Application of Numerical Models to Development of the Frio Brine Storage Experiment

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Application of Numerical Models to Development of the Frio Brine Storage Experiment

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Presentation to EPA 4/05 Houston TX

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- Schlumberger: T. S. Ramakrishna, Nadja Mueller, Austin Boyd, Mike Wilt
- Oak Ridge National Lab: Dave Cole, Tommy Phelps, David Riestberg
- Lawrence Livermore National Lab: Kevin Knauss, Jim Johnson
- Alberta Research Council: Bill Gunter, John Robinson, Bernice Kadatz
- Texas American Resources: Don Charbula, David Hargiss
- Sandia Technologies: Dan Collins, “Spud” Miller, David Freeman; Phil Papadeas
- BP: Charles Christopher, Mike Chambers
- SEQUIRE – National Energy Technology Lab: Curt White, Rod Diehl, Grant Bromhall, Brian Stratizar, Art Wells
- Paulsson Geophysical – Bjorn Paulsson
- University of West Virginia: Henry Rausch
- USGS: Yousif Kharaka, Bill Evans, Evangelos Kakauros, Jim Thorsen
- Praxair: Joe Shine, Dan Dalton
- Australian CO2CRC (CSRIO): Kevin Dodds, Don Sherlock
- Core Labs: Paul Martin and others

