Methodology for Overcoming Critical Scientific Roadblocks

- Outline
  - Scientific issues and goals
  - Examples of crosscutting roadblocks in geosciences
  - Examples of crosscutting applications
  - Impact of problems: Examples
    - ➔Bioremediation (Oyster)
    - ➔CO2 sequestration (Weyburn)
  - Lessons learned
  - Next steps

Scientific Issues and Goals

- Identify critical road blocks preventing advancement
- Must be able to break down and sub-catagorize the problem in manageable pieces
- Coordinate research pieces to derive an overall solution
- Transfer results to end users

Examples of Crosscutting Roadblocks in Geosciences

- Natural heterogeneity, Scaling, Multi-Property interaction
  - Imaging and manipulation
    - ➔Coupled processes
      - ★Appropriate and adequate theory
      - ★Accurate constitutive equations
    - ➔Sensors/Data
      - ★Processing and interpretation of data
      - ★Computation

Examples of Crosscutting Applications

- Fluid extraction from the subsurface
  - Oil and gas
  - Geothermal
  - Contaminant cleanup
  - Water supply
- Fluid injection
  - Disposal of waste
  - CO2 sequestration
  - Enhanced geothermal
  - Hydrofracturing
  - Oil and gas storage
  - Water supply
- Atmospheric Changes
  - Weather prediction
  - Climate change
  - Water supply

Example Problem: Bioremediation

- Elements
  - Define the microbial community
  - Define the critical subsurface properties controlling the microbial community transport, survival and growth
    - ➔Fluid content and transport
    - ➔Chemistry
    - ➔Attachment
    - ➔Nutrients
  - Define the minimum scale of understanding

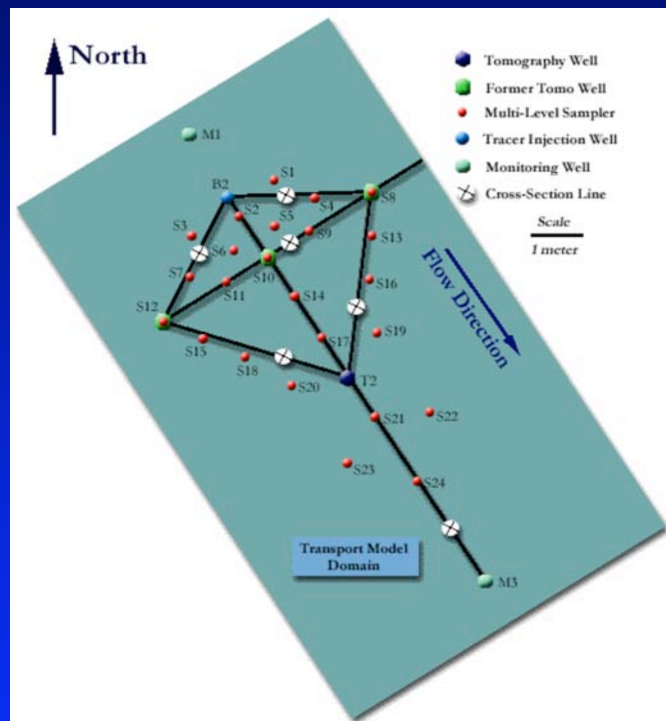
Investigating interactions between physical-biological-geochemical heterogeneity and coupled processes

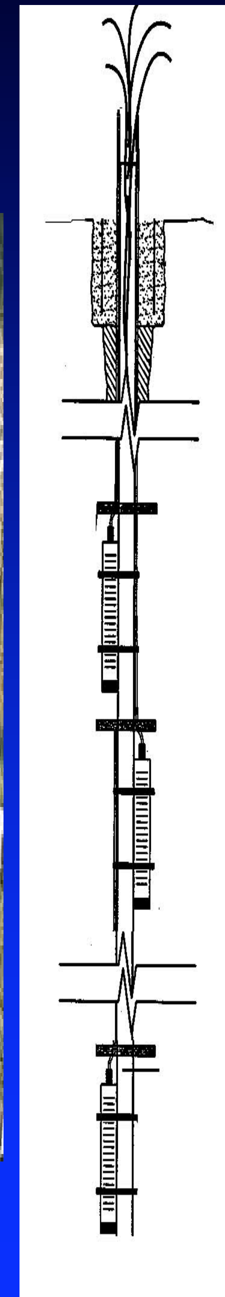
- **Goal: Understand what factors control bacterial transport *at the field scale.***
- **Approach: Using integrated lab and field experiments, investigate influence of:**
  - **➔Physical heterogeneity**
    - **Relative sizes of bacteria (~0.1-1 micron) to pore throat sizes (<0.05 micron clay, >20 micron sand)**
  - **➔Geo-chemical heterogeneity**
    - **Electrostatic interaction between negatively charged microbes and positively charged iron oxide coatings.**

Objectives: Investigate use of Geophysical Data for estimating hydrogeological-geochemical heterogeneity

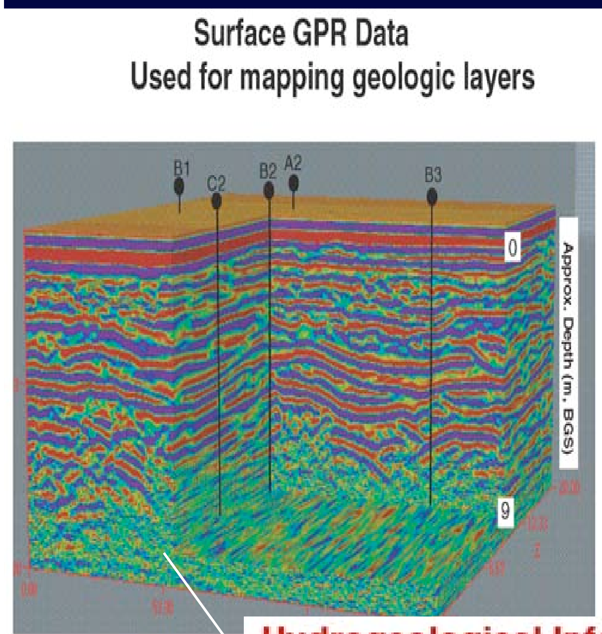
Injection Experiments: NC and SOFA

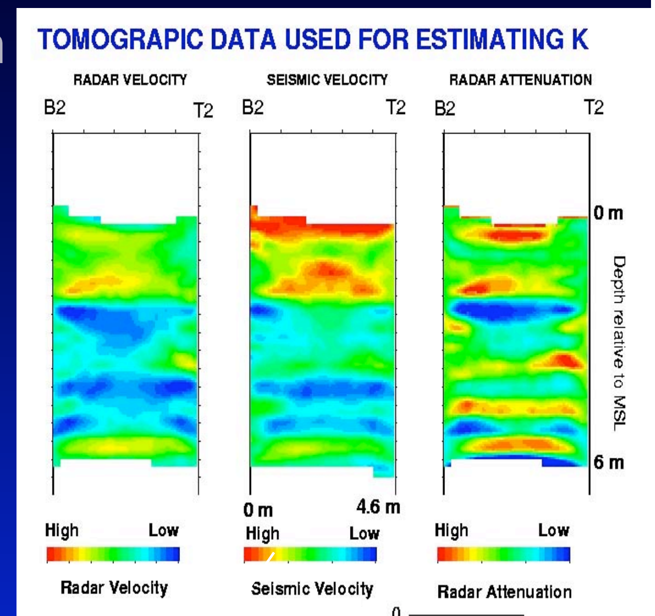
- 12 sampling ports in each MLS, ports spaced ~30 cm apart over 3 m
- 12 h injection pulse of
  - DA001 at NC (*Comomonos sp.*),
  - OY107 at SOFA *(Acidovorax Sp.)* and
  - Br
- 24 h sampling for 7 days
- ~4600 discrete samples

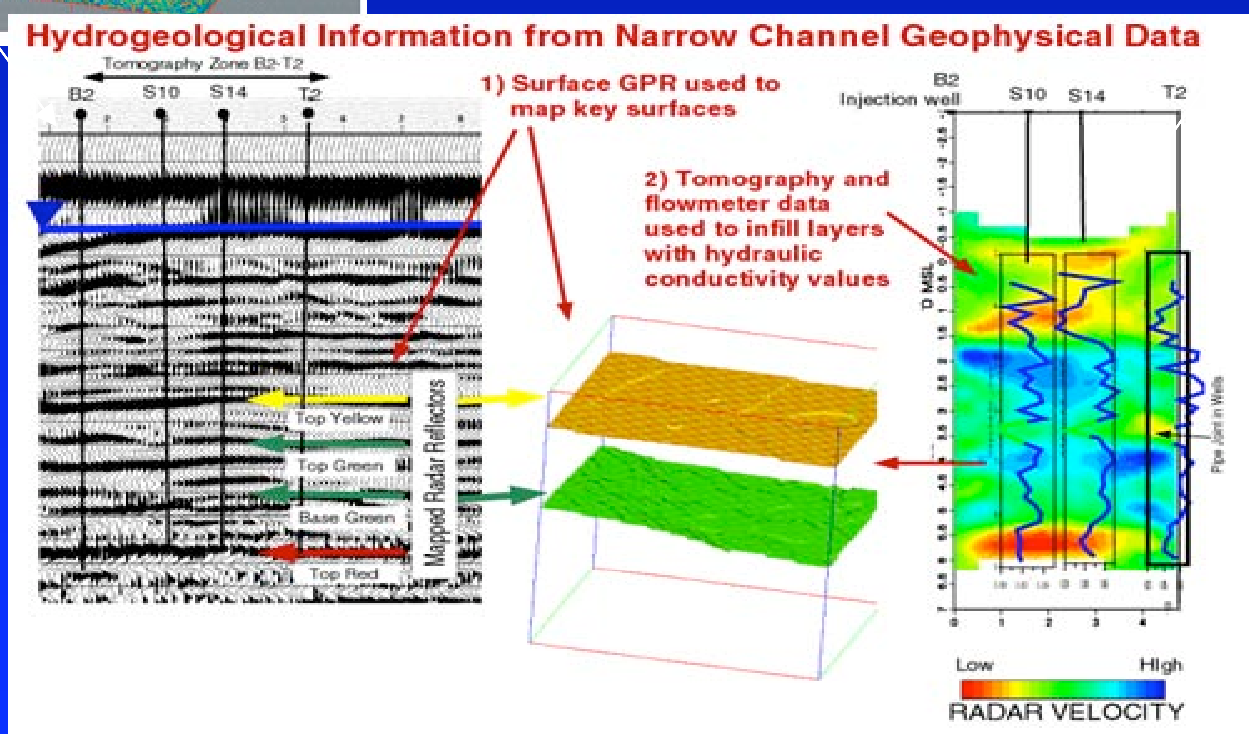


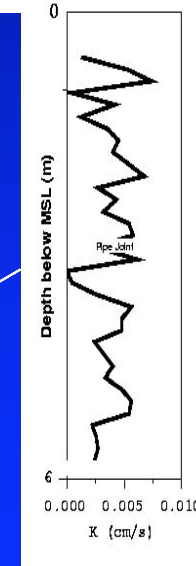


Detailed Characterization using GPR, tomographic and flowmeter data within the chosen focus areas

