EPA
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Agency

Geologic Sequestration Research: Progress Update

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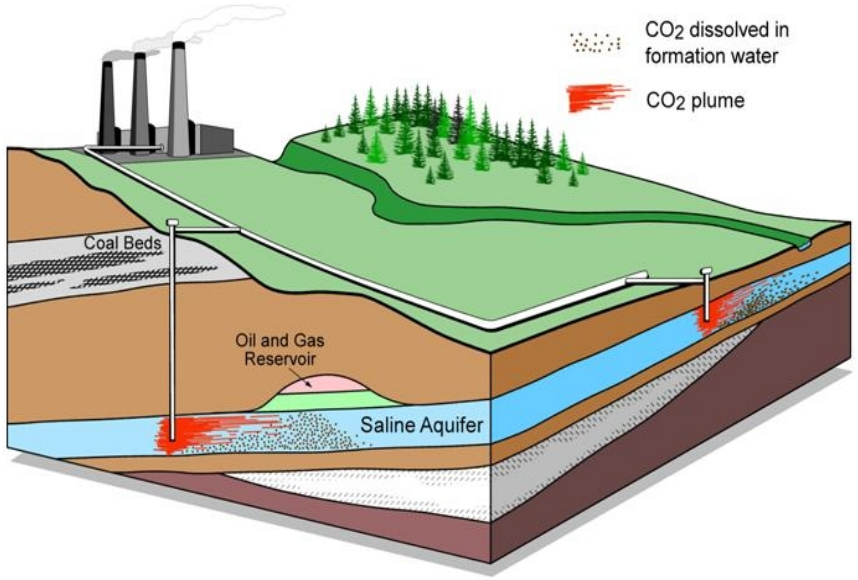
National Program Director

Geologic Sequestration Research Program
SAB teleconference
16 August 2010

Office of Research and Development
National Program for Drinking Water Research

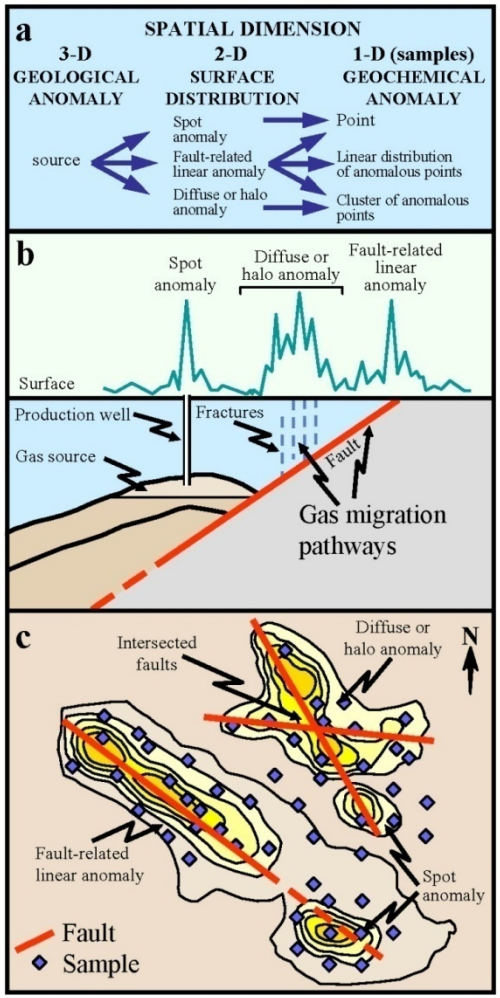
ORD's Geologic Sequestration Research Program

- Approach and timeline
- Research Priorities
- Overview of research projects
  - Field
  - Laboratory
  - Modeling
- Highlights of projects



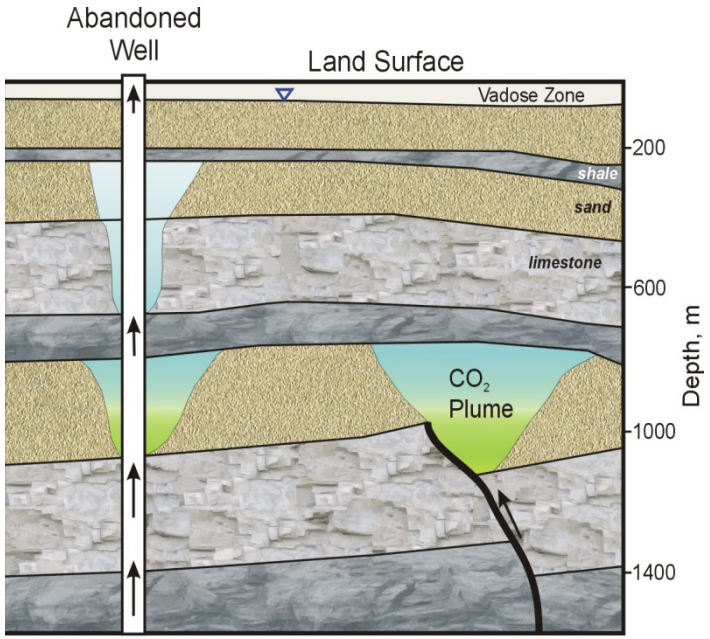
Geologic Sequestration Research Program Overview

- **Scope**
  - Research priorities defined in collaboration with OW, OAR, Regions
  - Primary focus on research support for new UIC rule and its implementation
- **Project development**
  - Research proposals
    - Cross-ORD solicitation (FY 07)
    - STAR solicitation (FY 09)
  - Peer review of proposals and technical advisory group
  - Coordinate among researchers and with other groups
  - Integrate into Drinking Water Research Program
- **Resources**
  - Projects initiated between FY 07- FY 10
  - Total Resources to date: $11M (includes FTE)
    - Intramural: 5 projects ($4.74M)
    - Extramural: 7 STAR grants ($6.26 M)
  - Current projects will be completed FY 11-14 (contingent on resources)



