EGI Energy & Geoscience Institute
AT THE UNIVERSITY OF UTAH

Aquifer Risk Assessment Framework (ARAF)

EPA STAR GRANT #R834386

Progress Review of STAR grant research on
Carbon Geosequestration
January 7-8, 2013

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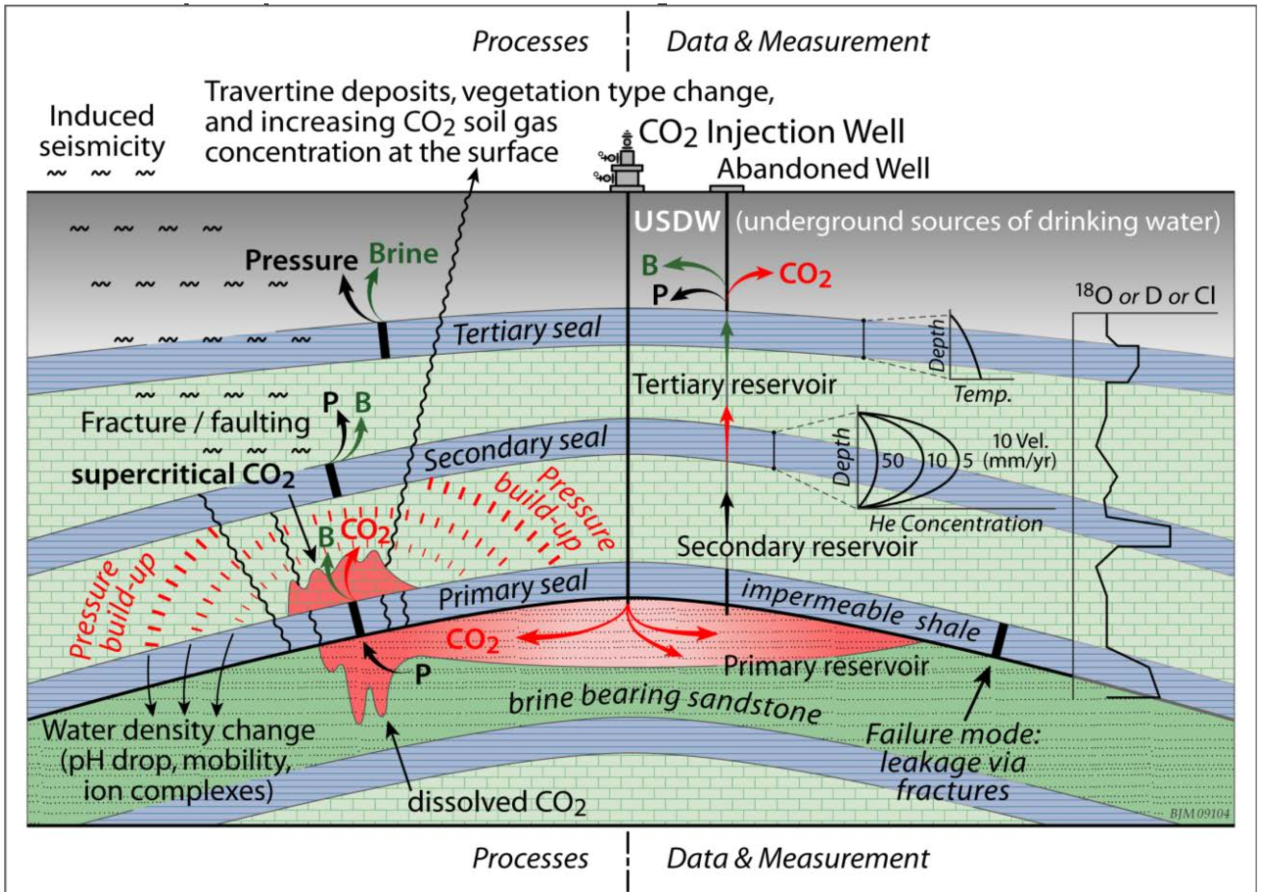
Overview

This research is funded by U.S. EPA - Science To Achieve Results (STAR) Program Grant # 834385



Evaluations of potential risks to USDWs

- Migration of CO2 brine and pressure
- Leakage through seals, abandoned wells, fractures or faults

Mitigation of the identified risks

- Elucidate and quantify the formal risks
- Develop a comprehensive set of protocol for identification and mitigation of the risks

Objectives

- Identify risks specific to USDWs and develop associated PDFs
- Quantify risks to USDWs by pressure/brine/CO_2 migration through seals
- Quantify risks to USDWs by lateral migration of pressure/brine/CO_2
- Determine conditions that minimize (or eliminate) the risks to USDWs

With these objectives

- Develop a formalized, practical methodology for characterizing risks to USDWs
- Develop mechanisms to minimize these risks
- Develop a general system that can be tailored for any specific site

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Outline

- ARAF
- ARAF team
- Site Screening and selection
- Simulation and modeling
- Isotope tracer analysis
- Microbial analysis
- Development of PDFs
- Progress to date
- Publications

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ARAF (Aquifer Risk Assessment Framework)

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Site Characterization and MVA

- BPM (NETL – Site Screening, Selection, and Initial Site Characterization)
- RMCCS Results to date
- Capacity protocols to date

Simulation Models

FEPs Registry

- Generic Quintessa
- System for tailoring for each site (GC to start)

Risk Quantification

- PDFs (technical)
- FMEA (non-technical)

Tracer analysis

- He Isotope analysis
- Calibration of permeabilities to Helium concentration

Microbial analysis

- Microbial concentrations in ground water samples
- Correlation to inorganic geochemistry

Carbon Storage Index

=f(Capacity, economics, PDFs/FMEA)

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ARAF Team

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Group	Role
Dr. Brain McPherson and Dr. Prashanth Mandalaparty	Project management Site Screening, Risk Analysis, Simulation and Model development, Overall Co-ordination
Dr. Ramesh Goel's Group	Microbial Analysis in ground waters
Dr. Kip Solomon's Group	He Isotope analysis in the cores
Dr. Milind Deo's Group	Development of PDFs and their calibration

ARAF Work Flow

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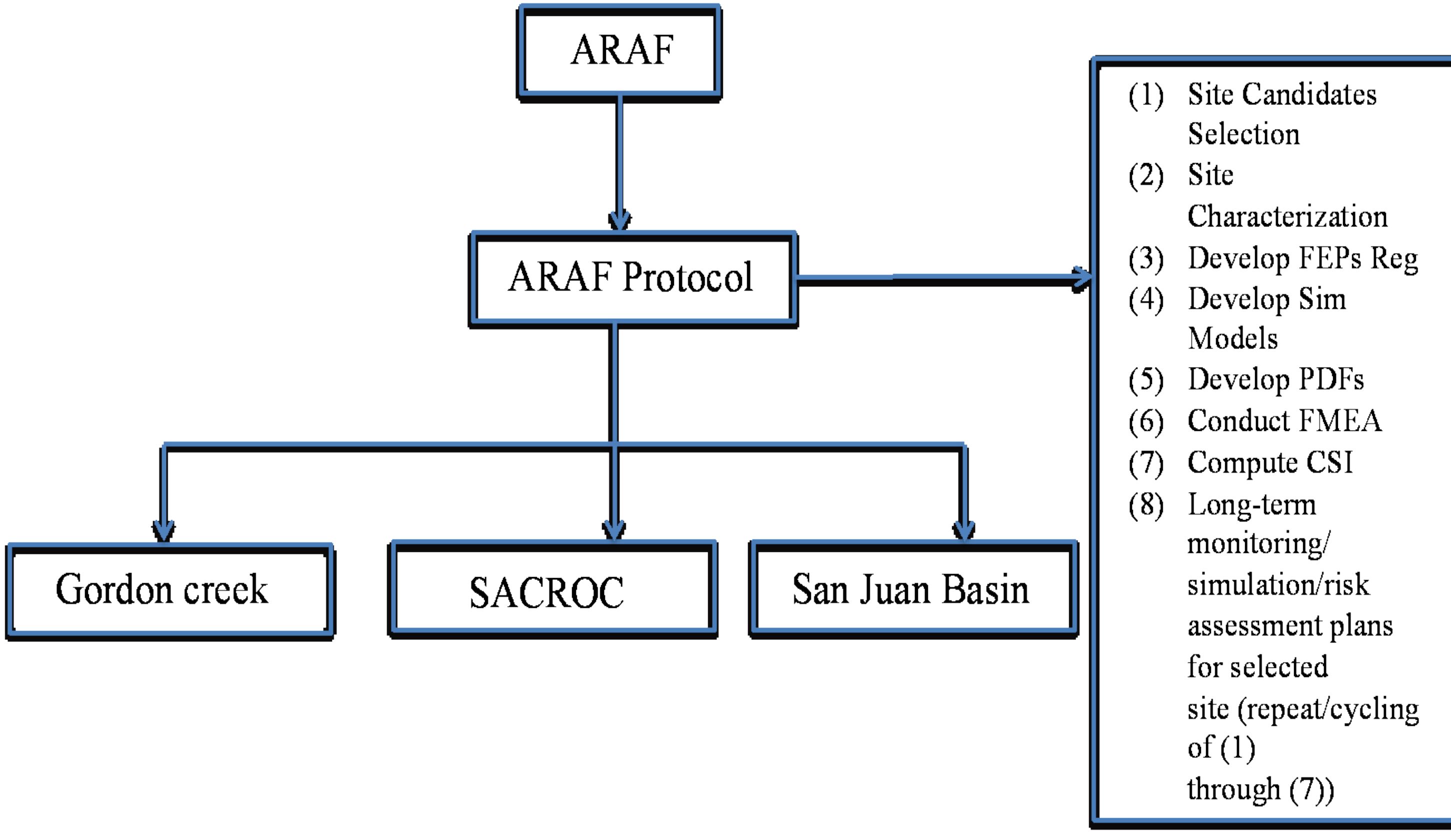

Site Screening

Site selection

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Sub Surface Data Analysis

1. Oil reservoirs
2. Deep saline Aquifers
3. Unmineable coal seams
4. Shale reservoirs
5. Basalt and other ultramafic rocks

