# High Resolution Site Characterization and Bioremediation in Fractured Rock

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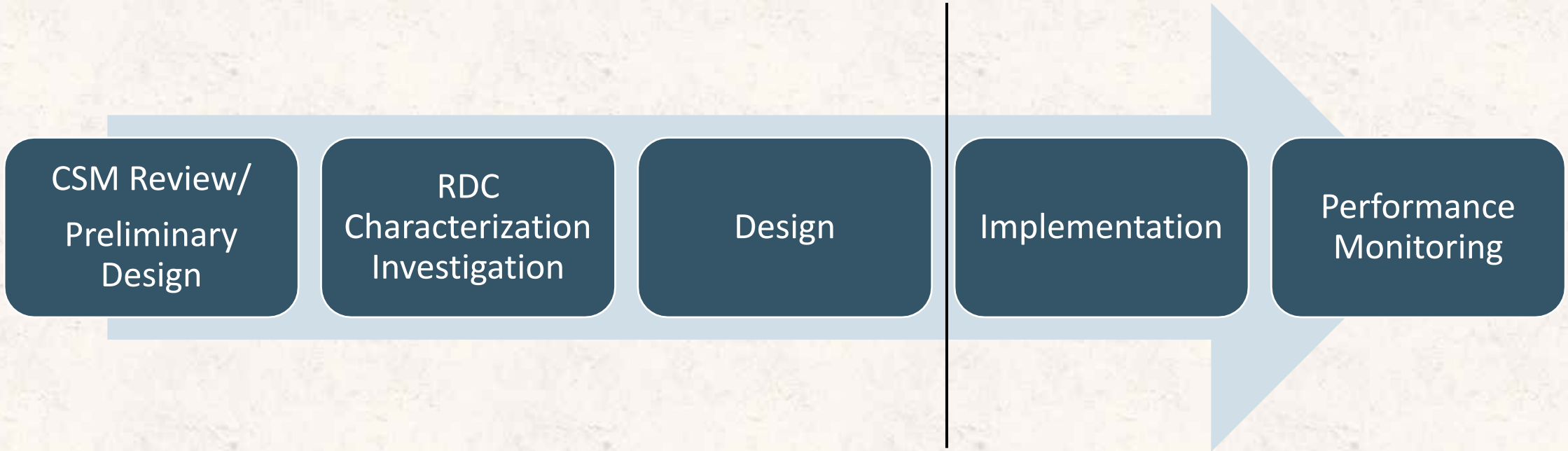
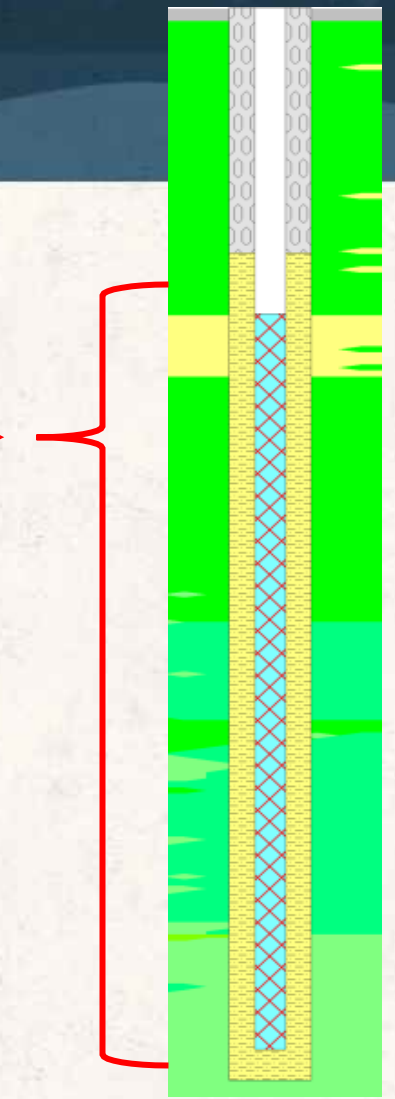
# Trap & Treat® Remediation Process (The Approach)



# Review and Design

Concerns

- Long well screens; cross bedrock interface; multiple zones
- Cased wells with constructed filterpack
- No groundwater characterization data
- Lithology logged from chips expelled during air rotary → need rock cores



Preliminary Designs and Estimates Based Upon:

- No differentiation of high/low concentration intervals
- Estimated porosities and hydraulic gradients
- Homogeneous stratigraphy
- Groundwater mass only

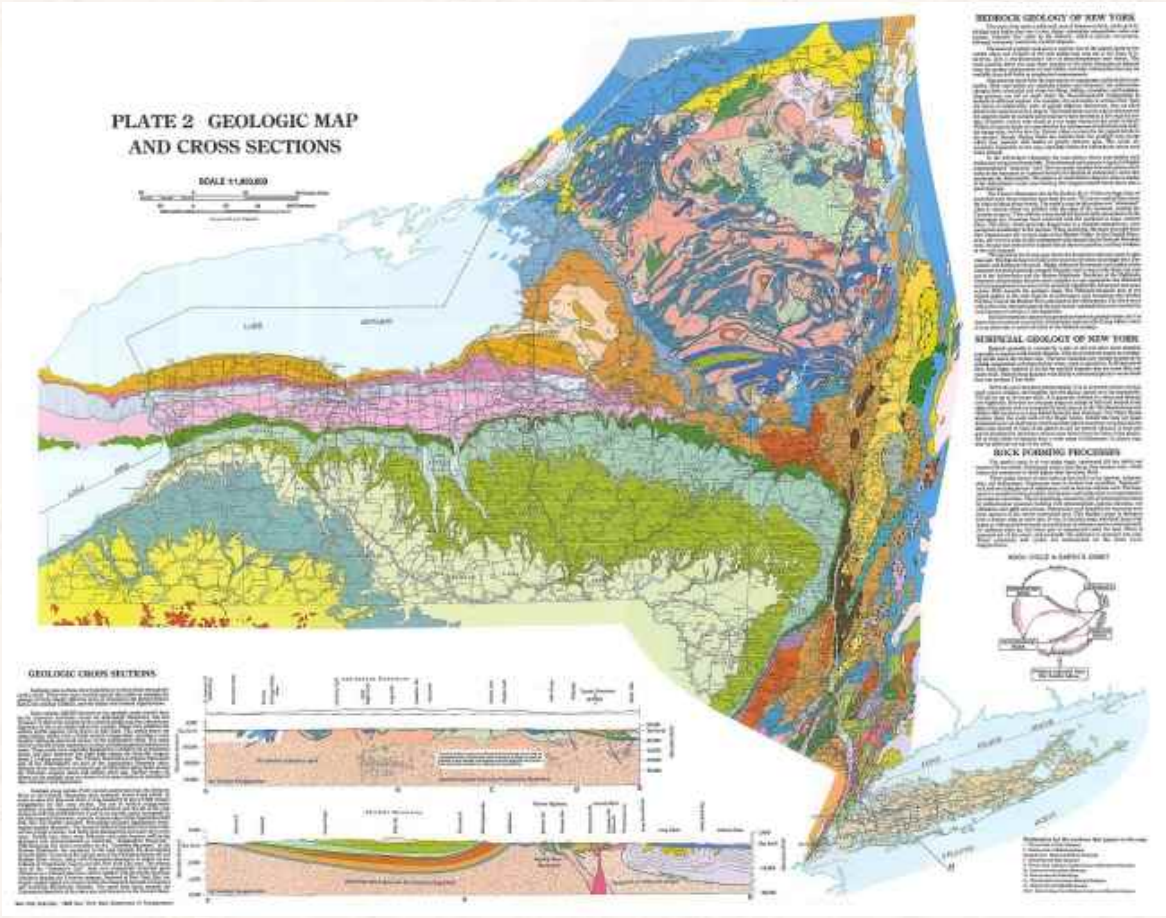
# Remedial Design Characterization (RDC)

