FutureGen 2.0: Subsurface Characterization and Modeling Data Overview

NRAP Webinar Series
Webinar #2

December 13, 2016

NRAP
National Risk Assessment Partnership

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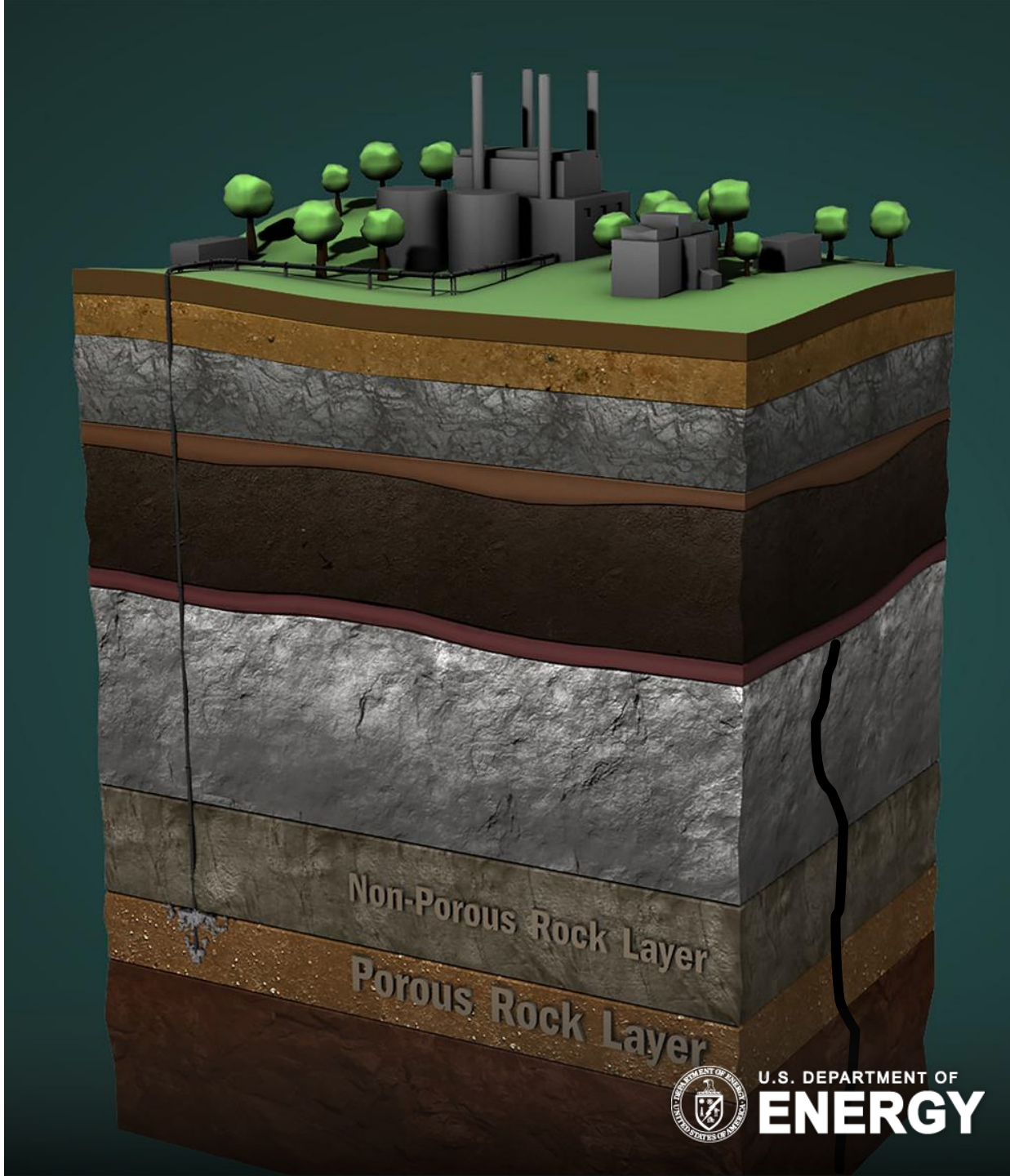

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Outline

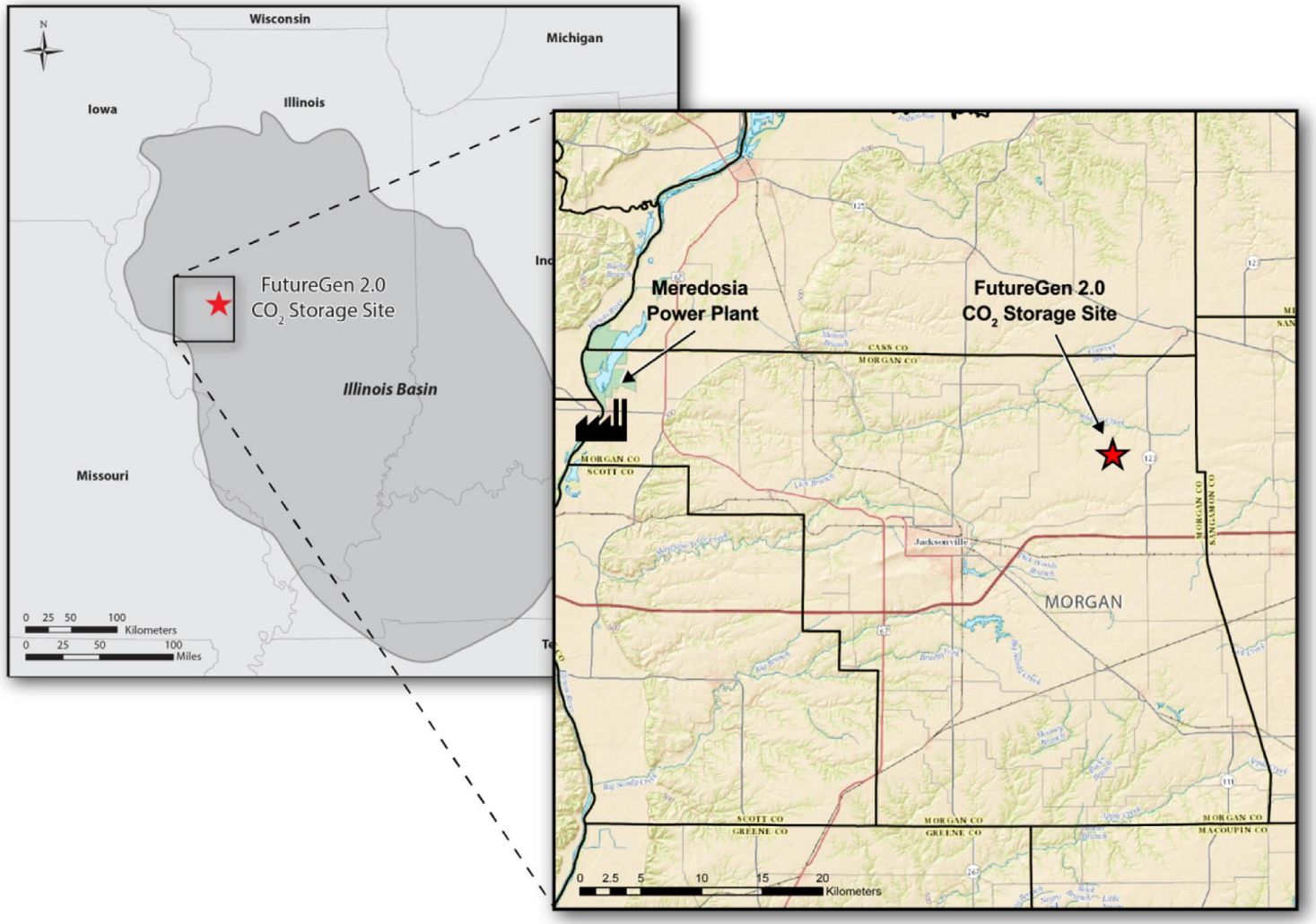
- **Introduction**
  - Objective of this webinar
  - Brief overview of the FutureGen 2.0 project and data
- **Subsurface characterization data**
- **Modeling data**

Objective of this Webinar

- **NRAP Phase II, Task 5: Validation of Risk Assessment Tools and Methodologies Using Synthetic and Field Data**
  - NRAP Toolset & NRAP-IAM-CS
- **FutureGen 2.0 project provides an opportunity to use actual large-scale field characterization information and associated modeling data for**
  - Validation and testing purposes
  - Compilation of a community dataset
- **Today's Objective**
  - Provide a brief overview of the available data from the FutureGen 2.0 project
  - Initiate/facilitate further discussions on specific types/categories of data

