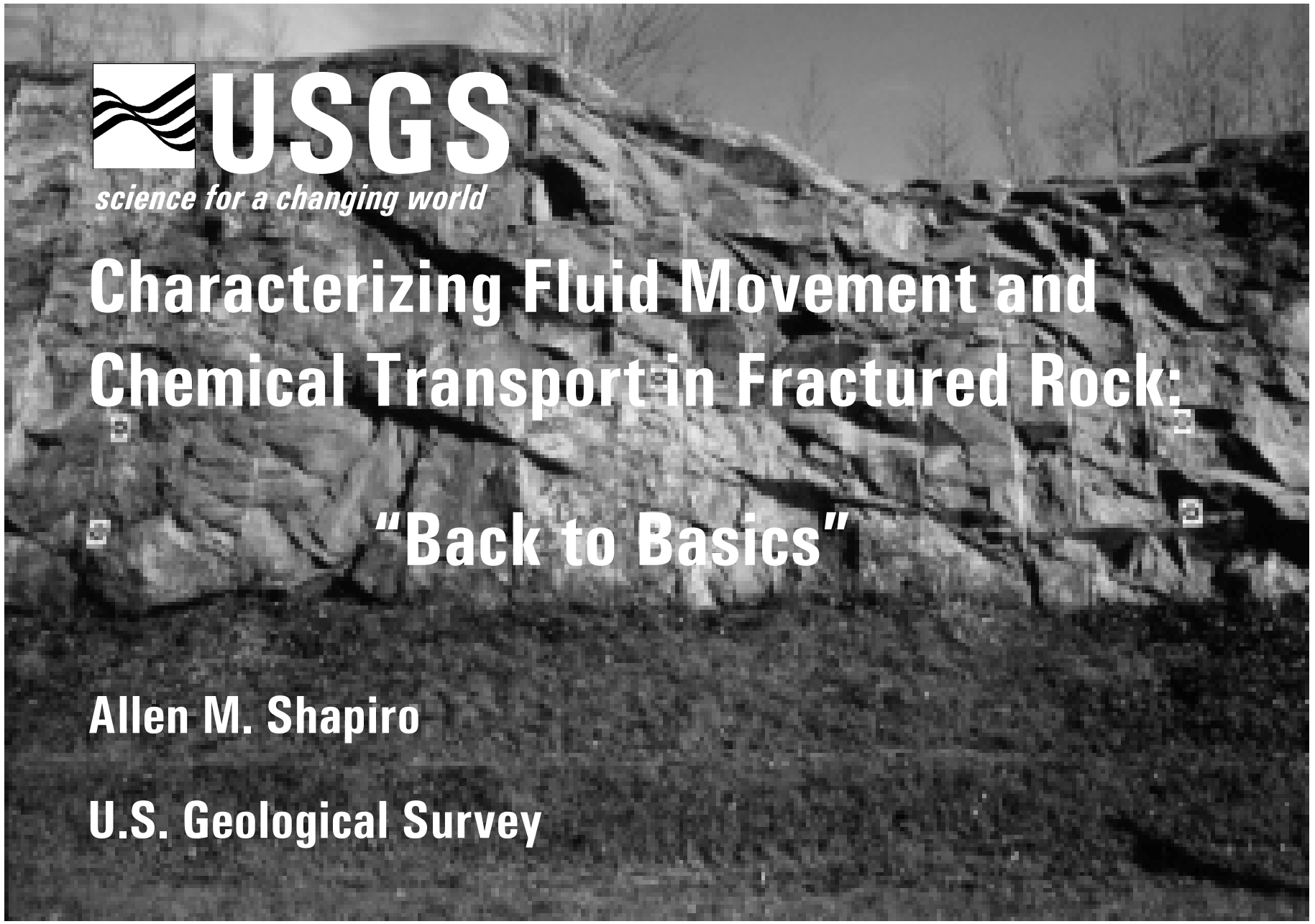
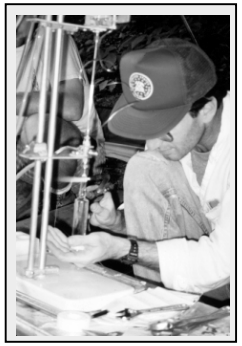

USGS
science for a changing world
Characterizing Fluid Movement and Chemical Transport in Fractured Rock:
"Back to Basics"
Allen M. Shapiro
U.S. Geological Survey

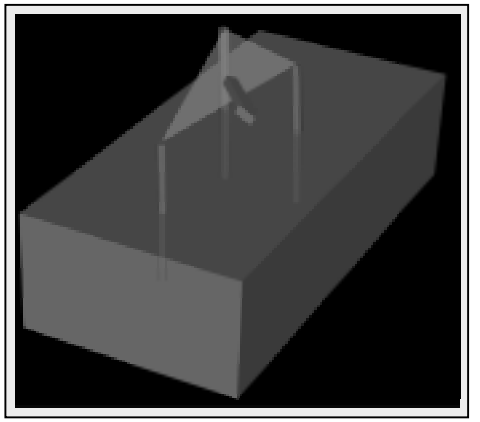
"The Basics"

- How is hydraulic head measured?

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



- How is fluid velocity measured?



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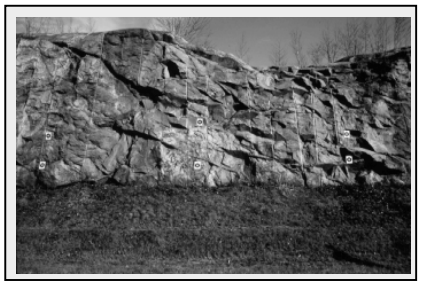
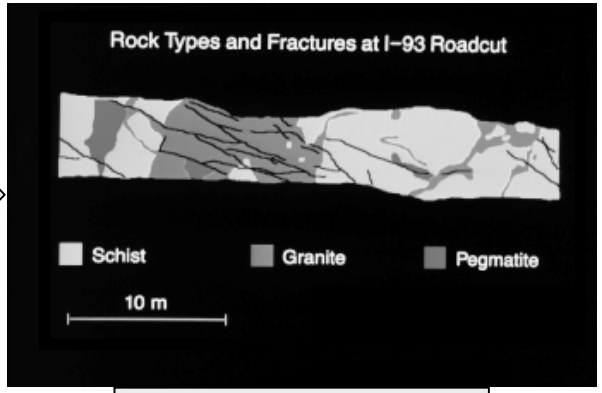
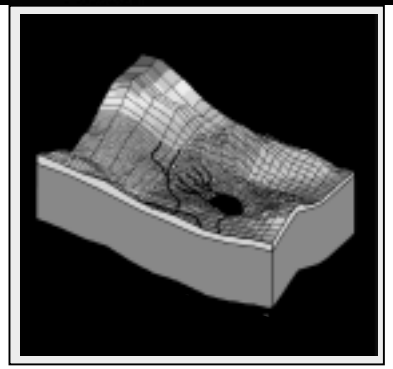
"Other Issues"

- The level of detail . . .

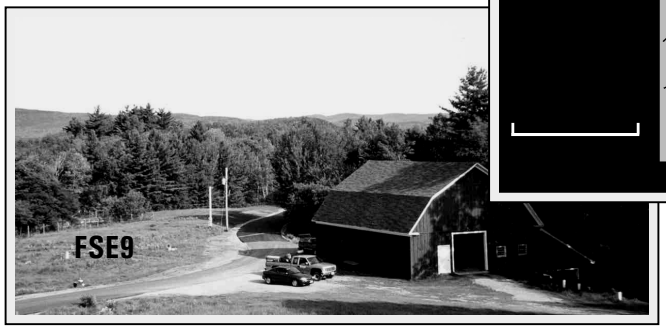


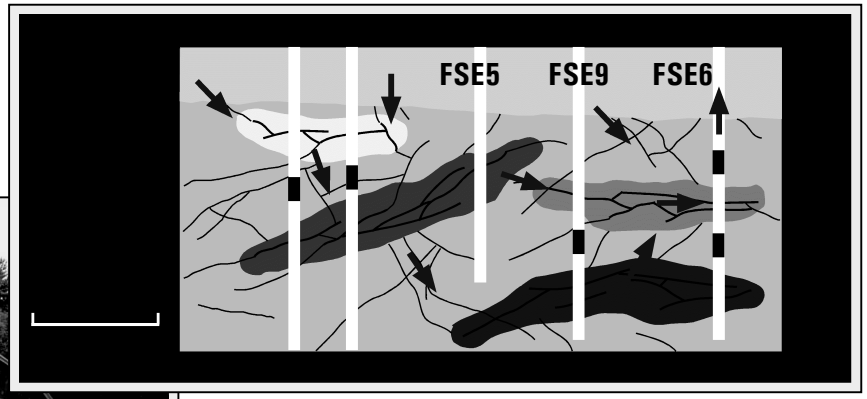




- Placing the site into a regional perspective . . .

- Synthesizing information . . .





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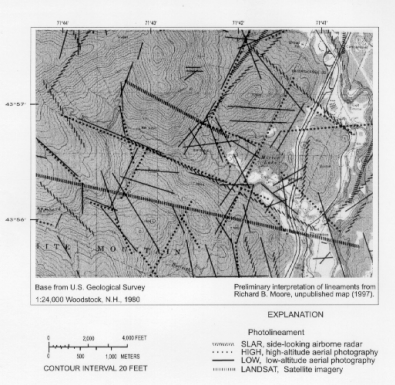
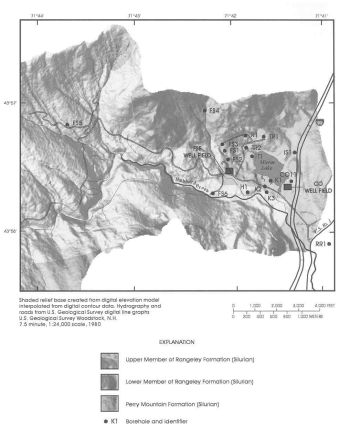
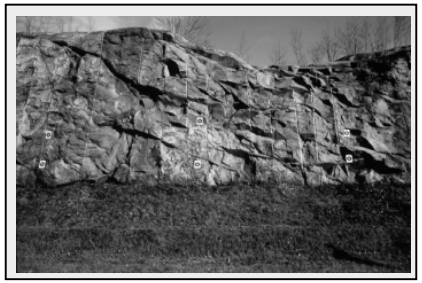
Remote Sensing