Surface Geophysics
- 2D Electrical Resistivity
- Seismic

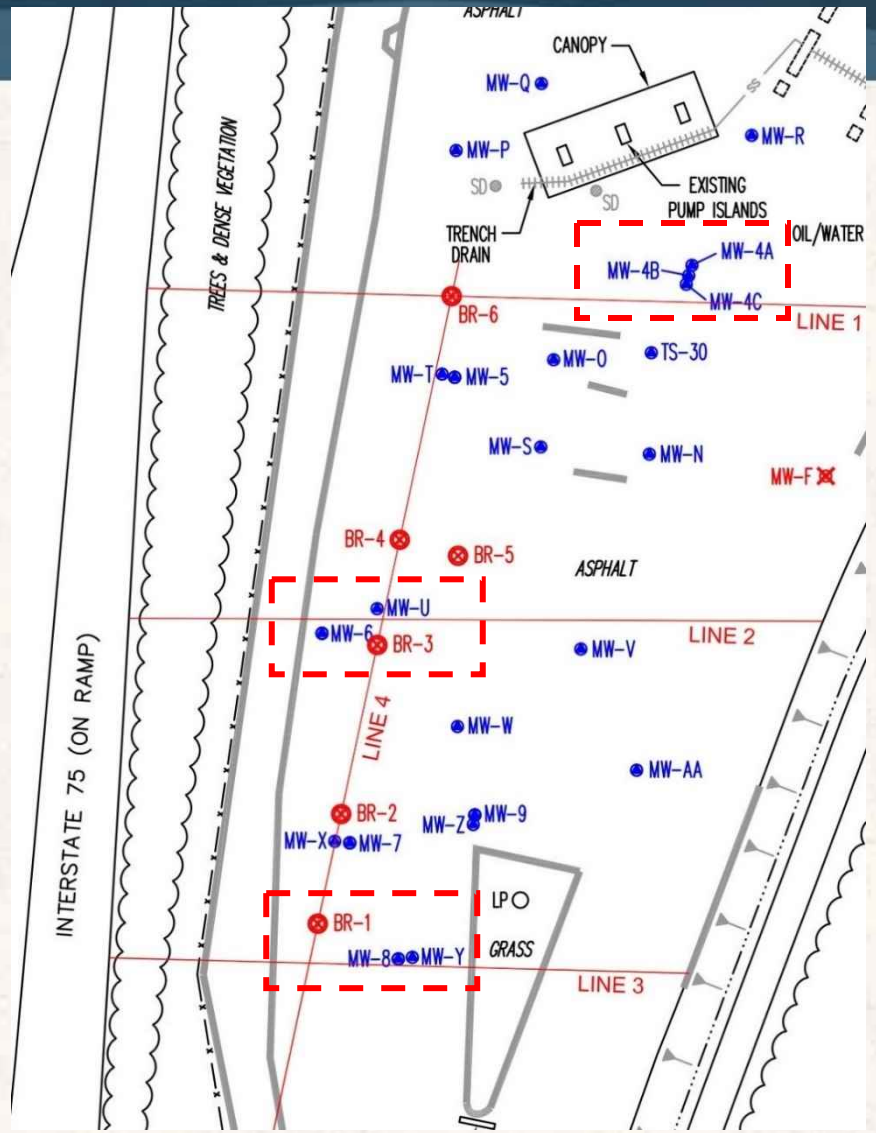
Characterization → Injection Wells
- Open Borehole with surface casing
- Rock Cores – logging and sampling of matrix

Borehole Geophysics
- Caliper, Acoustic Televiewer, Downhole Camera, etc.

Groundwater Characterization
- Pumping Tests
- Discrete Interval Analytical Sampling
- Response Data - Transducers