Regional proximity

1. Wet lands
2. USDW's
3. Regional species
4. Population centers
5. Existing resources

Social Context

Developing list of selected areas and rank them

Sub Surface Data Analysis

1. Injection zone
2. Confining zone
3. Trapping mechanisms
4. Potential injection
5. Existing seismic activity

Regulatory analysis

1. Well classification
2. Corrective actions
3. Containment mechanisms

Model development

1. Parameters
2. Data requirement
3. Boundary conditions
4. Existing seismic data

Site suitable analysis

1. Infrastructure
2. Area of research
3. Surface access
4. Pore space ownership

Qualification of the site

1. Frame site development plan
2. Evaluate economic feasibility

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Site specific risk registry

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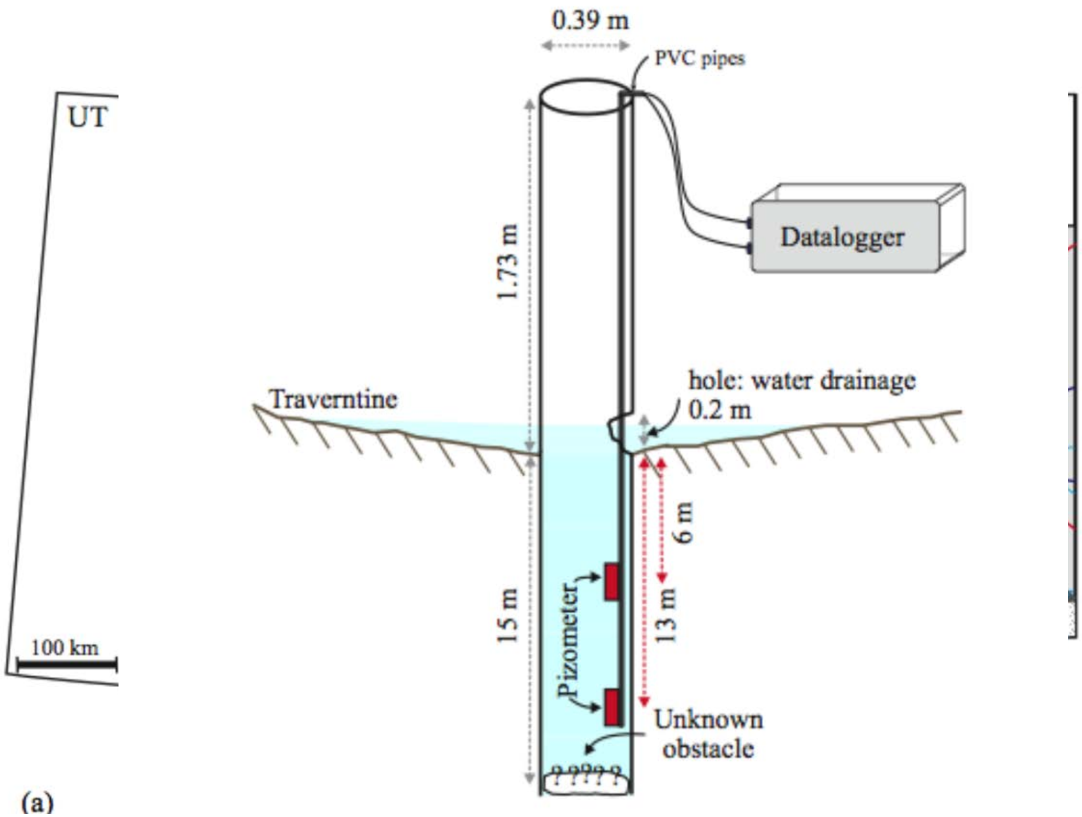
- Helps in identifying and assessing potential risks due to FEPs linked to CO_2 injection
- All the possible risks
  - Technical
  - Non technical
  - Probability of risks occurring at a particular site
- Helps in minimizing the risks
- Examples of FEPs
  - Features-Leaky well bores or faults
  - Events- Injection pressure increases or earthquakes
  - Processes- Gravity driven CO_2 movement or residual trapping
- For the EPA project risks to USDWs by GS
- Migration of CO_2, brine and pressure
- Permeable seals, abandoned wells , pre-existing fractures and faults and induced faults and fractures due to injection
- Lateral migration and migration through the high permeability zones is considered

Crystal Geyser Study

Detailed study of a natural leakage site : Crystal Geyser



(a) Geologra[Schematic diagram of well configuration and pizometer installation]ntral part of the Little grand wash fault where it splits into two main strands and cuts the hinge of the Green river anticline {Dockrill and Shipton, 2010)

Crystal Geyser Study

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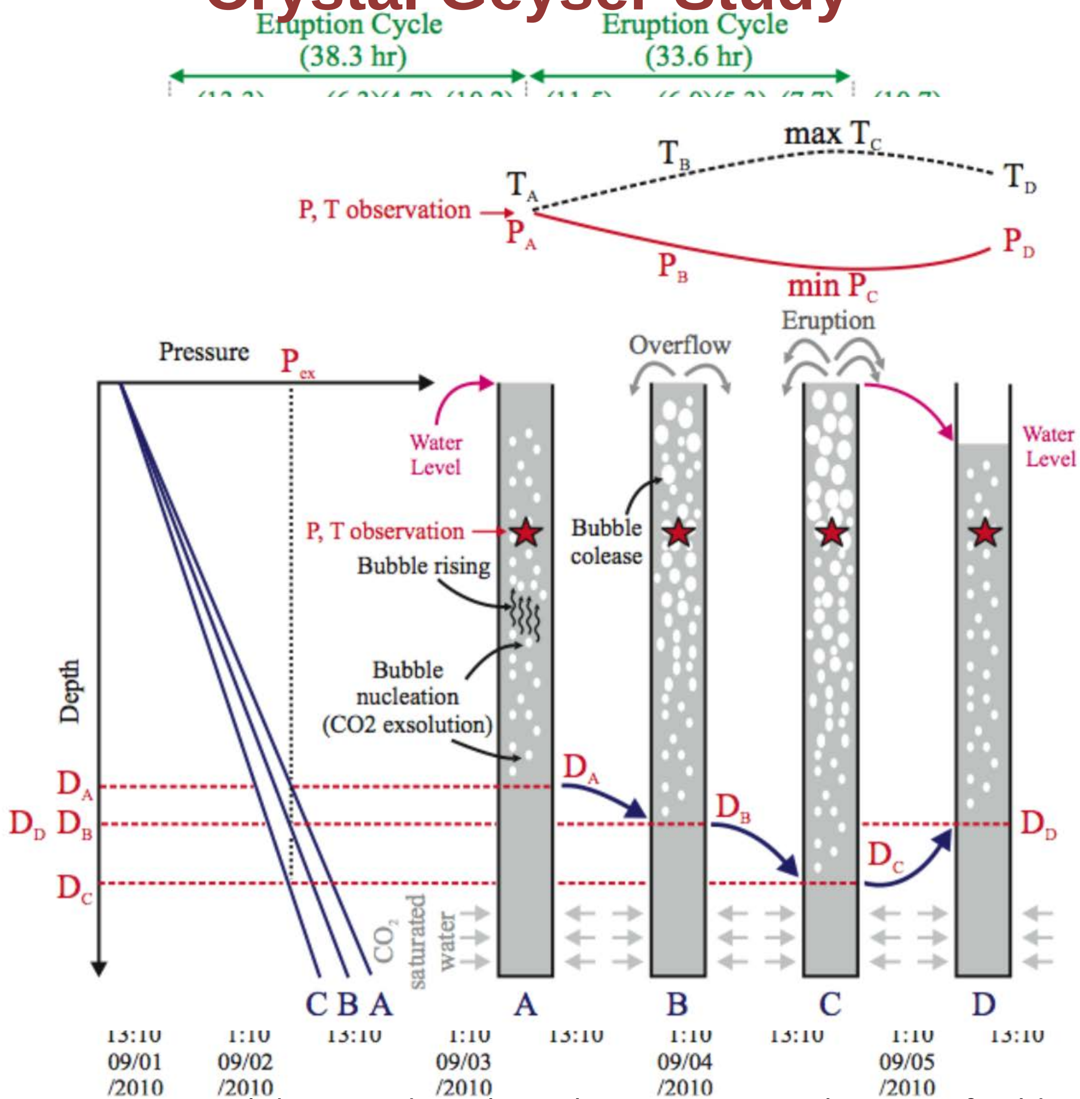

Conceptual diagram describing the eruption mechanism of cold CO_2 Geyser
Time series changes of pressure and temperature collected at Crystal Geyser