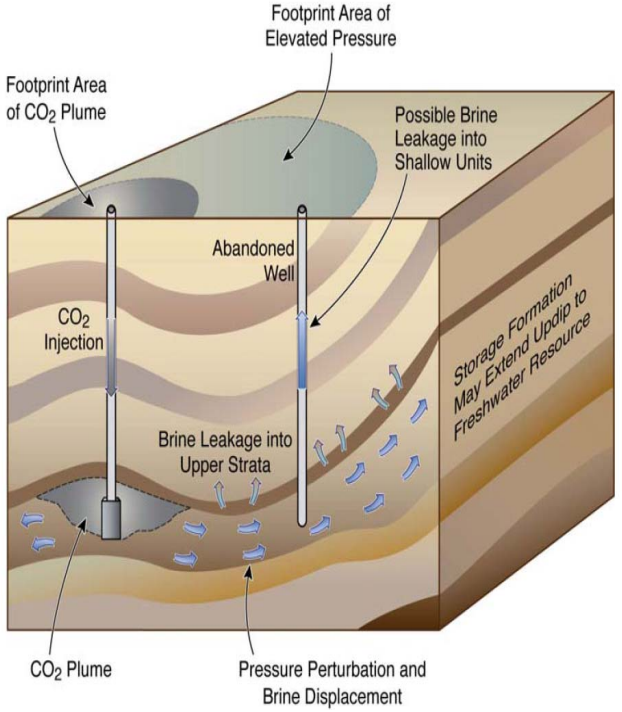
Key Water Issues Relevant to Geologic Sequestration

- Endangerment of Underground Sources of Drinking Water (USDWs)
- Leaks of injected fluid or displaced brines into other formations or the surface through fractures, faults, or well penetrations
- Release of metals or hydrocarbons into drinking water due to geochemical or biogeochemical changes (acidification)
- Alteration of water quality resulting from pressure perturbations associated with injection



Research Priorities

- Potential **ecological and health impacts** associated with changes in water quality associated with injected and mobilized contaminants
- Development of cost-effective **monitoring schemes** to track plume migration and detect leaks
- Methods to **predict and verify** capacity, injectivity, and effectiveness of storage in subsurface environments
- **Characterization & management of risks** associated with plume migration and pressure increases in the subsurface
- **Tools to identify artificial penetrations** (usually wells) in the proximity of GS injection sites
- **Maintenance & assessment of mechanical integrity** of injection and existing wells due to long-term exposure to injected fluids



Current Scope of ORD's Research Activities

- Potential ecological and **health impacts** associated with changes in water quality associated with injected & mobilized contaminants
- Development of cost-effective **monitoring schemes** to track plume migration & detect leaks
- Methods to **predict and verify** capacity, injectivity, & effectiveness of storage in subsurface environments
- **Characterization & management of risks** associated with plume migration & pressure increases in the subsurface
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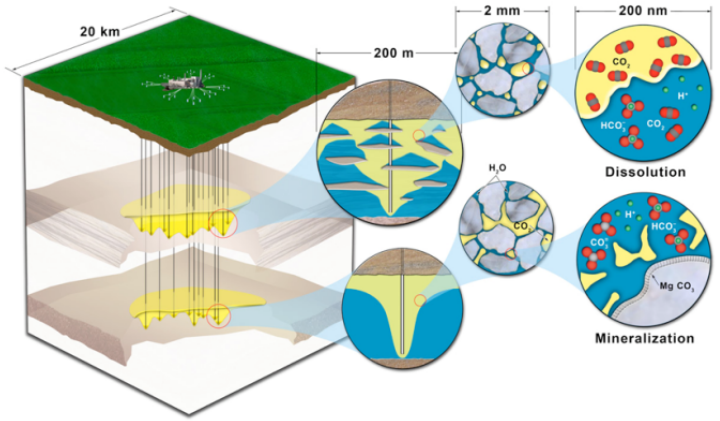
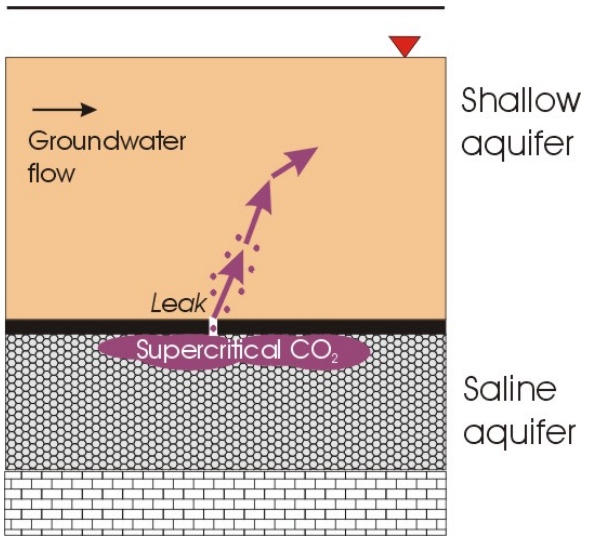




Monitoring schemes to track plume migration & detect leaks

- Development of Leak, Purge, and Gas Permeability Testing Methods to Enable Collection of Representative Soil-Gas Samples and Evaluation of Gas Leakage into the Vadose Zone from Geological Sequestration of CO_2

  D. DiGiulio (PI), R. Wilkin, K. Hargrove, K. Jewell, and R. Neill (NRMRL)

- Protecting Drinking Water by Reducing Uncertainties Associated with Geologic Carbon Sequestration in Deep Saline Aquifers

  STAR: W.R. Roy, S.M. Benson, P. Berger, I.G. Krapac, Y. F. Lin, E. Mehnert, S.V. Panno, R. Chittaranjan

  U of Illinois, Stanford, U of Hawaii

- Expert-Based Development of a Standard in CO2 Sequestration Monitoring Technology