Categories of Models

1) Planning models

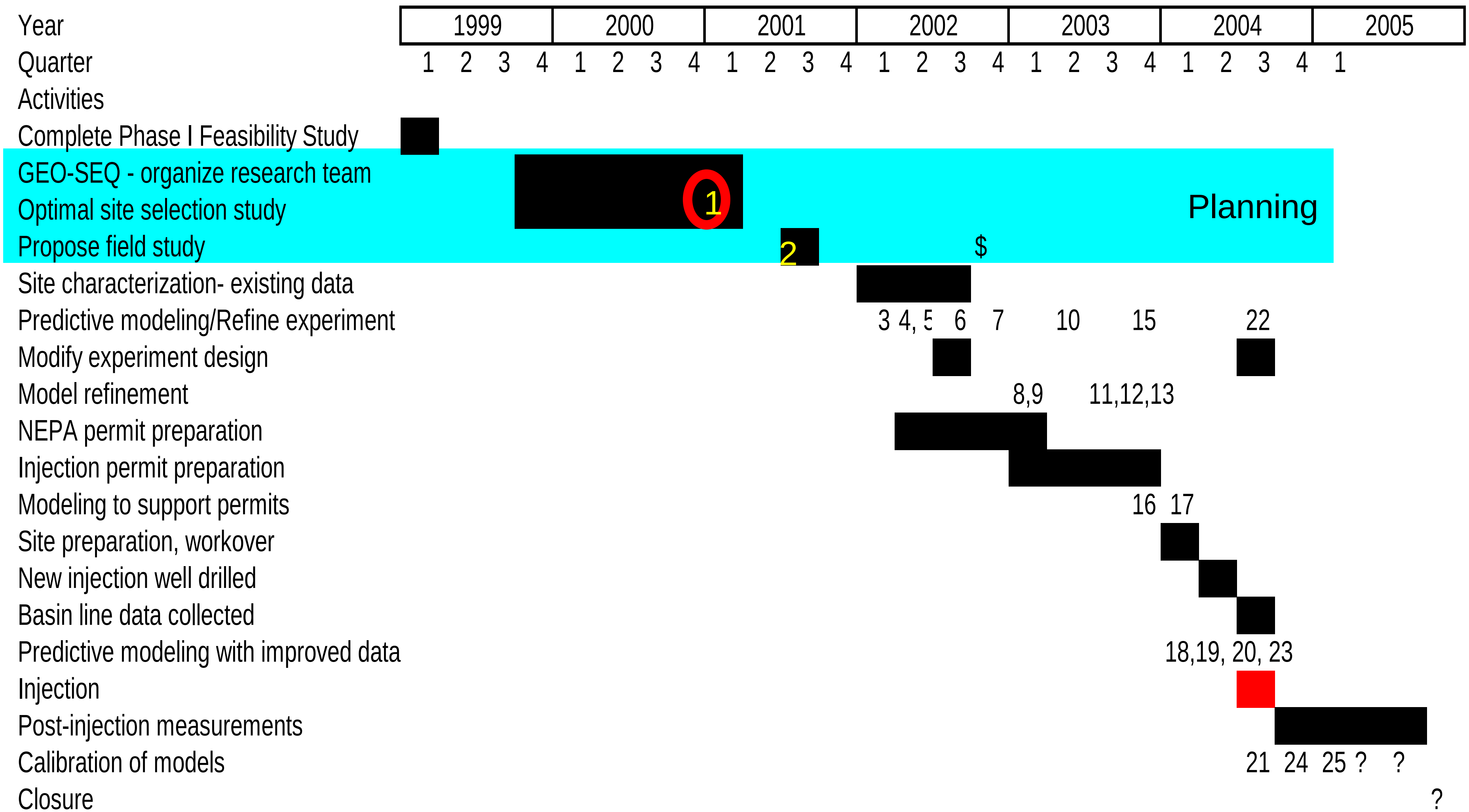
(2) Predictive models

(3) Calibration models

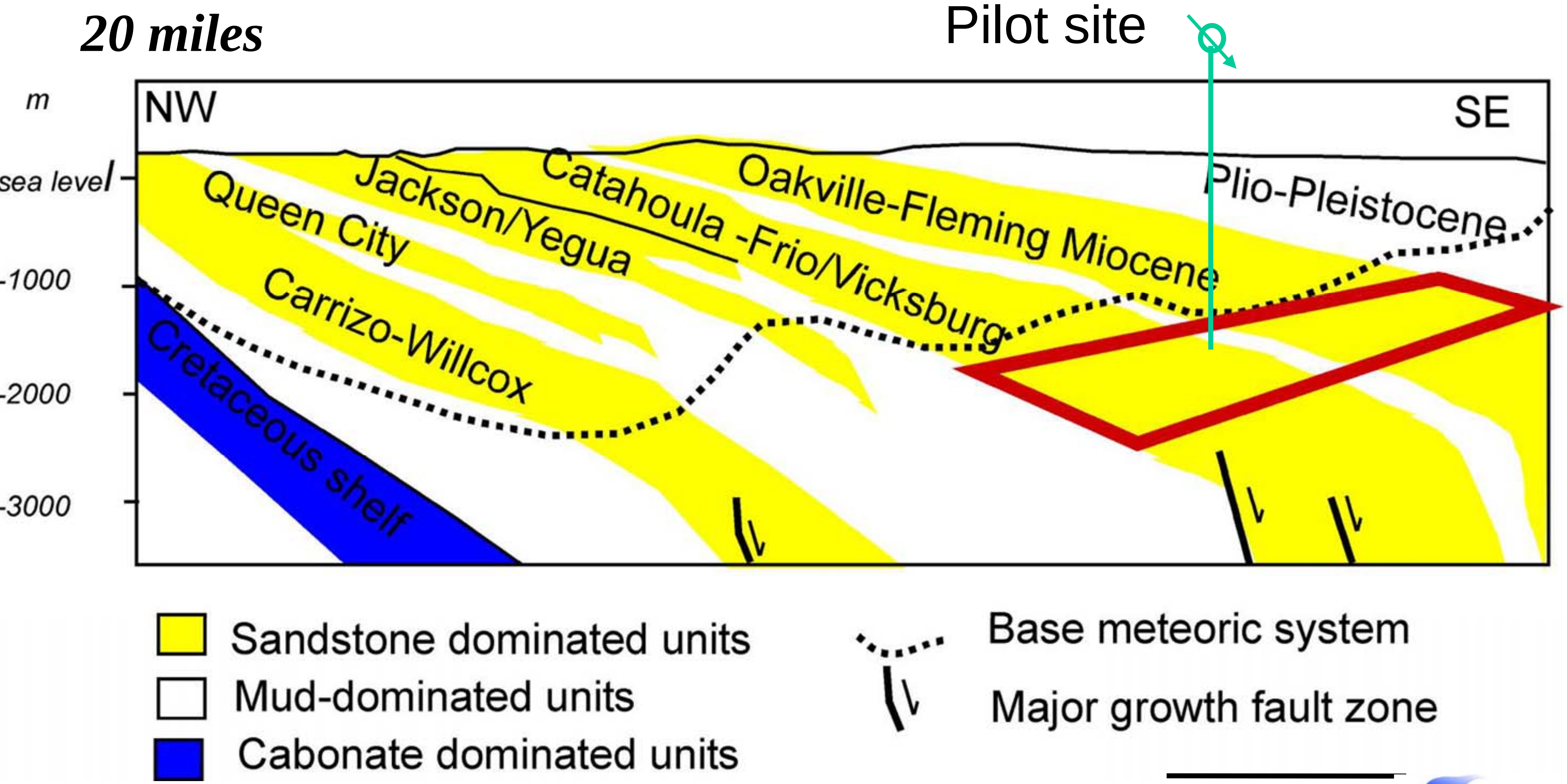
All models shown used LBNL TOUGH2

Other co-operating modeling teams: UT-CPGE, PNL, Schlumberger

Evolution of Frio Project – Role of Modeling

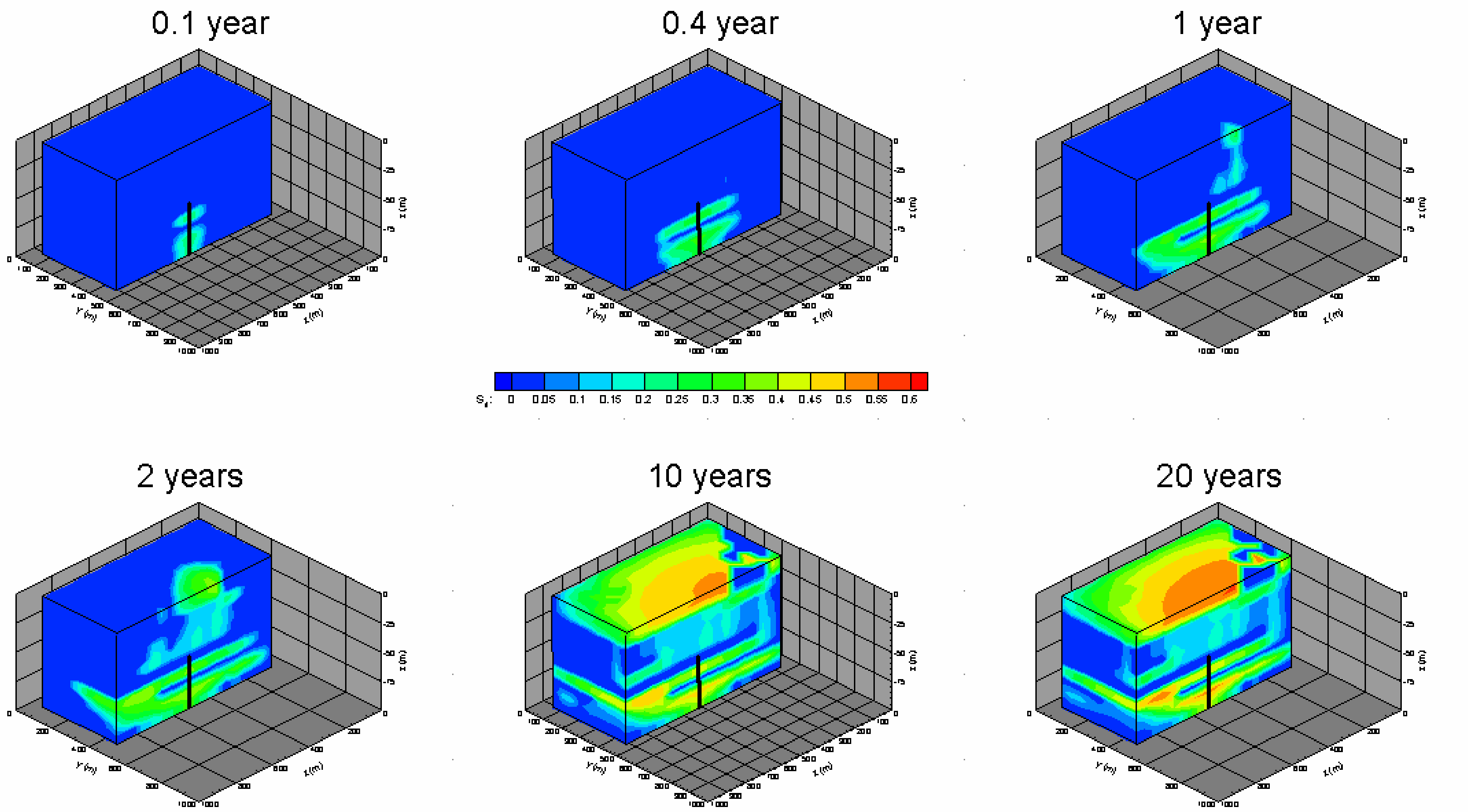


Selecting the Frio Formation as an Optimal Unit to Store CO2



Modified from Galloway and others, 1982

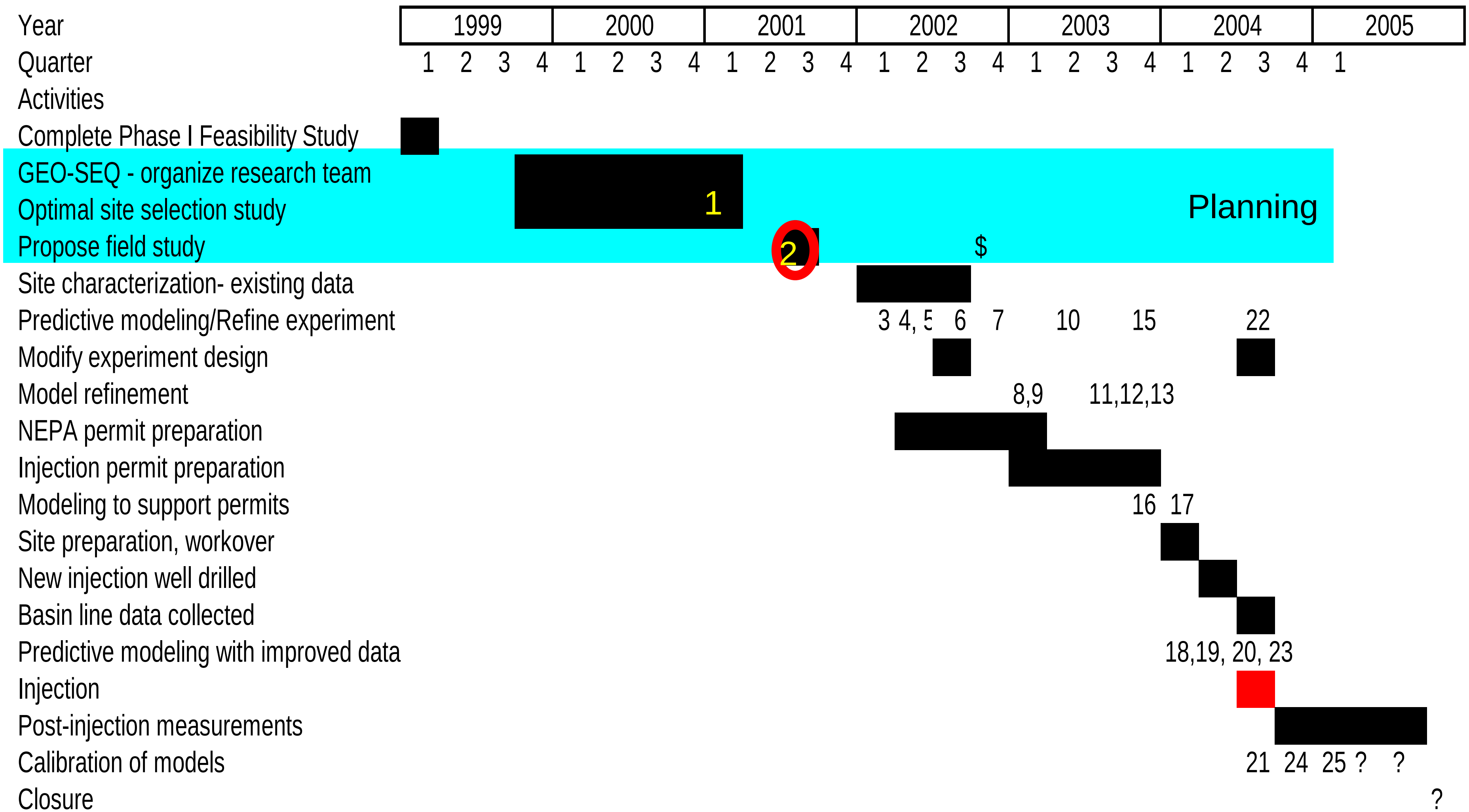
Generic Frio Model – Effect of Layering on Capacity Assessment



Probabilistically generated Frio-like heterogeneity

5/10/01

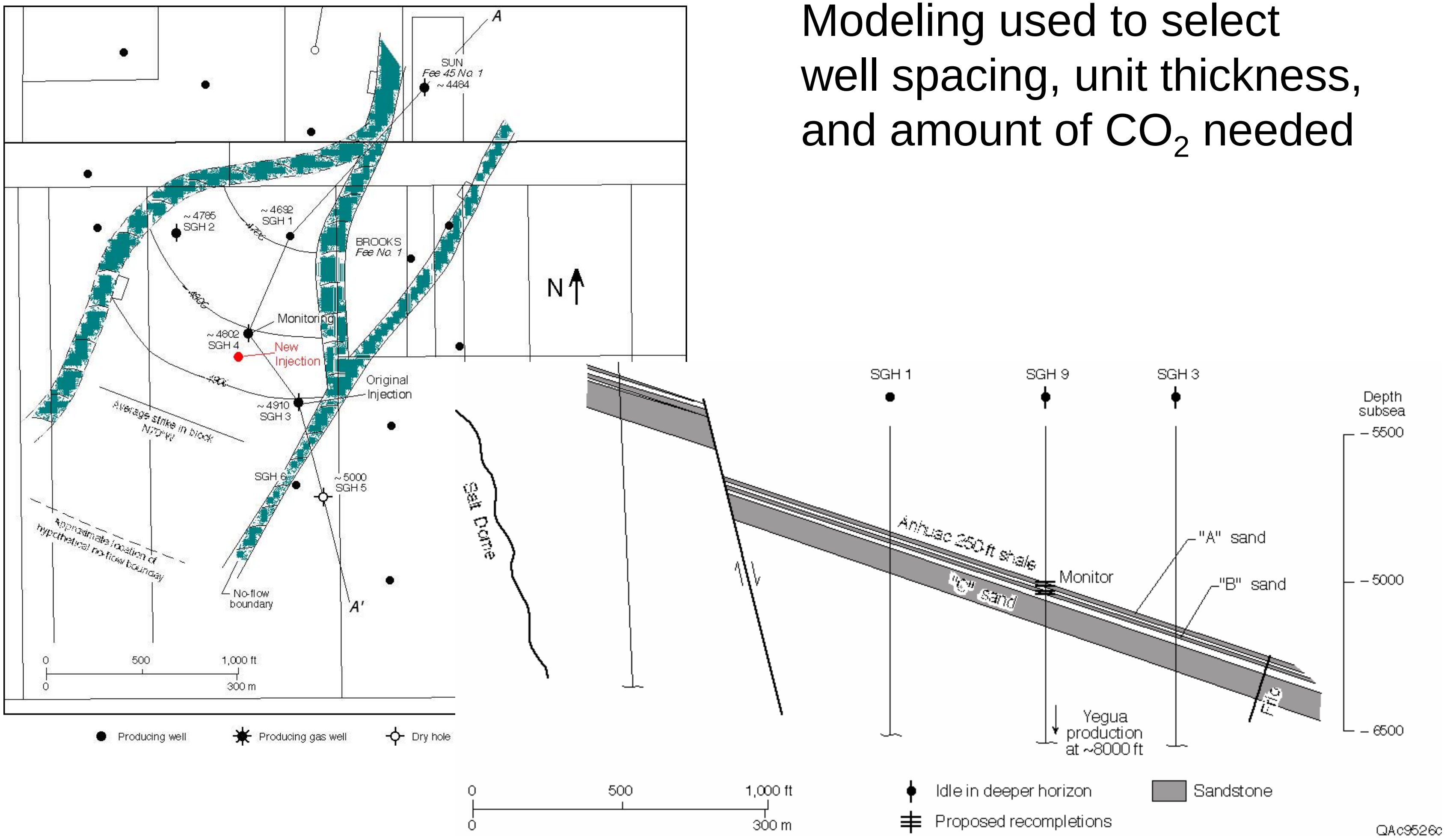
Planning



Year
Quarter
Activities
Complete Phase I Feasibility Study
GEO-SEQ - organize research team
Optimal site selection study
Propose field study
Site characterization- existing data
Predictive modeling/Refine experiment
Modify experiment design
Model refinement
NEPA permit preparation
Injection permit preparation
Modeling to support permits
Site preparation, workover
New injection well drilled
Basin line data collected
Predictive modeling with improved data
Injection
Post-injection measurements
Calibration of models
Closure
1999
2000
2001
2002
2003
2004
2005
1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1 2 3 4 1
1
Planning
2
$
3 4, 5 6 7 10 15 22
8,9 11,12,13
16 17
18,19, 20, 23
21 24 25 ? ?
?

