Los Alamos National Laboratory
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Sequestration of CO_2 in a Depleted Oil Reservoir: An Overview

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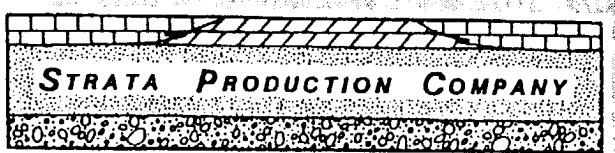

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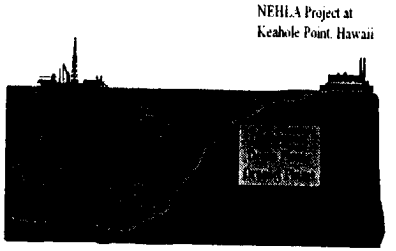
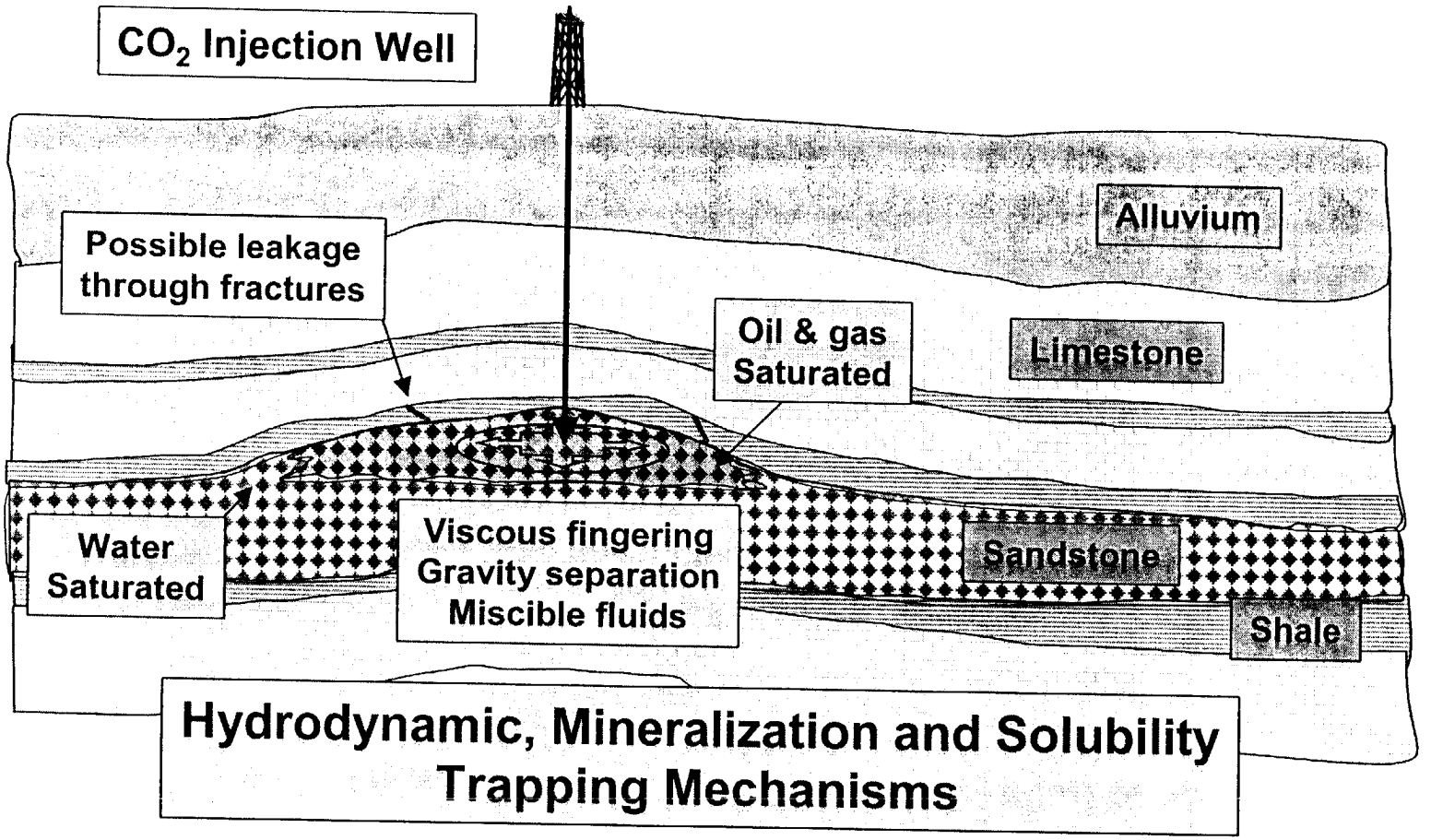
Background

- **DOE Scientific Research In CO_2 Sequestration**
  - – **Ocean** (>1400 Gt Est. Capacity)
    - » **Direct injection**
    - » **Enhance natural processes**
  - – **Terrestrial** (>10 Gt Est. Capacity)
    - » **Crops & land management**
    - » **Soil improvement**
    - » **Select/engineer C-species**
  - – **Geologic** (>300 Gt Est. Capacity)
    - » **Deep saline aquifers**
    - » **Unmineable coal beds**
    - » **Oil & gas reservoirs**



Estimated Current Anthropogenic Carbon Generation: 7.5 Gt/yr

CO_2 Sequestration in O&G Reservoirs



S&T Issues: CO_2 injection techniques, reservoir capacity, subsurface characterization, fluid migration, phase compatibility, long-term stability

DOE/FE/NETL Project

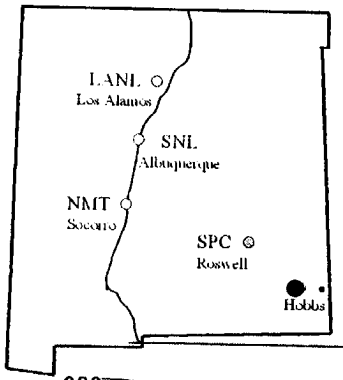
Sequestration of CO_2 in a Depleted Oil Reservoir

- **Research Goals**
  - Accurate Prediction Of Coupled Physicochemical Processes Involving CO_2-Water-Oil-Rock Phases
  - Development Of Accurate Monitoring Technologies
  - Provide Field Data For Model Validation
  - Evaluation Of Reservoir CO_2 Storage Capacity & Property Changes With Long-Term Sequestration
  - Long-Term Fate Of Injected CO_2 In Oil Reservoir

- **Multi-element approach**
  - Modeling and Simulation (geologic, flow & reaction)
  - Pilot Field Experiment (West Pearl Queen Reservoir)
  - Geophysical Monitoring (surface & borehole)
  - Laboratory Experiments (flow through & static)

West Pearl Queen Field

NETL CO_2 Sequestration Field Site



Structure Map - Top of Queen Sand

(T. 19 S., R. 34 W.; 20' contour interval; Datum S.L.)