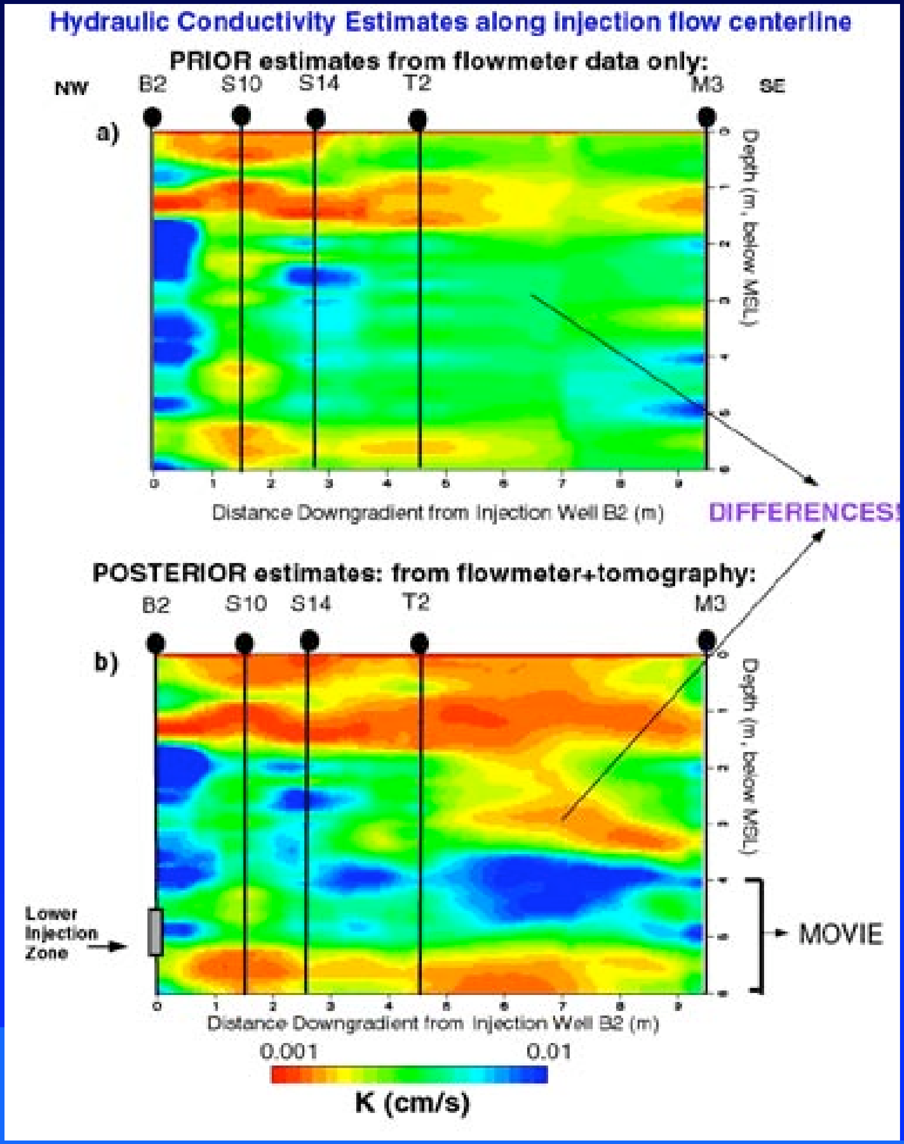








Estimates of Hydraulic Conductivity using different Density and Type of Data

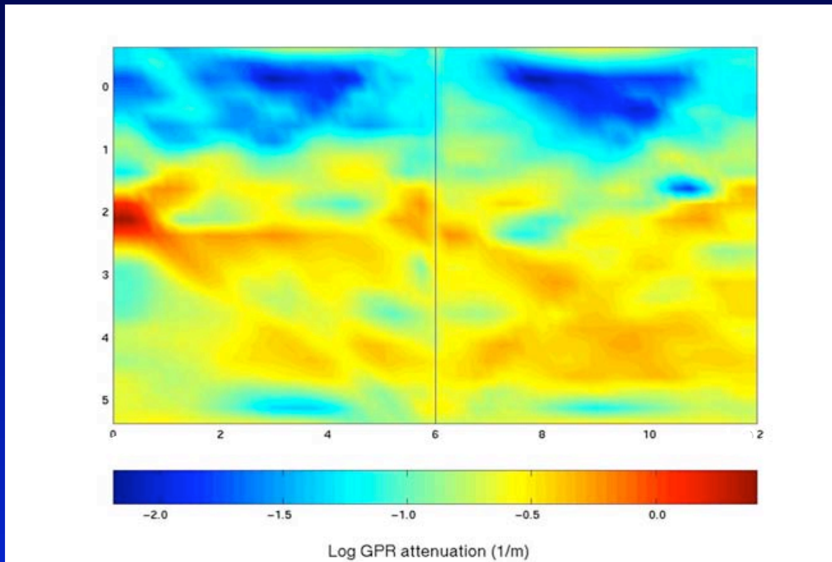


Differences between estimated using closely spaced borehole data and borehole plus geophysical data…..
These differences control transport

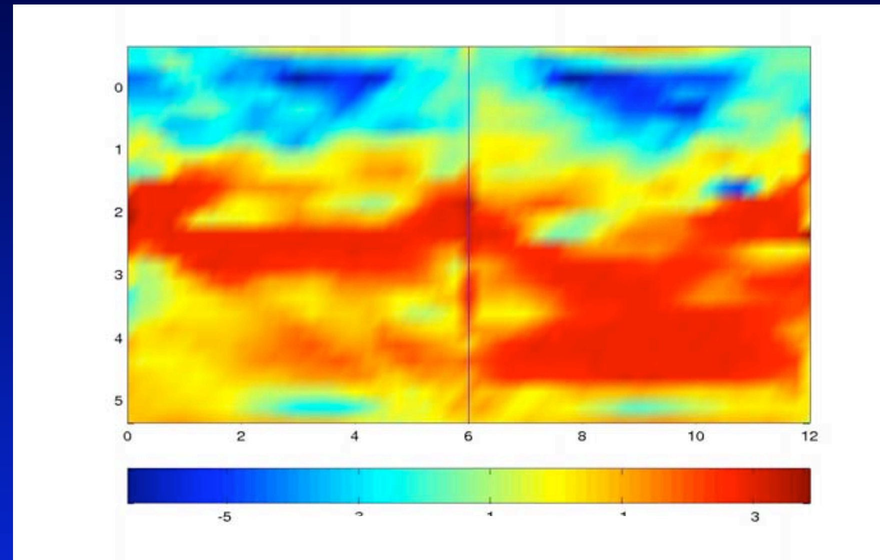
1/4m by 1/4 resolution – the mean value of the pdf is shown at each pixel