Simulation of Engineered storage sites

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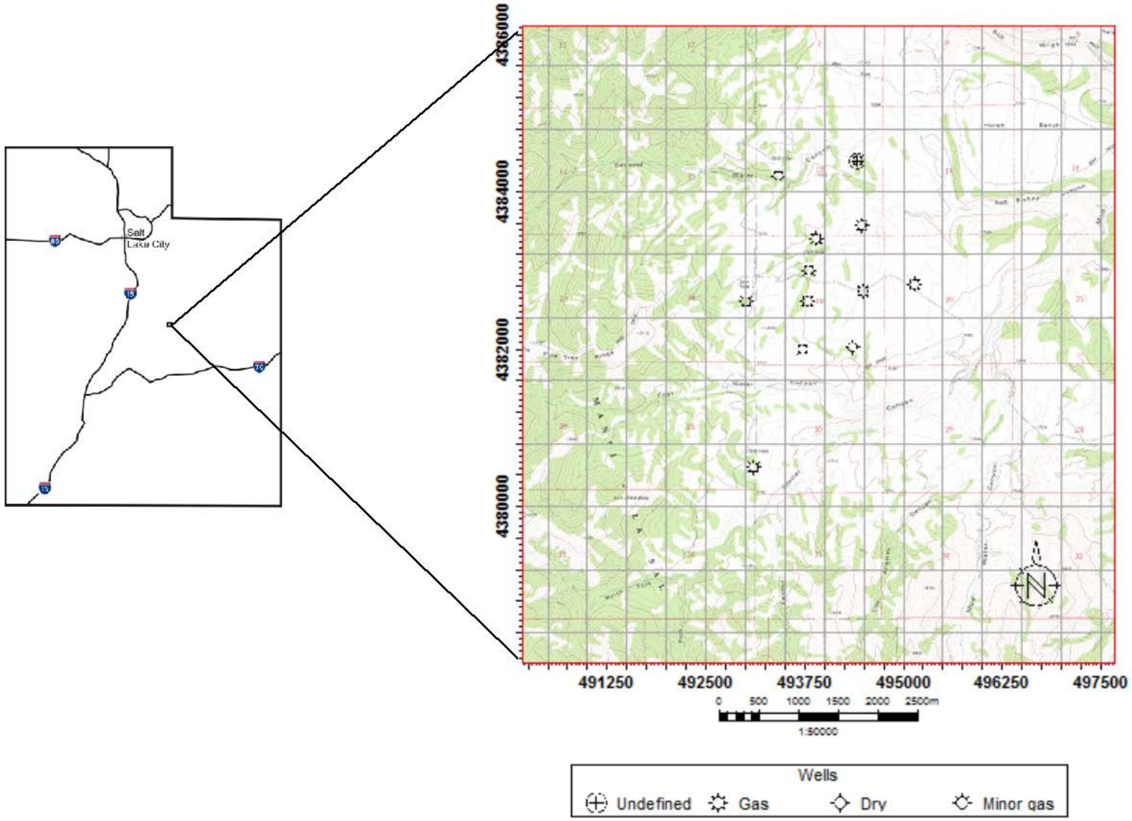
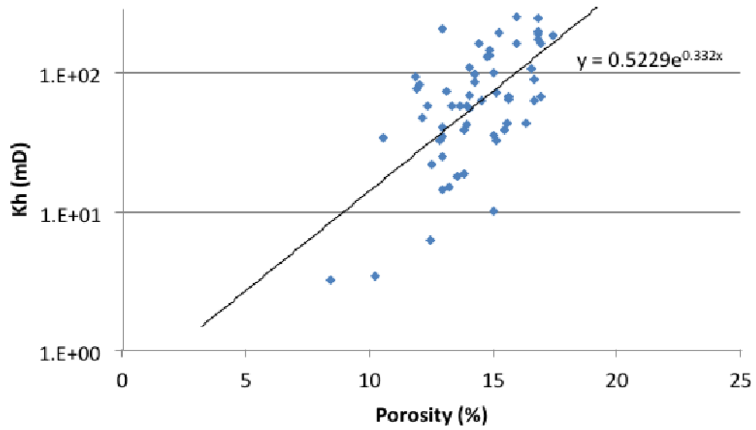
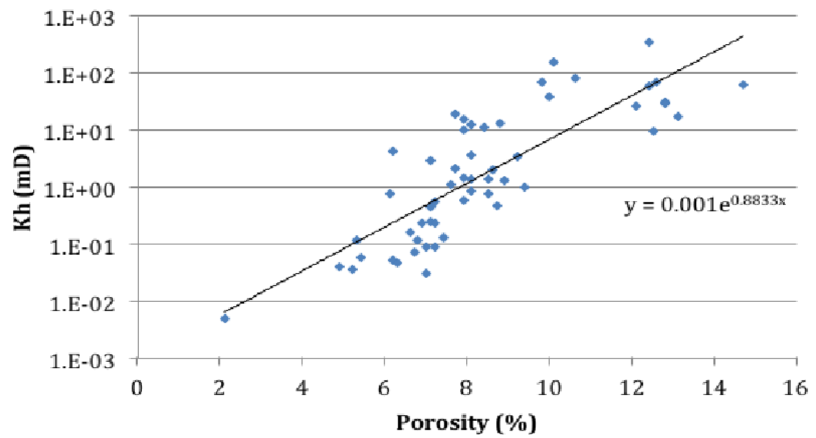
Gordon Creek Field

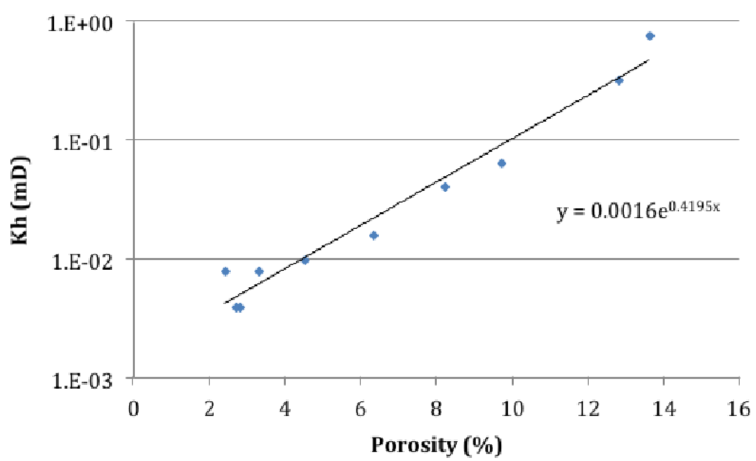


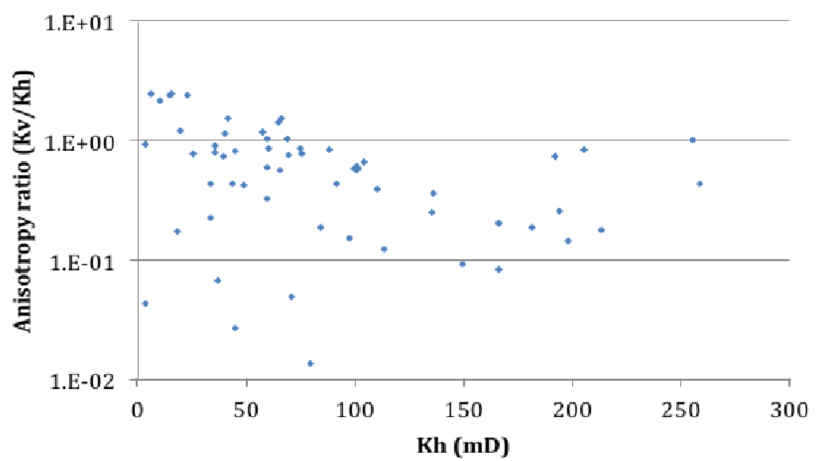
Location map of Gordon creek project area, Carbon County, Utah

Gordon Creek Field









Horizontal permeability vs. porosity in the Navajo, White Throne, Wolverine, Sinawava formation from the core plug sample and anisotropy ratio vs Kh for Navajo formation

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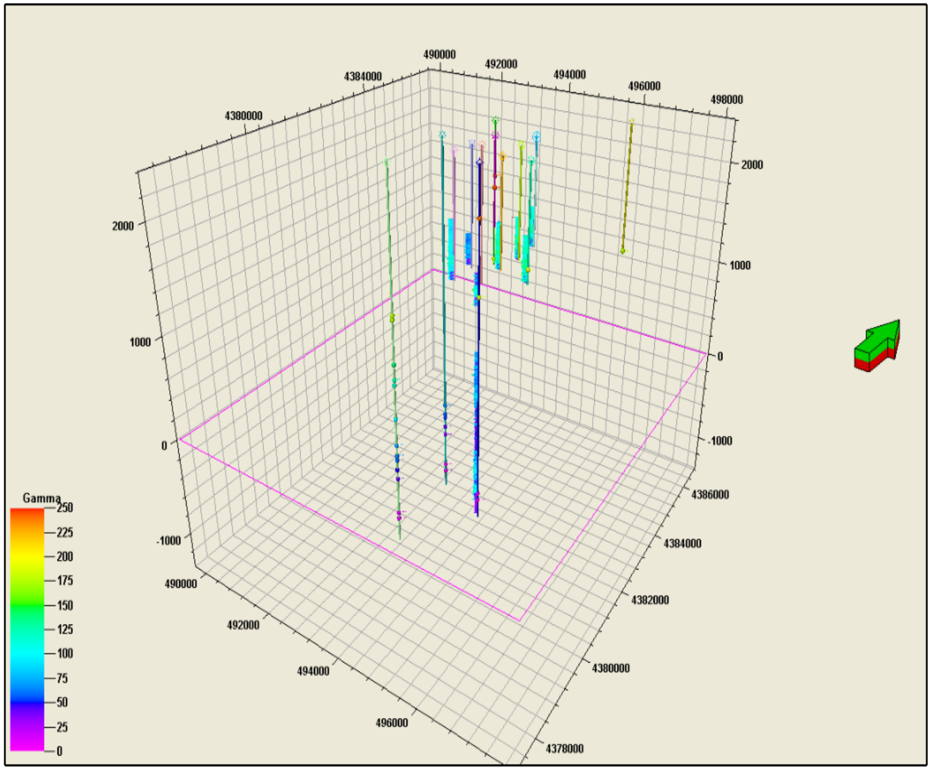
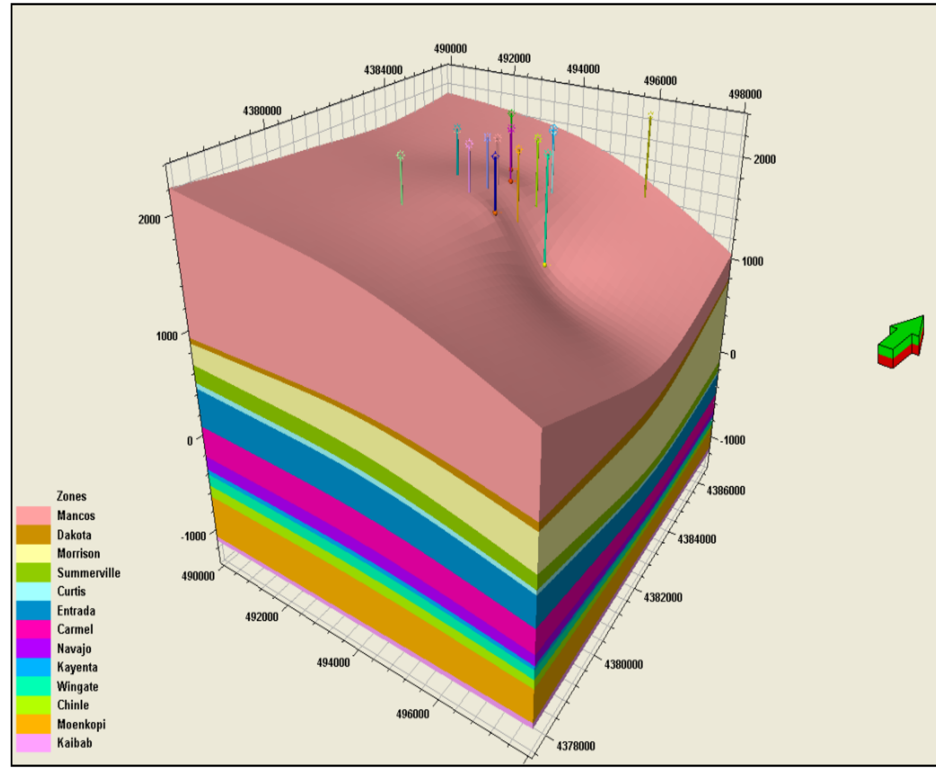
Gordon Creek Field