Simple Characterization for Proposal

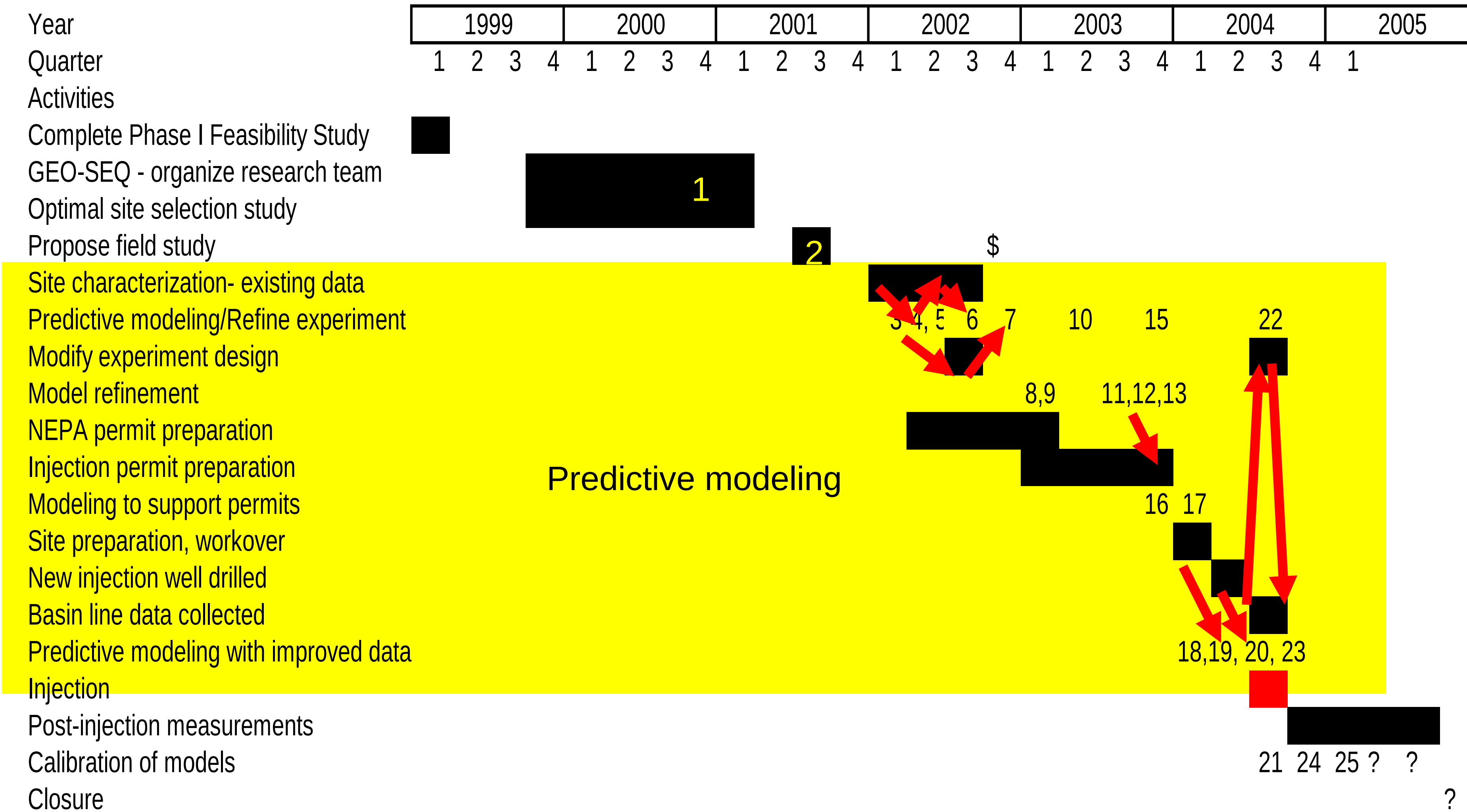
Modeling used to select well spacing, unit thickness, and amount of CO_2 needed



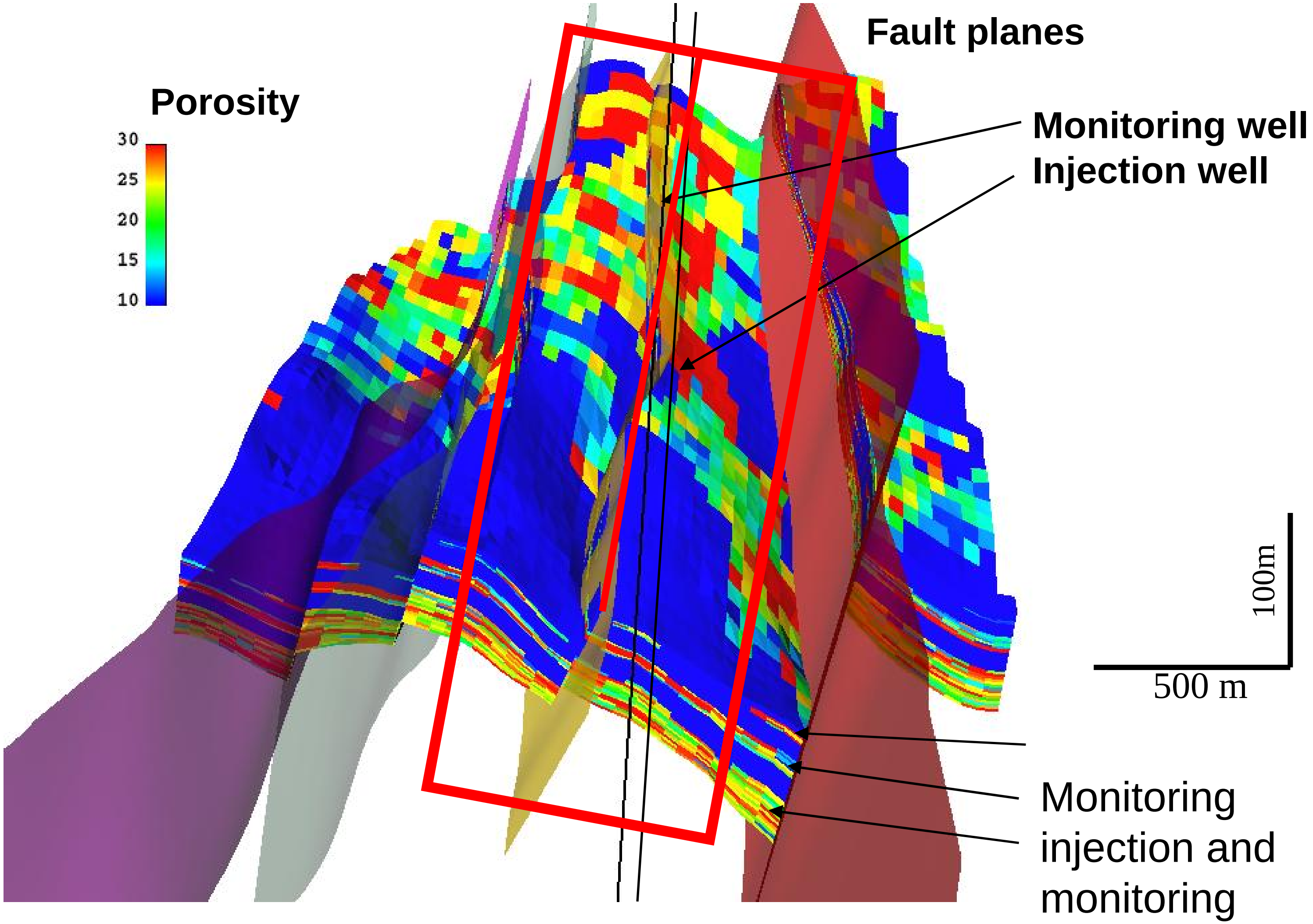
Using Modeling for Planning

- Pressure increase within regulatory limits
  - permeability, injection rate, outer boundary conditions
- CO_2 arrival at observation well
  - amount of CO2 injected, thickness of injection interval, well separation
- Affordable duration of field test
  - injection rate, thickness of injection interval, well separation

