
# WESTCARB Regional Partnership

## Subsurface Flow Modeling at King Island

***Christine Doughty***, *CADoughty@lbl.gov*
***Curtis Oldenburg***, *CMOldenburg@lbl.gov*
Staff Scientists
Lawrence Berkeley National Laboratory

WESTCARB Annual Business Meeting
Bakersfield, CA

October 15–17, 2012

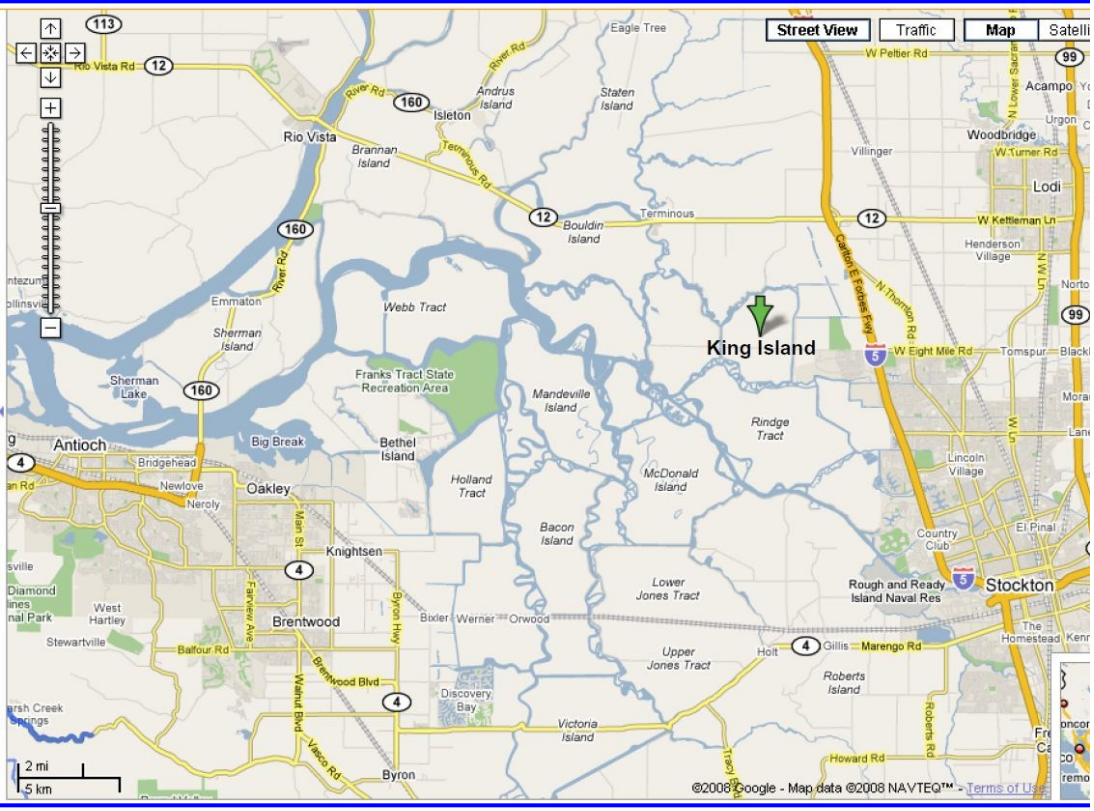
# Outline

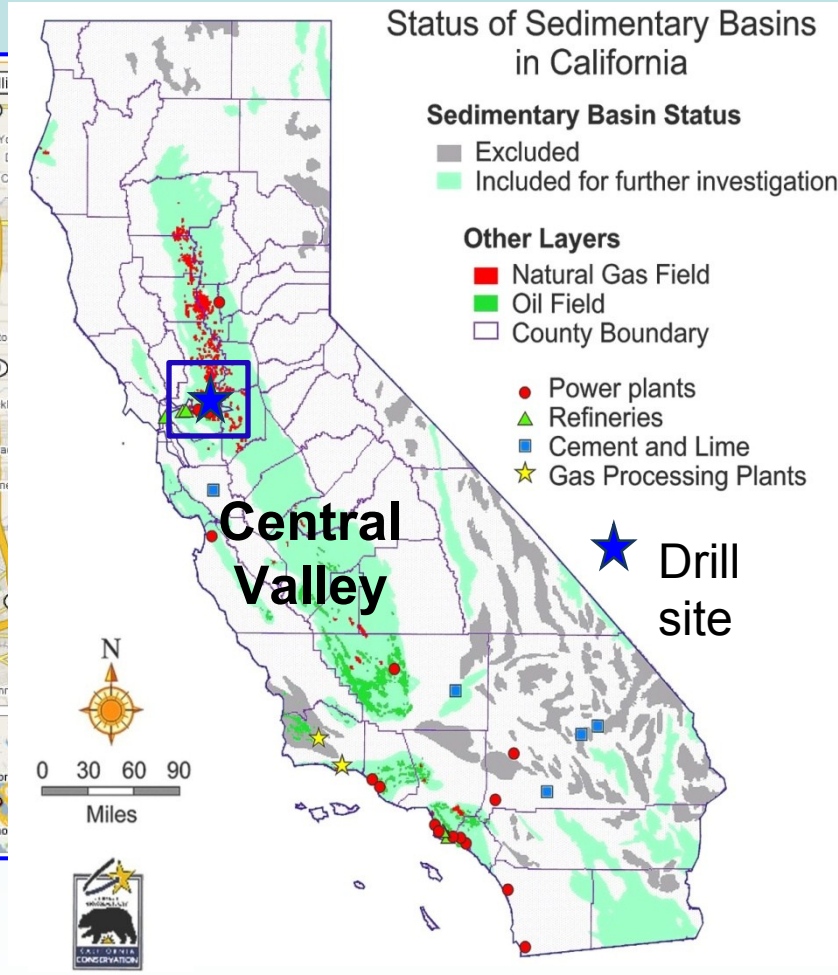
- Objectives
- Model Development
- Simulation Results
- Assessment of Data Use/Information Flow
- Future Work

# Objectives

- King Island Project as a Whole
  - Assess the suitability of the Southern Sacramento Basin for CO2 sequestration
  - Apply a variety of existing site characterization methods
  - Develop new site characterization methods
- Numerical Modeling
  - Predict movement and trapping of injected CO2 in the subsurface
  - Assess storage capacity
  - Estimate risk of leakage and pressure increase
  - Evaluate value of various site characterization methods for providing input to model

