Tools for Characterization and Monitoring of Contaminated Fractured Rock

Daniel J. Goode

USGS

. . . based on decades of research by many, many colleagues and partners

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Acknowledgements

USGS science for a changing world

Toxic Substances Hydrology Program
Pa, NJ, NY, Ga Water Science Centers
National Research Program (Water)
Office of Ground Water

Technology Innovation Program
Region 3

Naval Facilities Engineering Command

DoD EPA DOE SERDP Strategic Environmental Research and Development Program

State of New Jersey Department of Environmental Protection

Geosyntec consultants

Take Home

- Tools are available for characterization and monitoring in fractured rock
- Site Conceptual Models needed for selection of methods and synthesis
- Iterative synthesis of multiple investigations – "Continuous Characterization"

Fractured Rock Techniques

USGS can help develop three-dimensional subsurface conceptual models and evaluate remedy effectiveness in fractured-rock aquifers through:

- Geologic framework development
- Surface geophysics to delineate geologic heterogeneity
- Borehole geophysics to identify permeable fractures
- Straddle packer deployment for hydraulic testing and geochemical sampling
- Aquifer testing to identify site-scale hydraulic properties and connections
- Groundwater flow modeling to estimate flow directions and rates
- Tracer testing to identify transport properties and processes
- Measurement of contaminants in the rock matrix
- Monitoring to assess biodegradation and long-term water quality
- Empirical calculations and reactive transport modeling to understand processes controlling remediation and to estimate contaminant mass removal

British Columbia Ministry of Environment Golder Assoc. Ltd., 2010

REPORT ON:
Fractured Bedrock Field Methods and Analytical Tools
Volume I : Main Report

Submitted to:
The Ministry of Environment
April 2010

Submitted by:
Science Advisory Board
For Contaminated Sites in British Columbia

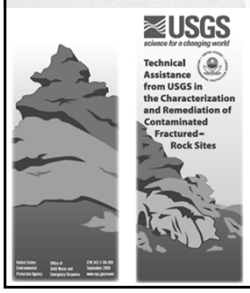
Prepared under contract by
Golder Associates Ltd.
Burnaby, British Columbia

Table 2. Characterisation recommendations by stage. Key to fonts: ***Essential***, Very Useful, Somewhat useful, *Research*

	Desk Study	Surface-Based Characterization	Single Well Characterisation	Monitoring and Completion	Multi-Well Characterisation
Geology	***Case histories and analog sites*** Lineament interpretation of existing air photo and Lidar data	***Map fractures in rock exposures (preferably quantitative)***	***Optical televiewer logging*** ***Core fracture description*** ***Acoustic televiewer logging***		**Correlation of key fractures between wells**
Geophysics	Existing Airborne Geophysics	Ground penetrating radar Resistivity sounding Seismic refraction/reflection	Temperature, fluid conductivity *Single hole radar reflection*		*Cross hole tomography*
Hydraulic Properties	***Case histories and analog sites***	Fracture mapping for aperture estimation and indicators of active flow, Assessment of fracture weathering from surface mapping	***Flow logging (pumping)*** Single hole transient tests	***Monitor heads for Responses during drilling and natural perturbations***	***Transient interference tests*** ***Monitor head perturbations***
Hydrodynamics	***Recharge and discharge locations*** ***Head data from existing wells***	***Measure heads in existing wells***	***Ambient flow logging or head measurements during detailed packer testing***	***Monitor hydraulic heads***	***Monitor hydraulic heads***
Transport Properties	***Case histories and analog sites***		Porosity measurements on cores	***Plume mapping***	Tracer tests
Water Chemistry and Contaminant	***Case histories and analog sites***	***Sample surface-water discharges***	***Plume mapping*** ***Checking core for***	***Sampling from multipoint***	Sample for water chemistry changes

Golder Assoc. Ltd., 2010

Fractured Rock Techniques



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Influence of Geologic Setting on Ground-Water Availability in the Lawrenceville Area, Gwinnett County, Georgia