-800
-820
-840
-860
-880
-920

28
27
34

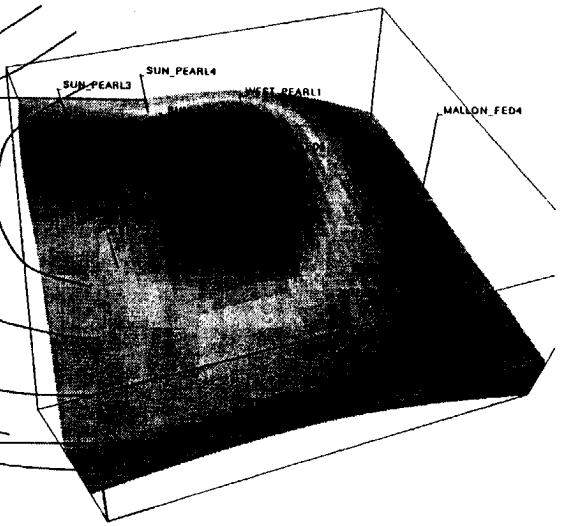
Manzano producing wells (monitor production)

-800

#2 #4 #5 #3 #1

Strata Stivason-Fed #4

80,000 bbls produced since '89
5-30 md permeability
18% porosity
23' (net) thick (4508-4531' depth)
30° API at 105°F
800 psi shut-in pressure
65% qtz, 25% fldsp, 5% clay
carbonate cement

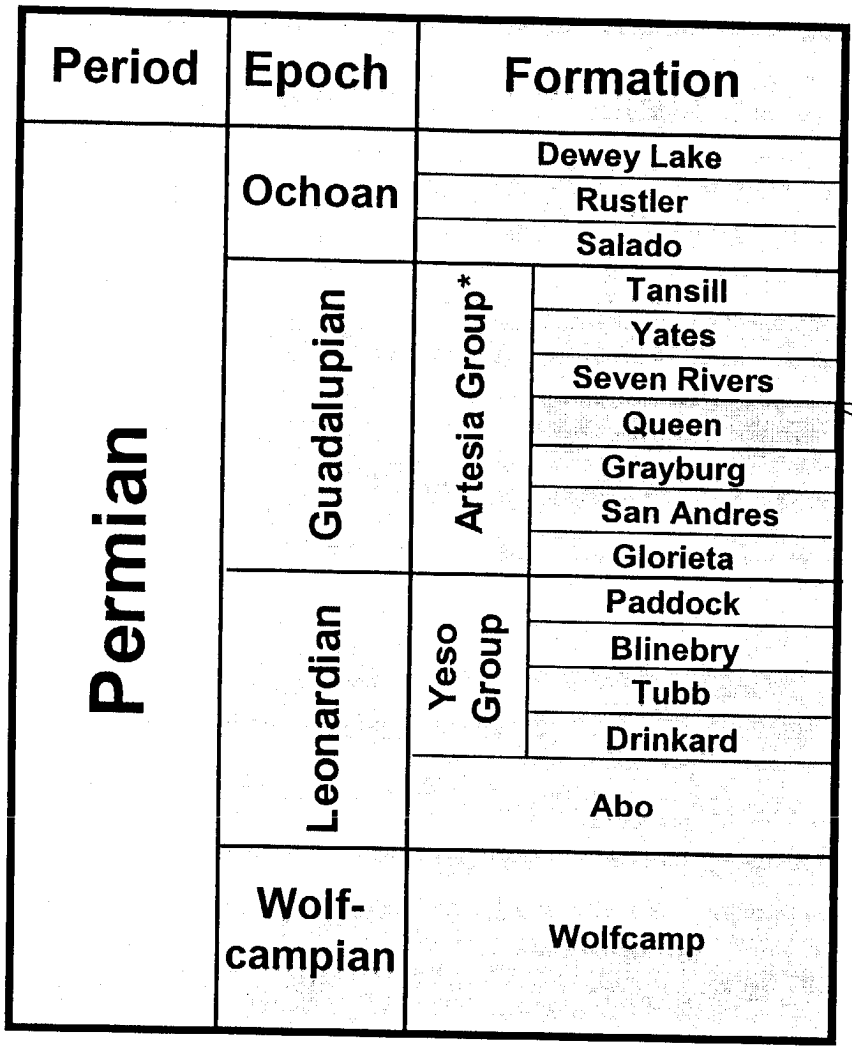


Strata Production Co. Wells

#4 CO_2 Injection & monitoring well (4.9" ID)
#5 Monitoring & producing well (4.9" ID)
#1&3 Waste water injector well (1.8" ID w. packer)
#2 Plugged well