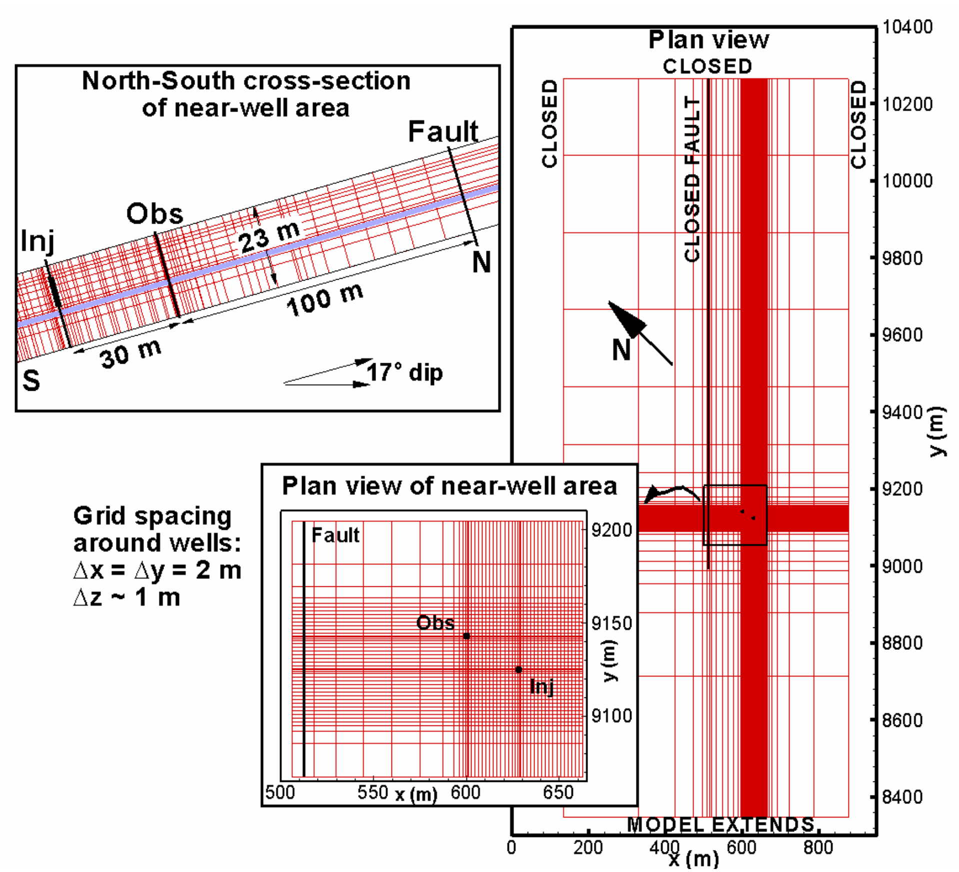
Predictive Modeling



Reservoir Model - Exported to numerical model



Final Model Grid

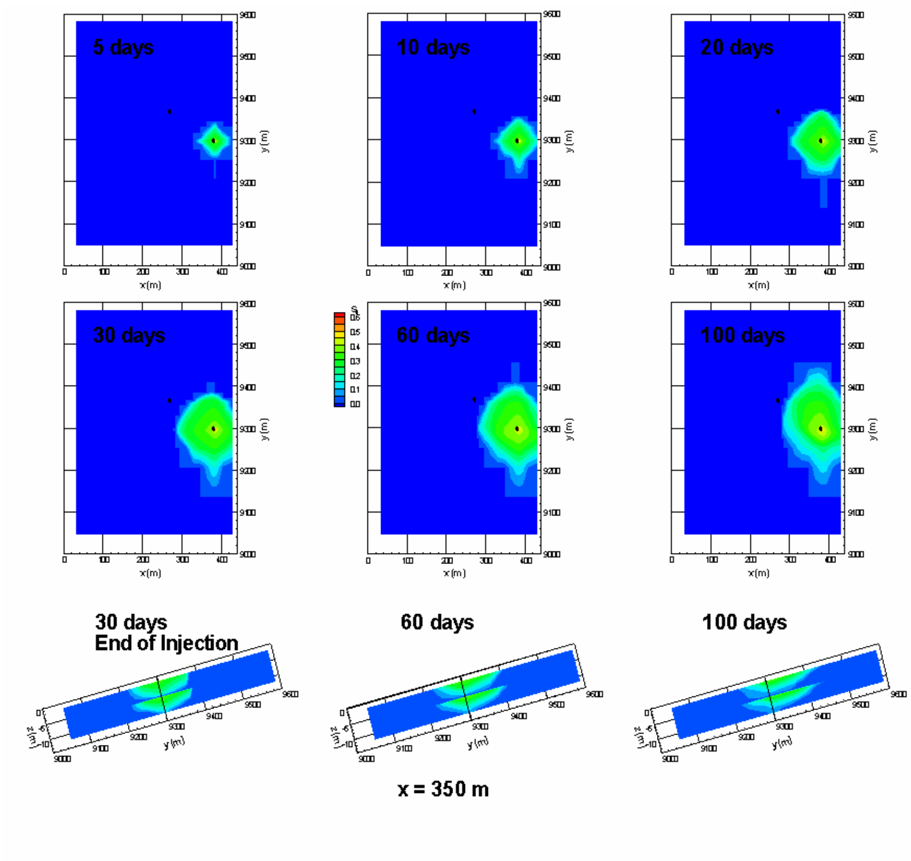


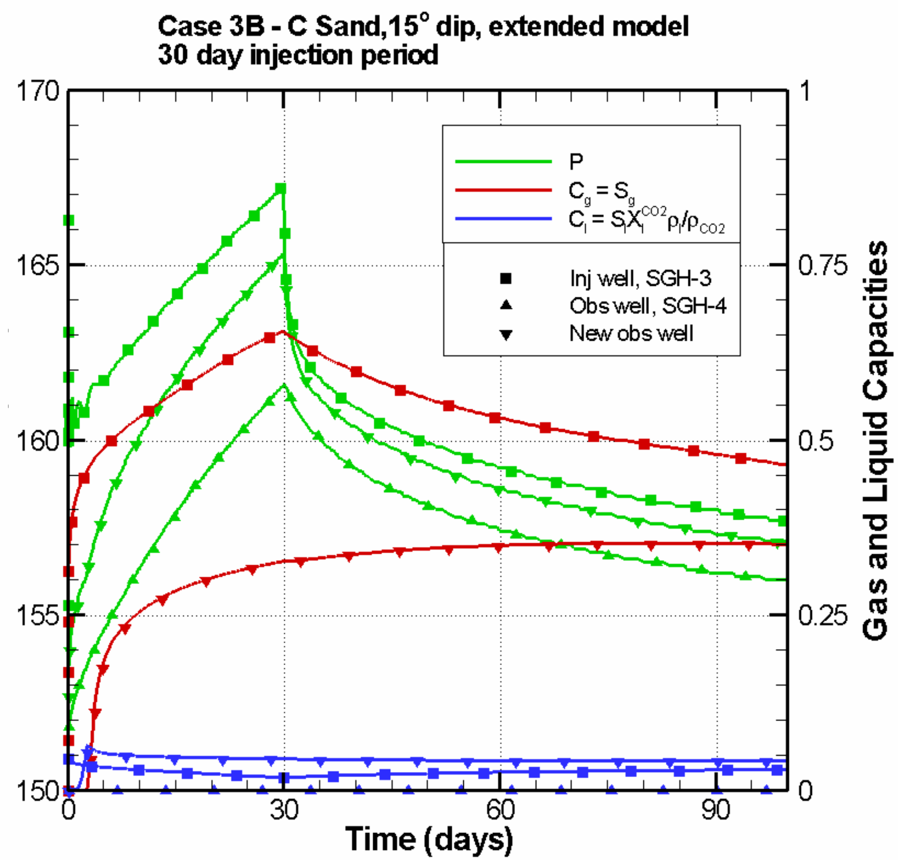
Predictive Modeling to Obtain Project Objectives

- Sensitivity analysis
  - Interaction of uncertainty in data, uncertainty in model parameter selection, and uncertainty in results
- Tool selection (Planning = hypothesis of tool success in detecting expected conditions)
  - Seismic, EM, Saturation logs
- Propose testable hypotheses
  - Saturation history resulting from predicted residual saturation; timing of breakthrough, geochemical processes

Will CO2 arrive?

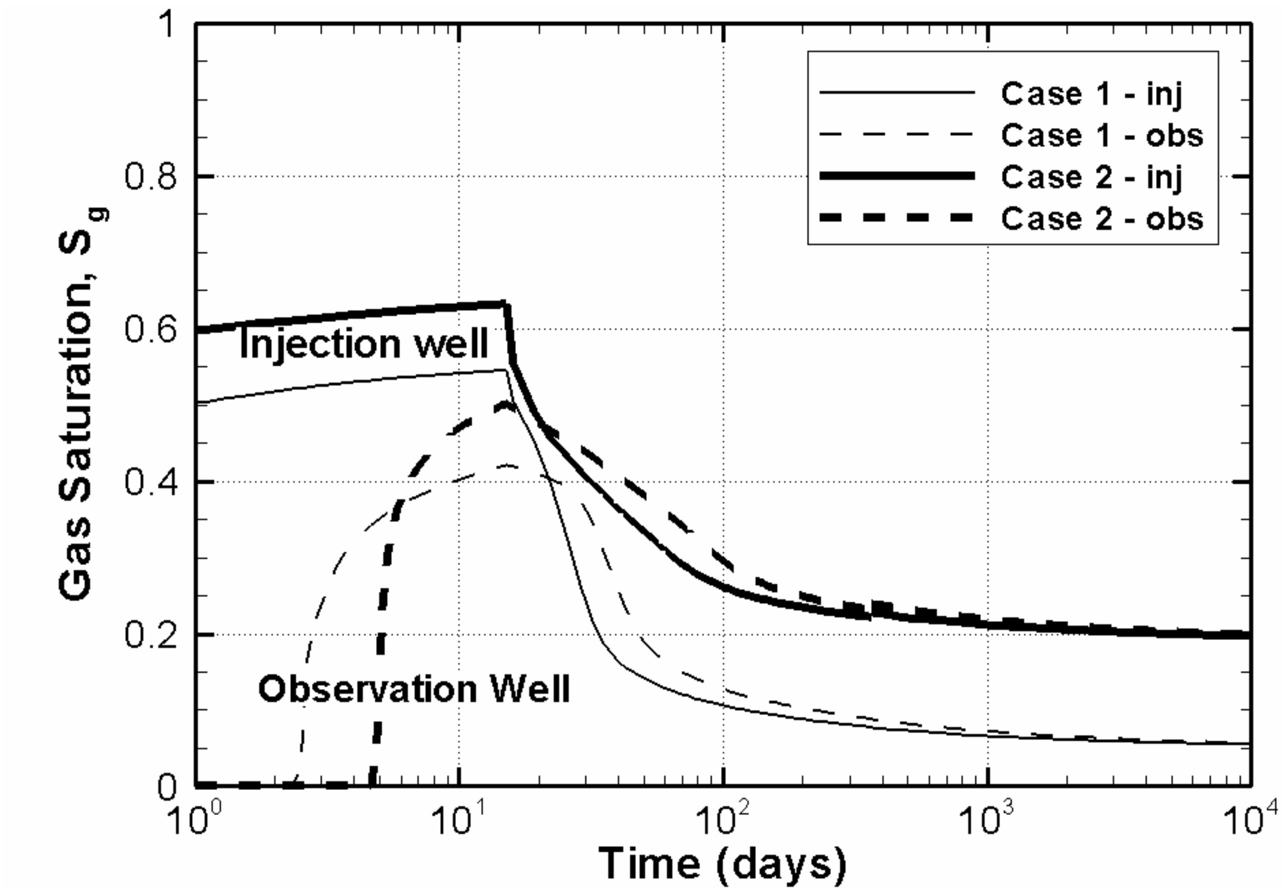
Experimental design interaction with geologic uncertainties





