Use Of Geophysical Toolbox to Characterize Ground-Water Flow in Fractured-Rock

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"Toolbox" Approach

- Multiple methods
  - Surface and borehole
- Measure different properties
- Range of scales
- Integrated interpretation

Reference: Shapiro, A.M., Hsieh, P.A., and Haeni, F. P., 1999

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Toolbox Approach - Advantages

- Reduce uncertainty
- Improve models
- Sampling and testing locations

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The Total Toolbox

Historical review of site
Geology
Surface Geophysics
Drilling
Cross-contamination prevention
Borehole Geophysics
Hydrologic testing and tracer tests
Discrete interval completion
Chemical sampling
Modeling
Integrated interpretation

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Surface Geophysics

- DC Resistivity
- Electromagnetics
- Continuous Seismic Reflection/ GPR
- Seismic Reflection
- Surface Radar (GPR)

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DC Resistivity

2-Dimensional

- Imaging Vadose zone, fracture zones, bedrock units
- Detecting, mapping, and monitoring conductive fluids

Reference: Powers, C.J., Singha, Kamini, and Haeni, F.P., 1999

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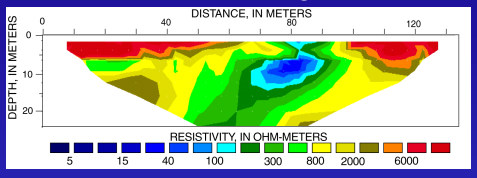
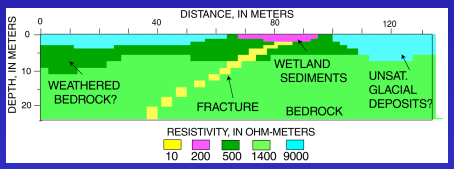
Modeling 2D Resistivity Data

South of Landfill

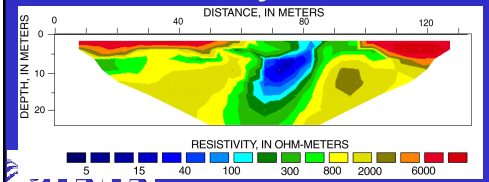
Inverted Resistivity Section



Model Resistivity Section



Synthetic Inverted Resistivity Section



DC Resistivity

Azimuthal

- Directional resistivity
- Fracture direction and depth

Reference: Lane, J.W., Jr., Haeni, F.P., and Watson, W.M., 1995

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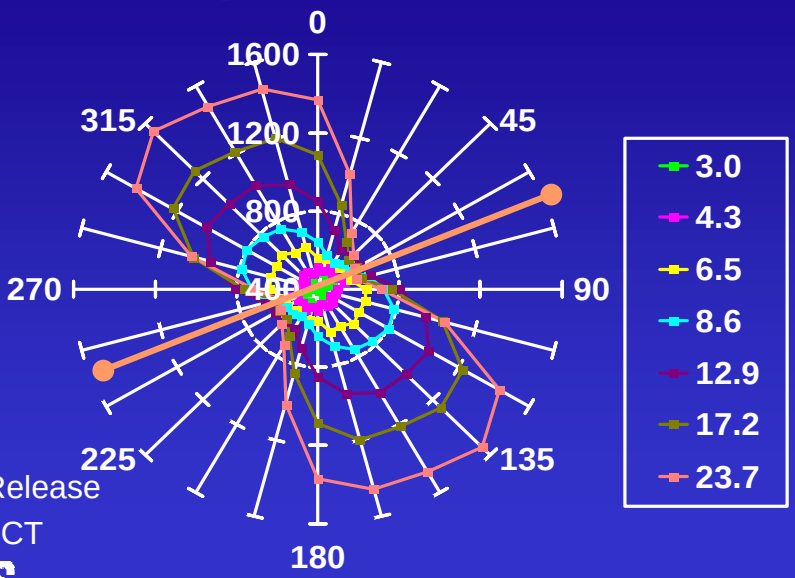
Square Array



LNAPL Release
Ashford, CT

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Disadvantages of DC-Resistivity Methods