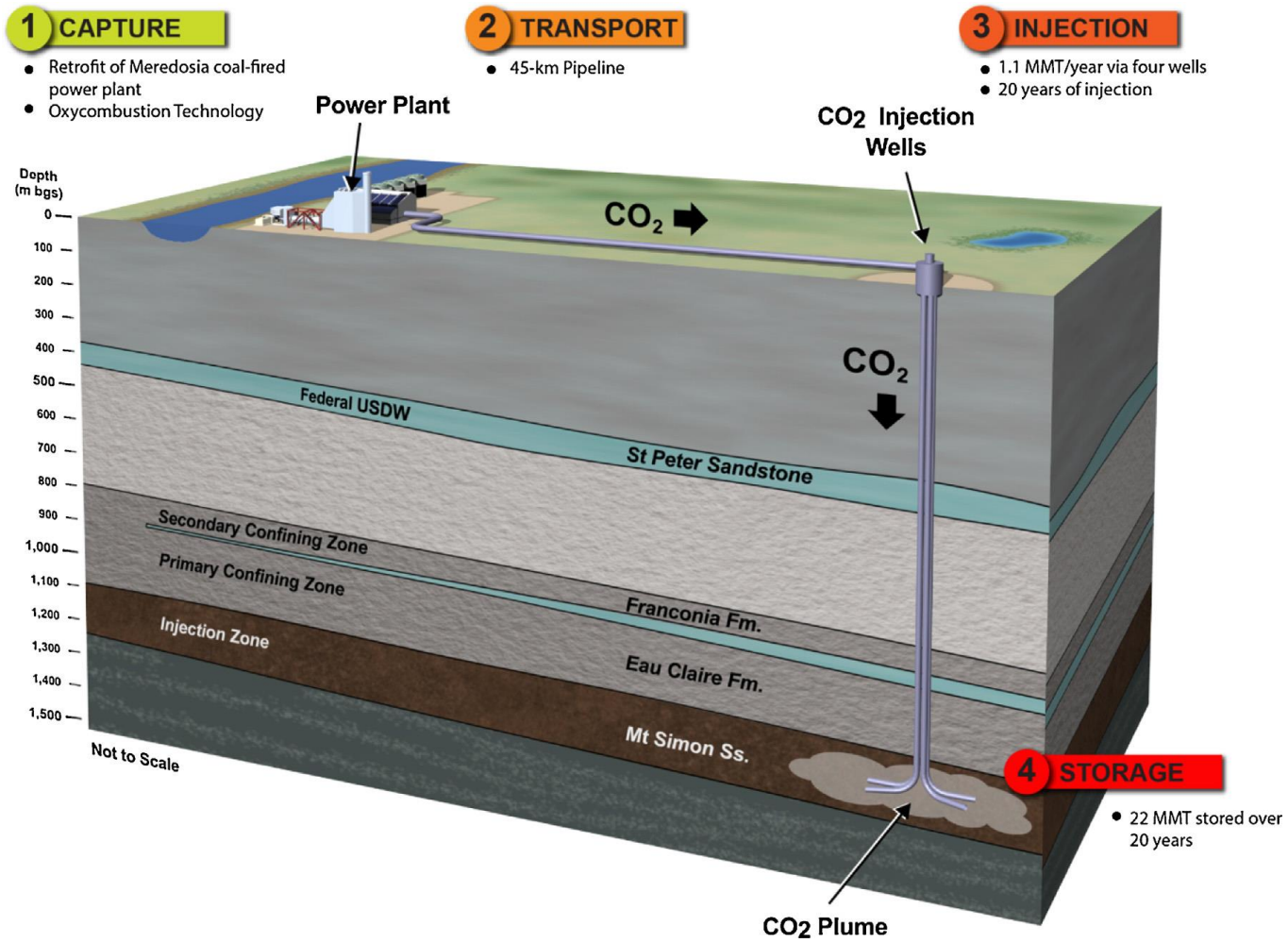
FutureGen 2.0: Project Description

- **FutureGen 2.0 was planned as an integrated near-zero emissions coal technology project in Illinois**
  - Oxy-combustion and carbon capture at Meredosia Power Plant
  - Transport of CO_2 through an underground pipeline
  - Injection/storage site in Morgan County, IL
- **Data discussed and provided focus on the storage component**



FutureGen 2.0: CO_2 Storage System

- **A total of 22 MMT was planned to be injected over 20 years – 1.1 MMT of CO_2 per year**
  - Injection formation: *Mount Simon Sandstone*
  - Number of injection wells: 4 horizontal wells
  - Injection depth: ~4,000 ft
  - Primary confining zone: *Eau Claire Formation*
  - Secondary confining zone: *Davis Member of Franconia Dolomite*

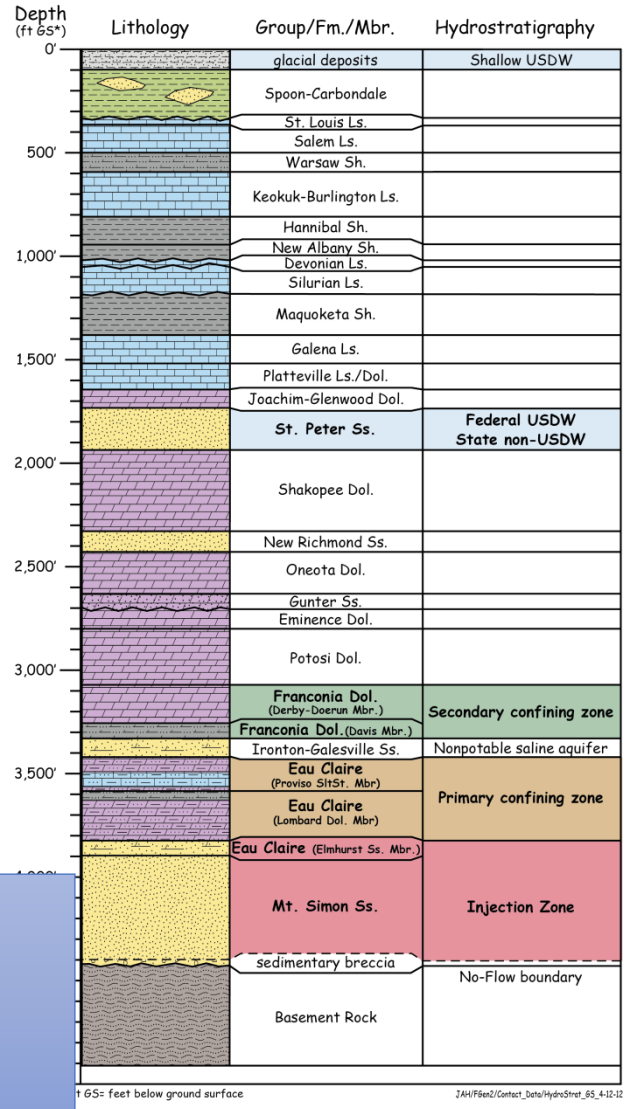


FutureGen 2.0 Data for Storage Component

- **A large volume of comprehensive data was generated during this project**
- **Subset selected for NRAP: Two primary categories of data**
  - Subsurface characterization: A comprehensive characterization program was implemented at the site for about 3 years
    - Regional characterization (review of available data) → site-specific activities at the storage site (drilling a stratigraphic well)
    - Direct and indirect measurements (e.g., seismic, fluid testing)
  - Modeling
    - Large-scale reservoir model was constructed and run to predict/assess:
      - plume/pressure behavior
      - reservoir capacity and injectivity
      - caprock integrity
    - A leakage model was developed to assess water quality impacts in the first permeable unit above the primary confining zone

FutureGen 2.0: Subsurface Characterization

- **The storage site was fully characterized using**
  - 2D Seismic
  - Borehole VSP
  - Geophysical logging
  - Core analyses
  - Gravity and geodetic surveys
  - In-situ stress characterization
  - Hydrologic field tests
- **A stratigraphic borehole (FGA-1) was drilled, capturing the entire stratigraphic sequence from ground surface to the Precambrian basement rocks in support of**
  - Reservoir capacity and caprock integrity evaluations
  - Initial reservoir models
  - Storage site and monitoring program designs
- **Total Depth:** 4,812 ft (1467 m)



Available data:

- Image map of characterization activities conducted in the stratigraphic well

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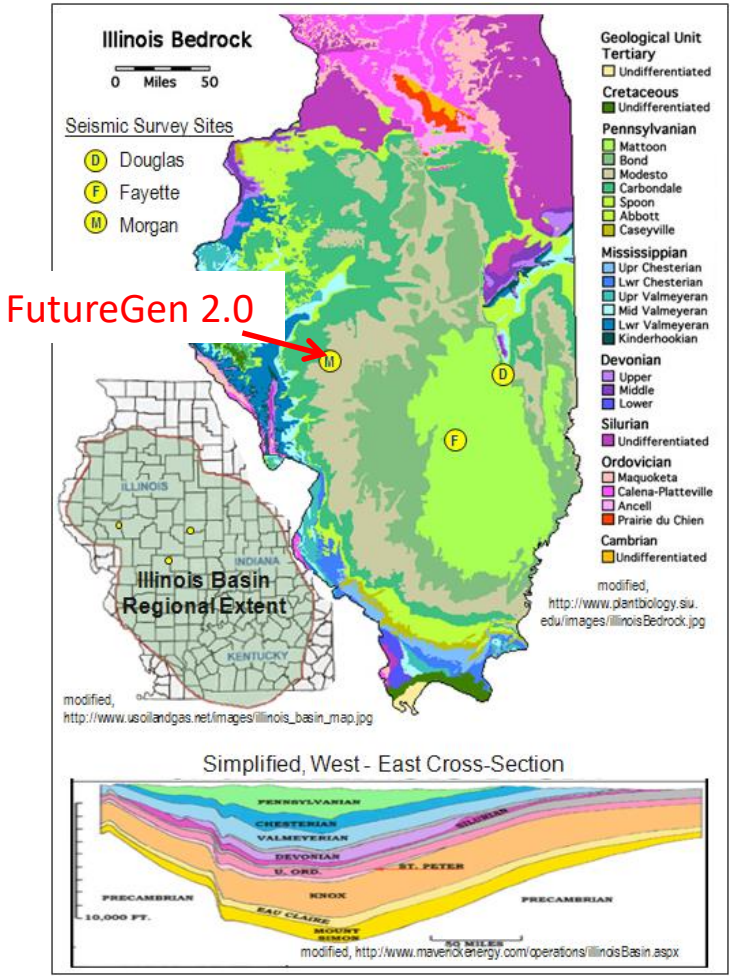
2D Seismic Surveys

- **Purpose**
  - Initial site screening and characterization
  - Imaging of the Mount Simon Sandstone and Eau Claire Formation to determine stratigraphic lateral continuity and conduct a structural analysis
- **The survey included five 2D lines from three different sites in Illinois**
  - Douglas County (2 lines)
  - Fayette County (1 line)
  - **Morgan County (2 lines) – 15 miles (24 km)**