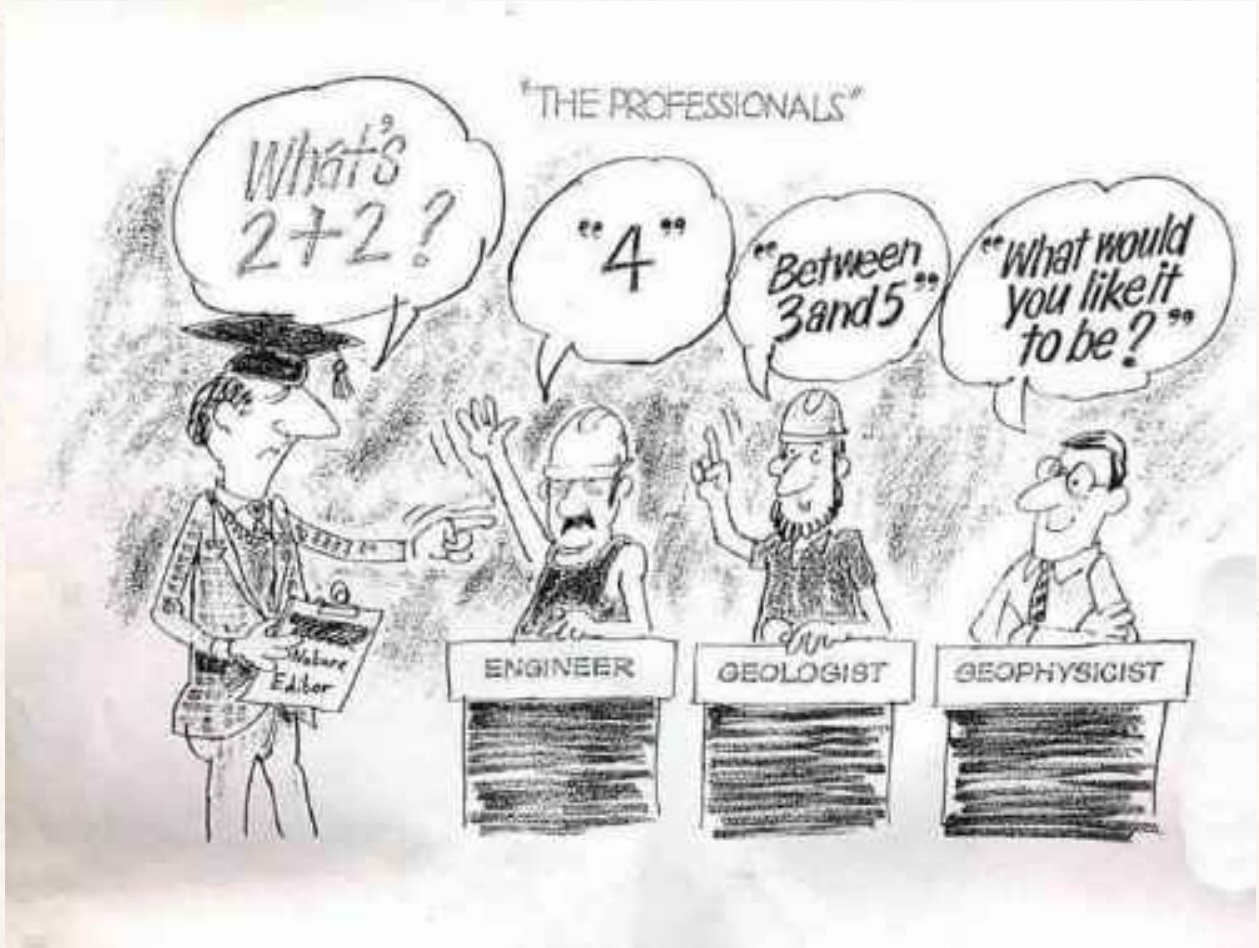


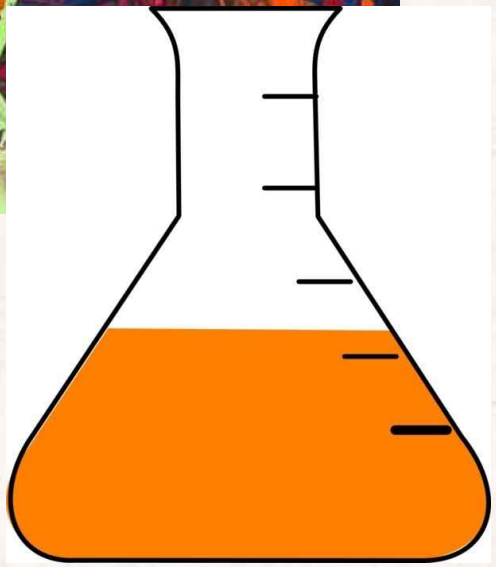
# Historical Data and Site Layout



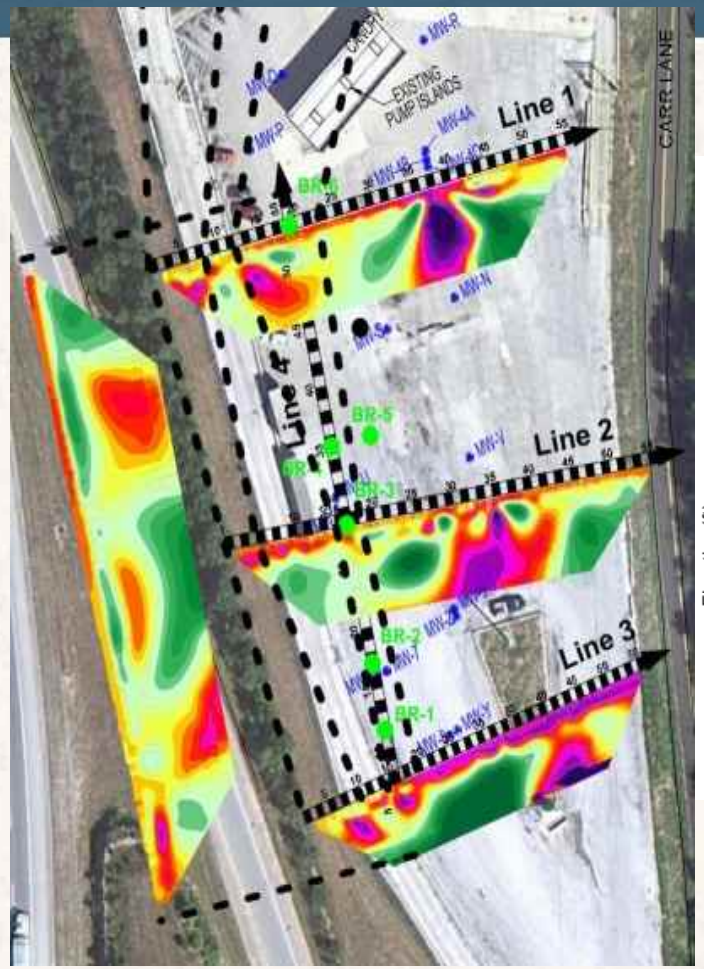

- Shallow bedrock
- Benzene higher in shallow wells near source
- Highest concentration MW-U – deep screen
- Shallow wells are most impacted further down gradient – MW-7, MW-8