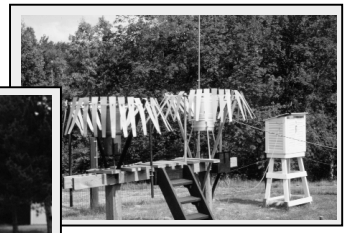
Surface Geophysics

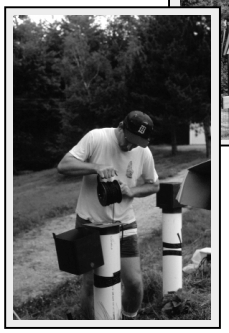
Geologic Mapping





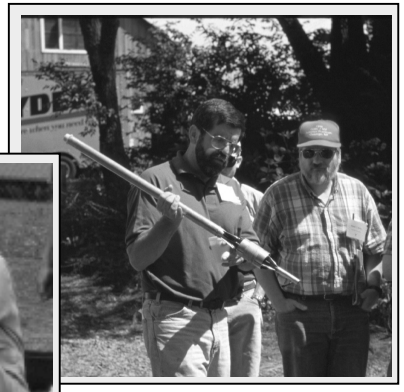
Fracture Mapping





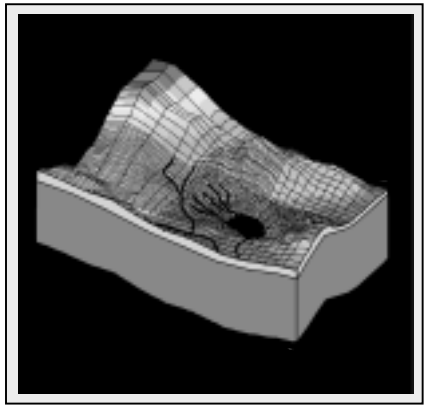
Regional Hydrology

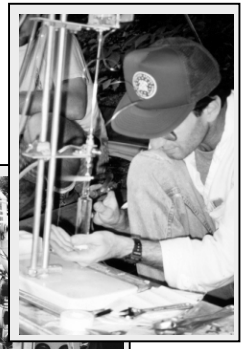
Borehole Geophysics



Hydrogeologic Characterization In Fractured Rock

Ground-Water Modeling

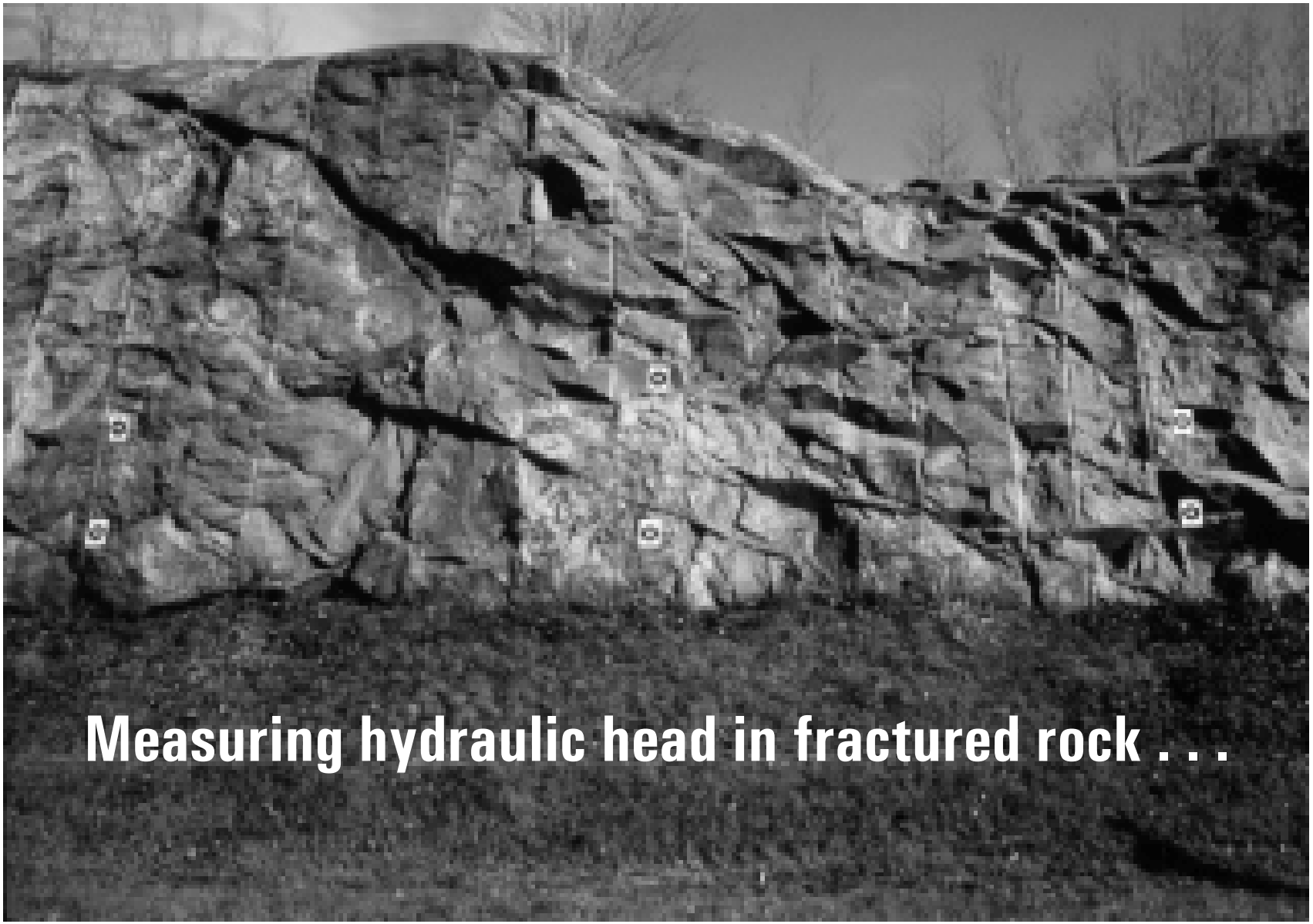