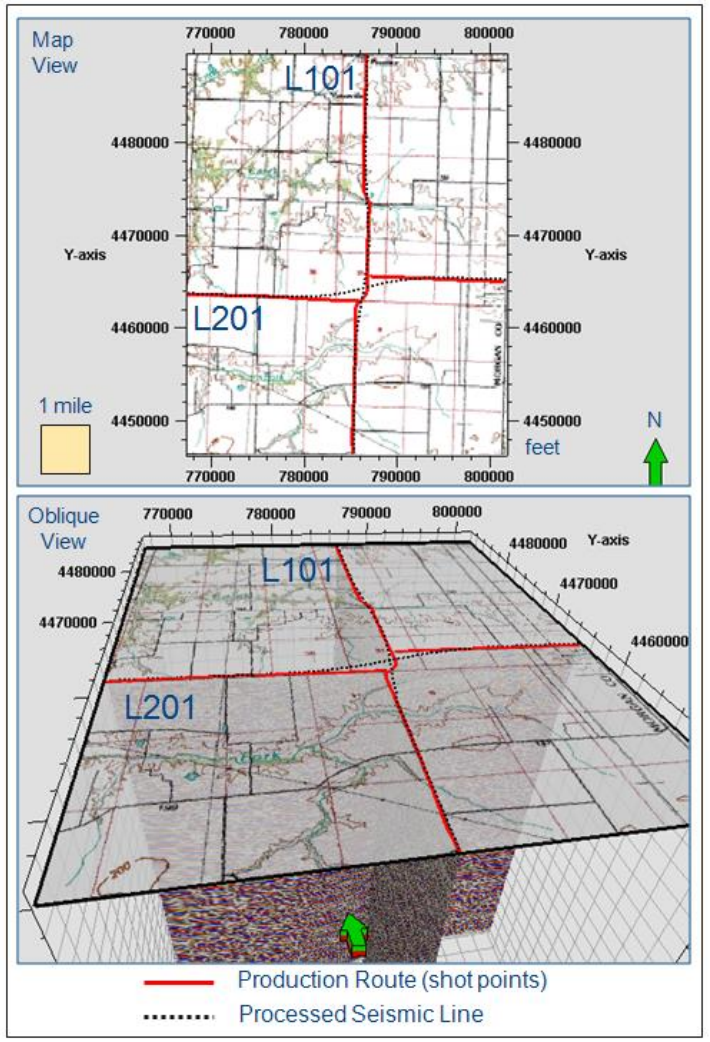
Location of the survey sites



2D Seismic Surveys

- **Challenges**
  - Processed images contain noise associated with lateral changes in the near-surface
  - Seismic frequency and data quality degrade below a two-way time of 250 ms (about 400 m depth) and severe attenuation of the seismic signal occurs below 400 ms (about 800 m)
  - The Eau Claire seal is poorly imaged, along with the top, bottom, and internal stratigraphy of the Elmhurst/Mount Simon Reservoir at a depth between 1170 and 1346 m

2D Seismic lines for Morgan County



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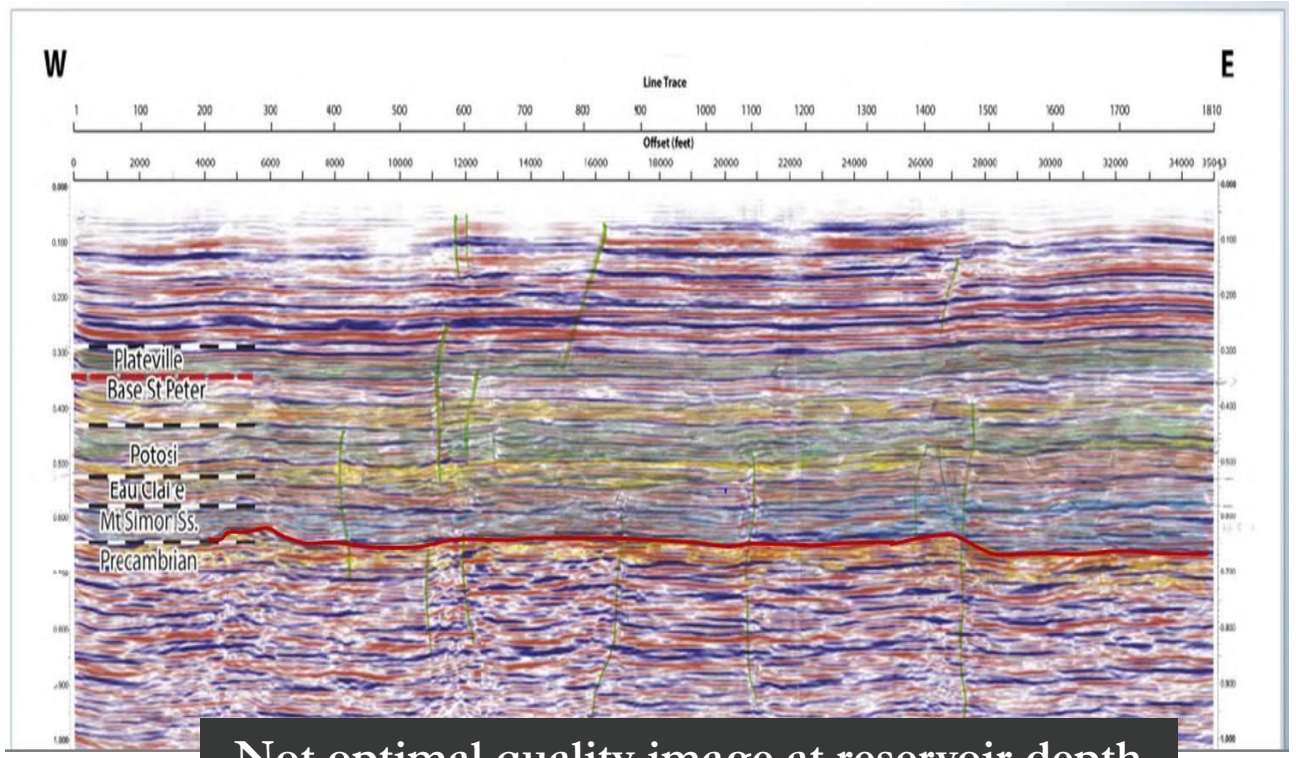
2D Seismic Surveys

- **Seismic data were reprocessed twice by Exploration Development, Inc. (EDI). A third enhancement was made to the reprocessing by EDI in January 2013.**

Available data:

- Raw and processed data, along with reports on acquisition, processing, and interpretation
- Regional 2D seismic data (Douglas County and Fayette County)

2011 Reprocessed N-S 2D Line



Not optimal quality image at reservoir depth

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Borehole VSP

- **Purpose**
  - Resolve P-P seismic data quality issues observed in 2D surface seismic data
  - Detect and image small-offset faults, karst features and fracture zones
- **Consisted of a zero-offset location and 15 offset locations**
- **Data acquired with 3C geophones allowing for both P-P and P-SV images to be made for fault detection and interpretation**

Location of the 2013 VSP program relative to the 2D surface seismic lines.

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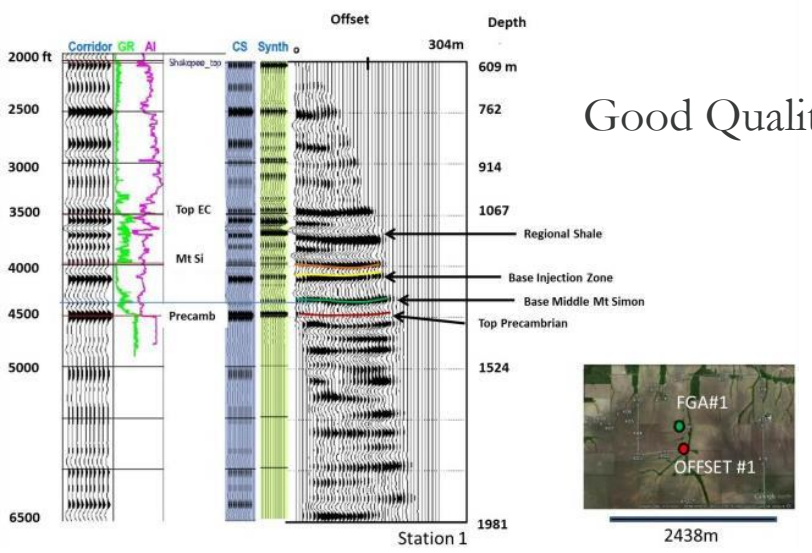
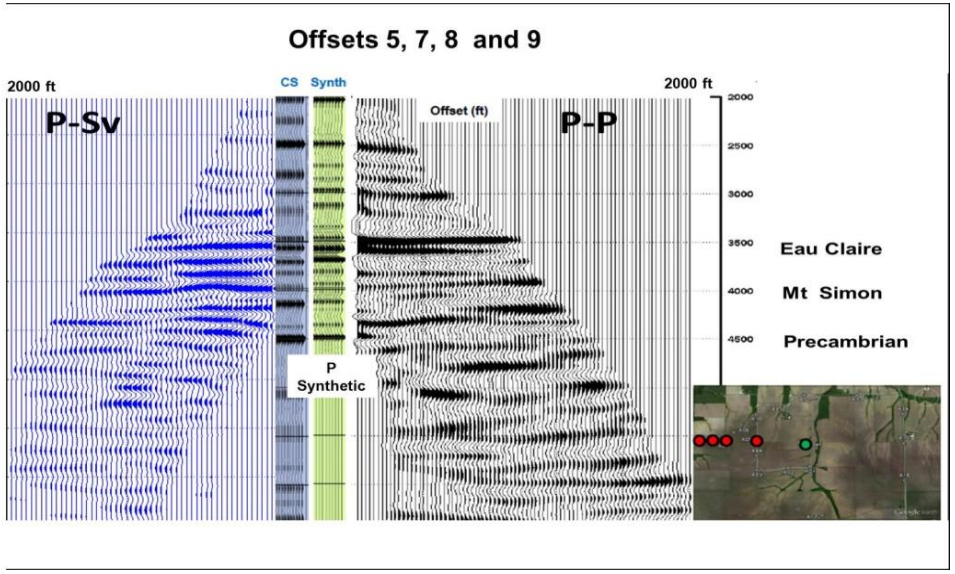
Borehole VSP

- Schlumberger processed both P-wave and P-SV
- Processed data indicated no resolvable faults and no vertical seismic anomalies
- P-SV VSP images have greater reflection strength, display less attenuation, and are higher resolution than the P-P images



Good Quality P-wave Data

Converted P-SV (Better Quality than P-wave)