  STAR: J-P. Nicot, S.D. Hovorka

  UT Austin

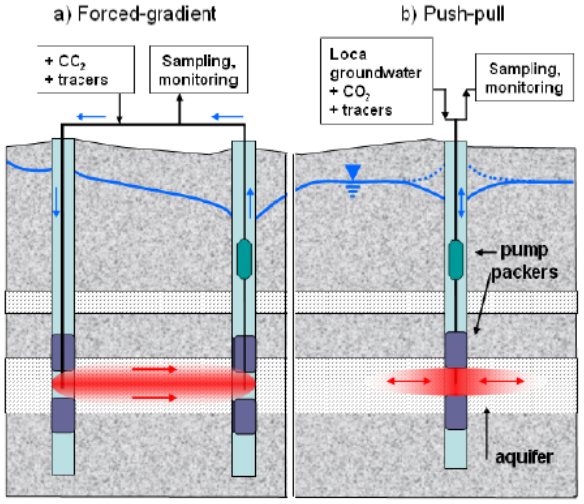
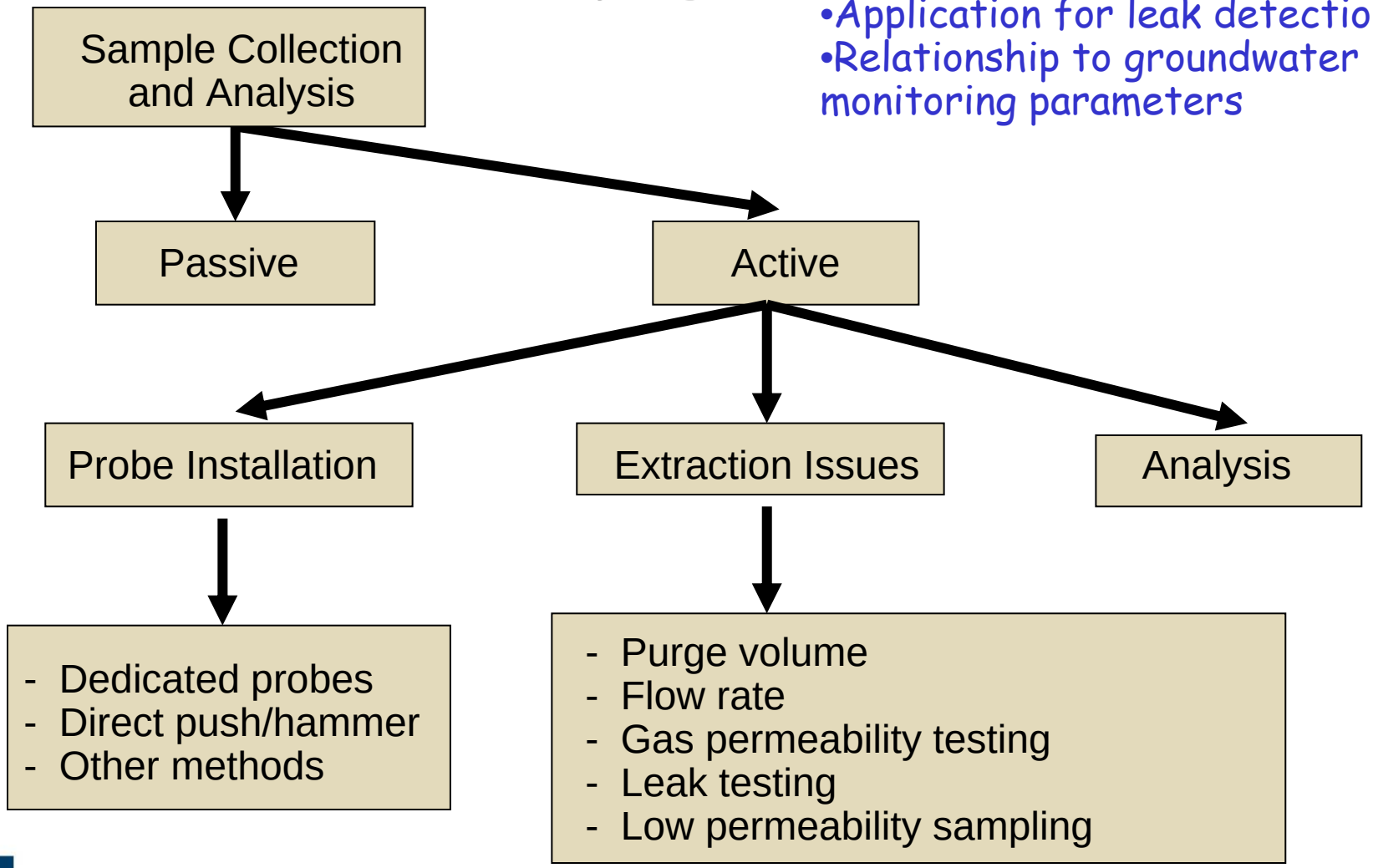


Fig. 3 Forced gradient (a) and push-pull (b) experiments

Soil-Gas Sampling

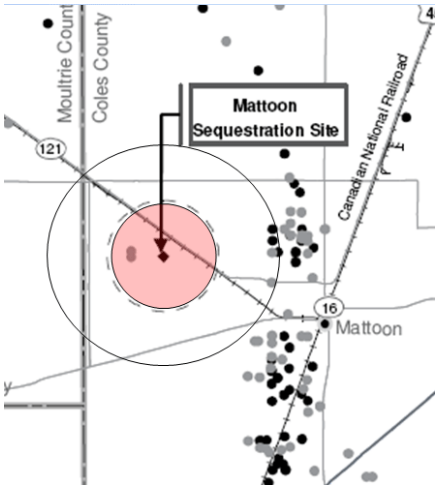
- Temporal and Spatial Variability
- Application for leak detection
- Relationship to groundwater monitoring parameters



Methods to predict and verify capacity, injectivity, & effectiveness of storage in subsurface environments

- Area of Review modeling and mapping associated with CO_2 deep injection for the purpose of geologic sequestration