- Pavement
- Underground utilities
- Needs open area
- Modeling not automated

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Electromagnetics

- Inductive Terrain Conductivity

Reference: Powers, C.J., Singha, Kamini, and Haeni, F.P., 1999

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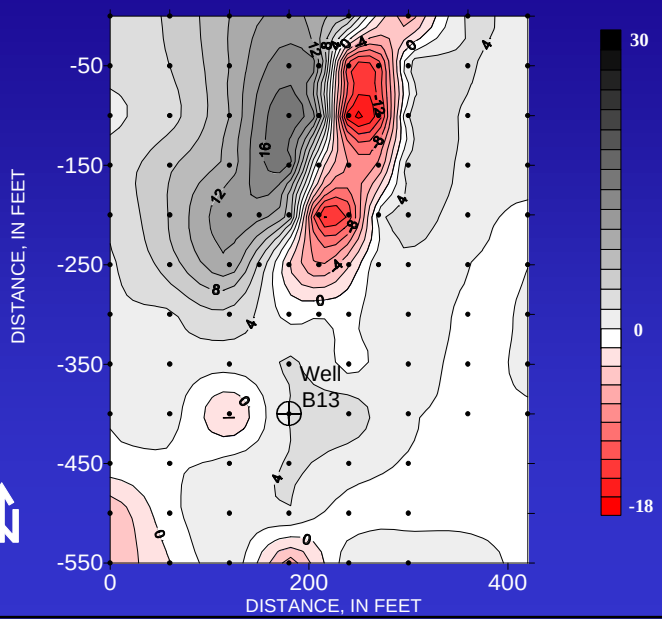
EM34 20-m Vertical-Dipole



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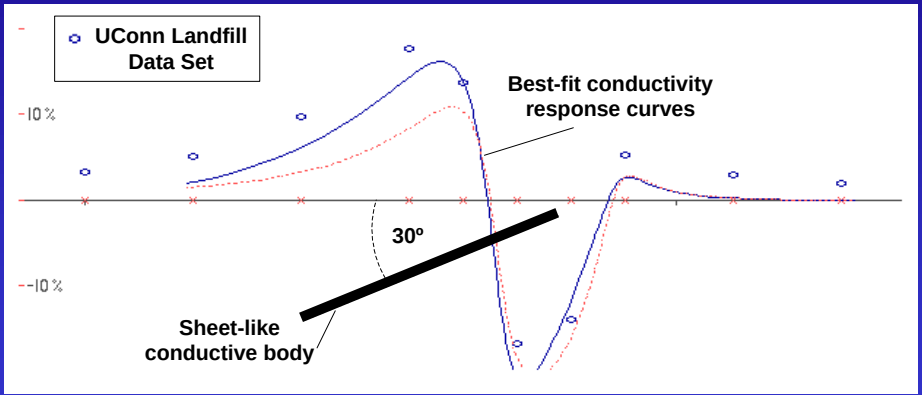
EM34 Forward Modeling

Vertical-dipole 20-m coil spacing



Slingram Interpretation Program, HLu 1989

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Disadvantages of Electromagnetics

- Cultural Interference
- Small anomalies
- Non-unique Interpretation

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Surface Geophysics Summary

- Areal information
- Optimize drill hole location
- Continuous profiles
- Collect data in difficult areas
- Determination of anisotropy

Reference: Powers,Wilson, Haeni and Johnson 1999

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Cross-contamination

- Vertical flow is due to differences in the hydraulic head in individual fractures.
- Ambient flow can cause the spreading of contaminants in open boreholes.
- Chemical sampling can be misleading

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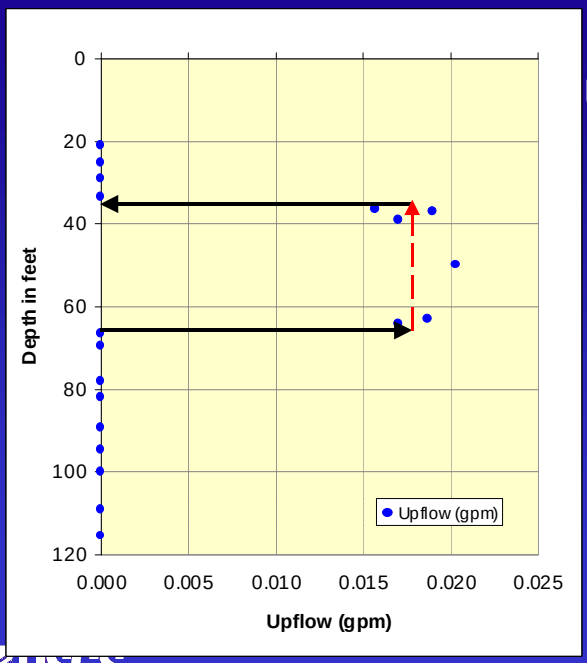

HPFM data Under Ambient Conditions:

Water exits the well at 35

Upflow of 0.018 gpm (26 gpd, 9,500 gpy)

Water flows into the well at 65 feet

MW101R

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Water -Filled Borehole Liners
Flute ® System

- "packs off" the entire length of the borehole.
- Prevents ambient vertical flow
- Minimizes the potential for cross-contamination.