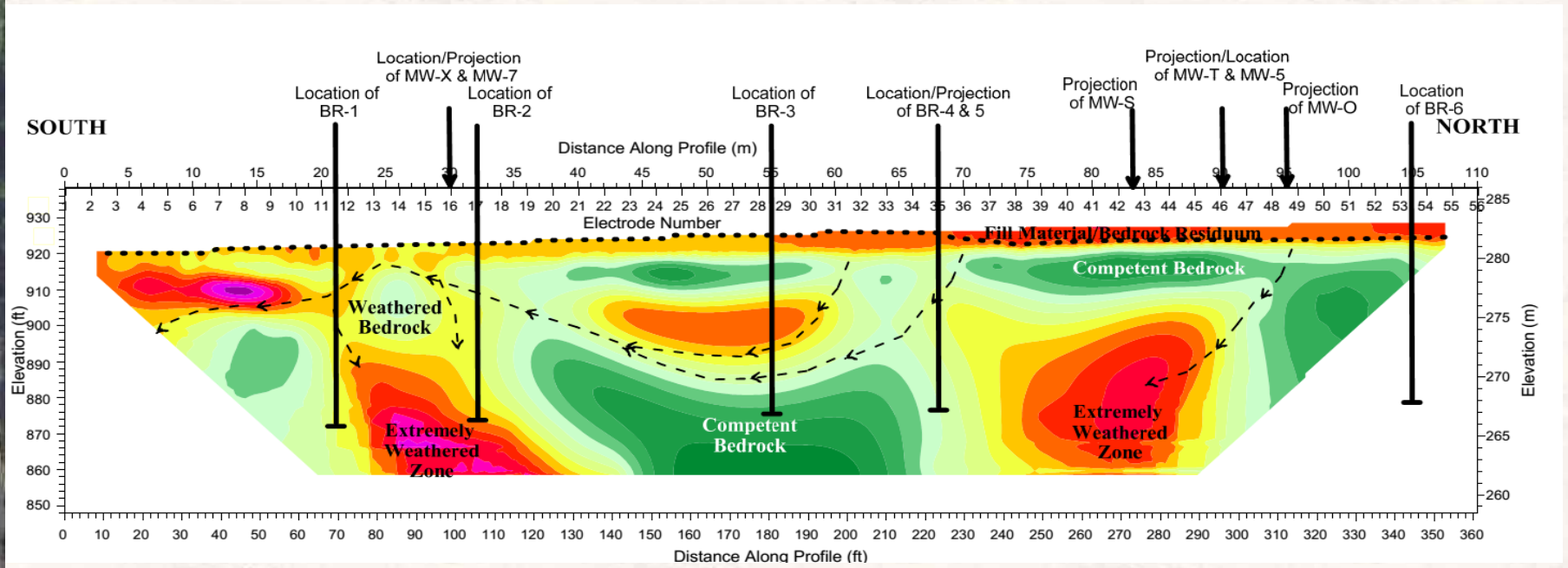
# Surface Geophysics



# RDC - 2-D Electrical Resistivity




Calloway Creek Limestone
Garrard Siltstone

# RDC - Rock Cores and Open Boreholes

Rock Cores

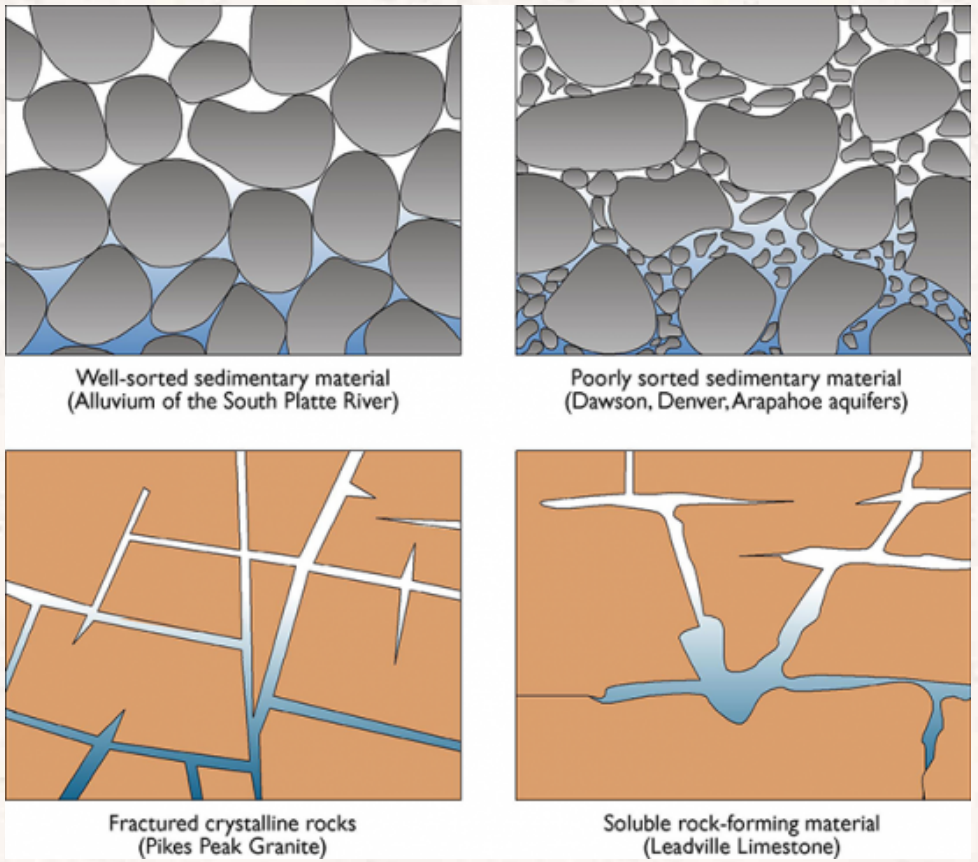
- Similar to dual tube prior to HSA
- Structure, texture, and variation in lithology visible in log perspective
- Look, touch, hold, or sample what you see in 2D wireline logs or downhole camera
- Matrix samples, collection
- Forensics?

Surface Cased Open Borehole Wells

- Characterization → Injection Wells
- Multi-purpose access: not just diluted dissolved chemistry monitoring