  S. R. Kraemer, J. Babendreier (NERL), D. DiGuilio (NRMRL), K. Bandilla (National Research Council Fellow)
  M.Celia (Princeton U)
  J. Birkholzer, Q. Zhou (Lawrence Berkeley National Laboratory)
  R. Truesdale (NWPP-RTI International)
  M. Tonkin (S.S. Papadopolus & Associates)

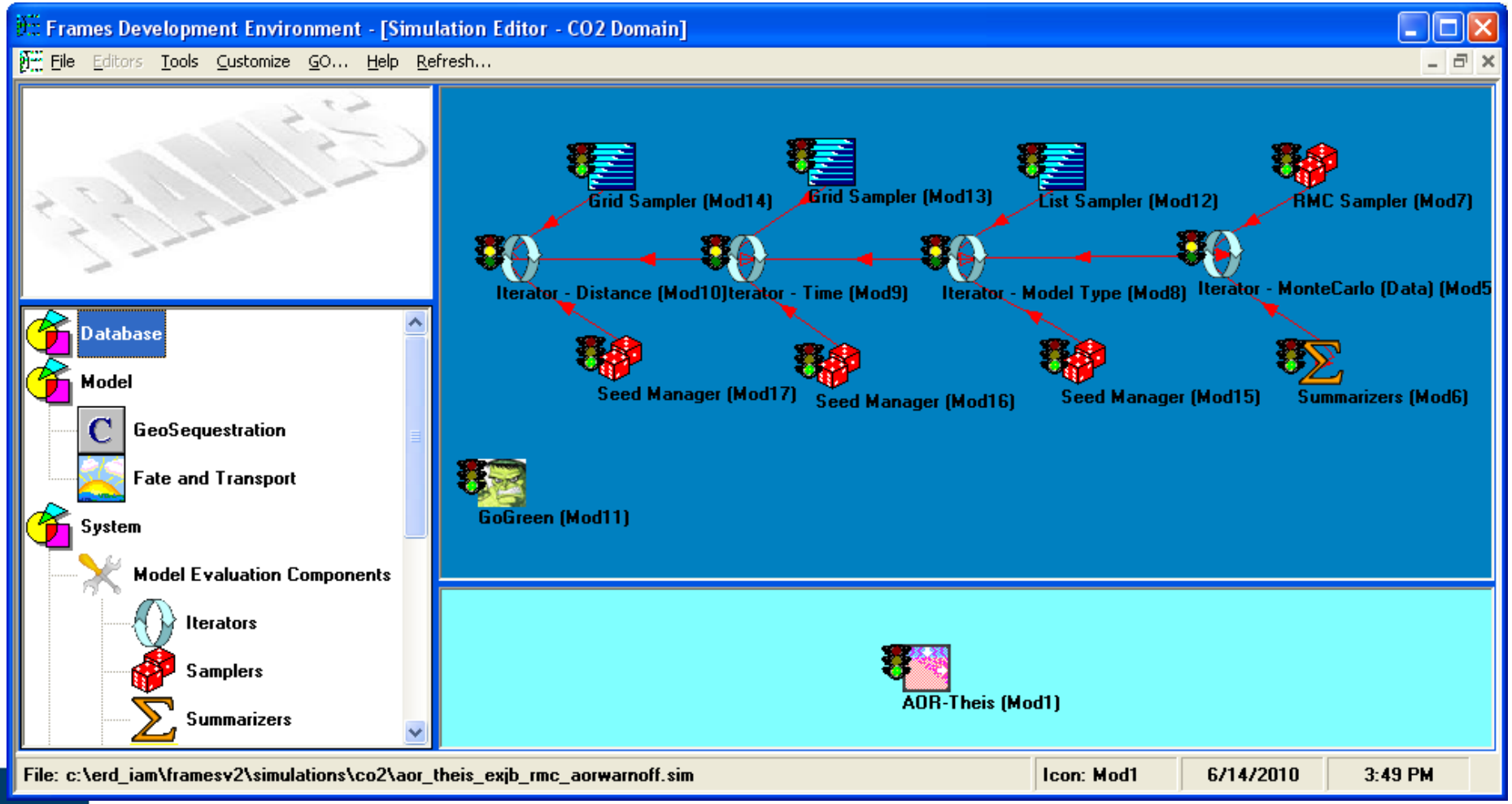


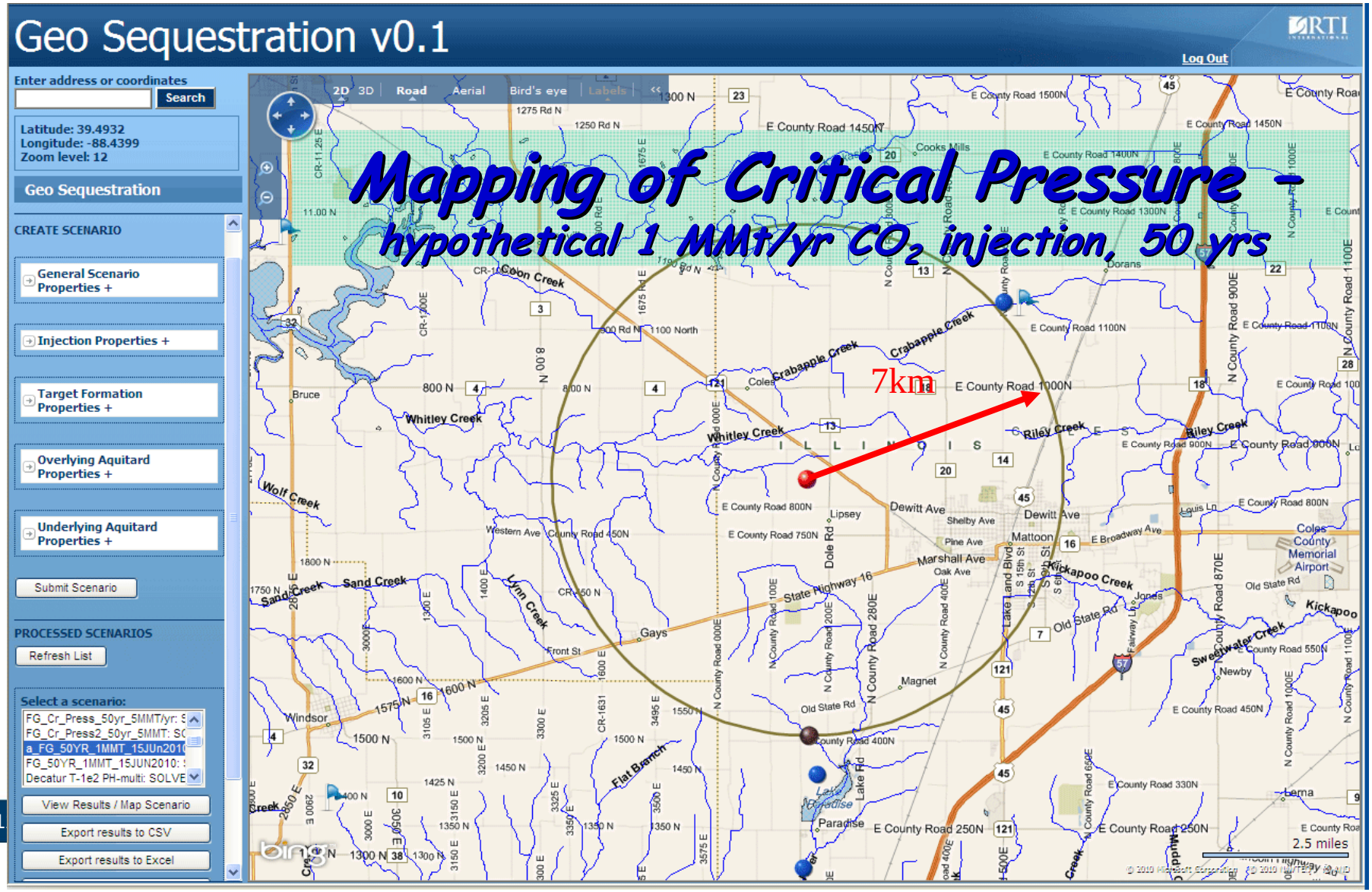
- A Hierarchical Modeling Framework for Geological Storage of Carbon

  STAR: M. Celia, Princeton

Example of Model Architecture

Monte Carlo simulator for cluster supercomputer (>300 PCs)




Geo Sequestration v0.1
RTI
Log Out
Enter address or coordinates
Search
Latitude: 39.4932
Longitude: -88.4399
Zoom level: 12
Geo Sequestration
CREATE SCENARIO
General Scenario Properties +
Injection Properties +
Target Formation Properties +
Overlying Aquitard Properties +
Underlying Aquitard Properties +
Submit Scenario
PROCESSED SCENARIOS
Refresh List
Select a scenario:
FG_Cr_Press_50yr_5MMT/yr:
FG_Cr_Press2_50yr_5MMT:
a_FG_50YR_1MMT_15JUn201
FG_50YR_1MMT_15JUN2010:
Decatur T-1e2 PH-multi: SOLVE
View Results / Map Scenario
Export results to CSV
Export results to Excel
2D 3D Road Aerial Bird's eye Labels
Mapping of Critical Pressure –
