NEW YORK STATE

Department of Environmental Conservation

Downhole Geophysical Investigations - Expectations and Applications to Contaminated Bedrock Groundwater Sites

February 18, 2025

Dedicated to:

Jutta L. Hager PhD
1942 - 2022

Course Outline

1. Geophysical Tools
2. Monitoring Well Considerations
3. Geophysical Survey Deliverables
4. Applications to a Remedial Site

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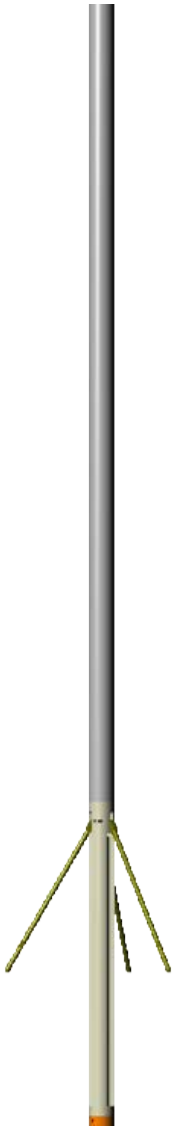

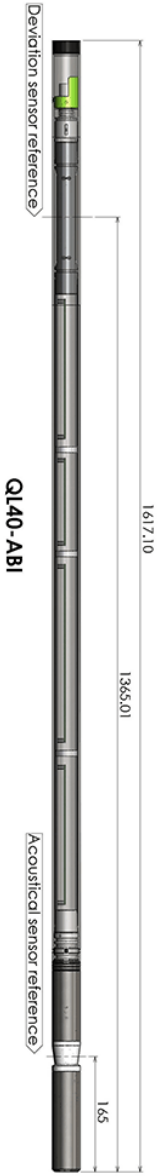

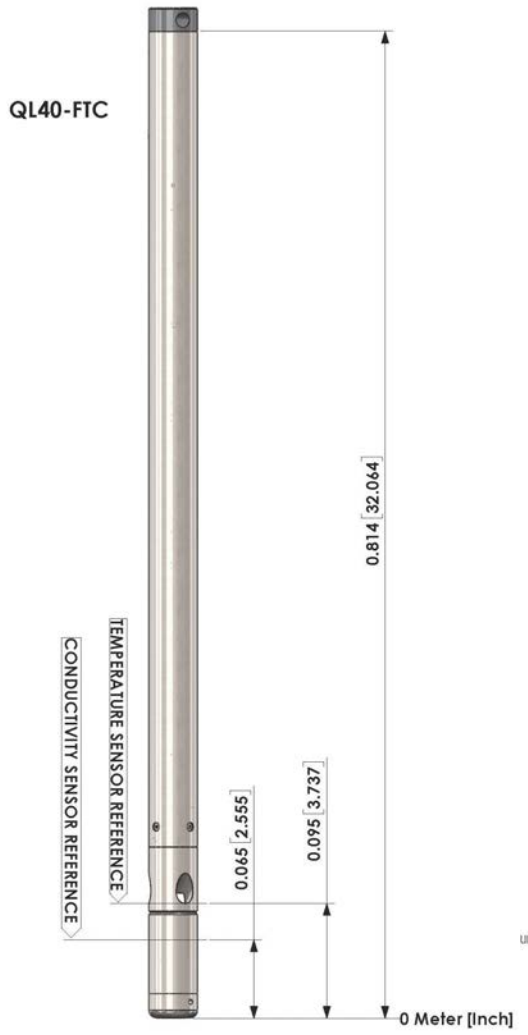

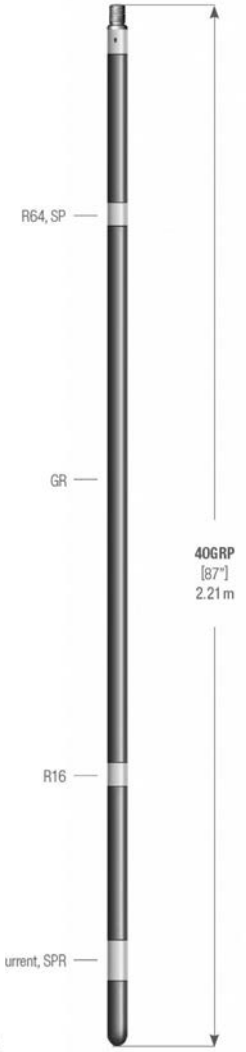

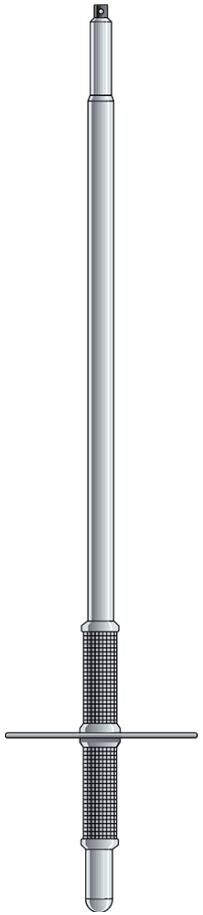

"Standard" Geophysical Tools

1. Caliper
2. OTV (Optical Televiewer)
3. ATV (Acoustic Televiewer)
4. Poly-electric & Fluid
5. Heat Pulse Flow Meter (HPFM)

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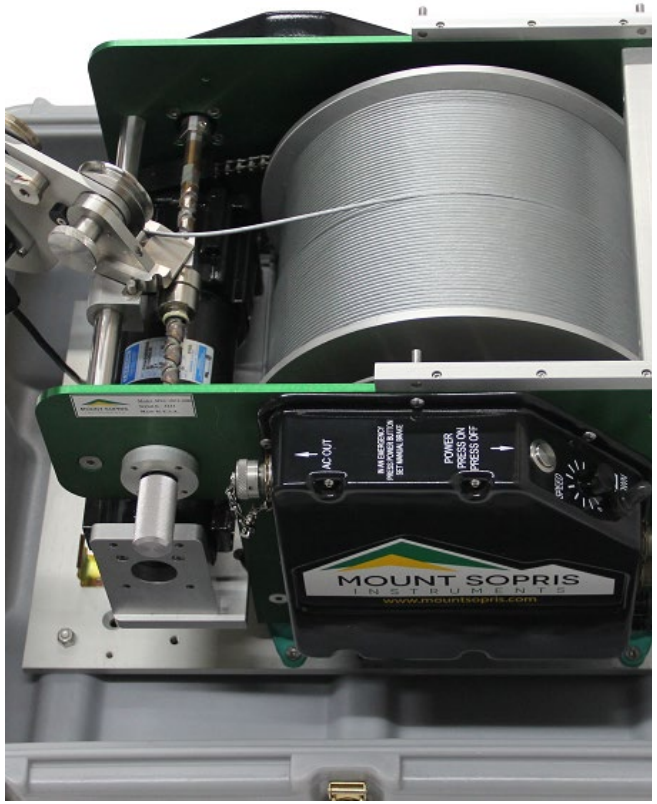
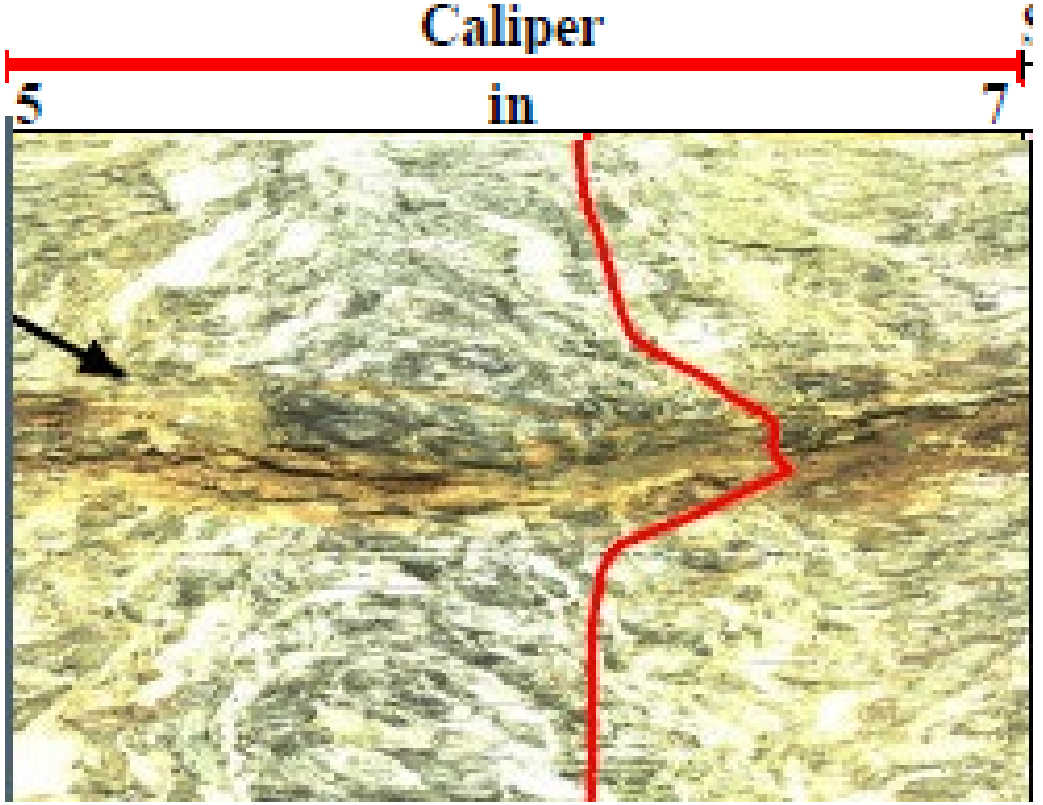
Downhole Geophysical Winch and Logging Set-up



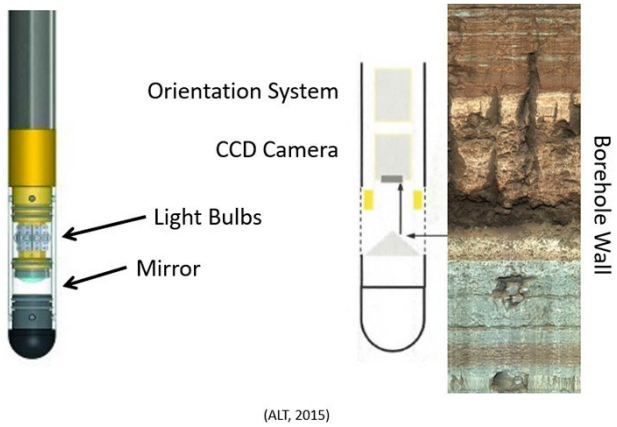
Caliper

- Confirm competent borehole walls without obstructions
- Three arms slide along borehole wall
- Locates fractures and changes in the borehole diameter
- Correlation with other geophysical logs

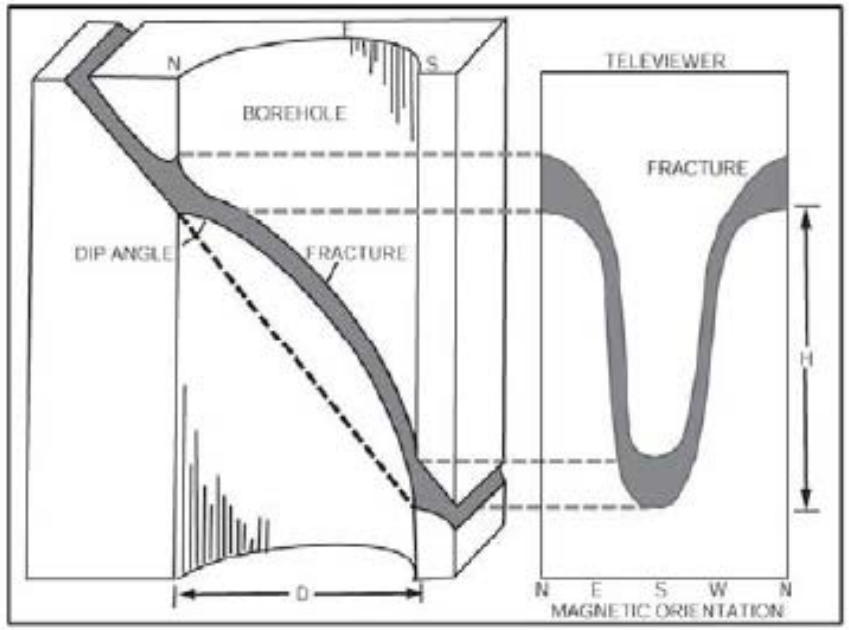


(OTV) Optical Televiewer

- High resolution images with a 360-degree unwrapped view of the borehole
- Can image in air and water filled borehole
- Does not image well with significant suspended sediment
- Visual analysis of lithology, mineralogy, borehole defects, fractures, staining & more
- Identify fracture strike, dip angle, and dip azimuth



(ALT, 2015)



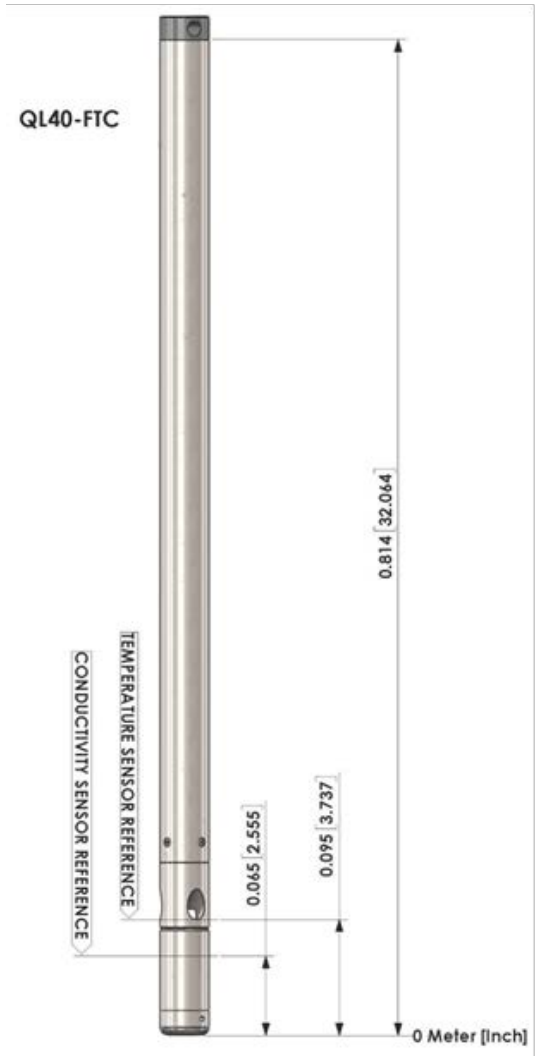
(ATV) Acoustic Televiewer

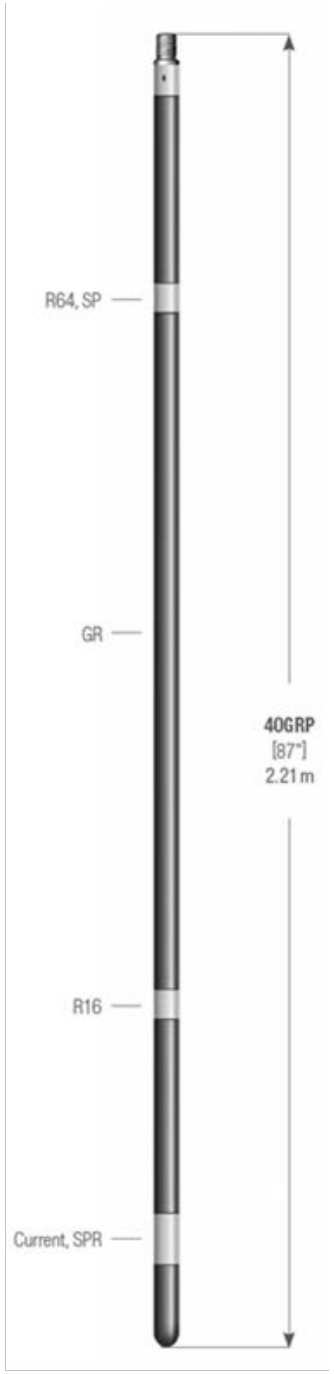
- 360 degree spinning acoustic emitter and receiver
- Only works in fluid filled portion of borehole
- Can image through suspended sediment
- Records acoustic returning amplitude, travel time
- 360-degree RGB false color image
- Identify fractures, relative density, casing bonding log (full waveform), borehole diameter
- Identify fracture strike, dip angle dip azimuth

Poly-electric, Gamma & Fluid Tool-stacks

Collect in an undisturbed water column (request first log collected in each borehole)

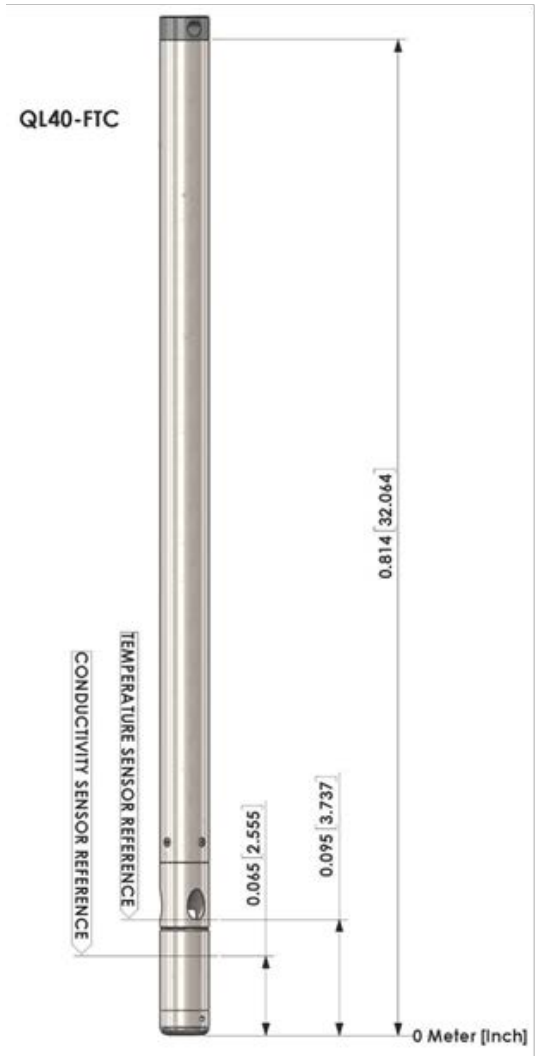
- **(Water) Temperature** – Measures changes in water temperature with depth
  - Identify transmissive fractures
- **(Water) Fluid Conductivity & Resistivity** – Inverse measures of the borehole fluid properties (Ohm-m and US/cm)
  - Identify transmissive and active fractures based on composition of the water

