

Fourth Annual Conference on Carbon Capture & Sequestration

*Developing Potential Paths Forward Based on the
Knowledge, Science and Experience to Date*

Geologic Sequestration

The Development of a Performance Assessment
Framework for Geologic CO₂ Sequestration

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- ZERT Partners

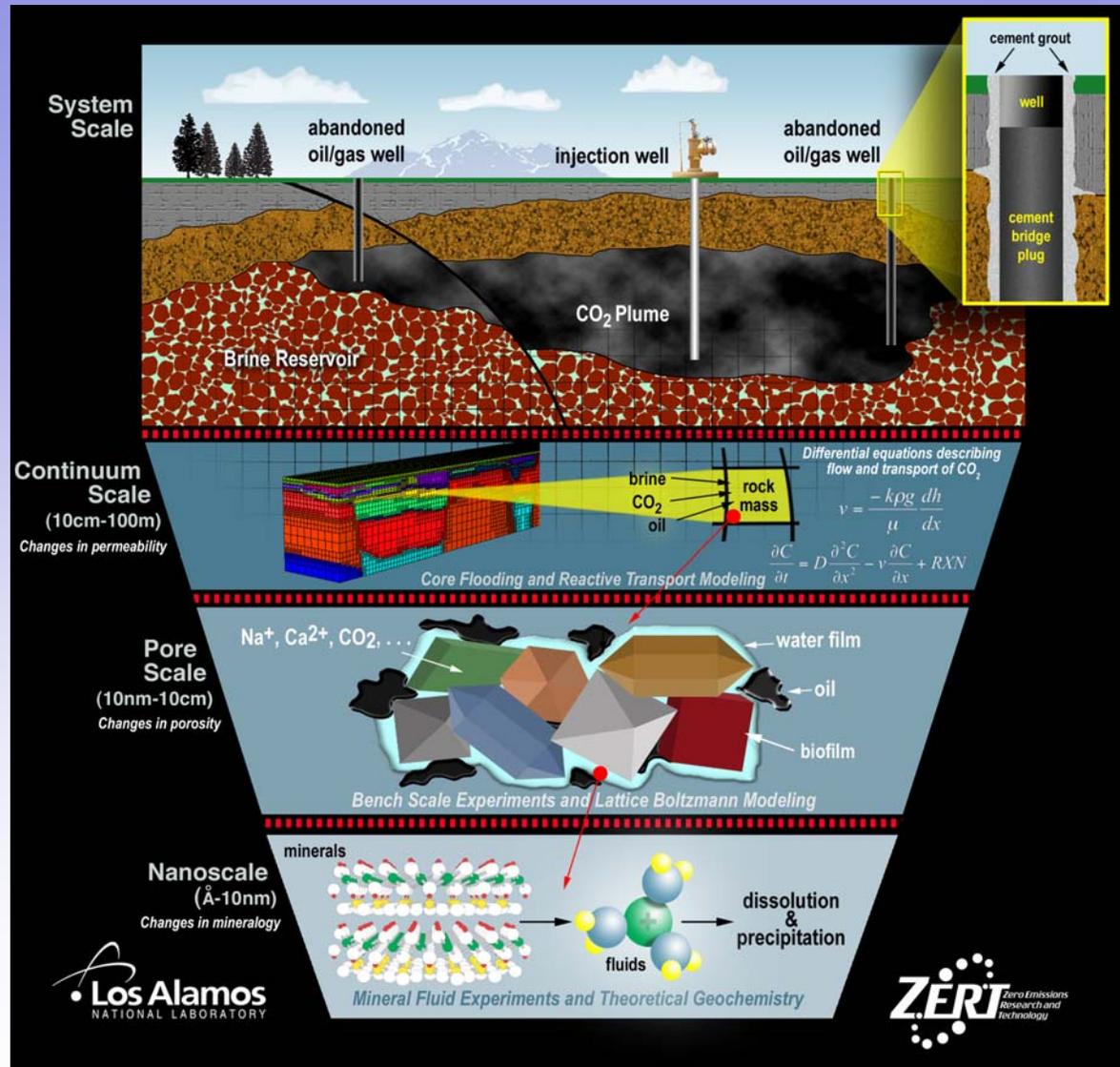


Overview of Contribution to ZERT

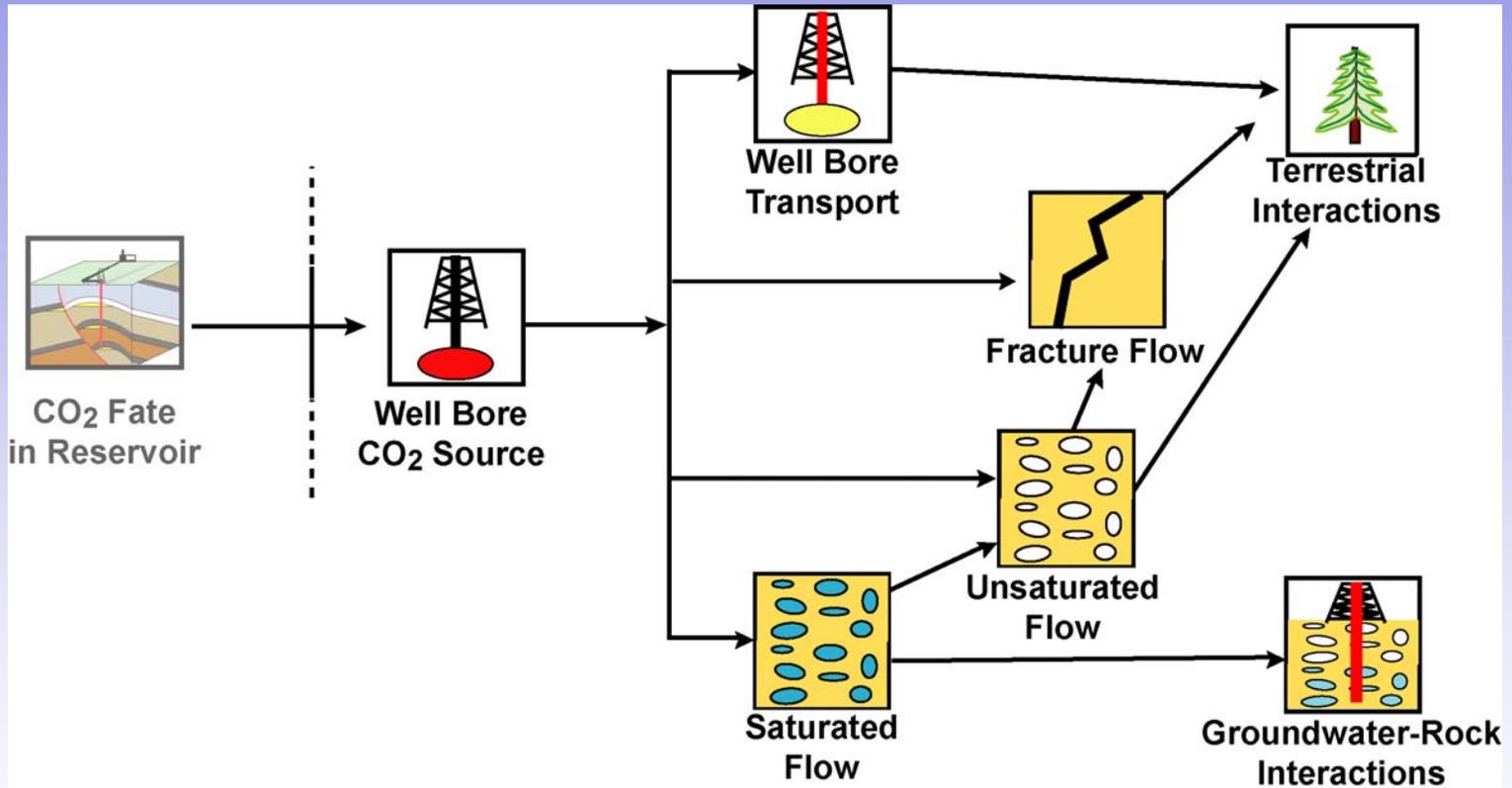
- Los Alamos is involved in many aspects of the ZERT Program, and we are integrating field measurements, laboratory experiments, and numerical modeling
- Overall performance assessment framework for simulating geologic carbon dioxide sequestration
- Coupling systems models and process models
- Focus on possible release pathways of CO₂ from a wellbore to the accessible environment



Systems and Process Level Models are being Integrated with Experimental and Field Observations



