DOE/EPA Collaborative Review
Tracking Geologically-Sequestered CO_2

Monitoring, Verification, & Accounting (MVA), Simulation, and Risk Assessment

Diagnostic Monitoring of Biogeochemical Interaction of a Shallow Aquifer in Response to CO_2 Leak

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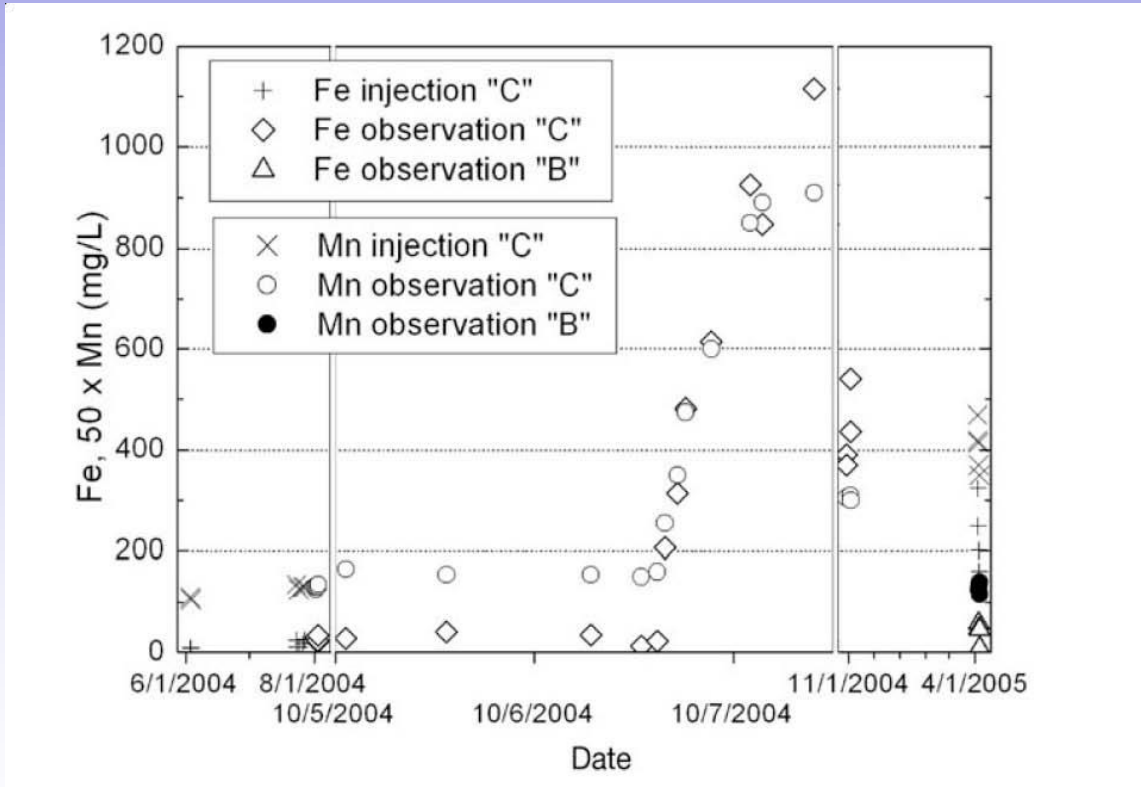
Outline

1. Research Objectives
2. Approach and Activities
3. Previous Field Tests – Selected Results
4. Methods
5. A Look Ahead

Release of Fe and Mn at Frio site (Kharaka, et al. 2006)



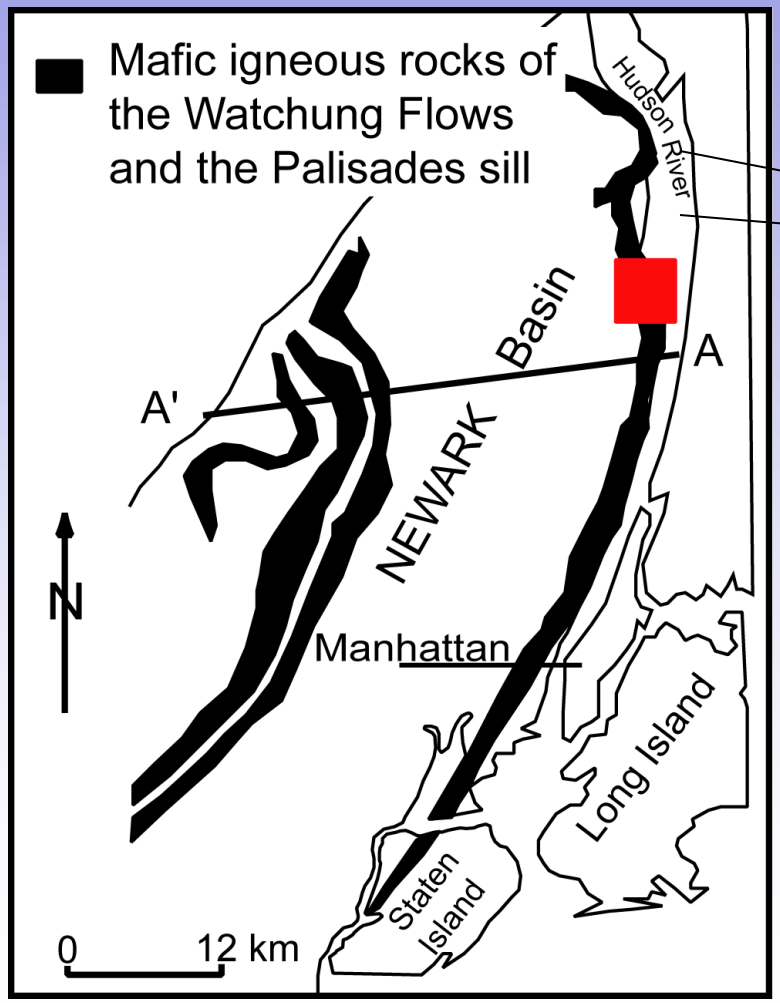
Research Objectives

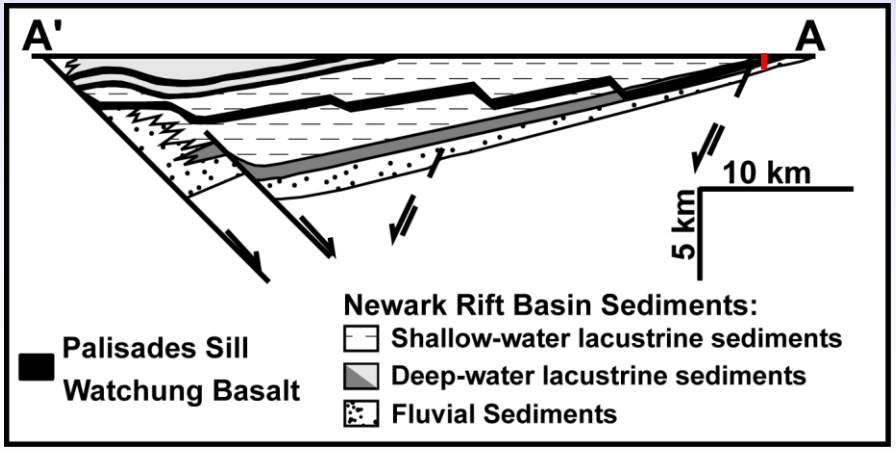
Question: How does an elevated-level CO_2 concentration caused by a hypothetical leakage of CO_2 affect the chemical and microbiological conditions in a shallow aquifer?