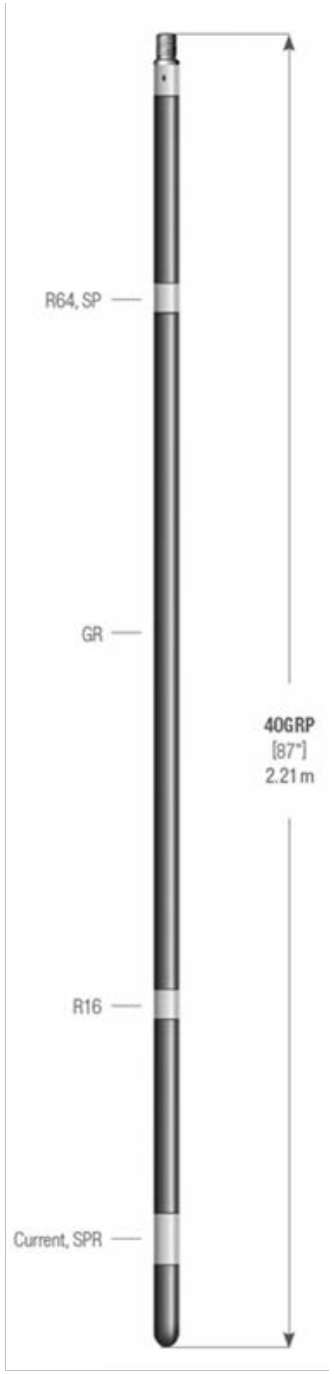




Poly-electric, Gamma & Fluid Tool-stacks

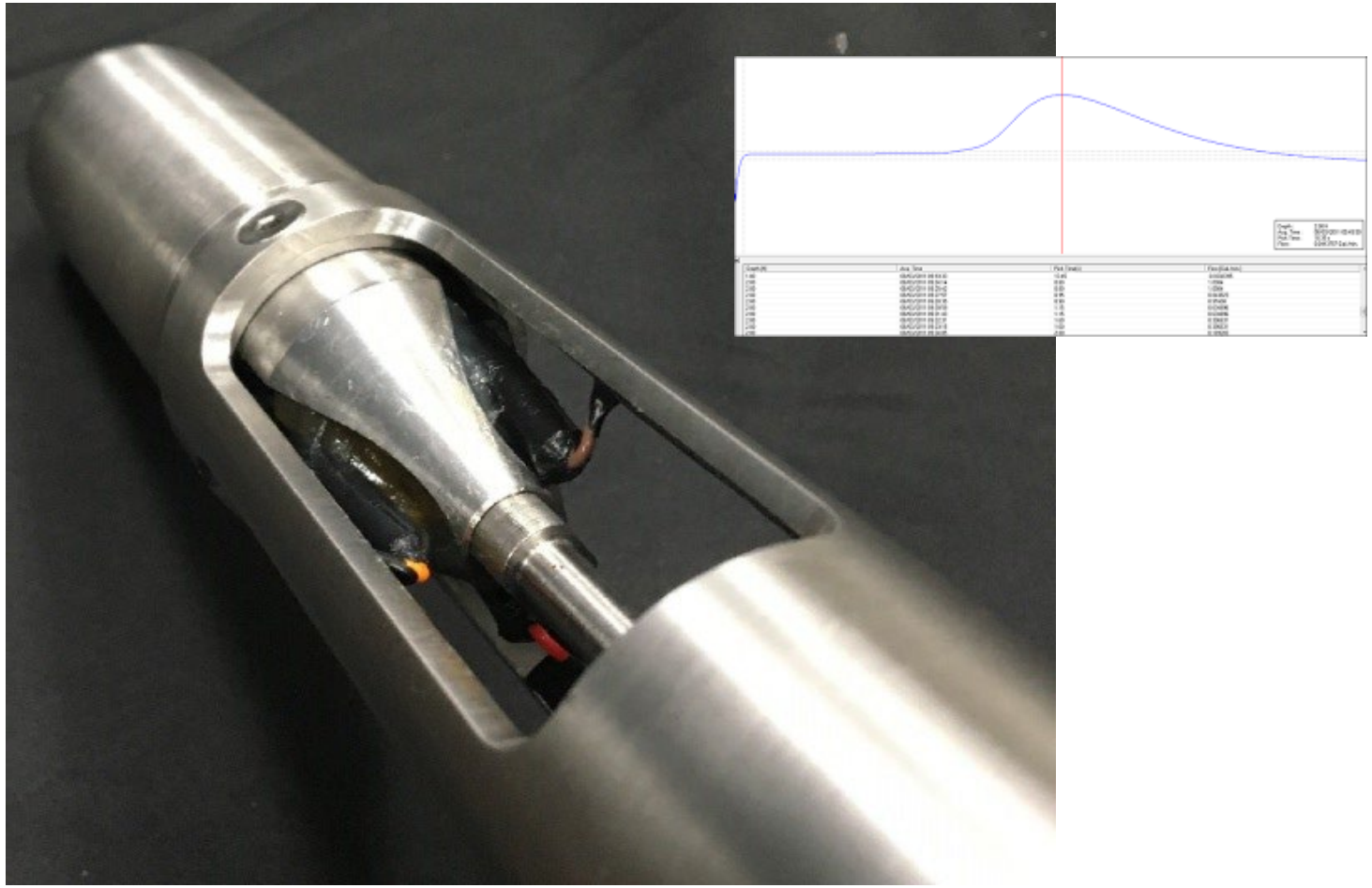
- **Resistivity Logs-** Four logs are at (8, 16, 32 and 64 inches in separation) measures rock resistivity
  - Run with isolation bridle
  - Rock resistivity values (Wenner)
  - Mineral composition, lithology, pore space
- **Spontaneous potential (SP) & (SPR)** – Determine relative permeability of the formation (measures potential in mV)
  - Water filled fractures display low potential / voltage
- **Gamma** – Records gamma radiation emitted by rock (counts / sec)
  - Clay and silica content of rock and fractures analyzed
  - Can be used in overburden or bedrock





(HPFM) Heat Pulse Flow Meter

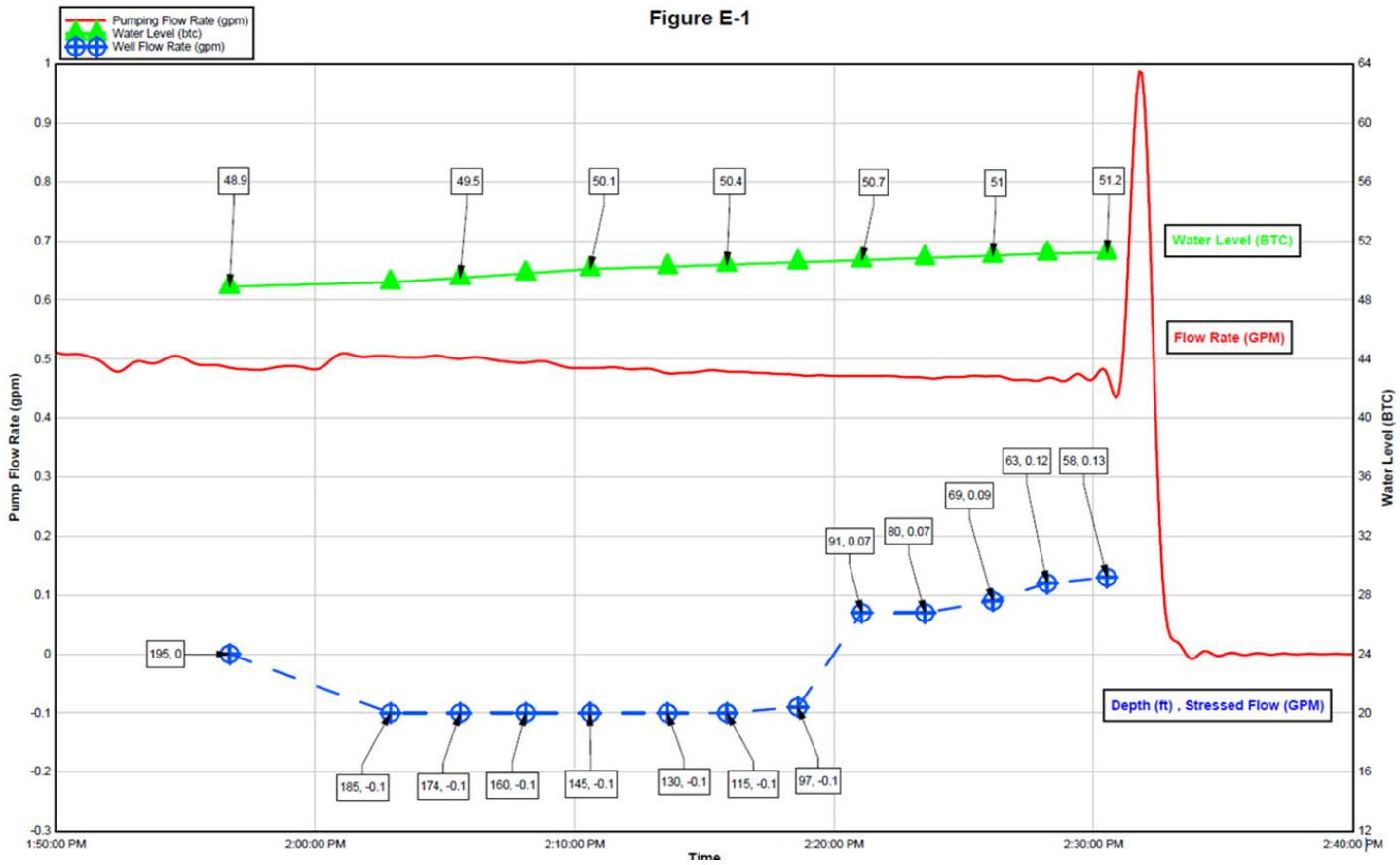
- Top and bottom thermistors measure temperature / heat dissipation from the central heat grid
- Survey locations are determined by prior logging data
- Ambient & stressed testing
- Designed for low flow conditions (~1 gpm max)
- Minimum flow for quantitative analysis is 0.03 gallons per minute

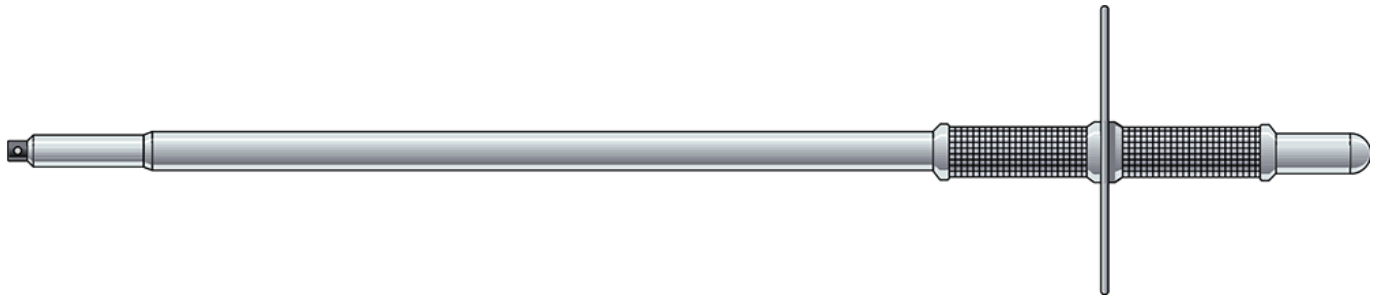


(HPFM) Heat Pulse Flow Meter

ASTM (C518) standards should be followed

- Stressed Testing (Pumping)
  - Pumping flow rate needs to be recorded
  - Bare minimum tested by hand before, during and after
  - Stressed Testing should be surveyed at steady state conditions at constant low flow (~1 gpm or less)
  - Groundwater head should be at equilibrium
  - Groundwater level in the casing
  - No changes to pump rate during testing
  - Pumping prior to testing may take 20-30 min to get borehole



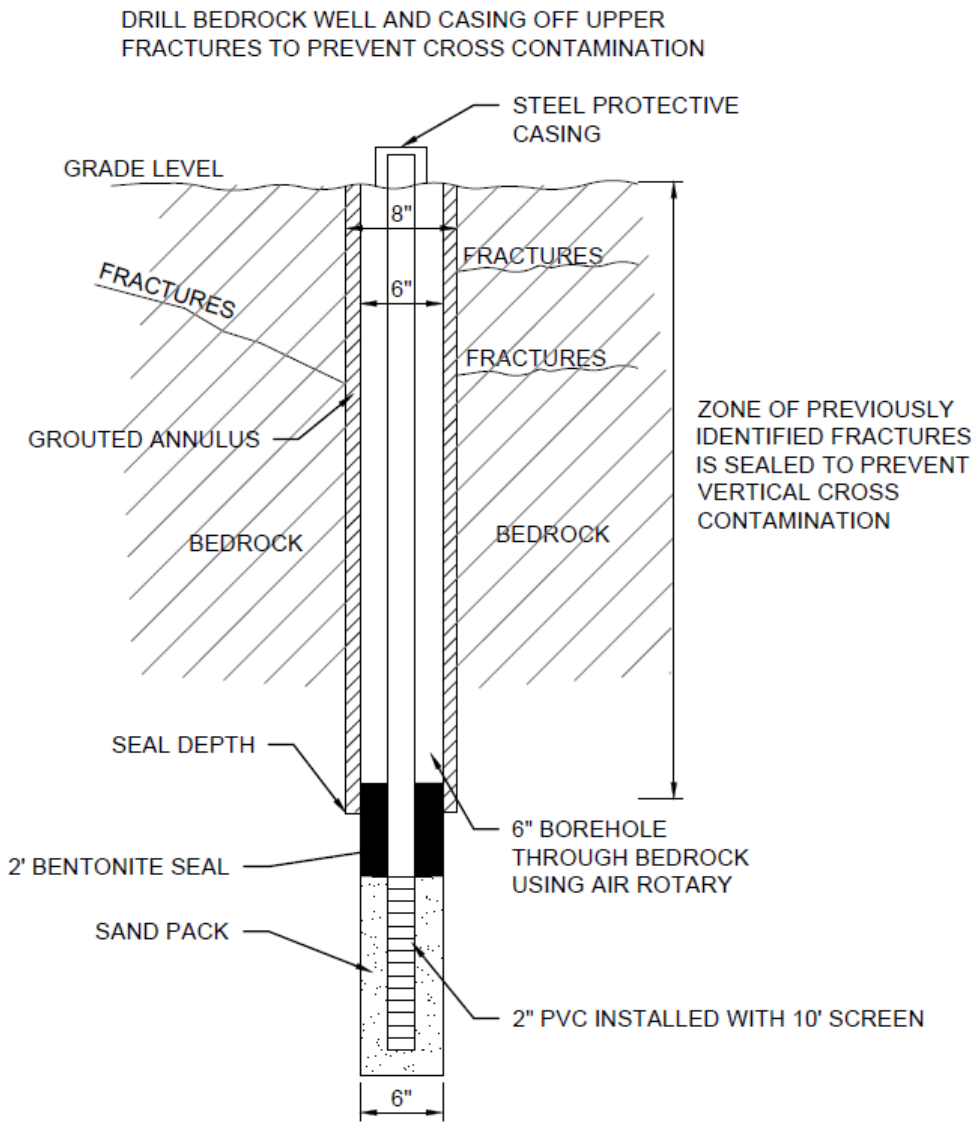


Downhole Camera

- Identifying mineralogy in rock matrix
- Breakout or void space inspection
- Casing inspection
- Obstructions inspection

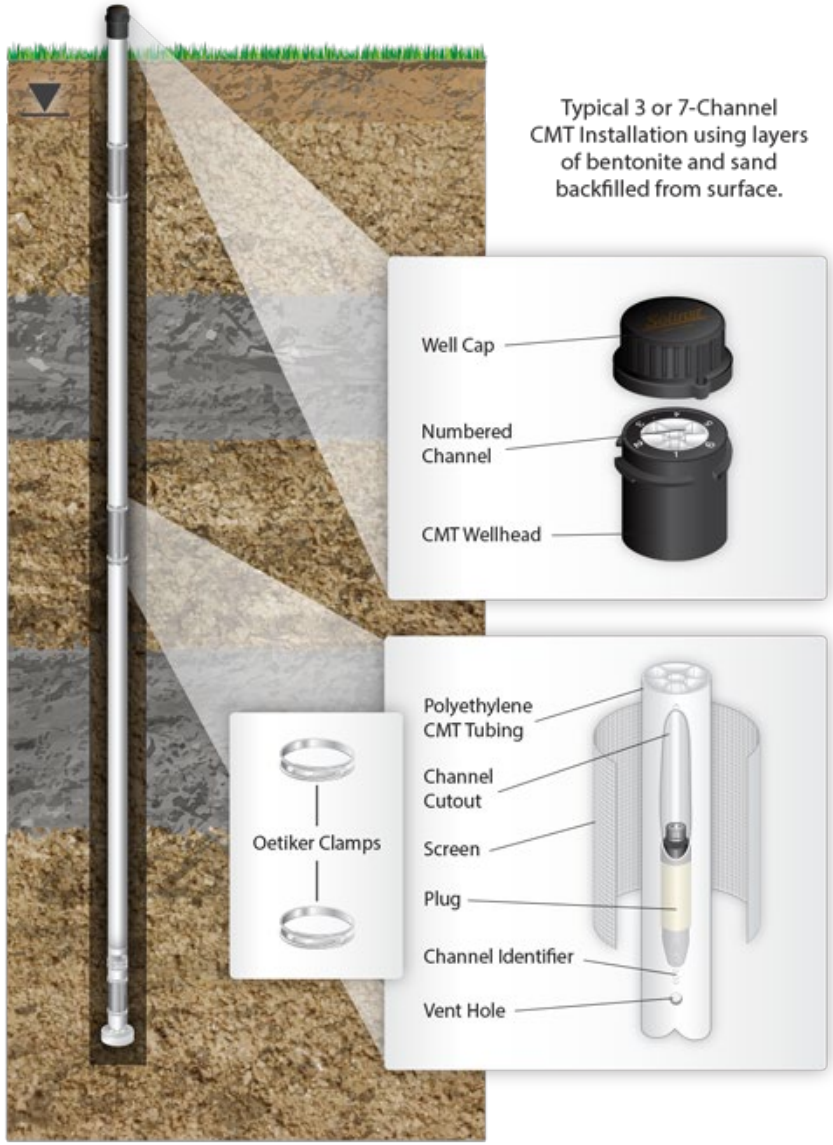
Drilling & Monitoring Well Considerations

- Drilling method
  - Air rotary
  - Coring
  - Vertical or angled boreholes
- Borehole diameter
  - Minimum 3-4 in diameter
  - Some tools will fit down 2 in
- Imaging not applicable for overburden
- Cross contamination considerations



Monitoring Well Cross-contamination Considerations

- Order of operations
  - Planning
- Drill borehole:
  - Geophysics to be completed in open hole!
- Next:
  - Packer Testing
- Finishing:
  - Single screen
  - Nested wells (shallow)
  - CMT (Continuous Multi-channel Tubing)
  - FLUTe (Flexible Liner Underground Technology)
  - Doubled cased wells



FLUTe

- FLUTe (Flexible Liner Underground Technology)
  - “blank liner”
  - NAPL liner
  - FACT liner (activated carbon)
  - Transmissivity Profiles
  - Water FLUTe (multi-level monitoring 3-16 channels)

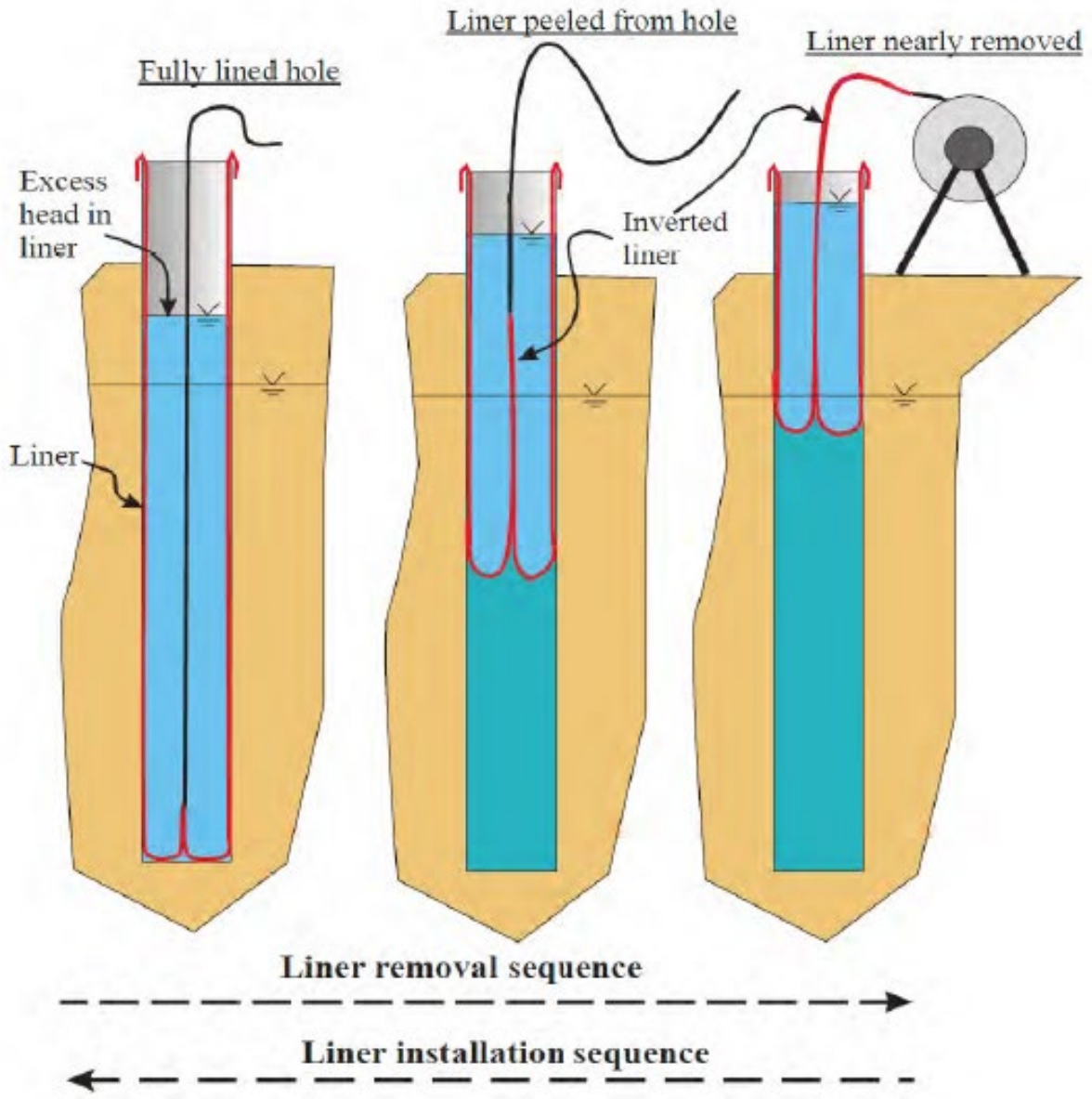


Figure 1: The process of eversion (installation) and inversion (removal)