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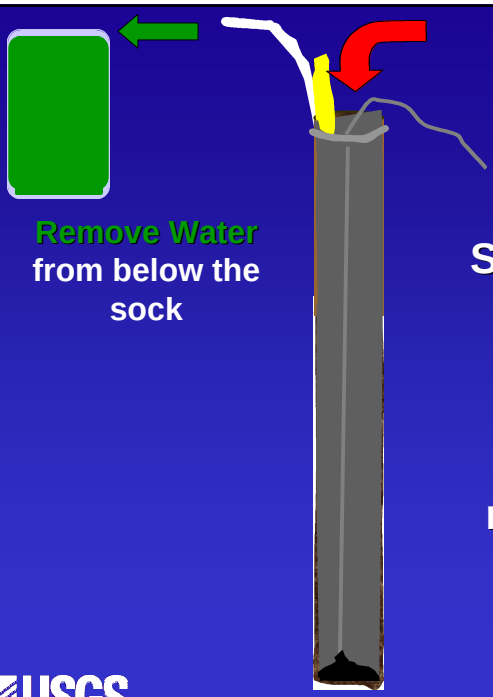
Well Sock Wrapped on Reel for Shipping

Attaching Well Sock to Borehole Casing



Add Water to the inside of the sock

Remove Water from below the sock

Sock installation is complete!

Water is no longer able to move vertically in the well.

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Disadvantages of Well Socks

- Temporarily prevents integrated head measurements
- Makes integrated sampling more difficult
- Lots of water is moved around

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Borehole Geophysics

- Conventional
- Borehole-Wall Imaging
  - Acoustic televiewer
  - Optical televiewer
- Flowmeter
- Radar Methods
- Tomography

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Borehole-Wall Imaging
Optical Televiewer

- Oriented video image and conventional fisheye
- Air- and water- filled holes (clear)
- Virtual Core
- Fracture and structural orientations
- Borehole deviation

Reference: Williams, J.H., and Johnson, C.D., 2000

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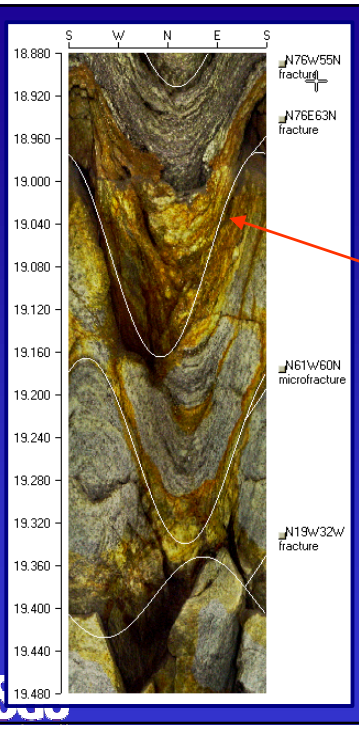
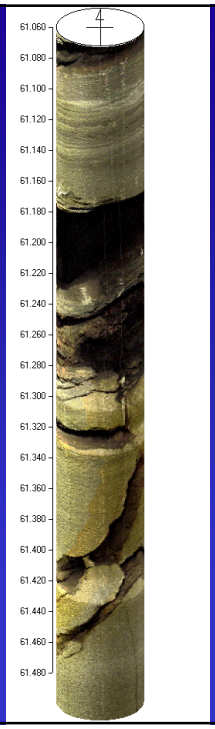