Approach and Activities

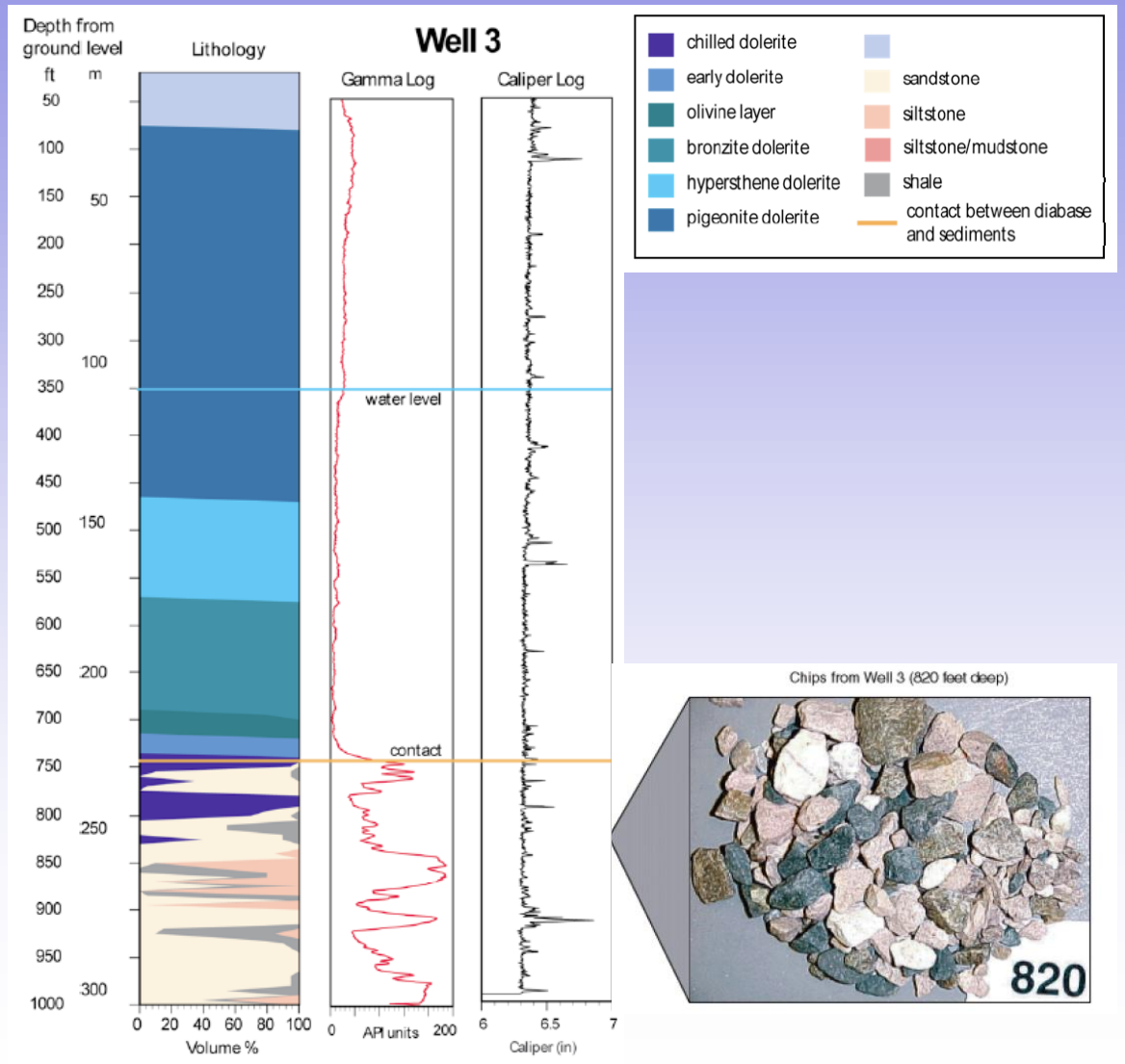
- Study a shallow aquifer system in the Triassic sand/clay sequences of the Newark Basin group using laboratory and *in situ* experimental methods
- Determine metal release rates as a function of pCO_2, the total CO_2 concentration, and pH
- Measure microbial community dynamics (role and persistence) as a function of pCO_2, the total CO_2 concentration, and pH
- Measure mobilization and immobilization of metals and metaloids under high-level CO_2 conditions

Test Site at Lamont-Doherty





Lithology


Well 3
Depth from ground level
ft
m
Lithology
Gamma Log
Caliper Log
water level
contact
Volume %
API units
Caliper (in)
chilled dolerite
early dolerite
olivine layer
bronzite dolerite
hypersthene dolerite
pigeonite dolerite
sandstone
siltstone
siltstone/mudstone
shale
contact between diabase and sediments
Chips from Well 3 (820 feet deep)
820

