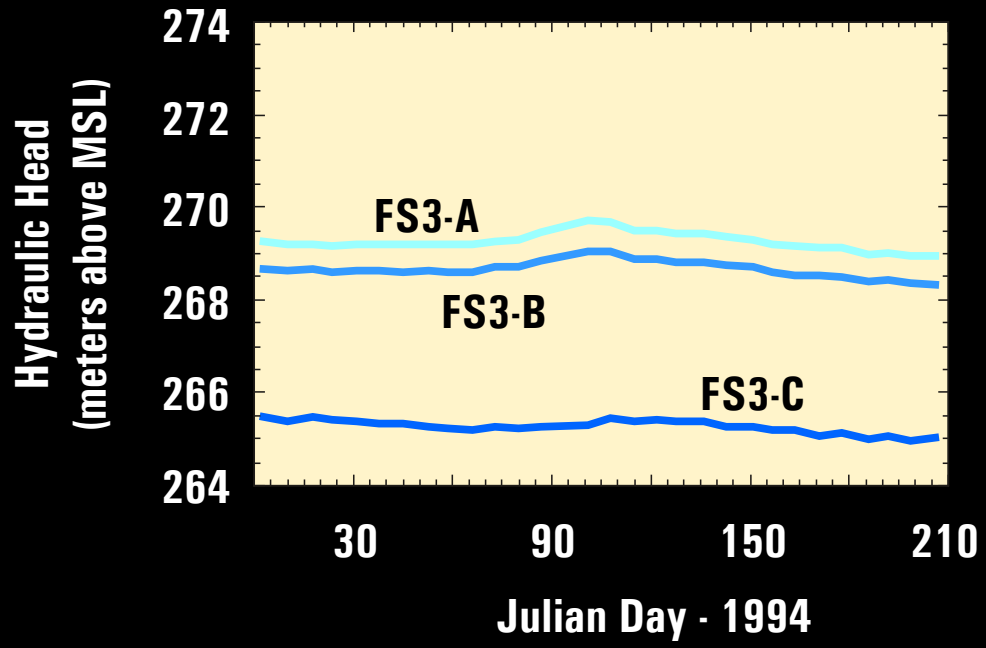
USGS

?