Optical Televiewer Interpretation MW-109R

N256°E, 63°N

Virtual Core Well RD-35B 61-61.5m



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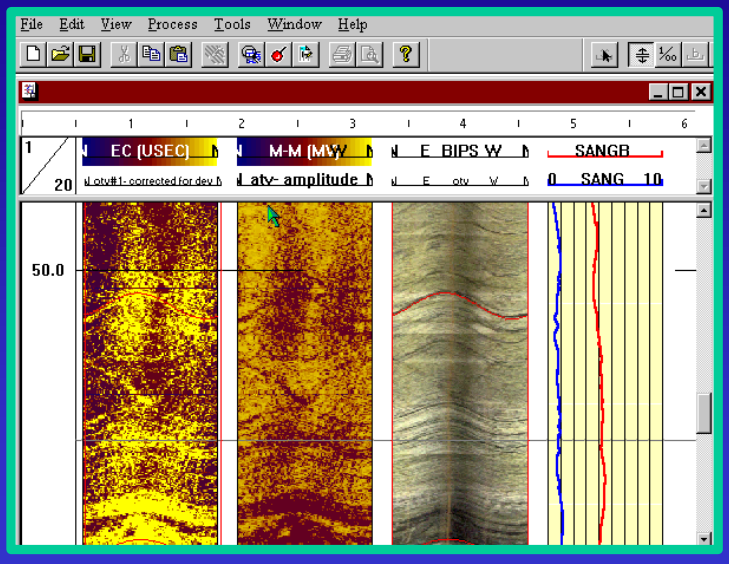
Interpretation



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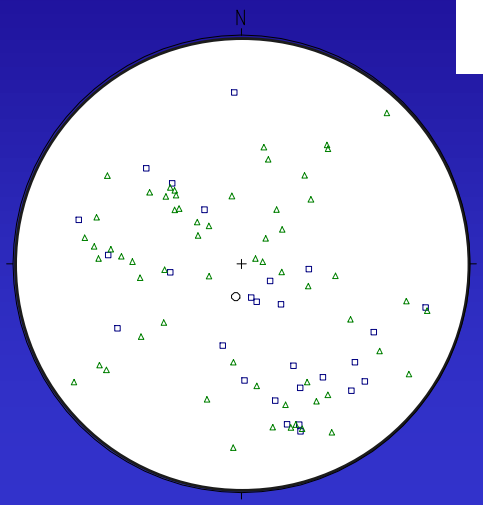
All Fractures

in 12 bedrock wells



Wide variation in orientations.

But which ones are transmissive?

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Flowmeter

- Detects borehole flow under static and pump conditions
- Delineates transmissive fractures
- Defines relative vertical hydraulic gradients
- Spinner, heat-pulse, and EM flowmeters