# Location Map



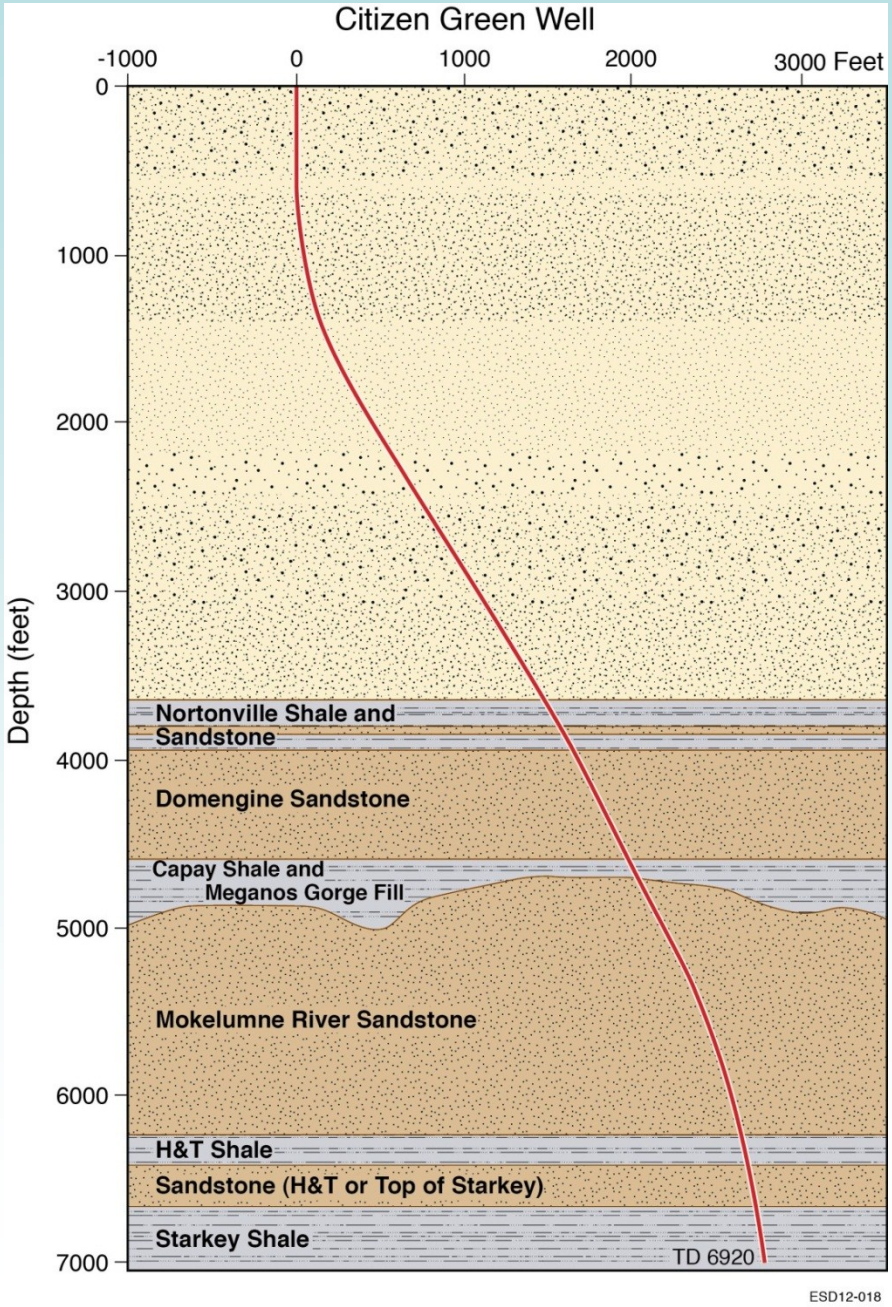

Southwestern Sacramento Valley provides closest potential storage site for San Francisco Bay Area refineries

# Model Development

- Target Storage Formations
- Structure
- Lateral Extent and Boundary Conditions
- Material Properties
- Initial Conditions
- Representation of Well