7/9/01• hrw 5

Generalized Stratigraphic Column



Back-reef depositional environment

23 ft Net Thickness
~40 ft Gross Thickness

Shattuck Sandstone Member

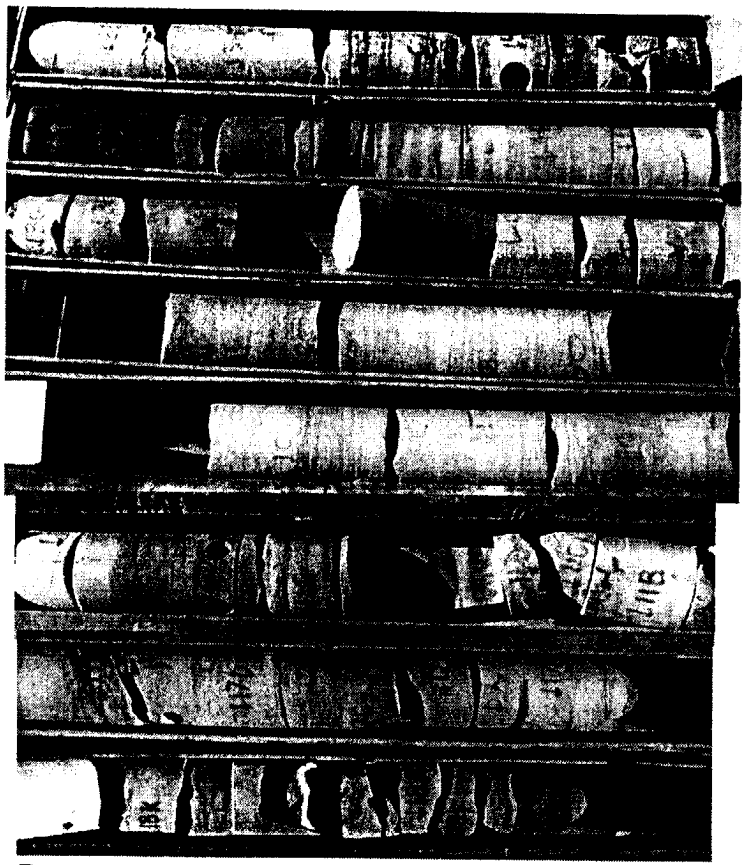
Irregularly bedded sandstones, siltstones, and sandy siltstones, containing irregular anhydrite beds and nodules. The sandstones are a heterogeneous mix of oxidized detrital sands and siltstones, with detrital and authigenic cements of dolomite, gypsum, anhydrite, and halite.

Modified from Talley, 1997

* Bell Canyon & Cherry Canyon Fms. In Delaware Basin fore-reef facies

Stivason Federal Well #1 Core

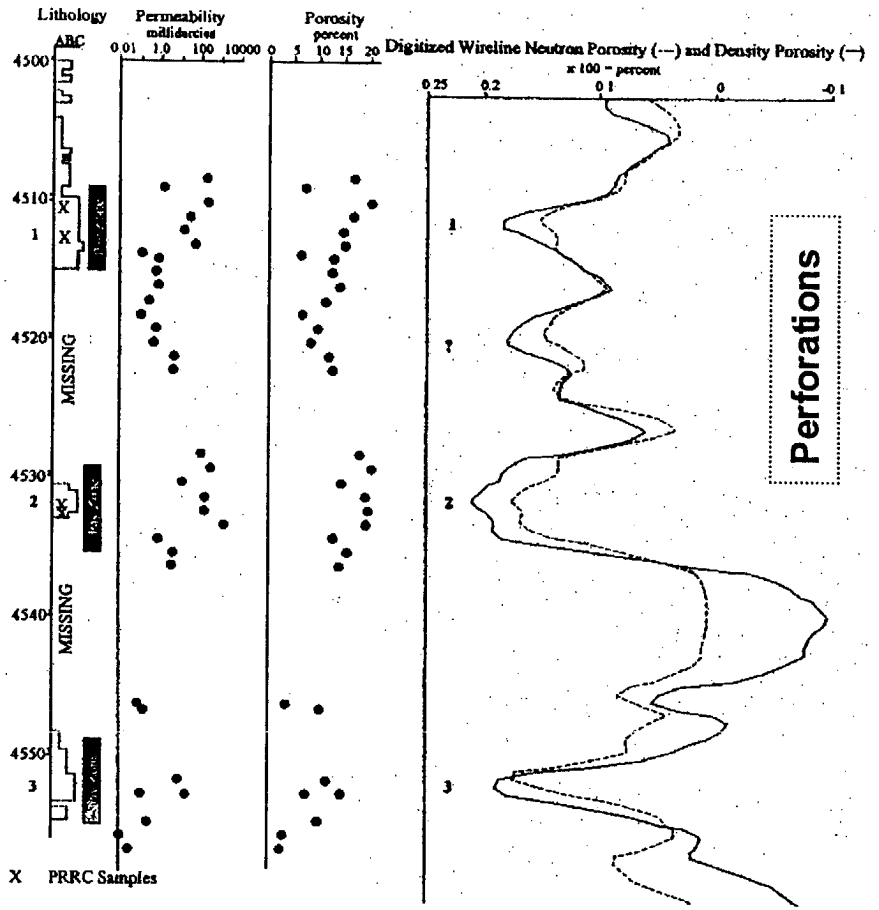
Top
4500'



Bottom
4555'