Geophysical Survey Deliverables

1. Geophysical Logs
2. Structure Tables
3. Rose & Stereonet Diagrams
4. Deviation Plots
5. HPFM Graphs
6. Reports

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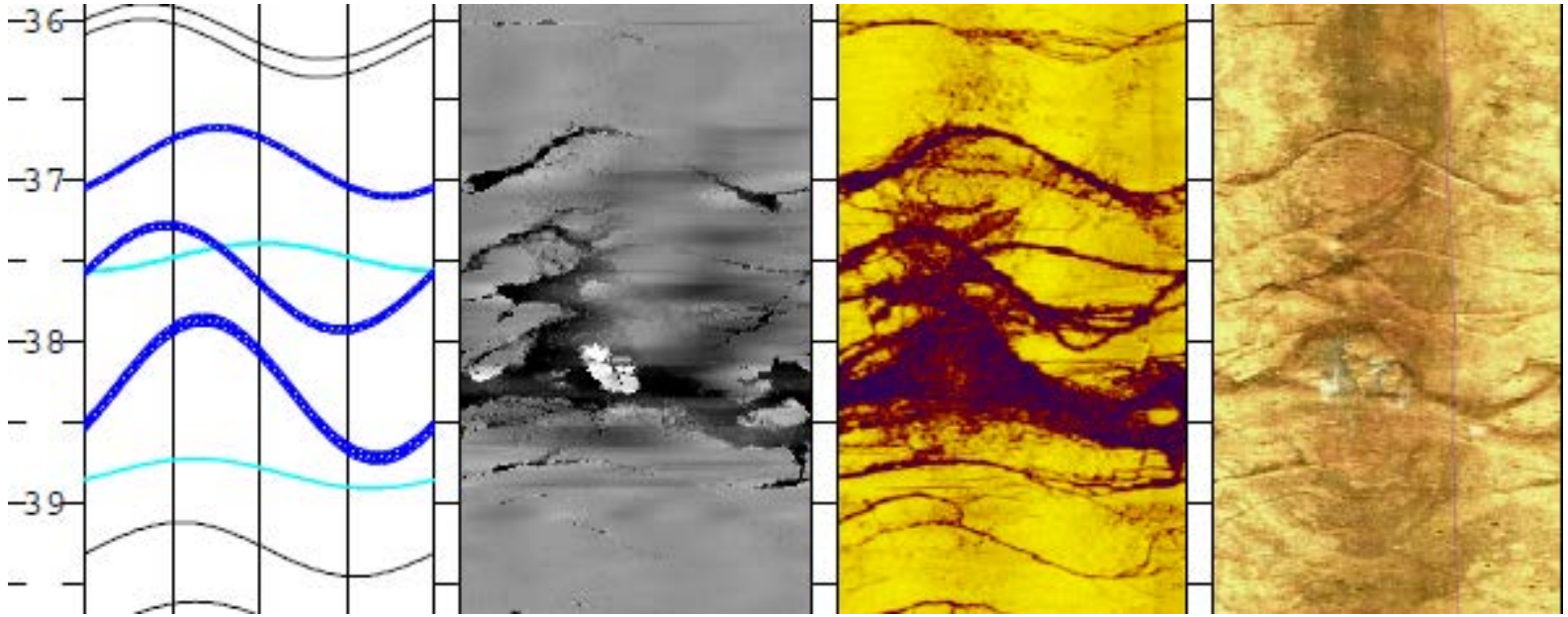
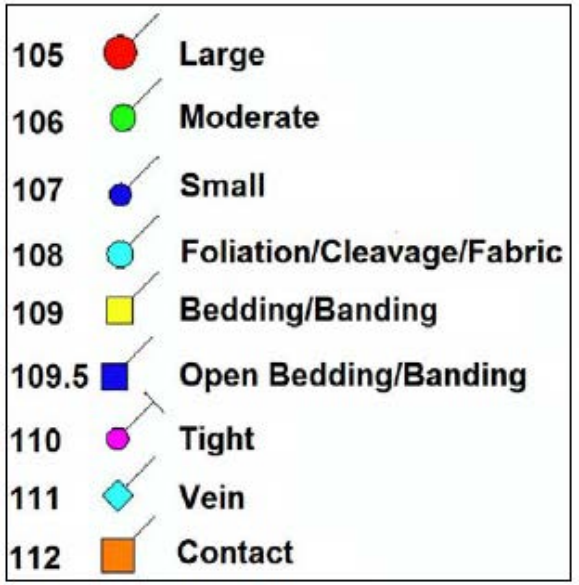
Geophysical Logs





- Image logs & Composite logs in PDF (print to your ideal resolution!)
- Fractures traced and categorized
- Orientation to true north or magnetic north
- Logs should be correctly scaled & labelled

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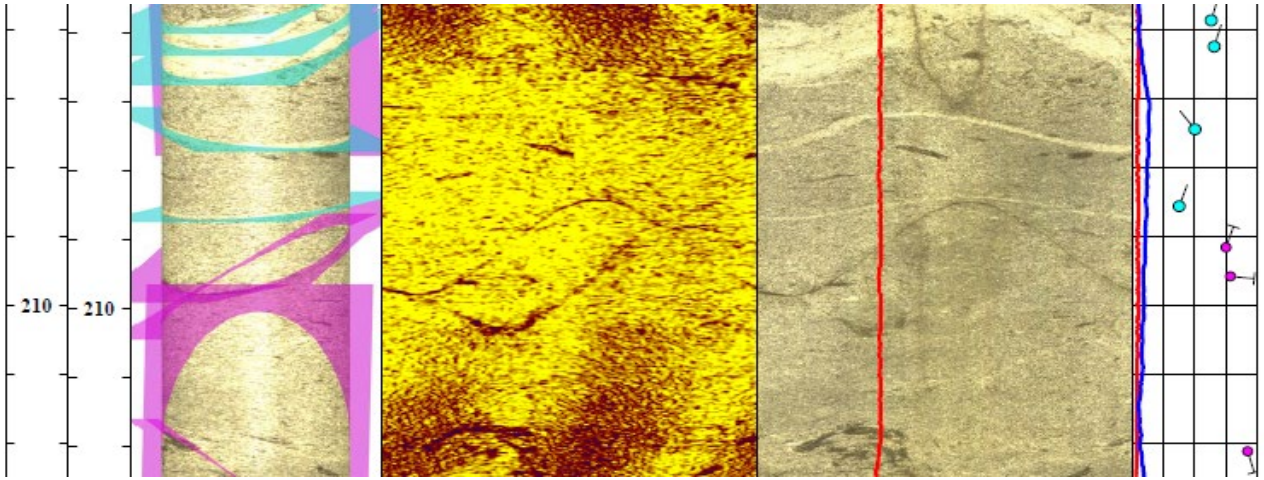
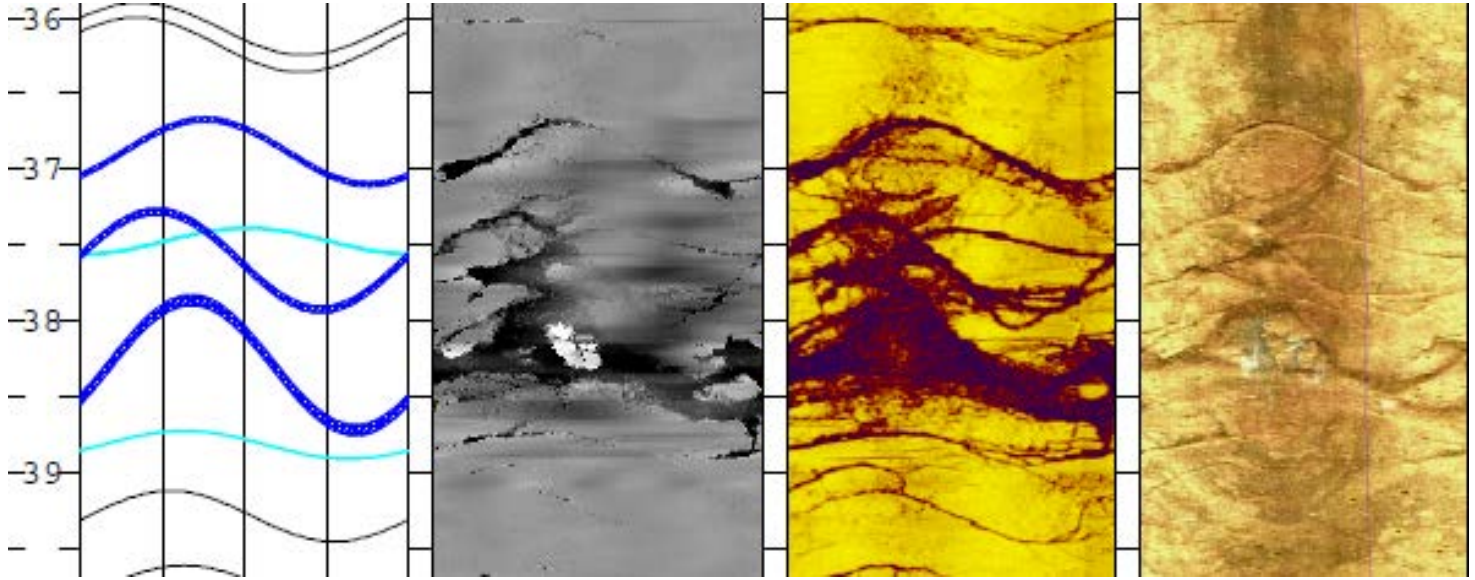
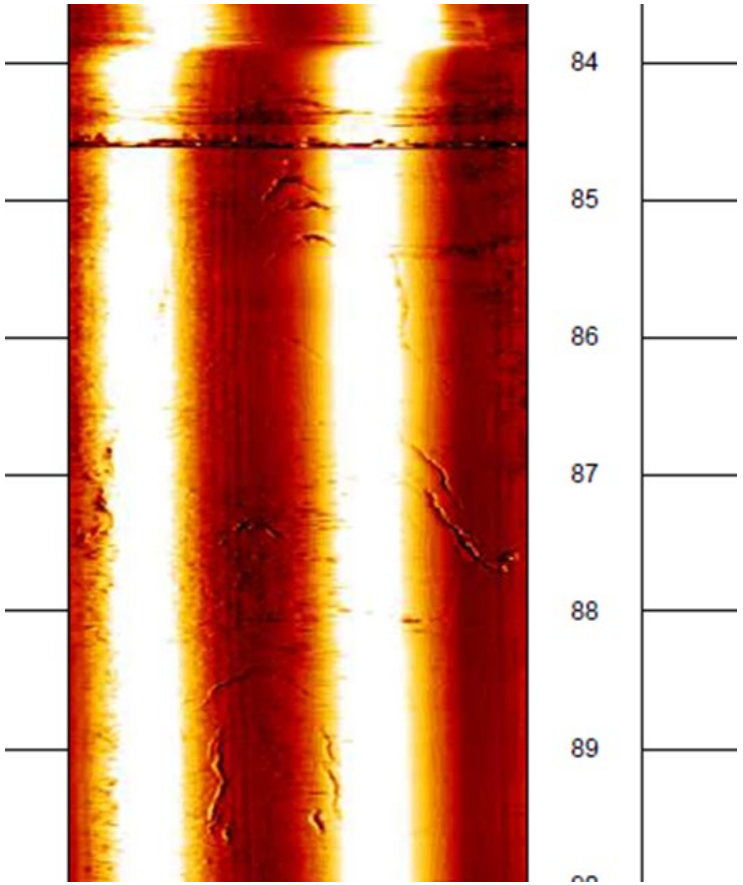
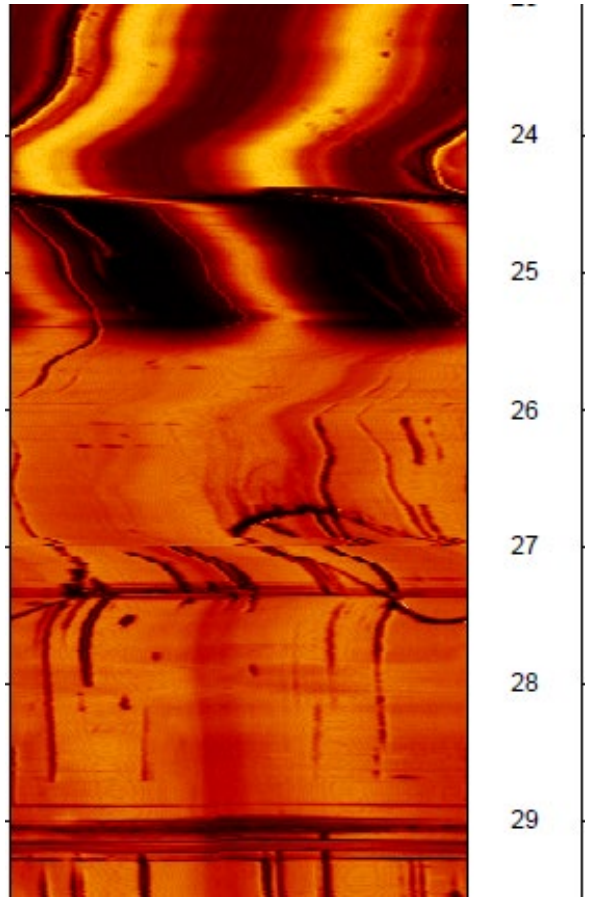
Good Optical & Acoustic Data