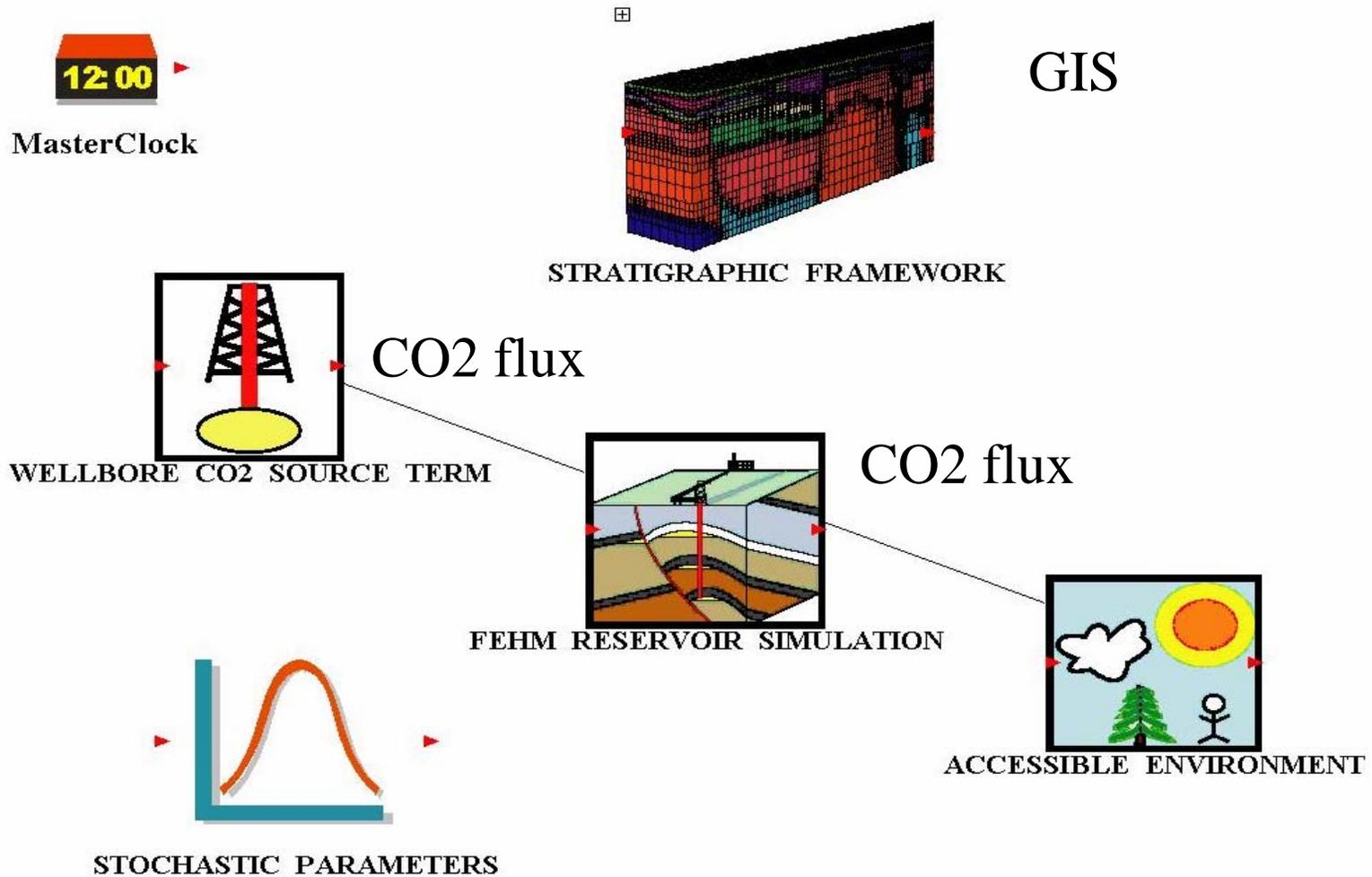
Framework: Borehole Critical Path



Examples of Framework Pieces

- Systems model is being constructed with Goldsim (used to develop TSPA models in various environmental applications)
- Abstracted process models are handled within Goldsim
- Process models that cannot be abstracted are coupled to Goldsim as dynamically linked libraries (dlls)
- Input parameters and results are stored in GIS knowledge base

Goldsim Systems Level Model



Abstracted Process Model: CO₂ release from a wellbore

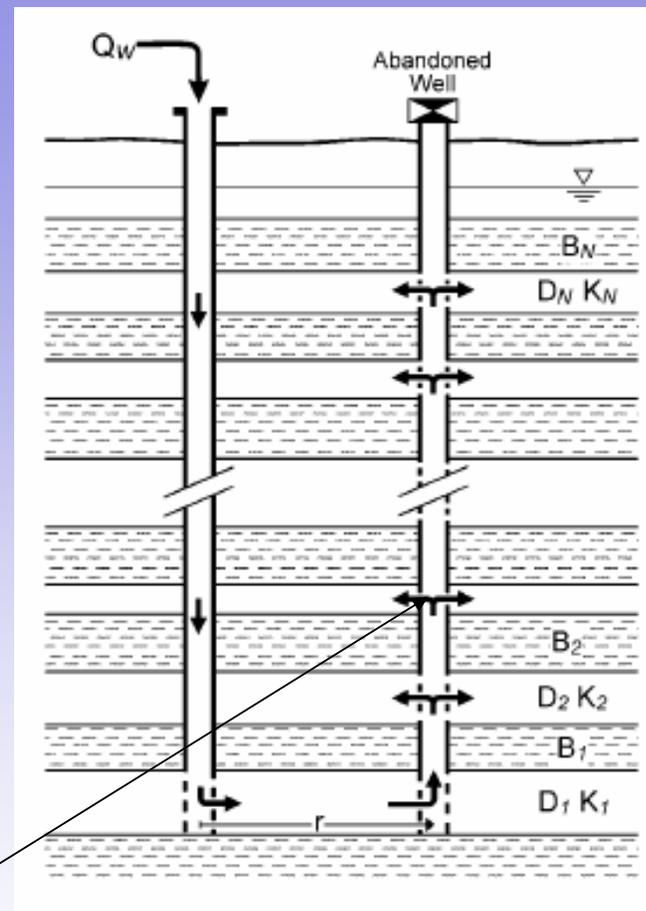
Analytical Solutions for Wellbore Failure

- Obtain leakage rates using Semi-analytical solution by Celia et al. (collaboration with Princeton)
- Current analytical solutions require **wellbore** permeability/porosity changes as a function of time and space

Porosity/Permeability Changes

- SACROC cement-host rock cores are being used to setup laboratory experiments
- SACROC cores are also providing observations and conceptual models for FLOTRAN modeling
- FLOTRAN used to model cement corrosion & precipitation rates in brine-CO₂-cement systems