Core Analysis
& Testing

Wireline neutron &
density porosity

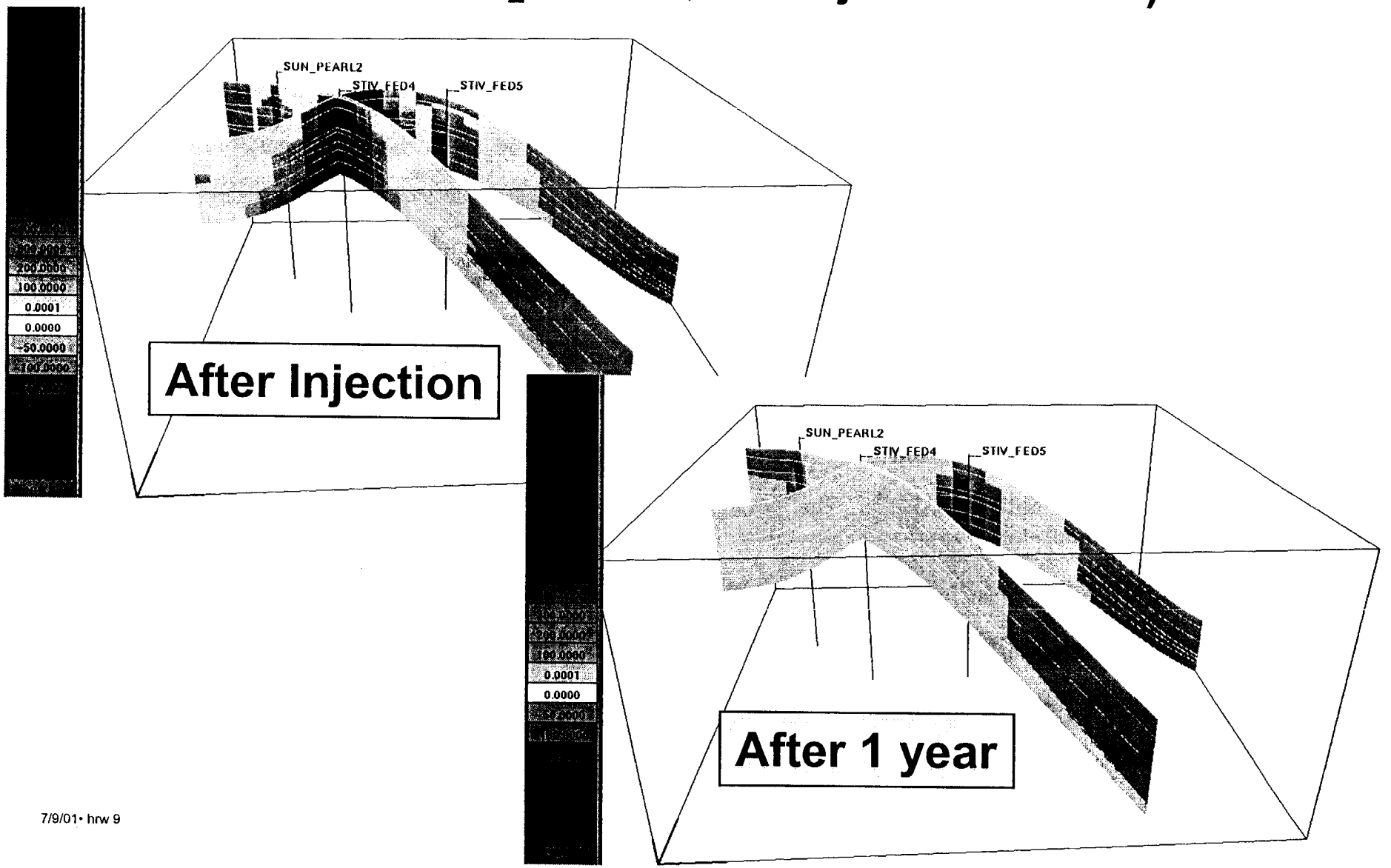


Modeling and Simulation

- Characterize the study site & improve understanding of the site geology and fluid flow dynamics
  - Develop a geologic model (well log data, core data)
  - Validate the geologic model through production history match
- Preliminary injection studies performed using black oil reservoir simulation models
  - Thermodynamic and geochemical interactions between CO_2, oil, water and reservoir rock ignored
- Multiphase flow simulations to determine feasibility of injecting 3000 tons of CO_2 in Queen sand
  - Injection rate constrained by state regulation on BHP (~2900 psi)
- Need to improve understanding of CO_2 migration & fate
  - Develop models for coupled physicochemical reactions to predict long-term fate of injected CO_2

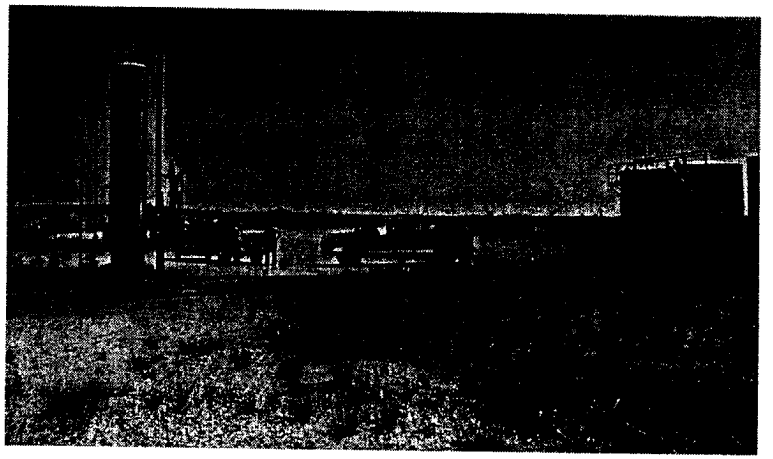
Reservoir Gas Pressure Disturbance

(2000 tons CO_2/month; Δ = Injected - Initial)