Williams, Kath, Crawford, Chapman, 2005

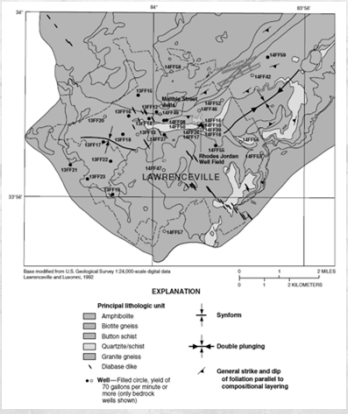
USGS GaWSC Univ. of West Georgia

Scientific Investigations Report 2005-5136

USGS

Williams, Kath, Crawford, Chapman, 2005

2 Hydrolgists & 2 Geologists ("Mappers")



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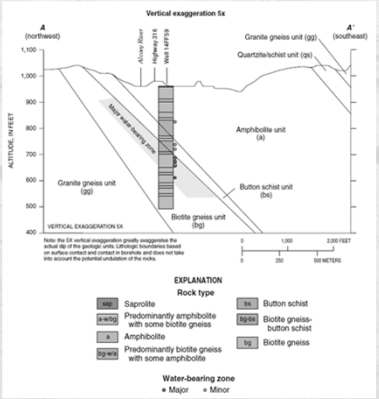
High-yield wells located near mapable geologic contacts in crystalline rock



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Williams & others, 2005

Importance of Hydrogeologic Characterization to Effective Bioaugmentation of Contaminated Fractured Sedimentary Rocks (NAWC, W. Trenton NJ)

Claire R. Tiedeman

USGS

NGWA Virtual Conference on Fractured Rock October 27, 2010

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Multidisciplinary Hydrogeologic Investigation Critical To Effective Bioaugmentation

- **Detailed stratigraphic framework**
- **Single & cross-hole hydraulic testing**
- **Tracer testing**
- **Flow and transport modeling**

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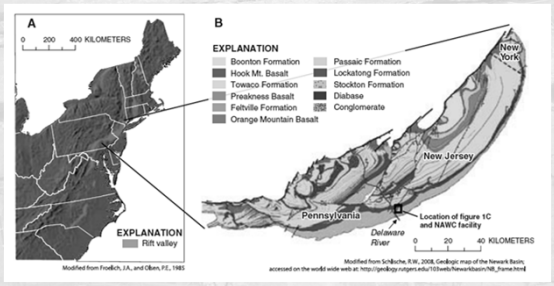
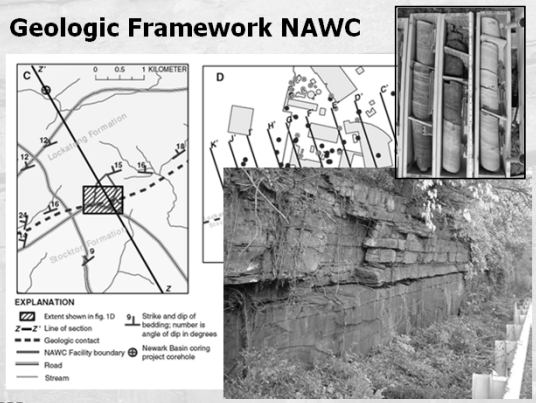
Geologic Framework NAWC



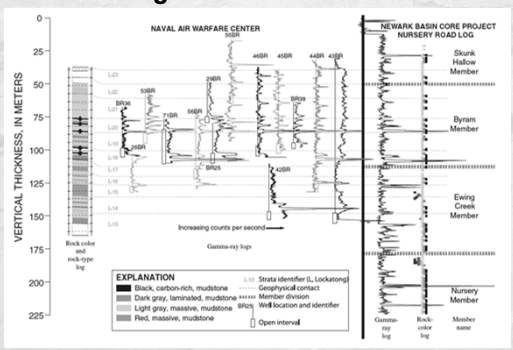
Lacombe & Burton, 2010

Geologic Framework NAWC



Lacombe & Burton, 2010

Geologic Framework NAWC



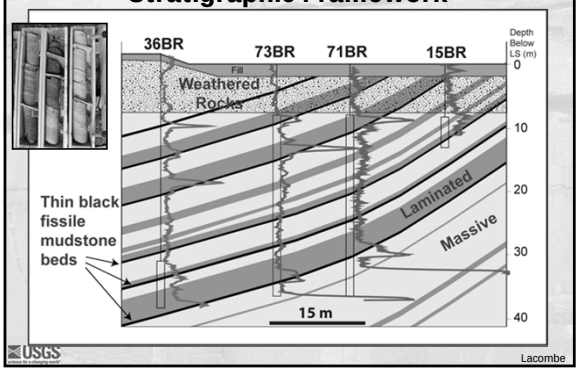
Lacombe & Burton, 2010

Geologic Framework NAWC

- **<1994: Initial Conceptual Model: Soil; Shallow; Deep**
- **2000: Preliminary stratigraphic model (~20 layers) useful for water levels**
- **2005: Detailed stratigraphic model (~60 layers) for VOC concentration patterns & paths**
- **2010+: Hydrostratigraphy refined, bedding is explanatory, but not the only factor**