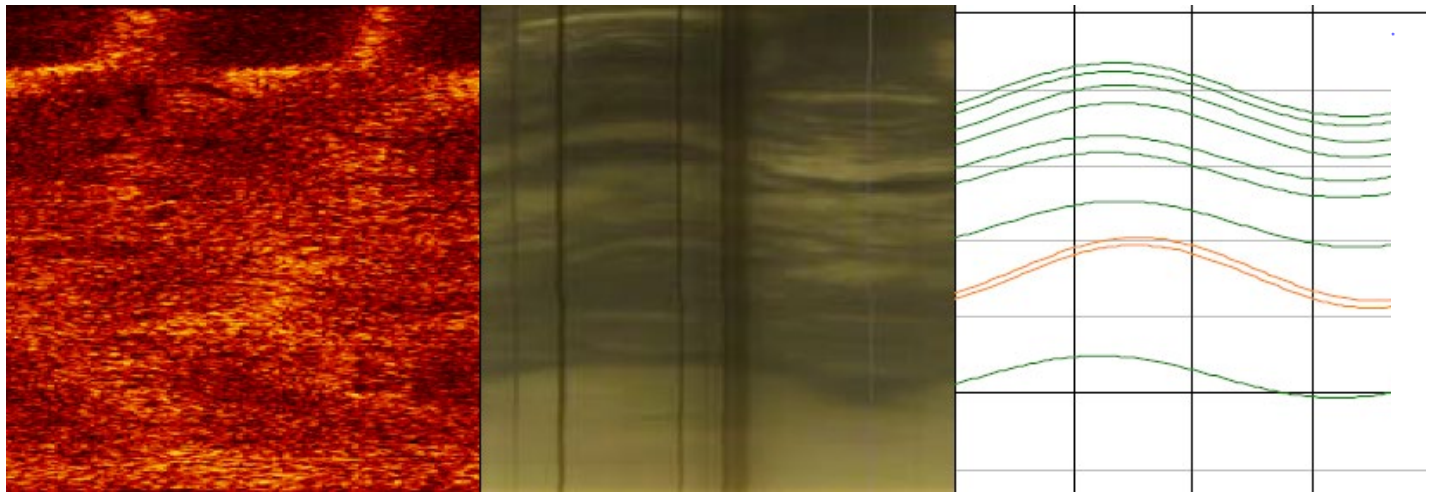


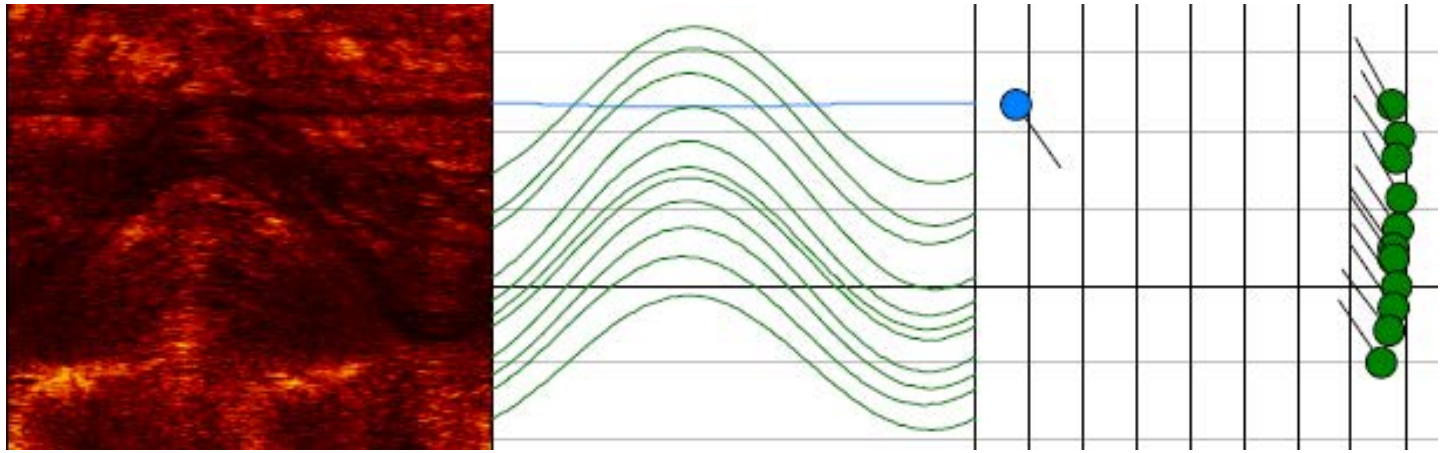
Bad Data Optical & Acoustic Data





Inconsistent Interpretation





Fracture/Feature

Hairline Fracture/Feature

Discontinuous Fracture/Feature

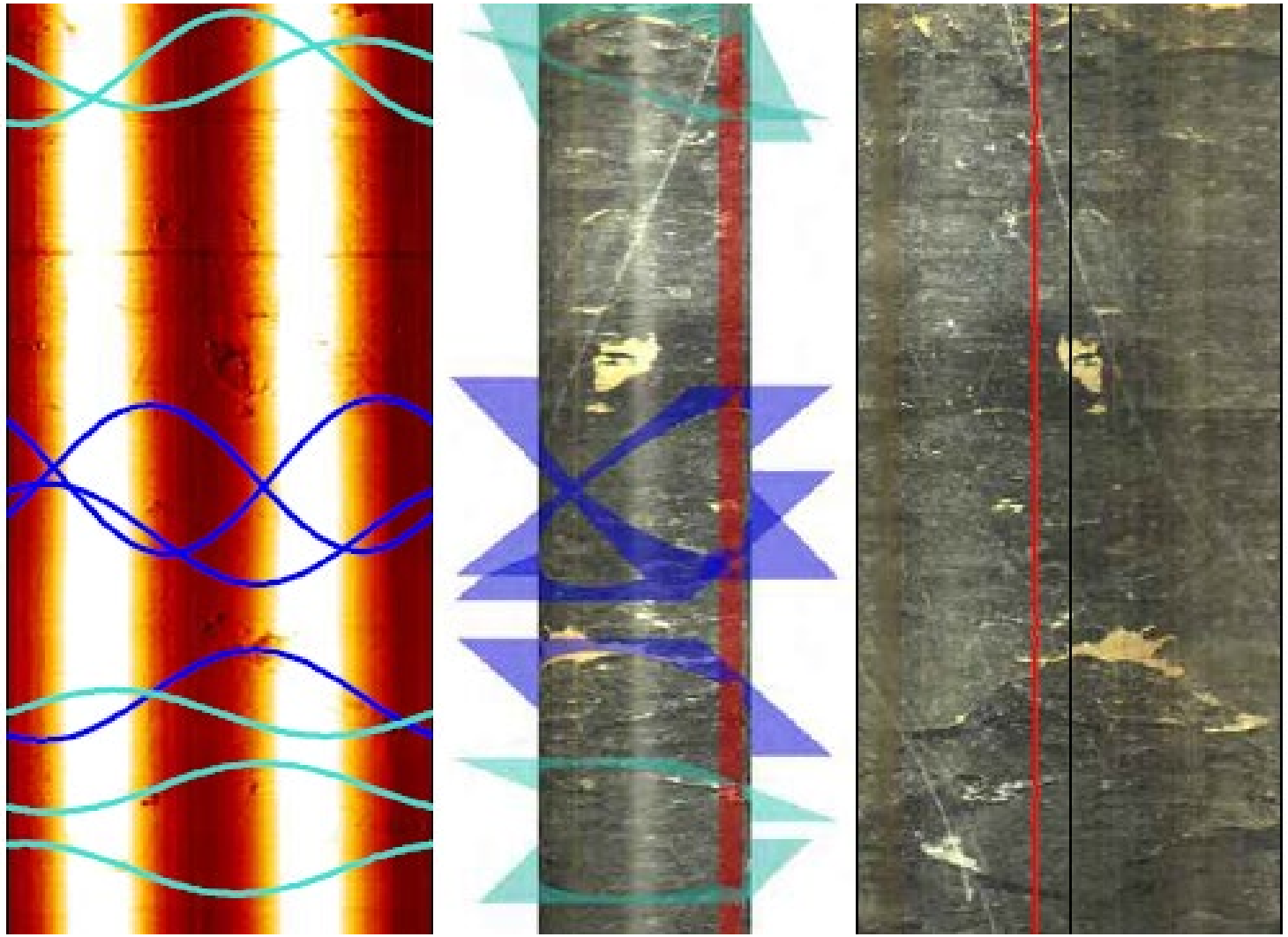
Discontinuous Hairline Fracture/Feature

Bedding/Change in Lithology

Features should be interpretated consistently in each borehole and across the entire site

Features can be picked off a single log but multiple logs are better

Inconsistent Interpretation



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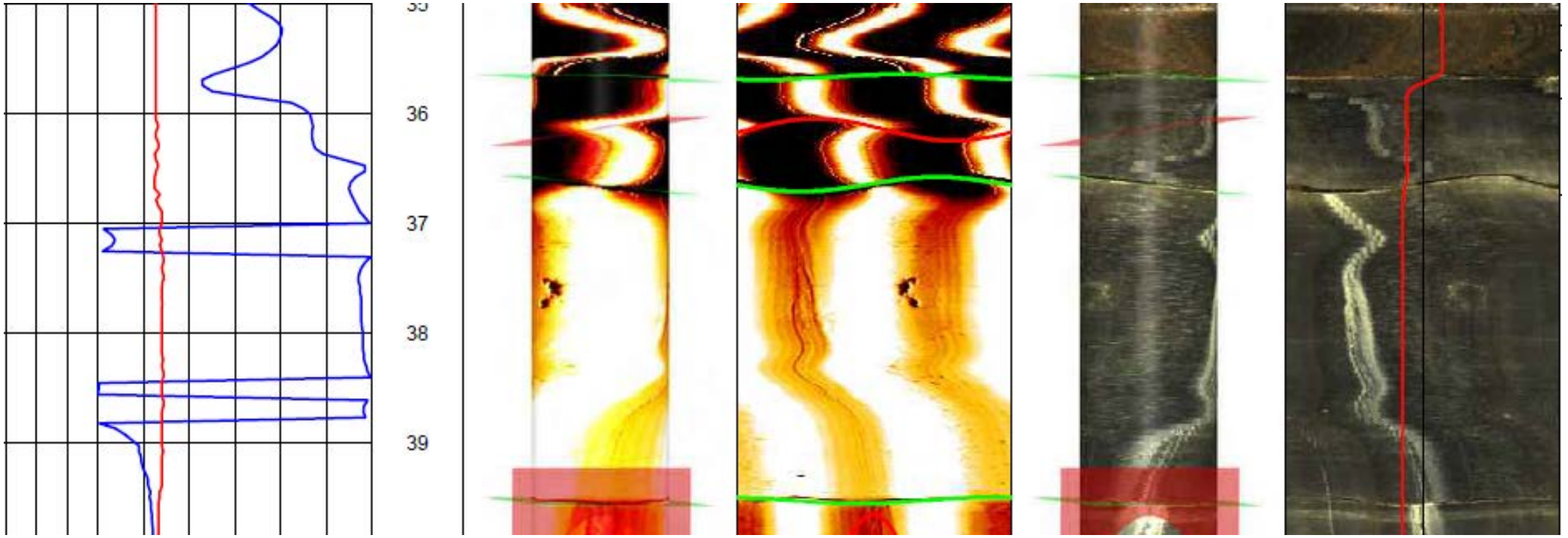
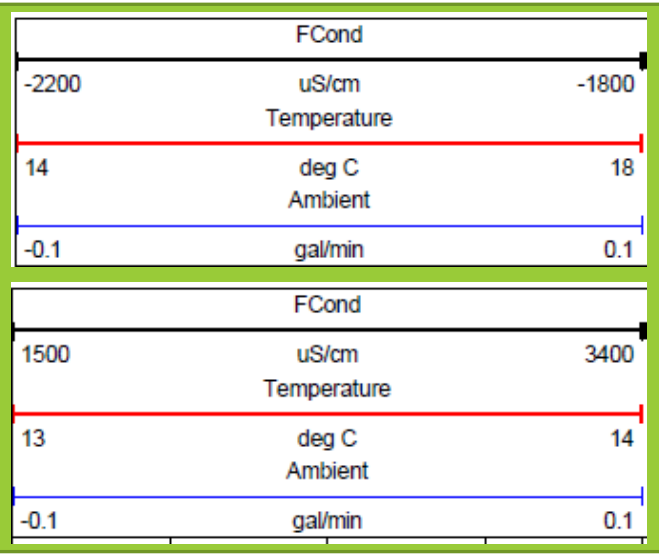
Orientation Errors



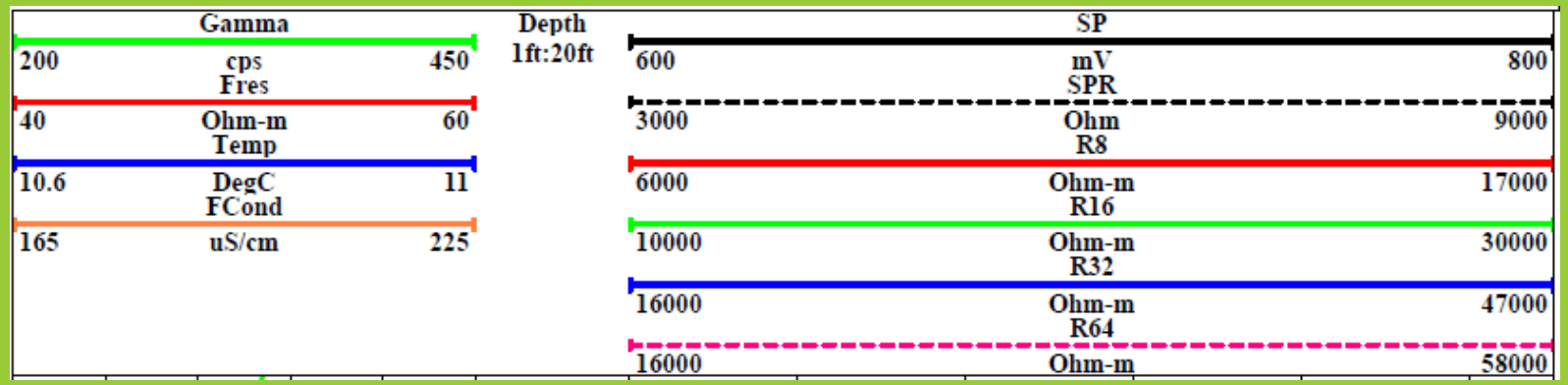
- True North vs Magnetic North
    - Declination correction
- Loose Tooling
    - Azimuth & Tilt
- Ask for supplemental logs if images look distorted
- Will affect all other geophysical products if orientation is wrong

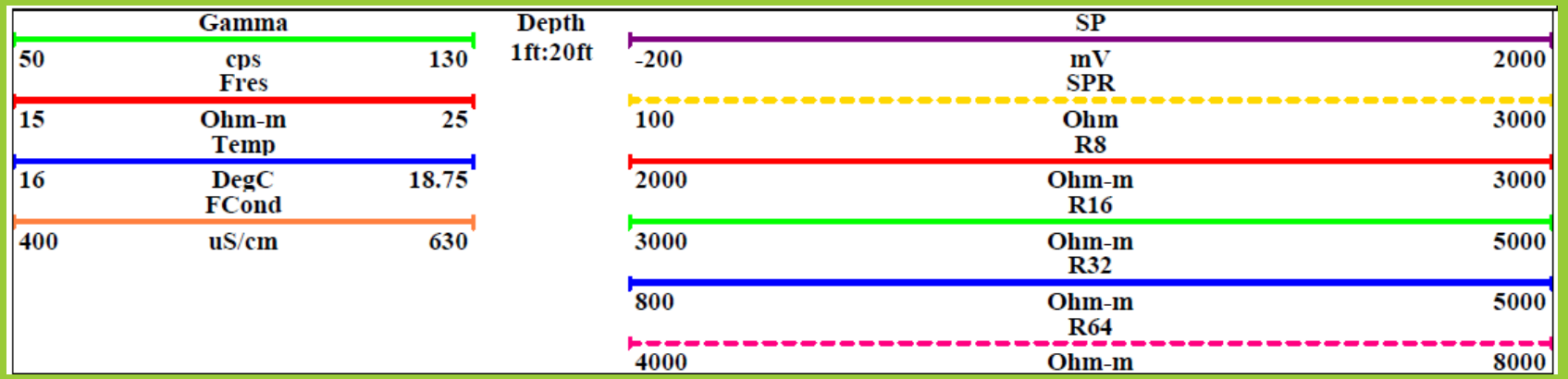
Fluid Data : Setting Reasonable Ranges



- These adjacent boreholes have wildly different ranges
- Fluid Conductivity should be a positive value
- Temperature range should show the variation in temperature and not be exceedingly large
- Raw data is recorded and can be provided as text file if needed

Setting Reasonable Ranges





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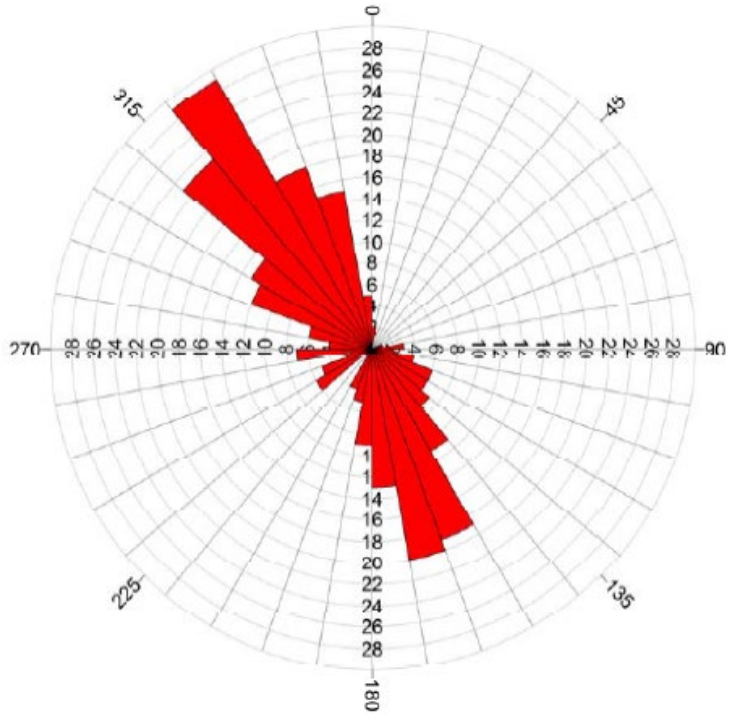
Structure Tables

Depth (ft bgl)	True Dip Azimuth	True Dip Angle	Apparent Aperture Code	Code Desc.	Code Color	Azimuth Strike (RHR)	Strike Direction (RHR)	Dip Direction Quadrant	Strike Direction Quadrant
145.36	313.4	33.79	107	Small	Blue	223.4	SW	NW	NE
145.77	326.62	39.44	107	Small	Blue	236.6	SW	NW	NE
146.06	316.2	44.32	112	Contact	Orange	226.2	SW	NW	NE
146.26	318.61	43.11	109	Bed/Band	Yellow	228.6	SW	NW	NE
146.54	293.1	52.52	110	Tight	Magenta	203.1	SW	NW	NE

Helpful data to be presented

Data columns to be provided at a minimum

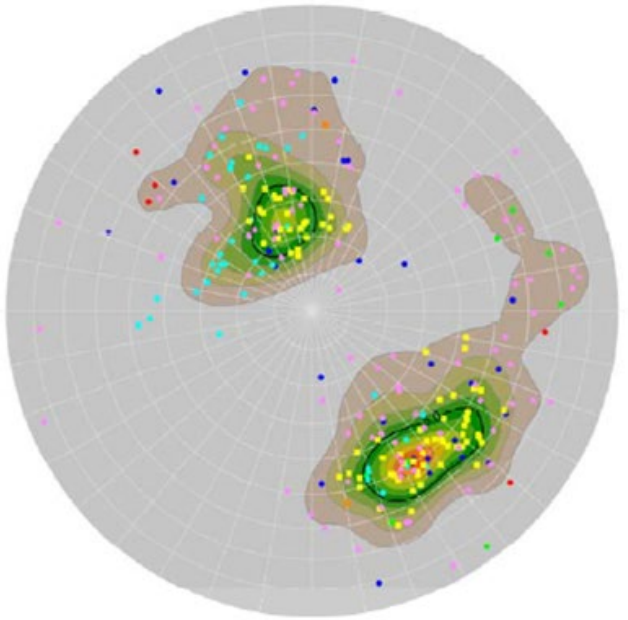
Rose & Steronet Diagrams



BR-6 Rose Diagram (All data)

Statistical Summary	
Calculation Method:	Frequency
Class Interval:	10.0 Degrees
Azimuth Plotting:	Undirectional
Data Type:	Undirectional
Population:	259
Total Length of All Lineations:	259.0
Maximum Bin Population:	28.0
Mean Bin Population:	8.63
Standard Deviation of Bin Population:	7.23
Maximum Bin Population (%):	11.2
Mean Bin Population (%):	3.33
Standard Deviation of Bin Population (%):	2.79
Maximum Bin Length:	28.0
Mean Bin Length:	8.63
Standard Deviation of Bin Lengths:	7.23
Maximum Bin Length (%):	11.2
Mean Bin Length (%):	3.33
Standard Deviation of Bin Lengths (%):	2.79
Vector Mean:	266.7 Degrees
Confidence Interval:	24.4 Degrees
	(95 Percent)
R-mag:	0.2

BR-6 Dip Direction and Azimuth (All data)



Statistical Summary	
Projection:	Schmidt (Equal Area)
Number of Sample Points:	259
Mean Lineation Azimuth:	122.9
Mean Lineation Plunge:	63.4
Great Circle Azimuth:	324.8
Great Circle Plunge:	79.4
1st Eigenvalue:	0.529
2nd Eigenvalue:	0.362
3rd Eigenvalue:	0.11
LN (E1 / E2):	0.38
LN (E2 / E3):	1.191
(LN(E1/E2)) / (LN(E2/E3)):	0.319
Spherical Variance:	0.304
Rbar:	0.606

Legend

- Large
- Moderate
- Small
- Tight
- Fabric
- Vein
- Bedding/Banding
- Open Bed/Band
- Contact

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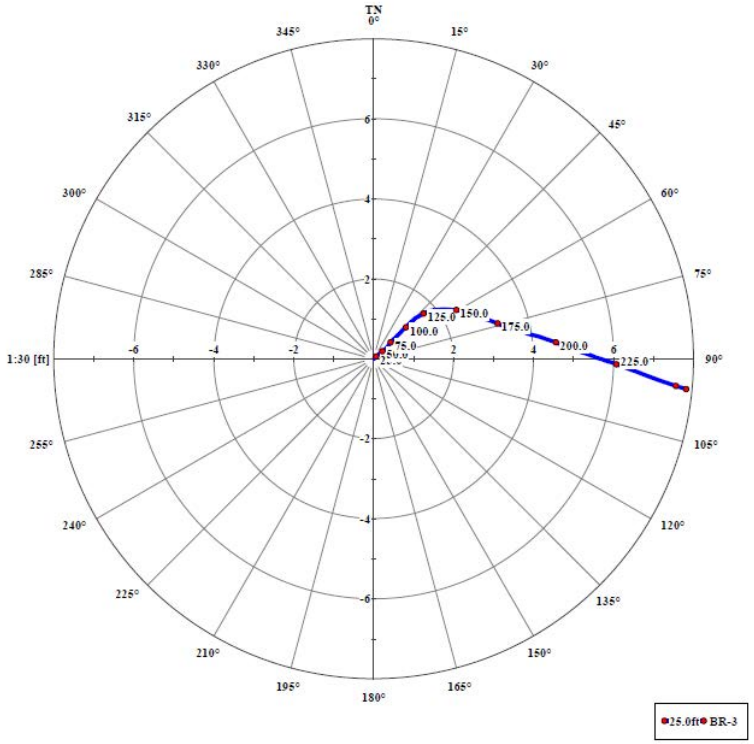
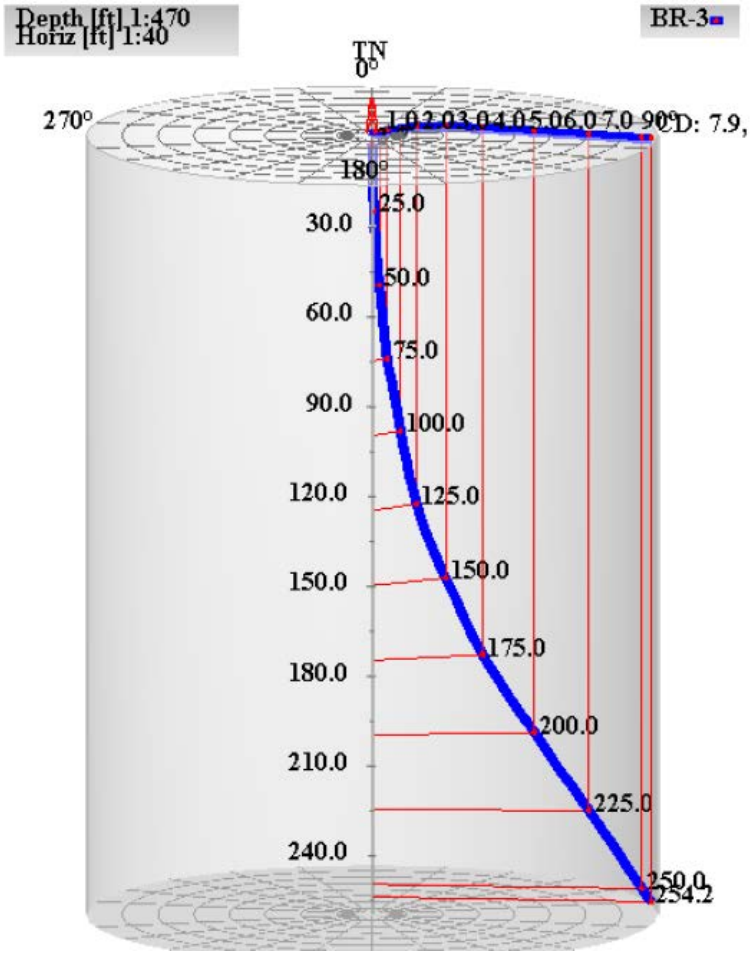
Deviation Plots