Field-Scale Estimation of Sediment Geochemical Heterogeneity

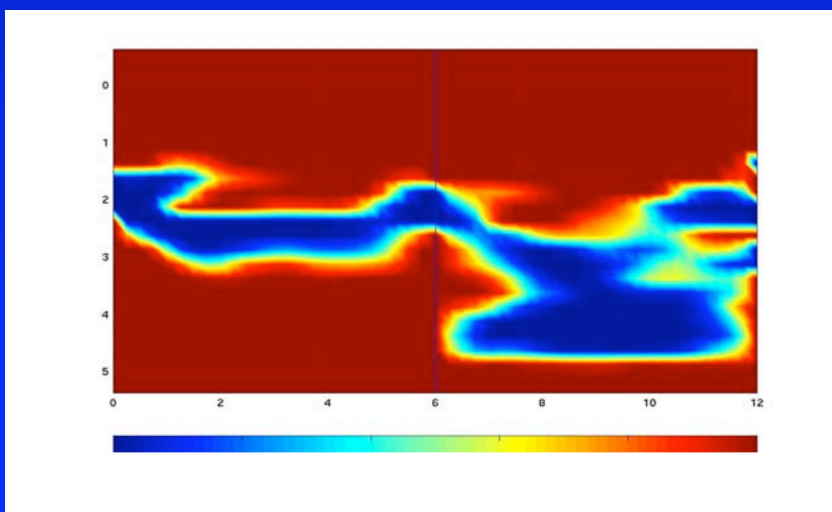
Radar Attenuation



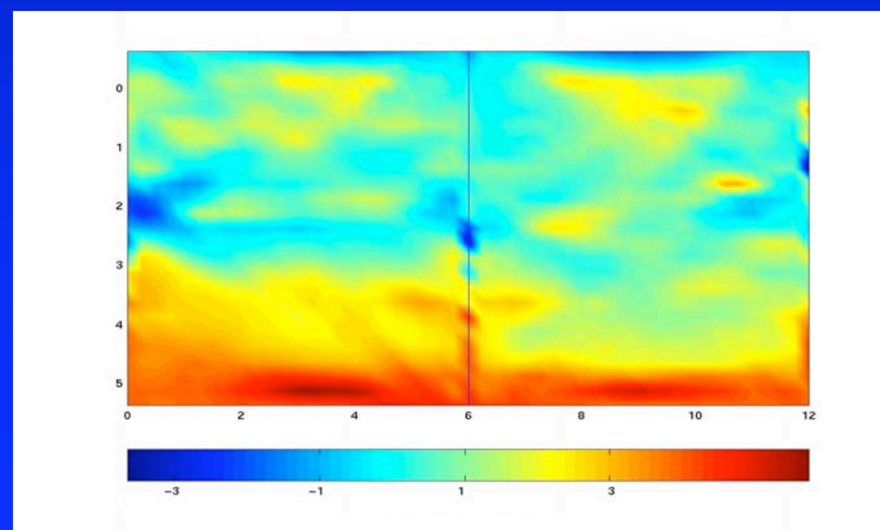
Estimated Fe2



Estimated Lithology



Estimated Fe3



Comparison of K Estimates vs. Chemical Transport Data

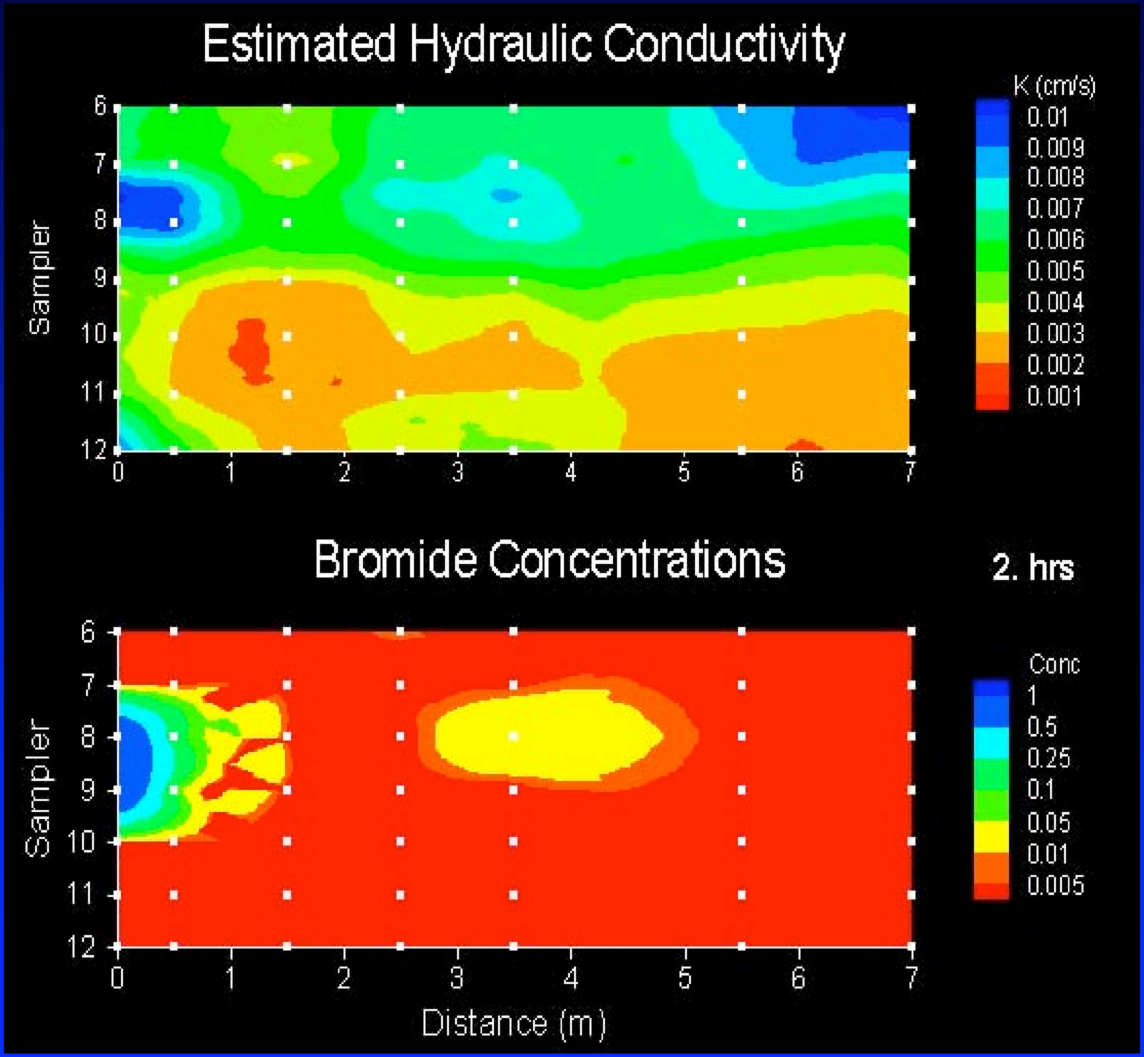
K Estimated using geophysical data

High K →

Low K →

High K →

Measured (interpolated) bromide tracer relative concentrations vs. time



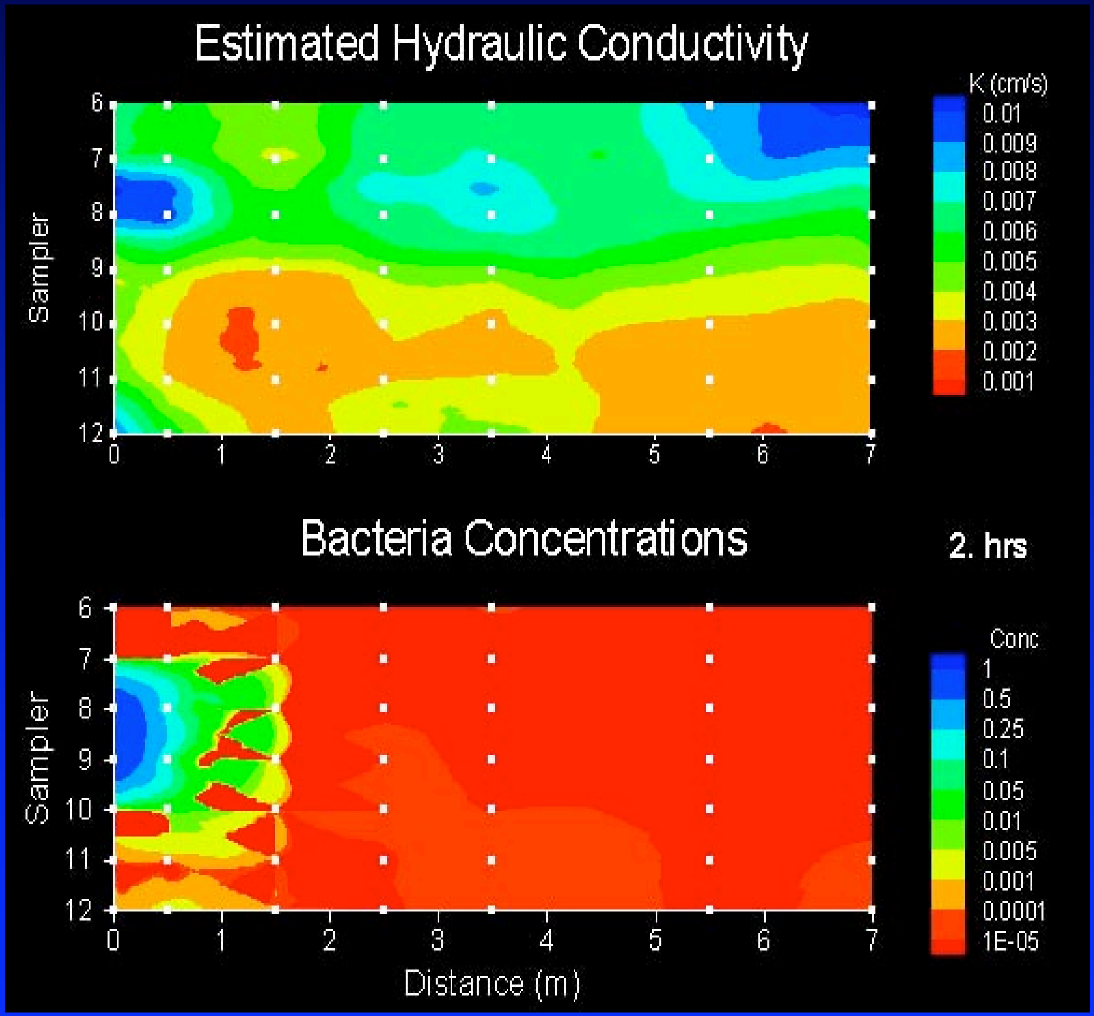
NABIR

Comparison of K Estimates vs. Bacterial Transport Data

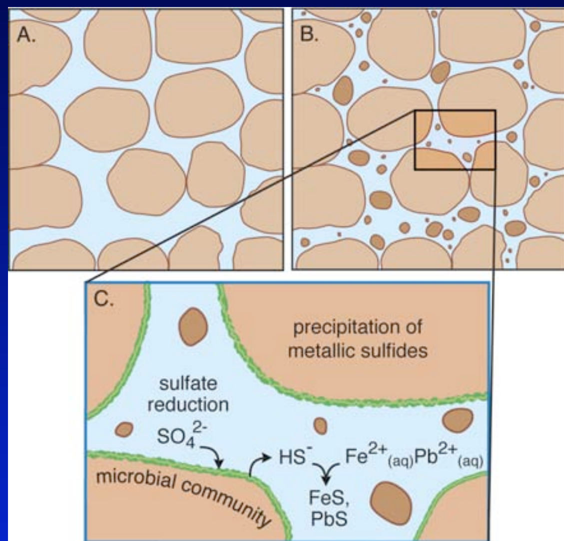
K Estimated using geophysical data

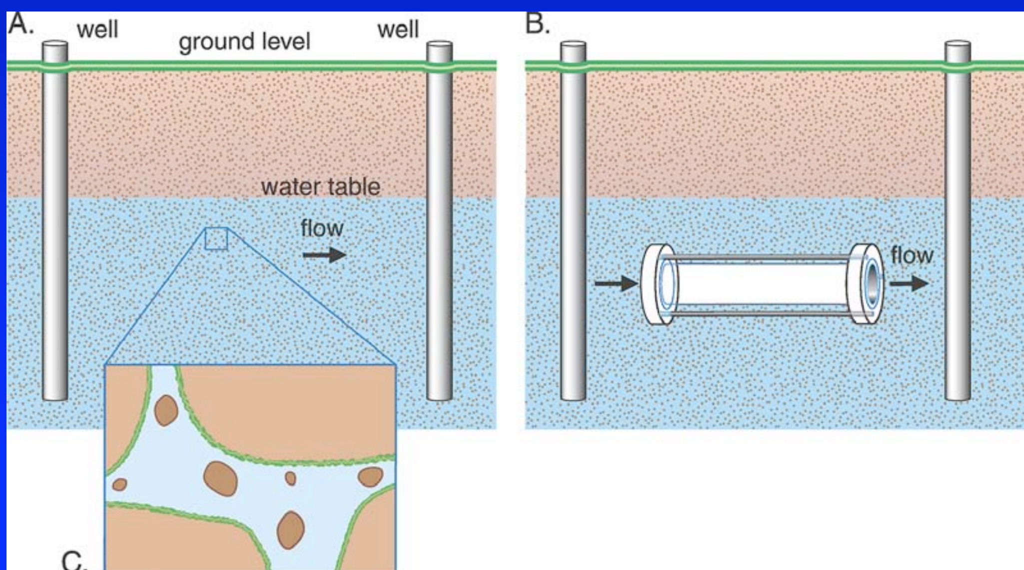
- High K →
- Low K →
- High K →

Measured (interpolated) Bacterial concentrations vs. time



Microbe-Induced Sulfide Precipitation in Porous Granular Media: Interactions between biogeochemical-geophysical-hydrological under DYNAMIC CONDITIONS



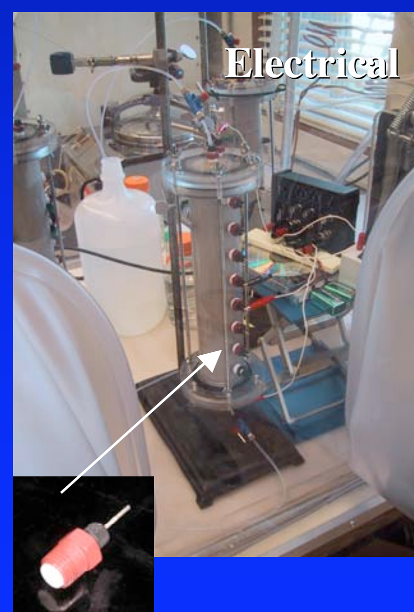


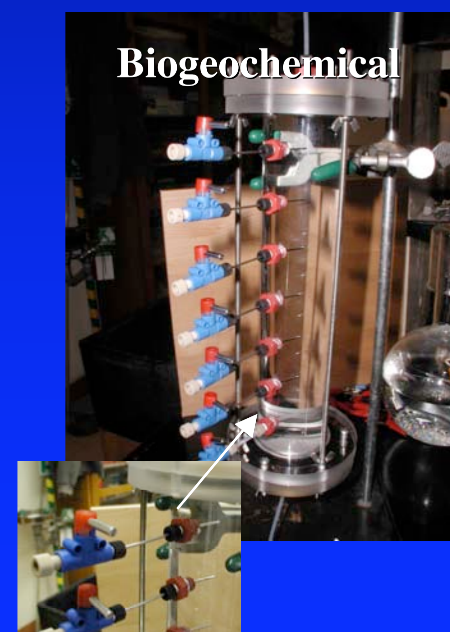
- ***Controlled Conditions:***
  - **Well-defined, saturated sediments of *known* grain size**
  - **Introduction of *single* microbial strain**
  - **Infiltration using *defined medium* with fixed substrate and metal concentrations**
  - ***Fixed* rate of advection**

Saturated Column Experiments:

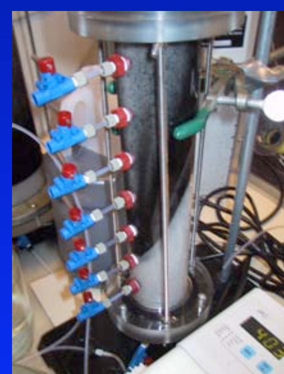
- Acoustic Method:
  - Cross-column acoustic pulses (10^5-10^6Hz)
  - Velocity and amplitude information
- Electromagnetic (TDR) Method
  - Time Domain Reflectometry (1-3GHz)
  - Velocity and amplitude information
- Complex Resistivity (10^{-1}-10^3Hz)

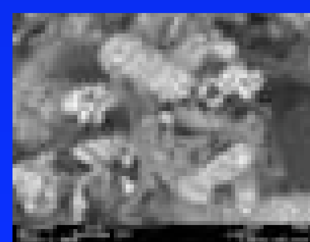
  in collaboration with Lee Slater, Rutgers
  - Non-polarizing (i.e. low-noise) Ag/AgCl potential electrodes
  - Gold current electrodes
- Biogeochemical
  - Fluid chemistry (anions, cations, organic acids, pH)
  - Biomass sampling (quantitative AODC, PLFA)
  - Nanoparticle sampling and analysis (XRD, SEM, TEM)
  - Electron microscopy of microbe-sediment associations



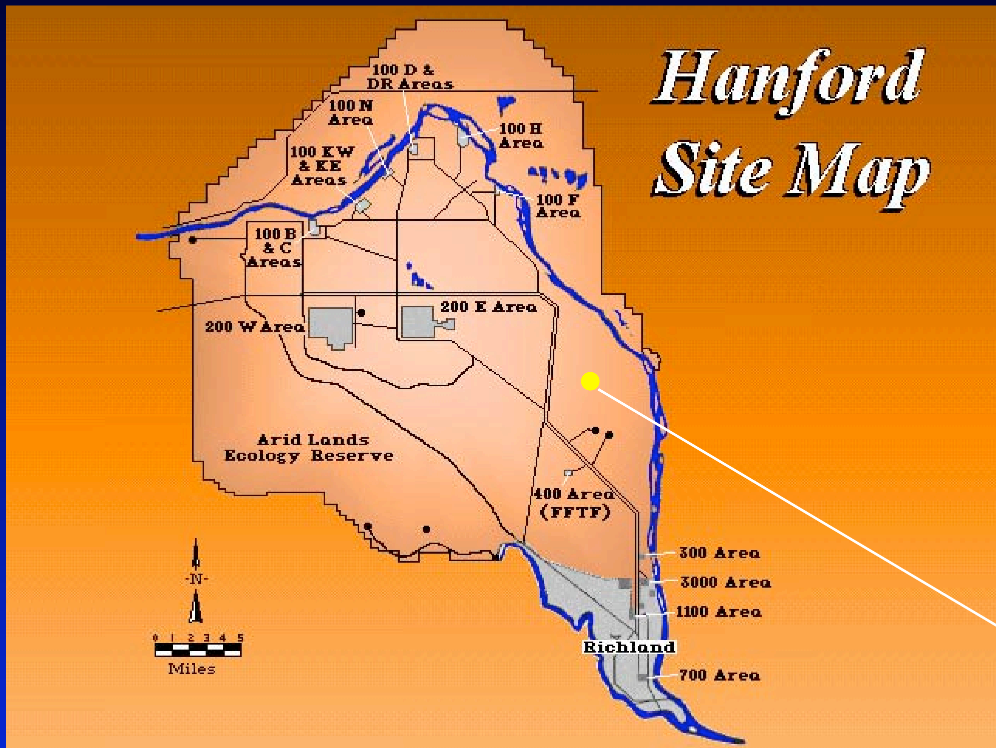


- Dynamic processes
- Strong spatio-temporal correspondence in geochemical-microbial-geophysical-hydrological measurements.
- Migration of microbial-encrusted microbes detectable using geophysical methods.

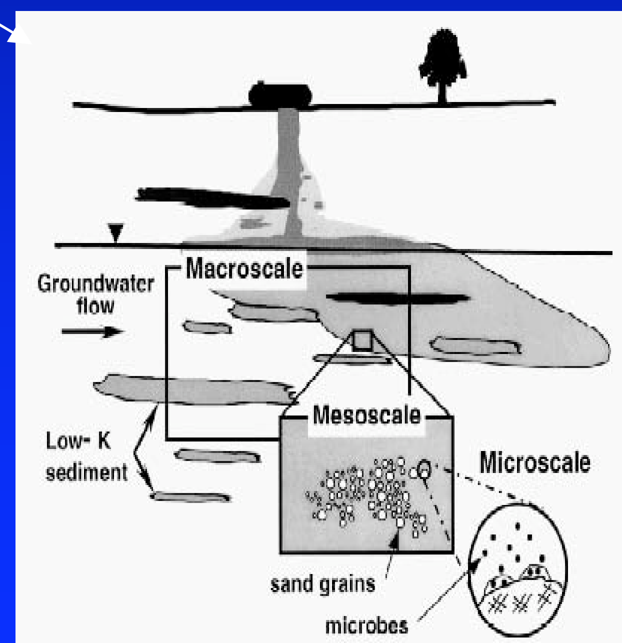




EMSP
Environmental Management Science Program



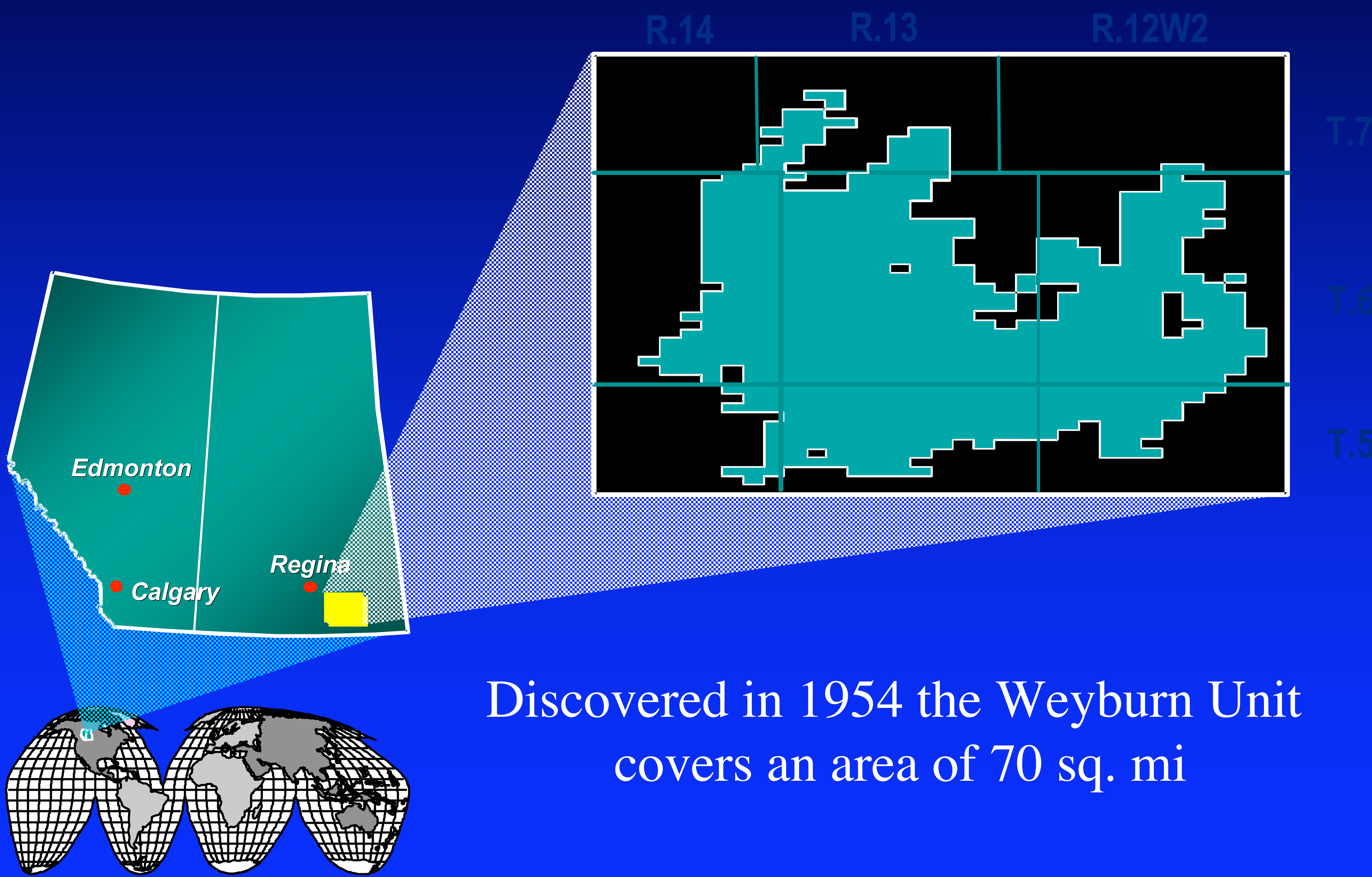
Obstacle:
If high resolution information is needed to accurately predict transport and to monitor coupled processes, how can we do this over large areas?