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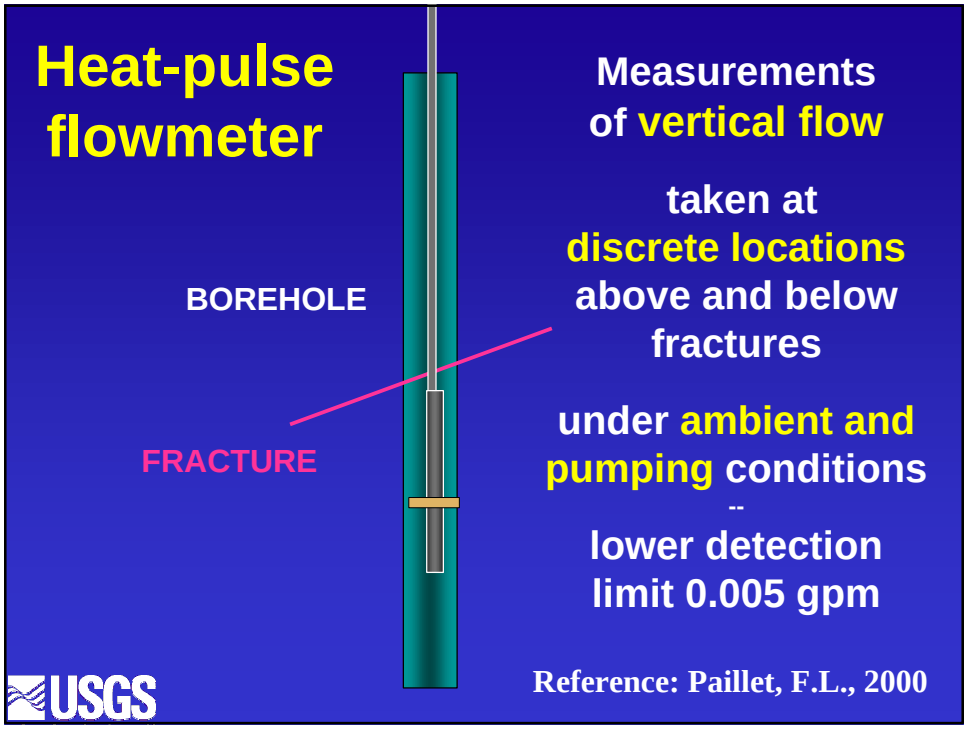
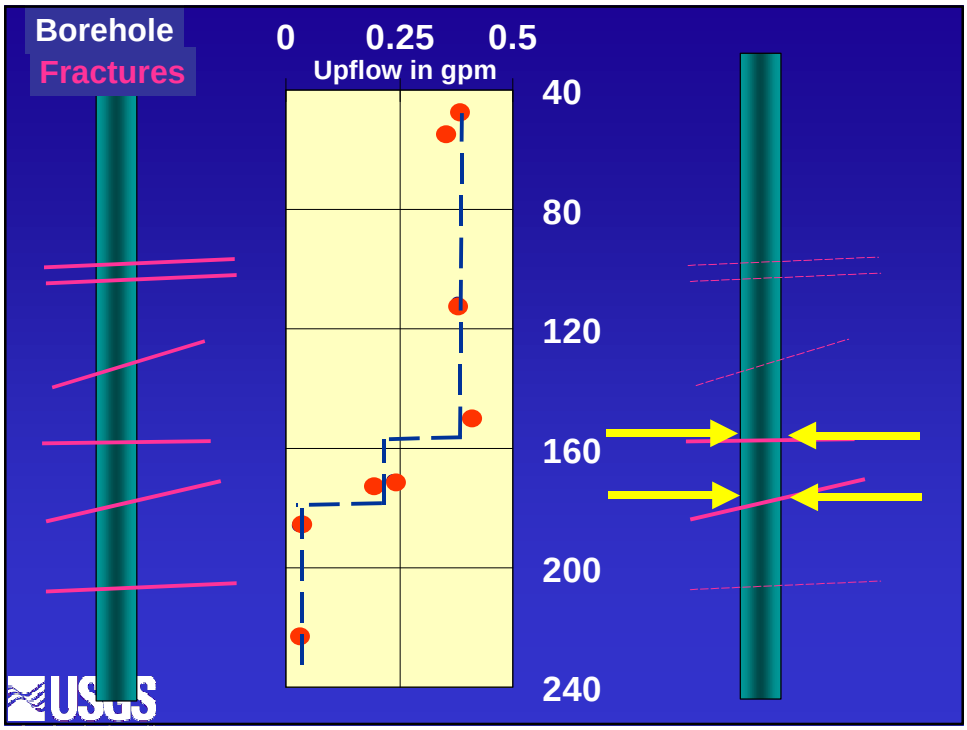
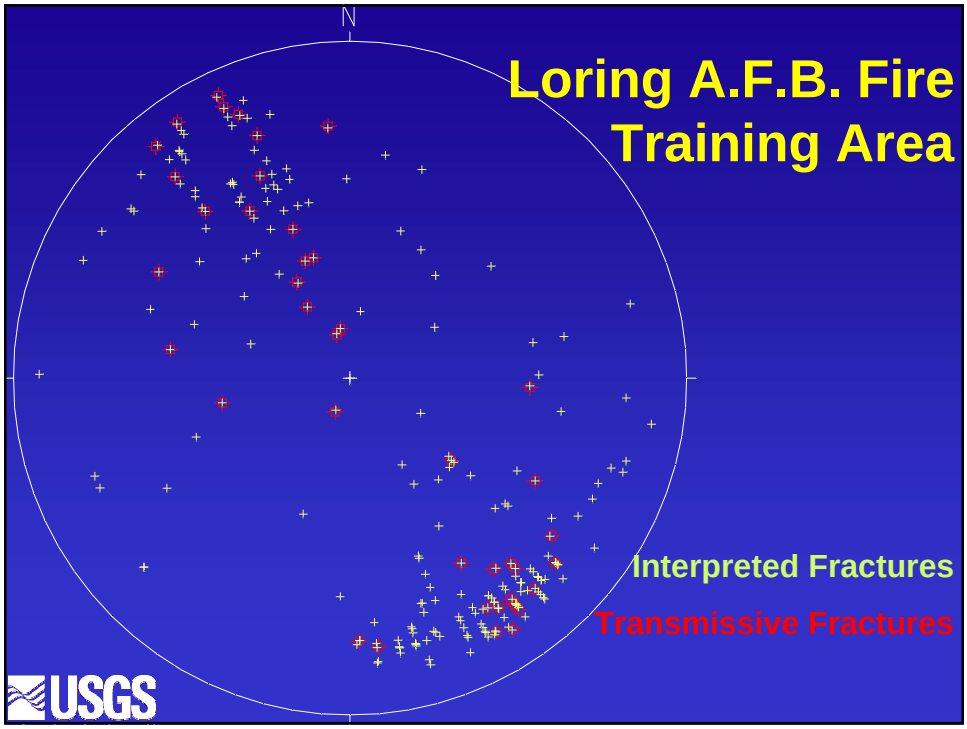