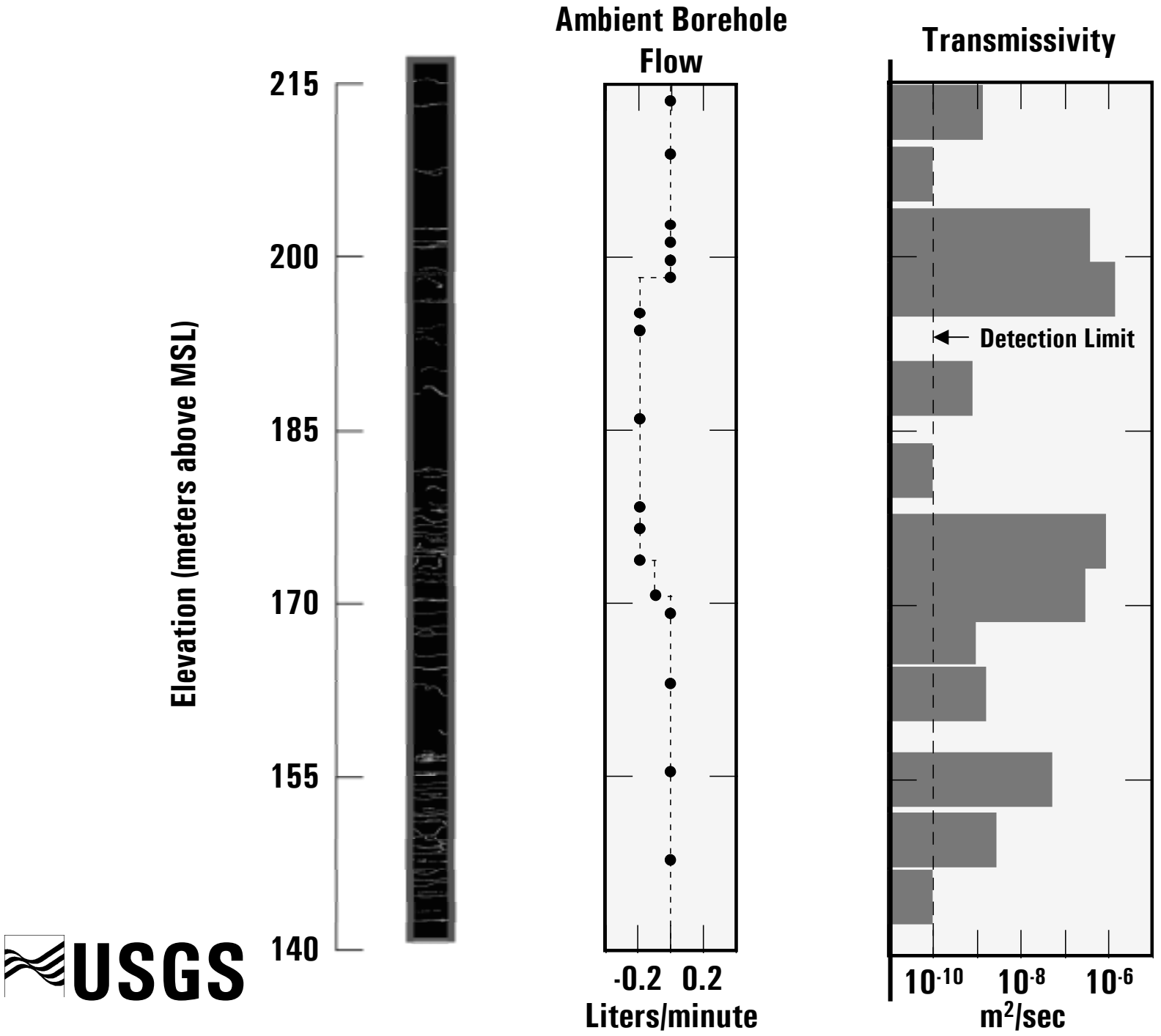
Geochemistry

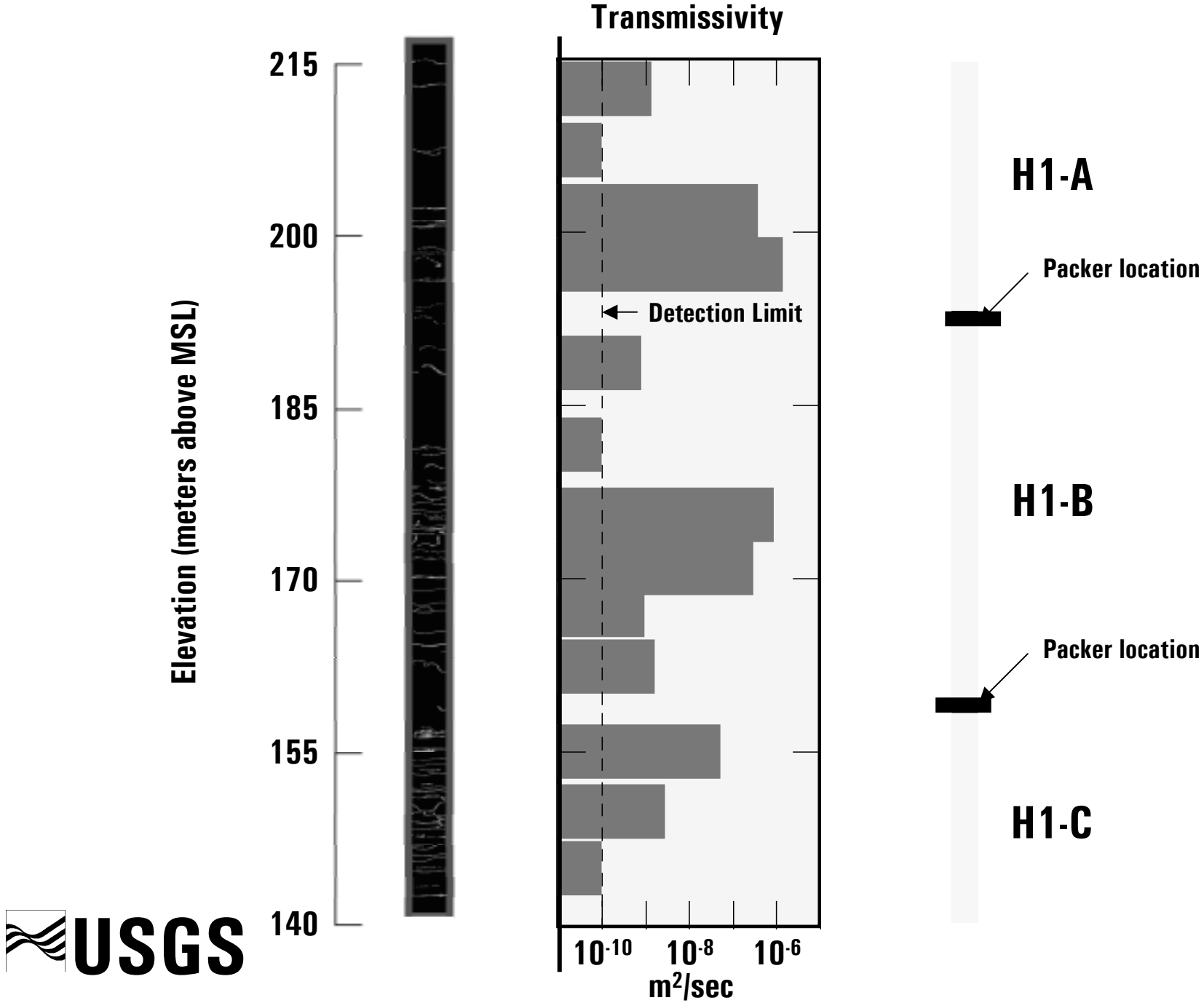
Hydrologic Testing

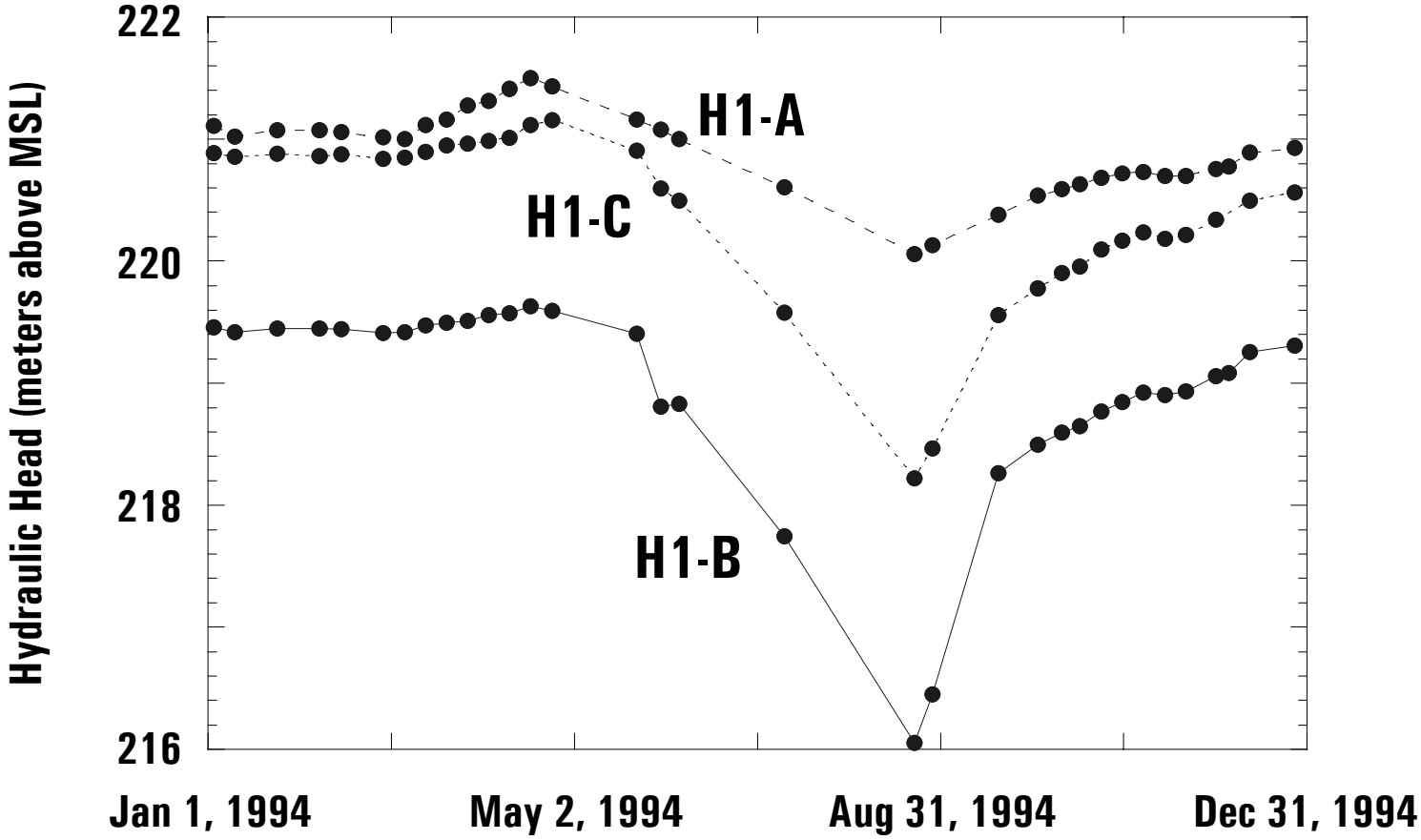
USGS



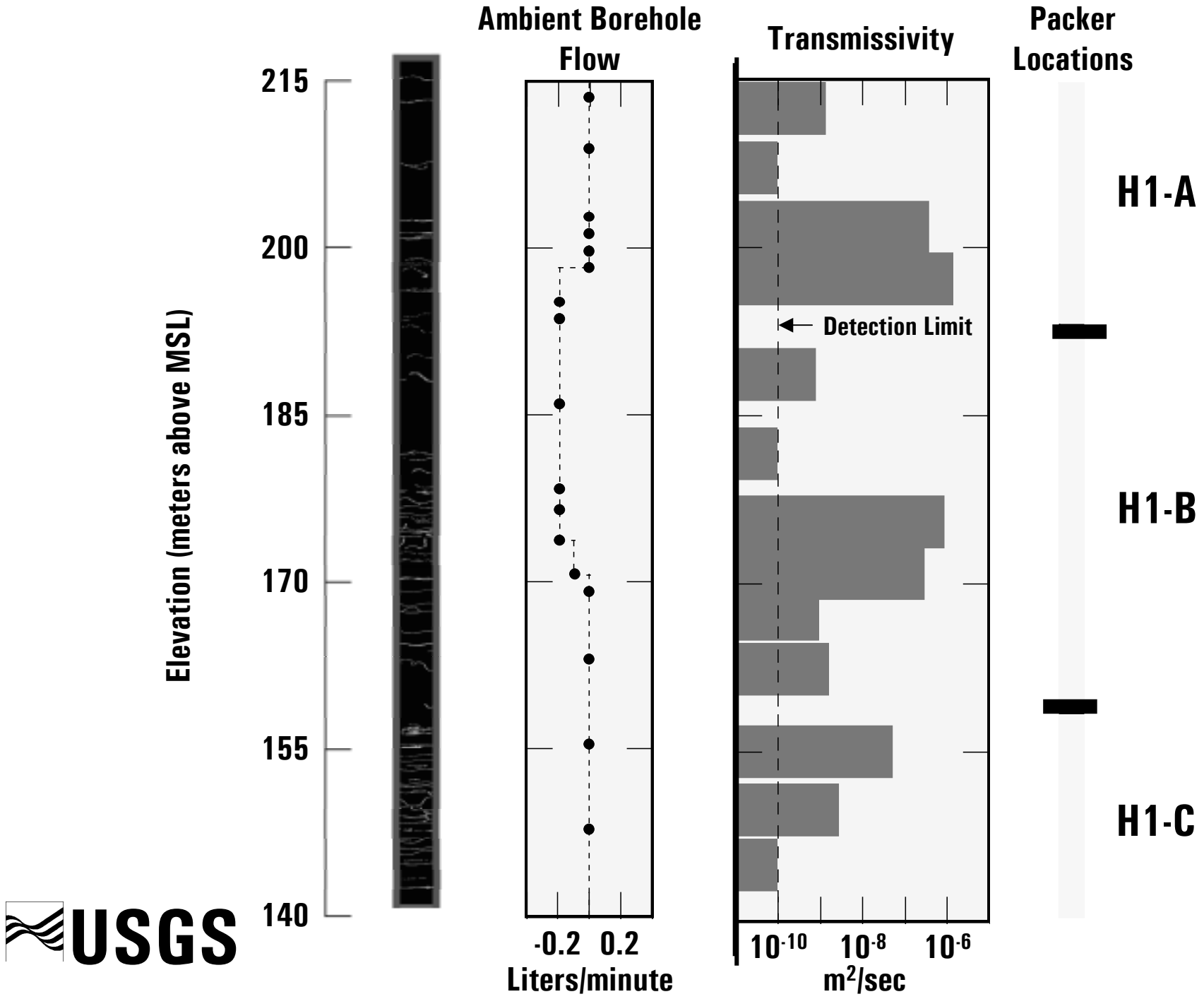
USGS


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

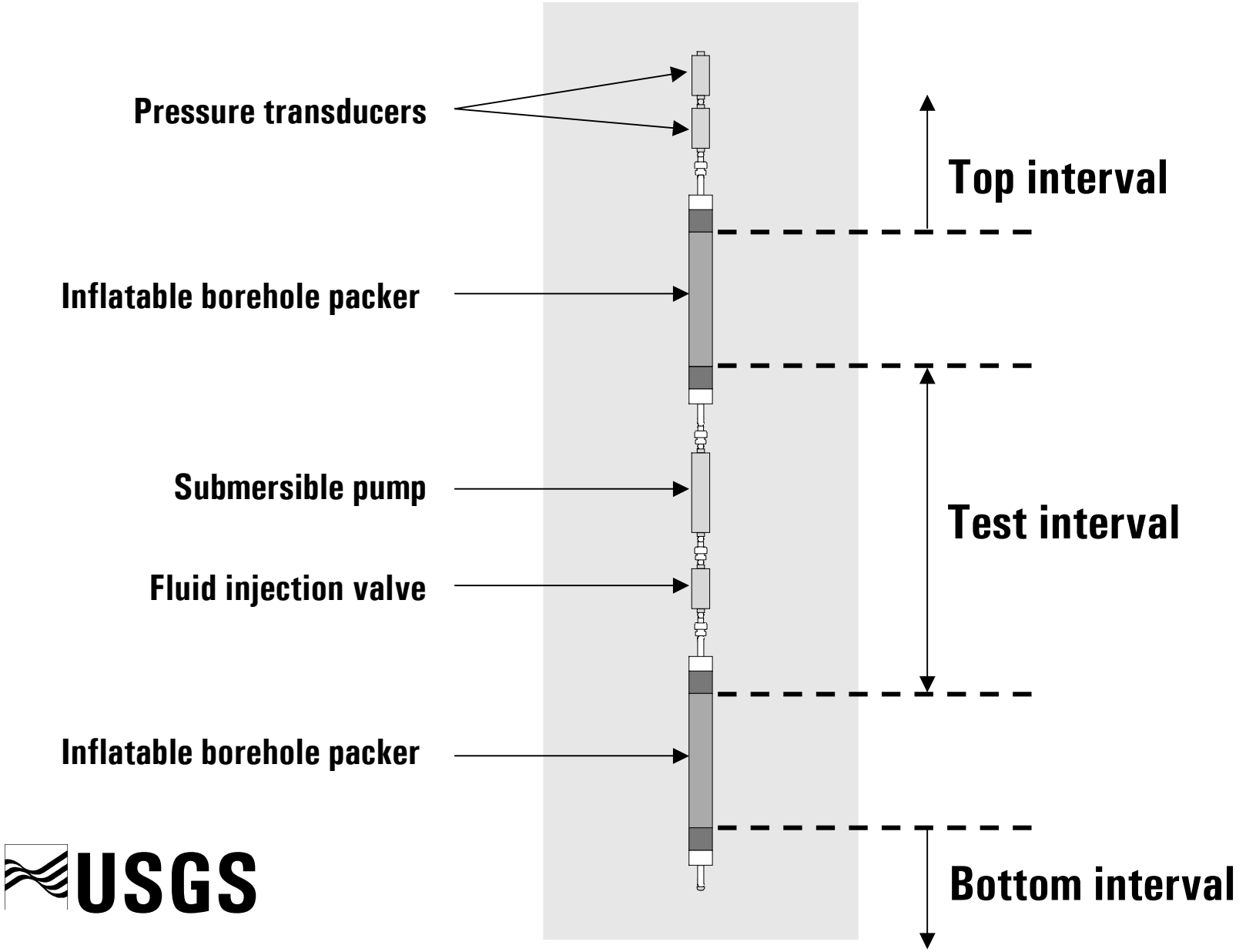

Transmissivity
215
200
185
170
155
140
Elevation (meters above MSL)
Detection Limit
H1-A
Packer location
H1-B
Packer location
H1-C
10-10
10-8
10-6
m2/sec
USGS