- Helpful for deep boreholes
- Essential for angled holes





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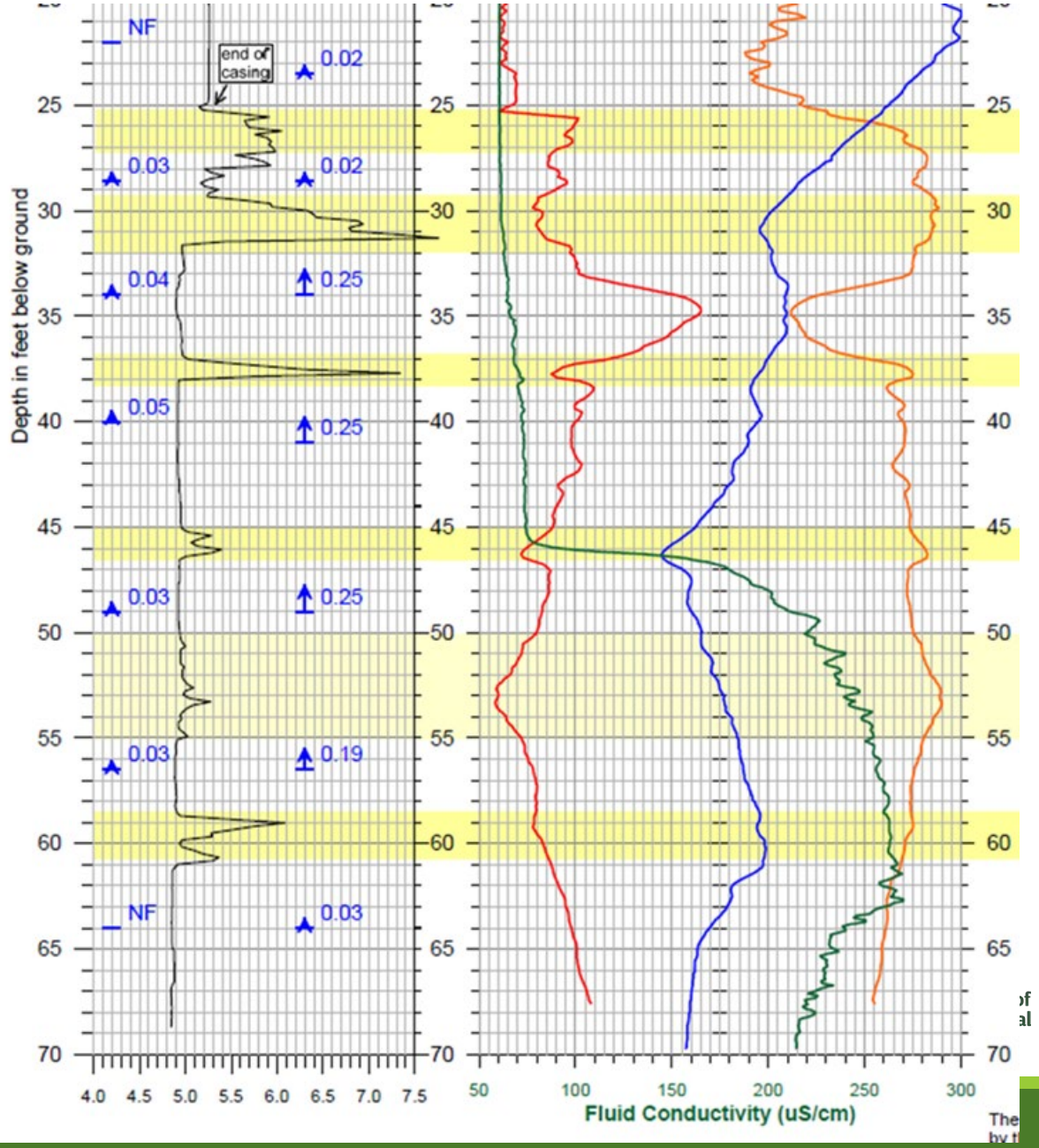
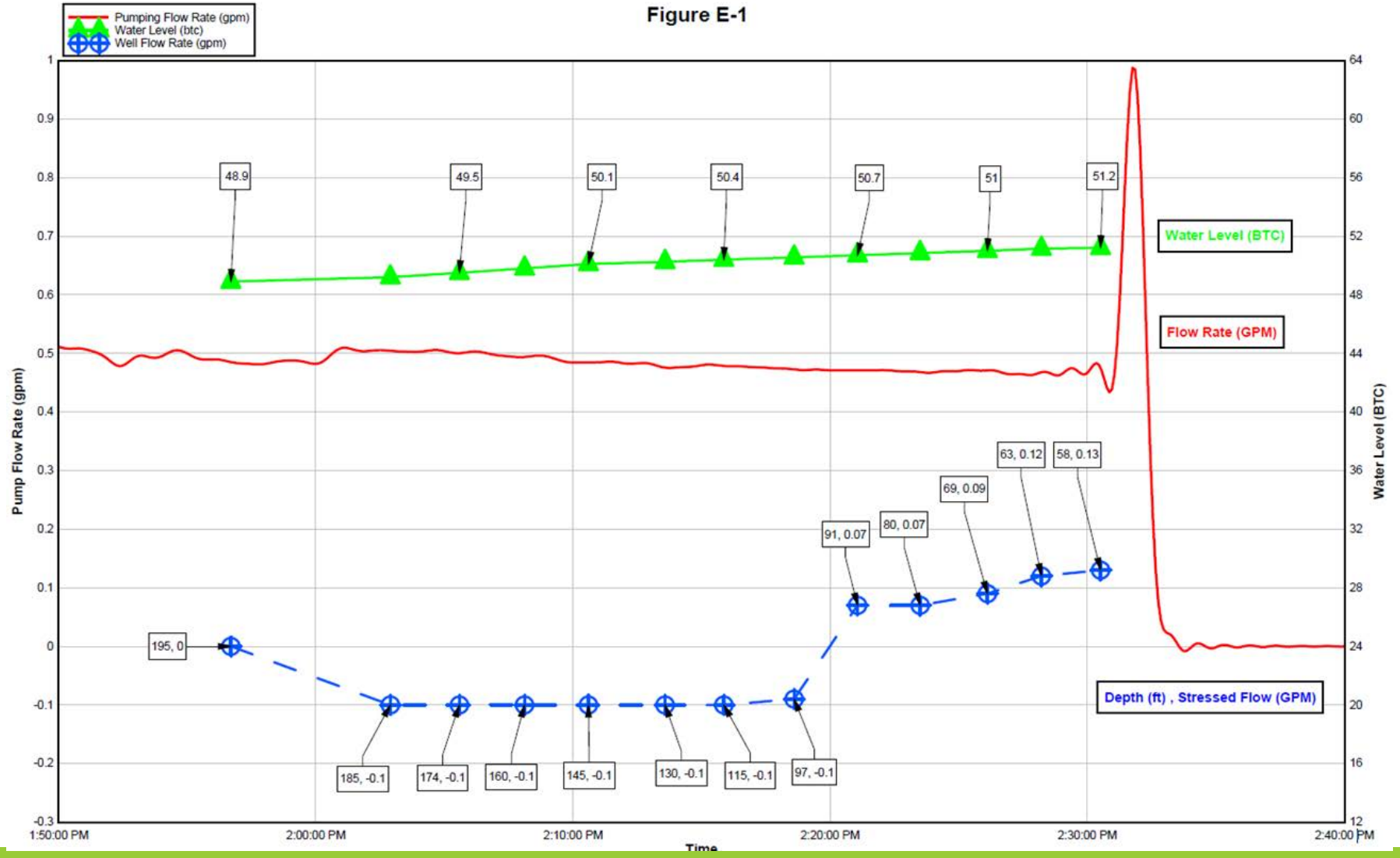
Heat Pulse Flow Meter

- Ambient Testing (No pumping)
  - Can identify the natural flow conditions in borehole
- Stressed Testing (Pumping)
  - Prepare for IDW of pumping water
  - Pumping flow rate needs to be recorded
- Stressed Testing should be surveyed at steady state conditions at constant low flow (~1 gpm or less)
  - Groundwater head should be at equilibrium
  - Groundwater level in the casing (If possible, for QAQC)
  - No changes to pump rate during testing
- HPFM Data presented (tables or graph & image logs)
  - Flow rate
  - Depth
  - HPFM response flow rate



HPFM Stressed Testing Flow Data



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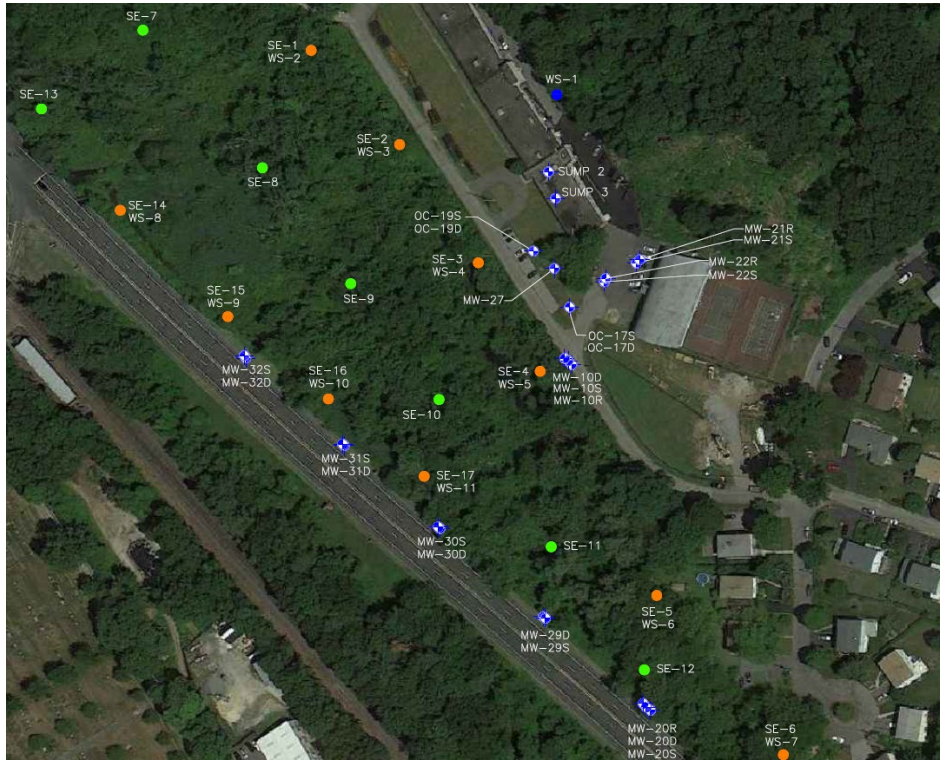
Reporting

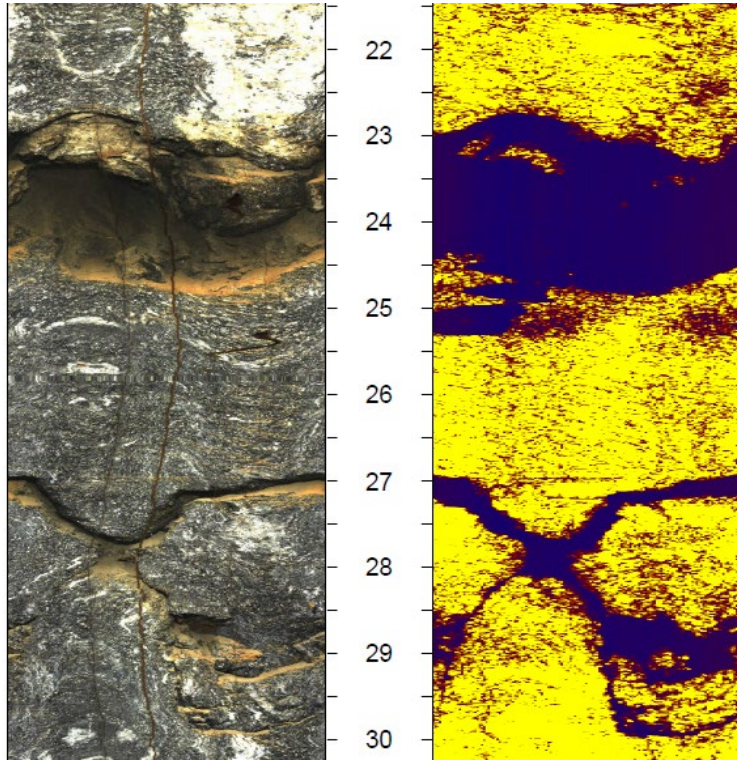
Report Analysis (Geophysical Contractor)

- Geological background
- Interpretation & conclusions supported by multiple lines of evidence
- Fracture orientations & transmissivity (data)

Application & Next Steps (Project Manager)

- Fracture projection, discrete fracture sampling
- Monitoring well construction considerations
- Update CSM (migration pathways)
- Use updated CSM for proper placement (horizontal & vertical) of any additional monitoring wells





Application of Geophysics to a Remedial Site

VOC Disposal History

- Operations at the Site included: machining of metals, photolithographic processing (including cupric etching), soldering, and electronic and mechanical assembly.
- Spent solvents (including trichloroethene [TCE] were historically released to the subsurface through the basement sump. As a result, VOCs have impacted overburden groundwater, bedrock groundwater, surface water and indoor air at the Site.
- Groundwater sampling indicates DNAPL may be present.

Groundwater Sampling Method Comparison
Extended Pumping vs. Low-Flow Sampling

Monitoring Well No.	Total Site-Related Contaminant Concentrations			
	Evacuation Cycle 1	Evacuation Cycle 2	Evacuation Cycle 3	Low-Flow Sampling
MW-21R	178,874	216,202	230,295	85,000
MW-22S	3,668	3,778	3,352	2,848
MW-22R	33,955	36,232	37,111	20,629

Note: All concentrations presented in ug/L.

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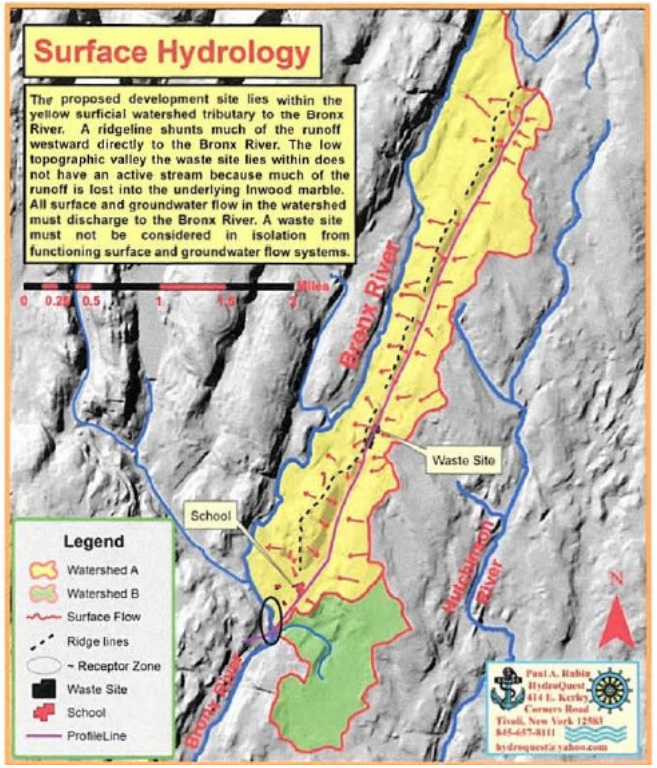
Check Regional Geology

- Geology : Manhattan Prong / Highland Province
- Faulting associated with Taconic Trusting
- Deformation and Isoclinal folding
- Differential weathering, localized watersheds



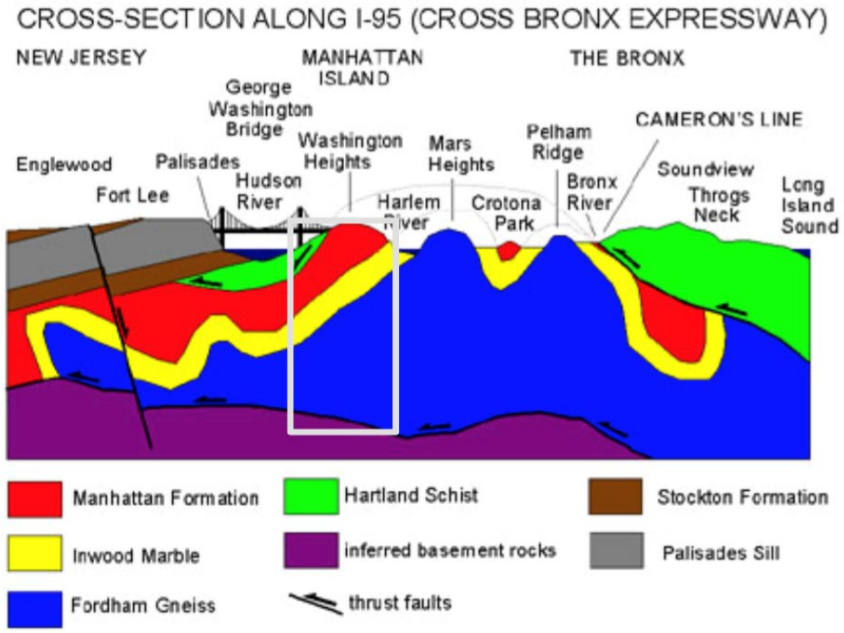
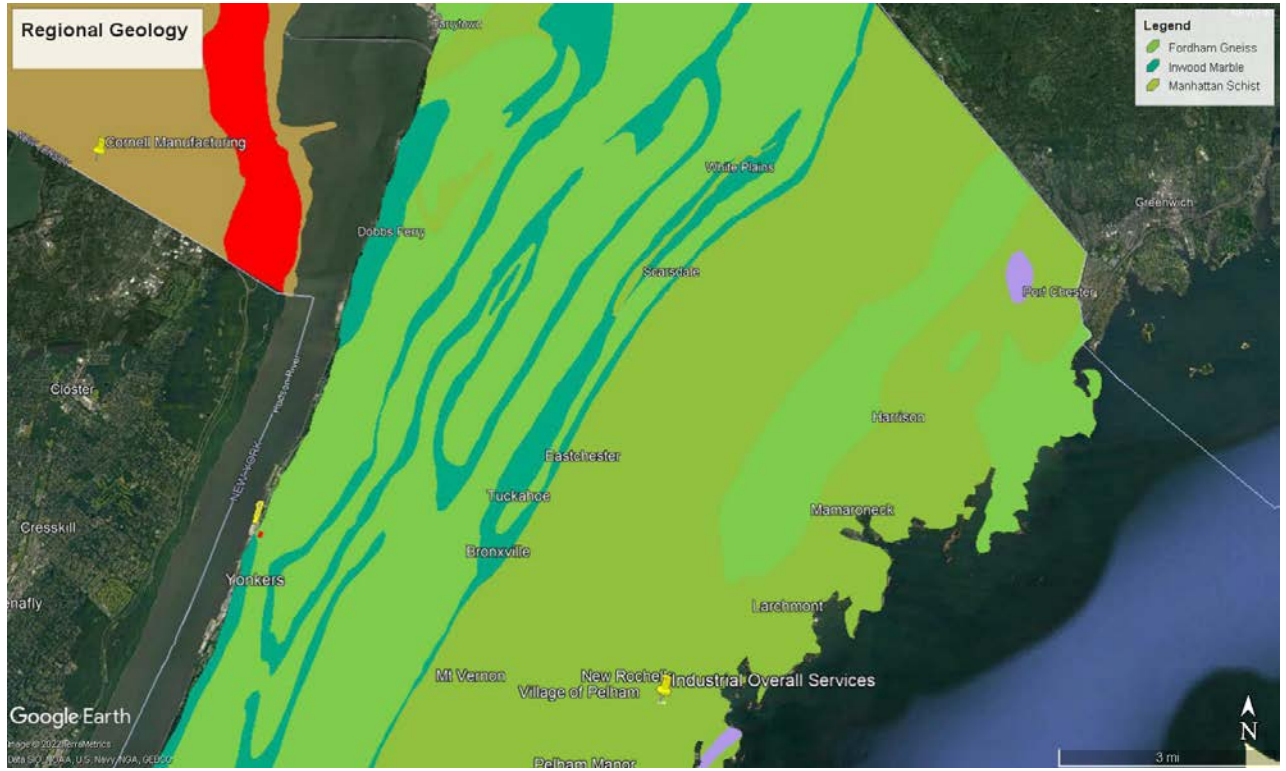