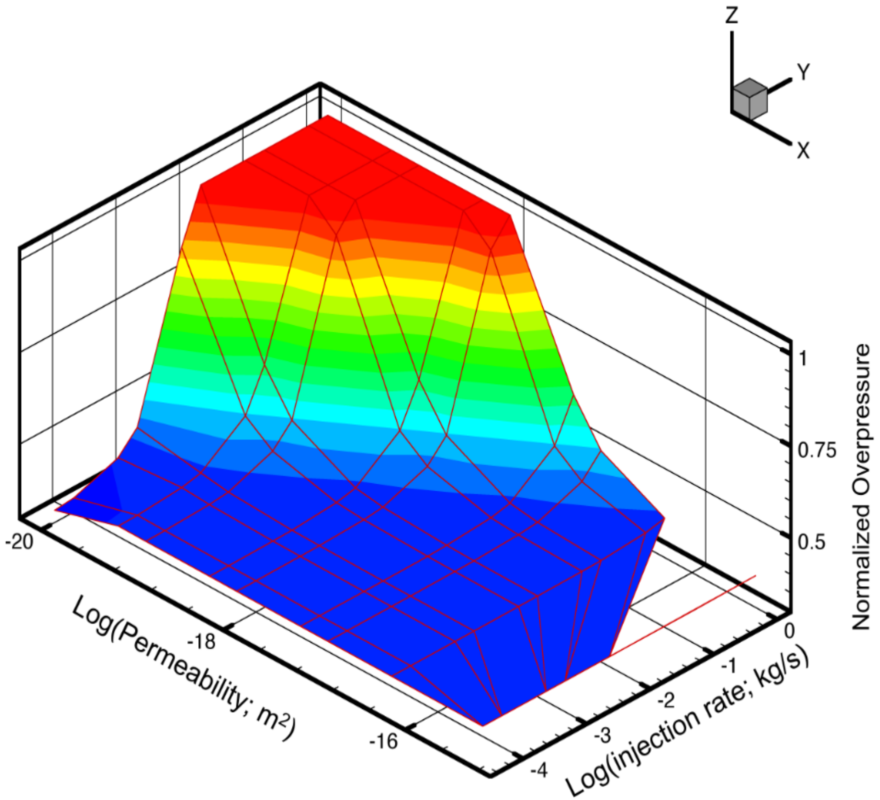


Location of wells with digitized gamma ray logs



Stratigraphic distribution of geologic formations within Gordon creek site boundary

Gordon Creek Field



Isometric projection of normalized overpressure vs injection rate and permeability

Isometric projection of normalized overpressure vs injection rate and fluid viscosity

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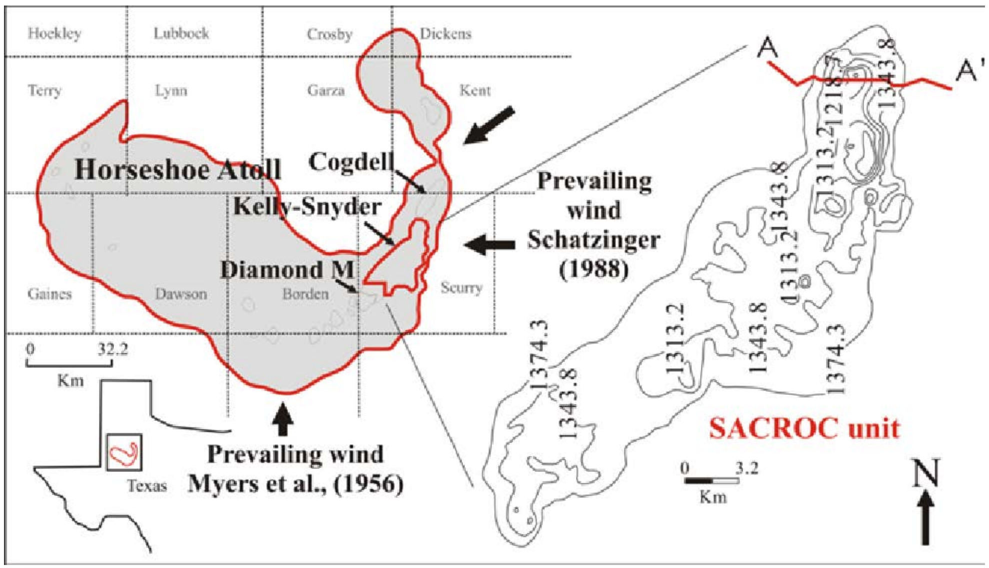
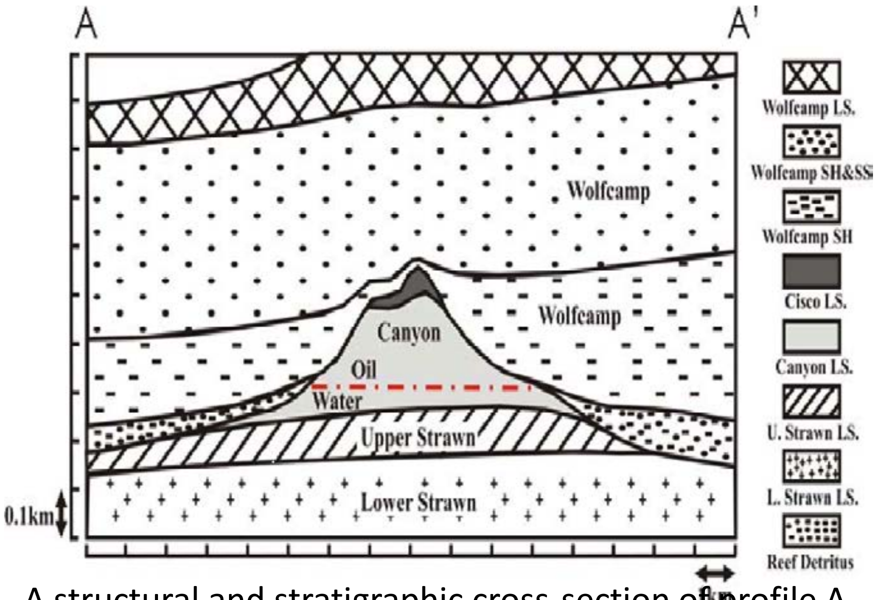
SACROC Field (EOR)



The location of SACROC Unit at the Horseshoe Atoll in western Texas and structural contour map showing subsea depth of the carbonate reef (Stafford, 1954). Contours are on the meter scale.



A structural and stratigraphic cross-section of profile A-A', located within the SACROC northern platform (Vest, 1970)..

SACROC Field (EOR)

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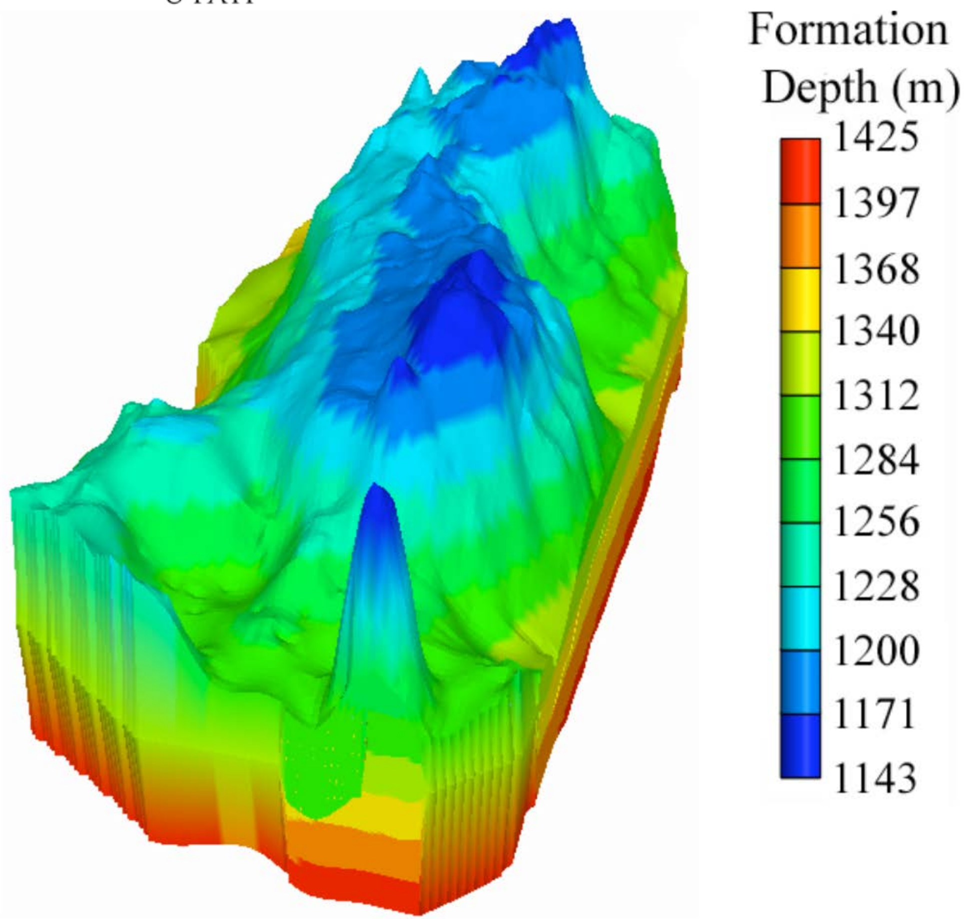
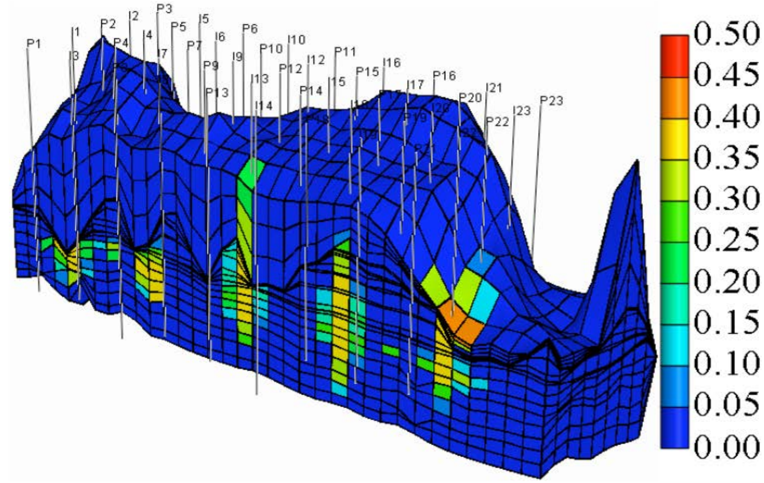
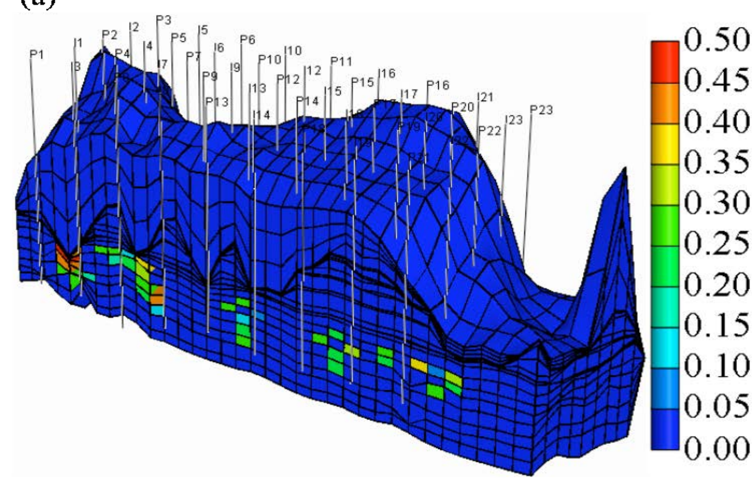