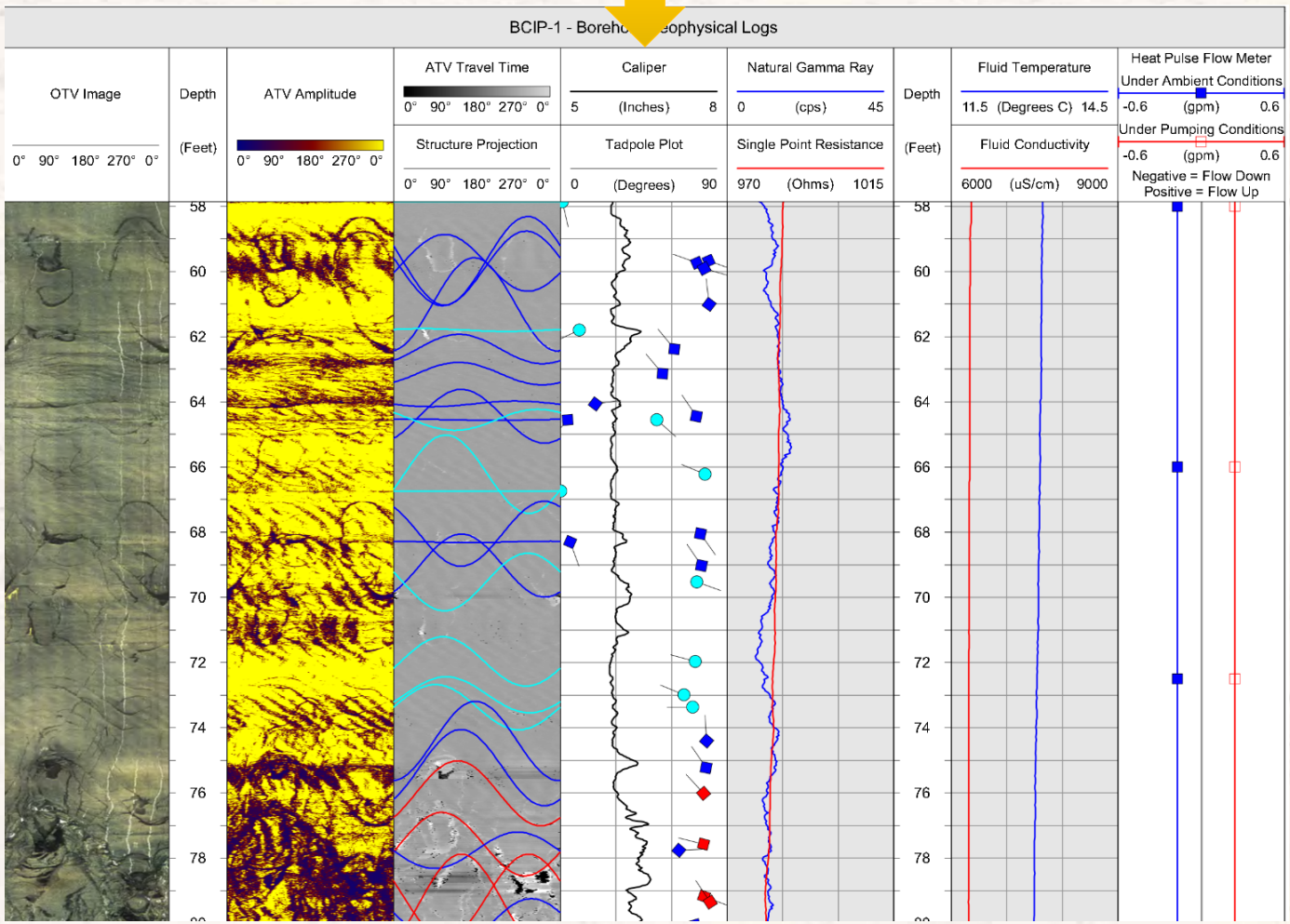
# What is a fracture? What is a feature?

- When associated to caliper logs…
  - Bedding plane separation
  - Joint/Fault
  - Lithologic contact
  - Hydraulic Zones (using our tools)
    - Producing
    - Receiving
  - Erosional Plane
  - Enlargement
  - Drilling-induced feature?
  - Total Porosity vs. Effective Porosity




Colorado Geological Survey [CGS], 2002.

# RDC - Borehole Geophysical Logs




## Standard Details

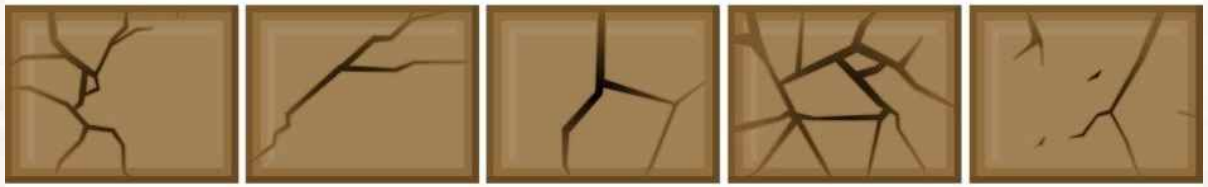
- 3 arm caliper*
- Natural Gamma
- Resistivity
- Fluid Temperature + Conductivity

## Additional Details

- OTV and ATV*
- Heat Pulse Flow Meter

# Fracture Determination

- What is an active fracture?
- Determination
  - Cores
  - ATV/OTV
  - HPFM

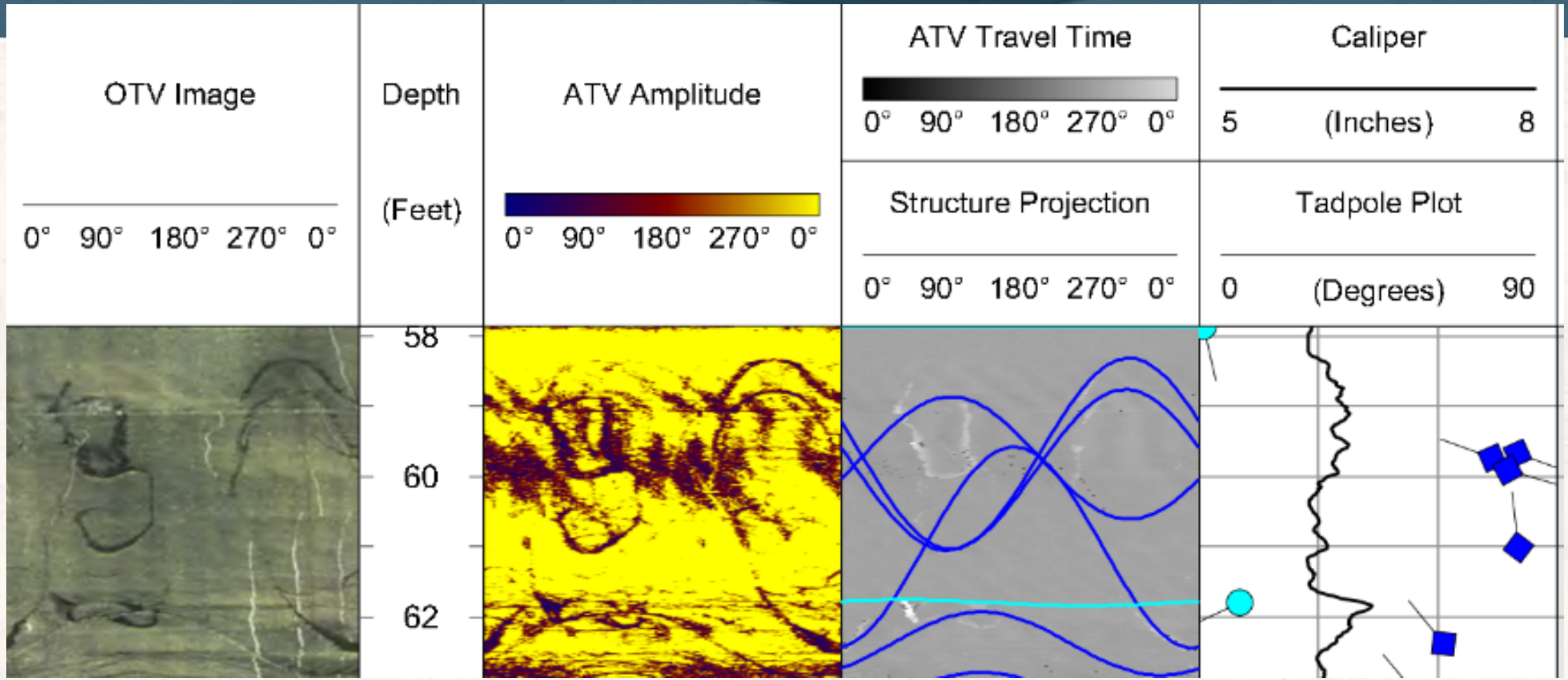


- “Walking the Packer”
- “Low dead volume” & sampling time
- Smaller straddles allow for individualization of fracture network
- Other methods
  - Packer-Slug test
  - Pump test