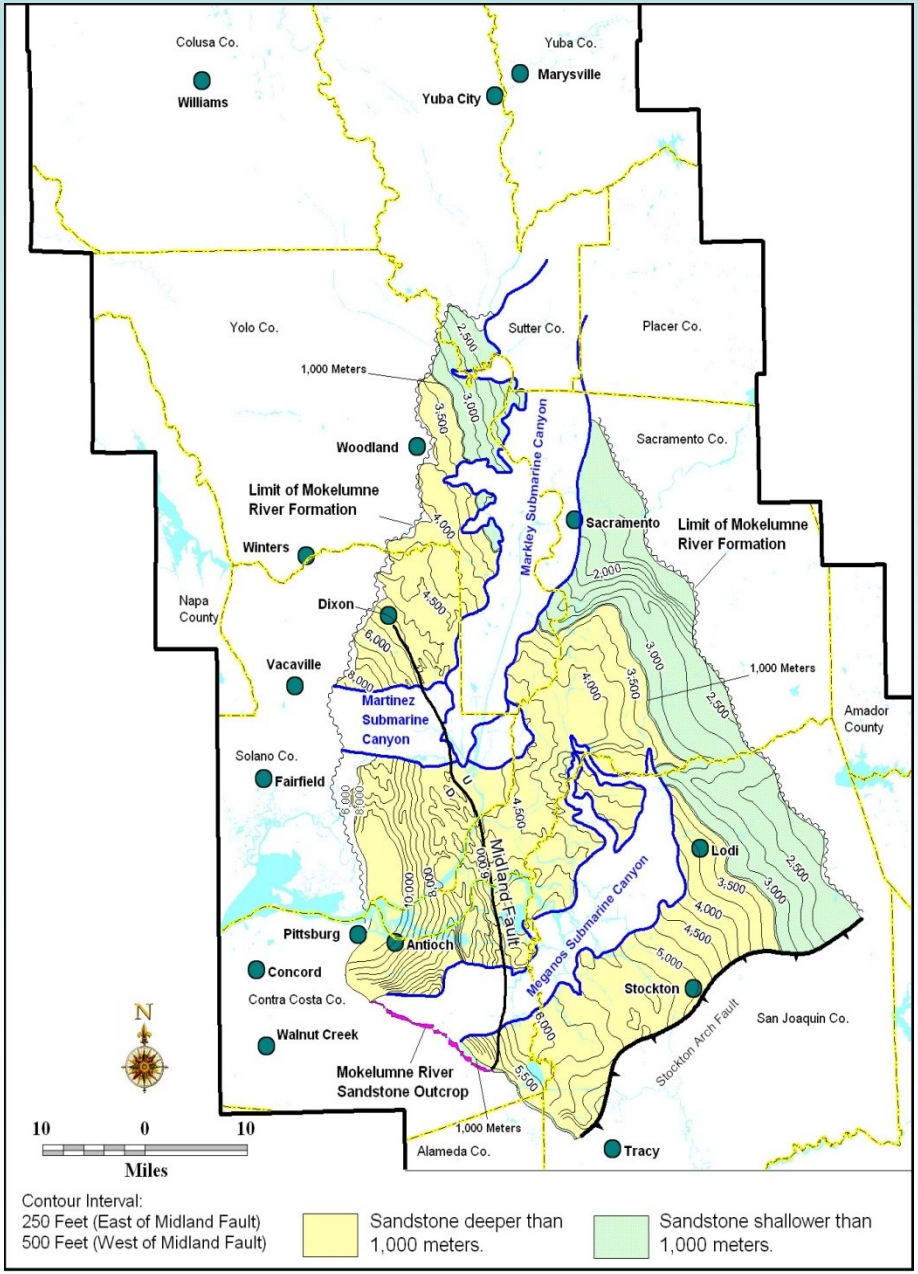
# Target Storage Formations

Note: gorge fill has shale-like properties; effectively creates undulations in sand-body caprock



# Model Structure

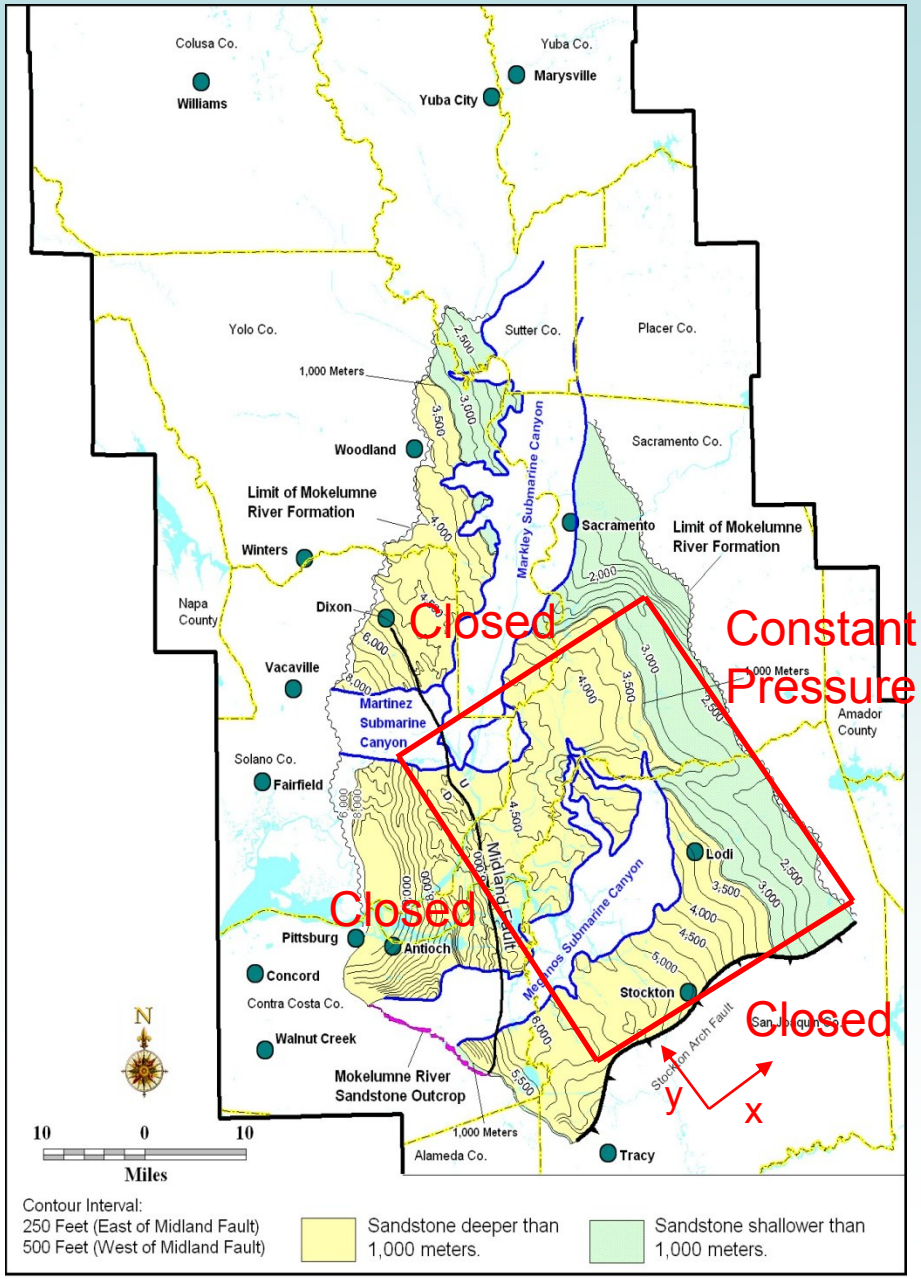
- Ignore gorges
- Approximate dip as uniform dip: 1.6$^{o}$ (up is to the ENE)
- Model is a tilted plane