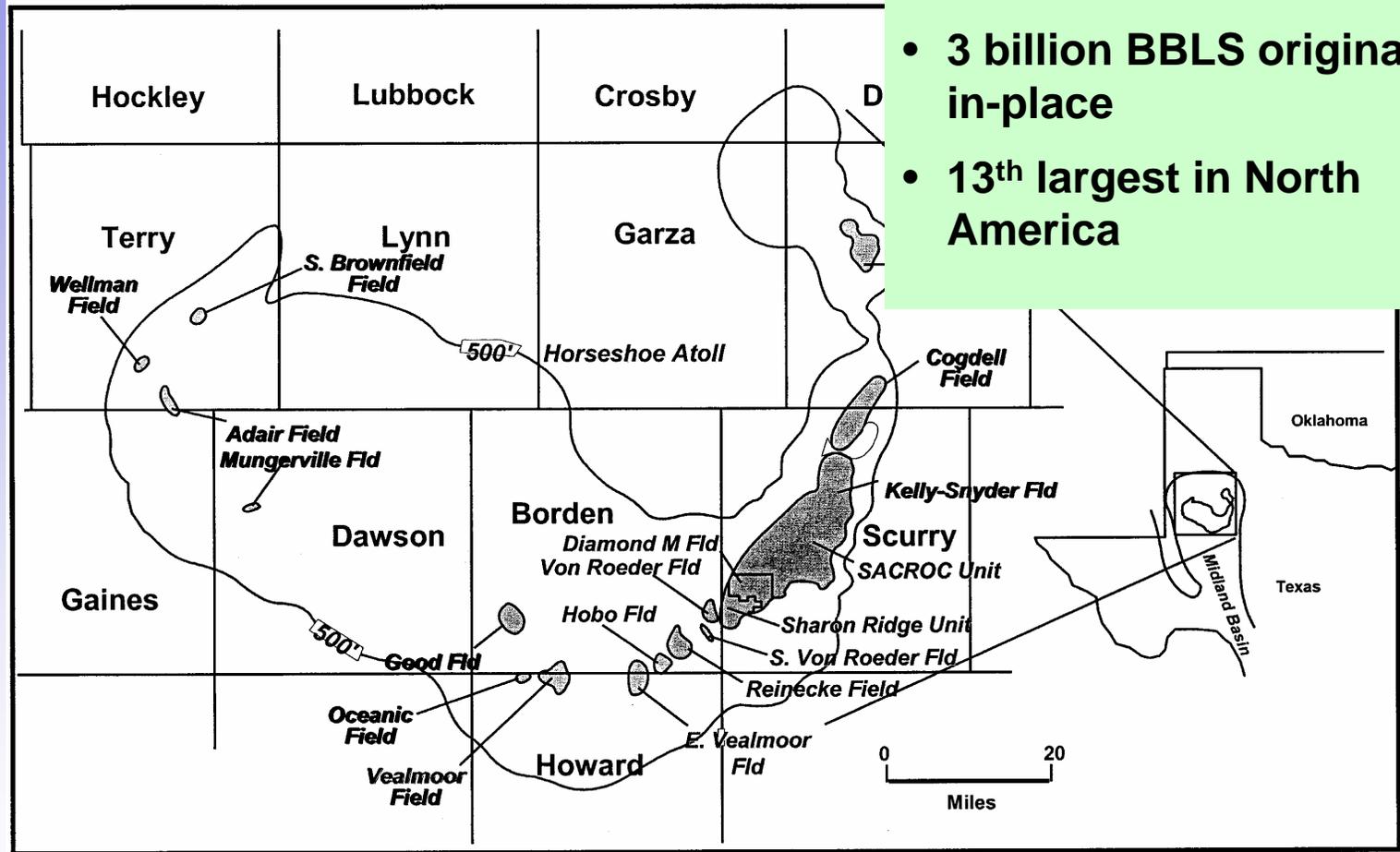
LANL experiments, observations and modeling link physical/chemical processes of cement failure to analytical solution



Nordbotten, J, M. Celia, S. Bachu, Water Resources Research, 2004.