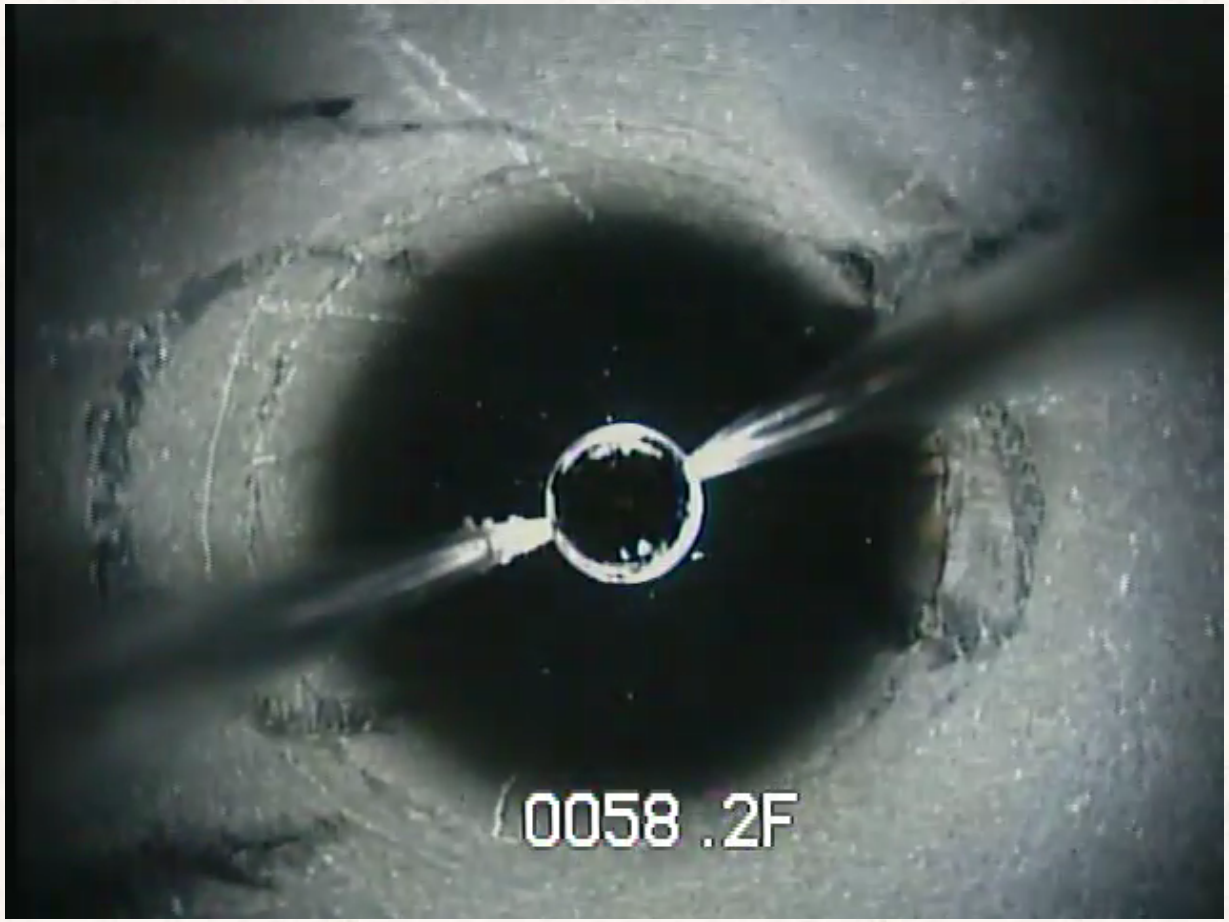
# Borehole Camera


# Borehole Camera

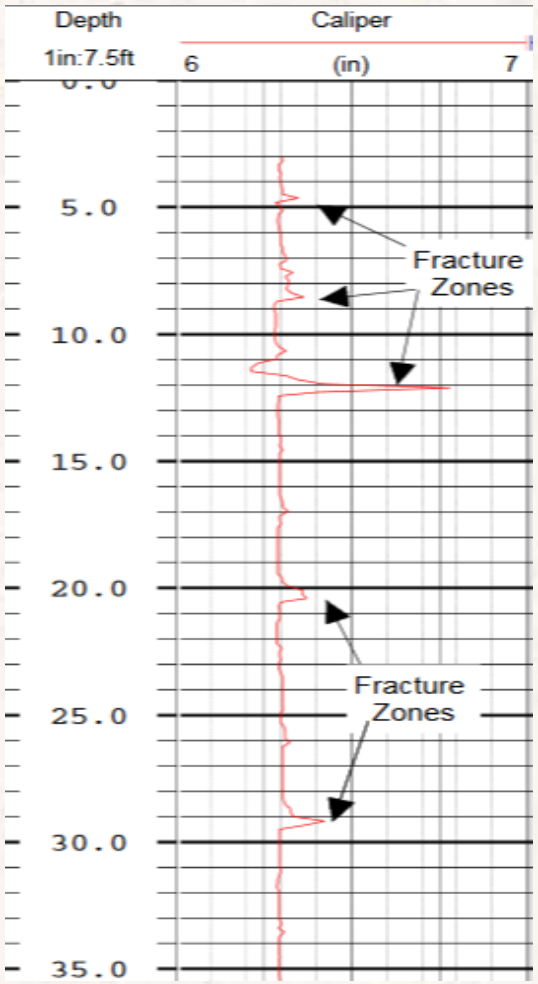
# RDC - Borehole Geophysical Logs



# RDC - Downhole Camera



# RDC – GW Characterization




## Aquifer Testing

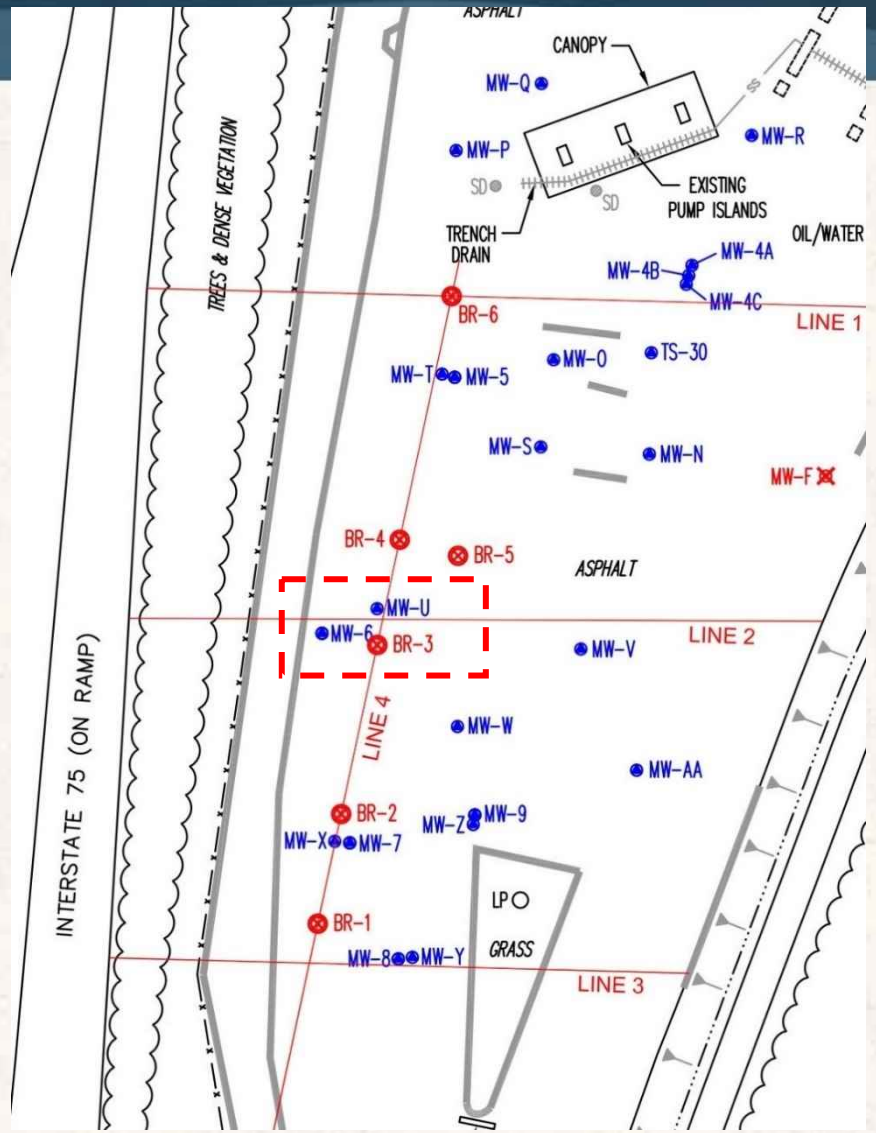
- Pumping Tests
- Discrete Interval Analytical Sampling
- Response Data – Transducers
- Many fractures are clustered at intervals
- Conventional packer strings make it very difficult to isolate individual features
- Custom Straddle Packer String
  - Pressure transducers
  - Integrated pump