From ***Downey and Clinkenbeard, 2011***

# Lateral Extent and Boundary Conditions

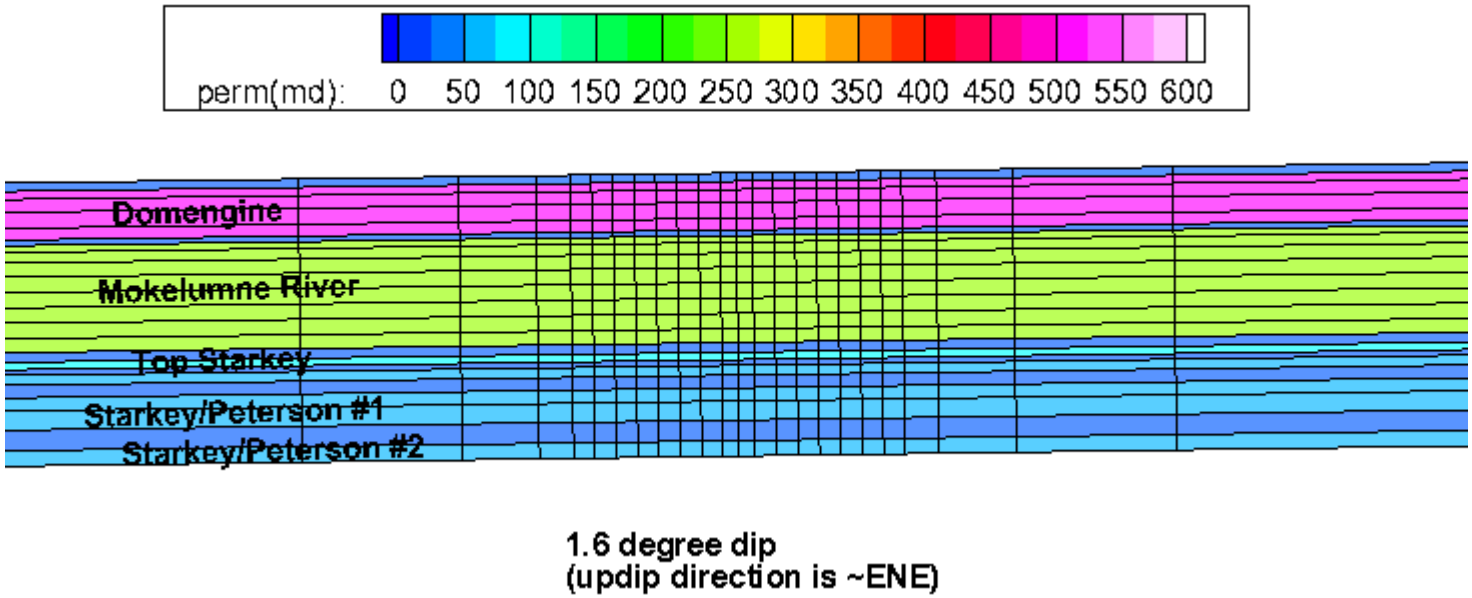
- Axes aligned with dip direction
- West and South boundaries approximately aligned with faults
- East boundary open as Mokelumne may abut another permeable formation



# Conceptualization of Entire Depth Interval (prior to drilling Citizen Green Well)

- Total thickness 1280 m
- Rough estimates and literature values
- Sands
  - Porosity 0.25-0.35
  - Permeability 50 – 500 md
  - Anisotropic: $k_v/k_h$ 0.01 to 0.1
- Shales
  - Porosity 0.10
  - Permeability 10 μd
  - Anisotropic: $k_v/k_h$ 0.1
- Properties are effective values that account for sub-grid-scale heterogeneity

Vertical cross-section of 3D model (aligned along dip direction)

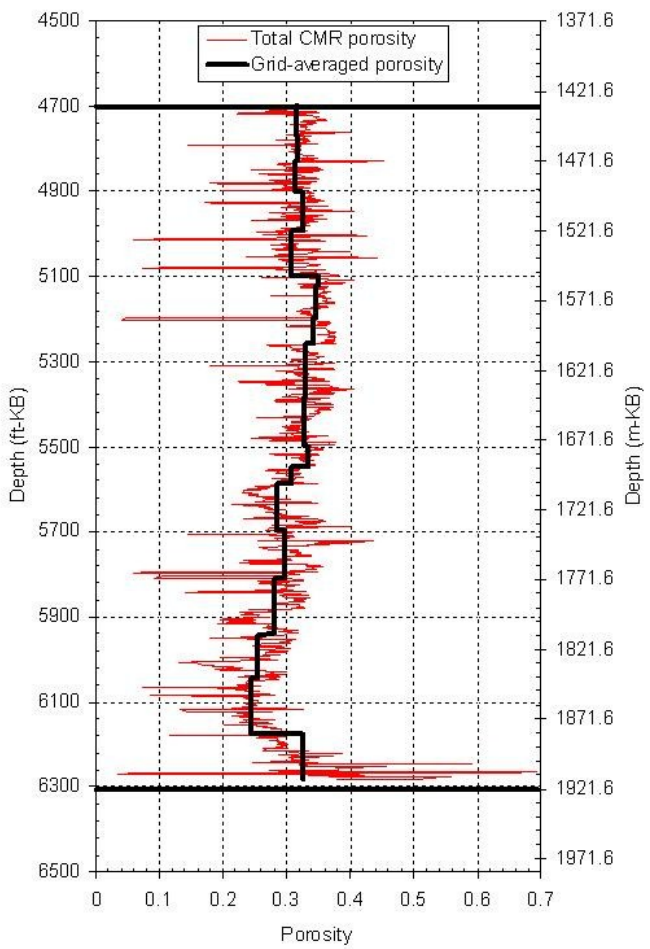


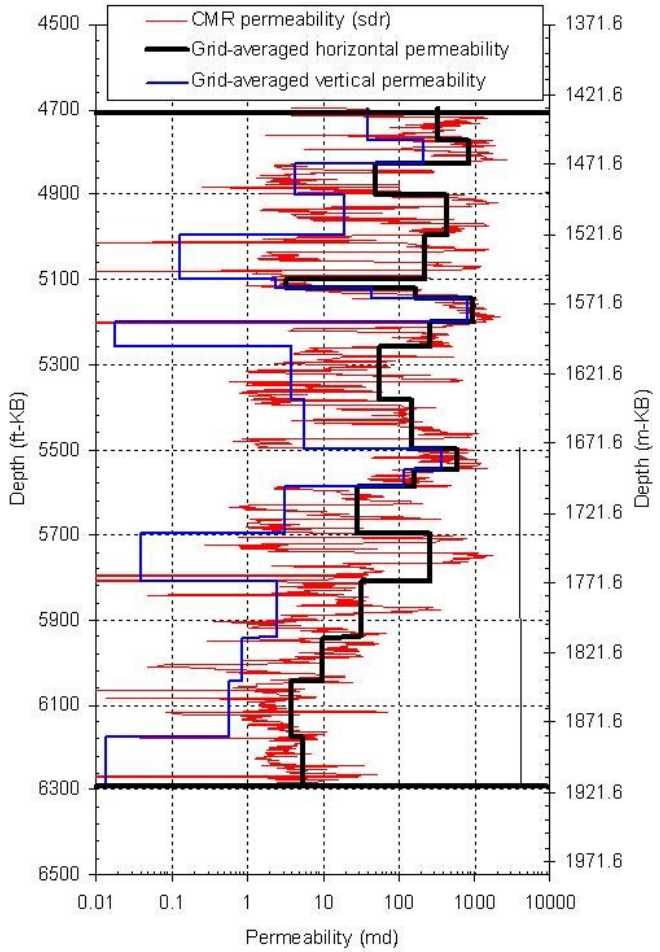
# Focus on Mokelumne River Sandstone (incorporating data from Citizen Green Well)