2/2/03

Predicted Saturation for History Match – Sensitivity to Residual Saturation

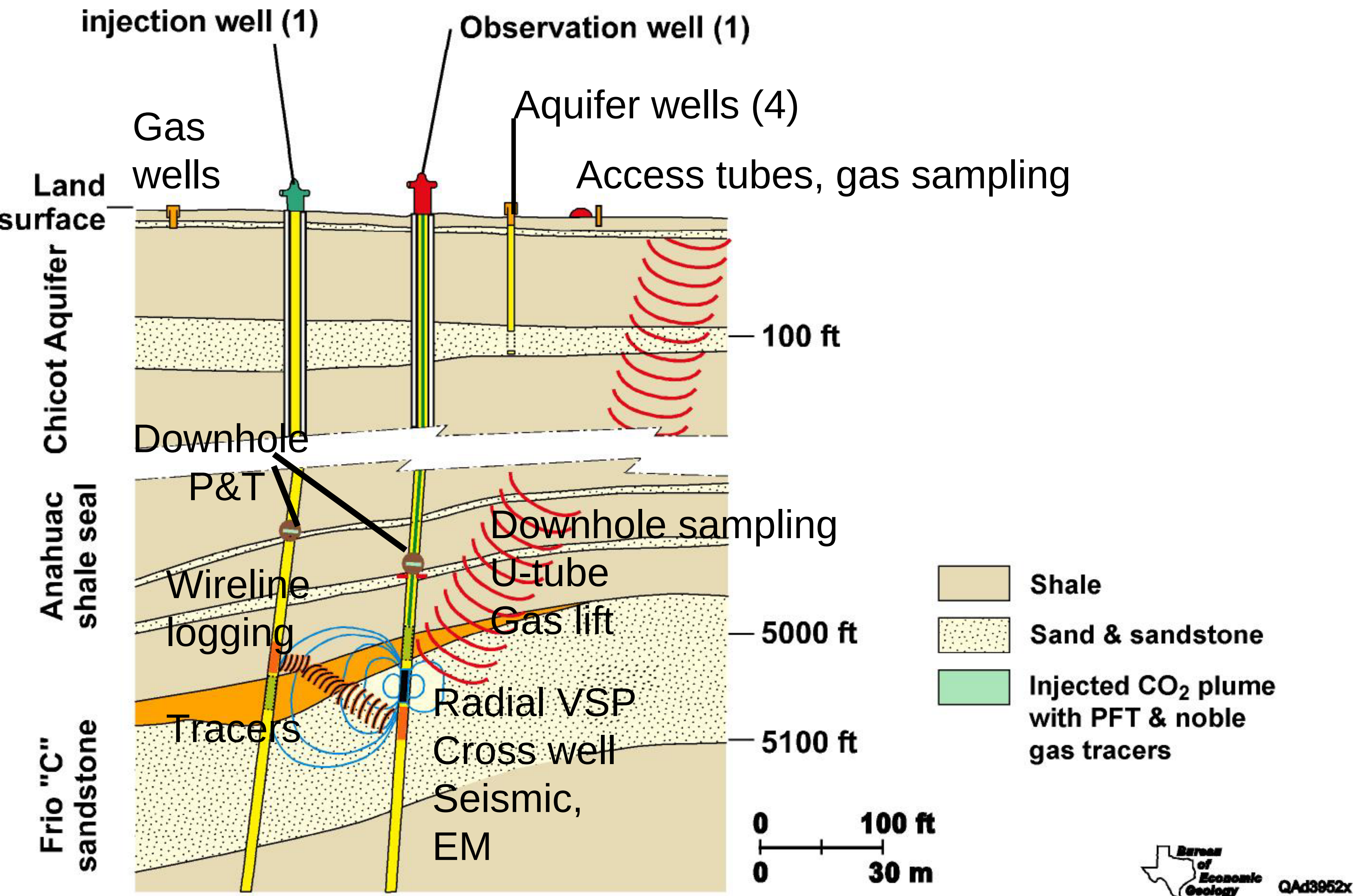


Case 1 Slr=0.30; Sgr=0.05

Case 2; Slr varies, ~ 0.10, Sgr varies, ~0.25

TOUGH2 model

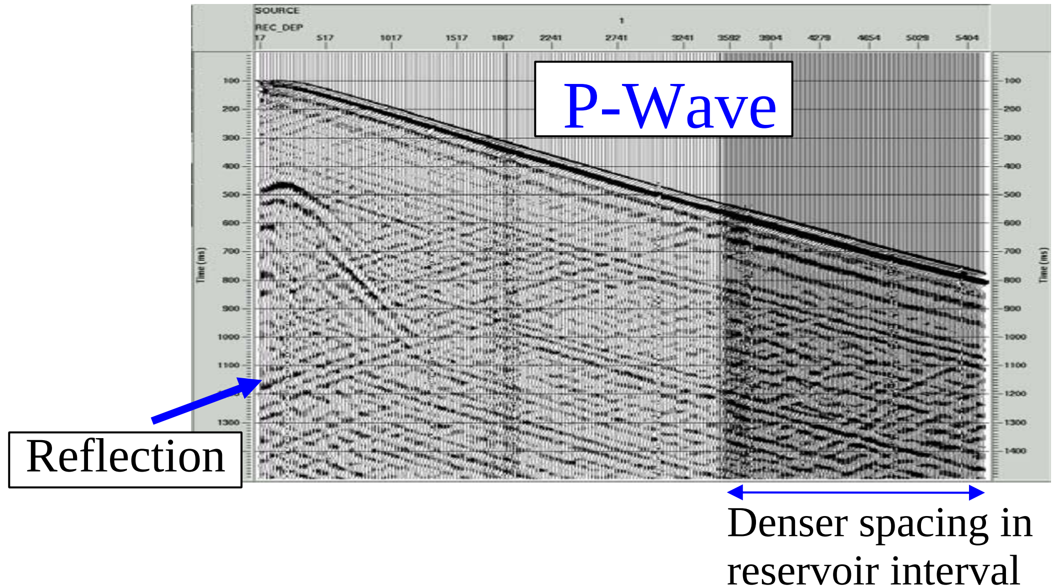
Final Design Monitoring Program at Frio Pilot



Models Used to Design Pre-Injection Geophysics

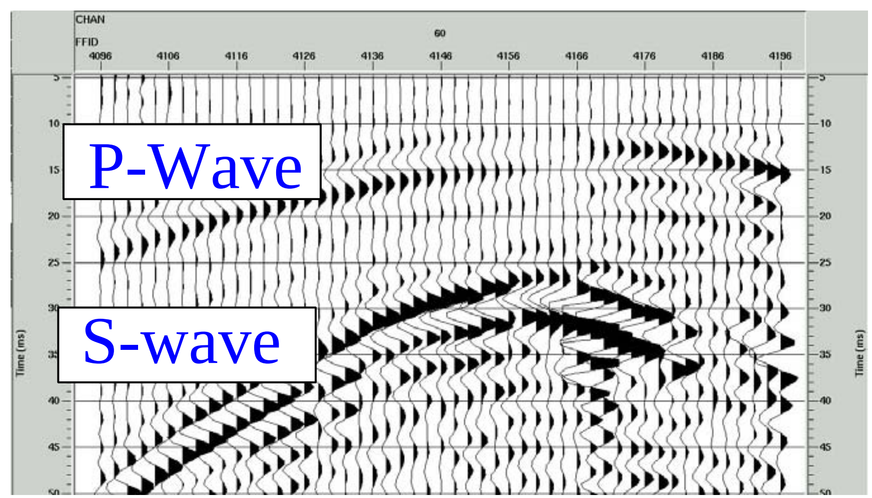
VSP

- Designed for monitoring and imaging
- 8 Explosive Shot Points (100 – 1500 m offsets)
- 80 – 240 3C Sensors (1.5 – 7.5 m spacing)



Cross Well

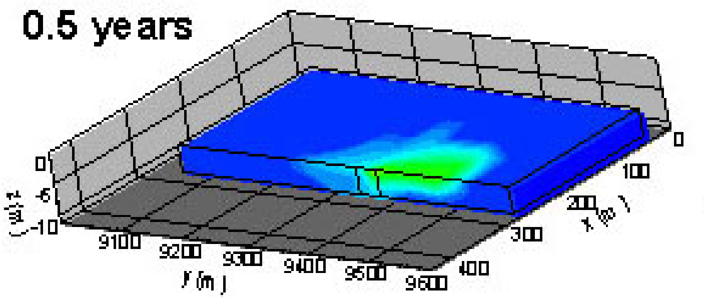
- Designed for monitoring and CO_2 saturation estimation
- P and S Seismic and EM
- > 75 m coverage @ 1.5 m Spacing (orbital-vibrator seismic source, 3C geophone sensor)
- Dual Frequency E.M.



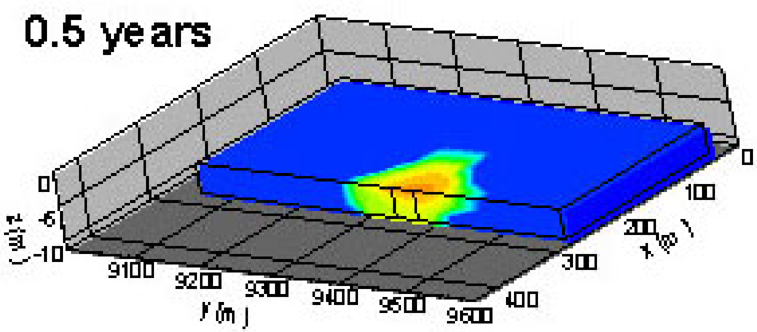
Tom Daley, LBNL: Paulsson Geophysical

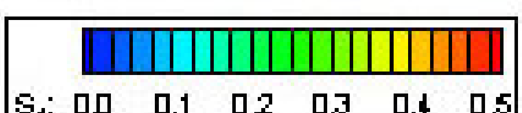
Hypothesis: Residual Saturation Controls Permanence and can be measured during experiment