Hydraulic head → Direction of of ground-water flow



Hydraulic Head in Bedrock Well FS3
Mirror Lake Watershed, Grafton County, NH



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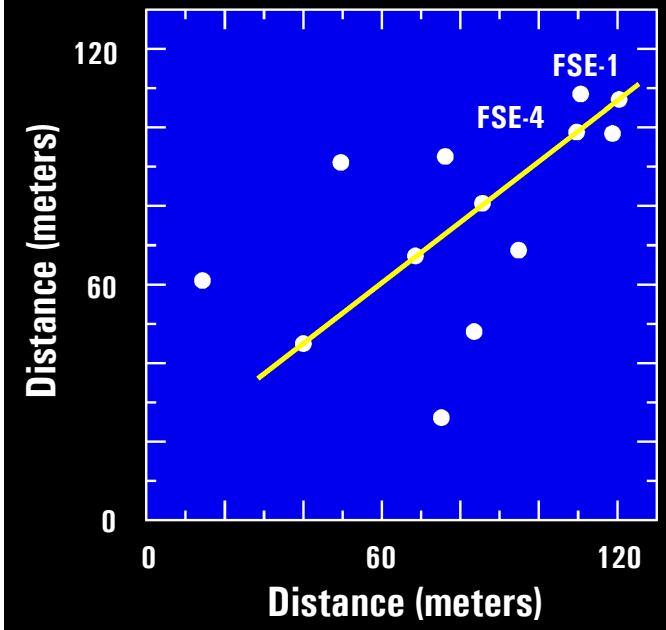
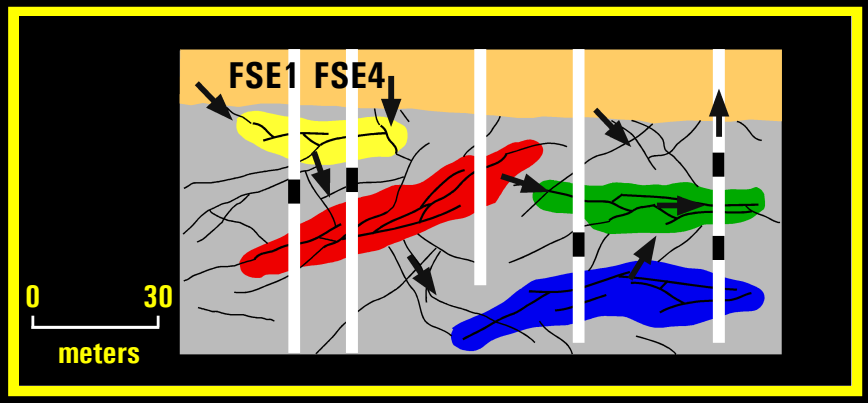
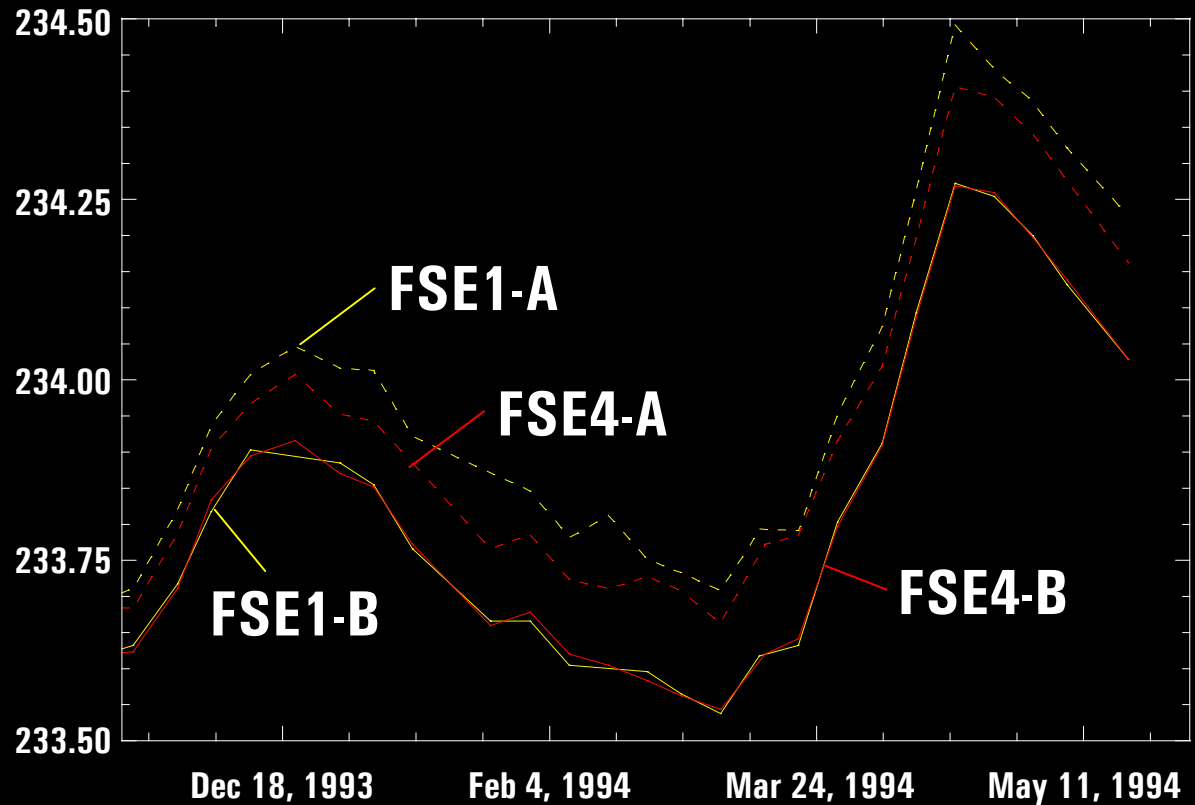
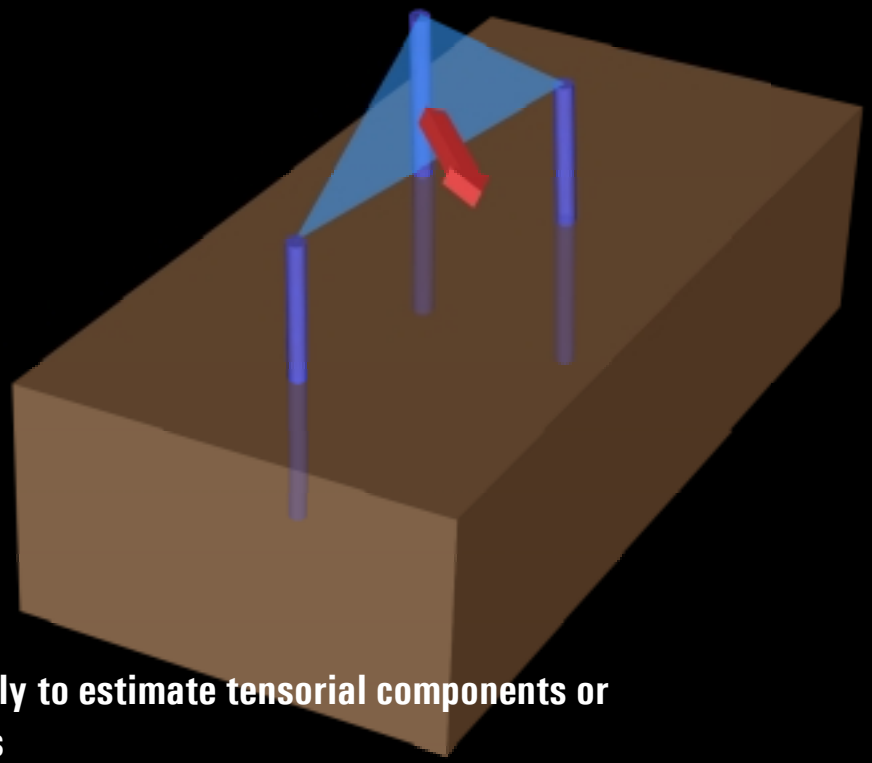

120
60
0
0
60
120
Distance (meters)
Distance (meters)
FSE-1
FSE-4


FSE1
FSE4
0
30
meters


234.50
234.25
234.00
233.75
233.50
Hydraulic Head
meters above MSL
FSE1-A
FSE4-A
FSE1-B
FSE4-B
Dec 18, 1993
Feb 4, 1994
Mar 24, 1994
May 11, 1994

USGS

$$\underset{\sim}{v} = \frac{\underset{\sim}{K}}{n} \bullet \underset{\sim}{\nabla} h$$



$\underset{\sim}{K}$ → ½-order of magnitude, unlikely to estimate tensorial components or heterogeneity between wells

n → from tracer tests magnitude varies (0.001 to 0.02)

$\underset{\sim}{\nabla} h$ → in highly permeable zones, can a gradient be estimated with confidence?

USGS

Summary

- Hydraulic head, chemical sampling, fluid velocity
- Multidisciplinary "Tool Box" approach
- Assessing uncertainty

USGS