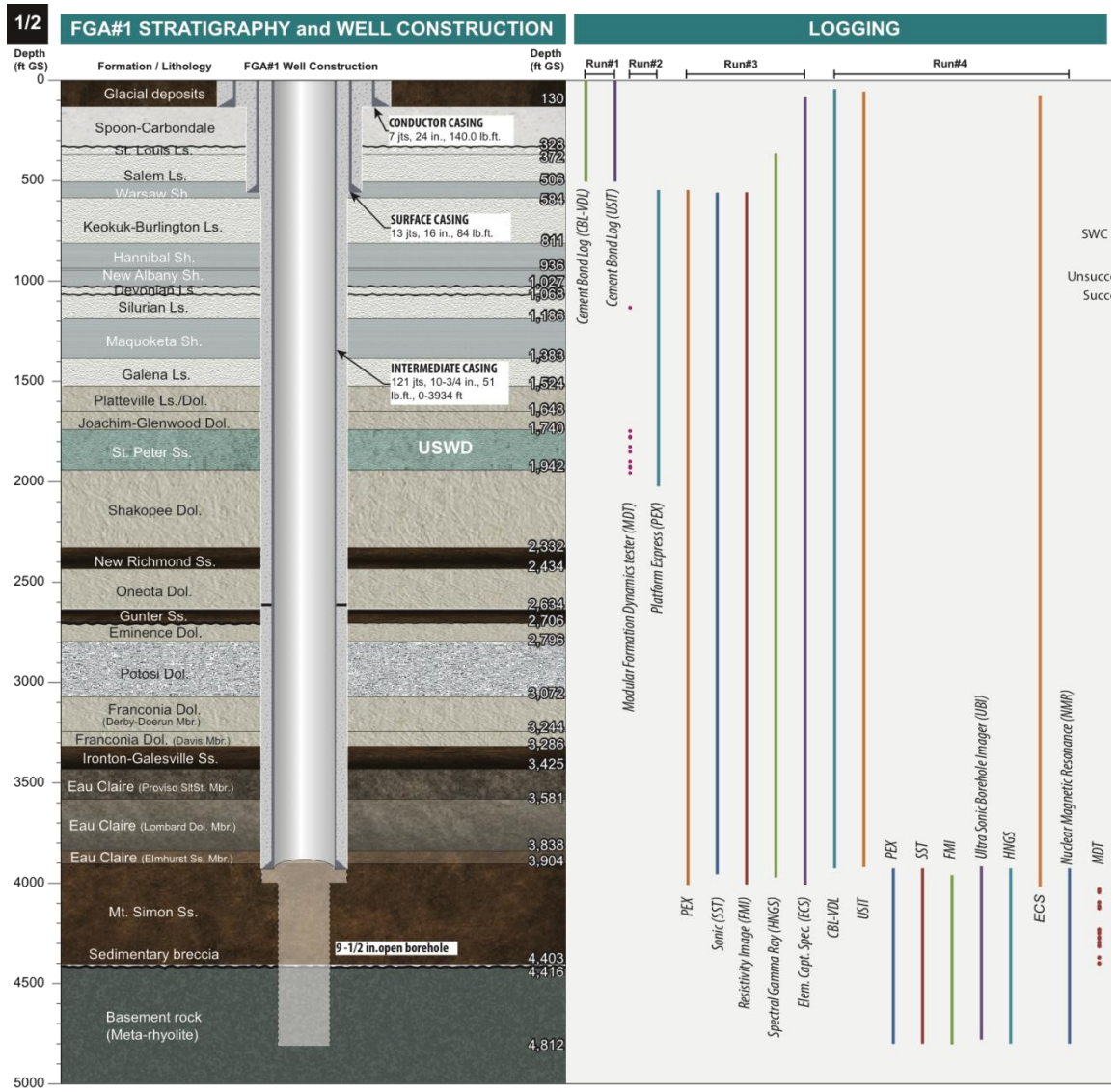
Available data:

- Reports, presentations, raw data and processed files

Geophysical Wireline Logs

- 4 separate logging events were conducted during the course of drilling well FGA-1

Run	Drilling Stage	Description
1	After installation and cementation of surface casing	Two types of CBLs (cement bond logs)
2	Drilling through St. Peter (USDW)	Open-hole logs and fluid sampling in St. Peter
3	After drilling of intermediate borehole	Open-hole logs
4	After drilling of deep borehole	Open-hole logs and CBLs



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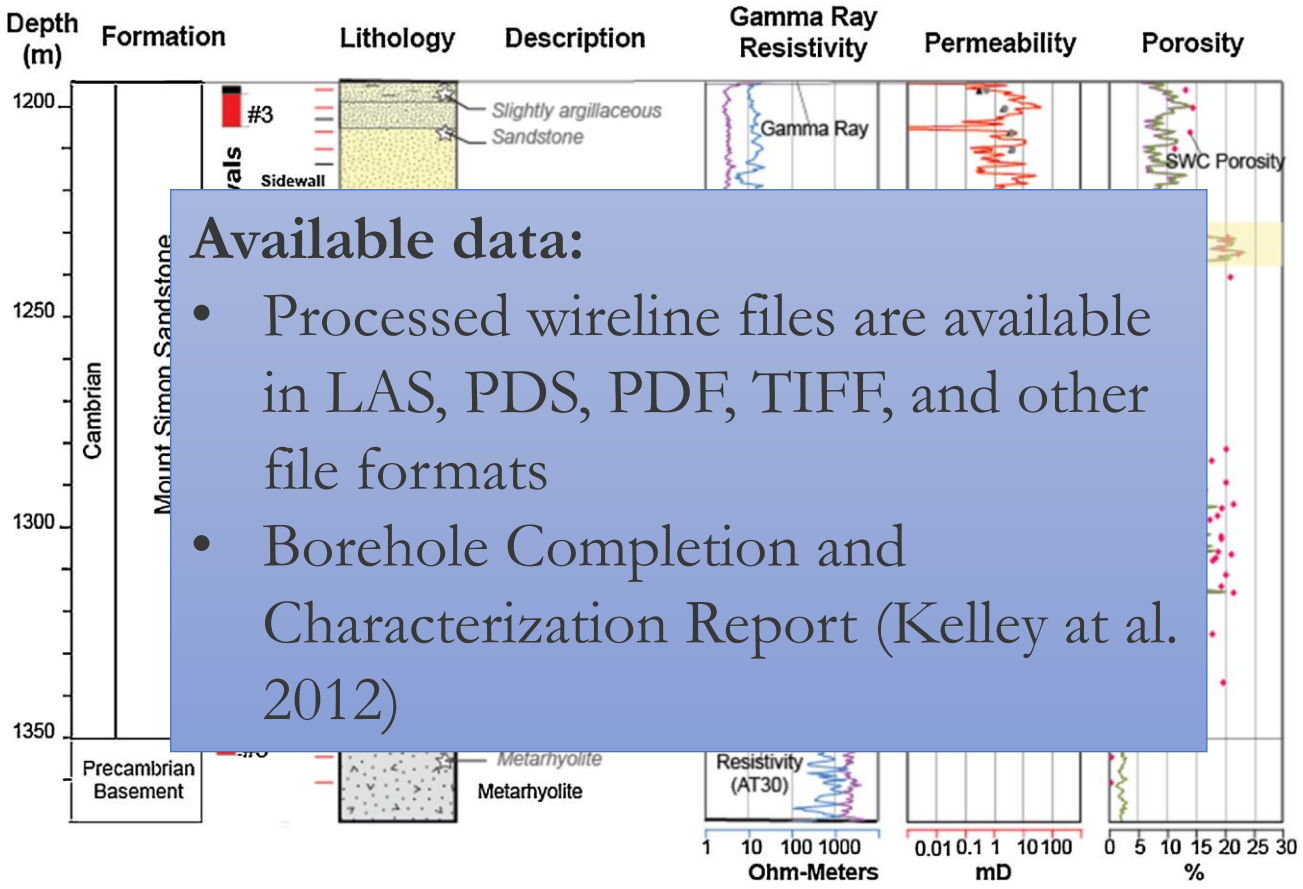
Log Types

- **Primary logs**
  - Cement Bond Log (CBL)
  - Modular Formation Dynamics Tester (MDT)
  - Platform Express (PEX) Compensated Neutro, Litho-Density
  - PEX Array Induction (Resistivity)
  - Elemental Capture Log
  - Nuclear Magnetic Resonance (NMR)
  - Resistivity Image (FMI)
  - Sonic Log (SST)
  - Spectral Gamma Ray (HNGS)
  - Caliper Log
  - Ultra Sonic Borehole Imager (UBI)
  - Geomechanical Field Test Log
  - Mud Log
  - **Processed logs: ELAN and Anisotropic & Elastic Moduli**

Mount Simon Sandstone Injection Zone Mineralogy, Wireline Log Characterization, and Hydrologic Units

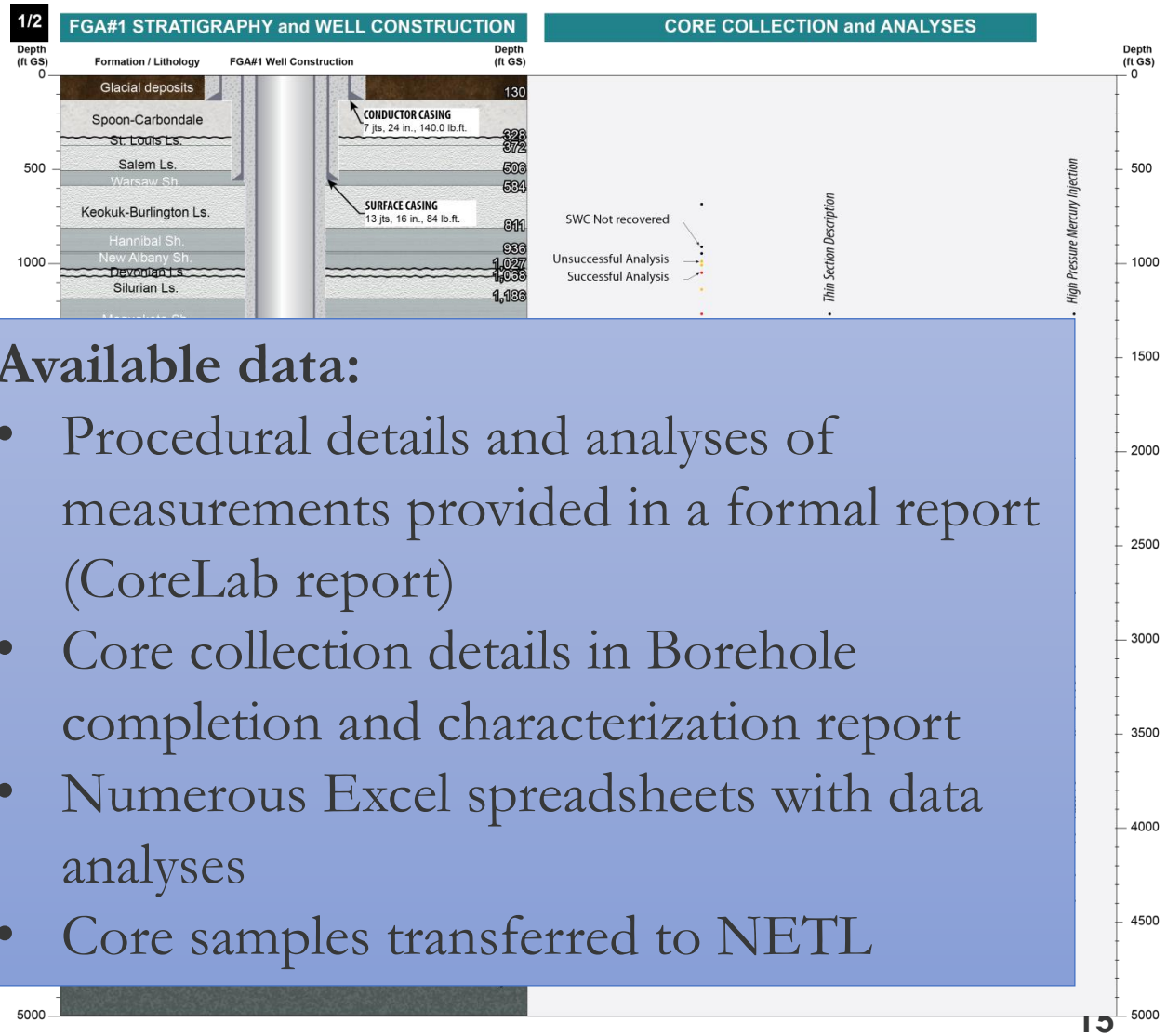


Available data:

- Processed wireline files are available in LAS, PDS, PDF, TIFF, and other file formats
- Borehole Completion and Characterization Report (Kelley at al. 2012)

Core Analyses

- **Core collection**
  - Full-hole core samples: 205 ft (62 m) in total (Mt Simon Ss. and Eau Claire Fm.)
  - Sidewall core: 139 cores collected (various depths)
- **Analyses performed**
  - Routine petrophysical property analysis (porosity, permeability, grain density)
  - Petrographic analysis (thin section description and general core description)
  - Series of special core analyses including
    - geomechanical property analysis
    - multiphase fluid flow properties
    - formation resistivity factor
    - high-pressure mercury injection



Available data:

- Procedural details and analyses of measurements provided in a formal report (CoreLab report)
- Core collection details in Borehole completion and characterization report
- Numerous Excel spreadsheets with data analyses
- Core samples transferred to NETL

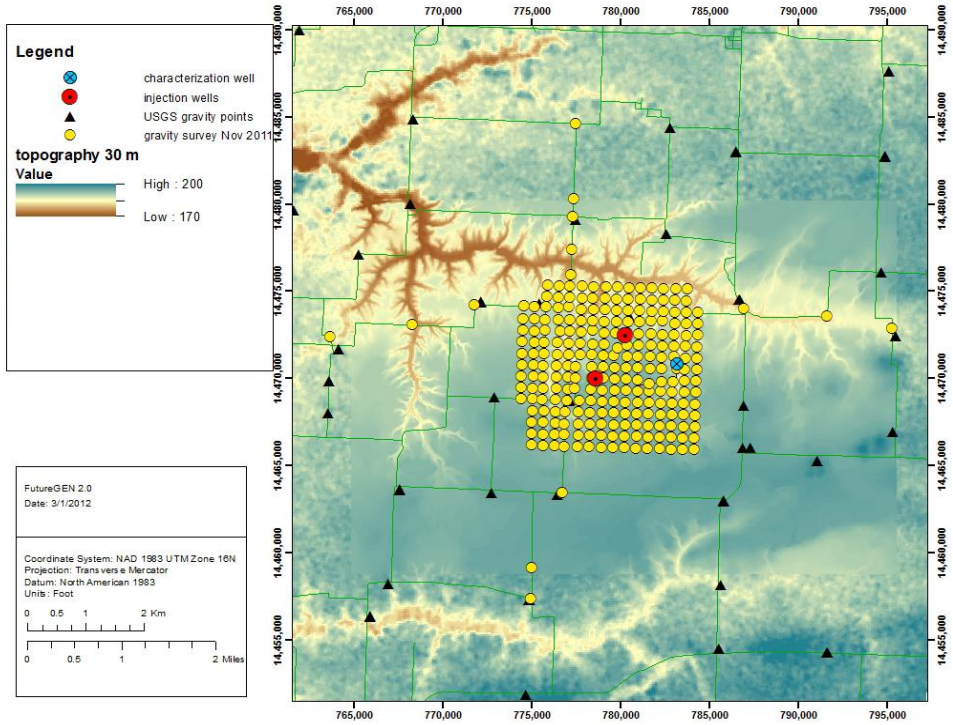
Gravity and Geodetic Surveys

- **Purpose**
  - Determine baseline for "future" gravity survey to evaluate variations of density in the subsurface associated with CO_2 injection
  - Determine baseline for future study of deformation
- **Comprises 245 gravity and GPS stations**
- **Designed to obtain 10 μGal level accuracy measurements of *g***

Available data:

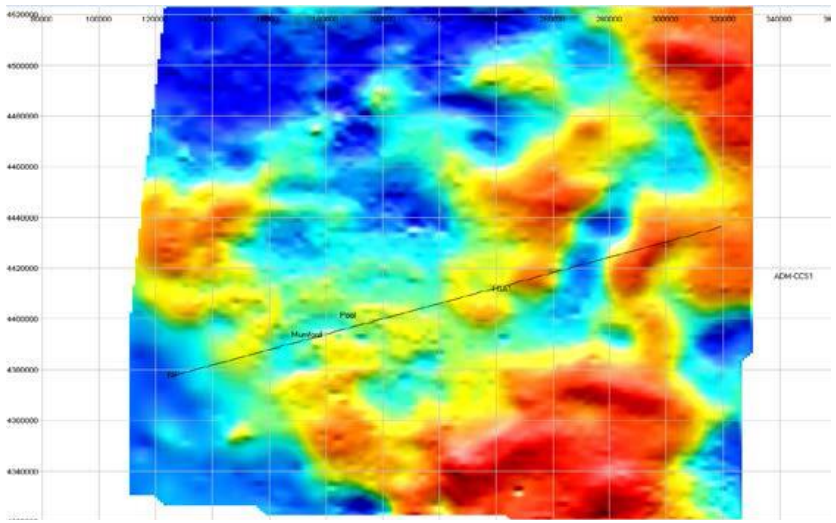
- All raw and processed data collected during the survey (Excel spreadsheets, text files)
- Report of the gravity and geodetic surveys

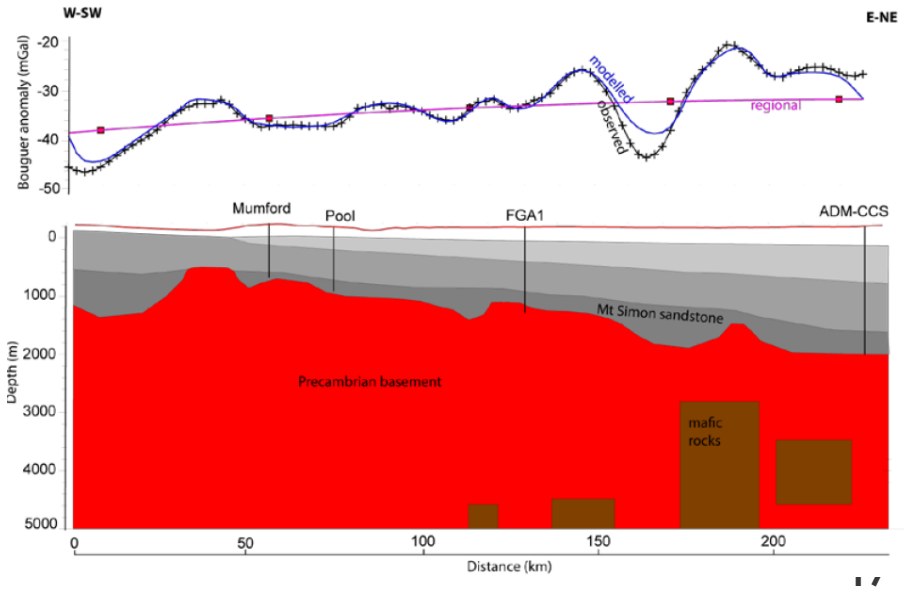
Gravity and GPS stations measured during November 2011 survey and previously existing USGS stations



Gravity Modeling

- **Purpose**
  - Locally improve the density modeling done with existing regional gravity dataset
  - Main goal was to define basement topography





Available data:

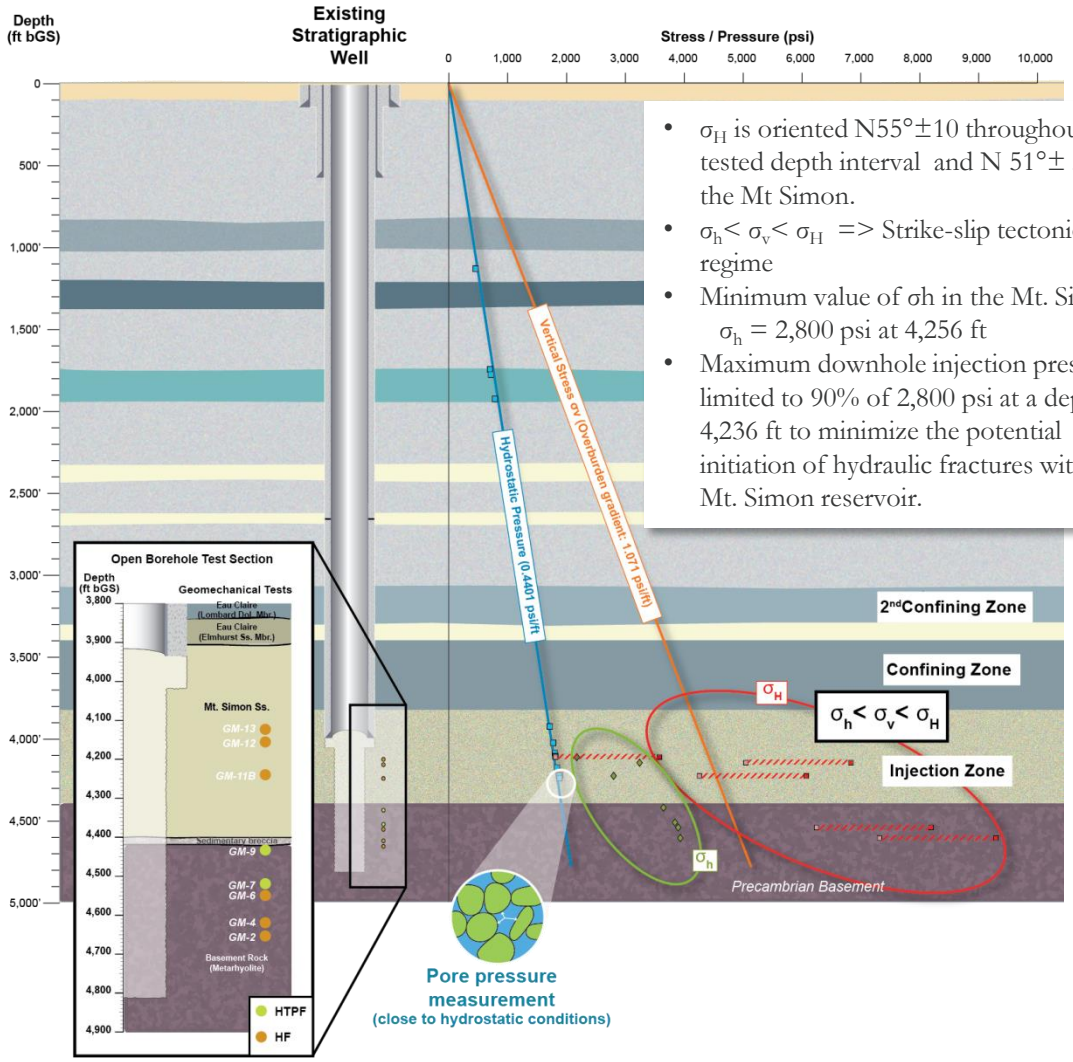
- All raw and processed data collected during the survey (Excel Spreadsheets, text files)
- Density modeling report