Example Problem: C02 Storage

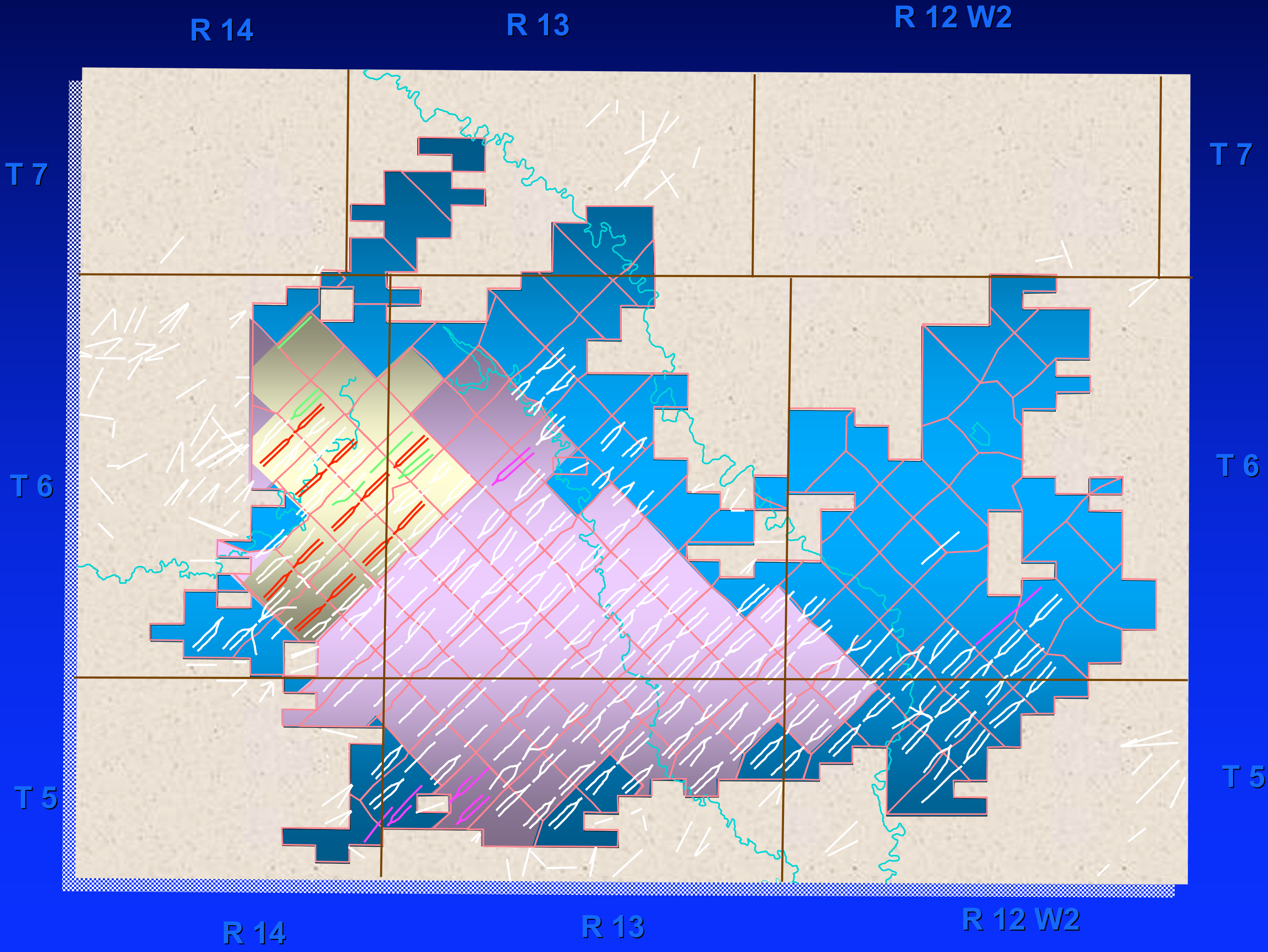
- Elements
  - Define the critical subsurface and surface properties controlling the transport and location of the CO2.
    - ➔Static and dynamic properties of matrix
      - ★Lithology, pores/fractures,stress tensor, etc.
    - ➔Fluid partitioning and transport properties
    - ➔Chemical (microbial) interactions
    - ➔Atmospheric interactions
  - Define the minimum scale of understanding