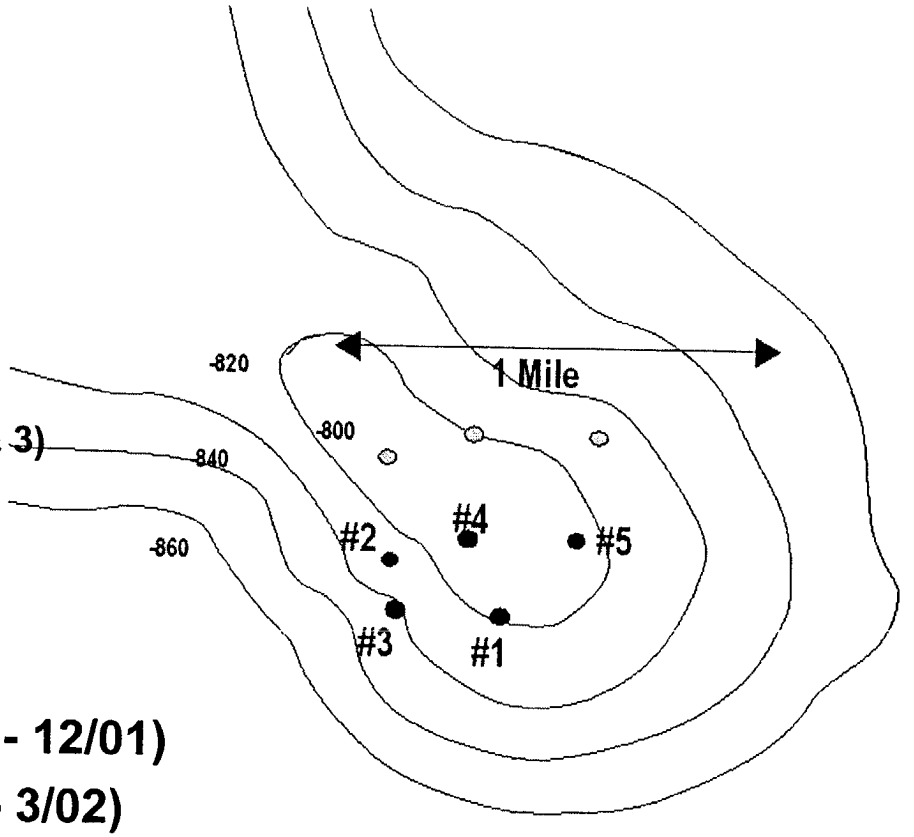
Micro-Pilot Field Experiment

- **Phase I (Pre-Injection)**
  - Design & construct wellhead CO_2 injection facilities
  - Site characterization (geophysical, chemical, geologic)
- **Phase II (Injection & Soak)**
  - Inject 2,000-3,000 tons CO_2
  - Soak
  - Geophysical characterization
- **Phase III (Post-Injection)**
  - Gas venting & pump out
  - Gas/fluid measurements & sampling
  - Geophysical characterization



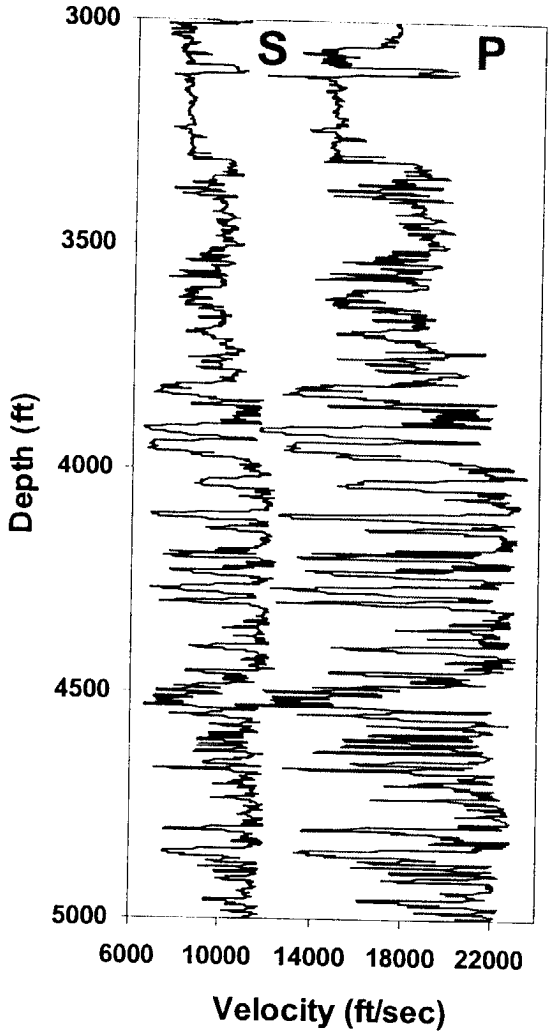
Geophysical Monitoring

- **Multiple seismic techniques to detect reservoir changes,** including borehole, surface to borehole & surface reflection seismic surveys
  - **4D Surface Seismic**
    - » **9C Survey**
  - **Crosswell Seismic**
    - » **3C Receivers (Wells 4-5)**
  - **Vertical Seismic Profiling**
    - » **3C Receivers (Well 4)**
  - **Microseismic Monitoring**
    - » **1 Multi-Level Array (Well 5)**
    - » **1 or 2 Single Receivers (Wells 1 & 3)**
  - **Dipole Sonic Logs (Wells 4 & 5)**
- **Schedule**
  - **Baseline (phase I; 2/01-9/01)**
  - **Injection & Soak (phase II; 9/01 - 12/01)**
  - **Post-injection (phase III; 12/01 - 3/02)**