hypothetical 1 MMt/yr CO2 injection, 50 yrs
7km
E County Road 1000N
E County Road 1450N
E County Road 1500N
E County Road 1400N
E County Road 1300N
E County Road 1100N
E County Road 900N
E County Road 800N
E County Road 750N
E County Road 550N
E County Road 450N
E County Road 400N
E County Road 330N
E County Road 250N
Coon Creek
Crabapple Creek
Whitley Creek
Riley Creek
Wolf Creek
Sand Creek
Lynn Creek
Flat Branch
Kickapoo Creek
Sweetwater Creek
Bruce
Coles
Dorans
Cooks Mills
Lipsey
Dewitt Ave
Mattoon
Gays
Windsor
Magnet
Newby
Lerna
Paradise
Lake Land Blvd
Dole Rd
Lake Rd
State Highway 16
Old State Rd
Marshall Ave
Pine Ave
Oak Ave
Shelby Ave
Western Ave
Front St
Jones
Fairway Ln
Louis Ln
Coles County Memorial Airport
ILLINOIS
2.5 miles
bing

Characterization and Management of Risks: Geochemical Studies

- Geochemical Impacts to Groundwater from Geological Carbon Sequestration

  R. T. Wilkin (PI), D. C. DiGiulio, (NRMRL)
  S. Choi (National Research Council Fellow),
  J. Apps, J. Birkholzer, N. Spycher (Lawrence Berkeley National Laboratory), J. Hakala (National Energy Technology Laboratory)

- Understanding and Managing Risks Posed by Brines Containing Dissolved Carbon Dioxide