- Total thickness 483 m
- Well log and sidewall core comparison (J.B. Ajo-Franklin) indicates:
  - NMR Total Porosity appears to best match helium porosimetry data from the sidewall samples
  - NMR permeability estimates appear to be relatively accurate for the formations encountered at the Citizen Green well

# Well Logs and Model Discretization

- Model layering from well-log permeability profile
- Sharp boundary to overlying Capay Shale - no-flow boundary a good approximation
- Layer properties
  - Porosity and horizontal permeability - arithmetic mean
  - Vertical permeability - harmonic mean
- Big variation of permeability > three orders of magnitude
- Model does not capture all detail, but hopes to represent key features
  - High permeability in upper half
  - Downward fining in lower half
  - Low-permeability baffles over whole thickness greatly decrease effective vertical permeability



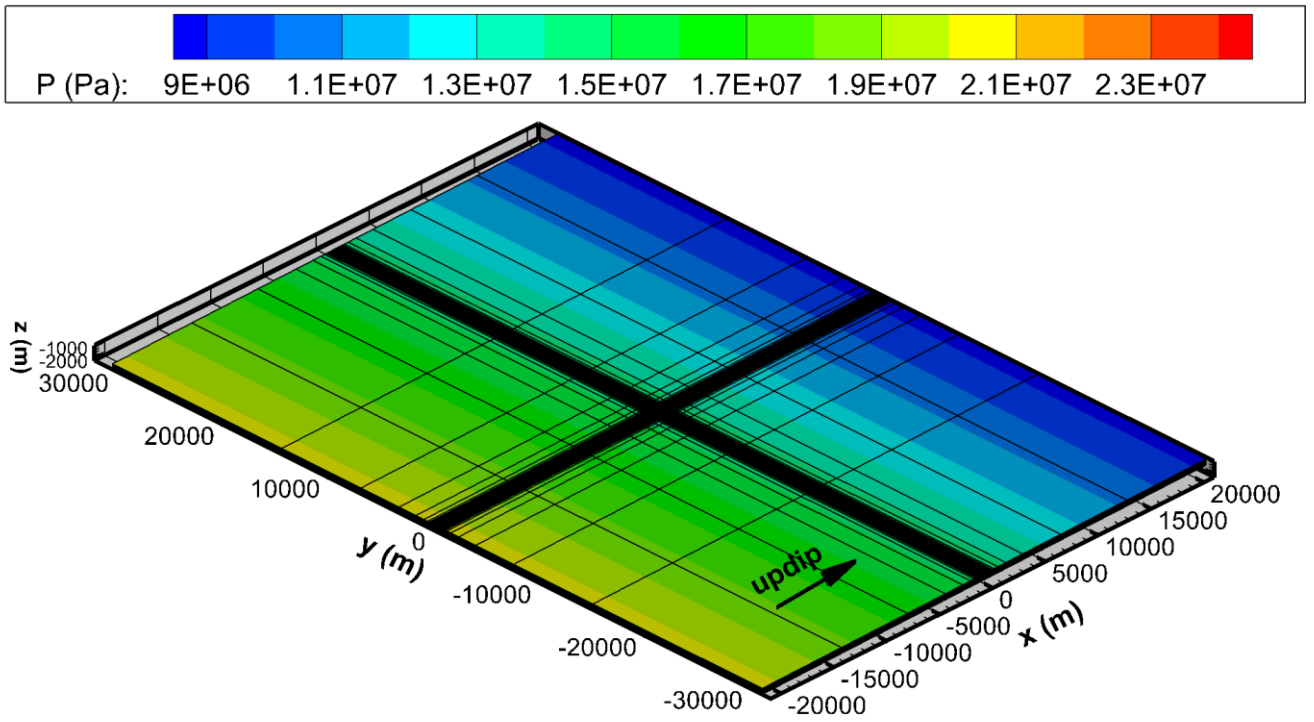

- 3D model, 37,620 grid blocks
- 483 m thick, 19 layers
- Lateral grid resolution near well 50 by 50 m, coarsens outward
- Lateral extent of model 42 by 60 km

# TOUGH2 Numerical Simulator

- Fully coupled multiphase fluid flow
- Equation of state includes $H_2O$, $CO_2$, NaCl
- Isothermal simulations
- Injected $CO_2$ forms a gas-like supercritical phase and dissolves in brine
- Variety of capillary pressure and relative permeability functions available
  - Can be fit to literature or laboratory data
  - Here use generic characteristic curves