Cores from the Newark Basin

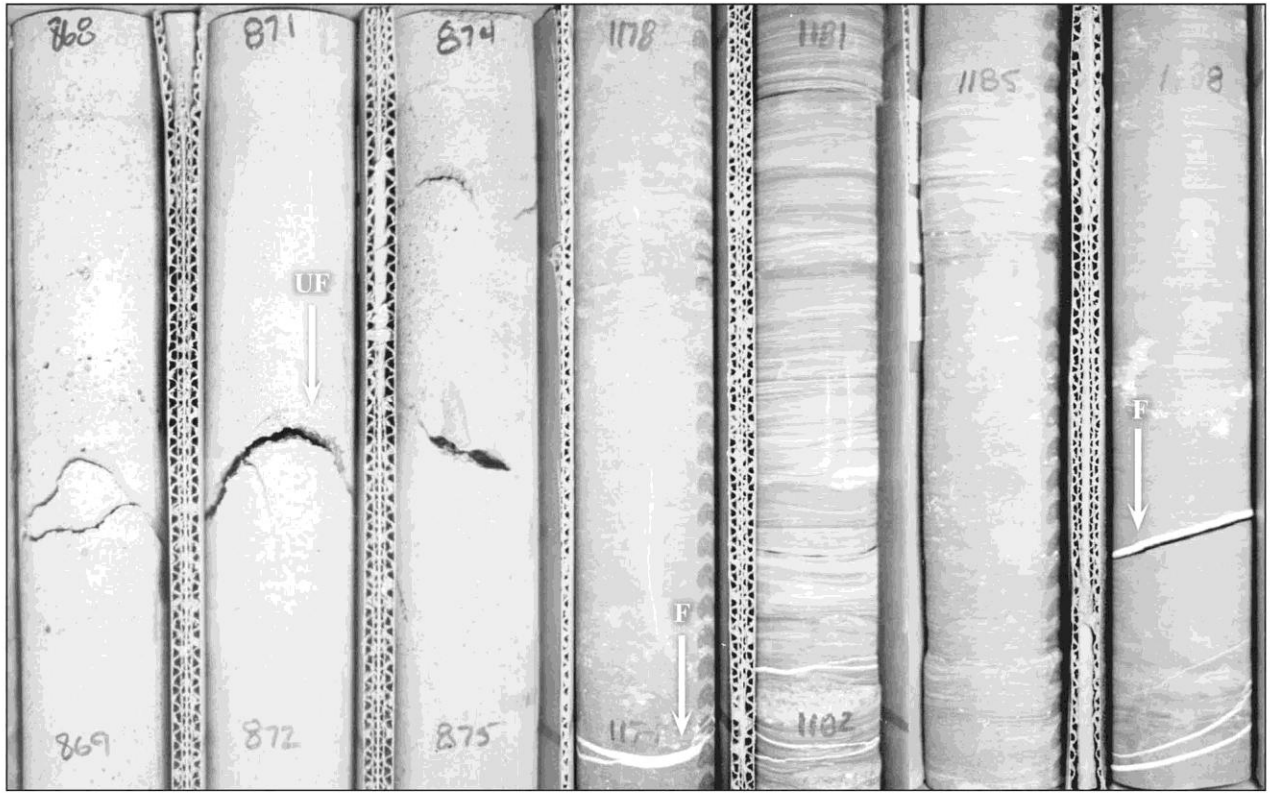
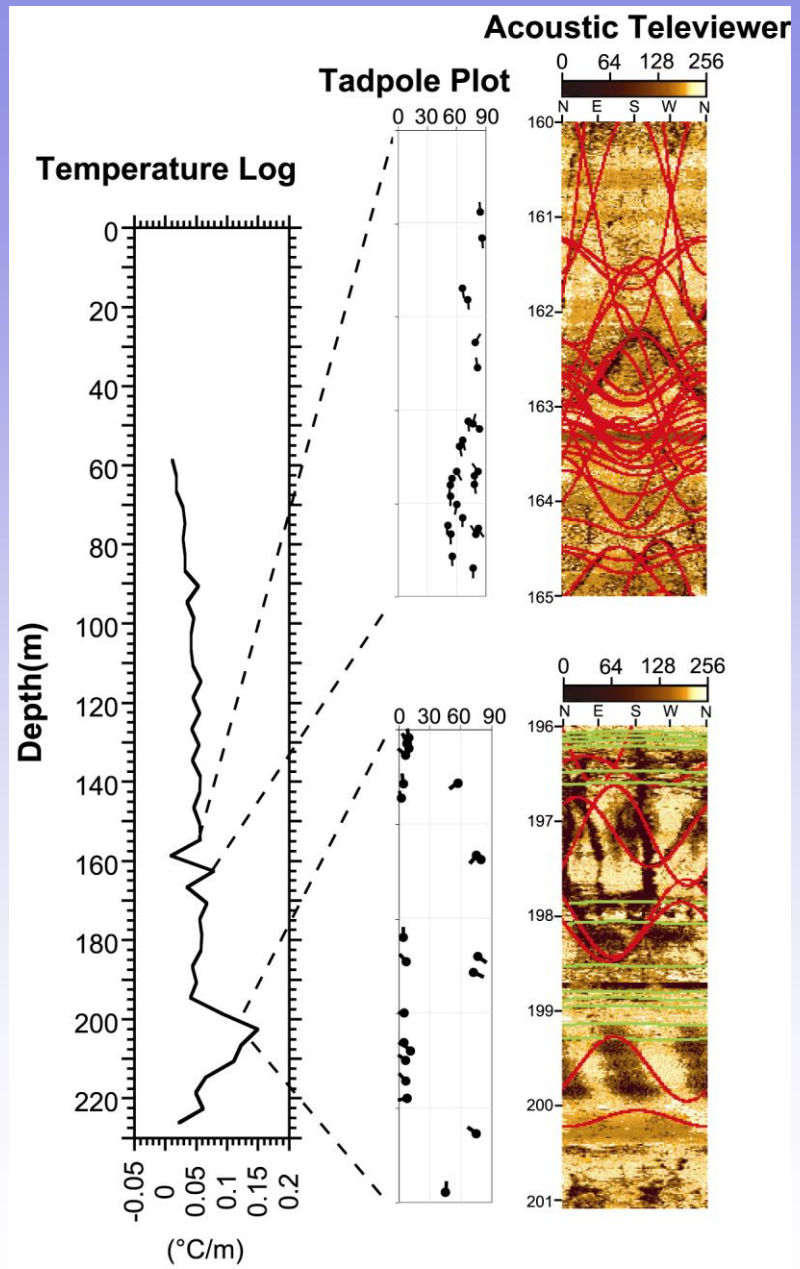
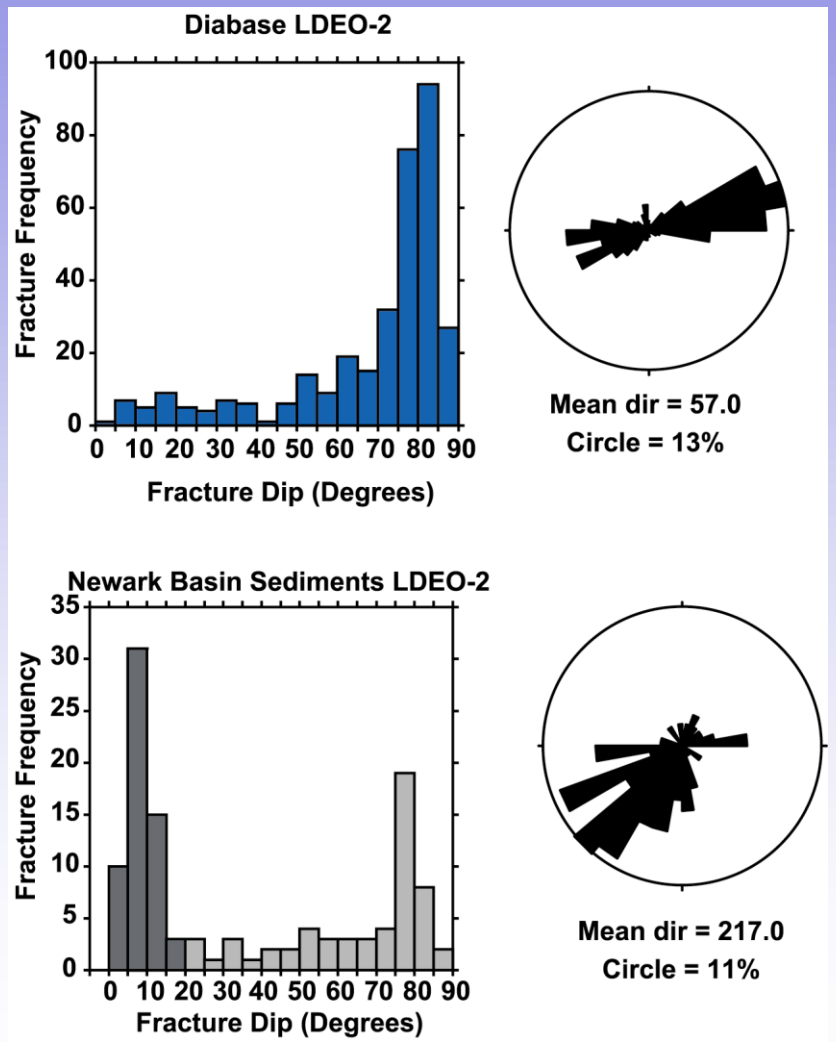