High resolution geocellular model representing the SACROC northern platform



(a)

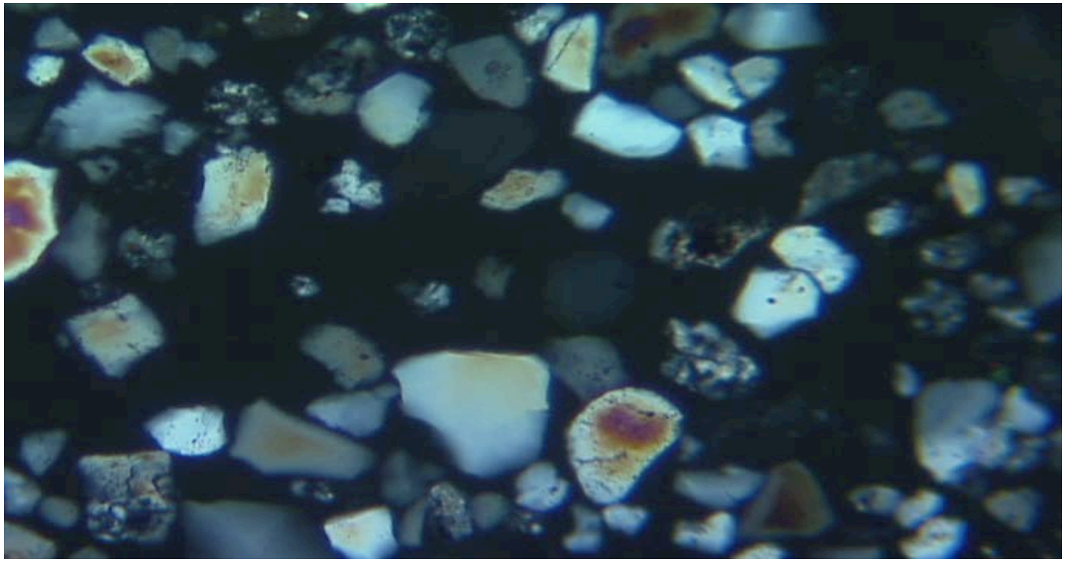


(b)

Two dimensional cross section view 30 yrs after CO2 injection (A) saturation of separate phase CO2 in brine only simulation and (b) CO2 in oil +brine simulation

Isotope analysis

- Caprock permeability is a critical aspect for geological CO2 storage
- Measurement of helium and other noble gases (natural tracers) in cap rock samples provides a good estimate of caprock permeability
- Presence of high helium concentrations indicates low permeability
- Samples from San Juan Basin, Gordon creek site and Craig Site



Photomicrographs of quartz separates
obtained from cores of shales (caprock).

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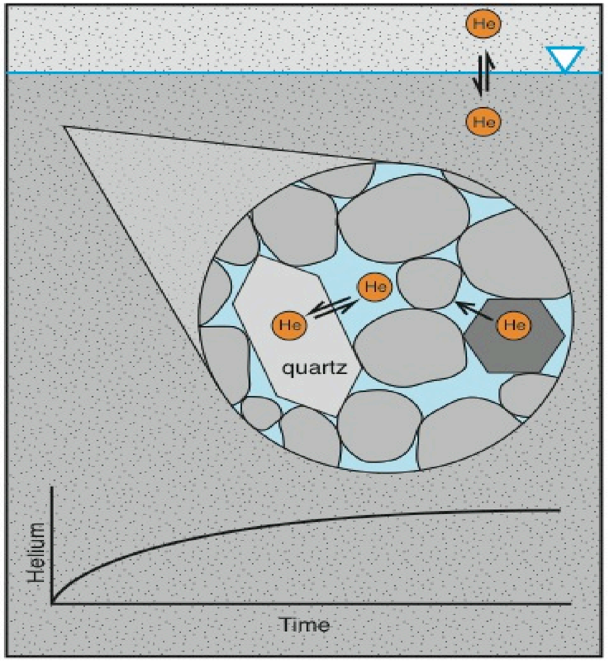
Isotope analysis

- Concentration of He dissolved in pore water is a function of the time water has been isolated from the atmosphere.
- The method relies on the insitu equilibrium of helium between pore water and quartz.



Right: An overview of helium partitioning. Helium partitions from the atmosphere to pore water at the water table. Below the water table helium is produced by radiogenic decay in minerals containing U and Th. Helium escapes these minerals into the pore water and a fraction of helium partitions into quartz. Helium concentrations increase in the pore fluid and quartz given a low groundwater flux rate.

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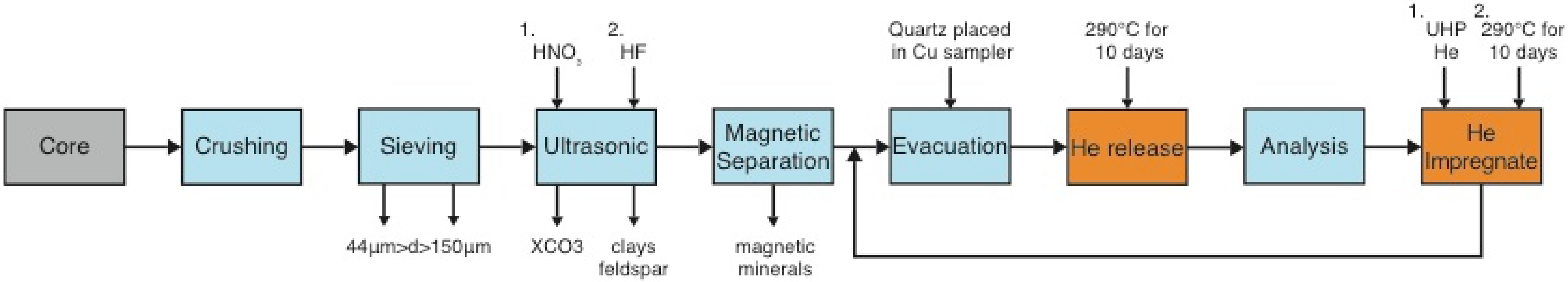
Isotope analysis



Quartz from each sample was pumped to high vacuum before being heated at 290°C for 10 days to release helium. After heating, He and Ne (to assess leaks) isotopes were measured on a MAP 215-50 sector field mass spectrometer and a quadrupole mass spectrometer, respectively.

Each sample was then impregnated with ultra high purity He at 290°C for 10 days. The impregnated quartz was then heated to release the helium and analyzed as described above.