Figure 2

Regional Geology



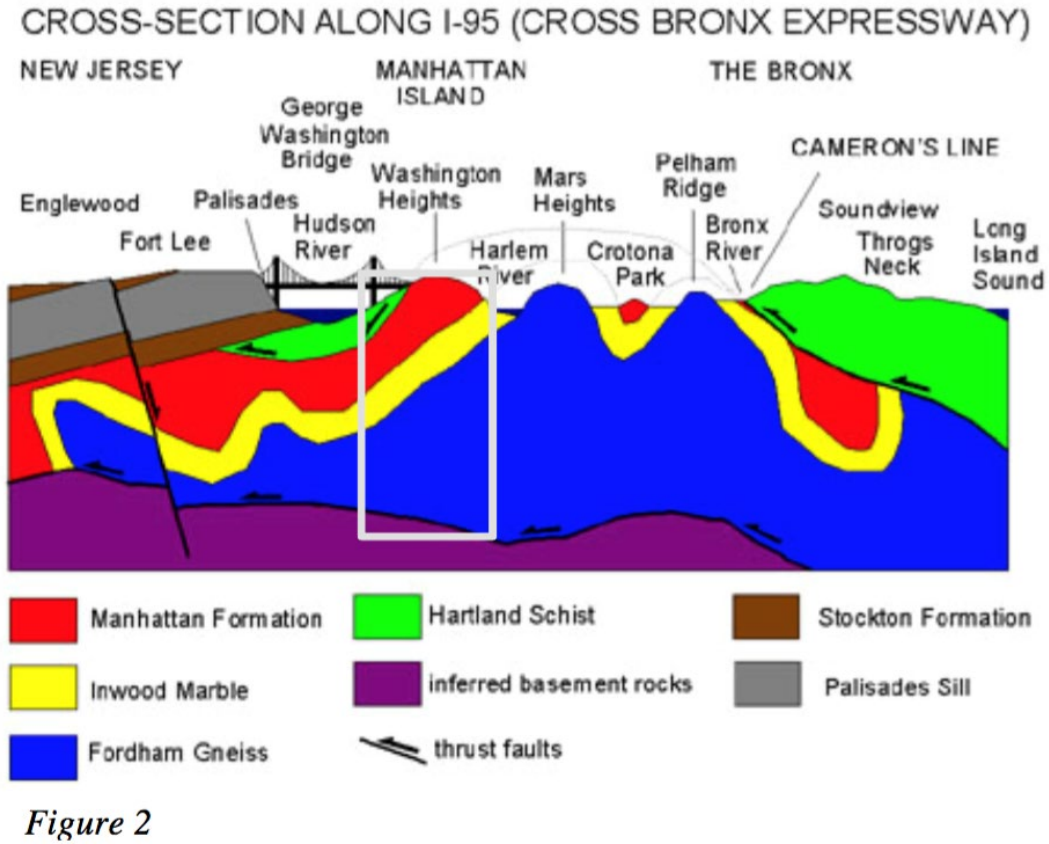


Figure 2

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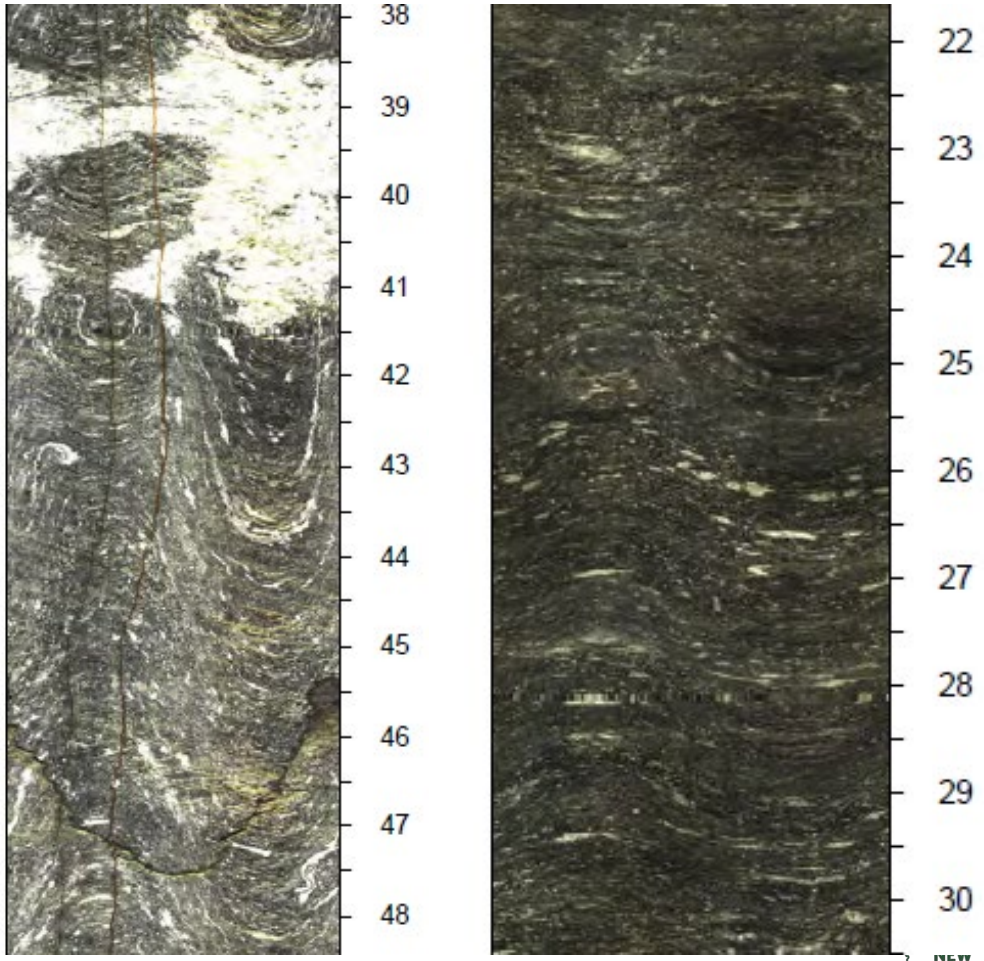
Fordham Gneiss



Groundwater Flow Direction

- Overburden vs. Bedrock
- Downward vertical hydraulic gradient
- Flow directions is in discrete bedrock fractures
- How will DNAPL migrate?

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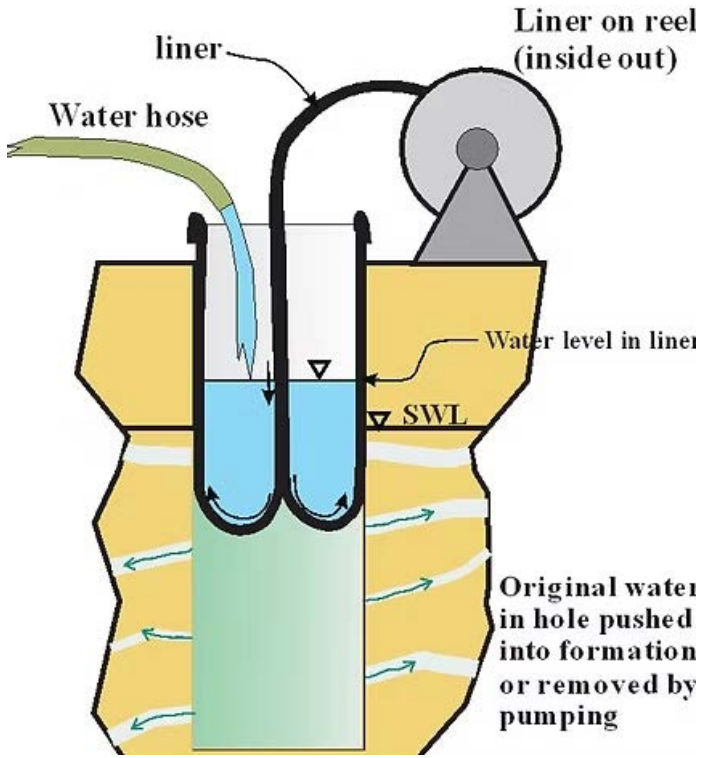
Monitoring Well Considerations

- “Blank” Flute liner / FACT liner to prevent DNAPL cross-contamination



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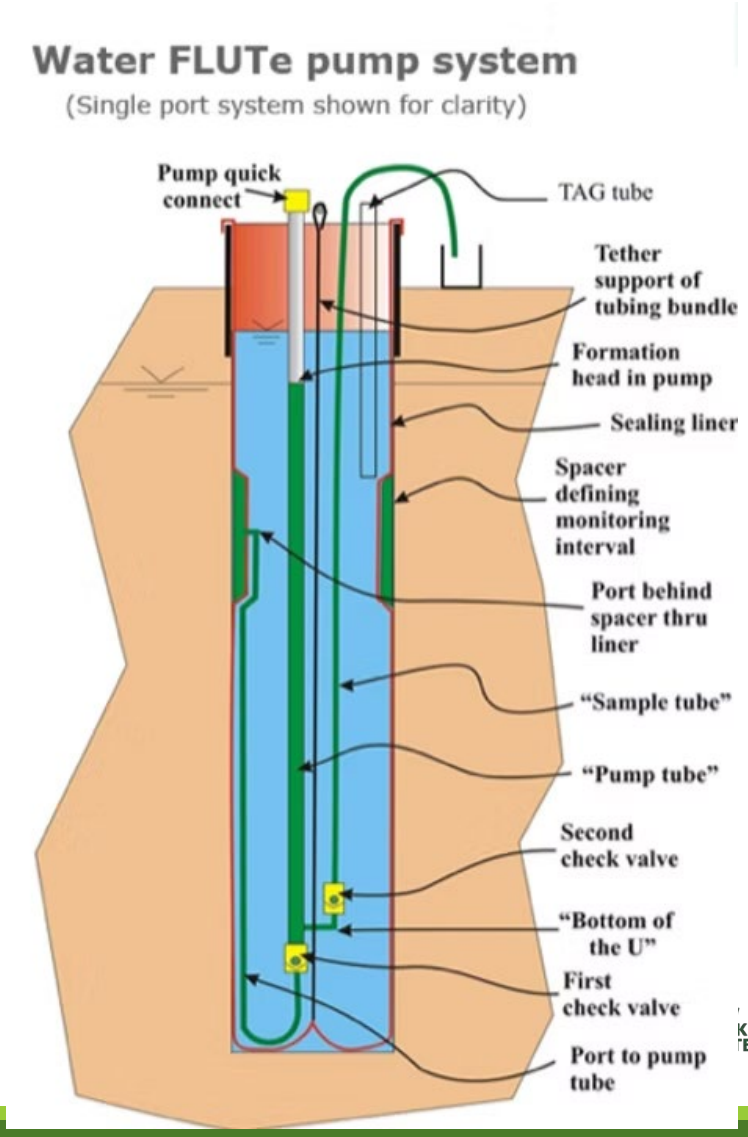
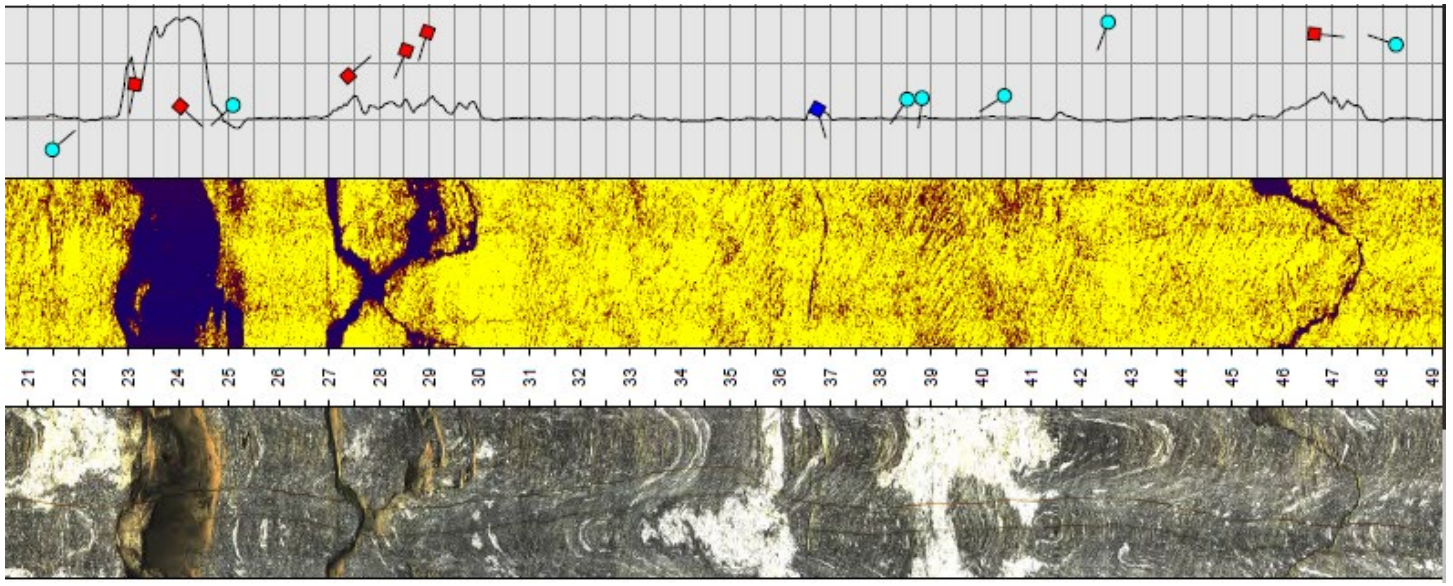
Monitoring Well Considerations (Long Term)



Geophysical Survey Data



MW-101-R - Summary of Borehole Flow Under Ambient & Pumping Conditions

Depth (Feet)	Comments (flow was not detected in the borehole under ambient conditions)
-1.0	Ground Surface
0.0	Top of the Steel Casing
4.8	Ambient Water Level
14.0 - 15.0	Location of Pump for HPFM Under Pumping Conditions
15.0 - 15.1	flow up the borehole in the casing at 0.40 gpm under pumping conditions
15.1	Bottom of the 8-Inch Steel Casing
15.1 - 15.5	possible minor flow into or out of the borehole based on the fluid temp & fluid cond data
15.5 - 22.7	flow up the borehole at 0.40 gpm under pumping conditions
22.7 - 24.9	flow into & up the borehole under pumping conditions
24.9 - 26.9	flow up the borehole at 0.02 gpm under pumping conditions
26.9 - 30.0	possible minor flow into or out of the borehole based on the fluid temp & fluid cond data
30.0 - 45.4	flow up the borehole at 0.02 gpm under pumping conditions
45.4 - 47.6	possible minor flow into or out of the borehole based on the fluid cond data
47.6 - 49.8	flow up the borehole at 0.02 gpm under pumping conditions
49.8 - 54.7	minor flow into & up the borehole under pumping conditions
54.7	Bottom of the Borehole (based on the geophysical logging)

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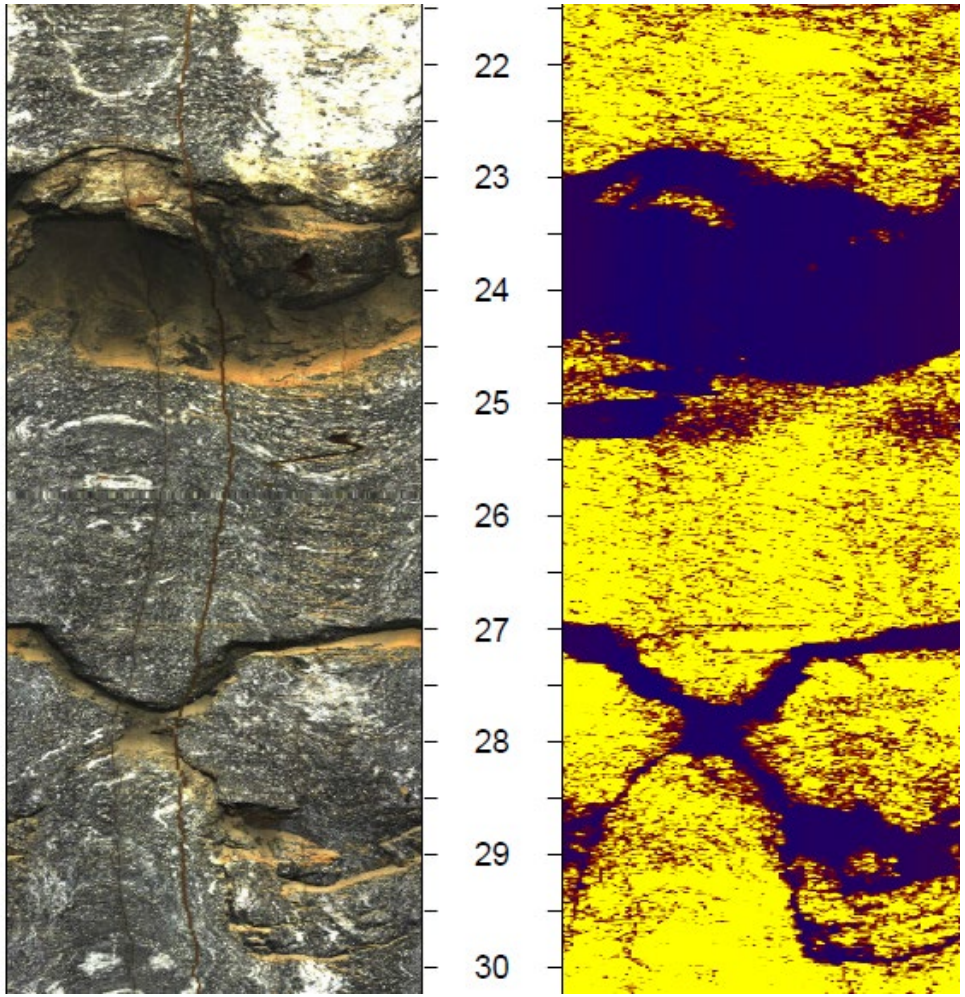
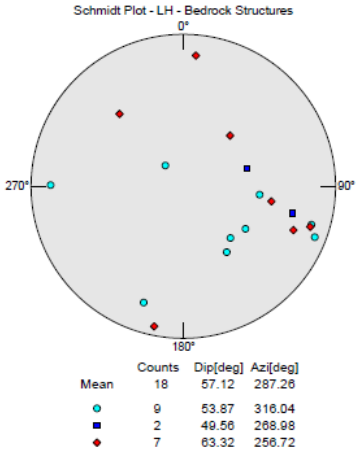
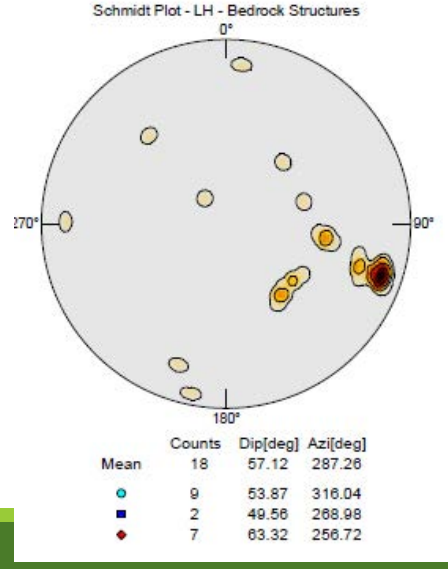
Bedrock Geophysical Fracture Projection