In-Situ Stress Characterization

- **Purpose**
  - Determine the vertical profile of the three principal stresses, their azimuths and the maximum injection pressure allowed
- **Conducted in the open-borehole section of the stratigraphic well**
- **Combination of hydraulic fracturing tests (HF) and hydraulic tests on preexisting fractures (HTPF)**

Available data:

- Field data, FMI logs and reports (from Dr. Francois Cornet)



- σ_H is oriented N55°±10 throughout the tested depth interval and N 51°± 3° in the Mt Simon.
- $\sigma_h < \sigma_v < \sigma_H$ => Strike-slip tectonic regime
- Minimum value of σh in the Mt. Simon: σ_h = 2,800 psi at 4,256 ft
- Maximum downhole injection pressure e limited to 90% of 2,800 psi at a depth of 4,236 ft to minimize the potential initiation of hydraulic fractures within the Mt. Simon reservoir.

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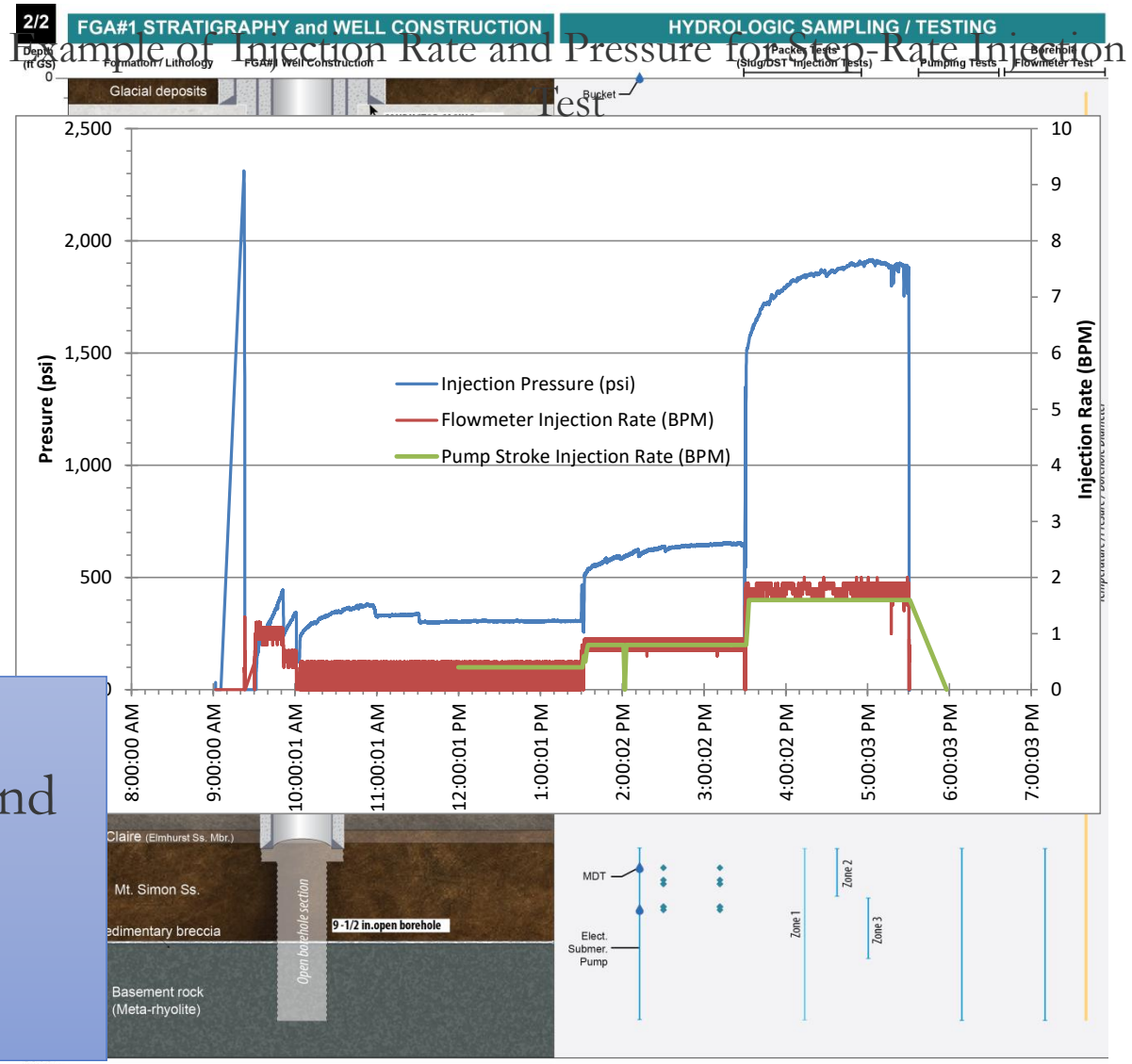
Hydrologic Field Tests

- **Purpose**
  - Provide detailed hydraulic property information for the Mount Simon reservoir
  - Determine in situ hydro-chemical and isotopic characteristics of formation fluid within the Mount Simon Sandstone and the St. Peter Sandstone (lowermost USDW)
  - Establish existing static pressure/depth profile for the storage site

Hydrologic Field Tests

- **Types of Tests**
  - Fluid Sampling (St Peter Sandstone and Mount Simon Sandstone)
  - Pumping Tests
  - Borehole Flowmeter Tests
  - Packer Tests
    - Zone 1 – Composite Mount Simon
    - Zone 2 – Lower Mount Simon
    - Zone 3 – Upper Mount Simon

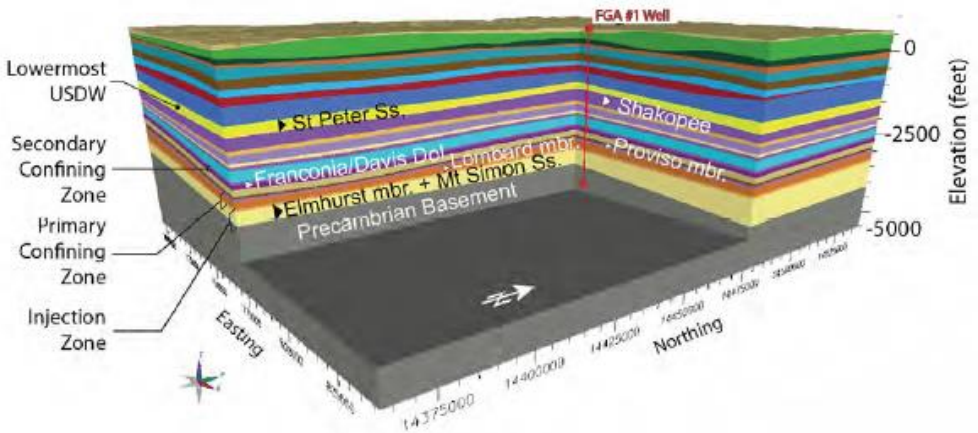


Example of Injection Rate and Pressure for Step-Rate Injection Test

Available data:

- All field data (e.g., pressure data, injection rate) and fluid sampling analyses
- Characterization and interpretation reports and additional technical memos

Geologic/Conceptual Model



- Stratigraphic conceptual model of geologic layers from the Precambrian basement to ground surface constructed using the EarthVision® software package
- Borehole data from stratigraphic well and data from regional boreholes and published regional contour maps were used as input data
- Units below the Shakopee Dolomite and above the Eau Claire Formation were assumed to have a constant thickness based on the stratigraphy observed at the stratigraphic well
- Includes regional dip of approximately 0.25 degrees in the east-southeast direction