Isotope analysis

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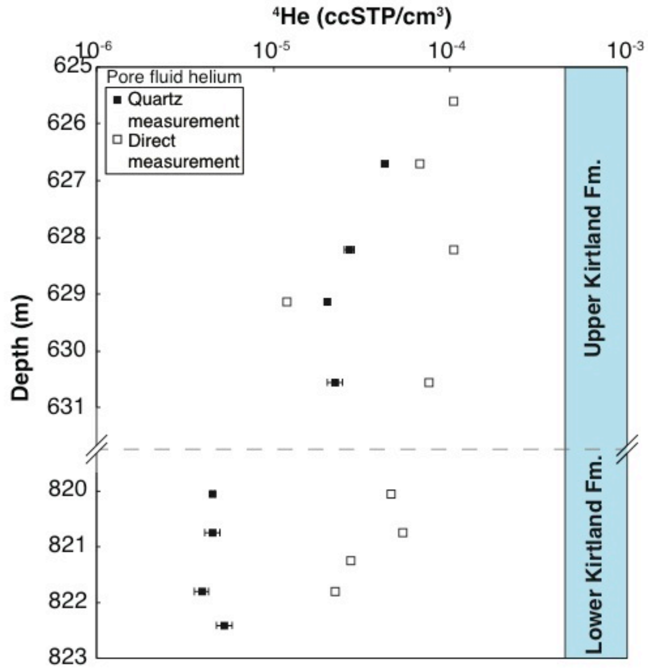
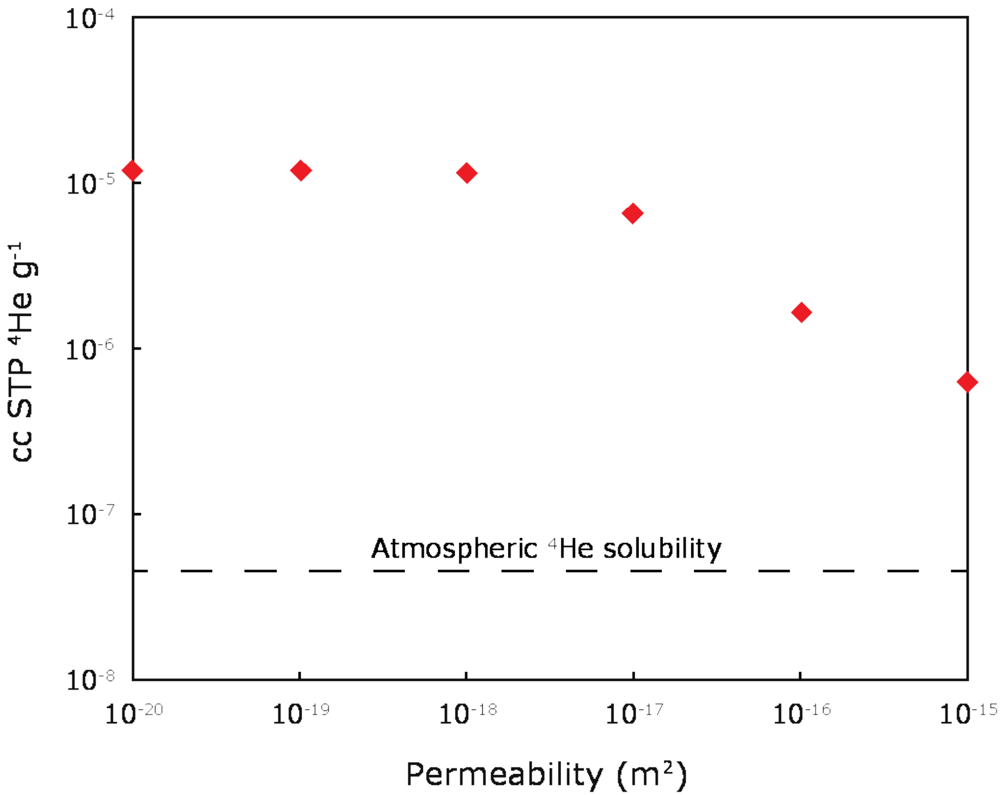
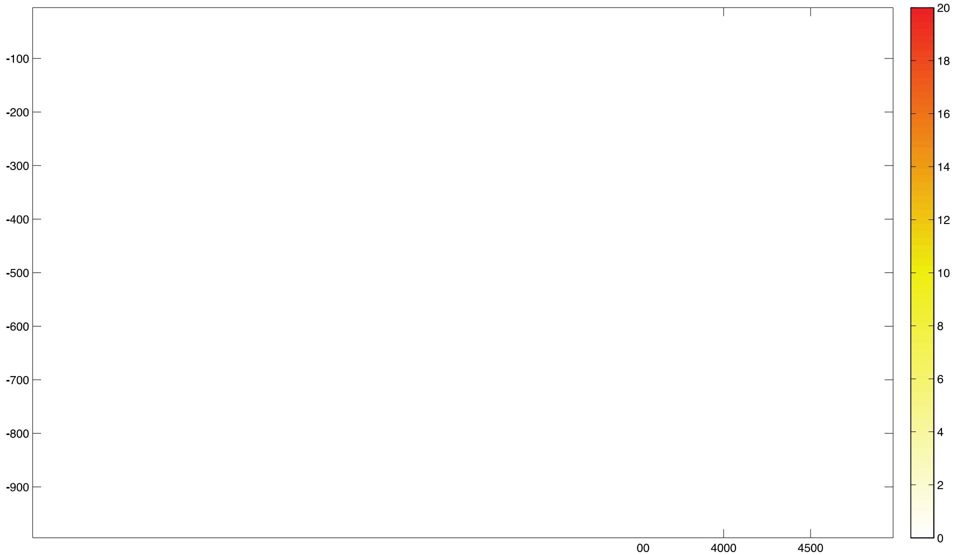


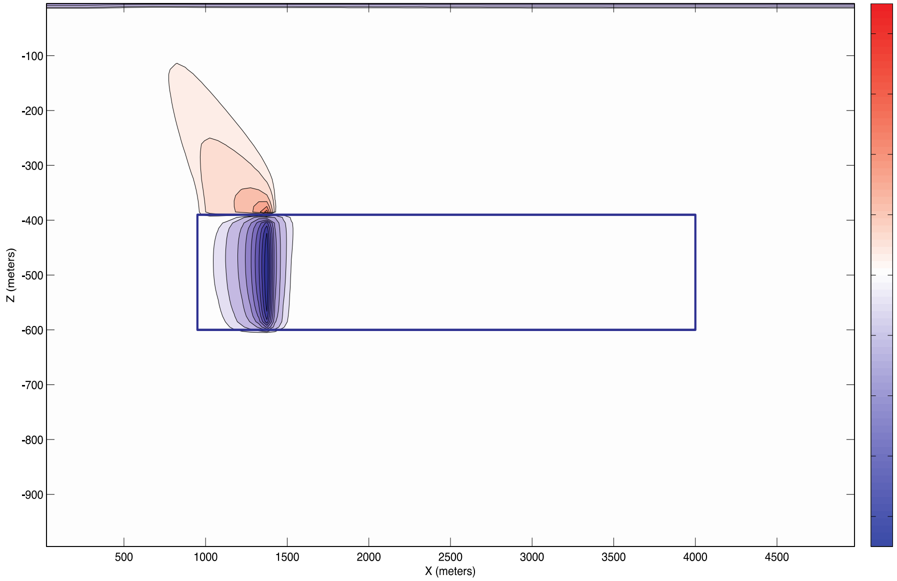
San Juan Basin concentrations vary between ~3x10^{-6} to 5x10^{-5} ccSTP/g: ~65-1000x atmospheric equilibrium. Direct measurements from Heath, 2010 and offsets in the Lower Kirtland Fm. may be caused by a gas phase.



Average helium concentration as a function of permeability

Isotope analysis





Helium modeling results. Lens horizontal permeability 10e-20 m^2. The contour interval is 0.2×10^{-5}cc STP He g^{-1} for concentration plots and 4% for helium remaining plots.

Perturbation in helium distribution due to fracture zone. Contour interval is 10% with the addition of the -5% and 5% level.

Microbial analysis

1. Study CO_2 effect on growth rate of Aerobic Autotrophs using a model Aerobic Autotrophic bacterium- *Nitrosospira multiformis* (ATCC 25196)
2. Study CO_2 effect on the growth rate of Anaerobic Autotrophs using a model Anaerobic archaeon- *Methanobacterium subterraneum* (ATCC 700657)
3. Profile the microbial community present in groundwater acquired from a site subjected to geological CO_2 sequestration
4. Microbial signatures from water sample from USDW provide crucial information on the quality of water
5. Growth rates and density of microbes in a particular sample yield CO2 influx into a USDW

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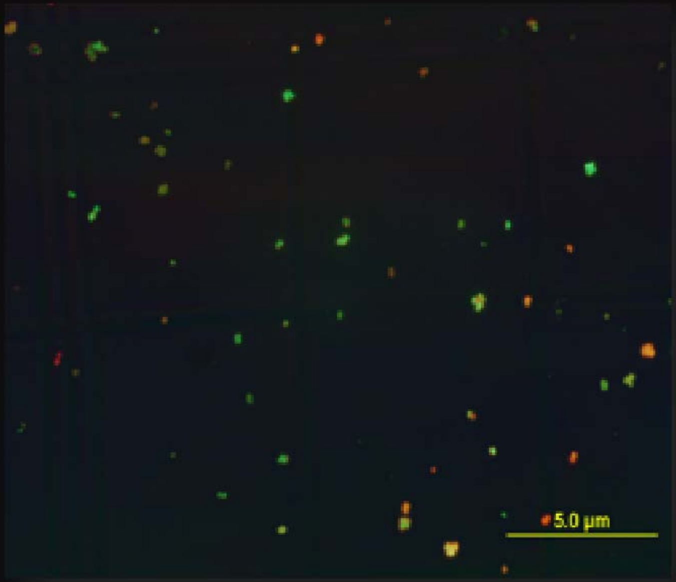
Microbial analysis

Experimental setup used for studying effect of CO_2 on *N. multiformis* which received inorganic carbon source in the form of A) CO_2 gas B) bicarbonate C) CO_2 gas and bicarbonate



Micrograph depicting Live (Green) / Dead (Red) assay used for enumeration of *N. multiformis*

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Microbial analysis

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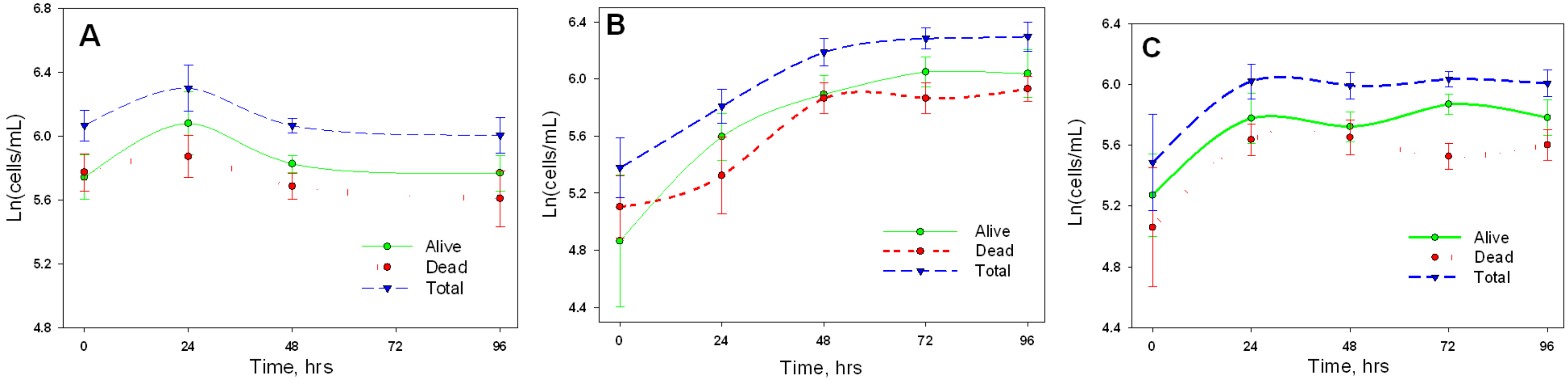

Figure 3. Cell counts in terms of dead, live, and total cell numbers for *N. multiformis* (aerobic autotroph) which received inorganic carbon source in the form of A) CO_2 gas B) bicarbonate C) CO_2 gas and bicarbonate