Weyburn Unit

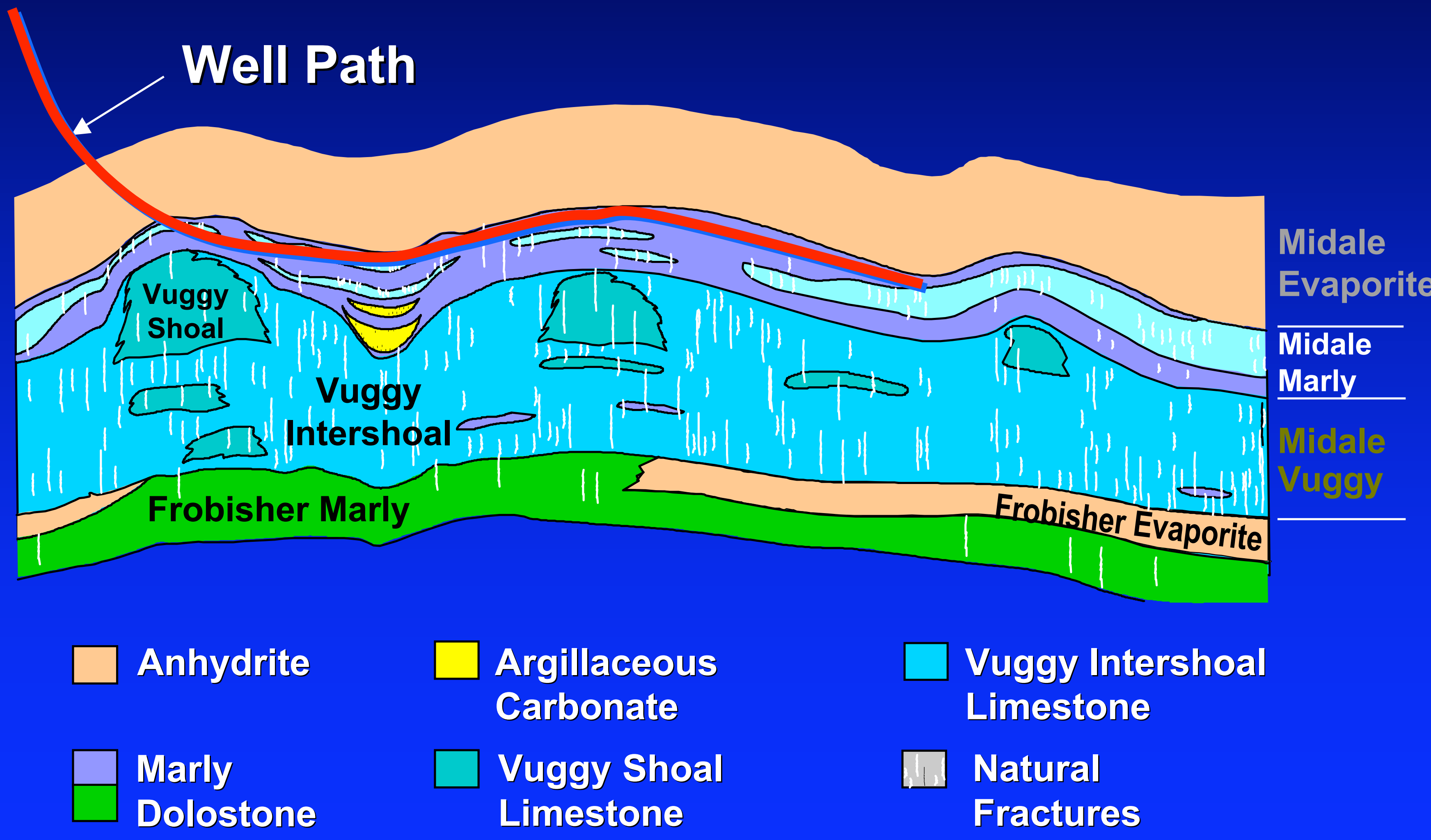


Discovered in 1954 the Weyburn Unit covers an area of 70 sq. mi

Weyburn Well Layout



Schematic East-West Geological Cross-Section



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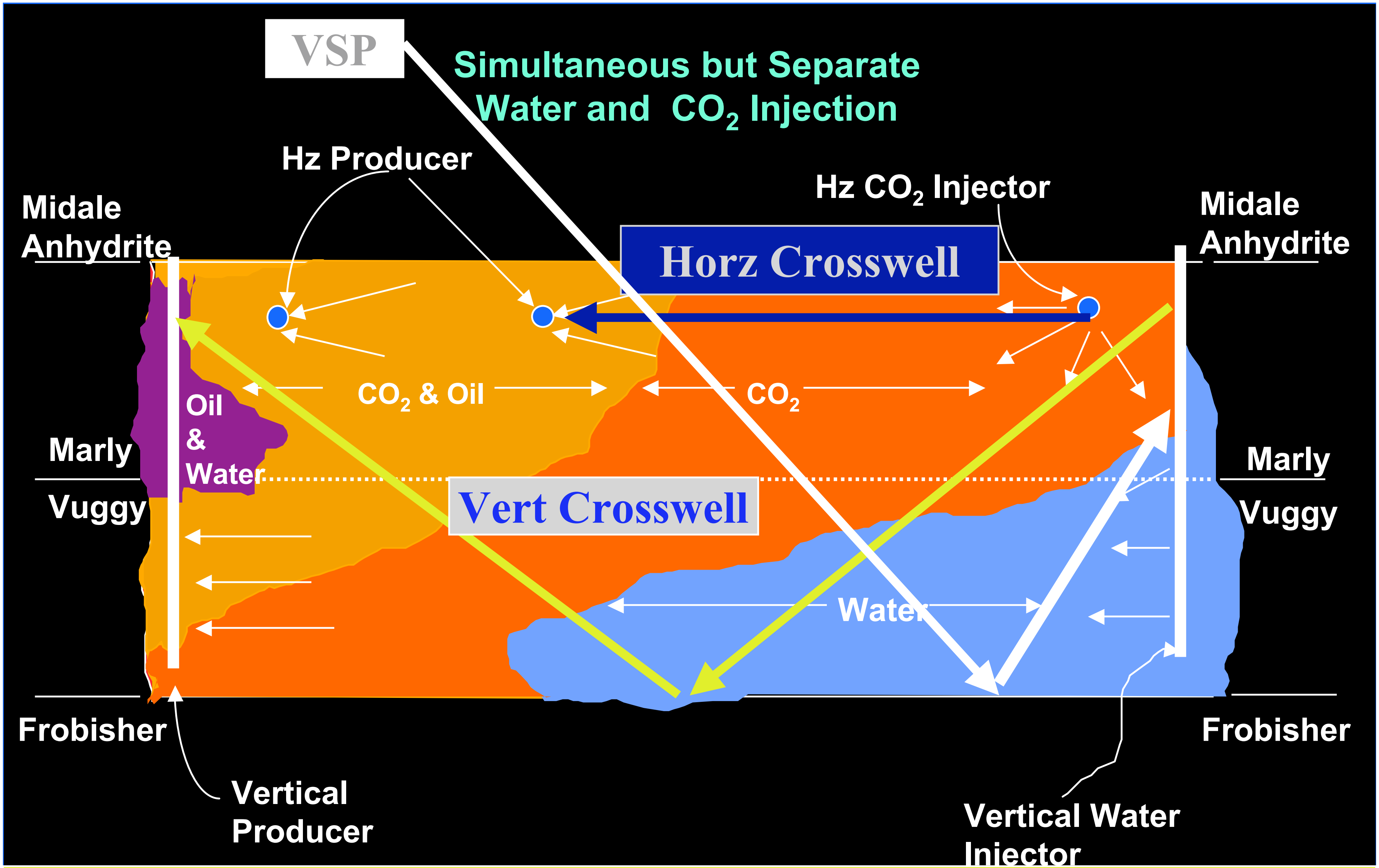
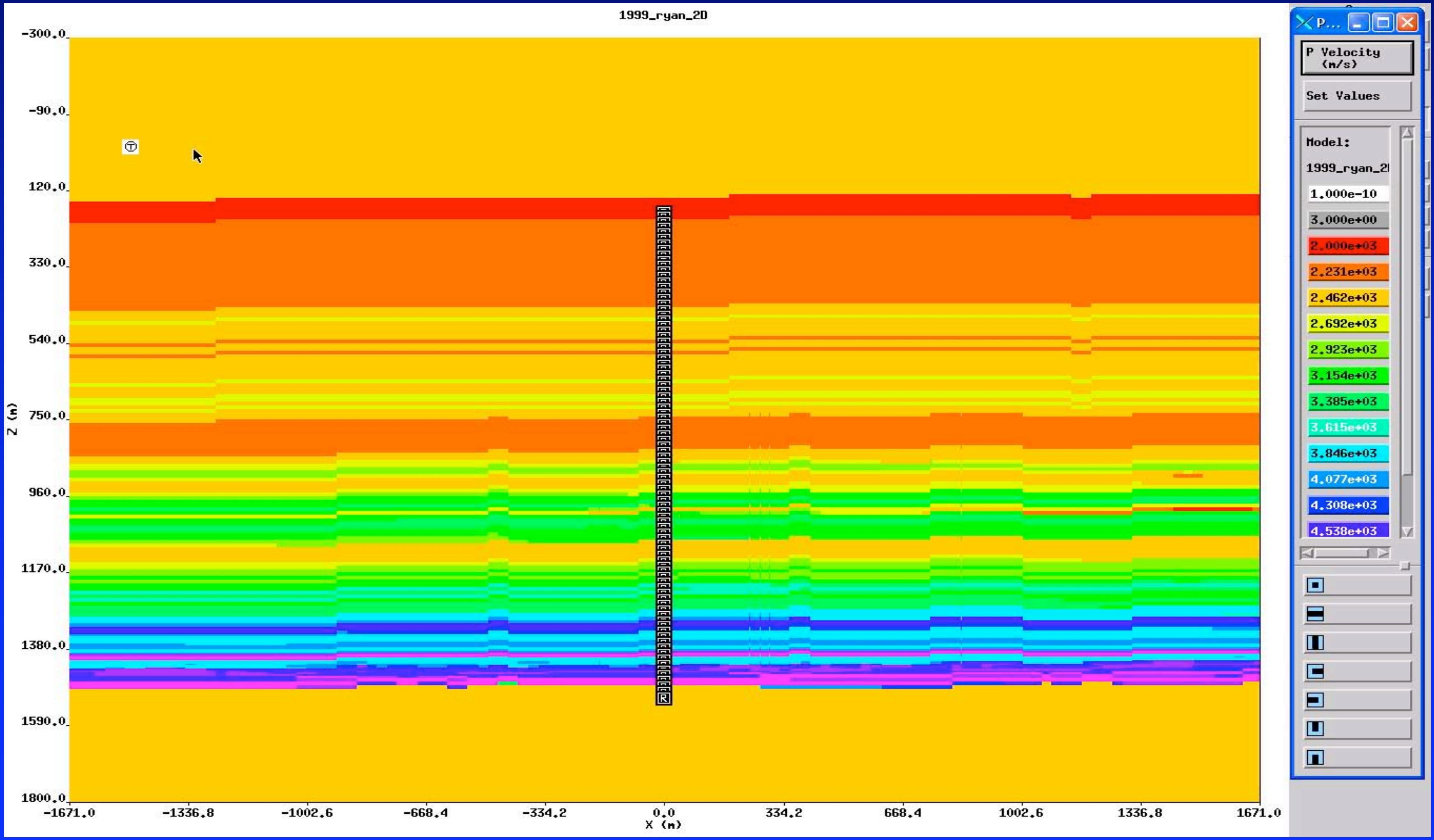
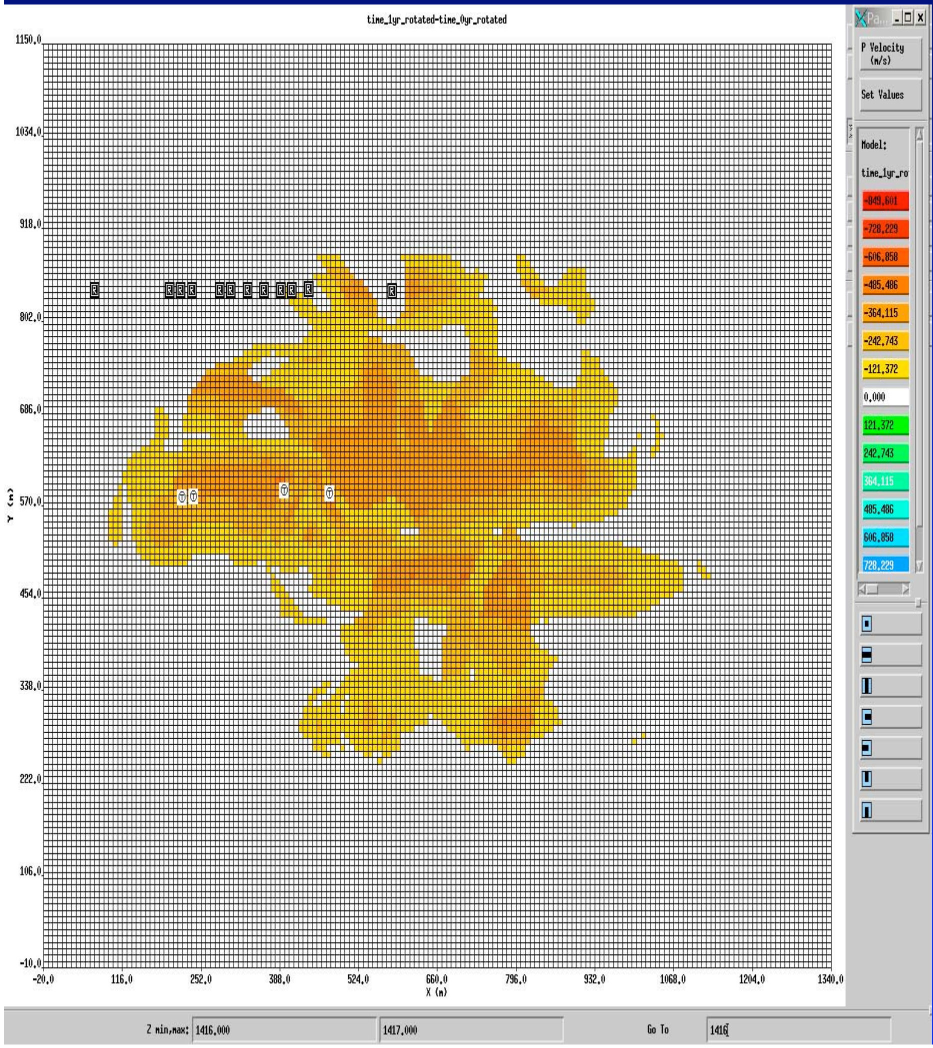


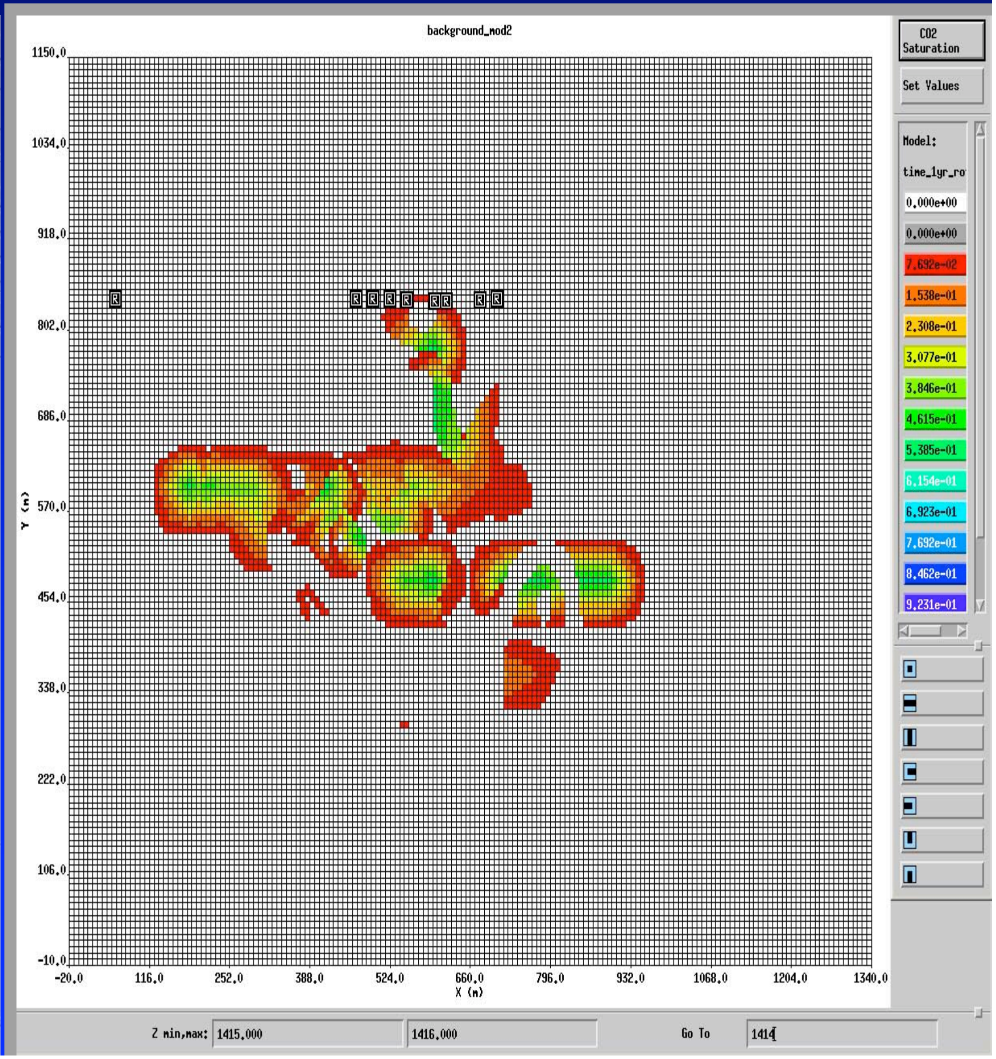
Can seismic methods verify critical processes ?

Model Derived from Reservoir Simulator and Well Logs

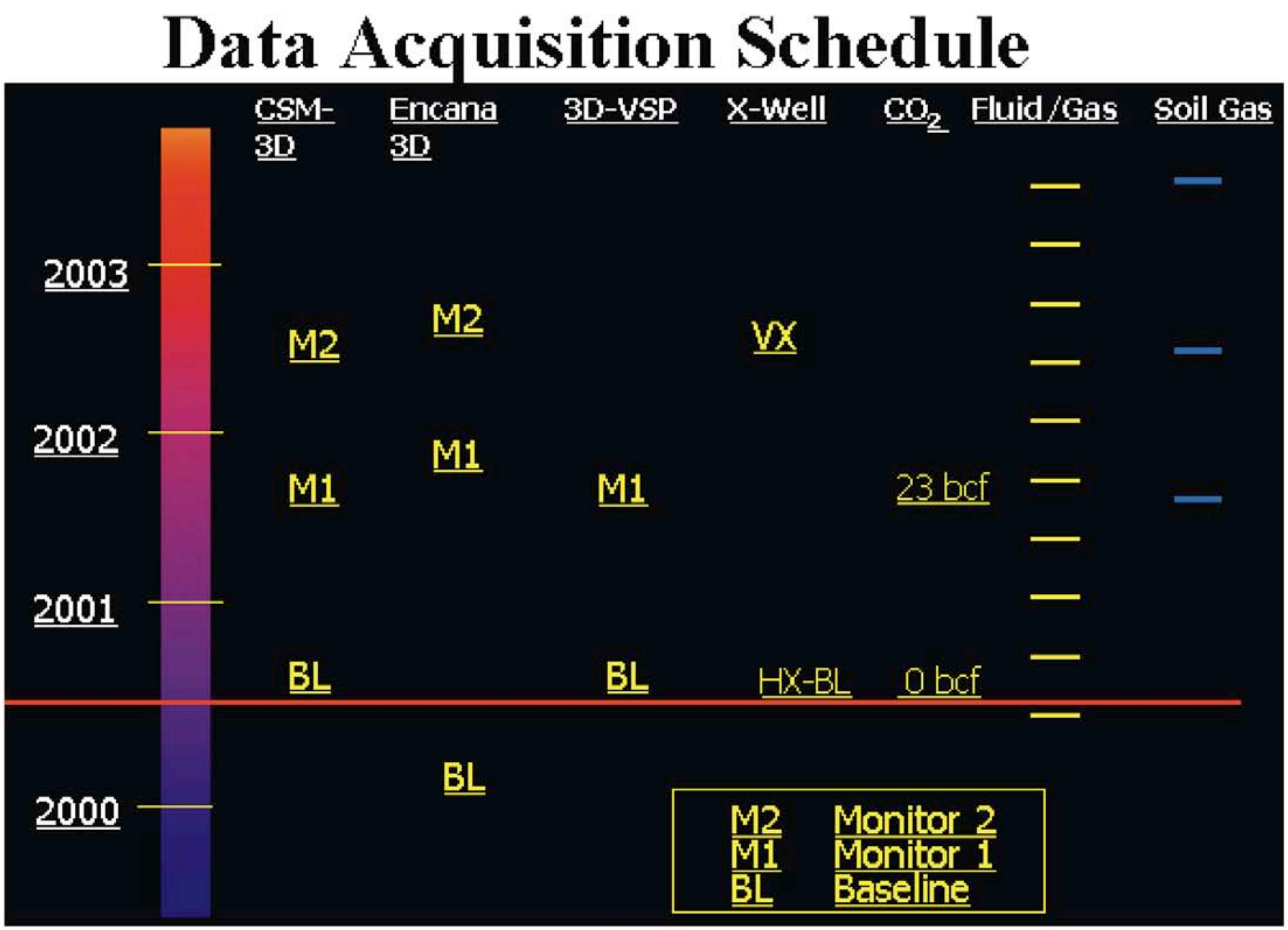


Plan view P-wave velocity change compared to CO2 (Year 1)