Residual gas saturation of 5%



Residual gas saturation of 30%

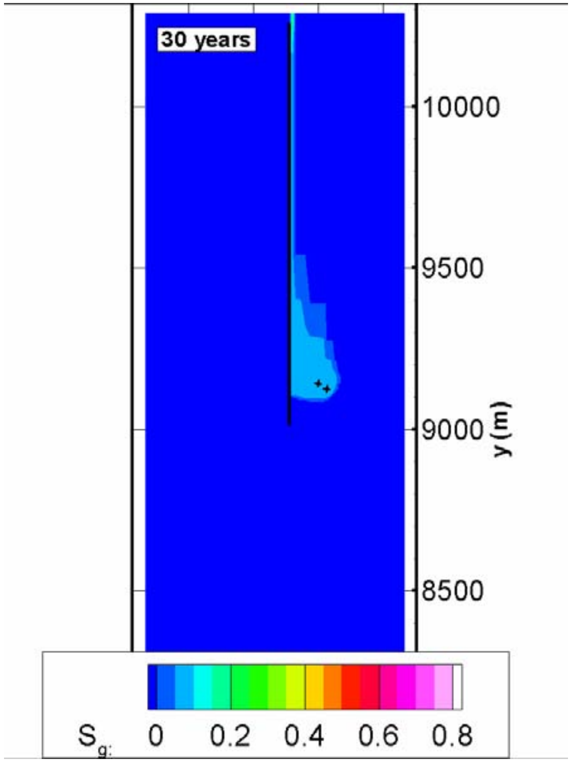




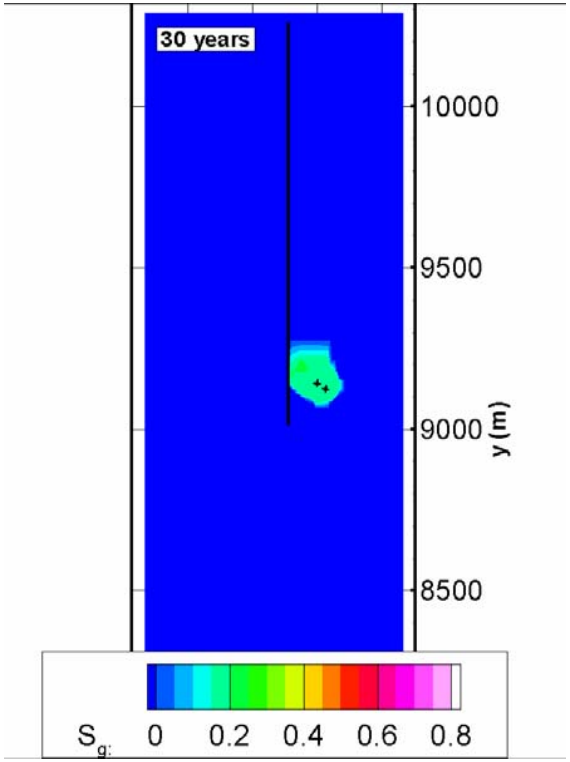
- Modeling has identified variables which appear to control CO_2 injection and post injection migration.
- Measurements made over a short time frame and small distance will confirm the correct value for these variables
- Better conceptualized and calibrated models will be used to develop larger scale longer time frame injections