Reactor	Carbon source	Specific growth rate, μ (h^{-1})	Nitrification rate
A	CO_2 gas	0.032±0.006	0.027
B	Bicarbonate	0.063±0.012	0.111
C	Bicarbonate+CO_2	0.071±0.016	0.108
Typical *Nitrosospira* range		0.018-0.070	

Microbial analysis

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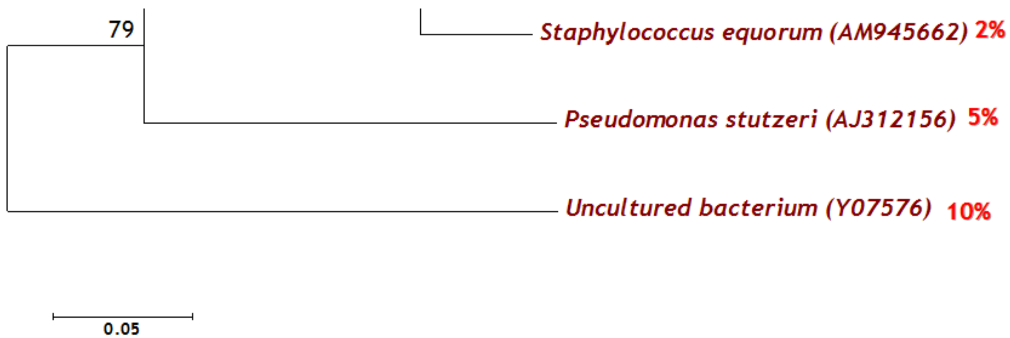
Analysis 1

Item	BR GW 1a	CB GW 2a	AWT3 PW	AWT4 PW	PW3 Main B
Chloride, mg/L	91.1	94.1	1876.7	1847.1	2123.3
Bromide, mg/L	25	40.9	49.8	45	55.8
Sulfate, mg/L	122.8	97.3	40.9	41.7	47.2
Nitrate, mg/L	36.3	56.6	30.2	24.6	10.4
Sodium, mg/L	82	81.5	1477.7	1498.3	1684.2
Ammonium, mg/L	2.9	2.1	1.8	1.1	N.A
Potassium, mg/L	12.9	5.7	3.9	3.7	12.9
Magnesium, mg/L	9.3	14.4	3.4	4	3.7
Calcium, mg/L	31.7	50.3	46.3	34.9	33.8

Analysis 2

Item	BR GW 1a	CB GW 2a	AWT3 PW	AWT4 PW	PW3 Main B
Floride, mg/L	4.6	5.7	NA	NA	20.6
Chloride, mg/L	90.1	92.7	1838.2	1768.4	2035.4
Bromide, mg/L	18.8		35.3	36.1	47.6
Sulfate, mg/L	112.2	89.8	39.9	37.2	39.6
Nitrate, mg/L					
Sodium, mg/L	89.2	87.1	1420.9	1438.1	1579.1
Ammonium, mg/L	4.7	2.4	NA	NA	NA
Potassium, mg/L	17	7.5	4.6	4.1	13.2
Magnesium, mg/L	12.9	18.2	4.8	5.1	4.4
Calcium, mg/L	41.4	60.1	53.1	39.5	37.2

Inorganic geochemical analysis of ground water samples obtained from wells near the Farnsworth site



Ecological diversity of the microbial communities detected in the groundwater samples

Development of PDFs

- Regression modeling
- Commonly referring to second-order model fit to the data/responses from the design of experiment.
- Utilized in probabilistic design to efficiently estimate a statistical linear model.
- Models are used to develop an understanding on uncertainty in projected outcomes.
- Measurements can be used to reduce the uncertainty of model prediction.
- The objective of this task is to develop a methodology for data incorporation to reduce uncertainty.

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Development of PDFs

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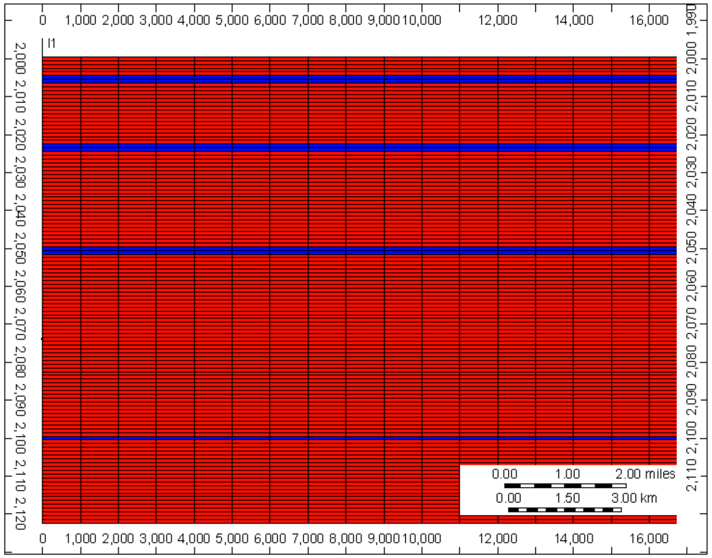
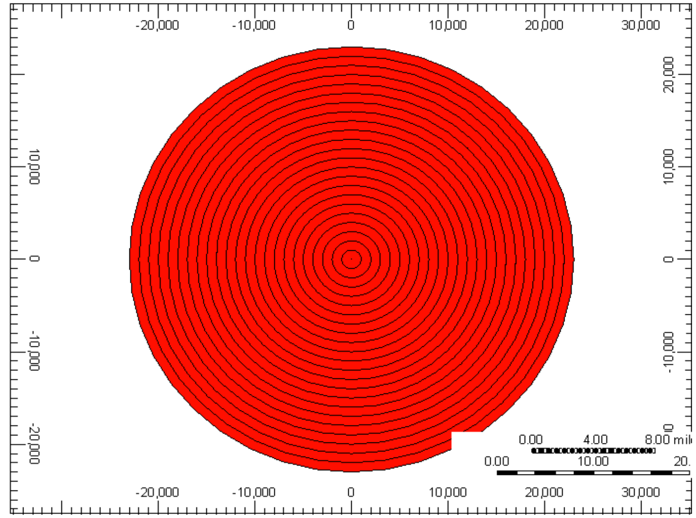
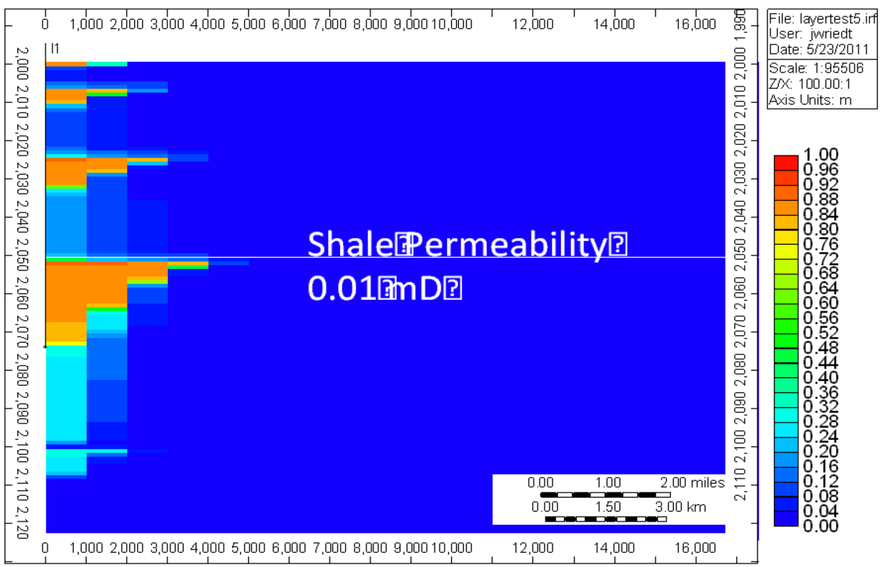
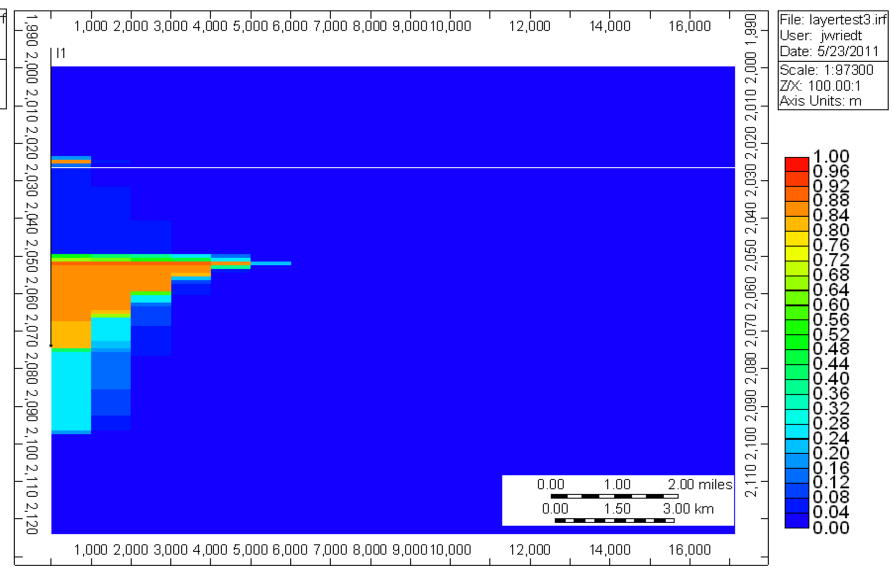
Initial simulations of Aquifer contamination