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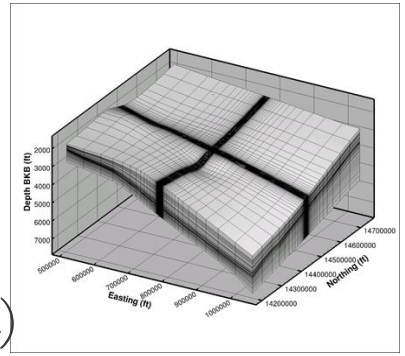
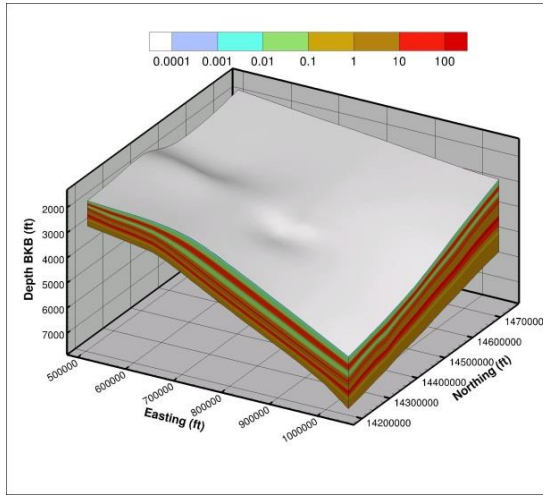
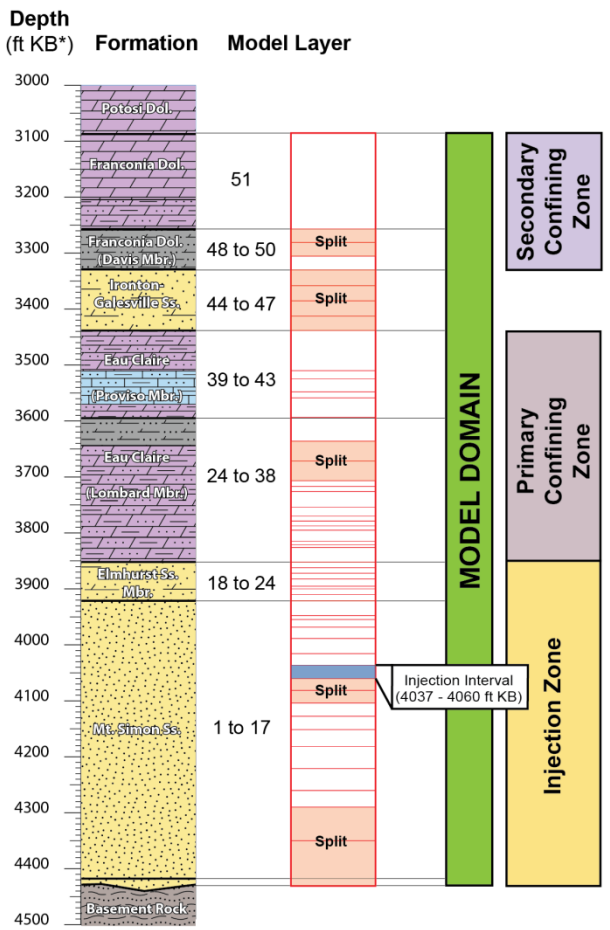
Reservoir Numerical Model

- **100 mile^2 lateral domain includes**
  - Injection zone (Mount Simon and Elmhurst)
  - Primary confining zone (Lombard and Proviso)
  - Ironton-Galesville
  - Secondary confining zone (Davis-Ironton and Franconia)
- **Boundary fitted grid represents dipping strata**
- **51 hydrostratigraphic layers with homogeneous properties within each layer**







Available data:

- STOMP input file including external grid file and external inactive nodes file
- Chapter 3 of permit application describing numerical model and AoR determination

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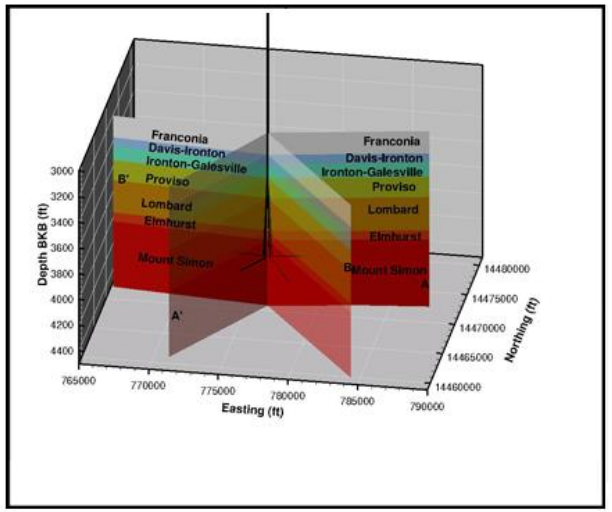
Reservoir Model Operational Parameters

- 4 horizontal injection wells
- Total injection rate of 1.1 MMT/yr for 20 years
- Injection rate was limited by fracture pressure
- Total simulation time = 100 years

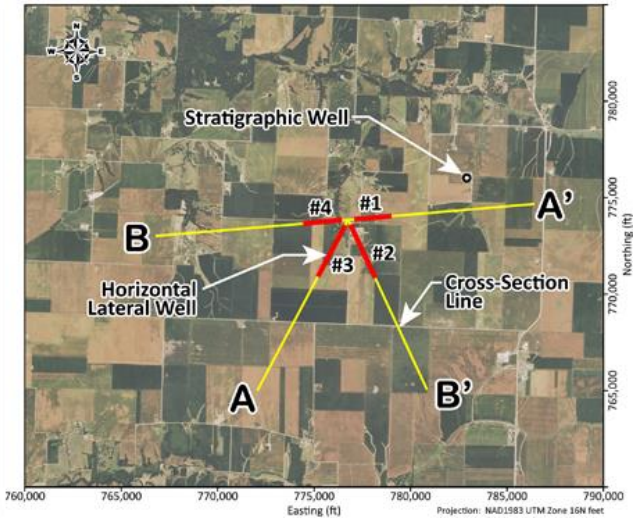
Available data:

- Well Trajectories
- Injection Rates for each well and maximum injection pressure (90% of fracture pressure)

3D View

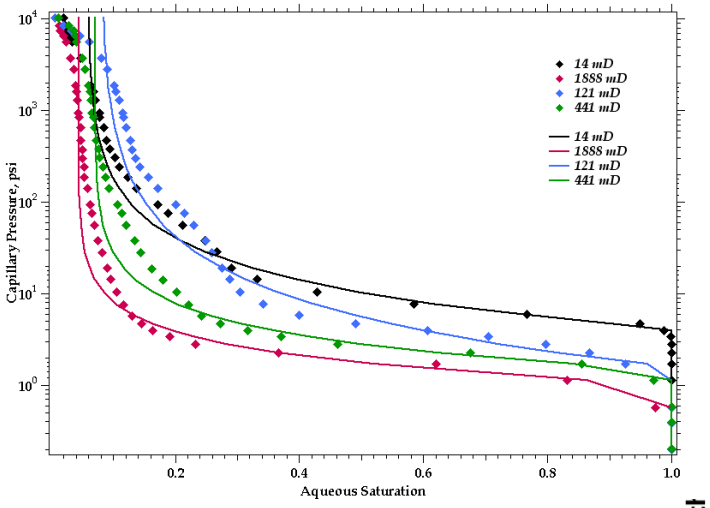


Plan View

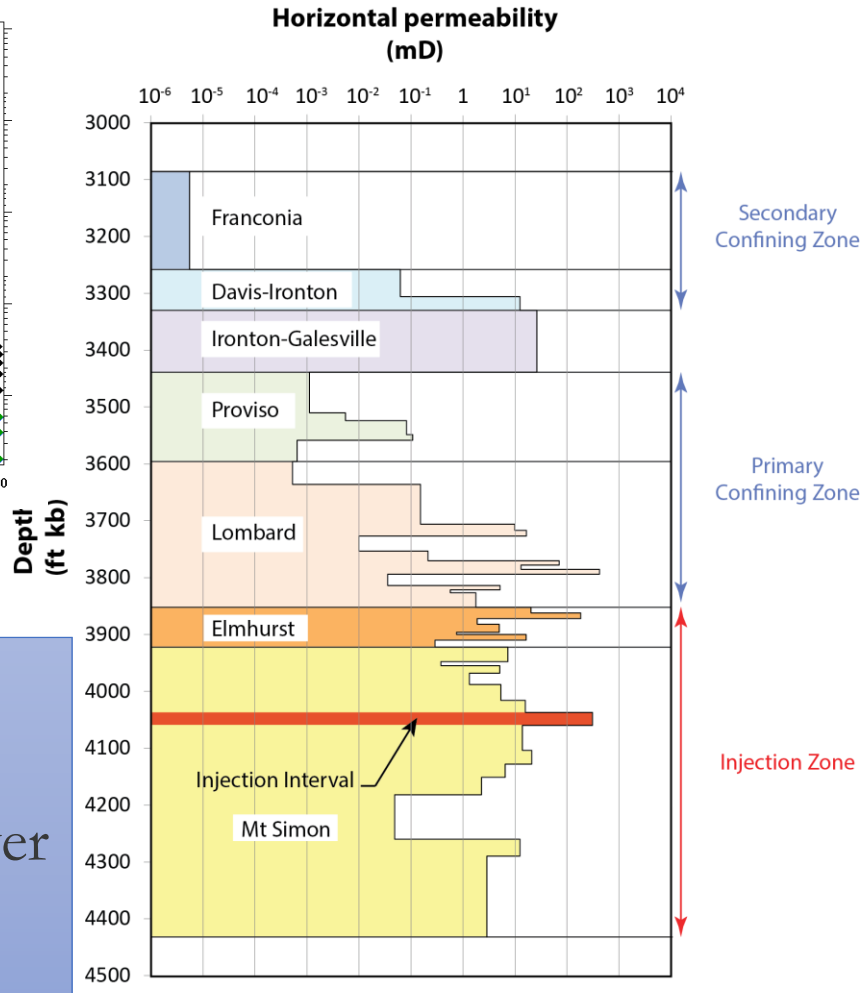


Reservoir Model Formation Properties

- **Stratigraphic well logs**
  - Intrinsic permeability
  - Porosity
  - Grain density
  - Fluid pressure
  - Fluid temperature
  - Salinity
- **Regional data sources**
  - Capillary pressure/saturation functions
  - Formation compressibility



Aqueous Saturation Versus Capillary Pressure Based on Mercury Injection Data from the Hazen No. 5 Well at the Manlove Gas Field in Champagne County, Illinois



Available data:

- ELAN log interpretation
- Excel spreadsheets with properties assigned to each model layer
- Mercury Injection data from Hazen Well and corresponding Brooks-Corey parameters
- Supporting documents describing data interpretations