Lacombe

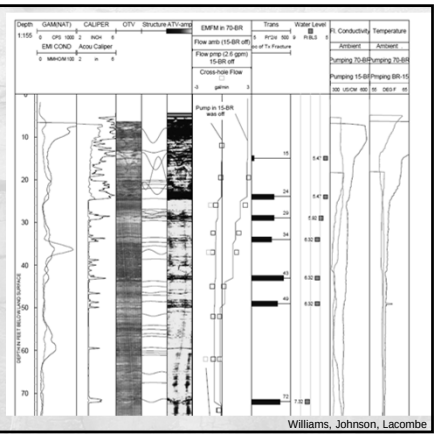
Gamma Ray Logging + Rock Core: Stratigraphic Framework



Lacombe

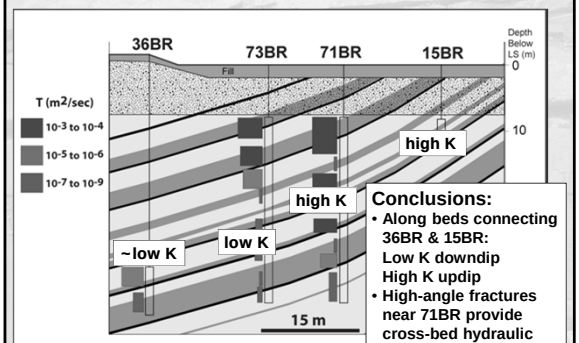
Borehole Geophysics

- **Imaging logs (OTV, ATV) aid correlation and fracture identification**
- **Borehole flowmeter (ambient & pumping) for transmissivity and water levels in water-yielding zones**
- **Not all fractures yield water**



Williams, Johnson, Lacombe

Single-Hole Hydraulic Testing

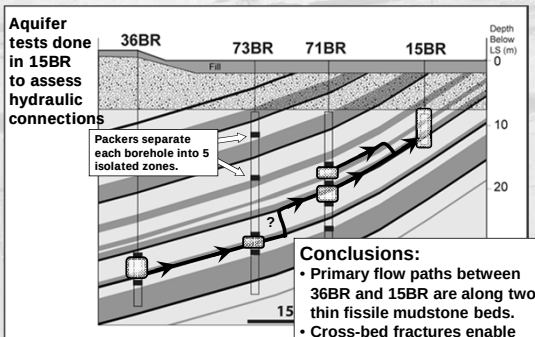


Conclusions:
- Along beds connecting 36BR & 15BR: Low K downdip High K updip
- High-angle fractures near 71BR provide cross-bed hydraulic communication.

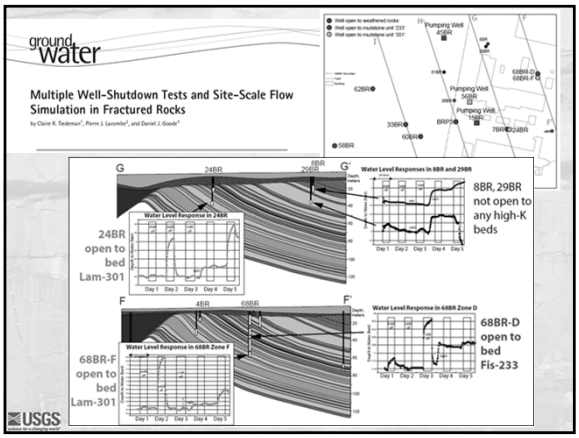
Shapiro & Tiedeman

Cross-Hole Hydraulic Testing

Aquifer tests done in 15BR to assess hydraulic connections

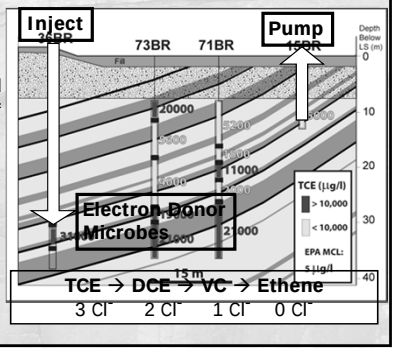


Conclusions:
- Primary flow paths between 36BR and 15BR are along two thin fissile mudstone beds.
- Cross-bed fractures enable flow between these two beds.