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

USGS

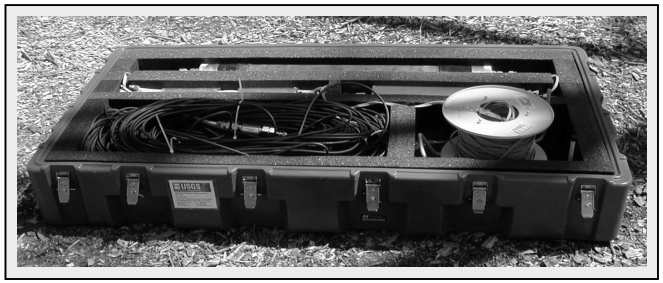

Ambient Borehole Flow
Transmissivity
Packer Locations
Elevation (meters above MSL)
215
200
185
170
155
140
Detection Limit
H1-A
H1-B
H1-C
-0.2
0.2
Liters/minute
10-10
10-8
10-6
m2/sec
USGS

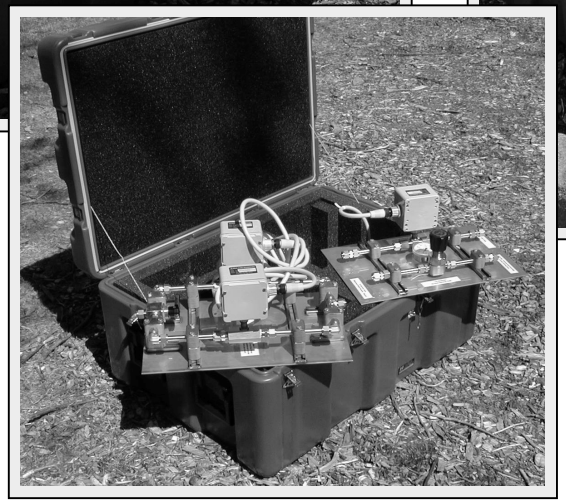
Transportable Multifunction Borehole Testing Apparatus



USGS

Transportable Multifunction Borehole Testing Apparatus

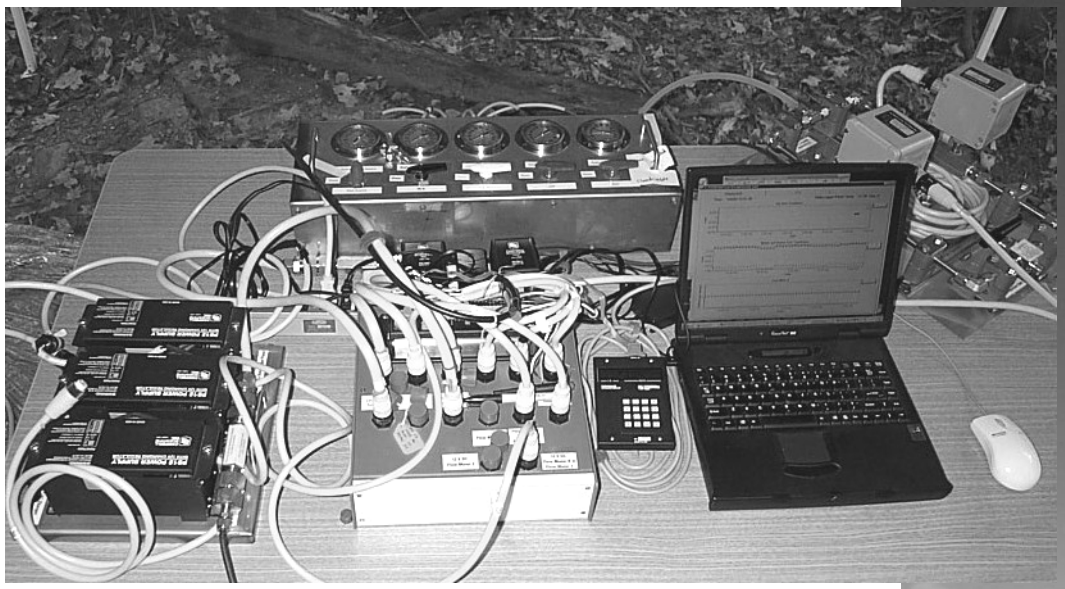


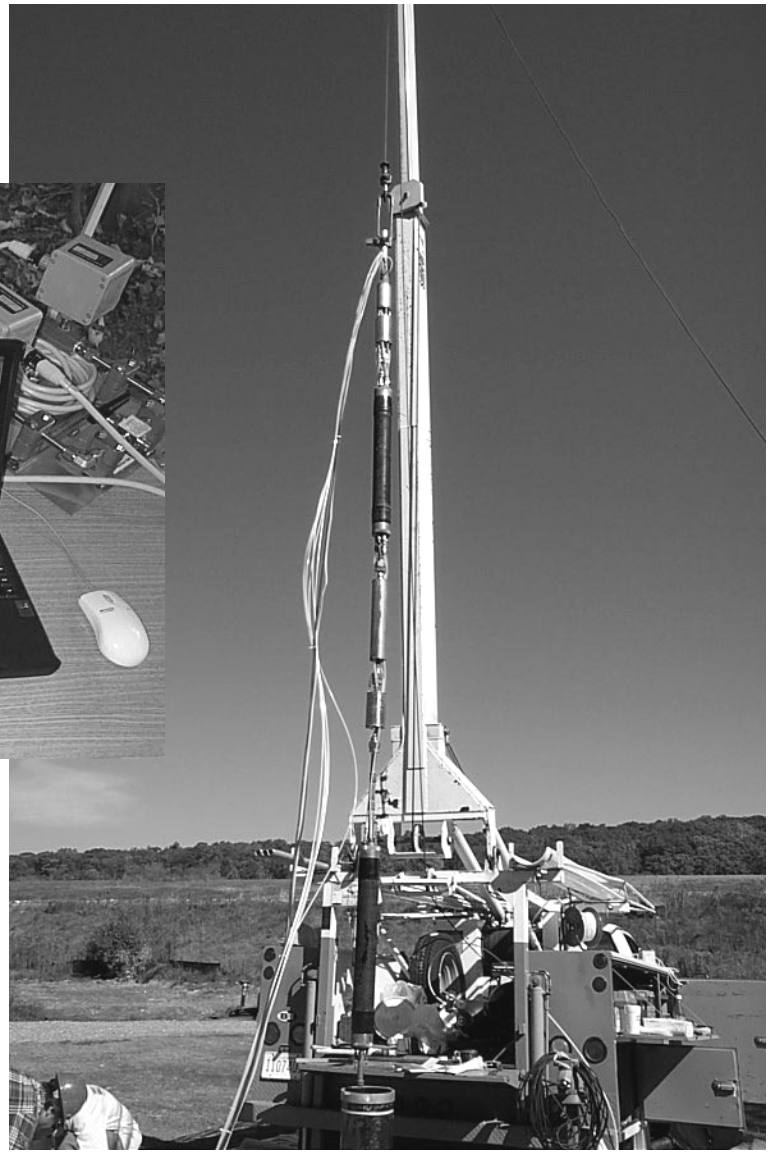


- Rapid assembly
- Isolate discrete intervals
- Geochemical sampling
- Hydraulic head
- Estimate hydraulic properties:
  - Fluid injection tests
  - Slug tests
  - Pumping
- Single-hole tracer tests
- Real-time data display & interpretation