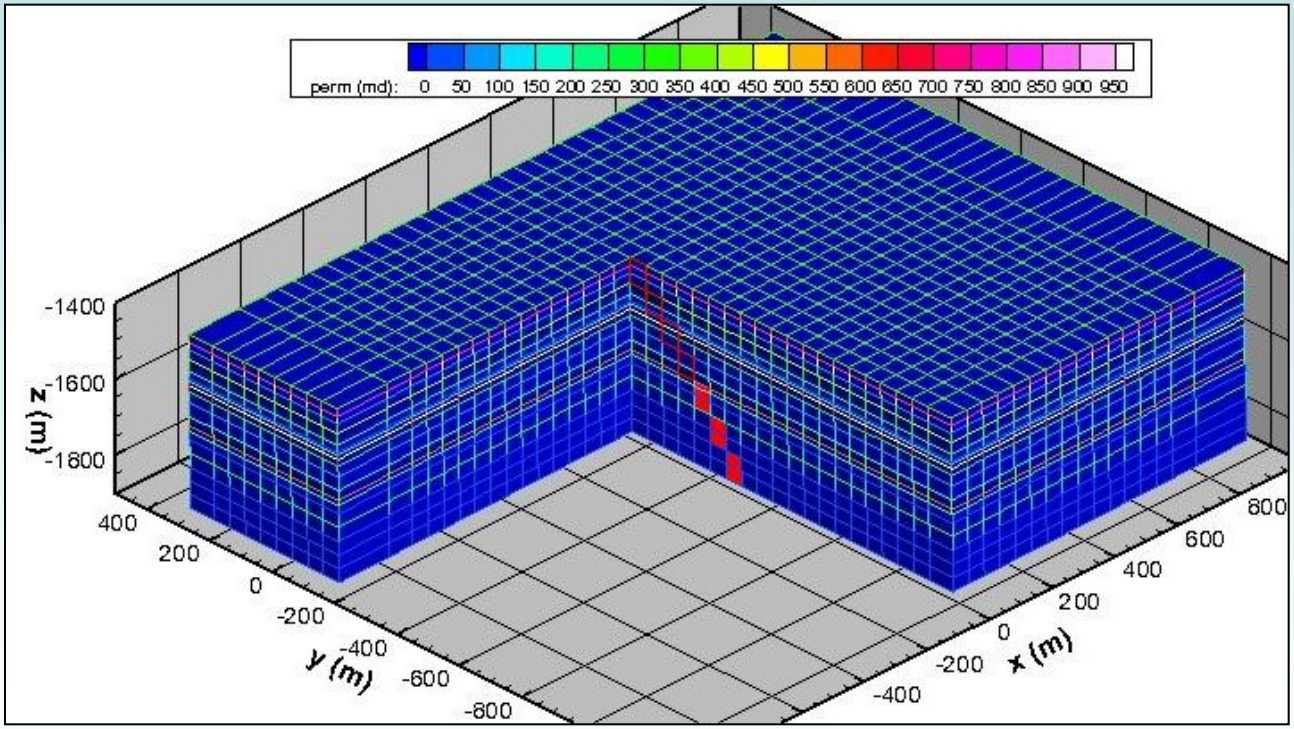
# Initial Conditions

- Single-phase liquid brine (salinity 50,000 ppm)
- Hydrostatic pressure profile (86-250 bars)
- Geothermal temperature gradient (50-80°C)



# Representation of $CO_2$ Injection

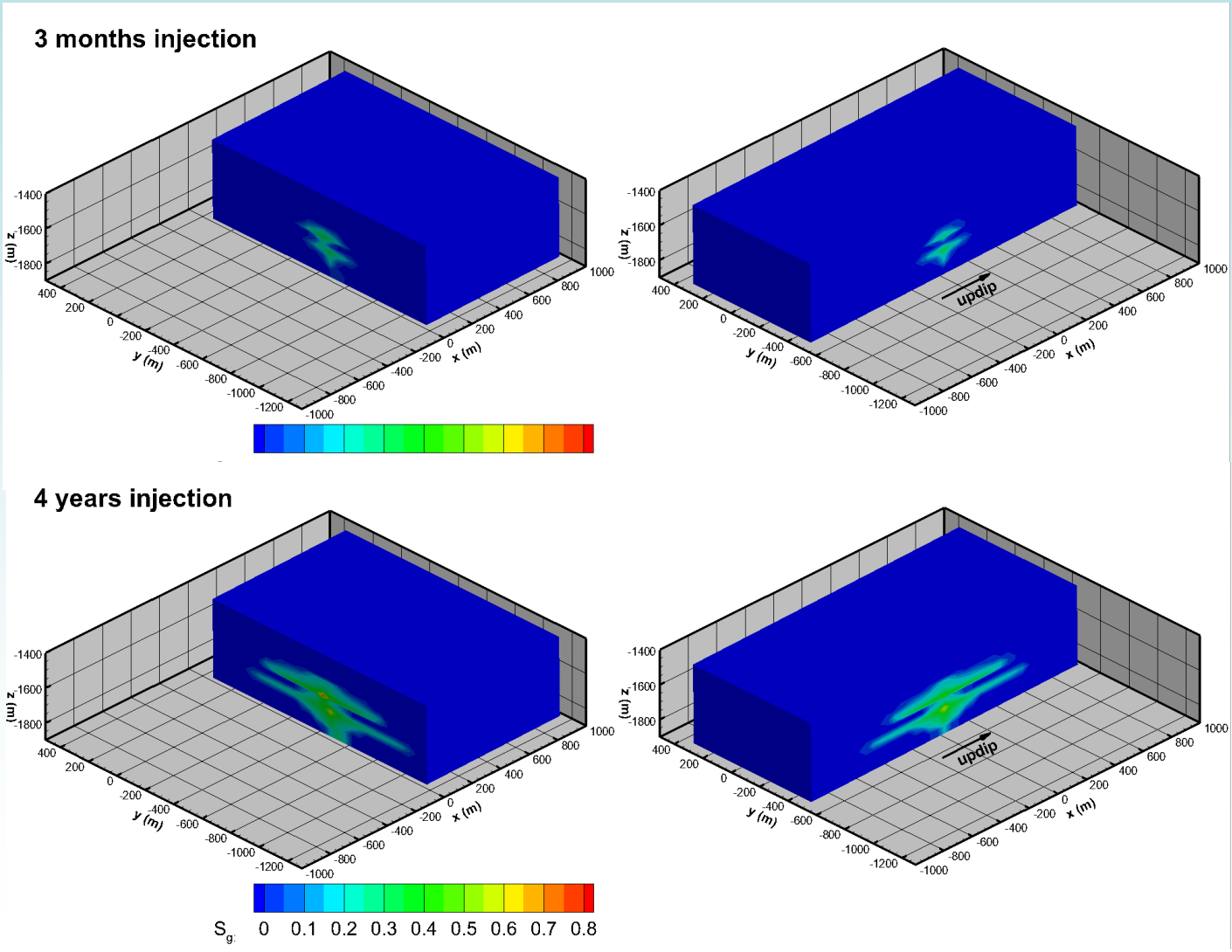
- Diagonal well represented by “stair-steps” in rectangular grid
- Assume well perforated over the lower half of the Mokelumne River
- Injection partitioned among grid block representing well according to permeability- thickness product
  - Does not account for different pressure gradients in well ($CO_2$) and formation (brine)
  - Over-estimates injection at greater depth