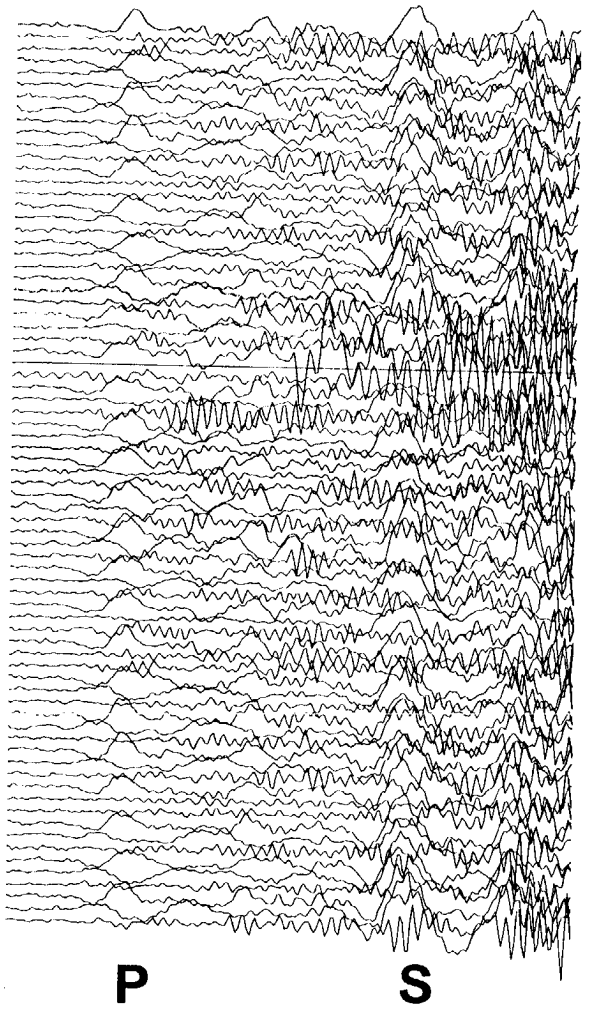
Geophysical Program In Progress

Dipole Sonic Log

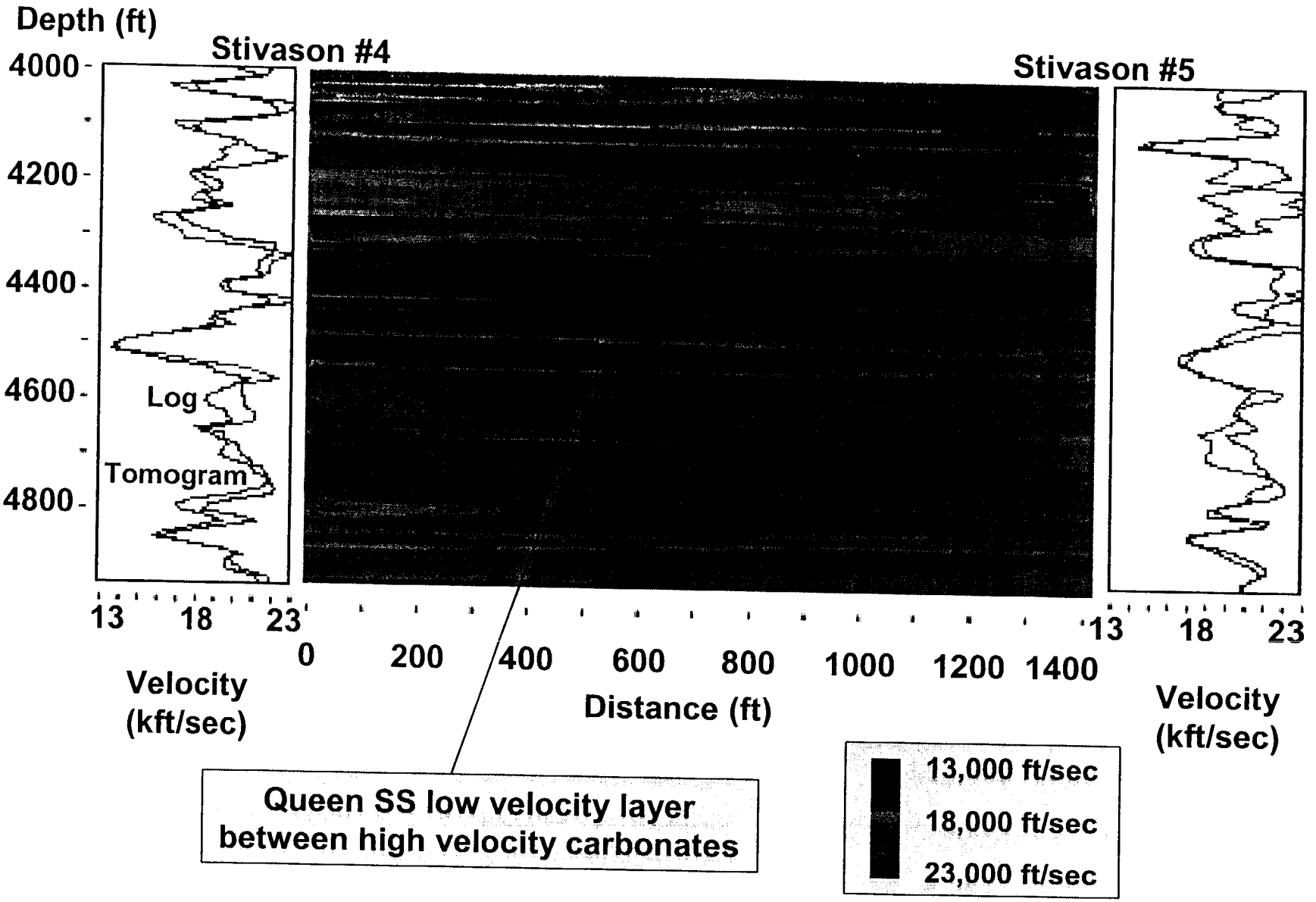


Processing of crosswell seismic data is in progress (J. Fairborn, Wellseismic Computing Services)