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Development of PDFs

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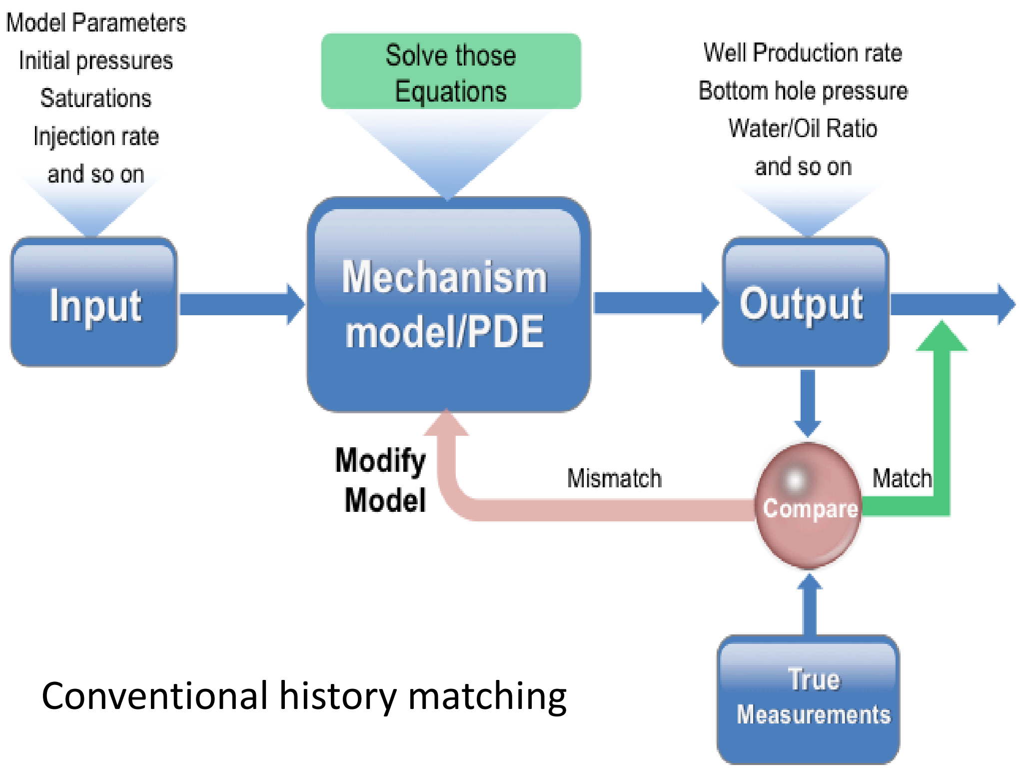
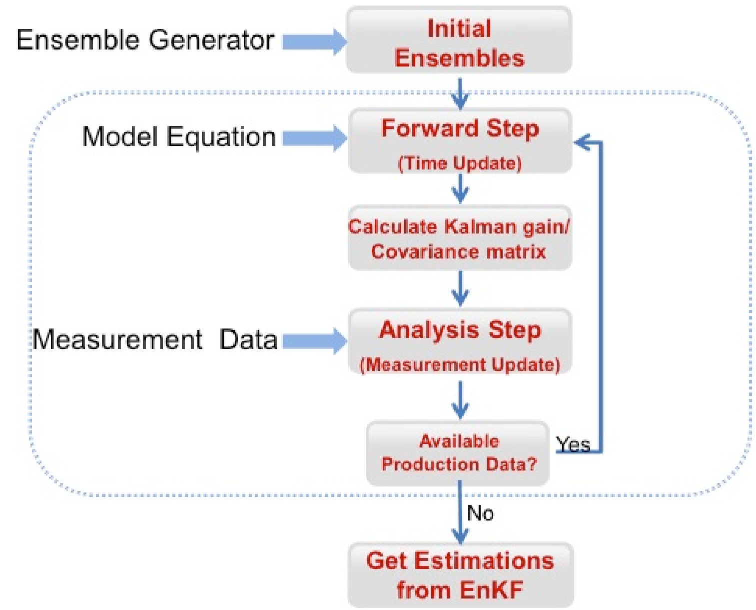
Data incorporation method



Conventional history matching



Ensemble Kalman data filter method used

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Development of PDFs

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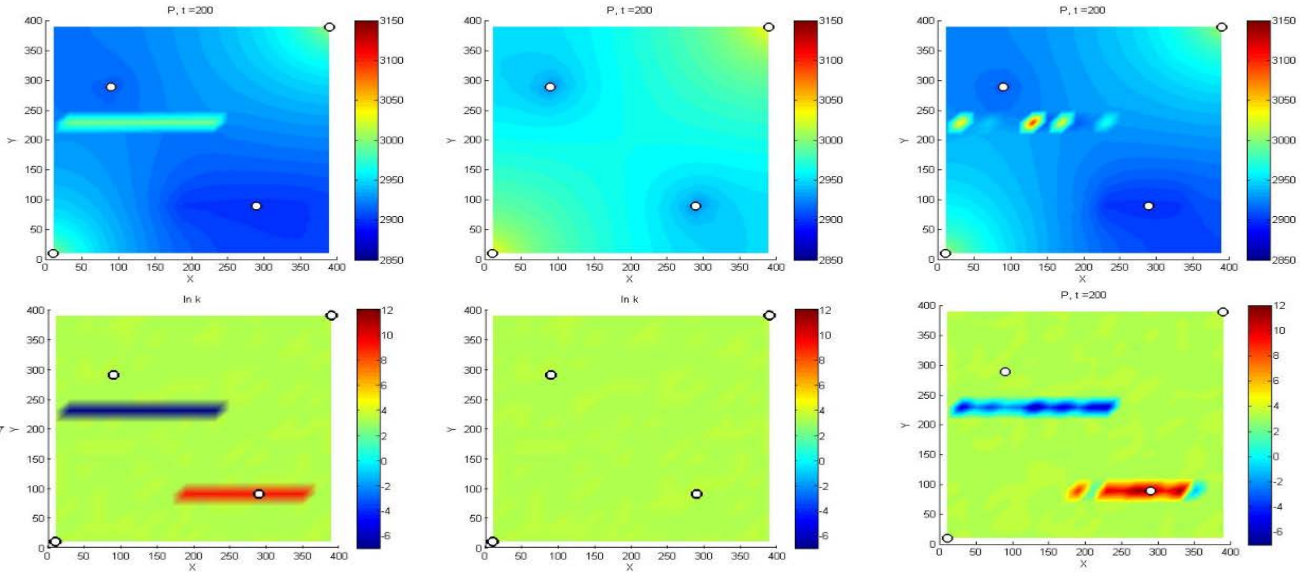
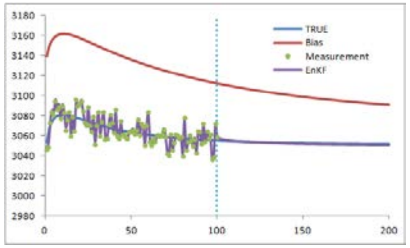
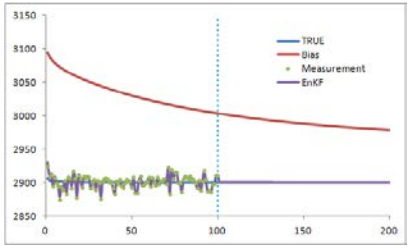
True Bias EnKF

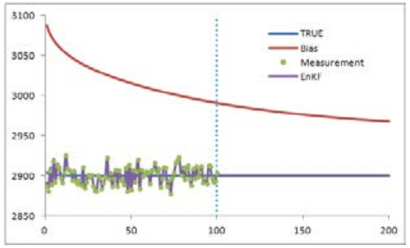
Pressure

Permeability









Development of PDFs

- Simulations with stacked aquifers show the extent of leakage into overlying aquifers based on seal permeabilities
- An approach is developed where by uncertain input data are changed so that consistency with the measurements is maintained
- Uncertainty in model outcomes is reduced by using Ensemble Kalman filter
- The method would allow locating measurement wells and using measurements to improve models and uncertain input parameters

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Progress to Date

- ✓ Task 1.0: Simulation of Natural Analog sites
  - Completed with a detailed analysis of Crystal Geyser Site (Southern Utah)
- ✓ Task 2.0: Simulation of Engineered storage sites Gordon Creek, SACROC and San Juan basin
  - Static models of Gordon Creek and SACROC sites have been completed. A preliminary model for San Juan basin has been developed and its refinement is in progress
- ✓ Task 3.0: Identification of Risk Elements and Development of PDFs
  - 3.1: Identification of appropriate FEPs (risk elements, including seal breach, brine displacement, induced seismicity, etc. etc.)
    - Site specific FEPs risk registries for Gordon Creek, SACROC and San Juan sites have been developed
  - 3.2: Identification of the specific PDF formulations (e.g., probability of what??)
    - PDF development for Gordon creek and SACROC has been completed
- ✓ Task 4.0: Calibration and Refinement of PDFs using Tracer/Microbiology/Chemistry/Physical Field Data
  - Refinement of PDFs for Gordon Creek and SACROC is in the last stage of completion (will be completed by end of August 2012) and refinement for San Juan basin has commenced
- ✓ Task 5.0: Calibration and refinement of simulation models using Tracer/Microbiology/Chemistry/Physical Field Data
  - Refinement for Gordon Creek and SACROC has commenced (completed by September 2012). San Juan basin model refinement will be completed by October 2012)
- ✓ Task 6.0: Integration and delivery of comprehensive Aquifer Risk Assessment Framework (ARAF)
  - Complete ARAF protocol for all the three sites will be completed by November 2012
- ✓ Task 7.0: Project Management
  - Project management has been in progress since the beginning of the project and annual reports and briefings are being delivered periodically
- ✓ Task 8.0: Education and Outreach
  - Groundwork for the website is completed and the website will be up shortly. Dr. Ramesh Goel has organized summer camps for HI-GEAR students hosted by the College of Engineering at the University of Utah

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Progress to Date

Site	Site screening and selection	Static model	Calibration	PDF's	Calibration	Risk Registry development	ARAF Protocol
Gordon Creek	✔	✔	✔	✔	✔	✔	✔
SACROC	✔	✔	✖	✔	✖	✔	✔
San Juan	✔	✔	✖	✖	✖	✔	✔

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Publications

- ✓ Masters Dissertation titled:

  HELIUM EQUILLIBRIUM BETWEEN PORE WATER AND QUARTZ: APPLICATION TO DETERMINE CAPROCK PERMEABILITY

  by

  Stanley Devaud Smith

  M.S., Geology and Geophysics

  May, 2012

- ✓ Masters Dissertation titled:

  EFFECT OF CO2 LEAKAGES ON AUTOTROPHIC GROWTH IN THE SUBSURFACE DURING GEOLOGICAL SEQUESTRATION

  by

  Nichole Michelle Comber

  M.S., Civil and Environmental Engineering

  May, 2012

- ✓ The following manuscript has been submitted and has been accepted for publication in Applied Geochemistry

  Testing helium equilibrium between quartz and pore water as a method to determine pore water helium concentrations

  by

  Stanley D. Smith, D. Kip Solomon, W. Payton Gardner

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- UGS for providing formation peak data for the Gordon creek field