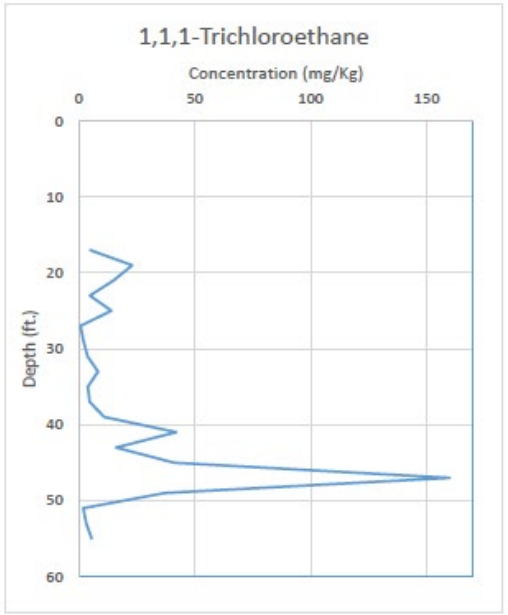
MW-101-R - TABLE OF BEDROCK FRACTURES

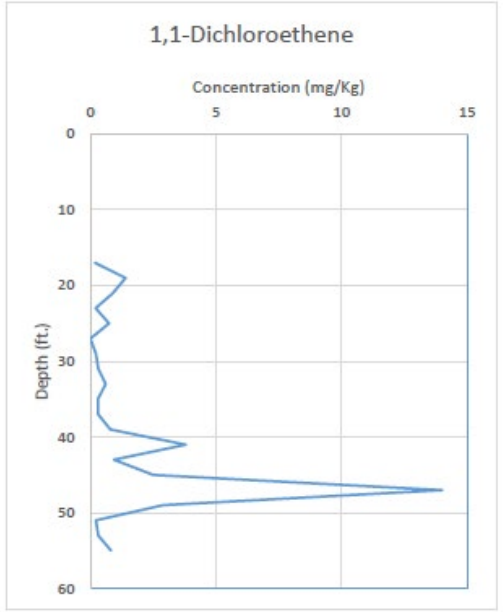
Depth (Feet)	Dip Azimuth (Degrees)	Dip Angle (Degrees)	Bedrock Fracture Category
16.6	91	76	Fracture Rank 1
18.7	287	77	Fracture Rank 1
19.4	284	63	Fracture Rank 2
21.5	140	15	Fracture Rank 1
23.1	280	49	Fracture Rank 3
24.0	223	38	Fracture Rank 3
25.1	318	38	Fracture Rank 1
27.4	139	54	Fracture Rank 3
28.5	292	67	Fracture Rank 3
29.0	288	76	Fracture Rank 3
36.7	254	36	Fracture Rank 2
38.5	304	41	Fracture Rank 1
38.8	276	42	Fracture Rank 1
40.5	327	43	Fracture Rank 1
42.5	291	82	Fracture Rank 1
46.6	186	76	Fracture Rank 3
48.3	19	70	Fracture Rank 1
52.2	12	84	Fracture Rank 3

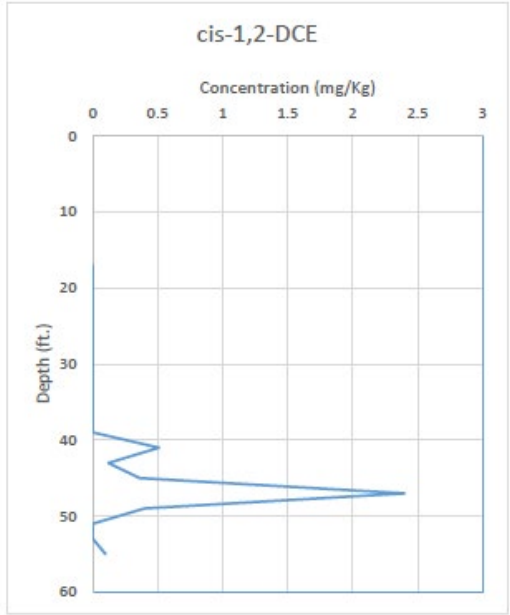


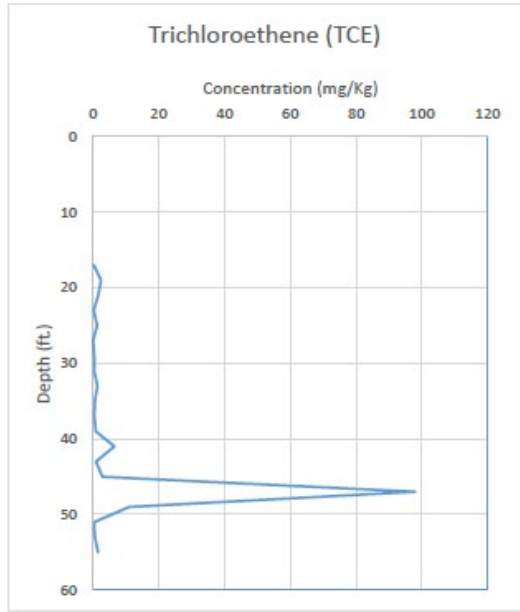


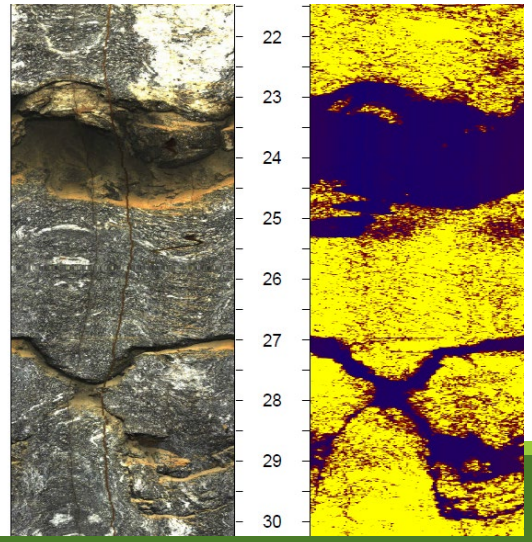
Bedrock Geophysics & FLUTe

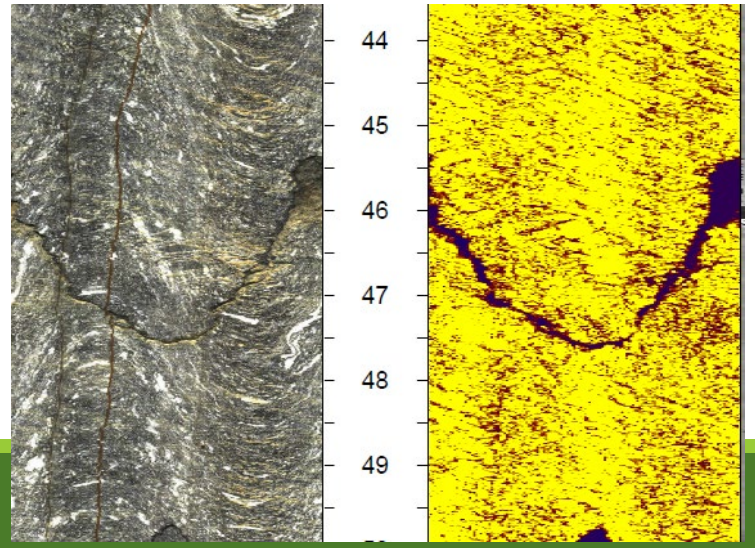












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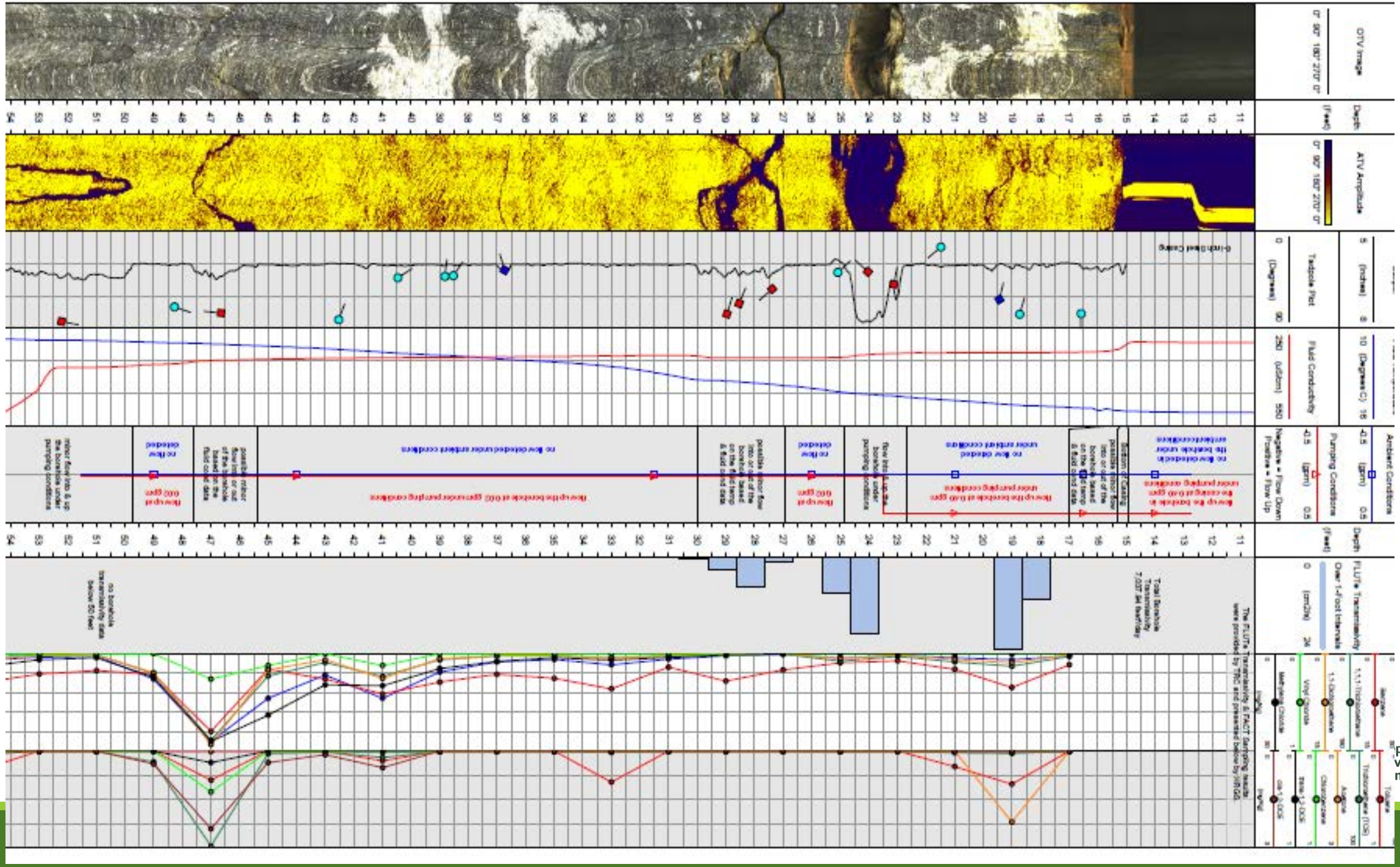

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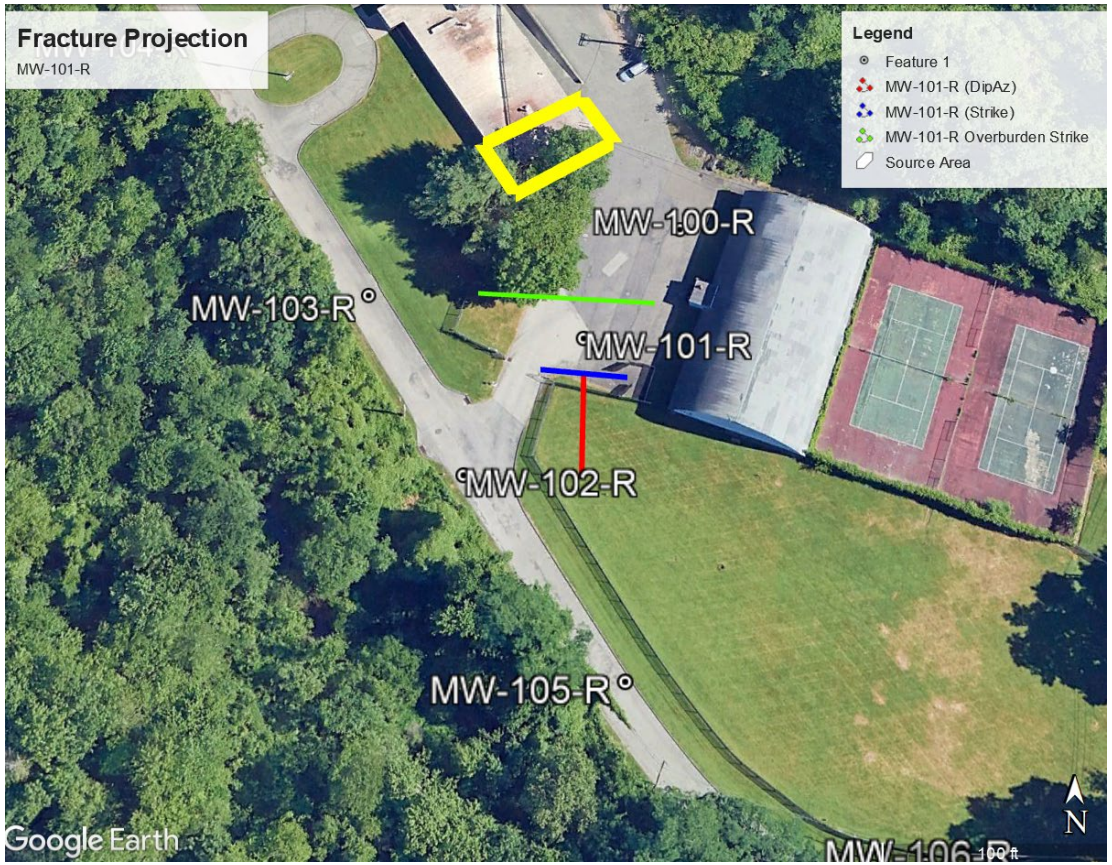
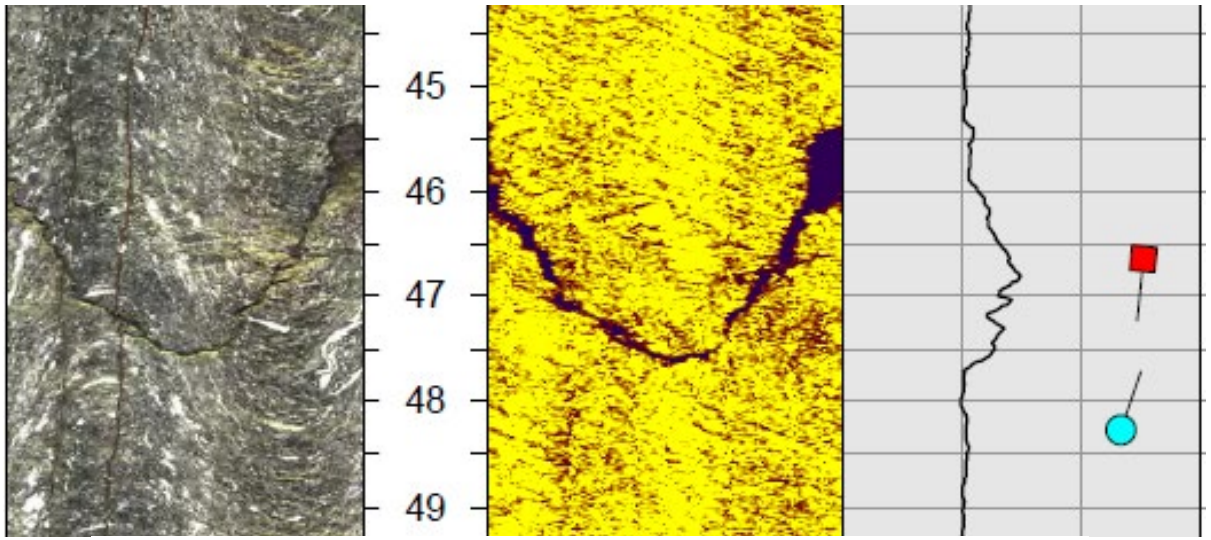
Geophysics & Fracture Projections (MW-101-R)





Depth (Feet)	Dip Azimuth (Degrees)	Dip Angle (Degrees)	Bedrock Fracture Category
46.6	186	76	Fracture Rank 3