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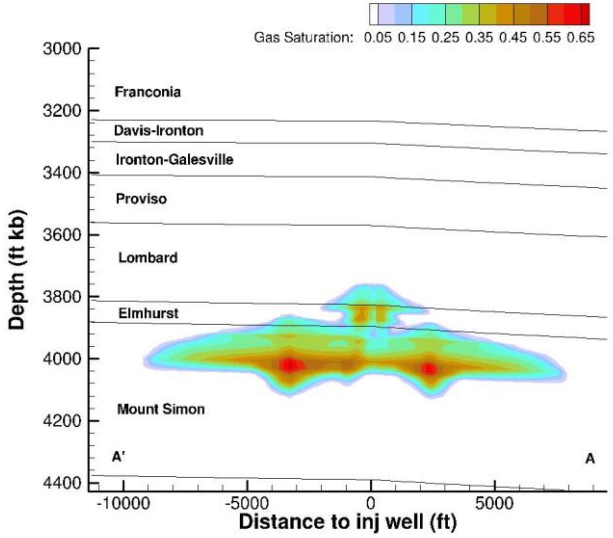
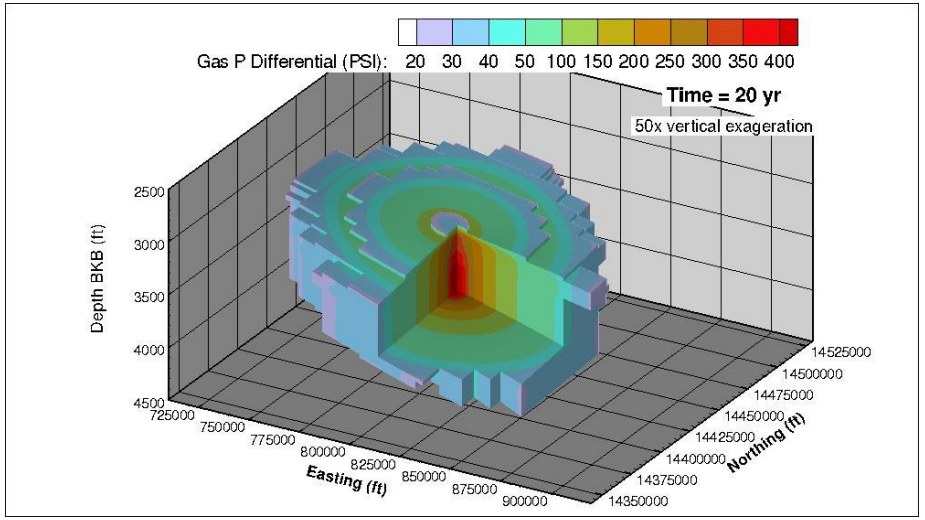
Reservoir Model Results

- **Spatial distribution of output variables at various time planes**
  - Rock/Soil Type
  - Gas Saturation
  - Salt Saturation
  - Salt Aqueous Mass Fraction
  - CO_2 Aqueous Mass Fraction
  - Gas Pressure
  - Aqueous Pressure
  - Trapped Gas Saturation
  - Vertically Integrated Gas Phase CO_2 Mass per Area
  - Vertically Integrated Gas Phase CO_2 Mass
  - Vertically Integrated CO_2 Mass per Area
  - Vertically Integrated CO_2 Mass
  - CO_2 Gas Mass Fraction
  - X-direction Intrinsic Permeability
  - Z-Direction Intrinsic Permeability
  - Z-Direction Gas Volumetric Flux
  - Z-Direction Aqueous Volumetric Flux
  - Z-Direction Salt Flux



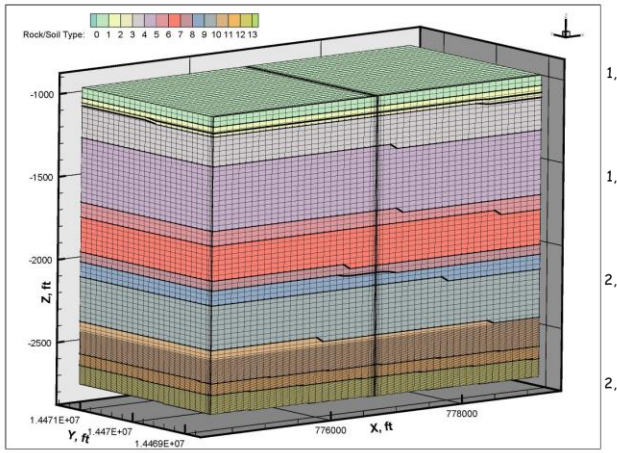
Available data:

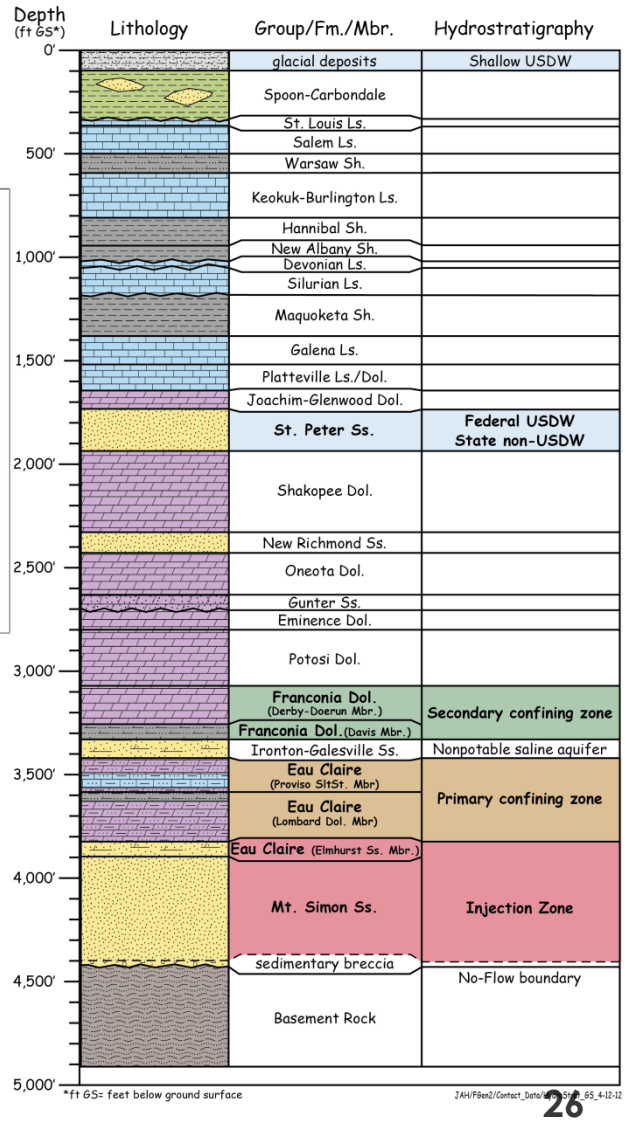
- Results in STOMP plot file format (text file containing grid cell coordinates and variables at each node for a given time plane)



Leakage Model

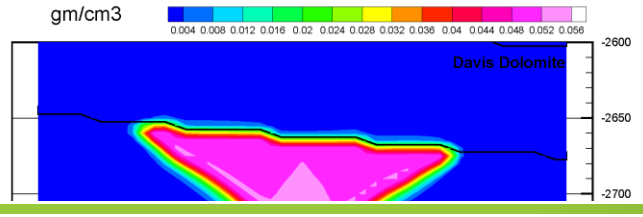
- **Purpose**
  - Investigate potential for water quality impacts associated with loss of $scCO_2$ and/or brine from CO_2 storage operation
- **Domain includes first permeable unit above the primary confining zone (Ironton Sandstone) to the Platteville Limestone**
- **Steady-State simulation run to determine initial conditions**
- **Source applied at a single node at bottom of the Ironton to approximate a leak from an artificial penetration**





Available data:

- Report describing the leakage model and listing the input parameters



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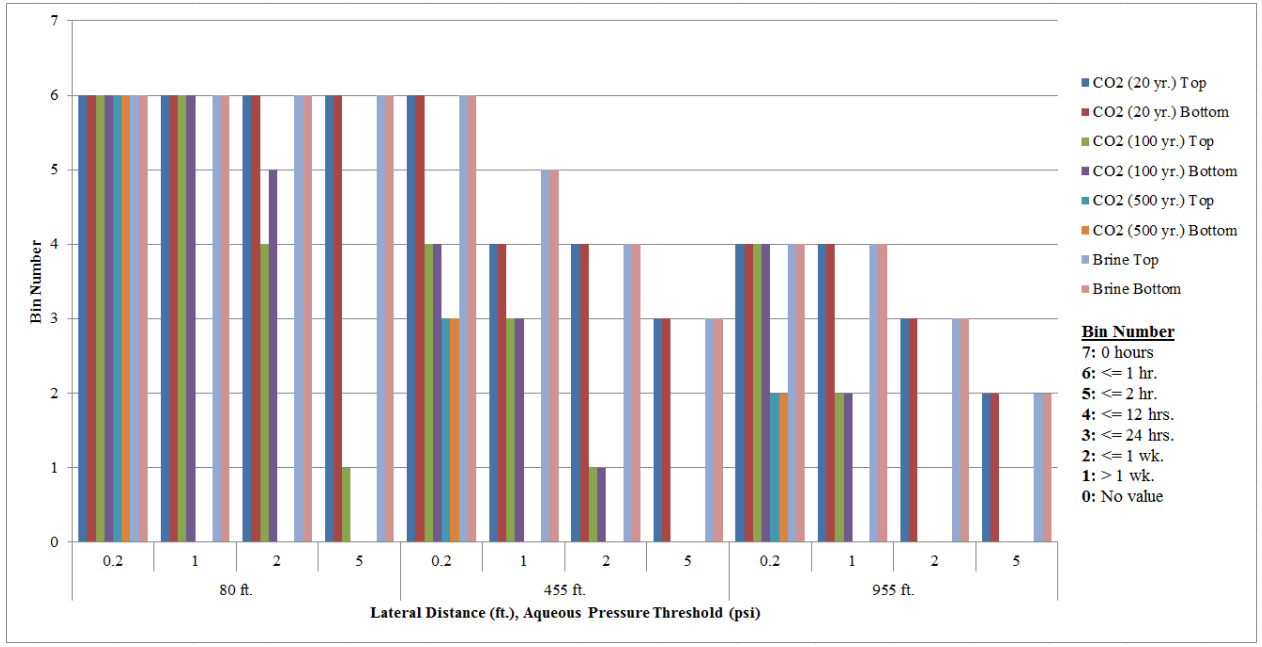
Leakage Model Scenarios

- **Assume that 1% of the total planned injected $scCO_2$ mass (22 MMT) has leaked over three different time periods**
  - 1% of total mass leaked over 20 years (0.011 MMT/yr)
  - 1% of total mass leaked over 100 years (0.0022 MMT/yr)
  - 1% of total mass leaked over 500 years (0.00044 MMT/yr)
- **20-year brine leakage case with brine volume equivalent to 1% of $scCO_2$ volume**



Available data:

- Steady-state simulation input and output files
- For each scenario: STOMP input file, output file (time series at selected reference nodes), and plot files (grid cell coordinates and variables at each node for selected time planes)

Summary

- Data will be made available to NRAP community via EDX
- Data distribution will be coordinated with the Community Data Task so that it is provided in the standardized project format
- Other data may be available – what are your additional data needs?

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References

A virtual special issue of the International Journal of Greenhouse Gas Control will be put on line soon, it will present the following 8 papers that have been published in 2015 and 2016

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