3 C Crosswell Seismic Survey
24 level system



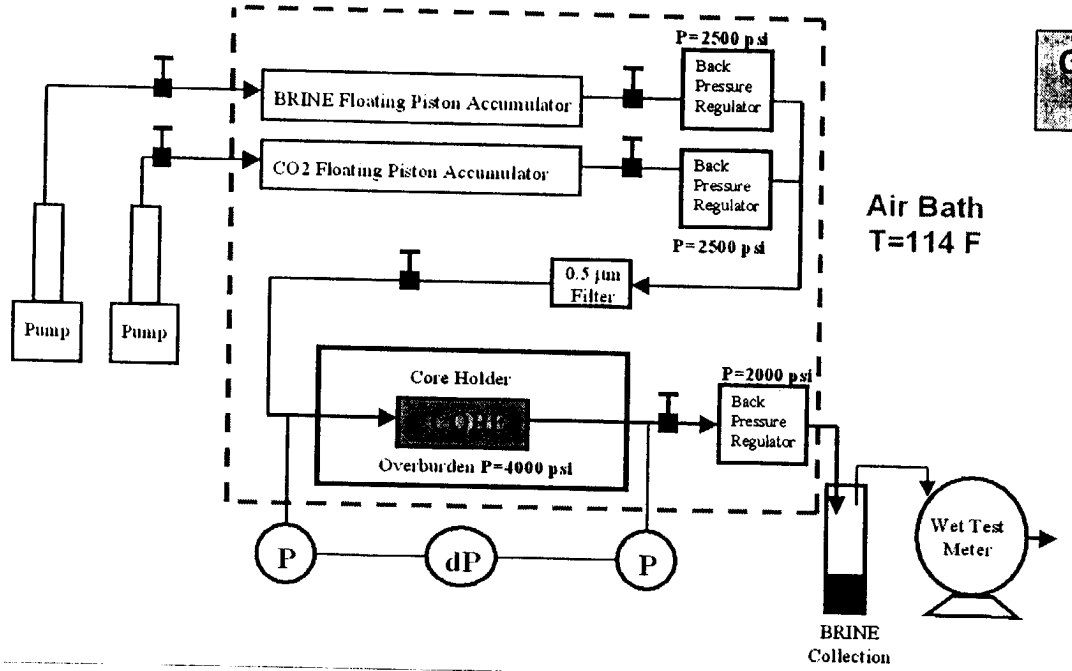
Crosswell P-Wave Velocity Tomogram



Other Field & Laboratory Tests

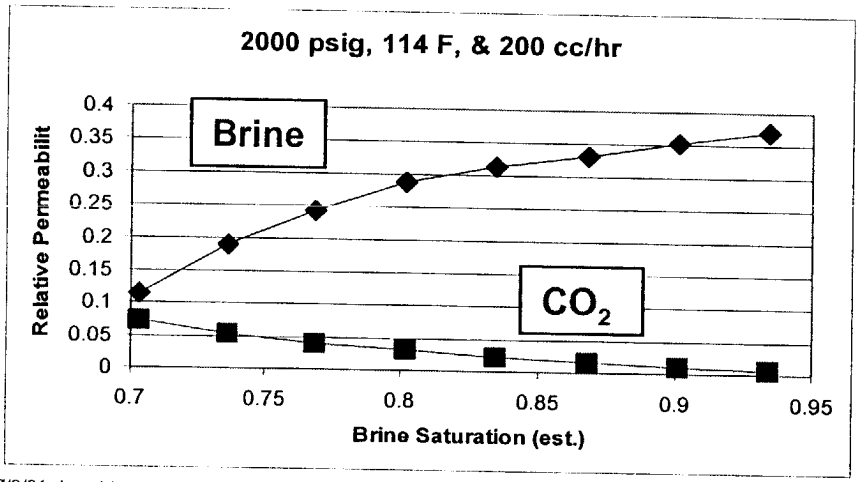
- **Fate and Migration of Injected CO_2**
  - **Physical (wellhead tests)**
    - » P transient tests prior to, during and after CO_2 injection
    - » T of reservoir, injected fluids and returned fluids
    - » Volume of returned fluids (cf. with production history)
  - **Chemical (fluid analyses)**
    - » Solid, liquid (both HC and aqueous), and gaseous sampling prior to, during and after CO_2 injection
    - » Stable isotopic analyses of liquid and gas samples of reservoir fluids/gases and returned fluids/gases
  - **Lab (ultimate fate of injected CO_2 over time)**
    - » Flow-through reactor tests (2 ϕ, open system)
    - » Static reactor tests using CO_2-H_2O fluids (closed system)

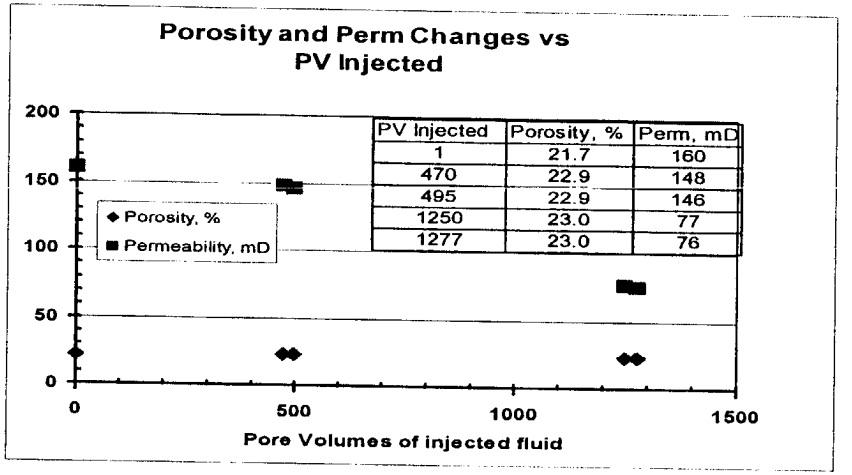
Experimental Core Flooding Tests



Air Bath
T=114 F

Core (Depth=4510,5 ft,) D=1.48", L=3.22"