FIGURE 7.6 Example photograph of Martinsville cores at various depths in red and gray mudstone. Each core is 3 ft. long and oriented top upward. Open and filled fractures are annotated. Similar photos were used to count fractures and estimate aperture, dip magnitude, and mineral infilling for the Martinsville and Nursery Road cores.

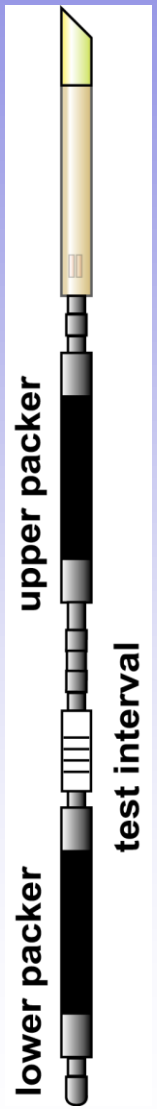
Goldberg, et al., 2003

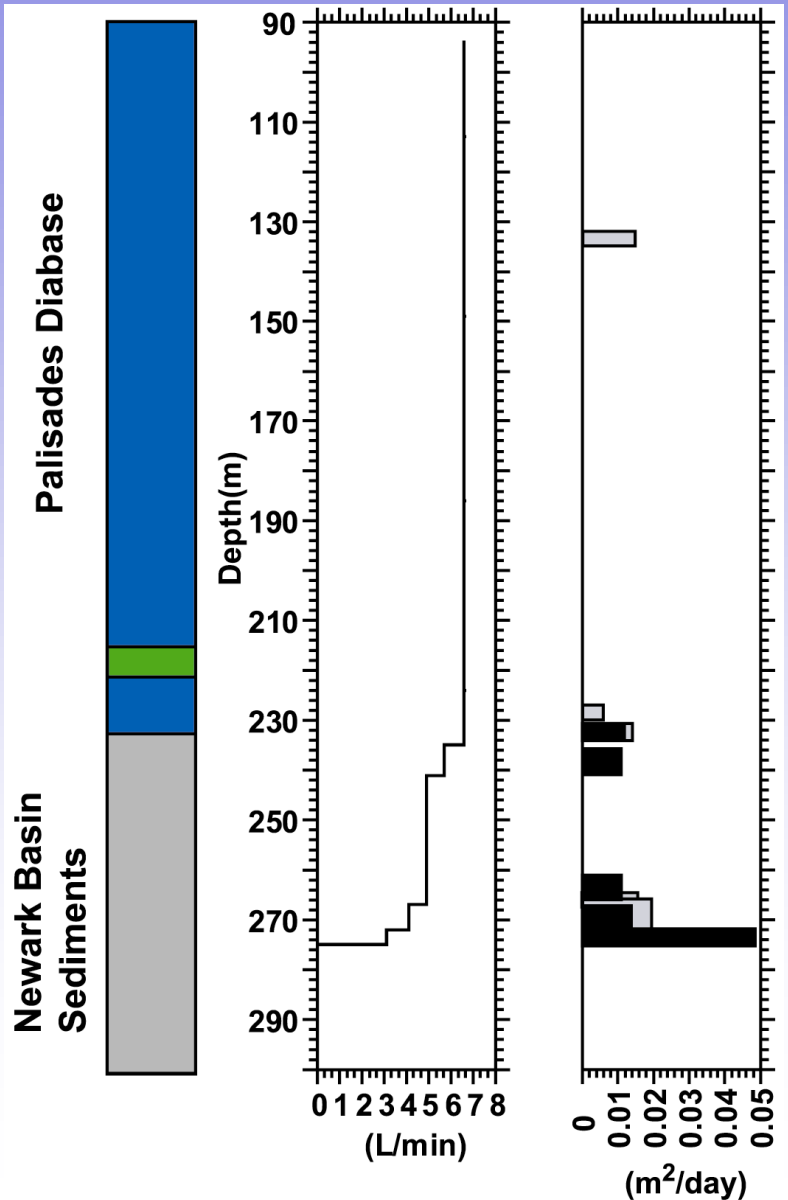
Fractures


Acoustic Televiewer
Tadpole Plot
Temperature Log
Depth(m)
(°C/m)
0 64 128 256
N E S W N
0 30 60 90


Diabase LDEO-2
Fracture Frequency
Fracture Dip (Degrees)
Mean dir = 57.0
Circle = 13%
Newark Basin Sediments LDEO-2
Fracture Frequency
Fracture Dip (Degrees)
Mean dir = 217.0
Circle = 11%