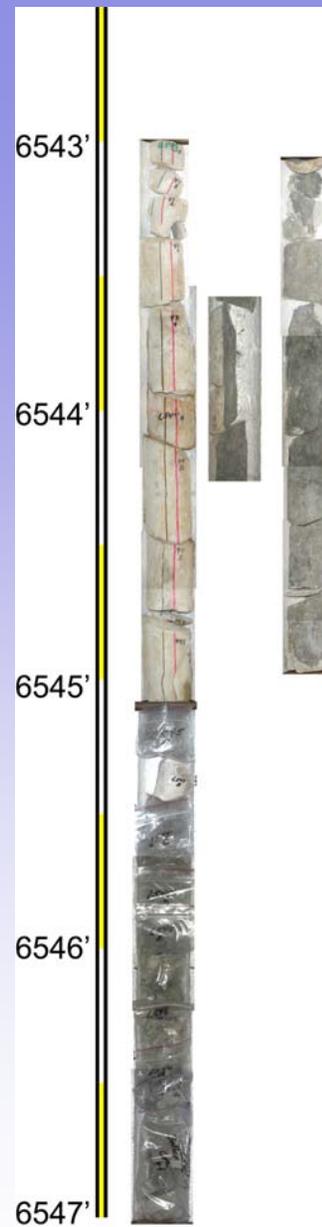
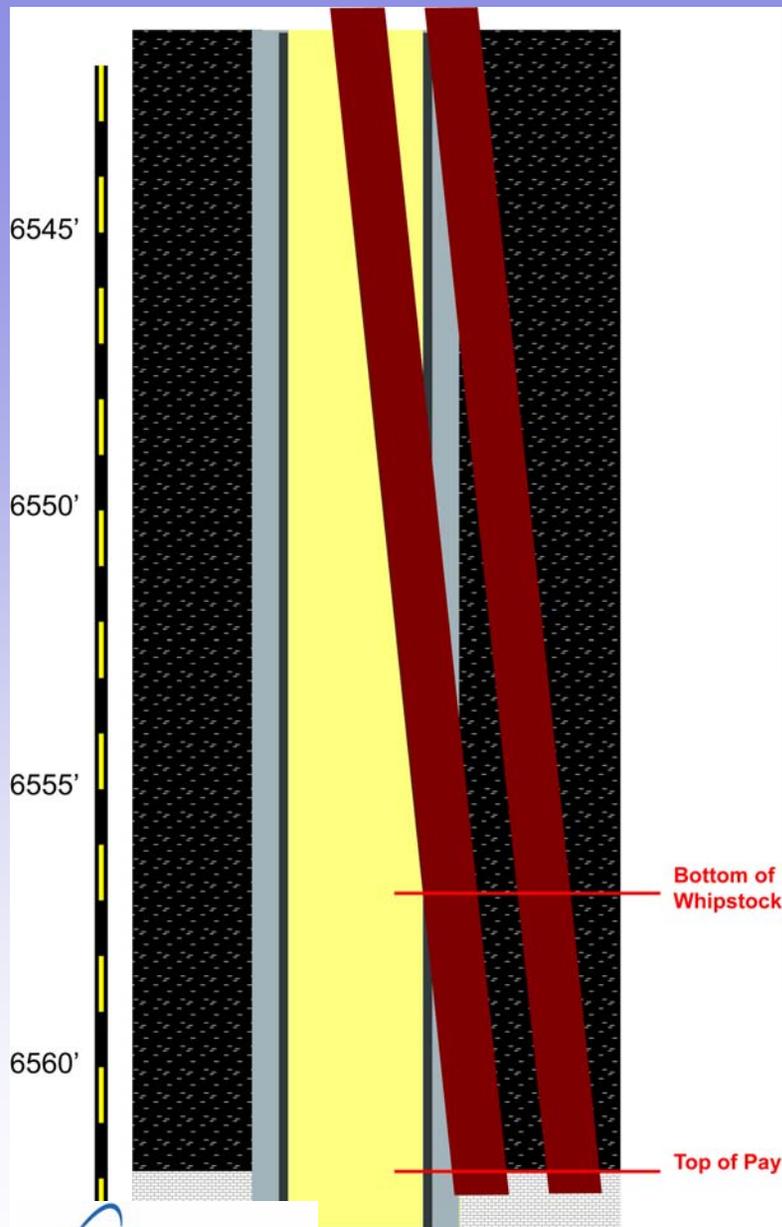
SACROC Overview

- Pennsylvanian age reef system
- Discovered 1948
- 54,000 acres
- 3 billion BBLs original oil in-place
- 13th largest in North America



SACROC Cores

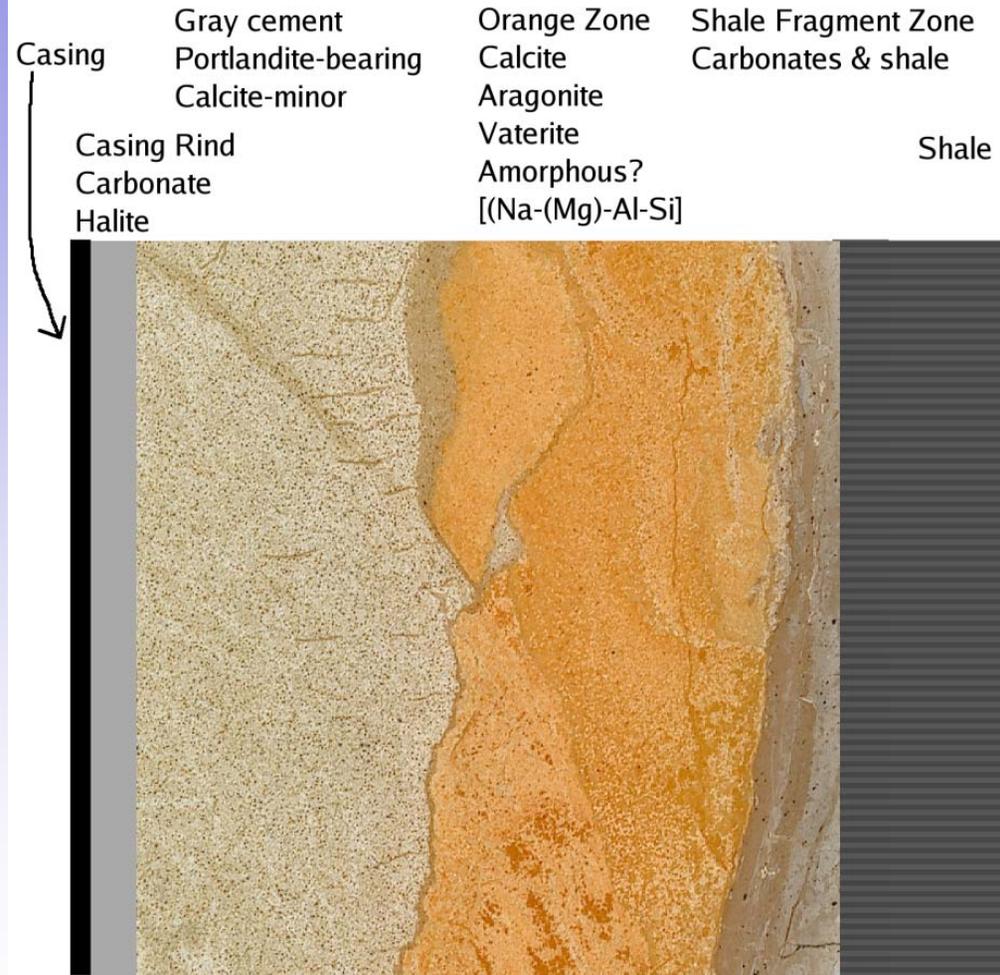
- **50+ yr old portland cement (no admixtures)**
- **30+ yr exposure to CO₂+brine+oil (producer/injector)**
- **shale caprock with limestone reservoir**
- **Test samples using a suite of techniques: thin section, QXRD, SEM, LA-ICP-MS, XRF, LIBS**
pH sensitive dyes, isotopes, strength tests, etc.