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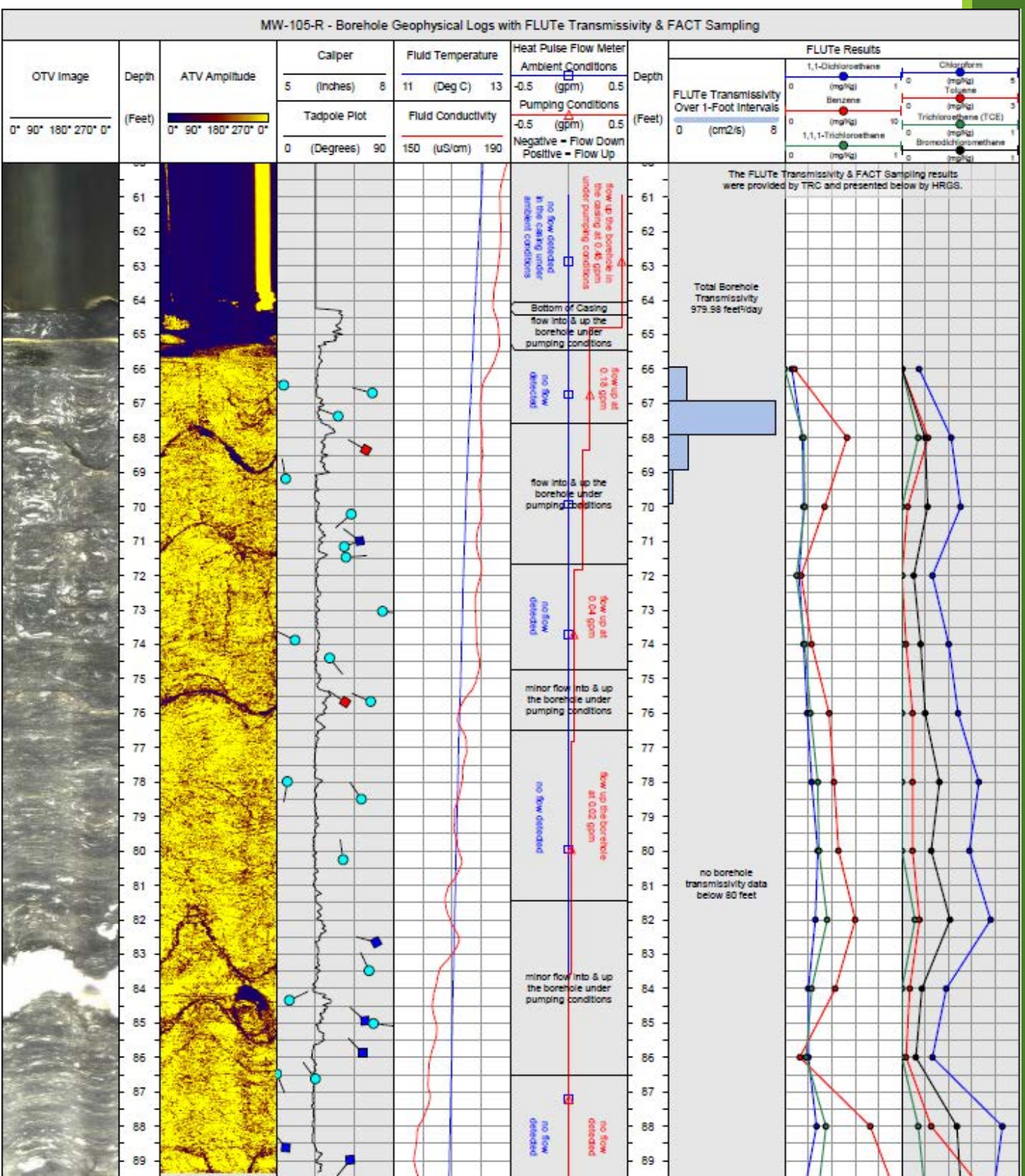
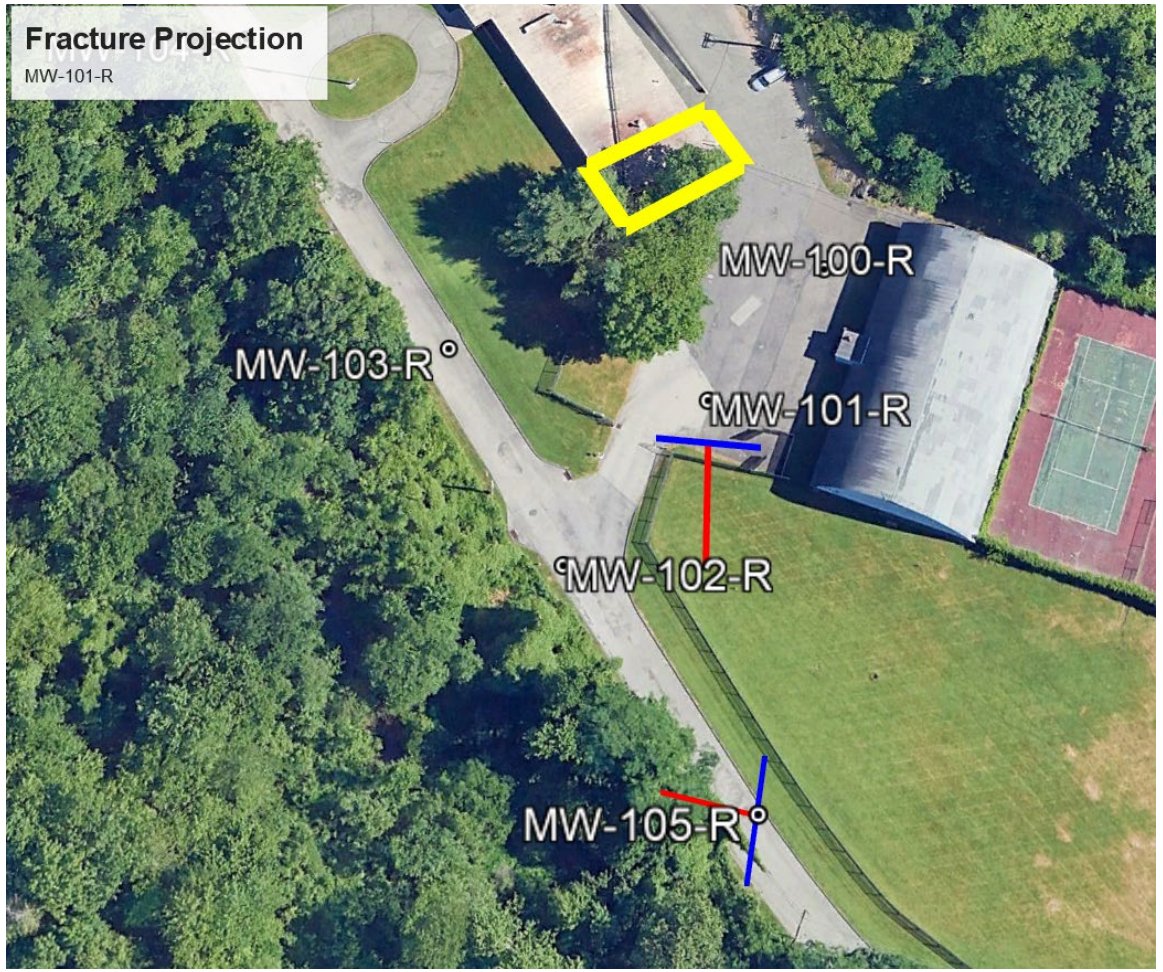
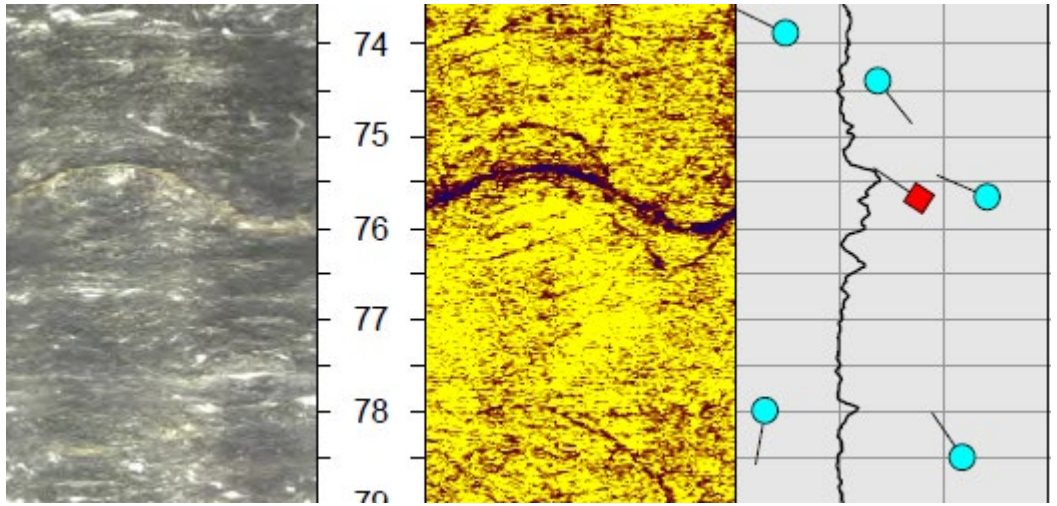

MW-105-R - Borehole Geophysical Logs with FLUTe Transmissivity & FACT Sampling
OTV Image
0° 90° 180° 270° 0°
Depth
(Feet)
ATV Amplitude
0° 90° 180° 270° 0°
Caliper
5 (Inches) 8
Tadpole Plot
0 (Degrees) 90
Fluid Temperature
11 (Deg C) 13
Fluid Conductivity
150 (uS/cm) 190
Heat Pulse Flow Meter
Ambient Conditions
-0.5 (gpm) 0.5
Pumping Conditions
-0.5 (gpm) 0.5
Negative = Flow Down
Positive = Flow Up
no flow detected in the casing under ambient conditions
flow up the borehole in the casing at 0.45 gpm under pumping conditions
Bottom of Casing
flow into & up the borehole under pumping conditions
no flow detected
flow up at 0.18 gpm
flow into & up the borehole under pumping conditions
no flow detected
flow up at 0.04 gpm
minor flow into & up the borehole under pumping conditions
no flow detected
flow up the borehole at 0.02 gpm
minor flow into & up the borehole under pumping conditions
no flow detected
no flow detected
Depth
(Feet)
FLUTe Transmissivity Over 1-Foot Intervals
0 (cm2/s) 8
Total Borehole Transmissivity 979.98 feet²/day
no borehole transmissivity data below 80 feet
FLUTe Results
1,1-Dichloroethane
Chloroform
Benzene
Toluene
Trichloroethene (TCE)
1,1,1-Trichloroethane
Bromodichloromethane
(mg/kg)
The FLUTe Transmissivity & FACT Sampling results were provided by TRC and presented below by HRGS.

(MW-105-R)

Geophysics & Fracture Projections (MW-105-R)





Depth (Feet)	Dip Azimuth (Degrees)	Dip Angle (Degrees)	Bedrock Fracture Category
75.7	304	53	Fracture Rank 3
84.9	311	68	Fracture Rank 2
85.0	97	75	Fracture Rank 1
85.9	317	66	Fracture Rank 2
86.5	158	0	Fracture Rank 1
86.6	323	30	Fracture Rank 1

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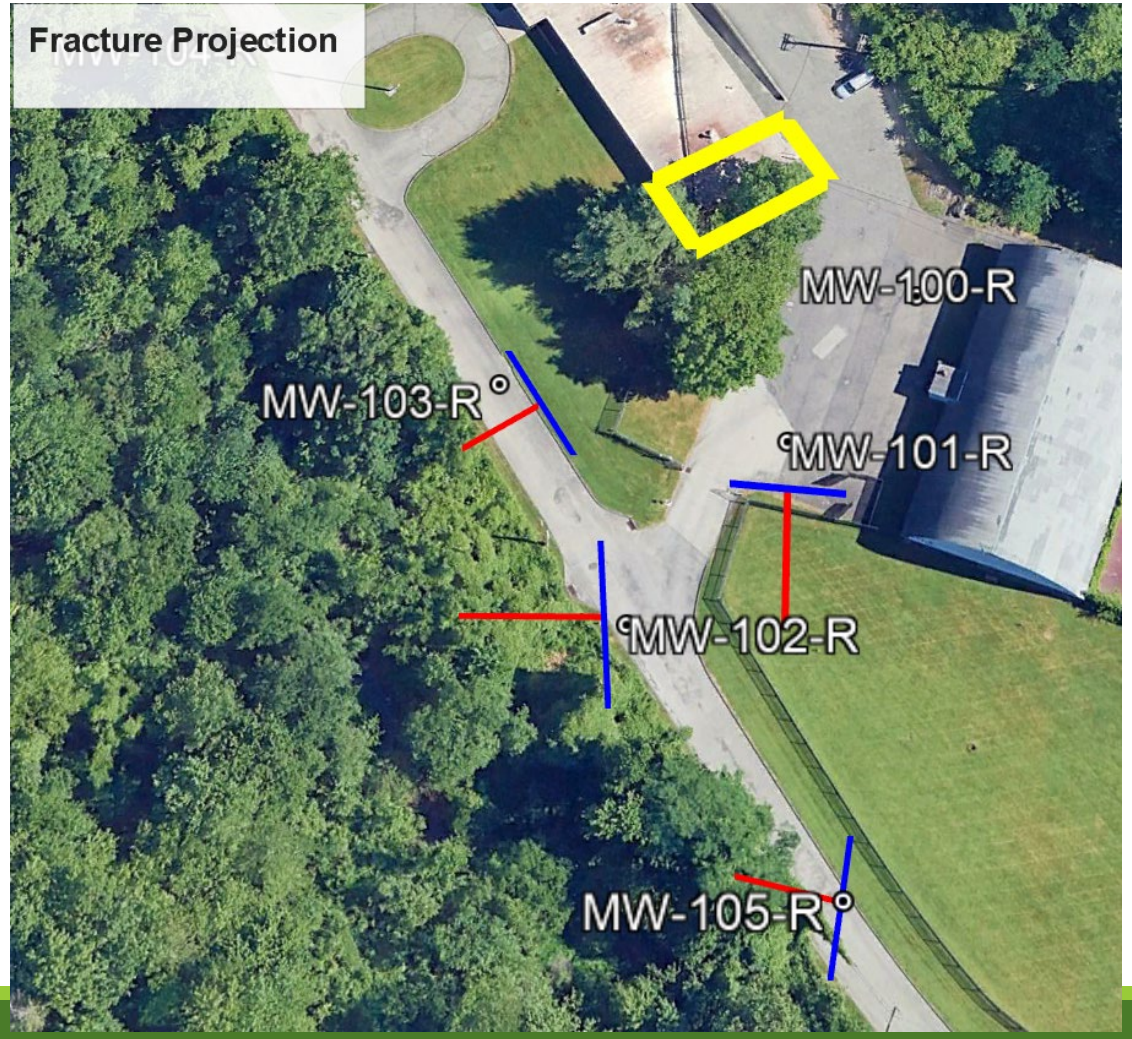
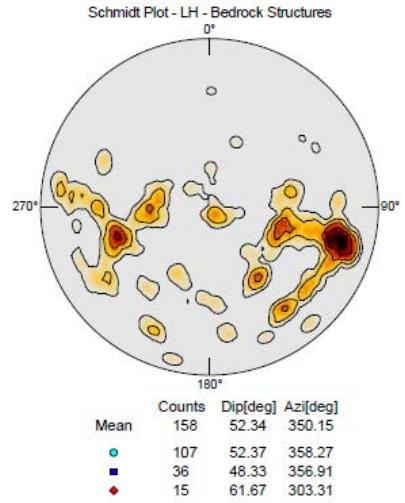
Geophysics & Fracture Projections (MW-102-R & MW-103-R)



Depth (Feet)	Dip Azimuth (Degrees)	Dip Angle (Degrees)	Bedrock Fracture Category
MW-102-R			
57.8	276	52	Fracture Rank 3
58.3	281	39	Fracture Rank 2
MW-103-R			
59.6	258	42	Fracture Rank 2
MW-105-R			
75.7	304	53	Fracture Rank 3



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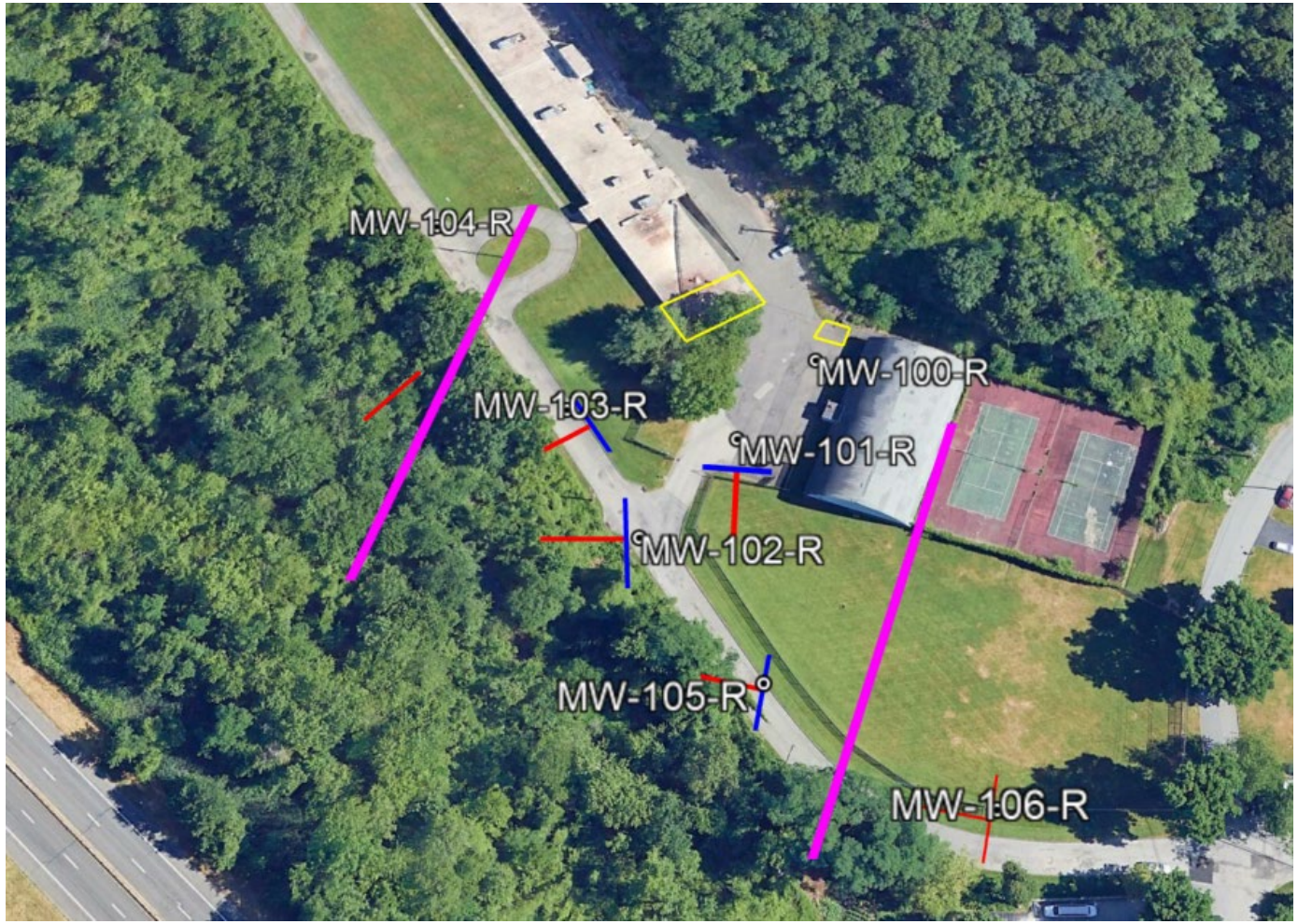
Geophysics & Fracture Projections (Updating CSM)



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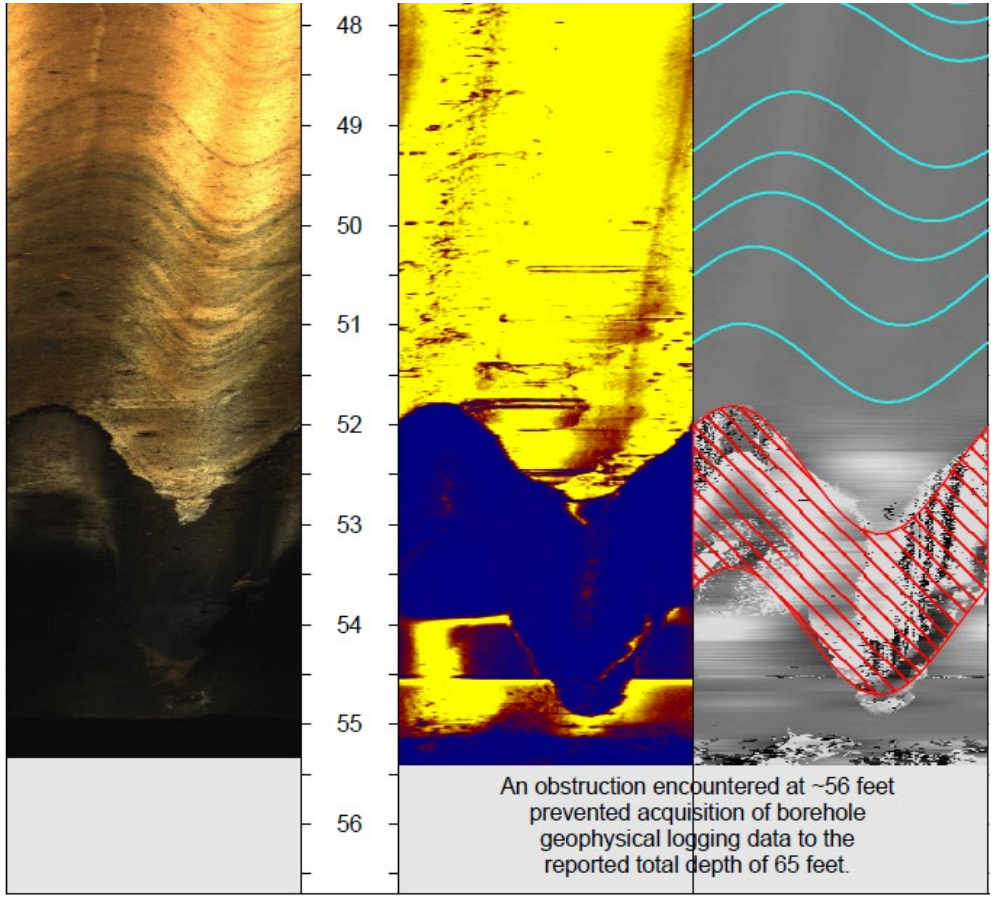
Applications of a Geophysical Surveys

- Updating geological understanding from regional geology to site specific geological properties.
- Identification of discrete and transmissive fractures with orientation data
- Creating an acceptable monitoring network which accounts for the primary fracture orientations in Fordham Gneiss and any folding structures
- Update Conceptual Site Model
- Optimization of remedial alternatives and design parameters



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Summary

1. Geophysical Tools
2. Monitoring Well Considerations
3. Geophysical Survey Deliverables
4. Application to a Remedial Site

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Questions?

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