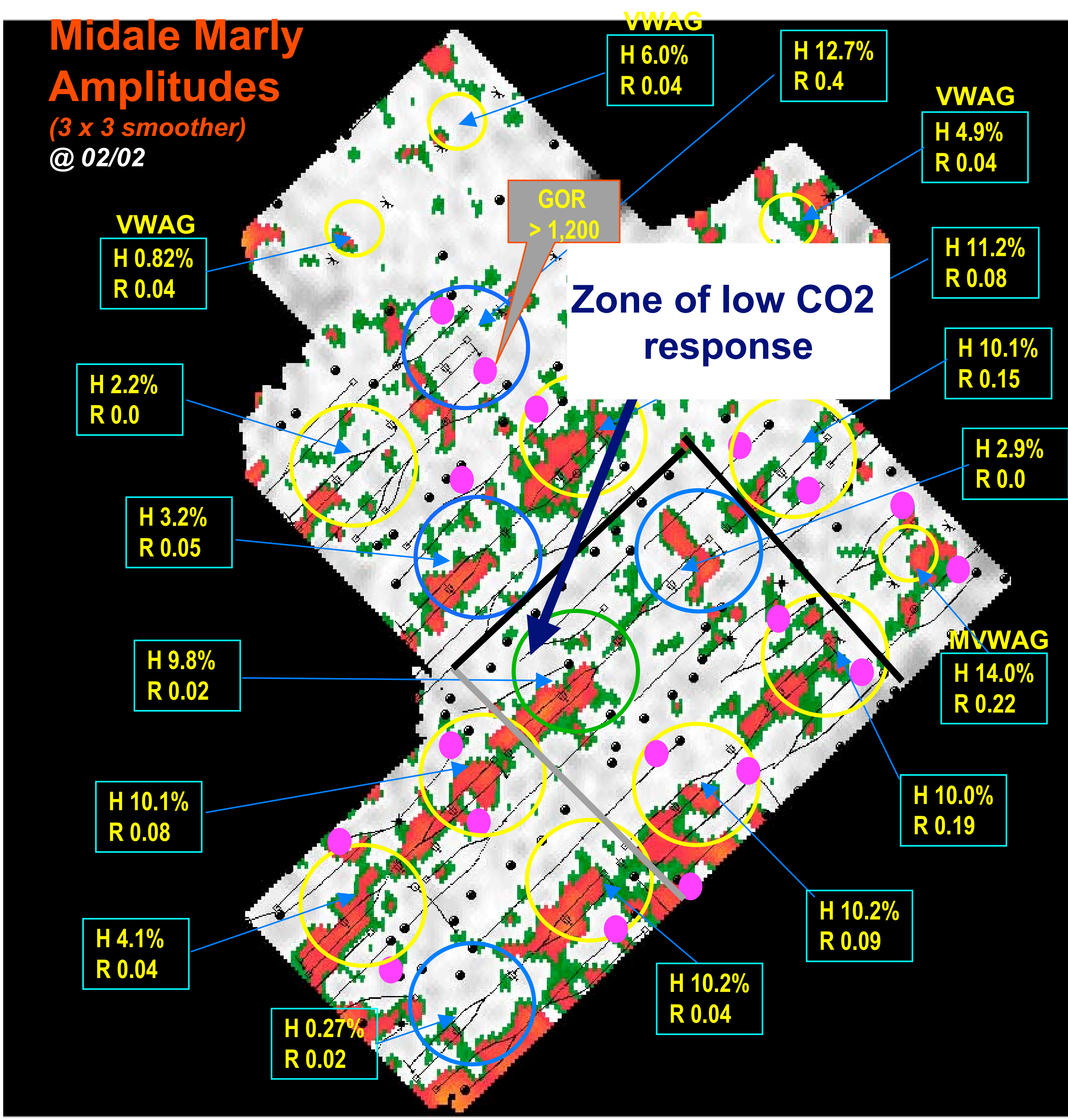
Time Lapse studies



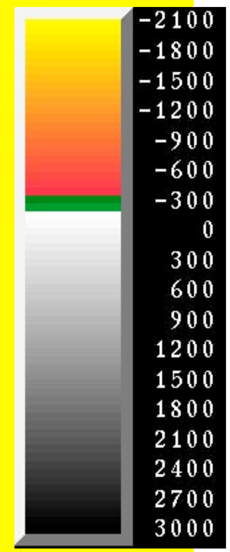
Location of Vertical Crosswell (and VSP), and Horz Crosswell Relative to Surface Seismic

Seismic Detection of Weyburn Field CO_2 Miscible Flood

EnCana et al.
4-D P-Wave Data
(Bin Size 40 x 40 m)