Heat-pulse flowmeter
BOREHOLE
FRACTURE
Measurements of vertical flow
taken at discrete locations above and below fractures
under ambient and pumping conditions
--
lower detection limit 0.005 gpm
USGS
Reference: Paillet, F.L., 2000


Borehole
Fractures
0
0.25
0.5
Upflow in gpm
40
80
120
160
200
240
USGS



Borehole Radar

Reflection and cross-hole methods

- Image beyond and between boreholes
- Estimate lateral extent of fractures and lithologic changes
- Can image features that do not intercept the borehole

Reference: Olsson, O., Falk, L., Forslund, O., Lundmark, L., Sandberg, E., 1992, Borehole radar applied to the characterization of hydraulically conductive fracture zones in crystalline rock, Geophysical Prospecting, Vol. 40 (2), pp. 109-142.

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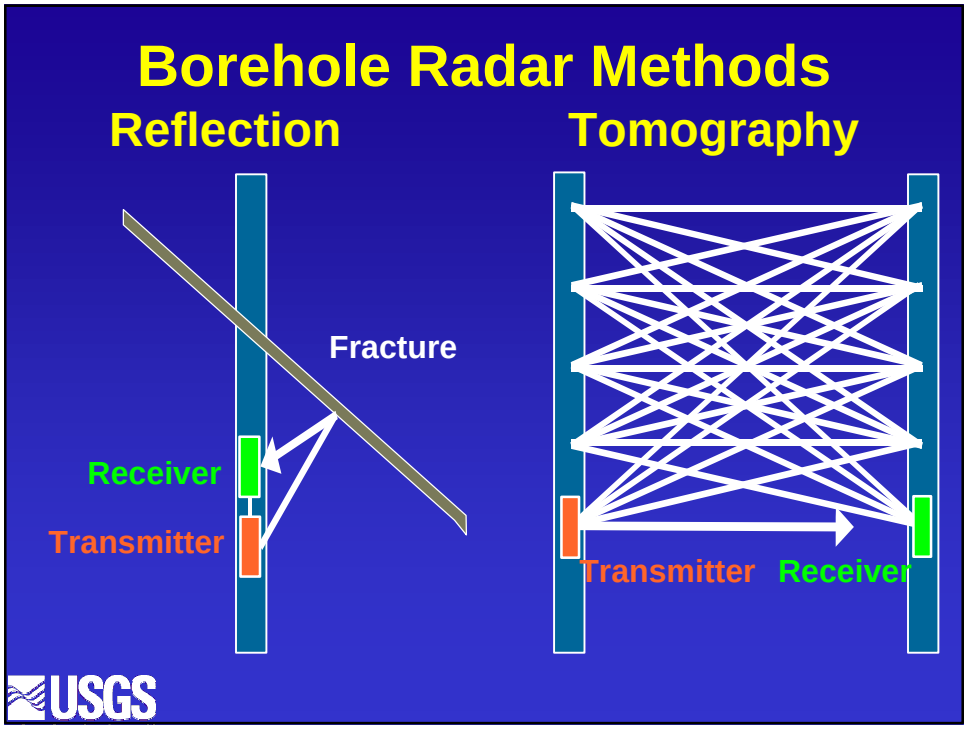
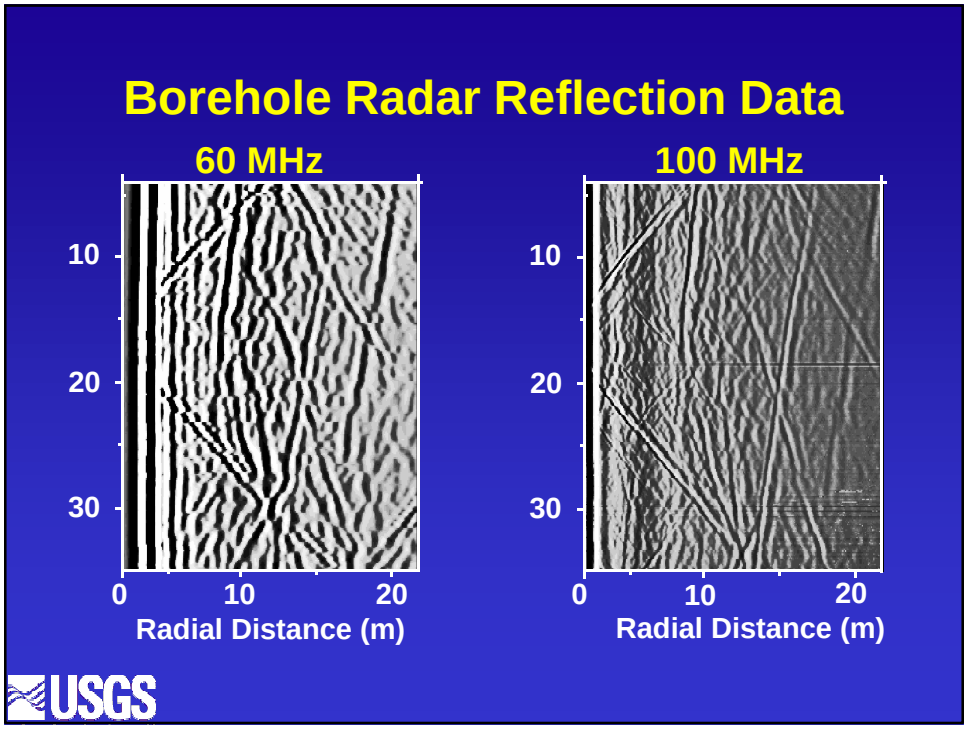