TOUGH2 simulations
C. Doughty LBNL

Modeled Long-term Fate - 30 years

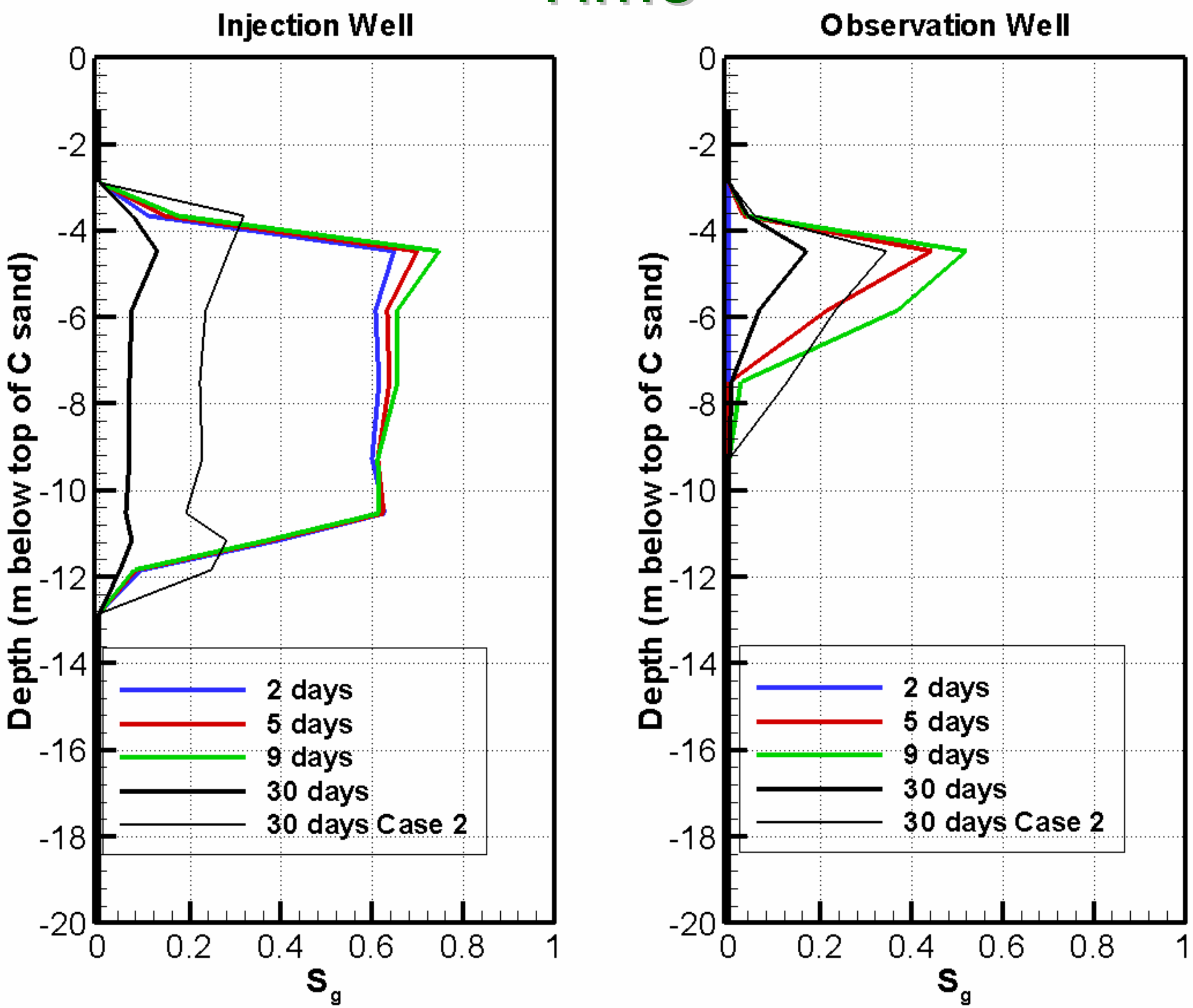


Minimal Phase trapping

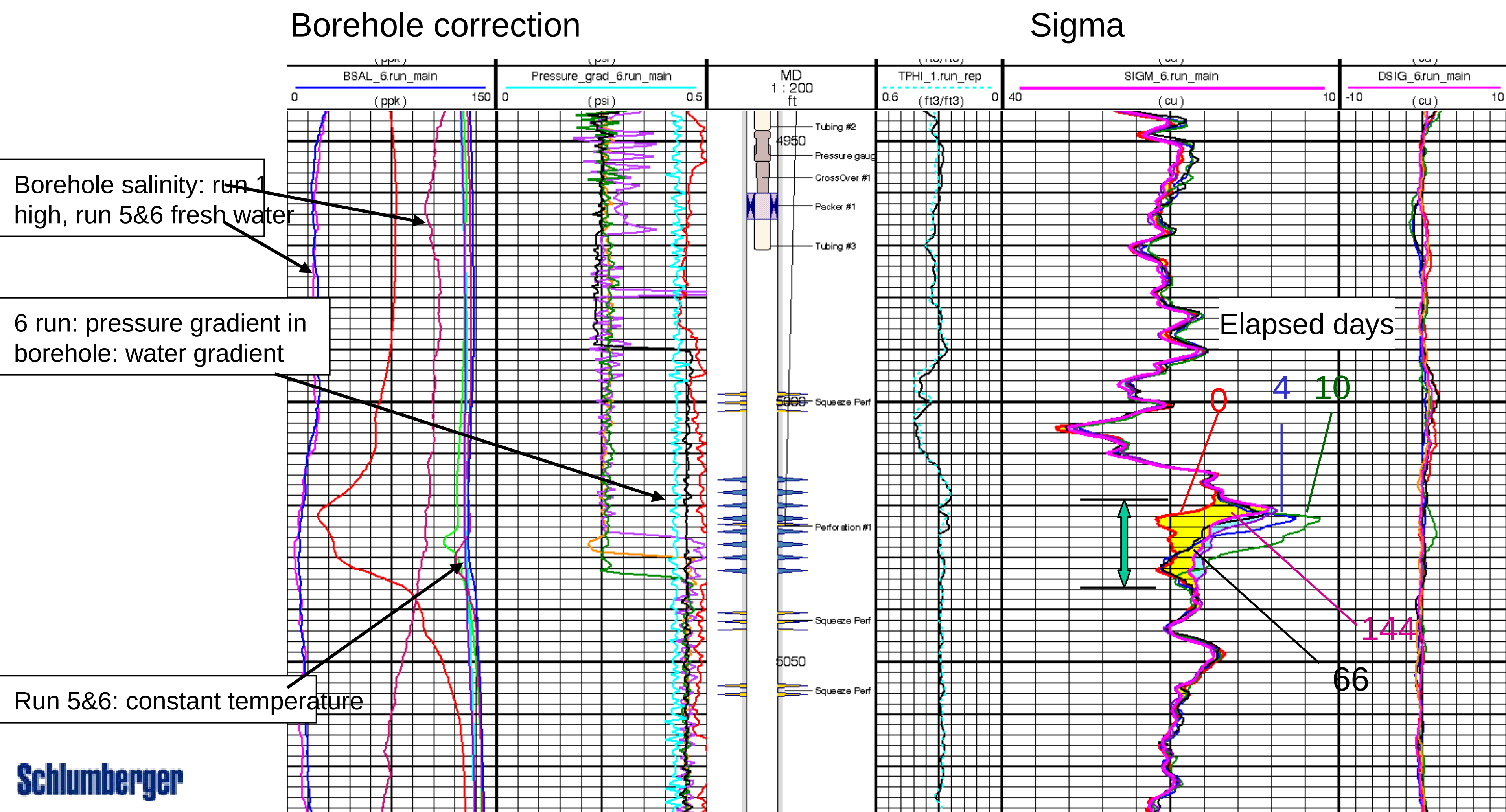


Predicted significant phase trapping

Predicted Saturation Distribution Through Time

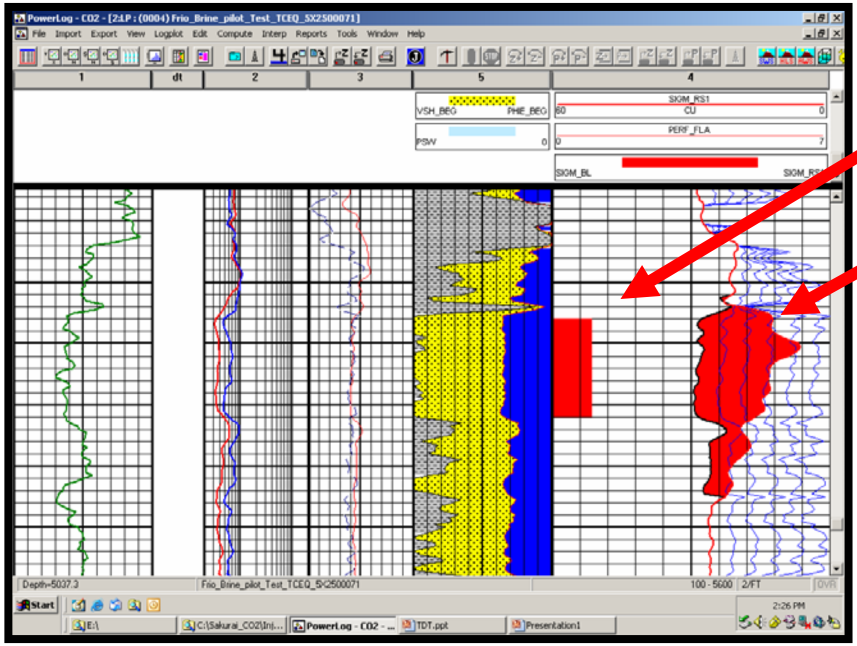


Observed Saturation Distribution Through Time-Injection Well



Schlumberger

Observed Saturation Distribution Through Time- Injection Well

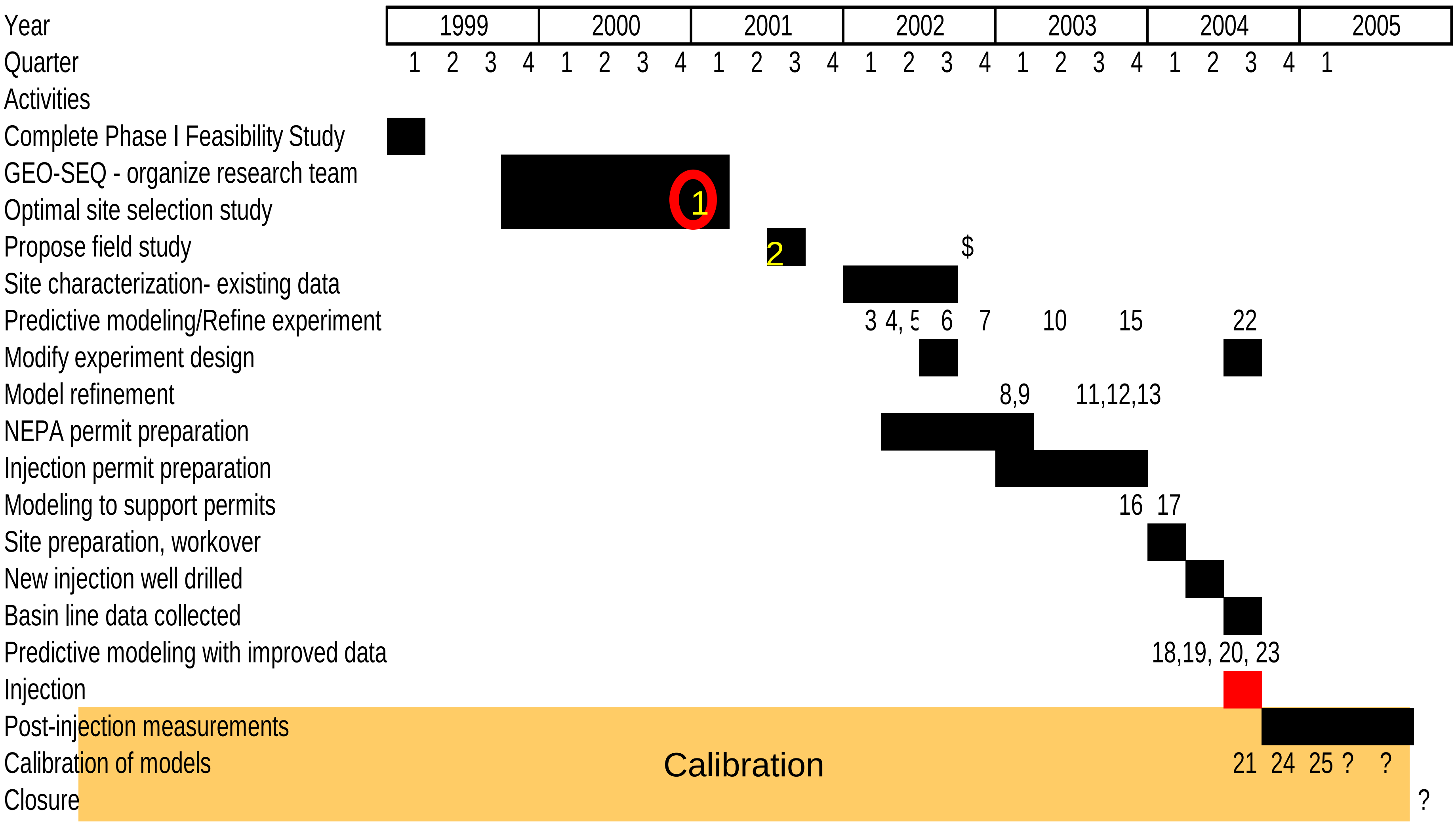


Perforations

Change in saturation

S.Sakurai, BEG

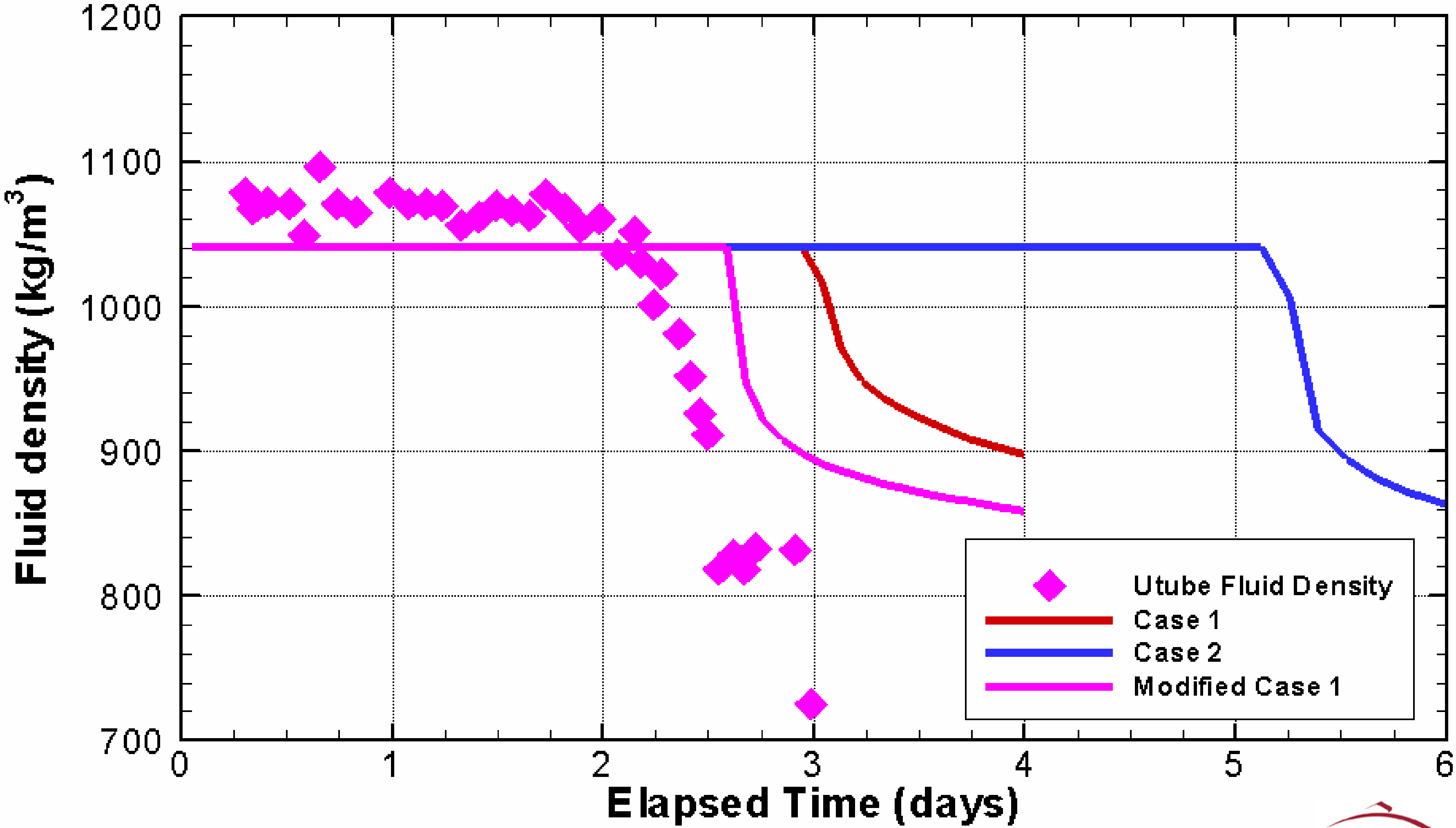
Calibration of Models



Calibration of Models

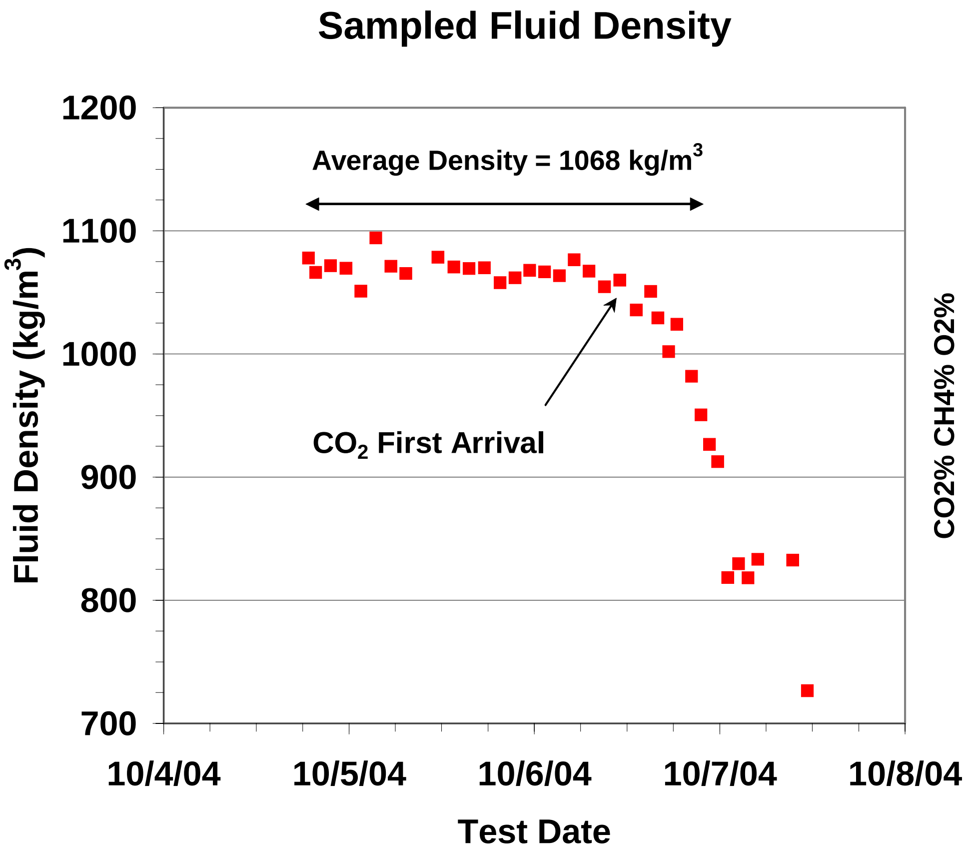
- Correctness of assumptions
- Synergy of results from several tools
  - Seismic/saturation logs/hydrologic tests
- Test hypotheses
  - Saturation history resulting from predicted residual saturation; timing of breakthrough, geochemical processes

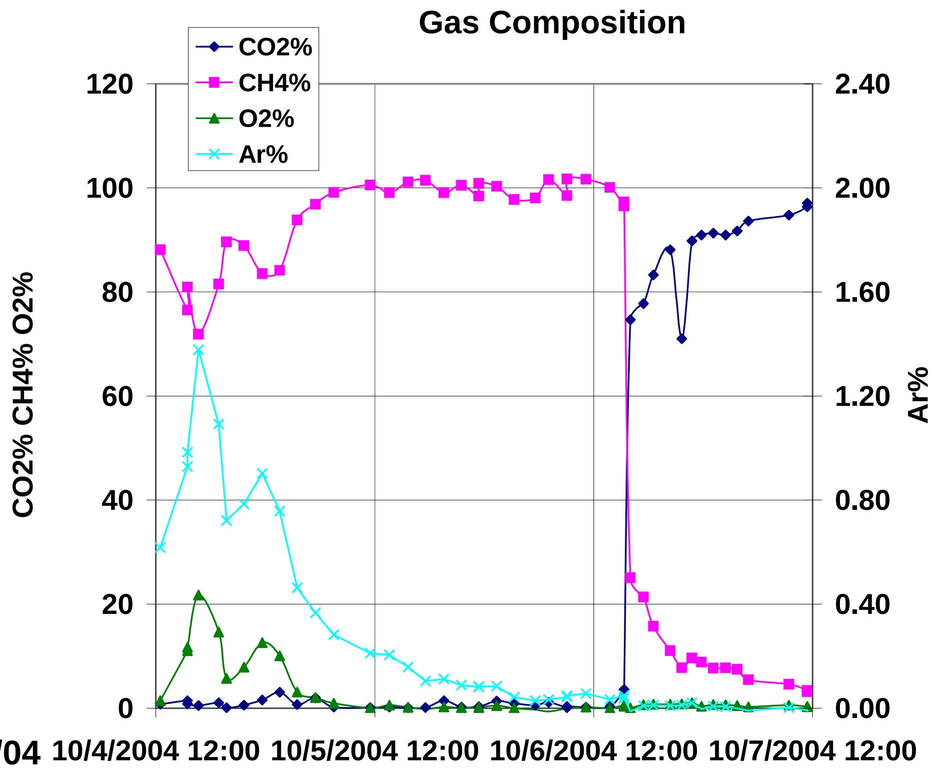
Model Calibration with Observed Data



Christine Doughty, Barry Freifeld, LBLN

Monitoring Well Sampling





- Hourly samples delineated the arrival and characteristic of the CO_2 breakthrough.
- Sample gas composition was monitored in real time using a quadrupole mass spectrometer.

Barry Freifeld LBNL

BERKELEY LAB

Modeling During Project Essential to Frio Project Objectives

Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.

1. **Demonstrate that CO_2 can be injected into a brine formation without adverse health, safety, or environmental effects**
2. **Determine the subsurface distribution of injected CO_2 using diverse monitoring technologies**
3. **Demonstrate validity of models**
4. **Develop experience necessary for success of large-scale CO_2 injection experiments**

More information: Gulf Coast Carbon Center
Frio Pilot Log

www.gulfcoastcarbon.org

MODELING TIMELINE

Date	Data Incorporated	Model Name (simulation name)	Model Features	Issues studied/Key results	Model output sent to
Aug. 2001	Regional Frio and Anahuac geology Oil-field characterization: well logs, 3D seismic	SLX	•B sand •3D: dipping formation, partially sealed fault block, stochastic lateral heterogeneity, vertical layering based schematically on well-logs of SGH-3 and SGH-4, •k = 100 - 700 mD, Δh = 6 m •150 m well separation	•Boundary effects on pressure •Lateral heterogeneity •CO_2 arrival time (t_{bt} = 30-60 days)	
Apr. 2002					CO_2 distribution to Mike Hoversten for geophysics modeling
June 2002		ARSLX	•Add Argon tracer	Chromatographic separation	CO_2 and Ar distributions to Karsten Pruess for tracer-test design
June 2002	Same as above	CPSLX	•C sand •3D: same as above •k = 100 - 700 mD, Δh = 6 m •150 m and 30 m well separation	•Inject into B or C sand layer (C) •Inject above or below thin shale in C (below) •New injection well or not (yes) •Injection rate (high) •t_{bt} = 1.9 days	
Sept. 2002	Frio literature S_{gr}	(CPV)	•Same as above, but large S_{gr}	•Effect of bigger S_{gr} •t_{bt} = 4 days	
Oct. 2002					Velocity fields to Kevin Knauss for geochemical

Feb. 2003			•C sand •Radial models	•Pressure transients for well-test design •Compare to 3D model	
Mar. 2003		5pt 9pt	•Uniform grid spacing •9-point differencing	•Grid resolution and orientation effects	