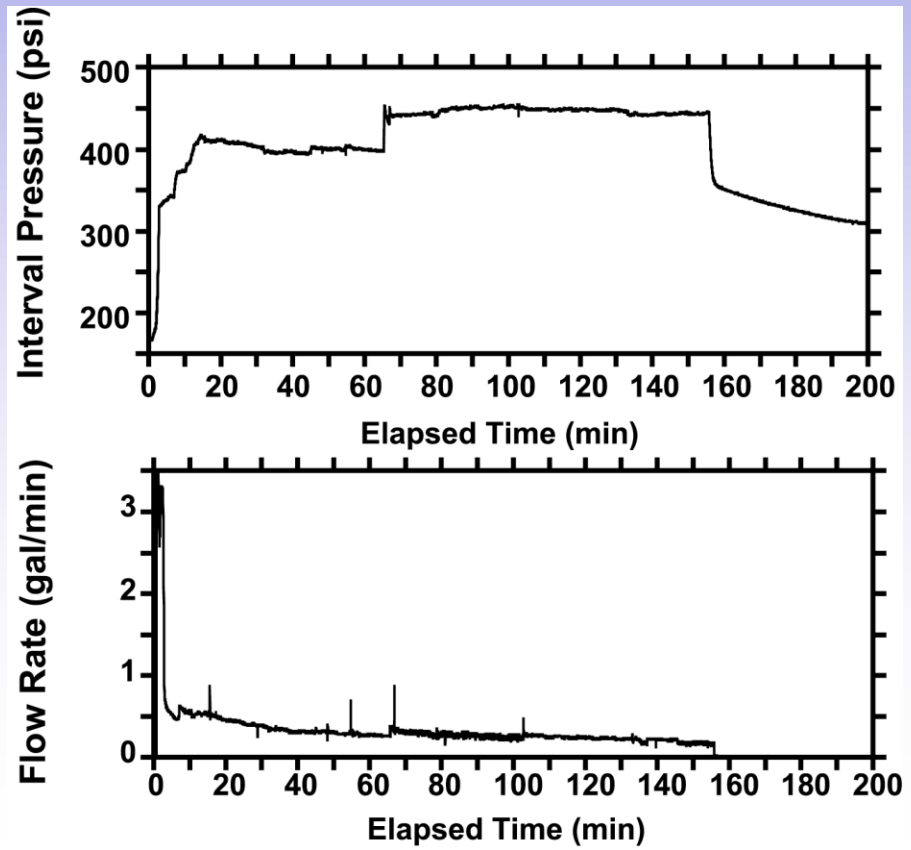
Hydrologic testing





Previous Injection Experiments

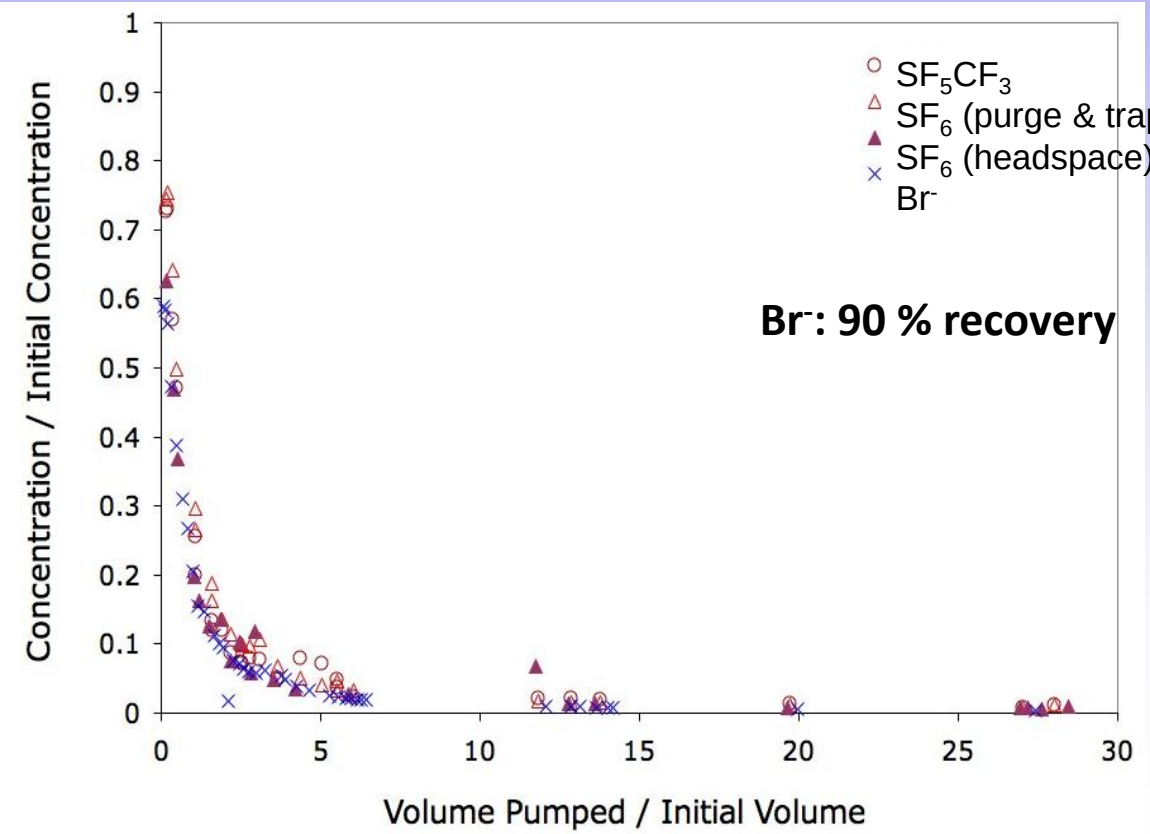
- **Single-Well Pump back Tracer Test**
- **Injection Fluid is a CO_2 Saturated Water (P_{CO2} 1 to 5 atm; pH ~ 4.0)**
- **Matter et al. (2006) *Hydrogeology*; Matter et al. (2007) *G*^{3}; Assayag et al. (2009) *Chemical Geology***