Borehole Radar Methods
Reflection
Tomography
Fracture
Receiver
Transmitter
Transmitter
Receiver
USGS


Borehole Radar Reflection Data
60 MHz
100 MHz
10
20
30
0
10
20
Radial Distance (m)
USGS

Borehole Geophysics Summary

- Strike and dip of transmissive fractures
- Ambient flow in borehole
- Design of discrete interval completions
- Sampling locations and methods
- Detection of features not intersecting the borehole
- Relation of geologic structure to transmissive fractures

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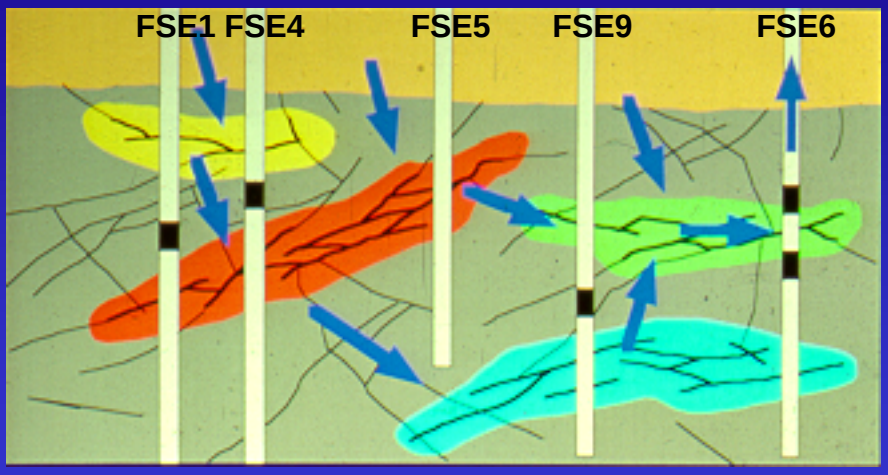
Conceptual Diagram of the FSE Wellfield



Reference: Shapiro, A.M., and Hseih, P.A., 1996

Summary: Benefits Of The Toolbox Approach

- Improved site characterization
- Sampling locations and model parameters
- Efficient remediation and monitoring design
- Determination of feasibility

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