  STAR: R.W. Falta, S.M. Benson, L.M. Murdoch,
  Clemson U, Stanford

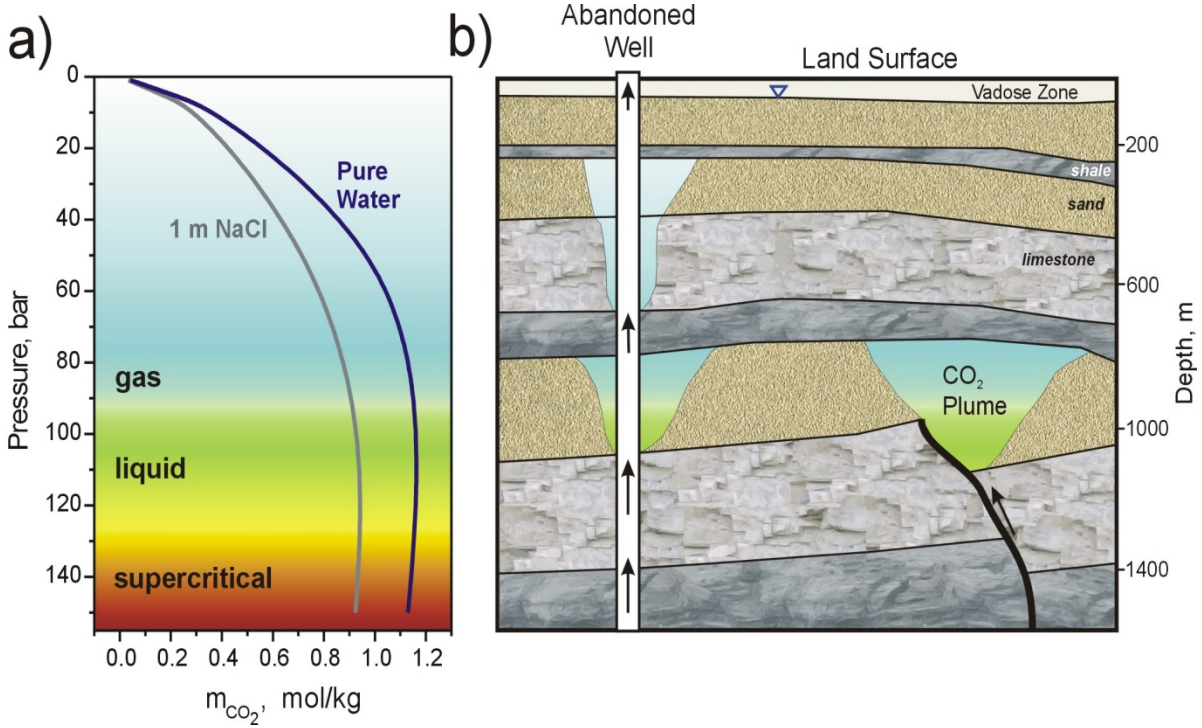
- Aquifer Risk Assessment Framework (ARAF)

  STAR: B.J. McPherson, M.D. Deo, R. Goel, S. Ramesh , D.Kip
  U of Utah

- Risk-Based Decision Making for Assessing Potential Impacts of Geologic CO2 Sequestration on Drinking-Water Sources

  STAR: J. McCray, J.Kaszuba, John , R. Maxwell, A. Sitchler,
  Colorado School of Mines, U of Wyoming

Context for Geochemical Investigations



- Injection as supercritical fluid
- Leakage along T,P trajectories
- Impact of increased partial pressure of CO_2 & H_2S on solubility

pH decrease: $CO_2(g) + H_2O = H_2CO_3 = HCO_3^- + H^+$

Trace metal reactions
- Solubilization
- Precipitation/sorption
- Biogeochemical interactions with aquifer matrix
- Oxidation/reduction

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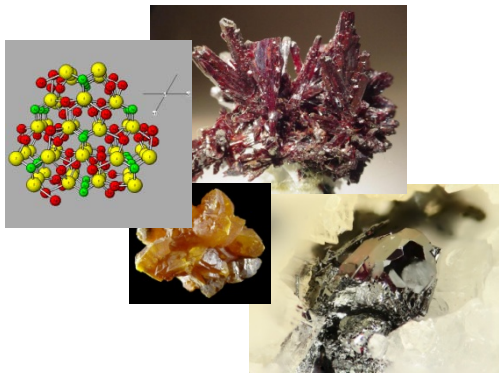
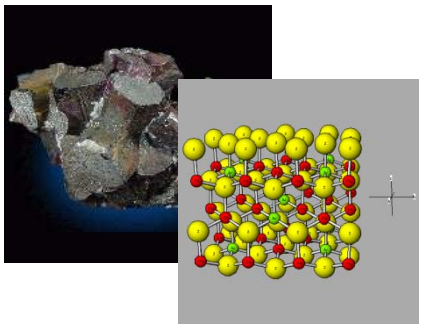
Geochemical Models to support field and laboratory investigations

- Reaction Path Models/Surface Complexation Models
- Review/Comparison of Thermodynamic Data: MinteqA2, Phreeq-C, EQ3/6, other
- Identify data gaps, uncertainties; Update with current data
- Construction of Phase Diagrams
- Key Elements: As, Ba, Be, Cd, Cr, Cu, Hg, Pb, Sb, Se, Tl, U



Thioarsenites
As(III)-S



Thioarsenates
As(V)-S

Table 1b. Solubility and ******* of Lead Carbonates and Bicarbonates and Hydr

Species or reaction data for standard state conditions, 298.15 K and 1 atm	Log K	Reference
Association?		
$PbCO_3(aq) = Pb^{2+} + CO_3^{2-}$	-7.24	Hem (1976)
	-6.60†	Bilinski and Schindler (
	-7.14	Taylor and Lopata (198
$Pb(CO_3)_2^{2-} = Pb^{2+} + 2CO_3^{2-}$	-10.64	Hem (1976)
	-10.06†	Bilinski and Schindler (
Solubility		
$PbHCO_3^+ = Pb^{2+} + CO_3^{2-} + H^+$	-13.23	Zirino and Yammamoto
$PbCO_3(s) = Pb^{2+} + CO_3^{2-}$	-13.13	Hem (1976)
	-13.35†	Bilinski and Schindler (
	-12.8	Wagman et al.
	-13.21	Taylor and Lopata (198
$Pb_3(CO_3)_2(OH)_2 + 2H^+ = 3Pb^{2+} + 2CO_3^{2-} + 2H_2O$	-17.64	Taylor and Lopata (198
	-16.91	Mercy et al. (1998)

† Corrected to ionic strength = 0 using extended Debye-Huckel equation

Species or reaction data for standard state conditions, 298.15 K and 1 atm	Log K	Database
Association?		
$PbCO_3(aq) = Pb^{2+} + CO_3^{2-}$	-6.53	MinteqA2
	-7.24	Wateq4f
	-6.58	V8.R6+
$Pb(CO_3)_2^{2-} = Pb^{2+} + 2CO_3^{2-}$	-9.94	MinteqA2
	-10.64	Wateq4f
	-9.40	V8.R6+
$PbHCO_3^+ = Pb^{2+} + CO_3^{2-} + H^+$	-13.23	MinteqA2
	-13.36	Wateq4f
	--	V8.R6+
$PbCO_3(s) = Pb^{2+} + CO_3^{2-}$	-13.39	MinteqA2
	-13.29	Wateq4f
	-13.54	V8.R6+
$Pb_3(CO_3)_2(OH)_2 + 2H^+ = 3Pb^{2+} + 2CO_3^{2-} + 2H_2O$	-18.76	MinteqA2
	-17.46	Wateq4f
	-18.81	V8.R6+