Inject 1 MT $CO_2$ per year for four years

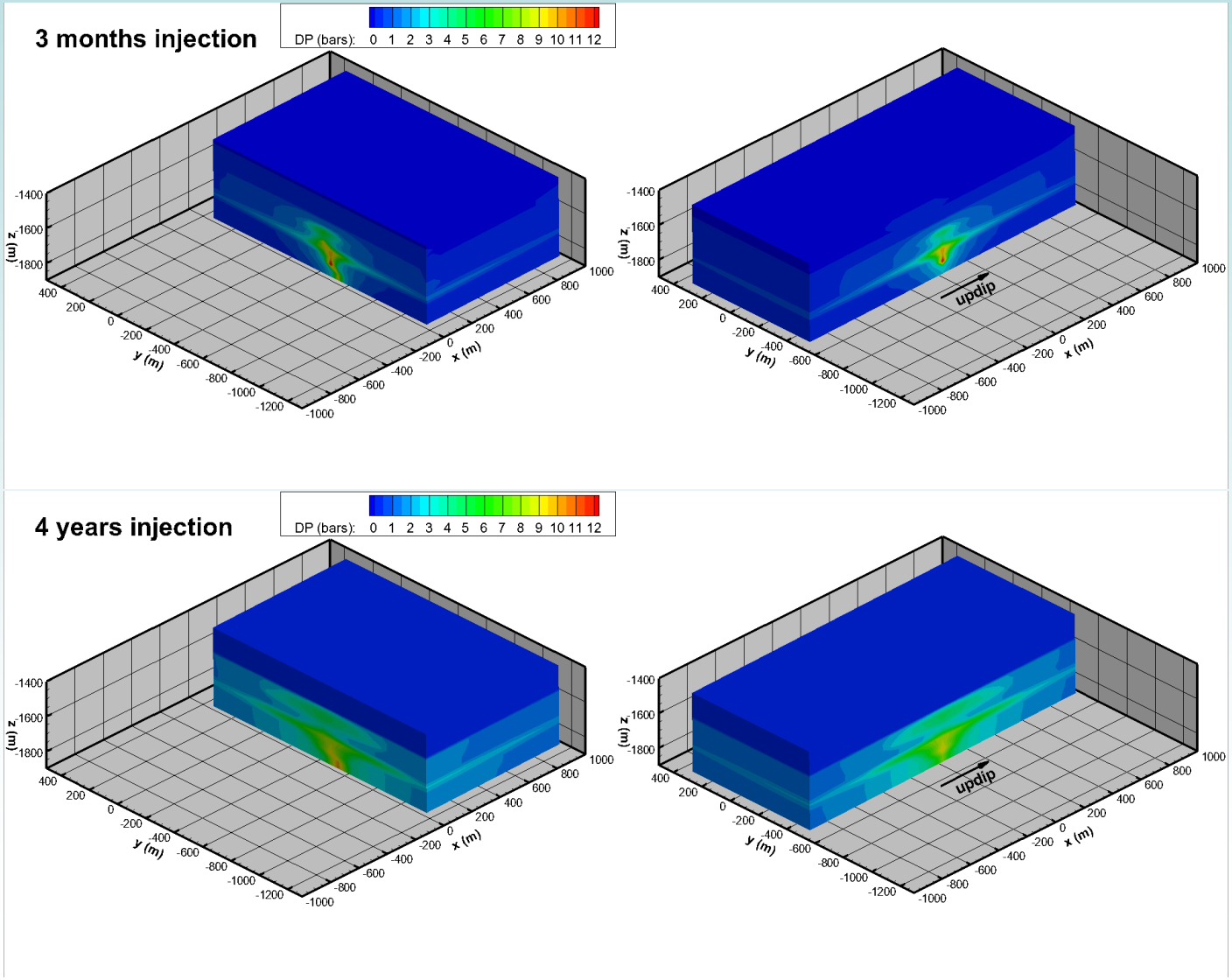
# Simulation Results
## $scCO_2$ saturation

- Strong preferential flow in high-permeability layers
- Strong buoyancy flow within high-permeability layers
- Slight up-dip migration



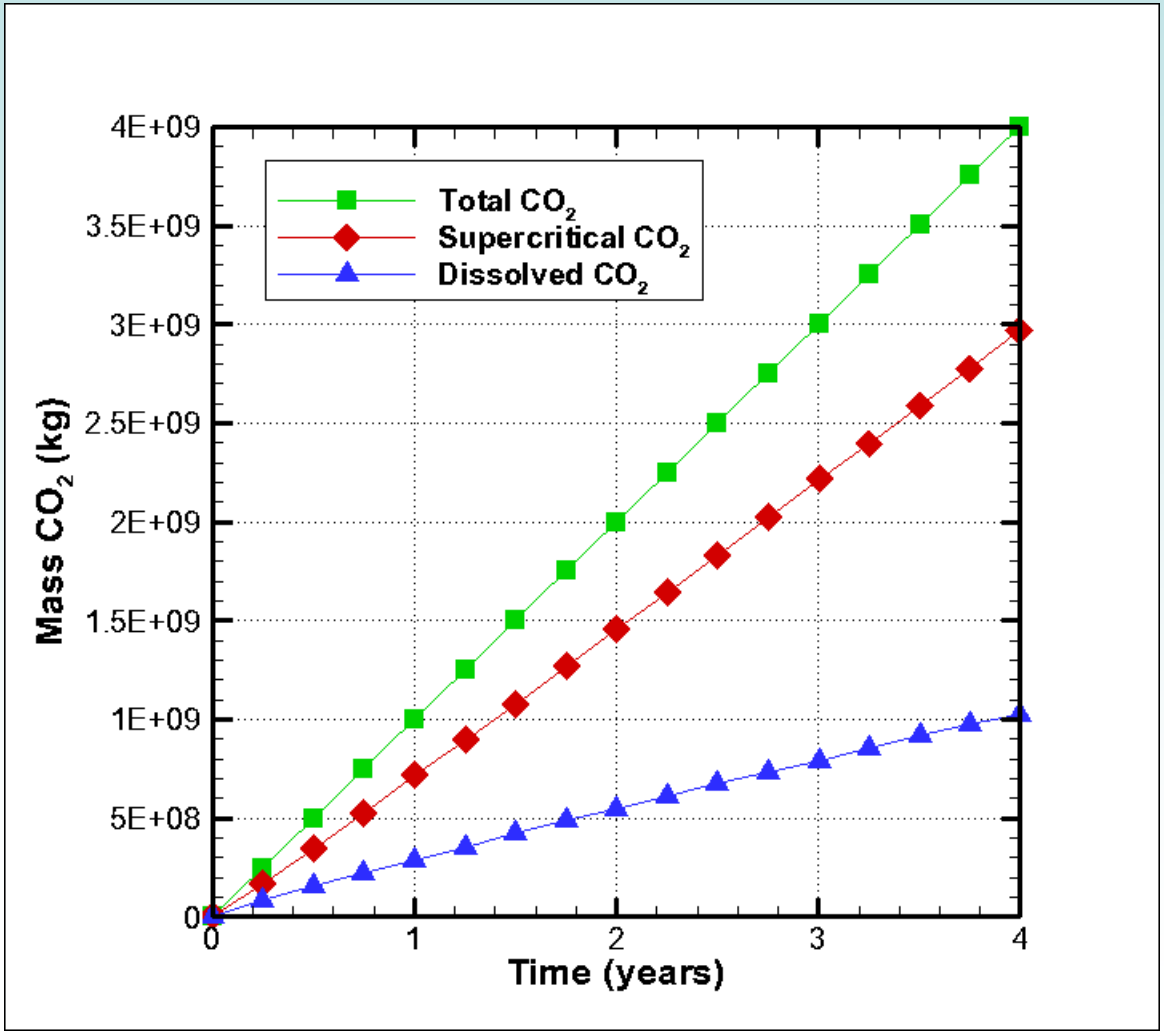
# Simulation Results
## Pressure Change Distributions