USGS

Transportable Multifunction Borehole Testing Apparatus





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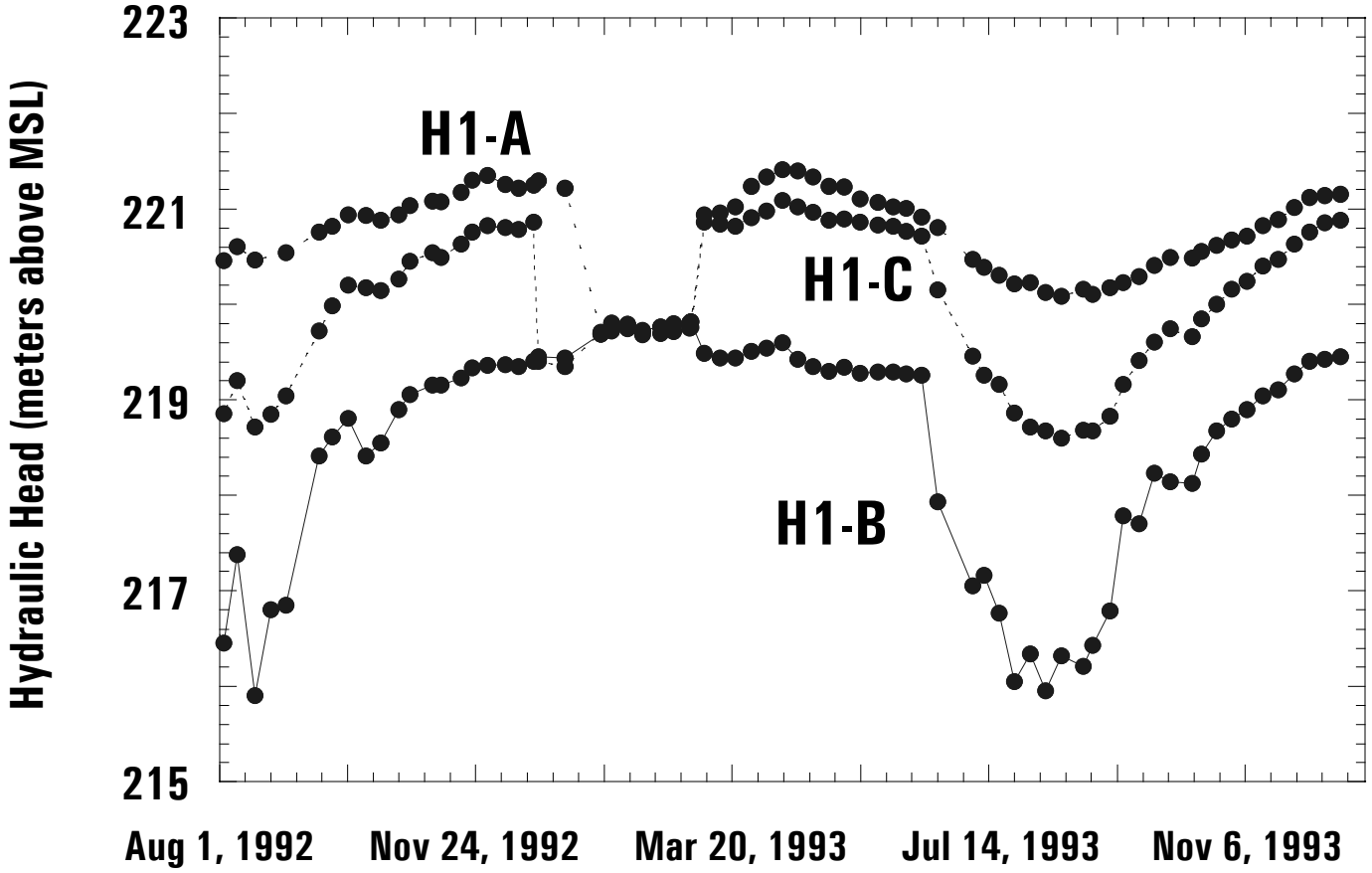
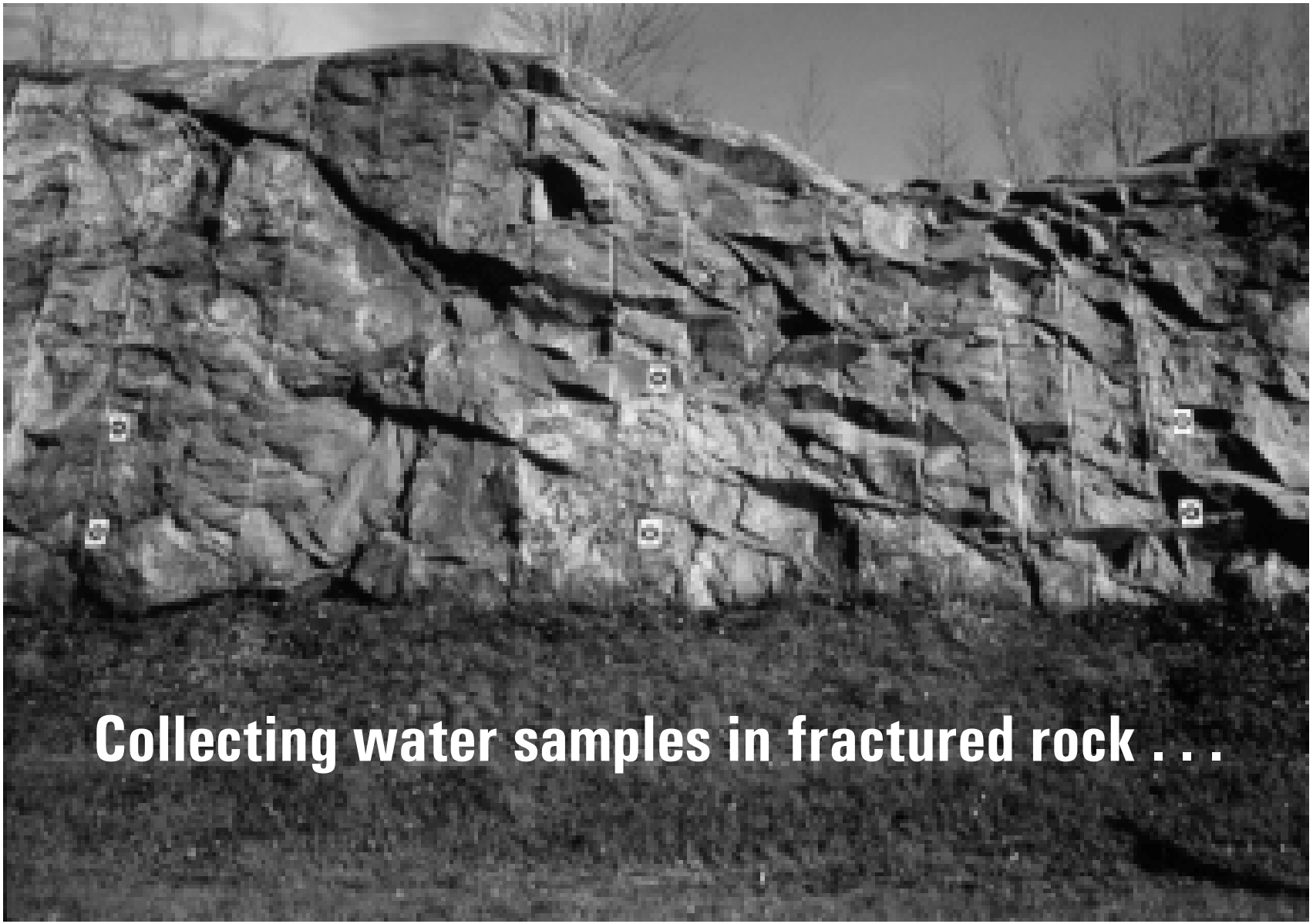
What is the meaning of an "open-hole" hydraulic head?