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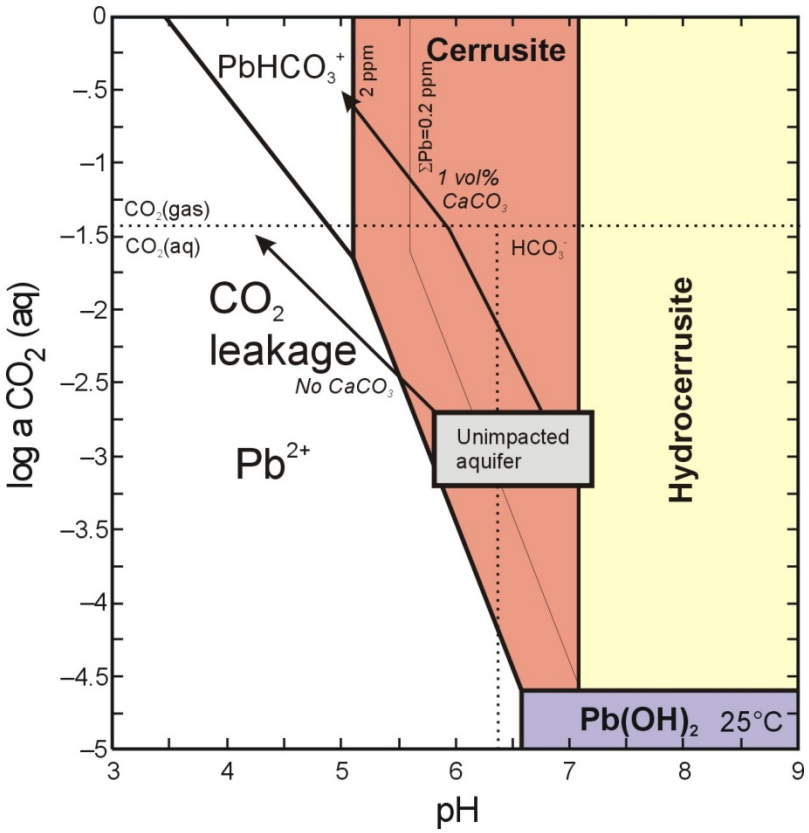
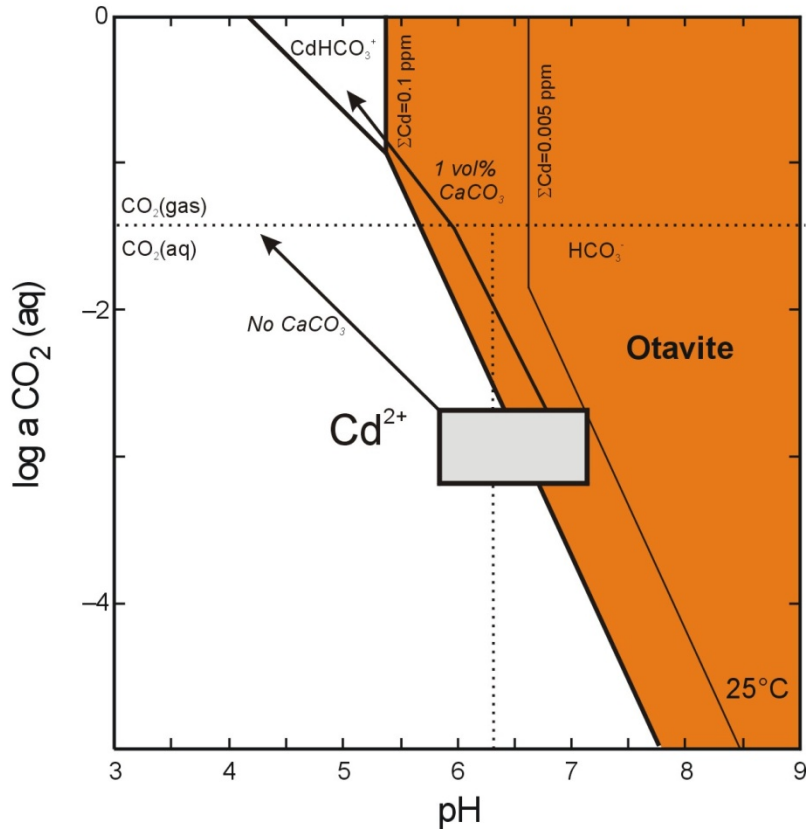
Metal Solubility System: Me-CO_2-H_2O



Lead



Cadmium

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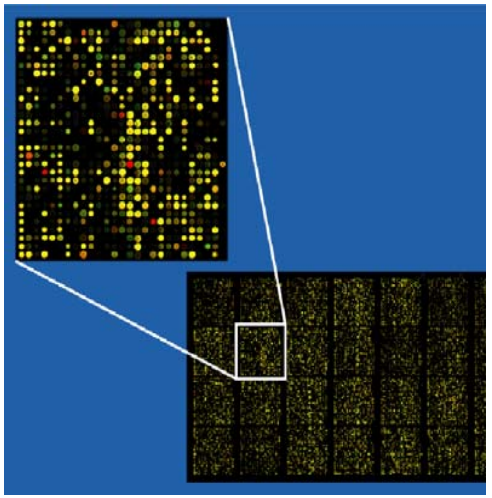
Characterization and Management of Risks: Biogeochemical Studies

- Phylogenetic and Functional Molecular Diversity of Subsurface Communities Exposed to Different CO_2 Concentrations