- Pressure increase moderate for high-permeability formation
- Extent of pressure change much greater than extent of $CO_2$

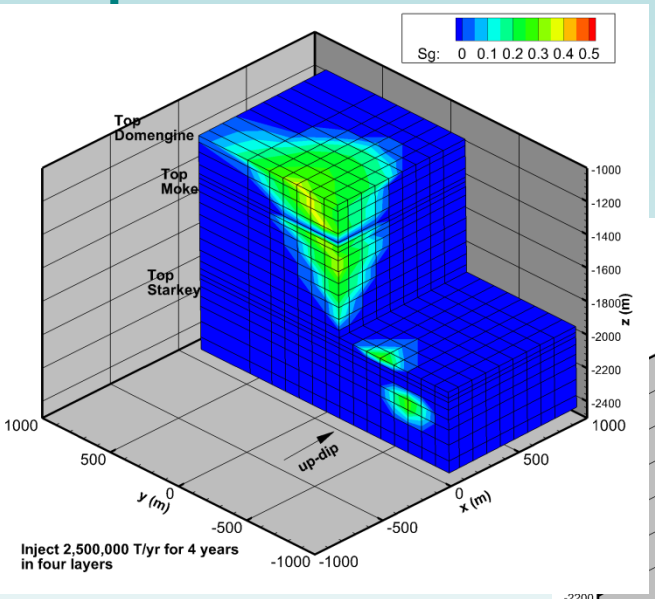


# $CO_2$ Mass Balance for Entire Model

- Injected $CO_2$ forms a supercritical phase and dissolves into the aqueous phase
- Dissolved fraction is consistently about 25%

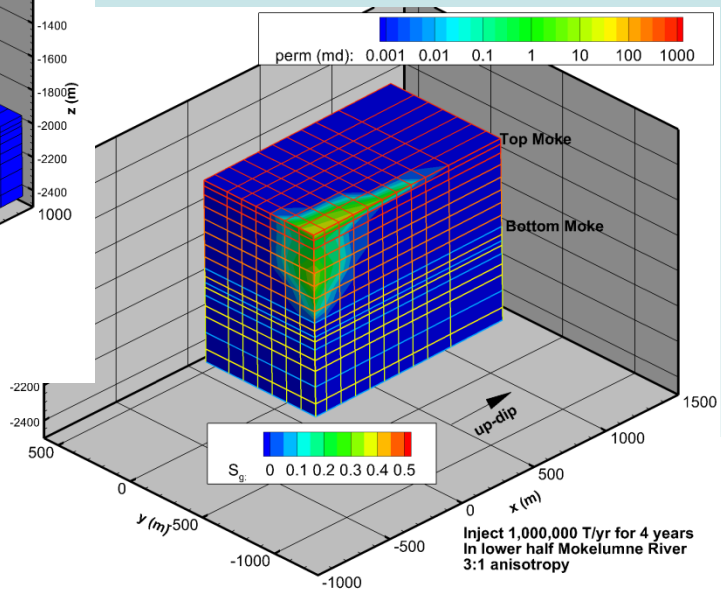


# Data Use/Information Flow




## Model 1

- Regional geology
- Inject into four sand layers

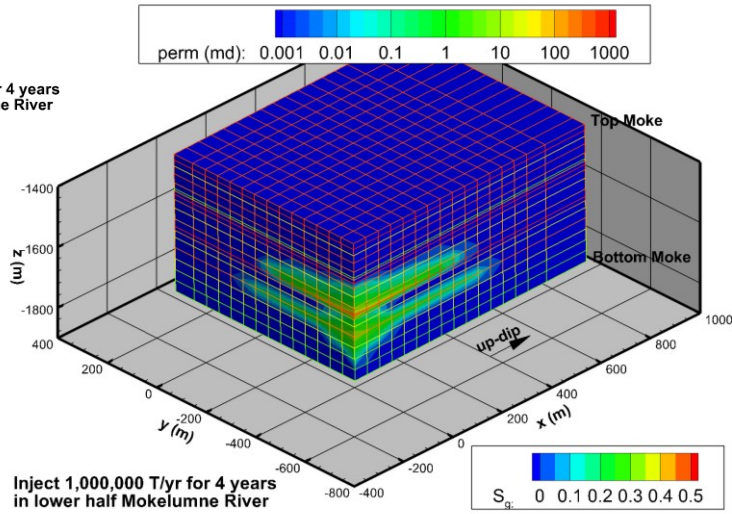



## Model 2

- Anecdotal information from lack of core recovery from Citizen Green well: high permeability in top Moke
- Inject into lower half Moke
- Strong buoyancy flow

## Model 3

- Well logs from Citizen Green well
- Sidewall core from Citizen Green well
- Inject into lower half Moke
- Layering restricts buoyancy flow



# Future Work

- Incorporation of additional data
  - Include lateral heterogeneity
    - Well logs available from 4 nearby wells
    - Use Citizen Green data to calibrate
  - Incorporate realistic characteristic curves
    - Micro CT and analytical solution
    - $CO_2$/brine flood sequence in Domengine core - seismic response shows strong hysteresis
- Simulations
  - Injection period: growth and movement of plume (pressure-driven and buoyancy flow)
  - Post-injection: plume evolution after injection ends (buoyancy flow, trapping mechanisms)