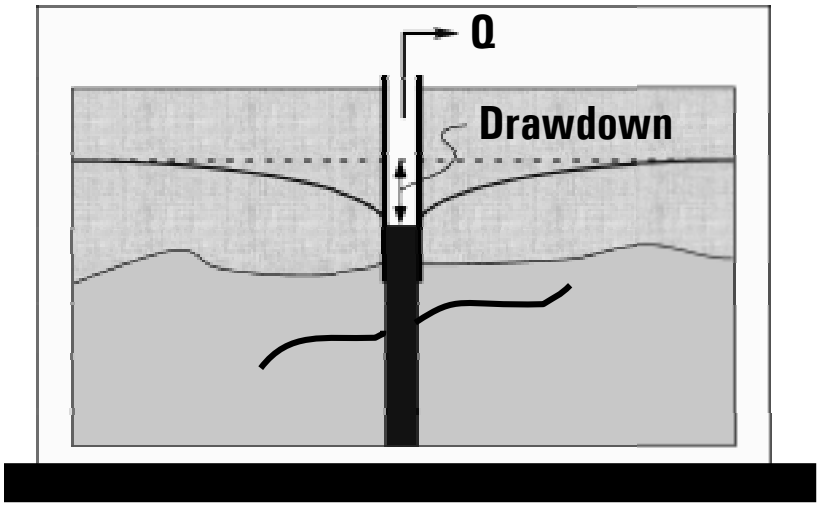


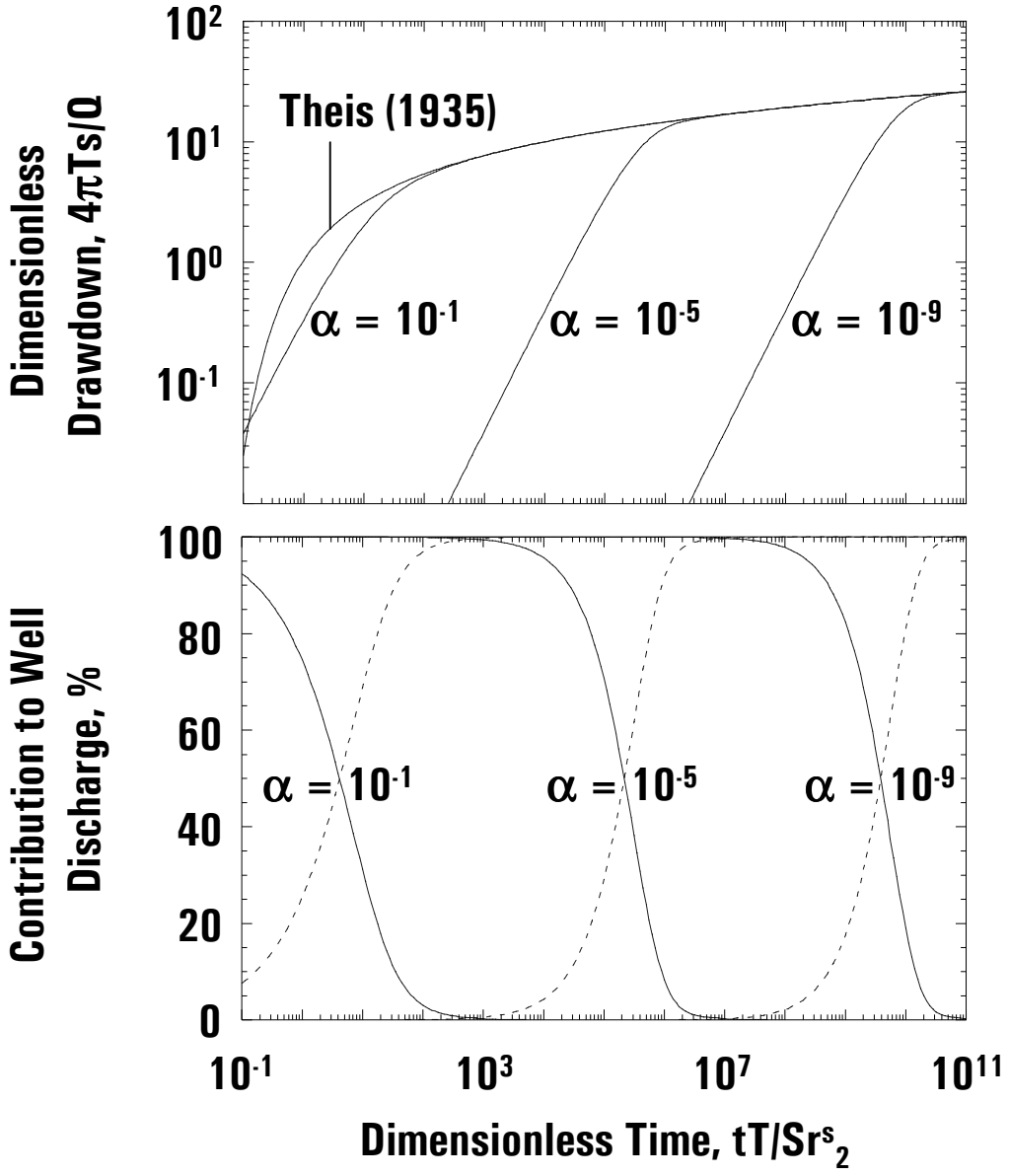
USGS



USGS

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





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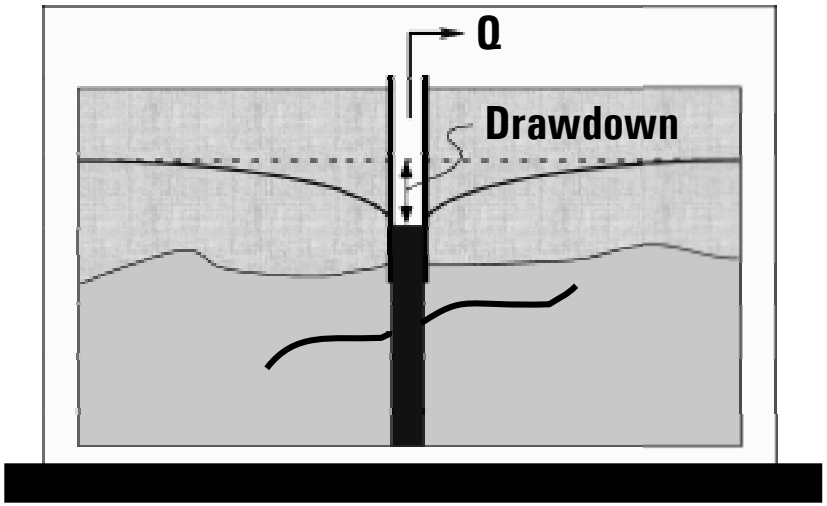
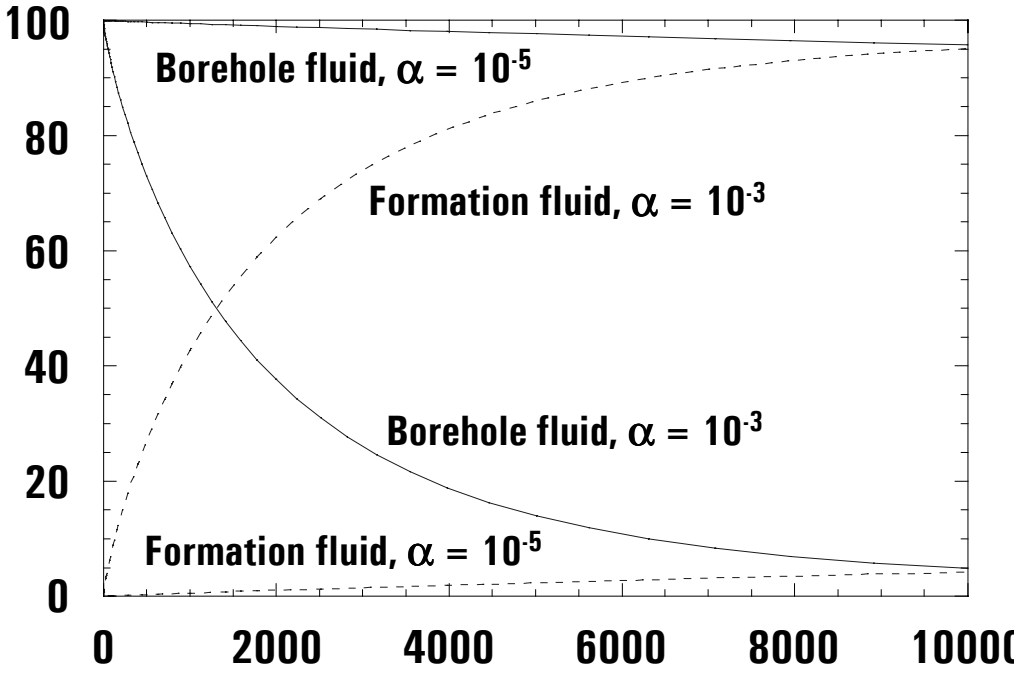
$\alpha = Sr_s^2/r_c^2$

Borehole fluid

Formation fluid



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



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Sampling in an "open-hole" - multiple fractures

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

for $r_s = 0.075$ m :

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

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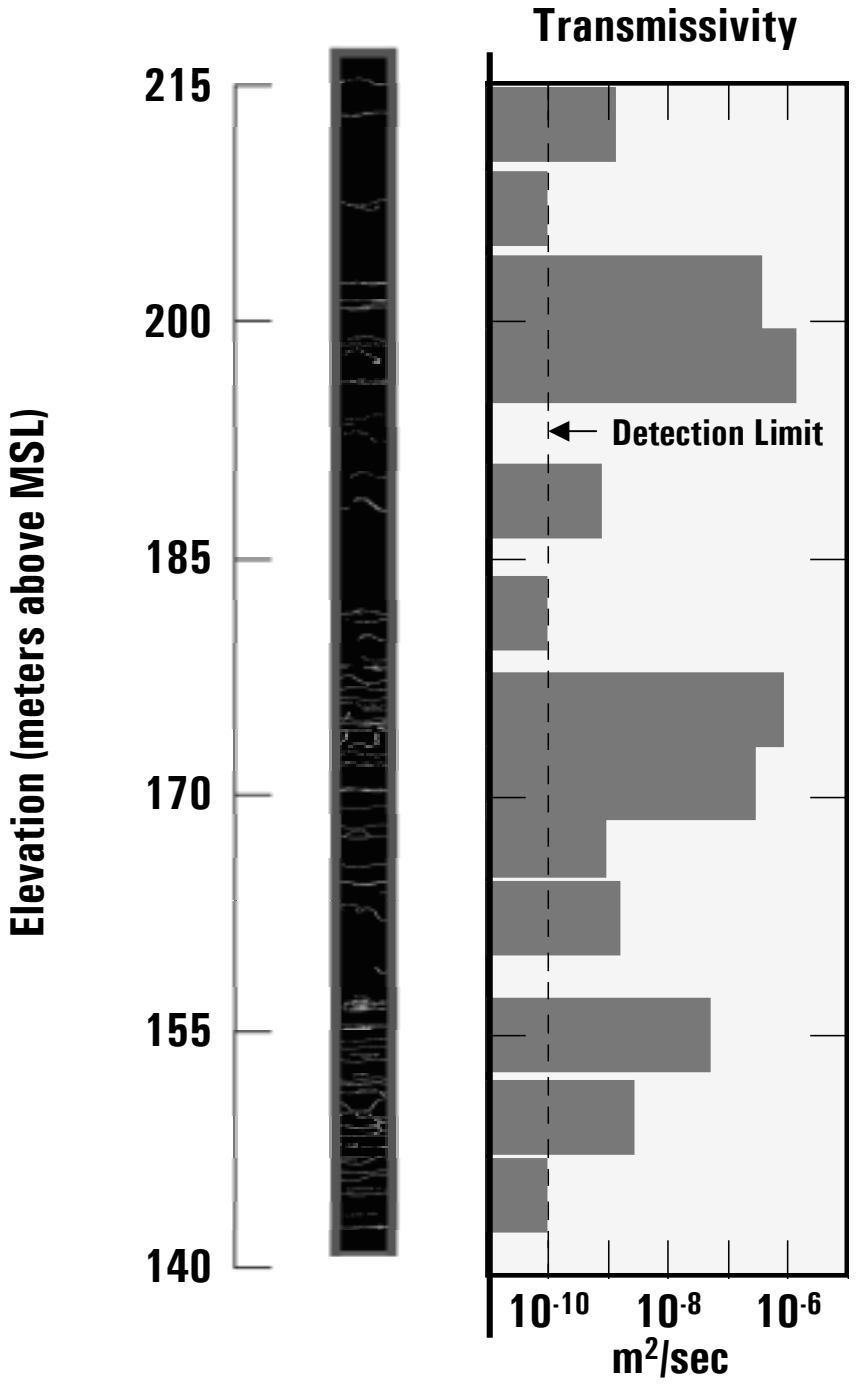
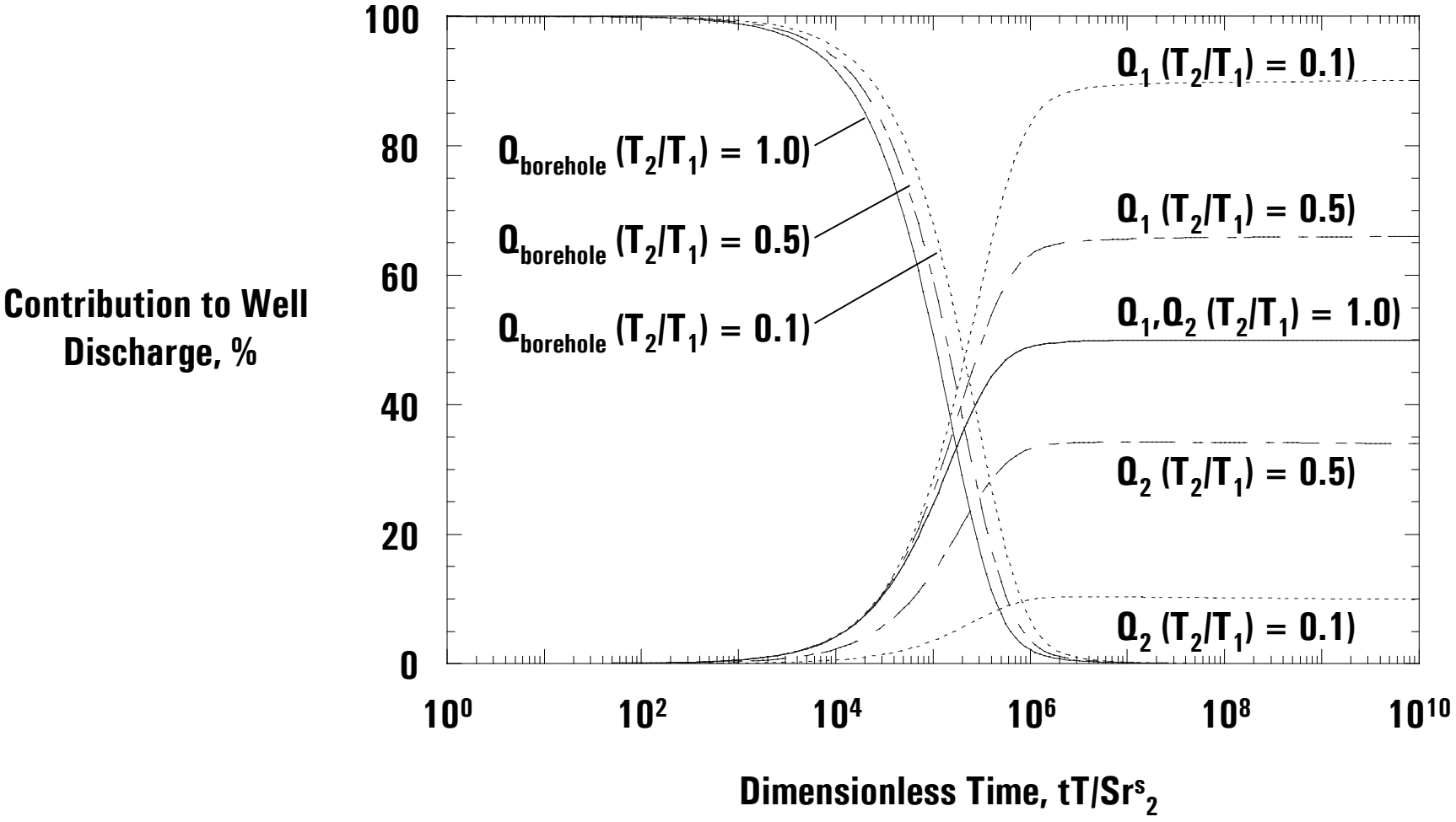