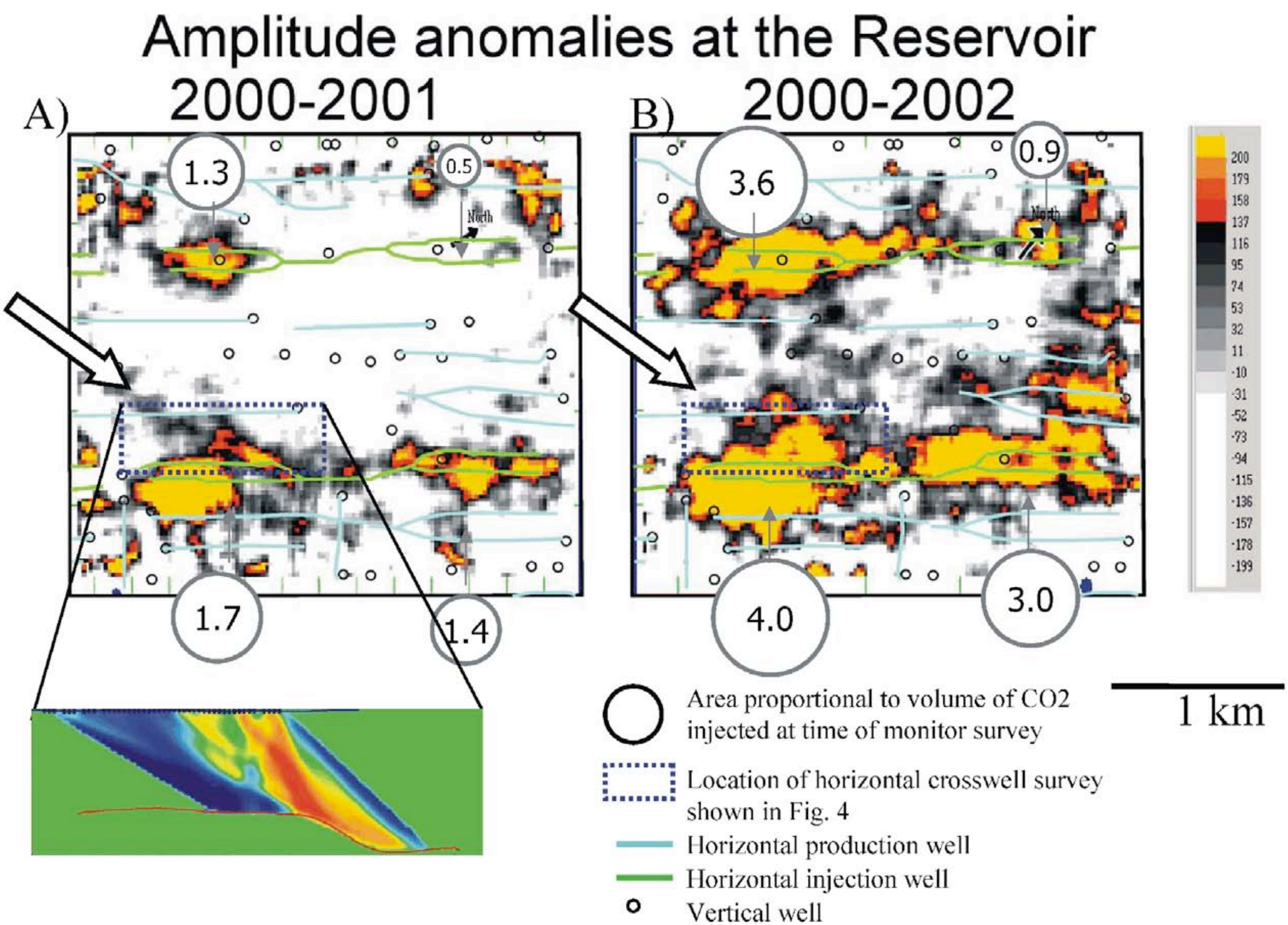
Amp Scale



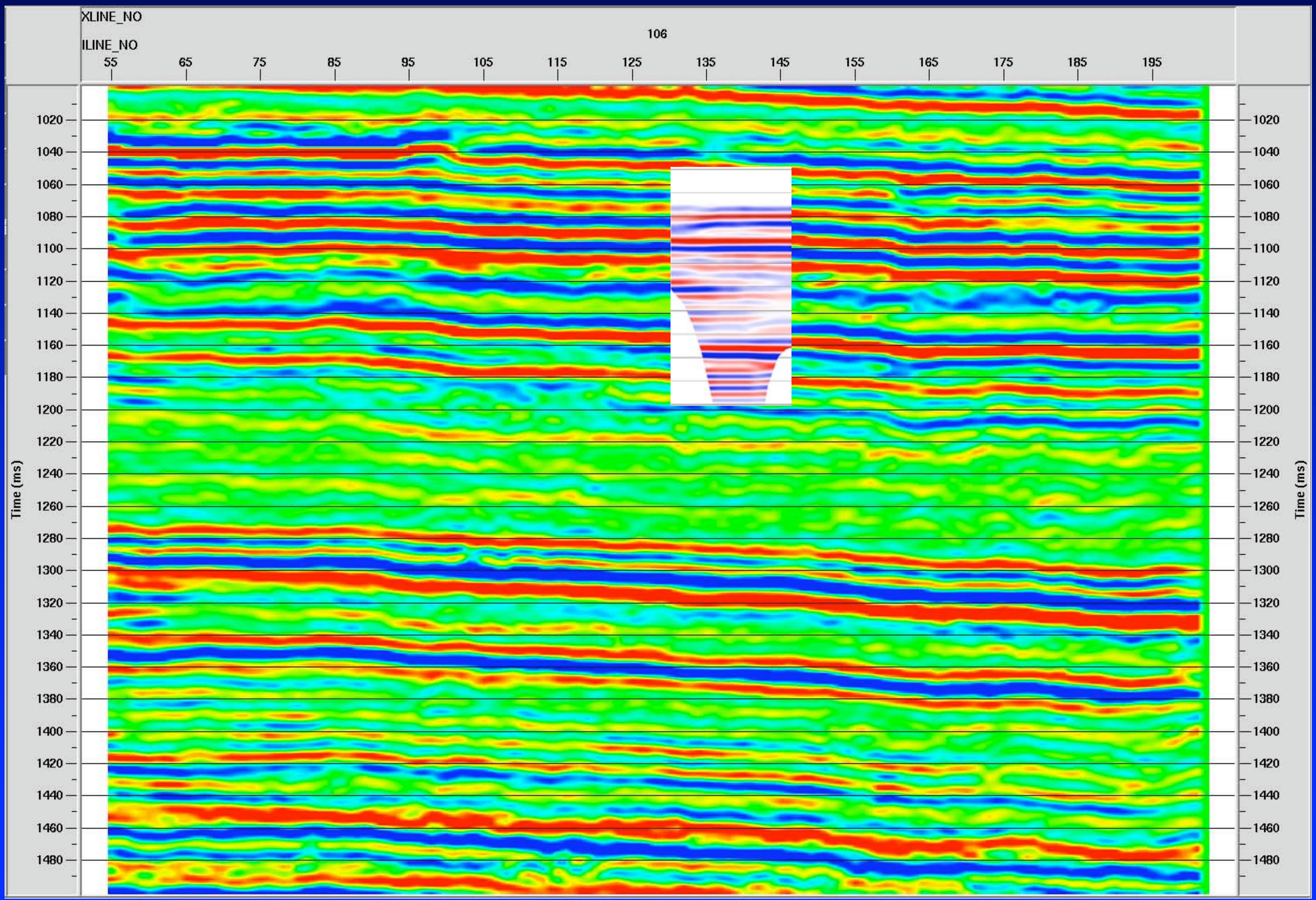
CO_2 Related Anomalies

H - HCPV
R - Recycle ratio
● - Response well

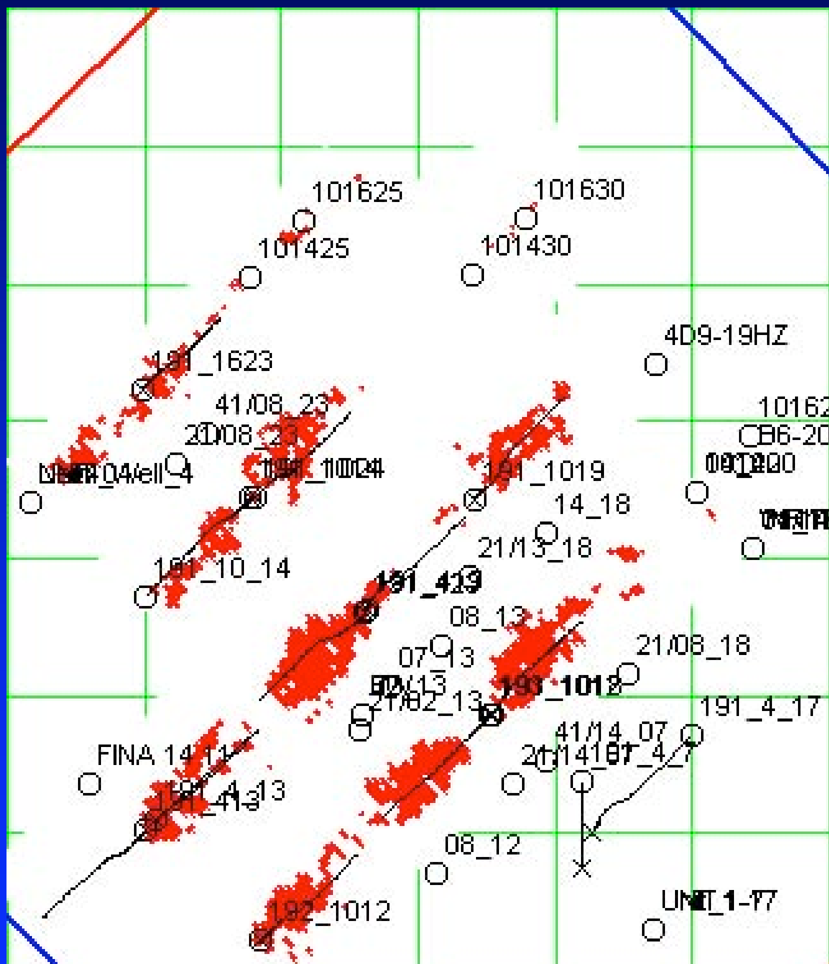
Seismic Measurements

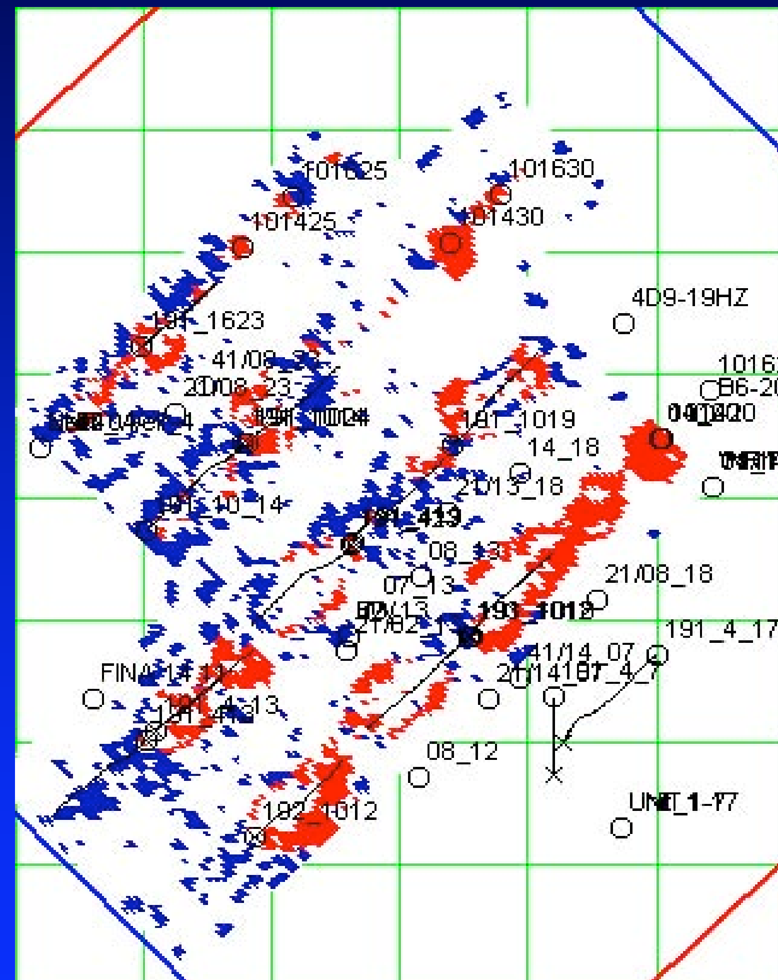


Cross Line 106 with Xwell Data

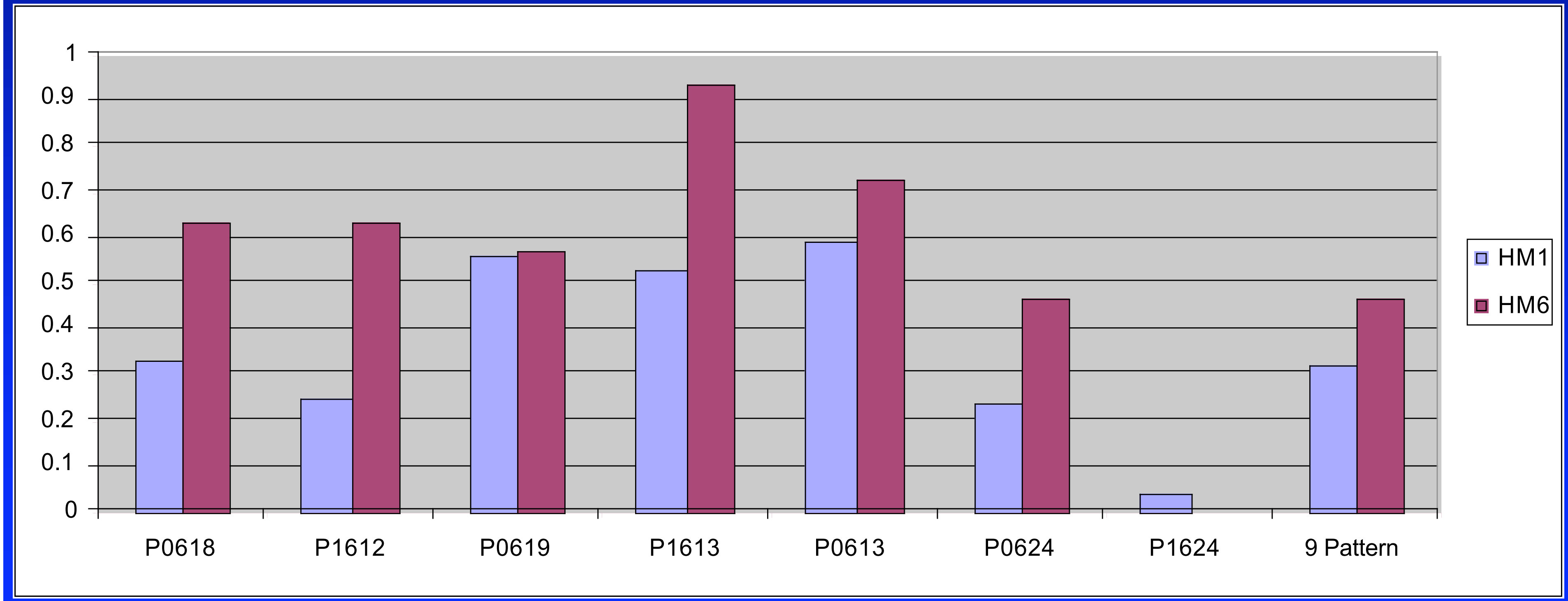


Seismic vs. Reservoir Simulation

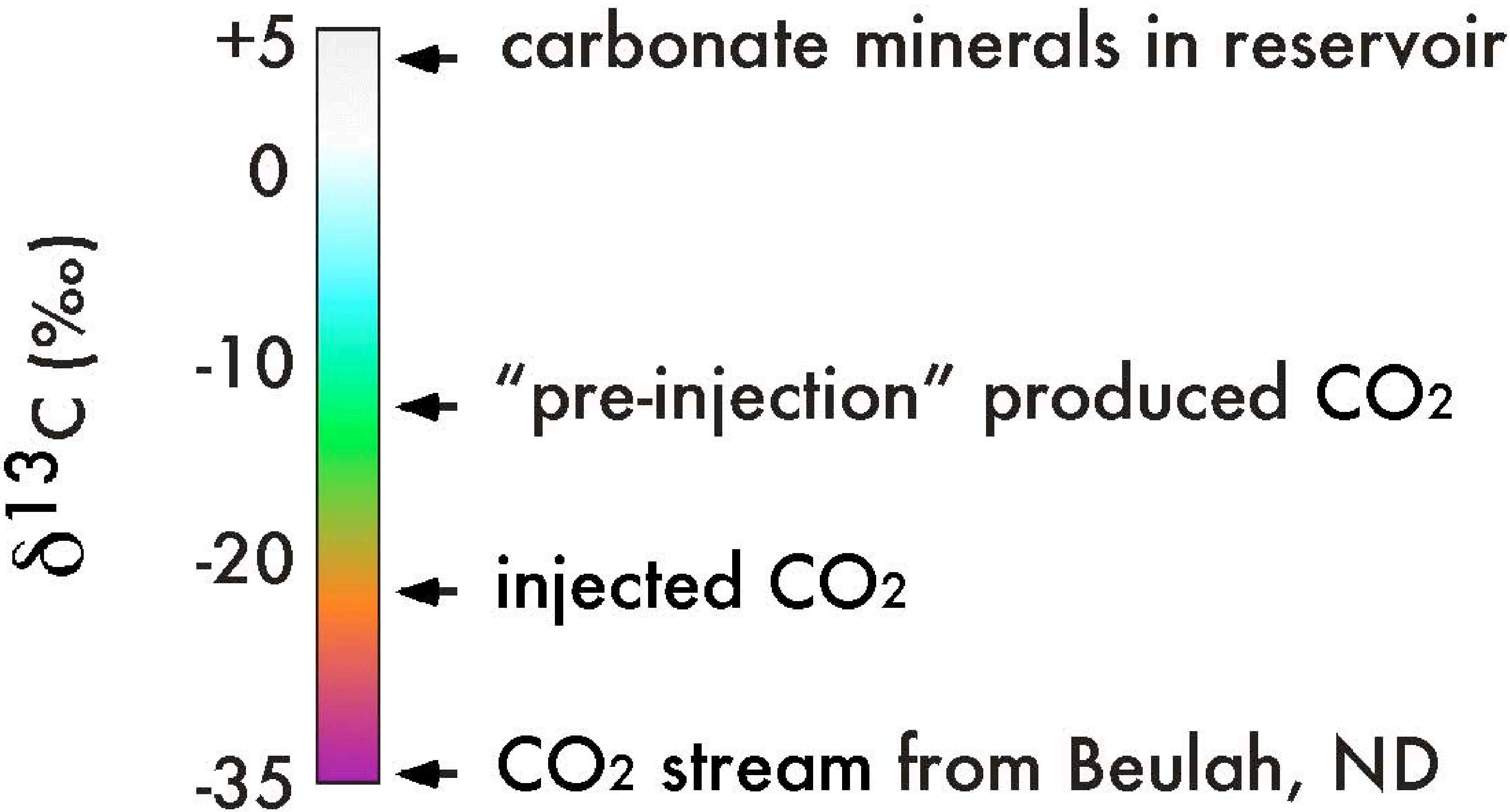




Fraction of injected CO_2 volume explained by cells in common between the time-lapse and simulator model. A much larger percentage of the volume is explained in model iteration 6 than the first iteration.