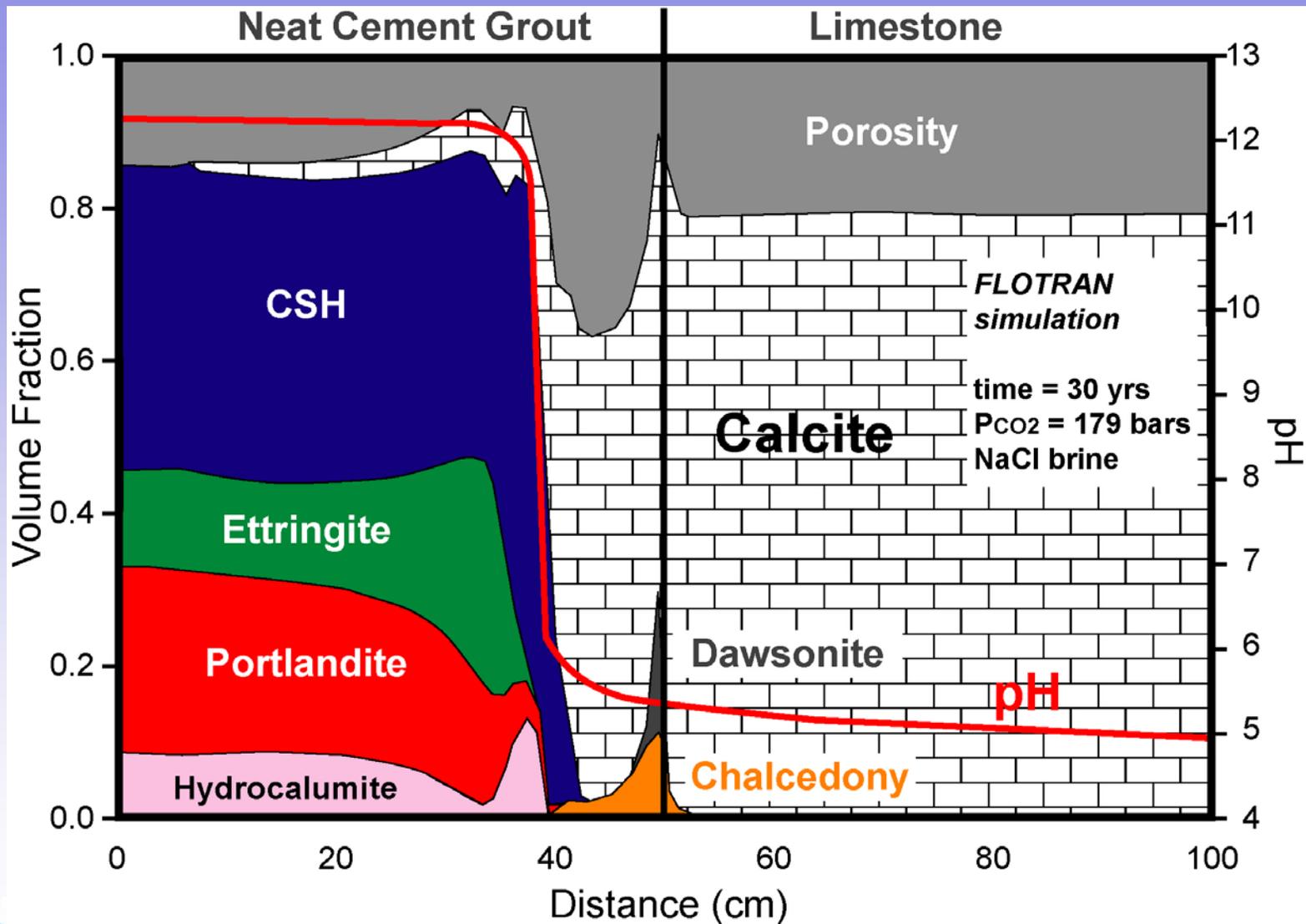
Composite “Section” Observation Summary

- Cement recovered: retains structural integrity
- Shale-cement interface not preserved: low bond quality?
- A thick orange carbonated zone occurs between cement and shale
- Shale fragment zone contains carbonate and “mobile” silica
- Gray cement contains portlandite [$\text{Ca}(\text{OH})_2$]
- FLOTRAN reactive transport model predicts a reaction zone with similar mineralogy