Sampling in an "open-hole" - the case of 2 fractures



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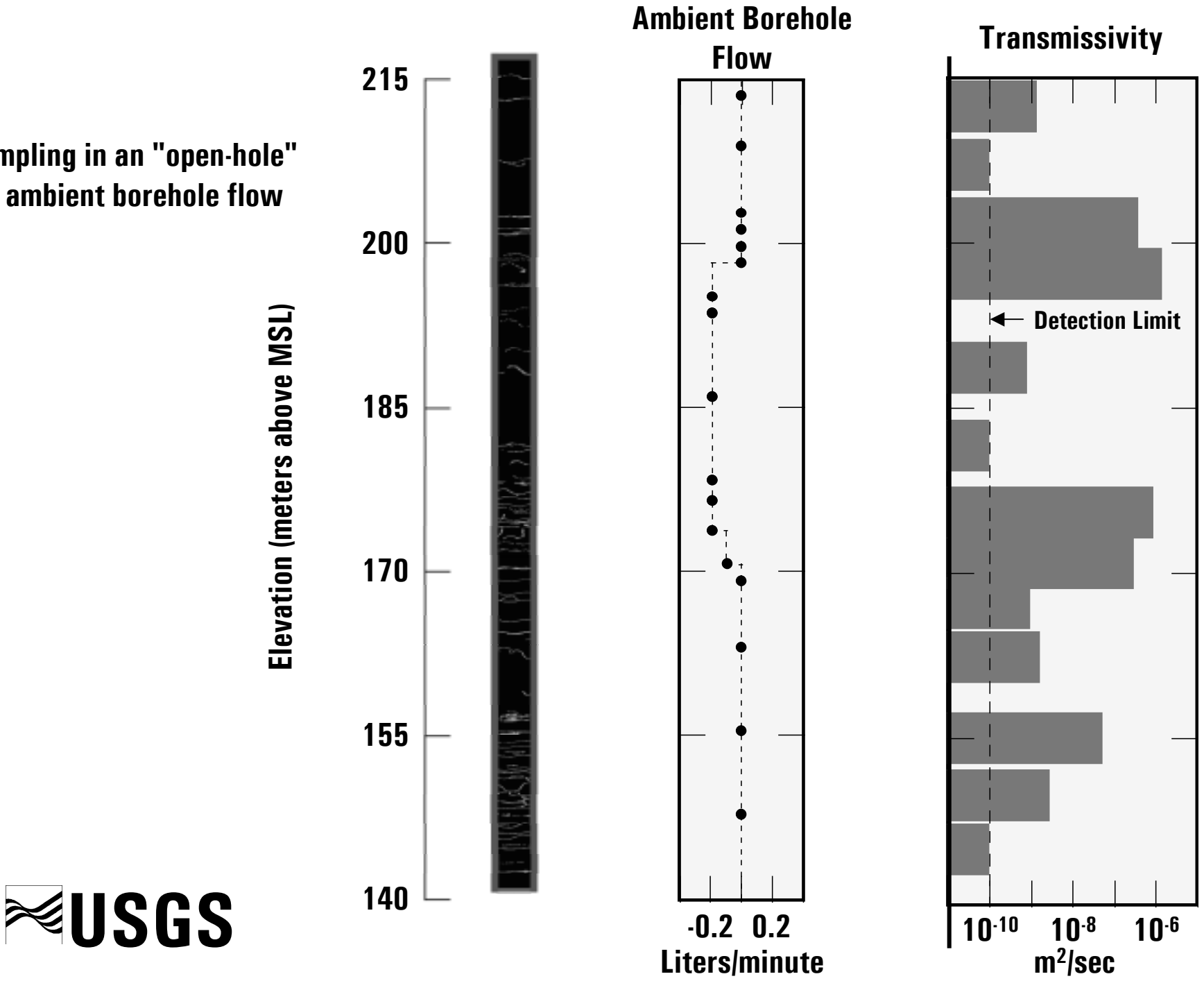
$\alpha = Sr_s^2/r_c^2 = 10^{-5}$ $S_1 = S_2$

Sampling in an "open-hole" – ambient borehole flow



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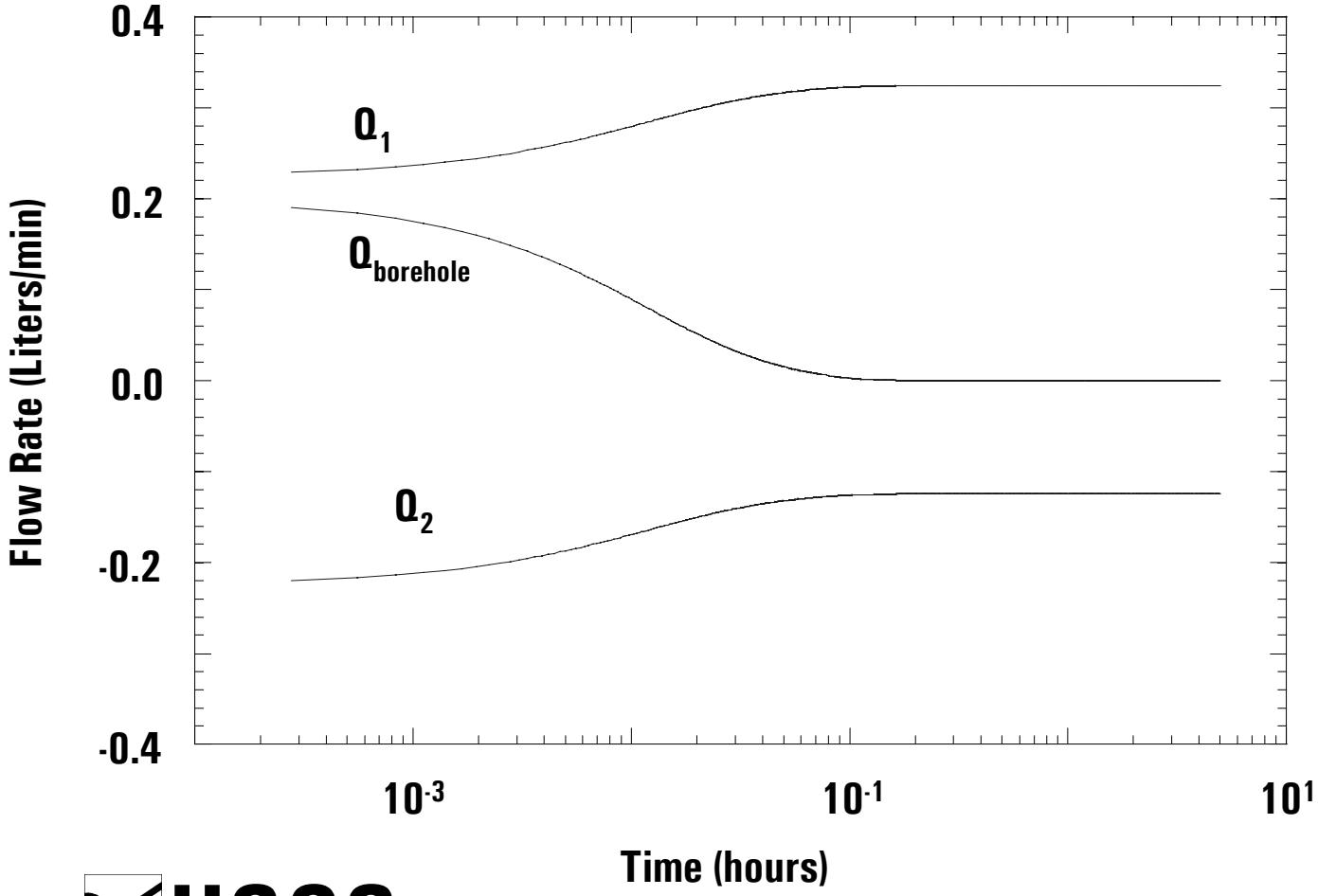
Sampling in an "open-hole"
- ambient borehole flow - the case of 2 fractures



$Q = 2.0$ Liters/min

$H_{01} = 0.05$ m

$H_{02} = 0.00$ m

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

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

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Isolate discrete intervals for collecting water samples

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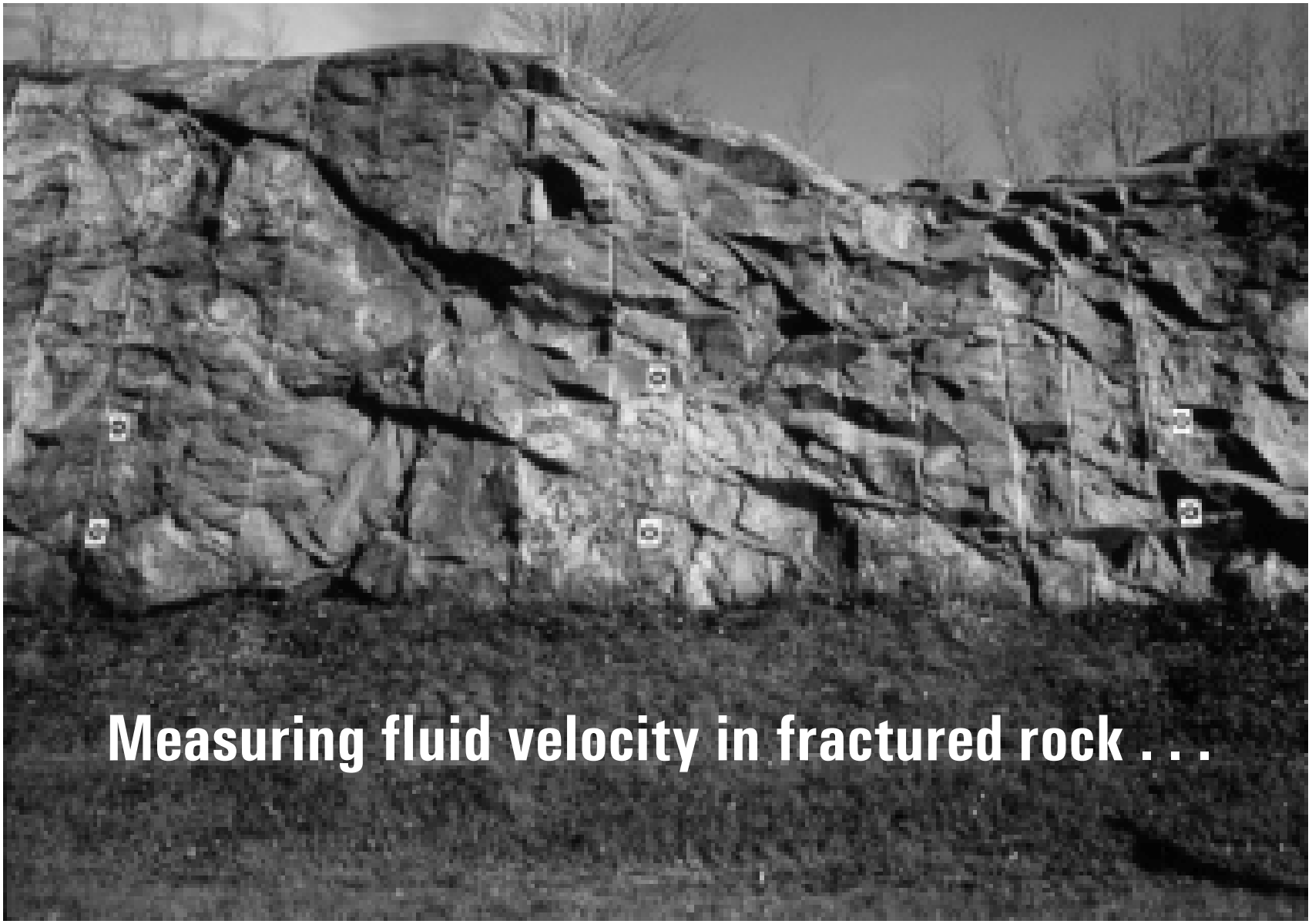