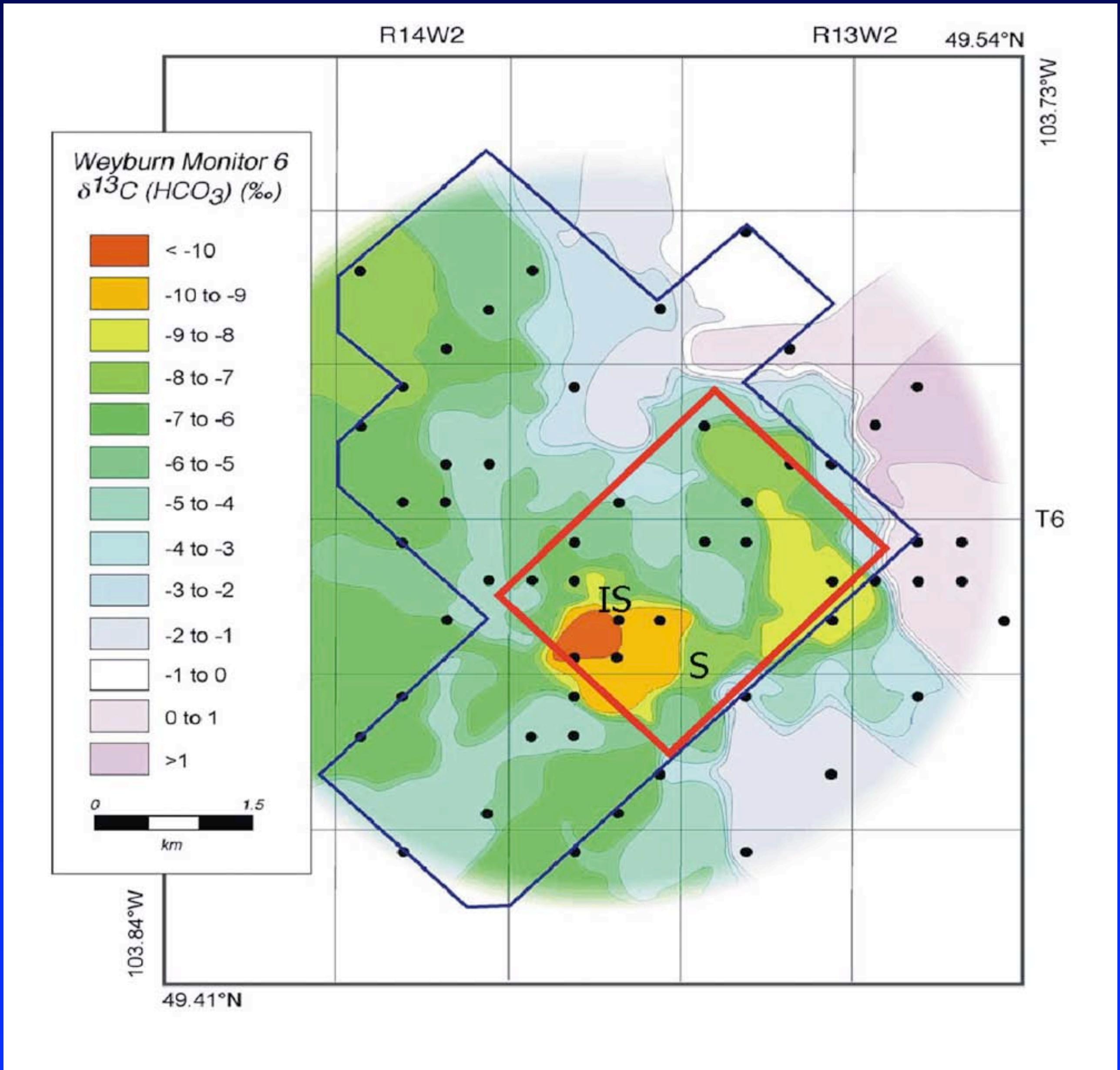


Geochemical Studies

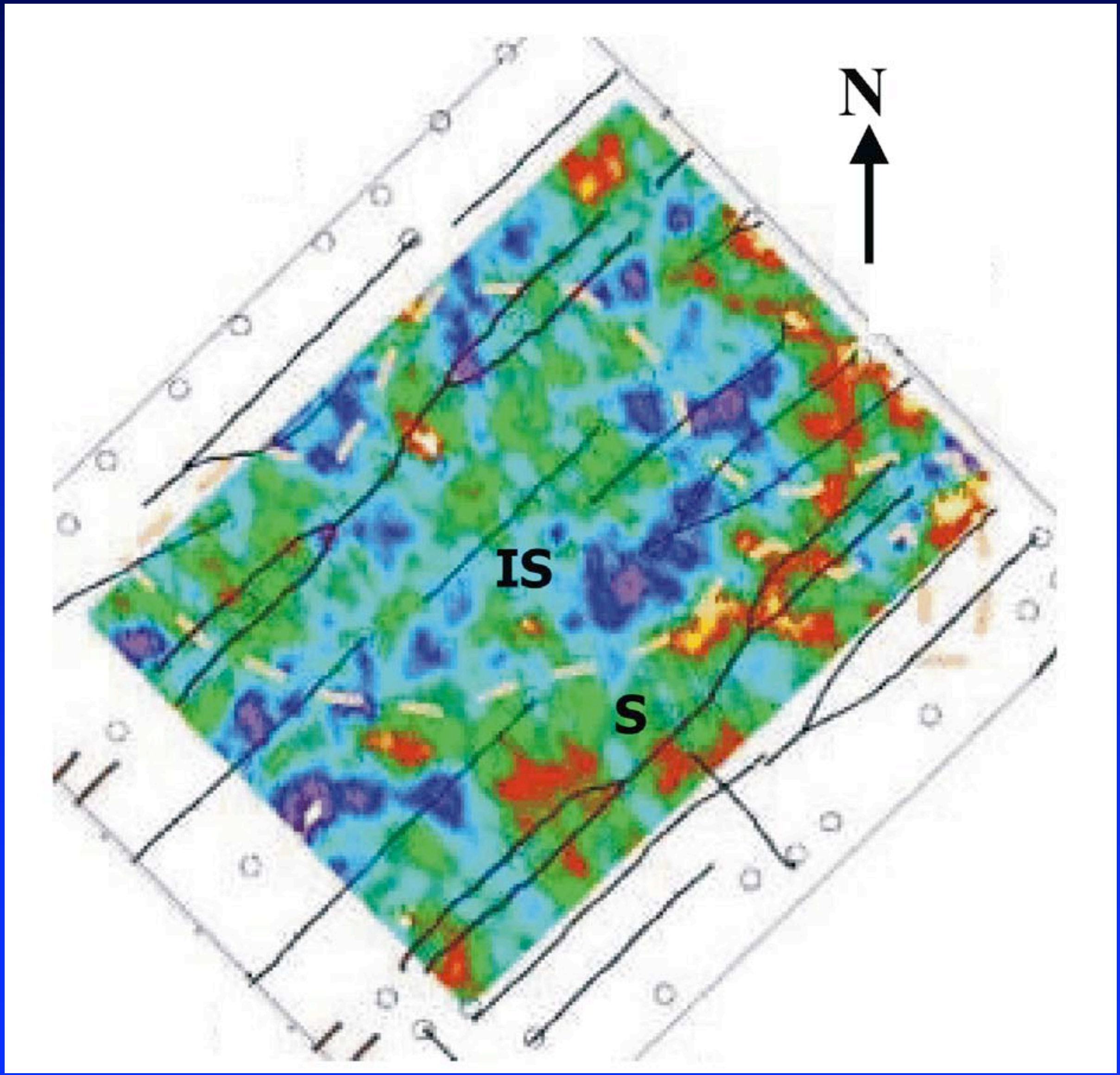


$\delta^{13}C$ Values. Mineral dissolution drives produced CO_2 and dissolved CO_2 (as bicarbonate) $\delta^{13}C$ values to a more positive value. Conversely, dissolution of injected CO_2 drives produced CO_2 $\delta^{13}C$ values to a more negative value.

Geochemical studies

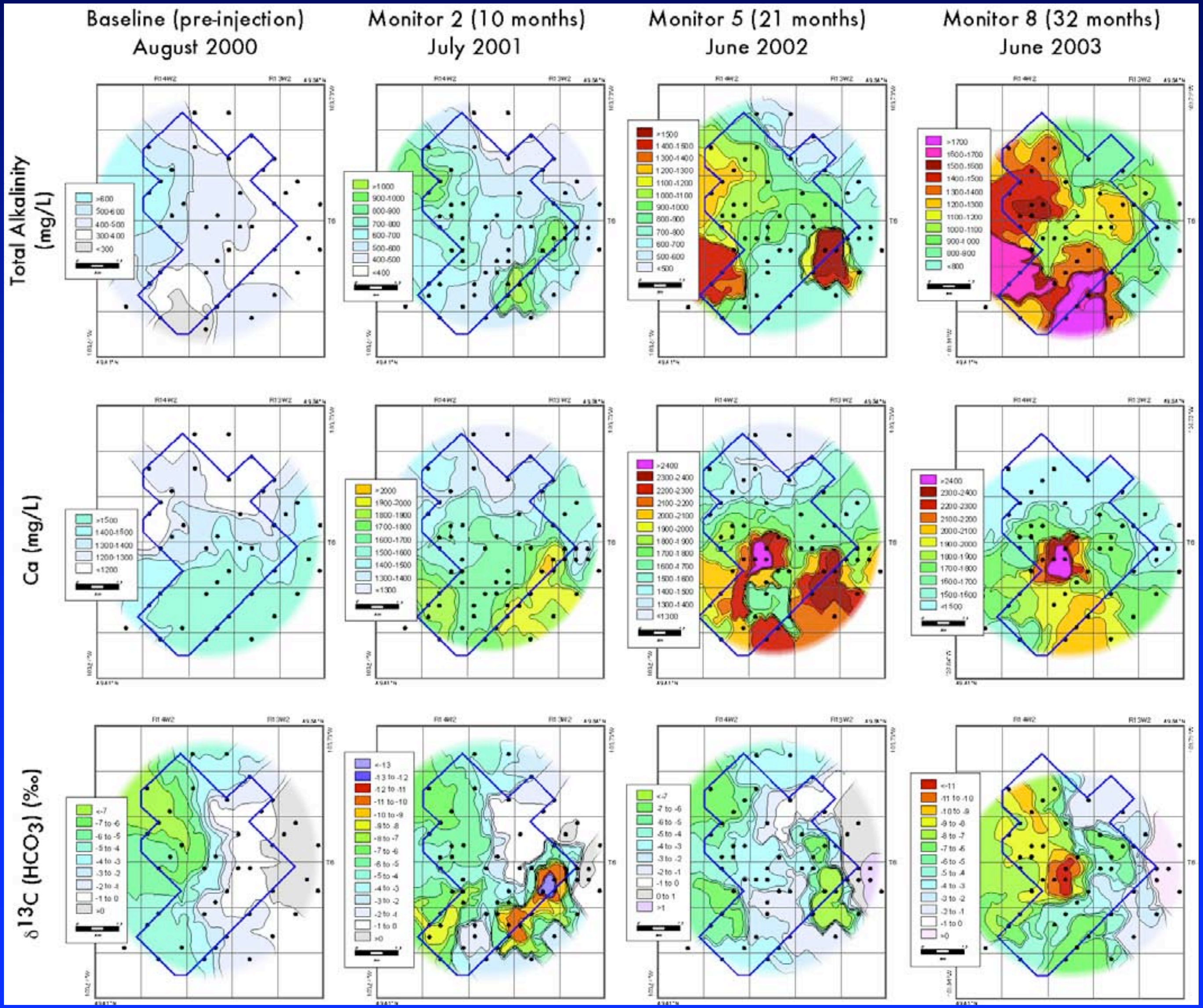


_[13]C values from the Monitor 6 survey (September, 2002).



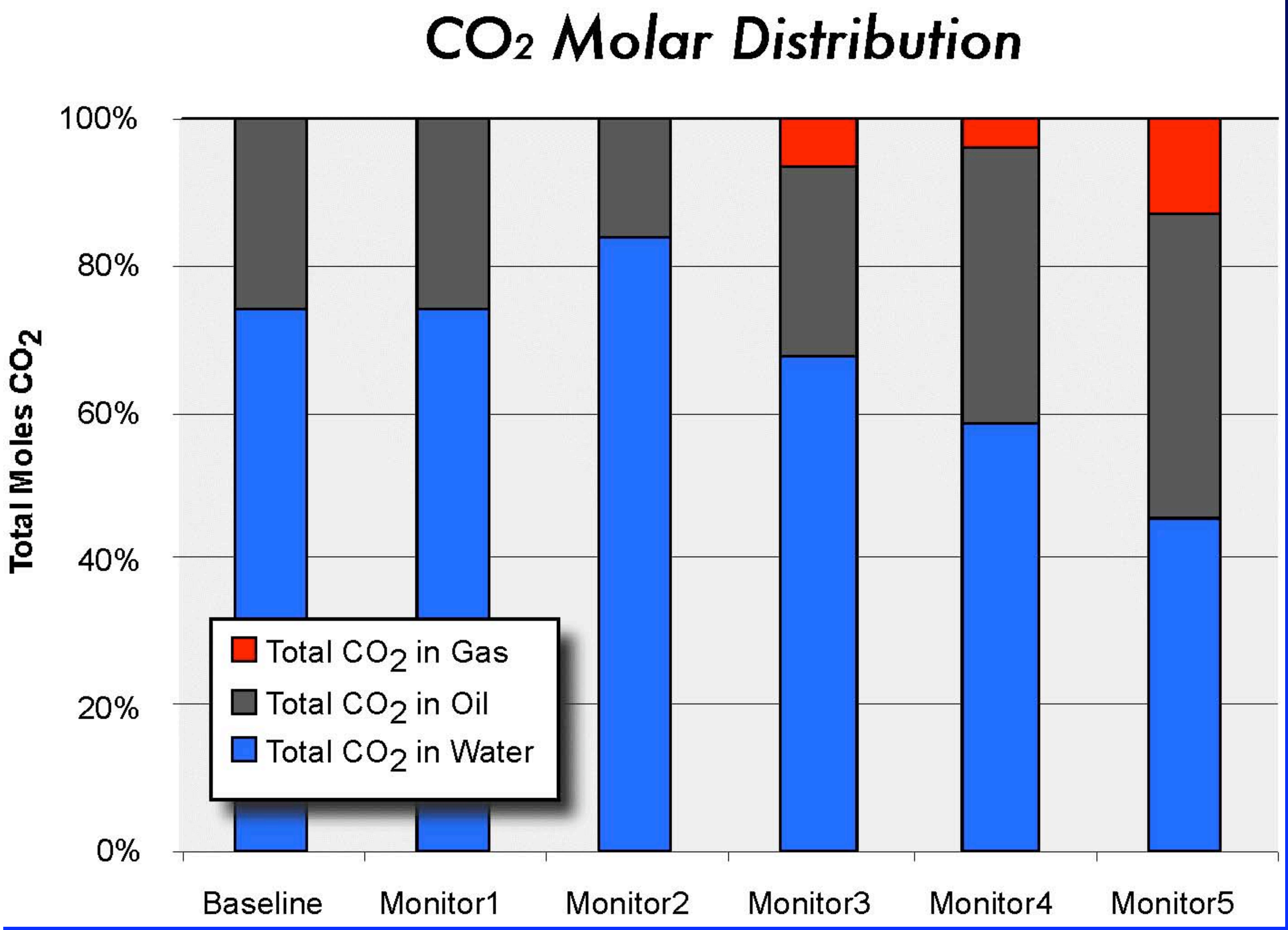
Shear wave splitting map for the monitor 2 survey (2002). IS=intershoal facies, S=shoal facies within the Vuggy unit

Calcium and C13 results



Contours of [Ca], and $\delta^{13}C_{HCO3}$ Pre-injection(left),post-CO_2 on the right. CO_2 dissolution is evident by 10 months, and carbonate dissolution is evident by 21 months,

Geochemical modeling



CO_2 distribution based on production data and solubility calculations to assess the gas distribution within the reservoir fluids and its interaction with reservoir rock at subsurface conditions through time.

Lessons Learned

- Even at the small scale we cannot adequately predict many processes
- Most progress was made when an interdisciplinary, diverse in interests team of scientists are coordinated
- Most productive when one has a mix of hypothesis driven science carried through to application
  - Theory , lab and field investigations
  - Manipulation and process driven work
- Almost always limited by sampling (data) and adequate understanding of coupled processes
- Usually we resort to deterministic and/or statistical solutions
- There will always be limitations due to inadequate technology and/or theory: <u>How do we deal with it!!!</u>

Next Steps

- Identify the process that will pick the critical challenges that if overcome will make the most impact
- Process adopted will identify critical roadblocks and sub-roadblocks as well as research pathways
  - Beyond the usual roadmap
    - ➔Specify work from beginning to implementation
    - ➔Specify how the work will be done not just what work will be done
    - ➔Specify mechanism that will be productive without hindering creativity
  - <u>Some may be fundamentally impossible</u>
- Implement work
  - Appropriate scientific oversight
  - Adequate resources