Cross-Section with 6 Distinct Zones



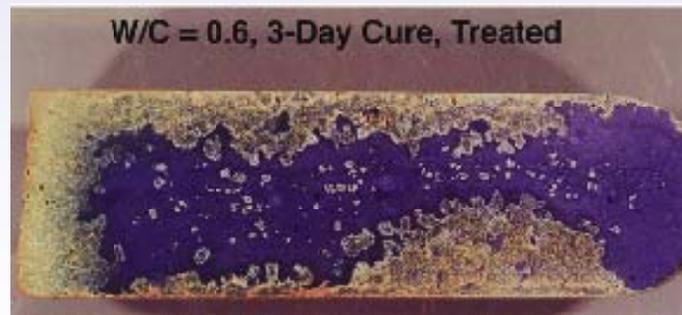
FLOTRAN Reactive Transport Model: Carbonation Front



CO₂-brine-cement Laboratory Experiments



- Experimental work is key to interpreting field observations and constraining modeling results
- Pressurized CO₂ (2000 psi) mixed into brine solution
- pH sensitive dyes Ca(OH)₂ (high pH) -> CaCO₃ (low pH)
- Determine critical role of cement water saturation on carbonation rate

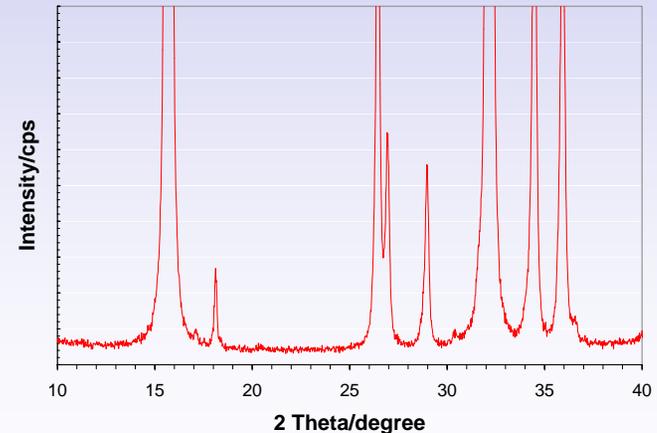
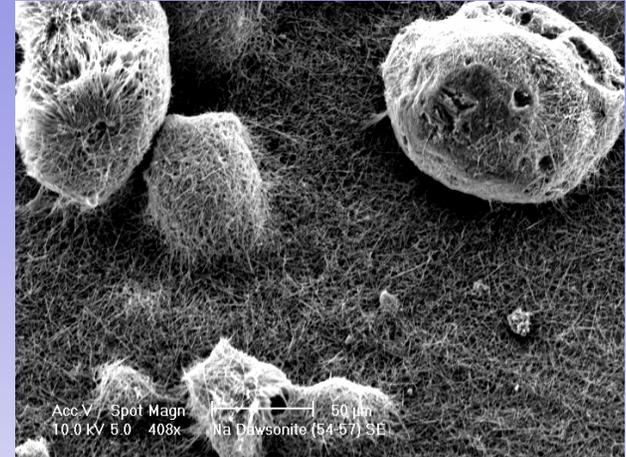


Mineral/Fluid Experiments: Synthesizing Dawsonite

Mineral-fluid experiments address nanoscale processes, including :

- Changes Mineralogy
- Precipitation/Dissolution

Dawsonite was synthesized at 150C from aqueous solution comprised of $\text{NaHCO}_3(\text{aq})$, $\text{Al}(\text{OH})_3(\text{aq})$, and DI H_2O . The solid was triple rinsed and centrifuged, then analyzed for crystallinity and purity using XRD.

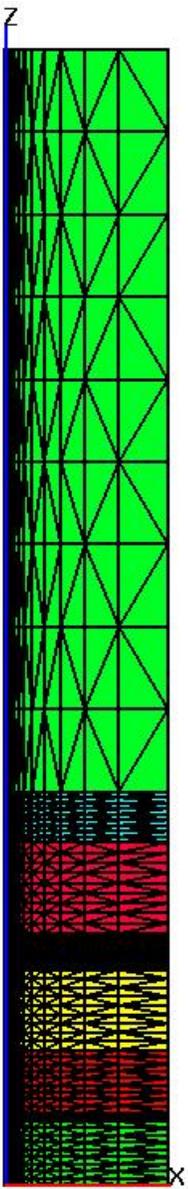


Field Scale Simulations using the Los Alamos code FEHM

- Multiphase heat and mass transfer in porous and fractured rock
- Finite-volume approach yields more accurate mass balances in complicated geometries
- Powerful grid generation capabilities
- Coupled flow, stress, and chemical reactions
- FEHM has been coupled to GOLDSIM in support of systems level environmental decision making (Repository Science, LANL Environmental Performance Assessment)