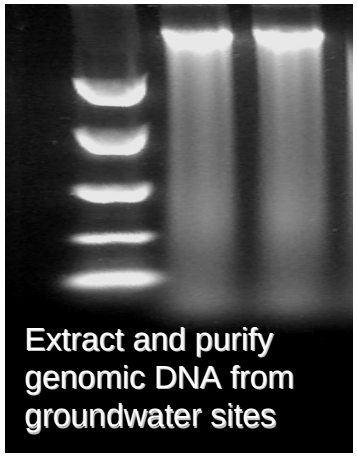
  J. Santo Domingo (NRMRL), N. Ashbolt (NERL)
  R. A. Sanford ,Wen-Tso Liu (University of Illinois),
  T. Hazen, G. Andersen (Lawrence Berkeley National Lab-DOE)

- Diagnostic Monitoring of Biogeochemical Interactions of a Shallow Aquifer in Response to a CO_2 Leak,

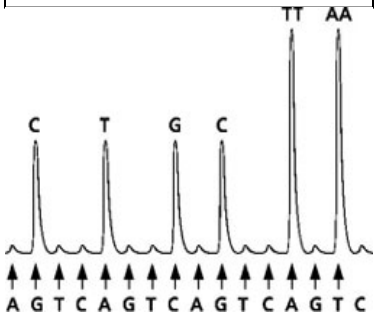
  STAR: D.S. Goldberg, David S. , J.M. Matter, G. O'Mullan, M., Stute, T.Takahashi
  Colombia University



Groundwater Molecular Ecology



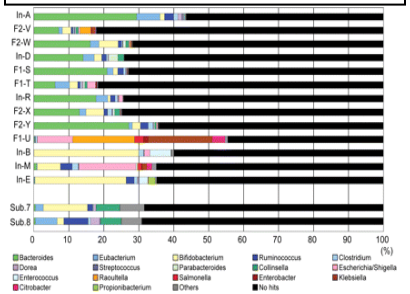
Send out for Sequencing



Group- and function-specific assay development

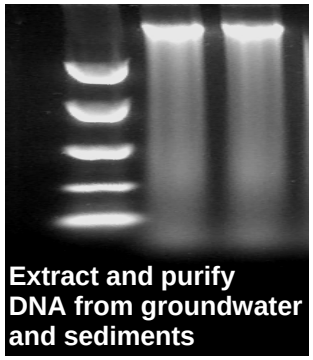
- Methods for collecting and processing ground water, biofilm, and sediment samples
- Statistical basis for identifying index organisms/gene markers.

***In silico* Comparative Genomics**



Annotation of Gene and genomes

Molecular Microbial Approach Used

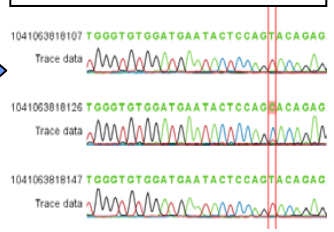


PCR Bacterial or
Achaeal 16S rRNA Genes

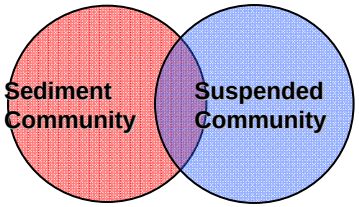
PCR primers
targeting
conserved regions

Cloning & Sequencing	
Phylogenetic & Function Specific Genes	Microbial population fingerprint
RT-PCR PCR QPCR	Microarray T-RFLP HOPE

Annotation of Clones



DIVERSITY ANALYSES



Assay Development
Host Specific &
Functional Markers

Predictive Models
Functional Dynamics
Field Application

- Assess the identity, diversity, and functional potential of prokaryotic microbial communities (bacteria and archaea) in subsurface environments exposed to different CO_2 levels
- Compare attached and planktonic bacterial populations
- Identify temporal changes in groundwater microbial community structure
- Progress to date:
  - >10,000 bacterial and archaeal 16S rDNA sequences
  - key populations: sulfate- and iron-reducers

Collaborators

University of Illinois
Lawrence Berkeley National Laboratory

Tools to identify artificial penetrations

- Development of Methods to Evaluate Gas Intrusion into Buildings from Geological Sequestration of CO_2 Using Natural and Anthropogenic Analogues.

  D. DiGiulio (PI), R. Wilkin, K. Hargrove, K. Jewell, T. Lankford (NRMRL)

  - Integrated air-water-soil monitoring
    - Evidence of gas intrusion using real-time data from soil-gas probes and radon mitigation systems
    - Parallel water quality data using ground-water monitoring wells to identify
      - Geochemical reactions that lead to elevated CO_2 and depressed O_2 in soil gas
      - Subsurface and meteorological factors that affect gas intrusion into homes
  - Develop and test measures to eliminate or reduce intrusion of oxygen displacing soil-gases (N_2 and CO_2) during heavy precipitation events.

Summary

- Research Program is addressing high priority research needs using integrated laboratory, field, and modeling approaches
- Strong collaboration across ORD, across EPA, and with external partners
- Active Program Office and Regional involvement in research process (priority areas, peer reviews, feedback on study plans, co-sponsor seminars, workshops)
- Anticipated products
  - Models that can be used for siting, permitting, design of monitoring programs
    - Regional monitoring tools for decision-makers
    - Web-based interactive models
  - Geochemical models that can be used to identify and manage risks
  - Incorporation of biogeochemical concepts into design of monitoring programs
  - Monitoring tools, Field data, Technical support
- **Publications to-date**
  - Wilkin, R.T. and D.C. DiGiulio (2010). Geochemical impacts to groundwater from geologic carbon sequestration: Controls on pH and inorganic carbon concentrations from reaction path and kinetic modeling. *Environmental Science and Technology*, v. 44, p. 4821-4827

Additional Information

ORD's Research Programs and Laboratories

http://www.epa.gov/ORD

STAR Grants

http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/research.display/rpt/abs/rfa_id/504

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