  - Discrete sampling or injection


# Rock Cores

- Structure, texture, and variation in lithology visible in log perspective
- Another level of data to use when updating the CSM
  - Look, touch, hold, etc. what you see in 2D wireline logs or downhole camera display
  - Sample Rock Matrix

# Rock Matrix Sampling

# Historical Data and Site Layout




- Shallow bedrock
- Benzene higher in shallow wells near source
- Highest concentration MW-U – deep screen
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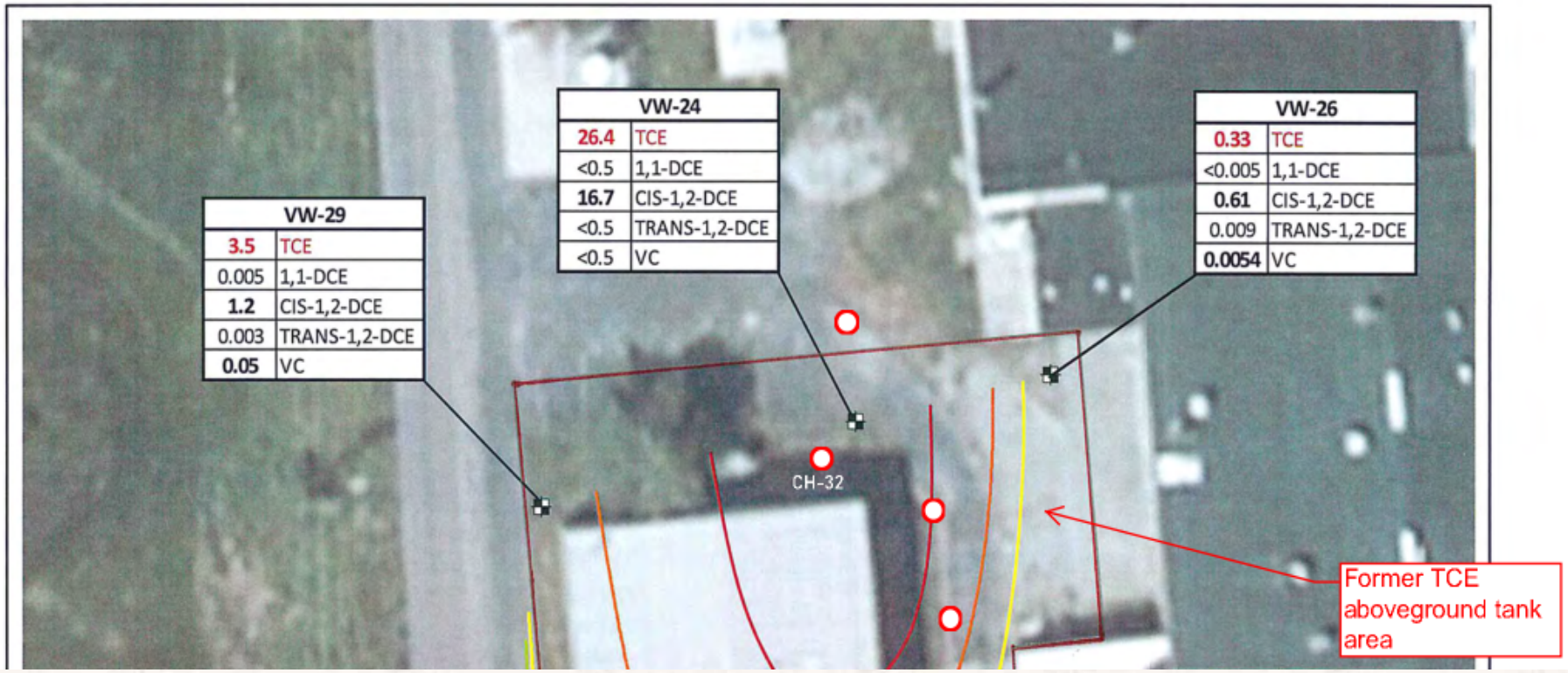
# Rock matrix samples vs groundwater results