Bioaugmentation in Dipping Fractured Mudstones at NAWC

- **Motivation:** Extremely high concentrations of TCE have persisted despite 15 years of pump and treat.
- **Objectives:** Evaluate effectiveness, longevity, spatial extent, processes.



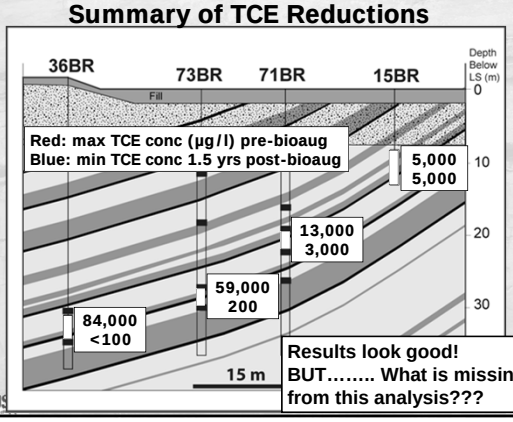
Bioaugmentation Implementation

- **Injected:**
  - Electron donor solution (EOS®) and microbes known to degrade TCE (KB-1®).
  - Flush water.
- **Total injection volume: ~160 gallons**
- **EOS® visible in 73BR-D2 water sample taken day after injection of amendments**

Injection bladders

EOS

Summary of TCE Reductions



Results look good! BUT…….. What is missing from this analysis???

VOC's in Rock Core

- Sediment analysis methods adapted to rock core
- Univ. Waterloo, Beth Parker, John Cherry & students
- Continuing research to improve accuracy
- Available from commercial contractor
- USGS approach is low-cost screening method: Lower accuracy and higher detection limit

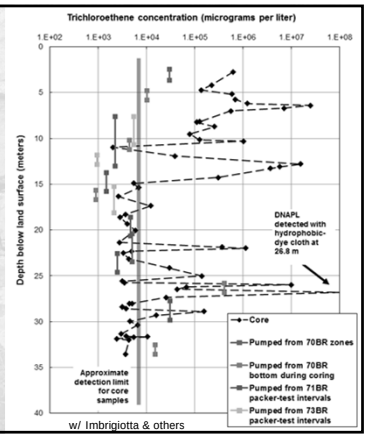
Voc concentration in the rock matrix are measured by methanol extraction from core samples, following Sterling and others (2005, Ground Water 43(4):557-573).

Rock core is sampled as it is removed from the core barrel, ideally with minimal exposure to the atmosphere. Broken or weathered core can be sampled directly. A chisel and hammer are used to sample intact rock core, which is then crushed by hand (practical for mudstone!). The sample is placed in a pre-weighed glass jar with 50 ml of methanol. Samples are analysed after several months of extraction in cold storage.

w/ Imbrigiotta & others

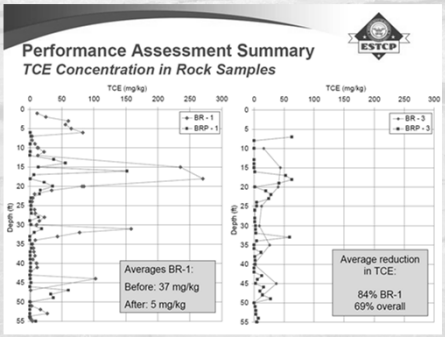
The Rock Matrix

- Profile shows TCE concentrations in primary porosity of rock core prior to bioaugmentation.
- Samples showing TCE in water pumped from multi-level monitoring wells and during packer testing
- All shallow samples have high TCE in rock matrix, but lower TCE in samples
- Highest sample TCE at depth, but highly variable TCE in rock matrix
- DNAPL at 26.8 m bls
- 2010 rock coring will identify bioaugmentation effect on matrix TCE



w/ Imbrigiotta & others

Thermal Conductive Heating Pilot Study



Lebron, Kueper, Heron, Navy, TerraTherm, Queens

Conclusions

- Hydrogeologic characterization at the NAWC was critical to achieving effective bioaugmentation of the rock fractures:
  - Designing strategy for injection of bioaugmentation amendments.
  - Determining importance of monitoring at intermediate wells.
  - Interpreting bioaugmentation results (ongoing).

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  - Hydrogeologic framework
  - VOC's in rock core
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