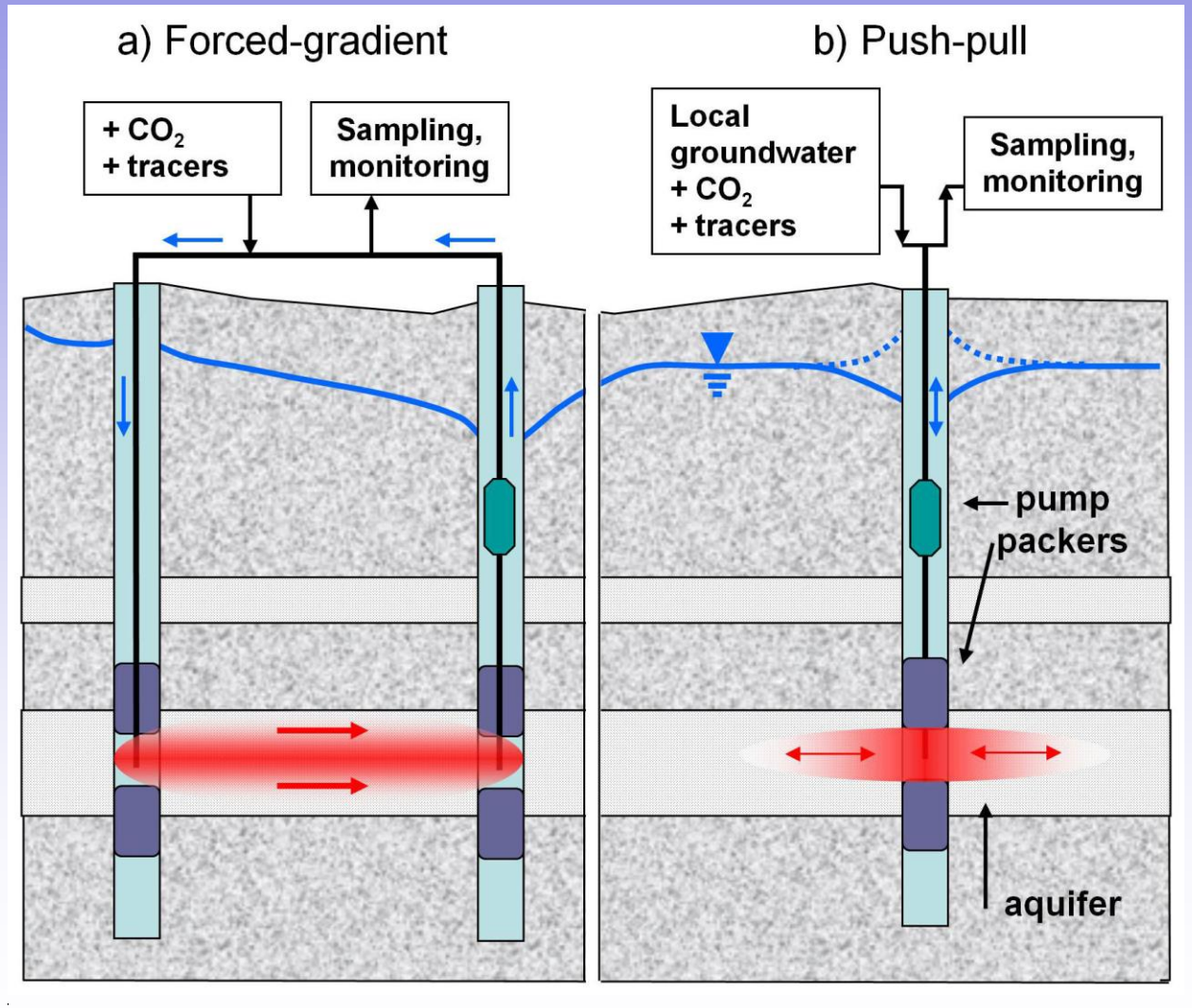
Conclusions from Prior Studies

Small-scale field injection experiment demonstrated hydraulic conductivity and porosity sufficient for small volume injections

Tracer recovery: short-term push-pull experiments



Single- and Dual- Well Injection Tests

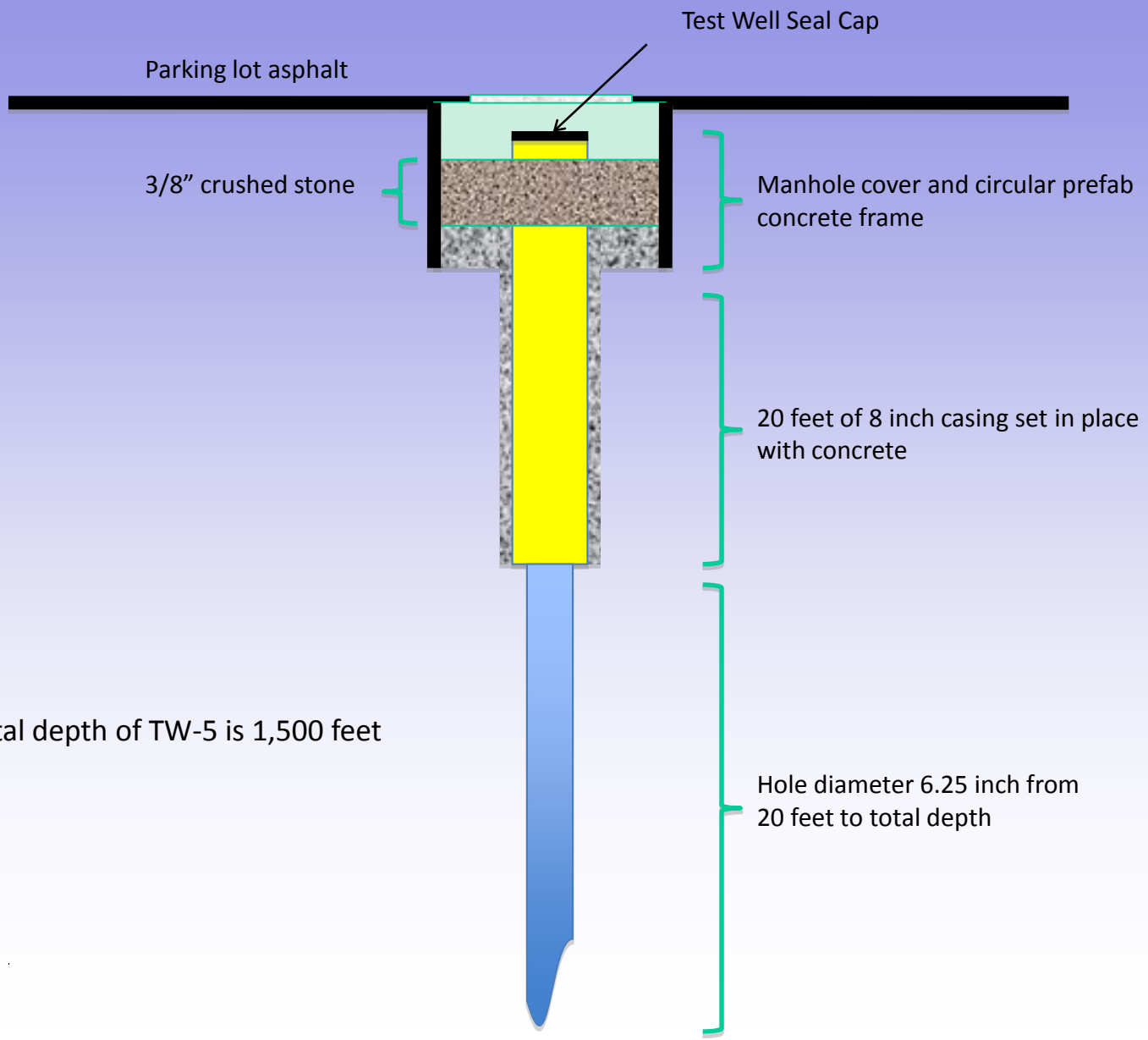


Comparison of Injection Experiments

Test Stats:

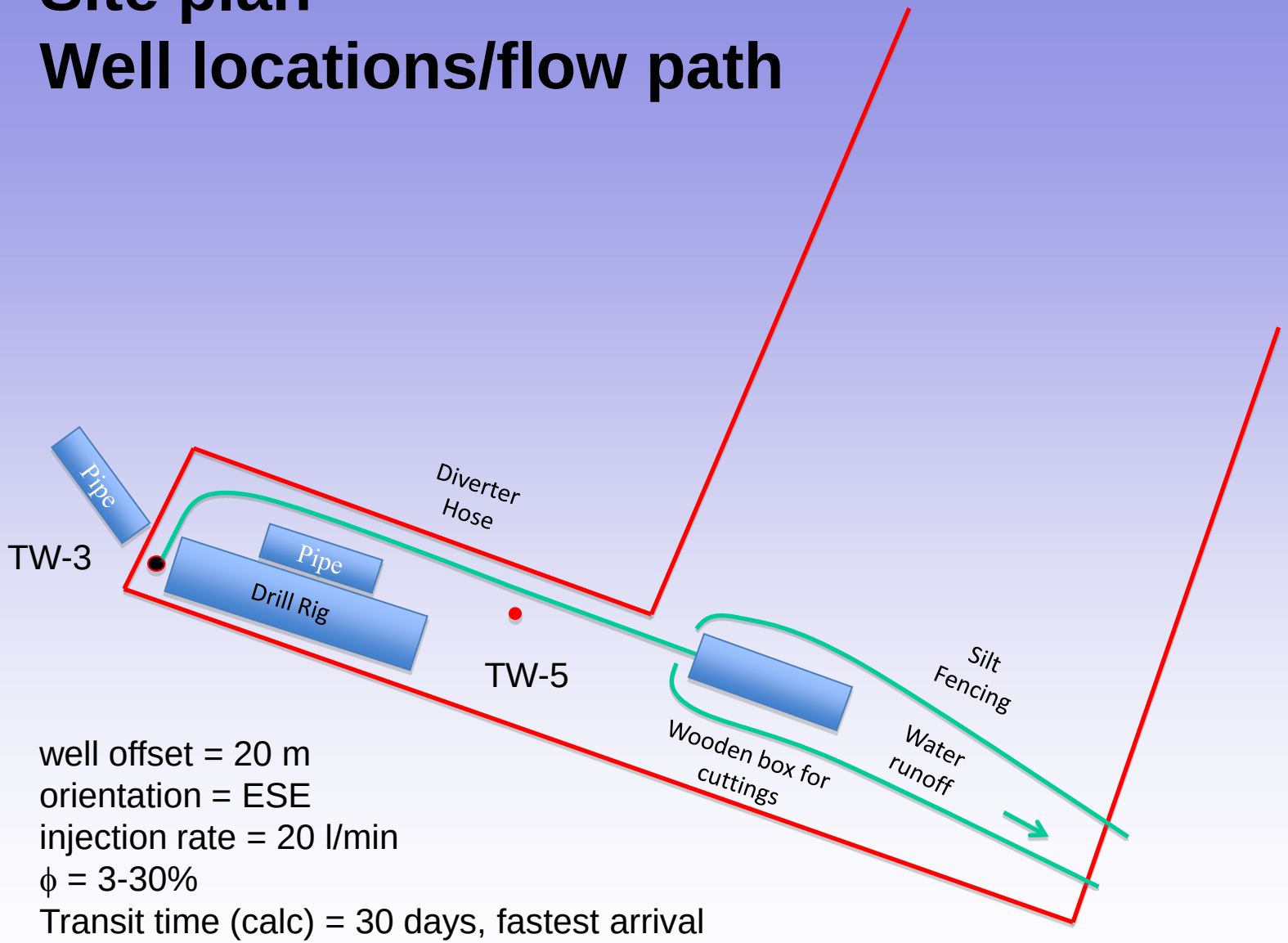
	2004	2011
Injection Fluid	Surface/Fm Water	Formation Water
pH	3.5-4.8	3.5-4
P_{CO2} (atm)	1-8 atm	1-5 atm
Tracers	Cl, Br, $\delta^{18}O$, $\delta^{2}H$	Cl, $\delta^{18}O$, $\delta^{2}H$, SF_6, SF_5CF_3
Depth (m)	220-270 m	300-450 m
Injection Volume (m^3)	1.4 m^3	2 to 10 m^3
Incubation Time (days)	7-20 days	> 30 days

Well characterization to 1500’



Total depth of TW-5 is 1,500 feet

Site plan
Well locations/flow path



well offset = 20 m
orientation = ESE
injection rate = 20 l/min
ϕ = 3-30%
Transit time (calc) = 30 days, fastest arrival
Transit time (calc) = 69 days, 50% arrival

Real-time Tracer Experiments

1 Measure in situ flow volumes and rates using Br^- and/or SF_6 tracers

2 Monitor baseline water chemistry and major element concentrations (e.g., Na, K, Mg, Ca, Si, Al, Cl, and SO_4)

3 Measure minor and trace element chemistry (e.g, As, Cd, Hg, Pb, and U)

Geochemical Experiments

1 Test rock samples using XRD/XRF for mineralogy

2 Test sample fluids for pCO_2, pH, and total CO_2 and oxygen concentrations at sequential time intervals

3 Use crushed rock samples in reaction vessels with sample waters (as well as negative control in replicate reactors) to measure release rates of major and minor elements using ICP-MS as a function pH, total CO_2 and oxygen concentrations dissolved in water

Microbiological Monitoring and Experiments

1 Establish microbial diversity at baseline and following injection
- 16S rRNA sequence libraries
- Heterotrophic plate count and sewage indicator enumeration
- Quantitative PCR assays on select microbial targets