| Sample ID. No. | MW-U | MW-U | | MW-U | | MW-U |
|---|---|---|---|---|---|---|
| Date Sampled | 5/2/2013 | 5/2/2013 | | 5/2/2013 | | 5/2/2013 |
| Sample Depth | 12-12.75' | 12-12.75' | | 19.75-20' | | 22-22.25' |
| | | (2nd Sample) | | | | |
| Units | ug/kg | ug/kg | | ug/kg | | ug/kg |
| | | | | | | |
| MTBE | 374 (4) | 336 (5) | | ND (6) | | ND (5) |
| Benzene | 1420 (4) | 1390 (5) | | ND (6) | | 16.5 (5) |
| Toluene | 2090 (4) | 2580 (5) | | ND (6) | | 7.67 (5) |
| Ethylbenzene | 417 (4) | 385 (5) | | ND (6) | | ND (5) |
| m/p-Xylenes | 1330 (4) | 1350 (5) | | 21.9 (6) | | 7.46 (5) |
| o-Xylenes | 641 (4) | 579 (5) | | 9.57 (6) | | ND (5) |
| 1,2,4-Trimethylbenzene | 114 (4) | 432 (5) | | 15.2 (6) | | 5.04 (5) |
| Naphthalene | 37.7 (4) | 118 (5) | | ND (6) | | ND (5) |
| TVPH (ppm) | 50.8 (2) | 46.7 (2.5) | | 260 (3) | | 15.8 (2.5) |

The highest benzene concentration from adjacent discrete gw sampling was 474 ug/L

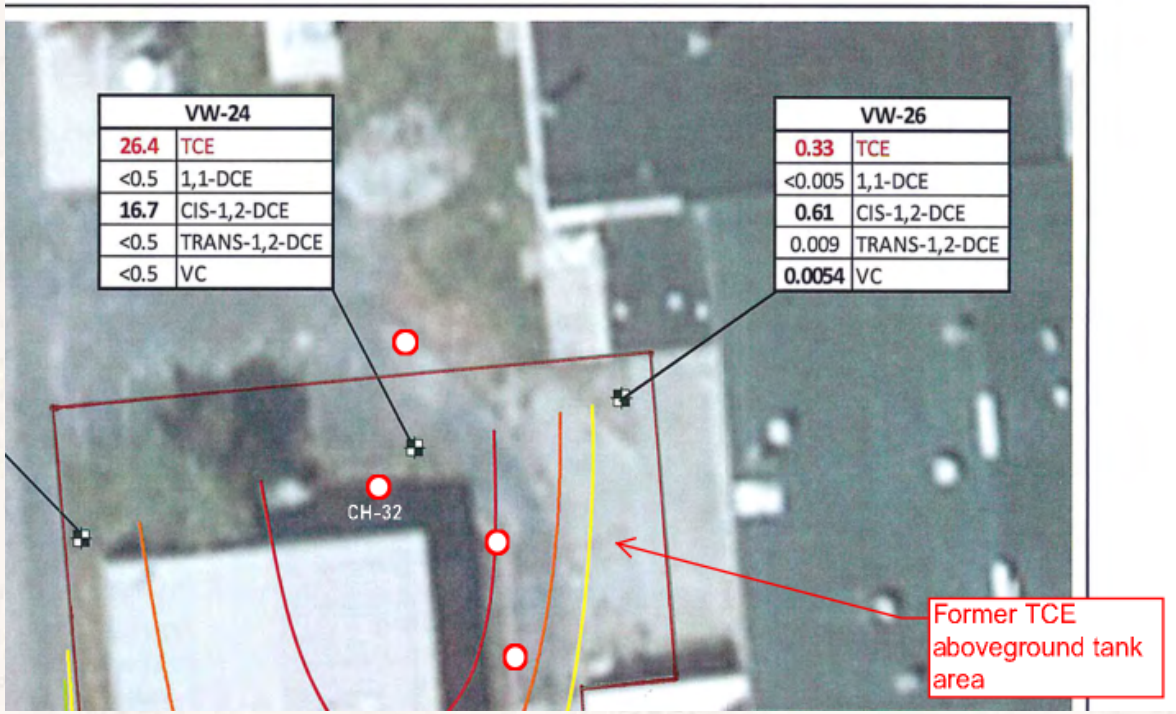
| | | | | |
|---|---|---|---|---|
| | | | 33.8 | Benzene |
| MW-U | 9/17/12 | 20.86 | | **6.4** |
| | 6/29/12 | 14.27 | | **9.3** |
| | 9/15/11 | 12.50 | | **3.4** |
| | 2/18/11 | 12.35 | | **5.9** |
| | 6/30/10 | 21.0 | | **6.3** |
| | 3/19/10 | 12.24 | | **5.7** |
| | 7/7/09 | 12.32 | | **10** |
| | 2/12/09 | 12.92 | | **1.8** |
| | 5/22/08 | 12.19 | | **2.2** |
| | 11/19/03 | 12.31 | | **3.2** |
| | 12/3/02 | 12.50 | | **0.5** |
| | 9/11/02 | 11.17 | | 0.021 |
| | 6/19/02 | 8.67 | | **0.66** |
| | 3/18/02 | 2.08 | | 0.052 |
| | 11/13/01 | 19.30 | | 0.00066 |
| | 8/14/01 | 10.58 | | **2.8** |
| | 1/3/01 | 15.00 | | **0.68** |
| | 7/7/99 | 11.05 | | **0.64** |
| | 3/2/98 | 10.40 | | **4.6** |
| | 12/17/97 | 33.81 | | **0.6** |

# RDC – Rock Matrix vs Groundwater Concentrations



# RDC – Rock Matrix Sample

| CH-32 Discrete Intervals | | | CH-32 | VW-24 |
|---|---|---|---|---|
| Sample Depth | TCE (ug/L) | TCE (ug/Kg) | TCE (ug/L) Water @ 34.80’ | TCE (ug/L) Water @ 18.70’ |
| 7 | Dry | 774 | | |
| 10.6 | Dry | 4780 | | |
| 15 | Dry | 197 | | |
| 20.6 | Dry | 25,400 | | |
| 22.7 | Dry | 336 | | |
| 27.4 | Dry | 78.0 | 204 | 26,400 |



# Thank You & Q&A

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