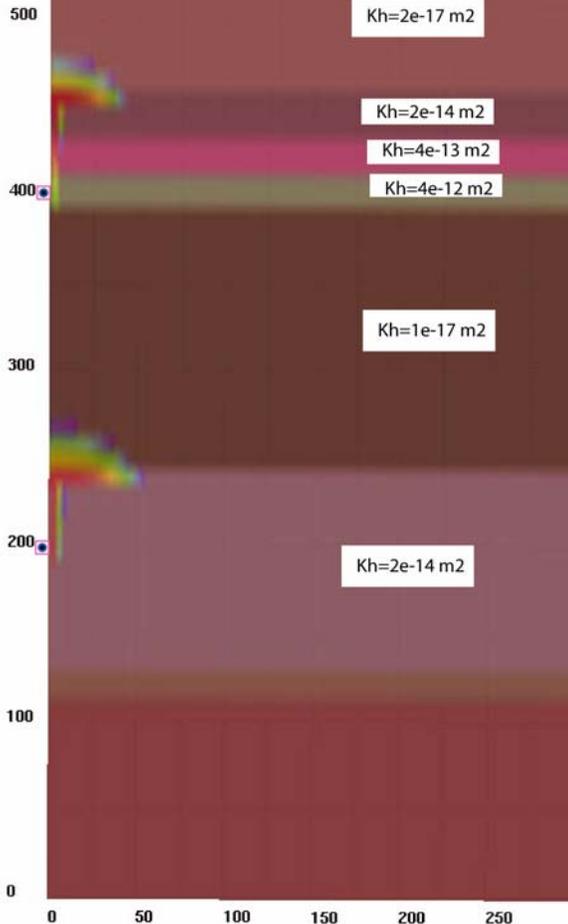
Reservoir Scale: FEHM Radial Leakage Simulation

- o Radial two-dimensional simulation
- o Leakage from a well-bore into the formation
- o Layers of shale, sandstone and limestone representing SACROC stratigraphy
- o Shale cap rock effectively traps leak for 30 yr simulation
- o Leakage above cap rock moves vertically



$K_v = K_h$ Injection at 200 m and 400 m
1890 tons in 3 years

Elevation

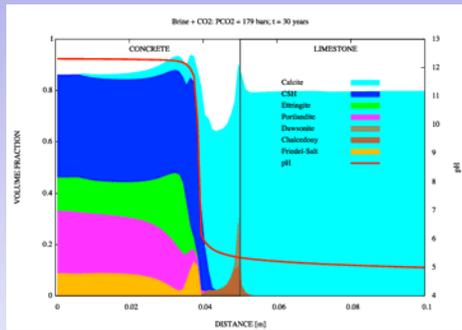


FEHM Simulation Results

- Preliminary calculations of leakage from a well
- Future work:
 1. FEHM will be linked to Goldsim
 2. Refining simulations of CO_2 migration through borehole following a leak

GIS Knowledge Base

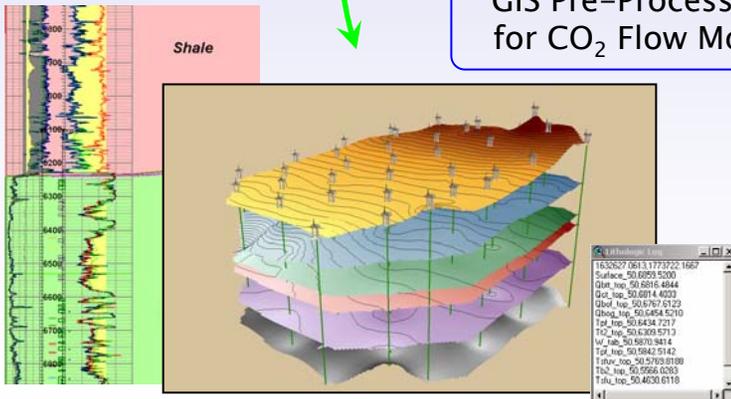
Cement Reaction Modeling



Cement Mineralogy
Brine Chemistry

Cement Degradation Rates

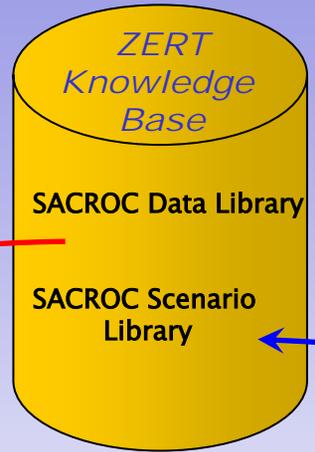
GIS Pre-Processing for CO₂ Flow Model



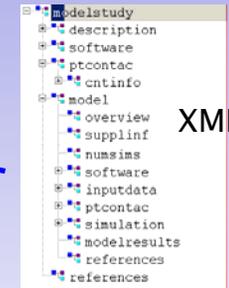
Stratigraphy
Material Properties
Location and fluxes of
CO₂ Leaks

CO₂ Flow Modeling

FEHM
CO₂ / water / heat /
reaction / stress /
flow model



Model Warehousing



XML

Model Documentation

Systems Modeling
CO₂ migration rates