Apr. 2003		CPSLX and CPV	•C sand model as above •Study operational features of CO_2 injection test	•Long open well needed for geophysics •Pump monitoring well during CO_2 injection	
July 2003			•C sane model as above, but do non-isothermal simulation (at reservoir depth only)	•Temperature effects are minor	
July 2003			•Begin hysteresis studies	•Small S_{gr} during drainage (CO_2 injection), large S_{gr} during rewetting (trailing edge of CO_2 plume)	
Aug. 2003	More geological detail (bigger fault block)	VERP5	•C sand •3D: dipping formation, partially sealed fault block, internal fault, no lateral heterogeneity, vertical layering from SGH-4 well-log •k = 50 - 150 mD, Δh = 6.5 m •30 m well separation	•More distant lateral boundaries •Small fault •Thin shale •S_{gr}: small=case 1, large=case 2 •Case 1: t_{bt} = 3 days •Case 2: t_{bt} = 6 days	
Oct 2003			•Add Poynting correction to Henry's law for CO_2 dissolution	•Minor effect	

Nov. 2003			•Well-test design studies	•Doublet variations	
Nov. 2003			•CO_2 injection studies	•Maximum ΔP allowed by regulators	
Feb. 2004			•Include methane (dissolved or immobile) in well-test design studies •Radial and 3D models	•In situ phase conditions and signatures in pressure-transients	
Mar. 2004			•Long-time plume evolution	•S_{gr}	
June 2004	Logs from new injection well	V2004	•As above, but vertical layering from well-log of new injection well •k = 150 - 600 mD, Δh = 5.6 m	•Inject above or below thin shale (above) •Case 1: t_{bt} = 4 days (above), 9.4 days (below) •Case 2: t_{bt} = 7 days (above), 14.5 days (below)	
June 2004			•High resolution RZ grid	•Grid effects (small for two-phase flow) •Fingering (not expected to be a problem)	
Aug. 2004	Core analysis from new injection well	V2004core	•As above, but core analysis results modify vertical layering •k = 2 - 3 D, Δh = 5.5 m	•Case 1: t_{bt} = 2.7 days •Case 2: t_{bt} = 5 days	
Sept. 2004	Well test results		•As above, but different assumptions for permeability of internal fault	•Confirm core-scale permeabilities apply at field scale •Late-time pressure transient suggests internal fault may not be sealing	

Sept. 2004			•Simulate post-injection period to help design "after" geophysics		
Sept. 2004	Tracer test results	13 layer	•Higher lateral resolution around wells, increased sand thickness •$k = 2 - 3$ D, $\Delta h = 7.5$ m •Compare to streamline model, higher-resolution XY model •Use calibrated model for final CO_2 prediction	•Thicker sand delays first arrival and peak of tracer •Grid effects on tracer transport are big •Case 1: $t_{bt} = 3.2$ days •Case 2: $t_{bt} = 6.1$ days	Prediction of 3.2 days for CO_2 arrival
Oct 2004 - March 2005	CO_2 injection results: $t_{bt} = 2.1$ days, initially small vertical extent of CO_2		•Same as above, but different P_{cap} strengths •Use actual CO_2 injection schedule with breaks •Bigger S_{lr} also shortens t_{bt} •Include wellbore model – little effect	•Effect of P_{cap} (less interfingering of phases, faster CO_2 arrival) •Case 1: $t_{bt} = 2.5$ days •Case 2: $t_{bt} = 3.8$ days	
Feb. 2005			•Same as above •Simulate CO_2 plume evolution after injection ends, to compare to VSP	•Big difference between cases 1 and 2	