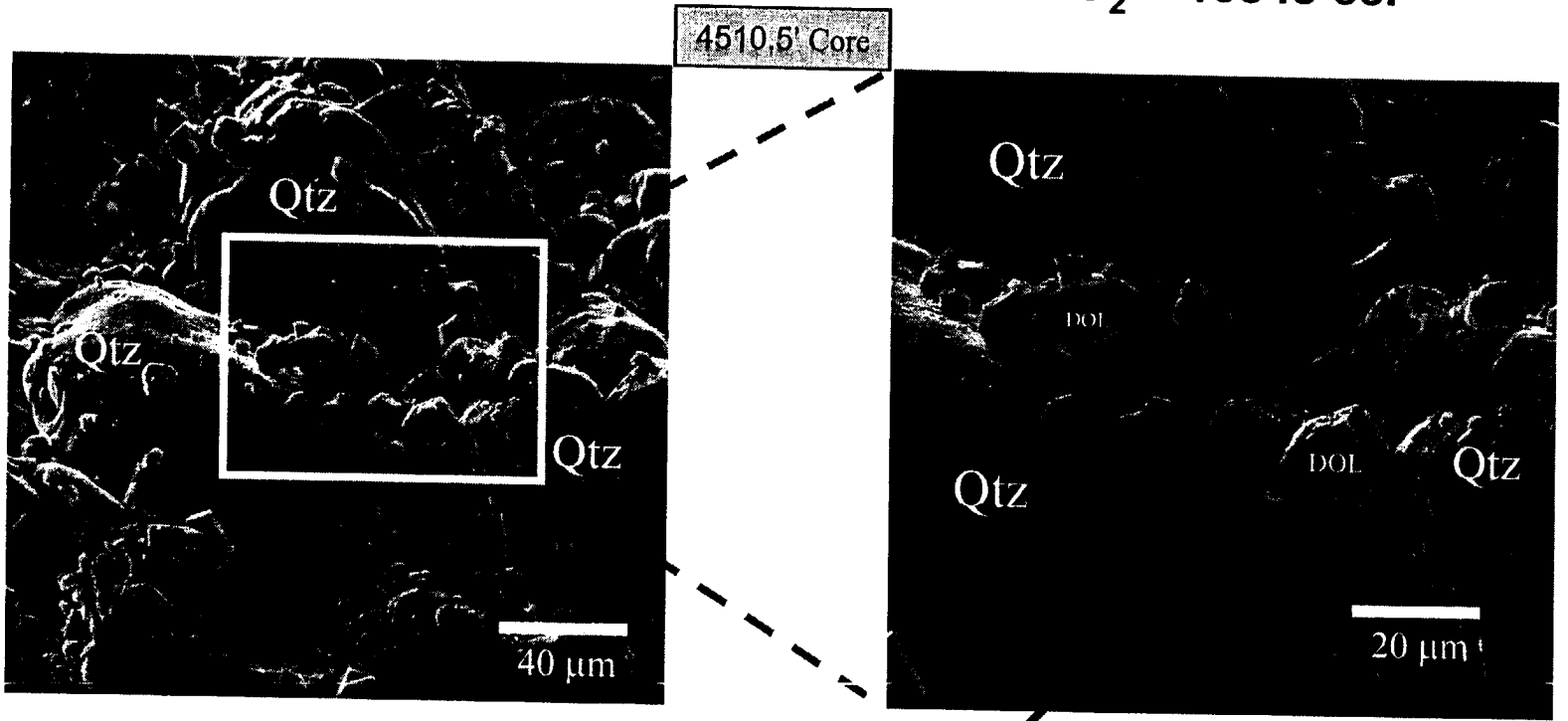




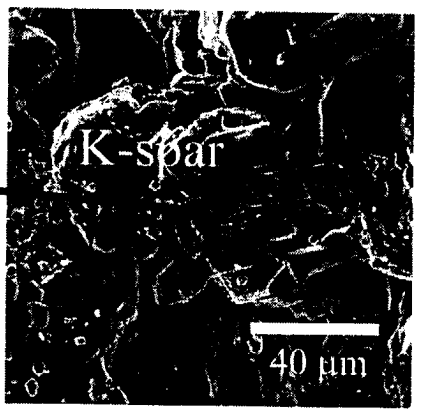
Reacted Queen Sandstone

Flow-Through Flood Tests at T= 45.5°C and P= 500 and 2000 psi

Total Fluid volumes: Brine = 17334 cc and CO_2 = 10548 cc.



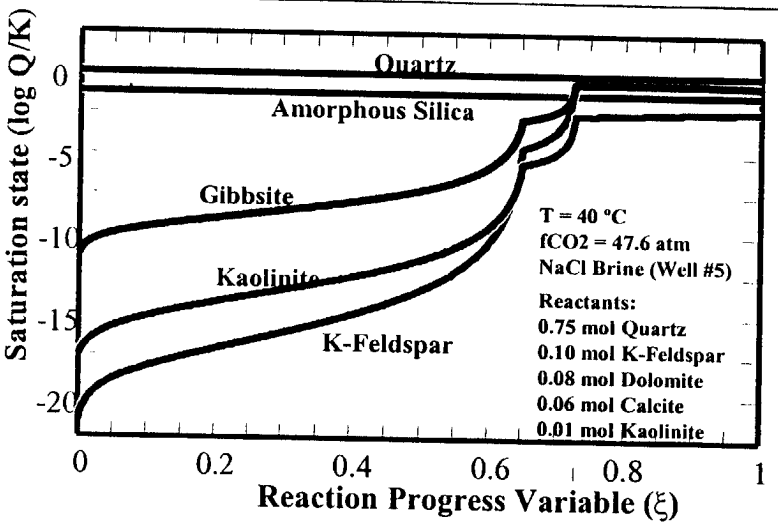
- **Euhedral carbonate phases**
- **Feldspar dissolution textures**
- **Mechanical integrity lost**

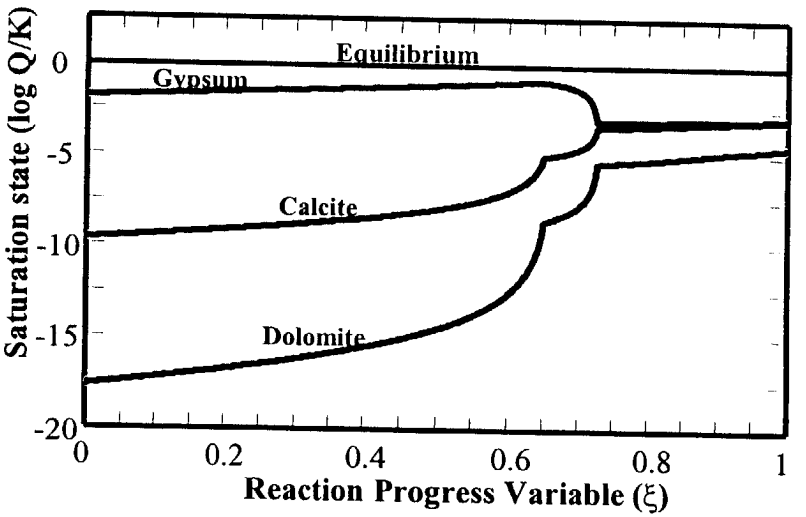


Geochemical Modeling

Average brine composition of wells Stivason Federal #4 and #5

Al(M)	Si(M)	Na(M)	K(M)	Mg(M)	Ca(M)	Cl(M)	Br(M)	SO_4(M)
0.00041	0.00014	2.07	0.0029	0.123	0.056	2.82	0.0041	0.0214





Upon CO_2 injection:

- Initial pH of brine is very low
- Quartz, gibbsite, and clay are stable
- Dolomite, calcite, K-feldspar, and gypsum are unstable

Overall reaction path describing fluid-rock interaction for the Queen Fm. mineralogy was calculated using GWB - REACT Software (Bethke, 1998) simulating a CO_2 and brine injection at T=40°C and f CO_2 = 47.6 atm.

Summary

- Pristine field site dedicated to sequestration
  - Recent development & production history, sandstone reservoir, no secondary treatment (H_2O or CO_2)
- Geologic and reservoir models completed
  - Simple geologic structure with zones of high permeability & porosity
  - At least 2000 t CO_2 can be injected into Queen fm. in a month
- Initial geophysical surveys completed
  - Dipole sonic, gamma ray and deviation logs; crosswell seismic
  - CSM/RCP contract being written
- Laboratory studies initiated
  - High pressure, flow tests show core degradation & fines movement
  - Geochemical reaction calculations predict carbonate dissolution
- Multiple agency collaborations & interactions
  - NETL, KinderMorgan, TrinityCO_2, LBNL, GEODISC, PTRC, Texaco, CCP
  - Potential for future studies or demonstrations