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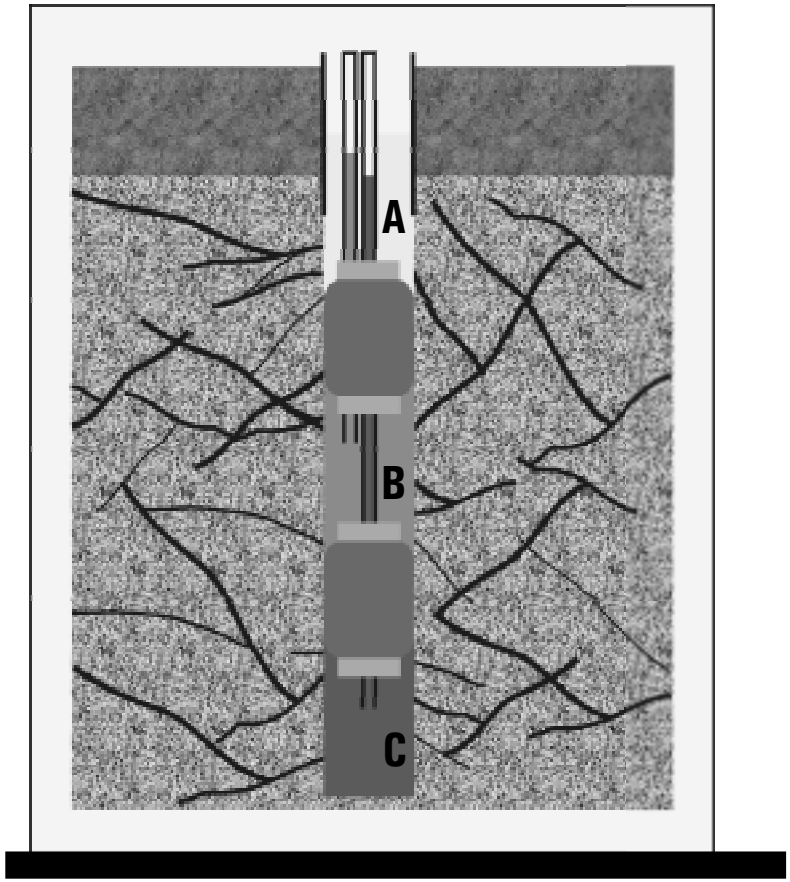
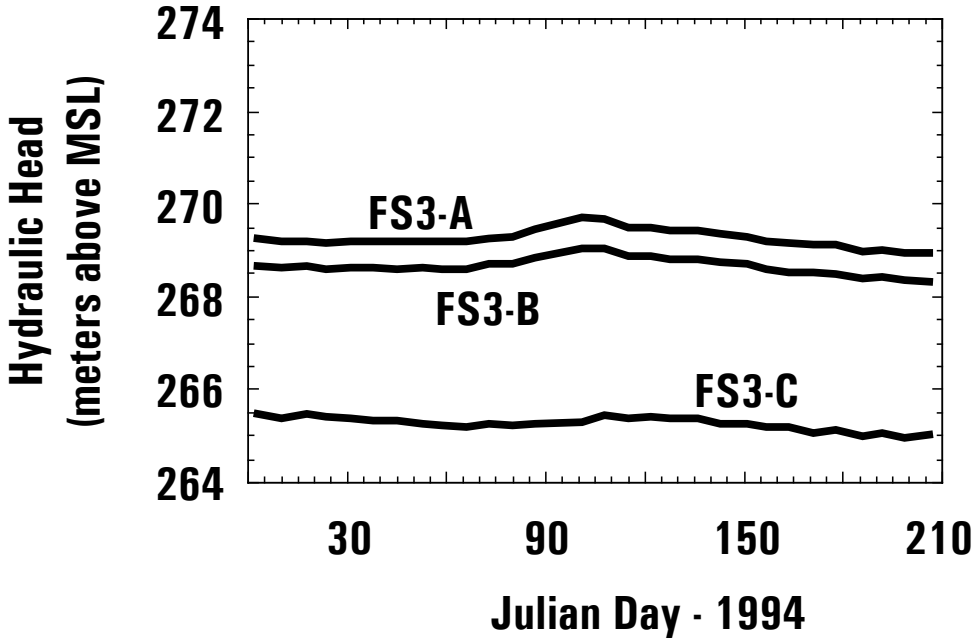
?

Hydraulic head → Direction of of ground-water flow



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



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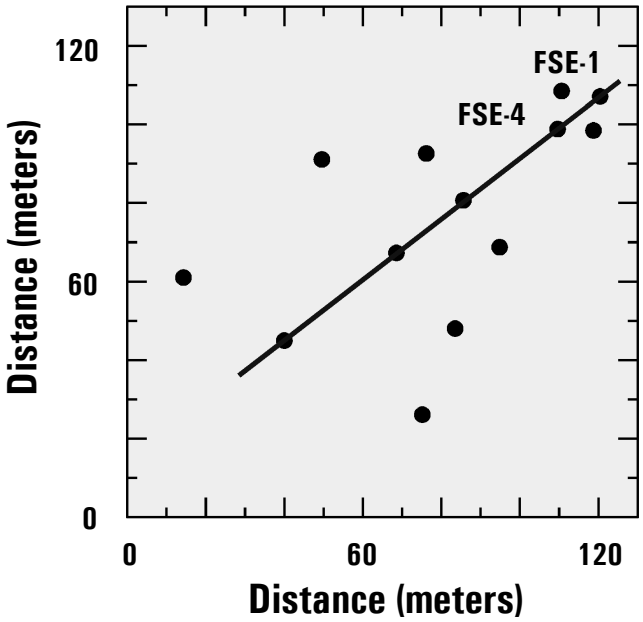
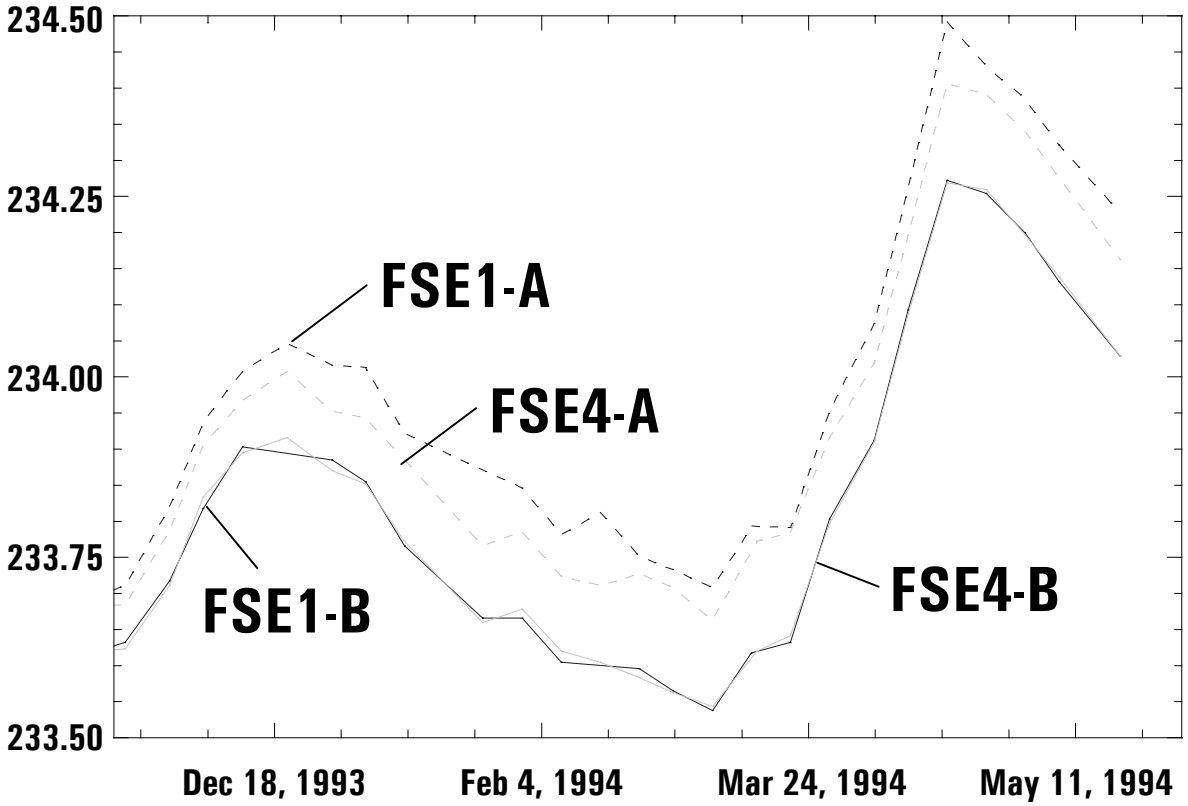

120
60
0
0
60
120
Distance (meters)
Distance (meters)
FSE-1
FSE-4


FSE1
FSE4


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

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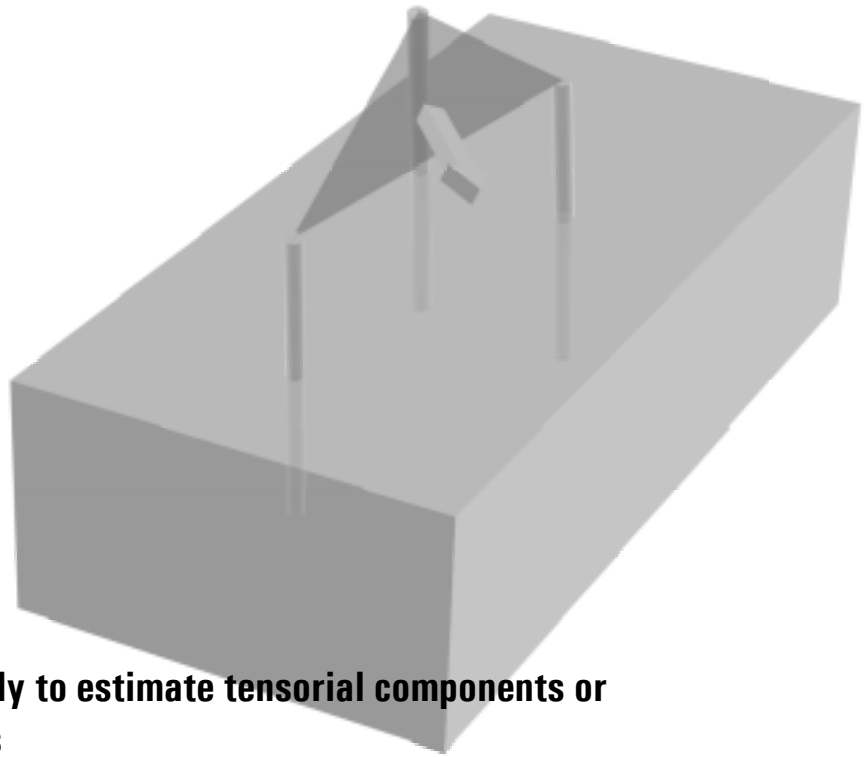
$$\underset{\sim}{v} = \frac{\underset{\sim}{K}}{n} \bullet \underset{\sim}{\nabla} h$$



$\underset{\sim}{K}$ ⇨ 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?

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

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