2 Reaction vessel experiments to investigate persistence of indicator bacteria under altered pCO_2 / pH conditions

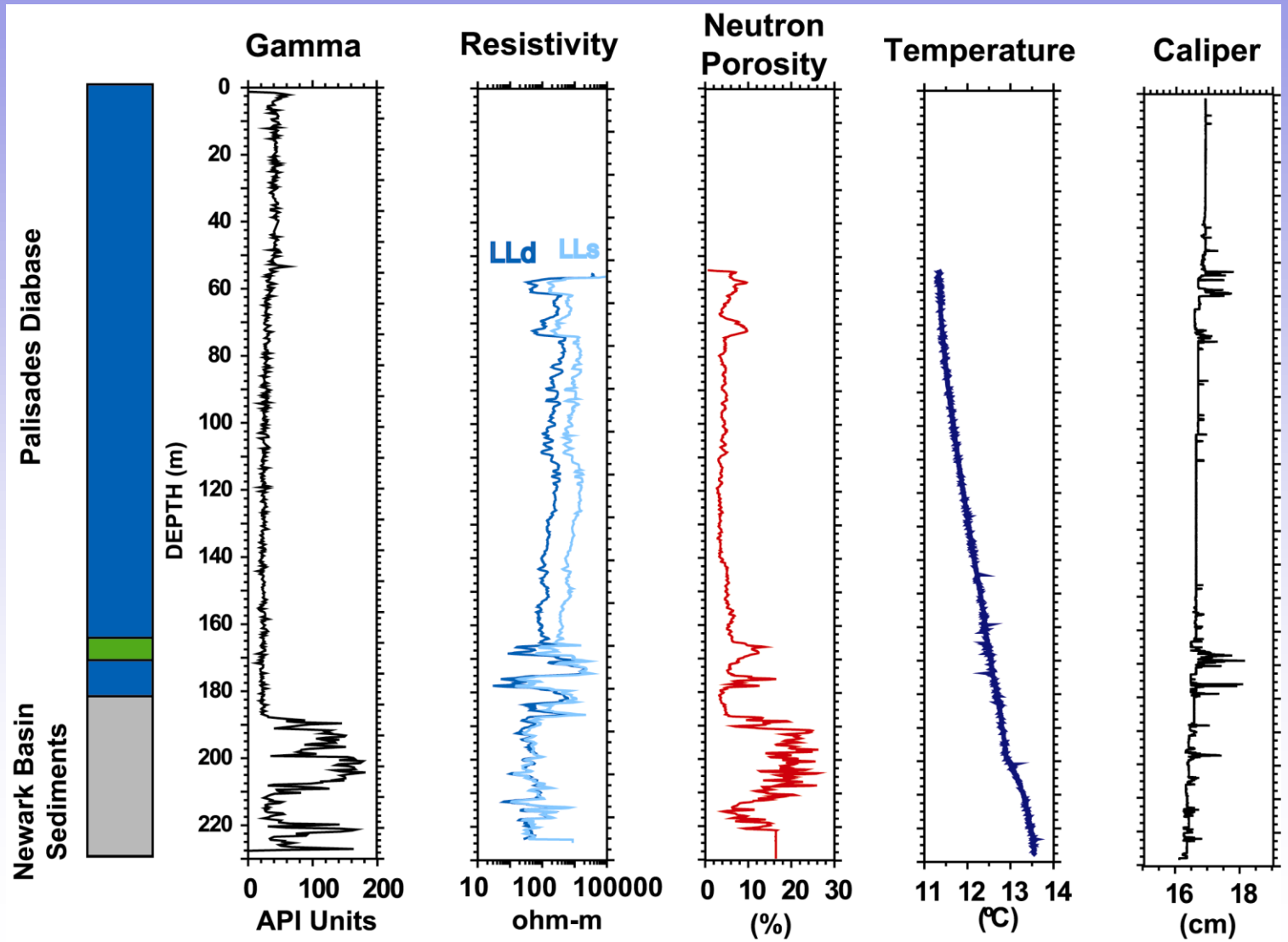
3 Reaction vessel experiments to investigate the role of microbes in metal mobilization under altered pCO_2 / pH conditions

Data compilation and distribution

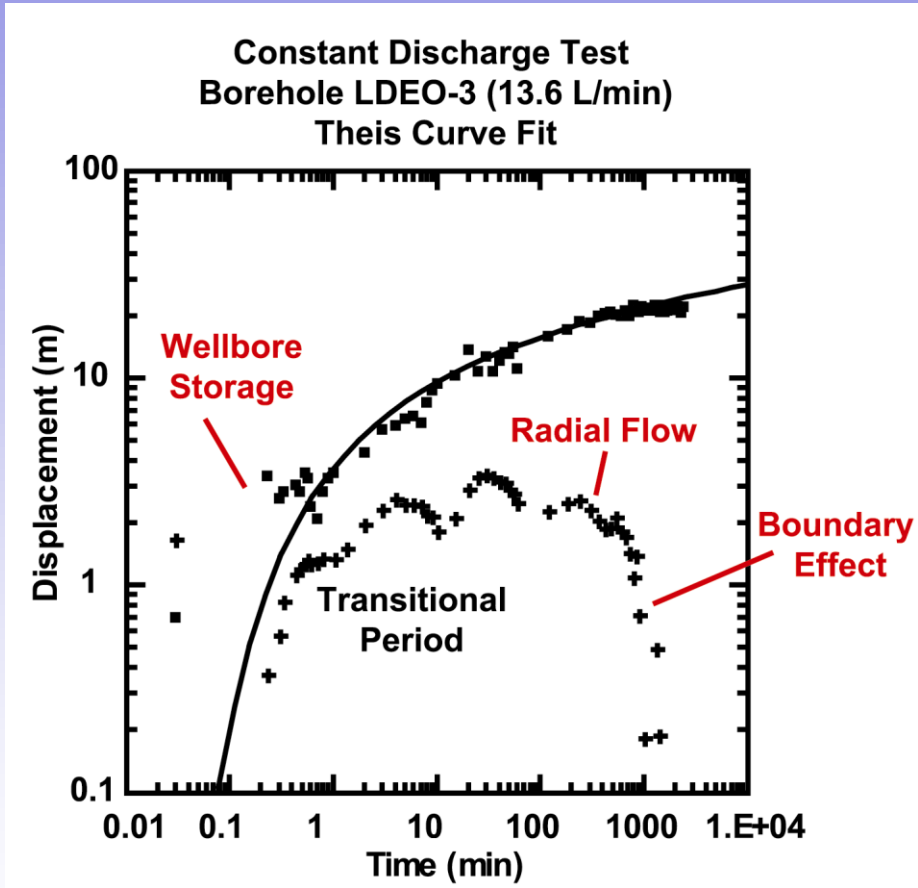
A Look Ahead

Task	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Well Completions to 1500': Deepen TW3 and Drill/Core TW4												
Site Characterization: Logging and hydrologic testing												
Sampling and in situ drill chips, core and in situ fluids												
Geochemical laboratory experiments on drill chips												
Microbiological laboratory experiments												
CO2 injections: TW3/TW4 push-pull and forced gradient tests												
Post-injection sampling and monitoring												
Final Reporting, Data Release and Publication												

Geophysical Logs



Mean Hydraulic Parameters



	T m^2/day	K (m/day)
Sill	0.01	0.0034
Contact Zone	0.02	0.006
N.B. Sediment	0.57	0.0075

Medium coarse sandstone

K = 0.8 m/day

Experimental Methods

1 Geological, geophysical and hydrological characterization

- Collect rock samples by drilling and/or coring
- Collect fluid samples from isolated intervals
- Establish baseline chemistry and microbial diversity in laboratory

2 Conduct in situ injection and fluid recovery experiments

- isolated injection intervals using packer system
- injected solutions of CO_2 (pCO_2 1-5 bars)
- forced-gradient and single-well experiments
- monitoring Br^- and/or SF_6, and other tracers
- microbiological monitoring of recovered fluids
- time-series monitoring major and minor element chemistry

3 Conduct laboratory experiments using fluid and rock samples

- geochemical evaluation of recovered fluids, altered pH and pCO2
- determine changes in microbial diversity with pH and pCO_2
- determine role of microbes in metal mobilization

4 Compile data for analysis, interpretation, distribution

N
Machine Shop
Parking
Parking
Garbage bin
20' shipping containers
TW-3
TW-5
Logging Truck
Warehouse

(1) determine metal release rates as a function of pCO_2, the total CO_2 concentration, and pH
(2) measure microbial community dynamics as a function of pCO_2, the total CO_2 concentration, and pH
(3) determine the role and persistence of microbial communities
(4) measure mobilization and immobilization of metals and metaliods under high-level CO_2 conditions
(5) determine the extent of geochemical trapping of leaked CO_2
(6) develop diagnostic monitoring techniques to assess water quality after CO_2 leakage